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

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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 state-of-the-art instrument in solar physics – a spectroheliograph – was installed at that 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 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 working at the Observatory of Meudon, Paris. D'Azambuja visited Coimbra to help install the new instrument. Costa Lobo's son, Gumersindo Costa Lobo, also played a pivotal role in the endeavor. Together they gave birth to the cooperation between Meudon and Coimbra, which persists today, being one of the oldest scientific exchanges between 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 (1864-1945) (Figure 1), first astronomer at the Astronomical Observatory of the University of Coimbra (UC), Portugal, arrived at Paris accompanied by Captain Carlos Nogueira Ferrão (1871-1938), and the Captain's son, Álvaro Ferrão, carrying the optical pieces of all instruments they would need to observe the solar eclipse announced for 21 August. Following the invitation of Nikolay Donitch (1874-1956), 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 the total solar 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 Observatory of Meudon, who warned him of the serious difficulties he would face in getting to Russia. On 31 July, Costa Lobo reached Berlin, finding 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 next day, Costa Lobo met Sidónio Pais, the Portuguese ambassador in Berlin and his former colleague in the Faculty of Mathematics at the UC, still trying to obtain the by-then-impossible transportation to Theodosia. He was eventually persuaded to give up and took, with his entourage, the last train to Basel, Switzerland. In the next five days, Costa Lobo kept the hope of getting 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 in the observation of a previous solar eclipse (17 April 1912), one concerning the Moon's polar flattening and the other the refracting effect in the Moon's valleys. Nevertheless, he was obliged to return to Portugal, and the only alternative left was the observation of the partial solar eclipse in Coimbra, at the Astronomical Observatory and at the Magnetic and Meteorological Observatory. The instruments that had arrived at Theodosia returned to Portugal only after the end of the war (Costa Lobo, F., 1914).

Figure 1: Francisco Miranda da Costa Lobo. (Amorim, 1955: frontispiece)

This episode reveals the determination of Francisco

Miranda da Costa Lobo in the pursuit of scientific knowledge. He had graduated in Mathematics and Philosophy in 1884, at the UC, with a high grade, being immediately invited by both faculties to become a teacher. He chose the Faculty of Mathematics, where he concluded his Ph.D. on 27 July of that same year with a thesis on the *Resolution of Undetermined Equations*. On 7 January of the following year, the by-then 21 years old Costa Lobo became substitute professor of Integral and Differential Calculus. And in 1892-93 he became 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 11 March 1905 by the same district, and was re-elected 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 for him its initial appeal and, although he became a member of the new Monarchic Party, his political activity was considerably reduced, being replaced by the academic life.

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 the Sun began in 1907, when he went on a scientific voyage to some important European astronomical observatories. His meeting with Henri Deslandres (1853–1948), Director of the Observatory of Meudon, convinced him to engage in the emergent area of astrophysics. Such participation should take place by the acquisition and installation of a recently invented apparatus which was revolutionizing the study of the Sun – the spectroheliograph. On 17 April 1912 he organized with his students, and with Captain Ferrão, who was an excellent photographer, the observation of a solar eclipse, in Ovar, close to Porto. They registered the most important phases of the eclipse with a small cinematographic apparatus (Bonifácio et al, 2010).[1] A communication 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), son of Francisco Costa Lobo, also worked in the field of solar astrophysics, participating in the investigations performed by his father in Coimbra.

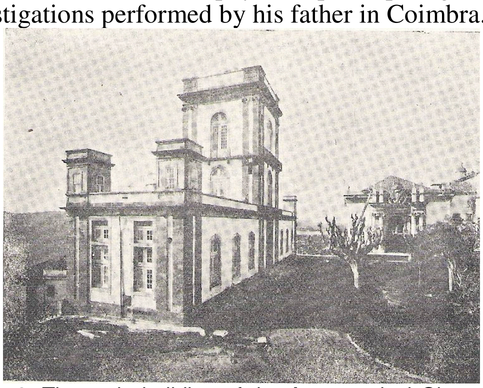


Figure 2: The main building of the Astronomical Observatory of the University of Coimbra. This house in the courtyard of the University was demolished in 1951 during the city renewal ordered by Salazar's regime. (Bandeira, 1942: 541).

The history of Coimbra's Astronomical Observatory goes back to 1772, when the Marquis of Pombal reformed the old University. The new statutes of the University determined its installation for practical lessons of astronomy and for longitude determination. Firstly an ambitious building located over the ruins of Coimbra's medieval castle was projected. The work was suspended in September 1775 due to problems with the location and funding shortages. A new and less ambitious building (Figure 2), located in the courtyard of the University, quite close to the beautiful Baroque University Library, was inaugurated in 1799 (Bandeira, 1942; Pinto, 1893).

In this work 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 astrophysical studies in the country but also cooperation – which continues to this day – with France in the field. We also analyse the scientific activity performed 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 astrophysics section in Coimbra. This was mainly due to 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 astrophysics were an outcome, at least in part, of the observations performed in Coimbra and the cooperation between the observatories of Coimbra and Meudon, following the general recommendation on international cooperation made by George Ellery Hale.

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 may 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 renowned foreign correspondents.

Costa Lobo was elected President of the IC in 1913 helding this position until his death in 1945. This period was also one of the most productive in the history of the institution: 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 managed to include many international astronomers as corresponding members of the society, in particular the following British names: Frank Dyson, Director of the Royal Observatory, Greenwich and Astronomer Royal, Harold Spencer Jones, Chief Assistant of the Observatory at Greenwich and later Astronomer Royal, John Henry Reynolds, President of the Royal Astronomical Society of London, Arthur Stanley Eddington, Professor of the University of 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) – and the French astronomers Henri Deslandres, Lucien D'Azambuja and Armand Lambert, from the Observatories of Paris and Meudon. 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 mentioned above, the list includes scientists from the French observatories of Lyon (J. Mascart), Marseille (I. Bosler) and Strasbourg (Ernest Esclangon), the Canadian Observatory of Ottawa (F. Henroteau), the Italian Observatory of Arcetri (Antonio Abetti), the Greek Observatory of Athens (M. D. Enginitis), the Spanish Observatory of Madrid (Enrique Gastardi) and the Polish Observatory of 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 (Dyson, 1932; Stratton, 1940). As a whole they portray the evolution of this discipline in Portugal, in particular the work done at the UC Astronomical Observatory with the creation and initial activity on the astrophysical unit and the study of the Sun, in the early twentieth century.

The IC and the Astronomical Observatory of the UC always had a connection, as shown by the successive articles in *O Instituto* coming 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 the Observatory's determinations of longitude and latitude. 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 the 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 in the solar surface. One example was the whitish halo that encircled the Moon's outline in a total eclipse of the Sun (the solar corona). On 8 July 1842, a total eclipse was visible in southern and central Europe, and many observers reported rose-colored prominences in the solar corona. (See, e.g., 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. Matias de Carvalho de Vasconcelos (1832-1910), a Portuguese professor of the Faculty of Philosophy, assisted the Belgian Adolphe Quetelet (1796-1874) in the observation of 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 the responsibility for the magnetic measurements, which he described in his first report to the Faculty of Philosophy published in *O Instituto* in that same year (Vasconcelos, 1858).

The new and relevant method in solar studies was spectral analysis, a technique developed by two Germans, the physicist Gustav Kirchhoff (1824–87) and the chemist Robert Bunsen (1811–99), in 1859, in Heidelberg. In 1863, an article by the French historian and engineer Auguste Laugel (1830-1914) describing this new tool was published in *O Instituto – The Sun, under the recent discoveries of Kirchhoff and Bunsen* (*O Sol, segundo os descobrimentos recentes de Kirchhoff e Bunsen).* The discovery of dark lines in the solar spectrum (the Fraunhofer lines) and their relation to the spectra of the chemical elements provided an excellent means to access the chemical composition of stars (see, e.g., Hearnshaw, 2010). The spectroscopic analysis laid down the foundations of astrophysics. The explanation of the dark lines confirmed the existence of a solar atmosphere enveloping the photosphere, whose elemental constituents absorbed light from the continuous photospheric spectrum.

The impact of sunspots and other solar events on the Earth generated a large interest in the study of the Sun, especially due to magnetic disturbances in telegraphic transmissions, a new technology 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 observation of a simultaneous solar flare made by Richard Carrington (1826-75) (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 were the groups that 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 of the Observatory of Coimbra (who would become director in 1866), Rodrigo Ribeiro de Sousa Pinto (1811-1891), published his measurements in *O Instituto* (Pinto, 1858).

Although the determination of exact longitudes was an important outcome of these 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 got the first useful Daguerreotype of a solar eclipse (De Vaucouleurs, 1961). The British astronomer and chemist Warren De la Rue (1815-89) introduced the wet collodion process into lunar photography 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 (Hufbauer, 1991: 49-52; Costa Lobo, G., 1933b: 440). Using a photoheliograph from the Observatory of Kew, he managed to register the successive appearance and disappearance of the prominences, on both sides of the lunar disc, an achievement that proved their belonging to the Sun (Hingley, 2001: 1.20).

An official Portuguese expedition, made up of Sousa Pinto, Jacinto António de Sousa (1818-80), both from Coimbra, João de Brito Capello (1830-1901), from the Infante D. Luiz Meteorological Observatory of Lisbon, and a technician, was sent to Spain to observe this same eclipse (Pinto, R.R. de S., 1861; Bonifácio *et al.* 2007a: 671). 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, none of them capable of photographic or spectroscopic functions. In August and September 1860, following the eclipse mission, Jacinto de Sousa[3] was commissioned to visit the most important European scientific institutions, especially those having meteorological and magnetic observatories (Malaquias, et al., 2005). After visiting the Observatory of Kew, where he arrived on 26 August 1860, he referred in his report to the photoheliograph, probably the same used by De la Rue, but, owing to its cost and the prospect of further improvements in the field, he discarded the prospect of its acquisition. He added that:

> The observation of sunspots, in relation to the discussed question [getting a relation between their position, magnitude and number and some variations in the elements of the earth magnetism], can meanwhile be performed by an ordinary telescope or other that also serves for astronomical observations (Sousa, 1861: 149).

In 1871, the Coimbra Observatory bought a photoheliograph made in Germany by Repsold & Söhne and Steinheil (Bandeira, 1942: 557). In the same year a daily solar photography research project started at the Infante D. Luiz Observatory, in Lisbon, in which Capello was actively engaged, developing international contacts with De la Rue, at Kew, the Italian priest Angelo Secchi (1818-1878), in Rome, and Pierre Jules Janssen (1824-1907), at Meudon. This programme ended in 1880, after several years with no significant progresses (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 the solar eclipses, but the intensity of the light emitted by the Sun's photosphere obfuscated the light emitted by its atmosphere. 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 thin 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 prominence spot on the Sun's rim, 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. The 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, in the outskirts of Paris, mainly devoted to the study of the Sun. Based on the ideas of Janssen and Lockyer, Henri Deslandres, the successor of Janssen at Meudon, and George Ellery Hale (1868-1938) in the USA, developed independently a new instrument which is still used today for studying the solar atmosphere – the spectroheliograph. Hale was the first person to build a usable instrument, in 1890/91, 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 part was to get a device capable of projecting a steady image of the Sun, obtained by a coelostat[4] (Figure 3) made up by two flat mirrors. One of the mirrors could rotate with an adequate speed in order to obtain a fixed image in the second mirror, which would be reflected to 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 get on a photographic plate a complete monochromatic image of the Sun, a synchronous motion of several parts of the apparatus was necessary.

The alternatives were maintaining the monochromator fixed and moving the solar image in the first slit at the same rate as the photographic plate or moving only the monochromator and fixing all the constituents, reproducing the equivalent motions by optical or mechanical devices (Kuiper, 1953: 617).

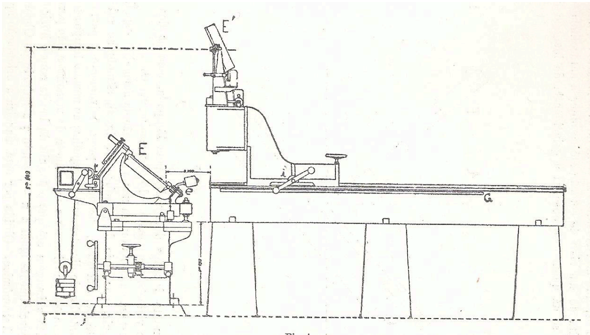


Figure 3: Schematic representation of the coelostat of Coimbra. (Costa Lobo, G.S., 1933b: 453).

4 SOLAR ASTROPHYSICS AT THE BEGINNING OF THE 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, using a modern unit, a line very close to one 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 called 'Coronium'. The arrival of this news in Portugal, in July 1870, instigated a mission of António dos Santos Viegas (1835-1914), a professor of the Faculty of Philosophy of the UC, to Rome to study the spectral analysis of the Sun with two of the leading Italian specialists: Secchi and Lorenzo Respighi (1824-89). His plan was to invite the international community to observe the solar eclipse which was due to occur on 22 December 1870 in Portugal and to map the eclipse path crossing this country (Bonifácio et al., 2007a: 673).

However, Young preferred a spot in Jerez de la Frontera, Spain, to observe this eclipse, and was clever enough to make a new 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: 96). This was called the flash spectrum since the spectrum only lasted for some seconds. These lines coming 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 chromosphere spectrum. Isolating the light from one of these lines, an image of the solar chromosphere could be taken. The monochromatic images of the Sun, obtained by the spectroheliograph, differed from the selected line, a phenomenon that suggested that they were being emitted at different altitudes of the chromosphere. From 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 one of them related 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. George Ellery Hale (1908), at Mount Wilson Observatory, California, confirmed this hypothesis in 1908, showing that many doublets were polarised in opposite directions. The polarisation of the sunspots was related to the direction of their vortices (Hufbauer, 1991: 78).

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, rotation rate and direction of motion and moved on to its physical and chemical constitution. It was established that it was composed of terrestrial elements with a photosphere with temperatures of about 6000 K and chromospheric activity that included an eleven-year cycle of sunspots, which were centres of strong magnetic fields (Hufbauer, 1991: 79).

O Instituto published a lecture given at the Valladolid Congress of 1915, where Costa Lobo had been present, by Victoriano Fernández Ascarza, astronomer of the Observatory of Madrid. In its first half, devoted to solar problems, Ascarza (1916) reported the major advances in solar physics and the problems that were still pending. A reference was made to the spectroheliograph, since Spain already had two of these instruments, the first having been installed at the Ebro Observatory, 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 filaments. In his article, Ascarza renewed Hale's appeal for an international cooperative effort to investigate the sunspots (Ascarza, 1916: 31). This cooperation should be based on the uniformity of the observation methods and its world-wide articulation to guarantee the continuity of the information gathered along whole periods of sunspots. Costa Lobo eagerly answered this appeal, starting the procedures that would culminate in the creation of a centre devoted to astrophysics at the UC.

5 POLITICAL AND SCIENTIFIC CONDITIONS FOR THE CREATION OF ASTROPHYSICS 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 without any immediate financial revenue.

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. 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 to 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.

All three politicians – Afonso Costa, member of many governments and prime minister on three occasions, Bernardino Machado, elected President of the Republic in 1915 and in 1925, and Sidónio Pais – were active members of the IC. Costa participated in a course of popular lectures organized by the IC to educate lower social classes in Coimbra, while Bernardino Machado was President of the IC between 1896 and 1908.

Interest in this new branch 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 compiled all observations performed in the meteorological observatory (temperature, humidity, rainfall and their statistical treatment) for fifty years. One chapter was devoted to the comparison of air temperature and other weather phenomena with the number of sunspots and solar irradiance. Based on sunspot numbers collected by Alfred Wolfer, published in the *Monthly Weather Review* before 1914, Ferraz de Carvalho did not confirm the idea that an increase in the number of sunspots corresponded to 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, promoted by the Spanish Association for the Advancement of Science, Costa Lobo laid the foundation of the Portuguese Association for the Progress of Science, whose presidency he occupied for several years. The creation and intensification of scientific relations between Portugal and Spain was one of his goals.[6] 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 spectroheliograph installation in Coimbra, the second joint congress of the Portuguese and Spanish Associations for the Advancement of Sciences[7] took place in that city with the collaboration of the IC. The inauguration speech by Costa Lobo, *Astronomy in Portugal in the Present Time*, published in *O Instituto* (Costa Lobo, F., 1925a), was certainly a response to Ascarza.

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 astrophysics project but also for the IC and the UC.

6 INSTALLATION OF THE SPECTROHELIOGRAPH IN COIMBRA

In 1912, Costa Lobo's plan to install a spectroheliograph in his Observatory started to be implemented. The instrument, similar to that in place at Meudon, was constructed following Deslandres's 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 Meteorological and Magnetic Observatory, which had been founded in 1864.

Figure 4: Pavilion where the spectroheliograph was installed. (Bandeira, 1942: 548).

Deslandres, who was a good friend of Costa Lobo, 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). Many were the problems associated with this enterprise, the most notorious being the budget, in view of the costs of the imported equipment and the technical expertise necessary. In the words of Gumersindo Costa Lobo (our translation):

> The accomplishment of this enterprise presented itself full of difficulties, if not impossible, hence […] the parts and instruments necessary are extremely expensive, the assemblies are considered the most delicate by the authorities in these issues, and the problem had never been approached in Portugal. In short, the problem of erecting what we might consider a major physics laboratory for the new studies of the Sun had to be solved in a way that investigations could be performed at the same level of perfection as those achieved abroad and managed at the beginning of the research in Portugal of this part of science, allowing our effective collaboration in the works of international cooperation (Costa Lobo, G., 1940: 10-11).

The pieces were ordered from instrument makers in several countries. With the outbreak of the First World War all these actions had to be suspended, but, as soon as peace was established, Francisco Costa Lobo reengaged the previous settlements, solving some problems originating in price increases (*idem*).

Gumersindo Costa Lobo played an essential role in the installation of the spectroheliograph. Being aware of the novelty of the new technology and the scarce readiness of Portuguese technicians to handle it, he decided to specialise in the subject. In 1923, at age 27, he departed on his own to Meudon, where he was trained under Deslandres and his assistant Lucien d'Azambuja. On his return to Portugal, later that year, "all the services of the installation and scientific investigation of the (new) section of Astrophysics of the Astronomical Observatory were entrusted to him" (Amorim, 1955: 26).

Figure 5: Lucien d'Azambuja and Henri Deslandres in 1903. (From Mouradian, 2007: 7).

The construction of the spectroheliograph pavilion started immediately after his arrival. Deslandres sent Lucien d'Azambuja (1884-1970) (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: He was the grandson of Diego, a Portuguese immigrant from Azambuja, a small city close to Lisbon (Mouradian and Garcia, 2007: 7). He became 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, and he got 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: 4).

In "Les Nouveaux Instruments Spectrographiques de L'Observatoire Astronomique de l'Université de Coimbra," published in *O Instituto* (1926), which followed his communication under the title "Astronomy in Portugal in the Present Time" (1925b), Costa Lobo described the new instrument. It was identical to that of Meudon, but contained new improvements that, in Costa Lobo's words, made it "le plus remarquable appareil pour l'étude de l'atmosphère solaire installé dans l'Europe" (the most remarkable instrument for the study of the solar atmosphere installed in Europe) (Costa Lobo, F., 1926: 129).

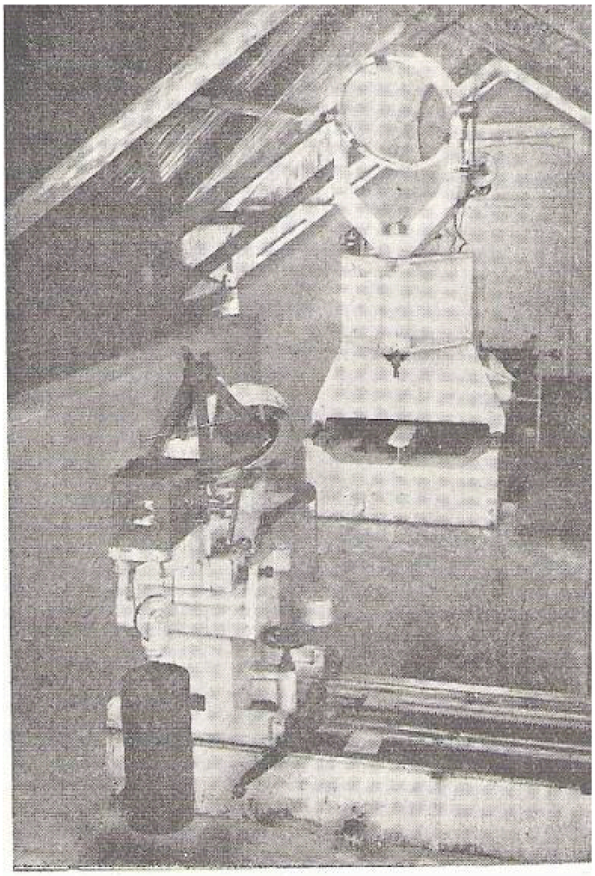


Figure 6: The ceolostat of Coimbra's spectroheliograph (Costa Lobo, F.M., 1933b: 145).

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 movable ceiling (Figure 6). The lower mirror facing the Sun rotated by means of a very precise clock mechanism, 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 with the calcium line K_3, 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. 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 of edge. The dispersed light was then projected into a second slit, which selected the spectral line, just before a photographic plate. These pieces rested in a movable platform similar to that of the objective and connected to a second Baudot motor. The motions of both motors, made at Jules Carpentier's workshop, were synchronised (Figure 7). Some of these pieces were manufactured locally (Costa Lobo, F., 1926: 129-134).

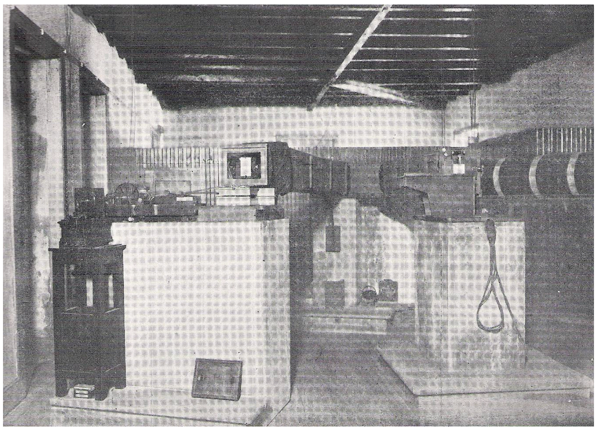


Figure 7: The spectroheliograph room. (Costa Lobo, F., 1933b: 146).

In the same article, Costa Lobo also described the stellar spectrograph, which had been acquired at the same time and which complemented the astrophysics section of the Observatory.

On 12 April 1925 the first spectroheliogram of the Sun with the K_3 line was carried out. The spectroheliograph has been working ever since.

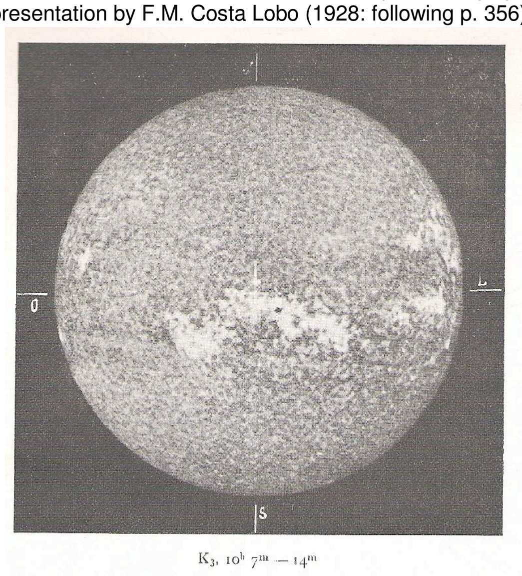
7 SUBSEQUENT SCIENTIFIC ACTIVITY

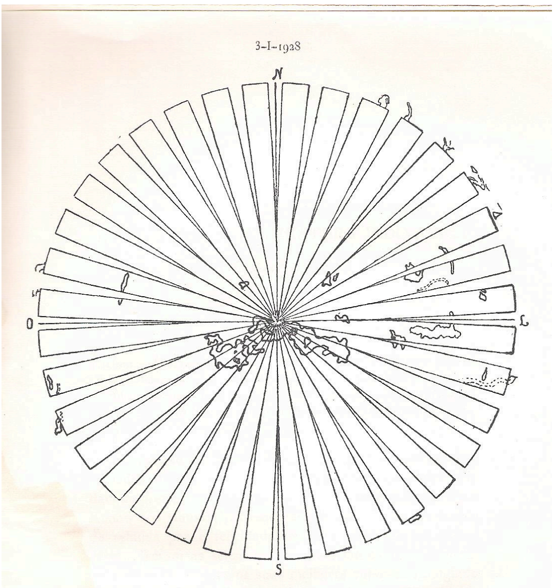
As a part of an international scientific effort, the requisites were very demanding. One of the first resolutions by Costa Lobo was to publish all the results in a new publication – *Anais do Observatório Astronómico da Universidade de Coimbra – Fenómenos Solares* (in English, *Annals of the Astronomical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

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, reporting 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 observation 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 K_3 and the other with K_1 lines. 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 suitable pieces were necessary, like a diffraction grating ordered from Adams Hilger & Company, which arrived in 1932 (Costa Lobo, G., 1940: 22). These images were sent to Meudon, which worked as an international hub, compiling all information arriving from all cooperating observatories. Since March 1919, d'Azambuja had been responsible for making a continuous mapping 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, 1998: 488), whose publication in the *Annales de l'Observatoire de Paris, section de Meudon* started in 1928 (Martres, 1998: 5). He used images from other observatories to fill in the missing days, such as Mount Wilson, in the USA, Kodaikanal, in India, and Coimbra, in Portugal (Kiepenheuer, 1953: 402). Since the Meudon and Coimbra instruments were identical, the spectroheliograms sent from Coimbra did not need further adjustments.

Figures 8 and 9: Spectroheliogram taken on 3 January 1928 with the calcium II line K_3 and correspondent graphical representation by F.M. Costa Lobo (1928: following p. 356)..





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 presented the communication "Quelques résultats obtenus par les observations spectro-heliographiques des années de 1926 et 1927" (Costa Lobo, F., 1928). In his paper a graphical representation invented by Costa Lobo to depict the image of the solar chromosphere was published (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, reproduced in an article in the *Comptes Rendus*:

> This first volume gather the observations of the year 1929. It reproduces the photographic samples of the 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).

Through the examination of the daily spectro-heliograms, the number, position and dimension of the principal solar structures were measured: sunspots, faculae, filaments and prominences. All parameters of solar activity were classified, being their evolution carefully documented.

Costa Lobo pointed out that the facular regions, bright areas in the solar surface with a wider extension than the sunspots, were more important than the sunspots. In 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 do Observatório Astronómico.* 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; 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 the faculae. Costa Lobo proposed that sunspots were a consequence of faculae and had the same nature, in spite of their different disposition. The formation of all spots inside facular regions and their disappearance before the faculae and the fact that they were more numerous in areas of maximal faculae 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 spots and the values of temperature and magnetic variations on Earth could therefore be explained. These influences were monitored in the *Anais*, which 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. The filaments were related to the eruptive prominences, being classified as thin, large, curved and discontinuous.

Gumersindo Costa Lobo's participation in the investigation was highlighted, 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 taking special knowledge of the works in solar physics at the Observatory of Meudon (Costa Lobo, F., 1929: 19).

The importance of the new research centre on solar astrophysics prompted a visit to Coimbra by British Astronomer Royal Frank Dyson on 26 November 1931. Dyson attended the celebration organized by the Faculty of Sciences of the UC and the IC in honour of Isaac Newton (Costa Lobo, F., 1934).[8]

As a representative of the Portuguese government, Costa Lobo attended the Congress of the International Astronomical Union in Cambridge, Massachusetts, USA, from 2 to 9 September, 1932 (Costa Lobo, F., 1933b). 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 being sent to Meudon and also to Zurich, Switzerland, to be included in the *Bulletin for Character Figures of Solar Phenomena*, a publication of the International Astronomical Union directed by the Swiss William O. Brunner, initiated in 1928 to report data from observatories around the globe. (It would be renamed the *Quarterly Bulletin on Solar Activity* in 1939 (Hufbauer, 1991: 85))

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.

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

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 was presented – a special sphere for facilitating the visualisation of the position of solar structures (Figure 10). He characterized his sphere as "an instrument with which it was possible that a single person could acquire the transformations that demand at least five persons using the ordinary process" (Costa Lobo, F., 1933a: 9). Also in 1933 the Congress of the Geographic and Geophysics International Union took place in Lisbon, 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).

8 GUMERSINDO COSTA LOBO AND THE CONTINUATION OF THE SOLAR STUDIES

When he became 70, on 18 February 1934, Costa Lobo was made emeritus, having to leave his job as Director of the Observatory and the chair he had held for 50 years. He was replaced by Manuel dos Reis (1900-93), 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 some notes referred to some particular events. The exchange of spectroheliograms with Meudon was maintained, except in the years of the Second World War (Reis, 1946: 8). Gumersindo (Figure 11) continued the investigations made by his father in the section of astrophysics.

Figure 11: Gumersindo Sarmento da Costa Lobo. (Amorim, 1955: after 24).

In fact, Gumersindo lived in the shadow of his father, a situation that probably prevented the recognition he deserved. He concluded his graduation in Mathematical Sciences in 1919 with a grade higher than that of his father (19/20 vs. 18/20), and was then appointed second assistant of the Mathematical Section. Always committed to astronomy, he became deeply involved in the installation of the astrophysical section. As already mentioned, in 1923 he was sent on a scientific mission to Meudon. 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 on the 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, he was also a painter and a musician, being particularly notable as a pianist.

His scientific activities, which led to many published articles and conferences, were largely devoted to the theme of his expertise – solar astrophysics, in particular the study and classification of the chromospheric events. Based on the analysis of around 4000 photos of the Sun, taken since 1925, Gumersindo Costa Lobo presented his first conclusions in a paper in the journal *A Terra – Revista de Sismologia e Geofísica* entitled "The classification of some chromospheric phenomena and their comparison with terrestrial phenomena" (1933a). 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), 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. 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 spectra (Figure 12). By analysing the displacement of each spectrum, it was possible to determine the speed of that portion of the solar chromosphere.

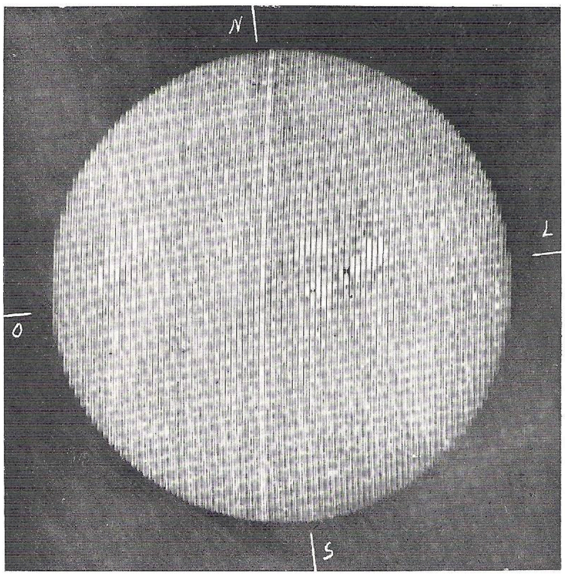


Figure 12: Picture of the Sun taken 2 July 1932 by the method of a wider second slit. (Costa Lobo, G, 1933b: plate IV).

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 a strong opponent of special and general relativity, supporting an alternative theory (till the end of his life) that kept the concepts of absolute time and absolute space (See Costa Lobo, F, 1917; 1936; 1937).

In his father footsteps, Gumersindo Costa Lobo attended the Congress of the International Astronomical Union (IAU) which took place in Paris in 1935, where he was elected a member of Commission 10, devoted to Sunspots and Characteristic Solar Figures. He was already there in one of his scientific visits to the Observatory of Meudon, one of the places where the sessions took place, another being the Observatory of Paris. Gumersindo described the congress and, in particular, the discussions of the solar physics commissions in which he participated (nos. 10 and 11) in a report published in *O Instituto* (Costa Lobo, G., 1938). The 90th volume of *O Instituto* included another paper written by Gumersindo Costa Lobo on "The observation of solar phenomena and some contributions for its interpretation" (Costa Lobo, G., 1936), where he explained some interpretations of the solar structures observed in Coimbra's spectrographic data. He also expressed the intimate relation between the filaments, the dark streaks observed in the solar surface, and the prominences, seen above the solar rim. He concluded that the "phenomenon that has been given, in general, the name filament corresponds to regions of greater absorption of a prominence, so that the phenomenon of the prominence, projected over the [solar] disc can, therefore, comprise a superior zone of the filament". This meant 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, G., 1940). There 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 (*idem*: 22-23).

The elder Costa Lobo published his three final articles in volumes 102 and 103 of *O Instituto*. In one of them, related to the origin of sunspots, he gave his last interpretations of these phenomena. He reaffirmed his belief, now shared worldwide, of the relationship between the sunspots and the faculae, and that the sunspots always appeared inside the faculae, the former disappearing before the latter, which meant that sunspots were a process resulting from faculae, both having common causes. According to Francisco Costa Lobo, convection currents, that sometimes could cause the eruptive prominences, produced the sunspots on the facular regions. The faculae had an origin external to the Sun. In respect 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 period for the frequency of sunspots, based on the interval 1880-1925 (1943: 461).

Based on this fact, Francisco Costa Lobo suggested that some rogue masses, of external origin, could be captured or deflected by Jupiter, sending them towards the solar surface. Their collision with the photosphere induced the formation of faculae. This scenario could also explain why the faculae only occurred in the "royal zone", between 2° and 40° latitude. Christoph Scheiner (1573-1650), in 1630, used this expression in reference to the narrow belt on both sides of the Sun's equator, where the sunspots appeared (Brody, 2002: 58).

Francisco Costa Lobo continued working until the end of his life, which occurred on 29 April 1945, after collecting a long list of honours, including the Jansen Gold Medal of the *Académie des Sciences de Paris*. He remained President and honorary member of the IC until his death.

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). 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 evolution in the number of sunspots with the solar cycle. In this cycle, with a general duration of 11 years between two minima, the first sunspots were generated at symmetrical higher latitudes between 30º and 40º, increasing in number towards the equator and disappearing before reaching it. Within the faculae, the sunspots were places with very high magnetic fields, opposite in both hemispheres, which were inverted in each cycle.[9] The proposed explanations were of two kinds: some people considered an external cause linked to the tides originated by planets, while others deemed the cause as being internal to the Sun.

Lucien d'Azambuja presented afterwards a report (1949) on "Progress of Research on the Solar Atmosphere in the Last Fifty Years." He described 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 disc a very bright and circular zone was formed. In this facular speck, little sunspots would almost immediately appear. Two principal spots, in the following days, surpassed the others in the enlarged facular region, one on the West (the head sunspot) and the other on the East (the queue 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 queue spot would fragment and disappear and, sooner or later, the same would happen with the head 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 the *chromospheric eruptions*. D'Azambuja also addressed the influence of solar activity on the Earth, especially the effects following chromospheric eruptions.

In the same year of the lectures delivered by the d'Azambujas, an article appeared in *O Instituto* authored by the Swedish astronomer Yngve Öhman (1903-88), a corresponding member of the IC, who explained the new methods of "Astronomical Investigation Based on Light Polarization" (Öhman, 1949) and their application to the study of the Sun.

In 1951, answering a new cooperation request made by the Meudon Observatory, the Director of Coimbra's Observatory issued a request to the dean of the University, who dispatched it to the Ministry of Education. The request of Manuel dos Reis was for sending Gumersindo Costa Lobo on another scientific mission to Meudon to gather information on the construction of a new device that allowed cinematographic registers of solar events. This instrument was to be installed in Coimbra and would allow Portugal's participation in an international effort to obtain a continuous solar film. Manuel dos Reis deemed Gumersindo Costa Lobo as the most capable for this assignment, given his vast expertise. It would 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 CONCLUSIONS

The cooperation between the astronomical observatories of Coimbra and Meudon is one of the oldest scientific programmes that involve two nations (Mouradian and Garcia, 2007: 8). From 1925 to the present day, the two observatories have been exchanging results, which are collected using similar instruments. Coimbra's spectroheliograph was transferred in 1966 to its new location in Santa Clara, Coimbra (Figure 13) (Silva, 1969), where it is still working (the observational process is now automatically controlled). These last renovations, which were undertaken from 1980 on, were made without changing the optical layout. They included new optical pieces, new dispersion gratings and high quality slits. The computer control, storage and data processing were enabled by the installation of a CCD camera (Mouradian and Garcia, 2007: 13).

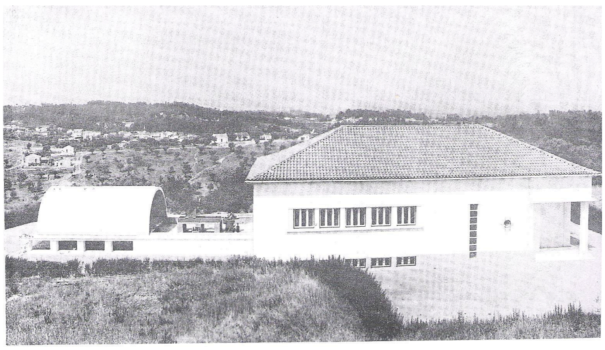


Figure 13: The present spectroheliograph building in Santa Clara, Coimbra. (Silva, A.S. da, 1969: est after 235)

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

Solar activity was an astronomical problem that prompted great attention due to the perturbation experienced on Earth as a consequence of major solar events. The important question was: *What might occur if profound alterations would extend beyond the limits in which human life can subsist*? (Costa Lobo, F., 1925a: 566). Having 250 days of solar exposure in a year, Portugal has a privileged position for solar observations. Coimbra's spectroheliograph was among the first ten (Kuiper, 1953: 728) to be built in Europe and one of the most advanced apparatus of its 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 Coimbra's Observatory) compared the methods for studying solar phenomena in Greenwich with those performed at Coimbra, concluding 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). 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). Gumersindo did not mention their locations, but we can assume that two of them were Meudon and Mount Wilson.

The *Anais do Observatório Astronómico de Coimbra* collected a massive set 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 singleness in some days. However, international historians of science have largely ignored Coimbra's investigations.[10] Several authors keep assigning the whole merit to Lucien d'Azambuja and the Meudon Observatory, and disregarding the contribution of Coimbra's Observatory, since 1931, to the *Bulletin for Character Figures of Solar Phenomena*. This situation could be due to the delayed publication of the astrophysical results, especially after Volume XI (for example the last volume of the *Anais do Observatório Astronómico de Coimbra*, number 16, on 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 (*idem*: 20). Unfortunately, Coimbra's Observatory and, in particular its astrophysics section, always faced a lack of skilled personnel to manage the abundant quantity 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 solar activity raised by the family Costa Lobo. Costa Lobo senior, besides his invention of the planar transformation to depict solar events (also called "Costa Lobo's system") and of his *Solar Sphere*, was among the first astronomers who recognized the connection between faculae and sunspots and the dependency of these two phenomena, providing a new explanation for their appearance. He was also a pioneer in classifying a new species of explosive prominences. Although he is relatively well-known in Portuguese academic circles, his son is largely unknown. If Costa Lobo senior found the means and had the contacts to create the astrophysics section, Costa Lobo junior provided the necessary technical know-how. Gumersindo Costa Lobo made continuous and impressive progress in classifying solar structures. He established the common nature of the 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 felt victim of the disease that took his life (Amorim, 1955: 28).

10 ACKNOWLEDGMENTS

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11 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, the latter also by the initiative of Francisco Costa Lobo, who was then the Director of the Faculty of Sciences of the UC. All the volumes of *O Instituto* are available on-line at http://www.uc.pt/bguc/BibliotecaGeral/InstitutoCoimbra/EdDigital.
3. Jacinto de Sousa was a professor at the Philosophy Faculty of 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 to establish in Coimbra a Meteorological and Magnetic Observatory, which was eventually built in 1862. Jacinto de Sousa supervised the installation of this observatory, being its first director. The meteorological and magnetic observations started there 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. An extensive article on the working of these instruments was published in *O Instituto* (Pinto, 1934).

5. The Jesuits had founded the Ebro Observatory in 1904. 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 (Selga, 1915: 22).
6. Costa Lobo also attended two other congresses of the Spanish Association for the Advancement of Science, which took place at Bilbao, in 1919, and at Salamanca, in 1923.
7. 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.
8. Frank Dyson's successor as Astronomer Royal and director of the Royal Observatory, Greenwich, Harold Spencer Jones, also 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.º, 377-378)
9. 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 from those of the previous cycle, near the solar equator. This situation gave way to a redefinition of the solar cycle's period as a 22 years magnetic cycle (Hale and Nicholson, 1925; Hufbauer, 1991: 87-88).
10. 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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