DE GRUYTER Open Astron. 2019; 28: 165–179

Research Article

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Solar observations at the Coimbra Astronomical Observatory

https://doi.org/10.1515/astro-2019-0015
Received Jun 19, 2019; accepted Jul 25, 2019

Abstract: In 2020, the Geophysical and Astronomical Observatory of the University of Coimbra will celebrate the 95th anniversary of its first spectroheliographic observation. Keeping a daily service of solar observations since then, making almost a century, led to one of the largest continuous solar data collections in the world. This long–term solar database is essential for studies where solar activity is involved. This work reviews the development of synoptic observations made at the Observatory of Coimbra since 1925 and presents a summary of some of the principal stages of the Observatory's history since its founding in 1772. We refer the main technical improvements and present some perspectives for the near future. One of the most significant upgrades was the installation of a CCD camera in 2007. The transition from photographic emulsion to digital recording methods allowed the development of image analysis algorithms to process solar images and improved data sharing with other institutions. This upgrade enabled also to carry–out modern climate and space weather studies. This valuable advancement makes it possible to create a new catalogue of solar observations to be published in the future.

Keywords: historic solar observations, spectroheliograms, solar phenomena, automatic detection

1 Introduction

The knowledge about the past solar activity is critical to understand the behavior of the future solar activity (Svalgaard 2013, *e.g.*). For example, solar activity waxes and wanes in on average 11-year cycles; which is now general public knowledge. We also know that the properties of the solar cycles vary on timescales of 100 years and even longer (Usoskin 2017). Thus, some of the most important processes on the Sun may take decades or centuries to reveal themselves (Owens 2013). However, we have hints for this because of existing long–term records. For that reason, the solar observation programs started several decades ago in different observatories around the world, such as Kodaikanal (Priyal *et al.*. 2014; Mandal *et al.* 2017) and Coimbra (Carrasco *et al.* 2018a,b), should be maintained. These observatories performed solar observations both in white-light and Ca II K. There are other examples of long historical solar observations programs. For instance, according to white-light observations, the Royal Greenwich Observatory (Willis *et al.* 2013) was the reference observatory during the 20th century and at the end of the 19th century. Other examples of that kind of historical solar observation are Debrecen (Baranyi *et al.* 2016), in Hungary, and the Spanish observatories (Aparicio *et al.* 2014; Curto *et al.* 2016). Regarding the solar atmosphere observations, several observatories started their solar observations in the first part of the 20th century using a spectroheliograph. Some of the reference observatories were Mount Wilson, in the USA (Lefebvre *et al.* 2005) and Meudon, in France (Mein & Ribes 1990). Other example can be found in the Arcetri Astrophysical Observatory where were produced observations of the solar atmosphere from 1926 to 1974 (Ermolli *et al.* 2009).

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The Geophysical and Astronomical Observatory of the University of Coimbra (hereafter COI) will celebrate, in 2020, the 95th anniversary of the first spectroheliographic observation. Keeping a service of solar images acquisition for almost a century led to one of the largest data collections in the world. The spectroheliographs of Coimbra (Portugal), Meudon (France), Kharkov (Ukraine) and Kislovodsk (Russia) are probably the only ones that are still active and run for more than 50 years. This equipment was constructed between 1912 and 1925 and, at that time, represented a state–of–the–art instrument in solar physics (Mouradian & Garcia 2007). The installation was finished in 1925, and the first solar image was acquired on the 12 April that year. Only in 1296, the regular acquisition had started daily, with spectroheliograms in the CaII K3 and K1 lines. Later, in 1989, the observations in the Hα line started. These three spectral lines cover the solar chromosphere and photosphere. The long–term collection of solar images obtained at COI with the same acquisition system led to a huge and homogeneous database. Such databases are important for the scientific community since it can provide valuable insights to understand the solar activity (Chatzistergos 2017; Chatzistergos *et al.* 2019; Ermolli *et al.* 2009, 2007; Foukal *et al.* 2009).

Several upgrades were made both in mechanical and optical components (Bualé *et al.* 2007). In 2007, the recording system was updated for a digital camera with computer control, storage and processing of data. This process has, among other things, made the process of acquisition of solar images faster.

The introduction of the digital process allowed the development of software tools to register and visualize the spectroheliograms and, more recently, for image processing. Such has allowed the development of an innovative process to detect sunspots and faculae regions, involving mathematical algorithms (Barata *et al.* 2018; Carvalho *et al.* 2016; Dorotovič *et al.* 2007a,b). Meanwhile, in order to have such homogeneous collection readily available for scientific purposes, the whole set of old photographic plates was digitised. For example, more than 100 years of observations of the Sun in CaII line (K1 and K3) taken by several observatories are being used in long–term variation studies of solar irradiance (Chatzistergos *et al.* 2019; Ermolli *et al.* 2009; Kariyappa & Pap 1996). Moreover, ground–based observations allow us to preserve and extend consistent data sequences and are also necessary to ensure the data continuity between different space missions.

This manuscript aims to disseminate the work done in the COI over the last 95 years with emphasis on the evolution of the solar observations study methods. For a better understanding, we present a brief historical note about the Astronomical Observatory of the University of Coimbra, we describe the spectroheliograph and the major improvements made on this equipment and on its data processing systems.

2 History of the Astronomical Observatory of Coimbra

In this section, we present a summary of some of the main stages of the COI's history, showing the most significant events in each one of them.

2.1 The birth of the COI

The idea of creating an astronomical observatory arose in 1772 during the reign of king D. José I when he decided to reform the University of Coimbra (Leonardo *et al.* 2011, *e.g.*). This reform led by the Marquis of Pombal, the prime minister at that time, was known as "*Pombalina Reform*". The Statutes of the University of Coimbra, approved in October 1772, stated the importance of Astronomy as a science essential for sea navigation. These statutes established the creation of an observatory with two main objectives: to teach astronomy lessons and to develop the astronomical sciences (Bandeira 1943). For instance, for Portuguese navigation use, the Observatory began the publication of "*Ephemerides Astronomicas*", a journal issued almost uninterruptedly until the beginning of the 21th century.

2.2 The initial project of the COI

The building planned in the 1772 University Statutes to house the astronomical observatory was finished only in 1799. The initial project, an ambitious building (Figure 1, top panels), was designed by William Elsden (?–1778), a British engineer. The construction of Elsden's project began in April 1773 and stopped in September 1775 due to the exaggerated cost (Bandeira 1943; Craveiro 1988).

2.3 An interim observatory

The rector of the University, D. Francisco de Lemos (1735–1822), aware of the time required to realize the initial project, ordered the construction of a temporary observatory. A small building was erected in the courtyard of the university, in "Paço das Escolas" (School Hall), to ensure the continuity

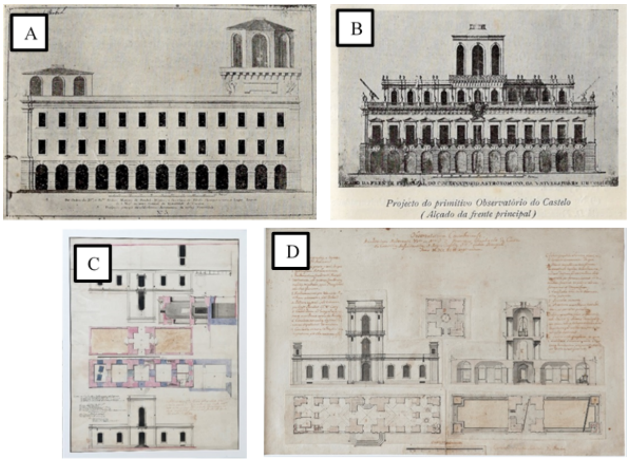

Figure 1. First (A) and second (B) version of the William Elsden's project (c. 1773) [Source: Bandeira (1943); Figueiredo (2011). Projects for the observatory building designed by Manuel Macomboa in 1790 (C) and in 1792 (D) [Source: Geophysical and Astronomical Observatory of the University of Coimbra].

Figure 3. The main building of the Geophysical and Astronomical Observatory of the University of Coimbra (A), together with the entrance (B), the Calouste Gulbenkian Foundation Astronomical Dome (C) where night sky observation evenings are made and the Planetarium (D).

Figure 2. The first building of the astronomical observatory, in "Paço das Escolas", designed by Manuel Macomboa (A) [Source: *Ilustração Portugueza*, 1907]. Aerial view of the University of Coimbra (B), in 1945, just before the demolition of the observatory building [Source: Bandeira (1943)].

of classes. This interim observatory was built between 1775 and 1779 and served almost exclusively for classes use until 1790, when the construction of the definitive observatory began.

2.4 The Macomboa's project

William Elsden died in 1778 (Franco 2016) and the observatory construction was assumed by Manuel Alves Macomboa (?–1815). The construction began in December 1790 and was finished in 1799 (Bandeira 1943). This building, more modest than the one designed by Elsden, served for about 150 years (Figure 2).

2.5 The new building in Santa Clara

In 1951, Salazar, the president of the Council of Ministers of the Portuguese Government, ordered the demolition of the observatory. This action made part of the University qualification plan performed between 1945 and 1951, which involved a profound urban intervention, clearly marked as a Salazar's product. To house the observatory, a new building was constructed in Santa Clara, in the outskirts of the city (Figure 3). At that time, this was an area with good conditions for sky night observations, with reduced human occupation, and low light pollution. The architect Edgard Duarte de Almeida was responsible for this new project and the inauguration took place in November 1951 (Rosmaninho 2006).

The new facilities in Santa Clara are located within an area of 75.886 m^2 and contain a central building, six domed pavilions, sightseeing towers and some buildings for support services (mechanical workshops, garages, residences, etc.). In 2011, the project "*A Universe of Stars Back to the Astronomical Observatory*" allowed, among other actions, the rehabilitation of two pavilions—the Photoheliograph Pavilion and the Troughton Equatorial Pavilion—intended to host the Calouste Gulbenkian Foundation Astronomical Dome (Figure 3 C) and the Planetarium, conceived and designed for education and public outreach programs (Figure 3 D). Nowadays, within the scope of its vocation, the COI organizes scientific events for specialists, such as conferences or lectures, and events for the general public, such as astronomical observations and school visits.

3 Instruments and data

The origin of spectroheliograph and their importance for solar physics, is describe in this section. Also, a brief history of the Coimbra spectroheliograph is referred here.

3.1 The origin of the spectroheliograph

It is generally considered that the birth of astrophysics took place in the early 19th century with the discovery of solar spectroscopy by Joseph Fraunhofer in 1814, and the invention of photography by Joseph Niepce in 1826 (Mouradian & Garcia 2007). The discovery of Fraunhofer lines in the solar spectrum allowed to study the chemical composition of the Sun, and its application in the observation of solar eclipses gave rise to the discovery of new structures on the solar surface (Noyes 1982). On the second half of the nineteenth century, many scientists focused on solar eclipses in order to study the solar atmosphere, visible during these brief events. However, in order to study the solar atmosphere on a regular basis, Jules Janssen (1824–1907), founder of the Meudon Observatory (located at the outskirts of Paris and merged with the Paris Observatory in 1927), decided to use spectroscopic methods. Just after the solar eclipse of August 18th, 1868, Janssen had the idea of selecting out the hydrogen line. By isolating this narrow part of the optical spectrum, it becomes possible to see prominences in the chromosphere even without an eclipse (Launay 2008). In 1889, Henri Deslandres was integrated into the Meudon Observatory to develop the spectroscopy technique. Deslandres was Janssen's successor at Meudon and in 1892, from Janssen's ideas, he built an instrument to register photographically images of the whole chromosphere. However, the spectroheliograph was also invented by George Ellery Hale, at the Kenwood Observatory, at about the same time as Deslandres, but independently (Hale 1890). According to Glass (2006), Hale was the first person to build a usable instrument, based on an idea that occurred to him in 1889 and which was the topic of his senior doctoral thesis, entitled "The Photography of Solar Prominences", at the Massachusetts Institute of Technology. The spectroheliograph was designed to obtain a monochromatic photograph of the Sun's chromosphere and proved to be a powerful instrument for solar physics, harnessed at Coimbra too. At least, 23 spectroheliographs were constructed during the first half of the 20th century, revealing the importance of this device (Chatzistergos 2017; Mouradian & Garcia 2007).

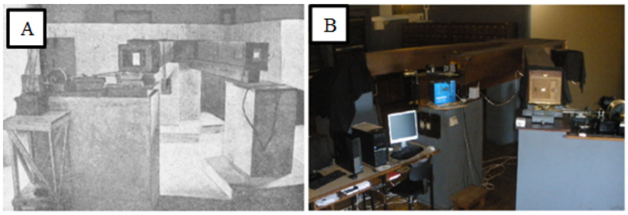

Figure 4. The spectroheliograph in 1926 (A) [Source: Lobo (1932)] and in 2019 (B).

3.2 The Coimbra spectroheliograph

Prof. Costa Lobo (1864–1945), an astronomer of the COI, was very interested in the study of the structure of the solar chromosphere and the influence that solar activity could have on terrestrial climate. For this reason and aiming to develop in Coimbra a scientific study of the Sun, Costa Lobo started in 1907 a visit to the main European observatories. He decided to install a spectroheliograph in Coimbra, equivalent to the one in the Meudon Observatory (Lobo 1932). Professor Henri–Alexandre Deslandres, director of the Meudon Observatory at that time, offered his expertise and the layout to build the spectroheliograph with the collaboration of Lucien D'Azambuja. Costa Lobo's son, Gumersindo Costa Lobo, also played an important role in this effort.

The spectroheliograph (Figure 4) was built by several enterprises. For instance, the coelostat was built by P. Gautier G. Prin Succrs., the telescope by the optician A. Jobin, the power units by Carpentier Co., and the dispersing prisms for the Ca–K spectral line observation was furnished by Germany's Zeiss Co. The installation of the spectroheliograph began in 1912, but due to the Great War it suffered some interruptions. It was finished in 1925 and the first spectroheliogram was acquired on April 12th, 1925 (Lobo 1928) (Figure 5).

The spectroheliograph pavilion was built next to the Geophysical Institute of the University of Coimbra (formerly, Meteorological and Magnetic Observatory of the University of Coimbra) (Figure 6 A, B) due to lack of space in the first COI building. The spectroheliograph was then moved to Santa Clara (a civil parish in the outskirts of Coimbra), its actual location, in 1967 (Silva 1968) (Figure 6 C, D).

The mechanical system of this instrument was designed and done so perfectly that, even after almost 95 years of operation, it shows very little signs of wear. The instruments of Coimbra and Meudon could acquire solar images with a diameter of 85 mm which was a great technical advance at that time (Mouradian & Garcia 2007).

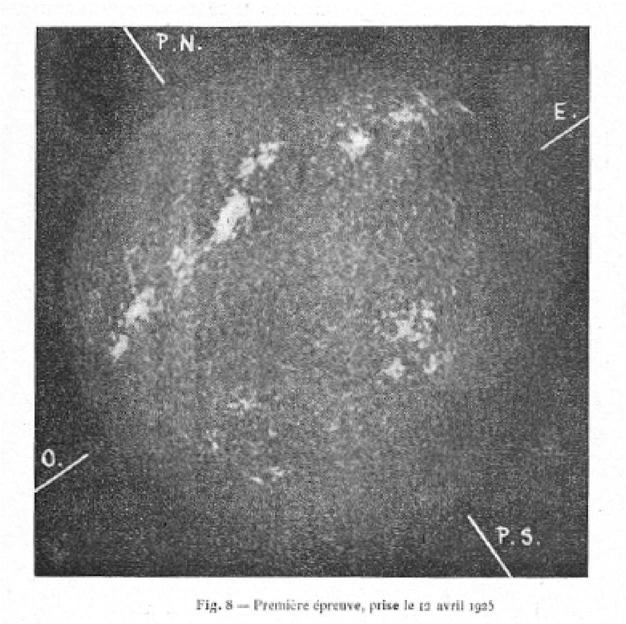

Figure 5. The first spectroheliogram acquired at the COI on April 12th, 1925 [Source: Lobo (1926)].

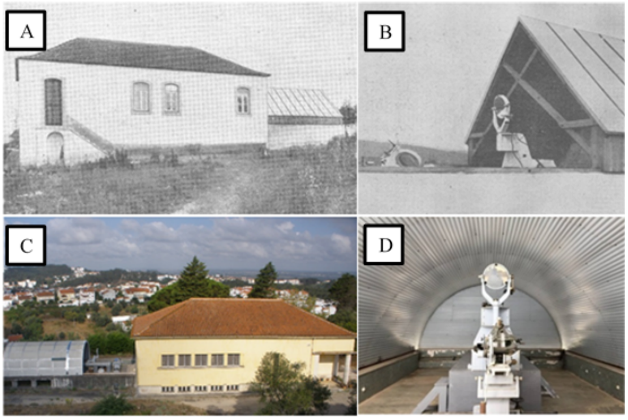

Figure 6. The spectroheliograph pavilion (A) and the coelostat (B) in 1926 [Source: Lobo (1932)]. The building where solar observations are currently made (C) and the coelostat, at the COI campus (D).

3.2.1 Description of the apparatus and improvements

The spectroheliograph is an instrument based on mechanical principles (Klvaňa *et al.* 2007). Due to the transversal shift of the objective lens, the solar disc moves gradually across the entrance slit of the spectroheliograph, and at the same time, a photographic plate moves synchronously in front of the exit slit. The moving plate is exposed to a narrow part of the spectrum that passed through the exit slit. This way, the whole solar disc in the selected narrow wavelength band is recorded on the plate make it possible to obtain spectroheliograms in each wavelength separately.

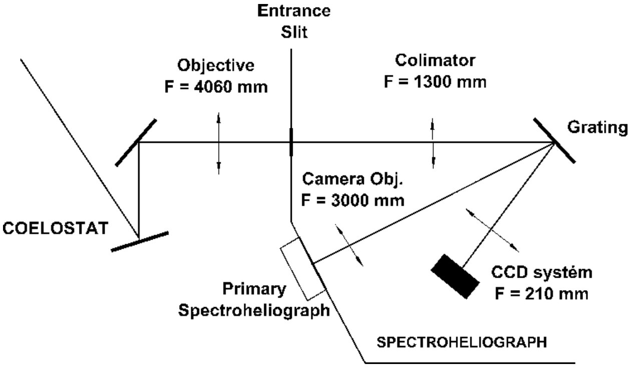

Figure 7. Optical system of the COI spectroheliograph [Source: Klvaňa *et al.* (2007)].

The optical system of the spectroheliograph is composed by a coelostat and a horizontal telescope (Figure 7) with an objective lens of focal length F = 4060 mm and diameter 250 mm. The coelostat is composed of two mirrors, a primary with 400 mm in diameter and a secondary with 305 mm, that send the solar light towards the telescope objective. The telescope is fed by the coelestat and then the light is projected through a first slit into a spectroscope. A second slit is used as a monochromator to isolate a single wavelength. The image of the Sun is obtained by scanning the entire solar disk at the desired wavelength, and then the solar disk is reconstituted by juxtaposition of all linear records.

Over the years, several interventions have been made on the optical and mechanical components of the spectroheliograph. In 1980, an upgrade of the scanning components was undertaken without changing the optical layout, to preserve the homogeneity of the spectroheliograms collection (Mouradian & Garcia 2007). From 1988 to 1992, the coelostat mirrors, the telescope, and the spectrophotometer optics were replaced. The old lenses were replaced by especially computed modern glass ones, the coelostat mirrors are now of low–expansion Zerodur glass, from the Schott Co., and the old three–prism dispersion system was replaced by a single blazed grating for Ca II K and Hα observations (Bualé *et al.* 2007). The image recording system was also updated. In the beginning, the image recording was made on a photographic emulsion, on a glass plate. In 1970, the glass plates were replaced by film, which allowed easier handling and avoided the risk of breaking. In 2007, with the collaboration of the Ondřejov Observatory (Czech Republic, Prague), the record system was updated by a 12–bit charge–coupled device (CCD). Recording spectroheliograms in digital format has many advantages, such as obtaining images at exactly defined wavelengths and calculate Doppler velocities. This update made it possible to add observations in the red continuum near the Hα line and, after an upgrade of the data–processing software in 2009, to obtain also Hα dopplergrams (Garcia *et al.* 2010b). The dopplergrams allow, with other information, to detect the effect of solar rotation. Finally, the usage of CCD cameras helps to prevent health damage of the observer, namely eye damage and respiratory tract damage, as it is greatly reduced the amount of time the observer needs to look at the Sun, regardless of being protected, and it is no longer necessary to handle chemicals to obtain the final image. The exposure time for CCD data is 80 seconds same as for plates.

For more technical information about the spectroheliograph and the process of registration and visualisation of spectroheliograms see Garcia *et al.* (2010a,b) and Klvaňa *et al.* (2007).

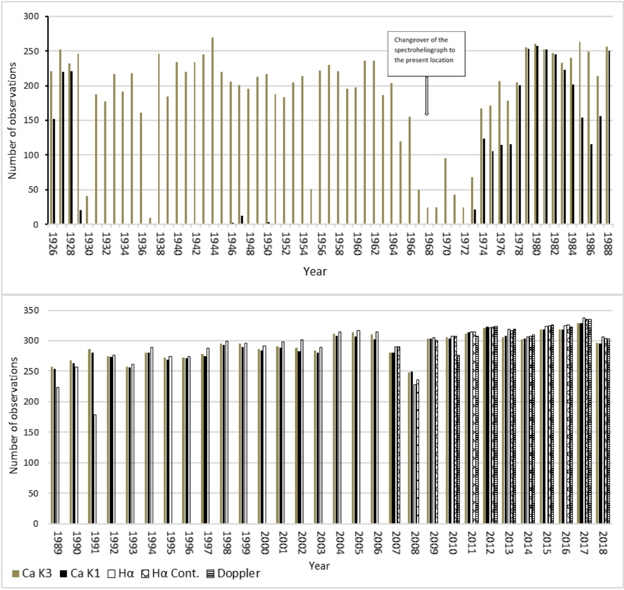

Figure 8. Number of observations at the COI since 1926.

3.3 The solar observations of the COI

In the COI it was possible to obtain CaII K1 and CaII K3 images daily since 1926, whenever the weather permitted it, corresponding to 8 solar cycles. The first experiments to obtain images in the Hα line were realized in 1939, after the installation of a dispersion grating. However, due to the Second World War, it was not possible to obtain the special plates needed to record this type of images (Reis 1940). Only after 1989, the acquisition of Hα images had started in a regular way.

Nowadays, high–quality full disc spectroheliograms can be obtained in four wavelengths: 3933.7 Å (CaII K3), 3932.3 Å (CaII K1), 6562.8 Å (Hα) and 6558.7 Å (Hα red continuum) (Garcia *et al.* 2010a). An image is usually 1000×1000 pixels large with a plate scale 2”.2/pixel, so that the diameter of the solar disc is approximately 880 pixels, *i.e.*, 86.4 mm (Garcia *et al.* 2011). The bandwidth in CaII K is 0.15 Å and in H-alpha is 0.26 Å.

Until April 2019, were acquired at the COI, about 48000 observations of which 30500 were made on plates and the remainder with the CCD. For the period between 1926 and 1964 the number of observations was about 200 per year and after moving the instrument to the new site it started to increase. Since 1998, the number of observations has been reaching about 300 days per year, because the work schedule began to include the weekends. The installation of the CCD camera in 2007 made it possible to increase this number. The reasons lie in two key factors: money and time. Regarding the monetary factor, due to the extremely high cost of plates or photographic films, the observations were only made if there was the certainty that the weather allowed a good observation. On the other hand, with the CCD camera, this problem is inexistent since the observations can be repeated without any additional cost. Relatively to the second factor, the time to get results, and to repeat again if necessary, is quite different. With the CCD camera, after 4 minutes, it is possible to see if an image is in required conditions. With the analogic method was needed at least 30 minutes, which could make the acquisition of the image unfeasible, especially in cloudy days.

It should be noted that the increase in the number of observation days over time is also related to climate change, since the atmospheric conditions now seem more favorable to observations, with less rainy periods.

For the period 2010–2018, the average annual values exceed the 315 observations per year, which is probably the best contribution currently available in Europe. The numbers of observations per year and wavelength, since 1926, are shown in Figure 8.

The data on sunspots can be found in Carrasco *et al.* (2018b), for instance, the Coimbra sunspot number for the period 1929 – 1941.

Total numbers of spectroheliograms in all wavelengths obtained in the period from 1926 to 2019, are summarized in Table 1.

The natural evolution of technology leads also to the emergence of new needs. Hence, to have a standardised collection available for several scientific purposes, the entire collection of old photographic plates was digitised, from 2000 to 2006. The digitised spectroheliograms are stored in the form of 8–bit JPEG images with a resolution of 12 pixels/mm (*i.e.*, 1”.8/mm) (Garcia *et al.* 2011).

Table 1. Total numbers of observations from January 1st, 1926, to Abril 30th, 2019.

Wavelength	Ca II K3	Ca II K1	Hα	Hα Cont.	Dopplergram	Total
Observations	20505	11612	8719	3889	3024	47749

The spectroheliograms have always been shared with Meudon, permitting to mutually fill most of the occasional gaps in the observations, and have been sent to Zurich to integrate the "Bulletin for Character Figures of Solar Phenomena", published by the International Astronomical Union (Reis 1940).

The collaboration between Coimbra and Meudon is one of the oldest scientific exchanges between Portugal and France (Mouradian & Garcia 2007), a collaboration that is very important to complete the solar archive at Meudon (Bualé *et al.* 2007).

Currently, all spectroheliograms are publicly available on the COI website (http://www.astro.mat.uc.pt/novo/observatorio/site/index2.html) ("*Centro de Dados-Arquivo Obs.Solares*"). This site provides solar images, in three spectral lines of Ca (K1 and K3) and Hα, obtained from 1926 to 2007. On the Bass2000 database (http://bass2000.obspm.fr/home.php?end=1562767787&exp=12) images after 2007 in four wavelengths: (CaII K3, CaII K1, Hα and Hα red continuum) and a dopplergram, are available daily. The Portuguese Institute for Sea and Atmosphere site (https://www.ipma.pt/pt/espaco/sol/) provides the same set of images. On the site of the Global High-Resolution H-alpha Network (http://ghn.njit.edu/index.php) images Hα (original data and contrast-enhanced) obtained at the COI are available.

4 Solar phenomena study

The study of solar phenomena, such as sunspots and facular regions, is important to understand the solar activity and its effects on the Earth's climate system (Haigh 2007; Usoskin 2017). This section refers to the advances made in Coimbra to analyze the spectroheliograms, from traditional to automatic methods, to extract parameters of solar activity.

4.1 Analysis of the COI spectroheliograms

In the early years, the parameters of solar activity were measured by hand on daily spectroheliograms. The position, dimension, number of structures, type and evolution of sunspots, plages, filaments and prominences were registered by the observer. To accomplish this task, the spectropheliograph allowed, since the beginning, the acquisition of projected images with 40 cm diameter (Lobo 1932). The solar light beam, sent by the coelostat, was deflected towards a vertical screen before reaching the first slit to obtain projected images. These images were used to perform the sunspots analysis by visual interpretation of the observer, who manually recorded their shapes, sizes, and positions. This process is still in use in many observatories worldwide to maintain the homogeneity of the sunspot number series. To specify the coordinates of solar phenomena, Prof. Costa Lobo proposed an innovative process: a planar transformation of the Sun images. Due to the distortion effect towards the solar limb it was necessary to correct the Sun images. The solar photosphere should be transformed into a flat surface, with coordinates, so the distortion of the shape of the solar characteristics is minimized. Costa Lobo proposed to divide the initial photographic image into nine parallels of 10° each and thirty–six equal–angle sectors displayed in a radial manner (Figure 9 A, B). The heliographic coordinates of the solar features were determined on the flattened image. With this method, it was possible to register the position of sunspots and faculae. This original solution was temporarily adopted by the Observatory of Meudon (Deslandres 1929). The area of sunspots was measured directly on the projected image, without loss of quality (Lobo 1932).

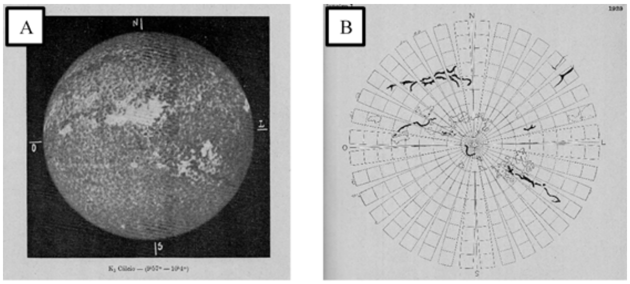

Figure 9. Ca K1 solar image acquired on January 1st, 1929 (A), and the planar transformation, of the same image, purposed by Costa Lobo to register the position of sunspots and facular regions (B) [Source: Lobo (1928)].

The process for referencing solar phenomena using planar transformation was time–consuming, even with the help of appropriate tables (Lobo 1932). Costa Lobo developed a second device to simplify this process, named "*Esfera Solar de Costa Lobo*" (The Costa Lobo's Solar Sphere). This device was used to perform the transformation of the

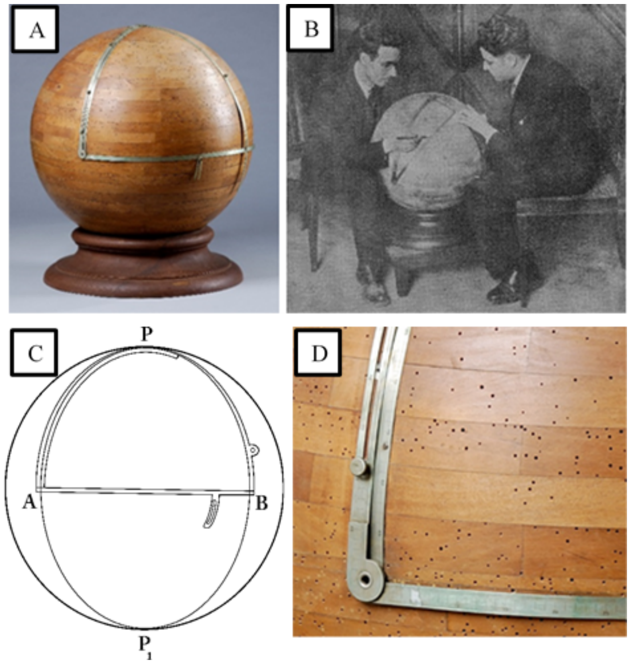

Figure 10. The Costa Lobo's Solar Sphere (A) (Photo by Gilberto Pereira) and the working process with the sphere (B) [Source: Lobo (1934). The outline draw of the metallic armature (C) [Source: Lobo (1934)] and a detail of the graduated armature (D).

position angle and distance coordinates to heliocentric coordinates with higher precision (0.1°). The sphere did not waive the use of the appropriate tables, but it reduced the time and number of people needed. Figure 10 shows the device created by Costa Lobo, to calculate the coordinates of solar phenomena, and the working process with it.

The sphere was constructed in wood, with a metallic armature calibrated to withstand temperature differences. It has a diameter of 573 mm, so that half a millimeter of the maximum circle arc corresponds to a tenth of one degree, *i.e.*, 6'. The graduated metallic armature allowed to obtain the heliocentric coordinates of sunspots by moving the sides PB and AB.

In the 1970´s, a more sophisticated coordinate system was adopted to register the position of solar phenomena. The helio–reference of solar events was made with the aid of Stonyhurst discs directly on the spectroheliograms (Figure 11). The Stonyhurst disk is a grid of meridians and parallels with an equidistance of 10°, which allows obtaining heliographic coordinates. For instance, to determine the heliographic latitude and longitude of sunspots, Stonyhurst disks are superimposed on images aligned along the North–South and East–West axis. A set of 8 disks is available for use depending on the position of the Earth relative to the Sun. Based on the grid of meridians and parallels and determining the scale factor to apply, it is possible to determine the heliographic coordinates with an accuracy of 1°. Presently, this process is still in use.

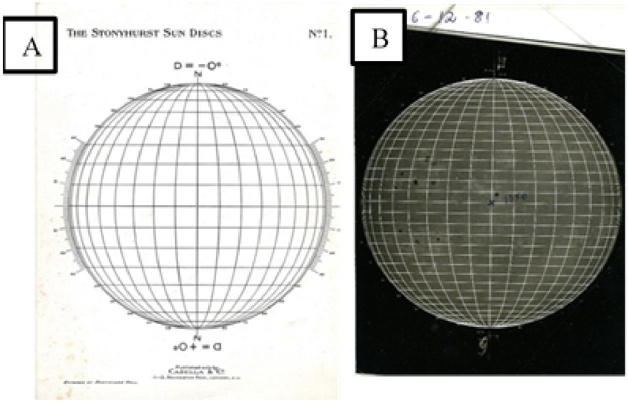

Figure 11. A Stonyhurst disk (A) and a spectroheliogram with the Stonyhurst disk, acquired at the COI on December 6th, 1981 (B) [Source: Geophysical and Astronomical Observatory of the University of Coimbra].

During the middle of the 20th century, the influence of solar activity on Earth began to be studied more intensively (Abbot *et al.* 1923; Smith & Gottlieb 1975; Eddy 1976; Reid 1987; Bond *et al.* 2001, *e.g.*). After the Second World War, scientists discovered that solar activity has an influence on the radio frequency propagation in Earth's upper atmosphere (Wells 1943). At the same time, the space era began (as well as the computational era), with new observation instruments on board of satellite missions like Ulysses (Wenzel *et al.* 1992), SOHO (Bonnet & Felici 1997), TRACE (Wolfson *et al.* 1997), and SDO (Pesnell *et al.* 2012).

The success of several solar missions in conjugation with the use of digital image processing techniques has allowed getting information about solar activity in a prompt and efficient way (Gill *et al.* 2010). Naturally, the automation of the Coimbra spectroheliograph in 2007, together with these digital methods, allowed to develop automatic methodologies for the extraction of facular regions and sunspots. Dorotovič *et al.* (2007a) had developed a semi–automatic method to detect facular regions using an intensity threshold–based software tool. Currently, Coimbra spectroheliograms are processed based on Mathematical Morphology (MM). Due to the geometry of the solar phenomena present in the COI spectroheliograms, automatic detection methods using MM were implemented and analyzed, both for sunspots on the Hα continuum spectral line (Carvalho *et al.* 2016) and for facular regions on the Ca II K3 spectral line (Barata *et al.* 2018). The results from different sunspot detection methods are also compared by Carvalho *et al.* (2016). Some examples of results obtained after the ap-

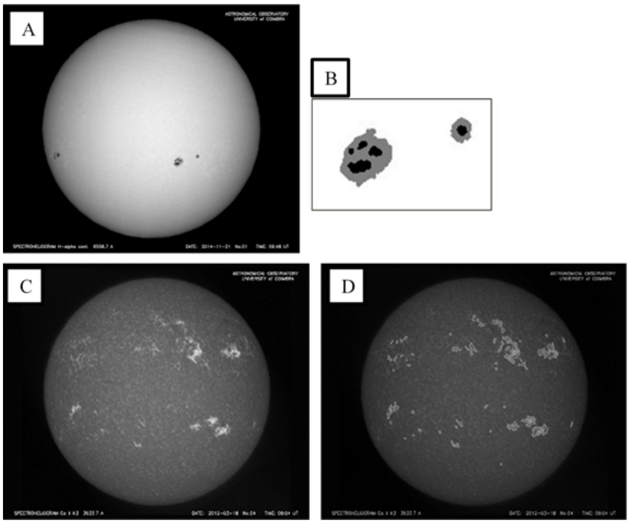

Figure 12. Sunspots observed on Hα continuum image (A) and the results of the automatic detection method (B) [Source: Carvalho *et al.* (2016)]. Facular regions observed on CaII K3 image (C) and results of the automatic detection method developed by COI members (D). Other examples can be consulted in Barata *et al.* (2018).

plication of mathematical methods to Sun images acquired in Coimbra are shown in Figure 12.

4.2 The COI catalogues

In 1922, Prof. Costa Lobo became Director of the COI and decided to publish the results of daily solar observations, made with the spectroheliograph. He then started the publication of a catalogue with the parameters of solar phenomena observed on the spectroheliograms. A first publication was made with the results for the years 1926 and 1927 (Lobo 1928). After that, a new catalogue was created under the title "*Anais do Observatório Astronómico da Universidade de Coimbra – Fenómenos Solares*" (Annals of the Astronomical Observatory of the University of Coimbra – Solar Phenomena). Between 1932 and 1986, 17 volumes were published, reporting information about the observations made during the period 1929–1944 and 1979 as well (see Appendix A). Parameters such as position, size, and number of sunspots, facular regions, filaments, and prominences were daily reported (Figure 13). This record constitutes a long and homogeneous study of solar activity for this period (Mouradian & Garcia 2007). The most significant spectroheliograms were also included in the last pages of those volumes, together with figures representing annual data.

The COI catalogues have been distributed by several astronomical observatories around the world, and they provided data for several scientific papers. Recently, these catalogues were digitised to produce a machine–readable version and the sunspot records have been compared with records made at the Royal Greenwich Observatory (Carrasco *et al.* 2018a,b). The results demonstrated that the historical catalogue compiled by the COI contains reliable sunspot data and therefore it can be considered for studies on solar activity (Carrasco *et al.* 2018b).

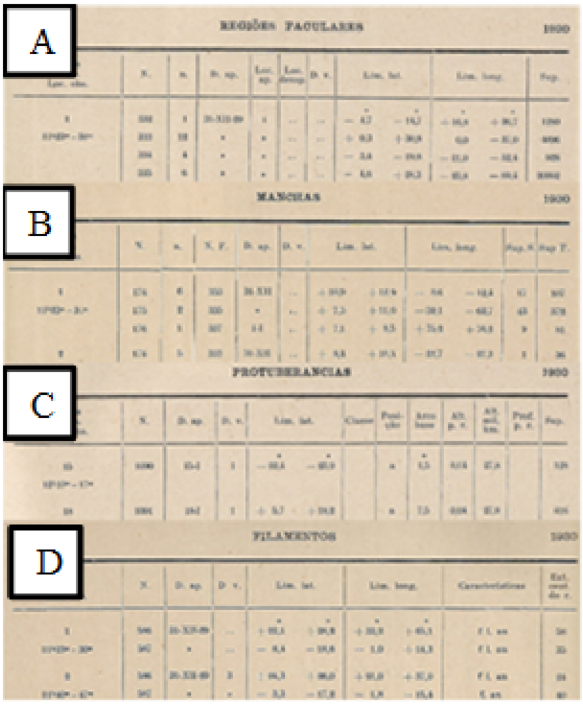

Figure 13. A composite image showing the types of charts published in the COI catalogue: facular regions (A), sunspots (B) prominences (C), and filaments (D) [Source: Lobo (1934)].

A monthly publication entitled "*Posição longitudinal das manchas solares e dos filamentos cromosféricos*" (Longitudinal position of sunspots and chromospheric filaments) was published from 1990 to 1991. It shows graphs on the longitudinal position of sunspots (diameter > 4000 km) and the main chromospheric filaments obtained from monochromatic images of the solar photosphere and chomosphere. In addition to the mentioned publications, solar observations in the Coimbra spectroheliograph allowed to produce science for almost a century. Examples of usage of the Coimbra spectroheliograms and international scientific collaborations are summarized in Table 2.

Table 2. International scientific collaborations with the Geophysical and Astronomical Observatory of the University of Coimbra, using data obtained by the spectroheliograph.

Reference	Subject
Andretta *et al.* 2000	Observational evidence of the efect of small–scale velocities in enhancing the intensity of the He II $\lambda 304$ line with respect to other transition region emission lines using COI Hα spectroheliograms.
Barata *et al.* 2018	Mathematical morphology approach applied to the COI's CaII K3 series, in order to create a tool to detect and analyze chromospheric plages during the solar cycle 24.
Bualé *et al.* 2007	Revision and improvements, both optical and mechanical, that the COI spectroheliograph underwent since its installation.
Bumba *et al.* 2007	Distribution and concentration of the solar magnetic fields from the Wilcox observatory synoptic charts (using COI spectroheliograms especially taken in the Ca II K lines).
Bumba *et al.* 2003	Photospheric background Doppler velocity field during the development of active regions (using the spectroheliograms taken at the COI in the CaII K3 and Hα lines).
Bumba *et al.* 1996	Investigation about the development of a complex activity, which took place in the Sun southern hemisphere between July 1991 and April 1992 using series of COI's CaII K3 line spectroheliograms.
Bumba & Garcia 1994	Comparison of active regions position, estimated from observations of the whole solar disk in COI's Ca II K_{1V} during the period 1977–1989, and 1) the time–dependent latitudinal distribution of background solar magnetic fields and 2) the latitudinal shifts of boundaries of their polarities.
Carrasco *et al.* 2018a	Analysis of the secular variation of the penumbra–umbra area ratio in sunspot groups with areas lower than 100 millionths of solar hemisphere. To study this ratio, proposed by Hathaway (2013), the data contained in the sunspot catalogue published by the COI from 1929 to 1941 was used.
Carrasco *et al.* 2018b	The sunspot catalogue published by the COI for the period 1929–1941 was digitized, in order to provide a machine–readable version. Reconstructions for the sunspot number index and sunspot area are made using the Coimbra catalogue and were compared with the 1) the sunspot number index (version 2) and 2) the Balmaceda sunspot area series (Balmaceda *et al.* 2009) and 3) with records made at the Royal Greenwich Observatory.
Carvalho *et al.* 2016	Automatic methods test for sunspots detection, on a set of Coimbra spectroheliograph Hα images belonging to the solar cycle 24.
Chatzistergos 2017	Analysis of historical solar observations and long-term changes in solar irradiance using Ca II digitised plates from the COI, among others.
Chatzistergos *et al.* 2018	Development of an automatic process and photometric calibration method, applied to historical COI's Ca II K digitised images from 1994 to 1996.
Dorotovič *et al.* 2010	Software tool to determine the NSA of the area of bright chromospheric plages, measured in the Ca II K3 spectroheliograms registered since 1926 in the COI as well as evolution of sizes of these areas from 1996 to 2006.
Dorotovič *et al.* 2007a	Results of a software tool for automatic image processing and feature recognition of sunspots, developed using images CaII K1 obtained at the COI.
Dorotovič *et al.* 2007b	Software tool to calculate the north–south asymmetry of the area of bright chromospheric plages, as measured in the COI CaII K3 spectroheliograms registered since 1926.
Garcia *et al.* 2010a	First results of velocity measurements of chromospheric velocity fields by means the Coimbra University spectroheliograph register.
Garcia *et al.* 2010b	Demonstration of the good quality of spectroheliograms recorded in 2010 by the COI spectroheliograph, taken during standard observing conditions, influence of clouds, and the effects introduced by a visualization filter.

Table 2. ...continued

Reference	Subject
Garcia *et al.* 2011	Characteristics description of the photographic and digital spectroheliograms, statistics of observations and utilization of Coimbra spectroheliograms by the solar community.
Gonçalves *et al.* 2014	Investigation of the dynamic evolution of time series describing plage regions areas observed daily at the COI, in each one of the solar hemispheres, during solar cycles 21–23.
Jordan *et al.* 1999	Role of the small–scale nonthermal velocities in enhancing the intensity of the He 304 Å line. The ground–based observations used in this work were taken at the COI.
Jordan *et al.* 1997a	Analysis of the four most energetic events occurring in the active–region NOAA 3804 during the period July 9–September 4, in the light of two different current models for prominence eruption and CME activation, using a time series of K3 spectroheliograms, taken at the COI.
Jordan *et al.* 1997b	Evaluation of the hypothesis that the 304 Å line is formed by collisional excitation in the quiet Sun where ground–based images in the 0.5 Å wing of Hα taken at the COI.
Klvaňa *et al.* 2007	Application of a CCD chip in the COI spectroheliograph and special issues that this action have brought, and presentation of alternative spectroheliograph usages for measuring Doppler velocities.
Koleva *et al.* 2012	Study on the morphology as well kinematic and helicity evolution of a loop–like prominence, during its eruption, using Hα images obtained at the COI, among others.
Lobo 1928	Results obtained from the Spectroheliographic Observations made in the years 1926 and 1927 at the COI.
Mouradian *et al.* 1995	Research about the location of filaments and active regions at the base of corona in order to associate them with various structures observed during the total solar eclipse of November 3, 1994. Spectroheliograms Hα, K3 and K_{1v}, taken at the Coimbra and Meudon observatories, were used in this work.
Rosales 2017	Role and dynamics of different current systems for storm-time activity at mid–latitude ground level, using observational data of the COI.

4.3 The present towards the future

In 2011, due to the similar and somewhat complementary missions of the Geophysical Institute of the University of Coimbra, founded in 1864, and the Astronomical Observatory of the University of Coimbra, it was created a commission to define the mission, strategy, internal organization and funding of these institutions. The result of this reflection was the merging of the two institutions into a new one joining all workers and resources. It was also recommended that the new institution should host research centers which develop research with the data collected by it, with the inherent advantage that the research centers can give technical and financial support to the instruments and other equipment, including new acquisitions. Thus, in 2012, both institutes merged into the COI, which also became the headquarters of the Center for Earth and Space Research of University of Coimbra (CITEUC). CITEUC develops research fundamentally on the areas of Astronomy, Solar Physics, Geophysics, and History of Science. CITEUC are also involved in several activities of dissemination and outreach, mostly of those of its hosting institution, the COI. By carrying out research on the aforementioned fields, CITEUC researchers ensure the continuity of the COI through various projects.

Regarding Solar Physics, the future began with the implementation of digital methods to study solar activity. The use of a CCD camera with computer control, storage and processing of data led to a great improvement, namely in the image quality and image exchange with other institutions. Digital spectroheliograms made possible the development of an innovative process to detect and record facular regions, involving mathematic algorithms (Carvalho *et al.* 2016; Barata *et al.* 2018). The excellent results of these works encourage to pursuit the research of new automatic algorithms to detect and track solar phenomena such as sunspots and filaments. Despite the interruption of the publication of the solar observation catalogues, the acquisition of Sun images and subsequent analysis on solar phenomena continues nowadays. The results were published in several works but there is no aggregation publication where all the information can be consulted. One of our goals is, precisely, to resume the publication of the catalogues, in digital format, with information equivalent to that of the last editions, but complementing it with other data obtained by the algorithms developed by Barata *et al.* (2018) and Carvalho *et al.* (2016). It is also a future goal to compare the results obtained from the application of these mathematical algorithms with the data resulting from analogical treatment of images (manual methods). This future digital catalogue of solar observations will be published and available online at the COI site.

The future of the COI also depends on their role to promote dissemination activities to the public in general, namely astronomical observations, visits to the historical collection of instruments and planetarium sessions. Over the last three years, an enormous effort has been made in all these activities. As a result, the COI now gets approximately 5000 visitants per year. Regardless of focusing exclusively on the studies of solar activity in Coimbra, which was our goal, we should mention that geophysics also plays a very important role in the COI (seismic, geomagnetic and meteorological stations).

5 Conclusions

The spectroheliograph of the Geophysical and Astronomical Observatory of the University of Coimbra has been acquiring solar images since 1925 and is one of the few ground-based instruments for solar observations that are still active and run for more than 50 years. It led to one of the largest continuous solar data collections in the world and provided valuable inputs to understand solar activity. The maintenance and preservation of this instrument are of incontestable value for scientific community.

The Coimbra spectroheliograph has been improved and updated following the technological developments. The several upgrades made on the mechanical and optical components and the implementation of digital methods allowed to easily share data with other institutions. Furthermore, this upgrade led to a great enhancement on the quality of images and allowed the development of an innovative process involving automatic methodologies for extraction of facular regions and sunspots. This upgrade will also make possible the study of long–term variations in solar irradiance and climatic studies among others.

The development of automatic methods to analyse solar images has brought advantages when compared with manual interpretation methods, especially in what concerns the subjectivity of the observer. Additionally, automatic methods are versatile due to their ability for characterizing and quantifying solar activity parameters, as well by applicability to any type of image such as high–resolution images or spectroheliograms. Presently, data on solar phenomena observed at the Astronomical Observatory of the University of Coimbra are processed with the new software tool developed by Barata *et al.* (2018) and a new catalogue of solar observations is being prepared for publication.

Even with new instruments and space missions, it is still important to keep the historical instruments running, such as the Coimbra spectroheliograph, since their data homogeneity and long data series are being very crucial to maintain such observational programs.

Moreover, ground–based observations allow us to preserve and extend consistent data sequences and are also necessary to establish the link and the continuity between different space missions. For that reason, the almost one century–old solar observation programs at the COI should be kept running.

Acknowledgment: This study was also partially supported by the Portuguese Government through the Foundation for Science and Technology–FCT, CITEUC Funds (project: UID/Multi/00611/2013), CMUC Funds (UID/MAT/00324/2019) and FEDER– European Regional Development Fund through COMPETE 2020–Operational Programme Competitiveness and Internationalization (project: POCI–01–0145–FEDER–006922) and FEDER–Junta de Extremadura (Research Group Grant GR15137 and project IB16127). Sara Carvalho's work has been funded by FCT grant SFRH/BD/107894/2015. Ana Lourenço´s work was supported by the project ReNATURE–Valuation of Endogenous Natural Resources in the Central Region (CENTRO–01–0145–FEDER–000007–BPD16). This research was supported by the Economy and Infrastructure Counselling of the Junta of Extremadura through project IB16127 (Víctor Carrasco).

Disclosure Statement: No potential conflict of interest was reported by the authors.

References

Abbot, C.G., Fowle, F.E., & Aldrich, L.B. **1923**, *Ann. Astrophys. Obs.*, 4, 177–215.

Andretta, V., Jordan, S.D., Brosius, J.W., Davila, J.M., Thomas, R.J., Behring, W.E., et al. **2000**, *Astrophys. J.*, 535, 438–453.

Aparicio, A.J.P., Vaquero, J.M., Carrasco, V.M.S., & Gallego, M.C. **2014**, *Sol. Phys.*, 289, 4335.

Balmaceda, L.A., Solanki, S.K., Krivova, N.A., & Foster, S. **2009**, *J. Geophys. Res.*, 114, A07104.

Bandeira, J. **1943**, *Universidade de Coimbra: edifícios do corpo central e Casa dos Melos*, Gráfica de Coimbra, Coimbra, Portugal (in Portuguese).

Baranyi, T., Győri, L., & Ludmány, A. **2016**, *Sol. Phys.*, 291, 3081-3102.

Barata, T., Carvalho, S., Dorotovic, I., Pinheiro, F., Garcia, A., Fernandes, J., et al. **2018**, *Astron. and Comput.*, 24, 70–83.

Bond, G., Kromer, B., Beer, J., & Muscheler, R., Evans, N., Showerset et al. **2001**, *Science*, 294, 2130–2136.

Bonnet, R.M. & Felici, F. **1997**, *Advan. in Space Res.*, 20, (12), 2207–2218.

Bualé, Z., Mouradian, Z., & Schmieder, B. **2007**, In: Heinzel, Petr, Ivan Dorotovič and Robert J. Rutten (Eds.), Proceedings of *The Physics of Chromospheric Plasmas*, 368, Astronomical Society of the Pacific Conference Series, San Francisco, 15–16.

Bumba, V., Klvaňa, M., & Garcia, A. **2007**, In: Heinzel, Petr, Ivan Dorotovič and Robert J. Rutten (Eds.), Proceedings of *The Physics of Chromospheric Plasmas*, 368, Astronomical Society of the Pacific Conference Series, San Francisco, 511-514.

Bumba, V., Klvaňa, M., & Garcia, A. **2003**, In: Proceedings of the ISCS "Solar variability as an input to the Earth's environment" (23–28 June 2003, Tatranská Lomnica, Slovak Republic).

Bumba, V., Klvaňa, M., Kálmán, B., & Garcia, A. **1996**, *Astr. & Astroph.*, Suppl. Ser., 117, 291–301.

Bumba, V. & Garcia, A. **1994**, *Sol. Phys.*, 155 (2), 257–265.

Carrasco, V.M.S., Vaquero, J.M., Trigo, R.M., & Gallego, M.C. **2018a**, *Sol. Phys.* 293, 104.

Carrasco, V.M.S., Vaquero, J.M., & Gallego, M.C., Fernandes, J., Barata, T., Lourenço, A. **2018b**, *Sol. Phys.*, 293,153.

Carvalho, S., Pina, P., Barata, T., Gafeira, R., & Garcia, A. **2016**, In: Dorotovic, Ivan, Catherine E. Fisher, and Manuela Temmer (Eds.). Proceedings of the *Ground–based Observations in the Space Instrumentation Era*, 504, Astronomical Society of the Pacific Conference Series, San Francisco, 125–129.

Chatzistergos, T. **2017**, *Analysis of historical solar observations and long-term changes in solar irradiance*, PhD thesis, Georg-August-Universität Göttingen.

Chatzistergos, T., Ermolli, I., Krivova, N., & Solanki, K. **2019**, *Astr. & Astroph.*, 625, A69.

Chatzistergos, T., Ermolli, I., Solanki, K., S., & Krivova, N. **2018**, *Astr. & Astroph.*, 609, A92.

Craveiro, M.L. **1988**, *Guilherme Elsden e a introdução do neoclassicismo em Portugal*. Instituto de História da Arte da Faculdade de Letras da Universidade de Coimbra (Ed.), Coimbra, Portugal (in Portuguese).

Curto, J.J., Solé, J.G., Genescà, M., Blanca, M.J., & Vaquero, J.M. **2016**, *Sol. Phys.*, 291, 2587-2607.

Deslandres, H. **1929**, *Comptes Rendus Academie Sciences de Paris,* 189, 277 (in French).

Dorotovicˇ, I., Rybaḱ, J., Garcia, A., & Journoud, P. **2010**, In: Proceedings of the 20th National Solar Physics Meeting (31 May – 4 June, Papradno, Slovakia), 58–63.

Dorotovič, I., Fernandes, J., Fonseca, J.M., Mora, A., Moreira, C., & Ribeiro, R.A. **2007a**, In: Heinzel, Petr, Ivan Dorotovič and Robert J. Rutten (Eds.), Proceedings of *The Physics of Chromospheric Plasmas*, 368, Astronomical Society of the Pacific Conference Series, San Francisco, 523-526.

Dorotovič, I., Journoud, P., Rybák J., & Sýkora J. **2007b**, In: Heinzel, Petr, Ivan Dorotovič and Robert J. Rutten (Eds.), Proceedings of *The Physics of Chromospheric Plasmas*, 368, Astronomical Society of the Pacific Conference Series, San Francisco, 527-532.

Eddy, J.A. **1976**, *Science*, 192, 1189–1202.

Ermolli, I., Solanki, S., Tlatov, A. G., Krivova, N. A., Ulrich, R. K., & Singh, J. **2009**, *Astr. Jour.,* 698, 1000-1009.

Ermolli, I., Tlatov, A., Solanki, S., Krikova, N., & Singh, J. **2007**, In: Heinzel, Petr, Ivan Dorotovič and Robert J. Rutten (Eds.), Proceedings of *The Physics of Chromospheric Plasmas*, 368, Astronomical Society of the Pacific Conference Series, San Francisco, 533–538.

Figueiredo, F. **2011**, *José Monteiro da Rocha e a actividade cientifica da "Faculdade de Mathematica" e do "Real Observatório da Universidade de Coimbra": 1772–1820*, PhD thesis, Universidade de Coimbra, Coimbra, Portugal (in Portuguese).

Foukal, P., Bertello, L., Livingston, W.C., Pevtsov, A.A., Singh, J., Tlatov, A.G., & Ulrich, R.K. **2009**, *Sol. Phys.*, 255, 229–238.

Franco, M.S. **2016**, http://www.matildesousafranco.com. (29/10/2108–11h a.m) (in Portuguese).

Garcia, A., Sobotka, M., Klvaňa, M., & Bumba, V. **2011**, *Contrib. Astron. Obs. Skaln. Pleso*, 41, 69–72.

Garcia, A., Klvaňa, M., & Sobotka, M. **2010a**, *Cent. Eur. Astr. Bull.*, 34, 47–56.

Garcia, A., Klvaňa, M., Sobotka, M., & Bumba, V. **2010b**, In: Proceedings of the 20th National Solar Physics Meeting (31 May – 4 June, Papradno, Slovakia), 206–209.

Gonçalves, E., Mendes–Lopes, N., Dorotovič, I., Fernandes, J., & Garcia, A. **2014**, *Sol. Phys.*, 289, 6, 2283–2296.

Gill, D., Fletcher, L., & Marshall, S. **2010**, *Sol. Phys.,* 262, 355–371.

Glass, I. **2006**, *Revolutionaries of the Cosmos: The Astro–Physicists*. Oxford University Press., Oxford.

Haigh, J. **2007**, *Sol. Phys*. 4, 2.

Hale, G. **1890**, *Tech. Quart.*, VIII, 4, 310–316.

Hathaway, D.H. **2013**, *Sol. Phys*., 286, 347.

Ilustração Portugueza **1907**, 92, Lisboa, Portugal (in Portuguese).

Jordan, S., Andretta, V., Garcia, A., Brosius, J., & Behring, W. **1999**, In: A. Wilson. (Ed.). Proceedings of the 9th European Meeting on Solar Physics (12–18 September, Florence, Italy), ESA SP–448, 303.

Jordan, S., Garcia, A., & Bumba, V. **1997a**, *Sol. Phys*., 173, 2, 359–376.

Jordan, S., Andretta, V., Garcia, A., & Falconer, D. **1997b**, In: A. Wilson (Ed.). Proceedings of the Fifth SOHO Workshop, (17–20 June, University of Oslo, Norway), European Space Agency, 439.

Kariyappa, R. & Pap, J.M. **1996**, *Sol. Phys.*, 167, 115–123.

Koleva, K., Madjarska, M. S., Duchlev, P., Schrijver, C. J., Vial J.–C., Buchlin, E., et al. **2012**, *Astr. & Astroph*., 540, A127.

Klvaňa, M., Garcia, A., & Bumba, V. **2007**, In: Heinzel, Petr, Ivan Dorotovič and Robert J. Rutten (Eds.), Proceedings of *The Physics of Chromospheric Plasmas*, 368, Astronomical Society of the Pacific Conference Series, San Francisco, 549-558.

Launay, F. **2008**, *Un Globe–trotter de la Physique Céleste, L'Astronome Jules Janssen*, Vuibert, Paris (in French).

Lefebvre, S., Ulrich, R.K., & Webster, L.S. **2005**, *Mem. Soc. Ast. It.*, 76, 862.

Leonardo, A., Martins, D., & Fiolhais, C. **2011**, *J. Astr. Hist. Herit*, 14(1), 41–56.

Lobo, F.C. **1934**, *Anais do Observatório Astronómico da Universidade de Coimbra. Tomo II*, Imprensa da Universidade de Coimbra, Coimbra, Portugal (in Portuguese).

Lobo, F.C. **1932**, *Anais do Observatório Astronómico da Universidade de Coimbra. Tomo I*, Imprensa da Universidade de Coimbra, Coimbra, Portugal (in Portuguese).

Lobo, F.C. **1928**, *Alguns resultados obtidos com as Observações Spectroeliográficas feitas nos anos de 1226 e 1927*, Imprensa da Universidade de Coimbra, Coimbra, Portugal (in Portuguese).

Lobo, F.C. **1926**, *O Instituto*, 73, 2, 128–141, Imprensa da Universidade de Coimbra, Coimbra, Portugal (in Portuguese).

Mandal, S., Hegde, M., Samanta, T., Hazra, G., Banerjee, D., & Ravindra, B. **2017**, *Astr. & Astroph*., 601.

Mein, P. & Ribes, E. **1990**, *Astr. & Astroph*., 227, 577.

Mouradian, Z. & Garcia, A. **2007**, In: Heinzel, Petr, Ivan Dorotovič and Robert J. Rutten (Eds.), Proceedings of *The Physics of Chromospheric Plasmas*, 368, Astronomical Society of the Pacific Conference Series, San Francisco, 3–14.

Mouradian, Z., Prevot, G., Zlicaric, G., & Garcia, A. **1995**, *Sol. Phys*., 158, 2, 379–381.

Noyes, R. **1982**, *The sun, our star*. Harvard University Press, 263.

Owens, B. **2013**, *Nature*, 495, 300.

Pesnell, W.D., Thompson, B.J., & Chamberlin, P.C. **2012**, *Sol. Phys.*, 275, 3.

Priyal, M., Singh, J., Ravindra, B., Priya, T.G., & Amareswari, K. **2014**, *Sol. Phys.*, 289,137-152.

Reis, M. **1955**, *O Instituto*, 117, 30–33, Coimbra, Portugal (in Portuguese).

Reis, M. **1940**, *Anais do Observatório Astronómico da Universidade de Coimbra. Tomo V*, Imprensa da Universidade de Coimbra, Coimbra, Portugal (in Portuguese).

Reid, G.C. **1987**, *Nature*, 329, 142.

Rosales, Y. **2017**, *Global and Mid–Latitude Impact of Ten Years of Solar Activity Using Observational Data of the Geophysical and Astronomical Observatory of the University of Coimbra*, PhD Thesis, Universidade de Coimbra, Coimbra, Portugal.

Rosmaninho, N. **2006**, *O poder da arte: o Estado Novo e a cidade universitária de Coimbra*, Imprensa da Universidade de Coimbra, Coimbra, Portugal (in Portuguese).

Silva, A. **1968**, *Publicações do Observatório Astronómico da Universidade de Coimbra*, 4, Coimbra Editora Lda, Coimbra, Portugal (in Portuguese).

Smith, E.V.P. & Gottlieb, D.M. **1975**, *Spec. Publ.*, 366, 97-117.

Svalgaard, L. **2013**, *J. Space Weather Space Clim*., 3, A24.

Usoskin, I.G. **2017**, *Liv. Rev. Sol. Phys.*, 14, 3.

Wenzel, K.P., Marsden, R.G., Page, D.E., & Smith, E.J. **1992**, *J. Astr. and Astrophy*. Supp., 92(2), 207-219.

Wells, H.W. **1943**, In: Proceedings of the IRE, 31(4), 147-157.

Willis, D.M., Coffey, H.E., Henwood, R., Erwin, E.H., Hoyt, D.V., Wild, et al. **2013**, *Sol. Phys*. 288, 117.

Wolfson, J., Bruner, M., Jurcevich, B., Lemen, J., Schrijver, K., Shine, R., et al. **1997**, *Bull. Am. Astron. Soc.*, 29, 887.

Appendix A

		Observation year	Publishing year
"*Alguns resultados obtidos com as Observações Spectroeliográficas feitas nos anos de 1926 e 1927*" (Some results obtained from the Spectroheliographic Observations made in the years 1926 and 1927)		1926 and 1927	1928
"*Anais do Observatório Astronómico de Coimbra–Fenómenos Solares*" (Annals of the Astronomical Observatory of the University of Coimbra–Solar Phenomena)	Tomo I	1929	1932
	Tomo II	1930	1934
	Tomo III	1931	1936
	Tomo IV	1932	1937
	Tomo V	1933	1940
	Tomo VI	1934	1941
	Tomo VII	1935	1942
	Tomo VIII	1936	1943
	Tomo IX	1937	1945
	Tomo X	1938	1947
	Tomo XI	1939	1949
	Tomo XII	1940	1957
	Tomo XIII	1941	1965
	Tomo XIV	1942	1974
	Tomo XV	1943	1974
	Tomo XVI	1944	1975
	————	1979	1986

Note: there are a great gap between the years of observations and the publication year due to the insufficient staff of the Observatory.