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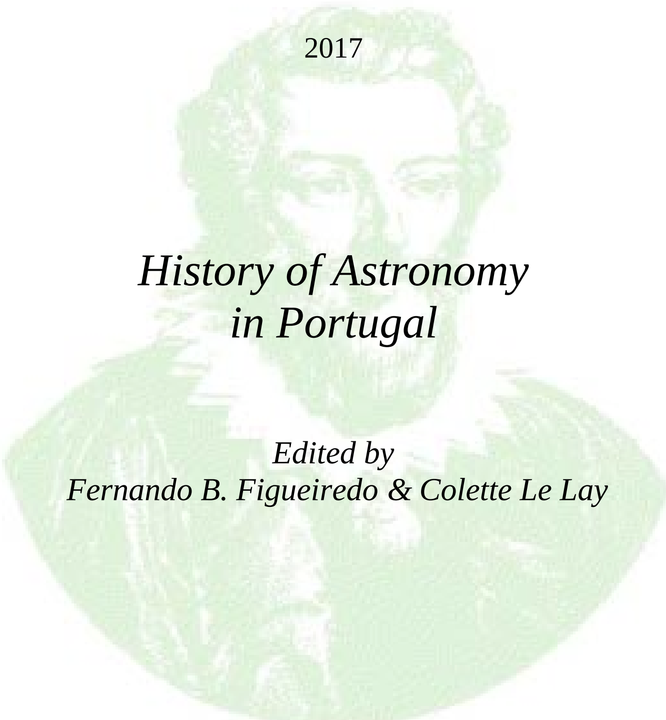

History of Astronomy in Portugal

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Avant-propos - *Stéphane Tirard*

Le projet de ce volume collectif sur l'histoire de l'astronomie au Portugal s'est concrétisé en février 2014 lors du séjour au Centre François Viète d'un groupe de collègues historiens des sciences portugais de l'université de Coimbra. Outre le colloque organisé au muséum d'histoire naturelle de Nantes, cette rencontre franco-portugaise a été l'occasion de stimulants échanges et de l'ébauche de projets communs, dont le premier était de dresser un bilan sur l'histoire de l'astronomie au Portugal.

Les contributions rassemblées par Fernando Figueiredo dans la présente livraison des *Cahiers François Viète* offrent une large vision de l'évolution de l'astronomie au Portugal entre le XIVᵉ et le XXᵉ siècle. Elles montrent à la fois les grandes évolutions de ce domaine au Portugal et soulignent les efforts de certaines personnalités qui à différentes époques agirent au développement de l'astronomie dans ce pays qui a souvent entretenu des échanges scientifiques privilégiés avec la France.

Dans un premier temps António Costa Canas décrit les développements de la navigation astronomique au Portugal dans le contexte de grandes découvertes aux XVᵉ et XVIᵉ siècles, dans lesquelles le Portugal eut un rôle si important. Bruno Almeida (Université de Lisbonne) s'intéresse particulièrement pour sa part au travail astronomique imprimé de Pedro Nunes (1502-1578), mathématicien et cosmographe portugais. Luis Tirapicos analyse comment dans la première moitié du XVIIIᵉ siècle un groupe d'astronomes jésuites, dirigé par Giovanni B. Carbonne, a activement participé au développement de l'astronomie portugaise. Fernando Figueiredo montre la place centrale occupée par l'Observatoire astronomique royal de l'université de Coimbra au tournant des XVIIIᵉ et XIXᵉ siècles. Vitor Bonifácio s'intéresse au XXᵉ siècle en présentant le rôle éminent de Francisco Miranda da Costa Lobo (1864-1945) avec notamment la construction à Coimbra d'une installation d'observation solaire à l'origine d'une durable collaboration avec l'observatoire de Meudon. Enfin, Pedro Raposo (Université de Lisbonne) étudie l'évolution du réseau des observatoires météorologiques et astronomiques du troisième empire portugais entre 1825 et 1957, notamment dans l'actuel Ouganda et au Mozambique.

L'ensemble de ces articles dresse donc un riche panorama de six siècles d'histoire de l'astronomie au Portugal et rappelle la complexité de ce champ scientifique. L'astronomie est en effet intimement liée aux mathématiques, tout en étant fondée sur l'observation. Le présent volume montre comment le développement de cette science a associé les œuvres de scientifiques portugais et la volonté d'implanter des observatoires au Portugal ou dans ses colonies.

Nous nous réjouissons donc de voir aboutir ici le fruit d'une collaboration internationale dont nous espérons qu'elle saura se prolonger dans le futur par l'accomplissement d'autres projets communs.

Le présent volume n'aurait pas vu le jour sans la volonté constante et le travail de fond réalisé par Jenny Boucard et Colette Le Lay, avec le soutien de Sylvie Guionnet. La relecture précise de la version finale du manuscrit par Georges Letissier, professeur au Département d'Études Anglaises de l'université de Nantes, et par ses étudiants de Master 2, François Duclos, Amani Jebali, Manon Leroyer, Baptiste Lescot, Marion Lotodé, Clémence Talec a également été très précieuse. Qu'ils et elles soient très chaleureusement remerciés.

Introduction - *Fernando B. Figueiredo*

The birth of a small Portuguese community of historians of science can be traced back to the 1930s, with the creation of the *Grupo Português de História das Ciências* (Portuguese Group of History of Science), encouraged by Aldo Mieli (1879-1950). Mieli was the leading promoter of the *Académie Internationale d'Histoire des Sciences* and visited Portugal in the early 1930s (Simões *et al.*, 2008; Fitas *et al.*, 2008, p. 213-233). This group became responsible for the publication of the first Portuguese journal in the history of science, entitled *Petrus Nonius* (1937-1951). The truth is that in Portugal the study of science in its historical and philosophical dimensions has just recently started to take firmer steps, supported by interdisciplinary working groups linking various departments, research centres, and universities.[1] Much remains to be studied. Some areas in the history of science are still in an embryonic stage – it is the case for the Portuguese history of astronomy.

The specific historical studies on astronomical science are very scarce since they are generally embedded in larger projects. Until very recently, Portuguese history of astronomy has been considered as a subsidiary field of the history of marine navigation and of mathematics. Nevertheless, among physical and mathematical sciences, astronomy is the most studied discipline over time in the country.

In fact, although Portugal and astronomy are mentioned together, the association will most likely resonate with maritime discoveries, scientific navigation and the use of astronomy to expand, map, and maintain a maritime empire. The Portuguese expertise in astronomy and related fields, if acknowledged at all, will certainly be associated with the Early Modern Period, and probably with an ensuing decline that immersed the country into a long-standing era of backwardness. A particular tradition of Portuguese scholarship on the relations between navigation, mathematical sciences and Portugal's seafaring ventures might well have contributed to reinforce this picture. Seeking to emphasise a purported national vitality in the pioneering maritime deeds of the Portuguese, it fostered a focus on the subject as a

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[1] Some statistics regarding the production on the Portuguese history of science during the period 2000-2004 can be seen in (Tavares & Leitão, 2006).

claim of priority for the sake of national pride, and implicitly as consolation for the country's subsequent diversion from the main roads of modernity.

Once it embraced the celebratory and nationalistic overtones of the political agenda of the Salazar regime, the Portuguese Group of History of Science produced much of its work on this issue. It emphasized a golden period of Portuguese science associated with the maritime discoveries and geographical expansion. From June 23 to December 2 1940, Lisbon hosted the great exhibition of the "Mundo Português" (Portuguese World) (Commemorating the date of the foundation of the Portuguese State (1140) and the Restoration of Independence (1640) was also a way to legitimise and celebrate the Salazar regime of Estado Novo. The Commemorations led to several colloquia on the history and identity of the country, which focused on the glorious time of the Discoveries. They corroborated the image of Portugal as the head of a majestic empire founded on a long legacy of great glories: a country that gave new worlds to the World (Comissão Executiva dos Centenários, 1940).

A wave of recent works has been setting the scene for a more balanced representation of the Portuguese contributions to the cultural encounters and the profound geographical and scientific reconfigurations that shaped the Early Modern world. Portuguese scholars, navigators, brokers, and other historical actors are now being studied, mainly regarding the wider circuits and networks through which their actions had an impact in the affairs of their day. While this approach undermines national-biased claims, it also leads to better recognise the importance of figures such as the mathematician Pedro Nunes in the mathematical sciences of the period. The theoretical discussion around issues such as the existence of an "Iberian science" also contributes to shed new light on the complex interactions between geographical boundaries, the emergence of seaborne empires, and the circulation of mathematical and natural knowledge.

Our argument in this thematic issue of the *Cahiers François Viète* is that bringing this period under a perspective similarly focused on circulation, networking, and exchange will not only allow to overcome somewhat parochial dichotomies such as backwardness/progressiveness, success/failure, and recognition/obscurity, but will also contribute to further our understanding of the wider networks and circuits of modern astronomy. As far as Portugal is concerned, there is, in fact, plenty of material to explore this line of research. This issue comprises six articles by the most respected researchers in the field, examining the Portuguese history of astronomy from the Discoveries to the 20th century.

The first article of the volume is devoted to the Portuguese astronomical navigation in the Age of Discoveries. António Costa Canas starts with a summary of the main contributions by the Portuguese to astronomical navigation, giving a brief description of the main bibliography published on this subject. While the leading experts are probably aware of it, itis not the case for a broader audience. Then, Costa Canas tries to answer the following question: when did astronomical navigation start? Even though at the beginning, Portuguese sailors did not use astronomical methods developed primarily in the Mediterranean Sea, they did later in oceanic voyages. Sailors could stay for long periods of time in the open ocean, out of sight of land. They needed new methods to sail ships safely. The Portuguese adapted techniques, instruments, and calculation processes to increase the accuracy of positions obtained on high seas. The author analyses the evolution of the Portuguese celestial navigation, focusing his attention on the methods for determining latitude and longitude of the ship at sea. Regarding latitude, the Portuguese sailors made use of the Polaris or the Sun. As regards longitude, although a satisfactory solution only became available in the 18th century, the same sailors used a method that made use of the conjunctions and oppositions of the Moon. That method was employed in Magellan's voyage (1519-1522), the first voyage around the world in human history. All this is explained and placed in the context of the nautical techniques of the 15th and 16th centuries when the Portuguese had proven themselves as navigation experts.

Bruno Almeida's paper is dedicated to the astronomical work of one of the most important figures in Portuguese history of science, the mathematician Pedro Nunes (1502-1578). Professionally, Nunes was a university professor and a Cosmographer (appointed in 1529), a practice that combined different scientific disciplines such as geography, mathematics and, of course, astronomy. Nunes' contributions to science are multiple and span from pure mathematics to mechanics, astronomy, algebra and navigation. In his paper, Almeida stresses that Nunes' astronomical activity was highly motivated by practical needs motivated by his professional activity as a cosmographer. He suggests that the texts that Nunes wrote about astronomy can be organized in three main categories: translations of earlier texts, commentaries to those texts and original research.

It has been common, in Portuguese historiography, to consider the period after Pedro Nunes's death and the beginning King José's reign (1714-1777), in 1750, as a period of inertia/slowdown, if not stagnation, for Portuguese science, i.e. mathematics and astronomy. two main factors were invoked to explain that phenomenon. One was the existence of a powerful Inquisition, and the other was the control of the Jesuits over Portuguese education. However, in the past few years, this image started to change due to the work of an emergent class of historians of science who have been studying the role played by the Jesuits in the teaching of science during the 17th and 18th centuries (Carolino & Ziller, 2005; Leitão, 2007; Leitão & Azevedo Martins, 2008; Martins, 1997; Saraiva & Jami, 2008; Saraiva, 2000; Saraiva, 2001). For example, Luis Tirapicos has been working in that field of research in the last couple of years.

Luis Tirapicos focuses his paper on the first half of the 18th century when the court of King João V (1689-1750) counted one of the most active networkers of the period, Giovanni Battista Carbone (1694-1750). This Italian Jesuit priest and mathematician became a central figure in the practice of astronomy during that period. Carbone, who came to Portugal on the invitation of the King with his fellow Jesuit Domenico Capassi (1694-1736), played a pivotal role in promoting astronomy and the internationalisation of observation work. Tirapicos argues that the discovery of large deposits of Brazilian gold and the dispute with Spain over the limits of the Iberian-American colonies were the driving forces for the development and patronage of astronomy by the King. As he points out: "there was a mutual relationship between Brazilian gold and astronomy. Astronomy was sponsored and paid for by American gold. In other words: state-sponsored science implied science to serve the State." As the King's assistant and consultant, Carbone became an active agent in the diffusion of astronomical data and knowledge, using commanding networks, diplomatic channels and the web of the Society of Jesus.

After D. João V's death, a radical transformation promoted by his son King José (1714-1777) occurred in the Portuguese society. Towards the end of the century, the Marquis de Pombal (1699-1782) – the all-powerful minister of the new King – encouraged the reformation of Coimbra University (1772). Thanks to this initiative, mathematics, astronomy, the Enlightenment and the concept of national/university observatory became the axes of a thorough search for international institutional standards.

My paper explores the scientific activity of the Royal Astronomical Observatory of the University of Coimbra, created in the context of the teaching reforms carried out by Pombal at Coimbra University. The reform meant for the University to not only be a teaching centre but also to produce knowledge in order to fulfil the technical and scientific needs of the country. First, I will start with a brief contextualization of the scientific panorama of the country in the first half of the 18th century, namely in the fields of mathematics and correlated sciences. Then I will focus on the scientific work carried out at the Observatory, compared with the practice of the most famous observatories in Europe. I will then explore how the astronomical work of its first director – Monteiro da Rocha (1734-1819) – which spanned from theoretical to practical astronomy, was in tune with the major astronomical problems of that time (e.g. the tricky problem of the determination of longitude at sea). Finally, my paper will examine the creation and activity of several academic institutions (e.g. the Royal Academy of Sciences of Lisbon, the Royal Academy of Navy, the Academy of Fortification, Artillery and Design and the Royal Maritime, Military and Geographic Society), that were created during the reign of D. Maria (1734-1816). These institutions reinforced the institutionalisation of modern science and its practice in the country, which had begun with the former reformist policies of Minister Pombal.

The creation of these new institutions revealed that the training, professionalisation and scientific specialisation of mathematicians, astronomers, engineers, botanists, chemists, and mineralogists was a reality in Portugal in the years that followed the reform of the University. In fact, in less than forty years, Portugal had undergone a paramount transformation in its educational and scientific paradigm. There are several examples to confirm this, such as the 1780 expeditions to Brazil in order to delimit the frontiers of the country after the Treaty of Santo Ildefonso (1777), in which several astronomers all doctorates in Mathematics, participated. These events contrasted with the expeditions that took place after the Treaty of Madrid (1750), which were mostly composed of foreign astronomers, mainly Jesuits.

The Napoleonic Invasions and the consequent departure of the Court to Brazil, on 29 November, 1807, (only returning in 1821) as well as the civil war (which only lead to political, social stability and peace in 1834) made the first decades of the nineteenth century very difficult for Portuguese science and its institutions.

By the mid-nineteenth century, Portuguese authorities engaged in an ambitious institutional project aimed at fostering the measurement of stellar parallax and further developing stellar astronomy, in close collaboration with no other than the Observatory of Pulkovo, the leading observatory at the time. Thus was born the Observatory of Lisbon (1861-1867), which would later become a major centre of expertise for the constitution of an imperial network of colonial observatories. The Astronomical Observatory of Lisbon (AOL) was founded in 1857 to collaborate with the Russian observatory of Pulkovo in the development of stellar astronomy, especially in the measurement of stellar parallax. However, this project did not materialise, and the observatory was readjusted to a more traditional observatory devoted to timekeeping. From the 1880s onwards, the AOL secured its status as a national timekeeper. In the last quarter of the 19th century, several attempts to introduce astrophysics in Portugal led to exchanges of observation work (namely in solar photography), as well as surveys and discussions on instrumentation and the institutional settings in which to foster this discipline. Although the scientific outcome of such efforts was overall meager, they reveal not only local setbacks but also the complex interplay between institutions, professional identities and international networks in the rise of the "new astronomy".

Vitor Bonifácio's paper is devoted to the efforts of the astronomer Francisco Costa Lobo (1864-1945) to initiate a Portuguese astrophysical research at the Coimbra Observatory in the first decades of the 20th century. The extensive travelling of Francisco Costa Lobo (1864-1945) in the first half of the 20th century – which was instrumental to the systematic programme of spectral-heliography that began in Coimbra in the 1920s – constitute more than a token of local effort to keep abreast of the international status quo. They offer a perspective on the international circuits of early-twentieth-century astrophysics and their routes, actors, and procedures, according to perceptions and aspirations. These elements allow us to draw a picture of this scientific *milieu* more nuanced than that provided by the historical narratives emanating from this very *milieu*. Even though Portugal's involvement with astrophysics in the early stages of the discipline still leaves the impression of a generally unaccomplished venture, the persistence of positional astronomy in the Observatory of Lisbon and the younger observatory of the University of Porto (established in the 1940s) – usually connected to international programmes and research agendas – hints at the importance of the "old" astronomy throughout the 20th century, an aspect often overshadowed by the history of astrophysics itself.

Pedro Raposo's paper entitled "Meteorology, Timekeeping and 'Scientific Occupation': Colonial Observatories in the Third Portuguese Empire", presents an overview of colonial observatories in the Third Portuguese Empire (1825-1957), and the attempts that were made to steer an imperial network of observation devoted not to astronomy but to meteorology. Raposo explores the creation and activity of the Luanda Observatory (later João Capelo Observatory) in 1879 and the attempt to upgrade it in the 1920s, the inauguration of the Campos Rodrigues Observatory in Lourenço Marques (now Maputo) in 1908, and the constitution of the National Meteorological Service of Portugal in 1946. These episodes are set in their political context and approached through the aspirations of imperial resurgence that underlay the Third Portuguese Empire.

During the 20th century, the professional astronomical activity was mainly supported by the universities and their observatories, mainly, Porto, Coimbra and Lisbon. However, until the end of the 1970s, it was very hard to find publications by Portuguese astronomers in international peer-reviewed journals. This quasi-non-existence of astronomical publications is a consequence of the reduced number of astronomers. Even if we do not have the real figures, we assume that there were no more than five to ten PhD researchers in astronomy and astrophysics in Portugal at the end of the 1970s. During the 1980s the situation started to change. Almost simultaneously – and curiously outside of the academic observatories – research groups in astronomy and astrophysics appeared in the Portuguese universities of Porto and Lisbon. These universities created under-graduation and graduation syllabi in order to train future astronomers and astrophysicists. The global strategy was to create a substantial amount of people able to rebuild Portuguese astronomy and astrophysics. The collaboration with the European Southern Observatory (ESO) was crucial, as with the ESA. Presently, Portugal has a very important and experienced research community of astronomers and astrophysicists involved in several international projects. Very recently, an SPA[2] study from 2013 showed interesting data concerning the impact of astronomy and astrophysics in Portuguese science, space science being the field with one of the highest rates.[3]

At the end of this brief introduction, we only can express our deepest hope that, by connecting the most recent research on the principal topics of Portuguese astronomy, our reader can get a clearer overview of the role and place of Portugal in the global endeavours of astronomical science. We hope this volume can provide a useful contribution in that direction and be a stimulus for new and contextualised research studies on Portuguese history of astronomy and correlated sciences.

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[2] The SPA (Portuguese Astronomical Society), was founded to contribute and to promote, in its broadest sense, the development of the Portuguese astronomy (www.sp-astronomia.pt).

[3] http://sp-astronomia.pt/comunicado_FCT2013

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The Astronomical Navigation in Portugal in the Age of Discoveries

António Costa Canas*

Abstract
This paper is about the evolution of astronomical navigation in Portugal, in the Age of Discoveries. We will focus our attention on the contributions, by the Portuguese mariners, to the determination of latitude at sea, using Polaris or the Sun. Besides the longitude issue has a solution only in the second half of 18th century, the Portuguese sailors intended a method to obtain this geographical coordinate, appealing to the conjunctions and oppositions of the Moon. This method was used in Magellan's voyage (1519-1522). In this paper, we will try to present these efforts made by the Portuguese, that allowed them to face the vast oceanic waves with some degree of confidence.

Keywords: Portugal, discoveries, astronomical navigation, latitude, longitude, Magellan circumnavigation voyage.

Résumé
*Dans ce texte nous analysons l'évolution de la navigation astronomique au Portugal, à l'époque des grandes découvertes. Les contributions des Portugais ont permis de déterminer la latitude en mer, principalement en ayant recours à l'étoile Polaire et au Soleil. De plus, la question de la longitude n'ayant de solution que dans la seconde moitié du XVIII*e *siècle, les marins portugais ont cherché une méthode pour obtenir cette coordonnée géographique, utilisant les conjonctions et les oppositions de la Lune. Cette méthode a été utilisée pendant le voyage de Fernão de Magalhães (Ferdinand de Magellan, 1480-1521), 1519-1522. Dans cet article, nous tenterons de présenter ces efforts faits par les Portugais, ce qui leur a permis de faire face aux vastes ondes océaniques avec un certain degré de confiance.*

Mots-clés : Portugal, découvertes, navigation astronomique, latitude, longitude, voyage de Magellan.

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THE HISTORIOGRAPHY of the Portuguese Discoveries has already more than five centuries. The set of works on the history of the Portuguese epic, in the various overseas "empires", is of great importance in technical-scientific and literary aspects.

However, it was in the 20th century that the theme was renewed in its approach and gained a new scientific and historiographic interest. This interest did not only come from the part of national researchers but also from the part of the international scientific community. It would be interesting for the reader to consult the work of João Marinho dos Santos and José Azevedo e Silva (Santos 2004), in which these authors try, through the publication and analysis of the correspondence of the main 20th century Portuguese researchers, to reconstitute and reanalyse the great scientific discussions around the theme of the Discoveries. This book also shows that the epistolary material exchanged between these historians and foreign scholars is itself a great documentary to be taken into account in future research about this subject.

Joaquim Bensaude (1859-1952), Luciano Pereira da Silva (1864-1926), Abel Fontoura da Costa (1869-1940), Gago Coutinho (1869-1959), António Barbosa (1892-1946), Avelino Teixeira da Mota (1920-1982) or Luís de Albuquerque (1917-1992), just to mention only a few of the most important authors, published hundreds of books and papers in which this subject is discussed. They published not only in Portuguese but also in some other languages.[1]

Through the impetus given by the systematic work of these men, as well as by foreign researchers, a solid historiography has been constructed, pointing out and highlighting the decisive role of Portuguese pilots and scholars in the great scientific work of the Iberian and European Discoveries made from the 15th century.

In this article, we will try to give a contextualised summary of the main contributions of the Portuguese to astronomical navigation

Astronomical Navigation: From Art to a Technique

- *The Influence of Mediterranean Techniques in the Portuguese Art of Navigation*

The majority of historians assume that the military conquest of Ceuta (1415) marks the beginning of Portuguese Expansion. This expan-

[1] In French, we highlight the following: (Bensaude, 1912; Fontoura da Costa, 1935, 1938; Beaujouan & Poulle, 1959; Cortesão, 1966).

sion went far beyond the Moroccan territory. The Portuguese started to explore the West Coast of Africa, venturing to regions more and more distant from land and therefore losing visual contact with the coastline, discovering new islands in the Atlantic Ocean. These islands were unknown by the Europeans until then. Later, they navigated to the Indian Ocean and travelled to India by sea. In less than a century, the Portuguese established regular routes across the Atlantic Ocean and the Indian Ocean. Their main destinations were Brazil, Africa and especially East India; from where they brought many very valuable goods, especially spices. In fact, we can speak of a European expansion that changed the world forever. This expansion was led by Portugal and followed by other major powers such as Spain, England and the Netherlands. This process has entailed many changes in the 'Art of Navigation'. When the expansion started, the ancient Mediterranean navigation techniques, developed in the Mallorca and Italian coast, were not enough for the new needs raised by the open oceanic voyages which had been carried out by Portuguese and European navigators from the 16th century onwards.

We have evidence of intense maritime activity in the Mediterranean Sea thousands of years ago. The Mediterranean seafarers used to sail instinctively. As they were often of rural origin and illiterate for the most part, their culture was made up of sayings, proverbs, lived experience, but also myths and extravagant foolishness (Pastoureau, 1992).[2] Despite this, we can talk about more or less complex techniques to conduct ships safely because in the absence of these techniques navigation was impossible. One of them was the introduction, by the end of Middle Ages, of compass on board ships. We do not know who was responsible for the introduction of this innovation, or the precise moment when it happened, but by the end of the 13th century, some navigators had compasses on board ships (Albuquerque 1972, p. 16-19).

The use of compass led to the development of the navigation method known as dead reckoning. To sail from one position to another position, the pilot needed to know the direction he must follow, reading it on the compass. He also needed to know the distance he had travelled. He did not have any instruments to measure speed, so he estimated the distances. This method was suitable for the needs of the sailors in the Mediter-

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[2] On the 'Partidas' of Afonso X de Castilla (1221-1284) are described which in the 13th century was considered essential to a sailor, knowing all the sea, where it is calm, and also the "winds and their changes [...] and the entrances and exits to guide the ship safely ["os ventos e as mudanças deles [...] e as entradas e saídas, para guiar o navio a salvo"]" (Albuquerque, 1972, p. 13-14).

ranean Sea. The errors associated with this method, such as those introduced by the lack of accuracy of the compass directions, or the wrong evaluation of the travelled distance and the unknown effects of the currents could somehow be neglected since the ships never sailed too far from shore. However, these errors can be very significant if ships spend weeks or even months without sight of land. This kind of unfavourable conditions did not occur in the Mediterranean Sea. To fix positions, the sailor used nautical charts based on compass directions and distances estimated. That charts, known as portolan-charts[3], had a grid of directions, usually 32, one for each direction of the compass, and also a scale to measure distances. The oldest known chart of this kind is the "Pisan Chart", from the end of the 13th century (or from the early years of the following century). The process described above spread from the Mediterranean Sea to the Atlantic coasts of Southern Europe.

It is very likely that the Portuguese sailors knew this method and had used it in the first exploration voyages in the Western African coast. During these voyages, they never stayed away from the sight of land for long periods. In this way, the method was perfectly appropriate for them. However, when they reached the region of the South of Cape Bojador (1734), the return voyage became very difficult due to meteo-oceanographic conditions. To solve this problem, they sailed into high seas, using the prevailing winds to take them back home. They spent long periods without sight of land.[4] Soon, they realised that by using only dead reckoning errors could increase considerably. It became convenient to know the approximate position of the ship, if not at all times at least each day, during a long voyage without any land reference. To sail in the open sea, out of sight of the coast, the Portuguese conceived and developed the astronomical navigation, making astronomy the faithful auxiliary of their enterprise of discovery.

[3] The name derives from portulano, because the information we can obtain from them is similar to the one we can get from portolans. These consist of a textual description of the paths connecting different harbours in one region. In portolans, we have information about directions and distances the pilot should follow to travel to the mentioned harbors. "Il Compasso di Navigare", dated from the middle of the 13th century, is the oldest known portolan.

[4] At the time of the Discoveries, this return was denominated "volta da Guiné" or "volta da Mina", because the ships that left Guiné or Mina moved in an arc towards the northwest, to gain the latitude of a certain point of the Portuguese coast. In modern historiography, especially after the studies of Gago Coutinho, this return is denominated "volta do largo" (Albuquerque, 1989, p. 74).

It was essential not only to travel safely in seas that had never been navigated before but also to return to the new lands that were discovered. Taking possession of new stop-over points required precise location, which could only be found in the heavenly vault. An issue is also intimately linked to the improvement of cartography.

Astronomical Navigation is opposed to navigation by esteem, but it is important to highlight that astronomical navigation did not completely replace dead reckoning, which remained the primary method to fix the position of the ship at any particular time. With astronomical navigation, the pilots were able to reduce errors resulting from the impossibility to correct positions observing landmarks. In the 16th century, the tools used by the pilots to conduct ships proved the importance of dead reckoning. The nautical charts kept the grid of directions and the scale to measure distances. Mapmakers just incorporated something else: a scale of latitude. Similarly, the routers, which replaced portolans, still had information about directions and distances from place to place. However, they incorporated lists of latitudes of places. With the Portuguese of the 15th century, Navigation passed, finally, from art to technique.

- *Astronomical Navigation*

One important contribution to the development of astronomical navigation in the Middle Ages is the fact that sailors were used to look at the sky regularly. They did not measure the altitude (the angle above the horizon) of the stars, but they observed celestial bodies to determine local time. The process was based on the observation of the relative positions of two stars: *Polaris* and *Kochab*, both from *Ursa Minor*. That meant that they observed the sky very often, especially in the direction of *Polaris*.

Used to observe the sky, Portuguese sailors noticed that the altitude of *Polaris* decreased as they travelled southward. Alvise de Cadamosto (ca. 1428-1483), a Venetian sailor who explored the African coast under the orders of Prince Henry, *the Navigator* (1394-1460), observed that. In 1456, in a local near to the mouth of Gambia river, he noticed that the star was very low: "... we saw it over the sea, at the altitude of a javelin..."[5] Of course, this is not astronomical navigation, but just the observation of the fact that the altitude of the star decreases when the ship sails to the Southern direction.

Nautical astronomy, or astronomical navigation, is based on methods and processes that allow the pilot to determine the approximate position of a ship thanks to observations of the stars. To do so, it must respond to

[5] Le Navigazioni atlantiche di Alvise Ca da Mosto, quoted in (Albuquerque, 1975, p. 16).

three problems: determination of the latitude during the day, by the sun; determination of latitude by stars at night; and determination of the difference in longitude between two places, calculated by the differences of time in which a given celestial event is observed.

Astronomical navigation developed step by step. The oldest known reference to the use of an instrument to measure the altitude of a star at sea is from around the middle of the 15th century.

It was registered by Diogo Gomes (c. 1425 - c. 1500) who sailed under the orders of Prince Henry. Gomes said that he observed the height of the pole[6] in a position close to one island of Cape Verde archipelago, registering this value in his quadrant. If this value is known, it should be easy to return to the island. To do so, the pilot should sail southward, until he observes the star with the same altitude previously obtained. Then he just needs to travel east or west, always keeping the star at the same altitude. This process is known as: "*equal altitude of the star*".

It is important to note that despite the evolution of astronomical navigation in the following decades, the process mentioned above remained in use. The safest way to arrive at any island in the middle of the ocean was to sail until the ship reached the latitude that was parallel to the island, and then sail along the parallel until the island was found. The ship should not head directly towards the island but to a position which would be east or west of the island. Using this procedure, the pilot knew which direction he should sail when he reached the latitude of the island.

Another process developed in the first years of astronomical navigation is the one we call "*altitude-distance*". The pilot assumed that one meridian arc is equivalent to a certain number of leagues. At sea, he measured the altitude of a certain celestial body, during several days. The difference between the altitudes observed equals an arc along the meridian, and this is equivalent to the distance travelled north or south. It was necessary to observe the star in similar conditions, which was more or less equivalent to observe it at the same time during both days. Even in the case of *Polaris*, whose height changed just a little amount of time, the fact that it was observed in different conditions from one day to the other could cause large errors in the distance calculated.

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[6] In fact, he probably registered the altitude of *Polaris*. Despite the fact that the star is very close to the North Pole, its altitude changes with time. For a given place, the difference between the highest and the lowest value is not negligible. To overcome this inconvenience, the altitude should be measured with the star always in the same position. It was not difficult to do so, due to the fact that Portuguese sailors observed *Polaris* very often.

We must fully take into account the fact that the notion of latitude is not present in any of the processes mentioned above. In the first one, the pilot just needed to know the altitude of one star, *Polaris*. When he reached this altitude, he sailed east or west, keeping the star with that altitude. Because the trajectory of the star described a small circle around the North Pole, its altitude varied during the night, even for an observer in a precise location. It was easy for the pilots to know the altitude values according to the different positions of the star around the pole; they just needed to observe the relative position between *Polaris* and *Kochab*, as they used to do to find out the time during the night.

In some of the oldest navigation books such as *Guia Náutico de Munique (c. 1509)*, *Guia Náutico de Évora (1516)*, or *Repertório dos Tempos (1518)*[7] by Valentim Fernandes (?- c.1518) there are diagrams showing eight values for the altitude of *Polaris* in Lisbon.

This kind of texts had more or less simple nautical instructions to be used by pilots. Most of the pilots of this time were men of little, or none, theoretical instruction. Thus, these manuals provided technical and scientific information considered useful, but the truth is that many of these men had serious difficulties in understanding the true meaning of these rules and procedures. For example, Pedro Nunes wrote some books solving certain navigation problems, but these texts were essentially theoretical and therefore virtually inaccessible to seafarers.[8]

The *Guia Náutico de Munique* (Munich Regiment, or Nautical Guide of Munich), is the oldest book known and printed with nautical rules. It was published in the workshop of Hermão de Campos in Lisbon, probably in 1509 and reprinted c.1516. The Munich Regiment includes a translation of the *Treaty of the Sphere* of Sacrobosco, through which many generations of pilots learned the rudiments of cosmography; two versions of the r*egiment* for determining the latitude from the meridian height of the Sun and its declination; a table with sun declinations; the regiment for the determination of latitude by the height of the Polar Star; a wheel with the heights of the Polar star in Lisbon. In the Munich Regiment, there is also a letter addressed by a "German doctor" to the King D. João II (1455-1495), translated by Álvaro da Torre. In this letter, dating back to 14 July 1493, Jerome Monetary or Münzer, the "German doctor", praises the Portuguese

[7] Published by Pablo Harus in Saragoça, in 1492; was translated to Portuguese by Valentim Fernandes in 1518 (Leitão & Martins, 2004, p. 36).

[8] See the article of Bruno Almeida in this volume.

king for the discoveries and instils him the way to the west to reach India more easily.[9]

In the following figure is reproduced the diagram "Polaris Wheel", by Valentim Fernandes.

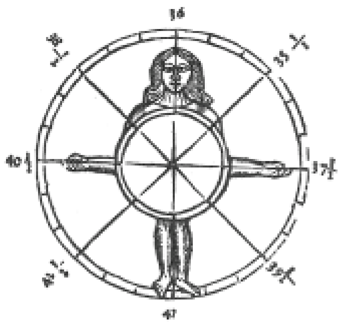

Figure 1 - Diagram "Polaris Wheel" (Source: Valentim Fernandes, "Reportorio dos tempos"*, Lisboa, Valentim Fernandes Alemão, 1518)*

The method explained in the previous paragraph was not user-friendly because there was the need for one diagram for each place that the pilot wanted to visit. The next step consisted in a small transformation of the diagram to allow its use for any place. To do so, the altitude values in the wheel should be replaced by the correction to apply to the observed altitude, to calculate the altitude of the pole. With this small change, it was easy for the pilot to calculate the latitude because it was equivalent to the altitude of the pole. This set of rules was known as *Regimento do Norte* (Regiment of the North Pole). They consisted of very simple rules, a set of numbers which should be added or subtracted to the value measured with one instrument, the star altitude, to obtain the latitude of the place.

The use of *Polaris* to obtain latitude was common to a wide community. There are examples of *Regimento do Norte* in almost all the texts about navigation from the 16th century and a large number from the 17th century. However, if Polaris was suitable for northern hemisphere, it was not for the southern hemisphere because it disappeared when a ship crossed the equator. In the southern hemisphere, there is no star as close to the South Pole as *Polaris* is close to the North Pole. Nevertheless, some pilots

[9] This lettter can be found in (Montaro, 1878).

used a set of rules similar to the *Regimento do Norte*, to be used with one of the stars of *Southern Cross*. Because this constellation was at a reasonable distance from the South Pole, this *Regimento* had serious flaws. For this reason, its use was not as wide as the *Regimento do Norte*.

There is a celestial body which can be observed all over the year, in both hemispheres: the Sun.[10] The astronomers modified some rules, used in land, to allow the use of Sun at sea, to obtain latitude. They call these rules *Regimento do Sol*, and they consist of a set of mnemonics to help pilots to perform calculations so they can obtain the latitude while measuring the altitude of the Sun (Roche, 1981; Sonar, 2010). The rules from *Regimento do Sol* were different from those from *Regimento do Norte*. In the *Regimento do Sol* the calculations were more complex because there was the need to cover all possible situations of the relative positioning of the Sun, celestial equator and the zenith of the observer. Despite this bigger complexity, the calculations remained additions and subtractions.

The Sun rises every day in the horizon, ascending into the sky until it reaches the highest altitude, in the middle of the day, then descending to disappear below the horizon. In its meridian transit, the highest altitude is reached when the Sun crosses the meridian, exactly south from our position.[11] The altitude at meridian transit changes slightly day by day, being affected by the latitude of the observer and the angle between the Sun and the celestial equator. This last angle is known as the declination of the Sun and changes with time, on a yearly basis. In this way, since there is a numerical relation among the three factors – latitude, the declination of the Sun and highest altitude of the Sun – it is easy to calculate one when you already know two of them. With an instrument to measure the altitude of the Sun, usually a mariner's astrolabe, the pilot just needs to know the declination of the Sun for each day. With those two figures and the fact that he applies the correct rule from the *Regimento do Sol,* the pilot can calculate the latitude of the place. As we said before, the correct rule depends on the relative position among the equator, the Sun and the observer's vertical.

The process to obtain latitude using the meridian transit of the Sun was used by astronomers long before the beginning of Portuguese discoveries. The Portuguese simplified these complex calculations by making them

[10] In fact, for very high latitudes, above polar circle, the Sun is not visible for all the days of the year. However, Portuguese ships did not reach those latitudes.

[11] This is always true for an observer in Europe. An observer between tropics can observe it sometimes to North, other times to South, and can even observe it exactly above its head. In the region of the South of Capricorn Tropic, the highest altitude of the Sun will always occur to the North of the observer.

easy enough to be executed by sailors, usually men with little school education. That was one of the most important contributions from Portugal to the development of the Art of Navigation in the 15th century.

In the last decades of the 15th century, some astronomers, like José Vizinho, sailed to the western coast of Africa, where they observed meridian transits of the Sun to obtain the latitude of many places. These expeditions also served as a test of the method. In all this process, the astronomers played a very important role, not only in teaching pilots the rules of the *Regimento do Sol* but also in preparing the tables with the daily value of the declination of the Sun, which changes day by day, on an annual basis, to be used by that same pilots.[12]

As we told before, to calculate latitude, the pilot must measure the altitude of the Sun and once again, the Portuguese simplified one instrument used by astronomers for a long time to adapt it in order to be used by sailors. Astronomers used planispheric astrolabes to perform complex astronomical calculations. This instrument had a scale to measure the altitude of stars. To do so, the user just needed to move the "alidade" towards the direction of the sunbeam to obtain the altitude in the scale. The mariner's astrolabe, also called sea astrolabe, is the simplification of that instrument made by Portuguese, removing everything useless to unlettered sailors and only leaving the scale and the alidade to obtain altitude of stars.

Portuguese mariner's astrolabes had one peculiarity that helped a lot the process to calculate latitude. To apply the rules from *Regimento do Sol,* the pilot had to convert the altitude of the star to zenithal distance.[13] To do this, he just needed to perform a very simple calculation because the zenithal distance is the complementary angle of altitude (zenithal distance is obtained subtracting the altitude from 90º). However, to avoid one supplementary operation, Portuguese mariner's astrolabes were graduated in the zenithal distance and not in altitude. With this simple modification in the astrolabe, it was possible, to make the use of the *Regimento do Sol* simpler by removing one operation. Figure 2 shows the scale from a Portuguese mariner's astrolabe, with 0º on top, to measure the angle starting at zenith.

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[12] The astronomers usually prepare tables for a cycle of four years, three common and one leap year because one year doesn't match an exact number of days, there is the need to have one extra day every four years. Strictly speaking, at the end of a four-year cycle, the Sun's position was not exactly the same position than the Sun is in the beginning of the cycle. However, the difference is so small that pilots could use the same tables during some cycles.

[13] We measure altitude starting at the horizon and zenithal distance starting at our vertical.

Figure 2 - Astrolabe São Julião III
(Source: Portuguese Maritime Museum, IN-II-174)

The oldest registered determination of latitude using the meridian altitude of the Sun, dated from the 15th century. In the first voyage of Vasco da Gama (1497-1499), the latitude of Saint Helena Bay (nowadays in South Africa) was calculated using this method. The pilot went ashore and used big mariner's astrolabes, made of wood and suspended from a tripod. But the same chronicler, who described this operation, tells us that they also had smaller brass astrolabes to be used onboard (Ravenstein, 1898, p. 167). Because they had little practice with this method, they preferred to make the observations ashore.

Longitude in Magellan's Voyage

By the end of the 15th century, the question of determining the latitude at sea was, as we described, no longer a problem. But different challenges appeared concerning longitude. At that time, some authors believed that the longitude problem was so complex that it was not worth finding a solution for it. That is the case of Duarte Pacheco Pereira (c. 1460-1533), who, at the beginning of 16th century wrote:

> […] and you must know that to measure the world width we must count the degrees from equinoctial towards each one of the poles, and how many degrees each pole rises over the horizon, which we can also call circle of the hemisphere. These same degrees are any place or man, standing there, distant from equinoctial line, and we measure the degrees of length, from Orient to Occident, that sailors denominate east and west, and because it is very difficult to calculate, because we don't have any fixed point, such as the pole to calculate width, I shall not talk about it anymore. (Pereira, 1991, p. 555)

However, some years after Pereira had written this, an event occurred, which made the determination of longitude a relevant issue.[14] In 1519, Magellan started his voyage, which would be the first circumnavigation. Magellan intended to prove that the Moluccas were placed in the Spanish hemisphere, defined by the *Treaty of Tordesillas* (1494). Magellan had never made plans to circumnavigate the globe. The obligation to navigate in waters where Spanish ships could sail explained his option to search for passage in South America from Atlantic to the Pacific Ocean. Navigation in the Indian Ocean was forbidden to Spaniards. For this reason, the return from the Moluccas was to be done by the reverse route. When the remaining ships of the fleet arrived at that archipelago, the sailors decided to come backcrossing the Indian Ocean. They chose to do that because some of the pilots had already sailed in the Eastern Indian Ocean before, whereas the route across Pacific was completely unknown.

Because Magellan wanted to prove the Moluccas were in the Spanish hemisphere, he needed to obtain the longitude of these islands. He asked the Portuguese cosmographer and astronomer Rui Faleiro (149?-?) to help him. Faleiro went to Spain with his brother Francisco, also a cosmographer, because they had problems with the Portuguese authorities – the same reason justifies the departure of Magellan. Rui Faleiro was one of the closest collaborators to Magellan in the preparation of the voyage. The cosmographer participated in the negotiations – conducted by Magellan – with Charles I (1500-1558).[15] They were supposed to participate in the voyage with the same rank: captain-general. However, Faleiro was dismissed from the project, for health reasons, because he started to present mental disorders (Mota, 1975, p. 317-318). Faleiro promised to Magellan one *Regimento* with procedures to calculate longitude. When he was dismissed from the project, Magellan asked Faleiro to give him the *Regimento* that he had prepared to obtain that coordinate. Faleiro acceded and suggested several methods and Magellan used one of them during the voyage.

The *"Regimento da altura de leste-oeste"*, a document that lies in Seville, is probably that text from Rui Faleiro (Mota, 1953, p. 910). In this text, the author proposed three methods to calculate longitude: (1) thanks to the latitude of the Moon, (2) thanks to conjunctions and oppositions of the Moon with stars and thanks to (3) magnetic variation. This last one was

[14] About the Portuguese and Spanish attempts to measure longitude in the 16th century, see (Randles, 1985).

[15] Charles I (1500-1558) of Spain, the famous Emperor Charles V, of the Holy Roman Empire.

very popular during the 16th century, although it was based on an incorrect proposition. The method of determining longitude by magnetic variation (or magnetic declination), suggested by João de Lisbon (? -1525) in his *Tratado da Agulha de Marear* (1514), is based on the fact that the magnetic declination seems to vary regularly with the longitude on the surface of the Earth. The magnetic compass needle points to the magnetic north, which does not coincide with the geographic north, the magnetic declination thus measures the difference between these two directions. For many years it was mistakenly thought that there was a law for magnetic declination, which would thus allow knowing the true direction of the geographic north and consequently the longitude of a place.

Regarding the first one, where Faleiro proposed the determination of longitude by the astronomical latitude of the Moon, the explanation in the text is very poor. Furthermore, as Mota observed, the daily variation of this coordinate was so small that it was not possible to measure this kind of variation using instruments available at that time (Mota, 1953, p. 146).

Faleiro's proposal for the second method is, in his words, the following:

> §4 by the conjunction which I know that the moon will have with some of the fixed stars at a given moment in Seville, and which may be known by any almanack, or also by the oppositions of the Moon that is opposite to the Sun. I can teach you at what time that opposition occurs earlier to the West, and you will be to West of Seville the same amount of time. This calculation is also very useful for those who sail for the West, and it is easy to calculate.
> §5 I will give you here an example. You should believe me, the Moon moves with a retrograde motion, relative to the sky, from West to East, with an average movement of about 13 degrees [per day]. And, for a better understanding, you should know the Moon is in the first sky, and the stars are in the eighth, and the Moon never joins the stars, because it is so big the distance from the Moon to the stars. We say that we have a Moon opposition to one star when the Moon put on our visual beam in the direction of the fixed star. That doesn't happen at the same time to those who are in Seville and to those who are in Valencia. You can check it in the figure[16]; for those who are in Seville, the visual beam is a: and for them, the visual beam to Valencia is u, and presupposed this, the amount Moon moves from West to the East, it moves in two hours, one degree and a few minutes, but sometimes the Moons conjunction with the star occurs before in Seville

[16] In the text of Faleiro, there is no figure but everything that follows his description presupposes that there was a diagram where the lines of vision of the two observers, one in Seville (a) and another in Valencia (u), were marked.

> than in Valencia. By the difference of time, we know the distance, in longitude, to Valencia […], and you should note that you must give to each hour of difference, 15 degrees, and to every minute of the hour, one degree.[17]

Once Faleiro had been withdrawn from Magellan's project, Magellan would choose the cosmographer Andres de San Martin (?-?) to be in charge of the operations carried out to obtain longitude. That was a crucial task to prove Magellan's ideas about Moluccas localisation. San Martin selected the procedure based in conjunctions and oppositions of the Moon to calculate longitude. Castanheda wrote that during the voyage, Magellan showed the *Regimento* to the pilots and to Andrès de San Martin to get their opinions about the applicability of Faleiro's methods (Teixeira da Mota, 1953, p. 318).

> He showed to the pilots and to the astrologer Andres de San Martin the *Regimento* that Faleiro gave him to obtain the altitude from East to West, as it has been said before. Everyone examined the *Regimento* and Magellan asked for each one's opinion, to know if they could use it during the voyage. All the pilots responded in writing that they could not use the *Regimento* and it was not possible to navigate using it. And they signed their statements. The astrologer answered similarly to all the thirty chapters of the *Regimento*, except for the fourth, which stated that it was possible to know the distance East-West from one place to another using the conjunction of the Moon with fixed stars or with the Sun.[18]

For the pilots, the *Regimento* was completely useless, but for San Martin, the fourth chapter could be useful to obtain longitude (Mota, 1975, p. 318). San Martin calculated longitudes for several places where the fleet stopped. The values that he obtained and the details from some of the observations that he made to calculate longitude were registered by Portuguese chroniclers João de Barros (ca. 1496-1570) and Fernão Lopes de Castanheda (c.1500-1559), by the pilots Francisco Albo (?-?) and António de Pigafetta (1491-1534) (Laguarda Trias, 1975, p. 155-156).

João de Barros mentioned five longitude determinations made by San Martin:

> In Rio de Janeiro, at seventeenth days of December five hundred and nineteen, he observed one conjunction from Jupiter with the Moon; and at

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[17] "Manuscrito de Sevilha" (Mota, 1953, p. 131-132).

[18] Fernão Lopes de Castanheda [História do descobrimento da Índia, livro VI, capítulo VII, tomo III] quoted by (Laguarda Triàs, 1975, p. 160-161).

> the first of February five hundred and twenty he took another position of the Moon and Venus, and at twenty-three of the same month and year, another from the Sun and the Moon; and at seventeen of April of the same year, a solar eclipse, and at twenty-three of December, after he crossed the strait, one opposition from the Sun with the Moon, and all the calculations have Seville meridian as reference.[19]

If we check Abraham Zacuto (1452-1515) Almanac, we note that on 23 February, or on the closest days, no opposition from the Sun with the Moon occurred. The closest one happened on the 3rd of the same month (Zacuto, 1986, p. 198).[20] We may be in the presence of a typo by the author, or by the person who registered the data, mistaking 3 with 23.

The same chronicler mentions another longitude calculation before the fleet reached the American coast. He does not clarify where they obtained it, but we believe that it possibly happened close to the Cape Verde islands. There is no agreement on whether the fleet stopped at that archipelago. Usually, observations were made ashore, where they could get the stability needed to use astronomical instruments. However, when they arrived at the doldrums region, they should have had enough stability to execute the observations when passing close to one of the islands of the archipelago (Laguarda Trias, 1975, p. 156).

On the American coast, the first observation was taken in Rio de Janeiro, on 17 December 1519. In a text by Antonio de Herrera y Tordesillas (1549-1626), who had access to the notes from the cosmographer, there is a detailed description of the calculations that San Martin had done. The calculations were a bit complex because for astronomical calculations the days began at noon, while civil days began at midnight:

> Staying in Rio de Janeiro on 17 December, at four hours and thirty minutes in the morning, that is to say seven hours and thirty minutes before noon, we saw the Moon over West horizon, with an altitude of 28 degrees and thirty minutes, and Jupiter above it, with an altitude of 33 degrees and 15 minutes: taking the altitude of the Moon from that of Jupiter, we found the difference of 4 degrees and 45 minutes, and considering the backward movement of the Moon, until the moment it sets in conjunction with Jupiter, it gives 9 hours and 15 minutes, in which the Moon moved the said

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[19] João de Barros [Décadas da Ásia, década III, livro V, cap. X, tomo III] quoted by (Laguarda Trias, 1975, p. 158).

[20] The Zacuto's tables were completed in 1478. In 1481, the original Hebrew text was translated into Spanish, followed by translations into Arabic and Latin. The first printed edition appeared in 1496 in Leiria, Portugal, prepared by Zacuto's disciple, Jose Vizinho.

> 4 degrees and 45 minutes. Taking these from 6 hours and 30 minutes of the night, it gives Friday, 16 of December, at 7 hours and 15 minutes afternoon. Consulting Zacuto's tables we obtain one hour and twenty minutes after noon, for Salamanca meridian, for Saturday, and for Seville meridian, at one hour and twelve minutes after noon. And by Regiomontanus almanac, they believe that it occurs the same Saturday, 17 December, in Seville meridian, at one hour and 10 minutes after noon; and considering this conjunction, which happen in this meridian, at 16 December, seven hours and fifteen minutes after noon, it gives a difference of 17 hours and 55 minutes, from this meridian to Seville [...].[21]

The longitude of Rio de Janeiro that was obtained was 268º45' West of Seville. This value is incorrect, although the calculations seemed to be correct. Andrés de San Martin justified the errors with the little accuracy of the tables he had used. It was a problem that he had already noted:

> [...] from that they concluded that there was an error in the equation of movements in the tables because it was impossible such a big value of longitude. And the pilot-cosmographer Andres de San Martin said that another time he observed a conjunction of Moon with Jupiter, and he found out an error of plus 10 hours and 33 minutes.[22]

But this justification received a sarcastic critique from João de Barros:

> Because the values weren't those he expected, he complains about Regiomontanus tables, saying that the numbers could be incorrect, being the printers the responsible for this.[23]

After passing through the Strait, San Martin kept calculating the longitude. On 16 March 1521, according to Francisco Albo, he obtained the coordinates of Suluan Island, in the Philippines. The value obtained meant that the island should be in the Portuguese hemisphere (Laguarda Trias, 1975, p. 168.

The issue was very delicate from the political and strategic point of view because it opposed the Portuguese and the Spanish crowns. They

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[21] António de Herrera [Historia General de los hechos de los castelhanos en las islas y tierra firme del Mar Oceano, tomo IV, década II, livro IV, cap. X] quoted by (Laguarda Trias, 1975, p. 159).

[22] António de Herrera, cited in (Laguarda Trias, 1975, p. 159).

[23] João de Barros [Décadas da Ásia, década III, livro V, cap. X, tomo III], quoted by (Laguarda Trias, 1975, p. 158).

were dealing with an issue that was a matter of state because the longitude value gave great arguments to the Portuguese pretensions on those lands. The processes used to obtain longitude were not accurate enough to be reliable, and it was very likely that divergences might occur among the values obtained by different persons. For example, Pigafetta presented different values, placing the islands on the Spanish side. There are some reasons to believe that San Martin had manipulated the values he obtained. Albo's testimonies showed that according to the values obtained, Portugal had sovereignty over the Moluccas. It is important to highlight the fact that Albo defended values that were not favourable to his monarch. That probably means that he was very confident in the values he presented, believing that he would be untrustworthy if he decided to change them just to agree with the wishes of his monarch (Laguarda Trias, 1975, p. 168-170).

In fact, some contemporary texts suggest a possible manipulation. João de Barros refers to a testimony of a sailor from the expedition, who said that the values were changed to put the Spice Islands in the Spanish hemisphere:

> Because they saw, by the calculations of the astrologer, and also by the route they had followed and the estimation according to the Art of Navigation, that the values obtained were more favourable to us than it was to them. For this reason, they placed the lands in the route with coordinates favourable to them, and not in accordance with Andres de San Martin calculations. And because of these, and other things were done maliciously; one of them, whose name was Bustamante, testified on his deathbed. He sailed in one of our ships, from Malacca to India, and he died when the ship stopped at Maldives because he was seriously ill. And in his will, as an afterthought, he declared that for some of the values obtained by the Castilian, in the Moluccas, he gave false values, just to be favourable to the Spanish.[24]

Laguarda Trías had a more radical opinion about the longitude of Moluccas. To him, a possible explanation for the death of Magellan was related to the fact that Magellan realised that he had failed his objective. When he obtained the longitude from Suluan Island, Magellan concluded that the Moluccas were not in the Spanish hemisphere. For this reason, he should have returned to Spain, and presented himself before the King as a man who failed his mission. To avoid this shameful situation, Magellan decided to expose himself to a reckless combat in which he died. According to Laguarda Trías, the manipulations of values occurred after Magellan's

[24] João de Barros [Décadas da Ásia, tomo III] quoted by (Laguarda Trias, 1975, p. 158).

death. Neither he nor San Martin nor Albo falsified deliberately the values they obtained (Laguarda Trias, 1975, p. 172-173).

San Martin could not have calculated Moluccas longitude because he died in May 1521 and the fleet reached the islands only in November of the same year. After his death, the longitude values were obtained by dead reckoning from the last value he had calculated in Suluan Island (Laguarda Trias, 1975, p. 173).

The history of longitude is, in fact, something fascinating, as we have just seen in the case of the Moluccas. There was still a long way to go until the longitude problem was solved with satisfactory results in late 18th century when new mathematical tools, as well as instruments, were developed, resulting in the appearance of the chronometer with reliable accuracy and the satisfactory practical implementation of the astronomical method of lunar distances.[25]

The oldest known reference to lunar distance method is from Johann Werner (1468-1522) who had explained in 1514 how to use it to obtain longitude and deserved the attention of some Portuguese scholars at the time. Rui Faleiro's proposals proved the interest of this issue. His suggestion to obtain longitude by the conjunctions and oppositions of the Moon is based on the same principle as Werner's method and can be seen as a particular case. One fact that we must emphasise is that the suggestion of the Portuguese cosmographer was used at sea. With the tables available at that time, the results could not be more accurate.

Conclusion

As mentioned in the introduction, we wanted to present an overview of the main contributions of the Portuguese to astronomical navigation during the Age of Discoveries. At the beginning of discoveries, the Portuguese used a method developed in the Mediterranean Sea, where sailors did not use any astronomical navigation techniques. In oceanic voyages, sailors could stay for several weeks, or months, out of sight of land. They needed new methods to conduct ships safely. The Portuguese adapted techniques, instruments and calculation processes, to increase the accuracy of the positions obtained at high seas.

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[25] In the last years, and much stipulated by the 300th anniversary of the Longitude Act (1714), a number of new books on the problem of the determination of longitude at sea were written, drawing new historiographical approaches to one very fascinating issue in the history of science (Dunn & Higgitt, 2014).

In 1415, when the Portuguese expansion began, some Portuguese sailors probably knew how to conduct ships using dead reckoning, a method developed in the Mediterranean. The process met the requirements of sailors sailing in this small sea, where it was possible to reduce errors every time the pilot sailed near a known shore. By the end of the same century, Portuguese had developed a new method of navigation which enabled them to sail out of sight of land during months, knowing their position and using astronomical navigation, by measuring the positions of the heavenly bodies.

The Portuguese adapted an instrument which was already in use in the scientific circles of the Middle Ages. The astrolabe that was originally used by astronomers was adapted to navigation. The simplification made by the Portuguese allowed to determine the height of the Sun and the stars easily. In connection with this question, it will be interesting to say something about the circulation of information between pilots and cosmographers. That circulation would have to exist in some way. The pilots used, for example, tables of declination, drawn up by astronomers and cosmographers. But there is no precise data on how this connection was made. What we have indicates that it would be normal that a very big gap exists between "scholars" and practical men of the sea. The mutual criticism between pilots and Pedro Nunes was real. If this were not the case, João Lavanha (c. 1550-1624) would not have had to mention in his first navigation manual for pilots, which was printed in 1595, that he had to make a series of approximations in the different processes he wanted to teach to fit the practice of the pilots. For instance, if pilots were people with a minimum level of studies, it would not have changed the scale of the astrolabe, putting the zero vertically to avoid a subtracting operation.

To determine the exact latitude of the ship, the Portuguese pilots found the necessary key in the observation of the sun at midday or the pole star at night. Of course, there were some technical problems related to the accuracy of the sun declination tables that were necessary, for example. Still, the question of the determination of latitude was practically solved during the voyage of Vasco da Gama (1469-1524), 1497-1498.

The longitude would be very different. The problem was of another kind with a much more difficult solution. Although the ideas for the determination of longitude had been suggested at the beginning of the 16th century, the truth is that it was only in the second half of the 18th century that it was solved in practice. But, the Portuguese sailors were also attentive and concerned about that matter, and there were attempts to try the astronomical methods that had been proposed in the meantime. Faleiro's proposal is something that deserves to be highlighted. One of his process to obtain longitude was used in Magellan's voyage.

It was, in fact, the Portuguese pilots and scholars who made a significant change from the art of sailing to the navigation based on scientific bases that will allow Europeans, eager to trade with the Eastern and expand their territories, to launch themselves into the great adventure of discovering the unknown frontiers of the world. For example, when England began to rise as a sea power in the 16th century, literally nothing was known about celestial navigation in England. Hence, Spanish and Portuguese navigators had to be employed, and their navigation manuals had to be translated into English (Sonar, 2010).

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For the Benefit of Cosmography: Notes on the Contributions of Pedro Nunes to astronomy

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Abstract

This paper addresses the astronomical work of the Portuguese mathematician and cosmographer Pedro Nunes (1502-1578) by focusing on his printed texts. It is mainly argued that this astronomical production was highly motivated by practical needs of his professional activity as a cosmographer. I start with identifying his main interests and contributions in order to show that his astronomical output can be divided into three main categories: translations of earlier texts, commentaries to those texts and original research. This gave way to new vectors of transmission of his work, to fellow scholars and cosmographers in similar professional situations. To exemplify this occurrence, I provide some details of the transmission of his work and its influence in French cosmography.

Keywords: Pedro Nunes, astronomy, cosmography, transmission of knowledge, nautical science, translation, commentary.

Résumé

Ce chapitre traite de l'œuvre astronomique du mathématicien et cosmographe portugais Pedro Nunes (1502-1578) en s'attachant à ses textes imprimés. Nous débutons par l'identification de ses principaux intérêts et contributions afin de montrer que ses travaux astronomiques peuvent être divisés en trois catégories : traductions de textes anciens, commentaires de ces textes et recherches originales. Nous démontrons que cette production astronomique trouve sa motivation essentielle dans l'activité professionnelle de cosmographe de Nunes. Cette production engendra de nouveaux canaux de transmission de son travail à des savants et cosmographes occupant les mêmes fonctions. Pour illustrer cet aspect, nous détaillons la transmission de son œuvre et son influence sur la cosmographie française.

Mots-clés : Pedro Nunes, astronomie, cosmographie, transmission de connaissances, sciences nautiques, traduction, commentaire.

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In 1577, the Vatican issued a missive with a project aiming to reform the Julian calendar: Aloysius Lilius' *Compendium novae rationis restituendi Kalendarium* circulated among scholars all over Europe and reached Portugal via diplomatic channels.[1] The Portuguese Chief Cosmographer Pedro Nunes briefly examined the text while on his death bed but, unfortunately, died in Coimbra, on the 11th of August 1578, without advancing much on the subject.[2] On the 30th of August, Fr. Luís de Souto Maior answered back to Lisbon saying that Nunes thought the text of the project contained some errors and that, under those conditions, nothing could be done to obtain a definitive solution to the problem of the calendar (Carvalho, 1952, p. x-xvi).

Due to this conjunction of facts, History does not list Nunes among those who had a direct impact on the reform of the calendar. It is known that, even retired from active duties, he was the main scientific authority of the country and was recognized as one of the finest European scholars of his generation. But it was only a coincidence that Nunes' last known technical opinion was about the calendar since he was not a full-time astronomer. Astronomy – which Nunes defined as: "the science that concerns with the path of celestial bodies and with the universal composition of the heavens, and not with the vain beliefs and almost rejected that issues judgments upon life and fortune" (Nunes, 1542, p. 141) – was not his main occupation but surely was of primary intellectual interest for him. Professionally, he was a professor of mathematics at the university and was also Chief Cosmographer (that is, the head cosmographer of the state) a practice that combined different scientific disciplines such as mathematics, astronomy and geography with managing duties, advising on nautical questions and teaching.

Most of the astronomical issues that interested Pedro Nunes were motivated by his professional duties as navigational advisor and cosmographer of the kingdom. The historian Henrique Leitão called attention to

[1] The works about the reform of the calendar are numerous. See, for example (Coyne, Hoskin & Pedersen, 1983).

[2] Pedro Nunes was a Portuguese mathematician, cosmographer and University professor. He was born in Alcácer do Sal, Portugal, in 1502. Not much is known about his family and his early life. He studied at the University of Salamanca, obtaining a bachelor degree in medicine in 1523. He returned to Portugal in 1527 and was appointed cosmographer in 1529. In 1544, he was appointed Professor of Mathematics at Coimbra's University. In 1547, was appointed Royal Cosmographer. He died in Coimbra in 1578.

this mixed mathematical practice, underlining that Nunes was driven by theoretical questions imposed by real problems (Leitão, 2013, p. 25) and that the techniques used to solve them were associated with mathematical astronomy. Also, it must be stressed that he was not an observational astronomer and that "(…) his texts do not give any indications concerning numerical work associated with astronomy (organizing tables, etc.) nor of any interest in astrology or physical-philosophical speculation on the universe's cosmological structure".[3]

Nunes' work on astronomical questions is found in his texts – five printed volumes, a small epitome and one manuscript. The great quality and relevance of these works made them very well known in Europe in the sixteenth and seventeenth century.[4] As an example, one of the scholars that most appreciated his work was the Jesuit Christopher Clavius (1538-1612), one of the main actors of the reform of the Julian calendar.[5] Those texts also provide very good information about his contact with earlier astronomers' works.[6] His books show a remarkable knowledge of the most important and relevant texts within the Ptolemaic-Aristotelic framework, produced by Greek, Latin or Arabic authors. He mastered the introductory texts, such as Sacrobosco's *Tractatus de sphaera* and Peuerbach's *Theoricae*, but also the more demanding like Ptolemy's *Almagest*. To those must be added other relevant texts by Alphonsus, the Wise, Erathostenes, Allacen, Tabit,

[3] "De notar que os seus textos não dão quaisquer indicações de ter feito trabalho numérico associado à astronomia (preparação de tabelas, etc.), nem de qualquer interesse por astrologia ou por especulações físico-filosóficas sobre a estrutura cosmológica do mundo." (Leitão, 2013, p. 24). Unless otherwise stated, all the translations of the quotations are from the author with slight revisions of the editorial team.

[4] On the general diffusion and impact of Nunes' work in Europe, see (Leitão, 2002); on the diffusion and transmission of Nunes' nautical work in Europe, see (Almeida, 2011).

[5] As an example, Christopher Clavius (1538-1612) referred Nunes as "(...) acerrimo vir ingenio, et nullo hac nostra aetate in Mathematicis inferior" (Clavius, 1611, p. 123).

[6] Nowadays, all of Nunes' books are available with extensive and valuable notes (in Portuguese). Recently, a web page was developed (in English) to serve as an introductory to Nunes' science and historiography. See http://pedronunes.fc.ul.pt. It has, by no means, as much information as the extensive and erudite notes of the modern editions but investigators not fluent in Portuguese can consult some studies, papers and find links to other interesting pages.

to cite a few.[7] Furthermore, he was much influenced by the more recent Germanic astronomical tradition represented by Regiomontanus, Johannes Stöffler, and Johannes Werner, among others.

In my opinion, Nunes' contributions to astronomy can be organized in three main vectors: translation, commentaries, and original research. The following lines will focus chronologically on Pedro Nunes' main texts and draw an overview of his astronomical work. I will also present a few considerations on Nunes' influence on astronomy and cosmography, paying particular attention to French cosmographic literature of the sixteenth and seventeenth centuries.

Tratado da sphera (1537)

Nunes was already thirty-five years old when he published his first book (Nunes, 1537). It consisted of translations of Sacrobosco's *Tractatus de sphaera*, of Ptolemy's book I of *Geography* and of the sun and moon chapters of Peuerbach's *Teoricae novae planetarum* into Portuguese.[8] He also added two original texts addressing navigation problems: the *Tratado sobre certas duuidas de nauegação* [*Treatise on some doubts about navigation*] and the *Tratado em defensam da carta de marear* [*Treatise in defence of the nautical chart*].

With the exception of his *Libro de Algebra* (written in Castilian Spanish and published in 1567), this volume was the only one written in a vernacular language.[9] In the dedicatory of the book to Prince Luís, Pedro Nunes stated that his main purpose was to "reveal" the necessary principles of cosmography in the Portuguese idiom. He specified: "science does not have a language [that is, it can be understood using any vernacular one]"[10] (Nunes, 1537, p. 5).

Nunes' first book presented him as a commentator of texts of science. The original *Tractatus de sphaera* by Sacrobosco was an introductory

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[7] More on some of Nunes' textual sources can be found in the catalogue of an exhibition celebrating the five hundred years of his birthday in 2002 (Leitão & Martins, 2002).

[8] As far as I know, the compilation of these texts in one volume is completely original. Nevertheless, there were editions combining two of those titles. As an example, a book comprising the *Sphera* and the *Theoricae* was edited in Venice, in 1482 (further editions in 1485, 1490, 1499, 1519). See (Nunes, 1537, p. 248-249).

[9] Nonetheless, he would later favour publishing in Latin, which was still the preferred idiom to communicate and share scientific novelties among scholars.

[10] "a sciencia não tem lingoagem: e que per qualquer que seja se pode dar a entender".

textbook to the study of astronomy, well known all over Europe. It brought out a large tradition of scholarly commentaries that motivated important scientific discussions.[11] The same important commentary tradition existed in Peuerbach's *Teoricae novae planetarum* case (although at a lesser scale due to the fact it was a more recent text). Nunes' translation was limited to the sun and moon chapters and included brief commentaries about the illustrations. It must be underlined that it was only the second commentary in vernacular to be published in the sixteenth century, after Oronce Fine's *La théorique des cielz, mouvemens et termes practiques des sept planètes* (1528).

This Portuguese translation of the *Sphere* included twenty-six commentaries. They were generally straightforward but there were some exceptions to be noticed. In particular, the *Annotação sobre as derradeiras palauras do Capitulo dos Climas* [*Commentary on the chapter of climes*]. In this note and for the first time in the history of science, trigonometry and geometry were used to explain the width of the *climate*. This notion was introduced in classical antiquity (as far as it is known by Aristotle) and it was used to divide the Earth in parallels (usually seven). Two consecutive parallels had a difference of thirty minutes in the length of the respective longest day of the year.

The *Commentary* enjoyed a large reputation thanks to Elie Vinet.[12] Starting in 1556, Vinet included a shorter version of Nunes' notes in his multiple editions of his *Sphaera emendata*.[13] This book had at least 32 edi-

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[11] These commentaries were personal notes, sometimes to clarify unproved passages of the original, sometimes to point out errors or to propose improvements. The amount of commentaries to the *Sphere*, that were the basis for an important intellectual tradition, shows that this was an extensively studied text. Commentators included, among others, the names of Michael Scot, Robert Anglicus, Cesco d'Ascoli, Elie Vinet and Christopher Clavius.

[12] Vinet was an admirer of Nunes' work. It is possible that they knew each other from the time when Vinet was teaching at the Colégio das Artes, in Coimbra, between 1547 and 1549. Besides the *Tratado da Sphera*, he knew and possessed other books by the Portuguese cosmographer, such as *De crepusculis*, and he also made a reference to the *De erratis Orontii Finaei* in his own *Definitiones Elementi quincti et sexti* (1575). Vinet had a very important role in the transmission of Nunes' work to some intellectual groups in Bordeaux linked to the Collège de Guyenne. For example, it is possible that the famous Jacques Pelletier became aware of Nunes' work through Vinet, when he was in Bordeaux. The other interesting link of Nunes' *Tratado da sphera* to France is that a copy reached the country through the ambassador Jean Nicot, who planned to translate it (Nunes, 1537, p. 562-563).

[13] Nunes' text was sometimes highlighted in the frontispiece as, for example, in the following edition: Vinet (1559) *Sphaera Ioannis De Sacro Bosco Emendata. Eliae Vineti Santonis Scholia in eandem Sphaeram, ab ipso authore restituta [...] et Petri Nonii Salaciencis Demonstrationem eorum, quae in extremo capite de Climatibus Sacroboscius scribit de inaequali*

tions until 1620, which made the *Annotatio* Nunes' most printed text. This fact was meaningful enough to motivate Bernardino Baldi (1553-1617) to include Nunes among the most famous mathematicians and astronomers writing commentaries on Sacrobosco's *Tractatus de Sphaera*.[14]

Considering the two original treatises from 1537, the first one was motivated by two questions related to astronomical routines of navigation, attributed to the nobleman Martim Afonso de Sousa (ca. 1490-c.a. 1571).[15] The answers to Martim Afonso de Sousa's questions introduced solutions to several navigational problems, specifically based on astronomical data and methods. Contrary to the common art of navigation (based in simple rules and processes) his suggestions implied many innovative tools, concepts and procedures resulting from a meticulous use of mathematics, astronomy and geography.

As a cosmographer Nunes was engaged in managing several technical aspects of navigation. Among other things, cosmographers were in charge of organizing the training of seamen. In his *Treatises* he supported the idea that seamen should improve their technical abilities in order to face different challenges in their practice.[16] He suggested general directives to the training of seamen, based on the knowledge of their professional environment using tools from mathematics, geography, astronomy, and even meteorology. Later, these ideas influenced the practice of many cosmog-

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Climatum latitudine, eodem Vineto Interprete. (Lutatiae, Gulielmum Cauellat). In a recent paper, Matteo Valleriani focused on the early modern tradition of commentaries on Sacrobosco's *Tractatus de sphaera*. In particular, he analyzed the diffusion of Nunes' demonstration and how it was published in other places and by different printers (Valleriani, 2017).

[14] (Baldi, 1998, p. 167). Baldi's text circulated in manuscript versions until 1707, when it was published in Urbino. Unfortunately, that edition was truncated and had errors. I use the modern edition of the original manuscript, published in 1998.

[15] It is my opinion that Martim Afonso de Sousa (c. 1490-1571), and even more D. João de Castro (1500-1548), represented Nunes' ideal of the "modern navigator", that is a new professional prepared with enough critical spirit and scientific knowledge to observe natural phenomena, interpret them and act in the best interest for their journey. They should also have the ability to communicate with the cosmographer, bringing relevant information from their voyages and, if possible, doubts like Sousa's.

[16] The author mentioned the *Tractatus de sphaera*, book I of *Geography* and the sun and moon chapters of the *Teoricae novae planetarum* as "the basic knowledge that anyone interested in understanding something about cosmography should have". The translation is mine from the original "(…) sam aquelles principios que deue ter qualquer pessoa que em Cosmographia deseja saber alguma coisa" (Nunes, 1537, p. 5).

raphers around Europe. For example, the Antwerpian cosmographer Michel Coignet, writing in 1581, showed awareness of the differences between a "practically" oriented and a "scientifically" oriented seamanship, making good use of the "(...) pratiques [maritimes] susdites de plusieurs autres reigles fort ingenieuses et instruments prins de l'art de l'Astronomie et Cosmographie (...)"[17] (Coignet, 1581, p. 5).

Among other suggestions, Nunes advised the use of lunar eclipses to solve longitude problems and he systematized the use of 23°30' for the inclination of the ecliptic (a value taken from Regiomontanus), substituting the common value of 23°33'.[18] He also proposed ways to simplify the customary rules to find latitude by using the position of the Sun at noon.[19] As he was also concerned with the determination of latitude by the position of the Sun, he suggested improvements in the use of the tables of declination of the Sun, calling special attention to its correct use.[20]

Nunes introduced improvements to the standard estimation of latitude at noon. He made new suggestions concerning the calculation of latitude at any given time of the day and about the determination of time aboard ships, when the Sun's position was previously known (Nunes, 1537, p. 147). Furthermore, in order to obtain time on board, besides knowing Sun's height, declination and azimuth, he suggested the pilot should also consider the latitude of the observer.[21] This procedure is linked to the problem of the "miraculous" sundial of Acaz, a phenomenon in which, under certain conditions, the Sun's shadow would present a retrograde path. In fact, this is a very difficult phenomenon to observe aboard and, in the opinion of the historian Henrique Leitão, it made Nunes a pioneer in using

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[17] Suggested translation: "(…) the above-mentioned practices and several other ingenious rules and instruments taken from the art of Astronomy and Cosmography".

[18] (Regiomontanus, 1490). The choice of Regiomontanus' value for the inclination of the ecliptic guarantied scientific excellence but provided also a "round" number easier to compute (Nunes, 1537, p. 142).

[19] One of the best studies about this can be found in (Albuquerque, 1988).

[20] That is, the Sun's declination varies slowly during the day, so the navigator should correct the tabulated values in the case he was observing the Sun from a distance of more than six hours away from the place where the tables were computed (Nunes, 1537, p. 142).

[21] This happens because the spherical triangle has two solutions. For a mathematical explanation, see (Smart, 1931, p. 10).

mathematical tools to demonstrate a phenomenon that had possibly never been observed before.[22]

Furthermore, he proposed new instruments to help seamen to determine their position when the Sun was visible. He designed a simple auxiliary instrument called *lâmina de sombras* (shadow instrument) that should be used together with a globe to mark their results. Afterward, he developed a second method using the same apparatus. Finally, he proposed graphic schemes to obtain Sun's declination more precisely.[23]

Nunes also wrote briefly about the use of the pole star to obtain the latitude and made some comments to a crucial parameter used by seamen: the distance between that star and the pole. Relying on Werner's calculations, the Portuguese cosmographer recommended that the value of the distance should be changed to 4°9' (or 10').[24] Seamen and other cosmographers used the value of 3°30' (in fact more accurate) and considered Nunes' suggestion as an error since it did not coincide with the values they observed. This may point out that, at the time, Nunes had made no previous observation of the star and just trusted a highly regarded scholar's authority.

De crepusculis (1542)

The motivation for Nunes' next book *De crepusculis* (Nunes, 1542) was another enquiry, this time by an eminent pupil. In the initial dedicatory lines to King João III, the cosmographer specified that the idea of writing about twilights – defined by him as the "(...) dubious middle light between day and night" (Knobloch, 2003, p. 118) – came from D. Henrique, the King's brother and also a future king.[25] The problem of twilights in differ-

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[22] (Nunes, 1537, p. 156-157). Nunes proved this phenomenon for the region between tropics. The city of Jerusalem is outside this zone, therefore Nunes "avoided" dealing with non-miraculous solutions. Later Clavius extended the mathematical solution to all latitudes. It is not known whether Nunes was also informed of this question by seamen like Aloisio Cadamosto that observed it in Sumatra, as described by Christopher Wren (Elmes, 1852, p. 103).

[23] In theory, these solutions were easy to use, despite needing sine tables and some basic notions of trigonometry. See more in the notes added to volumes I and IV of the *Obras*. Luís de Albuquerque (1988) has made several comments about this.

[24] Werner calculated this value in 1500, based on a rate of precession of 49000 years and on the *Alphonsine Tables*. (Werner, 1514).

[25] For more information about this book, besides the notes in (Nunes, 1542), see also (Vilar, 2006).

ent places of the Earth had been addressed before by astronomers of Latin and Arabic traditions such as Sacrobosco, Ibn MucĀdh and Stoffler, among others but Nunes believed that none of his predecessors obtained a definitive solution to the problem.[26]

The distinctive aspect of this work was that the Portuguese cosmographer addressed the problem from a mathematical point of view:

> [twilights'] durations can be easily obtained by arithmetical operations based on geometrical demonstrations on arcs and spherical angles, however, astronomers determine them on astrolabe's limbs (...) because in this way they achieve their objective easily. (Nunes, 1542, p. 147)

He organized his arguments in a "Euclidean" way, in the sense that the demonstrations were ordered in theorems and propositions put in a logical sequence. He also chose to write in Latin, which helped promoting his work to a wider international audience.

The book is divided in two parts. In the first one, the author listed general theorems and propositions. These were used in the second part to deal with aspects concerning the decreasing or increasing of the twilight during the year. The volume had extra bibliographic interest since Nunes also published for the first time the *Liber de causis crepusculorum* by Ibn Mu-cĀdh, which again emphasized his attention to early texts.[27] *De crepusculis* is a remarkable work for several other reasons: besides some interesting astronomical results, it dealt with the problems of optics applied to astronomy and suggested instrument improvements, such as the famous "nonius".

Many historians praised this short text and considered it as the greatest example of Nunes' style of dealing with practical problems using mathematical tools. Contemporary men of science (Clavius and Tycho Brahe among others) also acclaimed the book. Christoph Clavius was the first renowned mathematician to cite Nunes' book and one of its principal advocates. His commentaries suggest that he used the text in his classes. However, he considered the book was in some way difficult to read and for that reason he made some adjustments and simplifications. In fact, Nunes' approach to the subject was not straightforward, since at the time, many

[26] Furthermore, he was not comfortable with some of the technical aspects of these approaches: for example, the hypothesis of the equality of twilights for every day of the year and for all latitudes.

[27] Until recently the earlier Latin text was wrongly attributed to Allacen, because of the reference to Gerardo of Cremona. However, historian A. I. Sabra showed that it should be credited to Ibn MucĀdh (Sabra, 1967).

trigonometric functions were not yet available – for example, he used sines and cosines but not tangents. In 1815, Jean-Baptiste Delambre made the first critical comments on *De crepusculis*, which were later included in his *Histoire de l'Astronomie* (Delambre, 1819).[28]

In detail, Nunes considered that the twilights began or ended when the Sun was 18º under the horizon. The time to cover this distance depended on the observer's latitude and on the time of the year (position of the Sun on the Ecliptic). From a technical point of view, Nunes' process was based on the difference between the right ascension of the sun and of another star, whose distance regarding the meridian was previously determined. Among other things, he proved that on any given day, morning and evening twilights had equal durations. Equal length twilights occurred at equal latitudes; at the equator, the maximum twilight occurred at solstices and the minimum at the equinoxes.

Though very theoretical, the book revealed some connections with the author's cosmographical practice. One example is the discussion about what is probably his most popular contribution to science: the "nonius". This ingenious solution was designed to improve the precision when measuring of astronomical angles with circular scale instruments used by seamen, like an astrolabe or a quadrant.[29] The "nonius" was praised by authors as William Barlow, Andrés García de Céspedes, Tycho Brahe and Robert Dudley. Later, the "nonius" underwent several improvements, the best known being proposed by Pierre Vernier (1584-1638), in 1631 and consisting in reducing the system to two linear scales, one fixed and the other movable.

One last detail about this small volume is the presence of a short list of books at the end. It includes works that Nunes intended to publish and, among them, two are directly related to astronomy: *De ortu et occasu signorum* [*The rising and setting of the signs*] and *De astrolabio opus demonstrantiuum* [*Demonstration of the astrolabe*]. In fact, it is not known whether he managed to write these texts or not but the intention shows further about his intellectual interest and preoccupation to work on astronomical matters. Interestingly enough, the book he wrote next was not announced in that list.

[28] Knobloch underlined that Delambre considered it "(...) long-winded, lengthy, diffuse" (Knobloch, 2003, p. 117).

[29] About instruments of navigation, see (Albuquerque, 1988b).

De erratis Orontii Finaei (1546)

A few years later, in 1546, Nunes published a book entitled *De erratis Orontii Finaei* (Nunes, 1546). Its purpose was to show some erroneous procedures and demonstrations by the renowned Oronce Fine (1494-1555), professor at the Collège de France, in Paris (Ross, 1971). Fine had presented solutions for the famous classical problems of duplication of the cube, trisection of an angle and quadrature of the circle and published it first in *Protomathesis* (1532) and later in a compilation of works (1544). Other subjects also caught Nunes' attention like, for instance, Fine's assumptions on gnomonic and on the problem of determination of longitude.[30]

Nunes' book is much more than an array of criticism to a fellow scholar.[31] He presented a new point of view to sensible topics and an unusual domain of the most powerful mathematical tools of his time. The important historian of science Maxwell Clagett stated:

> The acutest and learned of the critics was the Portuguese mathematician Pedro Nunes. In his *De erratis Orontii Finaei* (Coimbra, 1546), Nunes not only corrected the errors of the French mathematician but revealed himself as the most penetrating student of Archimedes' technique of approximations yet to write in Latin. (Clagett, 1978, p. 1246)[32]

Though the text is mostly focused on mathematics, it is possible to find some passages related to astronomical subjects and applications to cosmography on chapters XV, XVI, XVIII and XIX. In Chapter XV – *How Oronce made a great mistake on the investigation of the longitudes of the places, due to*

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[30] The French scholar expressed thoughts about the determination of longitude in several texts, mainly in his *De inuenienda longitudinis locorum differentia, aliter quam per Lunares eclipses, etiam dato quouis tempore, Liber admodum singularis* (included in those collected works printed in 1544). Fine wrote about sundials in *De solaribus horologiis et quadrantibus*, a text included in his *Protomathesis*.

[31] (Leitão, 2009). Nunes was not the only scholar to point out inaccuracies in Fine's works: among the most "severe" was Jean Borrel (in 1554). Others, like Tartaglia (in 1560) and Adrianus Romanus (in 1597), also made some important remarks.

[32] Nunes was very well informed about the work of Archimedes. Though in previous works he had only made some brief references to works by the Syracusan, he revealed in *De erratis* a greater knowledge of the Archimedean texts, surely motivated by the recent publishing of his works with commentaries by Eutocius of Ascalon. He gave special attention to *De mensura circuli*, included in the edition *Archimedis Syracusani Philosophi ac Geometrae excellentissimi Opera*, from 1544.

the ignorance of basic rudiments of Astronomy,[33] Nunes showed the errors of Fine's proposition to determine the longitude of a place based on the observation of Moon's position. In fact, Fine's solution was a bit different from the one known as "Lunar distances method", previously proposed by Werner in his notes to Ptolemy's *Geography* (Werner, 1514). Fine based his own method on the meridian passage of the Moon rather than on the measurement of distances between the Moon and another celestial body. In detail, Nunes noticed that Fine was incorrect in his considerations about the lag of the Moon and about lunar parallax.

Chapter XVI was dedicated to several errors found in Fine's text *Planisphaerium geographicum, quo longitudinis atque latitudinis differentiae, tum directae locorum deprehenduntur elongationes*, included in *Quadratura circuli*. In this text, Nunes used several techniques of positional astronomy to explain a particular case of determination of the longitude and latitude of a place.

In Chapter XVIII, Nunes made minor comments on some of Fine's ideas about gnomonics and dials in his *De solaribus horologiis et quadrantibus libri IIII*, included in *Protomathesis*. Among other subjects, Nunes commented on the construction of a nocturnal clock. In chapter XIX Nunes kept on correcting the Frenchman about his propositions for the construction of sundials. It is interesting to notice that this last chapter led Clavius to praise Nunes among the "scriptores horologiorum" and Élie Vinet to write:

> Quand a la Theorique et demonstration, mon auis n'a esté d'i toucher: pource que le liure en eust esté beaucoup plus grand est obscur: mais s'il i a quelqu'un, qui doute de la doctrine ici baillée, qu'il aille lire et bien eplucher le liure q'un mien ami Pero Nunez Cosmographe du Roi de Portugal Jehan le Tiers, publia et fit imprimer a Coimbre Vniversité de Portugal, l'an M.D.XLVI: et il trouuera lá, qui le contentera. (Vinet, 1583, Conclusion)

Again, one can notice the direct and indirect connections with Nunes' cosmographic practice. Generally speaking, the study of gnomonics was fundamental to understand and devise a vast array of instruments. In the same way, the determination of longitude was vital to managing all the geographical information of the empire and was also necessary for navigation, tasks which were supervised by the Chief Cosmographer.

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[33] The original title in Latin is: *Orontium uehementer errasse in inuestigatione longitudinis locorum, ob ignorantiam primorum rudimentorum astrogiae*.

Petri Nonii Salaciensis Opera (1566)

The *Petri Nonii Salaciensis Opera* (Nunes, 1566) is a large volume compiling the most important achievements of Nunes' scientific activities. It is divided in two main parts: a short one consisting in the Latin version of his original treatises from 1537 and a larger one, in two books, named *Rules and instruments to find out the appearances of both maritime and celestial things.*[34] The book also included the Latin version of his notes on Peuerbach's theories of the planets.[35]

The publication of the *Opera* triggered a big impulse within the recent scientific field of theoretical navigation which influenced many European cosmographers. One of these people was Michel Coignet, mentioned earlier, who was inspired by the idea that a modern practice of navigation should include not only simple rules but also more sophisticated astronomical procedures. Nunes' influence can be seen in some instruments proposed by Coignet, such as the nautical hemisphere, which included a shadow apparatus in a graduated semi circle. Coignet advised the use of that instrument to determine the latitude at any time of the day, based in a procedure developed by the Portuguese cosmographer.

The association between strictly theoretical principles and practical solutions for everyday navigation problems is evident throughout the book. The knowledge of the position of the sun to determine latitude was very important to navigation and Nunes had addressed it before, in a less formal way, in 1537. Thirty years later, the cosmographer had developed his ideas and presented various comments and thoughts about Sun's theory and its parameters, such as the duration of the tropic year, precession rate and ecliptic obliquity. Related to this topic, in chapter 4, *Of Sun's declination*, he confirmed 23°30' as the optimal angle of the inclination of the ecliptic. Interestingly this value became widely accepted among cosmographers and mathematical practitioners such as Edward Wright (1561-1615) who stated that he used that value "agreeing with that excellent arts-man Germanies Euclide Regiomontanus, whom Petrus Nonius (compared by Ramus to Archimedes) and Clarius [sic] (a great Mathematician though a Iesuite) chose rather to follow, than either of the other [Copérnico and Tycho Brahe] (...)" (Wright, 1599, fl. Aa r).

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[34] From latin: *De regulis et instrumentis, ad uarias rerum tam maritimarum quam et coeletium apparentias deprehendendas, ex Mathematicis disciplinis.*

[35] The modern edition of Nunes (1566) was divided in two volumes. The navigation books (*De arte atque ratione nauigandi*) were published in volume IV (2008) and the notes to Peuerbach's text (*In Theoricas Planetarum Georgii Purbachii Annotationes*) were published in volume V (2011): see the bibliography.

Nunes maintained his commentaries regarding the use of solar tables and the necessity of corrections and adaptations. He also mentioned that the values of the Sun's declination in the tables were approximations that did not consider the trepidation of the eighth sphere.[36] This is a good example of a very specific topic that did not matter to seamen in a direct way, but could be useful to cosmographers and astronomers when calculating tables for nautical use. This also shows how very complex scientific knowledge could reach the relevant practitioners, a process mediated by the cosmographers.

It was also in Chapter 4 (and repeated in Chapter 11) that the author made a brief reference to Copernicus and his *De revolutionibus orbium caelestium* (1543). Nunes was one of the first European scholars to address this pivotal work, showing that he was well informed about contemporary astronomy. Contrary to other readers of Copernicus, Nunes did not worry much about the physical and philosophical implications of the Polish's cosmographical and astronomical theories. In fact, his comment on the determination of the movement of fixed celestial bodies is focused on Copernicus' mathematical inexactness in some passages of his book (Nunes, 1566, p. 329).

In *Opera* there are but few references to astronomical observations. Nevertheless, it is possible to find two of them in Chapter 4. In the first one, the author vaguely mentioned some "regular" observations of the skies. The second one is more specific and revealed the use of the astrolabe on a specific date and place: the 14th of September 1555, in Coimbra, Portugal.[37] In that observation he measured the distance of the Sun to the zenith, which was a simple procedure. In my opinion, these scarce occurrences support the idea that Nunes' astronomical reputation was not based on his observational skills.

Afterwards, in Chapter 5, Nunes proposed three procedures to obtain the inclination of the ecliptic, an essential value for a cosmographer. The first one was actually a graphical process that could be drawn on the back of a plane astrolabe or other plane instruments. The second process was based on Vitruvio's analema. The third one, often known as "quadrante de declinação", was the instrument previously described in the final pages of his *Tratado em defensam da carta de marear* (Nunes, 1537, p. 180-182).

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[36] The trepidation designates a hypothetical variation in the rate of the precession of the equinoxes.

[37] In what concerns ephemeris, the Sun entered Libra on this date.

Chapter 6 is also very important. It addresses subjects related to the measuring of astronomical observable distances such as parallax, atmosphere refraction, light beams, but also the height of atmosphere vapours. More importantly, the author focused on the instruments most commonly used in navigation: the astrolabe, the cross-staff and the quadrant. He reflected upon the limits and problems of those instruments and proposed some alternatives. As an example, he conceived a nautical ring destined to measure Sun's height. This instrument excluded the moving parts of the astrolabe and had the advantage of doubling the precision of the readings.[38] Again, the attention paid to instruments shows his concern with practical applications of theoretical ideas for the benefit of cosmography and navigation. The nautical ring is a perfect example of Nunes' *modus operandi* as Royal Cosmographer: in this case, he applied a simple geometric principle to an instrument to ease a common procedure in navigation. The ring was mentioned by later cosmographers such as the important George Fournier, who paid attention to it in his *Hydrographie*. The fourth chapter of Book X, was dedicated to the *Anneau gradué*, however with no mention to the name of its Portuguese creator. Nevertheless, Fournier praised the instrument, stating: "Cet Anneau est preferable a l'Astrolabe" (Fournier, 1643, p. 372). The famous Claude Deschales also made references to the ring in the Proposition XXIII – *De l'Anneau astronomique* in his *L'art de naviger* (1677):

> Nous appelons Anneau Astronomique une circoference de cercle, faite en forme d'un Anneau. Il doit estre suspendu librement, de méme façon que l'Astrolabe. (…) L'Anneau Astronomique ne peut servir que pour le Soleil, mais il a cette commodité, qu'on n'a besoing que d'une observation; sans estre obligé de baisser, ou de hausser la regle: et de plus, ses degrez sont plus grands que dans l'Astrolabe. (Deschales, 1677, p. 57)[39]

Concerning the quadrant, Nunes suggested practical improvements such as substituting the thread for a metallic rule which would allow a better use under unstable conditions like the ones experienced at high seas (Nunes, 1566, p. 360). Deschales was one of the authors agreeing with that

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[38] Nunes' argument was based on the idea that, because there was a lever effect, the astrolabe was not balanced. Later, it was proven that it had no influence on the instrument.

[39] "We call Astronomical Ring a circumference with the form of a ring. It should be hung freely, in the same manner as the astrolabe. (…) The Astronomical Ring can only be used for the Sun, but it is convenient, for one needs only one observation, without having to lower or to raise the rule; and, moreover, its degrees are larger than the Astrolabe's".

idea: "(...) au lieu d'un filet, mettez une regle qui puisse rouler autour du centre du quart de cercle, la chargeant de trois ou quatre livres de plomb par le bas pour empescher qu'elle ne branle"[40] (Deschales, 1677, p. 73). Another problem addressed in the *Opera* was related to the scales of the instruments so Nunes recalled one of his best-known solutions – the "nonius" – previously published in *De crepusculis*. Finally, he commented on the cross-staff, defending that the instrument should only be used aboard to find distances between celestial bodies separated by distances lesser than a quarter of a circle.[41]

In my opinion, the whole chapter dedicated to instruments is a good example of Nunes' concern about applicability and improvement of procedures aboard ships. Even if his writing style was very theoretical and hard to be understood by common seamen, it has been stressed that this apparent problem of communication could be counterbalanced by the intervention of other cosmographers that could interpret the theoretical information, adapt it and finally transmit it to seamen.

In Chapter 7 – about the distance of the polar star to the pole – Nunes commented again on the value for this distance and its variation according to the latitude of the observer. Here he maintained his compromise with Werner's proposal of 4°9' for the distance of the star to the pole instead of the value of 3° 30' common among seamen.[42] Nevertheless, he proposed the measuring of the distance from the pole star to the North Pole at its highest or lowest passage, in order to avoid seamen's interpolations and mistakes (Nunes, 1566, p. 383-384). He noticed that measuring the pole star out of its meridian passage, did not give constant values at all latitudes (Nunes, 1566, p. 384). This observation – that echoed in the work

[40] "Instead of a string, put a ruler that can roll around the center of the quarter circle, loading it with three or four pounds of lead from the bottom to prevent it from moving".

[41] Nunes' opinion did not go unnoticed. For instance, Simón de Tovar analyzed his suggestions and prepared a "defense" of the instrument in a book published in 1595 (Tovar, 1595).

[42] In my oppinion, in 1566 he was not so categorical. His writings showed some hesitation on Werner's results, probably because of the pressure that some negative commentaries and the observations of other astronomers put on him. He stated that "if the movement of fixed stars, as obtained by Werner using Alphonsine Tables, is true this distance (...) it is almost of 4° and 9'(...)", completing "(...) However, if we accept Albatenius opinion the distance is a bit less (...)" (Nunes, 1566, p. 375). Unfortunately for Nunes, Werner's calculus was wrong but I call attention to the passage "if it is true" that, in my opinion, does not show an absolute compromise towards the value of his most considered German peer.

of later cosmographers such as Andrés García de Céspedes in his *Regimiento de Navegacion* (1606) – led to the conclusion that the errors were in the order of a minute of a degree which, at the time, was almost indifferent for navigation purposes. Fournier, in Chapter XXIV – *Sçavoir si c'est à tort que Nonius reprend l'usage du Nocturlabe*, commented on Nunes' demonstration of the variation of the distance of the pole star to the pole, defending that these values were small and were not that important in practical terms.

One of Nunes' most relevant suggestions was about the methods to obtain latitude when the Sun was not on the meridian of the observer (that is, when out of mid-day). Again, this procedure was important to obtain latitude at sea at any time and intended to increase the set of techniques available to seamen. In Chapter 10 he analysed a preceding proposition by Peter Apian (1495-1552) and in Chapter 11, analysed another by Jakob Ziegler (c. 1470-1549) (Apian, 1524; Ziegler, 1531). He commented on the use of Ziegler's apparatus (similar to an armillary sphere, meant to solve several astronomical problems) and concluded on the inapplicability of the method, as he had done with Apiano's. Among others, these comments called Deschales' attention, as can be seen in his *L'art de naviger*. In Book VI – *De l'estime corrigé par la latitude*, he made several references to the conditions of application of the regiments of the Sun and pole star and gave some points as to the determination of the latitude at any time of the day. Chapter 11 also contained references to the problem of the sundial of Acaz.

In chapter 18, Nunes went back to subjects related to gnomonics and, assuming the role of cosmographer, he complained about the scarce usage of sundials by seamen. Like he had done in 1537, he recommended the use of an interesting "shadow" instrument to obtain Sun's azimuths. Then, he commented on the conditions under which sun beams were parallel – an important topic in optics and catoptrics – and, among other things, he noticed that the altitude of celestial bodies should be corrected by considering their geometric center (which was in fact important for the Sun and the Moon).

The second part of the *Opera* consisted in thirty-six annotations to Peuerbach's *Theoricae nouae planetarum*. When compared with the notes of 1537, this fresh approach to the text, was much more erudite and selective. It did not intend to comment the complete text but only what he thought needed a better explanation or clarification. The notes cleared and corrected some aspects of Peuerbach's text but also some parts of texts by his commentators such as Schreckenfuchs, Capuano and Reinhold to cite a few. Nunes' commentaries were always printed together with the first part dedicated to navigation (three editions in 1566, 1573, 1592). It is commonly admitted by scholars and historians that these notes are some of the most erudite ever published (for example, Pierre Gassendi included the text among the most important *Theoricae* commentaries) (Gassendi, 1658, vol. v, p. 521) and some extant copies are even bound together with Copernicus' *De revolutionibus*.[43]

Pedro Nunes' followed the original sequence of Peuerbach's text: theories for the Sun, Moon, outer planets, inner planets, "passion" of the planets and the movement of the eighth sphere. Due to its highly technical level, this text was not connected with practical cosmographic duties. Nevertheless, the subjects covered would be of interest to advanced cosmographers that used the original *Theoricae nouae planetarum* as an auxiliary textbook. Outside Portugal, Nunes' text was familiar to Spanish cosmographers such as Cedillo Dias and García de Céspedes and also to astronomers outside the peninsula such as Michael Maestlin (Kepler's professor) and Giovanni Antonio Magini to cite a few. The text entered Jesuit teaching network through Cristopher Clavius; Giovanni Battista Riccioli esteemed it; and it was cited by Claude Deschales in his famous *Cursus seu mundus mathematicus* (1674). Later, Jean-Baptiste Delambre made important and thorough references to it in his *Histoire de l'Astronomie du Moyen Âge* (1819), stating : "(...) il est encore de tous les commentateurs de Purbach, celui qui était le plus géomètre et le plus soigneux; il est aussi le plus instructif" (Delambre, 1819, p. 280).

When addressing the Sun's theory, Nunes considered the determination of the parameters of the orbit. He also improved the values of the eccentricity of the orbit and position of the apogee, a work that was praised later by Clavius, Riccioli and Deschales. His second annotation dealt with the relations between the mean movement and the true movement of the Sun and tried to find its equality conditions. Nunes also presented for the first time a demonstration about the important Moon theory that stated the equation of the center of the moon had a maximum (his notes 1 to 8). This was a meaningful contribution since it solved a maximum value problem without the use of differential calculus.[44] The last notes are also very interesting and dedicated to the movement of the eighth sphere, comparing Alphonsine's predictions with Thabit's. Delambre and Riccioli remembered Nunes for these contributions as one important commentator of Thabit's text.

To conclude, this paper aimed to show Pedro Nunes' foremost output in astronomy, namely his work on translations of earlier texts, commen-

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[43] See (Gingerich, 2002).

[44] The Portuguese historian Francisco Gomes Teixeira called it "a masterpiece of ingenious work and art" (Teixeira, 1934, p. 146).

taries to those texts and original research. Although many aspects were not explored and developed here, plenty was shown about the facets of that work and about how astronomy was integrated in his activity as a cosmographer. At the same time, another goal was to show that, contrarily to many previous mathematicians and astronomers who worked frequently on highly technical issues originating in classical problems, most of the subjects that attracted Nunes were rooted in his contact with the difficulties of seamen and artisans.

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Astronomy and Diplomacy at the Court of King João V of Portugal

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Abstract

During the reign of King João V of Portugal (r.1707-1750), astronomy took part in a movement of cultural renewal and gave impulse to notable international exchanges, which were promoted by the absolutist monarch himself. Using the Portuguese diplomatic network and the extensive epistolary networks of their own Society, a group of Jesuit astronomers – with Neapolitan Giovanni Battista Carbone in the leading role – developed an efficient program of precise celestial observations. This program met João V's political agenda in several ways: the creation of new observatories and the publication of results in European academic journals increased the prestige of the monarchy and a novel cartography of Brazil improved the geographical knowledge of the colony.

Keywords: astronomy, diplomacy, King João V, Jesuits, Giovanni Battista Carbone, Domenico Capassi, Aula da Esfera*, observatories.*

Résumé

Pendant le règne du roi João V du Portugal (r.1707-1750), l'astronomie a participé à un mouvement de renouveau culturel et a donné lieu à des échanges internationaux, incités par le monarque absolutiste. En utilisant le réseau diplomatique portugais et grâce aux nombreux échanges épistolaires de leur société, un groupe d'astronomes jésuites, dirigé par Giovanni B. Carbone, a développé un programme d'observations célestes précises. Ce programme a rencontré l'agenda politique de João V de plusieurs façons : la création de nouveaux observatoires et la publication des résultats dans les journaux académiques ont accru le prestige de la monarchie, et une nouvelle cartographie du Brésil a amélioré la connaissance géographique de sa colonie.

Mots-clés : astronomie, diplomatie, roi João V, Jésuites, Giovanni Battista Carbone, Domenico Capassi, Aula da Esfera*, observatoires.*

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Introduction: Between the Utrecht and Madrid Treaties

In 1722, the Portuguese representative in Paris, Dom Luís da Cunha (1662-1749), wrote in one of his letters to the court: "I can assure you that there is no person who does not think that Your Royal Highness is the richest Prince in Europe and that we are the richest vassals".[1] In his communications with Lisbon, in a more surprised and worried tone, Luís da Cunha would mention that his acquaintances in Versailles believed that the streets of Lisbon were covered with gold. The Portuguese ambassador knew very well that the streets of Lisbon were not covered with the precious metal but the riches discovered in Brazilian mines in the last decade of the 17th century had a profound effect on the reign of absolutist King João V of Portugal (r.1707-1750).[2]

On the mainland, the wealth arriving from Brazil allowed the investment in various architectural projects of which the Mafra *Royal Building* (a Palace-Convent-Basilica) was the largest example: the monumental construction in Mafra employed around 50,000 workers at its peak (António F. Pimentel, 2002, p. 125-156). Simultaneously, because important mineral riches were discovered in Brazil during this period, priorities in the complex interactions and administration of the Portuguese maritime empire shifted from East Asia to the Atlantic (Safier, 2009, p. 133-183).

The continued and sustained cultural activity developed during João V's reign is generally seen as the climax of Baroque culture in Portugal (Monteiro, 2009). Focused on the figure of the king, the monarch's policy promoted the image of a protector of the arts and sciences, an image that was spread throughout Europe. As Nuno G. Monteiro argued (Monteiro, 2009, p. 350), the cultural renewal during King João V's era was perhaps more effective in the arts and in architecture than in other areas, such as the sciences – But it is also true that the need for a geographical knowledge of the vast territory of Portuguese America, the development of manufacturing activities, and even the existence of practical needs associated with mining, navigation and cartography led to the promotion of Portuguese qualified intellectuals and technicians within the court, as well as the opening to experts from other European kingdoms.

[1] Arquivos Nacionais Torre do Tombo (ANTT, Lisbon), MNE, Livro 791, p. 61 (letter dated 2 February 1722). All translations in this paper are mine. On Dom Luís da Cunha see Cluny, 1999).

[2] On King João V (1689-1750) see for instance (Silva, 2006; Reis, 2009; Monteiro, 2009).

From an economic point of view, Portugal benefited from the peace achieved with the Utrecht treaties (1713-1715) – putting an end to the War of the Spanish Succession and to expenses connected with military efforts – and from the Crown's financial relief which was provided by gold and diamonds arriving from Brazil and especially by new or increased taxes. Besides, the Methuen Treaty, signed in 1703 with England, came to benefit the export of wine although it was detrimental to Portuguese wool exports. This economic context was certainly favourable to the creation and sponsorship by the King of different cultural institutions, such as the library of the Mafra Royal Building, the University of Coimbra library, the library of the Oratorian convent-palace of Nossa Senhora das Necessidades, and the enlargement of his own library at the Palace of Ribeira, which by 1750 reached around 70000 volumes. The foundation of the Royal Academy of Portuguese History in 1720 and its renowned editorial activity in which experts had an important role – such as the printer Pierre Rochefort de Massard who had worked for the Académie royale des Sciences in Paris – demonstrate the cultural dynamism of the Johannine period.

King João V considered the French, English and Roman cultural life as his main intellectual models (Pimentel, 2002, p. 65-73, 87, 98-99). Among other things, the monarch imported his own clothes from Paris and also borrowed different etiquette rules from various European courts. Therefore, it is not surprising that King João V started to observe eclipses with court astronomers as Louis XIV had done in Paris with members of the Académie royale des Sciences when the institution was created.

In the first half of the 18th century, the tension between Portugal and Spain over their possessions in South America was still strong since the borders between the two colonial regions were not precisely set and agreed on (Cortesão, 1984, p. 349) and Portugal's territorial influence extended well beyond the limits defined by the Treaty of Tordesillas.[3] In this context, detailed knowledge of South American inland geography was a state matter and João V's officials, diplomats, cartographers and astronomers became actors in the long political process that culminated in January 1750 with the signature of the Treaty of Madrid (Ferreira, 2001). This first diplomatic agreement regarding the disputed limits recognized Spanish rule over parts of the River Plate, Sacramento Colony, and the Philippines, while Portug-

[3] On June 1494, Portugal and Spain signed in Tordesillas a treaty dividing the newly discovered lands between the two crowns along a meridian 370 leagues west of the Cape Verde islands. The lands to the east would belong to Portugal while the lands to the west to Spain.

al's territorial claims over parts of northern and western Brazil were recognized.

Before the Treaty of Madrid, the definition of precise longitude and latitude by Jesuit astronomers was the main astronomical contribution to geographical explorations and cartography in Brazil (Cortesão, 2009). The human and material resources employed in these explorations were acquired almost entirely from outer kingdoms. In this importation of astronomical knowledge, astronomers and instruments, the Portuguese diplomatic network and the Society of Jesus played a crucial role.

In 1722, following King João V's request , the general of the Society of Jesus, Michelangelo Tamburini, sent Carbone and his fellow Jesuit Domenico Capassi (1694-1736) to Portugal. The aim was to employ the two missionaries in cartographical work on the Brazilian state of Maranhão, not only because its borders were under dispute with Spain but also because an urgent need of precisely demarcated administrative divisions was felt (Almeida, 2001). Apparently, the King treasured Carbone's character and skills since, around 1724, he entered Lisbon´s court and was nominated a royal mathematician. Dauril Alden argued that Carbone became the most influential and widely respected Jesuit in the kingdom, and there is in fact plenty of evidence that important responsibilities – such as the negotiations with the papacy or the payments of Mafra's works – were entrusted to Carbone (Alden, 1996, p. 610-612).

Astronomy Teaching in the *Aula da Esfera*

During João V's era, two royal mathematical lectures – one on navigation and the other on fortification – were delivered at the Palace of Ribeira. However, the most influential royal lecture on mathematics and astronomy was held by the Jesuits at the College of Santo Antão, where Giovanni Battista Carbone lived and coordinated the astronomical observatory between ca. 1739 and 1750.

Carbone's and Capassi's observational programs further developed the investigations and studies of celestial phenomena which were carried out in the College but turning to a more "experimental" method, that is with a clear focus on geographical applications (i.e. in the determination of geographical coordinates). The long-lasting tradition of teaching cosmographical and astronomical subjects which had been developed at Santo Antão and maintained until 1759, with its emphasis on navigation, remained a kind of a parallel program that reinforced the empirical activities of the two Neapolitan astronomers.

In Santo Antão, a lecture on mathematical subjects called *Aula da Esfera* (Class on the Sphere) was established around 1590, succeeding to previous and sporadic teaching of astronomy and cosmography (Leitão, 2007, p. 44-49). The *Aula da Esfera* was a special lecture outside the Jesuit curriculum and delivered in vernacular, open not only to Jesuit students but also to members of the nobility and other lay students. The lectures were of a secondary level rather than of a high or scholarly level. Nevertheless, the *Aula* had an important social impact by helping to train, among others, future royal cosmographers (Baldini, 2004; Leitão, 2008, p. 19-23). Many physical and mathematical topics were taught, ranging from geometry, arithmetic, (rudiments of) algebra, or plane and spherical trigonometry, to their application in navigation, geography, hydrography and cartography. Optics, perspective and scenography, gnomonics, and the construction of scientific instruments or simple machines were also taught, as well as statics and hydrostatics, military architecture and engineering. Even forbidden subjects, such as astrology and chiromancy, were sometimes included by the few *Aula*'s teachers who ventured onto those dangerous grounds, although a clear distinction was maintained between 'good' and 'bad' uses (Leitão, 2006).

From around 1620 until the expulsion of the Jesuits from Portugal in 1759, astronomy was taught in the *Aula* according to Tycho Brahe's system, as it was in all Jesuit schools and most universities during this period. The heliocentric system and the new Galilean observations were discussed but only with the aim of refuting them (Baldini, 2004, p. 19-23). Santo Antão's *Aula* was remarkable, not only for the exceptional international circulation of Jesuit experts – sometimes in transit to distant Portuguese missions – but for another reason. Actually, Giovanni Paolo Lembo (1570-1618), the most accomplished telescope maker after Galileo, taught his construction techniques in Lisbon during the period 1615-17, and his case is considered the first known historical case of telescope making in a teaching environment (Leitão, 2007, p. 50-58).

The *Aula da Esfera* also welcomed Jesuit mathematicians such as Christoph Grienberger (1564-1636) and Cristoforo Borri (1583-1632) as professors. This phenomenon was motivated, at least partly in the 17th century, by the small number of Portuguese members of the Society who were available to pursue the study of mathematics (Leitão, 2009).[4] Indeed, most Portuguese Jesuits took every opportunity to be engaged in missio-

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[4] For a detailed analysis of the complex factors determining the activity of Portuguese or foreign professors of mathematics in Portuguese Jesuit Colleges, see (Baldini, 2004).

nary work. In the 18th century, the situation changed and virtually all mathematics teachers in the *Aula* were Portuguese. Many were good mathematicians – such as João Inácio Vieira (1678-1739) and Manuel de Campos (1681-1758). Luís Gonzaga (1666-1747), who taught there between 1700 and 1709, had close connections with the court and became future King João V's mathematical tutor, certainly influencing the young prince's interests and his upbringing (Leitão, 2003). The change taking place in the 18th century was a consequence of a reform introduced by the Society's general Thyrsus Gonzalez (1624-1705) and completed by his successor Michelangelo Tamburini (1648-1730). Between 1692 and 1711, the two generals introduced regular mathematics teachings, within the philosophy curriculum, in Lisbon, Coimbra and Évora Universities (Baldini, 2004).[5] Therefore, the new situation allowed Portuguese members of the Society to have access to a mathematical training and filled the need of competent technicians in several posts – as missionaries in China, as professors in the *Aula da Esfera*, and as cartographers in Brazil.[6] For instance, Diogo Soares (1684-1748) occupied the last two positions and became an accomplished cartographer in South America. Jaime Cortesão showed that the geographical coordinates which were determined by Soares in Brazil and obtained with astronomical observations were fairly accurate when compared with modern values (Cortesão, 1958).

The Practice of Astronomy during João V's Reign

The central figure in the practice of astronomy at João V's court was the Jesuit Giovanni Battista Carbone (1694-1750). Carbone was born in Oria in the kingdom of Naples, in September 1694. In 1709, he entered the Jesuit novitiate in Naples and undertook most of his studies at the Neapolitan college. The college was famous for its mathematical teaching and, as the work of Romano Gatto has shown, a distinctive tradition of astronomical practice emerged there (Gatto, 1994, p. 150-158). Since the publication of Galileo's *Sidereus Nuncius* (1610), the college had been equipped with fine telescopes and some of its best mathematicians were enthusiastic advocates of positional astronomy. In the second half of the 17th century, the college also became the most important focus in the diffusion of Cartesian analysis

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[5] Coimbra was the main college in the Portuguese *Lusitania* province and Évora the only Portuguese Jesuit university.

[6] Interestingly, Gonzales reform had been motivated by the lack of Portuguese missionaries who were provided with mathematical training when the Portuguese Mission in China was challenged by the French Jesuit expedition of 1687.

in Italy, after the introduction of the teaching of François Viète's algebra in the 1620s (Gatto, 1994, p. 150-158, 283-284). It was in this stimulating environment that Carbone and Capassi studied rhetoric and philosophy as well as mathematics, since this last discipline was part of the philosophy curriculum (Almeida, 2001, p. 84).[7]

The 1720s represented an active period of astronomical observations for the two Neapolitan Jesuits in Portugal and in 1729 Giovanni Battista Carbone was elected member of the *Royal Society* of London. The same year, Capassi travelled with his fellow Jesuit Diogo Soares to South America, where, until his sudden illness and death in 1736, he produced fine and detailed maps of the territory (Almeida, 1999, 2001, p. 82-140). Those cartographic surveys covered parts of the coastline, and were improved thanks to a few inland excursions to the southern region of the Portuguese colony.

Carbone also served as rector of the Santo Antão College in the last year of his life. Carbone's influence was felt even in his office – the only administrative post he assumed within the Society. The surviving archives of the college document that a large building campaign started under Carbone's direction and with his strong support, most likely with royal patronage.[8]

To satisfy the need for astronomical training institutions regarding the intended American cartographic mission, two "observatories" were created in Lisbon by Carbone and Capassi, following King João V's orders – one at the Santo Antão College and another at the Royal Palace of Ribeira (Carvalho, 1985, p. 40-46). The precise date of foundation of these observing stations is uncertain. Apparently, the first observations started in 1723 and used no permanent structures. The word "observatory" itself – as Roger Hahn has noted – was employed ambiguously during the Enlightenment, sometimes simply referring to a place where portable instruments could be installed (Hahn 1986, p. 653-658). However, there is evidence that Carbone and Capassi performed regular astronomical observations in the 1720s at the Royal Palace, on Lisbon's waterfront, and also in Santo Antão, where ca. 1739 a *Especula*,(or permanent observatory) was finally erected over the college's church (Tirapicos, 2014).

The presence of the two Jesuits in Lisbon and the emergence of royal observatories construction projects prompted the need for larger and better instruments. In 1723, diplomatic contacts were established with the

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[7] Carbone´s official biographer, although in a panegyric tone, argued that he was a distinguished philosophy, theology and mathematics student in Naples (Barbosa, 1751, p. 4-5).

[8] ANTT (Lisbon), Cartório dos Jesuítas, Maço 92, nº2, fl. 88.

King's patronage by the Secretary of State, Diogo de Mendonça Corte-Real (1658-1736), in order to purchase mathematical instruments (mainly astronomical) from the best European instrument makers (Cortesão, 2009, p. 349-351). Apart from the case of nautical instruments, the production of scientific devices in Portugal was very scarce and circumscribed, and the necessary instruments generally had to be acquired abroad (author, 2010). In August 1723, a quadrant and a semicircle were bought in Rome, and on 6th July 1724: "um óculo em um bastão com retículo e graus" and "três cavaletes para óculos" (Rodrigues, 1931-1950, tom. 4, vol. 1, p. 415-416).[9]

There were further purchase of mathematical instruments in the following years, extending Portugue~~s~~e trading area to London, Paris and The Hague. A 3-feet sextant, certainly incorporating telescopic sights and made by Nicolas Bion (1655-1733), arrived from Paris as well as a 5-foot mural quadrant.[10] Quadrants and sextants of this period were typically equipped with telescopic sights (Bennett, 1987, p. 63-72). These new technical resources, along with the use of the micrometer, inaugurated an era of precise positional astronomy, which had emerged a few decades before, mainly based on the work of Jean Picard (1620-1682).

King João V's astronomers also had access to unique instruments, such as semicircles, which were very unusual devices according to Jim Bennett (Bennett, 1987, p. 76). Even if Jaime Cortesão did not make his primary source explicit, he has claimed that Carbone and Capassi preferred instruments which were made by Le Febvre over those manufactured by Bion, revealing the Jesuits' critical mind regarding instruments' accuracy and efficiency.[11] For example, the first maker supplied, at least, a 3-foot quadrant and a 2-foot azimuthal semicircle (Cortesão, 1984, vol. 2, p. 352).[12]

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[9] Citing a manuscript from Biblioteca da Ajuda (Lisbon); "um óculo em um bastão com retículo e graus" – a telescope in a bat with reticulum and degrees; "três cavaletes para óculos" – tree tripods for telescopes.

[10] On Nicolas Bion see (Marcelin, 2004). Concerning the sextant, see (Carbone, undated [observations in 1725 and 1726]).The mural quadrant is another instrument~~s~~ mentioned in this pamphlet. This quadrant, mounted in a hall, marks possibly the establishment of the first astronomical observatory with fixed structures in Portugal.

[11] The preference reported by Jaime Cortesão must have been linked with technical problems found in Bion's instruments. The 3-feet sextant was damaged during its transportation to Lisbon and the required specifications were not satisfied in a refracting telescope for the observation of eclipses; both were repaired in Lisbon: ANTT (Lisbon), MNE, Liv. 14, fl. 187v (telescope), fl. 199 (sextant).

[12] Carbone, *Observationes*; ANTT (Lisbon), Cartório dos Jesuítas, Maço 78, nº46.

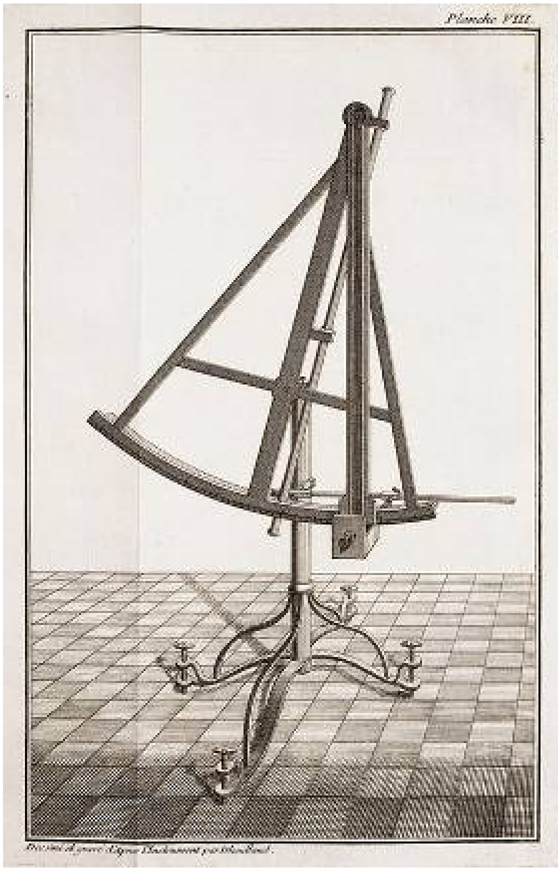

Figure 1 - A sextant, possibly similar to the one depicted in this engraving, was used by Jesuit astronomers Giovanni Battista Carbone and Domenico Capassi in Portugal in the 1720s. (Source: Cassini de Thury, M. Le Monnier, La Méridienne de l'Observatoire Royal de Paris*, 1744; courtesy of the Linda Hall Library of Science, Engineering & Technology)*

More instruments gradually arrived from London. In diplomatic correspondences, a letter dated 21th July 1724 proves that telescopes, pendulum clocks and a universal sundial have been required.[13] The pendulum clocks were commissioned from the influential clock and instrument maker

[13] Biblioteca da Academia das Ciências de Lisboa (BACL, Lisbon), Mss. 600, Série Azul (letter dated 26 December 1724).

George Graham (1673-1751).[14] Graham had begun to include the dead-beat escapement – invented by Thomas Tompion and Richard Towneley – on his clocks only a few years earlier. Therefore, the regulators available to João V's astronomers were certainly equipped with one of the latest technical innovations in time measurement. Moreover, two "big" telescopes were mentioned in another letter dated 13th August 1725. In this official letter, the Portuguese ambassador in London António Galvão de Castelo Branco reported to the Secretary of State Diogo de Mendonça Corte-Real that the two telescopes were examined by Samuel Molyneux (1689-1728)[15] before being sent to Portugal. Molyneux was the Prince of Wales's secretary, as well as fellow of the *Royal Society* of London (elected in 1712), Member of Parliament, and he also worked closely with James Bradley (1693-1762), a prominent astronomer of that time.[16] Actually, diplomats were, among other things, in charge of verifying the quality of the instruments and therefore António Galvão accompanied Samuel Molyneux several times on his visits to makers' shops.

A reflecting telescope with appropriate size and quality for the practical use of astronomical observations was first developed by John Hadley (1682-1744) in the early 1720s. Other artisans, who gravitated around Hadley and learnt his techniques, also started to produce reflecting telescopes, but more compact and manoeuvrable compared to their refracting counterparts. Molyneux was one of those artisans and in 1725 he offered King João Va 26-inch Newtonian model of his own construction, as a diplomatic gift. This was the first reflecting telescope – or one of the first – to reach continental Europe and another innovation added to the set of instruments available to court astronomers in Lisbon (Simpson, 2009; Tirapicos, 2010, p. 25-32).[17]

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[14] ANTT (Lisbon), Cartório dos Jesuítas, Maço 78, nº43, nº44.

[15] BACL (Lisbon), Mss. 601, Série Azul (letter dated 13 August 1725). On Samuel Molyneux see A. M. Clerke, rev. Anita McConnell (2004-2009) "Molyneux, Samuel" in *Oxford Dictionary of National Biography,* vol. 38 (Oxford: Oxford University Press), p. 559. In spite of being sometimes classified as an "amateur" in astronomy Samuel Molyneux was an accomplished astronomer and instrument maker. Molyneux's involvement in the discovery of the aberration of light is discussed in (Hirshfeld, 2001, p. 154-158).

[16] James Bradley was professor of astronomy in Oxford and the Astronomer Royal between 1742 and 1762. On Bradley see (Williams, 2004).

[17] This telescope was an offer to the king's observatory in the Palace of Ribeira (Molyneux's letter to Galvão de Castelo Branco, dated 6 September 1725, ANTT (Lisbon), Cartório dos Jesuítas, Maço 78, nº79).

As mentioned previously, larger instruments and devices that required a more permanent setup – such as the 5-foot mural quadrant – were included in the process of acquiring instruments for João V's astronomers. This shows that the Jesuits' strategy in the 1720s was not only to focus on training for the South American cartographic mission but also to generalise the use of larger observatory instruments. Such use of permanent instruments was a consequence of King João V's desire to establish observatories – following the notable examples of Paris and Greenwich – and possibly of his theatrical conception of power. Yet, the large majority of instruments used by Carbone and Capassi were in fact portable instruments. The large investment in instruments and the acquisition of quality devices also highlights the importance of accuracy to the cartographic mission in Brazil, a mission requiring the rigorous determination of longitudes and latitudes.

The Portuguese section of the Jesuits's extensive corporate network, the Portuguese Assistancy, was subdivided in provinces and sub-provinces occupying a large geographical region – continental Portugal, Brazil, the west coast of India, China, and Japan – and following the geographic organisation of the Portuguese Empire and trading routes (Harris, 1996). The circulation of letters, objects and men, within this organic and highly hierarchical structure, which was governed from Rome, helped the Jesuit network to become one of the most important international networks for the transmission of knowledge in the modern period. Analysing Jesuit correspondence, Steven Harris argued that the Society of Jesus was a sort of Republic of Letters within the Republic of Letters (Harris, 1996, p. 232). Some Jesuits were brought closer through the frequent exchanges of letters between them, and many others also became more familiar with the various [intellectual] schools of thought of the era through their exchanges with correspondents outside the Society. Besides, Harris has noted that Jesuits usually tended to trust other Jesuits rather than non-Jesuits. Therefore, it is not surprising to know that Carbone corresponded about astronomical matters with a few astronomers within the Society. Among others, he corresponded with Nicasius Grammatici (1684-1736) in Ingolstadt, Ignatio Kögler (1680-1746) and André Pereira (1689-1743) in Peking and Antoine-François Laval (1664-1728) in Toulon. Carbone used his political networks – mainly diplomatic – to communicate astronomical data to the *Royal Society* of London through his Jesuit correspondents (Carvalho, 1956). In doing so, he made a significant contribution to the prestige of the Society of Jesus but, at the same time, he shared the data obtained by other Jesuits with the larger community of astronomical practitioners.

Two documents emphasise Carbone's role as a major agent in the diffusion of astronomical knowledge and instruments in the vast Portuguese Empire, through the network of the Society of Jesus. These were found among his personal papers and consist in a list of telescopes and astronomical ephemerides that were sent to missions in boxes. The first list was sent to India but the fate of the other is not known.[18] The small telescopes listed in these documents confirm the idea that, in general, Jesuit missionaries had no access to high-quality instruments (Harris, 2005).

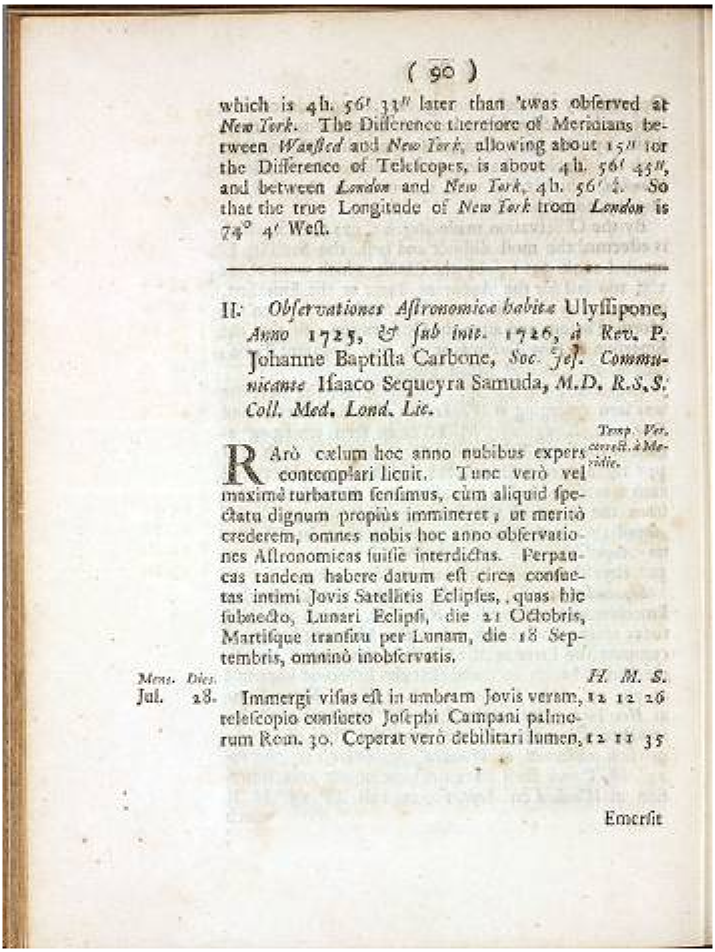
From 1730 onwards, Carbone became essentially a specialist mediator regarding bureaucratic matters and he was primarily concerned with facilitating negotiations with the papacy (Alden, 1996, p. 610). Previously, his position at court allowed for intense activity – apparently fulfilling the King's wishes – coordinating the acquisition of astronomical information and resources through Portuguese diplomatic networks. The ambassadors or special ambassadors in Rome, Paris, London, Vienna, The Hague and Brussels were asked to purchase astronomical instruments and books, following Carbone's demands. In the 1720s, a set of magnificent mathematical instruments – ordered for João V's large and encyclopaedic library – was bought under Carbone's supervision via the diplomatic network (Barchiesi, 1964; Delaforce, 2002; Tirapicos, forthcoming).

Portuguese ambassadors were responsible for initiating communication with the *Royal Society* in London and the *Académie royale des Sciences* in Paris. Moreover, diplomats had to make the initial contact with leading astronomers such as Samuel Molyneux (1689-1728), Francesco Bianchini (1662-1729), Giacomo Filippo Maraldi (1665-1729) and Joseph-Nicolas de l'Isle (1688-1768). Additionally, the network was at some point used for an inquiry in the astronomical observatories. In 1724, the Secretary of State issued an official note which included a questionnaire regarding the extant observatories in the main European kingdoms – detailed plans, descriptions and drawings were requested (Carvalho, 1985, p. 42-43). The mere existence of a program concerning the construction of a modern and well-equipped observatory clearly revealed the general interest and the political support for astronomy in Portugal at that time.

As a result of Carbone´s access to and efficient involvement in these two powerful networks – and in addition to his personal correspondence – astronomical observations were published in influential scientific periodicals such as the *Philosophical Transactions,* the *Histoire de l'Académie royale des sciences avec les mémoires de mathématique et de physique,* the *Acta Eruditorum,* the *Commentarii Academiae Scientiarum Imperialis Petropolitanae* and the *Journal de*

[18] ANTT (Lisbon), Cartório dos Jesuítas, Maço 78, nº89, nº90.

Trévoux. Through these journals, Carbone and Capassi's data – made to determine Lisbon's geographical coordinates accurately – reached a wider audience of astronomers, mathematicians and geographers. Comparing simultaneous observations, their results allowed other specialists to establish the longitudes of various important cities and ports, improving navigational and geographical knowledge of the globe.



(90)

which is 4h. 56′ 33″ later than 'twas observed at *New York*. The Difference therefore of Meridians between *Wansted* and *New York*, allowing about 15″ for the Difference of Telescopes, is about 4h. 56′ 45″, and between *London* and *New York*, 4h. 56′ ¼. So that the true Longitude of *New York* from *London* is 74° 4′ West.

II. *Observationes Astronomicæ habitæ* Ulyssipone, *Anno* 1725, & *sub init.* 1726, *à Rev. P.* Johanne Baptista Carbone, *Soc. Jes. Communicante* Isaaco Sequeyra Samuda, *M.D. R.S.S. Coll. Med. Lond. Lic.*

Temp. Ver. correct. à Meridie.

RArò cælum hoc anno nubibus expers contemplari licuit. Tunc verò vel maximè turbatum sensimus, cùm aliquid spectatu dignum propiùs immineret; ut meritò crederem, omnes nobis hoc anno observationes Astronomicas fuisse interdictas. Perpaucas tandem habere datum est circa confectas intimi Jovis Satellitis Eclipses, quas hic subnecto, Lunari Eclipsi, die 21 Octobris, Martisque transitu per Lunam, die 18 Septembris, omninò inobservatis.

Mens.	*Dies.*		*H.*	*M.*	*S.*
Jul.	28.	Immergi visus est in umbram Jovis veram,	12	12	26
		telescopio confecto Josephi Campani palmorum Rom. 30. Cœperat verò debilitari lumen,	12	11	35

Emersit

Figure 2 - Carbone's astronomical observations performed in Lisbon in 1725 and 1726 (Source: Philosophical Transactions, *vol. 34, 1726-1727, p. 90; courtesy of the Linda Hall Library of Science, Engineering & Technology)*

Carbone's involvement was also notable in a remarkable affair centred on diplomatic relations as well as in the establishment of the first solid interaction between the Hindu and Muslim astronomical traditions and the European astronomical tradition (Forbes, 1982). In 1727, in the Moghul Empire, Raja Sawai Jai Singh II of Amber (1668-1743) sent a fact-finding mission to Lisbon in order to recruit an expert astronomer (Sharma, 1995, p. 283-303). Manuel de Figueiredo – Jesuit rector of the Agra College – and Pedro da Silva – Portuguese layman born in India – took part in this scientific diplomatic mission to King João V's court. The Portuguese monarch answered the Raja's requests by sending back another diplomatic mission, thus encouraging good relations with the Moghul Empire and fostering the stability of Portuguese presence in the region. In Portugal, Pedro da Silva received training and guidance from Carbone before his return to India (Mercier, 1993). João V's royal mathematician was, almost certainly, the key adviser of the diplomatic mission organized in Lisbon. Furthermore, books and instruments were the principal gifts offered to Jai Singh. For example, one should mention La Hire's astronomical tables, a source used by Carbone for his astronomical work. The astronomical tables were one of the items offered to the Hindu ruler when the Portuguese diplomatic mission arrived in Jaipur, in July 1730.

Conclusion

During the reign of King João V (r.1707-1750), astronomy took part in a larger movement of cultural renewal encompassing sciences and the arts (including mechanical and the fine arts) and involving exchanges with European scholar centres. The practice of astronomy in Portugal in this period was not only driven by the King's enlightened interest in experimental sciences and other technical matters but chiefly by the need of a better geographical knowledge of Portuguese America. The discovery of large deposits of Brazilian gold, the dispute with Spain over the limits of Iberian American colonies and the need to demarcate the administrative divisions of Portuguese possessions were certainly key factors for the development and patronage of astronomy. Yet a mutual relationship existed between Brazilian gold and astronomy. Astronomy was sponsored and paid by the American gold but, at the same time, astronomical methods and instruments were political and diplomatic tools used to protect Brazilian mineral riches. In other words, state-sponsored science meant that science had to serve the State. Nonetheless, this 'state service' had different meanings. For example, the cartographical surveys were organized to fill imperial needs. Besides, the spectacular and theatrical representation of power of King

João V – consisting in public observations of astronomical phenomena and the establishment of royal observatories – had a prominent place in Portugal, even if the main royal observatory ended up in the Jesuit College of Santo Antão where a cosmographical and astronomical teaching tradition was well established. Moreover, several astronomical communications were published in European scholar journals and helped to promote João V's image as a patron of the arts and sciences.

At João V's court, the Neapolitan Jesuit Giovanni Battista Carbone occupied a central role in the practice of astronomy, in its multiple meanings. As the King's assistant, Carbone had a privileged political and institutional position, at the confluence of the Portuguese diplomatic network and the Jesuit transnational network. Fulfilling the King's wishes, Carbone was an active observational astronomer, organizer of observatories, and agent in the circulation of astronomical data and instruments within the vast Portuguese Empire as well as in the main European academic circles. In the process, he had access to some of the latest innovations in astronomical instrumentation, resources allowed by João V's exceptional patronage – as seen in the examples of Graham's pendulum clocks and reflecting telescopes.

In the 1720s, both Carbone and Capassi contributed to create a corpus of astronomical data that ultimately improved the navigational and geographical description of the globe. However, that result was only achieved thanks to the Jesuits's full adherence to the King's political agenda (with its multiple facets of "state service"). A pamphlet, written by the two astronomers on the lunar eclipse of 1st November 1724 and distributed all over Europe through the Portuguese diplomatic network, shows that they communicated precise and careful timings of the phenomena through a laudatory discourse about a royal and magnanimous protector of astronomy (Carbone & Capassi, 1724).

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The Portuguese Astronomical Activity in the Late 18th and Early 19th Centuries

Fernando B. Figueiredo*

Abstract

In the late 18th century and beginning of the 19th century, the Portuguese centre of gravity for astronomical research (and teaching) was the Royal Astronomical Observatory of the University of Coimbra. This scientific establishment was envisioned under the Pombaline reform of the University of Coimbra in 1772. Linked to the new Faculty of Mathematics, the Observatory played a pivotal role in the formation of the community of Portuguese astronomers during the first decades of the 19th century. In this paper, we will put in context the scientific work carried out at the Observatory, following the practice of the most famous observatories of Europe, then we will examine how the astronomical work of Monteiro da Rocha, which encapsulated theoretical and practical astronomy, was tuned with the major astronomical problems of that time.

Keywords: Portugal, 18th century, enlightenment, sciences mathematics, astronomy, Pombalina Reform, José Monteiro da Rocha, observatory, ephemerides.

Résumé

Au tournant du XIX^e^ siècle, le centre de gravité portugais de la recherche (et de l'enseignement) astronomique était l'Observatoire royal astronomique de l'Université de Coimbra, établissement scientifique créé sous la réforme Pombalina de l'Université de Coimbra en 1772. Relié à la nouvelle Faculté de Mathématiques, l'Observatoire joua un rôle central dans la formation de la communauté d'astronomes portugais pendant les premières décennies du XIX^e^ siècle. Dans cet article, nous étudierons le travail scientifique effectué à l'Observatoire, notamment par rapport aux pratiques développées dans les observatoires les plus reconnus d'Europe, puis nous analyserons comment le travail astronomique de Monteiro da Rocha, à la fois théorique et pratique, faisait écho aux problèmes astronomiques fondamentaux de cette époque.

Mots-clés : XVIII^e^ siècle, Lumières, sciences mathématiques, astronomie, Réforme Pombalina, José Monteiro da Rocha, observatoire, éphémérides.

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In the 18th century, particularly in its second half, astronomy developed around what is called the Newtonian program. This program is characterised by an intimate relationship between observational astronomy (astrometry) and the advances in theoretical astronomy (celestial mechanics) provided by the work of theoretical astronomers and mathematicians such as D'Alembert (1717-1783), Euler (1707-1783), Clairaut (1713-1765), Lagrange (1736-1813), and Laplace (1749-1827). Therefore, the scientific program of the major (national) astronomical observatories of the late 18th and early 19th centuries was characterised by a constant quest for accurate measurements of the positions of solar system bodies and stars, which would be able to contribute to the improvement of Newtonian theory and the mathematical tools involved in it. Concerning this particular issue, Laplace wrote:

> Astronomy, considered in the most general manner, is a great problem of mechanics, in which the elements of the motions are the arbitrary constant quantities. The solution of this problem depends, at the same time, upon the accuracy of the observations, and upon the perfection of the analysis. It is very important to reject every empirical process, and to complete the analysis, so that it shall not be necessary to derive from observations any but indispensable data. (Laplace, 1798, vol. 1, p. i)[1]

In this ongoing process (the development of instrumental methods of observation, observational data reduction and refinement of the theory) astronomical practice focused mainly on the angular measurement of right ascensions and declinations of celestial bodies passing observatories' meridians – which Jim Bennett calls an international meridian program consensus:

> Thus programs of meridian measurement came to be pursued in all the active observatories of Europe [...] they [the observational data] were accumulated by the activity that became the sine qua non of an astronomical observatory. (Bennett, 1992, p. 1)

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[1] "L'astronomie, considérée de la manière la plus générale, est un grand problème de Mécanique, dont les éléments des mouvements célestes sont les arbitraires ; sa solution dépend à la fois de l'exactitude des observations et de la perfection de l'analyse, et il importe extrêmement d'en bannir tout empirisme et de la réduire à n'emprunter de l'observation que les données indispensables." The English translation is from the translation of Laplace's *Mécanique céleste* by Nathaniel Bowditch (Boston, Hilliard, Gray, Little and Wilkins, 1829).

In Portugal, it was only after 1772, when the Pombaline Reform of the scientific studies in the University of Coimbra took place, that Portugal became seriously engaged with this global astronomical program. In fact, we can say that this Reform, along with the consequent creation of the Royal Astronomical Observatory of the University of Coimbra (henceforth OAUC) were the starting point of structured and consistent institutionalised astronomical activity (teaching/research) in Portugal.

Nevertheless, we can see that the period between the 1720s and the 1730s as the time when an astronomical activity, not attached exclusively to astronomical nautical issues, had emerged within the context of scientific and educational activities of the Society of Jesus, in Portugal.

The Context of Portuguese Astronomy in the First Half of the 18th Century

Until very recently, Portuguese historiography characterised the period of about 200 years after Pedro Nunes (1502-1578)[2] and until Pombal's modernising reforms of scientific education as being a period of actual and absolute stagnation. The Jesuits, as leaders of the Portuguese educational system, were the main culprits.[3] Recently, several and important studies began to overthrow that conventional narrative.[4]

In the first half of the 18th century, astronomy and mathematics were studied in two distinct locations: at the University of Coimbra and the Jesuit College of Santo Antão in Lisbon, in a class called *Aula da Esfera*.[5] In this period, while mathematical and astronomical studies went through a phase of decline at the University of Coimbra, Santo Antão College witnessed a more prosperous phase. Although the Society of Jesus had also been established in other European countries, in Portugal, their pedagogical action was wary of the ideas of the scientific revolution.[6] Scholastic philos-

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[2] Regarding the works of Pedro Nunes, see the article by Bruno Almeida in this volume.

[3] The Jesuits arrived in Portugal in 1540, and from that time onwards they opened various schools for the education of youth. By 1759 they had more than 40 schools (as well as one university, in Évora) which offered free education to more than 20,000 pupils (in an estimated population of 3 million). The University of Coimbra, although it did not belong to them, was greatly influenced by the Jesuit Colégio das Artes, a college devoted to the preparation of university studies.

[4] About the teaching of mathematics within the Jesuit colleges from 1640 onwards see (Baldini, 2004); about the teaching of mathematics and astronomy at Santo Antão see (Albuquerque, 1972).

[5] For the *Aula da Esfera* between 1590 and 1759, and the course of mathematics at Colégio de Santo Antão, see (Leitão, 2008).

[6] About the scientific panorama of Portugal before 1772, see (Martins, 1997).

ophy was widely taught in their Portuguese schools, the *Aula da Esfera* being an exception. Also, everything suggests that in the Brazilian Jesuit College of São Salvador de Bahia the teaching of scientific subjects was at a high level. José Monteiro da Rocha (1734-1819), who was to be one of the main designers of the new curricula for mathematics and astronomy within the scope of University Reform, undertook his studies there.

If the the Portuguese Jesuits' trend of teaching was, in fact, scholastic and assumedly averse to new scientific theories, it is nonetheless true that some men within the Society were aware of the most progressive scientific ideas of their time. The problem consisted in the ossification and rigidity of their thinking, along with their lack of openness to the ideas of Bacon, Descartes, Pascal, Galileo, Huygens, and Newton. In this respect, the Jesuits lost greatly to their rivals: the Oratorian Fathers. Generally speaking, the Oratorians embraced and incorporated the 'new science' within the organisational and pedagogical education system of their colleges (Carvalho, 1985a; Martins, 1997).

During the reign of King João V (1689-1750), the Portuguese scientific scene began to change. The improvement of the economic situation, allowed by the huge amount of gold coming from Brazil, began to foster a new cultural attitude. During this period, the dissemination and consolidation in Portugal of the new scientific ideas were mainly due to the *'Estrangeirados'*, an informal network of Portuguese men, mainly dilettanti and polymaths, who were in contact with European cultural and intellectual circles (many of them were sent by the king himself to establish diplomatic and scientific contacts with other countries and institutions).[7] This enlightened elite of *Estrangeirados* was largely responsible for the translation into Portuguese of some landmarks of the new sciences in the first half of the 18th century.

King João V gave particular attention to astronomy.[8] In 1722, with the aim of conducting a survey on of the Portuguese territories in South America, the king hired two Italian Jesuits astronomers, Giovanni Baptista Carbone (1694-1750) and Domenico Capassi (1694-1736). Carbone, who was to stay in Lisbon, founded the Royal Palace of Ribeira (Paço) Astronomical Observatory (1722-1755) and the Astronomical Observatory of the

[7] In (Carneiro *et al.*, 2000), the authors argue "that given their heterogeneous social origins, backgrounds and careers, they should not be seen as a homogeneous group. Rather, they were part of a fluid network, although they did not consider themselves as such. What they definitely shared was a common scientific culture", p. 1.

[8] See the article by Luis Tirapicos in this volume.

College of Santo Antão (1723-1759), with instruments coming mainly from France and England (Simões *et al.*, 1999).

Carbone was the first man in Portugal to make astronomical observations (a lunar eclipse on November 1, 1724) in a place intended for that purpose. For about eight years (1724-1732), Carbone was very active with regard to astronomical observations, exchanging correspondence with some European astronomers, mainly Joseph-Nicolas Delisle (1688-1768). He was elected member of the Royal Society (1729), publishing many of his astronomical observations in the *Philosophical Transactions* (Carvalho, 1956).

In the 1750s, there was intense astronomical activity in Portugal with João Chevalier (1722-1801), Miguel Pedegache (1730?-1794), Manuel Campos (1681-1758) and Soares de Barros (1721-1793)[9] at the Astronomical Observatory of the Congregation of the Oratory that was established in Lisbon at the Palàcio das Necessidades (1750-1768).[10]

During the reign of King José I (1714-1777), and prior to the expulsion of the Jesuits (1759), it is worth noting the astronomical activity of the Jesuit Eusébio da Veiga (1718-1798), the last teacher at the *Aula da Esfera* (1753-1759), who published in 1758, in Lisbon, an astronomical ephemerides for the years 1758, 1759 and 1760, named *Planetário Lusitano.*[11] It was followed by a period of about fifteen years during which all astronomical activities virtually ceased.[12] After the Pombaline Reform of the University, astronomical science would undergo an impulse like it had never experienced in the past.

[9] Joaquim José Soares de Barros studied and worked with Delisle at the observatory of the Hotel de Cluny (his observations on the transit of Mercury on May 6, 1753 were read by Delisle in the Académie royale des Sciences). Soares de Barros was elected corresponding member at the Académie royale des Sciences in Paris and of the Royal Academy of Sciences and Fine Arts in Berlin.

[10] João Chevalier became a corresponding member at the Académie royale des Sciences, where his observation of Halley's Comet on May 4, 1759 was read.

[11] The *Planetário Lusitano* was calculated, within the paradigm of the Tycho Brahe's model, for the meridian of Lisbon (probably the Santo Antão observatory's meridian) and consisted of 3 sheets per month with the ephemeris in true time of (I) the Sun, (II) the Moon, and (III) positions of the planets (Mercury, Venus, Mars, Jupiter and Saturn).

[12] With the exception of some observations made by António Miguel Ciera (1726-1782) between the years 1761-64, and by Soares de Barros: see (Carvalho, 1985b, p. 74-79, 110-111).

Pombal's University Reform (1772): the Creation of the Faculty of Mathematics and the Royal Astronomical Observatory of the University of Coimbra

The reforms of the Portuguese educational system were one of the most important features of the internal politicies carried out by King José I and his prime minister Sebastião José de Carvalho e Melo, Marquis of Pombal (1699-1782). The Reform of 1772 intended to make the University not only a teaching centre but also a centre for the production of knowledge that would meet the technical and scientific needs of the country. According to Gomes Teixeira, the Statutes of the Reformed University are:

> [a] remarkable dissertation about the teaching of sciences, delightful both in depth and form and a monument to healthy pedagogy and high philosophy, (…) where students are wisely advised and masters are given healthy precepts. (Teixeira, 1943, p. 180)

The idea of knowledge and science, particularly mathematics, embodied in the 3rd volume of the Statutes (which concerns the faculties of Medicine, Mathematics, and Natural Philosophy) is in perfect line with the ideas of the European Enlightenment, particularly with its French expression. The influence of D'Alembert's *Essai sur les Éléments de Philosophie* (1759) and *Encyclopédie* (1751-1772), one of the most significant editorial projects of the Enlightenment, is unequivocal.[13]

In fact, the establishment of scientific education at the University of Coimbra was one of the most important features of that Reform. One of the most salient accomplishments was the creation of the Faculty of Mathematics and the Royal Astronomical Observatory. It was the first Portuguese, university-based astronomical observatory. However, it also had characteristics of a national observatory.

The creation of the Mathematics Faculty (the first in the world) could be seen as a necessary consequence of a wider mathematical development across Europe. In the particular case of the astronomy chair, the University Statutes said:

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[13] The entire ideology that underlies the program of the different science courses, particularly those relating to the structure of the mathematics syllabus, strongly materialised the scientific matrix corpus of the French Enlightenment, reflecting the ideas of d'Alembert, as well as other French authors (such as the authors of the textbooks that were adopted, Bézout, Bossut, Marie, Lacaille, Lalande). On the influence of the French Enlightenment in the Reform of the University of Coimbra see (Figueiredo, 2011, p. 45-91; Saraiva, 2015).

> The advantages that result from studying Astronomy, with all parts of mathematics on which it depends, are of such great importance for the progress of human knowledge, particularly for Geography and Navigation. Astronomy has attracted the attention of all kings, who order the construction of Magnificent Observatories for the advancement of that science. (Universidade de Coimbra, 1772/1972, vol. 3, p. 213)

The syllabus of the mathematical course included seven disciplines (4 in the Faculty of Mathematics and 3 in the Faculty of Philosophy). In the first and second years, the disciplines of pure mathematics were taught, while in the last two, mixed or applied mathematics were more focused on.[14] Geometry and Algebra consisted of arithmetics, geometry, trigonometry, algebra, and differential and integral calculus. The third year curriculum consisted of the study of kinematics and dynamics, hydrodynamics, acoustics, and optics (which included the study of optical instruments). Although considered a branch of applied mathematical physics, "applied to the movement of the celestial bodies", Astronomy was studied separately in the 4th year. This disposition was justified by its vastness as a subject of study and its own importance within the mathematical sciences. The study of Astronomy included the history of astronomy; spherical trigonometry (spherical astronomy), the study of physical astronomy, including planetary movements, the three-body problem and theory of the Moon, comet movements, solar and lunar eclipses, and transits of Venus and Mercury. The students were expected to acquire skills in the use of the observational instruments and its vastness as a subject of study knowledge of astronomical calculations at the astronomical observatory – "throughout this course, the theory and the practice should always be studied together", reinforce the Statutes (Universidade de Coimbra, 1972, vol. 3, p. 195).

- *The Royal Astronomical Observatory of the University of Coimbra (OAUC)*

The role and practice required of the Observatory by the University Statutes established a particular dichotomy: as an astronomical university observatory versus a national observatory.[15] Its creation went much further than a simple facility for the teaching and practice of the astronomy course.

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[14] 1st year: Geometry, Rational Philosophy and Moral and Natural History; 2nd year: Algebra and Experimental Physics; 3rd year: Physics-Applied Mathematics; and in the 4th year: Astronomy. There was also a discipline of Drawing and Architecture that could be taken in the 3rd or 4th year.

[15] Regarding this concept of national versus university observatories see (Hutchins, 1999, vol. 1, p. 4-22).

The observatory was not only meant for students to carry out their astronomy practice. In fact, it was above all for professors and astronomers to conduct regular observations and to investigate fundamental astronomical measurements (astrometry) and theories (celestial mechanics). There was a higher purpose: the creation of a national astronomical observatory to publish its own ephemeris and to develop astronomical science.

The problem of determining longitude, both on land and at sea, was a central issue of astronomical and nautical science in the 18th century (Andrewes, 1993; Boistel, 2003). And the conception, calculation, and elaboration of astronomical ephemerides were one of the main objectives of the major European astronomical observatories until the 1820s or 1830s. Those questions were also the basis for the creation of the Royal Astronomical Observatory of the University of Coimbra. In fact, after the OAUC came into full operation in 1799, all its activity focused on the elaboration/development of its own astronomical ephemeris. The 7th paragraph of the Law Charter of OAUC (December 4, 1799) establishes unambiguously the calculus of the astronomical ephemerides as its main scientific purpose:

> The Astronomical Ephemeris should be calculated for the meridian of the Observatory, for its own use (a common practice of the most famous Observatories of Europe at this time), and for the use of Portuguese mariners; the Ephemeris should not be reduced or copied from the English Nautical Almanac, or from any other, but calculated immediately from the Astronomical Tables. (EAOAUC, 1803, p. viii)

The University statutes mandated the immediate construction of the observatory, although the OAUC was operational only after 27 years.

The first architectural plan (c.1773) was designed for the site of Coimbra's Castle, situated on the slope of the city not far from the University.[16] Unfortunately, all the construction works were suspended in 1775, largely because of the high cost of the works. The construction of the observatory in the Castle would never be resumed.

The problematical lack of a real and effective astronomical observatory in which to undertake real scientific research required a solution that developed around the years 1785-1787.[17] On February 5, 1791, the

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[16] This plan was for a large two-storey building (a façade of 58m and a height of 37m), in the middle of which the tower would rise.

[17] In 1775-1776 Francisco de Lemos (1735-1822), the University's rector, ordered the construction of a provisional observatory inside the University backyard to serve teaching purposes. This small building, which was demolished during the

University Council approved the new architectural plan for the construction of the definitive OAUC, and in 1799, the building, consisting of a horizontal body with a flat roof and a central tower with three floors (a front of 41m, a side of 11m and a height of 24m), was completed and ready for research to begin.[18]

The conclusion of this long process (1788-1799) of the definitive construction and foundation of the OAUC was entirely the responsibility of José Monteiro da Rocha, at the time Vice-Rector of the University and Professor of Astronomy.

José Monteiro da Rocha and the Scientific Activity of the OAUC

In fact, the role played by José Monteiro da Rocha was not restricted to the planning and construction of the OAUC, or even its subsequent astronomical activity, which made him one of the most recognised mathematicians and astronomers of Portugal during the late 18th and early 19th centuries. Actually, his importance dates back to 1770-1772, when he was one of the chief minds behind the creation of the scientific teaching structure undertaken by the Pombaline reform. The creation of the Faculty of Mathematics (vision, organisation, syllabus, etc.) was of his own responsibility.

Very little is known about Monteiro da Rocha's youth.[19] It is known that he joined the Jesuits in his younger years (1752) and left Portugal to go to Brazil where he studied at the Jesuit College of Salvador da Bahia (1752-1759). Following the expulsion of the Jesuits in 1759, Monteiro da Rocha left the Society of Jesus and later returned to Portugal (c. 1766). In 1771, he was called by Pombal to participate in the Educational Reform of the University. From this point on he was the lecturer in charge of the courses in Physics and Applied Mathematics (1772-1783) and Astronomy (1783-1804) at the University of Coimbra. In 1795, he was appointed dean and permanent director of the Faculty of Mathematics and Director of the Observatory (then under construction). He was also vice-rector of the University from 1786 to 1804. In 1800 Monteiro da Rocha became a member of the royal council of Prince Regent João VI (1767-1826). In 1804 he became the tutor of Prince Pedro (1798-1834) (future Emperor of Brazil and King of

construction of the definitive OAUC, never had the physical and material conditions for an effective, scientific astronomical research.

[18] For a detailed description of the construction of the OAUC and its instruments see (Figueiredo, 2014, p. 305-310, 313-317, app. p. 52-71; Figueiredo, 2015).

[19] About Monteiro da Rocha’s life and scientific work see (Figueiredo, 2011, 2014).

Portugal, as Pedro IV) and moved to Lisbon where he died on December 11, 1819.

His scientific work covered quite different mathematical and astronomical domains. The most significant part of his astronomical work was developed in the context of his academic career. As director of the OAUC, his work comprised of theoretical and practical. He was the scientific mentor behind the applied mathematical and astronomical methods, algorithms, and tables that allowed the OAUC to establish and publish its most important and significant scientific production : the *Ephemerides Astronomicas do Real Observatório Astronómico da Universidade de Coimbra* (henceforth EAOAUC) (Astronomical Ephemerides of the Royal Astronomical Observatory of the University of Coimbra). He also published works on the determination of comet's orbits; several papers on the calculation of eclipses and on longitude; astronomical tables of the sun, moon and planets and charts of Jupiter satellites; and papers on the use of the rhomboidal reticle and the calibration of the transit instrument. Some of these works were later translated and published in France by Manuel Pedro de Melo (1765-1833) (Rocha, 1808).

Manuel Pedro de Melo, a former student of the University and PhD in mathematics (1795) who became professor of the Royal Navy Academy, was sent to Europe to organise the discipline of Hydraulics, for which he had been appointed at the University in 1801. In France, in the 1800s, he worked with Jean-Baptiste Delambre (1749-1822) at the Observatory of Paris. As a result of this connection, Delambre wrote a small number of reviews of EAOAUC's volumes.[20] This visit by Pedro Manuel de Melo was in line with the statutes of the OAUC (December 4, 1799), which established scientific visits to astronomical observatories and other foreign scientific institutions on a regular basis (every ten years), in order to improve and exchange knowledge and scientific practice.

The charter of April 1, 1801, which initiated the creation of created the discipline of Hydraulics also created that of Practical Astronomy. At the time, the Faculty of Mathematics was facing new challenges which demanded new scientifically updated answers, and the implementation of these disciplines was an attempt to provide them. The creation of the latter was closely related to the future activity of the OAUC, inaugurated in the meantime, which involved working "assiduously in more accurate observa-

[20] CDT pour 1806, "Auteurs d'éphémérides", p. 412; CDT pour 1808, "Sur les éphémérides de Coimbre", p. 454; CDT pour 1809, "Sur les éphémérides de Coimbre année 1807", p. 459; CDT pour 1809, "Formule de M. Monteiro pour les éclipses", p. 459.

tions, to contribute, verify and rectify the Astronomical Tables [...] and to cooperate with more accredited European Observatories" (EAOAUC, 1803, p. viii). Hydraulics was connected to some important hydraulic engineering public works undertaken at the time by the government, chiefly the construction of Aveiro's bar (1781-1808) and the channelling of the Mondego River (1788-1808), for which the Faculty of Mathematics had been asked technical advice.

- *The Astronomical Ephemeris of the Coimbra Observatory (EOAUC)*

After its inauguration in 1799, the scientific activity of the OAUC was entirely focused on the calculations and publications of the EAOAUC. The charter of the OAUC (authored by Monteiro da Rocha and published on December 4, 1799), which established the staff, and its functional competencies and objectives, clearly states that all activity should start with the essential tasks for the preparation of the astronomical ephemerides for the year 1804 onward (EAOAUC, 1803, p. viii). According to these regulations, the entire teaching activity was completely minimised, so as not to interfere with the daily astronomical observations and practices of the OAUC. There is no doubt that this legislation reinforces the national, astronomical characteristics of the OAUC.

The first volume of the Coimbra's astronomical ephemeris was published by Coimbra's University Press in 1803 with all the conventional astronomical information for the following year (12 pages for each month).[21]

From the beginning, the EAOAUC adopted some particularities. They were calculated in reference to the mean Sun and not to the true Sun, used the 360° measure and not the widely-used zodiac signs, and they adopted a particular interpolation method to calculate the ephemeris of the Moon.[22] Unlike the foreign ephemerides, like the French *Connaissance des Temps* (CDT) or the English *Nautical Almanac* (NA), where the positions of the Moon were calculated for both noon and midnight directly from the astronomical tables, at the EAOAUC, only the noon position was directly calculated from those tables, with the position for midnight calculated using

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[21] Sun ephemeris (page I): longitude, right ascension, declination, equation of time, semi-diameter, time passing over meridian, hourly motion, horizontal parallax; observations and astronomical phenomena (page II); Planets ephemeris (page III): Mercury, Venus, Mars, Jupiter, Saturn, Uranus; Moon ephemeris (pages IV-VII): longitude, latitude, declination, right ascension (0h and 12h), horizontal parallax, semi-diameter, moon phases; Lunar Distances to Sun, stars and planets (pages VIII-IX); eclipses of Jupiter's satellites and their configuration (page X).

[22] For a detailed study on this method, see (Figueiredo, 2014b).

a particular interpolation method proposed by Monteiro da Rocha.[23] This method, which used finite differences up to the 8th order, also served to calculate the lunar distances to other instants (in the EAOAUC the lunar distances were tabulated every 12 hours). Similarly, to the CDT, or the NA, the EAOAUC also published scientific articles, most of them written by Monteiro da Rocha.

The first volumes of the EAOAUC were calculated using the astronomical tables published by Lalande in his *Astronomie* (3rd edition, 1792), except the positions of planet Mars, which were calculated using tables composed by Monteiro da Rocha himself in 1802.[24] The positions of the Sun and Moon published between 1807 and 1813 were calculated upon the tables of Burg and Delambre, published by the *Bureau des Longitudes* in 1806. In 1813 Monteiro da Rocha published *Taboas Astronomicas ordenadas a facilitar o calculo das Ephemerides da Universidade de Coimbra* (astronomical tables to facilitate the calculation of the EAOAUC), which would be the basis for calculating the EAOAUC until the mid-19th century.

Due to its characteristics, the EAOAUC was actually more oriented towards the activity of astronomers and their observatories than towards sailors and nautical astronomy. Navigators, especially in the merchant navy, preferred to use the *Ephemerides Nauticas* (nautical ephemeris) published since 1788 by the Royal Academy of Science of Lisbon because the Coimbra ephemerides were not so appropriate for nautical activities. This *Ephemerides Nauticas* (which we will examine in detail in section 4) was in most part copied from the English Nautical Almanac, but with all data shifted to the Lisbon meridian, presenting the lunar distances tabulated for every three hours.

In 1826, aware of these problems, the interim director of the OAUC, Joaquim Maria de Andrade (1768-1830), started a new section in the EAOAUC, entitled *Calendário Náutico* (nautical calendar). This *Calendário* provided the most important astronomical data "for the convenience of navigators [para a conveniência dos Pilotos]", such as the Sun's declination and right ascension in true time and the lunar distances tabulated every 3 hours, giving the possibility for using the direct proportionality to calculate the Moon's places for other instants. However, this lasted only three years (1825, 1826 and 1827). In 1840, when resuming the EAOAUC's publica-

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[23] This method was published on the EAOAUC (1808), p. 121-180.

[24] *Tábuas de Marte para o Meridiano do Observatório Real da Universidade de Coimbra*, EAOAUC (1803) p. i-xv.

tion after a break of 13 years, the Calendar was not inserted and, henceforth, the astronomical character of Coimbra's ephemeris prevailed.[25]

Monteiro da Rocha's Works on the Longitude Problem

The longitude problem is related to the question of finding the time difference between two locations. Nowadays, it can be solved easily with a simple wristwatch, but until the 18th century it was one of the greatest scientific and technical problems. With the need to stimulate a satisfactory solution to this question, the British government offered a series of potential rewards, up to £ 20,000 – the famous *Longitude Act*. By the end of the 18th century, the existence of accurate instruments for measuring the angles between the Moon, Sun or stars, together with accurate stars catalogues and the possibility of creating precise tables of the Moon's motion, paved the way for finding an astronomical solution.

At On the theoretical level, the answer came with the significant development of the *'Theory of the Moon'*, which enabled the construction of very reliable lunar and solar tables.[26] In 1758, Lacaille (1713-1762) published his solar tables and in 1753 Tobias Mayer (1723-1762) produced his tables of the Moon. Later improved by Charles Mason (1730-1786), they were the principal basis for the CDT and NA. The possibility to build accurate astronomical an ephemeris predicting, for instance the passage of the Sun or Moon across a meridian, the occurrence of eclipses, the moment when we can find certain Moon-Sun distances, or Moon-stars (called lunar distances) was a wish come true.

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[25] It is interesting to note that after 1833 the English NA made some changes and started to give its astronomical data in mean time, "The attention of the Committee was, in the first instance, directed to a subject of general importance, as affecting almost all the results in the Nautical Almanac; viz., whether the quantities therein inserted should in future be given for apparent time (as heretofore), or for mean solar time. Considering that the latter is the most convenient, not only for every purpose of Astronomy, but also (from the best information they have been able to obtain) for all the purposes of Navigation; at the same time that it is less laborious to the computer, and has already been introduced with good effect into the national Ephemerides of Coimbra and Berlin, the Committee recommend the abolition of the apparent time in all the computations of the Nautical Almanac; excepting only the place, &c of the sun at the time of its transit over the meridian", *Nautical Almanac* (1833) p. xii. As one of the referees observes this is a very apt example of an influence moving the opposite way from what would usually be expected. We greatly appreciate his/her suggestion for a further development of this subject.

[26] In 1758 Lacaille (1713-1762) publishes its solar tables, which together with Moon tables (1753) by Tobias Mayer (1723-1762), later improved by Charles Mason (1730-1786), will be the principal basis to elaborate the CDT and NA.

In 1759, Lacaille read a memoir at the Académie Royale des Sciences proposing the use of lunar distances as a solution for the longitude problem (Lacaille, 1765). In 1754, he had already presented to the same Academy a work on this subject, '*Projet pour rendre la méthode des Longitudes sur mer praticable au commun des navigateurs*. And he had also expressed his intention to give a nautical connotation to his *Ephémérides des mouvements célestes*. In 1766, the British Royal Astronomer, Nevil Maskelyne (1732-1811), created the *Nautical Almanac* where, for the first time, as Lacaille had proposed, lunar distance tables were published. In 1772, the French CDT also started to publish them, copied from the NA. Only in 1789 did the CDT start to publish its own lunar distances directly computed from observations and astronomical tables. In the following years, the scientific debate around the use of the lunar distances was intense.[27] In 1779, Jean-Charles de Borda (1733-1799) published a protocol that definitively put the lunar-distance method into maritime practice. This method, which became known as the Borda method, was immediately presented in the 1st volume (1788) of the Portuguese *Ephemerides Nauticas* of the Royal Academy of Sciences of Lisbon.[28]

The major practical problem of the lunar-distance method was related to the reduction of the observations (apparent distance to true distance). In the 18th century, the trigonometric equation proposed by Borda's method demanded a substantial calculation effort. As a consequence several direct and indirect methods (trying to reduce the true distance through successive corrective formulas of the apparent distance, taking into account the values of refraction and parallax correction) were proposed (Cotter, 1975, p. 305-328). Mendoza y Rios wrote 40 different formulas and nearly four decades later, Guépratte claimed to know around 100 (Rios, 1801, p. 3-37, 66-77; Guépratte, 1839, vol. 1, p. 219).

The *Cálculo das longitudes* (calculus of longitudes), published by Monteiro da Rocha in the first volume of the EAOAUC (1803, p. 213-230), is essentially a lunar-distance method, it was based on the 'approximation's

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[27] At the time, there were several competing lunar methods. The hour angle method proposed by Pierre C. Le Monnier (1715-1799) and Alexandre Guy Pingré (1711-1796) was one of them. On this subject, see (Boistel, 2003, p. 281-383).

[28] *Método do Cavalheiro de Borda para o cálculo das longitudes no mar, determinadas pelas distâncias da Lua ao Sol, ou às Estrelas* (Cavalheiro de Borda's method for calculating the longitude at sea, determined by the distance of the Moon to the Sun, and the Stars), Ephemerides Nauticas (1788) p. 170-181.

methods for reduction of the observations' set.[29] This method is very similar to another one that he had published in 1799: *Taboada Nautica para o cálculo das Longitudes* (nautical table for longitude calculation).

But there is one of José Monteiro da Rocha's unpublished manuscripts (212 pages) on the longitude problem that should be singled out – *Methodo de achar a Longitude Geográfica no mar y na terra Pelas observaçõens y cálculos da Lua Para o uso da Navegação Portugueza* (Method to be used by the Portuguese Navy for finding the Geographic Longitude at Sea and on Earth by Observations and Calculations of the Moon).[30] A very interesting manuscript on all levels, it was written in the 1760s, at a time when lunar distances became a serious matter in worldwide scientific discussions. It is a deeply researched and reflective work but, more than that, it has a didactic goal since Monteiro da Rocha aspires to introduce navigators into a completely new practice and instruct them about it. So, throughout the manuscript, we can see an author deeply concerned with the intelligibility of everything he writes.

The manuscript is dedicated to "Mr Count of Oeiras, Minister and Secretary of Foreign Affairs of the Kingdom", future Marquis of Pombal, from whom Monteiro da Rocha was seeking support for its publication:

> [with the use of these lunar-distance methods] the Portuguese will have the glory of being the first to implement observations of longitude, they will be the first to open the last frontiers of the world. And the highest price I can get is the glory of our Nation and the usefulness for the fatherland.[31]

The manuscript was begun in Brazil and finished in Lisbon. During his trip back to Portugal (1765), Monteiro da Rocha made a lot of observations, which would help him resolve and improve certain theoretical and practical issues (instrument observations and observation reductions). Monteiro da Rocha devoted particular attention to the problem of errors that can affect the determination of longitude: errors of the instruments and errors from astronomical data conveyed to the astronomical ephemeris. At that time, only a few had dealt with these issues (Boistel, 2006).[32]

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[29] It also presents a version of the method of corresponding heights to particular cases in which it is impossible to observe the luni-solar distances 2, 3 days immediately before and after the full Moon.

[30] This manuscript (henceforth Ms. 511) was found in Biblioteca Nacional, in 2005. Until that time, it was completely unknown.

[31] Monteiro da Rocha, Ms. 511, fl.17v.

[32] Boistel and I will shortly publish a paper about the study of this manuscript by Monteiro da Rocha entitled: 'José Monteiro da Rocha and the international debate

Monteiro da Rocha was acquainted with all the important literature and the principal key authors related to the longitude problem. His bibliography was up-to-date (throughout the text he makes 20 direct bibliographic references).

To Monteiro da Rocha, Lacaille's method had a major disadvantage, being connected to previous computed lunar distances. But, in spite of that, Monteiro da Rocha wrote that this "does not cancel the merit of his method which did not have the promotion it deserved because of Lacaille's death on March 23, 1762".[33]

The five methods proposed by Monteiro da Rocha on the manuscript did not make use of lunar distances but of the Moon's longitude.[34] They are all based on the determination (calculation) of the celestial longitude of the Moon at the time of observation and they all refer to comparison with the tabulated values in nautical ephemeris in order to determine the corresponding time of the meridian of Lisbon (or the geographical longitude referred to Lisbon). While this can be seen in some ways as an advantage the calculation effort required by it, as a matter of fact, was truly underestimated at a time when all these matters were new.

Monteiro da Rocha, besides some auxiliary tables to help with calculations, also proposed a nautical almanac with the Moon's ephemeris, calculated in mean time, every four hours, for the meridian of Lisbon.[35] As an example, and as a future model for that nautical ephemeris, he presented some tables with the astronomical data for Sun and Moon on the 25th, 27th, 29th, and the 31st of December of 1767, for the meridian of Lisbon.[36]

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in the 1760's on the astronomical methods to find longitude at sea: its proposals and criticism of the method of lunar distances of Lacaille', to be published in 2017.

[33] Monteiro da Rocha, Ms. 511, fl.15v.

[34] The first two are variants of the methods of corresponding heights, and the other three variants of the method of lunar distances.

[35] Sun's ephemeris: longitude, right ascension and declination; Moon's ephemeris: longitude, right ascension, declination, horizontal parallax and horizontal semidiameter; time equation.

[36] Aware of the importance of building astronomical tables with a high degree of accuracy, he wrote, "The actual theoretical progress is of great perfection [...]. Mayer's lunar tables calculated on the principles of Euler, and Clairaut's tables are of extraordinary accuracy, it is rare to have a minute in difference when compared with the more accurate observations of the Moon", Monteiro da Rocha, Ms.511, fl.14. We have in preparation a book about the Ms.511 manuscript where we will give details about the accuracy of these tables.

The manuscript ends with a stellar catalogue with right ascension, declination, and annual variation of about 70 stars.

- *The Determination of the Orbits of Comets*

There is another work by Monteiro da Rocha that is worth mentioning n the determination of the orbits of comets. It was published only in 1799, two years after Olbers's famous work on the same subject[37] was published, but in reality, its manuscript dates back to 1782.[38]

Already in his youth, at the age of 25, Monteiro da Rocha had written a small work on comets. It was a didactic text about the nature and orbits of comets, written on the occasion of the return of Halley's Comet in 1759, which he observed in S. Salvador de Bahia, Brazil, between 13th of March and late April, without realising that it was the famous comet.[39] The Comet's return would be a crucial test for Newton's theory and Monteiro da Rocha, a confident Newtonian. Well aware of this, he took the opportunity to spread didactically the gravitational theory of the English scientist. This text consists of two distinct parts. In the first, he examines "the sentences of the most famous philosophers and mathematicians showing that comets are true celestial bodies as old as rest of the heavenly bodies". Monteiro da Rocha summarises and criticises a set of scholastic theories on the nature of comets that described them as malevolent supernatural beings and not natural heavenly bodies. At the same time (1757-1759), other Portuguese men wrote on the same subject: (e.g. Miguel Tibério Pedegache (1730-1794), Bento Morganti (1709-?) and Francisco Henrique Ahlers (?-?) but, unlike Monteiro da Rocha they are somewhat confused and sometimes reserved in the defence of modern ideas. In the second part, entitled "Practical Astronomy in Order to Calculate the Motions and Comets' Ephemerides", Monteiro da Rocha presents the most common methods in use in the first half of the 18th century for comets' orbit calculation (basically geometrical methods). In several aspects, namely in defence of Newton's ideas and the mathematical part about orbit determination we can say that

[37] (Olbers, 1797) was published under the sponsorship of Franz X. Freiherr von Zach (1754-1832). A few years later, under Olbers's supervision, it was translated into English and published by the Royal Institution. In 1847, it was republished by Johann F. Encke (1791-1865).

[38] (Rocha, 1799). However, this work was first presented and read by Monteiro da Rocha to the Academy much earlier, on January 27, 1782.

[39] José Monteiro da Rocha (1760), *Systema Physico Mathematico dos Cometas* [manuscript, BPE, FM-506]. In 2000 the manuscript was publishded in Brazil : (da Rocha, 2000).

Systema Physico Mathematico dos Cometas is unique in the history of Portuguese astronomy of the first half of the 18th century.

However, his memoir of 1782/99 is completely different. It is a real scientific work on one of the major astronomical problems that had occupied many astronomers and mathematicians for over a century. In his *Principa* (1687) Newton had considered the determination of the orbits of comets as a *'Problema hocce longe difficillimum multimode aggressus'* (Newton, 1687, p. 492) and from that time on was studied by the most famous astronomers and mathematicians of the 18th century, such as Euler (1707-1783), Clairaut (1713-1765), D'Alembert (1717-1783), Condorcet (1743-1794), Boscovich (1711-1787), Pingré (1711-1796), Prosperin (1739-1803), Lalande (1732-1807), Lambert (1728-1777), Lagrange (1736-1813), Laplace (1749-1827), and others.

In 1772, the Berlin Academy of Sciences proposed a prize to be awarded in 1774 to anyone who discovered a simple method to determine the parabolic orbit of a comet using only three observations. This award was only granted in 1778 to Condorcet and Tempelhoff (1738-1808).[40] Nevertheless, it was Olbers who got the historical credit as the inventor of a simple and easily applicable method for this problem.

Monteiro da Rocha, in his academic memoir, presents an identical analytical method to Olbers'. The differences between the methods lie in the fact that Monteiro da Rocha's make use of an approximate relation between the geocentric distances of the middle position and the terminal position of the comet, and of the Euler-Lambert equation, not in its habitual form, but one obtained by squaring the two members of the theorem, while Olbers's is characterised by the employment of an approximate relation between the geocentric distances of the terminal positions of the comet and of the straight application of the theorem of Euler-Lambert.

Although the publication of Olbers's work had preceded Monteiro da Rocha's by two years, the timing of the invention of their methods was the reverse. This and the circumstance of having been written in Portuguese, meant that Monteiro da Rocha lost precedence to Olbers.[41] One

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[40] Monteiro da Rocha was aware of the Berlin contest but didn't know its outcome. Actually, it was this contest that encouraged Monteiro to study this subject (letter dated of July 17, 1780 to the Academy's Secretary, Academy's Library Archives Ms. Azul 1944).

[41] "It may be said that this was the only method, really worthy of being called like this, which, before that of Olbers, permitted the easy calculation of the orbital elements of a comet given by three observations." (Leite, 1915, p. 66). For a quantita-

thing is sure, however, the names of Monteiro da Rocha and Olbers must, therefore, appear together in the history of astronomy as the first inventors of a practical and easy method for the determination of the parabolic orbits of comets.

The Creation of the Royal Academy of Sciences of Lisbon and the Royal Naval Academy

After the death of King José I, the first years of Queen Maria's reign were somewhat troubled times with regard to University life, facing attacks from the most conservative forces of the society. But after some time, the modernisation effort initiated during the reign of her father continued. During the period known as *Mariano-Joanino*,[42] it can be stated that the government's teaching policy continued to be guided by the Pombaline model, despite the natural wearing down of institutions due to the instability of national life.[43] As Luis Carolino emphasises, the teaching reforms extended to technical education, with the creation of the *Academia Real da Marinha* (Royal Naval Academy) in 1779, and the *Academia Real de Fortificação, Artilharia e Desenho* (Royal Academy of Fortification, Artillery and Drawing) in 1790 (Carolino, 2012). In fact, it is in this period that scientific specialisation began and professional mathematicians, astronomers, engineers, botanists, chemists, and mineralogists emerged, with the Royal Academy of Sciences of Lisbon playing an important part.

The Royal Academy of Sciences of Lisbon (henceforth ACL) was created on December 24, 1779. The founders, João Carlos de Bragança (1719-1806), 2nd Duke of Lafões, being the most important of them, were influenced by Enlightenment values and aimed at using science and technology to develop the country economically and socially.[44] As with similar

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tive comparison of the two methods see (Figueiredo 2005) and for a brief discussion see (Figueiredo & Fernandes, 2006).

[42] This historiographical period covers two reigns: Maria I and João VI. In 1792 Maria I became mentally unstable and her son, prince João (1767-1826) – future king João VI – started to sign in her name. In 1799 the queen was considered insane and the prince took the regency of the kingdom. João VI reigned as king between 1816 and 1826.

[43] War of the Oranges with Spain (1801); the transfer of the court to Brazil (1807), the Napoleonic Invasions (1807-1811), and the country's submission as a British protectorate under the command of the general William Carr Beresford (1811-21).

[44] José Monteiro da Rocha was one of its first members, elected in January 16, 1780.

foreign academies, like Paris, Berlin and St. Petersburg, the ACL promoted scientific studies, mostly in applied science, agriculture, and industry but also in literature, law and Portuguese history. The ACL also had its own prize system, introducing almost every year a set of questions to be answered in a fixed period of usually 2 years, with a gold medal as a reward. Between 1780 and 1822, ACL launched 253 contests concerning observation and physical science (178) and exact science (mathematics, astronomy and navigation) (75). Until now, we have not found any contest for the years 1803-1806, 1809-1810 and 1813-1814 . Therefore, from a set of 34 years of available data, we found a total average of prize tenders of 7.44 per year. Observational and practical sciences being represented more than twice as often as the exact sciences (5.23/year and 2.21/year, respectively) (Figueiredo & Saraiva, 2013). In astronomy, most of the proposal questions were in practical nautical astronomy, the use and construction of nautical instruments (sextant, octants), and on the longitude problem (mostly on the research of other protocols besides that of Borda for lunar distances).

The deep understanding of the physical limits and economic potential of Portugal and its overseas regions in Asia, Africa and America was of much concern to Portuguese government and ACL academicians. Portuguese economic development of its overseas trade was dependent on well-qualified personnel in both naval and merchant fleets. Thus, in 1788, the ACL started to publish its nautical ephemeris, *Ephemerides Nauticas ou Diario Astronomico* (henceforth NE), with which some academicians and professors of the Royal Naval Academy were involved.

The Royal Naval Academy (henceforth ARM) was created in Lisbon in 1779 as a theoretical teaching establishment which set out to prepare navigators for the naval and merchant fleets and army engineers (the ARM operated until 1837). In 1782, a new Academy, the *Academia Real dos Guardas-Marinhas* (Royal Academy of Midshipmen), was also created. This institution had the purpose of training officers for the Portuguese Royal Navy.[45] The program of study for these academies included, among other matters, theoretical and practical mathematics, navigation and nautical astronomy. Its first teachers were graduates of the University of Coimbra.

In 1791, Francisco Antonio Ciera (1763-1814), Professor of Navigation at the ARM, proposed the construction of an observatory for teaching nautical astronomy classes. The Royal Naval Observatory (OAM) was inaugurated in 1798 (its regulation dates back to July 23, 1799) and assumed

[45] In 1807, as a result of the Napoleonic French Invasion, the Academy of Midshipmen followed the king and Portuguese government to Brazil. The Academy returned to Portugal in 1826 and was extinct in 1845.

formal scientific responsibility for the production of the ACL's nautical ephemeris (NE). From its first volume, the NE publication was under the responsibility of the ACL's astronomical observatory, which had been inaugurated in 1787.

- *The ACL's Nautical Ephemeris (NE)*

The ACL's project for the publication of a Portuguese nautical ephemeris started to be discussed among the academicians around 1781, but the first volume was only published in 1788. From the beginning, Monteiro da Rocha did not see any special interest in having a Portuguese nautical almanac as a recalculated copy from CDT or NA for the meridian of Lisbon, as the ACL wanted to do because Portuguese sailors had easy access to those foreign publications. What would be desirable would be to have a Portuguese almanac or ephemeris with lunar distances calculated directly from astronomical tables other

> then those of Mayer's, in which the calculations of the English Nautical Almanac were based, as also its copy of Connaissance des Temps, such as Clairaut's and Euler's tables.[46]

Monteiro da Rocha emphasised that such an almanac would be of interest to all maritime European countries, and would bring glory to Portugal. But at the time, such a project was impossible to carry out due to a lack of national technical and scientific capacity. In fact, it would be carried out by himself some years later at the OAUC.

The NE had 8 pages for each month with astronomical data calculated in apparent time for the Lisbon meridian.[47]

Its first director (1787-1795) was Custódio Gomes Villas-Boas (1744-1808), Professor of Astronomy at the ARM and also the first director of the ACL's astronomical observatory.[48] The next director was José Maria

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[46] Letter from Monteiro da Rocha to ACL's Secretary dated October 7, 1781 (ACL's Library Archives, Ms. Azul 1944).

[47] Page I: sun and moon declination; page II: moon birth, moonset, moon's passage over Lisbon's meridian; page III: Mars, Jupiter and Saturn ephemeris (birth, set, passage over the meridian, latitude and longitude) and sun semi-diameter, places of Moon's node; page IV: several astronomical phenomena and Jupiter satellites' eclipses; pages V-VIII: lunar distances. For a comparison between the EAOAUC and the ENACL see (Figueiredo, 2017).

[48] In 1804 Custódio Gomes Villas-Boas together with Francisco António Ciera (1763-1814) translated into Portuguese Flamsteed's famous stellar catalogue, *Atlas Coelestis* (London, 1729) that would be published by ACL: *Atlas Celeste, arranjado por*

Dantas Pereira (1796-1798), also a professor at the ARM. Between 1799 and 1805, the director of the ephemeris was the Frenchman Charles Marie Damoiseau de Montfort (1768-1846).[49] From the beginning until its suspension in 1863, the NE's publication was always the ACL's business.

- *Cartographic Works in Portugal and Brazil*

Since the Portuguese empire was largely maritime, the development of navigation, cartography and hydrographic charts was crucial to maintain and foster it. In the late 18th century, Portuguese government was well aware of the need to have robust and well-prepared merchant and war fleets, to serve as a bridge connecting the continental territory with the vast overseas dominions, promoting the Portuguese economic independence (Simon, 1983); Another important question was the true geographic knowledge of this vast overseas territory.

In the 18th century, the great technological advances in the accuracy of portable instruments and astronomical ephemerides enabled further improvements in cartography. A correct knowledge of inland regions, coasts and ports of the metropolitan and colonial territories, crucial to promote the better exploitation of natural resources and improvement of the efficiency of civil administration, was a matter of state for all European countries of that time.[50] Portugal was no exception. Besides, Portugal was one of the European countries with more scattered territories in Africa, Latin America, and Asia.

Flamsteed, publicado por J. Fortin, correcto, e aumentado por Lalande, e Mechain [...], Lisboa, ACL, 1804.

[49] Damoiseau de Montfort began his career as an artillery officer of the French army, but during the French Revolution he became an *émigré* (1792). In 1795, Damoiseau was in the service of the king of Sardinia in the Piedmont region of Italy. With the arrival of the French troops, he went to Portugal and joined the marine artillery. Back to France around 1808, he developed an extensive work on the tables of the Moon, having been elected a member of the Académie des Sciences, on August 1, 1825. On the death of Johann K. Burckhardt (1773-1825) in that year, Damoiseau took over as director of the observatory of the École Militaire. He was also a member of the Bureau des Longitudes. In 1831, he received the Gold Medal of the British Royal Astronomical Society for his astronomical works. In 1836, he published a set of tables on the satellites of Jupiter: *Tables écliptiques des Satellites de Jupiter [...]* (Paris, 1836), which replaced those of Delambre, and were used for the CDT from 1841 to 1914.

[50] In France, the first modern cartographic survey (known as Cassini's maps) was undertaken between 1744 and 1793, and it would serve as model for future cartographic campaigns in other countries.

As we had already indicated, the arrival of the Italians Carbone and Capassi was related to the demarcation of the Portuguese and Spanish territories in the colony of Sacramento and in the Plate river.[51] As a result of the Treaty of Madrid signed between the two countries in 1750, Miguel Ciera (c. 1726-1782), an Italian from Padua, was hired as a mathematician, astronomer, and geographer to join the team that would establish the limits of southern Brazil. During three years (1752-1756), this team, called *Terceira Partida de Limites*, went up the Paraguay River until they reached the source of the Jauru River, where they put a mark as a symbol of the demarcation of the Portuguese and Spanish lands (Costa, 2009). Ciera was later the first professor of Astronomy at the new Faculty of Mathematics (1772-1778) and Professor of Spherical Trigonometry and Navigation at the ARM (1779-1782). In 1783, he was formally replaced by Monteiro da Rocha in the teaching of Astronomy at the University of Coimbra.

In 1777, another campaign was launched in the same region to undertake new demarcations imposed by the new Treaty of Santo Ildefonso (the Treaty of Madrid was cancelled in 1761). This team was led by Antonio Pires da Silva Pontes (1750-1805) and Francisco José de Lacerda e Almeida (1750-1798), both recent PhDs in mathematics from the University of Coimbra and former students of Ciera and Monteiro da Rocha. A lot of information about the longitude of many places in inland Brazil, and some in Peru, resulting from this cartographic mission were published in the 3rd (1805) and 12th (1815) volumes of the EAOAUC.

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[51] In 1767 Louis-Antoine de Bougainville (1729-1811), on his journey around the world, passed this region and described the situation in the colony: "Before the last war, they carried on a prodigious contraband-trade with the colony of Santo Sacramento, a place in the possession of the Portuguese, upon the left side of the river, almost directly opposite Buenos Ayres. But this place is now so much surrounded by the new works, erected by the Spaniards, that it is impossible to carry on any illicit trade with it, unless by connivance; even the Portuguese, who inhabit the place, are obliged to get their subsistence by sea from the Brazils. In short, this nation bears the same relation to Spain here, as Gibraltar does in Europe; with this difference only, that the former belongs to the Portuguese, and the latter to the English." [Avant la dernière guerre il se faisait ici une contrebande énorme avec la colonie du Saint-Sacrement, place que les Portuguais possèdent sur la rive gauche du fleuve, presque en face de Buenos Aires ; mais cette place est aujourd'hui tellement resserrée par les nouveaux ouvrages dont les Espagnols l'ont enceinte que la contrebande avec elle est impossible s'il n'y a connivence ; les Portugais même qui l'habitent sont obligés de tirer par mer leur subsistance du Brésil. Enfin ce poste est ici à l'Espagne, à l'égard des Portuguais, ce que lui est en Europe Gibraltar à l'égard des Anglais] (Bougainville, 1771, p. 30-31). The translation is from the English edition by John Reinhold Forster, published in 1772.

But it was not only in Brazil that mapping issues were important. The non-existence of good maps of the Portuguese metropolis was also an issue. In Portugal, before the work on the *Carta do Reino* (map of the Kingdom) began in 1790, the maps used were usually adaptations of foreign ones.[52]

The project of creatinfa cartographic map of Portugal began to be discussed in the ACL at the end of 1788. According to the academician Custódio Gomes Vilas Boas, the project was to be coordinated by Monteiro da Rocha, which in fact did not happen. Instead, at the head of those cartographic works was Francisco António Ciera, at that time, professor at the ARM. Francisco Ciera was Miguel Ciera's son and had studied at the Faculty of Mathematics. But Monteiro da Rocha found himself directly involved in the project as the maker of the measuring rods used in the measurements of the main bases of the triangulation network.[53] In 1804, the works were interrupted without the whole country's triangulation being completed. The *Carta do Reino* project was resumed only in 1835 with Pedro Folque (1744-1848), and his son Filipe Folque (1800-1874), himself also a PhD in mathematics from theUniversity of Coimbra. Nevertheless, during the first half of the 19th century, several surveys of different parts and regions of Portuguese territory (mostly of coastal regions and main seaports) were conducted. Those cartographic surveys were designed underneath Ciera's triangulation network.[54] At the same time, some standardisation

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[52] One of the most important maps used was the *Mapa dos reinos de Portugal e Algarve* (Map of the kingdoms of Portugal and Algarve), by the Italian Zannoni (1736-1814), printed in Paris in 1762.

[53] "In Portugal no one can help me better than Dr. José Monteiro da Rocha, who was my professor in Coimbra. This man of rare genius, who no doubt can be enrolled in the great European Mathematicians group, can greatly contribute on this expedition. [Em Portugal ninguém pode me ajudar melhor do que o Dr. José Monteiro da Rocha, que foi meu professor em Coimbra. Este homem de gênio raro, que sem dúvida pode ser inscrito no grande grupo matemáticos europeus, pode contribuir muito nesta expedição]", Francisco Ciera in a letter from c.1790, cited in (Mendes, 1965).

[54] In 1801 a specific law was made (chart-in-law June 9, 1801), which intended to create in each district the profession of cosmographer (to a mathematician graduated by Coimbra's University) whose principal work would be to do a topographic survey of that region according to the rules established by the Carta do Reino, and 'intender on all public works [...]'. This law, whose wording is from Monteiro da Rocha, introduced a major reform in the administration of the territory, transferring to new employees of the central administration a set of competencies previously reserved to magistrates. According to Adrien Balbi, this law was inspired by the French model (Balbi, 1822, vol. 2, p. cvj).

procedures regarding scales were implemented (Dias, 2005). An illustrative example is the map of the *Province of Entre Douro e Minho* made by Custódio Gomes Vilas Boas (1771-1809) in 1794-1795 but only published after 1805.[55]

In those mapping and cartographic activities, we must highlight two institutions: The ACL which has already been mentioned, and the *Sociedade Real Marítima, Militar e Geográfica para o Desenho, Gravura e Impressão das Cartas Hidrográficas, Geográficas e Militares* (Royal Maritime, Military and Geographic Society for Drawing, Engraving and Printing of Hydrographic, Geographic and Military maps). The latter was created in 1798 by the Minister of Marine, Rodrigo de Sousa Coutinho (1745-1812), with the explicit goal to prepare and publish hydrographic charts, and military and hydraulic maps of the country. This Society did not last for a long period of time, ending in 1807. Among its members were officers and teachers of the ARM and of the Royal Academy of Fortification, Artillery and Drawing, four royal ministers, and two professors of the University of Coimbra, Monteiro da Rocha being one of them. The aforementioned *Taboada Nautica para o cálculo das Longitudes* (1799) by Monteiro da Rocha was a consequence of the Society's scientific activities.[56]

With regard to the topographic surveys of the country, the first steps were taken by José das Neves Costa (1774-1841) in the 1810s, culminating with the publication of a series of instructions for that purpose in 1840. But only with the creation of the *Direcção Geral dos Trabalhos Geodésicos* (General Directorate of Geodesic Works) in 1852 did that kind of work really start.

Conclusion

The creation of scientific studies established by the University Statutes of 1772, marks, without doubt, the beginning of a new era for Portuguese science. Clearly, this Reform intended to tune the country to the new scientific paradigm that emerged in Europe after the scientific revolution of the 16th and 17th centuries and to recover its delay, putting Portugal side

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55 On the cartographic surveys conducted between 1790 and 1807, see (Dias, 2007).

56 About the work of these individuals and the importance of these questions of longitudes and cartographic works for Portugal and its empire in the late 18th century, we are finishing a paper to be published soon entitled: 'The scientific activity of the Royal Maritime, Military and Geographic Society (1798-1807): making science for the country's and empire's needs'.

by side with the Enlightened Europe of the 18th century. With regards to astronomy, this ambition was undoubtedly fulfilled.

The mathematical course created at the Faculty of Mathematics formalised the teaching of Newtonian astronomy and celestial mechanics in Portugal. And the creation of the Royal Astronomical Observatory of the University, a true national astronomical observatory, promoted the progressive establishment of a future Portuguese astronomical community.

The astronomical activity planned for the OAUC – and effectively undertaken – placed it alongside the major European astronomical institutions of the time, like the Paris and Greenwich Observatories. Nothing similar had previously existed in the history of Portuguese astronomy. The primitive astronomical spaces founded by Jesuits in the reign of João V at Santo Antão College and at the Palace of Ribeira were not comparable in any aspect – not in size, nor as regards its instrument collection, and not even in relation to the astronomical program carried out by the OAUC.

The contribution of Monteiro da Rocha, to whom an entire generation of astronomers from the first half of the 19th century owed a debt, was had a seminal part in this breakthrough. He was a key actor behind the envisioning and creation of the Faculty of Mathematics syllabus. Later, as a professor of Astronomy, he was chiefly responsible for the conception, planning and construction of the OAUC, as well as its instrument provision and subsequent scientific activity.

Monteiro da Rocha was the scientific mentor behind the applied mathematical and astronomical methods, algorithms, and tables that allowed the OAUC to establish and publish its most important and significant scientific production: the *Ephemerides Astronomicas* (EAOAUC). These first Portuguese ephemerides to be systematically calculated from the astronomical tables can be seen as Monteiro da Rocha's life project, which dates back to the 1760s when he wrote his manuscript about the longitude problem (Ms. 511). The quest for longitude, a central problem in the astronomy and nautical science of the late 18th and beginning of the 19th centuries, was the main motive for the creation of the Astronomical Observatory of the University of Coimbra.

From its inception and throughout its history, the OAUC tried to follow and contribute to contemporaneous astronomical research trends and developments. Celestial mechanics and its applications were the institution's main research topic until the 1850s. Later, it would pursue the new avenues that became available thanks to the development of astrophysics and, in particular, that of solar studies.

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Costa Lobo (1864-1945), the Coimbra Spectroheliograph and the Internationalisation of Portuguese Astronomy[1]

Vitor Bonifácio*

Abstract

At the beginning of the 20th century, Portuguese astronomy was still firmly anchored in the past. Only astronometric research was pursued and Portuguese professional astronomers seldom published their results. This situation changed in the 1910s thanks to the actions of Francisco Miranda da Costa Lobo (1864-1945). Costa Lobo initiated the construction in Coimbra of a world-class solar observing facility in close co-operation with observatory astronomers based in Meudon. Recognising the importance of international relations, he made frequent scientific travels and disseminated his research to a wide audience. In this paper we improve on the current understanding of the Coimbra spectroheliograph installation. We argue that Costa Lobo's actions, foreign support and social skills played a fundamental role in the internationalisation of Portuguese astronomy.

Keywords: Francisco Miranda Costa Lobo, Henri Deslandres, solar studies, international co-operation, spectroheliograph, Coimbra Astronomical Observatory, Meudon Observatory.

Résumé

Au début du XX^e siècle, l'astronomie portugaise était ancrée dans le passé. Seules les recherches astrométriques sont poursuivies et les astronomes professionnels portugais publient rarement leurs résultats. La situation change dans les années 1910 en raison des actions de Francisco Miranda da Costa Lobo (1864-1945). Costa Lobo a été responsable de la construction à Coimbra d'une installation d'observation solaire de classe mondiale en étroite coopération avec les astronomes de l'observatoire de Meudon. Reconnaissant l'importance des relations internationales il a fait de fréquents voyages scientifiques et diffuse ses recherches vers un public vaste. Dans cet article, nous essayons d'améliorer la compréhension actuelle sur le processus d'installation du spectrohéliographe à Coimbra. Nous soutenons que les actions de Costa Lobo, le soutien étranger et ses compétences sociales ont joué un rôle fondamental dans l'internationalisation de l'astronomie portugaise.

Mots-clés : Francisco Miranda Costa Lobo, Henri Deslandres, études solaires, coopération internationale, spectrohéliographe, Observatoire Astronomique de Coimbra, Observatoire de Meudon.

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William Wollaston (1766-1828) discovered in 1802 the solar spectra dark divisions, today called absorption lines. These were extensively mapped by Joseph Fraunhofer (1787-1826) in the 1810s (Meadows, 1970). A paper read by Gustav Kirchhoff (1824-1887) at Berlin Academy on 27 October 1859 explained their origin. His interpretation authorised "conclusions therefrom respecting the material constitution of the atmosphere of the sun, and perhaps also of the brighter fixed stars" (Kirchhoff, 1860, p. 195).

Two years earlier, in 1857, the Portuguese government had approved the construction of a new astronomical observatory devoted to high-precision stellar astrometric measurements. Both the Coimbra University and the Lisbon Navy astronomical observatories had been deemed uncompetitive by international standards as a result of being poorly located and underequipped (Bonifácio *et al.*, 2009).

The first Portuguese astrophysical studies were to take place in 1870 in the wake of the total solar eclipse of 22 December. Prior to this date, no national expertise existed in the fields of astronomical spectroscopy and photography. Wishing to perform useful observations, the Portuguese scientific community sought advice from international colleagues, acquired – with a generous government support – new instruments and organised an eclipse expedition to the Algarve. Rain did not allow a successful observation but in the aftermath of the expedition they acquired three equatorial telescopes and one photoheliograph. Spectroscopes were also distributed to Infante D. Luiz Meteorological Observatory, Tapada da Ajuda Astronomical Observatory and Coimbra University Mathematics and Philosophy faculties. The latter had the responsibility of Coimbra University Astronomical and Meteorological observatories, respectively. Lacking willpower to face bureaucratic difficulties and/or to pursue a research project the Coimbra University Meteorological Observatory initiated no studies. The conceptions of astrometry and astrophysics confronted each other within Coimbra University Astronomical Observatory. Astrometry and ephemeris calculations remained the main observatory work following a botched attempt of reform in 1870-71 (Bonifácio, 2009). Tapada da Ajuda Observatory research project stayed faithful to its conception (Raposo, 2010, p. 296). At D. Luiz Meteorological Observatory in Lisbon, João Carlos de Brito Capello (1831-1901) introduced a solar photography project. He sought to obtain a daily record of the solar surface and highly magnified sunspot photographs in order to apprehend the interplay between Earth's magnetic field and solar activity. The project lasted until the early 1880s. The lack of staff and Jules Janssen's solar photographs supposedly caused the end of the project. Nevertheless, Capello maintained for a few years a worldwide network of correspondents and took some of the best solar photographs available (Bonifácio *et al.*, 2007).

The closure of the Navy Observatory in 1874 led to rethinking how astronomy was taught in Lisbon. A new observatory was built at Lisbon Polytechnic School. The research goals – in astrophysics and astronomical photography – of this new establishment were planned to complement the astronometric activity of Tapada da Ajuda Observatory. Financial difficulties prevented the acquisition of the 11-inch Alvan Clark & Sons telescope, which had been ordered. At the time, this instrument would be the best photographic telescope in Europe. Later, Henry Draper (1837-1882) used it to obtain the famous Orion nebula photograph on 30 September 1880. The observatory ended as a mere teaching facility (Bonifácio, 2009).

By the early 1880s, all Portuguese astrophysical research initiatives had either failed or had been interrupted. Portuguese professional astronomers at Coimbra and Lisbon either pursued research in astrometry or gave up research entirely. In the following decades, the situation remained unchanged and no new astrophysical equipment was acquired (Bonifácio, 2009). The inadequacy of Portuguese astrophysical instruments became apparent on the occasion of the total solar eclipse of 1900. In 1905, the astronomer Frederico Oom (1864-1930) from Tapada de Ajuda denied a possible Portuguese expedition to observe the total solar eclipse of 30 August 1905 and remarked:

> Astronomical expeditions – sometimes to exceedingly distant places – to observe solar eclipses cannot be justified unless there is a certainty or a likelihood to obtain relevant scientific data (Oom, 1905, p. 487).[2]

The rise of astrophysics followed Kirchhoff's discovery. At the end of the 19th century this new field already took the centre stage of astronomical research (Meadows, 1970; Gingerich, 1984, Herrmann, 1984; Hearnshaw, 1984, 1986, 2009). In Portugal, professional astronomers made no attempt to pursue astrophysical studies until 1912, when a 47-year-old Coimbra University professor, Francisco Miranda da Costa Lobo (1864-1945) pushed through the construction of a state-of-the-art solar observatory.

[2] The paper author translated all non-English quotes. "As expedições astronomicas para ir - ás vezes bem longe - observar eclipses do sol, não podem hoje justificar-se de modo algum, senão para quem, nessas expedições, tem a certeza ou a probabilidade de obter dados interessantes para a sciencia" (Oom, 1905, p. 487).

Francisco Miranda da Costa Lobo Early Life

Before Costa Lobo taught astronomy at the University, he published in a Portuguese scientific journal an astronomical paper detailing the partial lunar eclipse observation of 7 January 1898. He also led the already mentioned ill-equipped Coimbra expedition to observe the total solar eclipse of 28 May 1900 (Bonifácio, 2009). The situation was strikingly different to what would happen after 1912.

Francisco da Costa Lobo was born in 1864 and enrolled at Coimbra University in 1879 where he attended both Mathematics and Philosophy courses. He obtained a Ph.D. in Mathematics in 1885 and was soon hired as a faculty professor. In 1887, Costa Lobo became the astronomy substitute teacher. Since astronomers' positions were legally tied up to specific mathematical course units, he was appointed the third astronomer of the University Astronomical Observatory. In 1893, he became a fully fledged astronomy professor and the second astronomer. In 1904, he was promoted first astronomer before acceding to the Observatory directorship in 1922 (Univ. de Coimbra, 1888, 1894, 1904; República Portuguesa, 1922; Rodrigues, 1992; Bonifácio, 2009). During this period and despite his long involvement with astronomy, Costa Lobo – as far as it is known – did not publish any original research. There is nevertheless evidence that he followed astronomical developments and incorporated them into his teaching. The Astronomy course unit content – approved on 19 February 1903 following a reorganisation of the Mathematics course – included astrophysics and astronomical photography subjects. Within the national context, the novelty of this syllabus may be fully appreciated if compared to what was then taught at Lisbon Polytechnic School (Bonifácio, 2009, p. 347).

The question which arises is what brought about Costa Lobo's change? Amorim (1955) states that Costa Lobo's newfound scientific focus was a consequence of the revolution which overthrew the monarchy on 5 October 1910. As a monarchic, Costa Lobo reduced his political activities under the new republican regime. There is no doubt that Costa Lobo had been politically active since at least 1889 when he was appointed Coimbra's district substitute civil governor. In 1905, he was elected Member of Parliament. He did not run in April 1906 but was elected in August 1906, April 1908 and August 1910. (Amorim, 1955; Mónica, 2004) Still, Costa Lobo's biography shows that he maintained a multitude of interests after the republican revolution. For instance, in May 1911, he attended Madrid's ninth *Agricultural International Congress* as representative of the *Sindicato Agrícola de Coimbra* (Agricultural Union of Coimbra) (Commission Internationale d'Agriculture, 1912). In the 1910s he was involved in several political or politically motivated associations such as Causa Monárquica (Monarchical

Cause), União Patriótica (Patriotic Union) and Liga Nacional (National League). He briefly returned to parliament between 1918 and 1919 (Leal, 1998; Mónica, 2004).

An Auspicious Series of Events

According to one of Lobo's recollection in 1925 he "had the opportunity to visit [in 1907] the major European observatories, in order to get Coimbra Astronomical Observatory a solar facility equipped with the second type of spectroheliograph knowledgeably envisioned by Mr. Deslandres"[3] (Lobo, 1925a, p. 34). Later, he wrote that the 1907 trip convinced me of the advantages offered by Meudon's instrumental setup to perform solar atmospheric researches (Lobo, 1932a, p. 7). Despite our best efforts we were unable to independently confirm Costa Lobo's trip of 1907 really happened. No mention to it is found in the Faculty of Mathematics meeting minutes. In 1907, between 2 January and 11 April, Costa Lobo attended most of Parliament sessions but what he did during recess is open to speculation (Portugal, 1907). Furthermore, Costa Lobo was absent from the list of delegates attending the third conference of the International Union for Cooperation in Solar Research held at Meudon between 20 and 23 May 1907 (Anonymous, 1914a). At the time, Meudon's new spectroheliograph upon which the instruments in Coimbra would later be based was in an advance state of construction. It was fully operational in 1908 (Mouradian & Garcia, 2007). As no independent confirmation of Lobo's 1907 trip was found, we conclude that if it occurred it was likely to be a private affair and as such Costa Lobo had no obligation to procure new instruments for the Coimbra Observatory. Also, according to Lobo, the support from Meudon's Observatory director Henri Deslandres (1853-1948) only started in 1912 (Lobo, 1925a, p. 35).

On 19 August 1907, a new law increased the autonomy of higher education establishments. It allowed them, amongst other provisions, to manage their financial resources in order to fund scientific journeys abroad. Coimbra University professors first took advantage of this alteration in 1908 (Remédios, 1912). In July 1910 Costa Lobo was chosen by his colleagues from the Faculty of Sciences to undertake two scientific missions

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[3] "quando tive ocasião de visitar os principais observatórios da Europa, exactamente com o propósito de conseguir para o Observatório Astronómico de Coimbra uma instalação para o estudo do Sol, pelo segundo tio de spectroheliographo, sabiamente imaginado por Mr. Deslandres".

abroad to study matters related to his courses. Each mission could not exceed three-months.[4] The motivations for these missions appeared to be pedagogic rather than scientific.

We suspect Costa Lobo's plan likely developed between 1910 and 1912. It was helped by a set of auspicious coincidences as detailed below.

By the end of 1911, Costa Lobo had already completed his missions abroad. Unfortunately, the required mission documents reporting the whereabouts remain unknown. Consequently, we do not know which establishments were visited and when. What is certain is that from 1910 onwards, Costa Lobo became an avid scientific traveller. In June 1911, he attended the third meeting of the Asociación Española para el Progresso de las Ciencias (Spanish Association for the Advancement of Science) held in Granada where he presented two short papers. One discussed azimuth determination with meridian instruments and the other speculated upon the nature of Newton's gravitational force (Lobo, 1912a, 1912b). More importantly, we believe was his attendance to two communications detailing contemporaneous Spanish solar research. Ricardo Garrido (1878-1959) presented an overview of sunspot spectral studies emphasising the work carried out at Cartuja Observatory while presenting several still unanswered questions. After the presentation, photographs of sunspot spectra and equipment were shown to the audience (Garrido, 1912). The paper by the astronomers Francisco Iñiguez e Iñiguez (1853-1922) and Victoriano Fernández Ascarga (1870-1934) reviewed spectroheliograph development, types and usages before describing the characteristics of the new Madrid Observatory instrument. According to this paper it is clear that installing one of these instruments was a complex endeavour (Iñíguez and Ascarza, 1912). Following the total solar eclipses of 1900 and 1905, there was in Spain a surge of interest for astrophysical studies, particularly those related to the sun (López Arroyo, 2004; Ruiz-Castell, 2008).

Costa Lobo suddenly gained international visibility thank to his 17 April 1912 observation of the solar hybrid eclipse. The eclipse lasted an extremely short interval, 0.2 s according to modern calculations. It provided, in theory, a good opportunity to improve several astrometric parameters, e.g. the apparent diameter of the Moon. Costa Lobo organised a modestly equipped expedition to Ovar with his students and managed to film the eclipse with a borrowed movie camera. We are unsure if scientific

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[4] Universidade de Coimbra (1910), "Acta da Congregação da Faculdade de Mathematica, 10 de Julho, 1910" in *Actas da Congregação da Faculdade de Mathematica, vol. 7, 1886-1911*, Unpublished document, Arquivo da Universidade de Coimbra, IV-1a-D-3-1-81, Coimbra (Portugal).

or commercial arrangements motivated this expedition but after analysing the film frames Costa Lobo deduced an unexpected lunar polar flattening. This first astronomical hypothesis solely based on cinematographical observations was presented by Deslandres, on 20 May, to a session of the Académie des Sciences de Paris and it was published on the 28th May *Comptes rendus* volume (Lobo, 1912c). The results of the movie displaying the eclipse were discussed in a series of articles published in 1912 and were quickly disregarded by the astronomical community which favoured an explanation of the observations based upon the irregularities of the lunar profile (Bonifácio *et al.*, 2010). Nevertheless, the event allowed Costa Lobo to obtain the regard of the astronomical community and led to exchanges with Deslandres. Since he was advised not to present a follow-up communication to the *Comptes rendus,* Costa Lobo published instead an extensive paper in a new Coimbra University journal (Lobo, 1912d). In an approach, which was characteristic to Lobo, the article was published in French and we know that he circulated it. Three offprints appear in Paris Observatory Library Catalogue – two of which contain dedications by the author. Still, in 1912, Costa Lobo visited South Kensington solar observatory – a leading solar research institution then.[5]

The Coimbra Spectroheliograph

Before the end of 1912, Costa Lobo's project was already defined and Deslandres' support was secured. In 1913, the large spectroheliograph with 40 cm diameter mirrors had already been ordered from the French maker Amédée Jobin (1861-1945).
Costa Lobo's initiative had the potential to contribute to the advancement of solar studies., as may be ascertain by the Spectroheliograph committee's resolution adopted at the International Union for the Solar Research Bonn meeting, in 1913:

> That spectroheliographs of high dispersion capable of recording the details of the higher atmosphere with the K3 (calcium) or Hα lines combined with image-forming apparatus of long focus, should be installed wherever possible. (Anonymous, 1914c, p. 171)

[5] Solar Physics Observatory (1913), *Report upon the work of the Solar Physics Committee done in the Solar Physics Observatory, South Kensington from 1st January to 31st December 1912*, Unpublished document, Cambrige Library, Obsy B1 (ii), Cambridge (United Kingdom).

The spectroheliograph was a class of instruments independently developed by George Ellery Hale (1868-1938) and Henri Deslandres in the 1890s. In these instruments, a spectrograph entrance slit isolates a particular area of the solar surface image formed by an objective lens. Following dispersion by a prism train or a diffraction grating a second slit isolates a single spectral line. This produces a monochromatic image of the solar area selected by the first slit. In order to obtain a solar disk photograph, the slit and sun image have a relative motion. The spatial and wavelength resolutions of the instrument are defined by the first and second slits, respectively. In Hale's first spectroheliograph, which became operational in 1892, the two slits moved synchronously. A monochromatic image of the Sun was recorded on a fixed photographic plate placed after the second slit. In his model of 1907, Deslandres synchroniszed, instead, a movable objective and a movable photographic plate (Deslandres, 1909; Hearnshaw, 2009). This set-up lack of *a priori* constraints on the size of the instrument dispersion component was its main advantage. The Coimbra spectroheliograph is a copy of this model.

The beginning of the First World War considerably slowed down Costa Lobo's plans. The completion of the instrument was delayed until the 1920s. Still, this was a remarkable achievement when one takes into consideration the complex political and economic situation of the first Portuguese Republic. Political instability was widespread throughout this period. Between 1910 and 1925, 39 Republican governments succeeded each other. Public finances suffered and the country's slight 1910-1911 budget surplus became a large deficit by 1925-1926. High inflation and the rapid devaluation of the national currency (escudo) – especially after the war – diminished the purchasing power of foreign goods (Mata & Valério, 2003). On 6 May 1921,the need to increase the budget of the Observatory to take into account the sharp price increase of the ordered instruments due to the exchange rate variation was mentioned in parliament (Silva, 1921). Four months later, on 5 September, a joint bill by the Ministers of Finance and Education proposed a transfer of funds from the University's personnel budget to the purchasing of astronomical instruments (Ferreira & Machado, 1921). The proposal was not discussed since Parliament was suspended on 17 September. The year 1921 was a particularly troubled one. There were 6 successive governments and the upheaval of 19 October known as the "Bloody Night" (Maltez, 2005).

In August 1922, the Ministers of Education and Finance sent to parliament two important proposals for the future development of the Astronomical Observatory of Coimbra University. The first proposal advocated changing the observatory regulations while the second one authorised a fund transfer between the Ministry of Education budget and the Observatory budget. On 2 September 1922 the bill was approved and 65.000$ were provided for the "full payment of the instruments intended for astronomical observation and research" (Anonymous, 1922). On 23 September, Costa Lobo was appointed director of the Observatory. The previous director's scope of action was reduced to the supervision of the Observatory Ephemeris. (Ministério de Instrução Pública, 1922). Conditions were now in place to start-up a research programme at the observatory as soon as the instrument was fully functional.

The Coimbra spectroheliograph was inaugurated on 12 April 1925 (Lobo, 1944). Later that year, Costa Lobo predicted that from the month of October, the Coimbra Astronomical Observatory will finally lend to solar studies the assistance previously planned (Lobo, 1925b). In July, the Coimbra new facility was announced at the IAU General Assembly held in Cambridge, UK. Regular observations began in January 1926 (Lobo, 1932a).

One should point out that the setbacks due to the First World War did not diminish the relevance of the Coimbra spectroheliograph in the international context as can be inferred, for example, by Deslandres's 1924 report:

> Until now only three observatories photographed the upper [solar atmospheric] layer with a large spectroheliograph. These are the observatories of Mount Wilson in California, Kodaikanal in India and Meudon. Soon it will be necessary to add the Coimbra Observatory (Portugal) and a large solar observatory, which is under construction in the eastern part of Australia.[6] (Deslandres, 1925, p. 8)

Another indicator of Coimbra's instrument importance is the small number of spectroheliographs installed until 1925 (table 1).

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[6] "Or jusqu'ici trois observatoires seulement photographient la couche supérieure avec un grand spectrohéliographe ; ce sont les observatoires de Mont Wilson en Californie, de Kodaikanal aux Indes et celui de Meudon. Bientôt il faudra ajouter l'observatoire de Coïmbra (Portugal) et un grand observatoire solaire qui est en contruction dans la partie Est de l'Australie." Henri Deslandres (1925), *Rapport sur l'observatoire d'astronomie physique de Meudon. Année 1924*, Unpublished document, Bibliothèque de l'Observatoire de Paris, Paris (France).

Observatory	*Date*
Kenwood, USA	1892
Observatoire de Paris, France	1894 (1)
Observatoire de Meudon, France	1906 ; 08
Yerkes Observatory, USA	1903 ; 04
Kodaikanal Observatory, Kodaikanal, India	1904 ; 09
Potsdam Astrophysical Observatory, Germany	1904
South Kensington Solar Physics Observatory, United Kingdom	1904 (2)
Observatorio del Ebro, Tortosa, Spain	1904
Mount Wilson, California, USA	1905 ; 08 ; 12
Arosa Astrophysical Observatory, Switzerland	1911
Observatorio Astronomico de Madrid, Spain	1912 (3)
Cambridge Solar Physics Observatory, United Kingdom	1913
Tokyo Astronomical Observatory, Japan	1920
Utrecht solar tower, Holand	1922
Potsdam Astrophysical Observatory, Germany	1924
Observatorio Astrofisico di Arcetri, Firenze, Italy	1925
Observatorio Astronómico da Univ. de Coimbra, Portugal	1925

Table 1- Spectroheliographs installed prior to 1926. Dates and instruments should be considered as indicative due to disagreements between different references. More than one date, e.g. Meudon 1906; 08 indicates more than one instrument. Notes: (1) transferred to Meudon Observatory, (2) transferred to Cambridge Solar Physics Observatory, (3) Closed before 1920.

The Coimbra-Meudon Co-operation

The existence of a twin instrument placed at a different – and sunnier – location was surely a tempting proposition to Henri Deslandres. As a result, in 1912, a symbiotic relationship was initiated and lasted until today. In particular, the know-how and support of Meudon Observatory were fundamental to install the spectroheliography at Coimbra.

In his Meudon Observatory report for the year 1921, Deslandres (1922, p. 7) wrote:

> These first maps of the solar upper layer relate mostly to a series of observations made in the fine season – winter in Meudon – for the Sun is sometimes hidden for several consecutive days. The survey displays gaps which are troublesome. This difficulty will be overcome by an agreement with Mr Costa di [sic.] Lobo, Director of Coimbra Observatory (Portugal) who, be-

> fore the war, ordered a spectroheliograph identical to ours. In Portugal, the sky is pure during winter and the two Observatories will exchange their photographs.[7]

Similar statements are also found in other yearly reports (Deslandres, 1924, 1925).[8]

In the meantime, in 1923, Costa Lobo's son, Gumersindo da Costa Lobo (1896-1952), who was second assistant at the Coimbra University Faculty of Sciences did – at his own expense – an internship at Meudon Observatory (Lobo, 1944). He then became "responsible for all installation services and scientific research of the Astrophysics department of the [Coimbra] Astronomical Observatory"[9] (Amorim, 1955, p. 24). In 1925, Lucien d'Azambuja (1884-1970), who was an astronomer in Meudon

> was sent to Portugal from 13 March to 14 April to finalise the installation of Coimbra Observatory spectroheliograph which is identical to ours. Then, in the month of April, he made a complete study of a 25 cm diameter and 4 m focal length objective lens ordered by Coimbra Observatory from the manufacturer Jobin. The lens was shipped to Portugal, after necessary modifications.[10] (Deslandres, 1926, p. 21)

As soon as the Coimbra spectroheliograph became operational the desired exchange of photographic plates between the two observatories started.

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[7] "Ces premières Cartes de la couche supérieure se rapportent la plupart à des séries d'observations faites dans la belle saison ; car, en hiver, à Meudon, le Soleil est caché parfois pendant plusieurs jours consécutifs, et le relevé offre des lacunes qui sont gênantes. Cette difficulté sera levée par une entente avec M. Costa di Lobo, directeur de l'Observatoire de Coïmbra (Portugal), qui, avant la guerre, avait commandé un spectrohéliographe identique au nôtre. Au Portugal, le ciel est pur pendant l'hiver ; et les deux Observatoires devaient échanger leurs épreuves."

[8] Henri Deslandres (1926), *Rapport sur l'observatoire d'astronomie physique de Meudon. Année 1925,* Unpublished document, Bibliothèque de l'Observatoire de Paris, Paris (France).

[9] "foi encarregado de todos os serviços de instalação e investigação científica da secção de Astrofísica do Observatório Astronómico".

[10] "a été envoyé en Portugal du 13 mars au 14 avril, pour mettre au point le spectrohéliographe identique au nôtre, organisé par l'Observatoire de Coïmbra. Puis, au mois d'avril, il a fait une étude complète d'un objectif de 25 cm et de 4 m de distance focale commandé par l'observatoire de Coïmbra au constructeur M. Jobin. L'objectif après une retouche jugée nécessaire a été expédié en Portugal."

Meudon series of observations of hydrogen, Hα, and calcium, K1 and K3, spectral lines began in 1919. In order to fill observation gaps record spectrograms were exchanged with other observatories (Deslandres, 1925; Mouradian & Garcia, 2007, p. 3). In particular, from 1926 to 1934, the Kodaikanal and Mount Wilson observatories provided the Hα spectral images while Coimbra Observatory supplied the K3 ones. In this period, an average of 229 Calcium K3 images was obtained each year in Meudon while Coimbra Observatory contributed with approximately 64 extra images per year. Kodaikanal and Mount Wilson observatories each provided a similar number of Hα photographs yearly (table 2).[11]

<table>
<tr><td></td><td></td><td colspan="11">Year</td></tr>
<tr><td>Line</td><td>Obs.</td><td>1926</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td colspan="2">33</td><td colspan="2">34</td></tr>
<tr><td>K_1</td><td>M</td><td>168</td><td>188</td><td>264</td><td>235</td><td>209</td><td>189</td><td>211</td><td colspan="2">209</td><td colspan="2">189</td></tr>
<tr><td>K_3</td><td>M</td><td>232</td><td>231</td><td>219</td><td>267</td><td>225</td><td>229</td><td>230</td><td colspan="2">225</td><td colspan="2">206</td></tr>
<tr><td>K_3</td><td>C</td><td>76</td><td colspan="2">122</td><td colspan="2">96</td><td>70</td><td colspan="2">104</td><td colspan="2">63</td><td>81 (1)</td></tr>
<tr><td>Hα</td><td>M</td><td>191</td><td>197</td><td>235</td><td>249</td><td>226</td><td>200</td><td>227</td><td colspan="2">209</td><td colspan="2">211</td></tr>
<tr><td>Hα</td><td>K</td><td colspan="2">123 (2)</td><td colspan="2">30</td><td>29</td><td>36</td><td>27</td><td></td><td colspan="2">19</td><td>21 (1)</td></tr>
<tr><td>Hα</td><td>W</td><td colspan="2">70</td><td colspan="3">63 + 95 (3)</td><td>84</td><td colspan="2">89</td><td colspan="2">87</td><td>46 (1)</td></tr>
</table>

Table 2 - Number of spectroheliograms in the K1, K3 and Hα lines in Meudon's database from 1926 to 1934. Images are from Meudon (M), Coimbra (C), Kodaikanal (K) and Mount Wilson (W) observatories. Notes: (1) number includes first semester of 1935, (2) number from 1925 to 1927, (3) from the reports it is not clear if these numbers are independent.

Copies of images by Meudon Observatory were also sent abroad if requested. Kodaikanal received K3 and Hα images yearly. In Meudon reports we found only two occasions when images were sent to Coimbra: in 1929 and 1932, 9 and 97 images, respectively. Are these from different dates? We do not know yet but this is something to be investigated.

Two points are important, in our opinion. One is the small number of world-class solar facilities interchanging spectrograms. The other is that the exchange of images began under the auspices of the International Astronomical Union (IAU) (Esclangon, 1935, p. 32)

[11] Henri Deslandres (1927-1928), *Rapport sur l'observatoire de Paris. Années 1926 à 1928*. Ernest Esclangon (1930-1936), *Rapport sur l'observatoire de Paris. Années 1929 à 1935*. Each year corresponds to a different volume (see the bibliography section).

Coimbra astronomers were also interested in obtaining Hα images. A diffraction grating offered by Robert Williams Wood (1868-1955) was tested by Marguerite Roumens (1898-1985), Azambuja's future wife, in Meudon. The grating flaws, she concluded, prohibited its intended use (Esclangon, 1932, p. 32). In 1932, Roumens found the "new grating to be far superior to the previous one"[12] (Esclangon, 1933, p. 40). More importantly, one finds once more the idea that it will facilitate the exchange between the two observatories.

> It will enable the Observatory of Coimbra, which, by sending complementary photographs, participates in the survey of the chromospheric phenomena that we are pursuing, to obtain images Hα of quality comparable to that of the images Hα of Meudon.[13] (Esclangon, 1933, p. 40)

Good Hα images were only taken in Coimbra from 1941 onwards (Silva, 1969).

Nevertheless, obtaining regular observations and exchanging them was only the beginning of a solar physics section at Coimbra Observatory. Costa Lobo published a few papers analysing the data already collected in international journals (Lobo, 1926, 1927, 1929). In 1932, he started the periodic publication of the observatory results (Lobo, 1932b, 1932c). This new initiative by Costa Lobo, though logical, was a first for Portuguese observatories. The publication was well received. A IAU resolution at the 1932 general assembly stated that the:

> commission of Solar Physics – after examination of the publications of the Coimbra Observatory concerning the solar activity, and acknowledging the great importance of that work considers that the Observatory of Coimbra – should be able to continue to make these observations and this important publication. It is in fact necessary for the continuation of the international work that the Coimbra Observatory sends its results to Meudon and Zürich in order to make the synoptical charts and the character figures more complete. These are requirements that the Coimbra Observatory will be able to

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[12] "Le nouveau réseau s'est révélé très supérieur au précédent."

[13] "Il permettra à l'Observatoire de Coimbra qui, par l'envoi de clichés de complément, participe au relevé des phénomènes chromosphériques que nous poursuivons, d'obtenir des images Hα de qualité comparable à celle des images Hα de Meudon."

> follow with its important publications and its international collaborations.[14] (Commission 12 (Physique Solaire), 1933, p. 283)

Coimbra Astronomical Observatory is now a full-fledged actor in the international solar research community. An opportunity the spectroheliograph provided.

Joining the International Community

After 1911, one also finds that Costa Lobo was committed to establish international scientific relations. Costa Lobo made the advantages of these relations clear. For instance, he explained that a scientific meeting

> always represents a remarkable event because it shows an immense collective effort by the intellectual elite in order to better human knowledge, make as much discoveries as possible. these discoveries are either speculative by providing new satisfactions to the spirit, or of practical nature which may contribute to new inventions able to improve human living conditions.[15] (Lobo, 1922, p. 166)

After the First World War, other arguments were weighted in. In his opinion it was "the duty of the nations to preserve themselves and bind in accordance to their affinities in order to avoid or at least mitigate such horrific cataclysms."[16] (Lobo, 1922, p. 169) Following his attendance of the third Spanish Association for the Advancement of Science meeting held in Granada in 1911, Costa Lobo not only attended the association meetings of

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[14] "La Commission de Physique Solaire a examiné les publications de l'Observatoire de Coimbra au sujet de l'activité solaire : elle reconnait la valeur de ces travaux et elle est d'avis qu'il est nécessaire pour la continuation des recherches internationales que l'Observatoire de Coimbra envoie ses résultats à Meudon et à Zurich afin que les Cartes synoptiques et les Nombres caractéristiques soient rendus plus complets. La Commission espère bien que l'Observatoire de Coimbra pourra continuer ses publications importantes et sa collaboration internationale."

[15] "representa sempre um notável acontecimento, porque demonstra um intenso esforço colectivo da elite intelectual realizado com o fim de dar um largo desenvolvimento ao saber humano, e tornar possíveis mais descobertas, especulativas, de natureza a fornecerem ao espírito novas satisfações, ou de índole pratica, susceptiveis de contribuírem para que novos inventos melhorem as condições da vida da humanidade",

[16] "É dever de todos os povos precaverem-se e ligarem-se segundo as suas afinidades afim de evitarem, ou pelo menos atenuarem, tão horrorosos cataclismos".

Madrid (1913), Cadiz (1915), Sevilla (1917) and Bilbao (1919) but also worked towards a joint Portuguese-Spanish Congress. At his initiative the Associação Portuguesa para o Progresso das Sciencias (*Portuguese Association for the Advancement of Science*) was created in 1917 (Correia, 1922). The first joint Portuguese-Spanish Congress was held in Porto in 1921 (Bernardo, 2006). In a typical Costa Lobo manner, as a step was overcome, he was already thinking about the next one. In 1921, he proposed to include in future meetings the Latin American countries to which Spain and Portugal were bound by historical ties and friendly relations (Lobo, 1922). An ambitious idea which did not materialise.

Another example of Costa Lobo's motivation towards establishing international networks was the sharp increase of foreign mathematician members belonging to the Institute Association after Lobo attended the 1924 International Mathematical Congress (Ramos and Malonek, 2005; Costa and Malonek, 2006).

The solar observatory project provided the best opportunity to increase the internationalisation of Portuguese astronomy. The aim to continuously monitor the solar surface provides a clear argument for international collaboration. No Earth based observatory is able to uninterruptedly observe the Sun due to the rotation of the Earth. Consequently, several observatories at convenient longitudes are needed. Having more observatories also minimises the possibility of unfavourable weather at all observing locations.

At the initiative of George Ellery Hale (1868-1938) the National Academy of Sciences of the United States sent a circular asking various societies and academies to appoint committees for a meeting to be held in Saint-Louis in September 1904 to discuss a possible cooperation in solar studies. According to Hale it was unquestionable "that a science like our own cannot accomplish the most important advances without the collection of extensive data, beyond the reach of any individual or institution" (Hale, 1904, p. 310). At the meeting the delegates were:

> In favour of the organisation of a scheme of international co-operation in solar research, which shall encourage individual initiative, provide suggestions for definite lines of work, and facilitate the collection of results for publication. (Anonymous, 1904, p. 302)

Five conferences of the International Union for Solar Research were held between 1904 and 1913 (table 3).

Meeting	*Year*	*Held at*	*Date*
I	1904	St. Louis, USA	23 - 24 September
II	1905	Oxford, UK	27 - 29 September
III	1907	Meudon, France	20 - 23 May
IV	1910	Mount Wilson, USA	31 August - 2 September
V	1913	Bonn, Germany	30 July - 5 August

Table 3 - International Union for Solar Research Meetings

There were no Portuguese nationals in these gatherings. However, during the Bonn meeting, it was proposed that:

> the Observatories of Coimbra, Nice, and Starya Dubossary (Bessarabia), having now acquired spectroheliographs, should be added to our list, and that their directors, MM. da Costa Lobo, Chrétien, and Donitch, be invited to send delegates to our meetings. (Anonymous, 1914b, p. 97)

As a result, and despite his absence Costa Lobo was appointed to the "Photographic (using spectroheliograph, *enregistreur des vitesses*, spectrograph)" section of the Solar Atmosphere commission on account of Coimbra's future work. The commission members were "Hale (chairman); Chrétien, Cirera, Costa Lobo, Deslandres, Donitch, Evershed, Frost, Iñiguez, Kempf, W. J. Lockyer, Newall, Riccò, Slocum, St. John" (Slocum, 1913, p. 307).

The International Union for the Solar Research did not survive the First World War. After the war, the International Astronomical Union (IAU) was founded during the Constitutive Assembly of the International Research Council held from 18 to 28 July 1919 in Brussels. Since Portugal belonged to the War Allied Powers it was eligible for membership. For unknown reasons the country did not adhere immediately to the organisation. No Portuguese astronomers were present at the creation of the IAU, which may explain the delay in joining the union (AF, 1920). Neither were Portuguese delegates present at the first IAU General Assembly held in Rome in 1922 (Fowler, 1922). Nevertheless Costa Lobo attended the first meeting of the International Mathematical Union (IMU). As the Portuguese delegate he voted the IMU statutes (Ramos & Malonek, 2005). Lobo petitioned the government to join (Lobo, 1925b). In 1923, the government created the "Portuguese section of the International Astronomical, Geodesy and

Scientific Radiotelegraphic unions"[17] due to "the need to coordinate our astronomical, geodetic and radiotelegraphic services, so that [...] an easier collaboration with foreign similar services may ensue"[18] (Ministério de Instrução Pública, 1923). The positions of the section were to be filled by senior staff of relevant establishments and teachers from colleges where these issues were discussed. Costa Lobo was the first president of the section (Ministério de Instrução Pública, 1923).[19]

In 1924, Portugal officially joined the IAU. Table 4 summarises the portuguese participants in the general assemblies of the union held before the Second World War (Bonifácio, 2009, p. 355, and references therein).

Gen. A.	*Year*	*Held at*	*Portuguese participants*
I	1922	Roma, Italy	-
II	1925	Cambridge, United Kingdom	Costa Lobo, Francisco
III	1928	Leiden, Holland	Costa Lobo, Francisco
IV	1932	Cambridge, USA	Costa Lobo, Francisco
V	1935	Paris, France	Costa Lobo, Francisco Costa Lobo, Gumersindo
VI	1938	Stockholm, Sweden	-

Table 4 - Portuguese attendees at IAU General Assemblies held from 1922 to 1938

Unsurprisingly Francisco Costa Lobo and his son Gumersindo were responsible for all the Portuguese contributions mentioned in the General Assembly minutes during this period. However, the Costa Lobos were not the only Portuguese members of the IAU nor were they the only ones who belonged to the organisation committees (table 5) (Bonifácio, 2009, p. 357).

[17] "Secção Portuguesa das Uniões Internacionais Astronómica, Geodésica e Radiotelegráfica Scientífica".

[18] "Atendendo à necessidade de coordenar os nossos serviços astronómicos, geodésicos e radiotelegráficos, de forma […] resulte uma maior facilidade de colaboração com serviços similares instalados nos outros países".

[19] The section had the following members: Honorary president, Rear Admiral Carlos Viegas Gago Coutinho; president, Astronomy professor and Coimbra University Astronomical Observatory director; Dr. Francisco Miranda of Costa Lobo; vice-presidents, Lisbon Astronomical Observatory director, Frederico Oom, and general administrator of Topographic and Geodetic Works, António Nogueira Mimoso Guerra; general secretary Monsanto's radiotelegraph station chief, Captain-Lieutenant Alvaro Augusto Nunes Ribeiro (Ministério de Instrução Pública, 1923).

At this time, we are unable to evaluate the work done by other members within their respective committees since preparatory meetings and exchange of correspondence took place outside general assemblies. We know, for example, that Francisco Costa Lobo attended the preparatory meeting of the 1932 General Assembly, in Paris in 1931. Still the general assembly transactions references to scientific works done by Portuguese astronomical observatories only mention the solar research done by Coimbra University Astronomical Observatory.

Date	*Member*		*Commission*
1925	Andrea, Eduardo	16	Observations physiques des planètes, des comètes, et des satellites
	Da Costa Lobo, F.	12	Physique Solaire
	Mimoso Guerra, A.	19	Variation des Latitudes
	Oom, F.	8	Astronomie Méridienne
	Ribeiro, A. N.	18	Longitudes par Télégraphie sans Fil
1928	Andrea, Eduardo	16	Observations physiques des planètes, des comètes, et des satellites
	Da Costa Lobo, F.	12 18	Physique Solaire Longitudes par Télégraphie sans Fil
	Oom, F.	8	Astronomie Méridienne
	Ribeiro, A. N.	31	Heure
	Rodrigues, J. C. S.	4	Ephémérides
1932	Da Costa Lobo, F.	11 18	Phénomènes Chromosphériques Longitudes par Télégraphie sans Fil
	De Lemos, V. H.	18	Longitudes par Télégraphie sans Fil
	Ribeiro, A. N.	31	Heure
1935	Andrea, Eduardo	16	Observations physiques des planètes, des comètes, et des satellites
	Da Costa Lobo, F.	4 11 13 18 m 19 m 31	Ephémérides Phénomènes Chromosphériques Éclipses solaires Longitudes par Télégraphie sans Fil Variation des Latitudes Heure
	Da Costa Lobo, G.	10	Taches solaires et des Figures caractéristiques solaires
	De Lemos, V. H.	18 m 31	Longitudes par Télégraphie sans Fil Heure
	Peres, M.	19	Variation des Latitudes

Table 5 - Portuguese belonging to IAU or mixed (m) IAU and IUGG commissions from 1922 to 1935. Election date of IAU commissions is also presented.

Conclusions

Historical research undoubtedly shows that the Portuguese scientists were aware of international developments in a variety of scientific branches including astronomy. Acting upon this knowledge and implementing up-to-date research programmes was, by contrast, a difficult and rarely successful task due to individual, institutional and material constraints. The attempt to pursue the new field of astrophysics in Portuguese observatories was held-up by astrometric activities until the 1920s. It took the initiative of Francisco Costa Lobo – assisted by, amongst others, Henri Deslandres and his son Gumersindo – to install a state of the art spectroheliograph and launch an observational solar physics programme in Coimbra.

Costa Lobo's will to install a solar research facility at Coimbra Observatory likely started in the early 1910s when he undertook several trips abroad. He visited foreign observatories, begun to attend international congresses and established personal contacts with various astronomers, including Henri Deslandres. The project to establish a symbiotic relationship between Meudon and Coimbra astronomical observatories based upon similar research objectives and instruments was particularly important. The expertise of Meudon Observatory facilitated the acquiring, testing, installing and fine-tuning of the Coimbra spectroheliograph. As soon as the instrument was operational the exchange of information was made easier and the data analysis more efficient. According to Deslandres, from "1925, the preparation will be easier since we have at our disposal the Coimbra photographs, sent regularly by the very active director of the observatory"[20] (Deslandres, 1928, p. 28). It is worth stressing that Costa Lobo was at the time a 64-year-old man. One should also point out that other observatories such as Madrid Observatory opted to have their own spectroheliograph model. The solar physics section of Coimbra Astronomical Observatory had a clearly defined research programme and the observation results were regularly published from 1932 onwards.

Both the astronomers involved and the Portuguese and French governments valued Coimbra-Meudon co-operation. Azambuja travelling at the expense of the French government is a good example of this. Other pieces of evidence were provided by the attribution of honorific titles and prizes to those who were active in the process. Costa Lobo received the *Académie des Sciences de Paris* Janssen prize, on 13 December 1926, for his astronomical works (Anonymous, 1927a, 1927b, 1927c). Deslandres and

[20] "À partir de 1925, la préparation sera plus facile ; car nous aurons à notre disposition les épreuves de Coïmbra, envoyées régulièrement par le très actif directeur de l'Observatoire, le professeur da Costa Lobo."

Azambuja were awarded the Sant'iago da Espada military order by the Portuguese government in 1920 and 1929, respectively. The order distinguished literary, scientific and artistic merit (Presidência da República Portuguesa).

As we have seen, the Coimbra spectroheliograph opened a door within the International Union for cooperation in Solar Research and likely the IAU. Initially, Costa Lobo was the only beneficiary of this situation but others followed him. In fact, we suspect that Lobo had an instrumental role in putting other Portuguese astronomers in several IAU committees. Costa Lobo, as a committed internationalist, participated in other collaborative events such as the wireless longitude determination in 1933 and organised several international congresses (Stratton, 1946).

What the documents lead us to conclude is that despite bureaucratic, institutional and personal difficulties Costa Lobo – helped by a network of friends which he created, cherished and maintained – managed to put his plan into practice. A new world-class solar facility was built and observations were made, shared and published. Its astronomers collaborated with foreign colleagues and attended international conferences as equals. Costa Lobo's strategy created not only a long-standing international partnership with Meudon Observatory but also managed to take Portuguese astronomy out of its seclusion.

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Meteorology, Timekeeping and "Scientific Occupation": Colonial Observatories in the Third Portuguese Empire[1]

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Abstract
This paper presents a tentative overview of colonial observatories in the Third Portuguese Empire (1825-1957). The main issue under focus is the problem of action from a distance, that is, the attempts to steer an imperial network of observation from Lisbon, the tensions and obstacles that emerged in this undertaking, and the strategies implemented as a response. The paper develops around five key episodes: the attempt to create an imperial network of meteorological outstations controlled by the Infante D. Luis Meteorological Observatory (Lisbon), in 1857, the establishment of the Luanda Observatory (later João Capelo Observatory) in 1879, the inauguration of the Campos Rodrigues Observatory in Lourenço Marques (nowadays Maputo) in 1908, the attempt to upgrade the João Capelo Observatory in the 1920s, and the constitution of the National Meteorological Service of Portugal in 1946. These episodes are placed in their political context and approached with regard to the aspirations of imperial resurgence that underlay the Third Portuguese Empire.

Keywords: astronomy, meteorology, observatories, Third Portuguese Empire, colonial science.

Résumé
Ce chapitre présente un aperçu des observatoires coloniaux du Troisième Empire portugais (1822-1975). Il met essentiellement l'accent sur le problème de l'action à distance, c'est-à-dire des tentatives pour diriger un réseau impérial d'observation depuis Lisbonne, des tensions et obstacles qui apparurent, et des stratégies déployées pour y répondre. Le chapitre est organisé autour de cinq moments-clefs : la tentative de création d'un réseau impérial de stations météorologiques contrôlées par l'observatoire météorologique Infante D. Luis (Lisbonne) en 1857, la fondation de l'observatoire de Luanda (par la suite observatoire João

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Capelo) en 1879, l'inauguration de l'observatoire Campos Rodrigues à Lourenço Marques (aujourd'hui Maputo) en 1908, l'essai de rénovation de l'observatoire João Capelo dans les années 1920, et la constitution du Service National Météorologique du Portugal en 1946. Ces événements sont placés dans leur contexte politique et envisagés au filtre des aspirations à une renaissance impériale qui servirent de socle au Troisième Empire portugais.

Mots-clés : astronomie, météorologie, observatoires, Troisième Empire portugais, science coloniale.

OBSERVATORIES played an important part in the development of European colonial expansion (Aubin *et al.*, 2010, p. 2). Besides assisting navigation, metropolitan observatories supported colonial surveys, promoted the mapping of previously uncharted skies, and set the guidelines for the study of colonial climates. Colonial observatories were often founded as a consequence of these undertakings. In other cases, they emerged together with aspirations and agendas that equated local autonomy with scientific progress. All of these settlements were involved in complex networks that shaped the geographies of empire, as they nurtured the circulation of practitioners, instruments, ideas and techniques over vast geographical areas.

The establishment and development of a network of colonial observatories were an endeavour recurrently embraced by stalwarts of the Third Portuguese Empire[2], which lasted from the 1820s (after the independence of Brazil) to 1975. This paper stems from preliminary research on this subject; it is intended to provide a tentative overview of Portuguese colonial observatories and their relations with the metropolis.

The provisional picture conveyed in the pages that follow develops around five key episodes: the attempt to create an imperial network of meteorological observatories and outstations controlled by the Infante D. Luis Meteorological Observatory (Lisbon) in 1857, the establishment of the Luanda Observatory (later João Capelo Observatory) in Angola in 1879, the inauguration of the Campos Rodrigues Observatory in Lourenço Marques (nowadays Maputo) in Mozambique in 1908, the attempt to upgrade the

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[2] This expression is drawn from (Clarence-Smith, 1985). For a recent approach to the Portuguese empire in this period see (Jerónimo, 2012). For a more comprehensive picture of the empire in its several stages see (Disney, 2009; Bettencourt, 1988).

João Capelo Observatory in the 1920s, and the constitution of the National Meteorological Service of Portugal (based in Lisbon) in 1946. Approaching these undertakings requires us to go through distinct periods of Portuguese history: the liberal monarchy (1820-1910), especially the period known as Regeneração (1851-1890), the First Republic (1910-1926), and the Estado Novo (1933-1974).[3] Imperial and colonial agendas changed in the course of these political regimes but, one way or another, they were always grounded in the mythical idea of reviving the glories of the First Empire – that is, the maritime and commercial empire founded in the sixteenth century – and thus compensate for the loss of Brazil, the great colonial domain of the Second Empire. Africa, and especially Angola and Mozambique, constituted the focal point of these ambitions. The observatories and observing networks of these former Portuguese colonies will receive especial attention.

Colonial observatories constitute the subject of a growing body of literature. They have been approached, for instance, as focal points for the introduction and development of instrumental sciences in the colonial context, as undertakings entangled in conflicting views on how to assemble a proper observatory, and as nodes of the logistic circuits of empire (Zuidervaart, 2004; Schaffer, 2012; Mcaleer, 2013). These issues can also be identified in what follows, but this paper is mainly concerned with a more general problem: the problem of action from a distance,[4] that is, the attempts to steer an imperial network of observation from Lisbon, the tensions and obstacles that emerged in this undertaking, and the strategies implemented in order to overcome its predicaments.

Dreams of a "New Brazil"

Between 1853 and 1854, Guilherme Dias Pegado (1804-1885), a physics lecturer at the Polytechnic School of Lisbon,[5] steered the installation of a meteorological observatory in the premises of that school. Pegado was aware of the growing concerns with the standardisation of meteorological practices, an issue that was thoroughly discussed (albeit with limited success) at the international meteorological conference convened by Mat-

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[3] The Estado Novo ("New State") was preceded by a military dictatorship that lasted from 1926 to 1933.

[4] The classic study by Bruno Latour (1987, ch. 6), *Science in Action*, and especially the concept of "centre of calculation", are particularly useful here.

[5] Escola Politécnica de Lisboa.

thew Fontaine Maury (1806-1873) and held in Brussels in 1853 (Anderson, 2010, p. 245).

After decades of turmoil and instability (Bonifácio, 2009) – due to the Napoleonic invasions, a civil war between liberals and absolutists, and the frequent upheavals that followed – Portugal was seeking to pacify its political life and to find a place amidst the modern nations of Europe. A decisive *coup d'état* in May 1851 inaugurated a period known as Regeneração. It lasted roughly until 1890 and was marked by a significant investment in transport and communication infrastructures (railways, roads, a telegraphic network) (Telo, 2004). The organisation of a national meteorological service and its involvement with the international scientific milieu was very much attuned to this agenda of modernisation.

In 1856, the observatory founded by Pegado was named Infante D. Luis Observatory[6] (henceforth IDLO) after its patron Prince Luis (later King Luis I). The IDLO was meant to function as a centre of calculation for meteorology in the mainland. It was also assigned the supervision of meteorological observations carried out aboard Portuguese vessels (Simões *et al.,* 2013, p. 106-111). There was still a lot to do at the metropolis; a meteorological network would have to be built from scratch. But the overseas empire was not forgotten. In April 1857, the Minister of the Navy, Viscount Sá da Bandeira (1795-1886) ordered the installation of meteorological stations in Cape Verde, Angola, Portuguese India, and Macau (a station had already been installed in Lourenço Marques). Sá da Bandeira had been campaigning for a "New Brazil" in Africa since the 1830s. As a keen purveyor of Portugal's imperial rebirth, he did not hesitate to endorse this grand meteorological plan. Guilherme Pegado was required to supervise the assemblage of colonial stations from the metropolis. A decree dated 17 August 1857, also signed by Sá da Bandeira, determined that colonial governors should carry out a periodical inspection of instruments and observations, and present, at least, one report per year. Official documents from 1858 and 1859 mention the dispatch of instruments, as well as observing protocols and forms to Cape Verde, Bissau, Angola, Mozambique, and Goa (Ferreira, 1962, p. 6).

In general, the implementation of this plan progressed slowly. By that time, Portuguese colonies were generally regarded as the last stop for exiles and freebooters. Solid administrative frameworks (let alone educational systems and scientific institutions) were generally lacking. Thus, it is not surprising that there was no dedicated personnel for the meteorological stations. The first observations were usually performed by Naval officers

[6] Observatório Meteorológico do Infante D. Luiz.

and medical doctors deployed to colonial service (Ferreira, 1952, p. 14). Naval officers began to observe in Luanda in 1857. Religious missions, settled in the Angolan hinterland, also maintained some observing series. The first meteorological records concerning Cape Verde refer to observations made by medical doctors, from 1864 onwards. In Mozambique, regular work seems to have started much later, in 1876, by the hand of Naval officers. In Portuguese Guinea, systematic observations began in the early twentieth century only (Ferreira, 1952, p. 11).

The meteorological activity might have developed more steadily in Goa, where an observatory was installed in 1860 at the Mathematical and Military School of the Portuguese Engineering Corps in India.[7] In Macau, observations were made from 1862 onwards, first at the Military Hospital of the Peninsula, and later at the captaincy of Macau's port.[8] However, in the face of the "Scramble for Africa", Portuguese authorities increasingly directed their attention towards the African colonies, and especially to Angola and Mozambique. In 1875, the Lisbon Geographical Society[9] (henceforth LGS) was launched to promote the exploration of the African hinterland, which hitherto remained largely unknown (Medeiros, 2004). Portugal claimed to be the historical sovereign of those territories, but after the colonial conference held in Berlin in 1884-5, effective occupation became the sole criterion of sovereignty accepted by the other colonial powers.

It was in this context that an observatory was, for the first time, established in Portuguese Africa with a permanent character, within the institutional framework of colonial administration. The Luanda Meteorological Observatory was founded in April 1879, under the aegis of the Department of Public Works of Angola. Its regulations, issued in July 1879 (Government of Angola, 1879), prescribed a staff of two elements (the director and an assistant observer), who were expected to work in the observatory and to develop a network of meteorological stations. Each station was to be equipped with a barometer, thermometers, an udometer (rain gauge), an evaporimeter, a weather vane, an ozonometer, a print showing the different types of clouds, and some accessory devices. A detailed set of instructions for each kind of observation was also included in the regulations. All of these dispositions were sanctioned by the metropolitan authority of the IDLO, which, by that time, was directed by João Carlos de Brito Capelo (1831-1901). Educated as a Naval officer, Capelo becomes an ob-

[7] In 1871 the School was replaced with the Professional Institute of Goa, to which the observatory remained appended.

[8] *Boletim Oficial do Estado da Índia*, 2 October 1860.

[9] Sociedade de Geografia de Lisboa.

server at the IDLO in 1855. In 1875, he was appointed Director. Capelo's works on ocean streams, terrestrial magnetism, and solar activity garnered him recognition in Portugal and abroad (Bonifácio *et al.*, 2007). In 1916, the Luanda Observatory was rechristened João Capelo Observatory[10] (henceforth JCO) in his honour.

The original location of the Luanda Observatory was probably the captaincy of the city's port. In 1881, it was transferred to the former cathedral of Angola (the Church of Nossa Senhora da Conceição), whose tower was, by then, the tallest construction in Luanda (fig. 1). The Observatory was also equipped with instruments for magnetic observations (Sociedade de Geografia de Lisboa, 1882, p. 296-299), and with a time-ball, which suggests that there was an astronomical installation for timekeeping purposes as well. Unfortunately, the timekeeping activity of the JCO is poorly documented.

Figure 1 - The Luanda Observatory (*Source:* O Occidente, *n°166, 1883*)

As to meteorology, tables summarising observations for 10-day periods were regularly published in the official bulletin of the colony, at least from January 1879, that is, prior to the official foundation of the observatory. This suggests that the regulations of July 1879 were issued as an at-

[10] Observatório João Capelo.

tempt to consolidate on-going meteorological work, to justify the change of premises, and to foster the development of a meteorological network. It was not an easy task in a colony where the infrastructure and administrative framework were generally incipient. Observations were submitted to the IDLO, but over the next decades, the coverage of the territory would remain insufficient to provide for comprehensive climatological studies.

The Africanist agenda gained momentum in Portugal throughout the 1880s, but was seriously challenged in 1890. The Portuguese had been nourishing dreams of a great colony extending from the coasts of Angola to the shores in Mozambique, on the opposite side of the continent. However, England also intended to reinforce its African domain with a long railway connecting the Cape with Cairo, and did not want the Portuguese on the way. On 11 January 1890, Lisbon was compelled to order a retreat of Portuguese military forces deployed in disputed territories between Angola and Mozambique. The Portuguese authorities could do little more than to comply and seek a satisfactory deal in the ensuing negotiations (Teixeira, 1990). The episode, known in Portugal as the "British Ultimatum", triggered perceptions of imperial fiasco and national abashment, putting the Portuguese liberal monarchy in jeopardy. But it also gave a new thrust to imperial aspirations in the country. Over the next two decades the Republican ideology would get stronger and stronger, until taking over in the revolution of October 5th, 1910. And so did the idea of imperial re-enactment, which was keenly incorporated in the Republican propaganda and increasingly perceived as a formula for national rebirth.[11]

"An Outburst of Instruction": The Campos Rodrigues Observatory in Lourenço Marques

The Portuguese techno-scientific elite was generally keen to embrace this ideal and to shape it into a programme of rational colonialism. Ernesto de Vasconcelos (1852-1930)[12] featured among those who took on this task. A naval officer and hydrographical engineer by training, Vasconcelos paved a sound career in the politics and the administration of the empire. A founding member of the Lisbon Geographical Society, he became its Perpetual Secretary in 1911. This appointment allowed him to consolidate a *persona* he had been crafting for years: that of a mastermind commanding the techno-scientific resurgence of the Portuguese empire.

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[11] For a comprehensive picture of the First Portuguese Republic and its ideological foundations, see (Rosas & Rollo, 2010).

[12] For a biographical synopsis see (Canas, 2009, p. 69-79).

Meteorology and climatology – the study of climate in a certain region over extended periods of time for the purpose of infra-structural planning, agricultural programs, public health management and similar ventures – occupied an important place in Vasconcelos's musings. In 1901, he convened the first national colonial congress, in which he presented his outlook for Portuguese colonialism in Africa (Vasconcellos, 1901). A programme of colonial meteorology was necessary, he claimed, to correct a historical mistake. The first settlers had been seduced by luxuriant vegetation and natural harbours sheltered from the wind. Vasconcelos seemingly upheld to the out-dated theory of miasmas, according to which "bad air" (air contaminated by rotting organic matter) was the cause of epidemics (Halliday, 2001). He was particularly concerned with "mephitic" emanations and malaria bouts in the hotter lowlands, especially in the proximity of rivers and lakes. New colonial ventures, he claimed, should preferentially aim at higher-altitude plateaus where circulation of air was stronger. Systematic observations were needed to assess the climatic suitability of prospective sites. For this purpose, Vasconcelos proposed a network of meteorological stations covering both the seaside and the high-altitude areas in the hinterland. Religious missions would work the high-altitude stations, leaving observations in the coast to port captains and health delegates. This network was to be centred upon three interconnected observatories: the Luanda Observatory, a new observatory to be established in Lourenço Marques, and also a new observatory in Lisbon, which was to act as the imperial overlord of the whole network.

By the early twentieth century, Vasconcelos was widely respected in Portugal as a purveyor of scientific colonialism, but he was not the only one to nurture observatory projects. Without his knowledge, a new observatory started to take shape in Lourenço Marques in 1905. The idea had been launched by Vasconcelo's fellow Naval officer and hydrographical engineer, Hugo de Lacerda (1860-1944), by then the captain of Lourenço Marques' port and the head of a public works programme aimed to upgrade its facilities.

Lourenço Marques' port was crucial for Mozambique's economy. Together with a railway connecting the Mozambican capital with Johannesburg, it constituted a major gateway for people and goods in South-eastern Africa. After the South-African War of 1899-1902, the ports of the Cape and Durban emerged as serious competitors. The programme commanded by Lacerda was meant to secure the competitiveness of the Portuguese port.[13] Lacerda also saw it as an opportunity to present Portugal as a sophisticated colonial overlord, for which the establishment of an observatory in the port seemed very appropriate.

The Luanda Observatory had been officially in activity for a quarter of a century now, but it was not in Angola that Lacerda sought inspiration for his endeavour. Similarly to Vasconcelos, he had practised at the IDLO and at the Astronomical Observatory of Lisbon[14] (henceforth AOL) as part of his training as a hydrographical engineer. Lacerda maintained close ties with the AOL thereafter.

The AOL was founded in 1857 to collaborate with the Pulkovo Observatory (near St. Petersburg, Russia) in the development of stellar astronomy, namely in the measurement of stellar parallax. However, due to delays in its construction and to a shortage of qualified personnel, it was eventually refashioned as an observatory devoted to timekeeping, and accessorily to the measurement of stellar positions.[15] From the 1880s onwards the AOL firmed its status as a national timekeeper, transmitting the official time to a time-ball in the port of Lisbon.[16] The exactness of the Lisbon time signals became a badge of the AOL's commitment to precision. The astronomer César Augusto de Campos Rodrigues (1836-1919), also a Naval officer and hydrographical engineer by training, gave an important contribution to this state of affairs, with his technical contraptions and studies on observing methods. In 1904, he was awarded the Valz Prize of the Academy of Sciences of Paris. The prize consolidated his image as a local scientific hero, and firmed the AOL's status as an internationally respected centre of positional astronomy. This imbued Lacerda with the confidence necessary to engage in a transfer of timekeeping technology from the AOL to the remote harbour area of Lourenço Marques.

The AOL was in its heyday, contrasting with the IDLO. Over the previous decades, the IDLO had functioned as a one-man-observatory. It fell into decline after the demise of its virtuoso meteorologist João Capelo in 1902. The focal point of Portuguese meteorology gradually diverted towards the Azores, where the Army officer and science enthusiast Francisco Afonso Chaves (1857-1926) had recently established the Meteorological

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[13] (Castelo Branco, 1906). On the relations between Mozambique and South Africa in this period see (Katzenellebogen, 1982, p. 79-99).

[14] Observatório Astronómico de Lisboa.

[15] On the foundation and history of the AOL until 1910 see (Raposo, 2010).

[16] This time-ball was installed in 1885, in replacement of an older (and very inaccurate) time-ball that had been at work since the 1850s. The later probably served as a model for the time-ball of the Luanda Observatory, which can be seen in fig. 1.

Service of the Azores[17] (henceforth MSA), based at the Ponta Delgada Meteorological Observatory (Tavares, 2009). Chaves took advantage of the importance of Atlantic data for weather forecasts in order to firm the Azores as a major node in the international meteorological networks, and to fashion himself as a spokesman for Portuguese meteorology, in which he succeeded.

Lacerda made sure to consult the IDLO, but also brought Chaves in as an adviser. And the MSA provided more than a source of meteorological expertise. In 1901, the Ponta Delgada Observatory had inaugurated its own time service. In the face of the intense naval traffic that crossed the Azores, Chaves decided to complement the meteorological service with a chronometric checkpoint for navigation. Frederico Oom (1864-1930), astronomer at the AOL and Campos Rodrigues's sidekick, was required to supervise its installation. After discussing the costs and benefits of a proper astronomical observatory with Chaves, Oom recommended a parsimonious solution: a reliable clock at the Ponta Delgada Observatory, to be rated on a regular basis by an automatic time signal transmitted from Lisbon via the submarine cable. Oom himself supervised the installation of this system. This experience served as a test for further transfers of the AOL's timekeeping expertise and techniques.

Both Oom and Chaves travelled to the Mozambican capital, where they respectively coordinated the installation of the meteorological and astronomical departments of the new observatory. Before visiting Lourenço Marques, Oom also went to Hamburg, to study the observatory and the timekeeping system at work in the port of that city.

In 1908 the new observatory was inaugurated in Lourenço Marques and officially named Campos Rodrigues Observatory.[18] It was located near to the port, in an area of public estate, beside a major access to the city (Polana road). Lacerda conceived the observatory as a local monument of science: he wanted the surrounding parks to be freely accessed by passers-by, so that they could experience "a natural incitement to a burst of instruction".[19]

The meteorological building, which included the director's lodgings, sported the chalet style common in Lourenço Marques at the time (fig. 2). The astronomical facilities were, in comparison, much humbler. A small transit instrument was mounted on a pier inside a shed with meridian shut-

[17] Serviço Meteorológico dos Açores.

[18] "Observatório Campos Rodrigues".

[19] "(…) natural incentivo ao derramamento da instrução" (Observatório Campos Rodrigues, 1909, p. 7).

ters (fig. 3). Observations of stars were carried out with this instrument three times a week (weather permitting) by the American method, that is, by recording the observations with an electric chronograph. The observations were used to rate a sidereal time clock, and then, through the appropriate conversion, a solar mean-time clock. The two clocks were kept in a room appended to the meridian shed, which was also used as a computing office.

After some initial setbacks, time signals started to be sent regularly, via the telegraphic network, to a clock installed in the boarding area of the port. The signals were also relayed to a system of luminous semaphores that displayed the time in the freight area. This arrangement replicated the system of public time signals that Oom had saw at the Hamburg port. It was eventually adopted in Lisbon as well.[20]


Figures 2 and 3 - The meteorological and astronomical buildings of the Campos Rodrigues Observatory, 1908 (Source: Historical Archive of the Astronomical Observatory of Lisbon /MUHNAC)

Lacerda's astronomical ambitions actually went beyond timekeeping. He wanted the observatory to participate in the investigation of latitude variations, to measure and refine right ascensions of the southern stars, and to observe occasional phenomena such as eclipses and occultations (Observatório Campos Rodrigues, 1909, p. 4). A direct intervention in colonial surveying operations was not considered, because there was already a Surveying Department in Mozambique when the CRO was founded. But the CRO did participate in major geodesic campaigns such as the Portuguese Survey of South-Eastern Africa (1907-1914) and the resolution of a

[20] A very schematic and succinct journal written by Oom during this mission is kept at the Historical Archive of the AOL, in the file C648, together with correspondence exchanged with Richard Schorr (1867-1951), the director of the Hamburg Observatory at the time.

boundary dispute with England concerning an area known as Barotseland (nowadays in Zambia), as a coadjutant, not as an overlord (Santos, 1986 ; Observatório Campos Rodrigues, 1915, p. 4 ; Gago Coutinho, 1911).

The CRO also contributed with data for the study of latitude variations promoted by the International Geodesic Association (which Portugal had joined in 1867). However, the astronomical section remained essentially focused on timekeeping. Its apparatus did not allow for much more. Not all Portuguese dignitaries shared Lacerda's enthusiasm for the observatory. Mozambique's Governor Freire de Andrade (1859-1929), a military engineer and stalwart of colonial development,[21] questioned the CRO's relevance for the local economy. As a consequence, the colonial authorities provided limited funding. Lacerda and Oom were forced to order a Bamberg transit instrument, much less reliable than the Repsold instruments used for decades at the AOL. They also had to buy cheaper clocks, a predicament that Campos Rodrigues and Frederico Oom sought to circumvent by examining, testing, and whenever possible, improving the equipment before shipping it to the CRO.

However, the behaviour of instruments in the remote lands of South-eastern Africa was often deviant from their performance in the metropolis. This is well illustrated by the first mean solar time clock of the CRO, ordered from the Munich-based firm Riefler. Campos Rodrigues and Oom knew in advance that it would never perform at the same level as the AOL's clocks,[22] but tried to improve it as much as possible nevertheless. After thorough tests at the AOL they deemed it able to provide a satisfactory level of precision. But once installed at the CRO, its march proved so irregular that there was no option other than acquiring another clock.[23] In these circumstances, replacing or fixing an instrument usually required sending it back to the metropolis, from where it would be redirected to an expert firm abroad, or from where an order for a replacement would be placed and processed. The whole circuit of supply, test and delivery, which involved Lisbon, instrument workshops located elsewhere in Europe, and the Portuguese colonies, had to be re-enacted. The picture was worsened by the absence of advanced instrument and clockmakers in the Portuguese mainland itself.

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[21] Freire de Andrade held the post of Governor of Mozambique between 1906 and 1910. The observatory was already under construction when he took over.

[22] In Lisbon, Krille and Max-Richter clocks were used to keep, respectively, sidereal time and mean solar time.

[23] The acquisition of the CRO's instruments is documented in the above-mentioned file C648 of the Historical Archive of the AOL.

Staffing the CRO constituted an additional problem. The observatory was under the aegis of the port's captaincy, thus its personnel usually came from the ranks of the War Navy. But it was not easy to find officers as enthusiastic, talented or committed to science as Campos Rodrigues or Hugo de Lacerda. Most officers who sought appointments at the CRO did so to escape from other colonial appointments, and usually did not stay long. Military discipline, which played a pivotal role, for instance, in the early development of the Indian meteorological network (Anderson, 2010, p. 276-282), was of little use for the CRO. Directors and sub-directors were required to practice at the metropolitan observatories (AOL and IDLO) before starting to serve at the CRO. But this period of practice did not suffice to prepare them to deal with the technical quandaries that often emerged in the observatory's daily life. Moreover, the personnel often felt ill and maladapted to the tropical climate of the colony – or at least they claimed so, in order to justify their will to leave. Contrary to British India, where natives were used as cheap labour; Portuguese colonial authorities generally excluded the natives from such functions, which narrowed down the pool of prospective observers.

It was only from 1916 onwards that the CRO's staff found some stability, with the appointment of Manuel Peres Júnior (1888-1968) to the post of director. Peres had practised for two years at the AOL, after obtaining a degree in mathematics from the Faculty of Sciences of Lisbon.[24] Better prepared and more dedicated than his predecessors, Peres consolidated a tradition of accurate timekeeping in the colony, whilst promoting the development of the Mozambican meteorological network.

The meteorological equipment of the CRO comprised five basic sets of instruments, for the following measurements: air pressure; measurements in the shade (temperature, evaporation and humidity); precipitation and soil temperature; direction and intensity of winds; actinometry (study of solar irradiation). The apparatus also included some self-recording instruments, namely a thermograph, two barographs, a psychrometer (for humidity), an udograph (for precipitation), and a Jordan heliograph (an instrument that recorded sunlight on an especial type of paper) (Observatório Campos Rodrigues, 1909). A forecast system based on isobars was eventually implemented.[25] The data used in the production of the forecasts was collected through a network of meteorological stations that started to expand after

[24] The Faculty of Sciences of Lisbon was established in 1911 in the sequence of the Republican Revolution of 1910, replacing the Polytechnic School of Lisbon (Simões *et al.*, 2013, p. 106-111).

[25] On isobars and meteorological mapping see (Anderson, 2010, ch. 5).

the Great War. It counted on stations at port captaincies, administrative services, private companies, and also on amateur contributors. Peres placed a considerable effort in disciplining station observers, distributing standardised instructions and forms, offering apprenticeships at the CRO, and carrying out inspections in situ whenever possible. However, it was only with the professionalization of observers and the introduction of financial prizes in the early 1920s that the observing routines in the network reached a satisfactory level of stability and reliability.[26]

Peres also managed to secure a place for the CRO in the international networks of meteorology. In the second meeting of the International Union of Geodesy and Geophysics, held in Madrid in 1924, the acclaimed British meteorologist William Napier Shaw (1854-1945) included the Portuguese observatory in a group of eight observatories (among 50) which were to be favoured as observing nodes in the study of solar irradiation (Shaw, 1925, p. 85-128).

The news certainly pleased Lacerda, who, by this time, was in Macau commanding a new harbour venture. Garnering recognition from abroad was the utmost achievement he had desired for the Mozambican observatory. In fact, Lacerda had conceived the CRO as a catalyser of scientific liaisons between Mozambique and South Africa. As interim director of the CRO, a post he held between 1908 and 1909, he obtained the agreement of the Johannesburg Observatory to standardise meteorological telegrams in the whole region (Observatório Campos Rodrigues, 1909, p. 9); he also promoted joint longitude measurements and barometric investigations.[27] With the aim of strengthening these ties, Lacerda suggested that the South African Association for the Advancement of Science (SAAAS) hold one of its annual meetings in the Mozambican capital. The SAAAS had been founded in 1903, reflecting the importance of science and technology to the ideology of South African autonomy (Dubow, 2006).

Lacerda's idea was well accepted by the Association. Between the 1st and the 13th of July 1913, Lourenço Marques hosted the eleventh meeting of the SAAAS. The meeting evinced a blatant imbalance between the scientific milieus of the two colonial domains. While South-Africa sported various observatories, museums, and other cultural institutions where the sciences were enthusiastically cultivated, Mozambique had little more to

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[26] See the reports of the CRO (*Relatório do Observatório Campos Rodrigues em Lourenço Marques*) for the years 1914-1925.

[27] *Circular No.15, 1914, January 19, of the Union Observatory*; Augusto Teixeira, "Diferença de longitude entre Johanesburgo e Lourenço Marques", Historical Archive of the AOL, C648 (Observatório Campos Rodrigues, 1910).

display than the CRO. This imbalance was evident in the proportion of papers presented by South-African and Portuguese (or Mozambique-based) attendants, which was clearly favourable to South-Africa.[28]

The meeting served its purpose nonetheless. The South-African scientific community keenly accepted Mozambique as a scientific partner. Over the first decades of its existence, the CRO remained a favoured focal point for scientific exchange. Both sides valued the liaison, as it represented a form of regional affirmation against the backdrop of the British Empire. Joint scientific pursuits also helped to cultivate an atmosphere of inter-colonial friendliness, much needed since relations between Mozambique and South-Africa were often plagued by tensions concerning the Lourenço Marques port and the supply of workforce to the South-African mines.

In spite of its substantial achievements, the CRO was not always well regarded in Lisbon. In 1921, Vasconcelos wrote that the CRO represented a considerable expenditure but was still performing below the expectations (Vasconcelos, 1921, p. 455), a remark that echoed Freire de Andrade's criticism. Vasconcelos probably never reconciled with the idea of having been superseded by Lacerda in the foundation of an observatory in Mozambique. Moreover, his plan for a new imperial observatory never took off. His only achievement in this regard was to establish a service of colonial meteorology under the aegis of the Ministry for the Colonies, which, starting in 1915, published an annual report summarising meteorological data collected from all over the empire, under the title *Anais Meteorológicos das Colónias* (Meteorological Annals of the Colonies).

Another critic of the CRO was Manuel de Brito Camacho (1862-1934), a prominent Republican who governed Mozambique between 1921 and 1923. In 1926 Brito Camacho wrote that "almost nothing really scientific and clearly useful has been done with respect to meteorology in the colony, albeit there is in Lourenço Marques an observatory entrusted with these investigations."[29] It was true that by then the CRO was still dealing with a shortage of station observers, and striving to extend its coverage of the hinterland. Still, Brito Camacho's remarks were unfair. Given the circumstances, the CRO had reached a noteworthy level of performance, especially when compared to the older observatory of Angola.

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[28] The programme and the proceedings of the conference are presented in (SAAAS, 1913).

[29] "Quasi nada ha feito, até agora, de verdadeiramente scientifico e manifestamente util, com respeito à meteorologia da provincia, não obstante haver em Lourenço Marques um Observatorio destinado a esses estudos" (Camacho, 1926, p. 134).

"Scientific Occupation" and Imperial Circuits: the João Capelo Observatory in Luanda

In 1912, José Ribeiro Norton de Matos (1887-1955) was appointed governor of Angola. Norton de Matos is best remembered in Portugal for daring to present himself as a democratic presidential candidate against Oliveira Salazar's dictatorship, the Estado Novo, in 1948.[30] This initiative granted him an enduring aura of freedom's paladin; his colonial legacy is more controversial. The efforts he placed at modernising Angola are undisputed. But his action as colonial governor is also marred by a seeming penchant for authoritarianism, coupled with an ambivalent attitude towards native populations. Norton de Matos showed concern for their working conditions and stood for their inclusion in the colonial administrative apparatus. However, he did so always from a strongly Eurocentric perspective, grounded on equal amounts of racism and paternalism. The education and assimilation of natives should, in his view, be carefully limited so that they did were not seduced by independentism. Whenever they were and showed it, Norton de Matos responded with stark repression.[31]

Norton de Matos's faith in the imperial destiny of Portugal was apparently fierce, and so was his trust in science as a tool to fulfil such a destiny. A military surveyor by training, he firmly believed, like Vasconcelos, Lacerda and other contemporaries, that the erstwhile glories of the Portuguese maritime empire could be revived through a steady programme of rational colonialism focused on Africa, which he often referred to as "scientific occupation". To promote science in the African colonies was, in Norton de Matos's own words, to "re-establish, in everything that concerns us [the Portuguese], the historical truth"[32] that is, the continuation of a civilising mission deeply inscribed in Portugal's fate as an imperial nation.

Norton de Matos first governed Angola between 1912 and 1915. He returned in 1921 as High-Commissioner of the Portuguese Republic (a post

[30] Norton de Matos did not run in the end, arguing that the elections would be manipulated by the regime, as they were in fact. On Oliveira Salazar and his dictatorial regime see the last section of this paper, "Amorim Ferreira (1895-1974), the Estado Novo, and the National Meteorological Service".

[31] For an overview of Norton de Matos's political action in Angola see (Wheeler, 2009, p. 171-175).

[32] "Restabelecer em tudo que nos diz respeito a inteira verdade histórica: - que nos baste sempre a memória do que fizemos e o conhecimento do que somos capazes de fazer" (Matos, 1944, p. 15).

equivalent to governor), in which he stayed until 1924.[33] During his first tenure, Norton de Matos sought to reverse the generally backward state of the colony by reorganising its administrative framework: the departments for public works and agriculture, the customs, the mail and telegraph offices, among other services (Government of Angola, 1921, p. 55). His techno-scientific concerns dwelt primarily in the colonial health system and the surveying department (Government of Angola, 1921, p. 54), but meteorology was not forgotten. In a circular dated from April 1913, Norton de Matos demanded the higher civil servants of Angola to maintain a decent and "European" appearance in the premises they oversaw, to be aware of all legislation related to their assignments, and to obtain all instruments necessary to characterise the geography of their circumscriptions, which included their climatology.[34]

Norton de Matos's first tenure coincided, in fact, with a period of growth for the Angolan meteorological network. Between 1911 and 1915, roughly 30 new stations were installed. But the network as a whole remained incipient. Ever dissatisfied with the slow progress of meteorology in Portuguese Africa, Ernesto de Vasconcelos noted in 1915 that observations were often discontinued in Angola. The available series were not credible, he claimed, due to the lack of standardised instructions, to the frequent changes of personnel, and to the fact that many observers did not recognise the importance of their assignments. Vasconcelos also blamed the Portuguese National Press in Angola for adjourning the publication of meteorological reports (Vasconcelos, 1915, p. 5).

As far as astronomy was concerned, the time service of the JCO was seemingly in a deplorable state. In 1911, the AOL was informed that a Bamberg transit instrument used to carry out time observations had reached an advanced state of disrepair, and that the time-ball system was "the most primitive one": an assistant pulled a rope to release the ball upon hearing a ring clumsily activated by a clock. This arrangement rendered an average error of three seconds in the time signal,[35] which for the AOL astronomers was outrageous. The AOL published a quarterly report with the errors of the Lisbon time-ball to cents of a second. Frederico Oom liked to flaunt that the error of the Lisbon time signal rarely went above a few

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[33] For a detailed analysis of Norton de Matos's first tenure in Angola, see (Dáskalos, 2008).

[34] "Circular do Governador Geral de Angola, de 17 de Abril de 1913", in (Matos, 1953, p. 155-156).

[35] Unidentified sender to Campos Rodrigues, 21 January 1911, Historical Archive of the AOL, file DD601.

tenths of a second – a widespread benchmark of chronometric acumen in the late nineteenth century and the early twentieth century (Canales, 2011), which the AOL had militantly embraced.

A serious attempt to improve the general situation of the JCO took place in Norton de Matos's second tenure as head of Angola's administration. Adamant to extend the "scientific occupation" of the colony, he promptly launched the Geological Mission of Angola (Teixeira, 1979, p. 21), and endorsed a lavishly-funded congress of colonial medicine that took place in Luanda in July 1923. Counting on an international and intercolonial audience (with attendants from the British, French and Belgian domains in Africa), the congress was intended to show that Portuguese authorities were concerned with native populations and generally committed to developing their colony on rational grounds (Matos, 1944, p. 292; Government of Angola, 1922).

Colonial medicine was the focal point for techno-scientific liaisons, which left the JCO in a secondary position. But Norton de Matos also had ideas for the observatory. In a speech delivered on 15 March 1922 (Matos, 1926, p. 164), he declared that the JCO and its meteorological services required an urgent upgrade. A new supply of instruments was eventually demanded from the metropolis, in order to re-enact dismantled stations and develop the network. The High Commissioner also wanted the astronomical section to be revamped, for which he summoned Frederico Oom to Angola. The astronomer visited the JCO in August 1922. In his report on the visit,[36] Oom stated it was pointless to compete with well-established observatories such as those of Durban and the Cape; the Portuguese authorities should focus instead on a reliable time service instead, using the CRO as a model. A second of precision was, according to Oom, the minimum goal to be attained, if Luanda wanted to sport a trustworthy time signal. Portugal's prestige was at stake, he further remarked, as Luanda's time service was the only one available in the region. Ideally, an effort should be made to work on tenths of seconds. Consequently, Oom added, the JCO should be transferred to purpose-built premises. And time observations with a theodolite, a makeshift solution that had been adopted in place of the deranged Bamberg transit, were to be discarded altogether.

In the sequence of Oom's visit, several astronomical instruments were sent from the JCO to Lisbon for repair. Most of them were deemed

[36] Frederico Oom, "Novo Observatório em Luanda", 30 September 1922, Historical Archive of the AOL, file DD601.

useless, or, at best, to contain some reusable components.[37] A set of new instruments was ordered in 1923. It included a new Bamberg transit, a Max-Richter clock, and a Nardin chronometer. Once again, the instrumental circuits of the empire proved difficult to deal with. The chronometer was successfully tested in Lisbon, but in Luanda its march revealed irregularities. A clockmaker based in the Angolan capital was unable to repair it, thus the chronometer had to be sent back to Lisbon. A local clockmaker managed to fix it, but some accessories had to be ordered from the Nardin firm in Switzerland. The chronometer returned to Luanda in 1928 only. There was also trouble with the new Bamberg transit. Oom had asked Bernhard Wanach (1867-1928) of the Potsdam Geodetic Institute to test the instrument there, which caused a delay in its dispatch to Lisbon. And when the instrument was finally unpacked in Luanda in 1925, the personnel of the JCO were desolate to find that some components were missing. In the case of the clock, the situation was even more dramatic, as both the clockmaker and Wanach died before it was dispatched to Angola.[38]

Further research is needed to clarify what happened in the ensuing years, but it is certain that the assemblage of the new observatory was yet to be completed when Norton de Matos ended his second appointment in 1924. The construction of new premises was postponed due to financial difficulties[39] and workforce issues. European workers were scarce and generally regarded as cunning opportunists, whilst natives were deemed lazy and untrustworthy.[40] It was not easy to recruit personnel for the observatory either, a situation that changed only when wages were raised.[41]

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[37] These instruments included the already mentioned Bamberg transit, a 108-mm Bardou telescope, 3 chronometers (by Dent, Debbie, and Casella), a Fortin barometer, part of a Casella anemograph, and a barometer. See "Relação dos instrumentos astronómicos e meteorológicos, pertencentes ao Observatório "João Capelo" de Luanda, que foram recebidos em 16 de Julho de 1913 no Observatório Astronómico de Lisboa (Tapada), vindos da Agência Geral de Angola para se decider [sic] sobre o seu possível aproveitamento", 1 September 1923, Historical Archive of the AOL, file DD601.

[38] The problems surrounding the acquisition of these instruments are partially documented in the file cited in the previous note.

[39] Vasco Lopes Alves to Frederico Oom, 23 April 1925, Historical Archive of the AOL, file DD601.

[40] J. A. Bacelar[?] to Frederico Oom, 16 September 1913, Historical Archive of the AOL, file DD601.

[41] J. A. Bacelar[?] to Frederico Oom, 18 January 1923, Historical Archive of the AOL, file DD601.

Significant improvements seem to have taken effect only by the late 1930s. In 1937 a new publication was launched: the Meteorological and Climatological Elements of Angola (*Elementos Meteorológicos e Climatológicos de Angola*). Angola's meteorological network grew substantially in the ensuing years. By the early fifties, the JCO controlled more than 180 stations (Serviço Meteorológico de Angola, 1954, p. 7-8; Ferreira, 1952, p. 15) and presented its results in three different publications: annual proceedings, tables of high altitude observations with balloons, and reports of ground observations.[42] A time service with radiotelegraphic transmission of time signals was also at work.

By the same time, on the other side of the continent, the CRO counted on auxiliary observatories at Beira (the second major city in Mozambique), Lumbo (a coastal town close to the Island of Mozambique), and Tete (in the central area of the colony). It controlled a network that summed up to 105 stations for ground observations, with three additional stations for balloon surveys (Ferreira, 1952, p. 16). Magnetic observations were also carried out at the JCO (the CRO had abandoned this kind of work early in its history due to the development of electric traction in its vicinities).

By the mid-twentieth century the two major Portuguese observatories in Africa had consolidated their performance as colonial centres of calculation. But this did not mean, necessarily, more autonomy from the metropolis. On the contrary, they were now under the strict control of a new imperial overlord.

Amorim Ferreira (1895-1974), the Estado Novo, and the National Meteorological Service

In 1933, the Constitution of the Estado Novo was formally approved, firming the ground for a dictatorial regime that would last until 1974.[43] Fiercely commanded by António de Oliveira Salazar (1889-1970), the regime used the political instability of the First Republic (between 1910 and 1926 there were 39 cabinets and numerous episodes of political violence) as a major argument to impose a strict order, grounded on political surveillance and repression. Empire was embraced as a badge of grandeur and might, and reviving its erstwhile glories became one of the Estado Novo's foundational myths (Rosas, 2012, p. 34).

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[42] Respectively: *Anuário Meteorológico do Observatório João Capelo; Observações meteorológicas de altitude em Angola; Observações Meteorológicas de superfície em Angola.*

[43] For a comprehensive picture of the Estado Novo, see (Mattoso & Rosas, 1998).

Although akin to the regimes of Hitler and Mussolini, the Estado Novo collaborated with both sides in World War II. The defeat of the Axis was expected to favour the democratisation of Portugal and the independence of its overseas colonies. That was not the case. Salazar's government was occasionally defied in the ensuing years (for instance, by Norton de Matos), but the dictator and his entourage were adamant to keep up the status quo. The Estado Novo would now seek to project an external image of sophistication and benevolence while maintaining the nation and the empire under its strict rule, resorting to brutal repression in national and colonial affairs whenever it was found necessary.

The reorganisation of meteorology in the mainland and the empire was attuned to this agenda, as it could be used to sport scientific acumen while allowing for greater centralisation and control. The multiplication of meteorological services in Portugal over the first half of the twentieth century provided a convenient argument for centralisation. By the end of World War II there were seven state meteorological departments in Portugal, each operating more or less independently of the others: the IDLO, the SMA, and the meteorological services attached to the War Navy, the Ministry of the Colonies, the Department for Agriculture, the Secretariat for Commercial Flights, and the Ministry of War. In the colonies, meteorology was officially under the aegis of the War Navy, except in Guinea, where it was supervised by the local aeronautic authority. By then, the JCO and the CRO were very much regarded as independent by the IDLO, which was still the overlord of Portuguese meteorology, but just nominally.

The IDLO had been directed, since 1937, by Herculano de Amorim Ferreira (1895-1974) (Peixoto, 1980), a professor of physics at the Faculty of Sciences of Lisbon. During the interwar period, meteorology had become an academic discipline on its own right, increasingly relying on physics, and with its own community of practitioners (Harper, 2012; Neber, 1995). Amorim Ferreira sought to implement these trends in Portugal, while steering a new effort to centralise meteorological activity in the metropolis and the empire.

Once appointed director of the IDLO, Ferreira immediately sought to activate a legal disposition issued in 1923, which established a National Climatological Service under the guidance of the IDLO. This provided him with a leverage point to extend his influence and authority over all other meteorological services in Portugal. The fact that Ferreira was very well placed in Salazar's regime was obviously of great advantage. He was a member of parliament[44] for many years, and the Sub-Secretary of State for Education between 1944 and 1946. It was around this time that Salazar's government entrusted Ferreira with the reorganisation of Portuguese meteorology, an issue that, according to a biographer, the physicist discussed thoroughly with the dictator himself (Peixoto, 1980, p. 67).

The result was the National Meteorological Service[45] (SMN), founded in August 1946. Amorim Ferreira was promptly appointed Director, a post he maintained until retiring in 1965. Henceforth all meteorological work in the Portuguese mainland, the islands of Madeira and the Azores, and the overseas colonies was to be closely supervised by the SMN. In 1950 all colonies were officially endowed with a meteorological service constituting a sub-department of the SMN (Ferreira, 1952, p. 14). In the metropolis, all meteorological and geophysical observatories (IDLO, eventually renamed as D. Luis Institute of Geophysics; the Institute of Geophysics of the University of Porto, former Queen Amélia Observatory, and the Geophysical Institute of Coimbra) were equally placed under its aegis (Ferreira, 1952, p. 10). The constitution of this new meteorological overlord was accompanied by an effort to redefine the professional training and status of meteorologists and other practitioners of the Earth sciences. For that purpose, degrees in geoscience were established at the universities of Lisbon, Coimbra and Porto. Students enrolled in these new programmes were expected to take posts at the colonial observatories upon obtaining their diplomas (Ferreira, 1962, p. 29).

Angola and Mozambique remained the centres of the network, but the activity of other observatories in the Portuguese empire seems to have gained momentum as well. By the early 1950s, a central observatory in the Island of Sal, Cape Verde, controlled an ancillary observatory installed in Mindelo (S. Vicente Island), 30 stations for ground observations, and an outpost for aerial observations at Praia (Island of Santiago). The Cape Verde Observatory also supervised an ancillary observatory established in Bissau (Portuguese Guinea), which served as the main node for a twelve-station network. In the far-eastern edges of the empire, the Goa Observatory commanded 15 stations (Ferreira, 1952, p. 15-16). The Macau Observatory got an additional impulse in the 1950s from the Italian meteorologist

[44] It must be remarked that the parliament of the Estado Novo (Assembleia Nacional) was essentially an echo chamber of the dictatorial government, constitutionally prevented from questioning its decisions, and inaccessible to those who showed the least sign of opposition to the regime. There was an advisory board, the Câmara Consultiva, which acted more or less as a High Chamber. Amorim Ferreira was also a member for a number of years.

[45] Serviço Meteorológico Nacional.

Ernesto Gherzi, S. J. (1886-1973). Gherzi was a keen investigator of storms in the seas of China, and the former director of the Zikawei Observatory in Shangai. He stayed in Macau between 1950 and 1954, before moving to Canada.[46] The Portuguese government hired him during that period to steer the reorganisation of Macau Observatory, where, besides implementing the dispositions established by the SNM, Ghenzi also conducted investigations on cosmic rays. By the early 1960s, the Macau Observatory controlled a five-station network, deemed adequate to its small territory (Ferreira, 1960, p. 10). In East Timor, meteorology had been brought into a halt during World War II, as a consequence of the Japanese occupation of the island. All equipment and records maintained by the Portuguese authorities were lost at that time (Ferreira, 1960, p. 29). By the mid-1960s, Timor's meteorological network had been fully re-established and significantly extended. It comprised 26 stations and was controlled by an observatory located in the capital, Dili (Ferreira, 1960, p. 29-30). All of these colonial services included at least one station for aerial observations and maintained forecasting services.

In the metropolis, the SNM kept on amassing and publishing the data submitted by the colonies, as the IDLO and the Ministry of the Colonies had done prior to its foundation. Hitherto the function of the metropolitan "centres of calculation" had been essential to accumulate data from all over the empire. Apart from the elaboration of summary tables, few "calculations" had actually been performed. The development of the colonial networks and their tighter control from the metropolis put the SNM in a good stead to change this picture. In 1965, Amorim Ferreira presented a comprehensive study of dynamical climatology concerning Southern Africa (Ferreira, 1965), with data collected through the Mozambican and Angolan networks. Originally requested by the Portuguese Air Force, this work was crafted by Amorim Ferreira to serve a wide range of purposes: aerial navigation, agriculture, tourism, public health and urban planning, among others. The old dream of a steadfast imperial centre of meteorology in Lisbon, planning and fostering colonial development on the grounds of comprehensive climatological studies, was seemingly coming true. But as imperial meteorology started to get sounder, the empire began to crumble down. Salazar and his successor Marcelo Caetano (1906-1980)[47] fiercely resisted the post-war wave of decolonisation, to no avail. In 1961, Portugal lost its

[46] On Ernesto Gherzi see (Udías, 2003, p. 123-124; Bell, 1974).

[47] Marcelo Caetano succeeded Salazar in 1968 as President of the Governmental Council, which in practice meant that he became Portugal's new dictator. He was overthrown by the coup d'état of April 25th, 1974 (see below).

territories in India (Goa, Damão e Dio) after their occupation by Indian troops. In the same year, the Estado Novo launched a war against pro-independence groups in Guinea-Bissau, Angola and Mozambique. The war went on until the "Carnation Revolution" of April 25th, 1974, which finally put an end to the Estado Novo. This was also the end of the overseas empire. It was officially dissolved in 1975.[48] The former colonial observatories and their networks were eventually transformed into the national meteorological services of the new independent nations that emerged from the Portuguese Empire.

Concluding Remarks

Portuguese imperial climatology was entangled in a conundrum: it could have been helpful to architect consistent plans of colonisation, but without solid infrastructures and the human resources necessary to accommodate and maintain an efficient network of meteorological stations, and an observatory properly equipped and staffed to coordinate it in each colony, it could not take off.

Moreover, imperial grand plans and colonial undertakings were not always in tune, and this seems to have been one of the major issues. The case of the CRO is very illustrative: whilst Ernesto de Vasconcelos envisaged a great meteorological network to foster colonisation in the hinterlands of Angola and Mozambique, Hugo de Lacerda was more concerned with the immediate survival of Lourenço Marques as a harbour city, and with Portugal's status and prestige in the regional context. Freire de Andrade's reservations towards the CRO also indicate that commitment to colonial development, as seen from the colony itself, was not a guarantee of endorsement to observatory ventures.

Nevertheless, meteorology was relatively easy to accommodate with the idea of scientific colonialism, as exemplified by Norton de Matos's policies for Angola. With its potential benefits for the planning of new settlements, for the study of public health issues, for agriculture, and for the safety of navigation, meteorology had a strong resonance with colonial progress. It was different with astronomy. Accurate timekeeping was helpful for navigation and to project an image of scientific acumen. But apart from

[48] Due to its special statute, Macau returned to Chinese administration in 1999 only. In East Timor the situation was more nebulous. Portugal remained as the official administrator of the territory, but in 1975 it was invaded by Indonesian forces. It was only in 2002 that the independent Democratic Republic of East-Timor was recognised on the grounds of international law.

that function, astronomy had little to offer in terms of immediate colonial development, especially taking into account that surveying services usually preceded the foundation of observatories in the Portuguese colonies, thus astronomical departments were generally redundant in terms of territorial mapping and control.

Any attempts to engage in pursuits more ambitious than timekeeping would collide with the dubious quality of the available instruments, the enduring difficulties surrounding their installation and use, and the complex imperial circuits of instrument supply and repair - not to mention the scarcity of skilful personnel, let alone virtuosi practitioners such as Campos Rodrigues. It is also important to note that the AOL had itself been reshaped from an observatory suited to foster stellar astronomy into a rather modest establishment committed to positional astronomy, and mainly timekeeping. The AOL never engaged in astrophysical research; its few notable works always dwelt in positional astronomy, and its badge of public utility was timekeeping. The metropolitan observatory achieved recognition by concentrating its limited resources on this niche. A similar approach can be recognised in Frederico Oom's advice to the renewal of the JCO, which was certainly also informed by the setbacks experienced at the CRO.

It must be noted that the CRO and the JCO were not the only African colonial observatories where meteorology took over astronomy and other observatory sciences. The observatories of Mauritius and Madagascar, for instance, followed a similar path.[49] But in the neighbour South-Africa astronomy got a solid footing, especially at the observatories of the Cape and Johannesburg.[50] In fact, the latter began to function mainly as a meteorological observatory and ended up as a respectable centre of astronomy. Various factors contributed to this state of affairs: the solid traditions of astronomy and instrument making in the centre of the empire, Britain; the relatively early foundation (1820) and steady development of the Royal Observatory of the Cape; a network of learned institutions fomenting a south-Africanist ideology grounded in science; and the prestige garnered by astronomers such as David Gill (1843-1914) at the Cape and Robert Innes (1861-1933) in Johannesburg. The contrast with the Portuguese colonies is paramount.

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[49] On the observatory of Mauritius (Royal Alfred Observatory) see (Kirk-Greene, 2001, p. 170-171; Macmillan, 1914, p. 192; Anonymous, 1873, p. 243). Meterological reports for this settlement are available online at: http://docs.lib.noaa.gov/rescue/data_rescue_mauritius.html. On the Observatory of Madagascar see (Udías, 2003, p. 147-148; 169-170).

[50] On the history of these observatories see (Mcaleer, 2013; Evans, 1988, p. 107-109; Warner, 1979).

In any case, the main goal behind the promotion of an imperial network of observatories in the Third Portuguese Empire was the climatological characterisation of the Portuguese colonies. Amorim Ferreira upheld it as the main goal of National Meteorological Service, whose centralistic agenda was itself an image of the stern authoritarianism enforced by the Estado Novo. Although the Mozambique and Angola observatories (especially the CRO) managed to achieve a certain degree of autonomy before being engulfed by the NMS, a tighter control from the metropolis, together with advanced training for future staff members, seems to have been effective in spurring meteorological activity in the other colonies.

However, more research is needed to fully appreciate the history of all of these establishments prior to the NMS, and to calibrate the real impact of Amorim Ferreira's reforms. One idea likely to remain in the face of new historical evidence is that the Portuguese imperial network of observatories and its predicaments, the way the network was revamped by the Estado Novo, and its dissolution after the revolution of April 5th 1974, constitute a mirror image of the Third Portuguese Empire itself, as it can be inferred from the preliminary material presented in this paper.

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