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Unveiling the size of the Universe: the first accurate measurement of the Earth-Sun distance by Giovanni Domenico Cassini

Tesi di Laurea Magistrale

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Sessione I

“L’Astronomie est une Science
qui a pour objet la contemplation
de tous les Astres ou Corps Célestes.

(...)

Si l’on considère son origine,
elle est aussi ancienne
que celle du monde.”

Cassini Jacques, *Éléments d’astronomie.* (1740)

Abstract

Uno dei principali obiettivi di Luigi XIV (Re di Francia e Navarra dal 1643 al 1715), meglio conosciuto come il *Re Sole*, era far diventare la Francia la potenza dominatrice dell'Europa, non solo dal punto di vista militare, ma anche in campo letterario, artistico e scientifico.
Per realizzare il sogno di far vivere al suo paese una sorta di *età dell'oro*, il Re aveva deciso di conquistare il maggior numero di territori d'oltreoceano; il Primo Ministro di Stato, il visionario e diplomatico Jean Baptiste Colbert (1619, Reims, Francia - 1683, Parigi), gli suggerì di finanziare, oltre alle imprese militari, anche una serie di spedizioni scientifiche volte a determinare, con la massima precisione possibile, l'estensione dei possedimenti coloniali francesi, e dimostrare così la *grandeur* del *Re Sole* e del suo immenso regno.

Gli astronomi dell'*Académie des Sciences de Paris* (fondata nel 1666), essendo anche geografi e cartografi, vennero scelti come protagonisti di quelle pericolose spedizioni, organizzate in svariati luoghi della Terra, in quanto la determinazione delle coordinate geografiche (latitudine e longitudine) richiedeva le loro specifiche competenze. Il desiderio di gloria del *Re Sole* si tradusse quindi, inaspettatamente, in un grande sviluppo dell'astronomia.

Tutte le spedizioni furono organizzate sotto la supervisione attenta di **Giovanni Domenico Cassini** (1625, Perinaldo, Repubblica di Genova - 1712, Parigi), astronomo italiano giunto in Francia nel 1669, grazie a Colbert, e calorosamente accolto alla corte di Luigi XIV, che gli riservò un posto d'onore nelle sale dell'*Observatoire Royal de Paris* (della cui realizzazione fu artefice lo stesso Cassini).

Tra le diverse spedizioni organizzate da Cassini, quella che si svolse a Cayenne, nella Guyana Francese, negli anni 1672-1673, permise di ottenere una stima della distanza della Terra dal Sole (nota anche come Unità Astronomica - AU) con una precisione ragguardevole (137.592.200 km, rispetto ai reali 149.597.871 km).

Scopo del presente lavoro è quindi riportare alla luce la storia della missione scientifica a Cayenne ed anche alcuni aspetti poco noti della figura di Giovanni Domenico Cassini. Il contesto storico, politico e sociale si riferisce all'epoca che, anche grazie a queste spedizioni d'oltremare, precede l'Illuminismo.

In the ambitious plan of King Louis XIV, better known as the Sun King, France should have become culturally dominant in Europe. To create this sort of a "golden age" for his country, the King thought he should have conquered and annexed the largest number of key territories through military campaigns. The First Minister of State Jean Baptiste Colbert suggested him to finance also scientific expeditions aimed to determine, with the highest possible accuracy, the extension of French colonial possessions, as that was the right way to show that France was the strongest and largest European power.

The astronomers of the *Académie des Sciences* (founded in 1666), being also geographers and cartographers, were the "leading actors" of those dangerous expeditions, as measuring the terrestrial coordinates (latitude and longitude) strongly required their skills: the desire for glory of the *Roi Soleil* had unexpectedly turned out into an improvement of astronomy.

All the expeditions were supervised by the Italian astronomer **Giovanni Domenico Cassini** (1625, Perinaldo, Republic of Genoa - 1712, Paris) who had been warmly welcomed at the court of the Sun King, in 1669, and was living in the *Observatoire Royal de Paris* which had been organized by Cassini himself. Cassini instructed the scientists who would have taken part to the expeditions, checked their instruments, and compiled a list of instructions concerning the observations they should have carried out.

Among the several expeditions organized by Cassini, the one to Cayenne (French Guiana) deserves particular attention as thanks to observations carried out there (and simultaneously in Paris) Cassini obtained a value for the Earth-Sun distance (137.592.200 km) remarkably close to the real one (149.597.871 km). Unexpectedly that extraordinary result appears to have been forgotten and that was the reason motivating this thesis work.

Through a careful check and inspection of all the available original documents kept in the Archives of the *Académie* in Paris, the history of the Cayenne expedition and of the observations which were carried out there, has been reconstructed and is presented in this work. Moreover, some almost unknown details concerning Cassini's life and work are also shown.
The ambitious aim of this work is to make the reader go back in the past to perceive the atmosphere of an epoch in which, thanks also to the overseas expeditions, began to bloom what it was going to become the Age of Enlightenment.

Contents

Part I

Giovanni Domenico Cassini

Chapter 1

First years: Perinaldo and Genoa

"Qui, dunque, fra questi monti a grandioso anfiteatro in vista del mare,
nacque l'8 Giugno del 1625 Giovanni Domenico Cassini,
agli albori di una nuova era di scienza e conoscenza." [1]

Figure 1.1: Portrait of Giovanni Domenico Cassini (anonymous author, epoch XVII century). Oil on canvas, 86x70 cm, Museum of Palazzo Poggi, Bologna, Italy. Rector's inventory: QUA 305.

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[1] Cassini A., *Gio: Domenico Cassini Uno Scienziato del Seicento.* (2003) Comune di Perinaldo.

Giovanni Domenico Cassini was born in Perinaldo, Liguria, Italy, on June 8th, 1625 in a building named Castello Maraldi, which still exists and belonged to his family since about 1550. His parents were Giacomo Cassini and Tullia Crovese. At the time of Cassini's birth, Perinaldo was a part of the province of Nice, and only in 1818 it would have been incorporated in the province of San Remo, by the King of Sardinia, Victor-Emmanuel I.

Figure 1.2: The sculpture dedicated to Giovanni Domenico Cassini in Perinaldo, Liguria, Italy.

> *"Allì 10 di d.*^{0}
> *Gio.Dominico figlio di Giac. Cassino e di Tullia sua moglie*
> *è stato battezzato da me sud.*^{0} *Ber.*^{do} *curato,*
> *tenendolo m. Ant.*^{0} *Maria Crovese e Battista Cassina q. Antonio..."*

In the certificate kept in the Archivio Parrocchiale of Perinaldo, it is possible to find the name of his Baptism godfathers: Antonio Maria Crovese and Battista Cassina, the former one being his maternal uncle. Antonio Maria was a notary, as his father Ludovico Crovese was, and he took care of Giovanni Domenico's primary education. That was not an easy task at all and leaded to several disputes within the family which details however remain obscure, as in his autobiography [2], Cassini intentionally avoided to write about his private life. He chose instead to give emphasis to anecdotes and descriptions about his studies and his work.

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[2] Beretta, M., *Giovanni Domenico Cassini, Autobiografia* in *Icone di scienza. Autobiografie e ritratti di naturalisti bolognesi della prima età moderna.* (2020) Bononia University Press.

The autobiography of Cassini is a *unicum* which has not any further editions: there is only one printed copy edited in 1810 by his great-grandson Jean-Dominique, which is contained in the volume *Mémoires pour servir à l'histoire des sciences et à cells de l'Observatoire royal de Paris, suivis de la Vie de J.D. Cassini écrite par lui-même.* Part of Cassini's life is also documented in some manuscripts, such as the one written by an anonymous Parisian editor in an unknown period. This text has been found at the *Département Cartes et Plans* at the *Biliothèque Nationale de France (BnF)* and has been transcripted taking into account the phonetic and orthographic characteristics of the seventeenth century French. The text has been presented at the exhibition *Icons of Science* held in Bologna at the Museum of Palazzo Poggi, from July 2020 to September 2020.

From both Cassini's autobiography and the above mentioned text is possible to find out that Giovanni Domenico was a lively and intelligent child and that he attended the Jesuit College in Genoa, where he received an excellent cultural and spiritual education. In his autobiography he did not specify the exact period of time he spent in the college but it is likely to have been between 1638 (as he arrived in Genoa when he was 13 years old) and 1646.
He described very well, instead, his teachers, his College mates and all his experiences of a smart schoolboy together with the philosophical debates, and the doctrine he would have never forgotten. In the College only the best students learned the *art of rhetoric* and could fluently read and write in Latin; the other students graduated in Humanities, but it was however rather easy for them to find a good job in the jurisprudence field.
Giovanni Domenico immediately emerged among one hundred of students demonstrating a natural inclination for knowledge and Maths, which in the next years would have become his great passion. He read treatises famous all over Europe such as the geometry of Euclid (c. 300 BC), The Alphonsine Tables, and the Rudolphine ones, which had been published in 1627 by Johannes Kepler [3], who had used Tycho Brahe [4]'s observational data and star catalogues.

The young Cassini was not only interested in astronomy but also in astrology and thanks to some essays, that he read on that subject, he made predictions that turned out to be true. That disturbed him very much for two reasons: astrology was doomed by religion, and he could not find any scientific reasons supporting astrological predictions. He then read the treatise *Disputationes adversus astrologiam divinatricem* written by Giovanni Pico della Mirandola [5] but left unfinished

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[3] Johannes Kepler (1571, Weil der Stadt, Württemberg - 1630, Regensburg) more on appendix A.17.

[4] Tycho Brahe (1546, Knutstorp, Sweden - 1601, Prague) more on appendix A.4

[5] Giovanni Pico della Mirandola (1463, Mirandola - 1494, Florence) was an Italian Renaissance philosopher who proposed a synthesis between the Christian and pagan doctrines, Jewish and Arab derivation, and the medieval philosophy. He was a deeply religious man but he did not want to bow before the authority of the Church and its dogma. He gave to the humanist movement the doctrine that humankind, under God, was at the center of reality. His 1486 oration *Oratio de hominis dignitate* was the *manifesto* of Renaissance thought, in which freedom was identified as the fundamental characteristic of man. In the same year he also wrote

by the author and thus published posthumously, in 1494. Convinced that there was no science at all supporting astrology, Cassini literally buried his written predictions and notes, but curiously his ability in predicting events is likely to have played a role in his future career as a scientist.

After having finished his courses at the College, in 1646, Cassini decided to pursue his natural inclinations and continued studying mathematics, beginning also to do his first astronomical research. On of his teacher was surely Giovanni Battista Baliani [6], a famous physicist and astronomer, who corresponded with Galileo Galilei [7] about some common studies concerning the atmospheric pressure. Baliani gave Cassini a real astronomical instrument as a sign of succession.

Figure 1.3: Portrait of Giovanni Domenico Cassini (anonymous author, epoch XVII century). Oil on canvas, 52x59 cm, Museum of Palazzo Poggi, Bologna, Italy. Rector's inventory: BUB 546.

Conclusiones nongentae in omni genere scientiarum, a document divided into 900 theses: some of them were considered heretical.

[6] Giovanni Battista Baliani (1582 - 1666, Genoa) more on appendix A.2.

[7] Galileo Galilei (1564, Pisa - 1642, Arcetri) more on appendix A.11.

Chapter 2

Bologna: the beginning of a scientific career

In 1649 Cassini decided to leave Genoa under the continuous request of the Marquis Cornelio Malvasia (1616 - 1693, Bologna), senator in Bologna, who was extremely interested in science and astronomy. When the Marquis got to know (probably from Giovanni Battista Baliani) of a young and promising scientist, he started asking him to reach Bologna.
Malvasia wanted Cassini to take care of his private observatory in Panzano, Modena. Shortly later, the scientist would have had the chance to become a teacher of the Bologna University. There, he would have met famous mathematicians and astronomers, such as Giovanni Ricci (1497, Chiusi, Siena - 1574, Rome) and the Jesuits Giovanni Battista Riccioli (1598, Ferrara - 1671, Bologna) and Francesco Maria Grimaldi [1], who would have convinced him of the importance of accurate and systematic celestial studies and of the need for the construction of new astronomical instruments.

A that time the Bologna University had a huge fame, not only in Italy, but also throughout Europe. The lectures were held in the magnificent Archiginnasio palace, which had been built by Pope Pius IV, in 1563, for teachers and students who were coming to Bologna from very different places.
To have access to the manuscripts kept in the Archiginnasio, it was necessary to be older than twenty five, thus Cassini had to wait for the academic year 1650-1651 to submit his application. In it, Cassini wrote that he had already taught philosophy and mathematics to the Genoese nobility and that he would have been largely honored if he could have been given the chance of teaching in an important University as Bologna was.

Cassini was judged to be a *"very virtuous person, with an excellent cultural formation"* and thus, on April 12th, 1651, under the pontificate of Innocent X, the chair of astronomy was assigned to him and he was immediately registered in the official list of teachers:

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[1] Francesco Maria Grimaldi (1618 - 1663, Bologna) more on appendix A.12.

> *"Proficuum summopere studiosae Iuventuti Archigymnasioque decori lecturam Astronomiae profitendam arbitrantes... idcirco... Archigymnasio... conducendi ad cam Cathedram per quinquennium probatum eiusdem professionis virum D.Doctorem Jo. Dominicum Cassinum Januensem, eidem muneri parem credito illique stipendium librarum sexcentarum de pecunijs Gabella grossam assignandi(...)"* [2]

From the above reported few lines we get to know that Cassini held the astronomy chair in the Bologna University for five years and that his salary was 600 Bolognese Lire (roughly corresponding to 4.000 euros per year). He taught the theory of the planets together with Giovanni Ricci who was in charge of reading the geometry of Euclide text (both teachings were part of the single course, *Ad Mathematicam*).

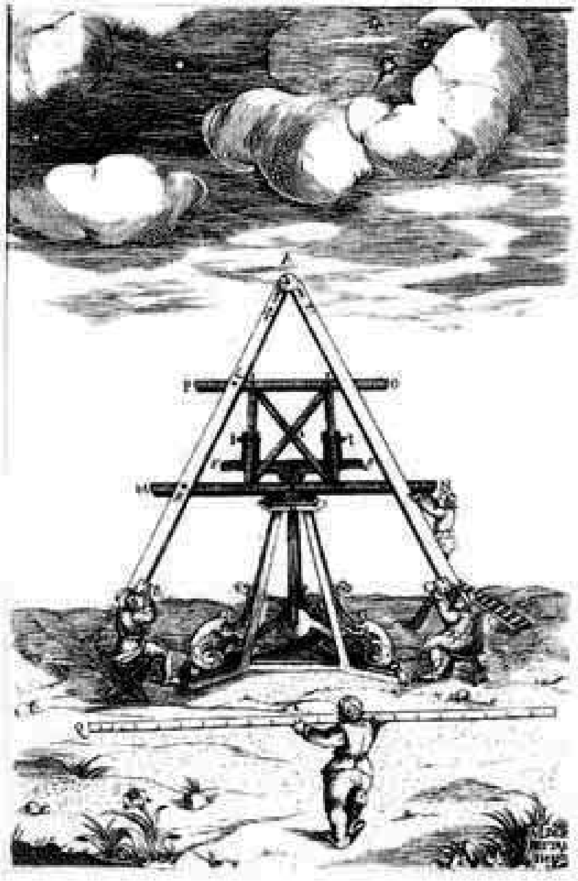

Figure 2.1: Cassini G. D., *De cometa anni 1652 et 1653.* (1653) Mutinae, apud Sulianum. The image represents the astronomical instrument used by Cassini to measure the angular distance between the stars. Cassini's project is illustrated in the work with a detailed explanation: by means of a system of mobile and fixed segments, two observers could determine the angular separation between the head of the comet and a reference star.

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[2] Senato, Partit Libro 36, f.52. State Archive of Bologna.

In 1652, few days before Christmas, Cassini observed, from the Specola of Panzano, a comet which appeared close to the Zenith. That was the first comet ever seen by Cassini;, thanks to some accurate observations, he was able to suggest that, at variance with Aristotelian hypothesis, comets were likely to be well above the orbit of the Moon. The work *De cometa* [3] containing the results of Cassini observations was his first astronomical published study.

2.1 The meridian line inside the Basilica of San Petronio

The fundaments of the new heliocentric system had been published by Nicolaus Copernicus [4] in his *De revolutionibus orbium coelestium* (1543), but experimental evidences that the Earth was not standing solidly in the center of the Universe were missing, and several people still believed that the Sun was circularly moving around an immobile Earth.
Trying to demonstrate that the Earth was revolving around the Sun, as the other planets did, was not so easy in Bologna, a State of the Church town, which was second in order of importance to Rome. Moreover, only twenty years had passed since Galileo had been condemned and the scientists believing that Copernico's model was the right one did not dare to publicly support it.

The inequality of the "solar motion" (i.e. the difference length of spring and summer as compared with autumn and winter) was well known since the antiquity but had a different interpretation in the two *Systems of the World.* In the geocentric model it had simply to be attributed to the different Earth to Sun distance, while in the heliocentric one, thanks to Kepler's second law [5] the difference was also related to the (different) velocity of the Earth.
The subject was carefully discussed by Cassini in his *Controversia* [6] of 1655, who was looking for a proof which could unambiguously rule out the geocentric system. Of course he did not write it explicitly, and exactly for that reason he had planned to build the meridian in San Petronio.

The new large meridian line inside the Basilica of San Petronio, Bologna, should have replaced a previous one which had been built in 1576 by Egnazio Danti (1537, Perugia - 1586, Alatri), a Dominican, cosmographer and professor of mathematics at the University of Bologna. Unfortunately, his work had been

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[3] Cassini G. D., *De cometa anni 1652 et 1653.* (1653) Mutinae, apud Sulianum.

[4] Nicolaus Copernicus (1473, Toruń, Poland - 1543, Frombork, Germany) more on appendix A.6.

[5] Kepler's first and second laws of planetary motion were originally described in his *Astronomia nova* which he published in 1609. The second law, which in origin was the one, states that the velocity of a planet varies in such a way that a line joining the planet to the Sun sweeps out equal areas in equal times.

[6] Cassini G. D., *Controversia prima astronomica ad maximum heliometrum D. Petronii examini exposita., Specimen observationum Bononiensium qaue novissime in D. Petronij templo ad astronomiae novae constitutionem haberi cepere.* (1666) Bononiae, typis HH Ducijs.

destroyed in 1653 because of the Basilica expansion and the demolition of the wall in which the “eye” of the instrument had been placed.
Against the project to replace Danti’s meridian line with a shorter one, Cassini proposed to make an instrument two and a half times longer than Danti’s one, to make more accurate observations.

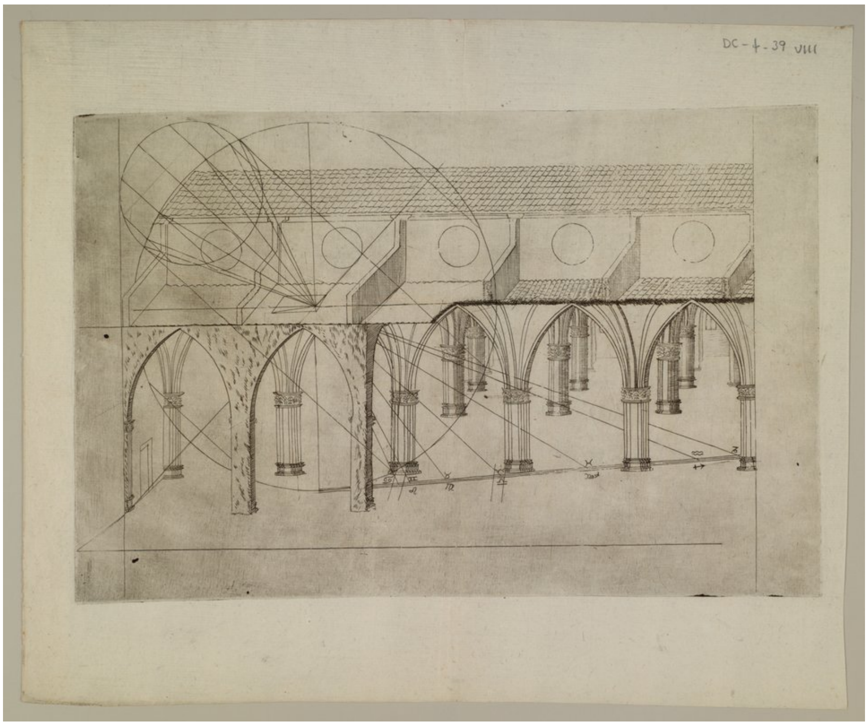

Figure 2.2: *Giovanni Domenico Cassini and the meridian line of S. Petronio in Bologna*, volume and document belonging to the Ancient Fund of the Department of Astronomy of the University of Bologna. The digitization has been carried out on the occasion of the celebrations of the Cassinian Year in 2005 (AMS Historica is a service of AlmaDl, the digital library of the University of Bologna). The image represents a drawing of the meridian line in the Basilica of San Petronio that G. D. Cassini signed and presented to the Queen of Sweden Cristina, in 1655.

Cassini’s real intention was resolving the controversy began with Copernicus but, obviously, he could not state it openly. He thus declared that with such a long meridian line he would have been able to measure, with high accuracy, the length of the solar year, to confirm the correctness of the Gregorian calendar reformation.

The Gregorian calendar [7] had been introduced in 1582 by Pope Gregory XIII (born Ugo Boncompagni, 1502 –1585) to replace the Julian calendar (introduced in 46 BC by Julius Caesar). The latter had 3 years of 365 days and one “leap” year of 366, but as the length of the solar year was 365 days, 5 hours, 48 minutes, 46 seconds, a little smaller (11 minutes and 12 seconds) of the assumed one (365

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[7] See more on Coyne, G. V., Hoskin M., Pedersen o., *Gregorian Reform of the Calendar.* in *Proceedings of the Vatican Conference to Commemorate its 400th Anniversary (1582-1982).* (1983)

days 6 hours) the alignment between the calendar and the seasons was changing of almost one day per century. The vernal equinox date, which had been established to be March 21st by the Council of Nicea (325 AC), had moved back to March 11th and since Easter date was related to it, if one had not corrected for the Julian calendar overestimation of the year length, Easter day would have continued moving backwards. Gregory XIII rearranged the dates, suppressing all the days between October 4th and 15th, 1582 and to avoid future problems he established that centurial years would have been leap years only if divisible by 4000.

To accomplish his ambitious project, Cassini had to overcome considerable economic and technical difficulties: the meridian line in fact touched the base of some columns. This was the greatest technical difficulty for Cassini, who managed to prevent the path of the Sun rays from being interrupted by the columns. The cost of the total work amounted to 2.500 Bolognese Lire (corresponding to 20.000-25.000 Euros) of which 500 were given to him. The length of the meridian line (66.8 meters) corresponded to one over six hundred thousands of the Earth circumference, something that Cassini described with these words:

> *"(...) una cosa assai maravigliosa, che aggiunge una straordinaria bellezza alle proprietà della meridiana di S. Petronio; ed è che ella si ritrova esser giustamente la seicentomillesima parte della circonferenza di tutta la terra".* [8]

That was, and still is, the longest meridian line in the world. The tiny hole allowing the sunlight entering in the Basilica (also called "eye") had a diameter of 27.07 mm and was placed in the fourth vault of the left aisle, at a height of 27.07 m. Cassini himself sketched a blazing and impressive Sun to be painted around the "eye" (in Fig. 2.3). [9]

On the summer solstice of 1655, Cassini invited the citizens of Bologna and his University colleagues to admire the beginning of the construction of his new instrument (as can be seen from the only document left and kept in the Historical Library of Department of Physics and Astronomy of the Bologna University) and three month later (on the autumn equinox) he was able to show that the Sun image was passing between the columns (most people were convinced that it could have not been possible).
Cassini could thus observe the diameter variations of the Sun image (projected on the floor of the church) with the incredible precision of about an arc prime and derive from them the variations of the Earth to Sun distance. He verified also (with his observations) that the Sun diameter (and hence its distance) did not decrease in the same way as its speed decreased: the Sun velocity variations during the year proved that the Earth was faster when it was closer to the Sun and slower when it was further away.

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[8] Letter of G.D. Cassini from Paris, November 27th, 1670. Bologna, Archives of the San Petronio's Fabbriceria, cart. 388. fasc. 8.

[9] More on Bonoli F., *Bologna Astronomica. Le vie delle stelle.* (2021) Bologna, Persiani. pp. 36-57.

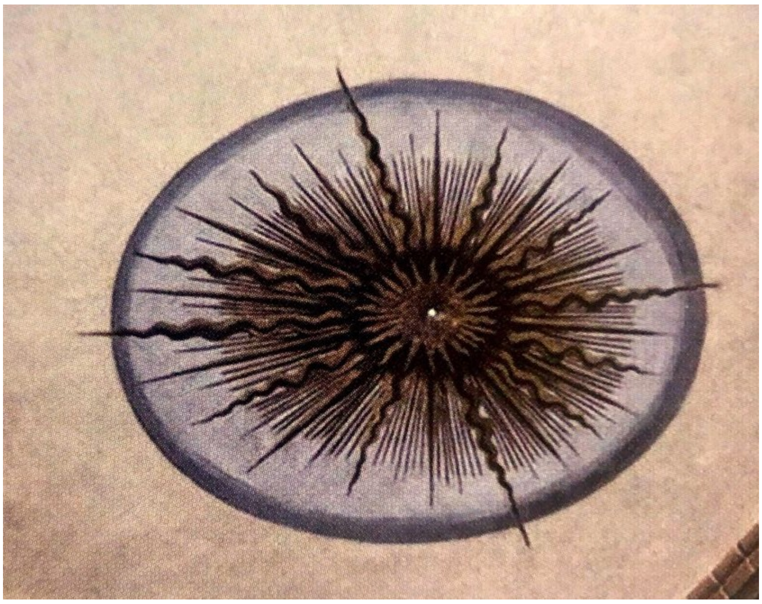

Figure 2.3: The "eye" of the meridian line in the Basilica of San Petronio, Bologna. Credits: Bonoli F., *Bologna Astronomica. Le vie delle stelle.* (2021) Bologna, Persiani, p.43.

That was the first observational confirmation of Kepler's second law proving that celestial bodies were not uniformly moving along circular orbits as astronomers had believed and tried to describe for over twenty centuries. Moreover, Cassini's measurements preceded of more than three decades the publication of Isaac Newton [10]'s *Philosophiæ naturalis Principia Mathematica* written by , which would have given a physical framework, the law of universal gravitation, to Kepler's empirical relations, experimentally proved by Cassini with his meridian.

Cassini reported [11] the first results of the fundamental observations of the Sun in 1656 dedicating the study to Queen Christina of Sweden. Thanks to the new meridian Cassini could calculate accurate solar ephemerides [12] and he determined also the obliquity of the ecliptic obtaining a value of 23°29'15" (the accepted value for his epoch being 23°28'53").

In 1776, a century after the sundial construction, Eustachio Zanotti (1709 - 1782, Bologna) director of the Bologna Astronomical Observatory, would have been requested to verify the meridian line condition as it looked seriously damaged and could not be used anymore. Three years later (between June and November

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[10] Sir Isaac Newton (1642, Woolsthorpe, Lincolnshire, England - 1727, Kensington, London) more on appendix A.22.

[11] Cassini G. D., *Specimen observationum Bononiensium quae novissimi in S, Petronij templo ad astronomiae novae constitutionem pareri cepere.* (1655) Bononiae, typis HH Ducijs.

[12] The term derives from the Greek *έφημερις* (meaning "diary") through the Latin *ephemeris.* Ephemerides contained the positions of different celestial bodies and were fundamentals for astronomers and navigators. Their computation required accurate observations performed for a long time by means of which future positions could be derived. Nowadays ephemerides are computed thanks to mathematical models able to accurately reproduce the motion of celestial bodies and of the Earth.

1779), several earthquakes would have struck Bologna. Zanotti would have been replaced the old iron line with a new one made of brass and the old marbles with new ones, without affecting the overall positioning of Cassini's instrument.

2.2 Galileian studies

The influence and importance of Giovanni Battista Baliani on Cassini formation is well known and documented but it is very likely that during the time he spent in Genoa, he had had several contacts with other scientist of strong Galilean orientation. It was obviously Galileo who, in the seventeen century, opened a "new experimental way" for physics and astronomy as well. He was the first watching the sky through a telescope and revealing to the world how things up there had revealed an unpredictable aspect. Much of that is reflected in a line of research carried out by Cassini with the help of Giuseppe Campani [13].

2.2.1 Giuseppe Campani

The seventeenth century was undoubtedly extremely important for science, and often recalled for the contribution given by Galileo, Cassini and Newton. Other less known scientists lived in the same period, among whom Giuseppe Campani. He was the youngest of four brothers who moved to Rome from their hometown Castel San Felice, near Spoleto. Part of Campani's biography included in an article of Silvio A. Bedini [14] was translated in Italian by Giuseppe Cicconardi and published in 1964 under the title *Contributo di Giuseppe Campani alla scienza ottica.* [15]

Once arrived in Rome, the four Campani brothers invented a silent watch to be used in night time and presented it, in 1656, to Pope Alexander VII, who allowed them to produce it: the reaction to this new invention was incredible and all the crowned of Europe wanted to have a watch like that. Apparently, not even one of those silent watches lasted until now but their internal structure was detailed in a small report [16] published in 1677 by Matteo Campani, the oldest brother, who continued his work in the Canonica of San Tommaso with Giuseppe, while Pier Tommaso (who was a watchmaker too) left the activity, probably because he got envious of the brothers.

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[13] Giuseppe Campani (1635, Castel San Felice, Perugia, Italy - 1715, Rome) more on appendix A.5.

[14] Silvio A. Bedini was the director of the Museum of History and Technology in Washington (now the National Museum of American History). He gave a lecture related to the history of Giuseppe Campani, entitled *The Optical Workshop Equipment of Giuseppe Campani* which was published in January 1961, in the Journal of the History of Medicine and Allied Sciences, Vol. XVI, Issue 1, pp. 18–38.

[15] The article was published in *Coelvm*, an Italian bimonthly periodical for the dissemination of astronomy, founded in 1997 by Guido Horn D'Arturo (1879, Trieste - 1967, Bologna) more on appendix A.15.

[16] Campani, M., *Horologium solo naturae motu, atque ingenio, dimetiens, et numerans momenta temporis, constantissime aequalia.* (1677) Roma, Ignazio Lazzari.

Between 1655 and 1660 Giuseppe Campani started to get interested in lenses probably because he had been given the opportunity to attend the workshop of Eustachio Divini [17]. He began to study and grind lenses himself and rapidly surpassed his mentor. The excellence of Campani's work become relevant at international level when Cassini (at the time professor at the University of Bologna) decided to use his lenses. At variance with other lenses manufacturers who were using rudimentary machines [18], Campani introduced a new technology allowing him to manufacture lenses with focal lengths even larger than one hundred meters (50 and 52 Roman palms, being 1 palm equal to 22 cm).
Campani did not make only the lenses, with them he built up several telescopes and in a short piece of writing [19] (43 pages only) published in 1664, Campani described what an astronomer could have observed with his homemade instruments.

Pope Alexander VII (who had commissioned Cassini to study the navigation of the Po and Reno Rivers) was interested also in the astronomical observations made with Campani's telescopes and invited Cassini in Rome to get an account of his discoveries. The astronomer not only told him about his work, but also gave him an engraved planisphere, in which he had represented the planets orbiting around the Earth, if the latter was considered motionless, as he wrote. Cassini was gently suggesting that in the second half of the seventeenth century there was no longer space or time for the old traditional doctrines.

2.2.2 Jupiter's satellites

Cassini may have had access to the tables of Jupiter's satellites made by Vincenzo Renieri (1606, Genoa - 1647, Pisa) who was an astronomer and mathematician disciple of Galileo. The four larger Jupiter Moon (Io, Europa, Ganymede and Callisto), had been observed for the first time by Galileo in 1610, who a couple of months later had published the *Sidereus Nuncius*, a small book of a few pages demonstrating the truthfulness of the Copernican heliocentric system.

Cassini's studies were not only limited to Jupiter's satellites, but included also the determination of the planet rotation around its axis, and identification of the bands and spots that appeared on its surface. From his first studies and after years of extremely complex work and calculations, Cassini managed to determine daily motions and the ephemerides of all the eclipses of the satellites and, in

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[17] Eustachio Divini (1610 – 1685, San Severino Marche, Macerata) more on appendix A.8.

[18] Carlo Antonio Manzini (1600 - 1677, Bologna), described the art of crafting lenses and all the manufacturing techniques in his treatise *Occhiale all'occhio, dioptrica pratica*, written in 1660 in Italian, instead of Latin, to foster its diffusion among the technicians. His treatise and other Manzini's books are portrayed in a big painting (which is a *unicum* in the University collection for his dimensions: 192x132 cm) at the Museum of Palazzo Poggi, in Bologna. In it, the scientist is represented while wearing the doctoral gown and sitting at his desk; according to the seventeenth century criteria for the scientific iconography, he is depicted in his entire figure and is surrounded with books and other scientific instruments.

[19] Campani, G., *Ragguaglio di due nuoue osseruazioni vna celeste in ordine alla stella di Saturno; e terrestre l'altra in ordine a gl'istrumenti medesimi, co' quali s'è fatta l'vna e l'altra osseruazione.* (1664) Romae, ex typographia Fabij de Falco.

1668, published *Ephemerides Bononienses mediceorum siderum.* The book contained also tables, that Cassini had derived from his ephemerides, enabling an easy and accurate determination of the geographic coordinates of any point on Earth. Cassini's book had an enormous diffusion, both because it represented the culmination of studies and research from Galileo's time (which could not be completed before, despite the efforts of many scholars) and for the practical usefulness of the tables. The latter were used for several decades and replaced by more precise ones that Cassini himself published in 1693.
The calculation of the ephemerides of Jupiter's satellites represented a great scientific achievement. The *Journal des Sçavans* indicated the discovery as:

> *"une des plus belles qui se soit encore faite dans le ciel."* [20]

Those astronomical studies were supposed to stimulate other researchers to work on improvements of their telescopes so that they could observe the other planets of the Solar System around which no satellites had been observed yet. Cassini and Campani worked jointly reaching great discoveries also in this field.

The first European scientific periodicals

The *Journal des Sçavans* (later renamed *Journal des Savants*), founded by Denis de Sallo (1626-1669), was the first scientific periodical published in Europe. Its first issue, a twelve-page pamphlet, appeared on Monday, January 5th, 1665. The journal ceased publication in 1792, due to the difficult situation resulted from the French Revolution, and it did not restart regular publication until 1816. From that time on, the periodical was published first under the patronage of the *Institut de France* and later of the *Académie des Inscriptions et Belles-Lettres.*

The first issue of the *Journal des Sçavans* appeared two months in advance of the *Philosophical Transactions* of the *Royal Astronomical Society of London* (March 6th, 1665). A periodical which would have soon gained importance and prestige: in its earliest days, it was a private venture of the *Royal Society*'s secretary and then became one of the first periodicals in the world exclusively devoted to science. It became an official society publication in 1752. The use of the word "philosophical" in the title refers to natural philosophy, which was the equivalent of what would now be generally called science.

Those periodicals dealt with a new experimental methodology explained by a scientist who recorded his observations with some illustration and tables to which he added the description of the conditions and instruments by and under which the data had been obtained. The old practice of hiding new discoveries in private jargon, obscure language, or even anagrams had gradually changed, in the seventeenth century, to leave place to the universal comprehensibility ideal. New canons of reporting were devised to make experiments and discoveries reproducible by others: that required high language precision and the willingness to share experimental or observational methods.

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[20] *Journal des Sçavans*, February 22nd, 1666.

2.2.3 An accurate study on Mars

In 1666 Campani observed Mars from Rome, noticing that it was rotating on his axis and had several spots on its surface. In the same period Cassini was making similar observations from Bologna: he described [21] them in an important document, providing also a one page description of his observations of the dark areas of Mars, which he took in February, March, and April, 1666.

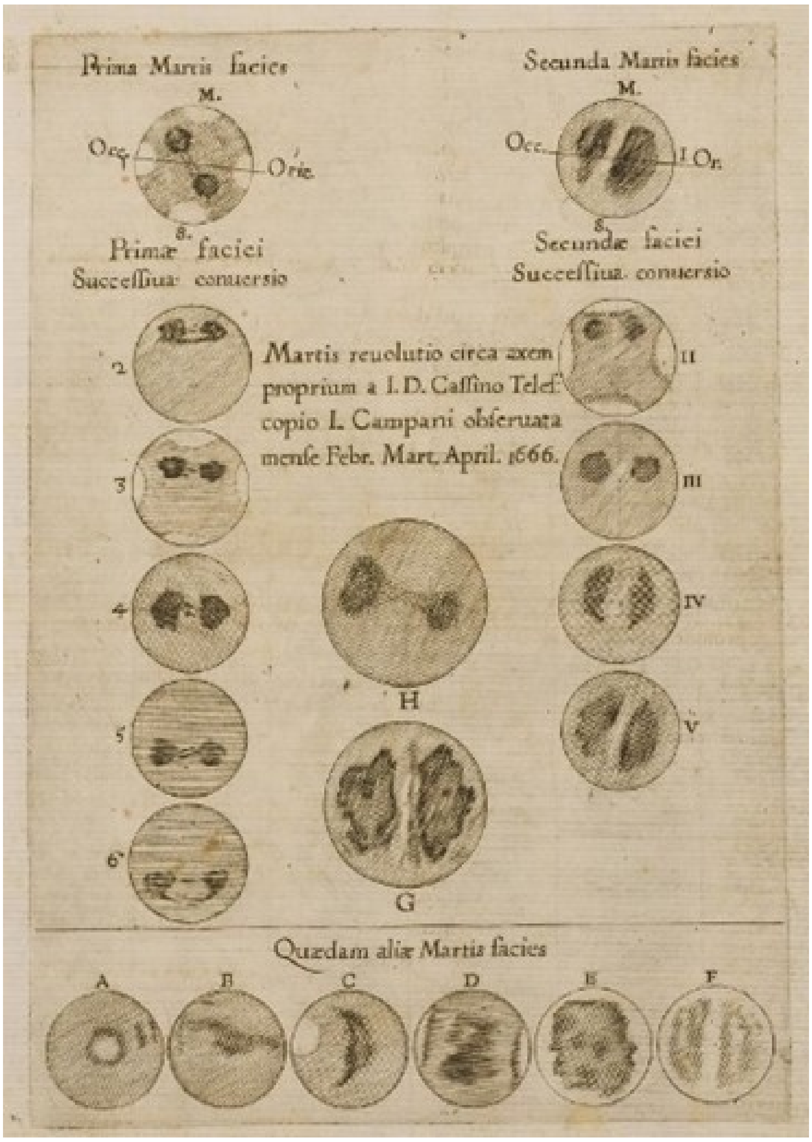

Figure 2.4: Cassini G. D., *Martis circa axem proprium revolubilis observationes Bononiae a Jo.Dominico Cassino habitae.* (1666) Bononiae, typis HH Ducijs. Engraved table representing the spots of Mars observed by Cassini in February, March and April, 1666. Part of this sketches appeared in the *Journal des Sçavans.*

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[21] Cassini G. D., *Martis circa axem proprium revolubilis observationes Bononiae a Jo.Dominico Cassino habitae.* (1666) Bononiae, typis HH Ducijs.

The planet's different phases (illustrated in Fig. 2.4), allowed Cassini to deduce that Mars rotated on its own axis, as well as to detect the planet's large, Earth-like inclination to the ecliptic. Several other astronomers observed the planet and its spots from Rome, and concluded that the planet rotation period around its axis was 13 hours. Cassini instead in his *De aliis Romanis observationibus macularum Marti* and *De Periodo quotidianæ revolutionis Marti* stated that his calculation had given for Mars a sidereal rotation time of 24 hours and 40 minutes, in very good agreement (only 3 minutes longer) with the true value. Roman astronomers were obviously wrong and Cassini had managed to correctly distinguished (thanks to the spots) the two planet faces.

Figure 2.5: Maria Clara Eimmart, 1693-1698, Specola Museum of Astronomy, Bologna. Table representing the planet Mars as seen by famous scientists such as the English physicist Robert Hooke and G.D. Cassini.

Cassini's drawings (as well as those of other astronomers) inspired the painter Maria Clara Eimmart (1676 - 1707, Nuremberg) who, under the guidance of her father Christoph Eimmart (1638, Regensburg - 1705, Nuremberg), cultivated drawing, painting, sculpture, and engraving. She painted numerous celestial phenomena and astronomical subjects on blue paper between 1693 and 1698: twelve of those tables [22] were donated by her father to Luigi Ferdinando Marsili [23]. Among the ten paintings remained in the Specola Museum of Astronomy in Bologna, the one in Fig. 2.5 is dedicated to Mars.

After the death of Giuseppe Campani, Pope Benedict XIV bought his workshop and donated it to the *Istituto delle Scienze* (more on Sect. 4.2.1) of Bologna; the value of the lenses and of the instruments was not understood at all by the supervisors and large part of them were given away. Only a few dozen lenses and metal shapes of various curvatures remain and are displayed in the optic room at the Museum of Palazzo Poggi, in Bologna.

2.3 Cassini's last years in Bologna

"Meravigliosi spettacoli espone all'occhio de' mortali nel Teatro del Cielo l'Anno presente mille seicento otto." [24]

Those were the words chosen by Cassini to present a new observation he made in March 1668. The appearance of a light path in the sky captured the interest of several astronomers throughout Italy and Cassini did not understand whether it was a meteor or a tail of a new comet, like those observed in the previous years. Unable to define its nature, he called it *"spina celeste"* and communicated (in a volume entitled *Spina Celeste* too) its first observation of a phenomenon to which he would have given the name of zodiacal light in 1693. Cassini was the first astronomer to suppose that the phenomenon was not meteorological (as believed by most astronomers), but cosmic.

Zodiacal light is a faint column of reflected sunlight broad at the horizon and narrowing as it extends up into the sky along the plane of the ecliptic. The light is reflected toward Earth by a cloud of tiny dust particles: it has been thought, for a long time, that the dust had been brought into the inner solar system by asteroids and comets.

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[22] The tables painted by Maria Clara Eimmart between 1693 and 1698 represent apparitions of comets, a full Moon, the phases of the Moon, Mercury, Venus, Jupiter and Saturn. In the donation made by L. F. Marsili there is the following quote: *"Tabulae XII. Chartacee ceruleo colore inductae, quibus caelestium corporum quorumdam Phases a Maria Clara Eimmart depictae sunt."*

[23] Luigi Ferdinando Marsili (1658 - 1730, Bologna) more on appendix A.19

[24] Cassini G. D., *Spina celeste meteora osseruata in Bologna il mese di marzo 1668 da Gio. Domenico Cassini.* (1668) Bononiae, typis Emilij Mariae, & Fratrum de Manolessiis.

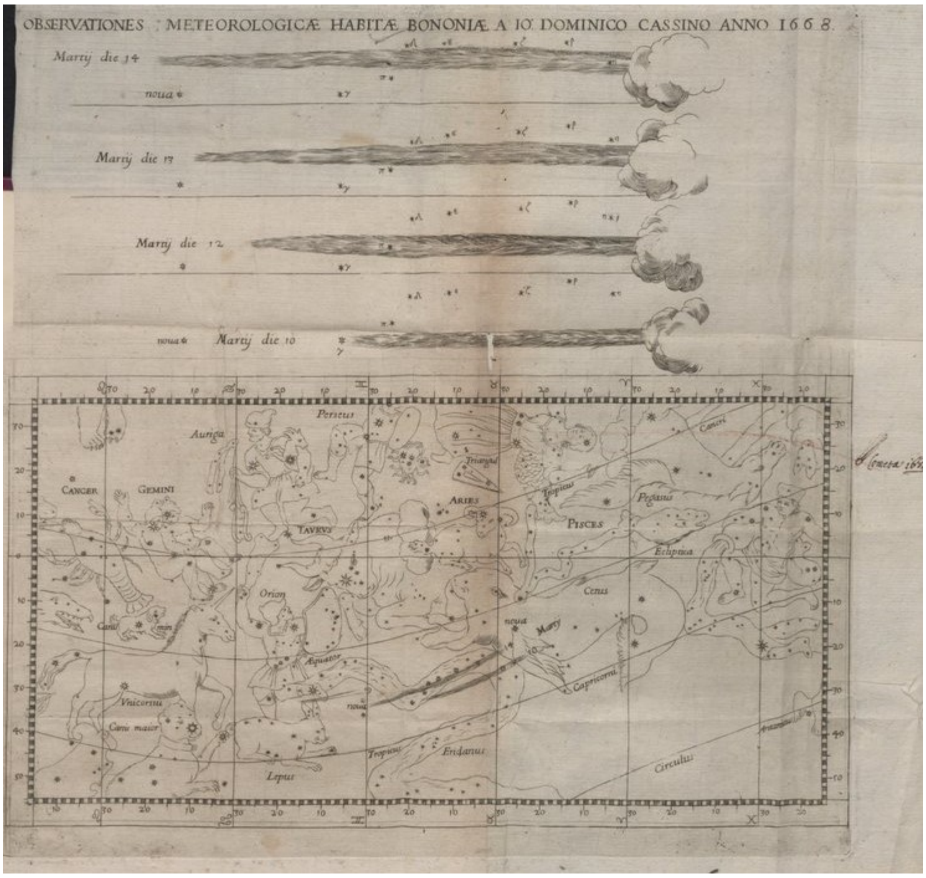

Figure 2.6: Cassini G. D., *Spina celeste meteora osseruata in Bologna il mese di marzo 1668 da Gio. Domenico Cassini.* (1668) Bononiae, typis Emilij Mariae, & Fratrum de Manolessiis. Table at the end of the volume representing the zodiacal light.

Recently [25] an instrument aboard the NASA's Juno spacecraft detected dust particles slamming into the spacecraft during its journey from Earth to Jupiter. The impact of the tiny interplanetary dust grains provided important clues on their origin and orbital evolution, resolving some mysterious variations of the zodiacal light. From the Earth, in fact, the zodiacal light is seen to vary, sometimes appearing very strong, and sometimes appearing faint and diffuse. The authors of the paper suggested that the dust originated from Mars (being its particles in a nearly circular orbit around the Sun at 2 AU [26], i.e. the distance from Mars to the Sun) and was taken towards the Earth thanks to its gravity.

Thanks to his ephemerides, Cassini became a famous scientist all over Europe; however, he never got a self-proud or arrogant behaviour, being on the contrary a very modest and kind person.

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[25] Jorgensen J. L., Benn M., Connerney J. E. P., *Distribution of Interplanetary Dust cetected by the Juno Spacecraft and its contribution to the Zodiacal Light.* (2020) Journal of Geophysical Research, Vol. 126, Issue 3.

[26] The Astronomical Unit (AU) corresponds to the average distance from earth to the Sun (149.597.871 km) and is used to express distances within the solar system or within other planetary or stellar systems. More on Chap. 6.

1668 was as important year for him: in May he began his contacts with French academics who asked him to send his works periodically to Paris to be read and discussed in the scientific assemblies. Moreover, in the same year, Cassini was asked by Count Luigi Ferdinando Marsili to talk about all his discoveries and studies in public. The first observation which worth of being communicated both to the Italian and French scientists, was the lunar eclipse occurred in May 26th, 1668, and observed by the astronomer from Rome.

> *"... la première information qui me parut digne d'être envoyée*
> *fut celle de l'éclipse de lune du 26 mai 1668.*
> *Je l'observai dans le palais du cardinal d'Estrée,*
> *en présence de l'élite des savans et de la noblesse de Rome."*

While waiting for the eclipse to begin, Cassini showed some interesting observations he had carried out in the previous years and which concerned Saturn ring, the spots of Mars and the diameter of the Earth's natural satellite. The scheme of the study on the Moon would have been developed by Cassini in a more extensive and complete way (described in Sect 3.5). The remarks about the eclipse in Rome were published in the *Journal des Sçavans* of July 30th, 1668.

Chapter 3

Paris

3.1 The Parisian environment

French astronomers received Cassini's ephemerides with great interest and the abbot Jean Picard [1] particularly appreciated the tables for their accuracy.
At the time, the French government was conducting a slow but systematic work aiming to get the best European scientists in Paris. The key-role in this operation was played by Jean-Baptiste Colbert [2] who was the first Minister of State under the rule of King Louis XIV (Fig. 3.1) from 1661 until his death in 1683. Colbert was very active in the organisation of his country politics and market and in summer 1668 he was charged by the Sun King to get Cassini's attention.
The latter was informed by a famous doctor and antiquarian who lived in Rome, Mr Vaillant, that King Louis XIV wished to have him in France at his court. Mr Vaillant had received instructions directly from Paris about that delicate diplomatic issue. Cassini accepted the news *"avec une agréable surprise"* getting to know that Girolamo Graziani (1604 - 1675, Pergola, Urbino), prime minister of Duca di Modena, was supposed to negotiate the dial. On the other hand, Graziani had already played a role in the beginning of Cassini relation with the *Académie des Sciences* as he had acted as an intermediary for sending Cassini's works to the librarian of the King in Paris.

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[1] Jean Picard (1620, La Flèche, France - 1682, Paris) more on appendix A.23.

[2] Jean-Baptiste Colbert (1619, Reims, France - 1683, Paris) was born in a family of merchants. After having held various administrative positions, his great opportunity came in 1651 when Cardinal Mazarin (the dominant political figure in France) was forced to leave Paris: Colbert became his agent in Paris, and when the politician gained his power back, he chose Colbert as his personal assistant. In that way Colbert got more and more confidence with Louis XIV, to whom Jean-Baptiste dedicated the entire life serving him both in his private affairs and in the general administration of the kingdom, becoming Secretary of State for the navy. For 25 years Colbert enhanced France power and prestige in arts; he founded the *Académie des Inscriptions et Belles-Lettres* (1663) charged to design inscriptions for medals and monuments celebrating the King's victories, the *Académie des Sciences* (1666) which aim was use the sciences to give advantages to the French kingdom and the *Académie Royale d'Architecture* (1671) charged to define rules which should have made French buildings to become the finest in the world. The *Observatoire de Paris* too (of which Cassini was charged), was founded by Louis XIV at Colbert's instigation.

Figure 3.1: Hyacinthe Rigaud (1659-1743), *Louis XIV en costume de sacre*, 1701. Oil on canvas, Musée du Louvre, Paris.

3.1.1 The *Académie Royale des Sciences* in Paris

The *Académie Royale des Sciences* was an institution established in Paris in 1666 under Louis XIV and his financial controller, Jean-Baptiste Colbert, to advise the French government on scientific matters. In 1699 the *Académie* received a formal constitution, in which six subject areas were recognized: mathematics, mechanics, astronomy, chemistry, botany, and anatomy. Academy membership was hierarchical: senior members (known as pensioners) received a small remuneration and had the most important role; below them were the associates and "on the smallest step" the assistants.

As a consequence of the French Revolution, the direction of the academy would have passed (in 1791) to the National Assembly which would have decided to replace the French system of weights and measures with the "metric" one. In 1793, due to "egalitarianism" the academy would have been abolished (together with other royal academies), because of its having been related to the King and for its having had an elitary structure. In 1795 the academy would have been reborn with the intent idea to have within the same organization the formerly separate royal academies, representing all together the different branches of learning and culture. Science, however, would have been ranked as first, according to the Enlightenment ideas and being the largest group. With the Bourbonic Restoration of Louis XVIII (in 1816), the academy would have taken again its former title. In 1835 the academy would have begin publication of its *Comptes rendus*, a weekly journal which would have enabled fast publication of scientific news. They would have largely superseded the annual volume of *Mémoires*, and are still nowadays the academy principal publication.

Figure 3.2: Henri Testelin (1616-1695), *Colbert présentant à Louis XIV les membres de l'Académie royale des Sciences*, second half of XVII century. Oil on canvas, Château de Versailles.

The *Académie* was a product of efficiency of the French government, an expression of the grandeur of the monarchy and of the King himself. Being members of it was a great honor for the scholars of that time and implied entering state-funded research groups.

3.1.2 Cassini's travel to Paris

In June 1667, the cardinal Giulio Rospigliosi was elected as Pope Clement IX and the event was solemnly celebrated in Bologna, where Cassini had an important role:

> *"... e l'inventione, e la dispositione, e l'opera... al Sig. Dottor Gio.Domenico Cassini, di cui... è nota non meno la Virtù, che l'accuratezza,*
> *e brama di adoperarsi à tutto quello che può essere conforme alla propensione,*
> *e volontà dell'Eminenza Vostra."* [3]

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[3] *Relatione delle festive dimostrationi fatte in Bologna nella creatione e coronatione della*

Cassini illustrated the values and merits of the new Pope, mentioning also some astronomical events that had occurred in the previous years and might be interpreted as bringing good luck for the new pontificate.
Clement XI had obviously appreciated Cassini talk and had decided to employ him for important issues, thus, the official request to have him in Paris at the court of King Louis XIV, had been addressed to both Bologna government and the Pontifex.

On February 25th, 1669, under the pressure of Colbert, Cassini left Bologna, receiving also the money he needed to afford the long travel. According to the original agreements, he should have stayed in France (with double guaranteed salary) for only eight or nine months; but Cassini already felt that his journey would have not lasted that short. Probably he had already taken his decision and that was why on his way to Paris he made some stops, allowing him to greet friends and colleagues he had known over the years and to retrace his past. After Modena and Genoa, he obviously stopped in Perinaldo, for what was the last farewell and meeting with his parents and with his native land.

The second and important part of Cassini's life was about to begin, bringing him the richness, honors, and a fame that, perhaps, Italy had never managed to give him.

3.2 The arrival in Paris and the construction of the new *Observatoire*

On April 4th, 1669 Cassini arrived to Paris and the librarian Monsieur Pierre de Carcavy (1600, Lyon, France - 1684, Paris) was the first to welcome him in the King's Library. However, the astronomer could not be lodged there because the rooms were occupied by Christian Huygens [4] and his family [5] who had been called in Paris since three years.
Two days after his arrival, Cassini was introduced by Colbert to the Sun King, who treated the astronomer with such a dignity and respect, that he almost immediately forgot Bologna. In Paris, Cassini had the chance to discuss and talk to other mathematicians, astronomers, and physicist by entering the *Académie des Sciences.*

The idea of constructing the *Observatoire Royal de Paris* rose up in the 1660s. The building should have been a magnificent new place for astronomical observations and geographical studies that the King himself was strongly desiring with

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Santità di Clemente IX. (1667) Bologna, H.H.del Barbieri, Municipal Library of teh Archiginnasio, 17-Storia Civile, Caps. F, n.10.

[4] Christiaan Huygens (1629 - 1695, The Hague, Netherlands) more on appendix A.16.

[5] *"... mais il n'y avoit pas de place qui n'étoit occupé par M. Carcavy et par sa famille et par le célèbre M. Huygens..."* Bibliographical notes of Cassini, University Library of Pisa, ms. 342, fasc. 31.

the purpose of making France illustrious in letters and sciences, as it was in military dominance and war. The *Observatoire* was intended to be a place celebrating both the King and the birth of a collective work within the academy, as scientists of the recently founded *Académie des Sciences*, would have been hosted within that inspiring environment, where they would have studied and discussed their ideas and discoveries.

The first plan of the construction of the *Observatoire* was drawn by the architect Claude Perrault (1613 - 1688, Paris) and had been handed to Cassini in 1668 by Adrien Auzout [6] who had been one of the founders of the *Observatorie* and a member of the *Académie* for only two years (1666-1668). He had left the academy (probably because of a quarrel with the other members) and Paris in 1668 and gone to Rome where he would have stayed until his death.

The first impression that Cassini got from the construction plan and the drawing of the building was negative as he thought that the astronomical technical requirements had not been sufficiently considered. Once in Paris, Cassini could carefully examine the original project for the building (which had been drawn in 1663 and is not anymore available as it has been lost), and his doubts were confirmed. The building had been planned to be very high and majestic and its massive walls and towers would have undoubtedly caused admiration in visitors, but its height would have also prevented the observation of a large part of the sky close to the horizon.

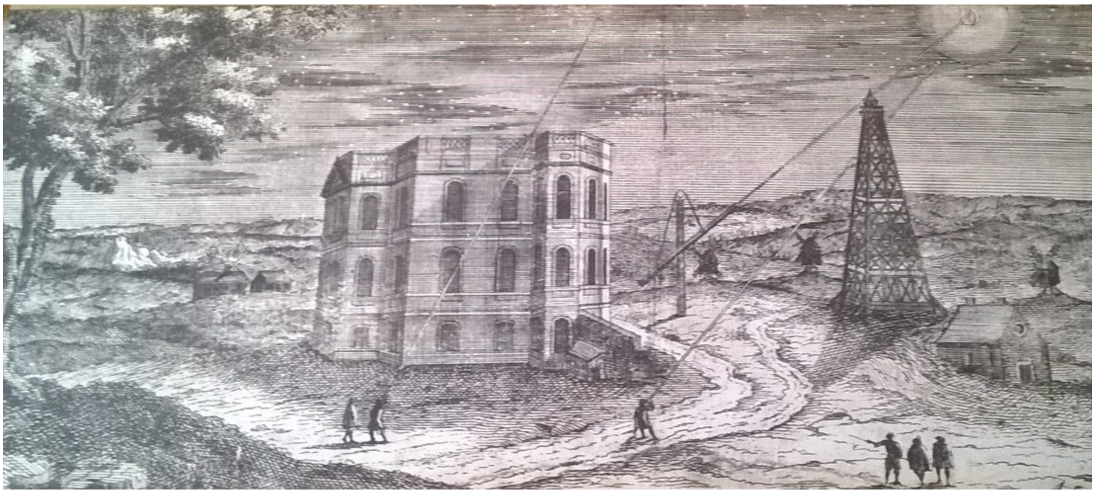

Figure 3.3: Antoine Coquart, engraving from *L'Atlas curieux ou le Monde represente dans des cartes generales et particulieres du ciel et de la terre (...)*, first half of XVIII century. Iron, approx. 1980/90 × 180 cm, Observatoire de Paris, inv. I.123. The engraving represents the plan of the *Observatoire Royal de Paris* on the design of the architect Mr Perrault.

In Cassini's manuscripts detailed description of the *Observatoire* project evolution and construction can be found. French scientists did not know how to organize that cultural place and asked Cassini for an opinion and the Italian astronomer made of it the most equipped and greatest observatory all over Eu-

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[6] Adrien Auzout (1622, Rouen, France - 1691, Rome) more on appendix A.1.

rope. His conception of *"esattezza"* [7] (a recurrent word in Cassini's manuscripts indicating a balanced mixture of accuracy and organization) resulted in the establishment of a collective work performed within the *Observatoire* which strongly improved knowledge circulation. At variance with the original plan aiming to have within the*Observatoire* all the kind of scientists (physicists, chemists, naturalists), Cassini wanted it to be exclusively an astronomical observatory.

Waiting for the observatory building to be finished, Cassini was hosted in the majestic royal palace Louvre. There, he had the honor of meeting very often the Sun King and his wife because they enjoyed knowing about Cassini's observations and astronomical discoveries which were used to improve the knowledge of geography and navigation. Cassini moved to his personal apartment at the first floor of the *Observatoire* on September 14th, 1671: he then lived and worked in this new building throughout the *Grand Siècle.*

"Anno 1671, die 14 septembris, Deo auspice, in regium observatorium veni,
ubi mihi parabantur cubicula,
qui plena erant fabris portas fenestrasque munientibus." [8]

Figure 3.4: Portrait of G. D. Cassini by Léopold Durangel (1879), with the *Observatoire* in the background, having the 34-foot telescope on its roof. Biliothèque de l'Observatoire de Paris.

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[7] Deias D., *Inventer l'Observatoire: sciences et politique sous Giovanni Domenico Cassini (1625-1712).* (2020) Paris, EHESS.

[8] Cited by Savorgnan di Brazzà, F., *Gli Scienziati Italiani in Francia. L'Opera del Genio Italiano all'Estero.* (1941) Roma, Libreria dello Stato.

3.3 Cassini's first observations in Paris and the issue of the language

Even if the Pope had asked Cassini to come back to Italy some months after his departure, he decided to remain in France. At the beginning, the astronomer used to speak in Italian, a language well known by both Colbert and the King. However, the official language in the assemblies was French and not Latin as it was in the Italian scientific environment. Thus, Cassini, unsatisfied with the translations of his discoveries made by the other *Académie* members, decided to learn French and began to write in this new language starting from 1683.

The first observations made by Cassini at the King's court were on sunspots: he tried to establish their positions on the Sun and follow them in their motion, which was not an easy task at all. He managed in doing it and since he saw the spots in the same position after 27 days, he estimated that to be the rotation period of the Sun (a value in good agreement with the 24 days established nowadays). Those observations were communicated in Latin by Cassini to the librarian Carcavy who translated them in French, and Colbert himself looked for the sunspots 27 days after.

Colbert had expressed the desire to try the instruments (made in Italy) that Cassini had brought to France, being particularly interested in the objectives built by Campani. With the approval of the King, Colbert requested directly to Campani a much more powerful lens than the ones he had made for Cassini. The Italian lens maker built a 34-foot telescope (more than 10 meters of focal length) which was paid more than one thousand scudi by the French government. According to a letter of Giovanni Domenico to Jean Picard:

> *"Haveremo presto di Roma di buoni e grandi cannocchiali (...)*
> *Campani e Divini fanno a gara a chi riuscirà meglio."* [9]

Thus, under the pressure of Colbert, a real competition was established in the manufacture of telescopes. On one hand, lens refinement resulted in an improvement of the observations, on the other hand it implied problems in the construction of telescopes which were getting increasingly larger.
Campani was surely the best lens maker of his epoch and he was repeatedly asked to reveal his secrets in exchange of money, but he always refused both that offer and the request to collaborate exclusively with the King. Perhaps because of his reticence, and fear of plagiarism, he had no students who learned his art and his technique died with him.

Concerning telescopes, Cassini developed a new mounting which he called *machine parallatique* and had a clockwork system by which stars might be kept fix in the field of view of the telescope.

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[9] Letter of G. D. Cassini to Jean Picard from Paris, December 3rd, 1671, Pisa, University Library, ms. 423, fasc. 14.

3.4 Dispute and observations around Saturn

In October 1671 with the telescope he brought from Italy, Cassini discovered a satellite of Saturn and gave it the name Iapetus, the mythological titan son of Heaven and Earth. Iapetus had brightness variations and Cassini realized that it was always showing to Saturn the same side, exactly as the Moon does with Earth.

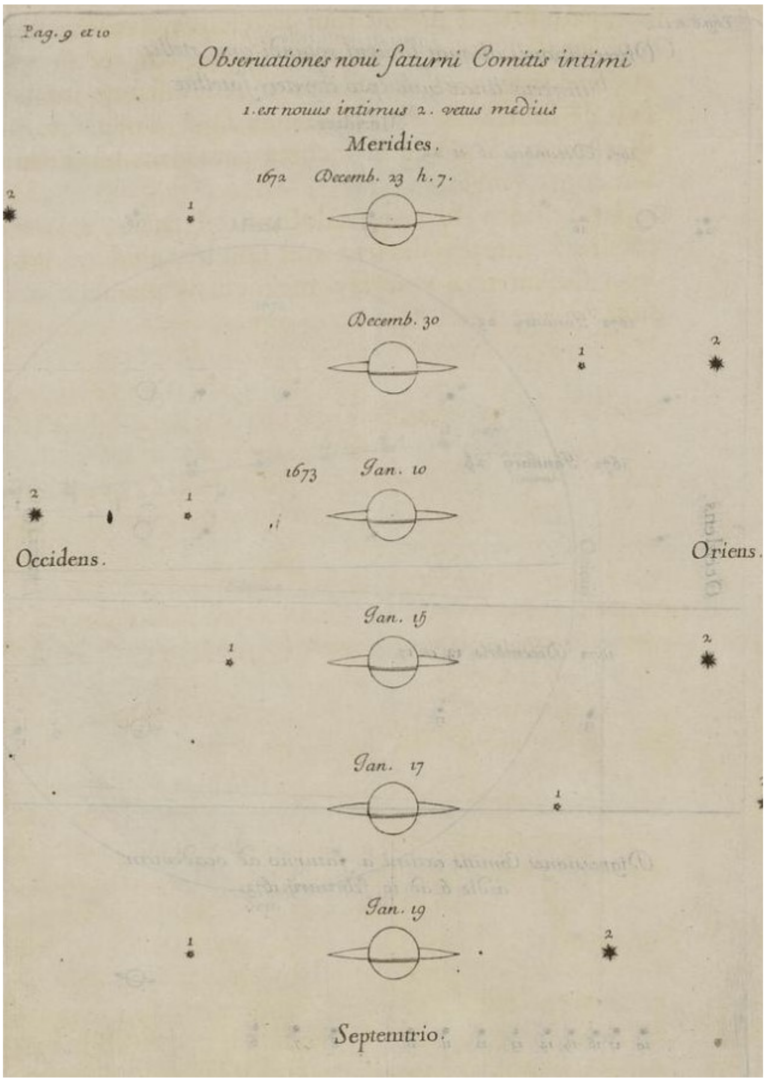

Figure 3.5: Cassini G. D., *Découverte de deux nouvelles planètes autour de Saturne.* (1673) Paris, S. Mabre-Cramoisy publishing. Discovering of Rhea (satellite of Saturn).

Cassini also accurately described the presence of dark region on Iapetus, which would have been named *Cassini Regio* in his honor. (The origin of that difference in albedo was unknown and debated for a long time [10].)

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[10] Studies of craters on Iapetus suggested that the dark surface absorbs large amounts of heat from the Sun, and because Iapetus rotates so slowly (once every 79 days), the dark surface is exposed to the Sun for a long time. Extensive analyses and modeling of Cassini spacecraft imaging and heat-mapping data have confirmed that temperature at the equator become high

His having discovered in December 1672 a second satellite of Saturn stimulated him to continue those studies. He called the satellite Rhea, who was the mythological Saturn's bride.

At the beginning of the seventeenth century Galileo had began to observe Saturn in a new way: with his *cannocchiale* he had noticed something surrounding the planet. He thought he had observed two satellites which at variance with Jupiter's ones did not change place or disappear during different observations:

> *"Saturno non è un astro singolo, ma è composto di tre corpi,*
> *che quasi si toccano, e non cambiano nè si muovono l'uno rispetto all'altro,*
> *e sono disposti in fila lungo lo zodiaco,*
> *e quello centrale è tre volte più grande degli altri due. . . "* [11]

In the sixties there was a lively debate on the existence of a system of concentric rings that encircled the globe of Saturn. This idea was first theorized for the first time by Huygens who published his own observations in the treatise *Systema Saturnium* in 1659. Talking about a thin, flat ring, nowhere adherent to the globe and inclined to the ecliptic, Huygens solved the mystery and recognized the various structures that Galileo had not been able to resolve. In his 1659 work he explained that his 1656 pronouncement was an anagram of:

> *"Annulo cingitur, tenui, plano, cobaerente nusquam, inclined eclipticam".* [12]

Using the new 100-foot focal length lens that Campani sent to Paris, Cassini noticed for the first time a dark band characterizing Saturn just below the equator; in addition, he carefully studied the structure of the ring that he masterfully described as divided by a dark line into two equal parts (the internal one closer to the globe, appeared very clear, and the external one was darker). Cassini also suggested that the ring was made of very small satellites, whose different movements were not singularly appreciable:

> *"La largeur de l'anneau étoit divisée par une ligne obscure en deux parties égales, dont l'intérieure et plus proche du globe étoit fort Claire, et l'extérieure un peu obscure. (. . .)*
> *L'apparence de l'anneau est causée par un amas de très petits satellites de différents mouvements qu'on ne voit pas séparément (...)"* [13]

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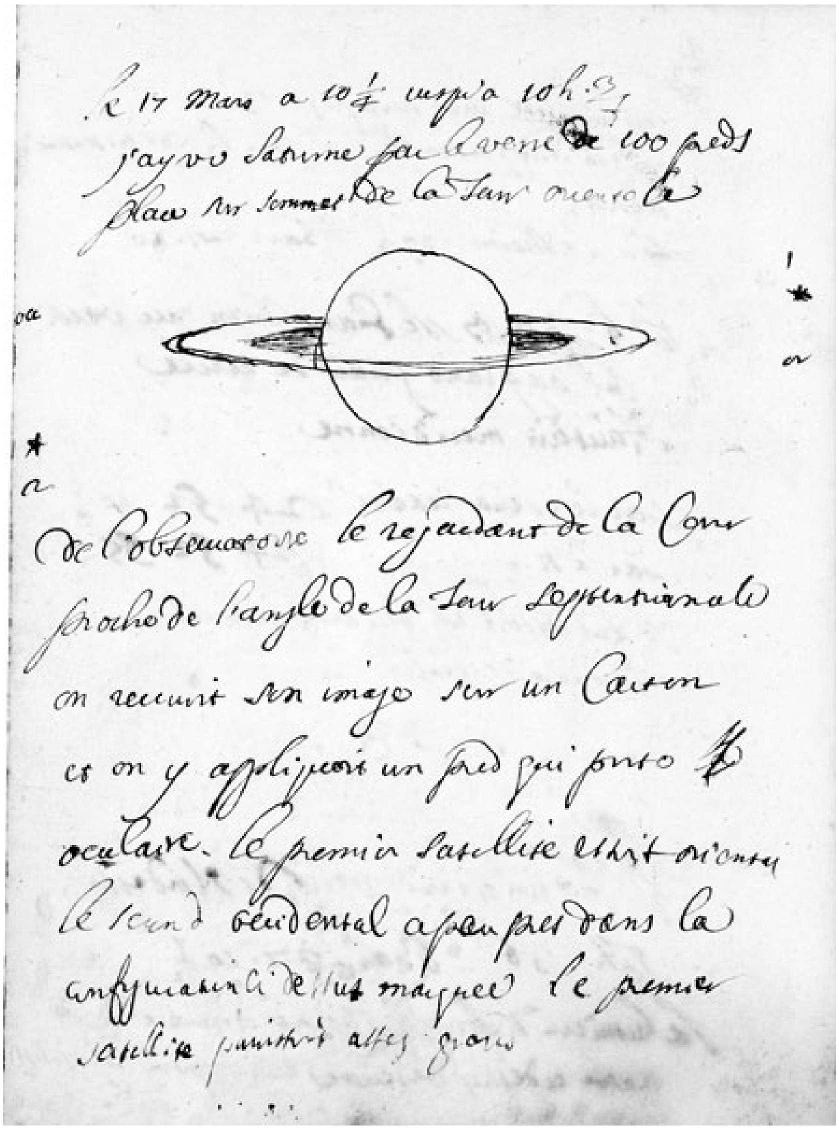
enough to trigger the evaporation of the ice under the dust. Ice condenses at the moon's poles, giving it its distinctive bright white appearance that contrasts with the dark, dusty side. More on Spencer J. R., Denk T., *Formation of Iapetus' Extreme Albedo Dichotomy by Exogenically Triggered Thermal Ice Migration.* (Jan. 22, 2010) Science, Vol. 327, Issue 5964, pp. 432-435.

[11] Galilei, G., *Sidereus Nuncius.* (1610) Venice, Tommaso Baglioni.

[12] Huygens C., *Systema Saturnium, sive de causis mirandorum Saturni phaenomenon, et comite ejus planeta novo.* (1659) The Hague, Adrian Vlacq.

[13] *Journal des Sçavans*, March 1st, 1677 p. 33.



Le 17 mars a 10¼ jusqu'a 10h¾
j'ay vu Saturne par la lunete de 100 pieds
placée sur sommet de la tour orientale

de l'observatoire le regardant de la cour
proche de l'angle de la tour septentrionale
on recevoit son image sur un carton
et on y appliquoit un pied qui porte l'
oculaire. Le premier satellite estoit orienta
le second occidental a peu pres dans la
configuration cy dessus marquée le premier
satellite paroissoit assez gros

Figure 3.6: Cassini G. D., *Journal des observations faites à l'Observatoire de Paris.* (1684). Sketches and description of Saturn as seen by Cassini.

The discovery of the division between the ring of Saturn was described in the *Journal des Sçavans* in which Cassini suggested that the rings were not a rigid body, but swarms of particles too small to be seen individually. Considering all the instruments he used and taking into account the chromaticity of the glass, the wave-front quality and atmospheric turbulence, researchers [14] reconstructed Cassini's observations on Saturn, showing that he was actually able to see the division named after him.

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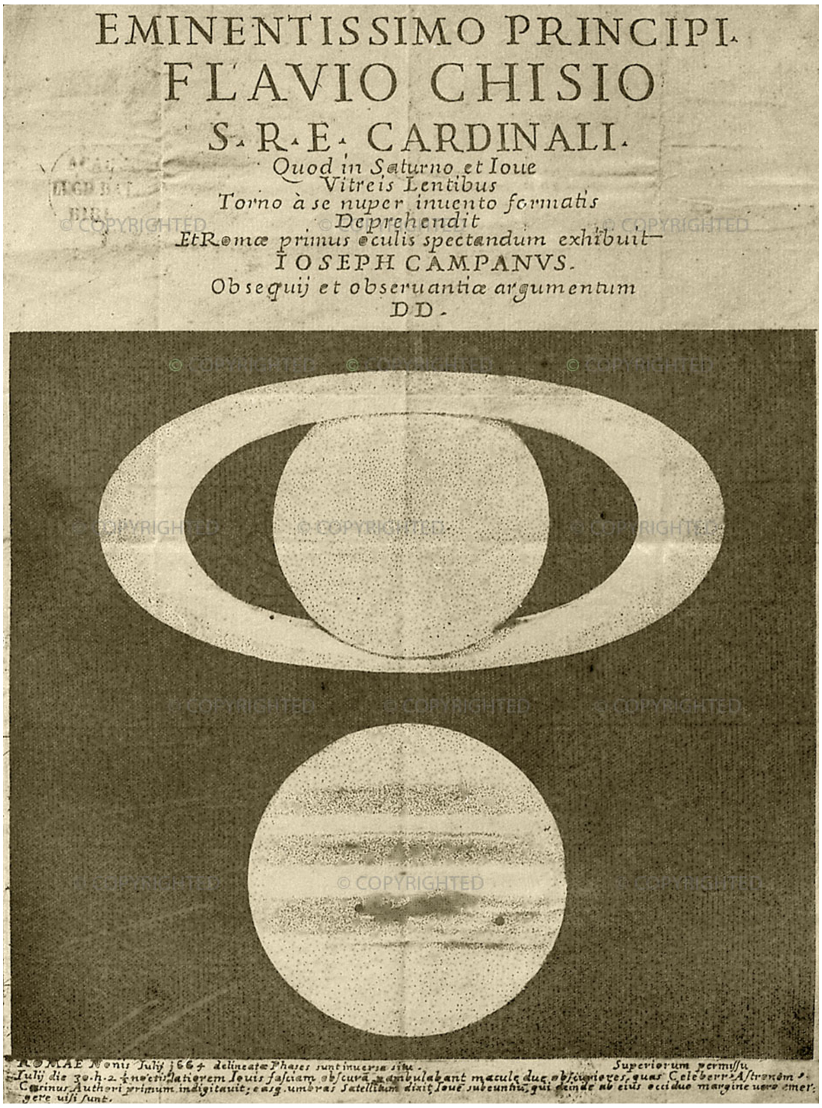
[14] Lozi J., Reess J. M., et al., *Could Jean-Dominique Cassini see the famous division in Saturn's rings?* (2013) Proceedings of SPIE, Vol. 8864.



EMINENTISSIMO PRINCIPI
FLAVIO CHISIO
S. R. E. CARDINALI.
Quod in Saturno et Ioue
Vitreis Lentibus
Torno à se nuper inuento formatis
Deprehendit
Et Romæ primus oculis spectandum exhibuit
IOSEPH CAMPANVS.
Obsequij et obseruantiæ argumentum
DD.

ROMAE Nonis Julij 1664 delineatæ Phases sunt inuerso situ. Superiorum permissu
Julij die 30. h. 2 ¼ noctis latiorem Iouis fasciam obscuram ambulabant maculæ duæ obscuriores, quas Celeberr. Astronom. Cassinus Authori primum indigitauit; easq. umbras Satellitum dixit Ioue subeuntiu, qui deinde ab eius occiduo margine uero emergere uisi sunt.

Figure 3.7: Title page of *Eminentissimo Principi Flavio Chisio S. R. E. Cardinali. Quod in Saturno et Ioue Vitreis Lentibus Torno a se nuper inuento formatis deprehendit. Et Romae primus oculis spectandum exhibuit Joseph Campanus. Obsequii et observantiae argumentum DD.* (1665), anonymous, Museo Galileo, Florence. Representation of Saturn (above) and Jupiter (below) as seen by Giuseppe Campani.

Campani had focused on Saturn too and had described correctly the ring conformation that he could observe between 1663 and 1664 thanks to his lenses:

"E ne raccolsi con mio sommo contento un fenomeno diverso da tutti gli altri,
che si sono fin'ora publicati (...)
mi dimostrarono distintamente i miei Cannocchiali,
esser Saturno cinto d'un cerchio quanto all'apparenza di forma Ellitica,
disteso in tal positura d'intorno al globo, che la parte superiore,
e verso il polo Artico, asconde una portioncella del detto globo,
come al contrario la porzione inferiore del cerchio, cioè quella,
che è verso l'Antartico, viene in parte dal medesimo adombrata, e coverta.

Si che la parte inferiore resta dietro, la parte superiore avanti alla stella;
come si fa sensibilmente comprendere dall'apparente sito e positura del cerchio;
e dai contorni medesimi così dell'istesso cerchio, come del globo,
o ver disco di Saturno, leggiermente ombreggiati (...)" [15]

The small book *Ragguaglio* published in 1664 had been immediately distributed among the astronomers of the time and many of them had considered Campani's print as a proof of the existence of the much-discussed rings of Saturn. Several documents and drawings had shown that important discovery that he had made without the help of any astronomers. (The issue has been discussed for years: why the ring division has been named after Cassini, if Campani had seen it a few years before?)

Only in 1856 James Clerk Maxwell [16] would have proved that the rings are made of minor fragments. His essay *On the stability of the motion of Saturn's rings* would have been awarded the 1856 Adams Prize, for the powerful ability to analyze a difficult problem mathematically. Maxwell is commemorated by a feature of Saturn Rings named after him (the *Maxwell Gap* within the C ring). At the beginning of the present century, the NASA Cassini mission [17] would have shown that Maxwell's conclusion and Cassini's brilliant intuition were right.

Figure 3.8: Saturn and its main rings as seen by Cassini spacecraft. Credits: NASA/JPL-Caltech/Space Science Institute, September 2017.

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[15] Campani, G., *Ragguaglio di due nuoue osseruazioni vna celeste in ordine alla stella di Saturno; e terrestre l'altra in ordine a gl'istrumenti medesimi, co' quali s'è fatta l'vna e l'altra osseruazione.* (1664) Romae, ex typographia Fabij de Falco.

[16] James Clerk Maxwell (1831, Edinburgh, Scotland - 1879, Cambridge, England) more on appendix A.20.

[17] Cassini-Huygens was a space-research joint mission of NASA (National Aeronautics and Space Administration), ESA (European Space Agency) and ASI (Italian Space Agency), taking the name from the two famous astronomers. NASA's sophisticated robotic spacecraft Cassini and ESA's probe Huygens lander were designed to reach Saturn and land on its largest Moon, Titan. Cassini-Huygens mission started on October 15th, 1997 (it entered Saturn orbit on July 1st, 2004) and ended on September 15th, 2018.

In 1684 Cassini amazed the royal court again by communicating the discovery of other two satellites of Saturn: Tethys (mythological titaness daughter of Heaven and Earth, mother of rivers, wife of Oceano) and Dione (nymph daughter of Heaven and Earth, mother of Aphrodite).

3.5 *Carte de la Lune* (1679)

In Paris, Cassini also dedicated 9 years (from 1671 to 1679) to an accurate study of the Moon: he made a careful micrometric analysis of lunar motions and presented his lunar maps to the *Académie* in 1679.
At the end of the nineteenth century the director of the *Académie*, Félix Tisserand, would have named *Lois de Cassini* the relations that the Italian astronomer had found to drive the different Moon motions. For the important studies on the Moon, a lunar impact crater [18] was named after Cassini and his second-born Jacques (1677, Paris - 1756, Thury, France).

Figure 3.9: Cassini G. D., Patigny J., *Carte de la Lune.* (1679) Observatoire de Paris.

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[18] The 56.88 km long lunar crater is located in the Northeastern part of the visible face of the Moon, in the *Mare Imbrium*, in an area that old lunar maps identified as *Palus Nebularum.*

To make the lunar maps, Cassini was assisted by two designers: Sébastien Leclerc and Jean Patigny. His first *Carte de la Lune* (Fig. 3.9) was a large engraving with a diameter of 53 cm, much more precise than the previous ones and it remained without rivals until the photography advent. Like most lunar maps, it was orientated towards the South (North was at the bottom as it was the image showed through a reversing telescope). Up to the present day, those drawings have been kept in the library of the *Observatoire*: the copies of this first edition are very rare.

In 1787 the great-grandson of G. D. Cassini, Jean-Dominique Cassini [19] today known as Cassini IV, would have rediscovered, in the *Observatoire*, the original copperplate of his great-grandfather *Carte* and would have reprinted it in a limited edition. The following year, he would have produced the *Réduction de la grande Carte de la Lune* (see Fig. 3.10).

Figure 3.10: Cassini J. D., Janinet J. F., *Réduction de la grande Carte de la Lune de J. Dom. Cassini.* (1788) Observatoire de Paris..

The *Réduction* differs from the Cassini's original map not only because of its smaller size, but also for some new labels describing the Moon surface features and for the addition of a running text explaining the history of the map.

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[19] Jean-Dominique Cassini (1748, Paris - 1845, Thury, France) (Cassini IV) was born at the *Observatoire* in Paris and succeded his father Cassini III and grandfather Cassini II, in the *Observatoire* direction in 1784. After the French Revolution he was requested to resign by the National Assembly and he was kept in prison for a short time. He then retired to Thury, where he spent the rest of his life.

Cassini IV in fact, labeled the lunar surface and added a list of notes (on its side) concerning eighteenth century scientific discoveries (most of which being the observations of William Herschel [20]). The *Réduction* labeled about 130 lunar features according to the terminology devised by Giovanni Battista Riccioli and marked the more prominent mountains and seas with names engraved in Roman letters. The names of the less visible features, instead, were marked with italic letters. In the text, Jean-Dominique Cassini stated that the first printings of the 1679 map, which had become *"extrement rares"*, had been difficult to be used by astronomy enthusiasts. The account books of the *Observatoire* report that the *Réduction* was published in 364 copies, a number of which intended to be close to the number of days in a year.

The gray-green image of the Moon was executed by the renowned print-maker Jean-François Janinet (1752-1814) who preserved in the map one of the more fanciful features of the original *Carte de la Lune*: the so-called *Lady in the Moon*. The remarkable detail on the influential lunar map can be seen in Fig. 3.11 where the *Promontorium Heraclides* is represented as a woman's profile with long wavy hair. This *Moon Maiden* is believed to be a portrait of Cassini I's future wife, Genèvieve de Laistre (probably born around 1643 and died in 1708). That hypothesis is supported by the fact that Cassini commissioned a pen-and-ink portrait of his wife in 1678 and the artist who made it was Jean Baptiste Patigny, son of the engraver of the map of the Moon. Cassini IV would have thus decided to preserve this enigmatic image of his great-grandmother.

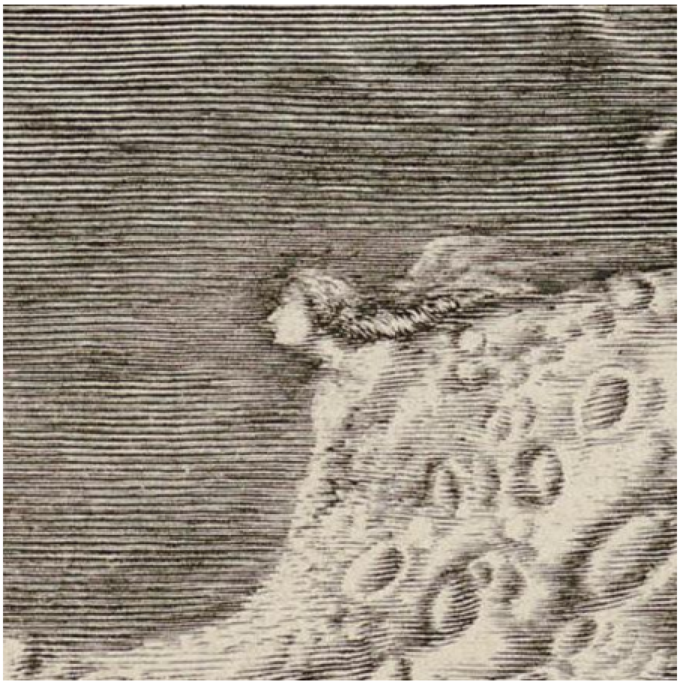

Figure 3.11: Cassini G. D., Patigny J., *Carte de la Lune.* (1679) Observatoire de Paris. Detail: female face.

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[20] Sir William Frederick Herschel, original name Friedrich Wilhelm Herschel (1738, Hannover - 1822, Slough, Buckinghamshire, England) more on appendix A.14.

Another odd marking, appears in the Sea of Serenity, (Fig. 3.12). Shaped like a heart, the Greek letter ϕ also begins the Greek word *philos*, meaning love or affection.

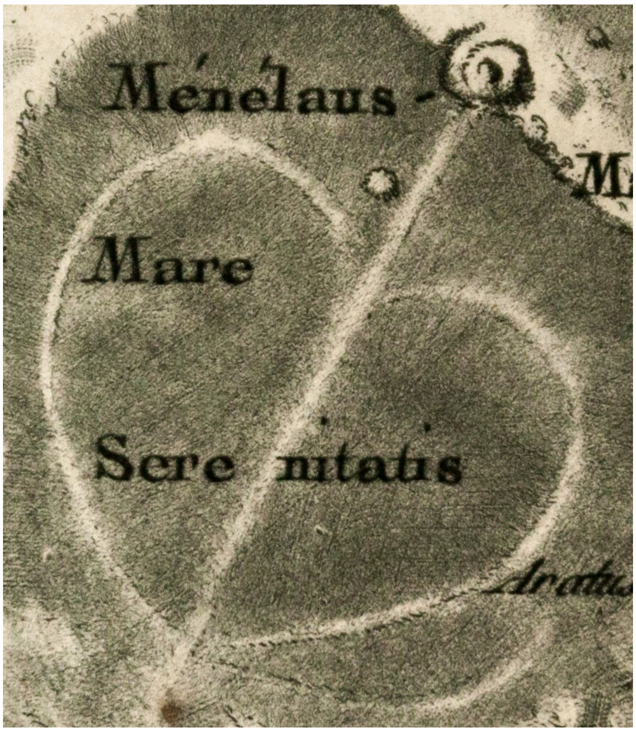

Figure 3.12: Cassini J. D., Janinet J. F., *Réduction de la grande Carte de la Lune de J. Dom. Cassini.* (1788) Observatoire de Paris. Detail: the greek letter ϕ shaped like a heart.

The lunar map both linked the four generations of astronomers from the Cassini family and explicated one of the most significant (and fanciful) images of seventeenth century lunar astronomy.

Chapter 4

The eternal bond with Bologna

4.1 Cassini's marriage

Any hope of having Cassini back in Bologna vanished on November 10th, 1673 when the astronomer married Geneviève de Laistre: she was a noblewoman, daughter of the lieutenant general of the Compte de Clermont, whose valuable dowry of landholdings included the Thury Castle in the Oise. With the marriage Cassini obtained the *act de naturalisation* from the King, becoming a French citizen and changing is name into Jean-Dominique. Thus, all legal ties with Italy and the Pontiff (who had already stopped to pay his salary and removed him from the astronomy chair in Bologna) vanished.

Cassini had two sons (and a daughter who died as an infant): the eldest son, Jean-Baptiste, embarked on a military career and was killed at the age of 18 in the naval combat of La Hague. Instead, the youngest son, Jacques, followed his father in his astronomer career becoming at first a collaborator and then his worthy successor. The Cassini family would have "reigned" at the *Observatorie* from its foundation until the French Revolution: four generations of astronomers would have guided astronomical studies in France for more than a century and a half, giving rise to a *véritable dynastie*.

4.2 Cassini's voyage to Italy

Cassini's bond with his native land, however, had not totally broken, thanks to a copious number of letters exchanged with Geminiano Montanari [1], who was an Italian astronomer and lens marker very close to Cassini. Geminiano described Cassini as *"il più vero, et Amorevole Amico, ch'io mai havessi"* [2] and, starting in 1684, Montanari warned Cassini that his meridian line in the Basilica of San Petronio had been damaged by earthquakes. Several scientists in Bologna began to criticize Cassini for his work, but Montanari always defended him.
Perhaps worried about his first major work, Cassini organized a travel to Italy.

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[1] Geminiano Montanari (1633, Modena -1687, Padua) more on appendix A.21.

[2] Letter of Montanari to Cassini, Padua, February 25th, 1684. Kept in Pisa, University Library, ms. 432, fasc.17.

On September 23rd, 1694, Cassini began that journey, accompanied by his son Jacques, who had already proved to be a promising astronomer and worthy successor of his father. His nephew Giacomo Filippo Maraldi (son of Giovanni Domenico's sister, Angela Caterina) who had joined Cassini at the *Observatoire* and had become his collaborator, remained in Paris. The two Cassini left with a carriage full of instruments: an octant with a double telescope, a pendulum marking the seconds and telescopes of different resolving power.

They obviously stopped in Perinaldo, where Cassini's parents had already died; Giovanni Domenico donated to the Church a painting called *"delle Anime"* on which some information about the donor had been written. In his hometown Cassini made some experiments concerning the distance measures corrected for atmospheric refraction.

Father and son then stopped in Florence (of which they established the meridian difference with respect to Paris) and in Loiano, a small village located 700 meters above the sea level: the elevated position on a wide valley looked to Cassini particularly suitable for astronomical observations. He could have never imagined that, more than 200 years later, the Astronomical Station of the Observatory of the University of Bologna would have been built exactly in that village.

As expected, once arrived to Bologna, Cassini immediately dedicated himself to the sundial, noticing that the iron line would have simply had to be repositioned to correct for a small misalignment due to the earthquakes (see Sect. 2.1). Cassini's return to the town that had allowed him to reach scientific maturity and gain fame all over Europe, was acknowledged by the local government that awarded the scientist with a medal. Furthermore, the return to Bologna renewed Cassini's desire to establish a lasting bond with the town: he thus asked the Senate to give him the citizenship of Bologna, that he would have got much later (in 1702).

4.2.1 The *Istituto delle Scienze di Bologna*

Cassini's stay in Bologna promoted a revival of astronomical studies in the city which would have taken form some years later with the birth of the Marsilian Observatory (1699) and of the *Istituto delle Scienze di Bologna*, which would have become fully operative by 1714 thanks to the intense work and dedication of Luigi Ferdinando Marsili. The latter had been a General of the imperial army and a lover of natural sciences too. His dream was to favor scientific research in Italy in the same way had been done in France by the King (with Colbert's support) [3].

Cassini would have given an important contribution to the realization of Marsili's project, both concerning the choice of the astronomical instruments tools, and being a guide and a reference for the Bologna scientists.

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[3] *"Fare in Italia come hanno fatto i francesi della Francia' diventa per Marsili un obiettivo di primaria importanza"*. Cavazza M., *Giandomenico Cassini e la progettazione dell'Istituto delle scienze di Bologna*, in *Scienza e letteratura nella cultura italiana del Settecento.* (1984) Cremante R., Tega W., Bologna, Il Mulino, pp. 109-132.

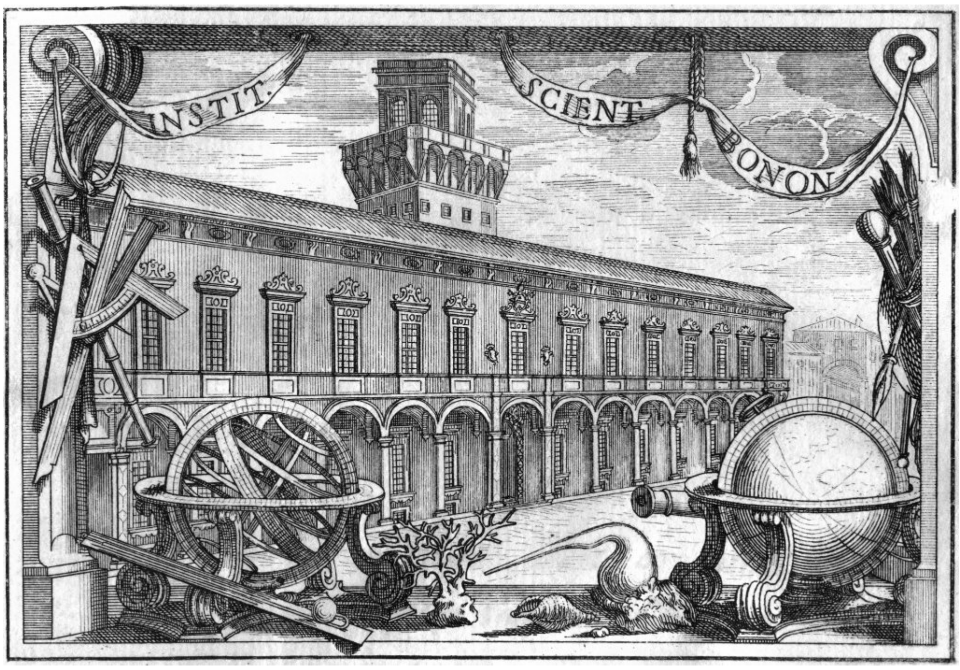

Figure 4.1: *Accademia dell'Istituto delle Scienze di Bologna: 1791. De Bononiensi Scientarium et Artium Instituto Atque Academia Commentarii. Tomus Septimus. Bononiæ: Instituti Scientarium.* (1746) Anonymous engraving representing the *Istituto delle Scienze di Bologna*, Museum of Palazzo Poggi, Bologna.

Marsili would have entrusted the young and promising astronomer Eustachio Manfredi [4], who would have become the first director of the newborn Specola of Bologna (built in 1711). Starting from 1699, a rich exchange of letters would have began between the young Manfredi (aged 25) and the old Cassini who, despite of his age (74), was still dealing with geographical and astronomical tools. A bond of mutual esteem was established between the two, leading Manfredi to affirm in an enthusiastic way, on October 31st, 1702, that the Marsilian Observatory had been finished, thanks to the personal contribution of Cassini, who not only had given him several useful advice but had also given as a gift a book collection of numerous volumes.

In 1742 the *Istituto delle Scienze* would have acquired the large collection of *"naturalia"* of the Italian naturalist Ulisse Aldrovandi (1522 - 1605, Bologna) and in the Napoleonic era, the collections would have began to be spread around, leading to the creation of new separate collections. The old rooms of the *Istituto delle Scienze* have recently become the Museum of Palazzo Poggi, in which part of the original collection can be found. In 1860 Marsili's great Museum of Natural Sciences would have been divided in three thematic collections belonging to the University of Bologna: the Zoological Collection, the Geological Collection and the Mineralogical Collection.

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[4] Eustachio Manfredi (1674 - 1739, Bologna) founded, with his brother Gabriele Manfredi, Vittorio Stancari and other very young scientists, the *Accademia degli Inquieti*, a group of active and enlightened researchers: together they represented the first nucleus of the *Istituto delle Scienze* established shortly thereafter. More on appendix A.18.

4.3 Cassini's last years

In the last year of his life, Cassini still went to the sessions of the *Académie*, discussing with young astronomers.
In 1708 Cassini's wife died and the following year he began to fall ill until he progressively became blind in 1710. The astronomer used to spend the last three years of his life praying in his room and dictating his memoirs to his secretary.

Cassini died on September 14th, 1712 (aged 87) after only two days of severe illness. He was buried in the Church of Saint Jacques du Haut-Pas, of which he was parish priest; on the tombstone is simply written:

J.D. CASSINI – ASTRONOME – MORT LE 14 SEPTEMBRE 1712.

That was exactly what Bernard de Fontenelle [5] said in the eulogy read to the *Académie* on November 16th, 1712, two months after Cassini's death.

> *"Ce sont les travaux des Astronomes qui nous donnent des yeux,*
> *et nous dévoilent la prodigieuse magnificence de ce Monde*
> *presque uniquement habité par des aveugles...* [6]

Cassini was an *Astronome*: a single word beginning with a capital letter which well described Cassini's life, that he chose to entirely dedicate to the sky.

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[5] Bernard Le Bovier, sieur de Fontenelle (1657, Rouen, France - 1757, Paris) more on appendix A.10.

[6] Fontenelle B.,*Éloges des académiciens de l'Académie royale des sciences morts depuis l'an 1666 jusqu'en 1699. Éloge de M. Cassini., Histoire et mémoires de l'Académie des Science.* (1756) pp. 134-147.

Part II

The 1672-73 scientific expedition to Cayenne (French Guiana)

Chapter 1

The foresight of the visionary Prime Minister: the birth of the new Colbert's policy

Figure 1.1: Claude Lefèbvre (1632-1675), 1665-1666, Oil painting on canvas, Versailles, Musée National des Châteaux de Versailles et de Trianon, MV 2185. Portrait of Jean-Baptiste Colbert, with the ordinary clothes of the ministers, black cape and short-sleeved jacket; on his shoulder, the silver embroidery of the Order of the Holy Spirit appears. The objects placed around him are symbols of his eminent position under the kingdom of the *Roi Soleil*.

In the ambitious plan of King Louis XIV, France should have become culturally dominant in Europe and then extend its influence in art, literature, and science all over the world. To create this "golden age" for the country, the King thought that he should have conquered and annexed as many *key territories* as he could. Colbert suggested him that to prove the political dominance of France over Europe, he should have first financed scientific expeditions aimed to determine, with the highest possible accuracy, the extension of French colonial possessions.

Following Colbert's advice, the newborn *Académie des Sciences* organized scientific expeditions to Canada, Denmark, French Guiana, Cape Verde Islands, Martinique, Senegal, Egypt, Siam, and China, taking also advantage of the *Compagnie des Indes Orientales*, an overseas trading company, which had been founded almost contemporary to the *Académie* in 1664. In that way, France both enforced her commercial strength, especially in Madagascar and in the Indian Ocean islands, and gave a strong impulse to nautical science.

Before 1670 no important scientific expeditions had taken place, with possibly just one exception: the 1637 expedition to Brazil of Willem Piso (1611, Leiden, Netherlands - 1678, Amsterdam) and Georg Marggraf (1610, Liebstadt, Germany - 1644, Luanda, Angola). Piso was a physician who had been nominated by the Governor of the Dutch Brasilian region to carry out a scientific mission about the medical practices leaded in the American land; the report of his huge work can be found in the first part of the *Historia Naturalis Brasiliae*, an opera in eight volumes published in 1648. Marggraf intead was a German naturalist who had been charged to be the leading astronomer of the expedition to Brazil. The second part of *Historia Naturalis Brasiliae* contains the results of Marggraf's detailed studies on Brasilian flora and fauna.
Little has remained of the astronomical observations performed by Marggraf: only a list, concerning the period between September 1638 and June 1643, is available among Joseph-Nicolas Delisle [1]'s papers at the *Observatoire de Paris*.

The idea of sending astronomers of the *Observatoire* on scientific expeditions was driven by the need of determining the geographical coordinates of the coasts and lands belonging to the kingdom and demonstrate, in that way, its greatness. Astronomers, being at that time also geographers and cartographers were the "leading actors" of those adventurous and dangerous expeditions, as the measure of the terrestrial coordinates (latitude and longitude) strongly required their skills. They did not miss the opportunity to observe the celestial bodies and make multiple measures concerning their nature, brightness and position, especially when they found themselves below the "different sky" of the Southern Hemisphere: the desire for glory of the *Roi Soleil* had unexpectedly turned out into an improvement of astronomy.

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[1] Joseph-Nicolas Delisle (1688 - 1768, Paris) more on appendix A.7.

The early *Académie* accomplishments and the strong relations between French science and navigation in the decades following the ascent to the throne of Louis XIV, have been, in general, underestimated or misunderstood. This work is intended to shed some light on them, analysing the social and scientific context under which the first scientific expeditions were developed.
After a general introduction concerning the *Académie* scientific aims, an interesting case study, the expedition to the island of Cayenne, in French Guiana, undertaken by a young and promising *élève astronome* of the *Académie*, will be shown and analysed in detail. Thanks to that scientific expedition, which was on of the first in history, a very important astronomical result would have been achieved.

1.1 Cassini's supervision

All the expeditions organized in those years were under Cassini's supervision, who, from Paris, coordinated astronomers work, received the results, and compared them with the measurements made by him from the *Observatoire*. He instructed the scientists, checked the instruments they were going to carry on in their travels, and compiled a practical reminder entitled *Instructions générales pour les observations géographiques à faire dans les voyages (4 feuillets)*, which would have later become the introduction to the *Recueil d'Observations*, published in 1693.
The astronomers taking part to those expeditions were *Académie* members and Cassini's collaborators in the various research projects. Thanks to his temper and authority, Cassini was able to coordinate researches which were taking place thousands of km apart, making Paris to become the centre of the data collection and processing. In those years Cassini could see, for the first time, his aspiration to work with colleagues for a common scientific purpose materialized. The term *"observer de concert"* occurred frequently in his writings and was precisely referred to a working group resulting from the astronomers collaboration.

The *Académie* members, first among them Cassini, were informed about what was happening abroad thanks to private correspondences with the astronomers who were travelling overseas. The first French expeditions not only gave the *Académie* strength and glory, but also offered originality and novelty, being a sort of prototype of the modern scientific expeditions. However, the scientific and astronomic relevance of those overseas expeditions has not be given the due account and have been, instead, somewhat neglected by history. It is difficult to understand why, as not only several long lasting problems (like e.g. the longitude determination) were solved thanks to those expeditions, but they made also science get out of the auto isolation in which had been kept for centuries: results obtained in the far countries were published on journals and started becoming spread around. World began to change thanks to Colbert's reformist policy, who firmly believed in science, and to King Louis' desire for power, a combination of intents that made possible to achieve important results.

"Mais de-quoy n'est point capable la nation Françoise quand il s'agit de servir un si grand Roi ?
Est-il quelque entreprise impossible à un Prince comme luy, qui n'épargne rien pour sa gloire ni dans les armes ni dans les arts, et qui entretient, par une magnificence toute Royale, tant de personnes si éclairées dans les Observations Astronomiques et Physiques dans son Academie,
pour rendre son Regne aussi illustre par la perfection des sciences qu'il l'est par ses glorieux exploits ?" [2]

1.2 Jean Picards' expedition to Uraniborg

During 1667 and 1668, the *Académie* members were planning this new important program of astronomical observation enterprises to be carried out overseas. One of the first chosen destination was Denmark, and more precisely the Hven island, where Tycho Brahe had established the Uraniborg Observatory one century before. The Abbot Jean Picard suggested [3] to send a commission up there to determine exactly the position of the observatory and to make possible the comparison with the astronomical results obtained in Paris.
The request was immediately approved by Colbert, and Picard himself left for Denmark on July 21^{st}, 1671, since some bureaucratic problems delayed his leaving. Picard's travel to Uraniborg, together with the voyages of other several German scientists in France, promoted the establishment of strong scientific relations between the Northern regions and France. [4]

The first thing made by Picard once arrived in Uraniborg, was to establish its latitude measuring the height of the Polar Star. Picard had been observing that same star from Paris for fifteen years noticing it was displacing within a year. It would have been the English astronomer James Bradley [5] to explain, almost sixty years later, in 1729, the reason for that displacement (which would have been named aberration) as due to the combination of the Earth motion (around the Sun) and the finite velocity of the light. [6]

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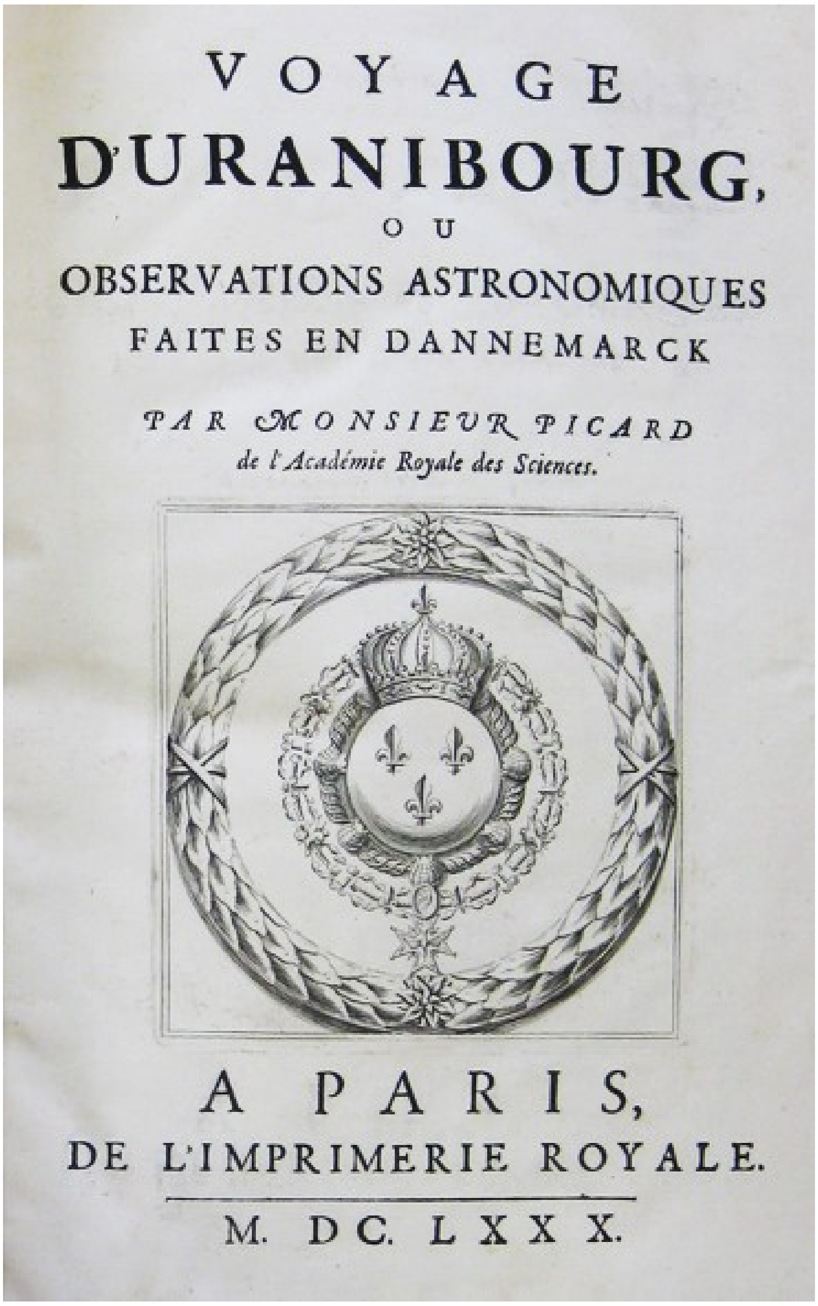
[2] Cassini G. D., De Varin, Deshayes, J., Glos G., *Élémens de l'astronomie vérifiez par M. Cassini par le rapport de ses Tables aux observations de M. Richer faites en l'isle de Caïenne. Avec les observations de MM. Varin, Des Hayes et de Glos faites en Afrique et en Amérique.* (1684) Paris, Imprimerie Royale, p.5.
To allow a better comprehension of the text the ancient way of indicating with a "f" the letter "s" has been modified.

[3] Bertrand J., *L'Académie des sciences et les académiciens de 1666 à 1793.* (1869) Paris, J. Hetzel, pp 27-36.

[4] Maury L. F. A., *L'Ancienne Académie des sciences.* (1864) Paris, Didier, pp 31.

[5] James Bradley (1693, Sherborne, England - 1762, Chalford, England) more on appendix A.3.

[6] A second effect, made known by Bradley in 1748, concerned phenomenon of nutation (which is the oscillation of the Earth's axis due to the forces of gravitational attraction of the Moon and the Sun) that affects the reference system used to measure the positions of the stars.



VOYAGE
D'URANIBOURG,
OU
OBSERVATIONS ASTRONOMIQUES
FAITES EN DANNEMARCK
PAR MONSIEUR PICARD
de l'Académie Royale des Sciences.

A PARIS,
DE L'IMPRIMERIE ROYALE.
M. DC. LXXX.

Figure 1.2: Picard J., *Voyage D'Uranibourg ou Observations Astronomiques faites en Dannemarck par Monsiur Picard De L'Académie Royale Des Sciences.* (1680) in *Mémoires de l'Académie Des Sciences.* (1729), Vol 7, Part 1, pp. 223-264. Paris, Imprimerie royale.

There is an abundant and interesting correspondence carried on between Picard and Cassini which is kept in the Archives of the *Observatoire* in Paris. Those writings are pervaded with friendly phrases and a sincere concern of Cassini, who put aside his characteristic authoritarian temperament to help a friend, as well as a collaborator, who was in trouble. Picard spent two difficult years in the Northern lands and Cassini tried to comfort him and suggested him to move to Copenhagen to feel somewhat less lonely as he used to be in the Hven island.

Figure 1.3: Alphonse Berget (1860-1934) *Portrait supposé de Jean Picard*, in *Le ciel.* (1923) Bibliothèque numérique, Observatoire de Paris. Illustration of Lucien Rudaux (1874-1947) probably representing Jean Picard.

Chapter 2

Organizing the two-year expedition to French Guiana

Although it has been generally recognized that scientific overseas expeditions strongly influenced the theoretical and practical aspects of science in the subsequent century, less well understood is how that form of scientific organization emerged and established in the centuries.

The voyage sponsored by the *Académie* to French Guiana in 1672-1673 is particularly suited to be analysed in detail as very important astronomical data were drawn out of it. The complete account of the astronomical observations can be found in *Observations astronomiques et physiques faites en l'isle de Caïenne, par M. Richer, de l'Académie Royale des Sceinces*, a big volume wrote in French and published in 1679.

During an assembly at the *Académie*, Adrien Auzout explained that an expedition with a merely scientific aim (and no economic purpose) should have been carried out in the famous island of Madagascar:

> *"On the eleventh day of January 1667 M. Auzout presented to the assembly a memoir which was read to the company on the observations that should be made at Madagascar."* [1]

That was the first proposal for a scientific expedition and Auzout presented it only three weeks after the first *Académie* formal meeting. The unpublished report of Auzout's talk is a fundamental document for the history of the expedition which contains details on the astronomical, geographical terrestrial and physical observations which should have been carried out.

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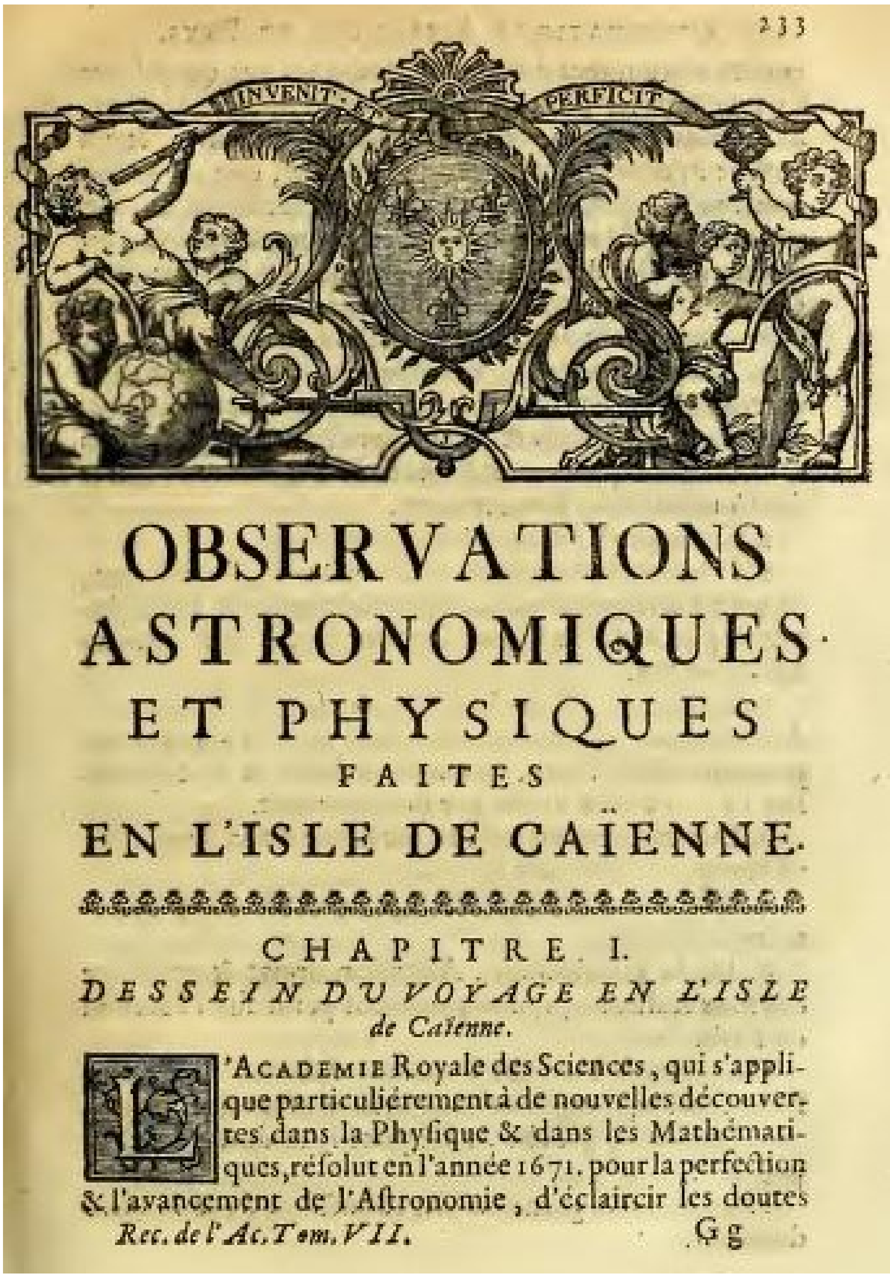
[1] Paris, *Régistres de l'Académie des Sciences, II (Mathématiques, 1666-68)*, pp. 155.



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INVENIT PERFICIT

OBSERVATIONS
ASTRONOMIQUES
ET PHYSIQUES
FAITES
EN L'ISLE DE CAÏENNE.

CHAPITRE I.

DESSEIN DU VOYAGE EN L'ISLE
de Caïenne.

L'Academie Royale des Sciences, qui s'applique particuliérement à de nouvelles découvertes dans la Phyſique & dans les Mathématiques, réſolut en l'année 1671. pour la perfection & l'avancement de l'Aſtronomie, d'éclaircir les doutes

Rec. de l'Ac. Tom. VII. Gg

Figure 2.1: Richer J., *Observations Astronomiques et Physiques faites en L'isle de Caïenne par M. Richer, de l'Académie Royale des Sciences.* (1679) Paris, Imprimerie Royale.

The purpose of that expedition was probably only one concerning the verification of some observational data which Cassini had already studied over the years. However, the *Académie* members established a sort of an astronomical observations calendar to be carried out to derive the following quantities:

1. The ecliptic obliquity, i.e. the angle between the Earth orbit and the equator plane (also known as the "tilt" of the Earth).

2. The equinox times.

3. The parallaxes of the Sun, Venus, and Mars.

4. The movements and parallax of the Moon.
5. The movements of Mercury, a planet that had been rarely observed from Europe.
6. Right Ascension (RA) and Declination (Dec) of the Southern stars which were not visible from Paris.
7. The refraction of light in places having a much lower latitude than Paris (see Sect. 4.2).
8. The times of new and full Moon.

To those eight quantities the *Académie* members added another three (a study on the barometer, the length of the pendulum timing one second and a study on the tides) more related to physics than to astronomy.

2.1 The expedition destination change: from Fort Dauphin (Madagascar) to Cayenne (French Guiana)

To carry out the observational geographical project, the members of the *Académie* had decided to send the observers far South, close to the equator. The original destination had been the main French settlement in Madagascar, Fort Dauphin, at the Southeast tip of the island (at a latitude of 25°).

The settlement of Madagascar by the Indonesians and Africans is very old (BC). Starting from the sixteenth century the Europeans power became very interested in that territory, which had been discovered by the Portuguese Diego Diaz, in 1500. In 1643, the French East India Company went to Madagascar and built a fortress in the Southern town of Fort Dauphin (today known as Tôlanaro). For the next thirty years, until 1674, the French maintained a fort there. In the nineteen century the whole island would have slowly passed under the French influence and in 1883, the French government would have sent a military expedition to Madagascar giving rise to an armed conflict; that one, known as the First Franco-Hova War (1883-1885), would have resulted in the island to become a French Protectorate. At the end of the war, a second conflict would have began (Second Franco-Hova War 1894-1895) ending with Madagascar becoming a French colonial possession. Independence of Madagascar would have been proclaimed only in 1960.

The latitude of Fort Dauphin prevented some astronomical observations to be carried out. Luckily, there was another important settlement of the King located in French Guiana: the island of Cayenne, which latitude (4°56' North) ensured the success of the expedition. Not only that, communications from Paris to Cayenne were faster than the ones to Madagascar.

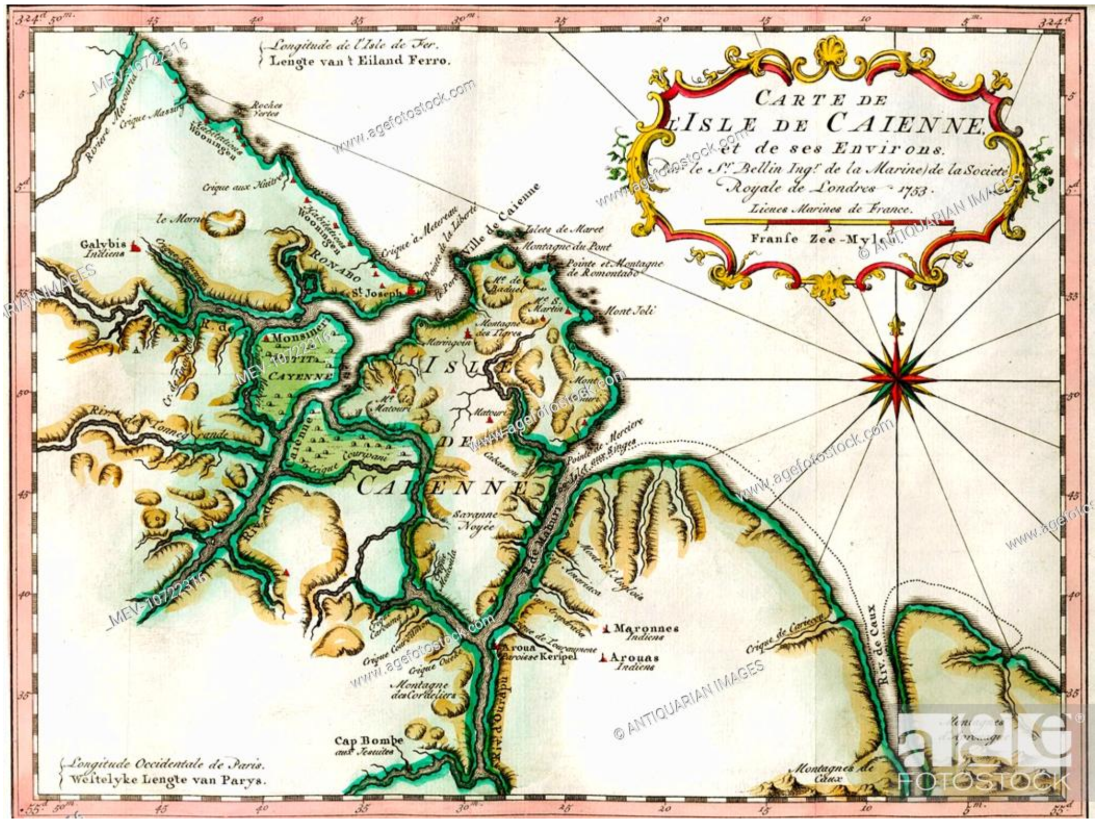

Figure 2.2: *Carte de l'Isle de Caienne et des ses Environs (...)*, Bellin, 1753. Colorized map of the coast of French Guiana locating the important fortifications and natural harbor of Cayenne. It is decorated with a fine title and a compass rose.

From that time on, Cayenne (rather than Madagascar) would have become the preferred destination for the major overseas astronomical expeditions, deemed necessary to the furtherance of their observational programs.

2.1.1 The history of Cayenne

Cayenne, located in the homonyms island, is the capital and Atlantic Ocean port of French Guiana. Ignored by the Spanish explorers (who found the region too hot and poor to be claimed) it was not colonized until 1604, when a French settlement was founded but almost immediately destroyed by the Portuguese, who were determined to enforce the provisions of the Treaty of Tordesillas [2].

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[2] On June 7^{th}, 1494, the governments of Spain and Portugal agreed to the Treaty of Tordesillas (named after the city in Spain in which it was created) which neatly divided the lands of

French colonists returned in 1643 and founded Cayenne as *La Ravardière* but they were forced to leave once more because of attacks from native people. In 1664 the French occupied again the settlement, established there and gave the island the name it has today. Over the next decade the colony was disputed among the European powers and then given back to France. It would have been invaded in 1809 by an Anglo-Portuguese coalition and administered by Brazil until 1814, when it would have returned under French control. In 1854, it would have become a French penal colony (according to Napoleon III decision of sending there the convicts having more than seven years to serve in prison). Prisoners would have been sent there until 1938 and the prison would have been officially closed in 1945. Today, Cayenne is a municipality of the French Republic, ruled by a major and a council.

2.2 The selection of the leading astronomer

The astronomer and engineer Delavoye (sometimes referred to as La Voye-Mignot, and having an unknown birth date), who had been elected *élève astronome* of the *Académie* in 1666, was the first one selected to head the expedition, but then there was a change, due to Cassini, who proposed Jean Richer (1630 - 1696, Paris).

2.2.1 Jean Richer's unknown life

Very little is known of Jean Richer's life other than his work for the *Académie Royale des Sciences*: he was a skilled observer, an excellent astronomer who had the chance to work with good instruments and made efforts to improve standards of observational accuracy. It is almost certain that he was born in France, but the place is not known, as unknown is the date of his birth. He is likely to be born around 1630, as indicated by the historical sources, since he entered the *Académie* as a junior astronomer in 1666, after having received a good education and having worked as an engineer. At the beginning he was an assistant astronomer and then in 1670 he was awarded with the title of *mathématicien de l'Académie*.

Almost everything that is known about Richer is that he was chosen to carry out two scientific expeditions (undertaken for purely scientific purposes) led in the second half of the seventeenth century for the *Académie*: the first one to Acadia, and the second one to Cayenne. In fact, in March 1670, Colbert wrote that the *Académie* had decided to send assistants Jean Richer and M. Meurisse to the East Indies:

> *"... to make various astronomical observations in connection with others which are to be made here [in Paris], and to test the clocks which have been constructed for the determination of longitude at sea."*

---

the "New World" between the two superpowers through a North-to-South line of demarcation drawn in the Atlantic Ocean.

> *“(. . .) send him to Acadia. It is a voyage from east to west during which he will be able to make his experiments; and, if he returns in time, it will be possible for him to embark on Le Breton [for the East Indies] in October.”* [3]

The voyage to the New England coasts and Acadia was the first oversea expedition organized by the *Académie* which made Richer and Meurisse the first members of that association to be charged with a mission to the “New World” (i.e. the countries of America discovered in the previous century).
During that travel, Richer studied the tides behavior and made some remarkably good determinations of latitude for Belle-Île, off the French coast and, once arrived in Canada, of the French fort Pentagoûët. The determination of that latitude was the most interesting achievement of Richer in his first scientific voyaging experience. The value he obtained (44°23’20”) was remarkably close to the correct one (44°23’25”), although not within the error (1”) estimated by Richer himself and accounting for both instrumental errors and refraction correction.
It must be stressed however that Richer was the first one providing a latitude estimate for a place located in the “New World” accurate to the arc second (all the other measurement had been given in degrees and minutes and it would have taken several years to have the latitude of a North American place estimated with an accuracy to the arc second).

Although Richer did not have a special emplacement for his instruments, as he would have had at Cayenne (where he would have also been equipped with the most advanced instruments available at the time in France and described in Sect. 2.3), it seems unlikely that such a good result might have been reached just by chance. Richer’s skill and the quality of his instruments played a relevant role on the accuracy of the results he was able to obtain thanks also to the favorable sky conditions. It is likely that Richer had used Picard’s original 28-inch quadrant, the same he would have used some years later in Cayenne. At that time Picard was successfully employing telescopically equipped quadrants, which he had taken with him in Denmark.

The surprising high accuracy achieved at that time by Richer has been found hard to accept by some commentators of the twentieth century, however it would be unfair assuming that he was simply luck and not, instead, an observer of extraordinary capacities.

The official report of the Acadia voyage was made by Richer to the *Académie* in early January 1671, where he presented a brief account of his mission. The text of the report, and the correspondence related to it, are likely to have got lost together with the *Procès-verbaux de l’Académie* for the years 1670-1674; however, a part of Richer’s report can be reconstructed thanks to a letter written by Huygens.

On September 1670, Richer was back in France and was officially charged to lead the expedition to Cayenne, assisted once again by Meurisse: his passport was

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[3] Olmsted J., *The Voyage of Jean Richer to Acadia in 1670: A Study in the Relations of Science and Navigation under Colbert.* (Dec. 15, 1960) Proceedings of the American Philosophical Society, Vol. 104, No. 6, pp. 612-634.

issued in September 1671. In the months he spent in Cayenne, Richer made many observations and measurements which would have led to important astronomical results that will be illustrated in detail in the next chapters.
Once returned to Paris, Richer was given the title of *ingénieur du Roi* and he was assigned to an engineering project in Germany. In 1679 he would have been elected to full membership of the *Académie*. Just a few years later (in 1675) the *Royal Observatory* in Greenwich would have been founded: a new institution which would have had largely promoted astronomical science. Concerning Richer no other information exists except the place, Paris, and year, 1696, of his death.

2.3 The equipment

Richer brought with him a 20-foot and a 5-foot telescopes appropriately chosen for the purposes of the expedition. He also chose to bring:

- A quadrant with a 2.5-foot radius.
  An astronomical quadrant (literally meaning one-fourth) is a graduated quarter of a circle, set up to measure the altitude of celestial objects above the horizon. The graduations from 0° to 90° are on the circumference, or limb of the instrument, over which usually a sight or index arm moves. Quadrants came in two forms: mural quadrants which were fixed to a meridian wall and used to measure meridian altitudes, and altazimuth quadrants which could be rotated to measure both altitude and azimuth.

- An octant with a 10-foot radius.
  The octant is another instrument used to determine the altitude of a star, and from that the latitude of the observer on sea. It consists of an arc of 45° (i.e. an eighth of a circle), from which its hence the name. During the seventeenth century, the arc was extended from one-eighth of a circle to one-sixth, and the instrument turned out into a sextant.

Both those instruments were of well-beaten iron (the limb with the graduation was of copper). The objective glass had been made by Jacques Borelly (1623, Villefranche-de-Rouergue, France - 1689, Paris), an optical glasses manufacturer and a chemist, who had entered the *Académie* in 1674.
Before leaving to Cayenne, Richer made a measurement test with both the quadrant and the octant from Paris, and then repeated the same procedure once he arrived in Guiana. Thus, he verified that his instrumentation had not been damaged during the transoceanic travel.

For measuring the time, he took with him two pendulum clocks (one marking the seconds and the other marking half a second), which had been made by Isaac II Thuret (1630–1706), the King watchmaker.

Figure 2.3: Richer J., *Observations astronomiques et physiques faites en l'isle de Caïenne.* (1679) Paris, Imprimerie Royale. This drawing was done by the illustrator Sébastien Leclerc (1637, Metz – 1714, Parigi) and may be intended as a portrait of Richer: it shows most of the astronomical instruments used by the astronomer of the *Académie*, one of the two pendulum clocks made by Isaac II Thuret, the 20-foot, the 5-foot telescopes and the large quadrant.

2.3.1 The pendulum clock

The inventor of the pendulum clock had been, in 1656, the Dutch mathematician, physician, and astronomer Christiaan Huygens who intended to solve the longitude at sea problem. Pendulum clocks, however had serious timing problems on sea as the ship rolling induced large irregularities in their timing and the first clocks made by Huygens produced, in 1668, unsuccessful results when tested in the Mediterranean by his assistants Delavoye.

Also Jean Richer took with him in Acadia pendulum clocks made by Huygens but failed in testing them because of a heavy storm the ship ran into, which seriously damaged the instrumentation. Once back home, Richer was accused of incompetence by Huygens who, in a letter, declared that Richer had not taken proper care of the clocks:

> *"Richer's handling of the clocks had been bad throughout the voyage.*
> *For want of a little oil, properly applied, the clocks had been needlessly damaged and afterward more or less ruined; for want of attention to the written instructions provided, they had not been started again after the storm so that they might be observed during the balance of the voyage."* [4]

> *"(...) the want of success on this occasion, as far as I can judge, stems more from the carelessness of the observers than from the failure of the clocks."* [5]

Huygens blamed the *élève astronome* for failing the tests and only several years later he admitted that the pendulum clocks were not likely to be the answer to the longitude problem.

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[4] *Oeuvres complètes de Christiaan Huygens*, VII, 54–55., Letter dating February 4th, 1671.

[5] *Oeuvres complètes de Christiaan Huygens*, XVIII, 116–117.

2.4 The vessel departure from La Rochelle

The history of modern scientific expeditions seems to have begun with the promising *élève astronome* Jean Richer, voyaging to Cayenne on board of a merchantman of the French West India Company heading towards the coasts of America. He sailed from the port of La Rochelle in February, 1672 (later than intended), ready for the overseas adventure, after having carried out some measurements on the tides amplitude.

In chapter I of the *Observations Astronomiques et Physiques faites en L'isle de Caïenne, par M. Richer* published once he came back to Paris, is written that the voyage began in winter:

> *"Je m'embarquay à La Rochelle le 8. de Février 1672, avec le sieur Meurisse qu'on m'avoit donné pour m'aider à faire mes Observations."*

while two letters of Richer to Cassini report a different date:

> *"(...) estans partis a la fin d'octobre."* [6]

> *"(...) vous saurez qu'il y aura un an au mois d'octobre que nous sommes partis de Paris et que nous esperons y retourner dans un an (....)."* [7]

The difference in the sources can be explained considering that about 500 km separate Paris from the port of La Rochelle, and Richer probably intended to arrive to La Rochelle some time in advance to avoid missing its departure. However, since the account of his travel was published six years after Richer's return to France and draw his diary and notes, it is also possible that some mistakes have occurred in the transcription.

On the other hand, all the information concerning the time spent by Richer after he left Paris and before he got aboard the ship is ignored in the published report *Observations Astronomiques et Physiques faites en l'isle de Caïenne* which make the travel to start directly from La Rochelle. So the discrepancy might just arise from a different choice of what should have been considered the starting point and time of the expedition.

The writer of the report might have thought that it was perhaps not important to indicate when Richer (and his assistant Meurisse) left Paris, which is somewhat strange as Richer considered it a not negligible detail and provided the *Académie* with letters (which will be examined in Chap. 3) containing all the information on his movements. In this way, the *Académie* members would have had an exact knowledge of the months he had spent travelling.

The two short extracts from Richer's letters reported below give an idea of how accurate he was describing also the needs he was having. In the first one he

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[6] Richer J., *Lettre de Richer à Cassini I, Cayenne le 4 mai 1672, Bibliothèque numérique, Observatoire de Paris.*

[7] Richer J., *Lettre de Richer à Cassini I, Cayenne le 20 juillet 1672, Bibliothèque numérique, Observatoire de Paris.*

was concerned about the provisions prepared, which were running out fast and, in addition, he underlined that the price of food was very high in Cayenne:

> *“(...) nostre correspondant de La Rochelle, lequel aura soin de nous envoyer (. . .) ce que nous est necessaire,*
> *toutes les commandes pour la vie (. . .) icy trois fois plus cheres qu’en France;*
> *(. . .) c’est ce que m’oblige a faire beaucoup plus de despense que ce je m’estais imagine.”*

In the same letter he requested additional money to carry out all the observations and possibly stay one year more in America:

> *“Vous saurez qu’on nous donna en partant pour la premiere année*
> *de nostre despense 2200 [livre turnois] qui est la moindre chose qu’on puisse donner pour la seconde,*
> *si on decide que nous restions icy plus de six mois apres nostre arrivéé. . . ”*

The currency Richer was referring to was the *livre tournois*, one among the several used in France in the Middle Ages. [8]

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[8] The 1262 monetary reform established the *livre tournois* as 20 *sous tournois*, or 80.88 grams of fine silver. The *franc à cheval* was a silver coin of one *livre tournois* minted in large numbers from 1360. In 1549, the currency was decreed a unit of account, and in 1667 it officially replaced the *livre parisis*; in 1726 it was devalued and it was the basis of the revolutionary French franc of 1795, defined as 4.5 grams of fine silver exactly.

Chapter 3

The two letters of Jean Richer to Cassini

In the Paris *Observatoire* Archive there are only two letters written, from Cayenne, by Richer to Cassini. They are in "ancient French" and shown in Fig. 3.1, 3.2, 3.3, 3.4, 3.5, 3.6. A pair of extracts from those two letters have already been shown (Sect. 2.4). No accent or punctuation have been changed, but the ancient way of indicating with a "f" the letter "s" has been modified (to allow a better comprehension of the text).
It is worth noticing the way Richer signed the letters to Cassini:

> *"Votre tres humble et tres obeissant serviteur.*
> *Richer"*

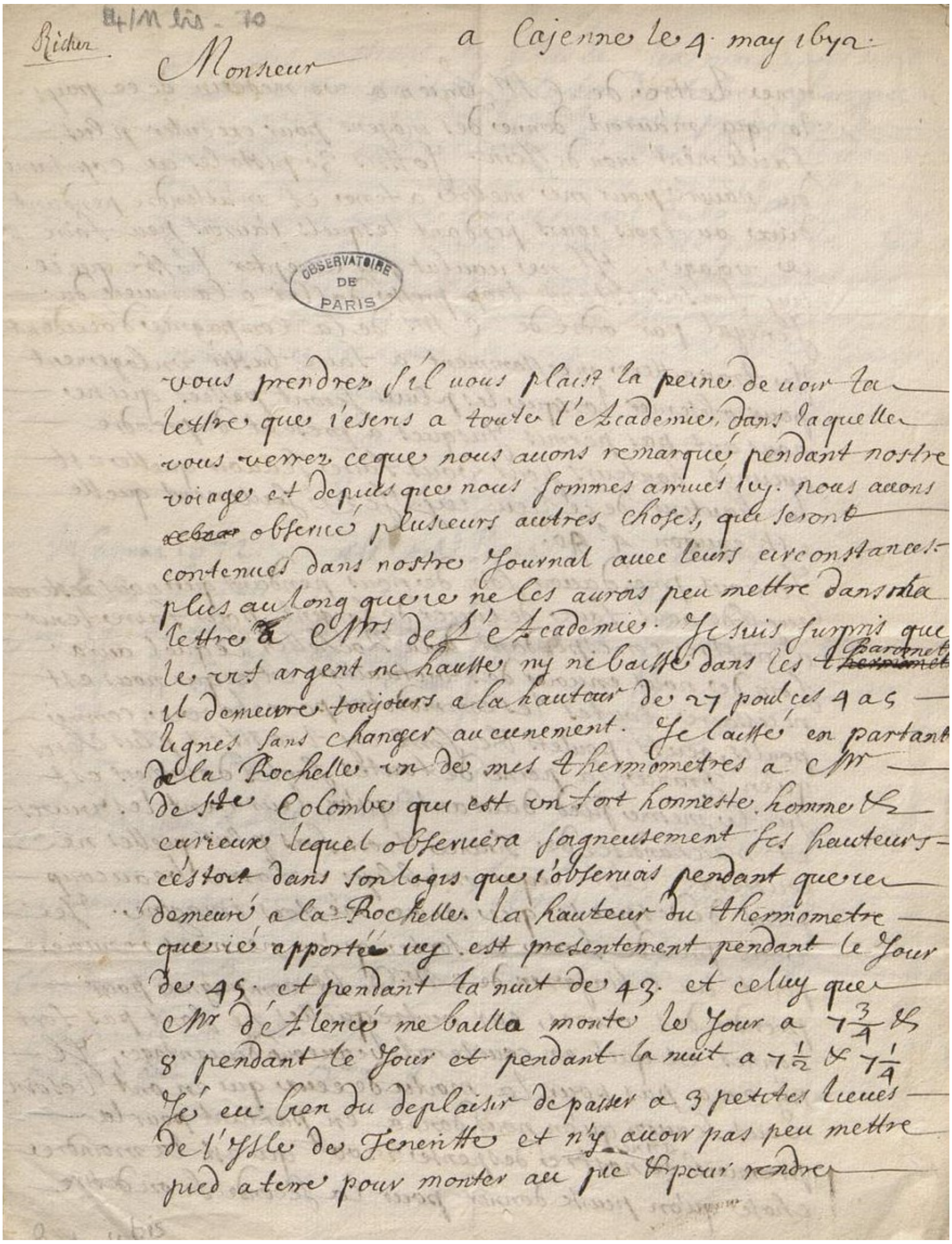
3.1 The first letter

It was sent by Richer on May 4th, 1672 and was intended to be simply the notification of the arrival in Cayenne and contained also an account of the significant observations made during the transatlantic voyage on board of the merchantman:

> *"lettre (...) dans laquelle vous verrez ceque nous avons remarqué*
> *pendant notre voiage et depuis que nous sommes arrivéz icy"*

During that sailing in fact, Richer accurately observed for fifteen days a comet in the constellation Andromeda: the celestial body, first noticed in the sky on March 15th, had the tail facing East.

According to Richer, the astronomers arrived in Cayenne on April 22nd, 1672 where they would have remained for about one year. Richer's assistant, M. Meurisse, would have died there in 1673 and soon after, on May 25th, 1673, a serious illness would have forced Richer to return to France earlier than he had planned.



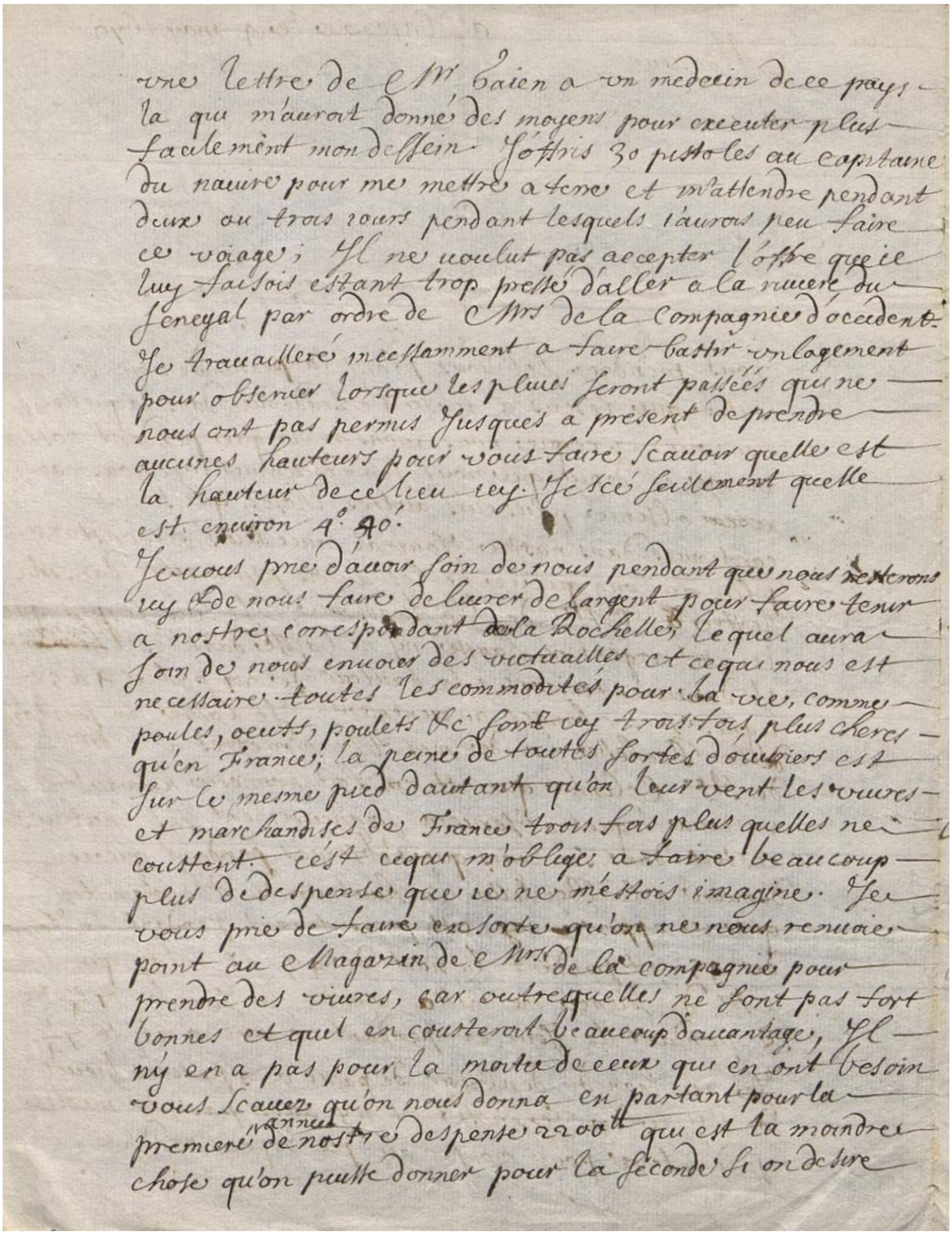
Richer

a Cajenne le 4. may 1672.

Monsieur

vous prendrez ſil vous plaist la peine de voir la
lettre que i'escris a toute l'Academie, dans laquelle
vous verrez ceque nous avons remarqué pendant nostre
voiage et depuis que nous ſommes arrivés icy. nous avons
~~ecbar~~ obſervé pluſieurs autres choſes, qui ſeront
contenues dans nostre Journal avec leurs circonstances
plus au long que ie ne les aurois peu mettre dans la
lettre ~~a~~ à Mrs de l'Academie. Je ſuis ſurpris que
le vif argent ne haulse ny ne baisse dans les ~~thermomet~~ Baromet
il demeure toujours a la hauteur de 27 poulces 4 a 5
lignes ſans changer aucunement. Je laissé en partant
de la Rochelle un de mes thermometres a Mr
de Ste Colombe qui est un fort honneste homme &
curieux lequel observera ſoigneusement ſes hauteurs
c'estoit dans ſon logis que i'observois pendant que ie
demeuré a la Rochelle. la hauteur du thermometre
que i'ay apporté icy est presentement pendant le Jour
de 45. et pendant la nuit de 43. et celuy que
Mr d'Alencé me bailla monte le Jour a $7\frac{3}{4}$ &
8 pendant le Jour et pendant la nuit a $7\frac{1}{2}$ & $7\frac{1}{4}$
J'ay eu bien du deplaisir de passer a 3 petites lieues
de l'Isle de Tenerife et n'y avoir pas peu mettre
pied a terre pour monter au pic & pour rendre

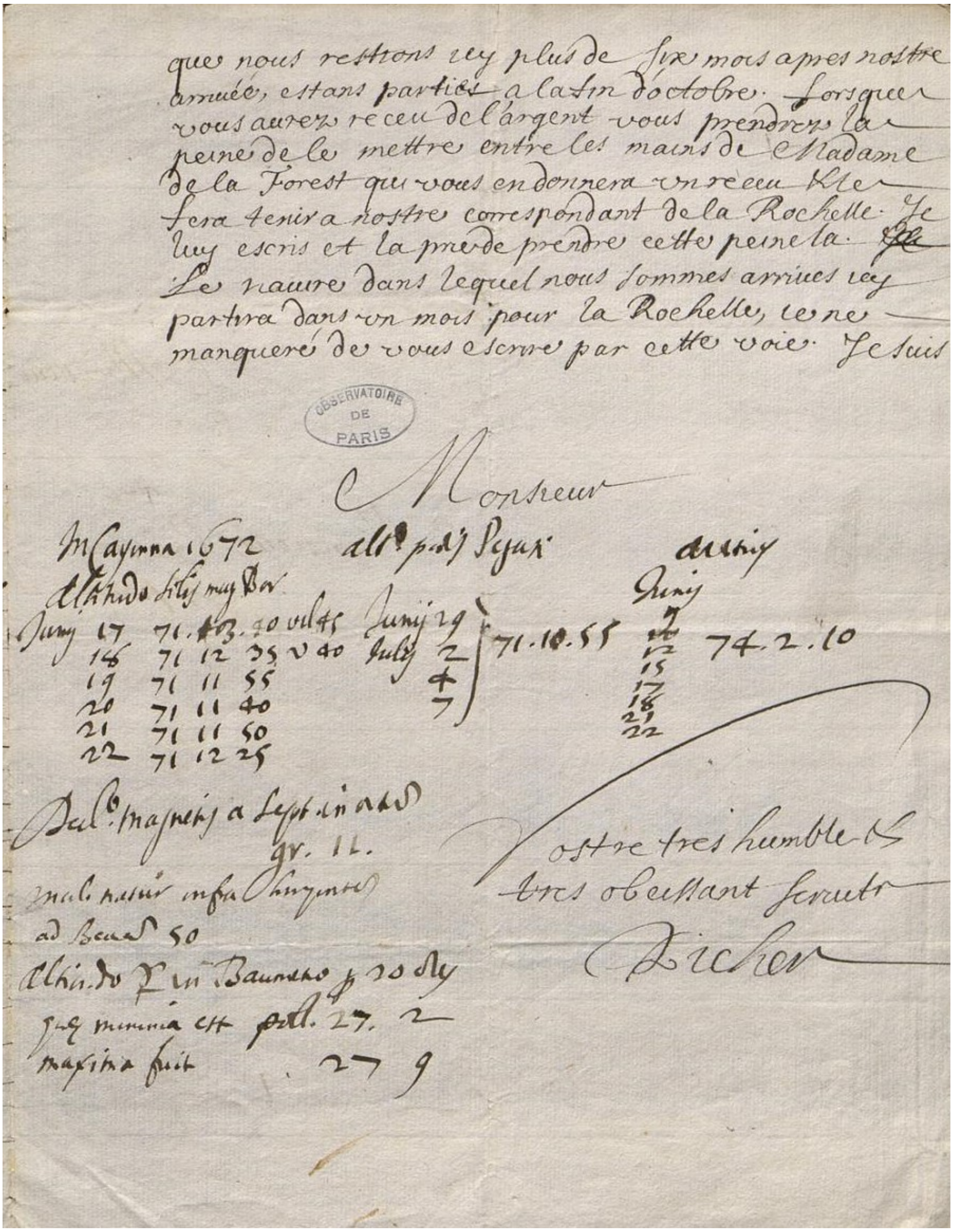
Figure 3.1: Richer J., *Lettre de Richer à Cassini I, Cayenne le 4 mai 1672*, Bibliothèque numérique - Observatoire de Paris, p.1.



vne lettre de Mr baien a vn medecin de ce pays la qui m'auroit donné des moyens pour executer plus facilement mon dessein. J'offris 30 pistoles au capitaine du nauire pour me mettre a terre et m'attendre pendant deux ou trois iours pendant lesquels i'aurois peu faire ce voiage; Il ne voulut pas accepter l'offre que ie luy faisois estant trop pressé d'aller a la riuiere du Senegal par ordre de Mrs de la Compagnie d'occident. Je trauailleré incessamment a faire bastir vn logement pour obseruer lorsque les pluies seront passées qui ne nous ont pas permis Jusques a present de prendre aucunes hauteurs pour vous faire scauoir quelle est la hauteur de ce lieu icy. Je scé seulement quelle est enuiron 4° 40'.

Je vous prie d'auoir soin de nous pendant que nous resterons icy & de nous faire deliurer de largent pour faire tenir a nostre correspondant de la Rochelle, lequel aura soin de nous enuoier des victuailles et ce qui nous est necessaire toutes les commodités pour la vie, comme poules, oeufs, poulets &c sont icy trois fois plus cheres qu'en France; la peine de toutes sortes d'ouuriers est sur le mesme pied dautant qu'on leur vent les viures et marchandises de France trois fois plus quelles ne coustent. c'est ce qui m'oblige a faire beaucoup plus de despense que ie ne m'estois imaginé. Je vous prie de faire en sorte qu'on ne nous renuoie point au Magazin de Mrs de la compagnie pour prendre des viures, car outre quelles ne sont pas fort bonnes et quil en cousteroit beaucoup dauantage, Il n'y en a pas pour la moitie de ceux qui en ont besoin. vous scauez qu'on nous donna en partant pour la premiere année de nostre despense 2200lt qui est la moindre chose qu'on puisse donner pour la seconde si on desire

Figure 3.2: Richer J., *Lettre de Richer à Cassini I, Cayenne le 4 mai 1672*, Bibliothèque numérique - Observatoire de Paris, p.2.



que nous restions icy plus de six mois apres nostre
arrivée, estans partis a la fin d'octobre. Lorsque
vous aurez receu de l'argent vous prendrez la
peine de le mettre entre les mains de Madame
de la Forest qui vous en donnera un receu & le
fera tenir a nostre correspondant de la Rochelle. Je
luy escris et la prie de prendre cette peine la. ~~Je~~
Le navire dans lequel nous sommes arrivés icy
partira dans un mois pour la Rochelle, je ne
manqueré de vous escrire par cette voie. Je suis

Monsieur

In Cayenna 1672 alt. pol. [illegible] [illegible]
Altitudo solis mer. Bor.
Junij 17 71.13.40 vel 45
18 71 12 35 v 40
19 71 11 55
20 71 11 40
21 71 11 50
22 71 12 25

Junij 29, Julij 2, 4, 7 } 71.10.55

Junij 7, 10, 12, 15, 17, 18, 21, 22 74.2.10

Decl. magnetis a Sept. in occas.
gr. 11.
[illegible] infra horizontem
ad [illegible] 50
Altitudo ☿ in Barometro p 10 dies
quae minima est poll. 27. 2
maxima fuit 27 9

Vostre tres humble &
tres obeissant serviteur
Richer

Figure 3.3: Richer J., *Lettre de Richer à Cassini I, Cayenne le 4 mai 1672*, Bibliothèque numérique - Observatoire de Paris, p.3.

3.2 The second letter

Neither Cassini nor the *Académie* astronomers answered to Richer's first letter as one can deduce from the very beginning of the second letter that Richer wrote on July 20th, 1672:

> *"J'espere que vous aurez recu la mienne du 4è May par laquelle*
> *je vous donnois avis de nostre arrive en ce lieu le 22 avril et (. . .)*
> *ceque nous avions remarqué de plus considerable pendant la traverséé."*

Cayenne had a very wet weather: the rainy season lasting from November to June, prevented Richer from making some of the planned observations:

> *"Vous saurez (...) que nous espérons (...) porter les observations des Solstices,*
> *des Eqinoxes, de Mars, Mercure*
> *et de cequil y aura de remarquable vers le Sud.*
> *J'espere que le temps nous sera assez favorable pour l'Equinoxe de l'automne*
> *et le Solstice d'hiver; pour cequi est de l'equinoxe du printemps*
> *je n'en respons pas à cause des pluies qui durent depuis de mois de Janvier*
> *jusque en Juillet."*

The second letter also contains references to the planned observations of the Moon, which Cassini had started to study the previous year in the Parisian environment:

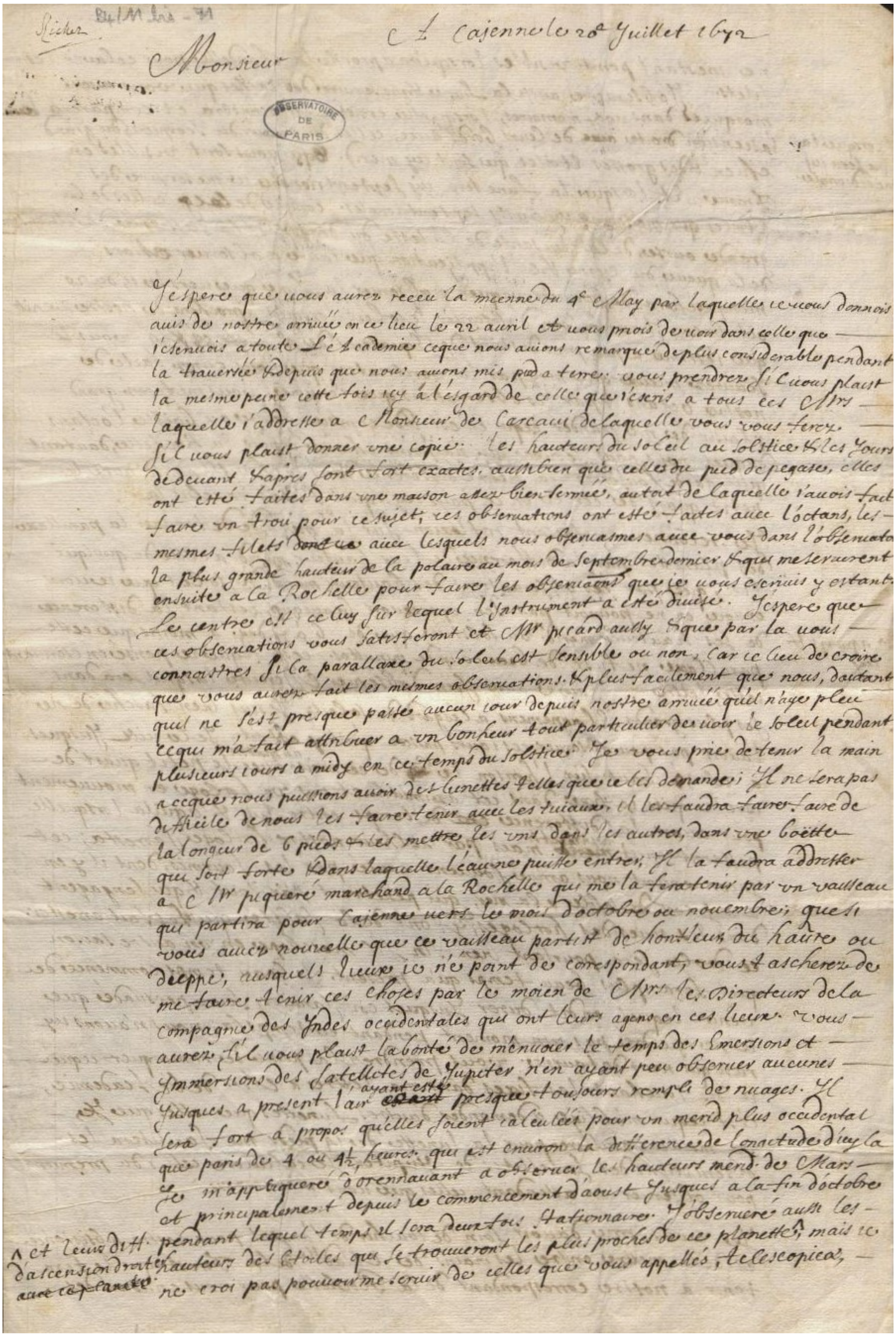
> *"J'observeré aussi la Lune (...)*
> *des taches que vous avez marqueéés dans vos memoires"*

Four entire pages of Richer's *Observations Astronomiques et Physiques faites en L'isle de Caïenne* would have been dedicated to the description of the measurements made by the astronomer on the meridian height of the Moon and its eclipses.

In the second letter there is also a reference to Mercury, a planet which movements were not well known by the European astronomers, due to the paucity of their observations:

> *"J'auré aussi soin d'observer Mercure lorsquil sera dan les plus grands*
> *elognemens a l'esgard du soleil"*

Richer did not have much luck, as due to the bad weather conditions he managed to see it only three times in the second half of his expedition.



Richer

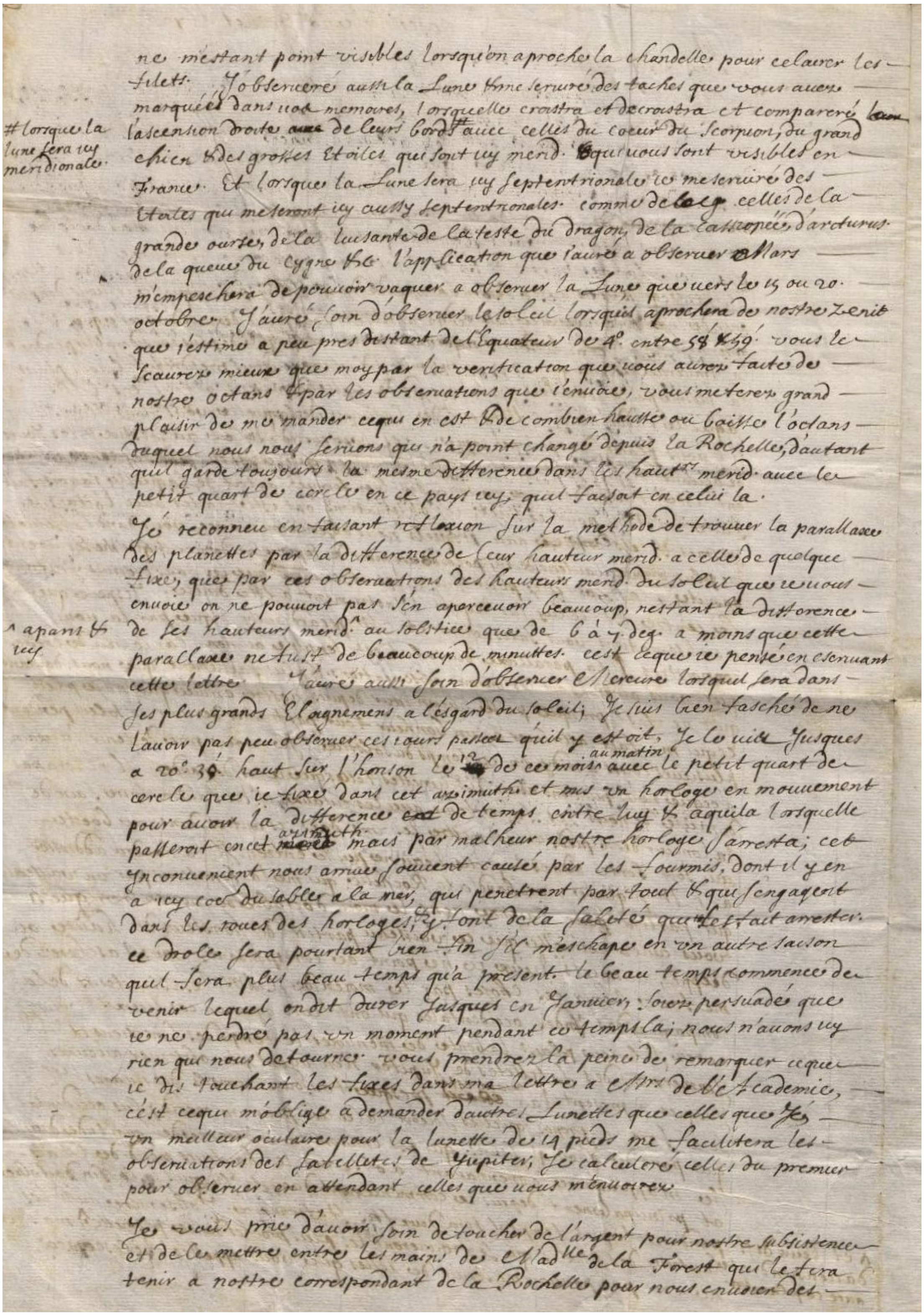
A Cayenne le 20e Juillet 1672

Monsieur

J'espere que vous aurez receu la mienne du 4e May par laquelle ie vous donnois
avis de nostre arrivée en ce lieu le 22 avril et vous priois de voir dans celle que
i'escrivois a toute l'Academie ceque nous avions remarqué deplus considerable pendant
la traversée & depuis que nous avons mis pied a terre. vous prendrez s'il vous plaist
la mesme peine cette fois icy a l'esgard de celle que i'escris a tous ces Mrs
laquelle i'addresse a Monsieur de Carcavi delaquelle vous vous ferez
s'il vous plaist donner une copie. les hauteurs du soleil au solstice & les Jours
dedevant & apres sont fort exactes, aussibien que celles du pied de pegase, elles
ont esté faites dans une maison assez bien fermée, au toit delaquelle i'avois fait
faire un trou pour ce suject; ces observations ont esté faites avec l'octans, les
mesmes filets ~~dont~~ ce avec lesquels nous observasmes avec vous dans l'observato
la plus grande hauteur de la polaire au mois de Septembre dernier & qui me servirent
ensuite a la Rochelle pour faire les observations que ie vous escrivis y estant.
Le centre est celuy sur lequel l'instrument a esté divisé. J'espere que
ces observations vous satisferont et Mr picard aussy & que par la vous
connoistrez si la parallaxe du soleil est sensible ou non, car ie lieu de croire
que vous aurez fait les mesmes observations & plus facilement que nous, d'autant
qu'il ne s'est presque passé aucun iour depuis nostre arrivée qu'il n'aye pleu
cequi m'a fait attribuer a un bonheur tout particulier de voir le soleil pendant
plusieurs iours a midy en ce temps du solstice. Je vous prie de tenir la main
a ceque nous puissions avoir des lunettes telles que ie les demande; Il ne sera pas
difficile de nous les faire tenir avec les tuiaux, il les faudra faire faire de
la longueur de 6 pieds & les mettre les uns dans les autres, dans une boëtte
qui soit forte & dans laquelle l'eau ne puisse entrer; Il la faudra addresser
a Mr piquere marchand a la Rochelle qui me la fera tenir par un vaisseau
qui partira pour Cajenne vers le mois d'octobre ou novembre; que si
vous avez nouvelle que ce vaisseau partist de honfleur du havre ou
dieppe, ausquels lieux ie n'ay point de correspondant, vous tascherez de
me faire tenir ces choses par le moien de Mrs les Directeurs de la
compagnie des Indes occidentales qui ont leurs agens en ces lieux. vous
aurez s'il vous plaist la bonté de m'envoier le temps des Emersions et
Immersions des satellites de Jupiter n'en ayant peu observer aucunes
Jusques a present l'air ~~estant~~ ayant esté presque toujours rempli de nuages. Il
sera fort a propos qu'elles soient calculées pour un merid. plus occidental
que paris de 4 ou 4½ heures qui est environ la difference de longitude d'icy la
Je m'appliqueré doresnavant a observer les hauteurs merid. de Mars
et principalement depuis le commencement d'aoust Jusques a la fin d'octobre
pendant lequel temps il sera deux fois stationnaire. J'observeré aussi les
hauteurs des Estoiles qui se trouveront les plus proches de ces planettes,^ mais ie
ne croi pas pouvoir me servir de celles que vous appellés, telescopicas,

^ et leurs diff. d'ascension droite avec ces planettes

Figure 3.4: Richer J., *Lettre de Richer à Cassini I, Cayenne le 20 juillet 1672, Bibliothèque numérique - Observatoire de Paris*, p.1.



ne m'estant point visibles lorsqu'on aproche la chandelle pour eclairer les
filets. J'observeré aussi la Lune # me serviré des taches que vous avez
marquées dans vos memoires, lorsquelle croistra et decroistra et compareré
l'ascension droite ~~avec~~ de leurs bords avec celles du coeur du Scorpion, du grand
chien & des grosses Etoiles qui sont icy merid. & qui vous sont visibles en
France. Et lorsque la Lune sera icy Septentrionale ie me serviré des
Etoiles qui seront icy aussy septentrionales. comme de celles de la
grande ourse, de la luisante de la teste du dragon, de la cassiopée, d'arcturus.
de la queue du Cygne &c. l'application que i'auré a observer Mars
m'empeschera de pouvoir vaquer a observer la Lune que vers le 15 ou 20.
octobre. J'auré soin d'observer le soleil lorsquil aprochera de nostre Zenit
que i'estime a peu pres distant de l'Equateur de 4°. entre 58 & 59'. vous le
sçaurez mieux que moy par la verification que vous aurez faite de
nostre octans & par les observations que i'envoie, vous meterez grand
plaisir de me mander ce qui en est & de combien haulte ou baisse l'octans
duquel nous nous servions qui n'a point changé depuis la Rochelle, d'autant
qu'il garde tousjours la mesme difference dans les haut^{rs} merid. avec le
petit quart de cercle en ce pays icy, qu'il faisoit en celui la.

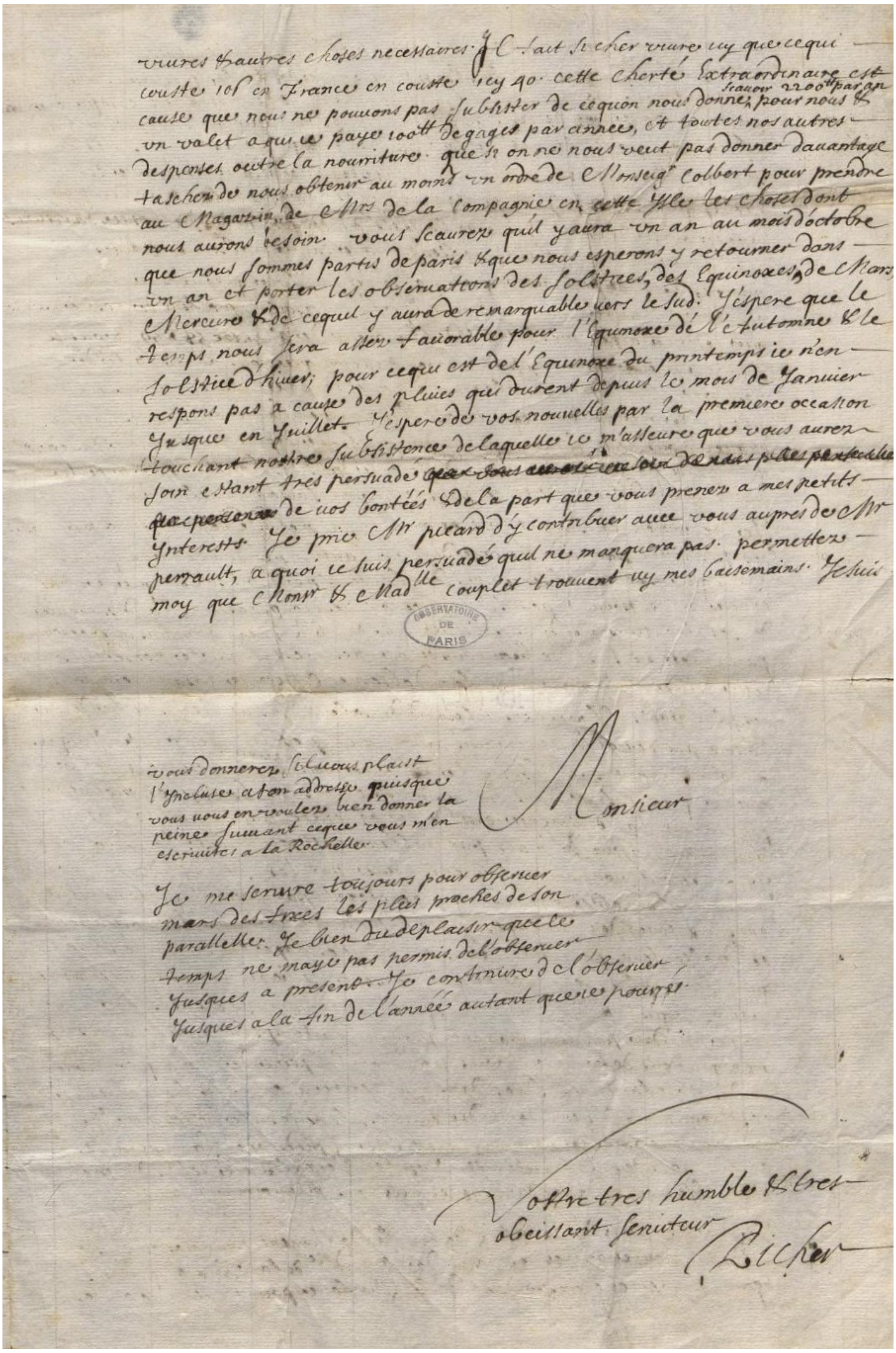
lorsque la lune sera icy meridionale.

Je reconneu en faisant reflexion sur la methode de trouver la parallaxe
des planettes par la difference de leur hauteur merid. a celle de quelque
fixe, que par ces observations des hauteurs merid. du soleil que ie vous
envoie on ne pouvoit pas s'en apercevoir beaucoup, n'estant la difference
de ses hauteurs merid^{ne} au solstice que de 6 à 7. deg. a moins que cette
parallaxe ne fust de beaucoup de minuttes. c'est ce que ie pensé en escrivant
cette lettre. J'auré aussi soin d'observer Mercure lorsquil sera dans
ses plus grands Eloignemens a l'esgard du soleil; Je suis bien fasché de ne
l'avoir pas peu observer ces iours passez quil y estoit, Je le vis Jusques
a 20°. 30'. haut sur l'horison le 12 de ce mois au matin avec le petit quart de
cercle que ie fixé dans cet azimuth et mis un horloge en mouvement
pour avoir la difference ~~est~~ de temps entre luy & aquila lorsquelle
passeroit en cet azimuth mais par malheur nostre horloge s'arresta; cet
ynconvenient nous arrive souvent causé par les fourmis, dont il y en
a icy coe du sable a la mer, qui penetrent par tout & qui s'engageant
dans les roues des horloges, y font de la saleté qui les fait arrester.
ce drole sera pourtant bien fin s'il m'eschape en un autre saison
qu'il sera plus beau temps qu'a present. le beau temps commence de
venir lequel on dit durer Jusques en Janvier, soiez persuadé que
ie ne perdré pas un moment pendant ce temps la; nous n'avons icy
rien qui nous detourne. vous prendrez la peine de remarquer ce que
ie dis touchant les fixes dans ma lettre a M^{rs} de l'Academie,
c'est ce qui m'oblige a demander d'autres Lunettes que celles que J'ay
un meilleur oculaire pour la lunette de 14 pieds me facilitera les
observations des satellites de Jupiter, Je calculeré celles du premier
pour observer en attendant celles que vous m'envoirez

^ apant & icy

Je vous prie d'avoir soin de toucher de l'argent pour nostre subsistence
et de le mettre entre les mains de Mad^{lle} de la Forest qui le fera
tenir a nostre correspondant de la Rochelle pour nous envoier des

Figure 3.5: Richer J., *Lettre de Richer à Cassini I, Cayenne le 20 juillet 1672, Bibliothèque numérique - Observatoire de Paris*, p.2.



viures & autres choses necessaires. Il fait si cher viure icy que ce qui —
couste 10s en France en couste icy 40. cette cherté extraordinaire est
sçavoir 2200# par an
cause que nous ne pouuons pas subsister de ce qu'on nous donne, pour nous &
un valet a qui ie paye 100# de gages par année, et toutes nos autres —
despenses outre la nourriture. que si on ne nous veut pas donner dauantage
taschez de nous obtenir au moins un ordre de Monseig.r Colbert pour prendre
au Magazin de Mrs de la Compagnie en cette Isle les choses dont
nous aurons besoin. vous sçaurez qu'il y aura un an au mois d'octobre
que nous sommes partis de paris & que nous esperons y retourner dans —
un an et porter les obseruations des solstices, des Equinoxes, de Mars,
Mercure & de ce qu'il y aura de remarquable vers le sud. J'espere que le
temps nous sera assez fauorable pour l'Equinoxe de l'Automne & le
solstice d'hiver; pour ce qui est de l'Equinoxe du printemps ie n'en —
respons pas a cause des pluies qui durent depuis le mois de Janvier
jusque en Juillet. J'espere de vos nouuelles par la premiere occasion
touchant nostre subsistence de laquelle ie m'asseure que vous aurez —
soin estant tres persuadé ~~que vous~~ [illegible]
~~que personne~~ de uos bontées & de la part que vous prenez a mes petits —
interests. Je prie Mr Picard d'y contribuer auec vous aupres de Mr
Perrault, a quoi ie suis persuadé qu'il ne manquera pas. permettez —
moy que Monsr & Madlle Couplet trouuent icy mes baisemains. Je suis

vous donnerez s'il vous plaist
l'yncluse a son addresse puisque
vous vous en voulez bien donner la
peine suiuant ce que vous m'en
escriuites a la Rochelle.

Monsieur

Je me seruire toujours pour obseruer
mars des fixes les plus proches de son
parallelle. J'ai bien du deplaisir que le
temps ne m'ayt pas permis de l'obseruer
jusques a present. Je continuerai de l'obseruer
jusques a la fin de l'année autant que ie pourrai.

Votre tres humble & tres
obeissant seruiteur
Richer

Figure 3.6: Richer J., *Lettre de Richer à Cassini I, Cayenne le 20 juillet 1672, Bibliothèque numérique - Observatoire de Paris*, p.3.

Chapter 4

The astronomical observations made by Jean Richer

One of the first things made by Richer in Cayenne was to identify the meridian line with great accuracy: he did that observing the Sun shadows for three consecutive days and drawing a line on the land.

4.1 Adrien Auzout's ignored requests

Adrien Auzout had made two observational request to Richer: the first one concerned the measure of the Sun, Moon and planets angular radius and the second one was about a telescopic observation and description of the Milky Way.
Galileo had proved, sixty years before, that the Milky Way seen through his *cannocchiale* resulted composed by a myriad of stars, unresolvable with the naked eye and Auzuot wanted a confirm of that. He was particularly interested in understanding weather the Milky Way, being composed by stars, had a different nature of the Andromeda Nebula. He was obviously wrong: we know since almost one century that both those nebulae are galaxies and that the possibility of resolving galaxies in stars depends only on their distance.
Going back to Auzout's requests, they were both ignored by Richer and the reason is likely to have been that they were of no interest for Cassini.

4.2 The effect of refraction

Among the astronomical observations which had been planned by Cassini, the study of the apparent motion of the Sun occupied a very special place. In the work *Élémens de l'astronomie vérifiez par M. Cassini (...)* published in 1684, Cassini had stated that the Rudolfine Tables were the most accurate ones ever compiled. The Rudolphine Tables included a star catalogue and tables indicating the position of the planets (and of the Sun too) and had been published in 1627 by Kepler, who had used the large bunch of accurate observational data collected by Tycho Brahe. The name had been given in homage to Rudolf II, the Holy Roman Emperor who had generously supported both Tycho and Kepler astronomical work. Despite their recognized accuracy, the Rudolphine Tables were far from being perfect and the spring and autumn equinox had an error of 3 hours (the former anticipated of 3 hours, the latter delayed of the same amount of time). It was then necessary to accurately measure the Sun position in the sky to correct for that error.

One of the main problems in determining the movement and position of the Sun was the refraction of light, which affected the direction of the light path through the Earth atmosphere. Although the existence of that phenomenon had already been found by Ptolemy [1] who had noticed that stars displaced increasingly as a function of their decreasing altitude above the horizon, no correction for it had been applied until Tycho Brahe. The latter had introduced a refraction correction table which he had estimated to amount at 34' at the horizon and 5" at an altitude of 45°. The Rudolphine tables were thus containing also refraction correction of Tycho.

A good refraction correction was important in determining the height of the Pole (i.e. the altitude of the Polar Star) which position is very close to the ideal line extending from the Earth rotation axis to the celestial sphere in the Northern direction. From that value (h) the latitude (ϕ) of any place in the Northern Hemisphere can be easily derived being exactly equal to it, and an error on h would turn out into an equal value error on ϕ.
Also the Sun altitude measure is subject to refraction effect and if not adequately corrected may result into a wrong estimation of the ecliptic obliquity (already defined in Chap. 2) which is easily obtained measuring the Sun meridian altitude at the solstices. Since the Sun meridian altitude depends on the latitude of the observing place, the refraction effect will be larger at larger latitudes and thus the ecliptic obliquity will be more precisely determined from places close to the equator. Richer measurements provided an ecliptic obliquity of 23°28'32", only 5" less than the value expected by Cassini. A difference that the latter admitted to be *"insénsible"* [2] or negligible, and therefore the measure was a success.
Finally, planets positions would have been determined with a larger accuracy from places where the Sun (and as a consequences also planets which orbits are close to the ecliptic) is found at zenith twice a year because according to Tycho refraction was negligible at zenith and that is exactly the reason why the *Académie* members changed the expedition destination from Fort Dauphin to Cayenne (see Sect. 2.1). Only places laying within the two tropics (i.e. $|\phi| \leq 23°27'$) have the Sun at the zenith twice a year and Fort Dauphin latitude (25°) did not fulfill the request.

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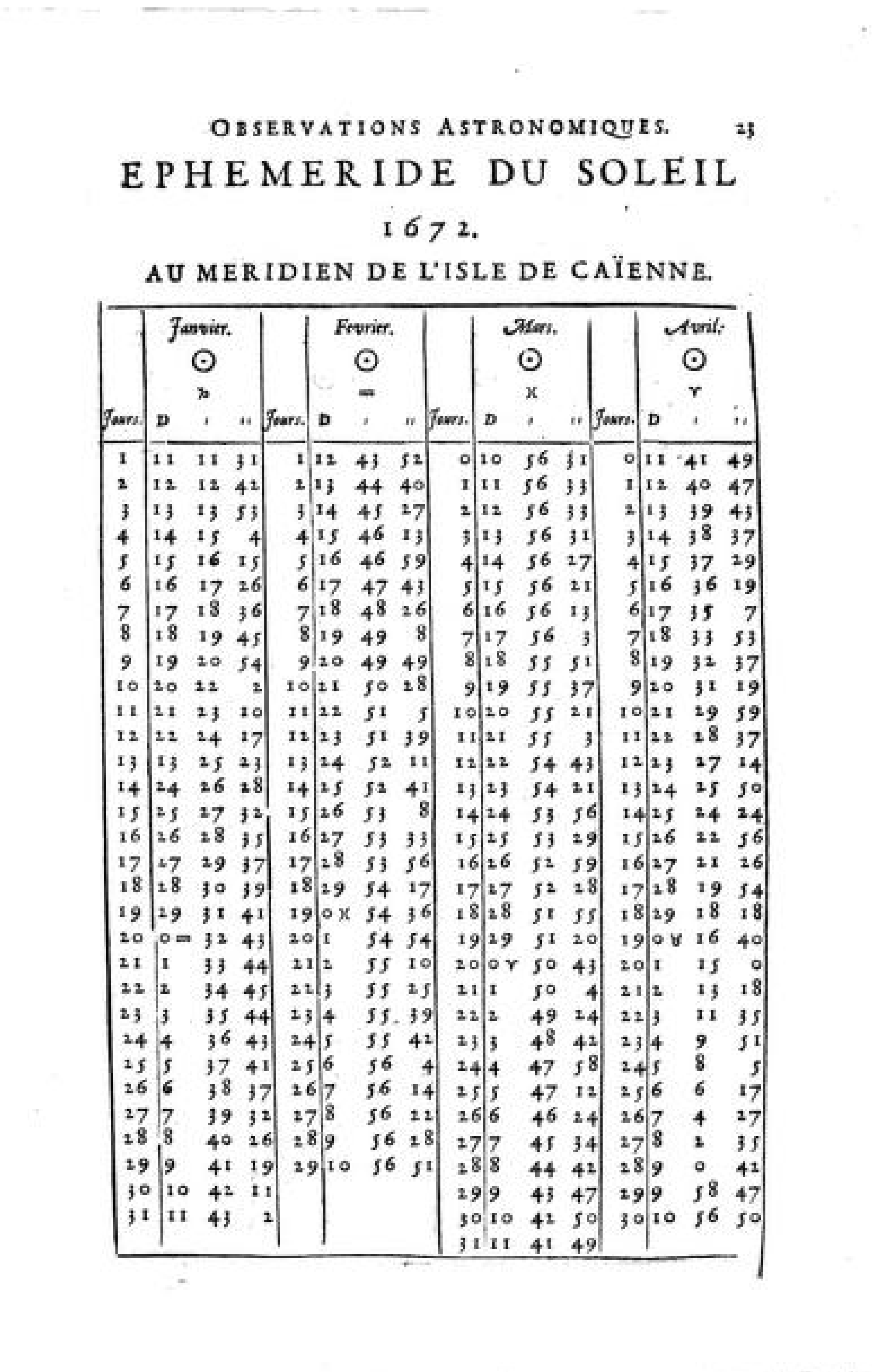
[1] Claudius Ptolemaeus (c. 100 CE - c. 170 CE) was an Egyptian astronomer, mathematician, and geographer of Greek descent who flourished in Alexandria during the II century CE. In several fields his writings represent the culminating achievement of Greco-Roman science, particularly his geocentric (Earth-centred) model of the universe now known as the Ptolemaic system.

[2] Cassini, G. D., *Élémens de l'astronomie vérifiez par M. Cassini par le rapport de ses Tables aux observations de M. Richer faites en l'isle de Caïenne. Avec les observations de MM. Varin, Des Hayes et de Glos faites en Afrique et en Amérique.* (1684) Imprimerie Royale, Paris, p.10.



OBSERVATIONS ASTRONOMIQUES. 23

EPHEMERIDE DU SOLEIL

1672.

AU MERIDIEN DE L'ISLE DE CAÏENNE.

	Janvier. ☉ ♑				*Fevrier.* ☉ ♒				*Mars.* ☉ ♓				*Avril.* ☉ ♈		
Jours.	D	′	″	*Jours.*	D	′	″	*Jours.*	D	′	″	*Jours.*	D	′	″
								0	10	56	31	0	11	41	49
1	11	11	31	1	12	43	52	1	11	56	33	1	12	40	47
2	12	12	41	2	13	44	40	2	12	56	33	2	13	39	43
3	13	13	53	3	14	45	27	3	13	56	31	3	14	38	37
4	14	15	4	4	15	46	13	4	14	56	27	4	15	37	29
5	15	16	15	5	16	46	59	5	15	56	21	5	16	36	19
6	16	17	26	6	17	47	43	6	16	56	13	6	17	35	7
7	17	18	36	7	18	48	26	7	17	56	3	7	18	33	53
8	18	19	45	8	19	49	8	8	18	55	51	8	19	32	37
9	19	20	54	9	20	49	49	9	19	55	37	9	20	31	19
10	20	22	2	10	21	50	28	10	20	55	21	10	21	29	59
11	21	23	10	11	22	51	5	11	21	55	3	11	22	28	37
12	22	24	17	12	23	51	39	12	22	54	43	12	23	27	14
13	13	25	23	13	24	52	11	13	23	54	21	13	24	25	50
14	24	26	28	14	25	52	41	14	24	53	56	14	25	24	24
15	25	27	32	15	26	53	8	15	25	53	29	15	26	22	56
16	26	28	35	16	27	53	33	16	26	52	59	16	27	21	26
17	27	29	37	17	28	53	56	17	27	52	28	17	28	19	54
18	28	30	39	18	29	54	17	18	28	51	55	18	29	18	18
19	29	31	41	19	0 ♓	54	36	19	29	51	20	19	0 ♉	16	40
20	0 ♒	32	43	20	1	54	54	20	0 ♈	50	43	20	1	15	0
21	1	33	44	21	2	55	10	21	1	50	4	21	2	13	18
22	2	34	45	22	3	55	25	22	2	49	24	22	3	11	35
23	3	35	44	23	4	55	39	23	3	48	42	23	4	9	51
24	4	36	43	24	5	55	42	24	4	47	58	24	5	8	5
25	5	37	41	25	6	56	4	25	5	47	12	25	6	6	17
26	6	38	37	26	7	56	14	26	6	46	24	26	7	4	27
27	7	39	32	27	8	56	22	27	7	45	34	27	8	2	35
28	8	40	26	28	9	56	28	28	8	44	42	28	9	0	41
29	9	41	19	29	10	56	51	29	9	43	47	29	9	58	47
30	10	42	11					30	10	42	50	30	10	56	50
31	11	43	2					31	11	41	49				

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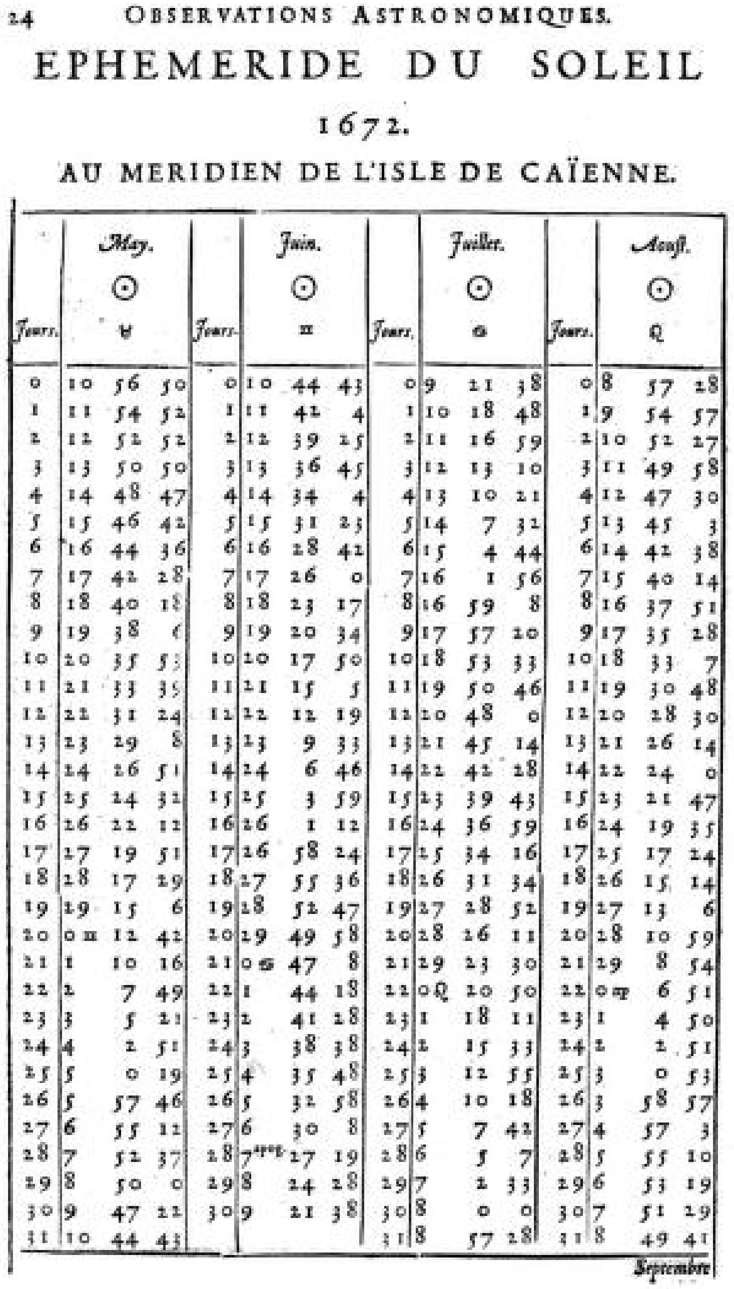
Figure 4.1: Cassini G. D., De Varin, Deshayes, J., Glos G., *Élémens de l'astronomie vérifiez par M. Cassini par le rapport de ses Tables aux observations de M. Richer faites en l'isle de Caïenne. Avec les observations de MM. Varin, Des Hayes et de Glos faites en Afrique et en Amérique.* (1684) Paris, Imprimerie Royale, p.23.



24 OBSERVATIONS ASTRONOMIQUES.

EPHEMERIDE DU SOLEIL

1672.

AU MERIDIEN DE L'ISLE DE CAÏENNE.

Jours.	May. ☉ ♉			Jours.	Juin. ☉ ♊			Jours.	Juillet. ☉ ♋			Jours.	Aoust. ☉ ♌		
0	10	56	50	0	10	44	43	0	9	21	38	0	8	57	28
1	11	54	52	1	11	42	4	1	10	18	48	1	9	54	57
2	12	52	52	2	12	39	25	2	11	16	59	2	10	52	27
3	13	50	50	3	13	36	45	3	12	13	10	3	11	49	58
4	14	48	47	4	14	34	4	4	13	10	21	4	12	47	30
5	15	46	42	5	15	31	23	5	14	7	32	5	13	45	3
6	16	44	36	6	16	28	42	6	15	4	44	6	14	42	38
7	17	42	28	7	17	26	0	7	16	1	56	7	15	40	14
8	18	40	18	8	18	23	17	8	16	59	8	8	16	37	51
9	19	38	6	9	19	20	34	9	17	57	20	9	17	35	28
10	20	35	53	10	20	17	50	10	18	53	33	10	18	33	7
11	21	33	35	11	21	15	5	11	19	50	46	11	19	30	48
12	22	31	24	12	22	12	19	12	20	48	0	12	20	28	30
13	23	29	8	13	23	9	33	13	21	45	14	13	21	26	14
14	24	26	51	14	24	6	46	14	22	42	28	14	22	24	0
15	25	24	32	15	25	3	59	15	23	39	43	15	23	21	47
16	26	22	12	16	26	1	12	16	24	36	59	16	24	19	35
17	27	19	51	17	26	58	24	17	25	34	16	17	25	17	24
18	28	17	29	18	27	55	36	18	26	31	34	18	26	15	14
19	29	15	6	19	28	52	47	19	27	28	52	19	27	13	6
20	0 ♊	12	42	20	29	49	58	20	28	26	11	20	28	10	59
21	1	10	16	21	0 ♋	47	8	21	29	23	30	21	29	8	54
22	2	7	49	22	1	44	18	22	0 ♌	20	50	22	0 ♍	6	51
23	3	5	21	23	2	41	28	23	1	18	11	23	1	4	50
24	4	2	51	24	3	38	38	24	2	15	33	24	2	2	51
25	5	0	19	25	4	35	48	25	3	12	55	25	3	0	53
26	5	57	46	26	5	32	58	26	4	10	18	26	3	58	57
27	6	55	12	27	6	30	8	27	5	7	42	27	4	57	3
28	7	52	37	28	7 [illegible]	27	19	28	6	5	7	28	5	55	10
29	8	50	0	29	8	24	28	29	7	2	33	29	6	53	19
30	9	47	22	30	9	21	38	30	8	0	0	30	7	51	29
31	10	44	43					31	8	57	28	31	8	49	41

Septembre

Figure 4.2: Cassini G. D., De Varin, Deshayes, J., Glos G., *Élémens de l'astronomie vérifiez par M. Cassini par le rapport de ses Tables aux observations de M. Richer faites en l'isle de Caïenne. Avec les observations de MM. Varin, Des Hayes et de Glos faites en Afrique et en Amérique.* (1684) Paris, Imprimerie Royale, p.24.

Richer dedicated six pages of his *Observations Astronomiques et Physiques faites en L'isle de Caïenne* indicating all the meridian heights of the Sun he had measured from Cayenne, specifying that they were relative to the Sun edge (much easier to identify) and not to its centre (which position was much more uncertain). He added also that to obtain the Sun altitudes relative to the center of its disk, it would have been necessary to correct his data by means of the Sun diameter tables, which had been accurately compiled by Picard in the previous years.

As a result of Richer daily Sun observations, Cassini would have compiled Sun Ephemerides as can be seen in Fig. 4.1 and 4.2, which show the Sun position within the different zodiacal constellations, which were assumed to extend 30° each along the ecliptic. Cassini's ephemerides of the Sun obtained both by the observations made in Cayenne and in Antilles [3], were referred to different seasons and were quite accurate. Together, all the observations of position provided a better knowledge of the effect of refraction, and of the amount of displacement caused by it at different altitudes, as well as a valuable check on the accuracy of existing tables.

4.3 Below a "different" sky

Crossing the equator implied the vision of a "different" sky as several well known stars and groups of stars (i.e. the constellations) were not anymore visible and other stars (and group of stars) started to appear. Star constellations which remained visible also from the Southern Earth Hemisphere appeared upside-down. Even not going that South (i.e. not crossing the equator) one would have, anyway, seen a gradual change in the sky, with circumpolar constellations (i.e. neither rising nor setting, such as the two Bears, Cassiopea, Cefeus, etc.) becoming occidual (i.e. rising and setting) and stars altitude in the sky becoming gradually lower. Thus, going South, astronomers could observe stars which they could hardly see (or they did not see from their European homelands) and observation of stars that could only be seen from colonial possession, became very interesting. As expected, Richer got the opportunity to focus on those stars and made an accurate report of the observations planned, to which he referred in his second letter written to Cassini:

> *"J'observeré aussi les hauteurs et les diff. d'ascension droite des etoiles (...) lorsque la Lune serait icy méridionale celles du cœur du Scorpion, du grand chier et des grosses etoiles qui sont icy merid. qui nous sont visible en France. Et lorsque la Lune sera icy septentrionale je me serviré des etoiles qui me seront icy aussi septentrionales comme (...) celles de la grande ourse, du dragon, de la teste la cassiopéé, d'arcturus, de la quene du cygne (...)"* [4]

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[3] Dew N., *Scientific travel in the Atlantic world: the French expedition to Gorée and the Antilles, 1681–1683.* (2009) Cambridge University Press.

[4] Richer J., *Lettre de Richer à Cassini I, Cayenne le 20 juillet 1672.* (1672) Bibliothèque

Richer decided to dedicate two entire chapters (about 45 pages) of his *Observations* to those stars, reporting their meridian height (i.e., their maximum altitude or culmination) which he measured on several nights with the octant. The astronomer did not observe only the stars which were not visible from Paris, he observed the whole sky of Cayenne and of the Northern stars (i.e. the stars having e positive value of the declination) he indicated (together with the observing data) names and constellations of which they were part.

Of the 34 equatorial constellations (i.e. visible from all over the Earth) he wrote notes about Canis (Major and Minor), Crater, Eridanus, Orion (more specifically he wrote notes on Rigel and on the three stars of its Belt: Alnitak, Alnilam and Mintaka) and Pegasus.

Finally, Richer wrote also notes on the Zodiacal constellations of Libra, Leo, Acquarius (*australior earum; Lucidior duarum in humero sinistro; spalla destra, in primo fluxo aquae, duarum sequens* [5]), Scorpius (*in eductione Chela Septentrionalis; in fronte ad Boream fulgentior prima; in fronte ad austrum tertia; ad Chelam austriam; in principio pedis secondi*) and Virgo.

Richer managed also to observe, only on a few nights, the Polar Star from Cayenne, which due to the latitude of that place (ϕ=5°) appeared 5° above the local horizon.

4.3.1 Southern Stars

Stars which were not visible from Paris were obviously the most important to observe and Richer reported their altitudes measured in different nights indicating also the stars which had not been represented on the celestial globes yet. Among the several Southern stars and constellations Richer wrote notes on:

- Ara.
  It is known also as the Altar and it is invisible from Europe and from places which latitude is larger than 30°. It is a little constellation located South of the Scorpion tail and has a characteristic shape making it similar to a butterfly. The name comes from the Greek Mythology according to which on the Ara the Greek Gods had sworn allegiance before fighting against the Titans. In Richer's account the constellation is called *Thuribulum.*

- Carina.
  This constellation is entirely visible at latitudes lower than 15°. It has a very bright star, Canopus, second only to Sirius in its apparent magnitude. In his notes Richer states that Canopus is similar (in the color) to Arcturus.

- Centaurus.
  This constellation had been already included by Ptolemy, the greatest astronomer of the Ancient World, in his list of 48 constellations as it is very

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numérique, Observatoire de Paris.

[5] Richer J., *Observations Astronomiques et Physiques faites en L'isle de Caïenne par M. Richer, de l'Académie Royale des Sciences.* (1679) Paris, Imprimerie Royale. Latin names of stars cited and described in chapters 8-9.

large. Today it is visible at latitudes below 30° but in the past, due to Earth precession motion, it was well visible in the Mediterranean area and well known by Greek and Roman people. The Centaurus brightest stars (α-Centauri) is the third in order of apparent luminosity of the whole sky and it was also believed to be the closest one to our Sun (4.4 light years) until a much weaker star (Proxima Centauri, which is 4.2 light years from the Sun) was discovered, in 1915. Richer mention five stars of this constellations as: *ultima quae australior; in thyrso duarum priorum australior; in cubitu laevo Centauri; sub alvo trum media; in summo pede laevo antecedente.*

- Columba.
  This constellation is visible from the whole Southern Hemisphere and in the Northern one from places having latitude less than 45° (i.e. not from Paris which latitude is 48°51'). It is very small but its shape reminding a flying bird and its brightest blue star (Phakt or α-Columbae) make it noticeable. Mithologically the constellation would represent the dove sent by Jason from the Argonauts ship to explore the dangerous Cianee Islands, as suggested by its location in the sky. The Columba is very close to the Argo Ship, an old Ptolemy constellation which was split into three (Carina, Puppies and Sails) by the French astronomer Nicolas Louis de Lacaille [6].

- Crux.

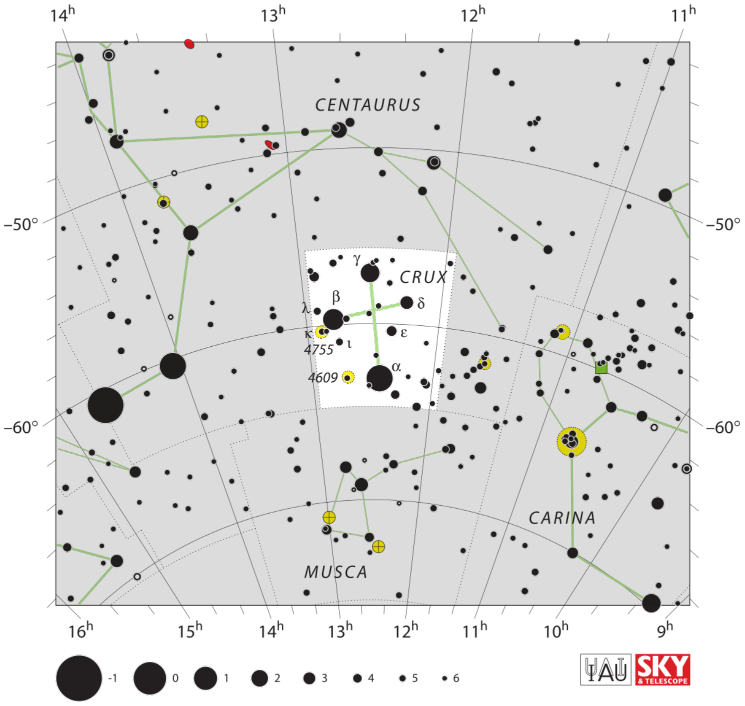

Figure 4.3: Crux constellation map by IAU and Sky & Telescope magazine.

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[6] Nicolas Louis de Lacaille (1713, Rumigny, France - 1762, Paris) was a French astronomer and geodesist who named 14 out of the 88 constellations. He studied the sky and the stars during his four-year trip at the Cape of Good Hope (South Africa).

It is the smallest among the 88 modern constellations in which the sky has been divided (each constellation corresponding to a larger region enclosing it) but it is very easy to identify as it is composed of four bright stars in form of a small crux. It is visible from any places of the Southern Hemisphere and from places in the Northern Hemisphere having latitudes less than 20°.

There is an interesting literary mystery involving the Crux constellation, as Dante Alighieri (1265, Florence - 1321, Ravenna, Italy) is likely to have mentioned it in his poem *La divina commedia.* The Crux is not visible from Europe, but it was in the past (because of the Earth precession motion) however, it was so low above the horizon that it was not considered a separate constellation: Ptolemy considered its four stars to be part of the Centaurus constellation (which was visible from the Mediterranean area). Going back to Dante's poem, when he and Virgil (the most famous ancient Roman poet of the Augustan period), got out of Hell, they found themselves in the Southern Hemisphere (which Dante indicated with the term *"l'altro polo"* meaning "the other pole") and realized that new stars and other constellations were shining in the sky, among which were four stars that might be interpreted as the four stars of the Crux. The proof that Dante had changed Hemisphere can be found (a few lines below the statement concerning the four stars) as he writes that he could not see anymore the Big Dipper (the best known constellation of the Northern Hemisphere).

"I' mi volsi a man destra, e puosi mente
a l'altro polo, e vidi quattro stelle
non viste mai fuor ch'a la prima gente.

Goder pareva 'l ciel di lor fiammelle:
oh settentrional vedovo sito,
poi che privato se' di mirar quelle!

Com'io da loro sguardo fui partito,
un poco me volgendo a l 'altro polo,
là onde il Carro già era sparito (...)" [7]

If Dante intended really to refer to the Crux Constellation (another interpretation sees in them an allegoric representation of the four cardinal virtues) then he either should know that the Crux had been visible in the past from the Northern Hemisphere (in that case *"la prima gente"* would have been his far ancestors) or he should have known about the Crux existence in the Southern sky, where he had located the Purgatory Mountain and (on top of that) the Heaven on Earth (*"la prima gente"* would have then been Adam

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[7] Dante Alighieri, *La Divina Commedia - Purgatorio.* (c. 1316) C. I, v. 22-30.

and Eve). If the latter were the case, how could Dante, writing in the very early 1300s, know about a constellation first seen by the Venetian explorer Alvise Cadamosto (1432–1477), who noted it while sailing the African coast in 1455, and more precisely described by later navigators (such as Amerigo Vespucci (1454-1512) and Ferdinando Magellano (1480-1521))? There is no answer to that question.

- Dorado.
  It is a small constellation, rather well known as it contains most of the Large Magellanic Cloud and the South ecliptic pole. It appeared for the first time in the Rudolphine Tables with the name *Xiphias* (the swordfish).
- Grus.
  It is a huge constellation extending for about 20° in the North-South direction and is entirely visible from regions having latitude less than 24°. Its shape has been associated to the crane one (Grus in Latin). It was not included in the 48 Ptolemy constellations and was identified at the end of the sixteenth century by the Dutch explorers Pieter Dirkszoon Keyser (1540-1596) and Frederick de Houtman (1571-1672).
- Phoenix.
  The Phoenix was an Egyptian mythological bird able to resuscitate from its ashes. The constellation (entirely visible from places having latitude less than 22°) was created by Pieter Dirkszoon Keyser and Frederick de Houtman to fill one void in the astronomical charts.

Using an online tool the night sky of Cayenne at Richer's arrival has been created and is shown in Fig. 4.4.

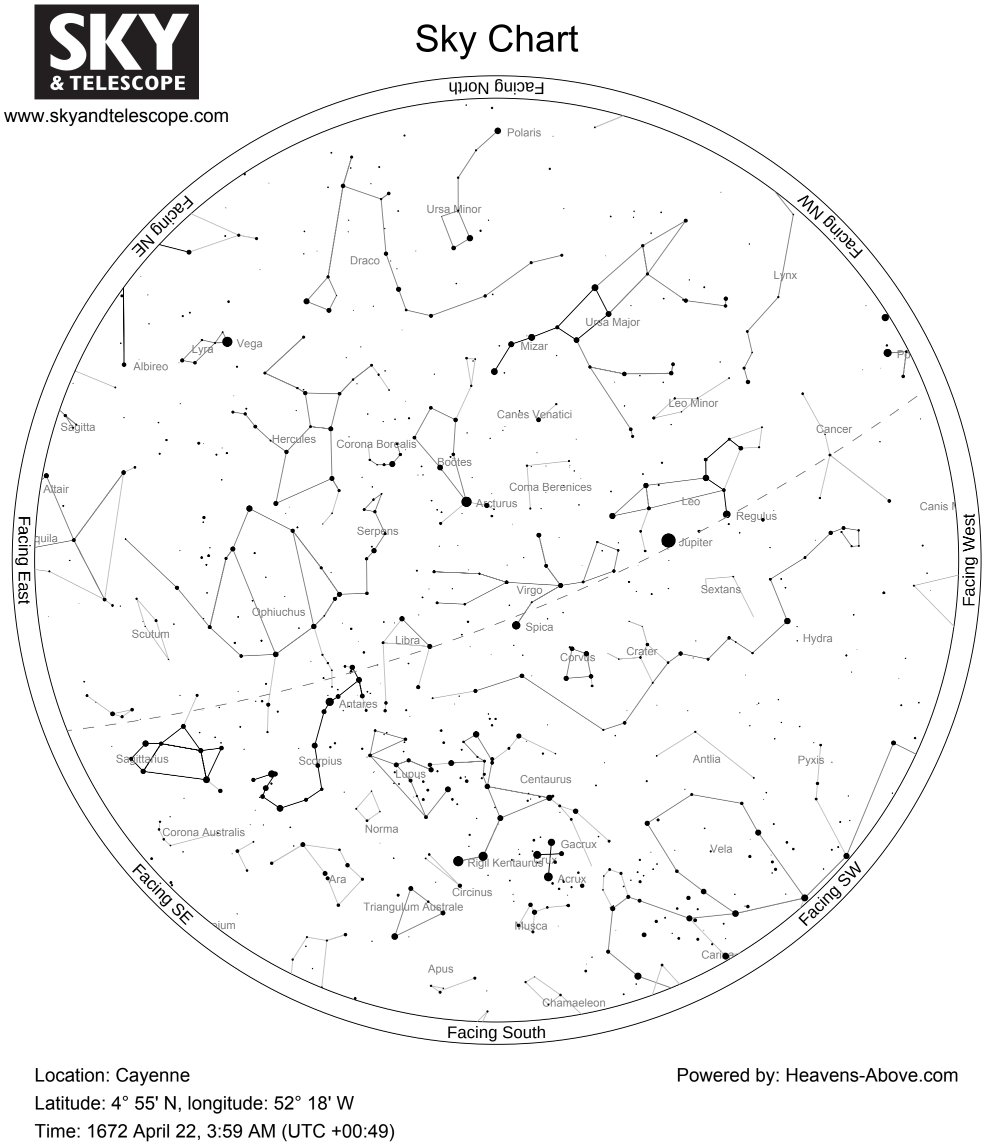

Figure 4.4: Charts of the night sky as seen by the altitude of Cayenne on April 22^{nd}, 1672. The map includes the Moon, stars brighter than magnitude 5, the five bright planets (Mercury, Venus, Mars, Jupiter, and Saturn), and the constellations. Powered by Heavens Above.

Chapter 5

The longitude problem

During the century which followed the “New World” discovery, the European powers wished to extend their overseas domains with new colonial possessions. Two basic conditions for safe and efficient navigation were thus mandatory: the capability of determining with high accuracy the vessel position in the oceans and accurate maps, to be used as a reference for the sail. Cartography improvement and navigation projects were thus proceeding side by side and since (as already stressed) astronomers were at the time cartographers and geographers, their expertise was fundamental for the development of accurate methods to determine the geographical coordinates (i.e. latitude and longitude).

The determination of latitude is quite an easy task, it has been shown (Sect. 4.2) that it equals the altitude of the Polar Star (if observers are located in the Northern Hemisphere) but it may be derived also using either the Sun (in day time) or the stars (in night time) heights at their culmination (i.e. when they reach the maximum altitude in the South direction). It was not difficult for transoceanic sailors to find out their ship latitude, with an accuracy of about 1° using instruments such as the astrolabe and the sextant.

Longitude was, however, a different matter: observations of the Sun and stars were of no immediate help because to determine the longitude with respect to a fixed place, navigators had to know the time difference between the two locations. It was then necessary to observe an astronomical phenomenon simultaneously from a ship and from another (reference) place on land: the times difference corresponded to the longitude difference. To make things worst was the difficulty of having time accurately measured on ships (as already stressed in Sect. 2.3.1) and for European nations engaged in trade with the East and West Indies, finding longitude at sea soon became a matter of national interest.
In the late sixteenth century the Spanish Crown instituted a “longitude” prize in the hope of a solution, an initiative which would have been followed by the French, Dutch, and English governments in the seventeenth century.

5.1 An old method to measure longitude: the lunar eclipses

The Spanish monarchy addressed to experts in navigation and to astronomers the request to produce a more accurate description of the world, as not only the longitude at sea had to be determined but also the maps prepared at the beginning of the sixteenth century had some inaccuracies. Thus, around 1580s, a ten years project, aiming to estimate the longitude of all of Spain's overseas territories using lunar eclipses, began. [1]

At that time astronomers made use of the lunar eclipses, adopting a method which had been used since Antiquity and had enjoyed renewed popularity after the publication of Ptolemy's Geography in the fifteenth century. Spanish astronomers interest in deriving accurate longitudes was largely driven by the need to adjust astronomical motions listed in the Alfonsine Tables -all based on the meridian of Toledo- to a local reference point to be determined by the longitudinal distance between Toledo and the point of observation. After the discovery of the new American lands, distances could not any longer be accurately estimated from terrestrial measures, but very often when an astronomer stated that he had determined the longitude of one place he had not made it observing a lunar eclipses, but simply calculated it on the basis of the predicted times of lunar eclipse phases taken from the ephemerides.
While several problems concerning eclipse observations, such as the Moon parallax, were well understood, others, such as the distortion on the apparent position of the Moon (due to atmospheric refraction), were only beginning to be better quantified (and the expedition to Cayenne would have provided refraction correction data, as already said in Sect. 4.2).

The way longitude was derived was deceptively simple: Moon eclipse was the event which had to be observed by different places on Earth and the local time of the contact phase had to be recorded. The time difference would have then been translated into longitude degrees, since one-hour difference in local times corresponds 15° of Earth rotation around its axis and consequently in longitude.

All that could work if clocks in both places had been well synchronized to their respective local meridians and were keeping accurate timing. The latter requirement being actually impossible at the epoch: only in 1753 the marine chronometer watch invention by the English clock maker John Harrison (1693, Foulby, Yorkshire, England - 1776, London) would have allowed exact timing on boats. Harrison's clocks would have been so accurate to have an error of only few seconds on an entire sailing to the East Indies. [2]

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[1] Portuondo M. M., *Lunar eclipses, longitude and the New World.* (2009) The Johns Hopkins University.

[2] On his second (1772-1775) voyage to the South Seas, the British naval captain, navigator and explorer, Captain James Cook (1728, Marton-in-Cleveland, Yorkshire, England - 1779, Kealakekua Bay, Hawaii), took with him a Harrison chronometer finding out that it was working

Along with the difficulties related to the timing problem on ships, was the rare occurrence of Moon eclipses, only about two per year. Moreover, Moon position on tables were not accurate at all, resulting into an estimated time of the eclipses phenomenon which could be easily wrong of fifteen minutes.

In his expedition report, Richer gave a detailed description of the lunar eclipses method to determine longitudes wherever on Earth.

5.2 A new method to measure longitude: the eclipses of Jupiter's satellites

In the late seventeenth century an almost revolutionary increase map accuracy took place, thanks to the successful longitude determination by a method which was practicable only on land and involved the determination of differences in local time by means of simultaneous observations of the eclipses of one of the four major satellites of Jupiter.

Studying the orbits of the four major Jupiter Moons, that he had discovered, Galileo observed for the first time in 1612 one of them disappearing quickly behind the planet. That phenomenon was an eclipse occurring because the satellite had entered the planet shadow cone and was not anymore illuminated by the Sun. Galileo measured the time between two eclipses of each of his *Medicean Moons* (which would have later been named Io, Europa, Ganymede and Callisto) deriving thus an estimate of their orbital period around Jupiter.
The regular occurring of those eclipses suggested him a new way to obtain the exact measurement of geographic longitudes. Those eclipses were instantaneous events: thus, if a navigator on the high seas had noted the local time and compared it with the local time at which it was predicted to happen in a European reference location, the difference in times and, as a consequence, in longitude, could easily have been found.

In 1613 Galileo started negotiations with the Spanish Crown: he would have provided Spanish navigators with tables indicating the time of Jupiter's satellites eclipses and with the telescopes which they would have needed to observe them. He worked several years trying to perfect his knowledge of the satellites motions but never published his results (probably because they were not accurate enough). The Spanish were not impressed by his method, as they thought that it would have been impossible to correctly timing the eclipses from the ship. Galileo decided thus to negotiate (through intermediaries) with the States General of the Netherlands, who had just announced a "longitude" prize. The Dutch government was favorable impressed by Galileo (he was awarded a gold medal and chain, which he could not accept because the Inquisition forbidden him to do it), but came however to the same negative conclusion reached by the Spanish before.

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perfectly fine.

By Galileo's death, in 1642, the only published tables concerning Jupiter's satellites motions were inaccurate, but the low frequency of lunar and solar eclipses, and of star occultation phenomena, made those methods less useful than the eclipses of Jupiter's satellites even on land.
That was the reason why Cassini was strongly convinced that Galileo's method would have led to remarkably achievements; also, he had already studied Jupiter's satellites movements and compiled their ephemerides while he was in Bologna (see Sect. 2.2.2). Cassini's persistent efforts to apply Galileo's method had been largely supported by his colleagues and members of the *Académie* and at the *Observatoire* all the data of the eclipses had been collected, thanks also to the observations of astronomers from the far countries.

In 1671-1672, using accurate pendulum clocks designed by Huygens, Picard and Cassini had been able to establish the longitude difference between Paris and Hven (the site of Tycho Brahe's famous observatory, see Sect. 1.2). Shortly after, Cassini would have asked Richer to observe Jupiter's satellites eclipses from Cayenne to derive, from comparison with observation he would have taken from Paris, the longitude difference between the two places. All the detailed instructions on how to take the measurements and then apply the method, could be found in the *Instruction Generale pour les Observations Geographiques et Astronomiques à faire dans les Voyages* that Cassini wrote for his overseas assistants.

Richer demonstrated his intention to observe Jupiter's satellites, but due to bad weather and adverse atmospheric conditions, he could observe them only in the second part of his staying in Cayenne:

> *"(. . .) le temps des emersions et immersions des Satellites de Jupiter*
> *n'en ayant peu observer aucunes jusques a present*
> *ayant este l'air presque toujours rempli de nuages (. . .).*
> *c'est ce que m'oblige a demander d'autres lunettes que celles que j'é,*
> *un meilleur oculaire pour la lunette de 14 pieds me facilitera les observations*
> *des Satellites de Jupiter."* [3]

On land, that method provided useful and accurate longitude measurements: Jean Picard from Hven and Cassini from Paris made joint observations in 1672 and obtained a value [4] of 42m10s (time) East of Paris, corresponding to 10°32'30". Being the longitude in Paris 2°20'55" and the one in Hven 12°41'28", the difference between the two values is 10°20'33"; thus, Cassini's measurement was about 12 minute of arc (1/5°) higher than the accapted value.

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[3] Richer J., *Lettre de Richer à Cassini I, Cayenne le 20 juillet 1672.* (1672) Bibliothèque numérique, Observatoire de Paris.

[4] Picard J., *Voyage D'Uranibourg ou Observations Astronomiques faites en Dannemarck Par Monsiur Picard De L'Academie Royale Des Sciences* in *Mémoires de l'Académie Des Sciences.* (1729), Vol 7, Part 1, pp. 223-264. Paris, Imprimerie royale.

Cassini also estimated [5] the longitude difference between two widely separated places such as Paris and Cayenne using three different methods:

- Lunar eclipse [November 7th, 1672.]
  Time in Paris: 5h15m40s
  Time in Cayenne: 1h47m12s
  ⟶
  Longitude difference between Paris and Cayenne:
  3h28m28s corresponding to 52°7'0".

- Conjunction of Jupiter's moons [April 1st, 1672.]
  Time in Paris: 12h43m4s
  Time in Cayenne: 9h16m40s
  ⟶
  Longitude difference between Paris and Cayenne:
  3h26'33" corresponding to 51°38'15".

- Comparison of the difference of the meridian altitude of the Sun at the Equinoxes [September 22th, 1672 and Mars 20th, 1673.]
  ⟶
  Longitude difference between Paris and Cayenne:
  3h42m corresponding to 55°30'.

The real longitude difference between Paris and Cayenne is 3h39m22s in time units (corresponding to 54°50'30") thus Cassini's estimates were in this case not accurate as they were for Hven, which is not unexpected due to the much larger distance of the two places. The best measure was the third one, providing an error of about 40', the first and the second instead resulted into an inaccuracy of about 3° (2°43' and 3°12' respectively).

Thus, using Galileo's method, Cassini was the first to obtain an accurate longitude measurement proving that although the method had turned out to be not feasible to obtain the longitude of a rolling ship, it had given excellent results on land. For geography, cartography and astronomy that was an epoch-making accomplishment.

In the 1670s, the French astronomers, under Cassini's guide, began to observe the satellites from places all over France. It resulted that the maps had overestimated France extension in both its West and South direction. There was 1° less land on the Atlantic coast and on the Mediterranean one as well. Earlier maps had underestimated the distances to other continents and exaggerated the outlines of the French nation which turned out to be significantly smaller than what it was believed to be. That, of course, was disliked by the King.

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[5] Cassini G. D., De Varin, Deshayes, J., Glos G., *Élémens de l'astronomie vérifiez par M. Cassini par le rapport de ses Tables aux observations de M. Richer faites en l'isle de Caïenne. Avec les observations de MM. Varin, Des Hayes et de Glos faites en Afrique et en Amérique.* (1684) Paris, Imprimerie Royale, pp. 13-15.

"King Louis XIV of France, confronted with a revised map of his domain based on accurate longitude measurements, reportedly complained that he was losing more territory to his astronomers than to his enemies." [6]

The method of determining longitudes observing Jupiter's satellites eclipses played a fundamental role in the eighteenth century evolution of geodesy: travelers and explorers routinely timed eclipses and sent their results back to Europe to determine the exact longitudes of places.

5.2.1 Ole Rømer's determination of the speed of light

Cassini soon realized that times between eclipses became shorter when the Earth was approaching Jupiter and longer when the Earth was moving away. That led him to conclude that light was taking time to reach the Earth, starting from Jupiter's satellites.

It was because of Cassini's tables that the Danish astronomer Ole Rømer [7] decided to focus on the eclipses of Jupiter's satellites.
With reference to Fig. 5.1 (derived from Rømer's original work), Rømer supposed the Earth to be in point L at Io emersion (point D) and when Io returned in D (after having revolved around Jupiter in 42.5 hours), the Earth had moved to K. Thus, the emersion would have been seen with a delay equal to the time needed for light to cover the distance from L to K, corresponding to about 210 terrestrial radii.
We now know that the time taken by the light to cover the distance between L and K is about 0.04 seconds, something impossible to be measured by Rømer, who adopted a different strategy. He measured 40 Io's eclipses when the Earth was on side F and another 40 ones when the Earth was on side K. The former were obviously shorter as the Earth was approaching Jupiter and the latter longer as the Earth was moving away.
Rømer found that the difference amounted to 11 minutes for the entire distance from point H to point E, to be compared with the true value of 16 minutes 38 seconds.

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[6] Sobel D., *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time.* (1996) New York, Penguin.

[7] Ole Rømer (1644, Århus, Jutland - 1710, Copenhagen) more on appendix A.24.

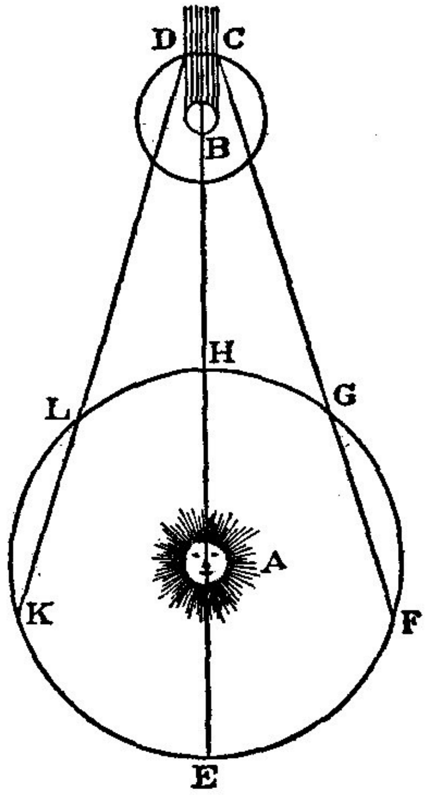

Figure 5.1: Sketch reproducing Rømer's original work *Démonstration touchant le mouvement de la lumière trouvé par M. Roemer de l'Académie des sciences.* (Dec. 7, 1676) Journal des Sçavans, pp. 276. It shows the Sun (A), Jupiter (B), and the Earth at different times of the year (G, H, L, K, and E) as Io begins to eclipse at C and emerge from Jupiter's shadow at D.

Rømer's result published on December 7th, 1676, in the *Journal des Sçavans*, was obviously wrong [8] but despite this, his method and his intuition were correct and even more important, he gave the first experimental proof that the light had not an infinite speed.

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[8] It must stressed that Rømer's original work is very difficult to interpret, and this is the reason why different authors gave different values for the speed of the light derived by him.

Demonſtration touchant le mouvement de la lumiere trouvé par M. Römer de l'Academie Royale des Sciences.

IL y a long-temps que les Philoſophes ſont en peine de decider par quelque experience, ſi l'action de la lumiere ſe porte dans un inſtant à quelque diſtance que ce ſoit, ou ſi elle demande du temps. Mr. Römer de l'Academie Royale des Sciences s'eſt aviſé d'un moyen tiré des obſervations du premier ſatellite de Jupiter, par lequel il démontre que pour une diſtance d'environ 3000 lieuës, telle qu'eſt à peu prés la grandeur du diametre de la terre, la lumiere n'a pas beſoin d'une ſeconde de temps.

Soit A le Soleil, B Jupiter, C le premier Satellite qui entre dans l'ombre de Jupiter pour en ſortir en D, & ſoit E F G H K L la Terre placée à diverſes diſtances de Jupiter.

Or ſuppoſé que la terre eſtant en L vers la ſeconde Quadrature de Jupiter, ait veu le premier Satellite, lors de ſon émerſion ou ſortie de l'ombre en D; & qu'en ſuite environ 42. heures & demie aprés, ſçavoir aprés une revolution de ce Satellite, la terre ſe trouvant

en K, le voye de retour en D: Il eſt manifeſte que ſi la lumiere demande du temps pour traverſer l'intervalle L K, le Satellite ſera veu plus tard de retour en D, qu'il n'auroit eſté ſi la terre eſtoit demeurée en K, de ſorte que la revolution de ce Satellite, ainſi obſervée par les Emerſions, ſera retardée d'autant de temps que la lumiere en aura employé à paſſer de L en K, & qu'au contraire dans l'autre Quadrature FG, où la terre en s'approchant, va au devant de la lumiere, les revolutions des Immerſions paroiſtront autant accourcies, que celles des Emerſions avoient paru alongées. Et parce qu'en 42 heures & demy, que le Satellite employe à peu prés à faire chaque revolution, la diſtance entre la Terre & Jupiter dans l'un & l'autre Quadrature varie tout au moins de 210 diametres de la Terre, il s'enſuit que ſi pour la valeur de chaque diametre de la Terre, il faloit une ſeconde de temps, la lumiere employeroit $3\frac{1}{2}$ min. pour chacun des intervalles GF, KL, ce qui cauſeroit une difference de prés d'un demy quart d'heure entre deux revolutions du premier Satellite, dont l'une auroit eſté obſervée en FG, & l'autre en KL, au lieu qu'on n'y remarque aucune difference ſenſible.

Il ne s'enſuit pas pourtant que la lumiere ne demande aucun temps: car aprés avoir examiné la choſe de plus prés, il a trouvé que ce qui n'étoit pas ſenſible en deux revolutions, devenoit tres conſiderable à l'égard

Figure 5.2: Ole Rømer, *Démonstration touchant le mouvement de la lumière trouvé par M. Roemer de l'Académie des sciences*, Journal de Sçavans, December 7th, 1676, pp. 276-277.

Chapter 6

The Earth-Sun distance

The Earth-Sun distance value (also called Astronomical Unit, AU) has been looked for since ancient time, with a first attempt to evaluate it due to the Greek astronomer Aristarchus of Samos (c. 310 BC - c. 230 BC) who, anyway, largely underestimated it, finding that the Sun should have been only 19 times farther, from the Earth, than the Moon. Subsequent estimations increased the AU value which however remained limited within one twentieth and one tenth of its real value. The Copernican revolution brought new ideas about the solar system and Kepler's third law offered a way to determine the AU, thus astronomers and other scientist like Picard, Cassini, and Newton, became interested in deriving the value of the distance from Earth to the Sun.

6.1 The Earth dimension

The measure of the Earth size dates back to the Ancients Greeks and, in particular, to Eratosthenes of Cyrene (c. 276 BC, Cyrene, Libya - c. 194 BC, Alexandria, Egypt) who, in the third century BC, proposed a method to derive the Earth radius. Eratosthenes had noticed that in Siene (located on the Cancer tropic) objects did not produce any shadow on the summer solstice midday, while they did it in Alessandria (which was located North of Siene). The difference between the altitude of the Sun in each place (90° in Siene and 83° in Alessandria) turned out to be 7° and corresponded to the angle, on the Earth surface, subtended by the two locations (i.e. their latitude difference). Measured the angle and the distance between the towns, the Earth circumference could be determined multiplying the distance for 360°/7°. The value obtained by Eratosthenes (40.500 km) was extraordinary close to the real ones (40.075 km at the equator and 39.941 km at the poles).

Between 1669 and 1670 Jean Picard presented ideas and three new instruments to be built (a portable quadrant, a zenith sector, and a level), to obtain a careful determination of the Earth dimensions. Also, in those years he performed and completed geodetic measurements along the meridian line coinciding with the *Observatoire* symmetry axis and accurately determined [1] he Earth diameter,

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[1] Débarbat S., *The French Savants, and the Earth-Sun Distance: a Resumé.* (2013) The

finding a value of 6.375 km, for the Earth equatorial radius to be compared with the real value [2] of 6.378 km). The following year (1671) he published *Mesure de la terre*, one of his most important work.

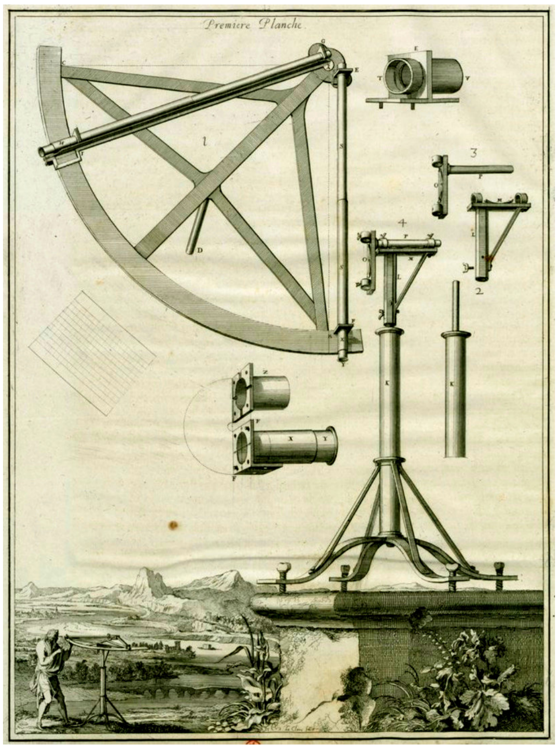

Figure 6.1: Picard J., *Mesure de la terre [par l'abbé Picard].* (1671) Paris, Bibliothèque nationale de France, département Réserve des livres rares, Rés.S-2. Quarter circle for angular measurements, "38 inches in radius", described in article V, pp.5 and following.

6.2 The solar parallax

The empirical relation $(\frac{a^3}{T^2} \simeq k)$ between the planets orbital periods (T), and their average distances from the Sun (a) (with k being a constant value) had been found by Johannes Kepler in 1619, and it is better known as Kepler's third law. This relation provided astronomers with a useful tool to derive the distances between the planets and the Sun as a function of the Earth-Sun distance. Planets orbital periods could be easily measured and planets distances from the Sun (in AU) could be derived too, with triangulation methods.

What was still missing was the real value of one AU, which would have also enabled the determination of the solar system extension, believed, at that time, to coincide with the entire Universe.

Journal of Astronomical Data, Vol. 19, pp. 109-120.

[2] The value adopted by the International Astronomical Union in 2009.

To obtain the AU value, one should have measured the angle π, under which an observer placed on the Sun surface centre would have seen the Earth equatorial radius R_E. That angle is the solar horizontal parallax which, coupled with R_E, enables derivation of the AU value by means of the very simple relation: $\frac{R_E}{AU} \simeq tan\pi$. Being π extremely small (8.8"), the relation reduces to $\frac{R_E}{AU} \simeq \pi$, from which: $AU \simeq R_E\pi$.

It is, obviously, impossible to "sit" on the Sun surface centre and measure an angle from there, however the solar parallax can be derived measuring from two (as much) distant (as possible) places on Earth the position of the Sun centre. That is not at an easy task at all, due to the difficulty of identifying, with high accuracy, the Sun centre from the Earth. One could then choose to measure the Sun limb position, but the lack of a marker on it and of stars (missing in day time) which might act as reference points, would result into an almost impossible identification of the exact position from the other observing station.
It must be stressed, however, that the measurements of the Sun (centre, or limb) height performed by (distant) places on Earth surface do not exactly correspond to the solar horizontal parallax but are related to it through geometrical calculations.

6.2.1 Parallax

Before going to Richer's measurements from Cayenne, let's say something more on the parallax starting from the term itself which comes from the Ancient Greek $\pi\alpha\rho\acute{\alpha}\lambda\lambda\alpha\xi\iota\varsigma$ meaning overlap. That is why the effect of viewing an object along two different lines of sight is an apparent horizontal displacement which increases as the separation between the points of view increases, and it is larger for closer objects. The parallax effect can be verified watching objects of different distance, alternatively closing the right and the left eye. Objects will appear move to the right when closing the left eye and to the left when closing the right one, and their apparent displacement will be larger for closer objects.

Also star distances can be obtained by means of the parallax (in that case named stellar parallax, see Fig. 6.2) measuring the apparent displacement in the sky of the nearby stars, with respect to the more distant ones, because of the Earth orbital motion around the Sun. As stars are more distant than the Sun, their parallaxes are smaller (less than 1") and their measurements are more difficult. The first stellar parallax (61-Cygni) was measured by the German astronomer Friedrich Wilhelm Bessel (1784, Minden, Brandenburg - 1846, Königsberg, Prussia) in 1837. In more recent times, parallaxes for over 100.000 stars have been measured, and ESA's Gaia mission is measuring them for more than one billion stars.

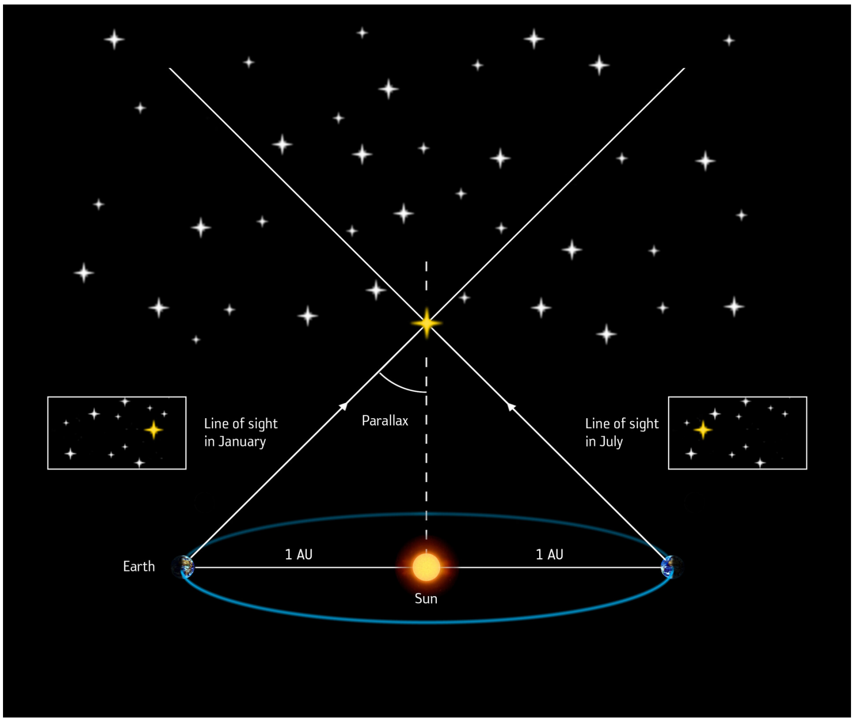

Figure 6.2: This illustration shows the shift in a star's position with respect to the distant stellar background between two observations that are separated by six months (for example, the first one in January and the second one in July). The extent of the parallax has been exaggerated for illustration purposes; even for the stars that are closest to Earth, the annual shift due to parallax is extremely small, requiring high-precision instruments. Credits: ESA/ATG medialab.

Coming back to Richer, he had been requested by Cassini to measure the Sun position from Cayenne, the angular value he would have obtained would have been subsequently compared with the one obtained simultaneously from Paris. In the second letter to Cassini is evident Richer's intention to perform that measurement:

> *" (...) connaitre si la parallaxe du soleil est sensible ou non, car j'ai lieu de croire que vous aurez fait les mêmes observations plus facilement que nous (. . .) ne s'est presque passe ancore jour depuis nostre arrivée qu'il n'aye pleu. (. . .) J'auré soin d'observer le soleil lorsquil aprochera de notre Zenit que j'estime a peu pres distant de l'Equateur du 4° entre 58' et 59' vous le saurez mieux que moy par la verification que vous aurez faites des nostre octans et par les observations que j'envoie (. . .)"* [3]

Richer did actually made several measures that he interrupted for reasons which remain unknown. It is likely, however, that he had realized that all his efforts would have not given any useful results.

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[3] Richer J., *Lettre de Richer à Cassini I, Cayenne le 20 juillet 1672, Observatoire de Paris.*

6.3 Mars parallax

Aware of the enormous difficulties related to the solar parallax measurement, Cassini had devised an alternative solution, well illustrated in Chapter XXVI of his *Élémens*, entitled *Recherche de la parallaxe du Soleil par le moyen de celle de Mars observé à meme temps à Paris et en Caïenne.* If one had measured the Mars parallax, the distance between Earth and Mars would have been obtained. Moreover, as that distance would have been also expressed in AU (as it would have been derived with triangulation methods), the AU to km correspondence would have been easily derived.

The smaller the distance of Mars from the Earth, the larger would have been its parallax, to which would have corresponded also an increase in the measure accuracy. The most favorable observational condition would have therefore had been the one in which Mars had been in opposition and hence close to the Earth. Not by chance, Cassini had decided to send Richer to Cayenne at that time as in the fall (August, September, and October) of 1672, Mars would have been at the point in its orbit closest to the Earth, after a period of time which had lasted for about fifteen years.

The best method to measure Mars parallax would have been to observe (with a telescope) the conjunction of the planet with a star. If astronomers had seen that conjunction from the two places (Paris and Cayenne) at the same time and in the same way without any difference, that would have been the proof that there was no perceptible parallax. If they had measured, instead, a time difference concerning the moment in which Mars edge had "touched" the star, that should have been due to the parallax.

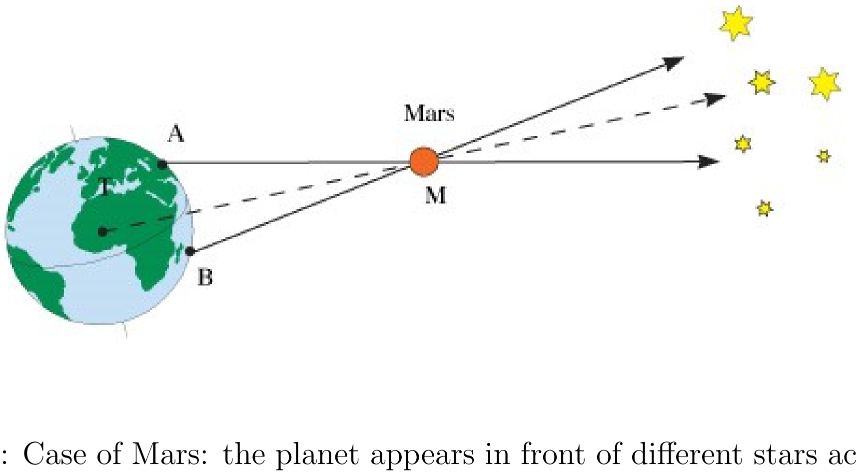

Figure 6.3: Case of Mars: the planet appears in front of different stars according to the observers' locations (in this case: Paris and Cayenne). For this planet, only the parallax principle and a calculation using a known baseline are needed to estimate the Earth-Mars distance. Credits: ESO.

Unfortunately, no close conjunction of Mars with a star would have been occurred in those months and thus Cassini had found out an alternative method: the astronomers would have both observed Mars meridian height and compared it with the meridian heights of some stars which were close to the planet.
Richer thus recorded meridian height of Mars (and of a few close stars), almost every day, from the end of July to the end of November, but his measurements were reliable only for three September nights because of unfavourable weather conditions. Cassini did the same from Paris, with better weather conditions.

Comparison of the angular displacement of Mars from the stars, allowed Cassini to derive the three following values for Mars meridian height:

- 12" on September 5th, 1672:

  > *"Mars parut donc moins élevé à Paris qu'au parallèle de Caïenne, de douze secondes."* [4]

- 13" on September 9th, 1672:

  > *"Mars parut donc moins élevé à Paris qu'au parallèle de Caïenne, de treize secondes."* [5]

- 17" on September 24th, 1672:

  > *"Mars parut donc alors plus bas à Paris qu'au parallèle de Caïenne, de dix-sept secondes."* [6]

6.4 The results

Mars meridian height was found to be lower in Paris than in Cayenne of respectively 12", 13" and 17". The third (and last) measurement resulted larger than the previous two, whereas, as Cassini stated, should have been smaller because the planet was a little further from the Earth at the end of September (while at the beginning of the month it was closer of the opposition). Thus, the observed increase of the angular difference had to be attributed to an imperceptible defect in the observations and Cassini was totally aware of that.

6.4.1 The parallax of Mars

Cassini adopted a mean value of 15" for the angular difference in Mars meridian height observed from Cayenne and Paris. From that value, he derived (see Fig. 6.4) the horizontal parallax of Mars which resulted $25''\frac{1}{3}$.

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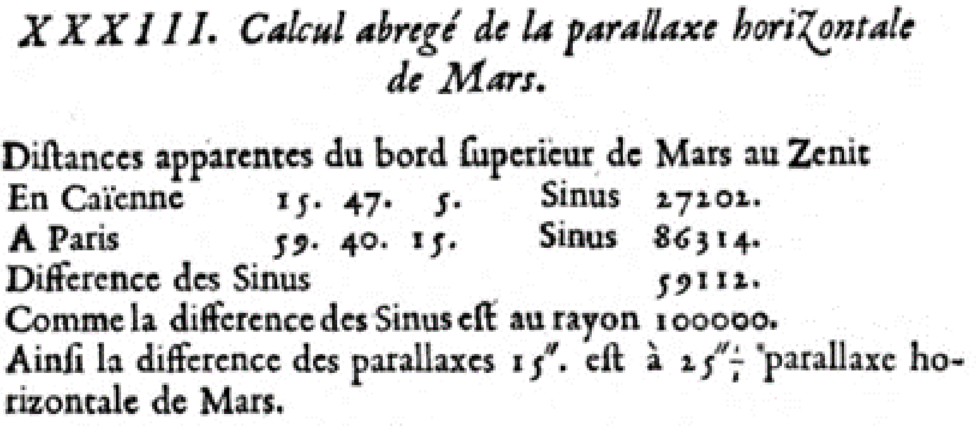
[4] G.D. Cassini, *Les Élémens de l'Astronomie verifiez par M. Cassini (...)*, p.37.

[5] G.D. Cassini, *Les Élémens de l'Astronomie verifiez par M. Cassini (...)*, p.38.

[6] G.D. Cassini, *Les Élémens de l'Astronomie verifiez par M. Cassini (...)*, p.39.



XXXIII. Calcul abregé de la parallaxe horiZontale de Mars.

Diſtances apparentes du bord ſuperieur de Mars au Zenit
En Caïenne 15. 47. 5. Sinus 27202.
A Paris 59. 40. 15. Sinus 86314.
Difference des Sinus 59112.
Comme la difference des Sinus eſt au rayon 100000.
Ainſi la difference des parallaxes 15″. eſt à 25″⅓ parallaxe horizontale de Mars.

Figure 6.4: Cassini G. D., De Varin, Deshayes, J., Glos G., *Élémens de l'astronomie vérifiez par M. Cassini par le rapport de ses Tables aux observations de M. Richer faites en l'isle de Caïenne. Avec les observations de MM. Varin, Des Hayes et de Glos faites en Afrique et en Amérique.* (1684) Paris, Imprimerie Royale, p.40. Cassini's original calculations for the parallax of Mars.

6.4.2 The Earth-Mars distance

Being the horizontal parallax of Mars $25''\frac{1}{3}$, Cassini could obtain the distance between Earth and Mars (when the planet was in opposition), which resulted to be about 8100 Earth radii with a possible error of ±1000 Earth radii, due to the measurement accuracy, estimated by Cassini to amount to 3".
The result obtained by Richer and Cassini gave a value for the distance between Earth and Mars of $51.60 \cdot 10^6$ km to be compared with the value, $55.76 \cdot 10^6$ km, that can be obtained nowadays with much more accurate techniques. Thus Cassini's estimated distance was only 7.5% lower of the real one, an extraordinary result to which should be given consideration and respect.

6.4.3 The parallax of the Sun

Since the distance between Earth and Mars related to the average Earth-Sun distance as $1' : 2'\frac{2}{3}$, the same relation had to occur between solar and Mars parallaxes (being the parallax inversely proportional to the distance). Hence, from an horizontal Mars parallax of $25''\frac{1}{3}$ (corresponding to about 25,3"), Cassini derived a Sun parallax $9''\frac{1}{2}$ (9,5") to be compared with the true, nowadays value, of 8,8".

6.4.4 The Earth-Sun distance

Adopting his derived value of 9”$\frac{1}{2}$ for the solar parallax, Cassini calculated the Earth-Sun distance as 21.600 in units of the Earth radius (to be compared with the real value corresponding to 23.485 Earth radii). Cassini thus underestimated the real value of the AU (149.597.871 km) by a quantity corresponding to less than its 8% obtaining for it a value of 137.592.200 km, which resulted however in a huge unpredictable enlargement of the solar system size.
Cassini himself was surprised to have achieved such a result:

> *“Voila de grandes distances que nous venons de conclure*
> *de trois petites parallaxes.”*

Chapter 7

The heritage of J. Richer and G. D. Cassini's achievements

7.1 The solar system size

Before Cassini, not even the greatest astronomers (such as Tycho Brahe of Copernicus) had been able to derive a value for the AU which was remarkably close to the real value, exception made for Huygens who, in 1659, more than ten years in advance with respect to Cayenne expedition, had found a value (12.543 terrestrial diameters) exceeding by 7% the real one.
Huygens described the method he had used in his *Systema Saturnium* work, but his result did not have a huge impact as he derived it assuming, without being able to prove it, that Venus and the Earth had equal size. Thus, having measured with accurate telescopic observations Venus angular diameter finding for it a value of 51" from the ratio of its true diameter (set equal to the Earth one) and the angular value, he had derived Venus distance (expressed in units of terrestrial diameters). From that, using Kepler's third law he had obtained the value for the AU. Huygens assumption was not totally wrong, but since Venus diameter is about 95% of the Earth one, Venus distance was overestimated and as a consequence was also the AU.

At variance with Huygens, Cassini was the first scientist in history to derive the AU value only on the basis of observations, without assuming anything.

7.1.1 The heritage of Cassini's AU measurement

Soon after Cassini, the first English Royal Astronomer, John Flamsteed [1] obtained similar values for Mars (25") and Sun (10") parallaxes observing he too Mars, in opposition, in 1672. His results appeared in the *Philosophical Transactions* of *the Royal Society.* The method used by Flamsteed was much more comfortable than Cassini's one: instead of sending someone to the other side of

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[1] John Flamsteed (1646, Denby, Derbyshire, England - 1719, Greenwich, London) more on appendix A.9.

the world to measure the angular displacement of Mars (as Cassini did), Flamsted measured the angular height of Mars from Greenwich (London) twice, letting some hours pass between his first and his second observation. In this way he exploited the Earth rotation around its axis: knowing, with a good approximation, the linear displacement due to the Earth rotation, he was able to derive Mars distance from its measured angular displacement in the sky. From it, similarly to Cassini, he derived the AU value, which turned out to be about 130.000.000 km, somewhat lower than Cassini's value but still in fair agreement with it.

Isaac Newton in his *Philosophiae naturalis Principia Mathematica* appears to have adopted a value for the solar parallax of 10.5", close to Flamsteed's one. His colleague and good friend Edmond Halley [2] in 1719, following some observations of Bradley, could only conclude that the parallax of the Sun was between 9" and 12". In France, other observers in the middle of the eighteenth century [3], thought it had to be within 11" and 15".

The French astronomer Nicolas Louis de Lacaille (famous for his having mapped the constellations visible from the Southern Hemisphere and having named most of them, see Sect. 4.3.1), would have launched in the 1750s a call to his European colleagues, with several objectives. Among them, there would have been the requests to test the lunar distance method [4] proposed by the British for improving navigation, and to observe Mars and Venus.
Lacaille would have left Paris in 1750, and once back home four years later he would have determined, among several other things, the Mars, Venus and solar parallaxes, comparing his observations from South Africa with those made from Europe. Despite the increased quality of his astronomical instrumentation as compared with Cassini's one, Lacaille's solar parallax 9,005" to 10,002" was quite similar to Cassini's one.

7.1.2 Venus transit

It had been the Scottish mathematician and astronomer James Gregory (1638, Drumoak, Scotland - 1675, Edinburgh), who had suggested [5] that the observations of a Venus transit (first predicted in 1628 by Johannes Kepler) could have been used to calculate the solar parallax and hence the AU.

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[2] Edmond Halley (1656 - 1742, London) more on appendix A.13.

[3] A concise essay written by François Arago (1786-1853), concerning the most famous determinations of the solar parallax obtained in the seventeenth and eighteenth centuries, can be found in *Astronomie Populaire* (1867).

[4] In 1475 the German mathematician Regiomontanus (1436-1476) had developed the lunar distance method to find longitude: it consisted in measuring the angular distance between the Moon and a star or between the Moon and the Sun. The method was sound, but instrumentation was not good enough and lunar tables were too inaccurate as well. It would have been only with the development of the sextant and the availability of more precise lunar tables, that the lunar distance method for determining longitude would have proved to be successful.

[5] Gregory J., *Optica promota, seu Abdita radiorum reflexorum et refractorum mysteria, geometrice enucleata.* (1663) London, J. Hayes for S. Thomson.

Edmond Halley, aware that would have not been alive when Venus would have passed over the Sun surface, devised a method to derive from data the solar parallax which he left, as a gift, to the next generation of astronomers to observe. Actually, he mad more than that, as he alerted them about the importance of those observations. [6]
Venus would have been the reference point to be identified on the Sun surface and as observers in different places would have seen it displaced, their observations combined all together would have provided the so long sought AU which would have been derived directly (and not through the parallax of Mars as Cassini had done). Even more important, the method devised by Halley did not require obtainment of any angular measurements, as measuring the length of the event, from as many places on Earth as possible, would have been sufficient. Observer thus would have needed only a telescope with colored lenses (to protect the eyes from the light of the Sun) and a reliable watch.

There are however a few complications due to the fact that both Venus and the Earth are moving (orbiting around the Sun) during the transit. Referring to Fig. 7.1 the points A and B (where observers are located) are moving due to the rotation of the Earth on its axis, and T and V are moving too due Earth and Venus orbiting around the Sun. Because of that, and also because of bad weather conditions and other accidents occurred during the 1761 Venus transit, only in the following one (1769) astronomers managed to obtain an Earth-Sun distance value (151.225.000 km) more accurate than the one obtained by Cassini almost one century before.

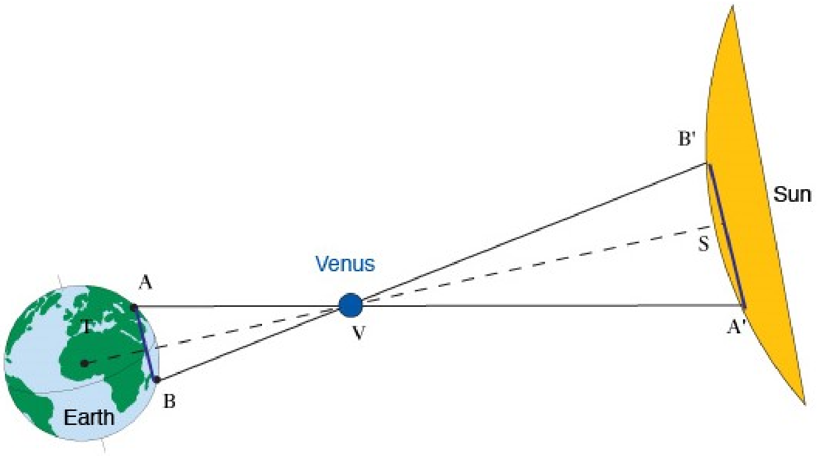

Figure 7.1: Case of Venus: the projection of the planet's dark disc on the solar disc at the time of a transit differs for two terrestrial observers. Credits: ESO.

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[6] Wulf A., *Il passaggio di Venere: La nascita della comunità scientifica internazionale attraverso una straordinaria avventura astronomica.* (2012) Milano, Adriano Salari Editore S.p.A.

7.2 The second great achievement: the length of the pendulum swing

One of the most noticeable Richer's achievement concerned the length of the pendulum swing he had brought with him (described in section 2.3.1). By keeping the time with another mechanical clock, the astronomer found out that there was a difference of *"une ligne et un quart"* in the length of the pendulum swing between Cayenne and Paris. Richer wrote that time keeping of his pendulum was right only if its swing was shortened in Cayenne by $1\frac{1}{4}$ lignes (2.8 mm) with respect to the length it had in Paris.

Thanks to that finding, which Richer wrote in his report, Huygens understood that the Earth rotation produced a centrifugal force, which lowered the body weights by a latitude depending factor. A body placed at the Earth poles would have had his weight unchanged, while if placed at the Earth equator would have undergone the largest decrease of its weight. Translated into "horological terms": the diminution of weight by centrifugal force implied that a pendulum working fine at the poles would have been late at the equator by a bit more than 2.5 minutes per day.

7.2.1 The birth of gravimetry

It would have been Isaac Newton who, using different observational data [7] would have explained the reason why bodies were diminishing their weights at the equator. Explaining, in the third book of his *Principia*, the basic principles of gravitation and the concept more commonly known as the $\vec{g}$ force, he had demonstrated that the force of gravity decreased with the inverse square of the distance between objects. Thus, the obvious conclusion to be drawn from pendulum data was that places near the equator (such as Cayenne) were farther than Paris from Earth center, and gravity was for that reason lower there.
The following Table shows the values of the latitude, the gravitational acceleration and the length of the pendulum in three places: Uraniborg, Paris and Cayenne.

Place	Latitude	$\vec{g}$	Length
Uraniborg	55°5428 North	9.8156	99.453
Paris	39°5426 North	9.8094	99.392
Cayenne	4°5559 North	9.7897	99.099

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[7] Newton referred to Richer's Cayenne data, Edmond Halley's data acquired in 1677 during his voyage to St. Helena, and also data from 1681-83 Varin and Des Hayes' expedition to the Caribbean islands of Martinique and Guadeloupe.

Isaac Newton and Christiaan Huygens had suggested that Earth was not a perfect sphere, being flattened at its poles: Richer was the first one who observed a gravitational force change on the Earth surface, starting in a way the science of gravimetry, which is the branch of geophysics dealing with the Earth gravitational field studies and measurements. Since that, pioneering epoch huge technological developments have occurred and now the gravitational field at the Earth surface is known in detail (see Fig. 7.2).

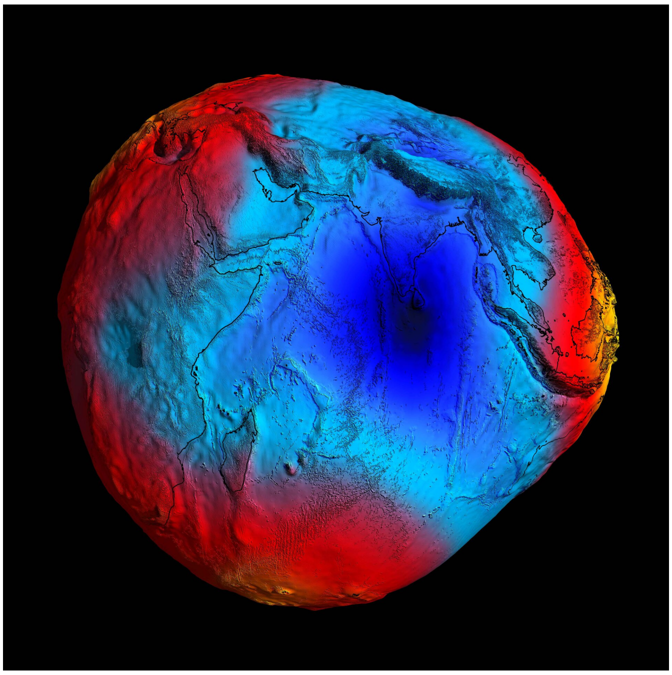

Figure 7.2: In 2011, ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission delivered a model of the geoid pictured in the image: the colours represent deviations in height (–100 m to +100 m) from an ideal geoid. The blue shades represent low values and the reds/yellows represent high values. Credits: ESA.

7.2.2 The birth of modern cartography

On the other hand, Cassini was strongly convinced that the Earth was elongated in the direction of its poles and for this reason in 1683 had proposed to measure an arc of meridian from the North to the South of France to determine the shape of the Earth. That project was part of the vast program of geodetic and topographical operations originated by Colbert's reformist policy aiming to obtain a complete knowledge of territories and ways of communication throughout France, together with an accurate mapping of the kingdom, which were very imprecise at the time.

Modern cartography was born, thanks also to the geodetic surveys carried out between 1668 and 1670 by Picard (considered because of those works the founder of geodesy). His topographic method (triangulation), which was detailed described in *Mesure de la terre [par l'abbé Picard]*, consisted in obtaining (by sightings) the angles of a triangle which vertices (tower, summit, bell tower, etc.) had been chosen because of their visibility. The first triangle was then chained to another one, which had one side in common with it (see Fig. 7.3), and the chain continued along the meridian which had to be measured.

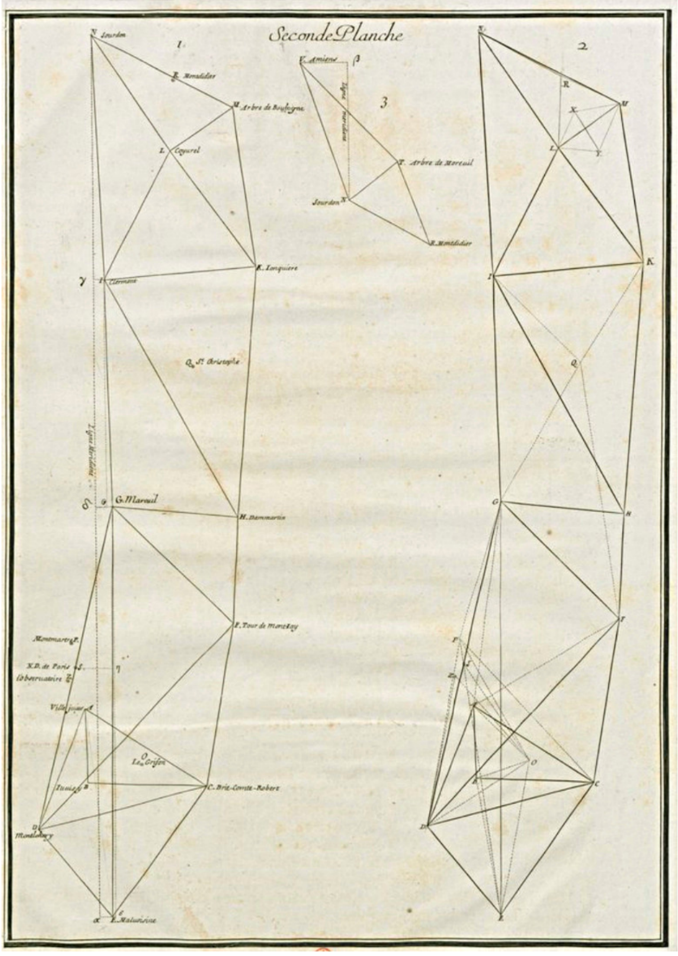

Figure 7.3: Picard J., *Mesure de la terre [par l'abbé Picard].* (1671) Paris, Bibliothèque nationale de France, département Réserve des livres rares, Rés.S-2, Article VI, (p.7 and following). Image describing distance determination by triangulation.

After having presented a first draft of the *Carte de France*, in 1682, Picard had died leaving to Cassini the task of finishing his work. Cassini's project was cancelled for financial reasons in 1684 when he had just arrived to Bourges (a town located almost exactly in the center of France) and because of that, Cassini abandoned the idea of finding evidence to prove the Earth's shape. However, ten years later, in 1693, a corrected map (see Fig. 7.4), based on different measurements, was published by him.

Completion the France detailed cartographic work would have been committed to Cassini's successors, and the "portrait" of the country (182 sheets), would have been presented to the *Académie* members in 1790 by Cassini IV, after almost one century and half of work.

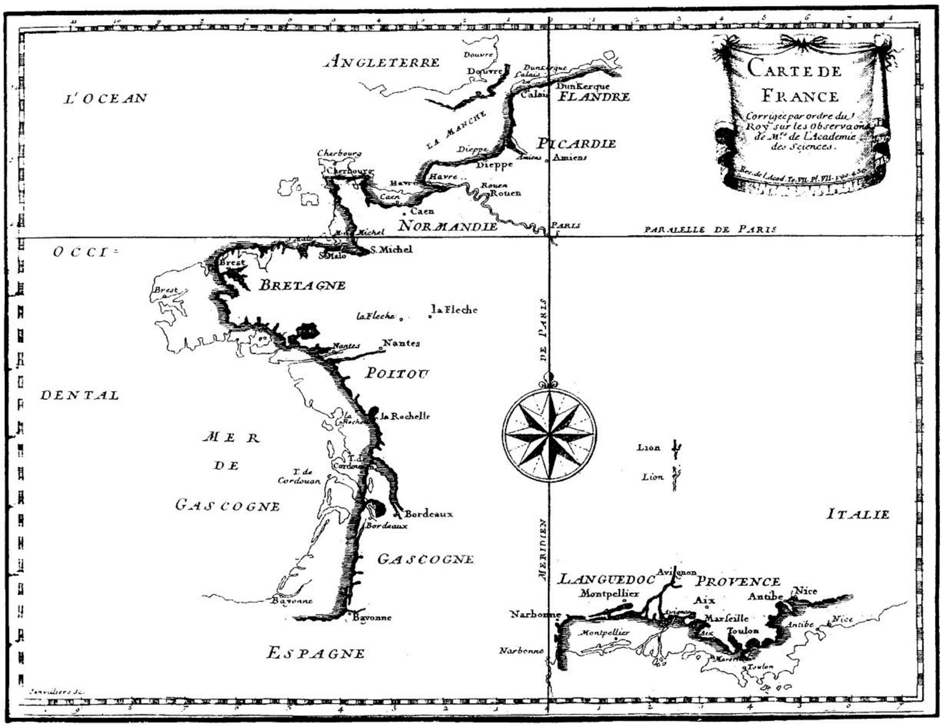

Figure 7.4: Cassini G. D., *Carte de la France* published in *De l'origine et du progrès de l'astronomie et de son usage dans la géographie et dans la navigation, Recueil d'observations faites en plusieurs voyages par ordre de sa Majesté pour perfectionner l'astronomie et la géographie.* (1693)

For what concerns the controversy about the shape of the Earth, after the publishing of the work *De la grandeur et de la figure de la Terre* by Jacques Cassini in 1720, the conflict in France among Newtonian and Cassini's supporters become serious.

7.3 Conclusions

The most impressive results of the Cayenne expedition were largely astronomical, and they were considerably advanced for the seventeenth century science. Because of the growth of scientific journalism, the results and principal achievements were published in French periodicals.

Jean Richer's 1673 return to Paris was duly celebrated and his accounts were discussed also in some *Parisienne salons*: Huygens, for example, is said to have read some of Richer's letters from Cayenne to a group of ladies at the salon of Madame De Cahunes. However, for unknown reasons, the publications of Richer's notes were delayed, and appeared only in 1679 in the work entitled *Observations Astronomiques et Physiques faites en L'isle de Caïenne par M. Richer, de l'Académie Royale des Sciences* (which has been largely described in the previous Chap. 2, 4 and 6).

The principal characteristics and achievements of the two-year expedition in Cayenne have been analyzed in this work and will be just briefly summarized here:

- The expedition had been carefully prepared both in its broad aspects and smallest details: a specific observational program had been decided before the astronomer left for the expedition.
- The "leading actor" was a promising astronomer and engineer, a skilled scientist who embodied the figure of scientific development in the late seventeenth century.
- The success of the astronomical observations was not only linked to the skills of the astronomer, but also to the instruments that had been chosen and tested for the expedition.
- Thanks to the development of periodicals, the results of the expedition were published and spread around European countries, despite being linked to very complex astronomical subjects. In a way it was as if science had become accessible to all.
- An attempt to investigate definite scientific problems (and not only to collect materials or data of general interest to science) started to grow up thanks to the expedition.
- The expedition represented at the same time the highest point of an older scientific tradition lasted for centuries, and the starting point for a new and innovative scientific method of investigation.

It must be stressed that, at the time, several sciences (such as botany, zoology, mineralogy, and other branches of natural history) were still predominantly based on collecting data which were simply observed, described, and classified. Much of that collecting did not have a specific intent. Criteria needed to perform critical selection of materials and data were still lacking.

Thus, a carefully planned voyage of a trained scientist, aiming to investigate specific phenomena and to find evidences for particular theories, was a remarkable innovation and resulted into an advance in scientific techniques. Of course, royal consent and financial assistance were absolutely indispensable, conditions which were fulfilled in France, for the first time, only shortly before 1670.
The expedition to Madagascar, which destination become Cayenne, was conceived in favourable circumstances as the technical, scientific, financial and political support all existed at the same time. Thus, it was because of the lack of all those conditions put together, that expeditions similar to the Richer's one had not be carried out before.

The success of Jean Richer's expedition to Cayenne promoted planning of other scientific voyages. In 1735, the French naturalist Charles-Marie de La Condamine (1701 - 1774, Paris) went to Peru to measure an arc of a meridian: his aim was to establish the shape of the Earth and solve the controversy (see Sect. 7.2) about it. La Condamine was also the first adventurer accomplishing the scientific exploration of the Amazon River.
Only one year later, to definitively solve the controversy on the Earth true real shape the *Académie des Sciences* promoted other two scientific expeditions charged to measure one meridian degree at the pole and at the equator: the 1736 voyage to Lapland, which was under the direction of the French mathematician and philosopher Pierre-Louis Moreau de Maupertuis (1698, Saint-Malo, France - 1759, Basel, Switzerland), provided the experimental proof of the universal gravitation theory, definitively showing that the Earth was a flattened spheroid.

The Baconian spirit and ideals spread on associations of scientists (such as the *Académie des Sciences* and the *Royal Society of London*), being Baconianism a philosophical framework derived from the thought of the scholar Francis Bacon (1561, York House, London - 1626, London), which was not characterized by adherence to specific scientific theories, but rather by the interest in new ways of creating knowledge.

The two-years voyage of Jean Richer not only provided significant astronomical results, but should also be considered as the first modern scientific expedition marking the end of an old scientific tradition and the beginning of a new one.

Appendix A

Something more about scientists, astronomers and instrument makers mentioned in this work

A.1 Auzout, Adrien

Adrien Auzout (born 1622, Rouen, France - died 1691, Rome) was the eldest child of a clerk in the court of Rouen, who had another three sons and three daughters. Adrien attended the Jesuit College in Rouen where he might have met and known the French mathematician Blaise Pascal (1623, Clermont-Ferrand, France - 1662, Paris): some authors state that Auzout and Pascal collaborated after Pascal had settled in Rouen in 1639. What is undoubtedly true is that both became interested in vacuum studies around 1646 either working together of individually.

In fall 1647, Auzout devised an ingenious experiment showing, incontestably, the role of the air pressure in the barometric experiment. In 1660 then, he started devoting himself to astronomical instruments: he gave a significant contribution to the final development of the micrometer, together with Jean Picard, with whom he started making systematic observations by means of their high quality new instruments.

Adrien was elected a fellow of the *Royal Society* in 1666 and was one of the founders of the *Observatoire de Paris*. He moved to Rome around 1670s, and there he died on May 23rd, 1691; little is known about his activity during the last 20 years of his life.

A.2 Baliani, Giovanni Battista

Giovanni Battista Baliani (born 1582 - died 1666, Genoa), son of a senator, was trained in the law and spent most of his life in public service. His scientific interests appear to have begun around 1611 in Savona.

In 1613 Filippo Salviati (the well known friend of Galileo) met Baliani and wrote to Galileo about him. Galileo started to correspond with Baliani about the experimental determination of the weight of air: the continuous correspondence between Baliani and Galileo that lasted for many years, shows that Baliani had been a talented experimenter and an ingenious speculator.

Concerning astronomy, although Baliani preferred Tycho Brahe's system to Copernicus' one, he speculated on a terrestrial motion as the possible cause of tides. In 1638 he published a short treatise on heavy bodies motions, which he reprinted in 1646 after having made several additions. Baliani's argument embodied an important step towards the mass concept and the acceleration analysis, but it was completely misunderstood and because of that, Baliani started to be associated with the hypothesis, rejected by Galileo, that free fall velocity increased with increasing path.

Baliani's unpublished works were collected and printed after he had died: they include several philosophical dialogues and discussions on light, action at a distance, vacuum existence and some experiments with prisms. Those works were republished in 1792 together with a biography by an anonymous writer and several letters stating the achievements reached, with notable ability and success, by that amateur scientist.

A.3 Bradley, James

James Bradley (born 1693, Sherborne, England - died 1762, Chalford, England) attended the Balliol College in Oxford and was instructed in observational astronomy at Wanstead, Essex, by his uncle, the Rev. James Pound, who introduced him to the famous astronomer Edmond Halley. On recommendation of the latter one, Bradley was elected fellow of the *Royal Society* in 1718.

In 1725, he made one of the two discoveries which made him acquire huge fame: he noticed that the star γ-Draconis had shifted towards South by an astonishing amount of 1" in three days: he correctly interpreted the apparent stellar shift as due to the combination of the Earth orbital motion (i.e. the parallax) and the finite speed of the light. Bradley communicated that discovery (to which would have been given the name of "light aberration") to the *Royal Society* in 1728 and on the basis of his observations, derived a value for the light speed (295.000 km/s) in very good agreement with the true one (299.792 km/s) .

Continuing his measures on stars positions (between 1727 and 1732) Bradley made his second discovery revealing what he would have called the "annual change of declination" in some of the fixed stars. That phenomenon could not be accounted for by light aberration and Bradley correctly concluded that it was caused by the slight and uneven nodding motion of the Earth axis (known as nutation) resulting from the direction changes of the Moon gravitational pull. For that finding he would have been awarded in 1748 the Copley Medal by the *Royal Society*.

The bulk of Bradley's observations would have been published after his death and the German mathematician Friedrich Wilhelm Bessel (1784, Minden, Brandenburg - 1846, Königsberg, Prussia), who would have organized and analyzed all Bradley's data, corrected them for their small instrumental errors and recomputed the star positions.

A.4 Brahe, Tycho

Tycho Brahe (born 1546, Knutstorp, Sweden - died 1601, Prague) studied in Copenhagen and then in Leipzig receiving a comprehensive education. He became interested in astronomy after he observed, in 1563, Jupiter and Saturn conjunction. In his *De nova stella* of 1573 he showed how his accurate measurements indicated that the new star appeared in the previous year, lacked the parallax expected in sub-lunar phenomena and had, therefore, to be located above the atmosphere and beyond the Moon. That new star was a supernova (SN 1572), belonging to our galaxy, which would have been named after Tycho. The lack of parallax for comets too, would have allowed Tycho to correctly establish also that comets were not atmospheric phenomena at all.

Tycho was author of a model in which the Earth was at the centre of the solar system and the Moon and the Sun were orbiting around it. At variance with Ptolemy's model, in Tycho's one the planets were orbiting around the Sun.

King Frederick II granted Tycho an estate on the Hven island where Tycho built two observatories: Uraniborg and Stjerneborg, which names respectively meant "The Castle of Urania" (Urania being the Muse of Astronomy) and "Stars Castle". They were observatories without telescopes, but nevertheless the huge quadrants projected by Tycho himself and made by the best craftsmen of the epoch, allowed Tycho to obtain excellent data (such as the ones concerning Mars which would have allowed Kepler to discover that the planet orbit was elliptical).

A.5 Campani, Giuseppe

Giuseppe Campani (born 1635, Castel San Felice, Perugia - died 1715, Rome) was an Italian optical instruments maker. Of peasant origin and youngest of four brothers, Campani studied in Rome where he learned to grind lenses and in 1656, together with his two brothers, invented a silent night clock which had an enormous success.

He then devoted himself, for about 50 years, to lens grinding and he made lenses and telescopes for famous astronomers and even for the *Observatoire* in Paris. In 1664 he developed a lens-grinding lathe, allowing him to make high quality lenses for telescopes. Concerning the latter ones, he improved their tubes, making them in durable wood and not in cardboard covered with leather, as they used to be (Campani's telescope would have been used until the nineteenth century).

With his own instrument that came to be known as the Campani eyepiece, he observed (between 1664 and 1665) Jupiter's moons and Saturn's rings. Campani achieved a huge fame not only in Italy, but also in Europe, however, he did not have a lucky life: he argued with his brothers, he had two daughters and his wife dead probably because of an epidemic plague, and he had no apprentices as he was afraid they could have stolen his secrets.

In the 1970's some science historians speculated about the existence of two Giuseppe Campani, who worked simultaneously in Rome (one being the silent watch inventor and the other one being the famous lens maker) as to them it seemed very unlikely that a single man could have done all that work.

A.6 Copernicus, Nicolaus

Nicolaus Copernicus (born 1473, Toruń, Poland - died 1543, Frombork, German) orphaned as a child, he studied in Kraków (thanks to his uncle who took care of him) where he learned Latin and astronomy. He then moved to Bologna where he stayed four years, studying to undertake an administrative career in the Church but the observations he made with Domenico Maria Novara (1454, Ferrara - 1504, Bologna) who was a Bologna University professor, made him understood that his true passion was astronomy.

After having traveled all over Italy and held astronomical lectures in front of the Pope, he returned home and wrote the *Commentariolus*, a manuscript in which he formulated an alternative version of the Ptolemaic geocentric system. It was the astronomer Georg Joachim Rheticus (1514, Feldkirch - 1574, Košice) who convinced Copernicus to publish the first part of his work, anonymously and later to publish its whole work *De revolutionibus orbium coelestium* in 1543, when Copernicus was about to die. The anonymous preface written by the Lutheran theologian Andreas Osiander (1498, Gunzenhausen - 1552, Königsberg) stated that the heliocentric model of Copernicus did not have necessarily to be true, but just useful for computational purposes, a mere mathematical hypothesis. That was not at all true, Copernicus model with the Sun at the centre and the Earth orbiting around it (similarly to all the other planets) and rotating around its axis from West to East was able to explain all the observations which did not fit Ptolemy's model. The only wrong thing in is work was that he kept the ancient vision linking sphere and circle to perfection and thus assumed that planetary orbits were circulars.

A.7 Delisle, Joseph-Nicolas

Joseph-Nicolas Delisle (born 1688 - died 1768, Paris) was an astronomer who suggested that the colored rings sometimes observed around the Sun were caused by sunlight refraction through water droplets in a cloud. In 1725 he went to St. Petersburg where he founded an astronomical institute: he stayed there for 22 years and trained the first generation of Russian astronomers.

In his *Mémoires pour servir à l'histoire et au progrès de l'astronomie*, of 1738, he gave the first method for determining the heliocentric coordinates of sunspots. Back in Paris, in 1747, he was appointed geographic astronomer in the naval department, and established an observatory in the Cluny Hôtel. In 1753, he organized a worldwide expedition aiming to determine the Earth-Sun distance (AU) through observations of the Venus transit, foreseen in 1761.

A.8 Divini, Eustachio

Eustachio Divini (born 1610 - died 1685, San Severino Marche, Macerata) remained orphan as a child and his brothers Vincenzo and Cipriano looked after him and gave him a basic education before moving to Rome, where he is likely to have attended lectures by Benedetto Castelli (1577/8 - 1643, a disciple of Galileo) who taught him the fundamentals of geometry and astronomy. He soon became one of the most skilled telescopes (and microscopes) makers of his epoch and sold top-quality instruments to both professional and amateur astronomers. He also wrote astronomical works, such as the *Brevis annotatio* in 1660 in which he dealt with the Saturn controversy began with Christiaan Huygens.

A.9 Flamsteed, John

John Flamsteed (born 1646, Denby, Derbyshire, England - died 1719, Greenwich, London) was the first Royal Astronomer of England. His poor health conditions had forced him to leave school at a young age, but he had studied astronomy on his own and later continued his education at the University of Cambridge. His 1675 report to the *Royal Society* about the need for a new observatory resulted in the foundation of the *Royal Greenwich Observatory* (of which he became director), but he discovered that he was supposed to supply all the instruments (exception made for few gifts) and thus he had give lectures to private pupils to augment his income.

In the last part of his life, Flamsteed was involved in a controversy related to the publication of his excellent star observations: he did not want his catalogue published before he had completed it but Newton and Halley needed those data and Newton led "the movement" for their immediate publication and the incomplete observations were edited by Halley (400 copies were printed in 1712). Flamsteed would have however finished his star catalogue, (*Historia Coelestis Britannica*) which would have been published in 1725 (six years after Falmsteed's death): in it more than 3000 stars would have been included with positions much more accurate than in any precedent work.

A.10 Fontenelle, Bernard Le Bovier

Bernard Le Bovier, sieur de Fontenelle (born 1657, Rouen, France - died 1757, Paris) was a French scientist and a man of letters, described by Voltaire as the most universal mind produced by the era of Louis XIV. Fontenelle was educated at the Jesuit college in Rouen: aged 30, he settled in Paris and became famous as opera librettos writer. Fontenelle's most famous work was the *Entretiens sur la pluralité des mondes* (1686), which charming and cultural dialogues were much more influential than any other work aiming to spread the Copernican system, still far from having reached a wide support. Fontenelle was elected permanent secretary of the *Académie* in 1697: he kept abreast of new developments in science, corresponding with scientists in most European countries.

A.11 Galilei, Galileo

Galileo Galilei (born 1564, Pisa - died 1642, Arcetri) played a major role as a physicist and astronomer in the scientific revolution made him to be often indicated as “The Father of Modern Science.” Despite his father Vincenzo (a rather known musician) wanted him to become a doctor, Galileo displayed soon a huge interest for physics which made him discover the pendulum oscillations isochronism and carry out the famous experiment of falling bodies.

In Padua, where he had got a position at the University, he got to know about the existence of an instrument (made by a Dutch glass-maker) able to make appear closer distant objects. He started working on it until he managed to make a *cannocchiale* of very good quality and at the end of 1609 he had the idea of watching the sky through it. What he saw (the Moon’s craters, Venus phases, the stars in the Milky way and four satellites around Jupiter) changed forever the ancient idea of the sky. In 1610 he published the short essay *Sidereus Nuncius* out of his observations and dedicated the four Jupiter’s satellites to Cosimo II de’ Medici (1590 - 1621, Florence) *signore di Firenze*, who offered him a much better payed position.

Florence, was however closer to Rome than Padua and the Church influence was much larger. Galileo was accused of supporting the heliocentric theory (which he actually did) and asked by Bellarmino Cardinal not to teach it anymore. He obeyed for some time but in 1632 he published the *Dialogo sopra i due massimi sistemi del mondo* and because of that, the next year, he was processed and forced to abjure heliocentrism.

He spent the last years of his life forced to remain at home but he managed however to make a work of his (*Discorsi e dimostrazioni matematiche intorno a due nuove scienze attenenti alla meccanica e i movimenti locali*) published in 1638, in Holland (out of the Inquisition jurisdiction).

A.12 Grimaldi, Francesco Maria

Francesco Maria Grimaldi (born 1618 - died 1663, Bologna) was an Italian Jesuit priest, a mathematician and physicist who taught at the Jesuit College in Bologna. He was Giovanni Riccioli’s assistant in theoretical and experimental astronomical studies. He observed the sunspots, and compiled a Moon detailed map (or selenograph) which nomenclature is still in use today. (The Moon Grimaldi crater has been named after him). Grimaldi’s studies on light diffraction can be found in his treatise *Physico-mathesis de lumine, coloribus et iride*, published posthumously in Bologna, in 1665. Grimaldi was the first who made accurate observations on that phenomenon and coined the word “diffraction”. Later on, physicists, as Newton, would have used Grimaldi’s work as an evidence in favor of the wave nature of light.

A.13 Halley, Edmond

Edmond Halley (born 1656 - died 1742, London) was interested in mathematics and astronomy since he was a child and, attending Oxford University, he was introduced to the Astronomer Royal John Flamsteed, who became his mentor.
Aged nineteen, he went to Saint Helena island where he set up an observatory equipped with a large sextant having telescopic sight. Thanks to the latter he catalogued the Southern Hemisphere stars: the account of the expedition was subsequently published under the name *Catalogus Stellarum Australium.*
As a member of the *Royal Society*, he got to know that Newton had been working on the universal law of gravitation, thus in 1684 he went to visit Newton in Cambridge and convinced him to publish his *Principia Mathematica*, which publication was financed by Halley himself. The deep estimation of Halley for Newton is clearly evident in the foreword (in form of a poem) that Halley wrote for the book.
Halley focused part of his studies on comets and following Newton's suggestion looked for possible repeated apparition of the same comet, by comparison of the orbital parameters he had derived through an accurate inspection of Flamsted observational data. He demonstrated that comets multiple apparitions could be predicted and that comets elliptical orbits were an observational proof of the heliocentric system and of the gravitational law. He derived the period of the 1P/Halley comet (named after him) he had observed in 1682, predicting that it would have shown up again between 1758 and 1759 (the comet appeared in the sky on 1758 Christmas night, but Halley had already died sixteen years before).

A.14 Herschel, William Frederick

Friedrich Wilhelm Herschel (born 1738, Hannover - died 1822, Slough, Buckinghamshire, England) followed his father's footprints, becoming a musician in the army. After the French occupation of Hanover in 1757, he escaped to England, where he became a music teacher, performer, and composer. In 1766 the intellectual curiosity he had acquired from his father led him from the practice to the theory of music, which he studied in Robert Smith's *Harmonics* and thank to that book he started to know the techniques of telescope construction.
At the beginning, and for several years, Wilhelm was helped by his brother Alexander, and sister Caroline. In 1781, during his third and most complete survey of the night sky, Wilhelm noticed an object that he had never seen before: he thought that it could have been a comet, but the object turned out to be a new planet (Uranus) instead. For that discovery, he was introduced and elected as a fellow of the *Royal Society.* The King George III, to whom Herschel had dedicated the new planet (named *Georgium Sidus*), appointed him as astronomer and gave him a new place, close to Windsor, where to live and build up a new large telescope. The latter one, finished in 1789, with its mirror (122 cm of diameter) made of speculum metal (a mixture of copper and tin) and its focal length of 12 m, would have become one of the technical wonders of the eighteenth century.

A.15 Horn D'Arturo, Guido

Guido Horn D'Arturo (born 1879, Trieste - died 1967, Bologna) was born in a Jewish family. After his father's death, he was grown up by his grandfather, Raffaele Sabato Melli, rabbi of Trieste. The particular atmosphere of that town exerted a deep influence on Guido whose culture was vast, and whose artistic interests included sculpture, music and literature. Guido Horn left Trieste to complete his studies in Austria, first in Graz and then in Vienna, where, in 1902, he got his PhD in astronomy. The next year he started to work as an astronomer at the observatory in Trieste from where he moved first to Catania and then to Bologna.

Aged thirty-five he volunteered in the First World War: he should have joined the army of Austro-Hungarian empire (as Trieste was not Italian at that time) but he felt Italian and thus decided to fight against them. Being under the constant risk of being arrested and executed for his desertion, he changed his surname into d'Arturo (being Arturo his father's name). After the war, he got Italian citizenship and his surname was definitely changed into Horn d'Arturo. In 1921 he was given an University chair in Bologna and the Observatory direction.

In 1926 he organized a successful expedition to Oltregiuba (an Italian colony within what is now Somalia) to observe the Sun corona during a total solar eclipse. He renewed all the instrumentation of the Bologna Observatory and decided to build an observatory far from the disturbing lights of Bologna, in Loiano, a very small town on the Appennines (35 km from Bologna). The observing station was finished in 1936 and its telescope (60 cm of mirror diameter) was the second largest in Italy.

A few years before, he had had an innovative idea: to replace the normal telescope mirrors, which weight increased with size, with much thinner mirrors made of small mirror tiles. He had started working at that project but the racial laws of 1938 stopped him: he was forced to leave his work and could come back to it only at the end of the Second World War. He finished to build up his "mosaic mirror" which was made of 60 hexagonal mirror tiles having all together a diameter of 1.80 m. The innovative idea of Guido Horn d'Arturo, not much appreciated when he was alive, would have been successfully applied several years later as all the huge mirrors are now made of mirror tiles.

A.16 Huygens, Christiaan

Christiaan Huygens (born 1629 - died 1695, The Hague, Netherlands) was educated at home by his father (a wealthy diplomat, poet, and musician) until he was sixteen years old. His liberal education included math, geography, logic, foreign languages, music, horse riding and dancing. Huygens entered Leiden University in 1645 to study law and mathematics.

In 1666, he moved to Paris, where he became a founding member of the*Académie des Sciences*. In those years, on the basis of Galileo's earlier studies, he invented the pendulum clock, an instrument which would have been the world's most accurate timepiece for the next 275 years. Nevertheless, there were some problems as Huygens thought that the pendulum clock could have been used on seas, but the ship rolling prevented it to work properly. As a result, his invention, well described in his *Horologium Oscillatorium* (containing also theoretical details on the physics related to it) did not obtain much success.

Huygens gave several contributions to the fields of mathematics and physics and he is remembered for his optics work: he described the refraction law, which he used to calculate the lenses focal distances and to build improved lenses and telescopes. Huygens also made experiments on double diffraction and in 1690 published his *Traité de la lumière*, illustrating his wave theory of light, which was in contrast with Newton's corpuscular theory (and would have been proved to be right in 1801 by Thomas Young's interference experiments).

He also dedicated large part of his life to astronomy: he built up telescopes and observed Saturn revealing the presence of its rings and discovering its first Moon, Titan. Huygens returned to The Hague in 1681, where he died at the age of 66.

A.17 Kepler, Johannes

Johannes Kepler (born 1571, Weil der Stadt, Württemberg - died 1630, Regensburg) was a German astronomer supporter of the Copernican system. Since he was a child, he was fascinated by astronomical events such as the eclipsed Red Moon he saw in 1580. He chose to study theology but his exceptional mathematical capabilities made him to be noticed. He became professor of mathematics at Graz University in 1593 and since the salary was very low, he had to make horoscopes to sustain himself.

In 1596 he published his first astronomical work: *Mysterium Cosmographicum.* It was a masterpiece in which Kepler was able to mathematically and geometrically reconcile the Copernicus' model with platonic suggestions. He also tried to find out a physical reason for the planetary motions and suggested that the Sun had to be considered the central engine able to impress a force to all the celestial bodies making them orbiting around the star. He sent a copy of its *Mysterium* to Galileo and that was the beginning of a scientific correspondence between the two. In 1609, he published *Astronomia Nova* in which his first two empirical laws on the planets motions appear (the third law, would have been published ten years later in his *Harmonices Mundi*).

A.18 Manfredi, Eustachio

Eustachio Manfredi (born 1674 - died 1739, Bologna) after having attended the Jesuit convent in Santa Lucia, he devoted himself to philosophical studies, then to juridical ones, graduating in 1692.

Aged sixteen he started organizing periodic meetings in which philosophy and mathematical problems, literature and history were discussed: an academy called the "Restless" was born from the Virgilian motto *"Mens Agitat"*. Eustachio, meanwhile, devoted himself to the disciplines that he felt most closely related to his interests: mathematics and hydraulics, having as a teacher Domenico

Guglielmini (1655, Bologna - 1710, Padua), together with geometry and astronomy.

A decisive and deep commitment to scientific research, especially in the astronomical field, was due to the meeting with Luigi Ferdinando Marsili. In the meantime, Manfredi had been appointed, in 1699, lecturer in mathematics, but he continued studying astronomy and carrying out observations from the Specola of the Marsili house.

In 1711 Eustachio was appointed by the Senate as astronomer of the newly founded *Istituto delle Scienze di Bologna* and the following year, the construction of the Tower, hosting the Observatory, began. In the Specola Tower, Manfredi carried out several observations on the stars, by means of a large mural semicircle (having the radius of 1.51 m), noticing that their positions were displaced in the course of the year. He had discovered the same phenomenon seen and correctly interpreted by James Bradley, as due to the combination of the Earth orbital motion and the finite light speed. But he published his result a few months later and more than that, he thought that the light velocity was infinite so he could not explain the observed displacement. One thing however he did, the name he gave to the phenomenon (aberration) in his 1729 work *De annuis inerrantium stellarum aberrationibus* was successful: it was adopted and is still in use.

Manfredi was an assiduous observer of the sky: he started to publish in 1715 the Ephemerides which would have been published by the directors of the Bologna Specola until 1844. Because of his accurate and large astronomical production Manfredi was appointed member of the *Académie des Sciences* in 1726 and of the *Royal Society* in 1729, while concerning his literal interests it is worth to mention that in 1702 he had been aggregated to the *Accademia della Crusca.*

A.19 Marsili, Luigi Ferdinando

Count Luigi Ferdinando Marsili (born 1658 - died 1730, Bologna) was an Italian geographer and naturalist. Born in an old patrician family, he was educated in accordance with his rank; he widened his education studying mathematics, anatomy, and natural history with the best teachers, and by himself. As a soldier he was sent by the Republic of Venice to Constantinople in 1679, one year later when the Turks threatened to invade Hungary, he offered his services to the Emperor Leopold but he was then taken prisoner for over one year.

Marsili devoted his spare time to science: he made astronomical observations, measured rivers sizes and water speed within them, studied animals, fossils of every land he visited, and also collected any kind of specimens, instruments, models, antiquities, etc. When he finally came back to Bologna, in 1712, he showed his entire collection to the Senate of his town where he founded his *Istituto delle Scienze e delle Arti*, which was formally opened in 1715. In that same year he was also elected foreign associate of the *Académie des Sciences*, while in 1722 he was elected member of the *Royal Society.*

A.20 Maxwell, James Clerk

James Clerk Maxwell (born 1831, Edinburgh, Scotland - died 1879, Cambridge, England) was a Scottish physicist best known for his formulation of electromagnetic theory. Maxwell was born and studied in Edinburgh and remained very close to his father especially because of his mother's premature death. He attended the Universities of Edinburgh and Cambridge studying mathematics, philosophy, and physics. He began to work on the theory of heat, the dynamics of gases and electromagnetism publishing articles which were financially supported by the *Royal Society* of London. In Cambridge he became professor of experimental physics.

In the preface to his *Treatise on Electricity and Magnetism* (1873), the best exposition of his theory, Maxwell stated that his major task had been to construct a mechanical model to put Michael Faraday (1791, Newington, Surrey, England - 1867, Hampton Court, Surrey)'s physical ideas into mathematical form. Maxwell's theory suggested that electromagnetic waves could be generated in a laboratory, a possibility which would have been shown to be true by Heinrich Hertz (1857, Hamburg, Germany - 1894, Bonn, Germany) only in 1887.

Maxwell made also major contributions to other areas of physics: he demonstrated his mastery of classical physics by writing a prizewinning essay on Saturn's rings, he investigated the transport properties of gases, viscosity, thermal conductivity, and gave a personal statistical interpretation of physics.

Maxwell died in November 1879, receiving no public honors and being buried quietly in a small churchyard in the village of Parton, in Scotland. Today, Maxwell is considered by most physicists as the nineteenth century scientist who had the greatest influence on twentieth century physics, and he is ranked with Sir Isaac Newton and Albert Einstein for the fundamental nature of his contributions.

A.21 Montanari, Geminiano

Geminiano Montanari (born 1633, Modena - died 1687, Padua) was an Italian physicist and astronomer, known for having registered as first, in 1670, the variability of Algol (a bright star in the Perseus constellation). In 1662 he met Cornelio Malvasia, a nobleman from Bologna who had a strong passion for astronomy and was helped by Montanari in the compilation of his volume of Ephemerides with a 38 cm in diameter detailed map of the Moon. Montanari left the court of Modena and went to Bologna (where he obtained, in 1664, the mathematics chair at the University) and Panzano.

He spent fourteen years teaching in Bologna, he founded a school called *Accademia della Traccia* (from which the Eustachio Manfredi's *Accademia degli Inquieti* would have originated, in 1670) and showed his exceptional skill in inventing and making precision instruments (the very large objective lenses that he made were appreciated by Cassini). In 1669 Montanari started being concerned about Cassini's sundial in the Basilica of San Petronio and in those years the University of Bologna suffered a financial crisis, thus Montanari decided to move to Padua, where a new chair of astronomy and meteorology was created for him.

A.22 Newton, Isaac

Sir Isaac Newton (born 1642, Woolsthorpe, Lincolnshire - died 1727 Kensington) was one of the greatest mathematicians and most influential scientists of all times playing a key role in the scientific revolution. Aged eighteen, he was admitted to the Trinity College of Cambridge University, where he met the professor Isaac Barrow (1630 - 1677, London), who would have been his mentor and would have let him the Lucasian chair in 1669.

Newton was extremely interested in optics and in 1704 he published *Opticks, or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light* written in Enligh (then in 1706 he published the treatise in Latin too). By means of a series of experiments with prisms he was able to prove that the white light resulted from the composition of different colors. He was strongly convinced of the corpuscular nature of light and because of that was criticized by Robert Hooke (1635, Freshwater - 1703, London).

Newton's most important work is *Philosophiæ Naturalis Principia Mathematica* first published in 1687, thank to the promotion and financial support by Edmond Halley. In the third and last book of *Principia* Newton described the planetary and satellites motion based on the universal gravitational law, and gave the theoretical explanation of Kepler's three empirical laws. Newton also explained the flattening of Earth at the poles due to the precession of equinoxes and confirmed the nature of comets as celestial bodies moving into elliptical orbits.

In 1703 Newton became president of the *Royal Society* (several years before, in 1671, he had presented to the academy his small telescope (aperture of 3.5 cm, focal length of 16 cm) which was the first reflector of the history). He died in Kensington in 1727 leaving a fundamental legacy to the following era of physicians.

A.23 Picard, Jean

Jean Picard (born 1620, La Flèche, France - died 1682, Paris) was as a French astronomer, who, in 1655, became professor of astronomy at the *Collège de France* in Paris. He was the first to accurately measure the length of a meridian degree (a measure used by Newton to verify his theory of gravitation) and from that value he computed the Earth's size.

Picard was also credited for the introduction of telescopic sights and the use of pendulum clocks which contributed to the achievement of a larger accuracy in the astronomical observations. In 1675 he made the first recorded observation of barometric light, i.e. the light appearing above the mercury in a barometer tube if the latter one is shaken.

In 1679 he founded and became editor of *La Connaissance des temps ou des mouvements célestes*, the first national astronomical Ephemerides.

A.24 Rømer, Ole

Ole Rømer (born 1644, Århus, Jutland - died 1710, Copenhagen) was born in 1644 in Denmark and started working as a young assistant of the mathematician Bartholin in Copenhagen. In 1671 he knew that the abbot Jean Picard was impressed by his skills and had decided to invite him to Paris at the *Académie*: arrived in Paris in 1672, Ole spent there nine years working at the *Observatoire*. In 1676, by studying the eclipses of the Jupiter's satellite Io, Rømer deduced that the light speed was such that the light took 22 minutes to cross the diameter of Earth's orbit. Christiaan Huygens used Rømer's ideas to derive a value for the speed of the light which was not too different to the value accepted today. In 1679 Rømer went on a scientific mission to England, where he met Sir Isaac Newton and the astronomers John Flamsteed and Edmond Halley. Upon his return to Denmark in 1681, he was appointed Royal mathematician and professor of astronomy at the University of Copenhagen. At the University observatory he set up an instrument with altitude and azimuth circles and a telescope, which accurately measured the position of celestial objects.

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