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An Overview of Surveys of Paris Meridian Arc Section Lengths in the 17th and 18th Century

Miljenko SOLARIĆ and Nikola SOLARIĆ

Faculty of Geodesy, University of Zagreb, Kačićeva 26, 10000 Zagreb, Croatia
miljenko.solaric@geof.hr, nikola.solaric@geof.hr

Abstract: A brief introduction is followed by description of the spread of the Paris meridian in France. Following is description of the survey of Paris meridian arc section lengths and production of contemporary maps of France: by Jean Picard, Philippe de la Hire, Jean-Dominique Cassini (Cassini I), Cassini II, Cassini III and Cassini IV.

Keywords: meridian arc length, Paris meridian, Paris Observatory, survey, trigonometric chain, contemporary maps, first maps produced in a certain scale

1 Introduction

Columbus's discovery of America in 1492 led to a surge in the development of economy, science and art, especially in some European countries. Thus historians refer to that year as the beginning of the Modern Age.

In the Modern Age, people strived to seize markets and there was a need to gain new knowledge. This is why academies of sciences were established in Germany, England, France and other countries in the 17th century. Observatories for astronomical observations and physical research were also founded. There was a need for accurate contemporary maps and a requirement for determining the size of Earth. However, new scientific research led to the discovery that Earth was not a ball. A theoretical explanation was provided by Isaac Newton and Christiaan Huygens, who determined Earth is shaped as a rotational ellipsoid flattened at the poles. The Cassinis stated the Earth's ellipsoid is bulging on the poles based on surveys of the Paris meridian. They sought to prove their assumptions by conducting new surveys. The scientific dispute was finally resolved by dispatching a surveying expedition to Lapland (near the pole) and Peru (near the equator).

Construction of the Paris Observatory was started in 1667 and completed in 1671. Its establishment was greatly influenced by French minister Jean-Baptiste Colbert (1619–1683). The Paris meridian is very important because it played a significant historical role in determining the shape and size of Earth, even after the Cassinis claimed the Earth's poles are bulging. This was the origin of the new scientific discipline of theoretical geodesy about the theory of the Earth's shape (URL 33).

2 Paris meridian

A section of the Paris meridian arc stretches from the North to the South of France, i.e. from Dunkerque to Perpignan, and which was subsequently extended to Barcelona and Balearic Islands. This line of the Paris meridian was the site of surveying the arc length of one meridian degree using trigonometric chains during a period of one and a half century. The word meridian is derived from Latin *circulus meridianus*, which means noon circle.

The first survey of the one degree length of the Paris meridian from Paris to Amiens was conducted by Jean Fernel (1497–1558) in 1528. He measured the distance by

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Pregled izmjera duljina dijelova luka Pariškog meridijana u 17. i 18. stoljeću

Miljenko SOLARIĆ i Nikola SOLARIĆ

Geodetski fakultet Sveučilišta u Zagrebu, Kačićeva 26, 10000 Zagreb
miljenko.solaric@geof.hr, nikola.solaric@geof.hr

Sažetak: Nakon kratkog uvoda opisano je pružanje Pariškog meridijana u Francuskoj, a potom je opisan rad na izmjeri duljina dijelova luka Pariškog meridijana i izradi suvremenih karata Francuske: Jeana Picarda, Philippea de la Hirea, Jean-Dominiquea Cassinija (Cassinija I.), Cassinija II., Cassinija III. i Cassinija IV.

Ključne riječi: duljina luka meridijana, Pariški meridijan, Pariški opservatorij, izmjera, trigonometrijski lanac, suvremene karte, prve karte izrađene u određenom mjerilu

1. Uvod

Nakon Kolumbova otkrića Amerike 1492. godine došlo je do naglog razvoja gospodarstava, znanosti i umjetnosti, posebice u nekim državama u Europi. Zbog toga povjesničari taj datum uzimaju kao početak novoga vijeka – novoga doba.

U novom vijeku željelo se osvojiti tržišta, te je došlo do potrebe za stjecanjem novih znanja. To je bio razlog zašto su u 17. stoljeću otvarane akademije znanosti u Njemačkoj, Engleskoj, Francuskoj i drugim zemljama. Također, bili su osnivani opservatoriji za astronomska opažanja i izvođenje fizikalnih istraživanja. Pojavila se potreba za sve točnijim suvremenim kartama, a u svezi s tim i za točnijim određivanjem dimenzije Zemlje kao kugle. Međutim, s novim znanstvenim spoznajama došlo se do saznanja da Zemlja nije kugla. Teorijsko objašnjenje dali su Isaac Newton i Christiaan Huygens, te ustvrdili da Zemlja ima oblik rotacijskog elipsoida i da je spljoštena na polovima, a Cassiniji su tvrdili na osnovi do tada izvedenih mjerenja na Pariškome meridijanu da je Zemlja ispupčena na polovima. Novim mjerenjima Cassiniji su nastojali dokazati svoje pretpostavke. Nastali znanstveni spor konačno je riješen slanjem geodetske znanstvene ekspedicije na Lapland (blizu pola) i u Peru (blizu ekvatora).

Radovi na izgradnji Pariškog opservatorija započeti su 1667. godine, a završeni 1671. Za njegovo osnivanje znatno je zaslužan francuski ministar Jean-Baptiste Colbert (1619–1683). Pariški meridijan odigrao je značajnu povijesnu ulogu u određivanju oblika Zemlje i njezinih dimenzija iako su na početku Cassiniji tvrdili da je Zemlja ispupčena na polovima. Nastala je tada nova znanstvena disciplina teorijske geodezije o teoriji oblika Zemlje (URL 33).

2. Pariški meridijan

Dio luka Pariškog meridijana u Francuskoj prolazi od sjevera do juga, tj. od Dunkerquea do Perpignana, a potom je produžen do Barcelone i do Baleara. Na tom pravcu Pariškog meridijana mjerene su duljine luka jednog stupnja meridijana s pomoću trigonometrijskih lanaca u vremenskom razdoblju od stoljeća i pol. Riječ meridijan je izvedena iz latinskog *circulus meridianus*, što znači podnevni krug.

Prvo mjerenje duljine jednog stupnja Pariškog meridijana izveo je Jean Fernel (1497–1558) 1528. godine od

Figure 1 Paris meridian and important locations in its vicinity

Slika 1. Pariški meridijan i važnija mjesta u njegovoj okolici

the number of wheel turns and observed the difference between latitudes astronomically. This was the time when there were no trigonometric grids in the world. Namely, Danish astronomer Tycho Brahe (1546–1601) was the first to survey the trigonometric network in Öresund from 1578 to 1579, but unfortunately he did not calculate it. It was not until later on that Dutch Willebrord Snellius (1580–1626) surveyed and calculated the trigonometric network from Bergen op Zoom to Alkmaar and published the results in the paper *Eratosthenes Batavus* in 1617 (Solarić, M. and Solarić, N. 2009).

The second survey was conducted by Jean Picard (1620–1682), who established a trigonometric chain between Malvoisine (South from Paris) and Sourdon (close to Amiens), while the survey results were published in 1671.

Following were a number of surveys of individual sections of the Paris meridian using trigonometric chains (Fig. 1 and 19), starting with Cassini I and La Hire I (1678), Cassini II, La Hire II and Maraldi I (1718), Cassini III, Lacaille and Maraldi II (1739), as well as Cassini IV and Méchain (1787), and their work is going to be described in the following chapters. The work by Delambre and Méchain (1792–1798), Biot and Arago (1806–1808) on surveying the Paris meridian is going to be described in the next paper (Paris Meridian Arc Length and the Definition of Metre).

Nowadays, it is known the Paris meridian passes through the Paris Observatory and that its longitude is 2° 20' 14.025'' counting from Greenwich (URL 1) (Fig. 1).

French King Louis XIII decided in 1634 that the island Ferro (nowadays El Hiero) in the Canary Islands (about

Pariza do Amiensa. Udaljenost je izmjerio brojanjem okretaja kotača, a astronomskim načinom razliku geografskih širina. U tom trenutku nije bila izvedena i izračunana ni jedna trigonometrijska mreža u svijetu. Naime, danski astronom Tycho Brahe (1546–1601) prvi je izmjerio trigonometrijsku mrežu u Öresundu od 1578. do 1579. godine, ali ju, nažalost, nije izračunao. Tek je poslije Nizozemac Willebrord Snellius (1580–1626) prvi izmjerio i izračunao trigonometrijsku mrežu od Bergen op Zooma do Alkmaara i rezultat objavio u radu *Eratosthenes Batavus* 1617. godine (Solarić, M. i Solarić, N. 2009).

Drugo mjerenje duljine jednog stupnja Pariškog meridijana izveo je Jean Picard (1620–1682), uspostavljajući trigonometrijski lanac između Malvoisinea (južno od Pariza) i Sourdona (pokraj Amiensa), a rezultate izmjere objavio je 1671. godine.

Slijedio je veliki broj određivanja duljina pojedinih dijelova Pariškoga meridijana uz pomoć trigonometrijskog lanca (sl. 1 i 19) počevši s Cassinijem I. i La Hireom I. (1678), Cassinijem II., La Hireom II. i Maraldijem I. (1718), Cassinijem III., Lacailleom i Maraldijem II. (1739), kao i Cassinijem IV. i Méchainom (1787), a o njihovu radu bit će riječi u sljedećim poglavljima. O radu Delambrea i Méchaina (1792–1798) te Biota i Aragoa (1806–1808) na izmjeri duljine Pariškog meridijana bit će riječ u sljedećem članku (Duljina luka Pariškog meridijana i definicija metra).

Danas je poznato da Pariški meridijan prolazi Pariškim opservatorijem i ima geografsku dužinu 2° 20' 14,025'' računajući od Greenwichkog meridijana (URL 1) (sl. 1).

Francuski kralj Luj XIII. odlučio je 1634. godine da otok Ferro (danas El Hiero) u Kanarskim otocima, koji su smješteni oko 500 km zapadno od granice Maroka i Zapadne Sahare, treba uzeti za početni meridijan. Pariški meridijan je više od 200 godina uziman za početni meridijan, a u različitim državama primjenjivani su i drugi početni meridijani, npr. Azorski, Beringov i Greenwichki. To je pomorce dovodilo do zabuna pa se tražilo rješenje u dogovoru, koji je sklopljen na Konferenciji o početnom meridijanu u Washingtonu 1884. godine. Tada je gotovo jednoglasno prihvaćeno da početni meridijan bude Greenwichki. Razumljivo je da su Francuzi željeli da Pariški meridijan postane svjetski priznati početni meridijan, ali prevagnulo je mišljene većine, jer je tada 3/4 karata već imalo ucrtan Greenwichki meridijan kao početni. Osim toga veliku ulogu odigrala je i činjenica što je američki sustav vremenskih zona bio već prije osnovan na Greenwichkom početnom meridijanu (URL 2). Međutim, Francuska je držala Pariški meridijan suparnikom Greenwichkom sve do 1911. za mjerenje vremena i do 1914. za plovidbu (za određivanje geografskih dužina) (URL 1).

Figure 2 One of the brass medallions in Paris in honour of Arago and the Paris meridian (URL 34)

Slika 2. Jedna od mjedenih oznaka postavljenih u Parizu u čast Aragou i Pariškom meridijanu (URL 34)

Pariški meridijan označen je s nekoliko stupova, koji su uistinu spomenici tom velikom i značajnom pothvatu. Osim toga Udruga Arago i grad Pariz naručili su 1994. godine od nizozemskog umjetnika Jana Dibbetsa prijedlog spomen-obilježja na francuskog znanstvenika François Aragoa (1786–1853), koji je bio i ravnatelj Pariškog opservatorija. Naime, Arago je početkom 1800-ih preračunao s većom preciznošću duljinu Pariškoga meridijana te se tako njegovo ime pojavljuje na 121 mjedenoj oznaci postavljenoj u Parizu uzduž meridijana od njegove sjeverne do južne granice. Svaka mjedena oznaka promjera je 12 cm s Aragoovim imenom, a na njoj je označen i smjer sjevera (N) i juga (S) (sl. 2) (URL 34).

Postoji i drugi projekt, *La Méridienne Verte* (Zeleni meridijan) iz 2000. godine, prema ideji arhitekta Paula Chemetova (1928–). Po tom projektu trebalo je posaditi nasade stabala duž cijele duljine Pariškog meridijana u Francuskoj (Murdin 2009, str. 4). Ideja je bila da se zelena linija izrađena od nasada stabala po Pariškom meridijanu vidi iz bližeg svemira.

3. Jean Picard

Jean Picard (1620–1682) (sl. 3) bio je slavni francuski astronom, kartograf, a može se kazati i jedan od prvih geodeta koji se bavio višom geodezijom, određivanjem Zemljinih dimenzija. Za njega se kaže da je osnovao modernu astronomiju u Francuskoj uvodeći nove metode rada, unaprjeđujući stare instrumente i dodajući nove, kao na primjer sat s njihalom, koji je patentirao veliki fizičar i matematičar Christiaan Huygens 1657. godine. Picard je postao profesor astronomije na *Collége de France* u Parizu 1655. godine (URL 3).

500 km west of the border between Morocco and Western Sahara) should be considered the prime meridian. The Paris meridian had been considered the prime meridian for more than 200 years, and different prime meridians existed in various countries, such as the Azores, Bering and Greenwich. This confused sailors and a solution was sought in the agreement reached at the Conference about the Prime Meridian in Washington in 1884. A decision was made almost unanimously to make Greenwich the prime meridian. It is understandable the French wanted the Paris meridian to be the prime meridian, but the majority won out, because 75% of maps had Greenwich as the prime meridian. In addition, the American time zone system had already been established on Greenwich (URL 2). Nevertheless, France preserved the Paris meridian as a rival to Greenwich for time determination until 1911 and for navigation (longitude determination) until 1914 (URL 1).

The Paris meridian is marked with several pillars, which are truly monuments to the great and significant enterprise. In addition, 1994 saw the Arago Association and the city of Paris commissioned a Dutch conceptual artist, Jan Dibbets, to create a memorial to French scientist François Arago (1786–1853), who was also the director of the Paris Observatory. Namely, at the beginning of the 19th century Arago precisely determined the longitude of the Paris meridian, so his name appears in 121 brass medallions in Paris along the meridian from its Northern to Southern borders. Each brass medallion has a diameter of 12 cm with Arago's name and also indicates the North (N) and South (S) (Fig. 2) (URL 34).

There is another project, *La Méridienne Verte* (The Green Meridian) by architect Paul Chemetov (1928–). The idea was to plant trees along the entire Paris meridian in France (Murdin 2009, page 4) and to be able to see the green line of trees from a small distance in space.

3 Jean Picard

Jean Picard (1620–1682) (Fig. 3) was a famous French astronomer, cartographer and can also be considered one of the world's first geodesists, because he was occupied with higher geodesy, determining the Earth's size. He is considered the founder of modern astronomy in France, by introducing new methods, improving old instruments and inventing new ones, e.g. the pendulum clock, which was patented by great physicist and mathematician Christiaan Huygens in 1657. Picard became an astronomy professor in *Collége de France* in Paris in 1655 (URL 3).

Picard was commissioned by the Academy of Science in Paris to determine the arc length of the Earth's meridian by measuring distances using the trigonometric network between Malvoisine (South of Paris) and Sourdon (near Amiens) (URL 4 and 7). Earth was considered shaped as a ball at the time.

Figure 3 Abbot Jean Felix Picard (1620–1682), famous French astronomer, cartographer and geodesist (URL 5)
Slika 3. Opat Jean Felix Picard (1620–1682), veliki francuski astronom, kartograf i geodet (URL 5)

Most historians of science assume that Dutch Hans Lipperhey (1570–1619) from Middleburg was the first to patent telescope in 1608. However, there are others who do not agree. After receiving partial information on telescope construction, famous Italian physicist and astronomer Galileo Galilei (1564–1642) produced his telescope in 1609. The telescope provided an upright virtual image, and Galilei used it to observe the Moon, Jupiter, the Sun and other celestial bodies. Nevertheless, the telescope could not be used to accurately direct the instrument to a certain point. In 1611, famous astronomer Johannes Kepler (1571–1630) realized the cross-hair has to be mounted in foci between the objective and the eyepiece (Fig. 4). The resulting image is rotated by 180°.

The mentioned innovations could not be applied at first in geodesy and positional astronomy because transfer of knowledge was slow at the time. Thus, Snellius measured angles in his trigonometric network in the Netherlands in 1616 and 1617 with dioptre without optical tools – telescopes.

In order to increase measurement accuracy of angles in the trigonometric network which consisted of 13 triangles set in a chain of triangles (Fig. 5), in 1667 Picard was the first to mount a telescope on instruments, and for accurate sighting he mounted cross-hairs constructed by William Gascoigne (1620–1682) (URL 8 and 5).

In addition, Picard was the first to use the micrometer (Fig. 6) for a more accurate determination of angles with his instruments (Fig. 7).

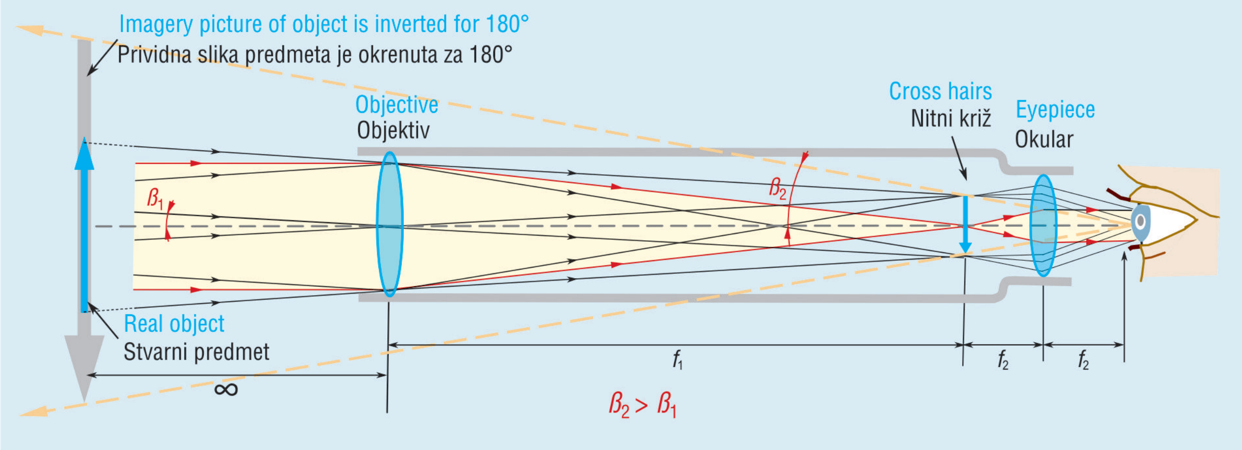

Figure 4 Construction of Kepler's telescope, where the image of observed object is rotated by 180° ($ß_1$ = angle under which object is seen without telescope and $ß_2$ = angle under which image of the object is seen through telescope, but rotated by 180°) and telescope can be accurately aimed

Slika 4. Konstrukcija Keplerova dalekozora, kojim se slika promatranog predmeta vidi okrenuta za 180° ($ß_1$ = kut pod kojim se vidi predmet bez dalekozora i $ß_2$ = kut pod kojim se vidi slika predmeta kroz dalekozor, ali okrenuta za 180°) i dalekozor se može točno usmjeriti prema cilju

Picard je dobio zadatak od pariške Akademije znanosti da točno odredi duljinu luka Zemljina meridijana mjerenjem udaljenosti s pomoću trigonometrijske mreže između Malvoisinea (južno od Pariza) i Sourdona (pokraj Amiensa) (URL 4 i 7). U to doba smatralo se da Zemlja ima oblik kugle.

Većina povjesničara znanosti pretpostavlja da je Nizozemac Hans Lipperhey (1570–1619) iz Middleburga 1608. godine prvi patentirao konstrukciju dalekozora, no ima i onih koji mu to pravo poriču. Nakon primljenih djelomičnih informacija o konstrukciji dalekozora, slavni talijanski fizičar i astronom Galileo Galilei (1564–1642) izradio je svoj dalekozor 1609. godine. Taj je dalekozor davao uspravnu virtualnu sliku, a njime je motrio Mjesec, Jupiter, Sunce i ostala nebeska tijela. Međutim, takav dalekozor nije se mogao upotrebljavati za točno usmjeravanje instrumenta na određenu točku. Godine 1611. slavni astronom Johann Kepler (1571–1630) shvatio je da nitni križ treba postaviti u fokuse između objektiva i okulara (sl. 4). Pritom se stvara slika koja je okrenuta za 180°.

Spomenuti pronalasci nisu se mogli odmah primijeniti u geodeziji i pozicijskoj astronomiji jer su se u to doba znanja prenosila sporo i sa zakašnjenjem. Tako je u Nizozemskoj Snellius od 1616. do 1617. mjerio kutove u svojoj trigonometrijskoj mreži pomoću dioptri bez optičkih pomagala – dalekozora.

Da bi povećao točnost mjerenja kutova u trigonometrijskoj mreži, koja se sastojala od 13 trokuta postavljenih u lanac trokuta (sl. 5), Picard je prvi 1667. godine postavio dalekozor na instrumente, a za točno viziranje ugradio je u njih nitni križ koji je izradio William Gascoigne (1620–1682) (URL 8 i 5).

Osim toga Picard je prvi upotrijebio mikrometarski vijak (sl. 6) za točnije očitanje kutova na svojim instrumentima (sl. 7).

U mjerenjima je rabio dvije vrste instrumenata:

- *oktante* dimenzija radijusa 6 feeta (182,9 cm) (vidi npr. sl. 22) i
- *kvadrante* dimenzija radijusa 38 incha (96,5 cm) s podjelom na limbu s mogućnosti očitanja kutova od (1/4)' (kutne minute), odnosno 15'' (kutnih sekundi) (sl. 7) (URL 5).

Mjerenje kutova s jednog vrha brijega do drugoga, gdje je bilo dugih stranica, opažalo se noću uz uporabu svjetiljki s reflektorima za koncentriranje svjetla u ispravnom pravcu uzduž stranice trokuta. To je imalo prednost, jer je po noći atmosfera na tako velikim udaljenostima stabilnija nego po vrućem danu. Osim toga i utjecaj bočne i vertikalne refrakcije je po noći manji pa su se kutovi mogli mjeriti s većom točnosti (Murdin 2009, str. 16–17). Kao trigonometrijske točke često su korišteni crkveni zvonici, kule, vjetrenjače, vrhovi planina i ostale karakteristične točke.

Dok je Picard radio na svojoj trigonometrijskoj mreži, 1669. godine Colbert je u ime kralja Luja XIV. pozvao talijanskog astronoma Giovannia Domenica Cassinija da posjeti Pariz i da radi na Opservatoriju. To je bio početak duge suradnje između dvaju astronoma (Murdin 2009, str. 23).

Picard je 1668. godine počeo s postavljanjem geodetske baze trigonometrijske mreže 10 km južnije od Pariza, između Villejuifa i Juvisya, duge 5633 toisea (11 037 m, sl. 8 i 5). Najprije je astronomskim načinom opažajući zvijezde odredio pravac meridijana u kojem je postavio

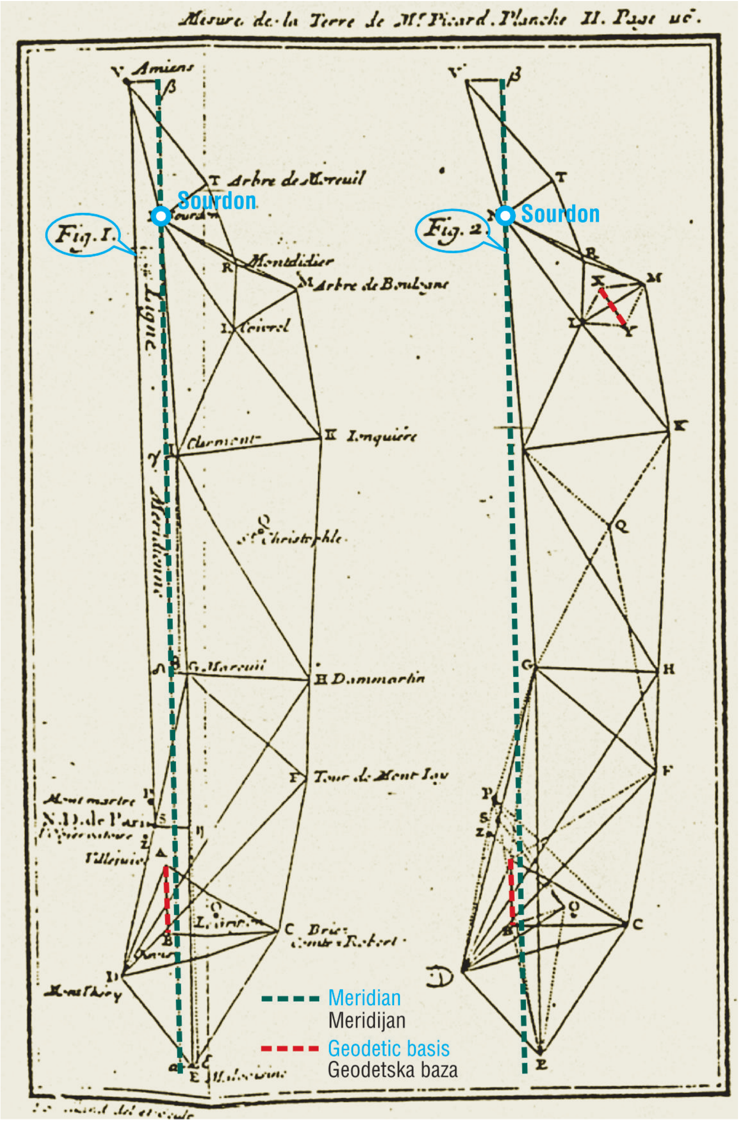

Figure 5 Picard's trigonometric network Malvoisine (South of Paris) – Sourdon (near Amiens) (URL 6)

Slika 5. Picardova trigonometrijska mreža Malvoisine (južno od Pariza) – Sourdon (pokraj Amiensa) (URL 6)

Picard employed two kinds of instruments:

- *Octants* with radius of 6 feet (182.9 cm) (e.g. see Fig. 22) and
- *Quadrants* with radius 38 inch (96.5 cm) and with the limb graduation enabling reading angles of (1/4)' (minutes of angle), i.e. 15'' (seconds of angle) (Fig. 7) (URL 5).

Measuring angles from one hilltop to another, where there were long distances was done at night using spotlights to focus light in a line along the side of a triangle. The advantage was that atmosphere at such long distances is more stable at night than during hot days. In addition, the effect of lateral refraction is lesser during night, making the measurements more accurate (Murdin 2009, pages 16–17). Belfries, towers, windmills, mountain tops and other characteristic points were often used as trigonometric stations.

In 1669, when Picard was working on his trigonometric network, Colbert asked Italian astronomer Giovanni Domenico Cassini on behalf of King Louis XIV to visit Paris and work at the Observatory. It was the beginning of a long collaboration between the two astronomers (Murdin 2009, page 23).

In 1668, Picard started establishing the geodetic baseline of the trigonometric network 10 km South of Paris, between Villejuif and Juvisy, 5633 toise (11 037 m) in length (Fig. 8 and 5). He first observed stars and astronomically determined the direction of the meridian in which he established the baseline. Such a requirement for establishing the geodetic baseline in the direction of the meridian was certainly not necessary. Then he measured the length of the baseline using 4 wooden poles of 2 toise[1] in length (about 3.90 m) were used in a leap-frog manner, setting them carefully in the baseline direction with a strained rope, and in a horizontal position (Murdin 2009, pages 15 and 17). According to the Czech source (Vykutil 1982), measurements were done with poles of 2 toise in length and there were two baselines, a 5633 toise (11 km) long one South of Paris and another one 45 km South of Amiens about 14 810 toise (7.6 km) long (fig. 2 on Fig. 5).

Endpoints of the trigonometric network baseline were subsequently marked with 8 m high obelisks called pyramids. Corresponding texts are written on them. The Southern endpoint contains the following French text:

PYRAMIDE DE JUVISY
EXTREMITE SUD DE LA BASE GEODESIQUE
DE VILLEJUIF A JUVISY
1670 (PICARD)
1740 (J. CASSINI ET LACAILLE)
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PROPRIETE DE L'ACADEMIE DES SCIENCES

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[1] Old units of length were: *Paris toise*, which had six pieds (pied = 0.3248 m)), one pied had 12 pouces, one pouce had 12 lignes. Etalon *toise du Châtelet* is the distance indicated between needles on the wall of the old Châtelet, where traders had to compare their measures. Its length was 1.949 m in 1799. According to Delambre, it is possible toise was somewhat shorter between 1670 and 1792 because it was damaged due to constant use (URL 36). Etalon of toise du Châtelet was destroyed in 1802 (URL 43).
In 1735, Claude Langlois, the king's engineer for astronomic instruments, constructed two standard toises based on the Chatelet toise. They took one of them to the Peru (today's Equador) expedition and the other one to the Lapland expedition. The Peruan toise was subsequently used to measure baseline lengths of the Paris Meridian trigonometric chain when the survey was conducted by Delambre and Méchain (URL 44). After that, toise du Pérou was named *toise de l'Académie*.

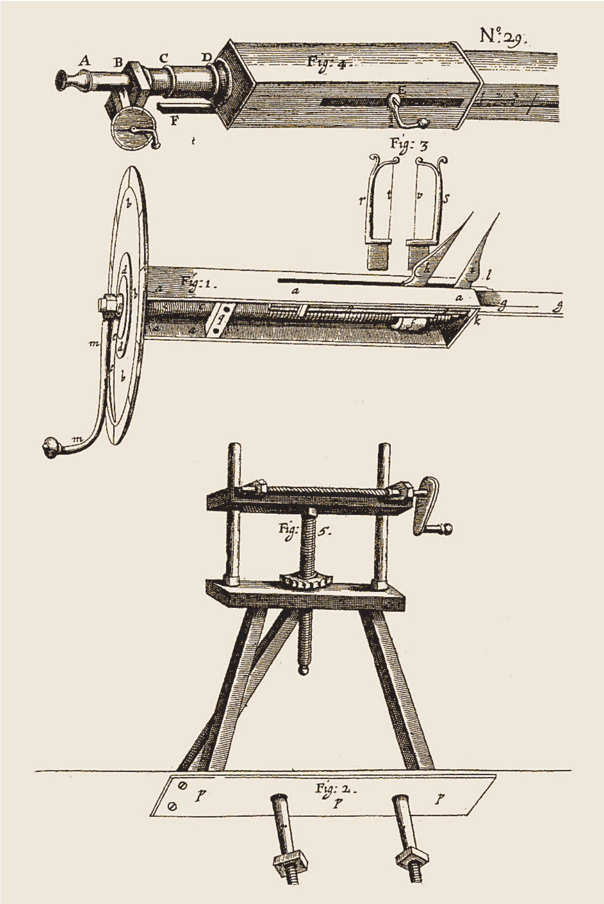


Figure 6 Gascoigne's cross-hairs and micrometer according to a drawing by Robert Hooke (URL 8)

Slika 6. Gascoigneov nitni križ i mikrometar prema crtežu Roberta Hookea (URL 8)

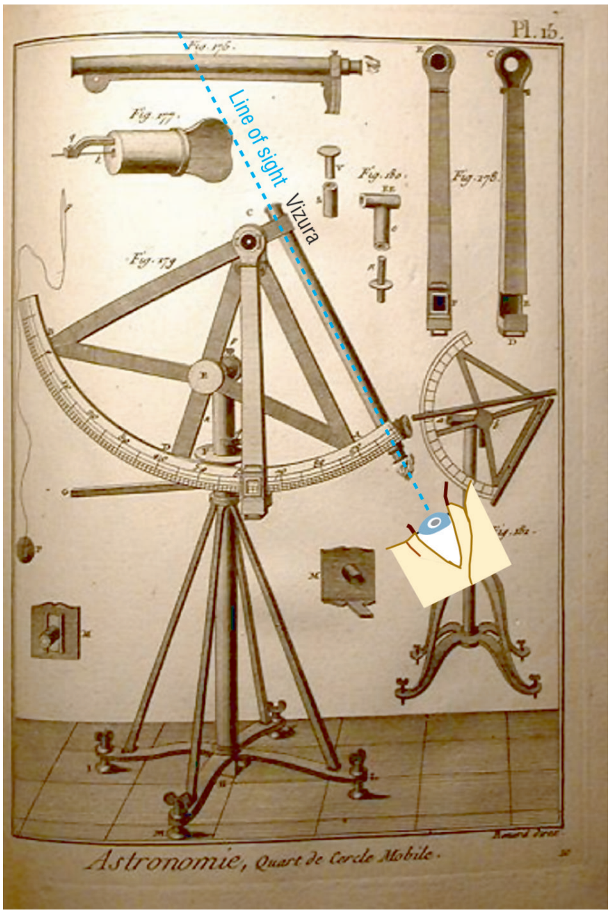


Figure 7 Picard's quadrant (according to URL 39)

Slika 7. Picardov kvadrant (prema URL 39)

bazu. Takav zahtjev za postavljanje geodetske baze u pravcu meridijana sigurno nije bio potreban. Zatim je duljinu te baze mjerio s 4 drvene motke, dugim 2 toisea[1] (oko 3,90 m), postavljajući ih naizmjenično pažljivo u pravcu baze na zemlju uz prethodno nategnuto uže, a i u horizontalni položaj (Murdin 2009, str. 15 i 17). U češkom izvoru (Vykutil 1982) piše da je mjereno letvama dugim 2 toisea i da su bile 2 baze, jedna duga oko 11 km južnije od Pariza i druga baza 45 km jugoistočno od Amiensa duga oko 3899 toisea (7,6 km, fig. 2 na sl. 6).

Krajnje točke baze trigonometrijske mreže poslije su u znak sjećanja označene stupovima obeliscima visokim 8 m, nazvanim piramidama. Na njima su ispisani odgovarajući tekstovi. Na južnoj krajnjoj točki na francuskom jeziku piše:

PYRAMIDE DE JUVISY
EXTREMITE SUD DE LA BASE GEODESIQUE
DE VILLEJUIF A JUVISY
1670 (PICARD)
1740 (J. CASSINI ET LACAILLE)
-
PROPRIETE DE L'ACADEMIE DES SCIENCES

[Piramida Juvisy, južna krajnja točka geodetske baze od Villejuifa do Juvusya 1670 (Picard), 1740 (J. Cassini i Lacaille) – Vlasništvo Akademije znanosti.]

[1] Stare jedinice za duljinu bile su: *Pariški toise*, koji je imao šest stopa (pieds; pied = 0,3248 m), jedna stopa imala je 12 palaca (pouces), jedan palac imao je 12 linija (lignes). Etalon *toise du Châtelet* je udaljenost označena između dvije igle na zidu staroga Châteleta, gdje su trgovci bili dužni usporediti svoje mjere. Njegova je duljina iznosila 1,949 m 1799. godine. Prema Delambreu vjerojatno je da je toise bio nešto kraći u razdoblju od 1670. do 1792., jer je zbog stalne usporedbe mjera trgovaca došlo do njegova oštećenja (URL 36). Etalon toise du Châtelet je uništen 1802. godine (URL 43).
Claude Langlois, kraljev inženjer za astronomske instrumente, izradio je 1735. godine dva standardna toisea na temelju toisea iz Chateleta. Jedan su ponijeli na ekspediciju u Peru (današnji Ekvador), a drugi na ekspediciju u Lapland. Peruanski toise poslije je korišten i u mjerenju duljina baza trigonometrijskog lanca Pariškog meridijana kad su izmjeru izvodili Delambre i Méchain (URL 44). Nakon toga je toise du Pérou nazvan *toise de l'Académie*.

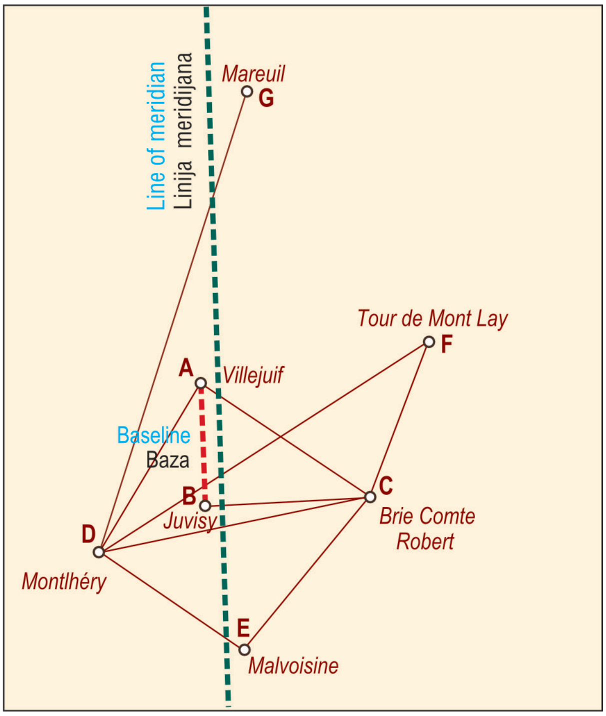


Figure 8 Part of Picard's trigonometric network and the baseline of the trigonometric network near Paris (according to URL 38)

Slika 8. Dio Picardove trigonometrijske mreže i baza trigonometrijske mreže kraj Pariza (prema URL 38)

[Juvisy pyramid, Southern endpoint of the geodetic baseline from Villejuif to Juvisy 1670 (Picard), 1740 (J. Cassini and Lacaille) – Owned by the Academy of Science]

A similar pyramid was placed at the Northern endpoint of the geodetic baseline in Villejuif. The two pillars are geodetic monuments to beginnings of measuring lengths of meridian arc sections in France, as well as to beginnings of higher geodesy in France and in the world.

Picard expressed lengths of triangles in toise. In order not to lose that basic unit of length, which had happened to his predecessors, he conceived comparing toise length to the length of the second's pendulum in Paris (URL 7). Thus, it was possible to reproduce its normal measure at any time, making it somewhat of a predecessor to the international metre, present international unit of length (URL 4). In 1664, famous Dutch physicist Huygens (1629–1695) was the first to propose the length of the second's pendulum as the basic unit of length (Brezinšćak 1971). At the time, it was believed that gravity is the same everywhere on Earth.

Picard published results of his measurements in *La Mesure de la Terre* in 1671. He calculated that:

- The difference in latitudes between Amiens and Malvoisine is 1° 22' 55''.
- The distance between Amiens and Malvoisine is 78 850 toise.
- The meridian arc of one degree of latitude on the Earth's surface is 57 060 toise long (= 111.2 km), which means the Earth's radius amounts to 3 269 300 toise (= 6372 km) (Bialas 1982, page 100).

It can be noted that Picard placed the meridian passing through a tower in Sourdon and through Paris.

In 1671, Picard travelled to Uranieborg, to the site of the demolished astronomical observatory of famous Danish astronomer Tycho Brahe (1546–1601) in order to compare experiences from the Paris observatory with astronomical observations of the famous astronomer. To achieve this, the French had to astronomically determine the difference between longitudes of meridians passing through the two observatories. In order to determine the difference in longitudes, Jupiter's moons' eclipses were observed at the same time as suggested by Galileo Galilei, and Picard was helped by young Ole Christensen Römer. Picard's method of determining longitude became universally accepted after 1650, but only on land (Sobel 2000, page 29).

Picard was among the first to apply scientific methods using trigonometric networks to produce maps. Namely, in 1678 engineer David Viver produced a map of the Paris region using Picard's trigonometric network (URL 38), and he subsequently joined the project of producing a map of France.

Picard collaborated with famous astronomers at the Paris Observatory: Jean Cassini (Cassini I), Ole Christensen Römer and Philipp de la Hire (La Hire I.).

In addition, Picard also worked in Versailles on the project of water supply, so he needed accurately determined heights. Thus in 1674 he produced a level with a pendulum, which is practically automatically adjusted to the vertical position and the telescope horizontal (Fig. 9). The instrument can be considered the first geodetic automatic level. Picard's paper *Traité du nivellement* with supplement was published posthumously by Philippe de la Hire in 1684.

Picard started publishing the yearbook *Connaissance des temps* in 1679 and continued publishing it until he died. Other scientists continued to publish it.

In 1681, based on his experience from the trigonometric network in the direction of the Paris meridian, Picard defined a plan for extending the trigonometric network to North and South along the entire Paris meridian through the entire France and measuring arc lengths by parallels to the East and West. According to Picard, the work was supposed to serve as a base for producing maps and connecting them. Unfortunately, Slična piramida postavljena je i na krajnjoj sjevernoj točki geodetske baze u Villejuifu. Ta su dva stupa geodetski spomenici početaka izmjere duljine dijela luka meridijana u Francuskoj, ali i početaka više geodezije u Francuskoj i svijetu.

Picard je duljine stranica trokuta izražavao u toisima, a da se ne bi izgubila ta osnovna jedinica za duljine, što se događalo njegovim prethodnicima, zamislio je kompariranje duljine toisea s duljinom sekundnog njihala u Parizu (URL 7). Na taj način bilo je moguće reproducirati njegovu normalnu mjeru u bilo kojem trenutku, te je to, na izvjestan način, prethodnica internacionalnog metra, kao danas međunarodno priznate jedinice za duljinu (URL 4). Slavni nizozemski fizičar Huygens (1629–1695) prvi je predložio 1664. godine da se za osnovnu jedinicu duljine uzme duljina sekundnog njihala (Brezinšćak 1971). U tom trenutku mislilo se da je ubrzanje sile teže na Zemlji jednako na svim mjestima na Zemlji.

Rezultate svojih mjerenja duljine luka meridijana Picard je objavio u knjizi *La Mesure de la Terre* 1671. godine. Izračunao je:

- da je razlika geografskih širina između Amiensa i Malvoisinea 1° 22' 55'',
- da je udaljenost između Amiensa i Malvoisinea 78 850 toisea,
- da je meridijanski luk jednog stupanja geografske širine na Zemljinoj površini dug 57 060 toisea (= 111,2 km), a iz toga proizlazi da je Zemljin radijus 3 269 300 toisea (= 6372 km) (Bialas 1982, str. 100).

Može se naglasiti da je Picard postavio meridijan da prolazi kroz toranj u Sourdonu i kroz Pariz.

Picard je 1671. godine otputovao u Uranieborg na mjesto srušenog astronomskog opservatorija slavnoga danskog astronoma Tycha Brahea (1546–1601) kako bi usporedio stečena iskustva u Pariškoj zvjezdarnici s astronomskim opažanjima toga slavnog astronoma. Da bi to mogli učiniti, Francuzi su morali astronomskim načinom odrediti razliku geografskih dužina između meridijana koji prolaze kroz ta dva opservatorija. Za određivanje razlike geografskih dužina korišteno je istodobno opažanje pomrčine Jupiterovih mjeseca, kako je to predložio Galileo Galilei, a Picardu je u radu pomagao mladi Ole Christensen Römer. Picardova metoda za određivanje geografske dužine postala je općeprihvaćena nakon 1650. godine, ali samo na kopnu (Sobel 2000, str. 29).

Picard je među prvima primijenio znanstvene metode s pomoću trigonometrijskih mreža za izradu karata. Naime, inženjer David Viver izradio je 1678. godine kartu regije Pariza koristeći se Picardovom trigonometrijskom mrežom (URL 38), a poslije se pridružio projektu izrade karte Francuske.

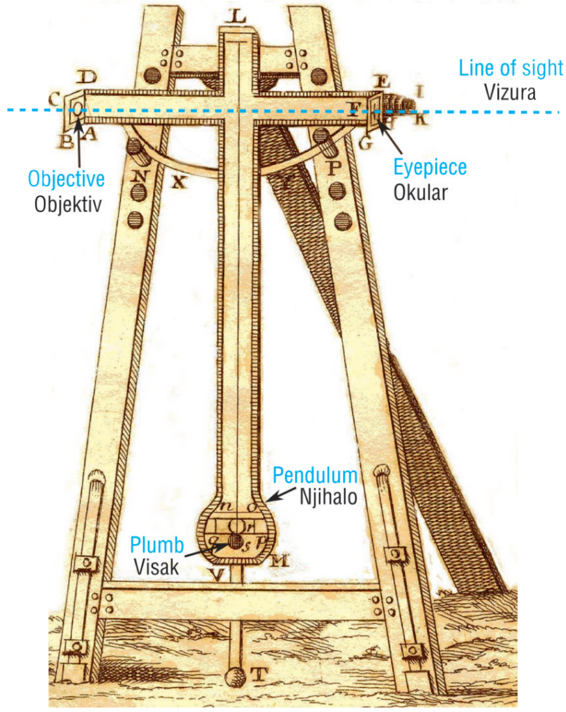


Figure 9 Picard's instrument for levelling with a pendulum (Scherffer 1770)

Slika 9. Picardov instrument za niveliranje s pomoću njihala (Scherffer 1770)

Na Pariškom opservatoriju Picard je surađivao s poznatim astronomima: Jeanom Cassinijem (nazvanim Cassini I.), Oleom Christensenom Römerom i Philippom de la Hireom (nazvanim La Hire I.).

Osim toga, Picard je radio i u Versaillesu na projektu opskrbe vodom te su mu bile potrebne dobro određene visine. Za te potrebe izradio je 1674. nivelir s njihalom koje se praktično automatski postavljalo u vertikalni položaj, a durbin u horizontalni (sl. 9). Može se reći da je taj instrument prvi geodetski automatski nivelir. Njegov rad *Traité du nivellement* s dodatkom posmrtno je objavio Philippe de la Hire 1684. godine.

Picard je 1679. počeo s izdavanjem godišnjaka *Connaissance des temps*, koji je izlazio sve do njegove smrti. Poslije su objavljivanje preuzeli drugi znanstvenici.

Na osnovi stečenog iskustva, izvođenjem trigonometrijske mreže po pravcu Pariškog meridijana Picard je 1681. godine definirao plan za produženje trigonometrijske mreže na sjever i jug po čitavom Pariškom meridijanu kroz cijelu Francusku te mjerenje duljine lukova po paralelama na istok i zapad. Ti bi radovi po Picardu služili kao osnova za izradu karata i njihovo povezivanje u jedinstvenu cjelinu. Nažalost, Picard je ubrzo nakon toga umro (1682. godine), a njegov plan preuzeo je 1683. Cassini I. s podrškom ministra Colberta. Tako je Cassini I. vodio ekspediciju na jug prema Perpignanu, a Philippe de la Hire (La Hire I.) išao je na sjever (Murdin 2009, str. 31).

Picard passed away not long after, in 1682, and his plan was taken up by Cassini I in 1683 with support of Minister Colbert. Thus Cassini I led an expedition to South toward Perpignan, and Philippe de la Hire (La Hire I) went North (Murdin 2009, page 31).

Jean Picard was a modest and unselfish man and proposed his rival, Italian astronomer Cassini for the director of the Paris Observatory to Colbert and King Louis XIV.

4 Philippe de la Hire (La Hire I)

Philippe de la Hire (1640–1718) (Fig. 10) called La Hire I was an eminent French mathematician and astronomer. He became a member of the Academy of Science in 1678, and he is famous in astronomy for calculating tables of Sun, Moon and planet movements (URL 9 and 10).

He observed and surveyed the French coast, assisting Picard and Cassini I from 1679 to 1682. After Picard died, de la Hire presented the Map of the French Coast (Fig. 11) in the Academy of Science in Paris in 1683. The map represents the coast of the Atlantic Ocean and the Mediterranean Sea as perceived previously (brighter line) and as determined by the new survey (darker line). His result was that Brest (coast of the Atlantic Ocean) was 140 km closer to Paris than it had been thought. The area of France was reduced by 20%. The "dramatic" map was published ten years later, in 1693 as *Carte de France / Corrigee par ordre du Roy sur les observations de Mss. de l'Academie des Sciences* (Map of France Corrected According to Decree by King Louis XIV). It was the first map to represent the Paris meridian.

After Picard died, La Hire I joined the survey of extending the Paris meridian to North of Amiens, while

Figure 10 Philippe de la Hire (La Hire I) (1640–1718) (URL 9)
Slika 10. Philippe de la Hire (La Hire I.) (1640–1718) (URL 9)

Jean-Dominique Cassini (Cassini I) worked on extending the Paris meridian from Malvoisine to South.

La Hire I had two sons. The older son, Gabriel-Philippe de la Hire (called La Hire II) was a mathematician who later joined the meridian length survey and in 1718 participated in extending the Paris meridian from Amiens to Dunkerque (URL 11). His second, younger son Jean-Nicolas de la Hire was a botanist.

5 Giovanni Domenico Cassini (Jean-Domenique Cassini, Cassini I)

Giovanni Domenico Cassini (1625–1712, Fig. 12) was born in Perinald near San Remo, at the time a part of the Republic of Genoa. He was educated by Jesuits. As a young man, he became interested in astrology and subsequently astronomy. He worked as an astronomer in the observatory in Panzano from 1648 to 1669, and he also became a professor of astronomy at the University of Bologna (URL 12).

He achieved significant scientific results as a young astronomer in Italy. Thus he and English physicist Robert Hooke (1635–1703) are credited with discovering the Great Red Spot on the Southern part of Jupiter. Observing the Great Red Spot, Cassini determined that the rotational period of Jupiter is 9 hours and 56 minutes (URL 13). He also determined that the rotational period of Saturn is 24 hours and 40 minutes. In 1666, he recorded that Jupiter is very oblate and that the flattening equals about 1/15. The same conclusion was reached at the same time in England by John Flamsteed (1646–1719) (Fig. 13) (URL 16). It was not until later that Isaac Newton and Christiaan Huygens explained the phenomenon by the speed of planet's rotation around its axis. Cassini I forgot about that fact and from his own measuring on Paris meridian he stated the Earth is a prolate spheroid (a rotational ellipsoid extended at the poles), and not oblate. Namely, he thought his surveys of the Paris meridian length led him to the wrong conclusion. Nowadays, we know the semi-major axis of Jupiter (in the area of its equator) equals 71 400 km, and the semi-minor axis (i.e. in the area of poles) equals 67 000 km (Vujnović 1989, page 220). In addition, we also know Saturn is the most oblate planet and that its semi-major axis equals 60 000 km and that its semi-minor axis equals 53 500 km (Vujnović 1989, page 230).

During 1668, Cassini compiled a table of position and movement of Jupiter's four largest moons (satellites) and published first tables of those movements in Bologna in *Ephemerides Bononienses Mediceorum siderum*. Between 1666 and 1668 he discovered an irregularity in the movement of Jupiter's moon Io. Subsequently in

Jean Picard bio je skroman i nesebičan čovjek te je predložio Colbertu i kralju Luju XIV. za voditelja Opservatorija u Parizu svojega konkurenta, talijanskog astronoma Cassinija.

4. Philippe de la Hire (La Hire I.)

Phillppe de la Hire (1640–1718) (sl. 10), nazivan La Hire I., bio je eminentni francuski matematičar i astronom. Izabran je za člana Akademije znanosti 1678. godine, a u astronomiji je poznat po računanju tablica gibanja Sunca, Mjeseca i planeta (URL 9 i 10).

Od 1679. do 1682. opažao je i mjerio francusku obalu asistirajući Picardu i Cassiniju I. Nakon Picardove smrti, 1683. godine prezentirao je Kartu francuske obale u Akademiji znanosti u Parizu (sl. 11). Na njoj je prikazana obala Atlantskog oceana i Sredozemnog mora onako kako se prethodno smatralo (svjetlija linija) i ona određena novim mjerenjem (tamnija linija). Dobio je da Brest na obali Atlantskog oceana leži 140 km bliže Parizu nego što se do tada mislilo. Površina Francuske bila je smanjena za 20%. Ta "dramatična" karta bila je objavljena deset godina kasnije, 1693. godine, kao *Carte de France / Corrigee par ordre du Roy sur les observations de Mss. de l'Academie des Sciences* (Karta Francuske korigirana po nalogu kralja Luja XIV.). To je ujedno prva karta na kojoj je ucrtan Pariški meridijan.

Nakon Picardove smrti La Hire I. priključio se izmjeri produživanja Pariškoga meridijana na sjever od Amiensa, dok je Jean-Dominique Cassini (Cassini I.) preuzeo zadatak produživanja Pariškog meridijana od Malvoisinea na jug.

La Hire I. imao je dva sina. Stariji sin Gabriel-Philippe de la Hire (nazvan La Hire II.) bio je matematičar, koji se poslije priključio i izmjeri duljine meridijana, te je tako 1718. godine sudjelovao u produženju Pariškog meridijana od Amiensa do Dunkerquea (URL 11). Mlađi sin Jean-Nicolas de la Hire bio je botaničar.

5. Giovanni Domenico Cassini (Jean-Domenique Cassini, Cassini I.)

Giovanni Domenico Cassini (1625–1712) (sl. 12) rođen je u Perinaldu, u blizini San Rema, u to doba u Republici Genovi. Školovao se kod isusovaca. U mladosti se zainteresirao za astrologiju, a potom i za astronomiju. Radio je kao astronom u zvjezdarnici u Panzanou od 1648. do 1669., a bio je i profesor astronomije na Sveučilištu u Bologni (URL 12).

Već kao mladi astronom u Italiji postigao je zapažene znanstvene rezultate. Pripisuje mu se, kao i engleskom fizičaru Robertu Hookeu (1635–1703), otkriće velike crvene

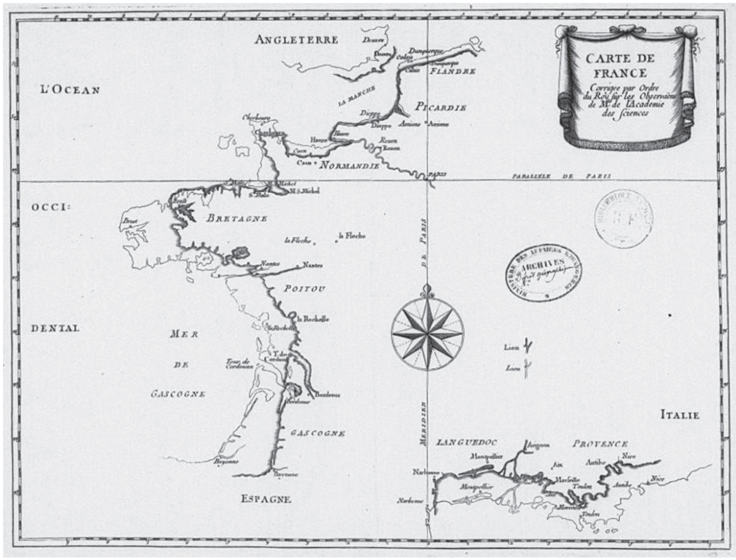


Figure 11 *Carte de France / Corrigee par ordre du Roy sur les observations de Mss. de l'Academie des Sciences* (Map of France Corrected According to Decree by King Louis XIV). It was published in 1693. It is the first map to represent the Paris meridian (URL 45)

Slika 11. *Carte de France / Corrigee par ordre du Roy sur les observations de Mss. de l'Academie des Sciences* (Karta Francuske korigirana po nalogu kralja Luja XIV.), objavljena je 1693. To je prva karta koja prikazuje Pariški meridijan (URL 45)

pjege na južnom dijelu Jupitera 1665. godine. Opažajući Veliku Jupiterovu pjegu odredio je da rotacijski period Jupitera iznosi 9 sati i 56 minuta (URL 13). Također je odredio da je rotacijski period Saturna 24 sata i 40 minuta. Godine 1666. zabilježio je da je Jupiter jako spljošten na polovima i da spljoštenost iznosi oko 1/15. Do istog zaključka u Engleskoj je istodobno došao John Flamsteed (1646–1719) (sl. 13) (URL 16). Tek poslije su Isaac Newton i Christiaan Huygens protumačili tu pojavu brzinom rotacije planeta oko vlastite osi. Tu je činjenicu Cassini I. zaboravio jer je na temelju svojih mjerenja na Pariškom meridijanu tvrdio da je Zemlja ispupčena na polovima, a ne na ekvatoru. Naime, mislio je da je mjerenjima duljine luka Pariškog meridijana došao do suprotnog zaključka. Danas znamo da velika Jupiterova poluos (u području njegova ekvatora) iznosi 71 400 km, a mala poluos (tj. na polovima) 67 000 km (Vujnović 1989, str. 220). Također, danas se zna da je Saturn najspljošteniji planet i da mu velika poluos iznosi 60 000 km, a mala poluos 53 500 km (Vujnović 1989, str. 230).

Tijekom 1668. godine Cassini je sastavio tablicu gibanja i položaja četiriju najvećih Jupiterovih mjeseca (satelita), te je u Bologni objavio prve tablice tih gibanja u *Ephemerides Bononienses Mediceorum siderum*. Između 1666. i 1668. otkrio je nejednakost u gibanju Jupiterova mjeseca Io, a poslije u Parizu 1675. godine analiziranjem dolazi do zaključka da je ta nejednakost korelirana s

Figure 12 Giovanni Domenico Cassini (1625–1712) changed his name to Jean-Domenique Cassini (called Cassini I) in France, the first head of the Paris Observatory (URL 12)
Slika 12. Giovanni Domenico Cassini (1625–1712) u Francuskoj je uzeo ime Jean-Domenique Cassini (nazvan Cassini I.), prvi voditelj Pariškog opservatorija (URL 12)

Figure 13 Bust of John Flamsteed (1646–1719) in the Royal Greenwich Observatory museum (URL 15)
Slika 13. Bista Johna Flamsteeda (1646–1719) u muzeju the Royal Greenwich Observatory (URL 15)

Paris in 1675, he reached the conclusion the irregularity correlates to the distance between Jupiter and Earth, i.e. that the difference is the greatest when the Sun is near the line between Earth and Jupiter. Cassini later abandoned the idea. Cassinis data and other newer measurements were used subsequently in Paris by Ole Römer, who was the first to determine the speed of light in 1677. Römer's solution was not supported by Cassini and was acknowledged only half a century later when James Bradley discovered and explained the aberration of light in 1728 (URL 17).

French King Louis XIV invited Cassini to Paris in 1669, when he was a famous European astronomer – scientist. It was then that Cassini became a member of the new Academy of Science in Paris. He became the first head of the Paris Observatory when it was opened in 1671. In 1673, he became a naturalised citizen of France, changed his name to Jean-Dominique and married a French woman.

Cassini discovered four Saturn's moons in Paris: Iapetus (1671), Rhea (1672), Tethys and Dione (1684) and in 1675 also discovered a gap between Saturn's rings which is now referred to as the Cassini Division (URL 13).

Cassini I was the first to successfully survey the longitude by using eclipses of Jupiter's moons as a clock, a method proposed by Galileo Galilei (URL 14). The method was applied for the first "accurate survey" of the French territory.

As the head of the Paris Observatory, Cassini I sent Jean Richer (1630–1696) (Fig. 14) to South America to Cayenne (French Guiana) on a scientific expedition from 1671 to 1673. Cassini stayed in Paris to observe Mars, so the two of them determined the parallax of Mars from concurrent astronomical observations in Paris and Cayenne. Namely, the distance to a near planet can be determined by measuring their parallax, i.e. the angle between two positions of planets in the celestial sphere measured from two locations on Earth of which the distance is known. Thus it was possible to calculate the distance from Mars to Earth and from Earth to Sun, as well as other planets. They obtained that the distance from Earth to Sun equals 140 million km, which is not far from the known value of 149 597 870.66 km (URL 18 and 19). Thus, it was possible for the first time to employ astronomical measurements in Paris and Cayenne and by using the third Kepler's law and the time planets need to rotate around the Sun to calculate true distances of other planets of the Solar System from the Sun, i.e. the extent of the Solar System (URL 17).

In addition, Richer made a very significant discovery. The pendulum clock, which was accurately calibrated in Paris (latitude of 48°50') did not display the accurate time in French Guiana in South America, near the equator and at a latitude of +5°. Namely, it was about two and a half minutes late each day, which Richer determined by

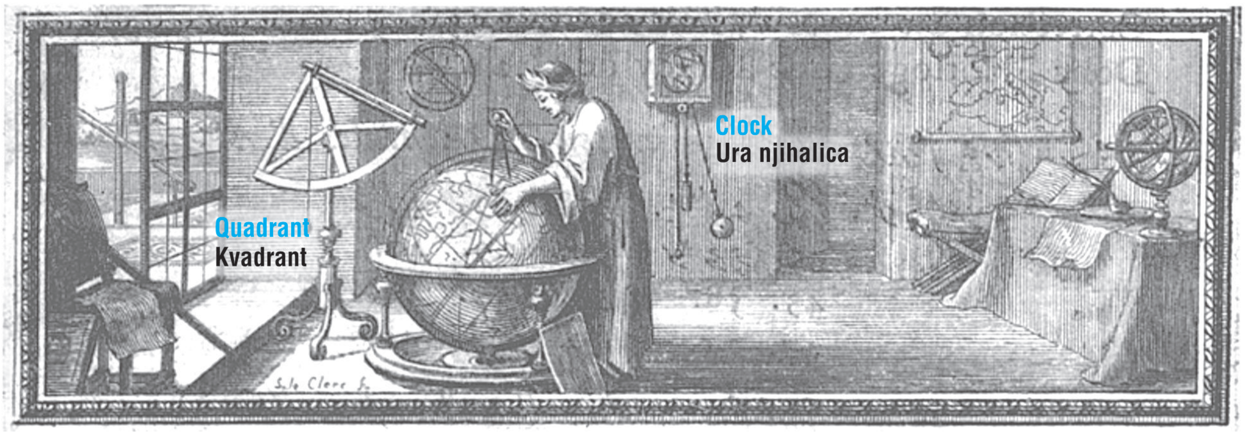


Figure 14 Jean Richer measuring in Cayenne (engraving by Sébastien Leclerc, URL 18) with a pendulum clock in the background which was accurate in Paris, while Richer had to shorten its pendulum for about 3 mm in order for the clock to accurately display the time in Guiana.

Slika 14. Jean Richer pri mjerenjima u Cayenneu (gravura Sébastiena Leclerca, URL 18) dok je u pozadini ura njihalica koja je bila točna u Parizu, a u Gvajani je Richer morao skratiti njezino njihalo za oko 3 mm da bi ura pokazivala točno vrijeme.

udaljenosti između Jupitera i Zemlje, odnosno da je ta razlika najveća kad se Sunce nalazi kraj pravca Zemlja–Jupiter. Od te ideje Cassini je poslije odustao. Tim Cassinijevim podacima i drugim novijim mjerenjima kasnije se koristio Ole Römer u Parizu i prvi put u povijesti odredio brzinu svjetlosti 1677. godine. To Römerovo rješenje Cassini nije podržao, a bilo je priznato tek nakon pola stoljeća, kad je James Bradley 1728. godine otkrio i protumačio aberaciju svjetla (URL 17).

Francuski kralj Luj XIV. pozvao je Cassinija u Pariz 1669. godine kad je već bio afirmiran i slavan europski astronom i znanstvenik. Tada Cassini ulazi u novoosnovanu Akademiju znanosti u Parizu, a kad je 1671. otvoren Pariški opservatorij, postavljen je za njegova prvog voditelja. Godine 1673. postao je naturalizirani Francuz, promijenio je ime u Jean-Dominique i oženio se Francuskinjom.

Cassini je u Parizu otkrio četiri Saturnova mjeseca: Iapetus (1671), Rhea (1672), Tethys i Dione (1684), a 1675. otkrio je i procjep između Saturnovih prstenova, koji danas nosi po njemu ime Cassinijeva pukotina (URL 13).

Cassini I. prvi je uspješno izvodio mjerenja geografske dužine s pomoću pomrčine Jupiterovih prirodnih satelita kao sata po metodi koju je predložio Galileo Galilei (URL 14). Ta metoda bila je iskorištena za prvu“ točnu izmjeru” teritorija Francuske.

Cassini I. kao voditelj Pariškog opservatorija poslao je Jeana Richera (1630–1696) (sl. 14) u Južnu Ameriku u Cayenne (u Francusku Gvajanu) u znanstvenu ekspediciju od 1671. do 1673. godine. Cassini je ostao opažati Mars u Parizu pa su njih dvojica iz istodobnih astronomskih mjerenja u Parizu i u Cayenneu odredili paralaksu Marsa. Naime, udaljenost do bliskog planeta moguće je odrediti metodom mjerenja njihove paralakse, tj. kuta između dva položaja planeta na nebeskom svodu mjerenih iz dvije lokacije na Zemlji poznate međusobne udaljenosti. Tako je bilo moguće izračunati udaljenost Marsa od Zemlje i Zemlje od Sunca, kao i ostalih planeta. Dobili su da udaljenost Zemlje od Sunca iznosi 140 milijuna km, što je približno danas poznatoj udaljenosti od 149 597 870,66 km (URL 18 i 19). Na taj su se način iz astronomskih mjerenja u Parizu i u Cayenneu i uz pomoć III. Keplerova zakona i izmjerenih ophodnih vremena planeta oko Sunca prvi put mogle izračunati stvarne udaljenosti ostalih planeta Sunčeva sustava od Sunca, drugim riječima veličina Sunčeva sustava (URL 17).

Osim toga, Richer je došao do vrlo značajnog otkrića da ura njihalica, koja je bila točno baždarena u Parizu (na geografskoj širi 48° 50'), nije više pokazivala točno vrijeme u Francuskoj Gvajani u blizini ekvatora, na geografskoj širini +5°. Kasnila je oko dvije i pol minute svaki dan, što je utvrdio astronomskim mjerenjima položaja Sunca i zvijezda. Zato je morao skratiti duljinu njezina njihala za 1¼ linije (lignesa, oko 3 milimetra). Da bi bio siguran u svoja mjerenja, ponavljao ih je svaki tjedan tijekom 10 mjeseci u raznim temperaturnim ciklusima. Tako je potvrdio da to nije zbog temperaturne razlike između tropske Gvajane i temperature u Francuskoj. Naime, razlika koju je Richer dobio u Gvajani bila je suviše velika da bi se mogla pripisati samo temperaturnim razlikama (Murdin 2009, str. 43). Rezultate svojih istraživanja objavio je u radu *Observations astronomiques et physiques faites en l'isle de Cayenne 1679* (URL 19).

Cassini je 1682. poslao ekspedicije na Kapverdske otoke i na Antile koje su potvrdile Richerovo otkriće o promjeni duljine sekundnog njihala (URL 20). Taj je

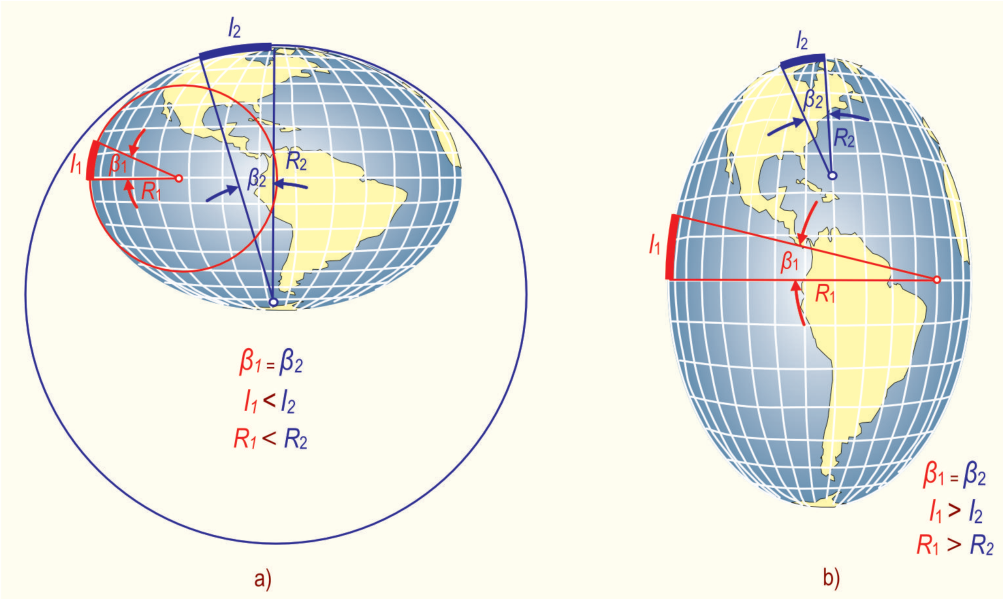


Figure 15 Graphical representation: a) Earth is an oblate spheroid (a rotational ellipsoid extended at the equator) as claimed by Newton and Huygens; b) Earth is a prolate spheroid (a rotational ellipsoid extended at the poles), as claimed by Cassini
Slika 15. Grafički prikaz: a) Zemlja spljoštena na polovima, kako su tvrdili Newton i Huygens; b) Zemlja ispupčena na polovima, kako je tvrdio Cassini

astronomically measuring positions of Sun and stars. Therefore, he had to shorten its pendulum by 1¼ lignes (about 3 millimetres). In order to be confident in his measurements, he repeated them every week through 10 month with various temperature cycles. He was able to exclude the effect of the differences in temperature between the tropical Guiana and France. Namely, the difference Richer obtained in Guiana was too large to attribute solely to differences in temperature (Murdin 2009, page 43). Richer published results of his research in *Observations astronomiques et physiques faites en l'isle de Cayenne 1679* (URL 19).

In 1682, Cassini sent expeditions to Cape Verde Islands and The Antilles. The expeditions confirmed Richer's discovery of the change in the length of the second's pendulum (URL 20). Richer's result elicited a great scientific discussion in the entire Europe. Answers to the question were provided by Isaac Newton (1642–1727), Christiaan Huygens (1629–1695) and other famous scientists.

After Picard died, Cassini I became responsible for extending the Paris meridian in 1683, so he extended it towards South and Philippe de la Hire (La Hire I) extended it toward North. Unfortunately, Minister Colbert died in the same year and was replaced by François Le Tellier (Marquis de Louvois), who was not supportive of the meridian arc length measuring project. By the end of 1684, the meridian was measured from *Mont Cassel* (North, near Calais) to *Montluçon* (central France, to the Massif Central). There was a lot of snow in the winter of 1683, so Marquis de Louvois suspended the work and requested expeditions to wait until spring and more adequate weather conditions. However, he never reactivated the expeditions due to a lack of funds and giving priority to other state needs. Marquis de Louvois died in 1691 and was succeeded Comte de Ponchartrain. Cassini I requested permission and finances to restart the project of establishing the Paris meridian. His request was accepted in 1700 and work continued toward South from the Bourges cathedral tower. Cassini I was helped by his son Jacques Cassini (called Cassini II) and nephew Giacomo Filippo Maraldi (called Maraldi I). The expedition reached the French border with Spain in 1701 when the War of the Spanish Succession broke out (1701–1713), interrupting the work on measuring the Paris meridian once again (Murdin 2009, page 31).

Measurements and calculations for the Paris-Bourges part of the meridian were completed in 1701 and Cassini I obtained the arc length of one degree of the meridian equals 57 097 toise, and he stated the value measured from Paris to Amiens by Picard was 56 996 toise (Murdin, 2009, page 49). From these results he concluded that each degree of meridian is shorter by 1/800 (0.1%) when approaching the pole. Cassini's conclusion was also embraced by his son Cassini II, who continued to claim the Earth is a prolate spheroid (Fig. 15b). However, it was contrary (Fig. 15a) to Newton's and Huygens's theoretical derivations. Cassini II published measurement and calculation results in 1713, after his father passed away.

Cassini I died in 1712 and King Louis XIV in 1713, which terminated the survey of the Paris meridian.

Richerov rezultat izazvao veliku znanstvenu diskusiju u čitavoj Europi. Odgovor na to pitanje ponudili su Isaac Newton (1642–1727), Christiaan Huygens (1629–1695) i neki drugi poznati znanstvenici.

Nakon Picardove smrti sveukupnu brigu oko produživanja Pariškog meridijana preuzeo je 1683. godine Cassini I. koji ga je produživao prema jugu, a Philippe de la Hire (La Hire I.) prema sjeveru. Nažalost, te godine umro je ministar Colbert, a na njegovo mjesto došao je François Le Tellier (Marquis de Louvois), koji nije bio sklon projektu mjerenja duljine luka meridijana. Do kraja 1683. godine meridijan je bio izmjeren od *Mont Cassela* (na sjeveru, pokraj Calaisa) do *Montluçona* (u središtu Francuske, do Središnjeg masiva). U zimi 1683. godine palo je mnogo snijega te je Marquis de Louvois obustavio radove i pozvao ekspedicije da čekaju do proljeća kad će doći prikladniji vremenski uvjeti. Međutim, on ih nikad nije ponovno aktivirao zbog nedostatka sredstava, dajući prioritet drugim državnim potrebama. Marquis de Louvois umro je 1691., a naslijedio ga je Comte de Ponchartrain. Cassini I. zatražio je dozvolu i financije za nastavak radova na projektu uspostave Pariškoga meridijana. Njegov je zahtjev prihvaćen 1700. godine, te su radovi nastavljeni prema jugu od tornja katedrale u Bourgesu. U radu su mu pomagali njegov sin Jacques Cassini (nazvan Cassini II.) i nećak Giacomo Filippo Maraldi (nazvan Maraldi I.). Mjerna ekspedicija došla je do francuske granice sa Španjolskom 1701. godine, kad je počeo Rat za španjolsko nasljedstvo (1701–1713) pa su radovi na izmjeri Pariškoga meridijana ponovno prekinuti (Murdin 2009, str. 31).

Na temelju završenih mjerenja i računanja za dio meridijana Pariz–Bourges Cassini I. je 1701. godine dobio da duljina luka jednog stupnja meridijana iznosi 57 097 toisea, a naveo je da je duljina jednog stupnja meridijana koji je mjerio Picard od Pariza do Amiensa 56 996 toisea (Murdin, 2009, str. 49). Iz tih je rezultata zaključio da je svaki stupanj meridijana kraći za 1/800 (0,1%) kako se približava polu. Taj je zaključak poslije prihvatio i njegov sin Cassini II. i dalje uporno tvrdeći da je Zemlja ispupčena na polovima (sl. 15b). Međutim, to je bilo suprotno (sl. 15a) Newtonovim i Huygensovim teorijskim izvodima. Cassini II. je objavio rezultate mjerenja i računanja nakon očeve smrti 1713. godine.

Cassini I. umro je 1712. godine, a kralj Luj XIV. 1713. godine, što je izazvalo prekid izvođenja izmjere na Pariškome meridijanu. U tim otežanim uvjetima sin Jeana Cassinija Cassini II. preuzeo je brigu o projektu uspostave Pariškog meridijana.

Jean-Dominique Cassini (Cassini I.) postao je osnivač "dinastije" Cassini od četiri astronoma: njegov sin Jaques Cassini (Cassini II.) (1677–1756), unuk César François Cassini (Cassini III.) (1714–1784) i praunuk Jean-Dominique Cassini (Cassini IV.) (1748–1845) bili su voditelji, odnosno ravnatelji Pariškog opservatorija.

6. Isaac Newton

Isaac Newton (1642–1727) (sl. 16) bio je engleski fizičar, matematičar i astronom, jedna od najznačajnijih ličnosti u povijesti znanosti, veliki Cassinijev protivnik (URL 21 i 22). Razmišljajući o uzrocima zbog kojih se Mjesec giba oko Zemlje, 1666. dolazi do zaključka da ista sila (gravitacija) koja uzrokuje padanje tijela na Zemljinu površinu drži Mjesec na njegovoj putanji oko Zemlje. Prvi je uveo pojam sile i postavio tri aksioma kao temeljna

Figure 16 Isaac Newton (1642–1727), famous English physicist (URL 21)

Slika 16. Isaac Newton (1642–1727), slavni engleski fizičar (URL 21)

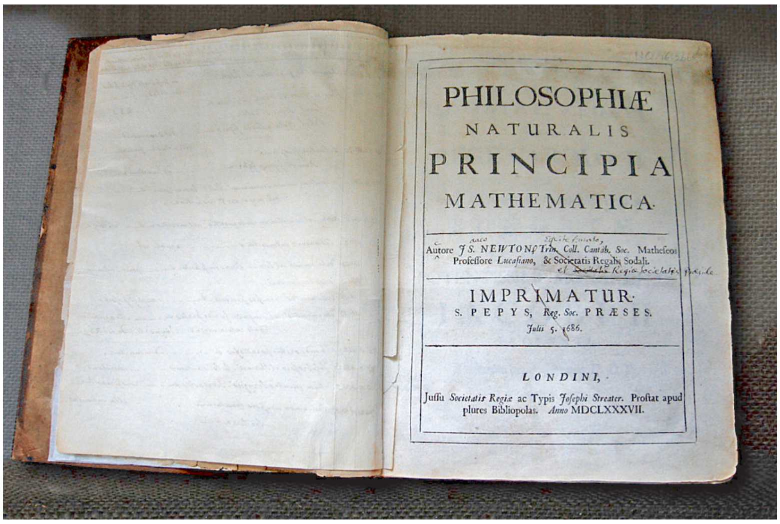


Figure 17 Copy of the first edition of Newton's book Philosophiæ Naturalis Principia Mathematica (Mathematical principles of the philosophy of nature) from 1687 (URL 21)

Slika 17. Kopija prvog izdanja Newtonove Philosophiæ Naturalis Principia Mathematica (Matematički principi filozofije prirode) iz 1687. godine (URL 21)

Cassini II, son of Jean Cassini took up the project of establishing the Paris meridian in these difficult conditions.

Jean-Dominique Cassini (Cassini I) established the Cassini "dynasty" of four astronomers in Paris: his son Jaques Cassini (Cassini II) (1677–1756), his grandson César François Cassini (Cassini III) (1714–1784) and great-grandson Jean-Dominique Cassini (Cassini IV) (1748–1845) who were heads or directors of the Paris Observatory.

6 Isaac Newton

Isaac Newton (1642–1727) (Fig. 16) was an English physicist, mathematician and astronomer, one of the most significant individuals in the history of science and great rival to Cassini (URL 21 and 22). Thinking about why the Moon rotates around Earth in 1666, he reached the conclusion that the same force (gravity) which causes objects to fall down to the Earth's surface holds the Moon in its trajectory around Earth. Newton was the first to introduce the concept of force and formulated three axioms of classical mechanics (Newton's mechanics). Newton solved the problem of moving celestial bodies in 1666, but it was not until 19 years later that he published his theory of gravitation when he was persuaded by astronomer E. Halley.

In 1687, Newton wrote his great work *Philosophiæ Naturalis Principia Mathematica* (Mathematical principles of the philosophy of nature) (Fig. 17). This work changed the view of the world and it combines research of Galileo Galilei, Johannes Kepler and Christiaan Huygens. Newton established the foundation of classical mechanics, mathematically described the movement of celestial bodies, formulated a theory of gravitation and theoretically determined Earth should be shaped as a rotational ellipsoid flattened at the poles (Fig. 18).

Namely, Isaac Newton assumed Earth was liquid and that its density was 5.5 times greater than water and calculated the Earth's flattening was 1/230. He used data on the Earth's size determined using a trigonometric network by Jean Picard in 1671. Newton also calculated how lengths of a degree of the Earth's meridian arc vary according to latitude (Table 1).

Dutch Christiaan Huygens (1629–1695) also formulated a theory on the Earth's shape in relation to the Earth's rotation around its axis and the centrifugal force in *Discours sur la cause de la pesanteur*, published in 1690. He concluded Earth had to be shaped as a rotational ellipsoid extended at the equator, with the flattening equal to 1/576 (URL 16).

Table 1 Newton's calculation of lengths of one degree of the Earth's meridian arc d in various latitudes $\varphi°$ and differences in meridian arc lengths Δ (Murdin 2009, page 48)

Tablica 1. Newtonov račun duljina jednog stupnja Zemljina meridijanskog luka d na različitim geografskim širinama $\varphi°$ i razlike u duljinama meridijanskog luka Δ (Murdin 2009, str. 48)

Za svakih 5° geografske širine od 0° do 90°
For every 5° of latitude from 0° to 90°

φ°	d (toise)	Δ	φ°	d (toise)	Δ	φ°	d (toise)	Δ
0°	56 637		30°	56 823		60°	57 196	
		+5			+59			+54
5°	56 642		35°	56 882		65°	57 250	
		+17			+63			+45
10°	56 659		40°	56 945		70°	57 295	
		+28			+65			+37
15°	56 687		45°	57 010		75°	57 332	
		+37			+64			+28
20°	56 724		50°	57 074		80°	57 360	
		+45			+63			+17
25°	56 769		55°	57 137		85°	57 377	
		+54			+59			+5
30°	56 823		60°	57 196		90°	57 382	

Za stupanj geografske širine od 40° do 45°
For a degree of latitude from 40° to 45°

φ°	d (toise)	Δ	φ°	d (toise)	Δ
40°	56 945		45°	57 010	
		+13			+12
41°	56 958		46°	57 022	
		+13			+13
42°	56 971		47°	57 035	
		+13			+13
43°	56 984		48°	57 048	
		+13			+13
44°	56 997		49°	57 061	
		+13			+13
45°	57 010		50°	57 074	

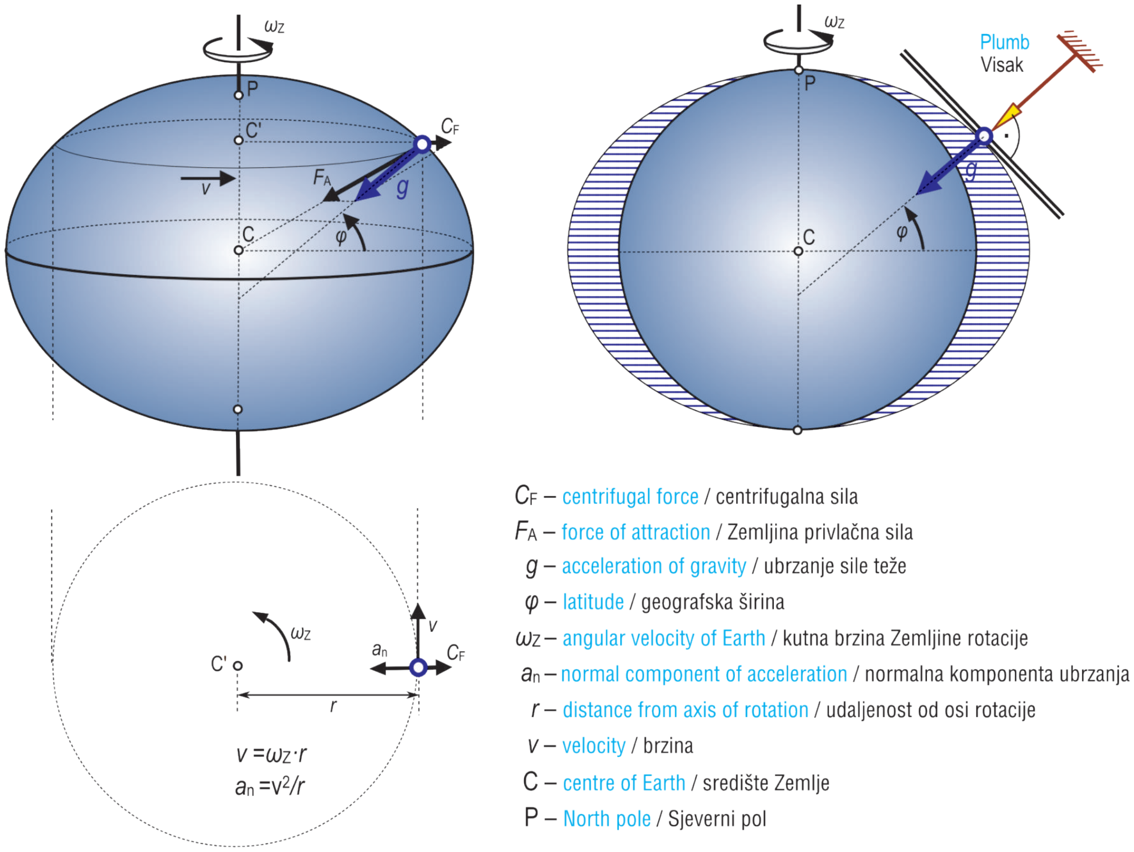


Figure 18 Explanation of the centrifugal force which causes Earth to be a rotational ellipsoid extended at the equator

Slika 18. Objašnjenje nastanka centrifugalne sile koja izaziva istezanje Zemlje na ekvatoru

zakona klasične mehanike (Newtonova mehanika). Problem gibanja nebeskih tijela Newton je u principu riješio već 1666. godine, ali je svoju teoriju gravitacije objavio tek 19 godina poslije, i to na poticaj astronoma E. Halleya.

Godine 1687. Newton je napisao kapitalno djelo *Philosophiæ Naturalis Principia Mathematica* (Matematički principi filozofije prirode) (sl. 17). To djelo promijenilo je pogled na svijet, u njemu su ujedinjena istraživanja Galilea Galileja, Johanna Keplera, a i Christiaana Hygensa. Newton je postavio temelje klasične mehanike, matematički opisao gibanje nebeskih tijela, izgradio teoriju gravitacije i teorijski odredio da bi Zemlja trebala imati oblik rotacijskog elipsoida spljoštenog na polovima (sl. 18).

Naime, Isaac Newton je uz pretpostavku da je Zemlja u tekućem stanju, da je njezina gustoća konstantna i da je 5,5 puta veća od gustoće vode izračunao da je Zemljina spljoštenost 1/230. Pritom se koristio podacima o Zemljinim dimenzijama koje je mjerenjem uz pomoć trigonometrijske mreže odredio Jean Picard 1671. godine. Newton je također izračunao i kako se mijenjaju duljine jednog stupnja Zemljina meridijanskog luka na različitim geografskim širinama (tablica 1).

I Nizozemac Christiaan Huygens (1629–1695) postavio je svoju teoriju o Zemljinu obliku uzevši u obzir ovisnost o Zemljinoj rotaciji oko vlastite osi i centrifugalnu silu u radu *Discours sur la cause de la pesanteur*, objavljenom 1690. godine. Zaključio je da Zemlja mora imati oblik rotacijskog elipsoida i da je spljoštena na polovima te da ta spljoštenost iznosi 1/576 (URL 16).

7. Jacques Cassini (Cassini II.)

Jacques Cassini (1677–1756), poznat kao Cassini II., bio je sin Jeana Cassinija (Cassinija I.) (URL 23 i 25). Bio je izvrsno obrazovan i vrlo rano se posvetio izučavanju astronomije. U Akademiju znanosti u Parizu primljen je 1694. godine, kada je počeo sa znanstvenim radom na projektima koje je vodio njegov otac. Zajedno s ocem posjetio je Italiju 1695. godine, a zatim Flandriju i Englesku, gdje upoznaje poznate znanstvenike Isaaca Newtona (1642–1727), Johna Flamsteeda (1646–1719) i Edmonda Halleya (1656–1742). U Engleskoj je bio izabran u *The Royal Society (Kraljevsko društvo).*

Cassini II., poput svojega oca, bio je zainteresiran za astronomska opažanja i za precizna geodetska mjerenja. Radio je na određivanju vlastitoga gibanja zvijezda i dimenzija Zemlje. Po povratku u Francusku sudjelovao je u projektu, koji je vodio njegov otac, na produživanju Pariškoga meridijana na jug Francuske, od tornja katedrale kod Bourgesa. Mjerna ekspedicija došla je 1701. godine do granice Francuske i Španjolske, gdje je postavljen stup na

Figure 19 Trigonometric chain of the Paris meridian Dunkerque – Perpignan (Collioure) and arc perpendicular to the Paris meridian Brest (Saint Molo) – Strasbourg (URL 16)

Slika 19. Trigonometrijski lanac Pariškog meridijana Dunkerque–Perpignan (Collioure) i luk okomit na Pariški meridijan Brest (Saint Molo)–Strasbourg (URL 16)

7 Jacques Cassini (Cassini II)

Jacques Cassini (1677–1756) known as Cassini II was son of Jean Cassini (Cassini I) (URL 23 and 25). His education was excellent and he started studying astronomy early on. He was accepted into the Academy of Science in Paris in 1694, when he started doing scientific work on projects led by his father. The two of them visited Italy in 1695 and later also Flanders and Italy, where he met famous scientists Isaac Newton (1642–1727), John Flamsteed (1646–1719) and Edmond Halley (1656–1742). He became a member of *The Royal Society* in England.

Like his father, Cassini II was interested in astronomical observations and precise geodetic surveys. He worked on determination of star movement and size of Earth. When he returned to France, he participated in a project led by his father of extending the Paris meridian to the South of France, from the Bourges cathedral tower. In 1701, the expedition reached the border between France and Spain, when a pillar was mounted to the 2780 m high Pic du Canigou. Unfortunately, soon after all geodetic work on the Paris meridian was terminated due to the War of the Spanish Succession from 1701 to 1713.

Cassini I started being sick in 1709, and his son, Cassini II, first helped him and subsequently succeeded him as the head of the Paris Observatory in 1712. In 1713, Cassini II proposed a new method for determining longitudes on Earth using Moon eclipses of stars and planets, i.e. when stars and planets go behind the Moon. By applying the occultation methods and using data from measuring the Paris meridian from Paris to Perpignan in 1700, he claimed to have evidence that: *"...the* vrhu Pic du Canigou, visokom 2780 m. Nažalost, ubrzo je došlo do prekida geodetskih radova na Pariškome meridijanu zbog Rata za španjolsko nasljedstvo od 1701. do 1713. godine.

Cassini I. počeo je pobolijevati 1709. godine, te ga je Cassini II. na početku zamjenjivao, da bi ga 1712. naslijedio kao voditelj Pariške zvjezdarnice. Godine 1713. Cassini II. je predložio novu metodu za određivanje geografskih dužina mjesta na Zemlji uz pomoć pomračenja zvijezda i planeta Mjesecom, tj. kad zvijezde i planeti zađu iza Mjeseca. Primjenjujući tu metodu okultacija i uporabljujući podatke mjerenja na Pariškome meridijanu od Pariza do Perpignana iz 1700. godine, tvrdio je da ima dokaze *"....da duljina jednog stupnja Zemljina meridijana postaje manja idući od ekvatora prema polu"*, drugim riječima da je Zemlja ispupčena na polovima i spljoštena na ekvatoru (sl. 15b) (URL 23).

Cassini II. je uz asistenciju Maraldija I. i Gabriel-Philippea de la Hirea (La Hire II., sin La Hirea I.) ponovno izmjerio trigonometrijsku mrežu uzduž meridijana na sjever i kompletirao je produžetak od Amiensa na sjever do Dunkerquea 1718. godine. Na taj je način uspio završiti izmjeru Pariškog meridijana od Dunkerquea do Collourea (sl. 19) (Murdin 2009, str. 34).

Rezultate mjerenja Pariškog meridijana objavio je 1722. godine u djelu *De la grandeur et de la figure de la terre*, u kojem je ponovno podržao očevu i svoju netočnu teoriju o Zemljinoj ispupčenosti na polovima (URL 23).

Pariški meridijan poznat je i kao *Cassinijev trigonometrijski lanac* koji je Cassini izračunao na osnovi triju izmjerenih duljina baza:

1) kod Dunkerquea, duge 5564 toisea (oko 10 844 m)
2) kod Villejuifa (danas na južnoj periferiji Pariza), duge 5663 toisea (oko 11 037 m)
3) kod Leucatea (36 km sjevernije od Colliourea i 10 km sjeveroistočno od Perpignana), duge 7246 toisea (oko 14 122 m) (Leucate – Sant Nazary).

Duljine baza mjerene su drvenim motkama postavljenim na zemlju u horizontalni položaj i uz uže nategnuto u smjeru baze. U račun su uzeta astronomska mjerenja izvedena:

1) na astronomskom opservatoriju u Parizu na geografskoj širini 48º 50' 10''
2) u Dunkerqueu, sjeverno od Pariza, na geografskoj širini 51º 02' 25'' i
3) u Collioureu, južno od Perpignana (10 km od granice sa Španjolskom), na geografskoj širini 42º 31' 14".

Cassini II. je izračunao da duljina dijela luka Pariškog meridijana od jednog stupnja iznosi:

- za južni dio segmenta Pariz–Collioure 57 097 toisea (oko 111 272 m) i
- za sjeverni dio segmenta Pariz–Dunkerque 56 960 toisea (oko 111 015 m) (URL 16 i Bialas 1982, str. 122).

Na temelju toga je zaključio: *"Da je evidentno da jedan stupanj geografske širine luka meridijana ima veću duljinu što je bliže ekvatoru i da jedan stupanj geografske širine luka meridijana ima manju duljinu što je bliže polu"*. Tako je po njemu empirijski, iz mjerenja duljina susjednih dijelova luka Pariškog meridijana, proizašlo da je Zemlja ispupčena na polovima, odnosno da je spljoštena na ekvatoru (sl. 15b). To je bilo u suprotnosti s teorijom Newtona i Huygensa, koji su tvrdili da Zemlja mora imati oblik rotacijskog elipsoida, ali spljoštenog na polovima i ispupčenog na ekvatoru.

Postavlja se pitanje kako to da se Cassini I., a poslije i Cassini II. nisu pitali zašto je Jupiter spljošten na polovima, što je već prije otkrio Cassini I. u Italiji 1666. godine, a istodobno u Engleskoj John Flamsteed. Znanstvenici su se podijelili u dva tabora – jedni su podržavali Cassinijevo mišljenje, a drugi Newtonovo i Huygensovo. Među pristašama Newtonova mišljenja u Francuskoj bio je posebno istaknut Pierre Louis Moreau de Maupertuis.

Cassiniji su imali teškoća pri izvođenju tako opsežnih radova na izmjeri duljine luka meridijana i pri donošenju svojeg mišljenja o obliku Zemlje:

1) Mora se spomenuti da je trigonometrijska mreža posebice u južnom dijelu Pariškog meridijana bila nepovoljno postavljena, tj. konfiguracija trokuta bila je vrlo slaba, drugim riječima bilo je šiljastih kutova u trokutima pa su se tako skupljale pogreške u duljini meridijana (URL 16). Da bi izbjegli te probleme, Bošković i Maire posvetili su posebnu pozornost na pravilnost trokuta u lancu, tj. da to budu po mogućnosti približno istostranični trokuti (Solarić 2013).

2) Treba istaknuti da su razlike geografskih širina prve i posljednje točke meridijanskog luka morale biti određene manjom mjernom nesigurnosti od 1 kutne sekunde (1"). Naime, 1" na Zemljinoj površini daje pogrešku u duljini meridijanskog luka od oko 30 metara (oko 15 toisea). Taj zahtjev sigurno nije bilo moguće jednostavno ispuniti zbog pogrešaka mjerenja, ali i utjecaja atmosferske refrakcije. Poslije su tom problemu posebnu pozornost posvetili Ruđer Bošković i Chistopher Maire pri svojoj izmjeri duljine meridijanskog luka Rim–Rimini 1755. godine (Solarić 2013).

3) Cassiniji su donosili zaključak o spljoštenosti Zemlje iz izmjerenih duljina jednog stupnja luka Pariškog meridijana, koji su bili jedan uz drugoga, gdje je razlika u duljini jednog stupnja meridijana mala. To se vidi i iz tablice 1, gdje je razlika između duljine jednog stupnja luka meridijana na geografskim širinama oko 45° samo oko 13 toisea (26 m), a razlika u duljini jednog stupnja meridijana na polu i ekvatoru iznosi 745 toisea (1490 m).

length of one degree of the Earth's meridian becomes shorter moving from the equator towards a pole", i.e. the Earth is a prolate spheroid. (Fig. 15b) (URL 23).

With the help of Maraldi I and Gabriel-Philippe de la Hire (La Hire II, son of La Hire I), Cassini II measured once more the trigonometric network along the meridian to the North and completed the extension from Amiens towards North to Dunkerque in 1718. Thus he managed to complete the survey of the Paris meridian from Dunkerque to Collioure (Fig. 19) (Murdin 2009, page 34).

He published the results of measuring the Paris meridian in *De la grandeur et de la figure de la terre* in 1722 in which he again supported his father's and his own incorrect theory of the Earth's shape (URL 23).

The Paris meridian, also known as *Cassini's trigonometric chain*, was calculated on the basis of three measured baselines:

1) At Dunkerque, 5564 toise long (about 10 844 m)
2) At Villejuif (nowadays on the Southern outskirts of Paris), 5663 toise long (about 11 037 m)
3) At Leucate (36 km North of Collioure and 10 km Southeast of Perpignan), 7246 toise long (about 14 122 m) (Leucate – Sant Nazary).

Baselines were measured using wooden poles by placing them on the ground in the horizontal position and with a strained rope directed in the direction of the baseline. The following astronomical measurements were taken into calculation:

1) Measurement at the astronomical observatory in Paris, at the latitude of 48º 50' 10''
2) In Dunkerque, North of Paris, at the latitude of 51º 02' 25'' and
3) In Collioureu, South of Perpignan (10 km from the border with Spain), at the latitude of 42º 31' 14''.

Cassini II calculated the length of one degree of the Paris meridian equals:

- 57 097 toise (about 111 272 m) for the Southern part of the Paris-Collioure
- 56 960 toise (about 111 015 m) for the Northern part of the Paris-Dunkerque (URL 16 and Bialas 1982, p. 122).

Based on that, he concluded: *"It is evident that one degree of latitude of the meridian arc is greater the closer it is to the equator and that one degree of latitude of the meridian arc is smaller the closer it is to a pole"*. According to him, empirical measuring of neighbouring parts of the Paris meridian arc resulted in Earth's shape is a prolate spheroid (Fig. 15b). This was contrary to Newton's and Huygens's theories, according to which Earth had to be shaped as an oblate spheroid.

The question raised considering how it is possible that neither Cassini I nor Cassini II were not curious why Jupiter's is an oblate spheroid, which had been found earlier by Cassini I in Italy in 1666, and at the same time by John Flamsteed in England. Scientists took sides – some supported Cassinis, while others stood with Newton and Huygens. Pierre Louis Moreau de Maupertuis was an especially distinguished proponent of Newton's theory in France.

Cassinis had difficulties in such extensive work on measuring the meridian arc length and expressing their thoughts about the Earth's shape:

1) It has to be noted that the trigonometric network, especially in the Southern part of the Paris meridian was adversely placed, i.e. triangle configuration was very weak, meaning there were acute angles in triangles, resulting in errors in the meridian length (URL 16). In order to avoid these problems, Bošković and Maire paid special attention to the regularity of triangles in the chain, i.e. using approximate equilateral triangles as much as possible (Solarić 2013).

2) It has to be noted that differences in latitudes of the first and last point of the meridian arcs should have been determined with a greater accuracy of 1 second (1''). Namely, 1'' on the surface of Earth yields an error of about 30 meters (about 15 toise) in the length of the meridian arc. This requirement was certainly not easy to fulfil due to measurement errors, as well as the effect of atmospheric refraction. This issue was tackled subsequently by Ruđer Bošković and Chistopher Maire when they measured the length of the meridian arc Rome–Rimini in 1755 (Solarić 2013).

3) Cassinis deduced Earth was a prolate spheroid from measured lengths of one degree of the Paris meridian arc which were next to each other and the difference in the length of one degree was small. This can be seen in Table 1, where the difference of one degree of meridian arc in latitudes of about 45° is only 13 toise (26 m) and the difference in length of one meridian degree at the pole and equator equals 745 toise (1490 m).

In 1733, Cassini II organized the second project of measuring the Earth's arc perpendicular to the Paris meridian from *Saint Malo* to *Strasbourg*, and he was assisted by his son, who appears in history as Cassini de Thury, called Cassini III (URL 23). Geodetic surveys were done from Paris toward West and Saint-Malo in 1733 and from Paris East toward Strasbourg in 1734.

In order to get a definite answer to the question of the Earth's shape, the *Royal Academy of Sciences* from Paris organized two geodetic scientific expeditions with the task of measuring lengths of one degree of meridian. To obtain a reliable solution, they decided to send them to locations with great differences in latitudes, because those are cases with greater differences in lengths of one degree, as can be seen from Table 1. Namely, in those

Cassini II. je 1733. godine organizirao drugi projekt mjerenja Zemljina luka okomitog na Pariški meridijan od *Saint Maloa* do *Strasbourga*, a asistirao mu je i sin koji se u povijesti pojavljuje kao Cassini de Thury (nazvan Cassini III.) (URL 23). Geodetska mjerenja obavljali su od Pariza zapadno prema Saint-Malou 1733. godine i od Pariza na istok prema Strasbourgu 1734. godine.

Kako bi se konačno odgovorilo na pitanje je li Zemlja spljoštena na polovima ili na ekvatoru, *Kraljevska akademija znanosti* u Parizu organizirala je dvije geodetske znanstvene ekspedicije sa zadaćom da izmjere duljine jednog stupnja meridijana. Da bi se dobilo pouzdano rješenje odlučili su ih poslati na mjesta sa što većom razlikom geografskih širina, jer je u tom slučaju, kao što se vidi iz tablice 1, razlika duljina jednog stupnja veća. Naime, u tom slučaju pogreške mjerenja ne bi znatnije utjecale na donošenje odluke o Zemljinu obliku.

Dodajmo da rad Cassinija II. nije bio ograničen samo na astronomiju i geodeziju. On je pisao članke i o primjenama matematike, elektricitetu, barometrima, zrcalima i trzajima oružja pri pucanju iz njih.

Figure 20 César-François Cassini de Thury (Cassini III) (1714–1784) (URL 26)

Slika 20. César François Cassini de Thury (Cassini III.) (1714–1784) (URL 26)

8. César François Cassini de Thury (Cassini III.)

César François Cassini de Thury (1714–1784) (sl. 20), poznat i kao Cassini III., prvu je naobrazbu primio na Pariškom opservatoriju, o čemu se brinuo njegov ujak Jacques-Philippe Maraldi (URL 25). Na početku je stekao iznimno vrijedno iskustvo asistiranjem svom ocu Cassiniju II. na njegovu projektu postavljanja trigonometrijskog lanca okomitog na Pariški meridijan od Saint-Maloa (Bresta) do Strasbourga (sl. 19). Svrha tog projekta bila je pomoći pri donošenju odluke o obliku Zemlje, o čemu su se suprotstavila znanstvena mišljenja na jednoj strani Newtona i Huygensa, a na drugoj Cassinija. Tako su Cassini II. i Cassini III. uz pomoć drugih znanstvenika 1773. godine mjerili okomito na Pariški meridijan, zapadno od Pariza do Saint-Maloa. Sljedeće godine mjerili su okomito na Pariški meridijan istočno od Pariza do Strasbourga. Cassini II. i Cassini III. vodili su izmjeru zbog proširenja geodetskih trigonometrijskih mreža u Francuskoj 1735. i 1736. godine. Cassini II. postao je član *Kraljevske akademije znanosti* u Parizu 1735. godine.

Cassini III., iako još mlad, ukazao je *Kraljevskoj akademiji znanosti* 1733. godine na važnost geodetskih mjerenja koja je izvodio s ocem da bi se odredio Zemljin oblik. Podaci do kojih su došli pokazivali su da je Zemlja izdužena na polovima. Nakon nekog vremena protivnici teoriji Cassinijevih u *Kraljevskoj akademiji znanosti* organizirali su ekspediciju u Peru (današnji Ekvador) na čelu s Bouguerom, La Condamineom i Godinom u svibnju 1735., a drugu u Lapland u Švedsku (danas na granici Švedske i Finske) na čelu s Maupertuisom, Clairautom, Le Monnierom i Celsiusom. Oni su krenuli u Lapland iz Dunkerquea u svibnju 1736.

Kad se Maupertuis vratio u Pariz iz Laplanda u kolovozu 1737. imao je čvrste podatke u prilog Newtonovoj i Huygensovoj teoriji o Zemljinu obliku prema kojoj je Zemlja spljoštena na polovima. Međutim, to nije bilo dovoljno jako Cassiniju II., koji nikad nije priznao poraz. Tada je Cassini III. donio tešku odluku te je promijenio mišljenje i suprotstavio se obitelji, koja je dugo uporno tvrdila da je Zemlja ispupčena na polovima. Novi pregled trigonometrijske mreže obavio je Cassini III. od 1739. do 1740. godine. Ti su podaci potvrđivali da je Zemlja spljoštena na polovima, a svoje zaključke objavio je u *La méridienne de l'Observatoire royal de Paris vérifiée dans toute l'étendue du royaume* 1744. godine.

U tom razdoblju u radu na Pariškom opservatoriju i na ponovnoj izmjeri pomagali su mu Nicolas Louis de Lacaille (sl. 21) (1713–1762) i Jean-Dominique Maraldi (Maraldi II., nećak Maraldija I.) (URL 40 i 41). Za rad na meridijanu Lacaille je počašćen postavljanjem njegova imena u natpisu na piramidi u Juvisyju. Lacaille je 1750. vodio astronomsku ekspediciju u južnu Afriku na Rt dobre nade. Ondje je 1751. uspostavio astronomski opservatorij i započeo sustavna astronomska mjerenja na južnom dijelu nebeskog svoda. Odredio je položaje oko 10 000 zvijezda na južnom nebeskom svodu, koje se sve ne vide iz Europe. Godine 1752. započeo je s postavljanjem cases measurement errors should not significantly affect the decision about the Earth's shape.

Let us add that Cassini II's work was not limited to just astronomy and geodesy. He also wrote papers about applications of mathematics, electricity, barometers, mirrors and weapon kicks when firing them.

8 César François Cassini de Thury (Cassini III)

César François Cassini de Thury (1714–1784, Fig. 20), also known as Cassini III received his first education in the Paris Observatory from his uncle Jacques-Philippe Maraldi (URL 25). At first, he gained exceptionally valuable experience by assisting his father Cassini II on his project of establishing the trigonometric chain perpendicular to the Paris meridian from Saint-Malo (Brest) to Strasbourg (Fig. 19). The purpose of the project was to help in making the decision about the Earth's shape, about which there were competing scientific positions of Newton and Huygens versus Cassinis. Thus Cassini II and Cassini III and other scientists measured perpendicular to the Paris meridian, West of Paris to Saint-Malo in 1733. The next year they measured perpendicular to the Paris meridian, East of Paris to Strasbourg. Cassini II and Cassini III led the survey for extending geodetic trigonometric networks in France in 1735 and 1736. Cassini II became a member of the *Royal Academy of Sciences* in Paris in 1735.

In 1733, although he was young, Cassini III drew the attention of the *Royal Academy of Sciences* to the importance of geodetic surveys he conducted with his father to determine the Earth's shape. At the time, Cassini III's data indicated the Earth was an oblate spheroid. After some time, opponents of the Cassini theory in the *Royal Academy of Sciences* organized an expedition to Peru (nowadays Ecuador) led by Bouguer, La Condamine and Godin in May of 1735 and another one to Lapland, Sweden (nowadays border between Sweden and Finland) led by Maupertuis, Clairaut, Le Monnier and Celsius. They travelled from Dunkerque to Lapland in May of 1736.

When Maupertuis returned from Lapland to Paris in August of 1737, he had strong data in favour of Newton's and Huygens's theory about the Earth's shape. However, they were not strong enough for Cassini II, who never admitted defeat. Cassini III made a difficult decision and changed his position and opposing his family. Cassini III made the review of trigonometric network through Paris from 1739 to 1740. His new data confirmed the Earth is an oblate spheroid, and he published his conclusions in *La méridienne de l'Observatoire royal de Paris vérifiée dans toute l'étendue du royaume* in 1744.

Between 1739 and 1740, Cassini III was helped in working at the Paris Observatory and in the new survey by Nicolas Louis de Lacaille (1713–1762) (Fig. 21) and Jean-Dominique Maraldi (Maraldi II, nephew of Maraldi I) (URL 40 and 41). For his work on the meridian, Lacaille was honoured by engraving his name into the Juvisy pyramid. In 1750, Lacaille led an astronomic expedition to the Cape of Good Hope, South Africa. In 1751, he established an astronomical observatory there and started systematic astronomical measurements in the South part of the celestial sphere. He determined positions of about 10 000 stars in the Southern celestial sphere which can not be seen from Europe. In 1752, he started establishing a 137 km long trigonometric chain from Cape Town with a measured baseline North of Darling, 6457.25 toise long (12 585 m) (URL 42). He wanted to contribute the determination of the Earth's shape by measuring that meridian arc length. His length of one degree of meridian arc was 57 037 toise at the middle latitude of 33° 18' 30'' S (Bialas 1982, page 154 and URL 42).

When this result is compared with values of meridian arc length for one degree expressed in toise and entered into Table 2 for various latitudes on which surveys were conducted, it can be seen the length is greater than the one expected on that latitude. This means Lacaille's results were that Earth was a prolate spheroid, which was contrary to what Newton and Huygens claimed.

Suggested by George Everest in 1838, Thomas Maclear repeated the measurements on Lacaille's meridian arc and found out that Lacaille made an error in not taking into account the gravitational effect of nearby mountains. He found that the deflection of the verticals in the direction of the meridian is +7'' on the Northern point and –1'' on the Southern point, meaning Lacaille calculated with an incorrect difference in latitudes of –8'' (URL 42).

Let us note that Lacaille also measured in South Africa with a seconds pendulum and determined the gravity g = 9.7978 m/s2 (URL 42).

Cassini III's work on measuring the meridian arc length was not as extensive as his work on surveying France and producing an accurate map of France. In 1740, he started preliminary research, when he reported setting 400 triangles and accurately measuring 18 lengths of trigonometric bases to be used for producing his first map of France. The map's scale was 1:870 000 and it consisted of 18 sheets. The *Royal Academy of Sciences* announced it would publish the map in 1745, but it was not published until 1746 and 1747 (URL 25).

France was at war with Austria at the time. When Cassini III showed his maps of Flanders and The Netherlands to King Louis XV, he immediately understood the military importance of such quality maps and commissioned Cassini III to produce a map of the entire France at the scale 1:86 400. Cassini planned to produce a map of trigonometrijskog lanca dugog 137 km od Cape Towna, s mjerenom duljinom baze sjeverno od Darlinga, dugom 6457,25 toisea (12 585 m) (URL 42). Izmjerom te duljine luka meridijana želio je dati svoj prilog određivanju Zemljina oblika. Dobio je da duljina jednog stupnja luka meridijana iznosi 57 037 toisea na srednoj geografskoj širini –33° 18' 30" (Bialas 1982, str. 154 i URL 42).

Kad se usporedi taj rezultat s vrijednostima duljina luka meridijana za jedan stupanj izraženim u toiseima i upisanim u tablici 2 za različite geografske širine na kojima su izvedena mjerenja, vidi se da je ta duljina duža od one koja bi se mogla očekivati na toj geografskoj širini. To znači da je Lacaille dobio da je Zemlja ispupčena na polovima, što je bilo suprotno tvrdnji Newtona i Huygensa.

Na sugestiju Georga Everesta, Thomas Maclear ponovio je 1838. godine mjerenja na Lacaillevu meridijanskom luku i dobio da je Lacaille pogriješio jer u račun nije uzeo gravitacijski utjecaj susjednih planina. Pronašao je da je na sjevernoj točki otklon vertikala u smjeru meridijana +7'', a na južnoj –1'', te da je tako Lacaille računao s pogrešnom razlikom geografskih širina od –8'' (URL 42).

Spomenimo da je Lacaille u južnoj Africi također izvodio mjerenja sekundnim njihalom i odredio da je ubrzanje sile teže $g = 9{,}7978\ m/s^2$ (URL 42).

Cassini III. je na mjerenju duljine luka meridijana radio manje nego na dugogodišnjoj izmjeri Francuske i izradi njezine točne karte. Godine 1740. počeo je s preliminarnim istraživanjem, te je izvijestio da je postavio 400 trokuta i točno izmjerio 18 duljina trigonometrijskih baza kojima će se koristiti za izradu svoje prve karte Francuske. Karta je imala mjerilo 1:870 000 i sastojala se od 18 listova. *Kraljevska akademija znanosti* objavila je izdavanje te karte 1745. godine, no ona je stvarno izdana u razdoblju od 1746. do 1747. (URL 25).

U to doba Francuska je bila u ratu s Austrijom. Kada je Cassini III. pokazao svoje velike karte Flandrije i Nizozemske kralju Luju XV., on je odmah uvidio vojni značaj takvih kvalitetnih karata te je Cassiniju III. dao zadatak da izradi kartu cijele Francuske u mjerilu 1 : 86 400. Tako je njegov plan bio izraditi kartu Francuske na 182 lista, dimenzija 1,04 m × 0,73 m. Za tako velik pothvat trebao je imati velike stručne ekipe pa ih je počeo uvježbavati za rad na terenu, a pronađen je i novac za financiranje toga projekta. U proračunu je predviđao da će mu za taj pothvat trebati uz punu kraljevu potporu 20 godina. Međutim, Francuska je u međuvremenu bila uključena u više ratova i 1756. godine francuski je kralj povukao financijsku potporu projektu (URL 25 i 27).

Zato je Cassini III. morao zamoliti *Kraljevsku akademiju znanosti* za pomoć i potporu u organiziranju privatnog financiranja projekta. Oformljena je udruga u kojoj je bio kralj i oko pedeset osoba koje su financirale projekt i dobile pravo na prodaju karata na trideset godina. Cassini III. je mogao dobiti novac i od francuskih pokrajina koje su bile zainteresirane za dobivanje dijela karte njihove

Figure 21 Nicolas Louis de Lacaille (1713–1762) (URL 40)
Slika 21. Nicolas Louis de Lacaille (1713–1762) (URL 40)

Table 2 Survey of meridian arcs and their lengths for one degree of latitude (Bialas 1982, page 155) (t – toise)
Tablica 2. Izmjera meridijanskih lukova i njihove duljine za jedan stupanj geografske širine (Bialas 1982, str. 155) (t – toise)

Br. / No.	Sred. geo. širina / Middle latitude	Duljina 1° / Length for 1°	Opažači / Observers	Godina / Year	Regija / država / District / country
1	66° 20'	57 422 t	Maupertuis	1736/37	Lapland / Lapland
2	49° 23'	57 074 t	Cassini III	oko / about 1740	Francuska / France
3	43° 01'	56 979 t	Bošković/Maire	oko / about 1752	Crkvena država / Papal State
4	- 1° 31'	56 753 t	Bouguer/Lacondamine	oko / about 1740	Peru / Peru
5	- 33° 18'	57 037 t	Lacaille	oko / about 1752	Južna Afrika / South Africa

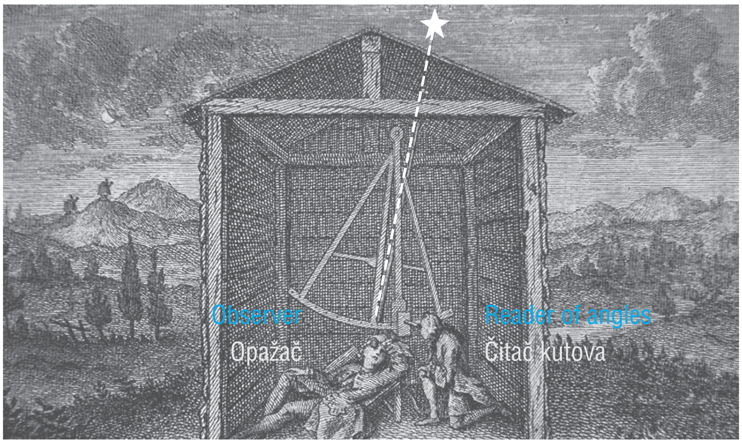


Figure 22 Two of Cassini III's observers observe positions of star with an octant placed in a pavilion. One of them views the stars while the other reads the angle on limb using a microscope (URL 27)

Slika 22. Dva opažača Cassinija III. opažaju položaje zvijezda oktantom smještenim u paviljonu. Jedan opažač vizira na zvijezde dok drugi očitava kut na limbu s pomoću mikroskopa (URL 27)

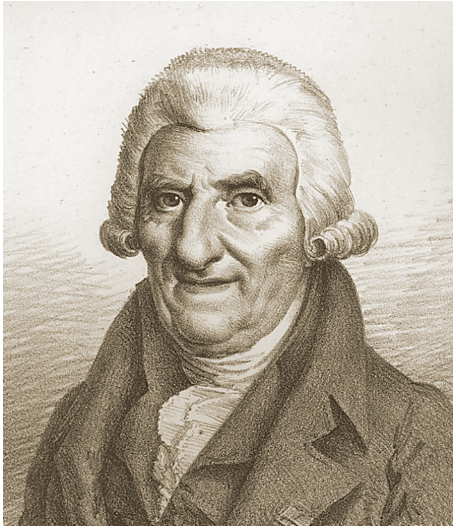


Figure 23 Portrait of Jean-Dominique Comte de Cassini (Cassini IV) by Julien Léopold Boilly (URL 29)

Slika 23. Portret Jean-Dominiquea Comte de Cassinija (Cassinija IV.), djelo Juliena Léopolda Boillyja (URL 29)

France consisting of 182 sheets with the size of 1.04 m × 0.73 m. In order to accomplish this challenging task, he required large expert teams, so he started training them in the field and finding money to finance the large project. He planned to finish the project in 20 years with the king's full support. However, France was involved in several wars in the meantime and the French king withdrew the financial support in 1756 (URL 25 and 27).

Therefore, Cassini III had to ask the *Royal Academy of Sciences* for help and support in organizing private financing of the project. An association was established consisting of the king and about fifty people who financed the project and had the right to sell maps for thirty years. Cassini III was also able to obtain money from French provinces which were interested in obtaining parts of maps representing their provinces. He did not just have financial difficulties because the local population also resisted geodetic measurements. He published *Description géometrique de la terre* (Geometrical description of Earth, 1775) and *Description géometrique de la France* (Geometrical description of France, 1783) about that cartographic work. When Cassini III died of smallpox in 1784, only two out of 182 sheets of his map of France were not completed yet. According to some sources, the total number of sheets composing Cassini's map was 180. This means he did not manage to complete the first map of France in 20 years, as he promised the king, but in about 30 years. Nevertheless, it was a great accomplishment.

In 1771, King Louis XVI made Cassini III the first director of the Paris Observatory. A French scientist said of Cassini III: "While he was a good geodesist and talented cartographer, he was a second-rate astronomer. However, he is going to be remembering for the first map of France, which was also the first map in the world produced in a particular scale according to contemporary principles."

9 Jean-Dominique Comte de Cassini (Cassini IV)

Jean-Dominique Comte de Cassini (1748–1845) (Fig. 23), also known as Cassini IV received early education at the Paris Observatory, after which he attended the *Collège du Plessis* in Paris and *Collège Oratorien* of Juilly. However, he did not want to become a priest, which was the primary education in those schools. He chose to follow family tradition and continue his education studying physics, mathematics and astronomy.

He embarked on a scientific journey to America in 1768, then to coast of Africa and back to Brest, France. The purpose of the journey was to test the accuracy of the new marine chronometer invented by Pierre Le Roy. Namely, a chronometer is used to determine longitudes, which was very important to sailors. Cassini IV published a report about the journey in 1770 and he became a member of the *Royal Academy of Sciences* in the same year.

Cassini IV knew he was going to become the director of the Paris Observatory after his father had died because it was the king's decision. Thus he joined the large project of producing a map of France led by his father. He took over the Paris Observatory after his father had died in 1784. The map was completed in 1790 and Cassini IV presented the map of France to the National Assembly (URL 28).

In 1787, Cassini IV, Adrien-Marie Legendre (1752–1833) and Pierre François-André Méchain (1744–1804) pokrajine. On nije imao samo financijskih teškoća, jer je geodetskim mjerenjima otpor pružalo i lokalno stanovništvo. U vezi s tim kartografskim radovima objavio je *Description géometrique de la terre* (Geometrijski opis Zemlje, 1775) i *Description géometrique de la France* (Geometrijski opis Francuske, 1783). Kada je Cassini III. umro od boginja 1784. godine, samo dva lista njegove karte Francuske nisu još bila završena od ukupno njih 182. U nekim izvorima piše da je ukupan broj listova Cassinijeve karte 180. To znači da nije uspio završiti prvu kartu Francuske za 20 godina kako je obećao kralju, već za oko 30 godina. Međutim, i to je, mora se priznati, bio velik uspjeh.

Godine 1771. kralj Luj XVI. postavio je Cassinija III. za prvog ravnatelja Pariškog opservatorija s time da će taj položaj biti nasljedan. Naime, prije su Cassiniji bili samo voditelji Pariškog opservatorija. Za Cassinija III. jedan je francuski znanstvenik rekao: "Dok je on bio dobar geodet i talentirani kartograf, kao astronom bio je drugorazredan. Međutim, ostat će zapamćen po izradi prve karte Francuske, ali i prve karte u svijetu, koja je izrađena u određenom mjerilu u skladu sa suvremenim načelima."

9. Jean-Dominique Comte de Cassini (Cassini IV.)

Jean-Dominique Comte de Cassini (1748–1845) (sl. 23), poznat i kao Cassini IV., u ranoj je mladosti odgajan i obrazovan u Pariškom opservatoriju, a zatim je pohađao *Collège du Plessis* u Parizu i *Collège Oratorien* kod Juile. Međutim, nije se želio posvetiti svećeničkom pozivu, što je bilo primarno obrazovanje u tim školama, već je slijedio obiteljsku tradiciju i nastavio studirati fiziku, matematiku i astronomiju.

Već 1768. godine otputovao je na znanstveno putovanje u Ameriku, a zatim na obalu Afrike i natrag do Bresta u Francuskoj. Svrha toga putovanja bila je ispitivanje točnosti tada novog pomorskoga kronometra, koji je izumio Pierre Le Roy. Naime, s pomoću kronometra određuju se geografske dužine mjesta, što je bilo osobito važno pomorcima. Izvješće o tom putovanju objavio je 1770. godine, a iste godine izabran je i u *Kraljevsku akademiju znanosti*.

Cassini IV. je znao da će nakon očeve smrti postati ravnatelj Pariškog opservatorija, jer je njegova oca postavio kralj, i to s nasljednim pravom. Zato se uključio u veliki projekt izrade karte Francuske koji je vodio njegov otac. Nakon očeve smrti 1784. godine preuzeo je Pariški opservatorij. Do tada su od planiranih 182 lista karte Francuske ostala nedovršena samo dva lista, koja su završena tek 1790. godine. Tada je Cassini IV. predstavio kartu Francuske u Nacionalnoj skupštini (URL 28).

Godine 1787. Cassini IV. bio je imenovan zajedno s Adrien-Marieom Legendreom (1752–1833) i Pierreom François-Andréom Méchainom (1744–1804) u povjerenstvo za precizno određivanje udaljenosti između opservatorija u Greenwichu i Parizu s pomoću trigonometrijskih mreža (sl. 24). To je bio zajednički projekt povezivanja francuskih i engleskih znanstvenika. Pritom su Cassini IV., Legendre i Méchain mjerili s francuske strane Bordinim repeticijskim krugom, a engleski general William Roy (1726–1790) s engleske strane Ramsdenovim teodolitom (Solarić 2010, str. 66–67), kojega je mjerna nesigurnost bila samo 1''. Tada je Méchain bio asistent Cassinija IV. i dobio je zadaću provjeriti rezultat starijom opremom, a Cassini IV. je mjerio Bordinim

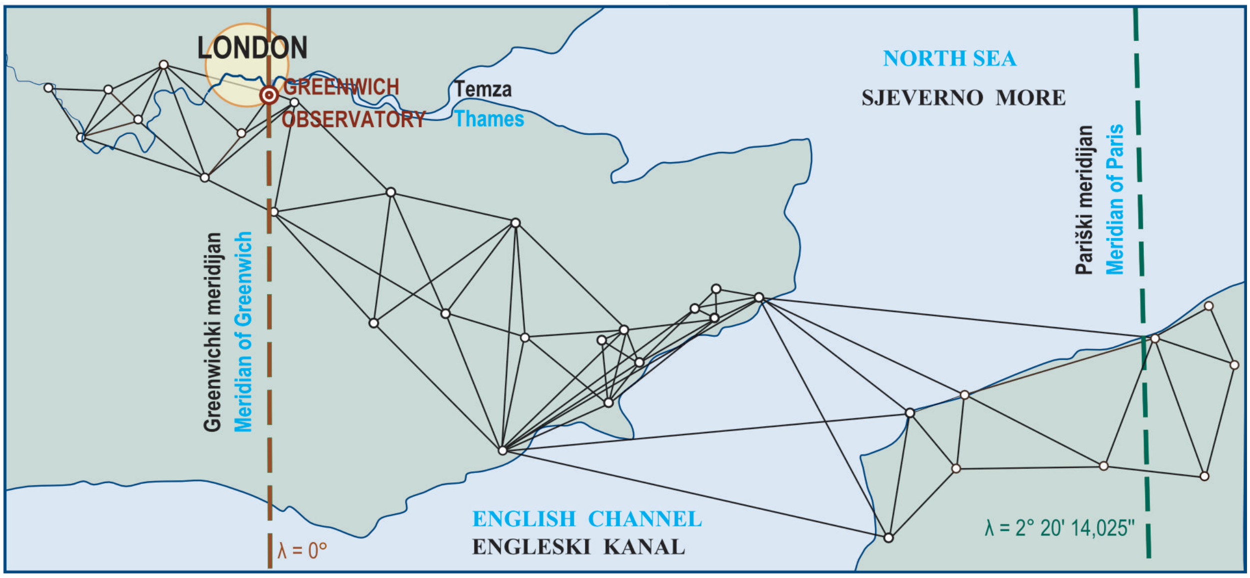
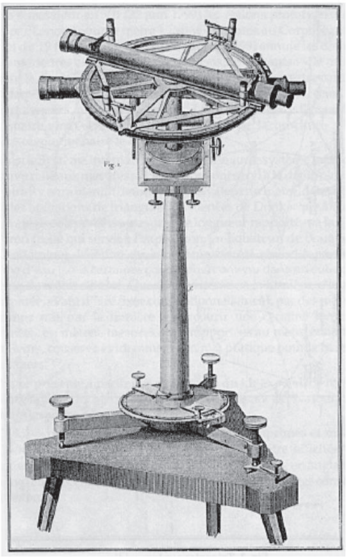


Figure 24 Trigonometric network connecting the Paris meridian and the Greenwich meridian in 1787 (according to URL 37)

Slika 24. Trigonometrijska mreža kojom su povezani Pariški i Greenwichki meridijani 1787. godine (prema URL 37)



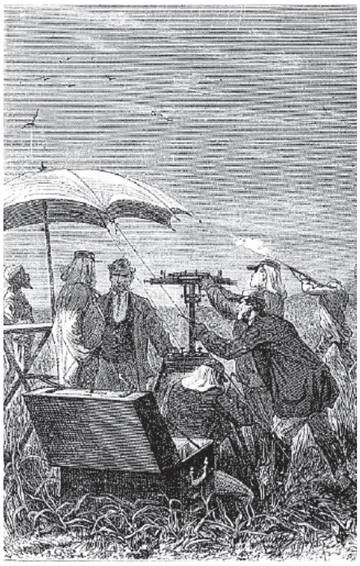


Figure 25 (left) Borda repetition circle with circle division with standard deviations of one second of arc and two telescopes, (right) Measuring angles using the Borda repeating circle in the field (URL 32)

Slika 25. (lijevo) Bordin repeticijski krug s ucrtanom podjelom kruga sa standardnim odstupanjem od jedne kutne sekunde i dva teleskopa, (desno) mjerenje kutova s pomoću Bordina repeticijskoga kruga na terenu (URL 32)

were nominated members of a committee for determining the distance between the Greenwich Observatory and the Paris Observatory using trigonometric network (Fig. 24). It was a mutual project of connecting French and English scientists. Cassini IV, Legendre and Méchain measured from the French side with the Borda repeating circle, while English general William Roy (1726–1790) measured from the English side using the Ramsden theodolite (Solarić 2010, pages 66–67) with measuring uncertainty of only 1''. Méchain was Cassini IV's assistant and he had to verify results using older equipment, while Cassini IV measured with the Borda instrument and was overjoyed with its measuring uncertainty of just 1 second of arc (Fig. 25). Subsequently in the project Méchain gained a reputation of the most careful observer (URL 31).

The Borda repetition circle was used in astronomy by placing the measuring circle parallel to the line between stars. It was used in geodesy by placing the circle horizontally. One surveyor focused one telescope to the first object *A* and fastened it. Another surveyor focused a second telescope to point *B* and fastened it (Fig. 26). The angle β between lines drawn from the standpoint to points *A* and *B* could be read on the circle. However, measuring the angle β was not over yet. The second surveyor rotated both telescopes fastened together and passed his telescope to the first surveyor so that the second telescope sight point *A*. After that he unclamped the second telescope and passed it back to the second surveyor to sight point *B*. He was than able to read the angle on the circle which was two times greater than angle β (Murdin 2009, page 92). Enlarging the angle could be continued as many as ten or twenty times and

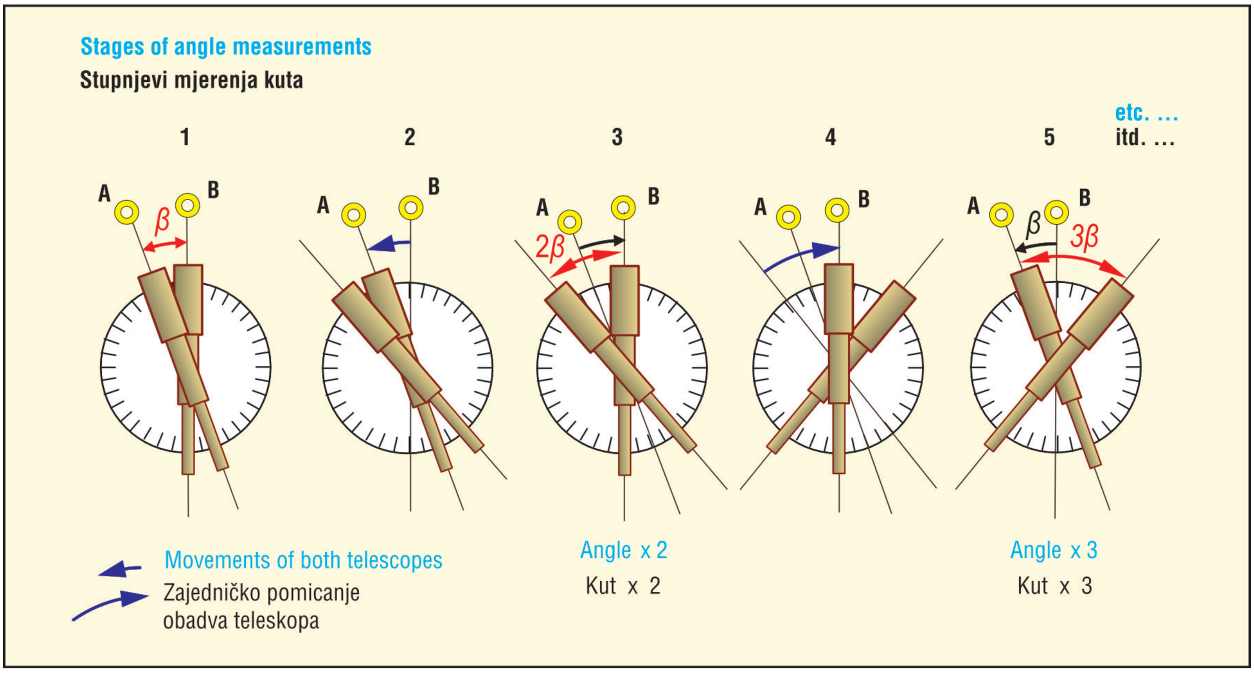


Figure 26 Graphical representation of measuring angle β using the Borda repetition circle, where β is enlarged 3 times (according to URL 46)

Slika 26. Grafički prikaz mjerenja kuta β s pomoću Bordina repeticijskog (ponavljajućeg) kruga, gdje je kut β povećan 3 puta (prema URL 46) instrumentom s mjernom nesigurnosti od samo 1 kutne sekunde, kojom je bio oduševljen (sl. 25). Poslije je Méchain u projektu ubrzo stekao reputaciju najopreznijeg opažača (URL 31).

Ako je Bordin repeticijski krug bio korišten u astronomiji, mjerni krug bio je postavljan paralelno s linijom između zvijezda, a ako je bio korišten u geodeziji, podjela kruga postavljana je horizontalno. Prvi mjernik vizirao je jednim teleskopom na prvi objekt *A* i učvrstio ga. Drugi mjernik vizirao je drugim teleskopom na točku *B* i također ga učvrstio (sl. 26). Na podjeli kruga mogao se pročitati kut β , koji zatvaraju pravci povučeni iz stajališta na točke *A* i *B*. Međutim, time nije završeno mjerenje kuta β. Nakon toga je drugi mjernik rotirao oba teleskopa zajedno dodajući svoj teleskop prvom mjerniku tako da on navizira na točku *A*. Zatim on otkoči drugi teleskop i doda ga drugom mjerniku da navizira na točku *B*. Sada se na podjeli kruga mogao pročitati dva puta veći kut od kuta β (Murdin 2009, str. 92). Povećanje kuta moglo se nastaviti čak deset puta ili dvadeset puta i tako progresivno reducirajući pogrešku viziranja i mjereći kutove na raznim dijelovima podjele kruga reducirajući sustavne pogreške ugravirane podjele kruga. Tako se na tom tada novom instrumentu moglo pročitati kutove možda 5 ili 10 puta preciznije nego prije. Konačna veličina kuta izračunala se dijeljenjem pročitane veličine na repeticijskom krugu s brojem ponavljanja mjerenja kuta β.

Njemački matematičar i astronom Johann Tobias Mayer (1723–1762) prvi je osmislio repeticijski krug, a Jean-Charles Borda ga je prilagodio za praktičnu primjenu, te je tako nazvan Bordin repeticijski krug. Izrađivao ih je Étienne Lenoir (1744–1825), kojega je francuski kralj imenovao certificiranim kraljevskim inženjerom, pa su u literaturi takvi instrumenti nazivani i Borda–Lenoirovim repeticijskim krugovima. Na taj način Lenoir je odigrao važnu ulogu u perfektnoj izradi repeticijskoga kruga (Murdin 2009, str. 91–93).

Opći ekonomski razvitak Francuske očitovao se u brzom usponu trgovine, industrije i pomorstva tijekom 18. stoljeća, ali dolazi i do sve većih suprotnosti u feudalno-apsolutističkom sustavu. Buržoazija posjeduje sve veći dio dobara, no politički je bespravna i podvrgnuta samovolji režima, koji parazitskom plemstvu i visokom kleru daje sve beneficije privilegirane klase. Rasipnički dvor, visoko plemstvo koje vuče novčanu pripomoć iz državne blagajne te troškovi vođenja rata s Engleskom povećali su državni dug 1789. godine na više od 4,5 milijardi franaka. Tako su nastali osnovni uzroci Francuske revolucije, koja je počela 1789. godine.

Cassinija IV. je 1791. pogodila tragedija kad mu je umrla supruga, a on se morao brinuti za svoje petero djece. Te je godine *Kraljevska akademija znanosti* postavila projekt uspostave novih mjernih jedinica jer su to tražile sve veće trgovačke veze u Francuskoj i svijetu. Nastojala se definirati nova jedinica za duljinu nazvana metar, kao 10-milijunti dio luka meridijana od sjevernog pola do ekvatora, ali i ostale mjerne jedinice, i to u decimalnom sustavu. Tako je *Kraljevska akademija znanosti* u travnju 1791. imenovala Cassinija IV., Legendrea i Méchaina u povjerenstvo za izvršenje toga osjetljivog, velikog i važnog zadatka. Cassini IV., Legendre, Méchain i Borda posjetili su Luja XVI. 19. lipnja 1791., kada je kralj pitao

Table 3 Surveys of meridian arc lengths between 1750 and 1803 and their arc lengths for 1° (Bialas 1982, page 166)

Tablica 3. Izmjere duljina meridijanskih lukova između 1750. i 1803. i njihove duljine lukova za 1° (Bialas 1982, str. 166)

Br. No.	Godina Year	Opažač Observer	Country /Zemlja	Sred. geogr. širina Middle latitude	Duljina Length toise	km
1.	1750-52	Bošković/Maire	Papal State / Crkvena država	43° 01'	56 979	111.054
2.	1751-53	Lacaille	South Africa / Južna Afrika	-33° 18'	57 037	111.167
3.	1763-64	Beccaria	Piemont / Piemont	44° 44'	57 060	111.230
4.	1764-68	Mason/Dixon	North America / Sjeverna Amerika	39° 12'	56 888	110.877
5.	1768	Liesganig	Austria-Hungary / Austro Ugarska	47° 20'	56 984	111.064
6.	1784-90	Roy, Cassini IV. / Méchain, Legendre	Great Britain-France / Engl.-Francuska	50° 09'	57 086	111.263
7.	1790-92	Burrow	East India / Istočna Indija	23° 28'	56 725	110.559
8.	1798	Nouet	Egypt / Egipat	~ 30°	~ 56 880	110.9
9.	1801-03	Svanberg	Sweden / Švedska	66° 20'	57 196	111.477
10.	1802	Lambton	East India /Istočna Indija	12° 32'	56 762	110.631

progressively reduce the viewing error and by measuring angles in various parts of the circle in order to reduce systematic errors of circle engravings. The new instrument enabled reading angles 5 or 10 times more precise than it was possible before. The final angle was calculated by dividing the repeating circle value with the number of iterations of measuring the angle β.

German mathematician and astronomer Johann Tobias Mayer (1723–1762) was the first to conceive the repetition circle, but Borda adapted it for practical applications, so it became known as the Borda repetition circle. They were produced by Étienne Lenoir (1744–1825), who was nominated a certified royal engineer by the French king and such instruments are sometimes also referred to as Borda-Lenoir's repetition circles. Thus, Lenoir played an important role in the perfect construction of the repetition circle (Murdin 2009, pages 91-93).

The general economic development of France manifested in successes of commerce, industry and navigation during the 18th century, but there were also increasing polarities in the feudal-absolutist system. The bourgeoisie owned a significant part of goods but had no political rights and were subject to autocracy, which provided all benefits of the privileged class to parasitic nobility and high clergy. A wasteful court, high nobility straining the treasury and expenses of waging war with England increased the national debt to more than 4.5 million francs in 1789. These were the basic causes of the French revolution, which began in 1789.

In 1791, tragedy struck Cassini IV when his wife died and he had to take care of his five children on his own. The *Royal Academy of Sciences* then initiated a project of establishing new units of measurement since it was requested by all major commerce connections in France and the world. The intention was to define a new unit of length called the meter as the 10 millionth part of the meridian arc from the North Pole to the equator, as well as other units in the decimal system. Thus the *Royal Academy of Sciences* nominated Cassini IV, Legendre and Méchain members of the committee responsible for the sensitive and important task in April of 1791. Cassini IV, Legendre, Méchain and Borda visited King Louis XVI on June 19, 1791 when the king asked Cassini IV: *"You are going to measure your father's and grandfather's meridian which they measured before you? Do you think you can do it better?"*. Cassini answered: *"My liege, I would not flatter myself if I thought I could surpass them if I did not have an exceptional advantage. My father's and grandfather's instruments had a measuring insecurity of 15 seconds of arc, while Borda's instrument has a measuring insecurity of one second of arc..."*

One day later, King Louis XVI fled to Varennes and was arrested. Cassini IV was deeply loyal to the king, and when it was time for him to go and measure the Northern part of the meridian, he was reluctant and had great concern for his children. Thus he proposed that he stay in Paris and that assistants do field work. The *Royal Academy of Sciences* did not believe he could lead the project without being in the field, so they replaced him in May of 1792 with Jean Baptiste Joseph Delambre (1749–1822), who became a member of the *Royal Academy of Sciences* in 1792.

Cassini IV was humiliated by the National Assembly and resigned his position as the director of the Paris Observatory on September 6, 1793. The National Assembly seized his maps as his property, and he was taken into custody after objecting. After getting out of prison, he went to live in his family's castle in Thury. Delambre and Lalande asked him to resume his scientific research, but he refused and said his family was more important to him. He was especially critical of new units of measuring. In 1810, he wrote memoirs in which he emphasized his family's reputation. However, that valuable document has remained lost so far. Cassini IV died in 1845 being 96 years old, which was especially rare at the time.

10 Conclusion

It is clear from the presented information that the measuring arcs of the Paris meridian using trigonometric chains in the 17th and 18th century was an ordeal lasting about a century and a half. In addition, one is able to perceive the great bond between astronomy and geodesy and that the greatest physicists and mathematicians were interested in determining the Earth's shape. In other words, those sciences were in the focus of global science at the time, like atomistics and molecular genetics are today.

In order to gain a partial chronological overview, Table 3 features some other meridian arc length surveys from 1750 to 1803.

Acknowledgments

We would like to thank the reviewers for their useful comments, which contributed to the quality of this research of geodetic past, i.e. historical overview of trigonometric network surveys of the Paris meridian.

We would also like to thank the Ministry of Science, Education and Sport of the Republic of Croatia for partially financing this paper, which was produced within the project *Development of Scientific Surveying Laboratory for Geodetic Instruments* no. 007-1201785-3539.

Cassinija IV.: "*Vi ćete mjeriti meridijan Vašeg oca i djeda kojeg su mjerili prije Vas? Mislite li da Vi to možete učiniti bolje?*"

Cassini mu je odgovorio: "*Gospodaru, ja ne bih sebi laskao da mislim da bih ih mogao nadmašiti da nemam izrazitu prednost. Instrumenti mojeg oca i djeda mogli su mjeriti s mjernom nesigurnosti od 15 kutnih sekundi, ali Bordin instrument može mjeriti s mjernom nesigurnosti od jedne kutne sekunde.*"

Idućeg dana Luj XVI. je pri bjegu u Varennese uhićen. Cassini IV. je osjećao duboku odanost kralju, a kad je trebao krenuti na mjerenja na sjeverni dio meridijana, nerado je to prihvatio imajući veliku brigu i za djecu. Tako je predložio da ostane u Parizu, a da asistenti mjere na terenu. *Kraljevska akademija znanosti* nije vjerovala da on može voditi projekt bez svakodnevnog rada na terenu, te su ga u svibnju 1792. smijenili i za voditelja postavili Jeana Baptistea Josepha Delambrea (1749–1822), koji je 1792. izabran za člana *Kraljevske akademije znanosti.*

Cassini IV. doživio je razna poniženja od Narodne skupštine, te je dao ostavku na mjesto ravnatelja Pariškog opservatorija 6. rujna 1793. Zatim mu je Narodna skupština oduzela karte kao njegovu imovinu, a kad je prigovorio, bio je uhićen. Nakon izlaska iz zatvora otišao je živjeti u obiteljski zamak u Thury. Delambre i Lalande zamolili su ga da se vrati svojem znanstvenom radu, ali je odbio tvrdeći da mu je obitelj važnija. Bio je posebno kritičan i prema novim mjernim jedinicama. Godine 1810. pisao je memoare u kojima je naglašavao ugled svoje obitelji. Međutim, taj vrijedni dokument je za sada izgubljen. Umro je u dubokoj starosti 1845. godine, u 97. godini života, što je u to doba bila posebna rijetkost.

10. Zaključak

Iz izloženoga je razvidno da je mjerenje duljina lukova Pariškog meridijana s pomoću trigonometrijskih lanaca u 17. i 18. stoljeću bilo mukotrpno i potrajalo je oko stoljeće i pol. Osim toga vidi se velika povezanost astronomije i geodezije te da su za problem određivanja Zemljina oblika bili zainteresirani najveći fizičari i matematičari toga doba. Drugim riječima to su bile znanosti koje su u to doba bile u žiži svjetske znanosti, kao što su danas atomistika i molekularna genetika.

Da bi se dobio djelomičan kronološki pregled, u tablicu 3 redom su svrstane neke druge izmjere duljina meridijanskih lukova od 1750. do 1803. godine.

Zahvala

Najljepše zahvaljujemo recenzentima na korisnim primjedbama kojima su pridonijeli boljoj kvaliteti ovog istraživanja geodetske prošlosti, tj. povijesnog pregleda izmjera trigonometrijskih mreža na Pariškom meridijanu. Zahvaljujemo također Ministarstvu znanosti, obrazovanja i športa RH, što je djelomično financiralo ovaj rad, koji je izrađen u okviru projekta *Razvoj znanstvenog mjeriteljskog laboratorija za geodetske instrumente* br. 007-1201785-3539.

References / Literatura

Bialas, V. (1982): Erdgestalt, Kosmologie und Weltanschauung, Konrad Wittwer, Stuttgart.
Brezinšćak, M. (1971): Mjerenje i računanje u tehnici i znanosti, Tehnička knjiga, Zagreb.
Levallois, J-J. (1969): Géodésie générale Tom I, Éditions Eyrolles, Paris.
Murdin, P. (2009): Full Meridian of Glory, Springer Science + Business Media, tiskano u USA.
Scherffer, P. C. (1770): Institutionum geometricarum pars secunda sive trigonometria plana, f ig. 93, Vindobonae.
Sobel, D. (2000): Longituda (prijevod s engleskog na hrvatski) Naklada Jesenski i Turk, Zagreb.
Solarić, M. i Solarić, N. (2009): Prvi začeci klasičnih trigonometrijskih mreža, Kartografija i geoinformacije, br. 11, 102–122.
Solarić, M. i Solarić, N. (2010): Himalaja i pregled određivanja visina Mt. Everesta, Kartografija i geoinformacije, br. 9, 58–97
Solarić, M. i Solarić, N. (2013): Boškovićeva i Maireova trigonometrijska mreža pri određivanju duljine dijela meridijanskog luka Rim–Rimini, u tisku, Zagreb
Vujnović, V. (1989): Astronomija 1, Školska knjiga, Zagreb.
Vykutil, J. (1982): Vyšší geodézie, Kartografie, Praha.
URL 1: Paris Meridian http://en.wikipedia.org/wiki/Paris_Meridian (28.5.2011.)
URL 2: Nulti meridijan http://www.islambosna.ba/nauka/6779-nulti-meridijan (28.5.2011.)
URL 3: Jean-Felix Picard http://sl.wikipedia.org/wiki/Jean-Felix_Picard_(astronom) (5.1.2009.)
URL 4: Jean Picard http://www.newadvent.org/cathen/12073b.htm (8.8.2005.)
URL 5: Jean Picard http://en.wikipedia.org/wiki/Jean_Picard (9.1.2009.)

URL 6: Mesure d'un meridien par triangulation http://expositions.bnf.fr/ciel/maths/pdf/mesurm1.pdf (13.2.2009.)
URL 7: Jean Picard http://oce.catholic.com/index.php?title=jean_Picard (3.3.2009.)
URL 8: William Gascoigne (scientist) http://en.wikipedia.org/wiki/William_Gascoigne_(scientist) (7.1.2009.)
URL 9: Philippe de la Hire http://en.wikipedia.org/wiki/Philippe _de_la_Hire (2.2.2009.)
URL 10: Philip de la Hire http://archimedes.mpiwg-berlin.mpg.de/cgi-bin/archim/dict/hw?lemma=HIRE&step=entry&id=d006 (10.1.2009.)
URL 11: Gabriel-Philippe de la Hire http://galileo.rice.edu/catalog/newFiles/lahire_gab.html (2.2.2009.)
URL 12: Giovanni Domenico Cassini http://en.wikipedia.org/wiki/Giovanni_Domenico_Cassini (22.6.2011.)
URL 13: Giovanni Domenico Cassini (Jun 8, 1625 –September 14, 1712) http://seds.org/Messier/xtra/Bios/cassini.html (11.2.2009.)
URL 14: Giovanni Domenico Cassini http://hr.wikipedia.org/wiki/Giovanni_Domenico_Cassini (11.2.2009.)
URL 15: John Flamsteed http://en.wikipedia.org/wiki/John_Flamsteed (6.3.2009.)
URL 16: Modèle ellipsoidal de la Terre http://fr.wikipedia.org/wiki/Mod%C3%A8le_ellipso%C3%AFdal_de_la_Terre (24.6.2011.)
URL 17: Kassini, Džovanni Domeniko http://ru.wikipedia.org/wiki/%D0%9A%D0%B0%D1%81%D1%81%D0%B8%D0%BD%D0%B8,_%D0%94%D0%B6%D0%BE%D0%B2%D0%B0%D0%BD%D0%BD%D0%B8_%D0%94%D0%BE%D0%BC%D0%B5%D0%BD%D0%B8%D0%BA%D0%BE (28.6.2011.)
URL 18: Jean Richer http://fr.wikipedia.org/wiki/Jean_Richer (26.6.2011.)
URL 19: Jean Richer http://ru.wikipedia.org/wiki/%D0%A0%D0%B8%D1%88%D0%B5,_%D0%96%D0%B0%D0%BD (27.6.2011.)
URL 20: Jean Richer http://sl.wikipedia.org/wiki/Jean_Richer (27.6.2011.)
URL 21: Isaac Newton http://en.wikipedia.org/wiki/Isaac_Newton (27.6.2011.)
URL 22: Isaac Newton http://hr.wikipedia.org/wiki/Isaac_Newton (27.6.2011.)
URL 23: Jacques Cassini http://www-history.mcs.st-and.ac.uk/Biographies/Cassini_Jacques.html (2.7.2011.)
URL 24: Jacques Cassini http://en.wikipedia.org/wiki/Jacques_Cassini (10.3.2009.)
URL 25: César François Cassini de Thury http://www-history.mcs.st-and.ac.uk/Biographies/Cassini_de_Thury.html (2.7.2011.)
URL 26: César François Cassini de Thury http://en.wikipedia.org/wiki/C%C3%A9sar-Fran%C3%A7ois_Cassini_de_Thury (2.7.2011.)
URL 27: César François Cassini de Thury http://decouverte-bocage-gatinais.fr/cartographie.php (2.7.2011.)
URL 28: Jean-Dominique Comte de Cassini http://www-history.mcs.st-and.ac.uk/Biographies/Cassini_Dominique.html (2.7.2011.)
URL 29: Jean-Dominique Cassini http://fr.wikipedia.org/wiki/Jean-Dominique_Cassini_(1748-1845) (2.7.2011.)
URL 30: L' histoire du metre http://www.suite101.fr/content/lhistoire-du-metre-a7606 (4.7.2011.)
URL 31: Pierre Méchain http://www-history.mcs.st-and.ac.uk/Biographies/Mechain.html (6.7.2011.)
URL 32: Figure de La Terre et histoire du metre http://fr.wikipedia.org/wiki/Figure_de_la_Terre_et_histoire_du_m%C3%A8tre (4.7.2011.)
URL 33: Figure de la Terre et méridienne de Delambre et Méchain http://fr.wikipedia.org/wiki/Figure_de_la_Terre_et_m%C3%A9ridienne_de_Delambre_et_M%C3%A9chain (12.7.2011.)
URL 34: Francois Arago http://en.wikipedia.org/wiki/Fran%C3%A7ois_Arago (12.7.2011.)
URL 35: Jean-Baptiste Biot http://www-history.mcs.st-and.ac.uk/Biographies/Biot.html (1.8.2011.)
URL 36: Figure de la Terre et gravitation universelle http://fr.wikipedia.org/wiki/Figure_de_la_Terre_et_gravitation_universelle (19.7.2011.)
URL 37: Joining the observatories of Paris and Greenwich http://rsnr.royalsocietypublishing.org/content/63/4/355.full (23.9.2011.)
URL 38: Histoire de la triangulation en France http://fr.wikipedia.org/wiki/Histoire_de_la_triangulation_en_France (27.9.2011.)
URL 39: Wikimedia Commons: Quartdecercle.jpg http://commons.wikimedia.org/wiki/File:Quartdecercle.jpg (27.4.2012.)
URL 40: Nicolas Louis de Lacaille http://en.wikipedia.org/wiki/Nicolas_Louis_de_Lacaille (28.9.2011.)
URL 41: Nichola Louis de Lacaille (March 15,1713 – March 21, 1762) http://www.maa.clell.de/Messier/E/Xtra/Bios/lacaille.html (3.11.2009.)
URL 42: The Belgian Contribution to the 30th Meridian Arc in Africa, Jan De Graeve http://www.fig.net/pub/cairo/papers/wshs_02/wshs02_03_graeve.pdf (11.10.2011.)
URL 43: Un historique du metre http://www.industrie.gouv.fr/metro/aquoisert/metre.htm (20.7.2011.)
URL 44: Langlois, Claude http://www.encyclopedia.com/doc/1G2-2830902471.html (21.9.2011.)
URL 45: Carte de Cassini http://fr.wikipedia.org/wiki/ Carte_de_Cassini (5.7.2011.)
URL 46: The Cassini and Maraldi families http://www.catnaps.org/cassini/cart.html (20. 7. 2011.)