History of Geodesy

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Definitions

What is geodesy?

The objective of geodesy is the determination of the potential function $W(x,y,z)$.

Ernst Heinrich Bruns
1848–1919

What is geodesy?

Geodesy is the science of measuring and mapping the Earth surface.

Friedrich Robert Helmert
1843–1917

What is geodesy?

Geodesy is what geodesists do for their living.

Helmut Moritz
1933–

What is geodesy?

Geodesy is a discipline that deals with measurement and representation of the Earth, including its gravity field, in a three-dimensional time varying space.

NRC, 1973
(Vanicek & Krakiwsky, 1982)

What is geodesy?

Geodesy is a discipline that deals with the measurement and representation of the shape of the Earth, its orientation in space and its gravity field, in a 3D time varying space.

The four pillars of Geodesy

Etymology

Geo – desy = Earth – dividing

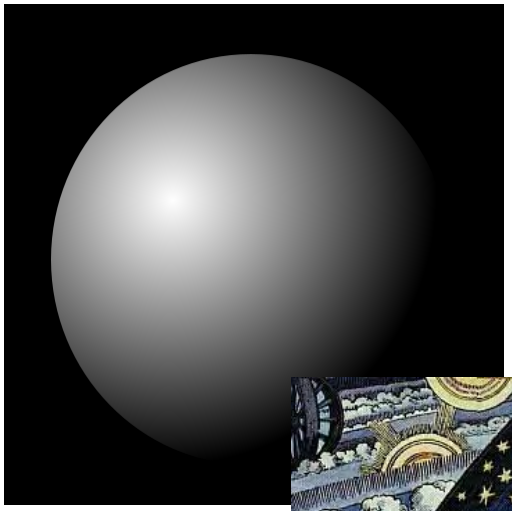
- geo (← γη)
  = Gaia, goddess of the Earth
  = Earth, land, town, acre, soil, estate
- desy (← δαιομαι, δαιεσθαι) = divide, allot, distribute

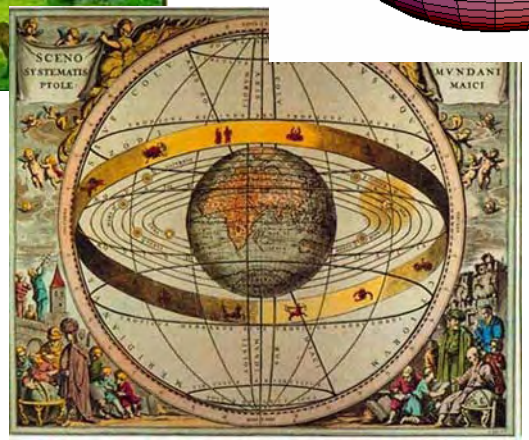
Example: Nile valley

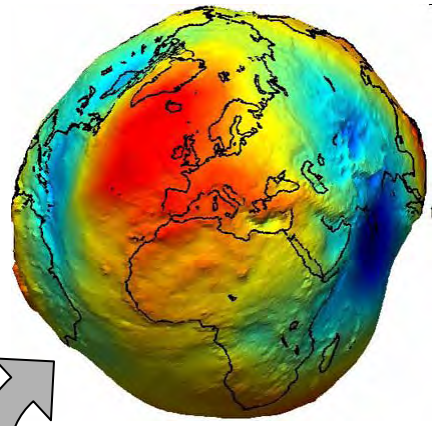
- border demarcation
- surveying
- mapping
- cadastre
- real estate regulation

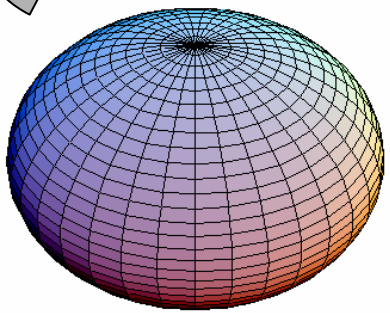
GIS

The quest for Earth´s shape





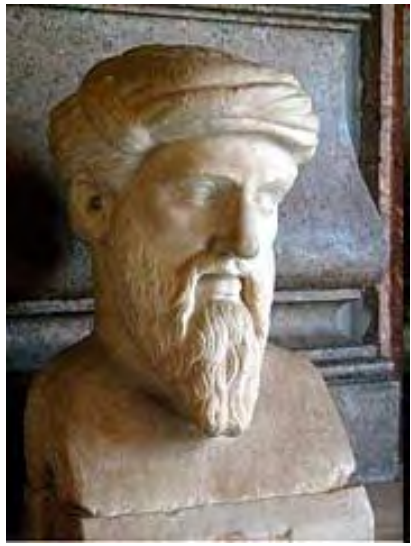




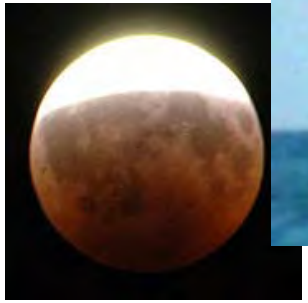
Sphere: the perfect solid

ancient Greek world

- Pythagoras of Samos (~570–510 BC)
  - View of the world based on aesthetical and metaphysical reasoning:
    - The most perfect geometric solid is a sphere.
    - Spherical Earth is the center of the cosmos.
    - Stellar sphere travels westwards.
    - Sun, Moon and planets (5) travel eastwards
    - Motion on regular circles

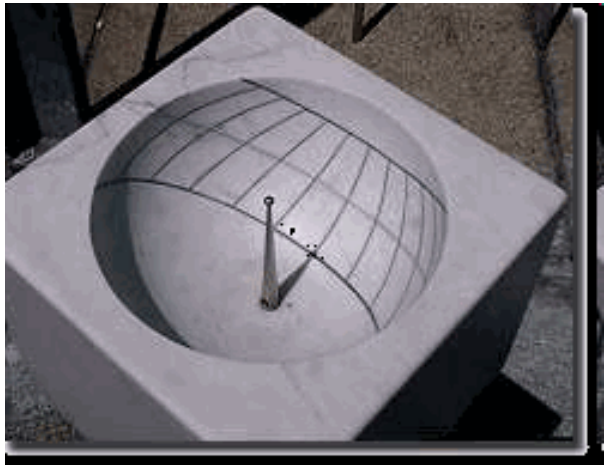


- Aristoteles (384–322 BC)
  - Reasoning is based on observations
    - Stars' visibility depends on latitude: curved surface
    - Ships "sink" behind horizon
    - disk-shape lunar eclipses



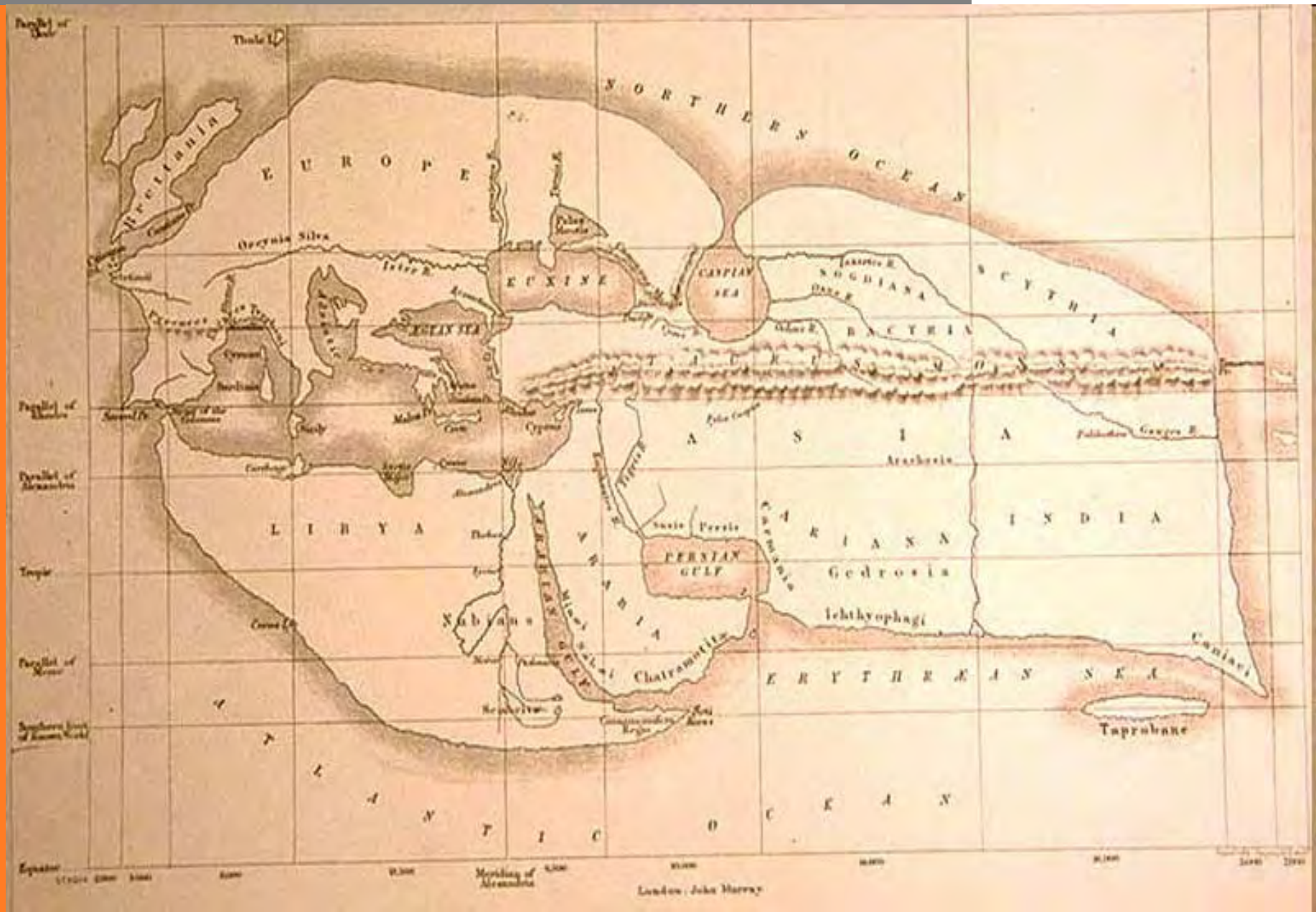
Eratosthenes of Cyrene

- 276–195 BC
- Greek mathematician, geographer, astronomer and poet
- invents a system of latitude and longitude: first cylindrical projection
- maps the ancient world based on the geographical knowledge of the era.
- first to calculate the Earth's circumference



Horologium

Eratosthenes of Cyrene



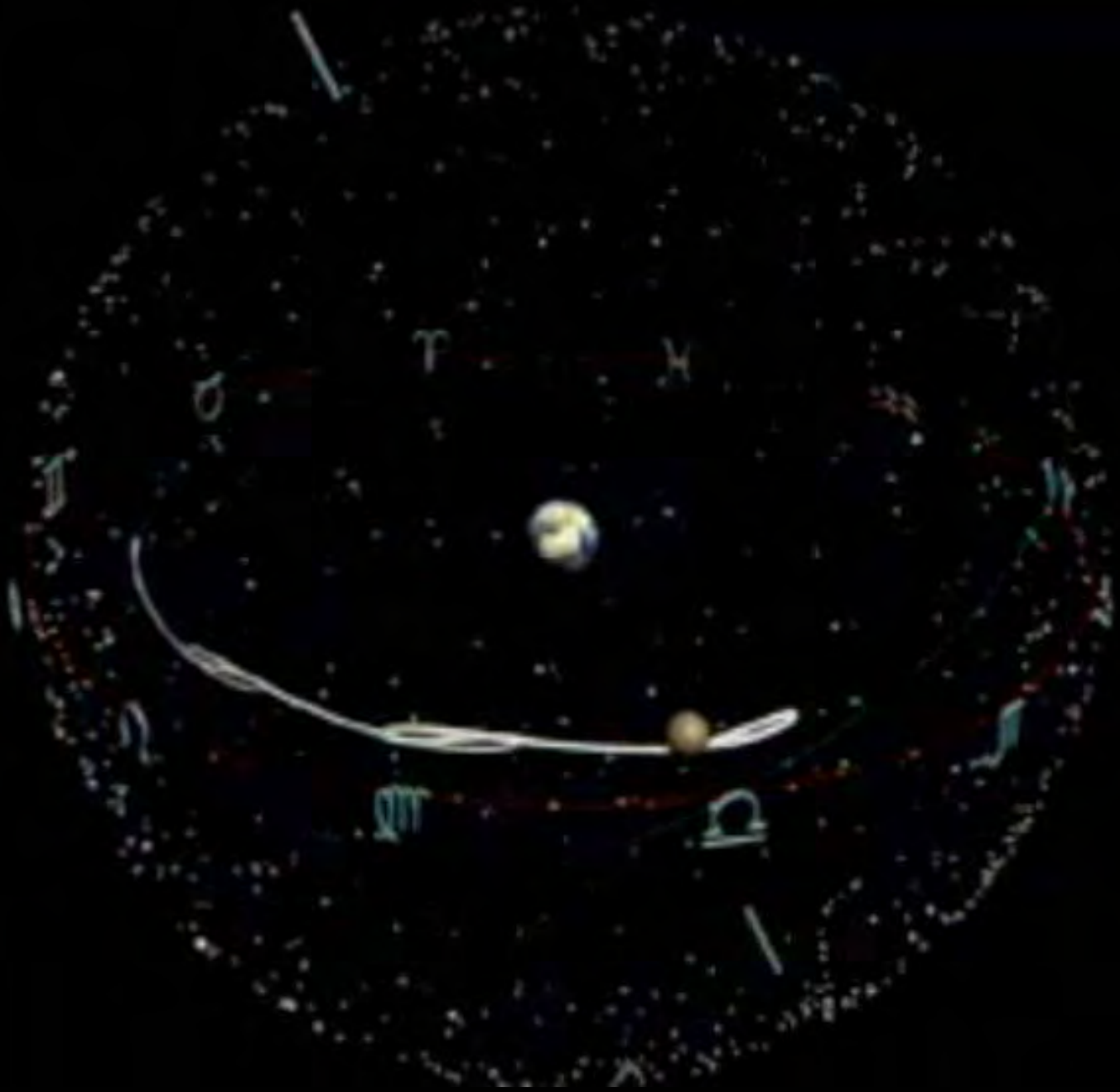
Eratosthenes of Cyrene

1 Stadion = ?

Stadion	Value	Earth circumference	Error
Eratosthenes	148,5 m	37400 km	7 %
Egyptian	157,5 m	39700 km	1 %
Roman	185,6 m	46800 km	17 %
…	…	…	…

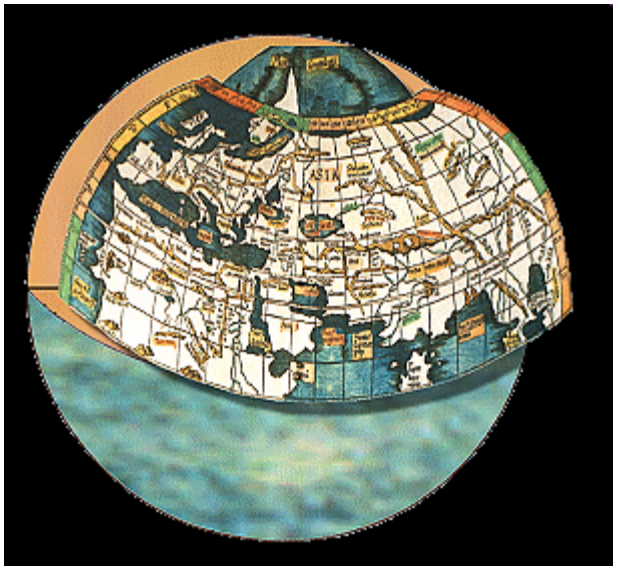
Claudius Ptolemaeus

- 83–161 AD
- Alexandria
- astrologer, astronomer, geographer mathematician
- geocentric model (due to gravity!)
  - Earth is in the center
  - Sun, moon and planets travel on spheres + epicycles
  - remained more precise than the heliocentric model till Kepler realized the ellipticity of the orbits
- author of several scientific treatises:
  - *Almagest* (on astronomy)
  - *Geography*
  - *Tetrabiblos* (on astrology)



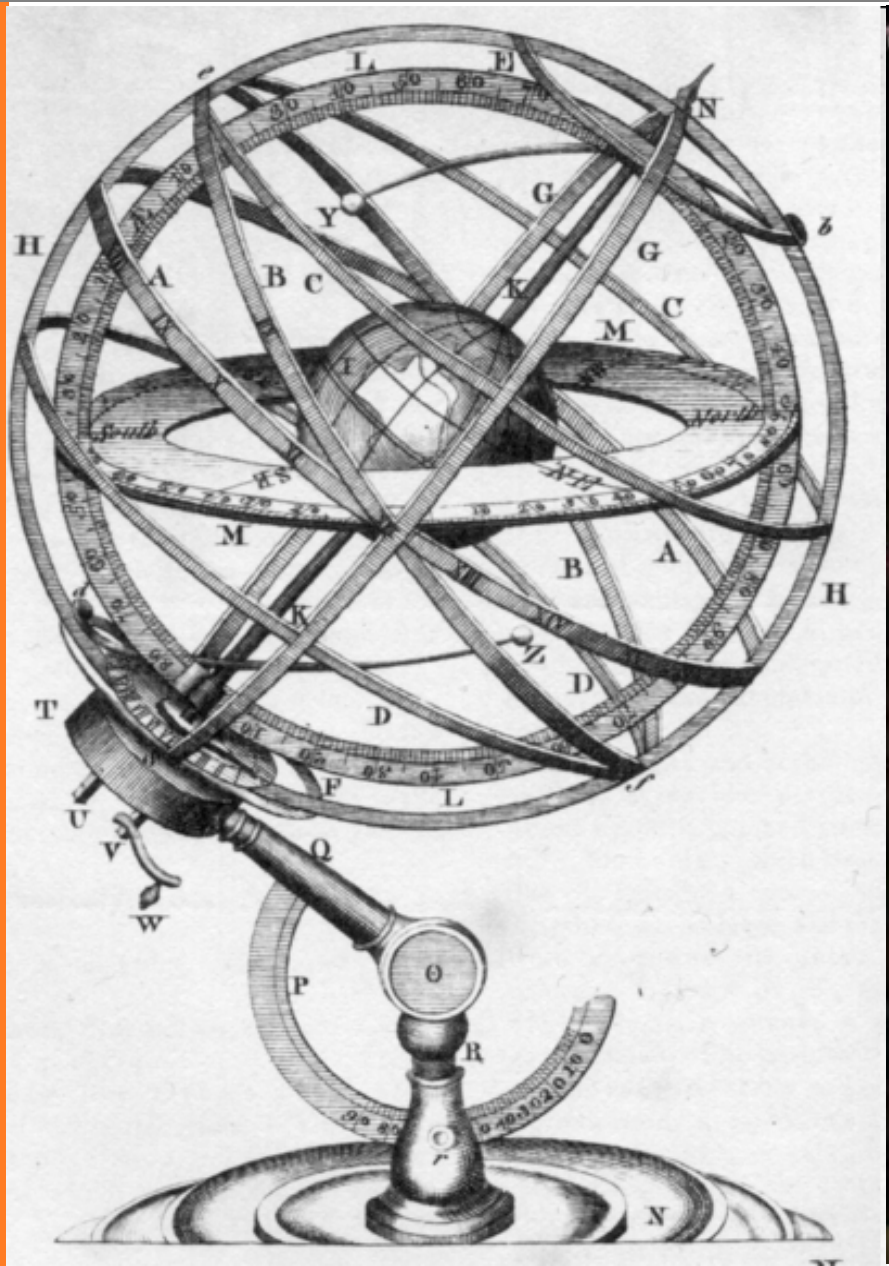
Sphere or Plane?

The middle ages



- Both ideas exist alongside
- Common people: plane (indoctrinated by the church)
- Educated population and clergy: spheroidal Earth but only few dare to challenge the church: accusation of heresy
  - Virgilius of Salzburg, 700–784, bishop, called the geometer
  - Pope Sylvester II, 946–1003
    - introduces arabic knowledge to mathematics and astronomy;
    - brings the armillary sphere to Europe
    - is accused of being a a sorcerer in league with the devil

The middle ages

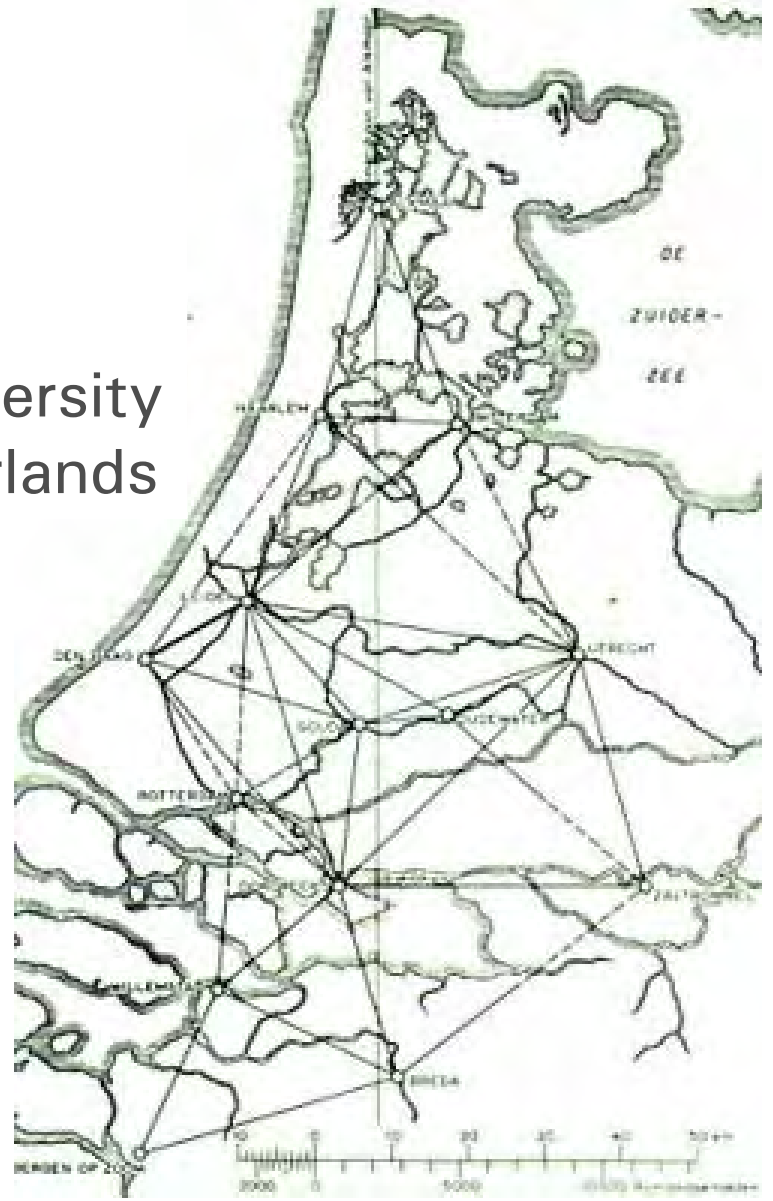


Proof of a spheroidal Earth

- Christopher Columbus (1451–1506)
  - voyage to America
  - calculated circumference = 25500 km
- Ferdinand Magellan (1480–1521)
  - voyage around the world: 5 ships + 237 men
  - dies in the battle of Mactan
  - *Victoria* returns with 18 men after 69800 km

Willebrord Snell van Roijen

- 1580–1626
- a.k.a. “Snellius”
- astronomer, mathematician
- professor at University of Leiden, Netherlands



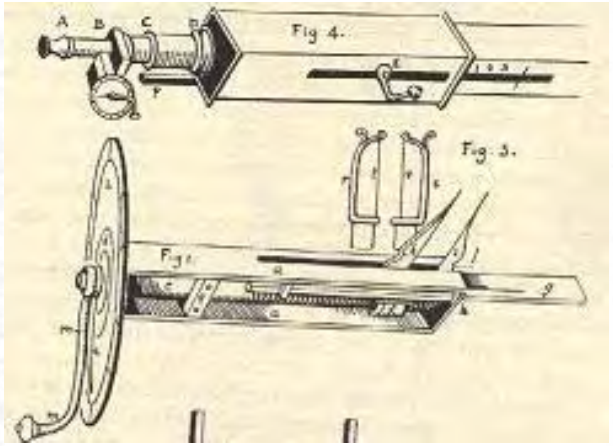
- Methodology of triangulation
- *Eratosthenes Batavus*
- uses triangulation between Alkmaar and Bergen op Zoom

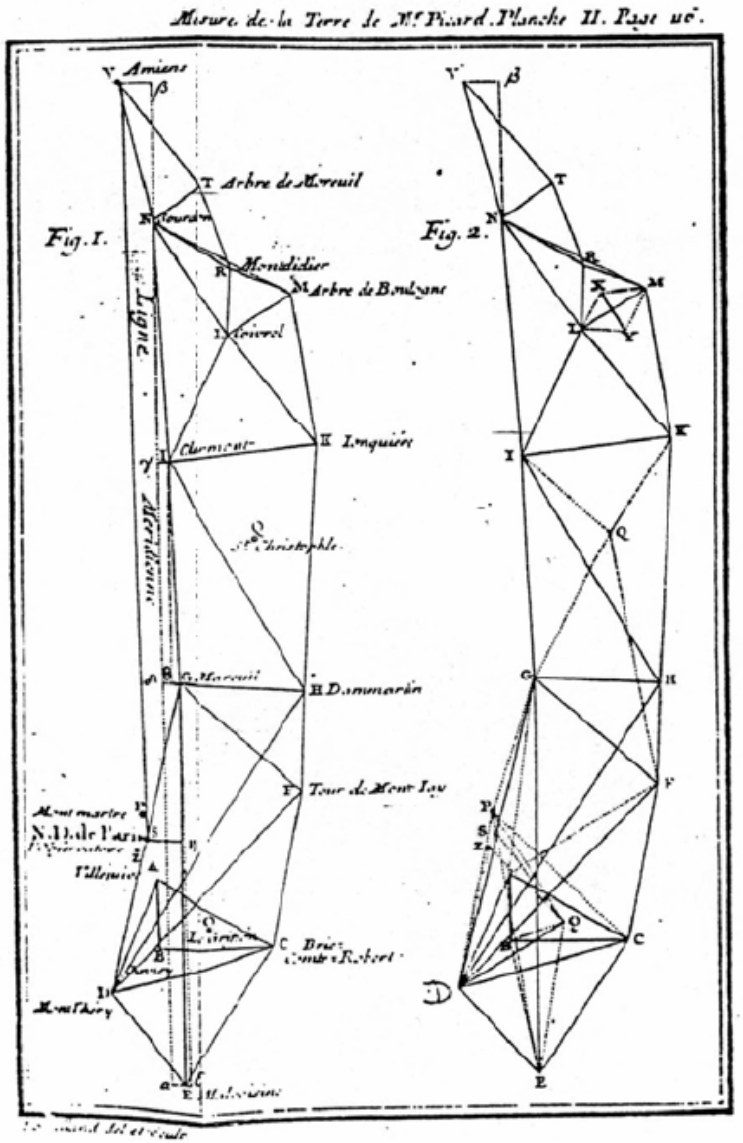
$1° = 107.395$ km

$360° = 38662.20$ km

$\varepsilon \approx 3\%$

Jean-Felix Picard





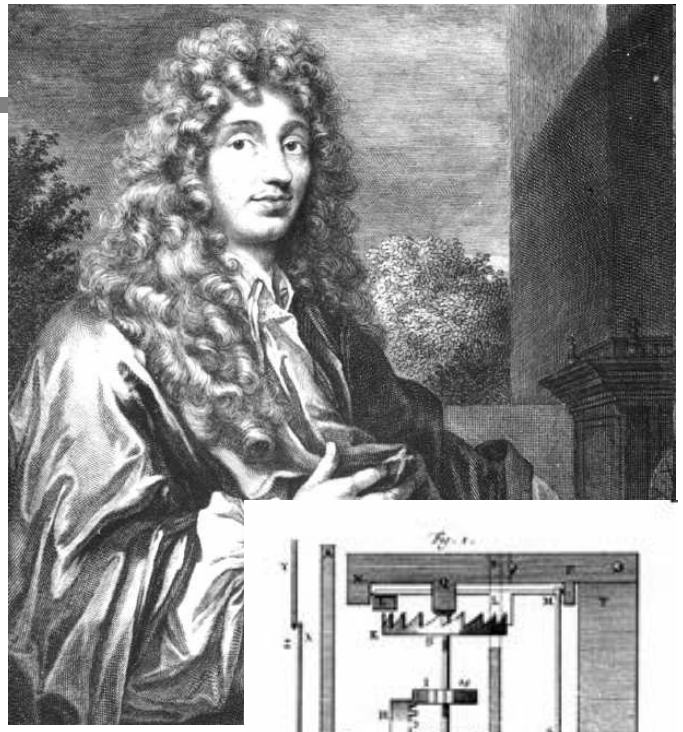
- 1620–1682
- astronomer, priest
- uses the micrometre of Gascoigne
- measures along the Paris meridian to the clocktower of Sourdon, near Amiens
- 1° = 110.46 km

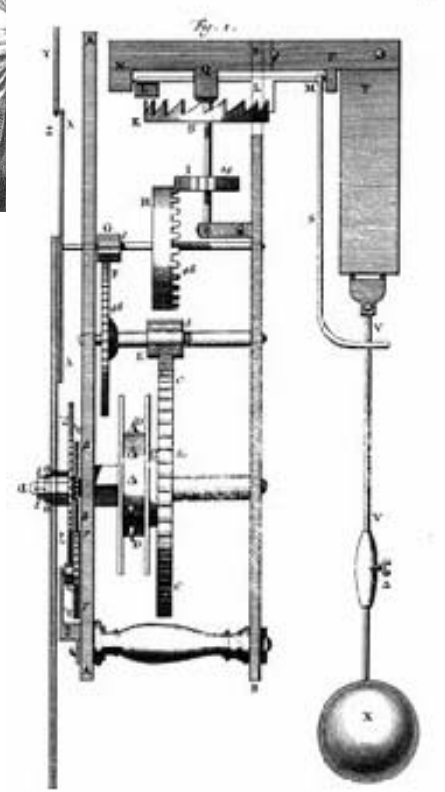
  360° = 39765.6 km, ε = 0.7%

GIS

Ellipsoid

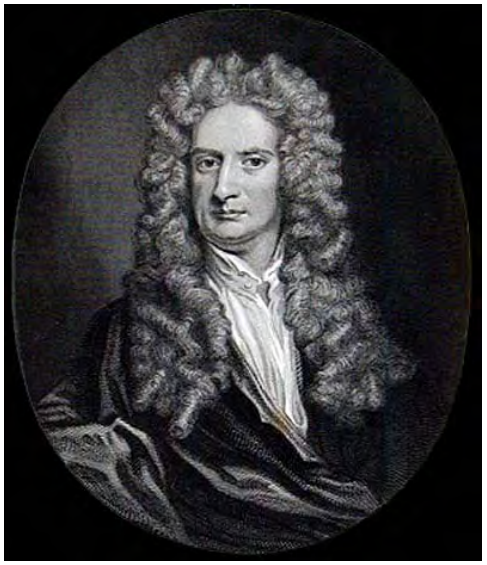
Christiaan Huygens





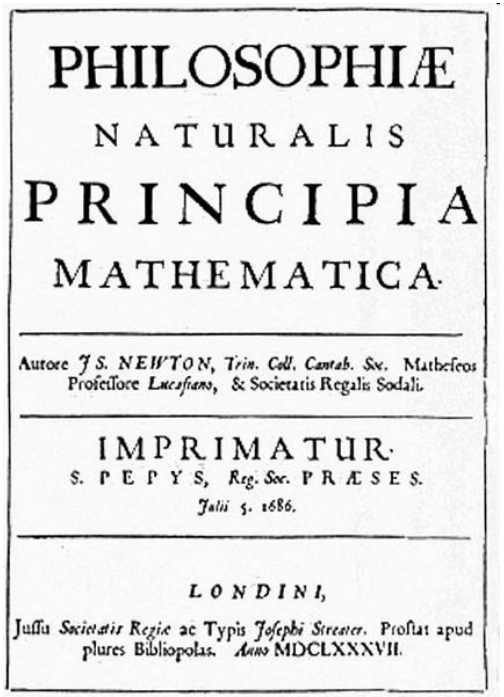
- 1629–1695
- astronomer, mathematician, physicist, horologist
- develops theory of mathematical and physical pendulum
- uses pendulum measurements for gravity determination
- realizes the dependency on the latitude
- hydrostatics → flattening
- Noted for his theory of light:
  - argued that light consists of waves
  - dispute with Newton

Isaac Newton



- 1643–1727
- physicist, mathematician, astronomer, philosopher, alchemist, theologian
- constructs the Newton telescope
- describes light as particles
  → dispute with Huygens

- uses the measurement of Picard to verify the gravitational laws
- describes the universal gravitation and the three laws of motion
- centrifugal effect → flattening
- proves consistency with Kepler's laws and, thus, heliocentric model



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

Autore *J. S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Justu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

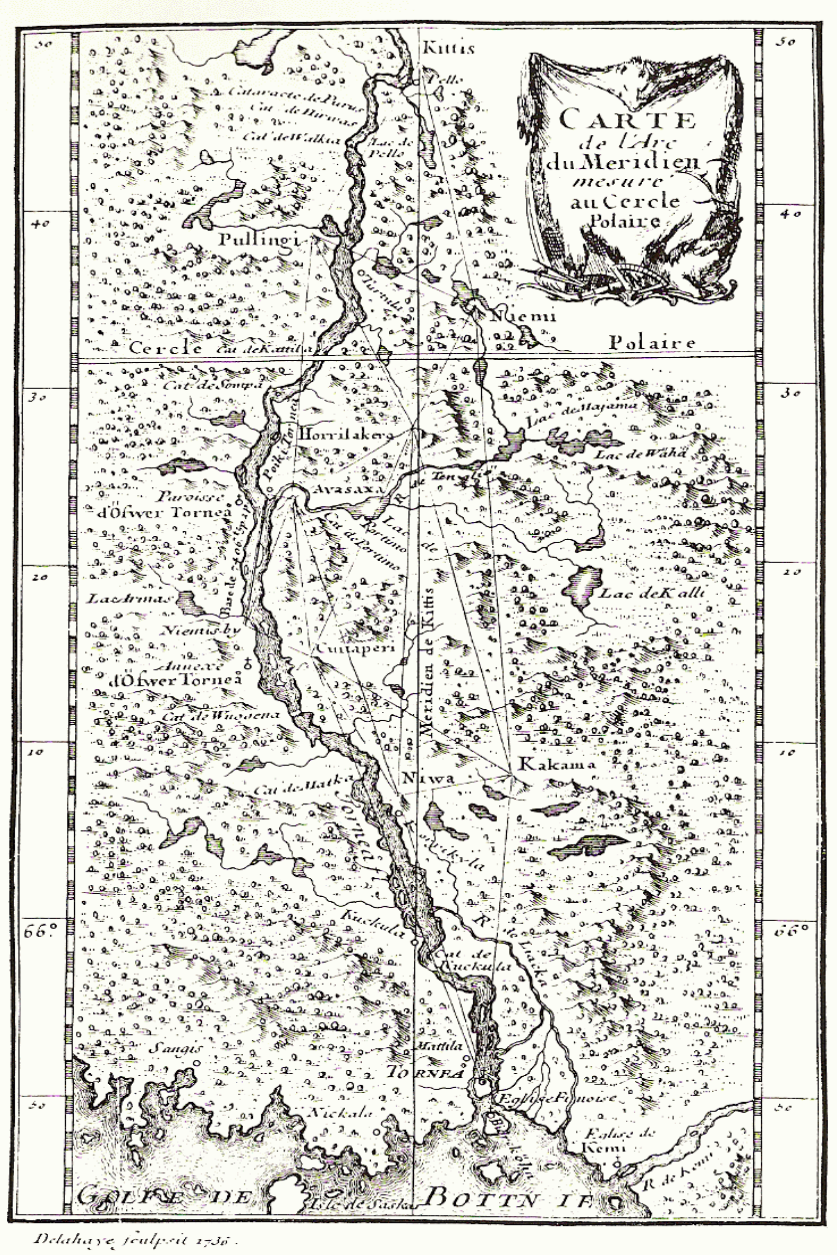
René Descartes

- 1596–1650
- a.k.a. Cartesius
- philosopher
  “cogito, ergo sum”
- mathematician
  “Cartesian coordinates”
- (meta-) physicist
  vortex theory
- vortices → prolate Earth

Giovanni Domenico Cassini

- 1625–1712
- astronomer, mathematician
- member of the Académie des Sciences in Paris
- 3 objectives:
  - form of the Earth
  - mapping France
  - measuring the solar system
- observes flattening of Jupiter

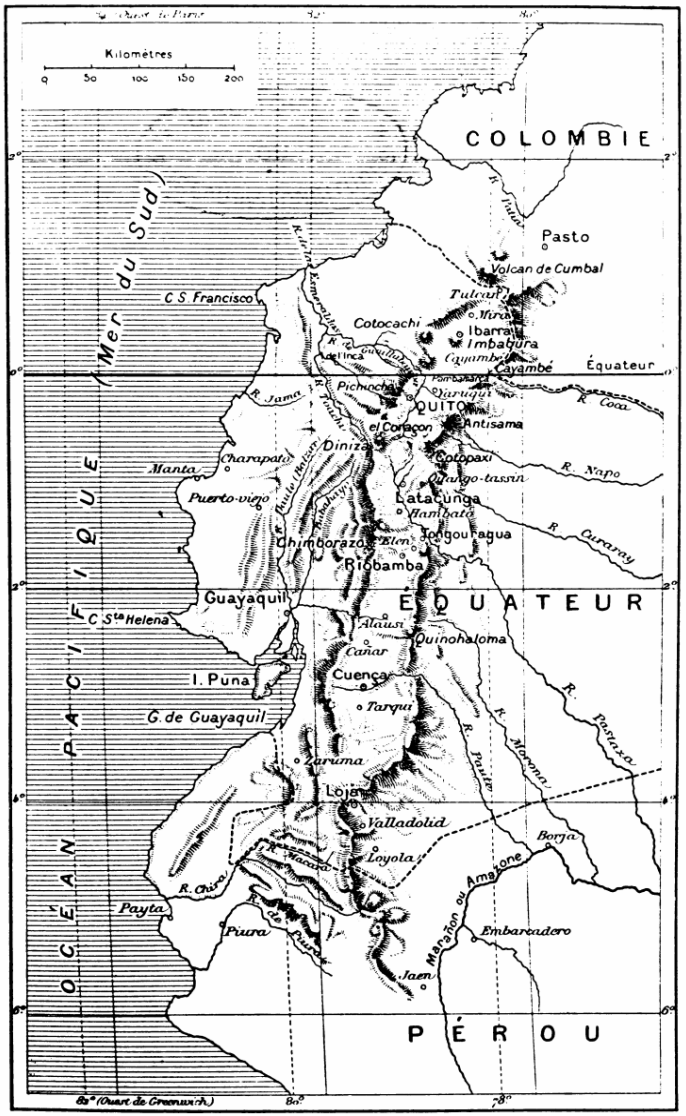
Pierre-Louis Moreau de Maupertuis



Delahaye fculpsit 1736.

Pierre Bouguer in Peru

- 1698–1758
- astronomer, geodesist, physicist
- expedition to Peru 1735–1741 on behalf of the Académie des Sciences
- recognizes the effect of mountains on the deflection of the vertical and gravity
- *La figure de la terre* (1749)
  - description of gravity measurements o the mountain Pichincha
  - describes free-air & Bouguer reduction



Geoid

Mathematical foundations / potential theory

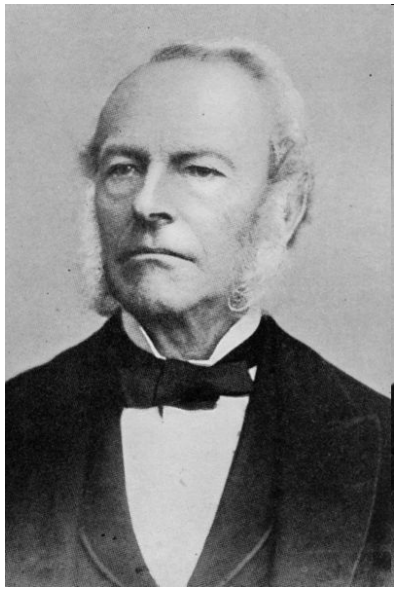
- Adrien Marie Legendre (1752–1833)
- mathematician, geodesist
- develops the least-squares method
- Legendre polynomials
- triangulations Dunkirk-Boulogne and Greenwich-Paris
- member of the metric commission

- Carl Friedrich Gauss (1777–1855)
- mathematician, astronomer, geodesist, physicist
- triangulations in Hannover
- develops least-squares adjustment
- predicts the orbit of Ceres with this method
- priority dispute with Legendre
- divergence theorem: transform a volume integral into a surface integral

Geoid

- George Gabriel Stokes (1819–1903)
- mathematician and physicist
- fluid dynamics
- solution of the geodetic boundary value problem

$$N(P) = \frac{R}{4\pi\gamma} \iint_{\sigma} \mathrm{St}(\psi_{PQ})\, \Delta g(Q)\, \mathrm{d}\sigma$$

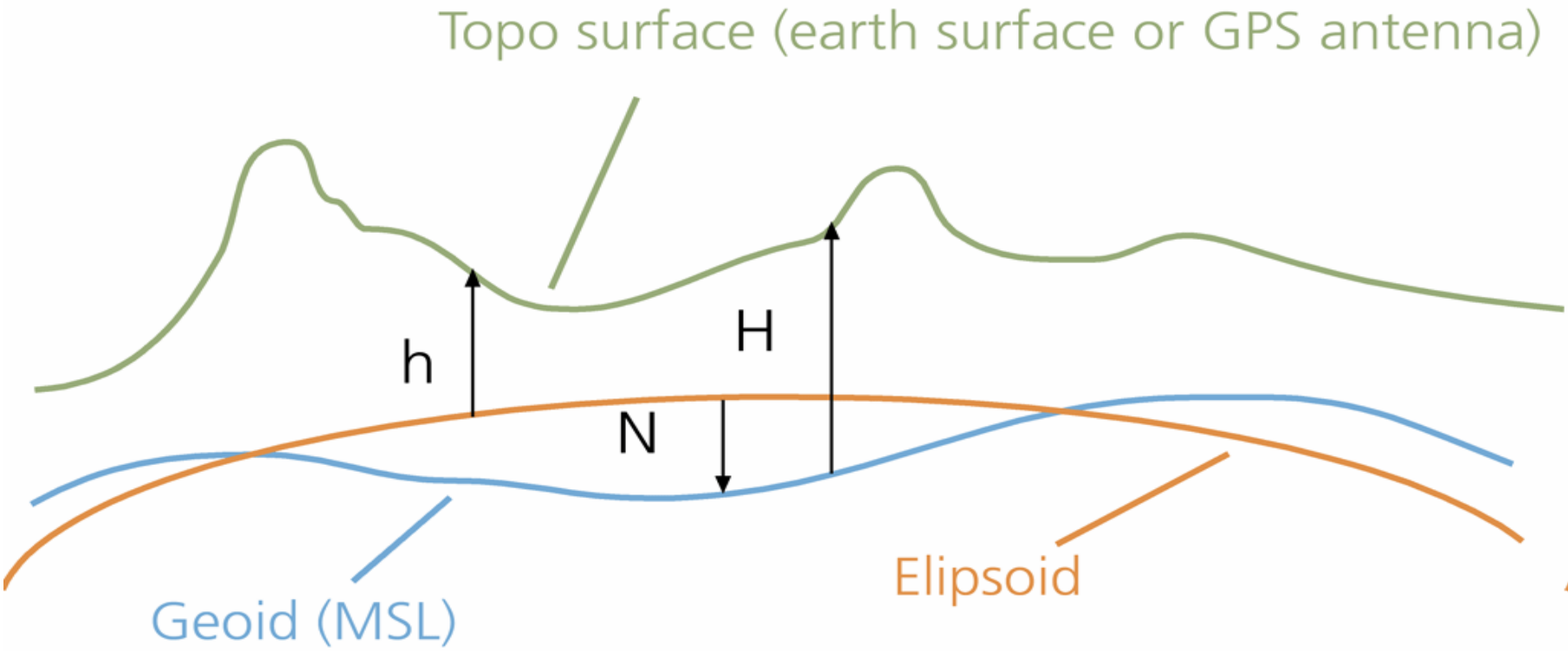


- Johann Benedikt Listing (1808–1882)
- mathematician (student of Gauss)
- coins the term **geoid**:

The geoid is the mathematical and geometrical shape of the Earth as an equipotential surface at mean sea level

What is the geoid? Why do we need it?

- Equipotential surface at mean sea level
  - Every mass has the same potential energy at this level
  - It indicates the flow of water (higher → lower potential)
  - It connects GPS-heights (h) with levelled heights (H)
- Almost every geodetic measurement is connected to the plumbline and/or the geoid.



Today

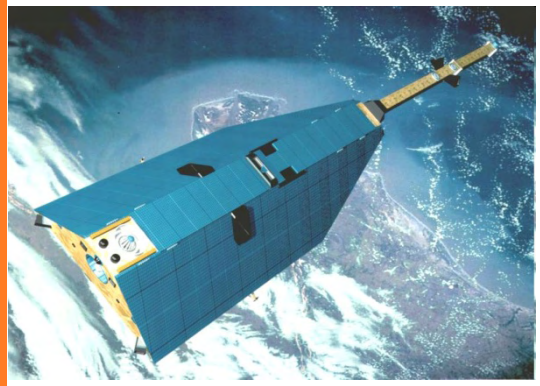
Gravimetry

relative

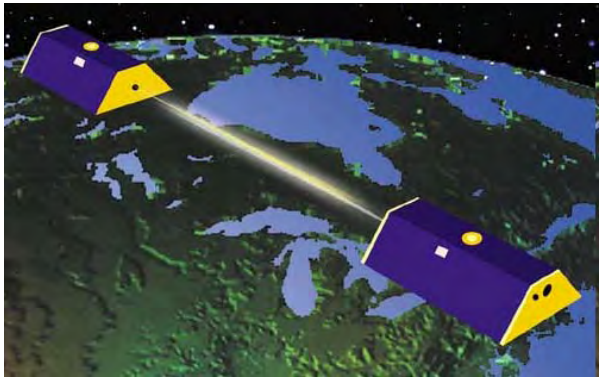
absolute

air-/shipborne

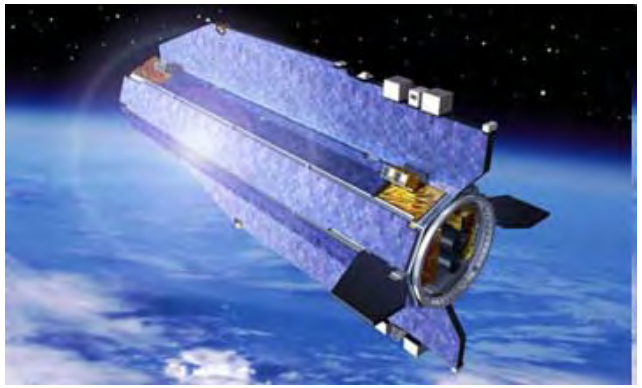
Satellite missions



CHAMP



GRACE



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