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Cahill / Caltech

The Astronomical Victories of Ancient Greece

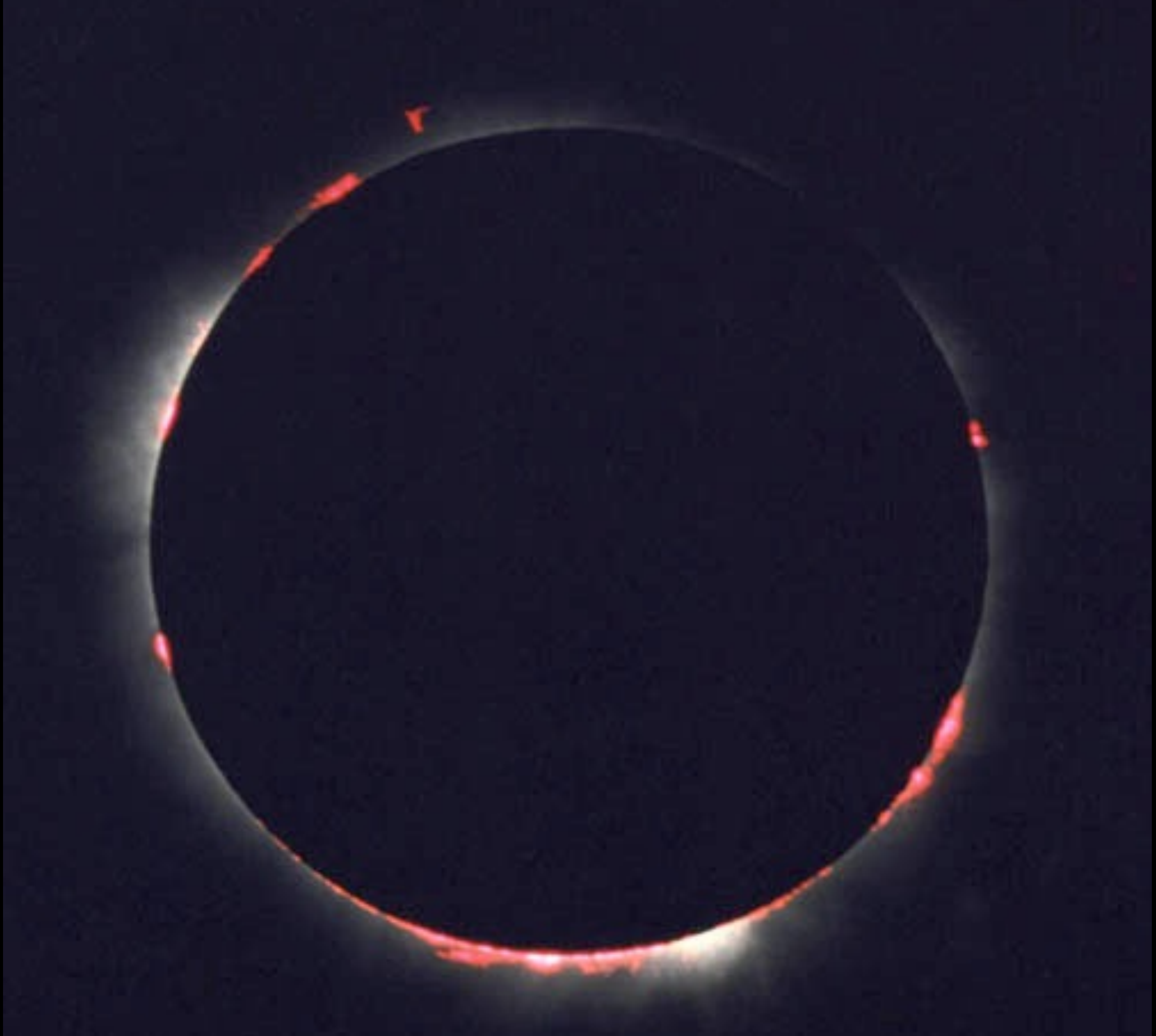
Georges Meylan
Laboratoire d'astrophysique

Ecole Polytechnique Fédérale de Lausanne

Human beings have always been
impressed, fascinated, even frightened
by numerous astronomical phenomena
such as comets and total solar eclipses.

Nevertheless, since the most remote times, some humans
have been inhabited by an intellectual appetency,
by a thirst for knowledge,
by the need to know and to understand the space that surrounds them.

All understanding has always been the consequences of progress
in mathematics and physics for the theory and
in technology for the observations.



Total solar eclipse of August 11, 1999

Mondaufgang am Meer (c. 1821) Caspar David Friedrich (1774 – 1840) Hermitage Museum, St. Petersburg, Russia

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Long struggle of influence between scientific rationality and
the irrationality of myths and other religious revelations,
or the intellectual arrogance of authoritarian people.

THE DAWN OF SCIENCE

Mesopotamia, Egypt, Greece: the three cradles of our civilization

with the locations and the names of the Seven Wonders of the World

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The Acropolis of Athens (1805) Watercolor by Edward Dodwell (1767 - 1832)

The Acropolis of Athens nowadays

The School of Athens by Raphael (1510-1511)

Vatican Museum in Rome

Five of the great victories of Greek astronomy

Presented in chronological order

Victory of Samothrace

About 190 B.C.

representation
of the goddess Athena Nike,
messenger of victory
(original, not a roman copy)

A victory for arts

Discovered in 1863
on the island of Samothrace

Louvre Museum Paris

I

<u>Discovery of the difference</u>
<u>between</u>
<u>the sidereal and solar days</u>

heliocentrism instead of geocentrism

<u>Heraclides</u> (born c. 388 B.C. in Heraclius of Pontus, died c. 315 B.C.)

Great hypotheses
with little immediate impact

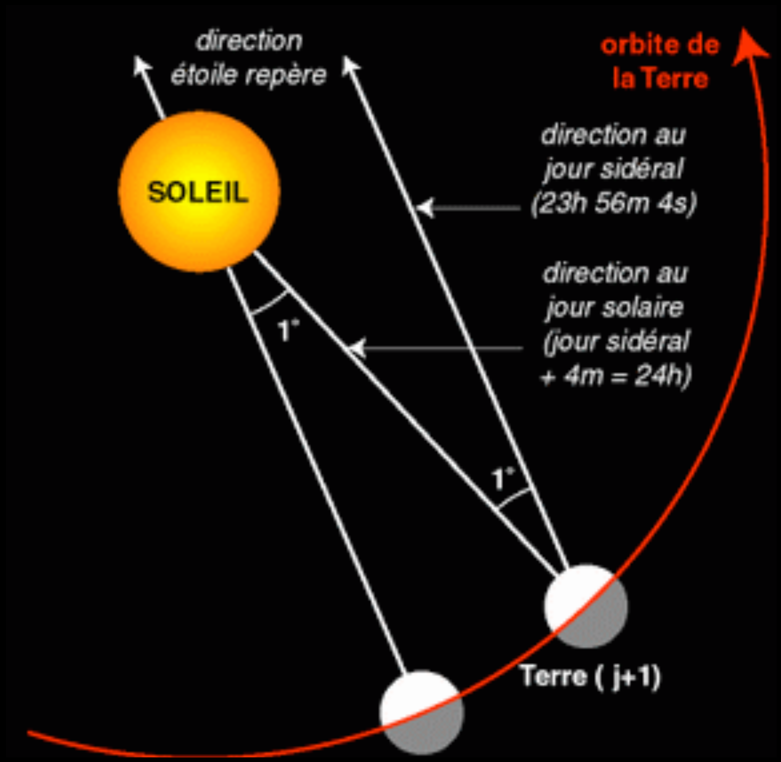
Heraclides (c. 388 B.C. in Heraclius of Pontus, died c. 315 B.C.)

He explains the diurnal movement by a direct and uniform rotation of the Earth around its axis passing through the two poles, while orbiting the Sun.

This rotation takes place in one sidereal day, and Heraclides observed that its duration is slightly shorter (by four minutes) than the solar day.

one sidereal day shorter than one solar day

by 3 min 56 sec



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II

The inner and outer planets

heliocentrism instead of geocentrism

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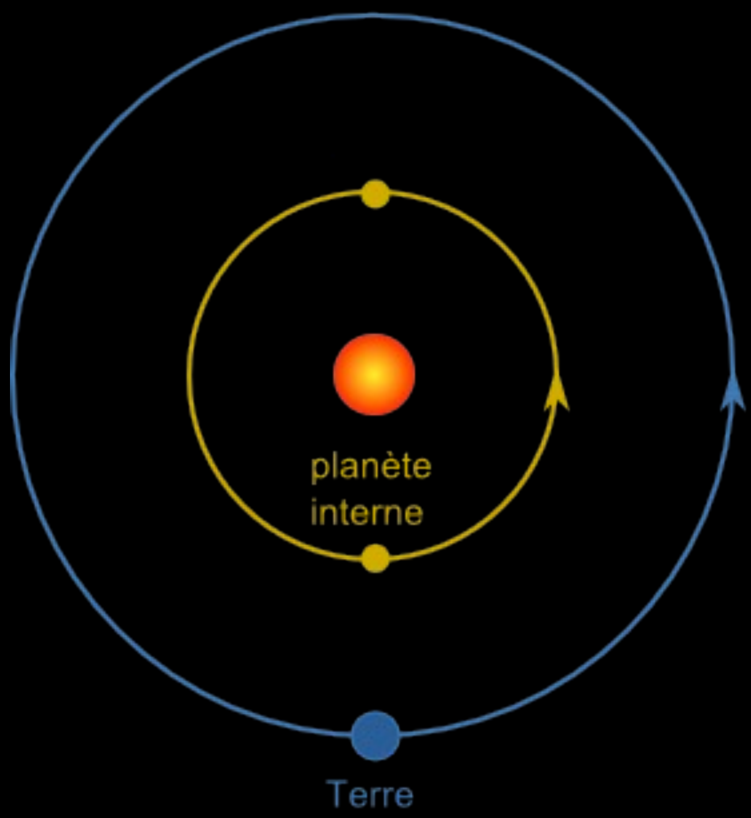
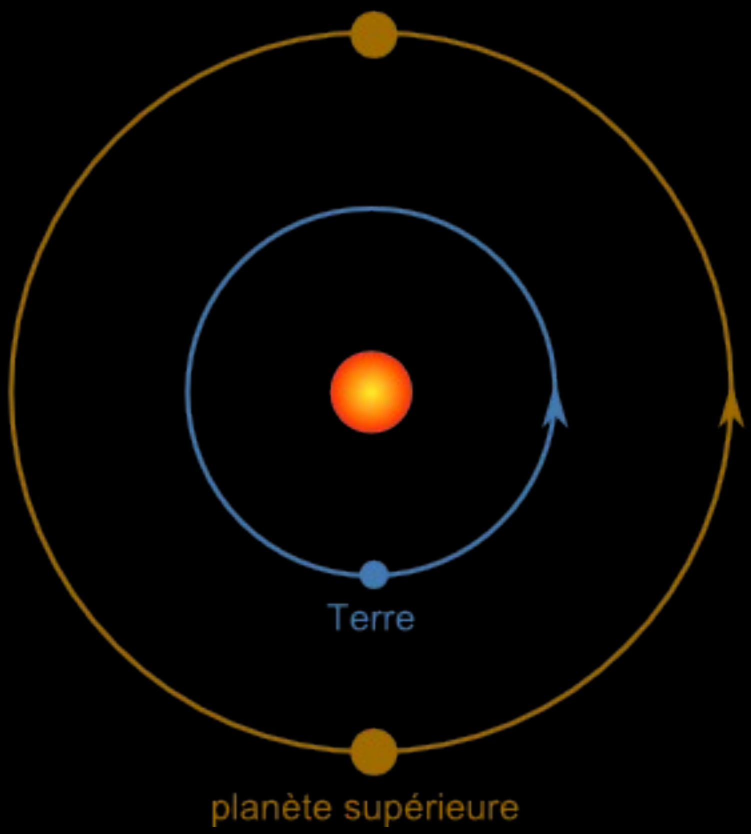
Mercury and Venus disconcert astronomers: their march on the celestial sphere depends visibly on that of the Sun. Heraclides' model postulates that the Sun is immobile at the center of the world. The Earth and five other planets describe circular orbits around the Sun. The circles of Mercury and Venus are inside the Earth's orbit, while the circles of Mars, Jupiter and Saturn are outside. The Moon revolves around the Earth, whose own rotation produces the appearance of diurnal motion.

inner planets



Mercury - Venus

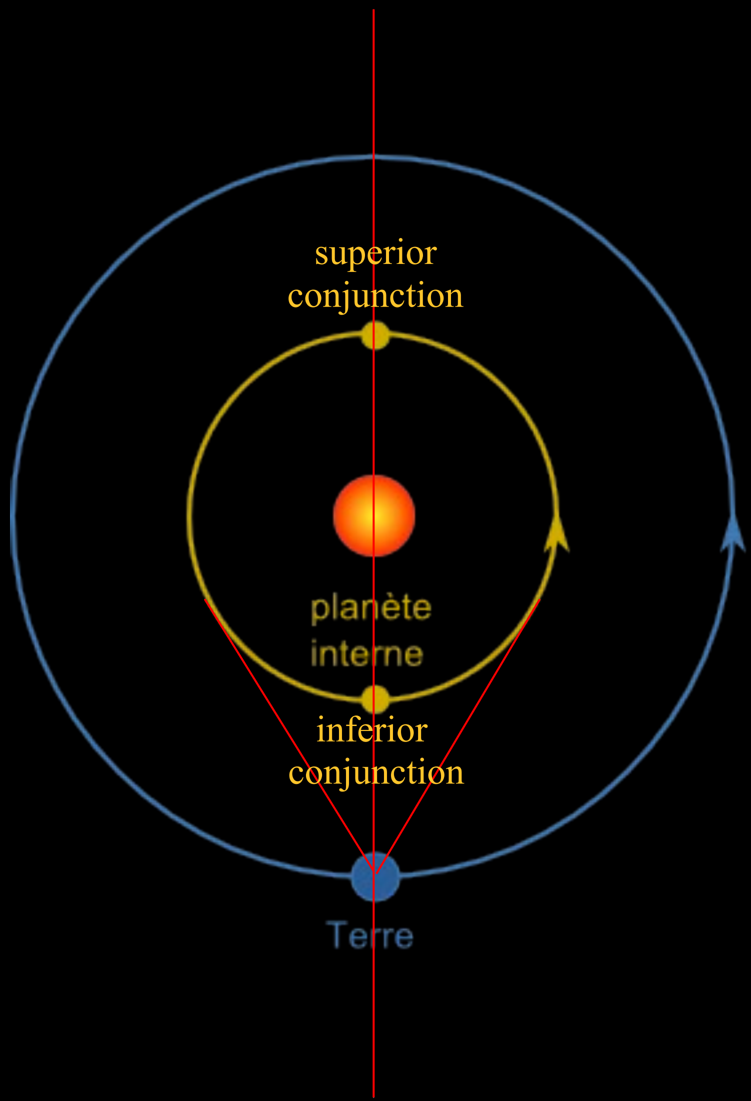
outer planets



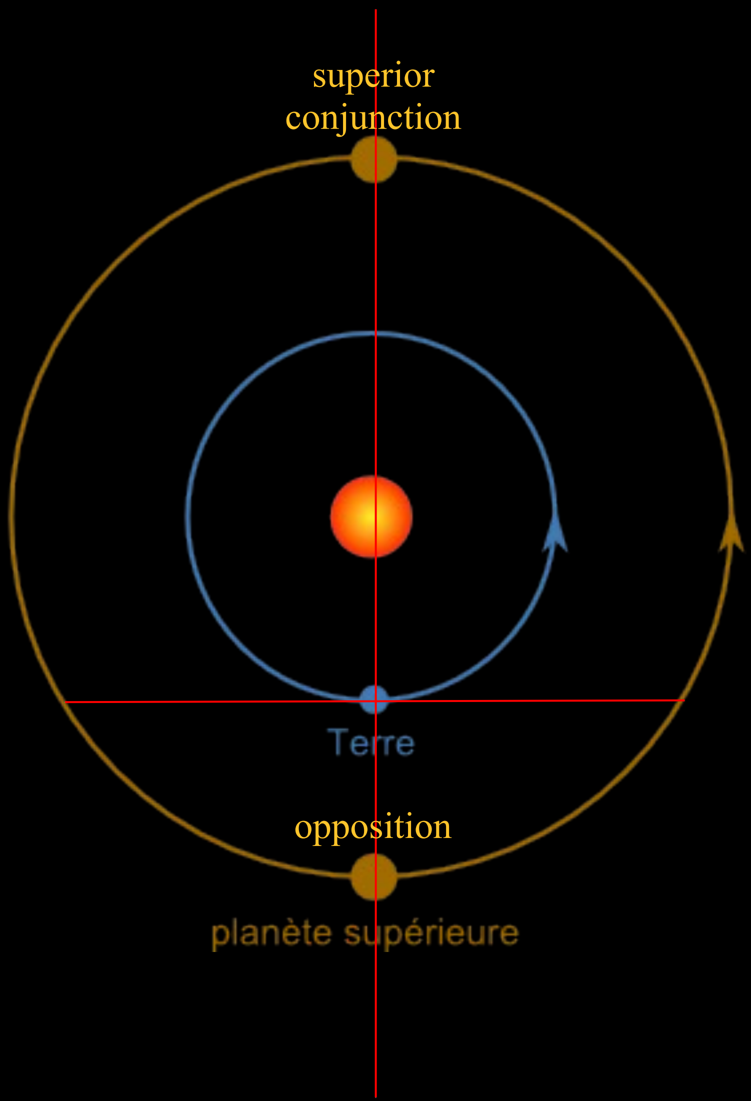
Mars – Jupiter - Saturn

inner planets

outer planets



Mercury - Venus



Mars – Jupiter - Saturn

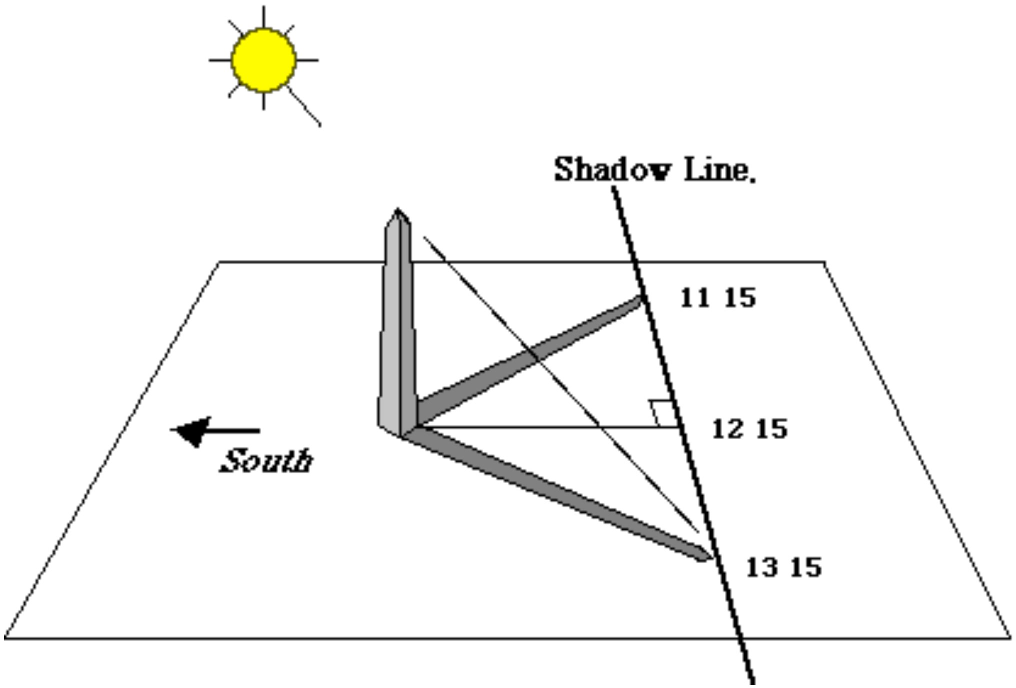
III

<u>The measurement of the circumference of the Earth</u>

Eratosthenes (born c. 276 B.C. in Cyrene Libya, died c. 196 B.C.)

gnomon : from China to Chaldea and Egypt,

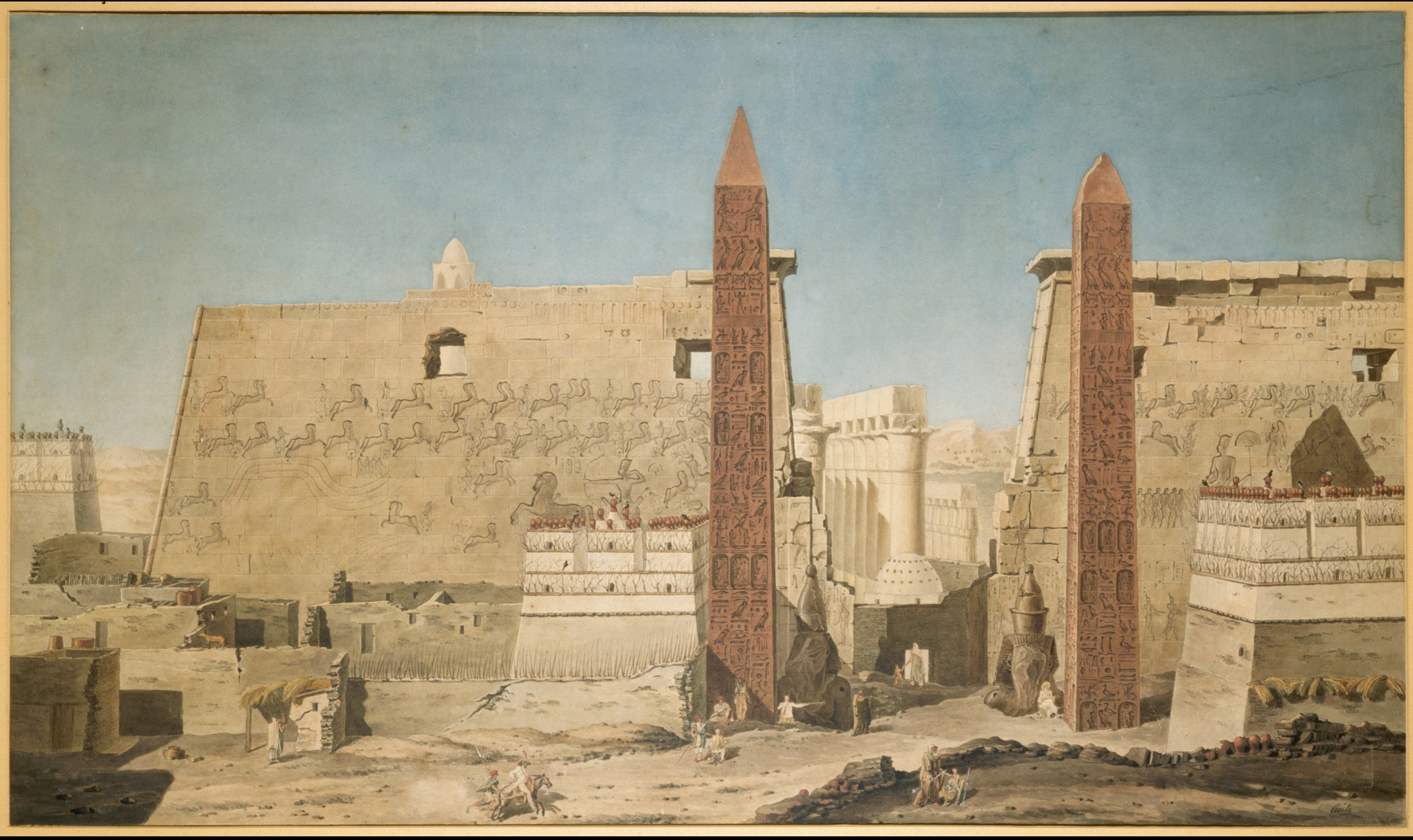
then to Greece in the 6th century B.C.



Determination of the height of an astronomical object.

Astronomical hypothesis : the solar rays in a given place are parallel, so the Sun is very distant and very large.

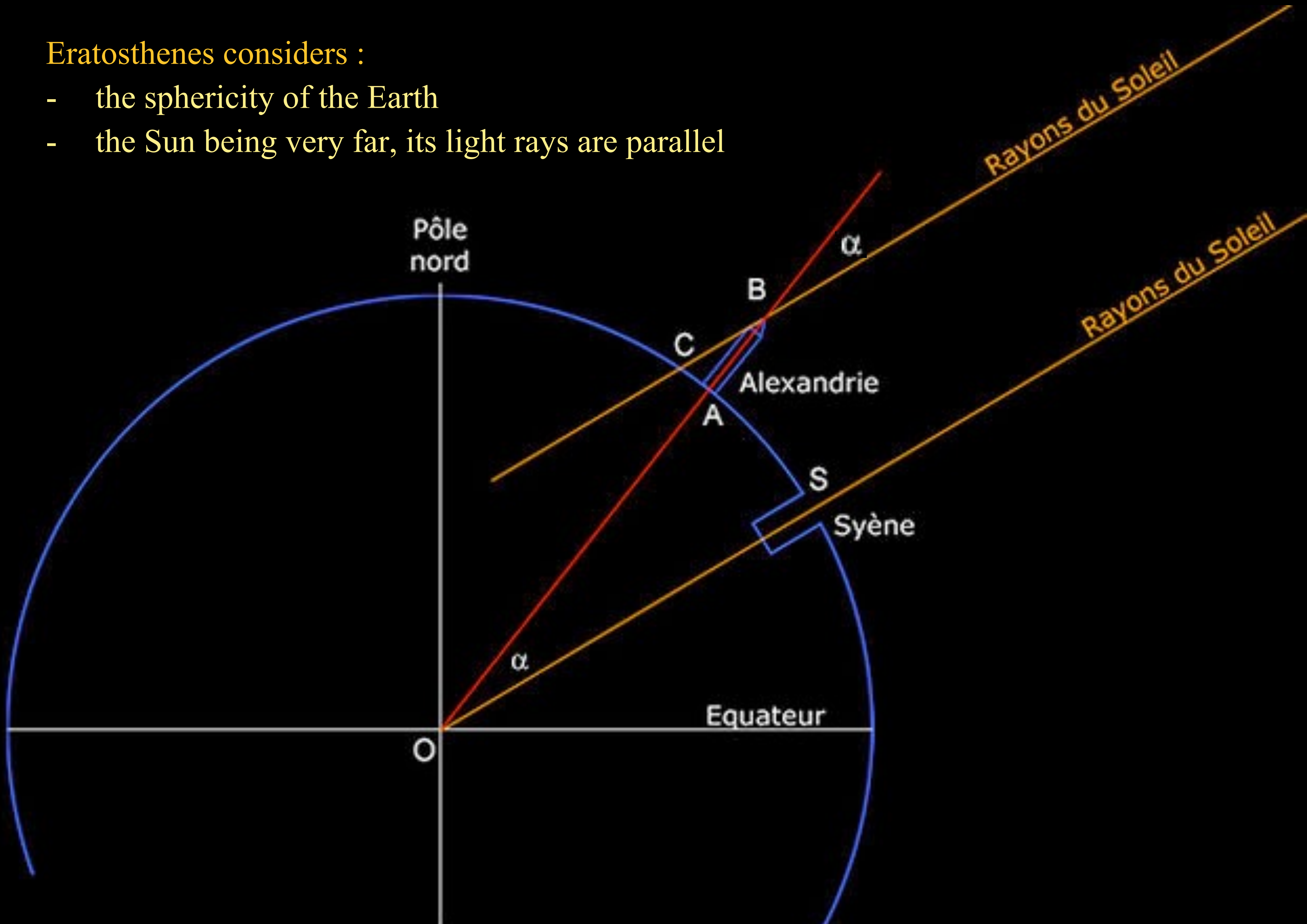
An obelisk used as a gnomon



Obelisks of the Luxor temple, built by the pharaoh Ramses II in the 13th century BC.
The one on the right is since 1836 at the Place de la Concorde in Paris.
Watercolor around 1800 by François-Charles Cécile (1766-1840). Louvre Museum, Paris.

Eratosthenes considers :

- the sphericity of the Earth
- the Sun being very far, its light rays are parallel



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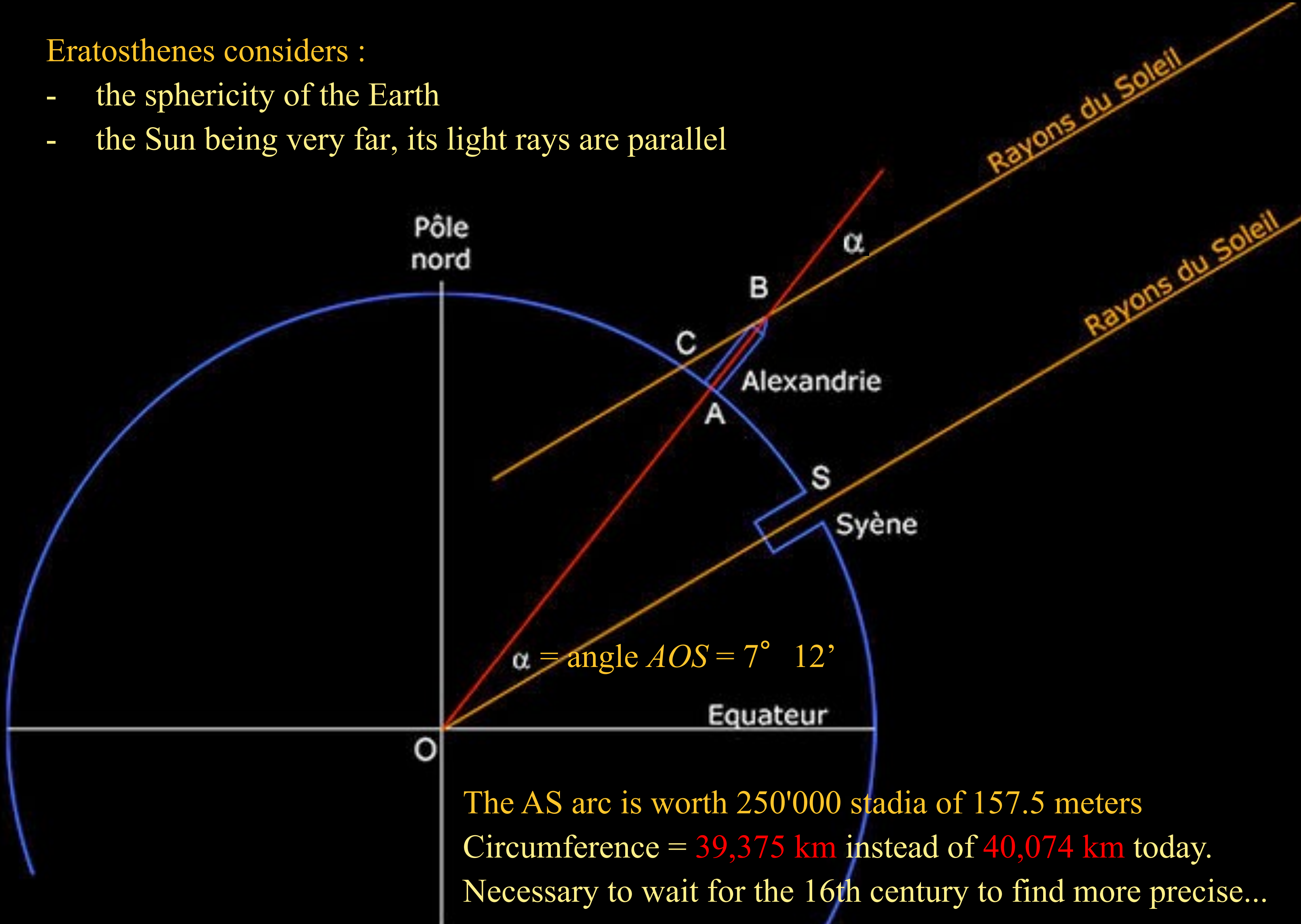

α = angle *AOS* = 7° 12’

The AS arc is worth 250'000 stadia of 157.5 meters

Circumference = 39,375 km instead of 40,074 km today.

Necessary to wait for the 16th century to find more precise...

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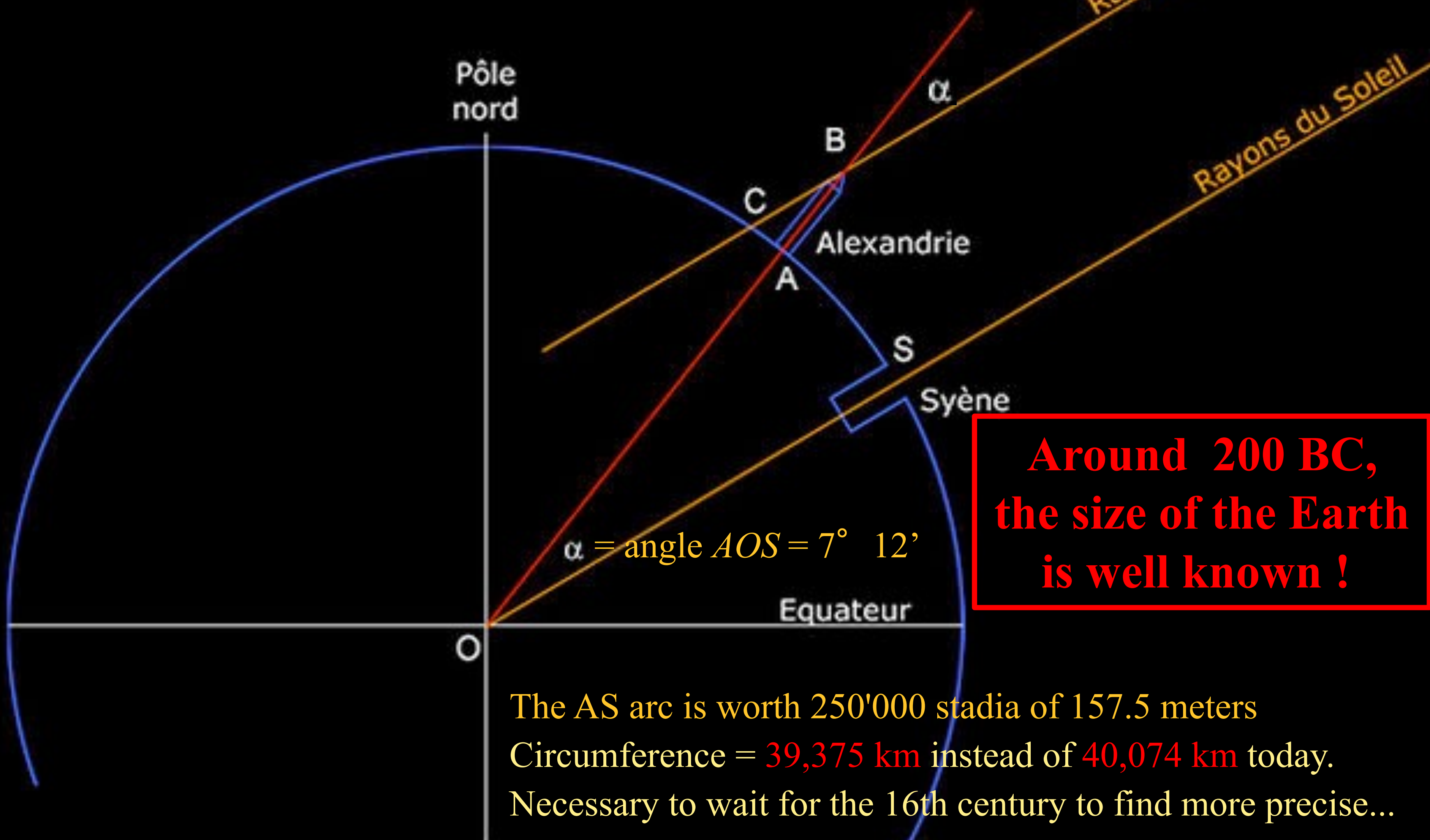

α = angle *AOS* = 7° 12’

Around 200 BC, the size of the Earth is well known !

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IV

<u>The precession of the equinoxes</u>

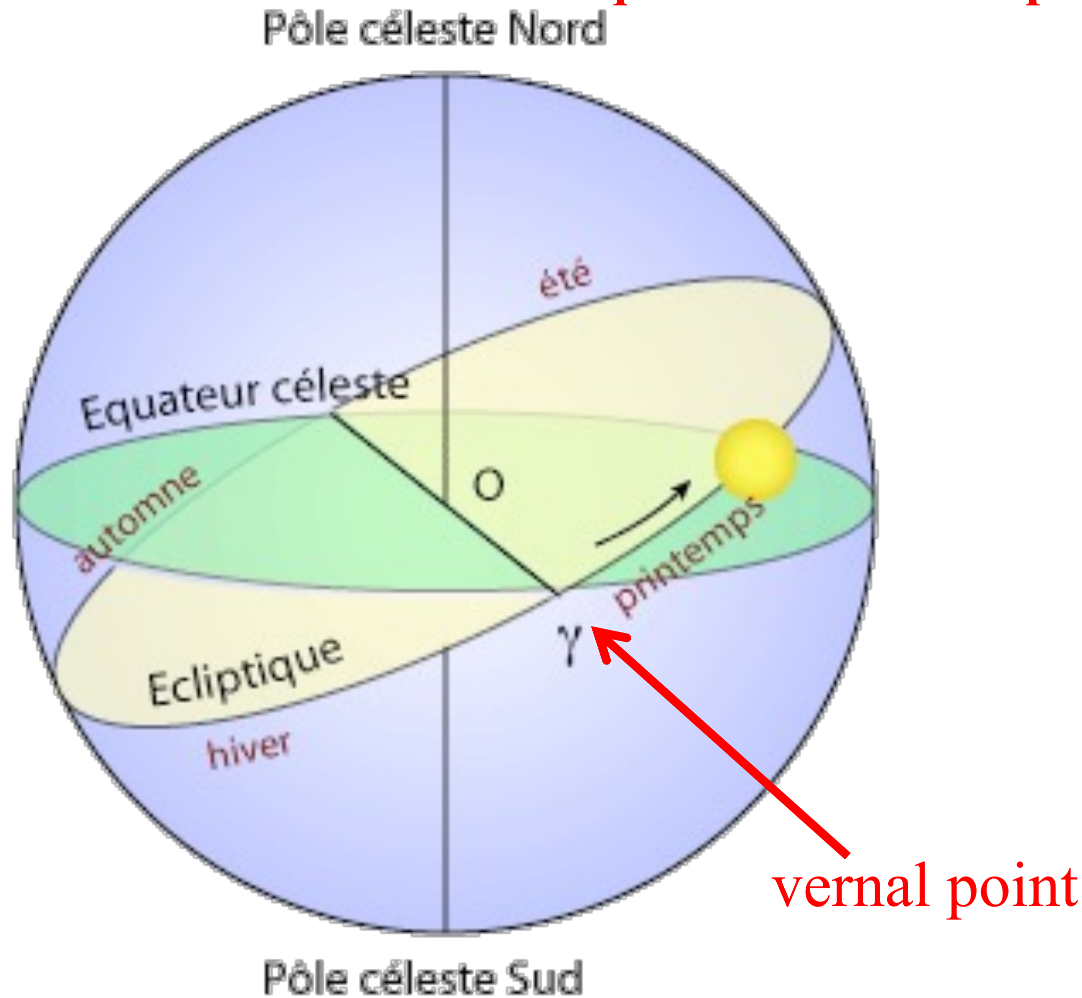
Hipparchus (born c. 190 BC in Nicea, Turkey, died c. 120 BC)

Celestial equator and ecliptic

The vernal point γ is the intersection between the celestial equator and the ecliptic

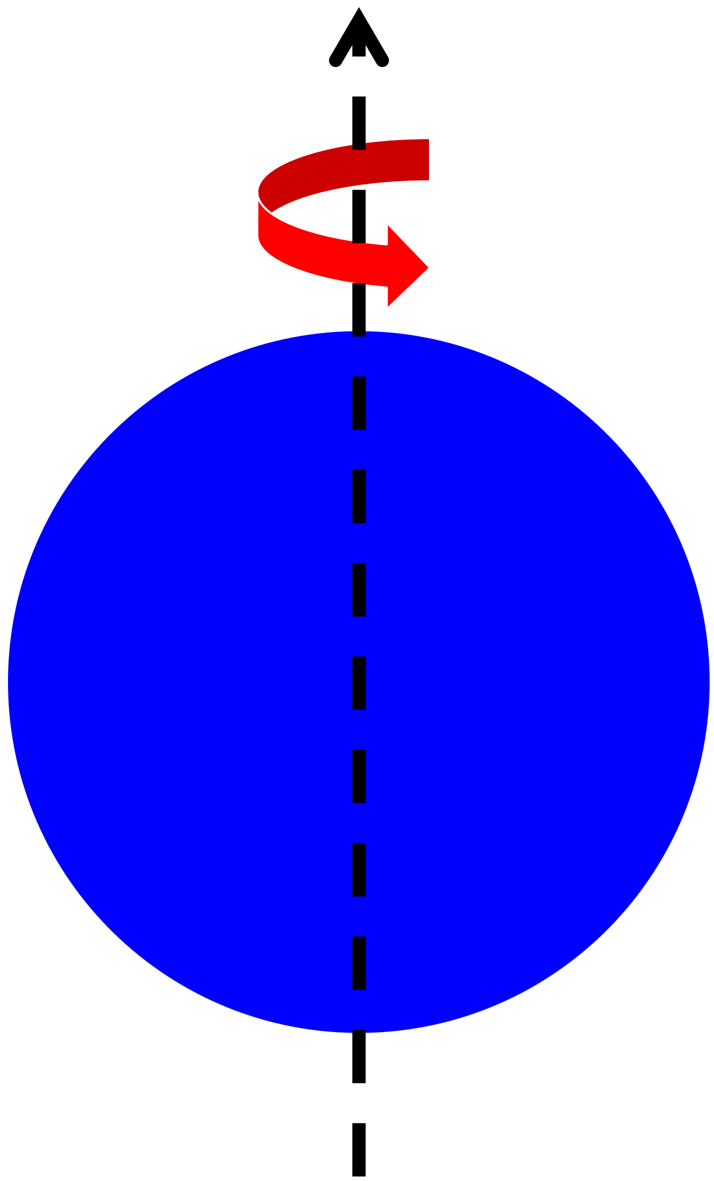
After observing a nova,
Hipparchus has the idea to create
a catalog of 1025 stars
with their coordinates.
By comparing his observations with old observations of about 170 years, he discovered,
in ~135 BC,
the precession of the equinoxes:
the longitudes of the stars grow of 50 arc seconds per year (~1/36 of the solar diam.)

precession with
a period of 25'725 years



The position of a point on the celestial sphere is defined by two coordinates:
The roght ascension α or **the hour angle** H and the **declination** δ

Rotation of the Earth



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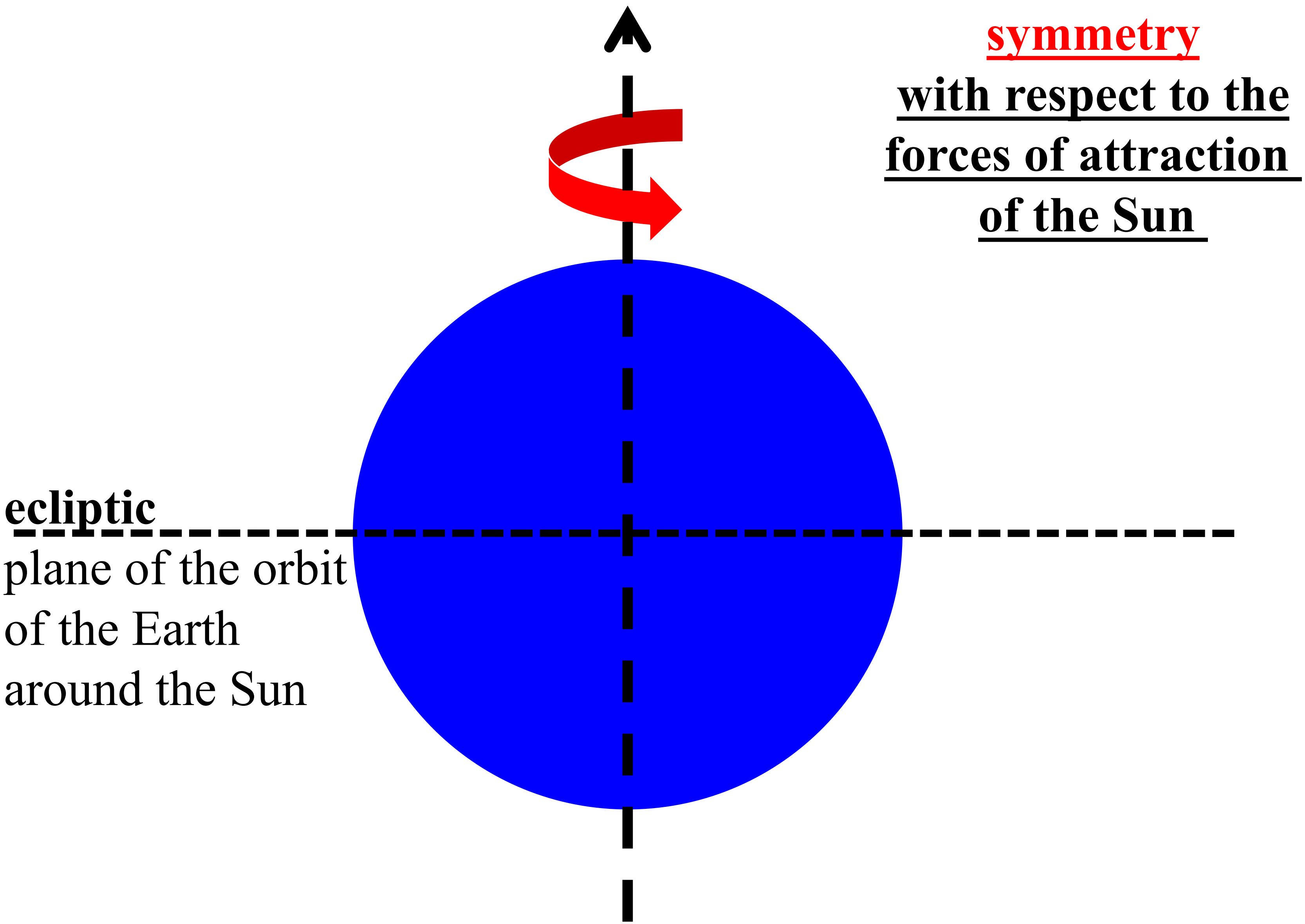

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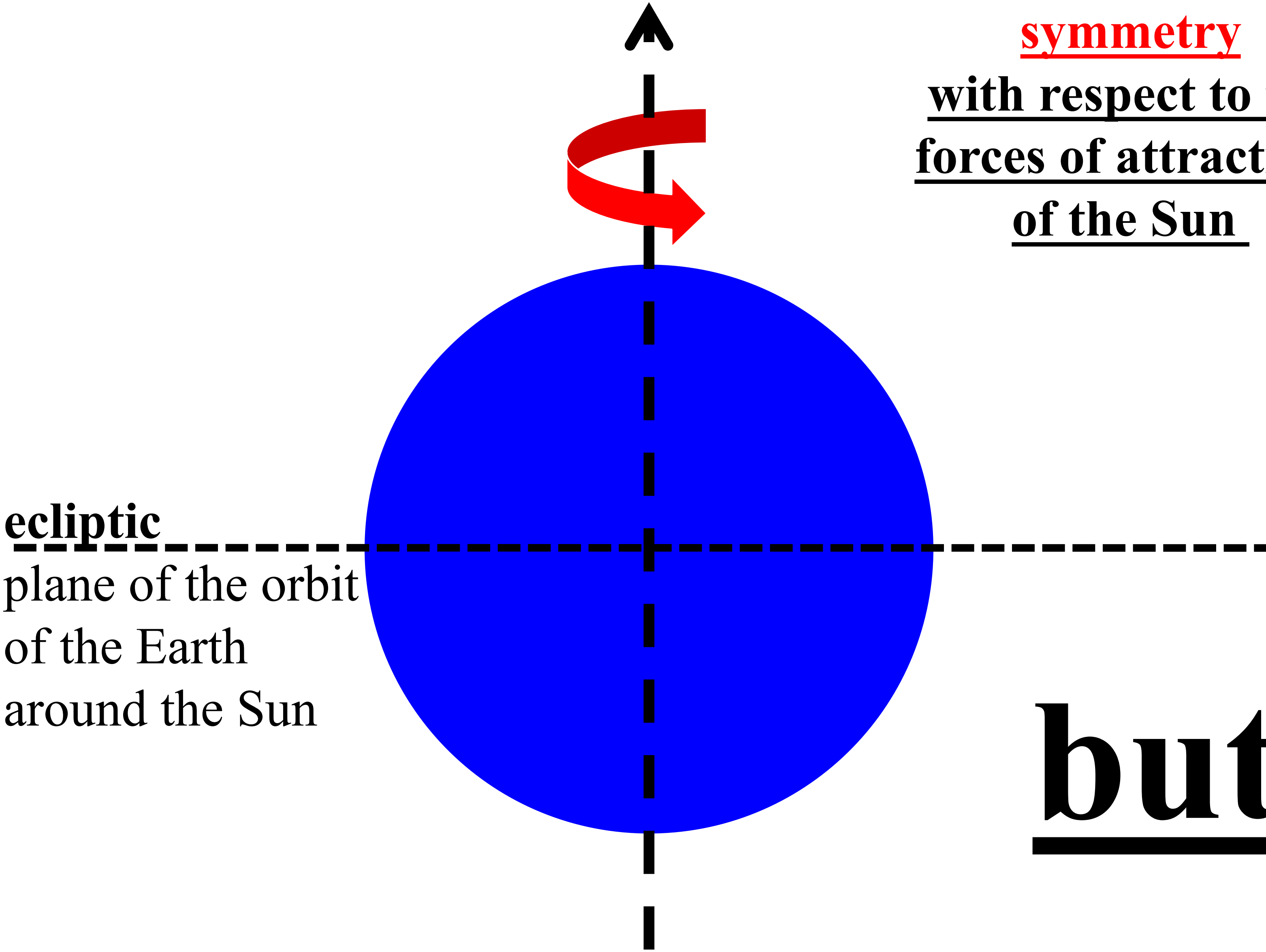
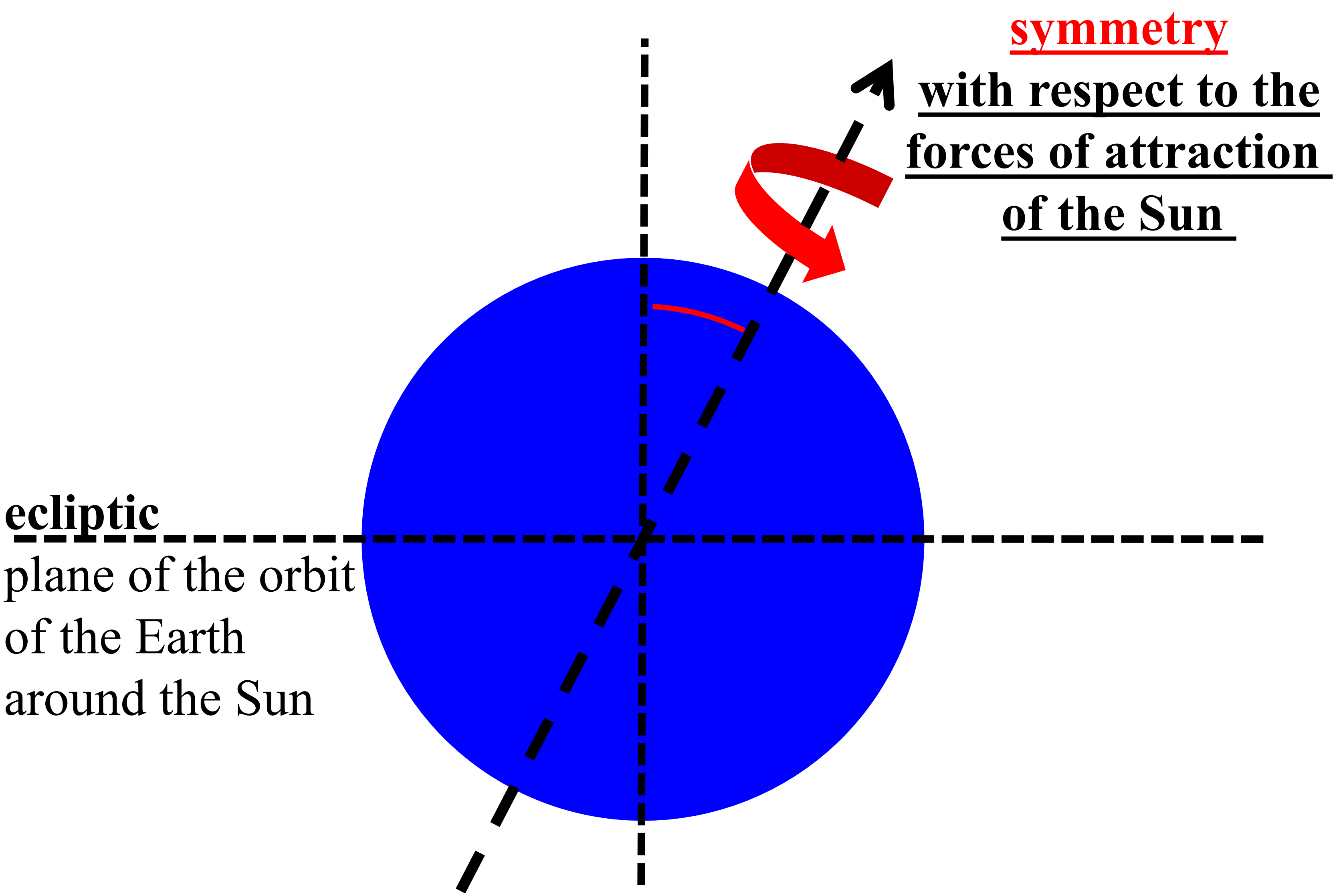


but

Rotation of the Earth



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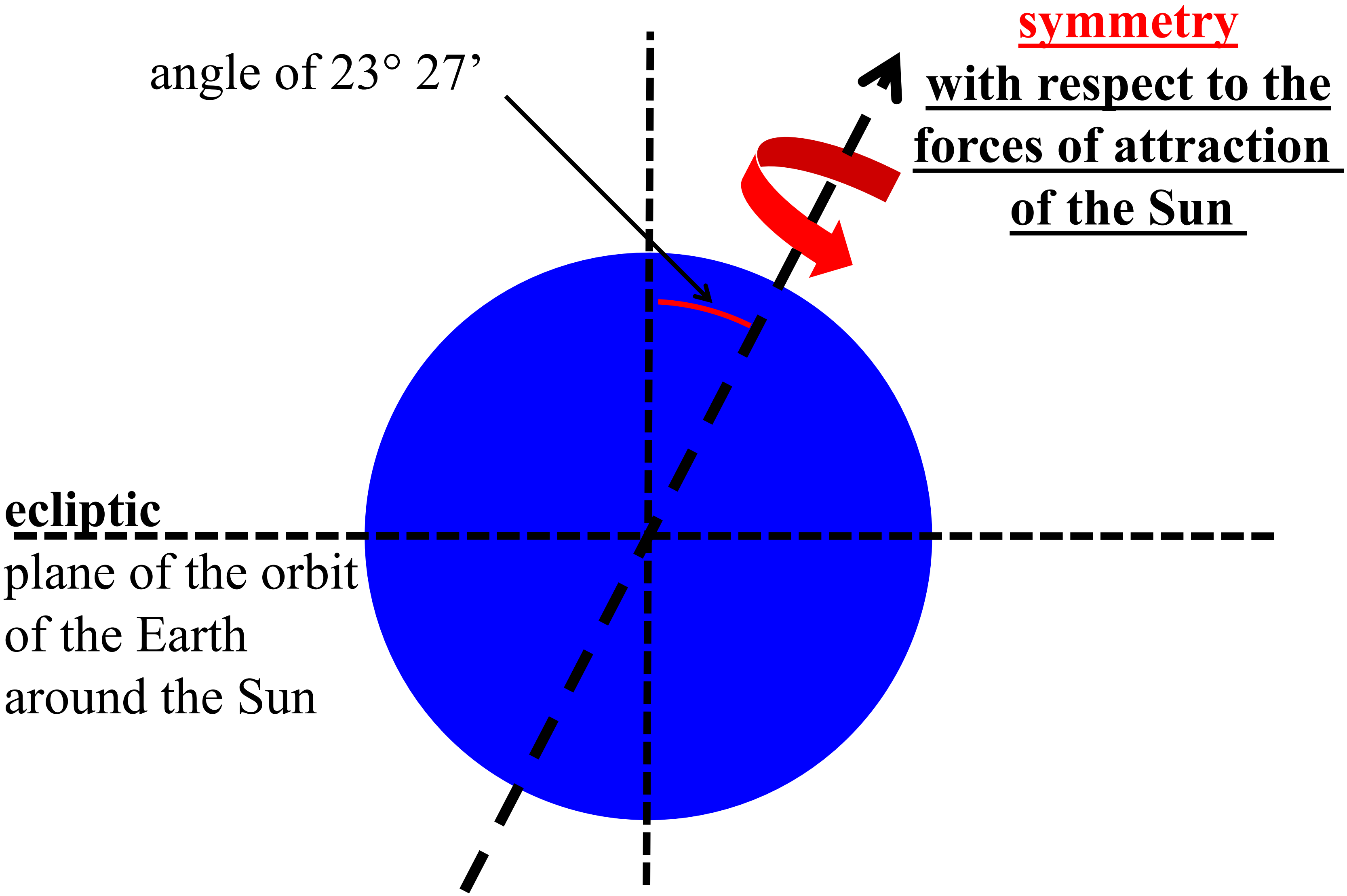

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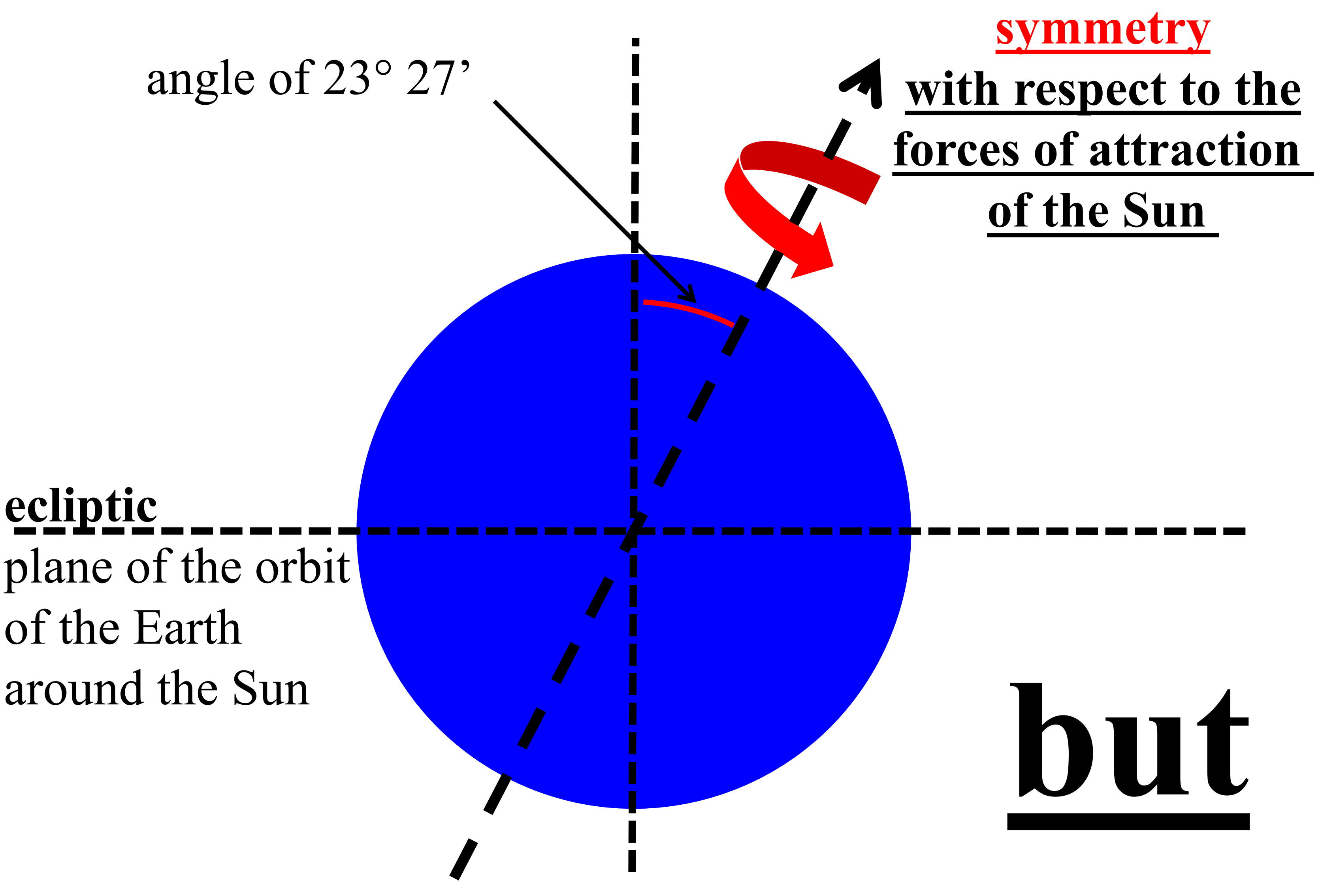

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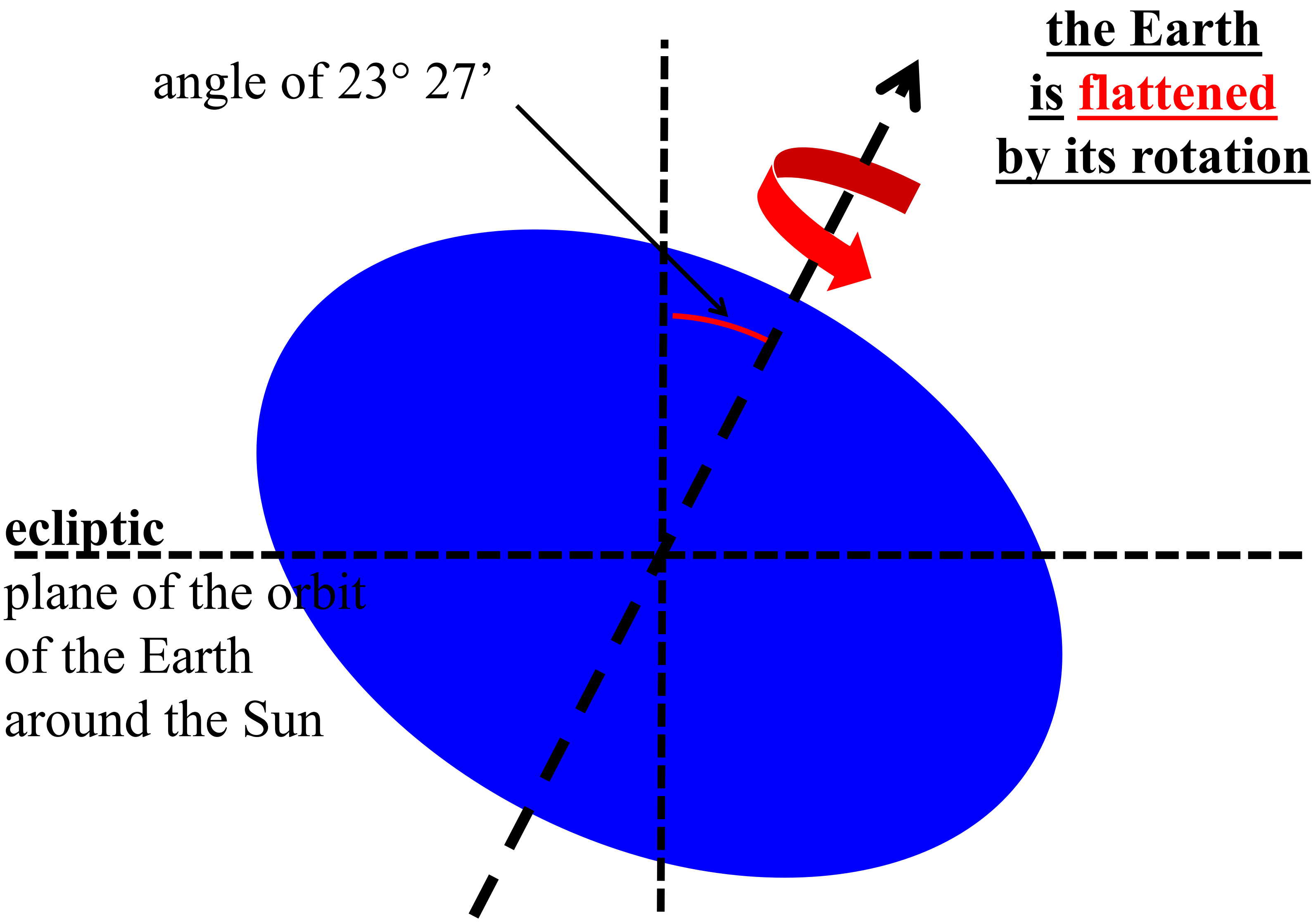

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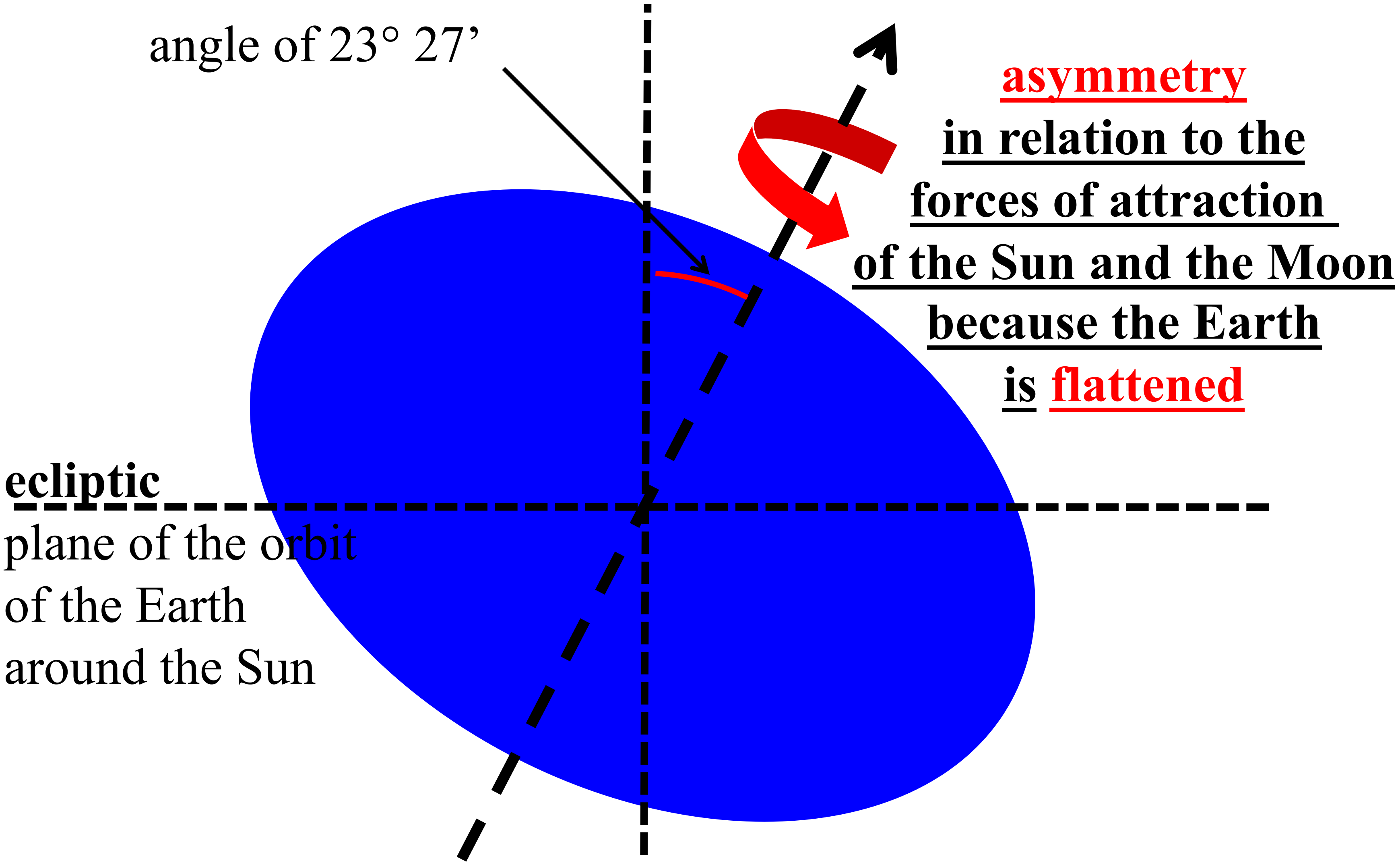

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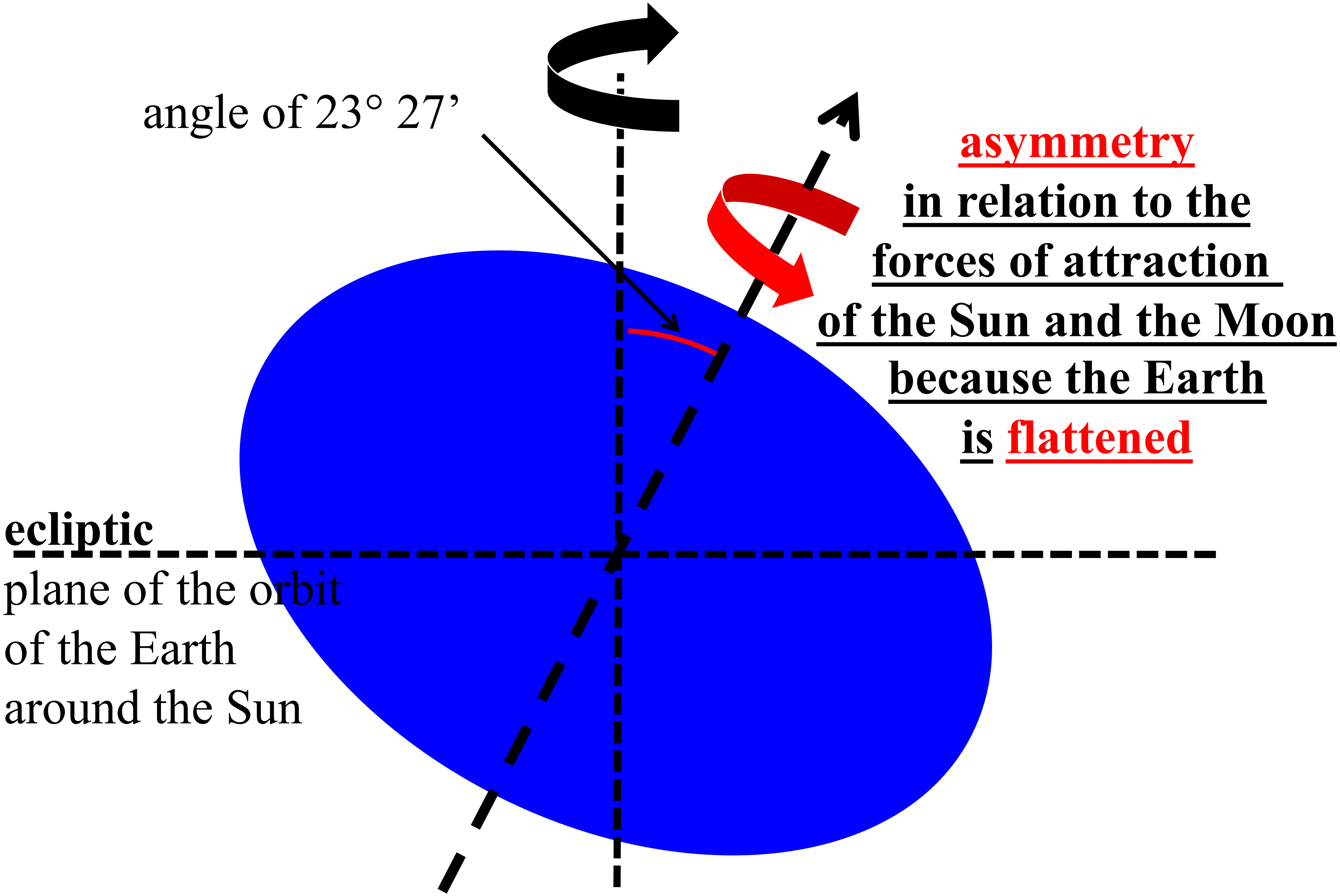
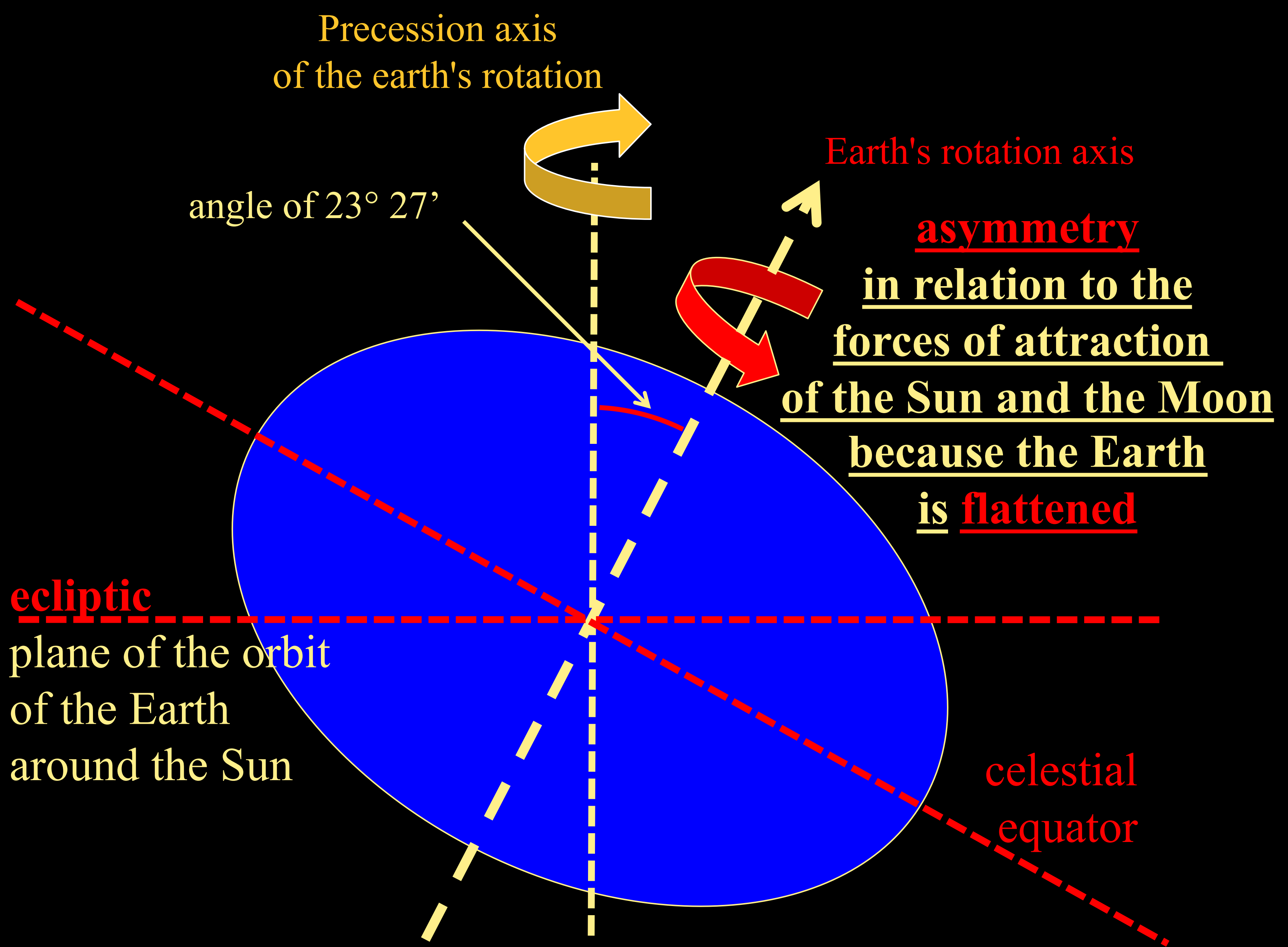
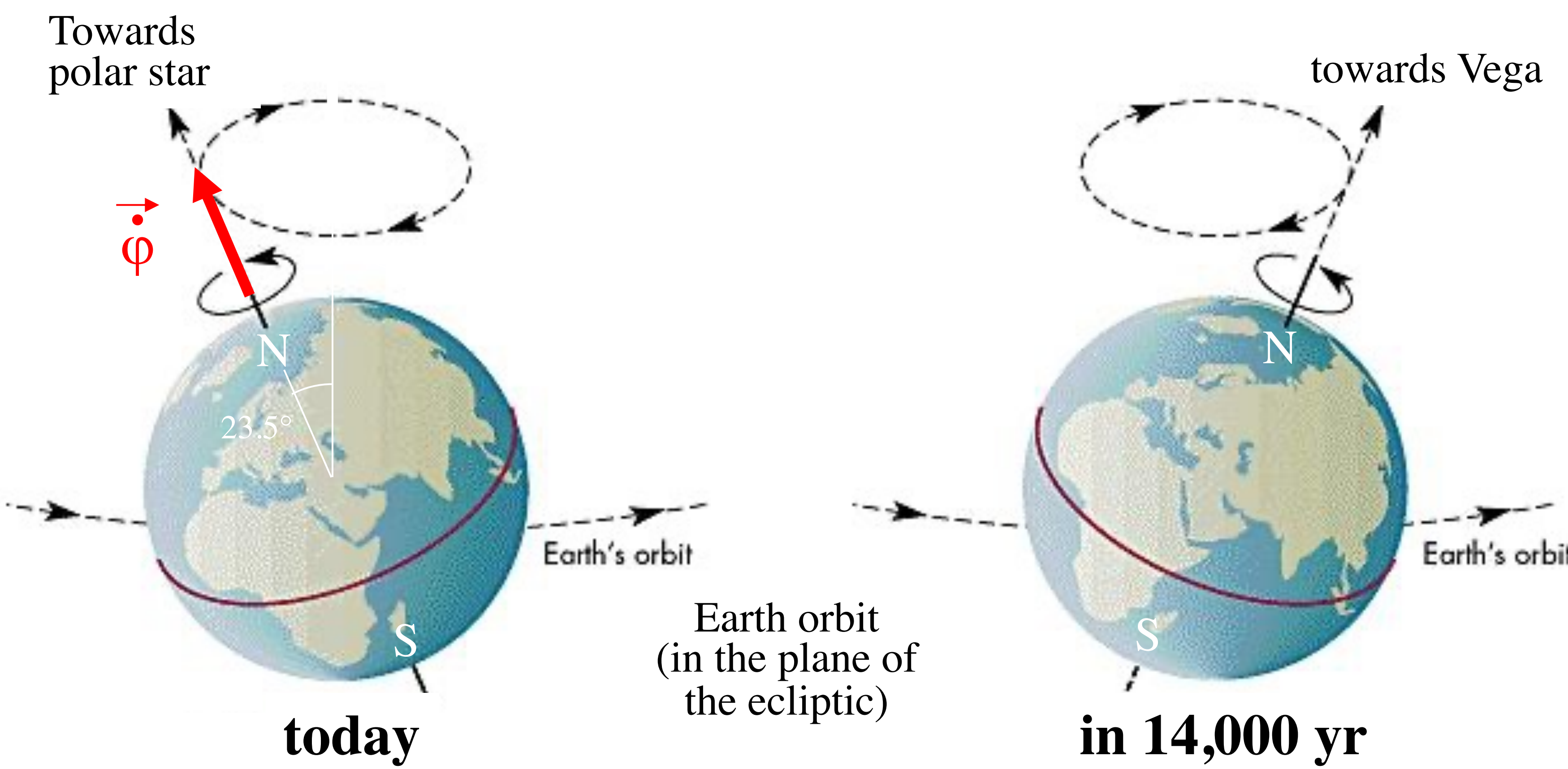



Precession axis
of the earth's rotation
Earth's rotation axis
angle of 23° 27’
asymmetry
in relation to the
forces of attraction
of the Sun and the Moon
because the Earth
is flattened
ecliptic
plane of the orbit
of the Earth
around the Sun
celestial
equator

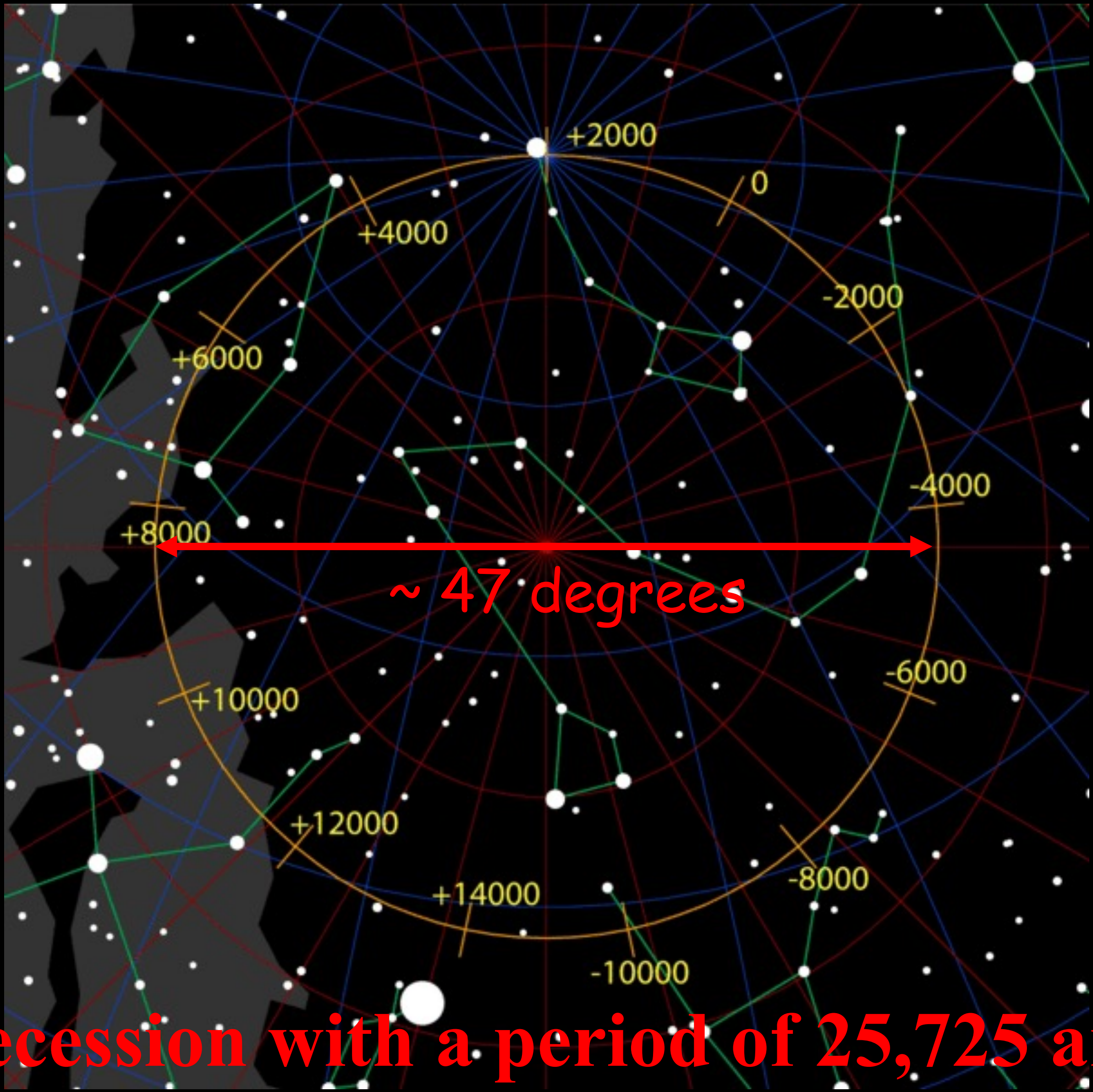
Precession of the equinoxes



precession with a period of 25,725 ans

Precession of the equinoxes

North pole



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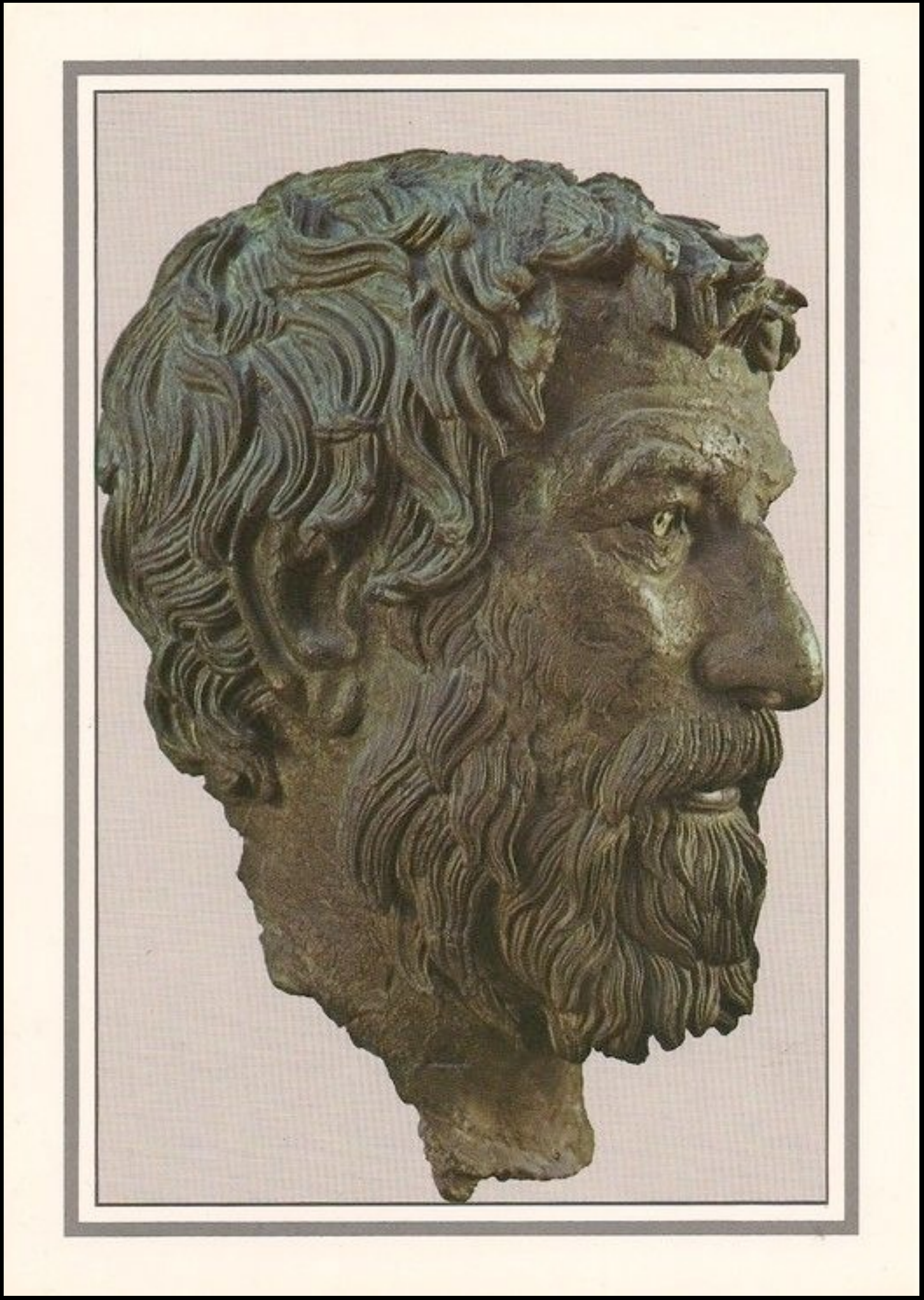
V

<u>The Antikythera mechanism</u>

This object, probably not unique, dates from about 100 BC


Antikythera


Antikythera

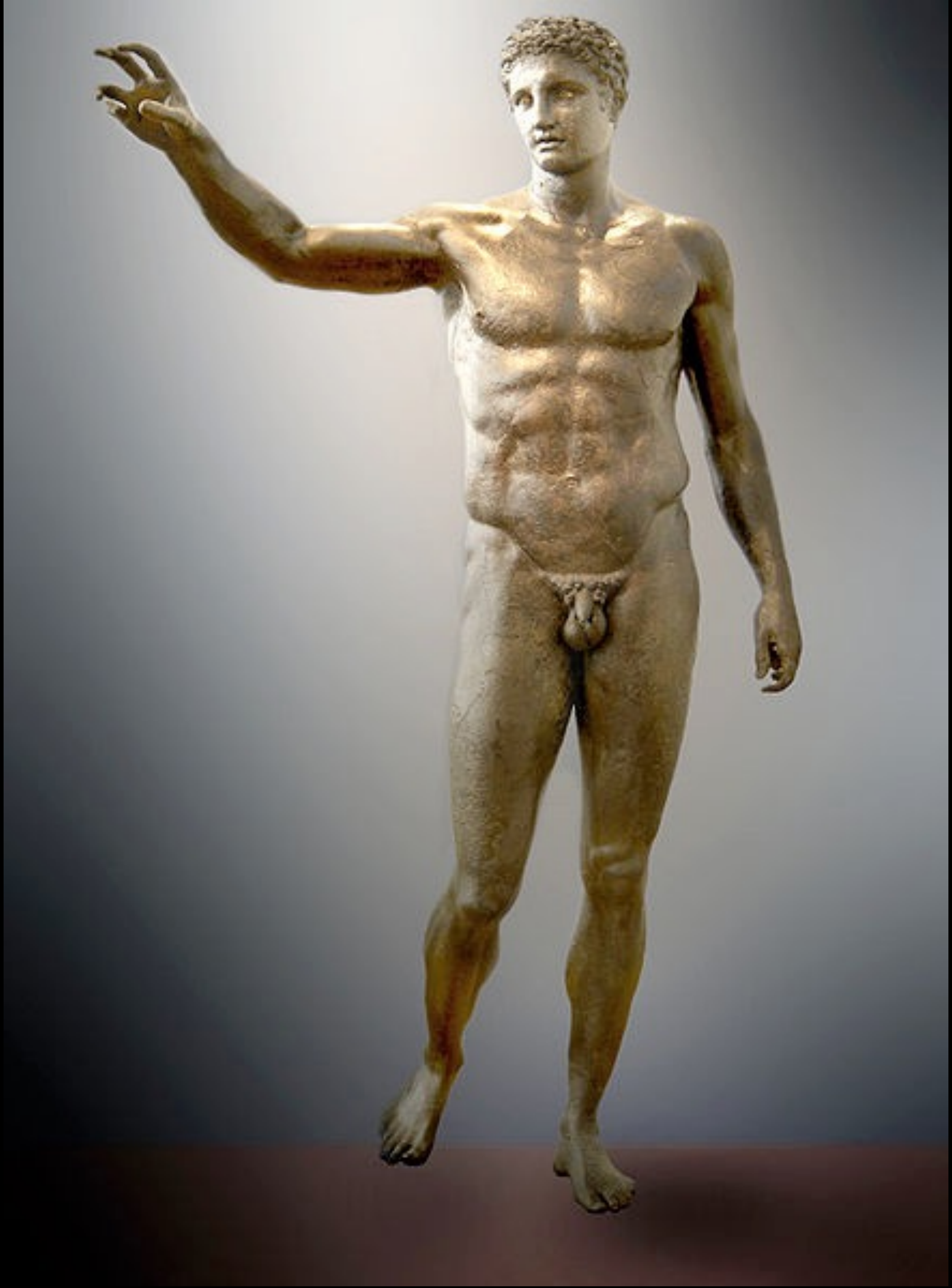


The philosopher of Antikythera

~ 450 B.C.
bronze attributed to Polyclète

Shortly before Easter 1900, Greek sponge fishermen, discover near Antikythera, by chance, an ancient wreck lying at a depth of 62 m. During the following year, many statues and statuettes in bronze and marble were brought to the surface.

National Archaeological Museum Athens



The Ephebe of Antikythera

~ 340 - 330 B.C., bronze, 1.94 m
attributed to Euphranor or Lysippus

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National Archaeological Museum Athens

The Antikythera mechanism

On May 17, 1902,
the archaeologist Valerios Stais realizes
that a piece of stone brought back from the site
contains inscriptions and encrusted gears.

An examination reveals that in fact of stone,
it is about a rusted mechanism,
of which there remain only
three large pieces and 82 smaller fragments remain.

Main fragment of the Antikythera mechanism

Reverse side of
the Antikythera mechanism

Realization, in 1902, of the presence of inscriptions and gears

Secondary fragment of the Antikythera mechanism.

Realization, in 1902, of the presence of inscriptions and gears

National Archaeological Museum Athens

Realization, in 1902, of the presence of inscriptions and gears

National Archaeological Museum Athens

The Antikythera mechanism

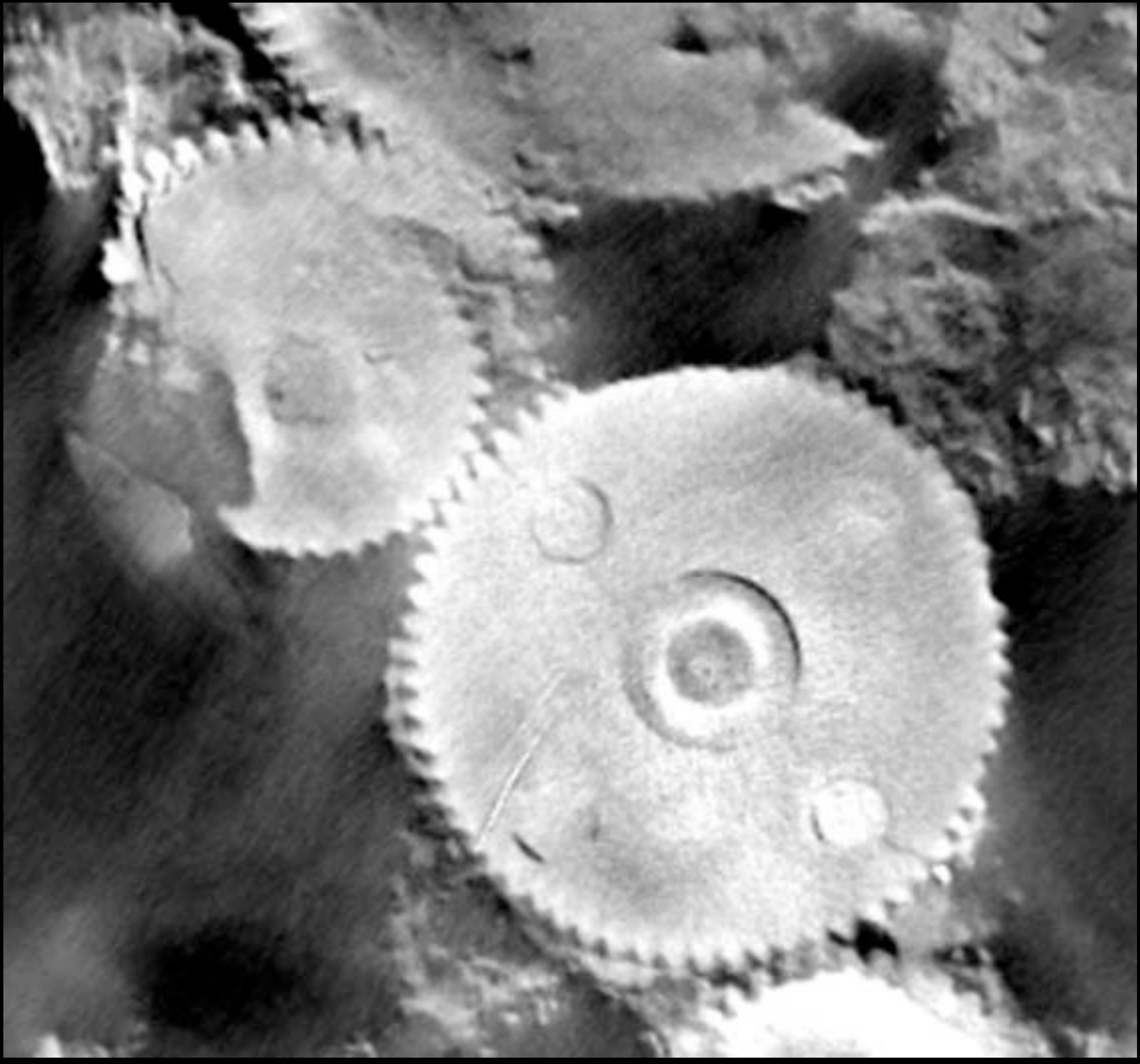
In the 1950s, Derek de Solla Price, a physicist and historian of science at Yale University, verified whether it was a calculator. Using X-rays, he studied the disk and revealed an extremely complex device, including, in addition to the twenty or so cogwheels already listed, axes, drums, moving hands and three dials engraved with astronomical inscriptions (~ 900 characters).

In 1959, he published a preliminary article in Scientific American.
In 1973, he recorded the results of all his research in a book entitled :
Gears From The Greeks: The Antikythera Mechanism,
A Calendar Computer from Circa 80 BC.

Radiography
X-ray
of the main
fragment of the
mechanism
of Antikythera

During the 1950s
Derek de Solla Price,
of Yale University,
identifies hundreds of
of inscriptions
and astronomical signs

Zoom in on the radiography of the main fragment of the Antikythera mechanism



Zoom in on the radiography of the main fragment of the Antikythera mechanism

skeleton watch

The Antikythera mechanism

In 2000, astronomer Mike Edmunds of Cardiff University and mathematician Tony Freeth used a scanner.

In 2005, Edmunds assembled a multidisciplinary team of a few astronomers, physicists, mathematicians, and paleographers.

2,000 new characters are deciphered (Price had deciphered "only" 900), including on the disks inside the machine. These texts are at the same time an instruction manual of the machine and a treatise of astronomy.

The machine is much more complex and subtle than initially assumed.

Reconstruction of the machine seen here from both sides.
33 cm high and 18 cm wide, the antique object had dials on two sides.

HUBLOT
GENEVE

Matthias Buttet of Hublot has recreated a miniature model of the Antikythera mechanism, the 2033-CH01 caliber, made of 495 components. Respecting the technologies of the time, he has miniaturized it and simply added a tourbillon watchmaking caliber to animate it.

The Antikythera mechanism

The mechanism consists of a complex system of 32 wheels and plates.

The mechanism is a solar and lunar calendar machine, capable of determining the time on the basis of the movements of the Sun and Moon, their relationship (prediction of eclipses) and the movements of the planets known at that time.

The mechanism was probably built by an ingenious mechanic from the school of Poseidonius in Rhodes. Cicero, who visited the island in 79/78 BC, reports that such devices were indeed designed by the Stoic philosopher Poseidonius of Apamea.

definitely

The machine is [definitely] much more complex and subtle than initially assumed.

2009
LUN
DEC

Weight = 1.100 kg
Thickness = 41,07 mm
Diam = 88,2mm

184 wheels, 332 screws, 415 pins, 429 mechanical elements, with a total of 1,728 components. In addition to the sophisticated calendar functions, including a tourbillon escapement and astronomical indications, there is also a unique calendar that displays the moving date of Easter.

Weight = 1.100 kg
Thickness = 41,07 mm
Diam = 88,2mm

in 2014, Sotheby’s Geneva sold it for $24 millions

184 wheels, 332 screws, 415 pins, 429 mechanical elements, with a total of 1,728 components. In addition to the sophisticated calendar functions, including a tourbillon escapement and astronomical indications, there is also a unique calendar that displays the moving date of Easter.

Similar objects in ancient literature

- Cicero mentions two similar machines. This would mean that this technology existed as early as the third century BC.
- The first, built by Archimedes, was found in Rome thanks to the general Marcus Claudius Marcellus. The Roman military brought it back after the siege of Syracuse in 212 BC, where the Greek scientist died. Marcellus had great respect for Archimedes (perhaps due to the defensive machinery used in the defense of Syracuse) and brought only this object back from the siege. His family kept the mechanism after his death and Cicero examined it 150 years later. He describes it as capable of reproducing the movements of the Sun, the Moon and five planets *Cicero, De Re Publica I, 14 (22)*.
- Cicero mentions a similar object built by his friend Poseidonius *Cicero, De Natura Deorum II, 34 (88)*.
- The two mechanisms mentioned were in Rome, fifty years after the date of the wreck of Antikythera. **It is therefore known that there were at least three such devices.**

Throughout antiquity

the victories of the arts

are numerous

Queen Nefertiti
~1350 B.C.
Pergamon Museum Berlin

Taming the grief of death

Funerary stele, 500 - 400 BC, National Museum of Archaeology, Athens

Male head
Roman civilization
Rome

Between the 1st century BC
and the 1st century AD

Barbier-Mueller Museum
Geneva

Throughout antiquity

the victories of science

<u>equal</u>

the victories of the arts

The scientific knowledge of our distant ancestors,
theoretical, observational, and technological
were much more advanced than previously suspected

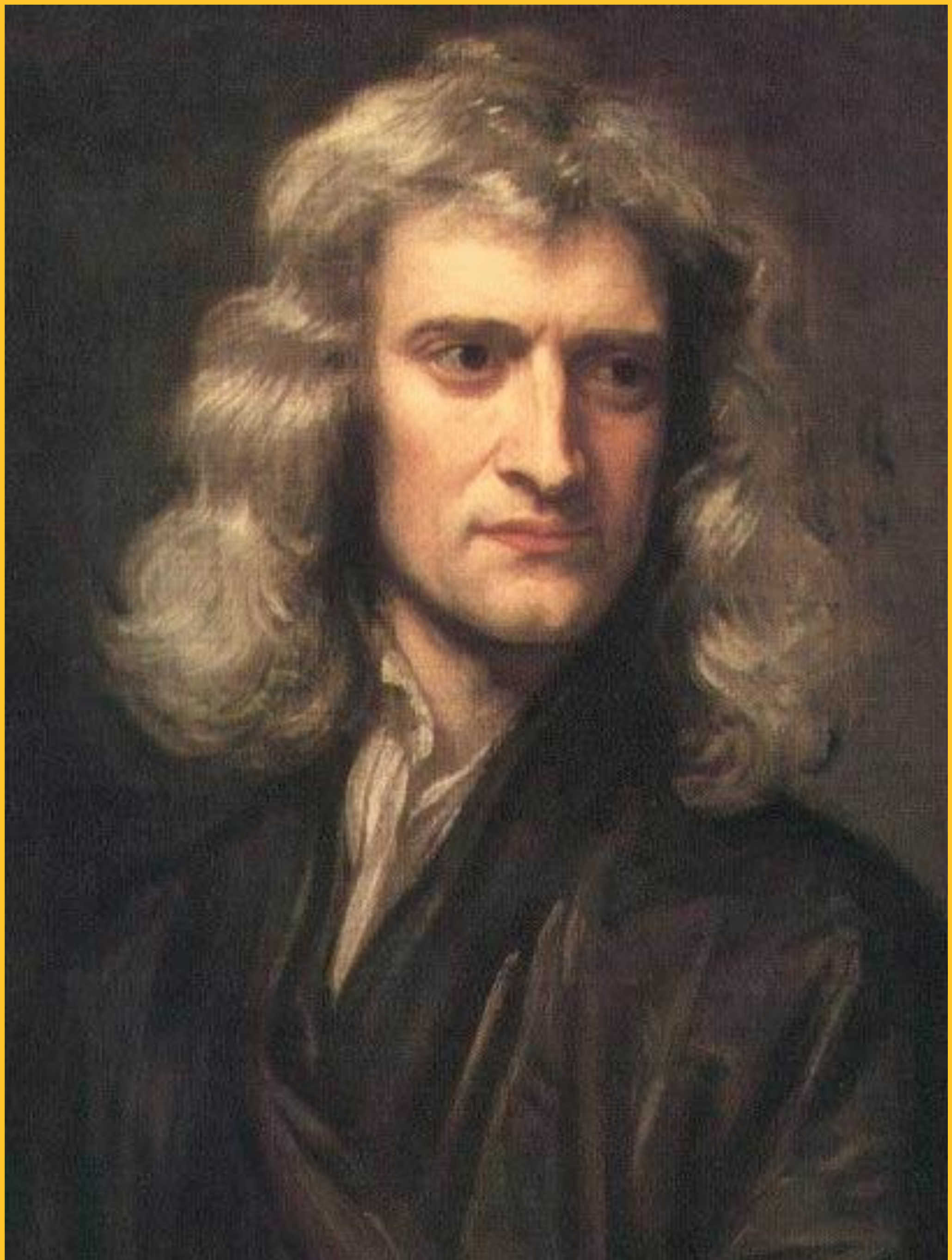
Throughout antiquity

the victories of science

<u>equal</u>

the victories of the arts

The scientific knowledge of our distant ancestors,
theoretical, observational, and technological
were much more advanced than previously suspected
<u>and then forgotten for the next 15 centuries</u>



Portrait d’Isaac Newton peint par Godfrey Kneller en 1689

Isaac Newton
1643-1727

He published in 1687 "Philosophiae naturalis principia mathematica

Mathematical principles of natural philosophy

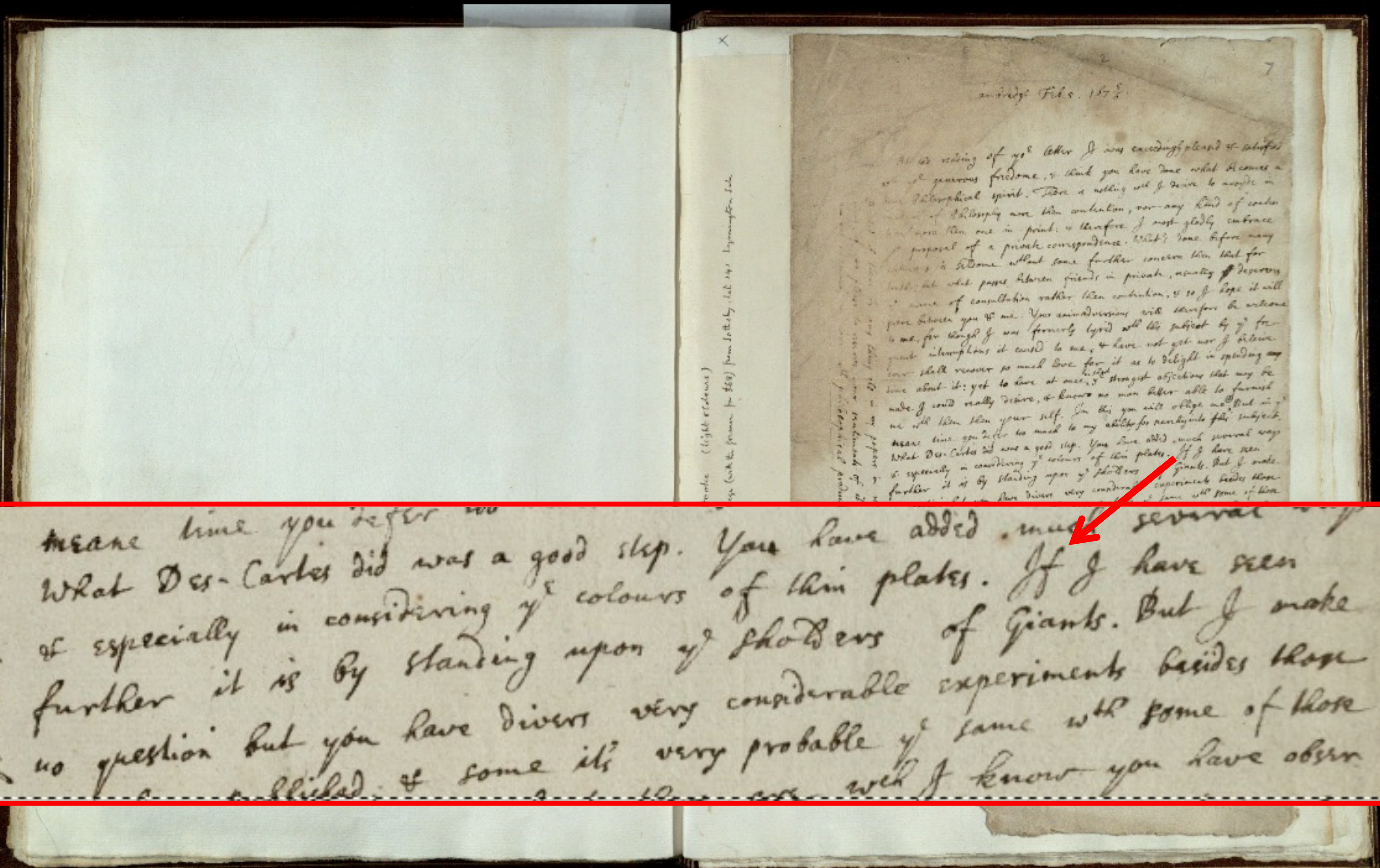
Three laws of Newton

Law of universal gravitation

$$F = -G\frac{mM}{r^2}$$

« If I have seen further it is by standing upon the shoulders of giants. »

from a letter written by Isaac Newton to Robert Hooke, 5 Feb. 1676



Among the giants Newton thinks of,
there are his immediate predecessors,
Copernicus, Kepler, Galileo

but also

the numerous geniuses of Greek antiquity,
Pythagoras, Heraclides, Eratosthenes, et al.