



the Scientific Revolution:

the Cosmos Mechanized

Ptolemaeus to Copernicus

One school in history of astronomy:

minor imperfections in the original Ptolemaic system were discovered through observations accumulated over time.

It was mistakenly believed that more levels of epicycles (circles within circles) were added to the models to match more accurately the observed planetary motions.

The multiplication of epicycles is believed to have led to a nearly unworkable system by the 16th century.

Copernicus created his heliocentric system in order to simplify the Ptolemaic astronomy of his day, thus succeeding in drastically reducing the number of circles.

With better observations additional epicycles and eccentrics were used to represent the newly observed phenomena till in the later Middle Ages the universe became a 'Sphere/With Centric and Eccentric scribbled o'er,/Cycle and Epicycle, Orb in Orb'

Alfonsine Tables

- Tables of solar, lunar and planetary positions wrt. fixed stars
- Called after Alfons X of Castile the Wise (el Sabio) (1221-1284)
- composed in 1252, in Toledo
- assembled by translators of Toledo
- based on observations and studies of Islamic scholars
- most popular astronomical tables for 300 years (incl. Copernicus)

Ptolemaeus to Copernicus

- As a measure of complexity:
 - the number of circles is given as 80 for Ptolemy,
 - versus a mere 34 for Copernicus
- *By this time each planet had been provided with from 40 to 60 epicycles to represent after a fashion its complex movement among the stars. Amazed at the difficulty of the project, Alfonso is credited with the remark that had he been present at the Creation he might have given excellent advice.*

15th century CE

Nicolas de Cusa, 1401-1464

De Docta Ignorantia (1440)

- first European work stating that other stars would be other worlds:

“Life, as it exists on Earth in the form of men, animals and plants, is to be found, let us suppose in a high form in the solar and stellar regions. Rather than think that so many stars and parts of the heavens are uninhabited and that this earth of ours alone is peopled we will suppose that in every region there are inhabitants, differing in nature by rank and all owing their origin to God ...”,

- work explicitly states a “Cosmological Principle”

“The universe has no circumference, for if it had a center and a circumference there would be some and some thing beyond the world, suppositions which are wholly lacking in truth. Since, therefore, it is impossible that the universe should be enclosed within a corporeal center and corporeal boundary, it is not within our power to understand the universe, whose center and circumference are God. ”

1584

Giordano Bruno, 1548-1600

De l'Infinito, Universo e Mondi (1584)

”Innumerable celestial bodies, stars, globes, suns and earths may be sensibly perceived therein by us and an infinite number of them may be inferred by our own reason.”

The Scientific Revolution

- 1543

Nicolaus Copernicus

- publishes heliocentric universe in *De Revolutionibus Orbium Coelestium*
- implicit introduction Copernican principle: Earth/Sun is not special

- 1576

Thomas Digges (1546-1595)

A Prognostication everlasting (1576)

First expose – in appendix - of Copernican heliocentric model of the Universe in English language.

Digges states – going further than Copernicus - that the Universe is infinite, and contains infinitely many stars.

“Digges’ original contribution to cosmology consisted of dismantling the starry sphere throughout endless space

... Digges pioneered ... the idea of an unlimited sphere filled with the mingling rays of countless stars.” (E. Harrison)

- 1572

Tycho Brahe

Tycho’s supernova

Ultimate evidence and challenge against the Aristotelian view of a serene unchanging Universe.

- 1609-1632

Galileo Galilei

by means of (telescopic) observations, proves the validity of the heliocentric Universe.

- 1610 , **Siderius Nuncius**

first published work on observations made by telescope

- 1632, **Dialogue Concerning the Two Chief World Systems**

Debate between Salviati, exposing the Copernican heliocentric Universe and Simplicio, defending the old traditional Ptolemaic geocentric model.

The Scientific Revolution:

Mechanization of the Universe

- **1609/1619**

Johannes Kepler

- the 3 Kepler laws, describing the elliptical orbits of the planets around the Sun

- **1687**

Isaac Newton

Philosophiae Naturalis Principia Mathematica

- discovers Gravitational Force as agent behind cosmic motions

- publishes his Principia (*Philosophiae Naturalis Principia Mathematica*), which establishes the natural laws of motion and gravity (the latter only to be replaced by Einstein's theory of GR)

- **1576**

Thomas Digges

Following his statement of an infinite universe, filled with an infinite number of stars, Digges is the first to identify the “*dark night sky paradox*”.

- **1610**

Johannes Kepler

Letter to Galilei (1610)

Puzzled by the night’s darkness: in 1610 he wrote in a letter to Galileo that in an infinite universe filled with stars, “the whole celestial vault would be as luminous as the Sun.” Kepler’s proposed solution to the paradox is that the universe has to be finite(this fell in line with Kepler’s religious beliefs that the entire universe was “for man’s sake.”)

- **1686**

Bernard le Bovier de Fontenelle (1657-1757)

Entretiens sur la pluralité des mondes/Conversations on the Plurality of the Worlds (1686)

Book describes new Copernican cosmology, and speculates on the plurality of worlds.

In a series of conversations between a philosopher and a marquise, who walk in the latter's garden at night and gaze at stars, the philosopher explains the heliocentric model and also muses on the possibility of extraterrestrial life.

- **1755**

Immanuel Kant

- asserts that nebulae are really galaxies separate from and outside from the Milky Way,
- calling these Island Universes



Nikolaus Copernicus
(1473-1543)

Nicolaus Copernicus

Birthhouse
Copernicus,
Torun

- 1473 – born in Torun (Poland)
- 1491-1495 – study Univ. Krakow
- 1496-1501 – 3 years Univ. Bologna – canon law
- 1503- – Warmia
- 1514 – Frombork

Languages: Latin , German

1514 - Commentariolus

Nicolai Copernici de hypothesibus motuum coelestium a se constitutis commentariolus

- + theoretical treatise on heliocentric mechanism
- + 40 pages, 7 basic assumptions

Tower (living) Copernicus, Frombork



Frombork Cathedral

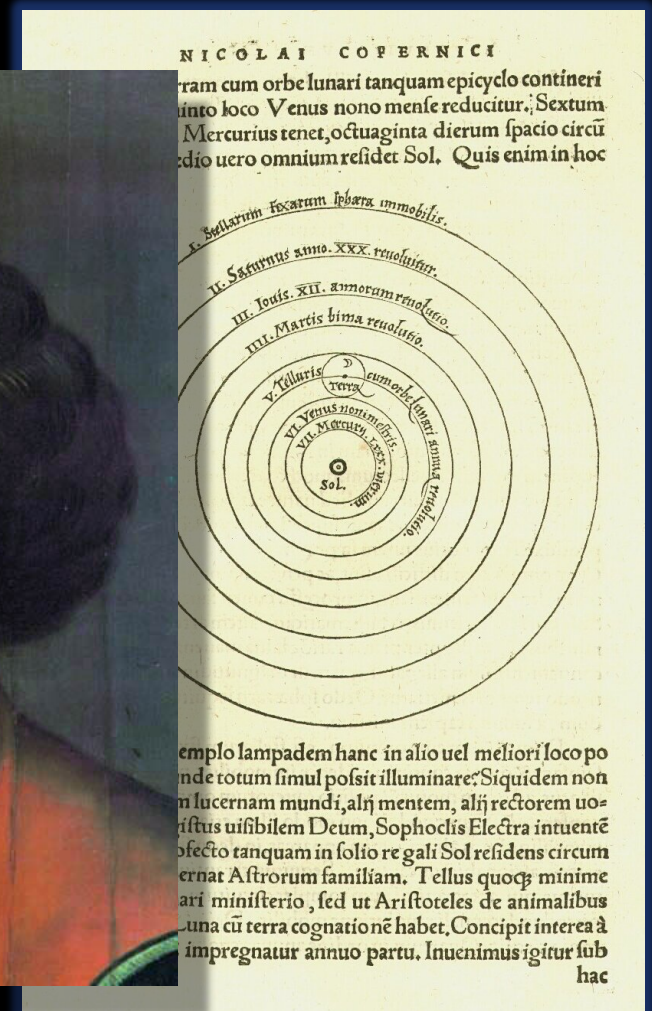
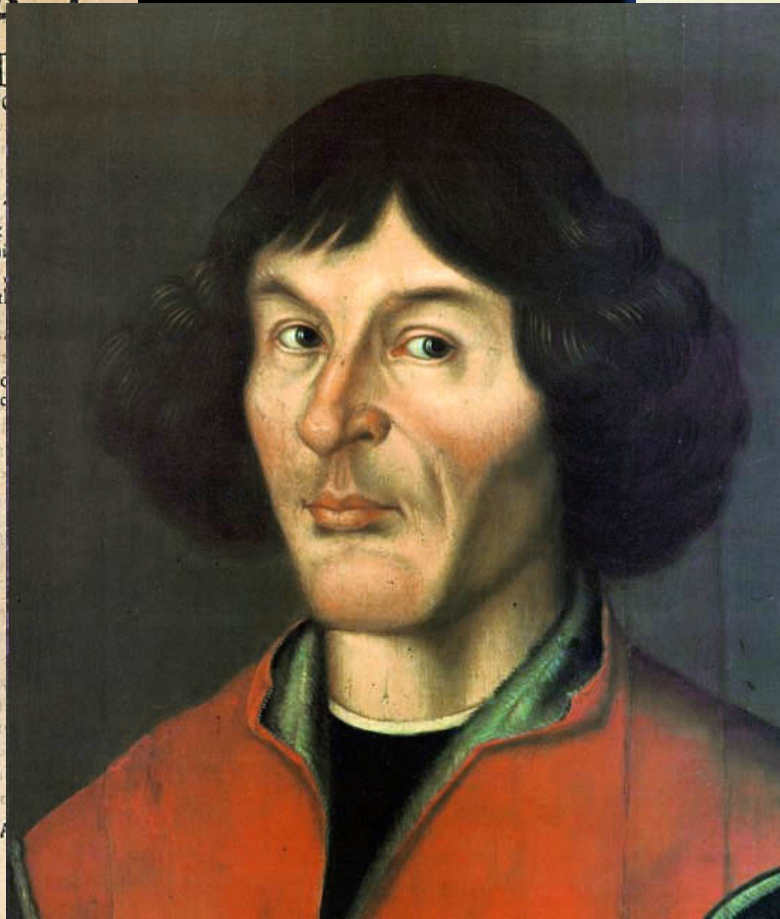
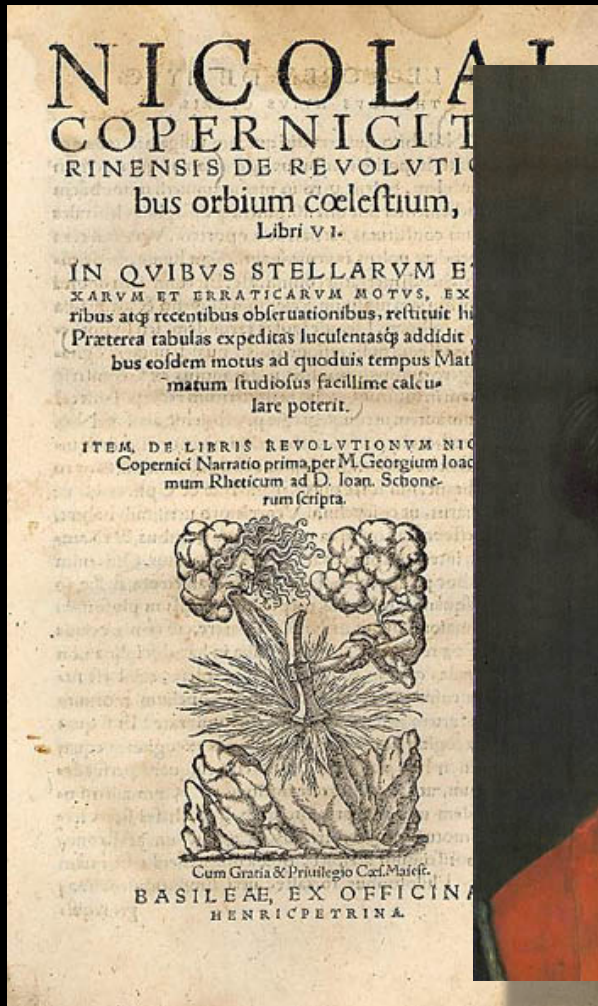


Commentariolus



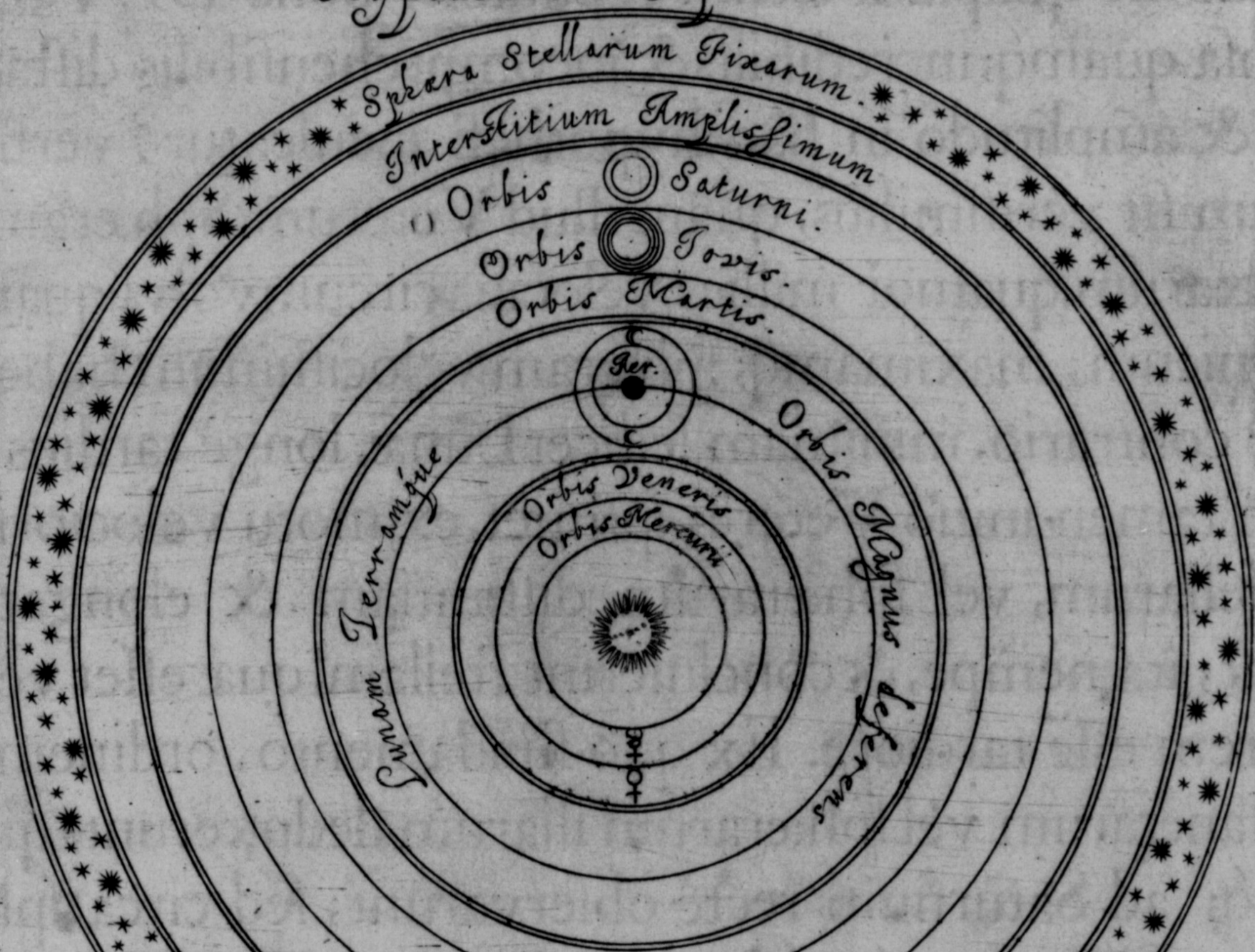
1. There is no one center of all the celestial circles or spheres.
2. The center of the earth is not the center of the universe, but only of gravity and of the lunar sphere.
3. All the spheres revolve about the sun as their midpoint, and therefore the sun is the center of the universe.
4. The ratio of the earth's distance from the sun to the height of the firmament (outermost celestial sphere containing the stars) is so much smaller than the ratio of the earth's radius to its distance from the sun that the distance from the earth to the sun is imperceptible in comparison with the height of the firmament.
5. Whatever motion appears in the firmament arises not from any motion of the firmament, but from the earth's motion. The earth together with its circumjacent elements performs a complete rotation on its fixed poles in a daily motion, while the firmament and highest heaven abide unchanged.
6. What appear to us as motions of the sun arise not from its motion but from the motion of the earth and our sphere, with which we revolve about the sun like any other planet. The earth has, then, more than one motion.
7. The apparent retrograde and direct motion of the planets arises not from their motion but from the earth's. The motion of the earth alone, therefore, suffices to explain so many apparent inequalities in the heavens.

De Revolutionibus



Orbium Coelestium

Hypothecis Copernicana.



Nicolaus Copernicus

1543 – publication
De Revolutionibus Orbium Coelestium
(On the Revolution of the Celestial Spheres)

1514- **Commentariolus (Little Commentary)**
1532 – finished work on Revolutionibus

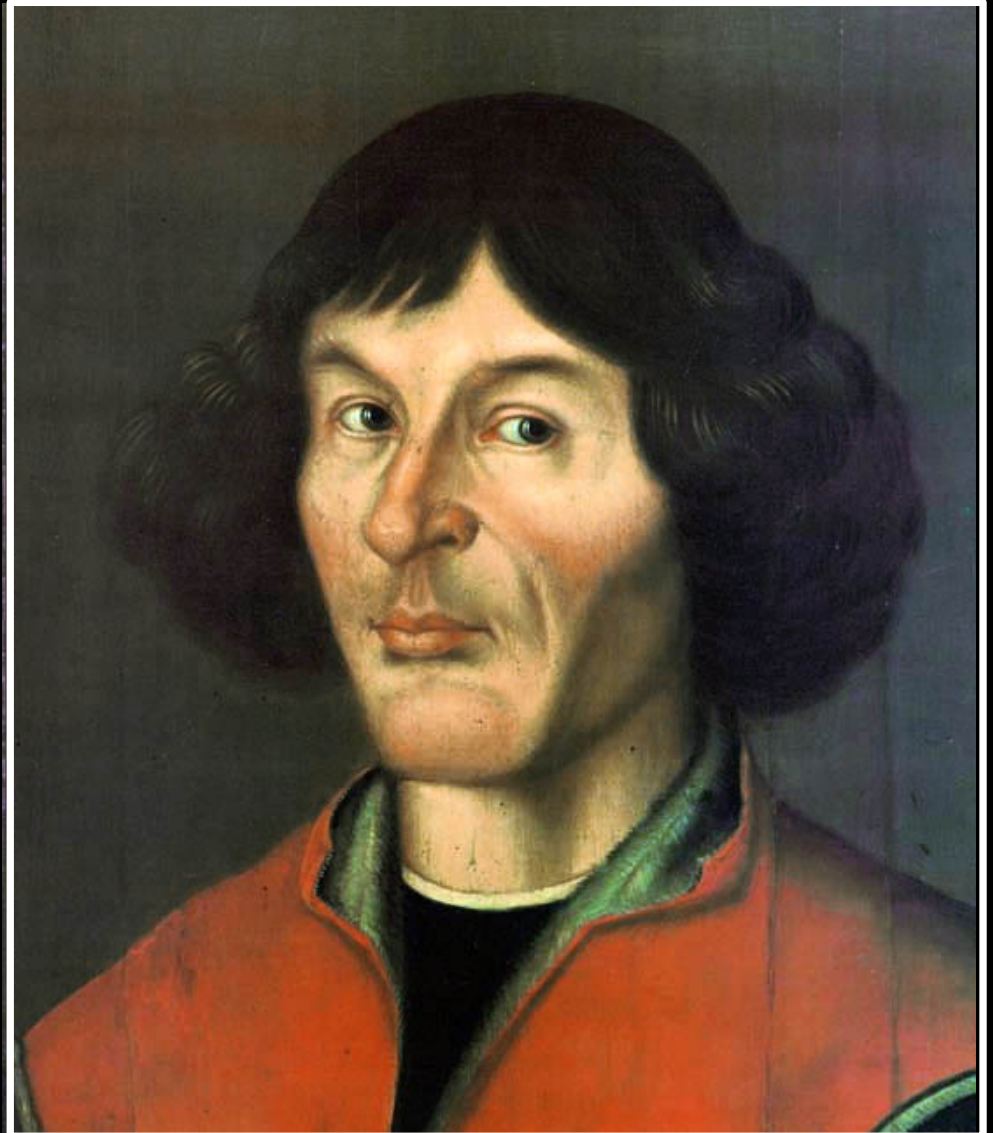
1543 - publication pushed and processed
by George Joachim Rheticus
(mathematician Wittenberg)

- printed by
Johannes Petreius, Nuremburg

May 24, 1543 - death Copernicus
- legend: presentation last
pages printed Revolutionibus

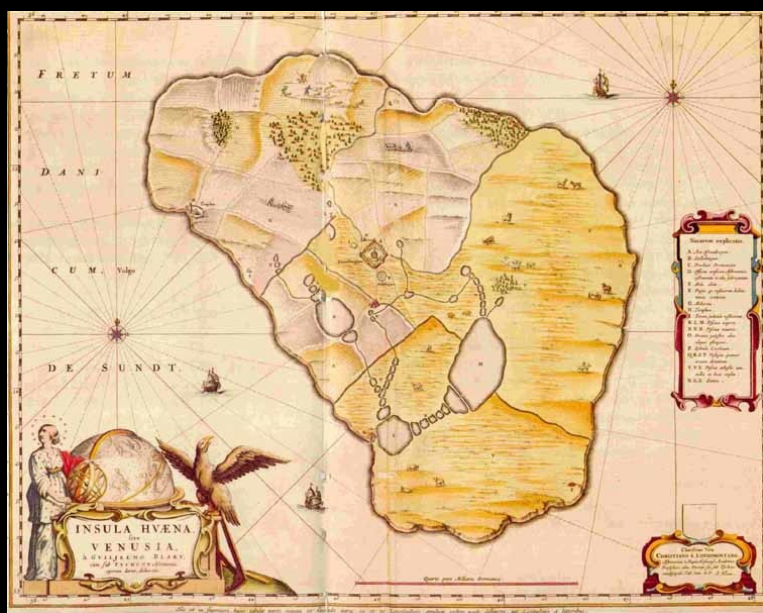
Note:

Copernicus cited Aristarchus of Samos in an early (unpublished) manuscript of De Revolutionibus (which still survives), though he removed the reference from his final published manuscript.





Nikolaus Copernicus
(1473-1543)



Tycho Brahe
(1546-1601)

Observatory Uraniborg
on island Hven (nowadays between Sweden-Denmark)

Tycho Brahe (1546-1601)

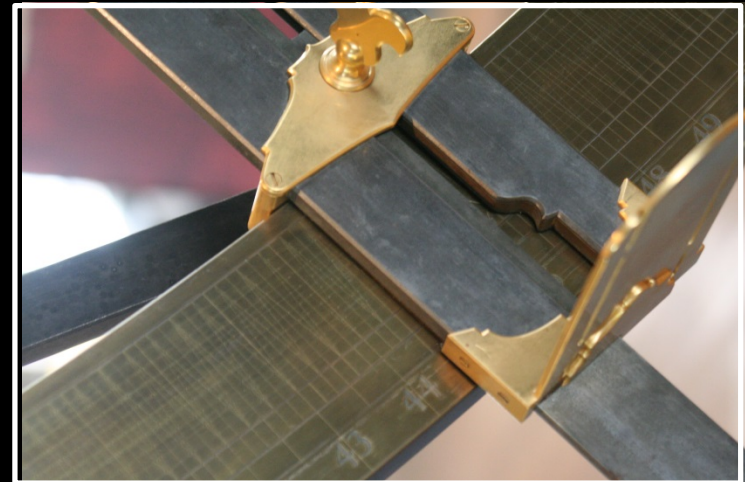


- Danish nobleman
- astronomer, astrologer, alchemist
- Observatory Uraniborg on island Hven
- Hven was his fiefdom
- entire island Hven devoted to exploitation for observatory
- Brahe famous for high
+ accuracy
+ quantity
astronomical and planetary observations
- before telescope
- Key to Scientific Revolution



Quadrant

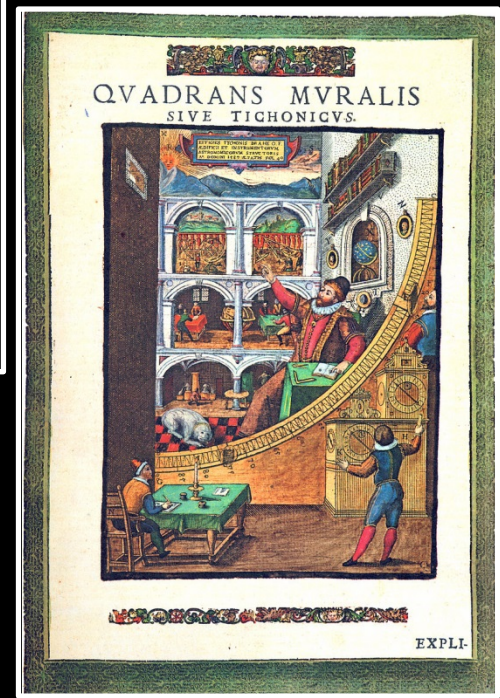
Achieved Accuracy
~1'-2'



Uraniborg

Uraniborg

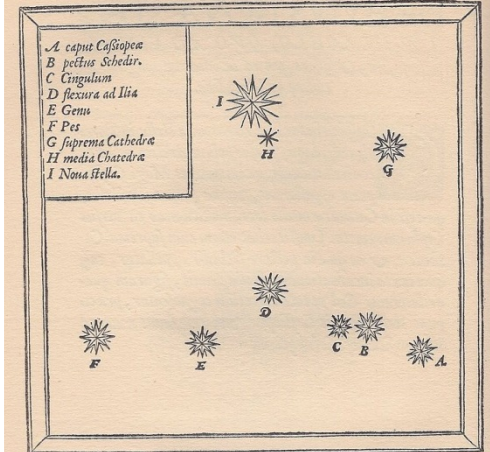
- Island Hven given to Tycho by Danish King Frederik II
- 1576:
building of Uraniborg
- 1581:
building of annex,
Stjerneborg
- cellar Uraniborg:
alchemy experiments
- 1576-1597
~ 100 students & assistants
- research community in
Research Center &
Institution of Education



De Nova Stella (1572)

End of the Aristoteleian cosmological view that
- the world beyond the Moon is eternally unchanging

- 11 Nov. 1572
Tycho observed
a new star
- Constellation Cassiopeia
- At hindsight it has
been 1 of the 5 visible
supernovae that have
exploded in the Galaxy
over the past 1000 years
- distance: 7500 lightyears
- Tycho published this
in De Nova Stella

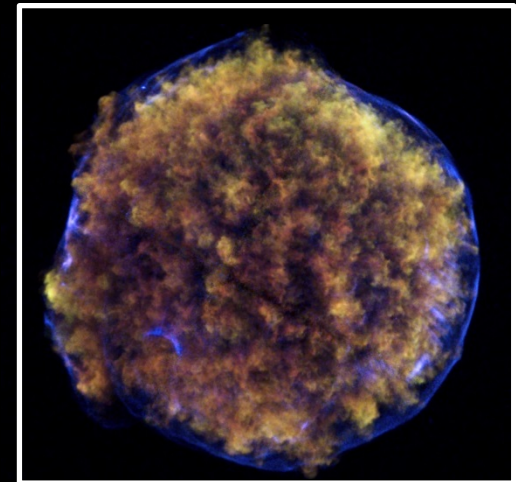


*Distantiam verò huius stelle à fixis aliquibus
in hac Cassiopeie constellatione, exquisito instrumento,
& omnium minorum capacj, aliquoties obseruavi. In-
ueni autem eam distare ab ea, quæ est in pectore, Schedar
appellata B, 7. partibus & 55. minutis: à superiori
verò*

Supernova remnant

SN₁₅₇₂
Tycho's SNR (1572)

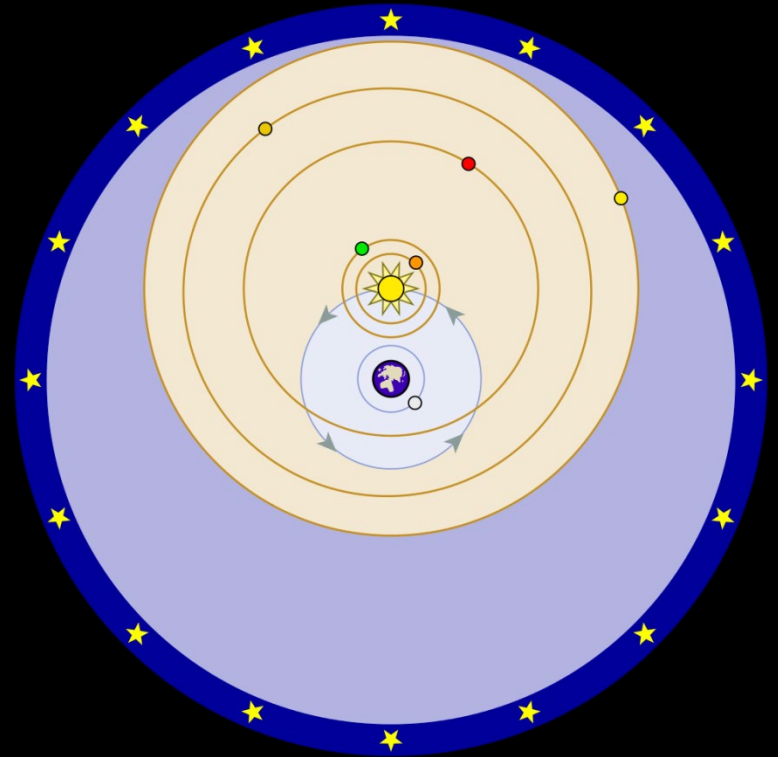
Exploding star



Geo-Heliocentric Model

Tycho's Geo-Heliocentric Model:

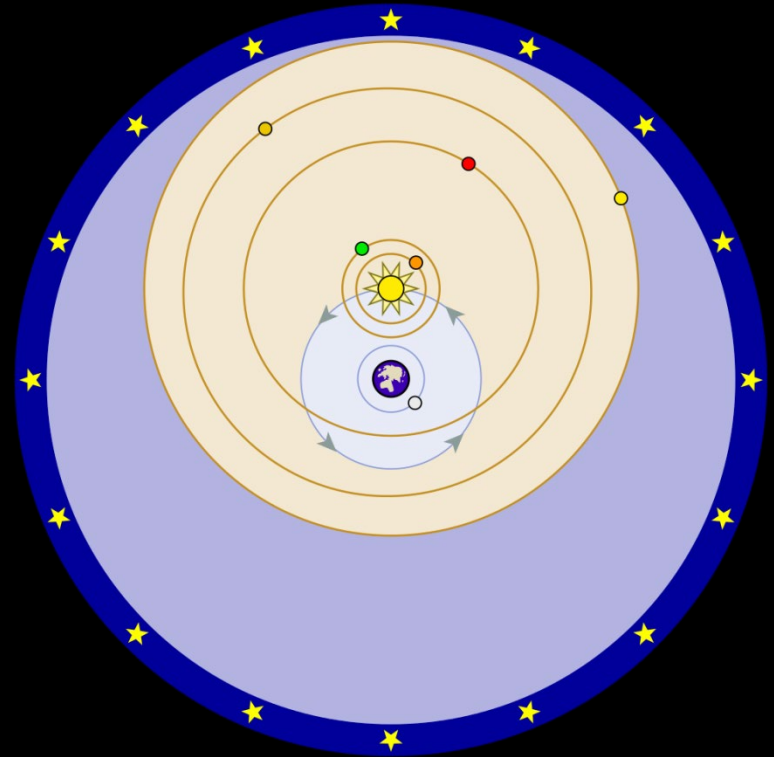
- Sun circles the Earth
- Planets circle the Sun



Geo-Heliocentric Model

Tycho did not accept the heliocentric view of Copernicus:

- Observational data in 16th century were not good enough to prove it.
- No stellar parallax could be measured: would imply stars to be so distant they would be larger than Sun
- Completely eliminated the ancient (Aristotelean) idea of heavenly spheres
- "Earth is a lazy body":



"such a fast motion could not belong to the earth, a body very heavy and dense and opaque, but rather belongs to the sky itself whose form and subtle and constant matter are better suited to a perpetual motion, however fast"



Brahe & Kepler

Arguably, the most significant step in Tycho's career:

- move to the German imperial court in Prague (following tensions with new Danish king Christian IV)
- meeting up with (young) Johannes Kepler

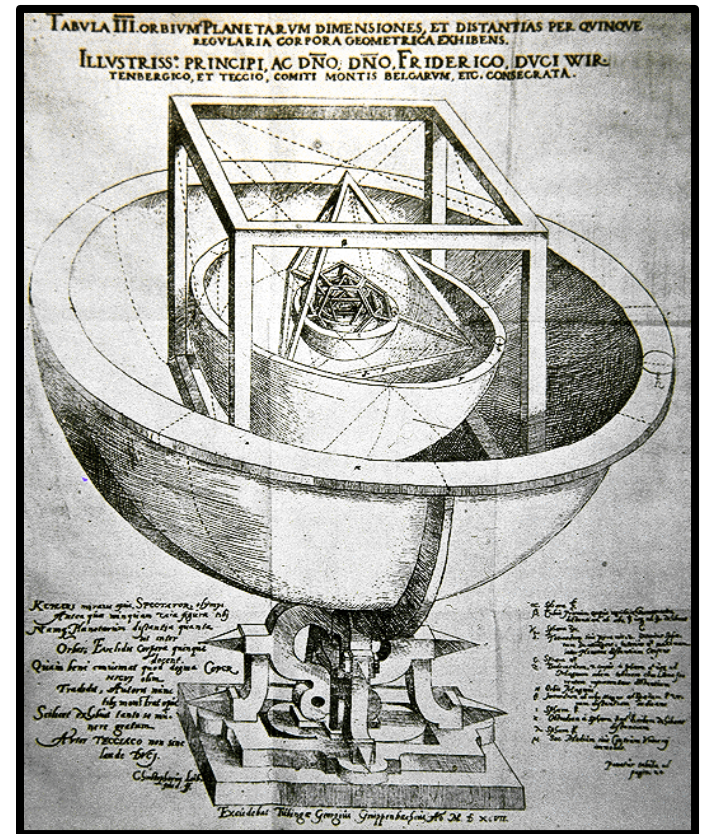


The analytical genius of Kepler gained access to the state of the art accurate observations of Tycho Brahe, opening up the path towards unravelling the laws of motion in the solar system.



Johannes Kepler

(1571-1630)



Mysterium Cosmographicum

Johannes Kepler

(1571-1630)



Johannes Kepler may be considered as THE key genius of the European Scientific Revolution

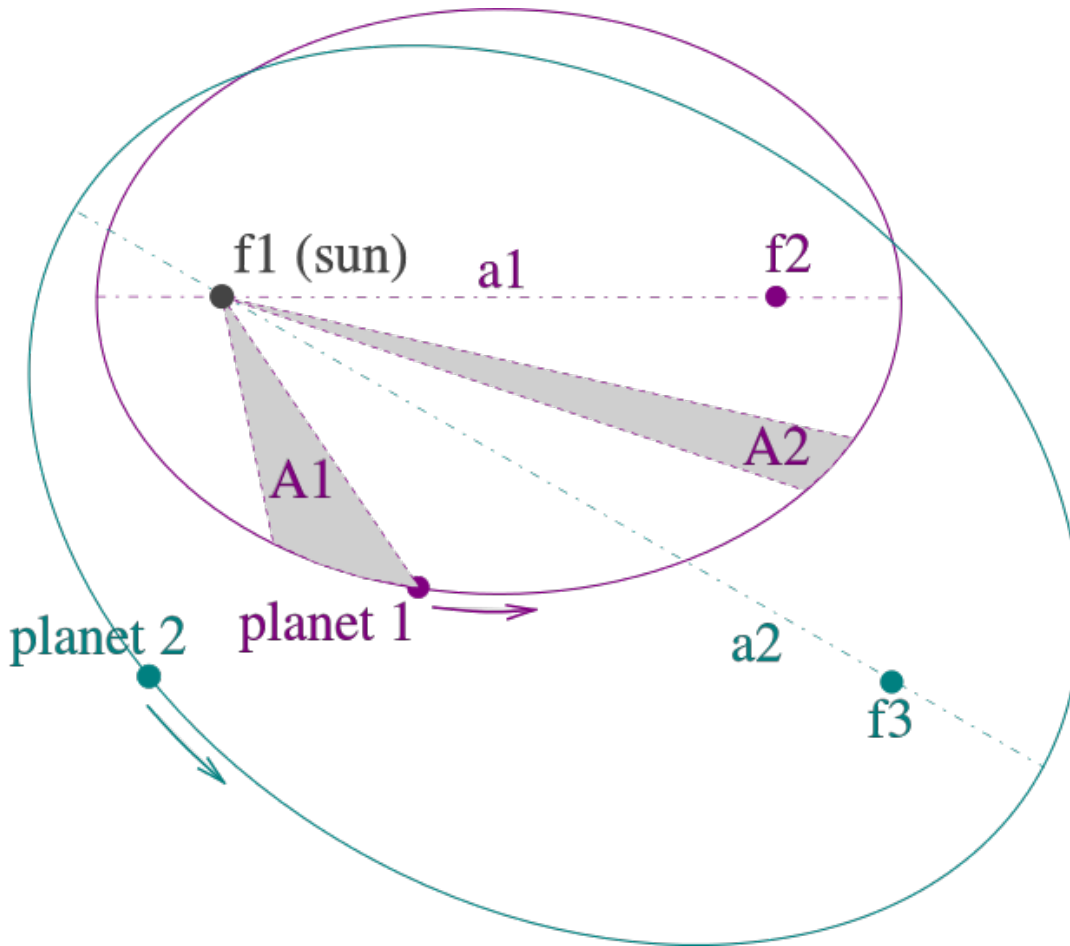
In his 3 books he established an entirely new, revolutionary, look on the workings of the Universe, **the cosmology of Kepler**,

- **Mysterium Cosmographicum** 1596
- **Astronomica Nova** 1609
- **Harmonices Mundi** 1619

His main goal was to reveal the **divine laws and plan** dictating the motion of the planets according to Copernicus heliocentric system,

- establishing that the orbits of the planets are **elliptical** and formulating the **3 laws of Kepler for planetary motion**
- strongly leaning on mathematics as the language of nature, much in line with **Pythagoras** and **Plato**.

Kepler Laws



Kepler laws of planetary motion

1. The orbit of a planet is an **ellipse** with the Sun at **one focus**.
2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.

(planets do not move with uniform speed along their orbit).

3. Relation Orbital Time - Size orbit:

The **square of the orbital period** of a planet is proportional to the **cube of the orbit's semi-major axis**

$$T^2/a^3 = \text{const.}$$



Johannes Kepler (1571-1630)

Fields:

astronomy, astrology, mathematics,
natural philosophy

Kepler described his
new astronomy as "celestial physics":

his entire astronomical career devote to
elaboration of the following questions:

- why are there six planets (then known) ?
- why are they spaced around the Sun as they are.
- why do they move as they do ?



Johannes Kepler (1571-1630)

Fields:

astronomy, astrology, mathematics,
natural philosophy

Kepler described his
new astronomy as "celestial physics",

as

"an excursion into Aristotle's *Metaphysics*",
and as

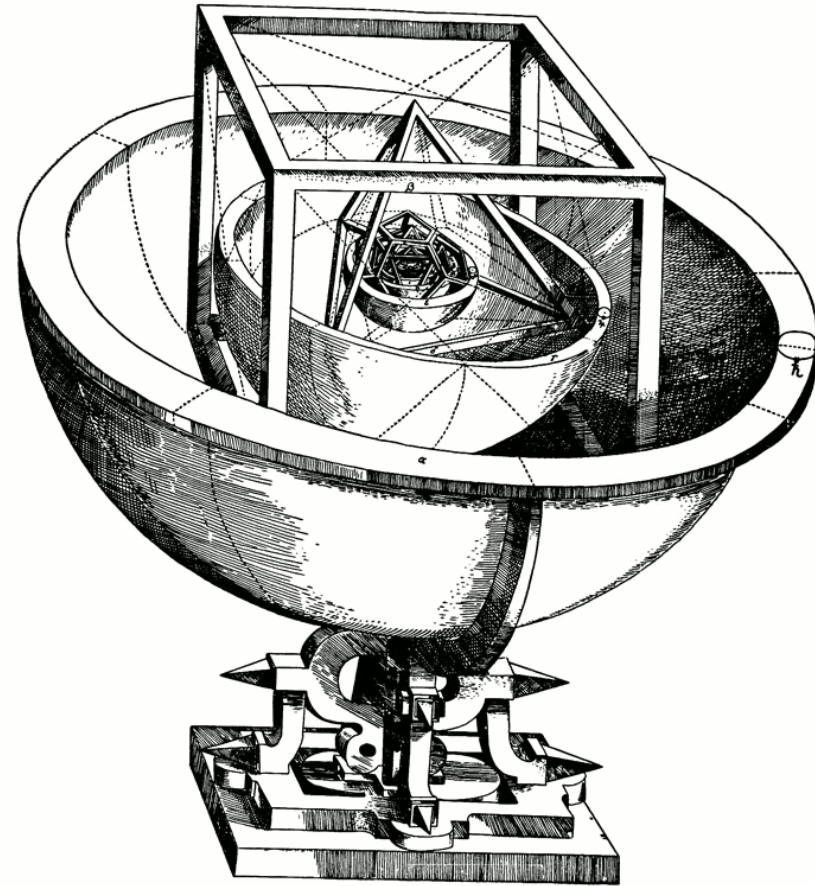
"a supplement to Aristotle's *On the Heavens*",¹

transforming the ancient tradition of physical
cosmology by treating astronomy as part of a
universal mathematical physics.

Mysterium Cosmographicum

Prodromus dissertationum cosmographicarum, continens mysterium cosmographicum, de admirabili proportione orbium coelestium, de que causis coelorum numeri, magnitudinis, motuumque periodicorum genuinis & proprijs, demonstratum, per quinque regularia corpora geometrica

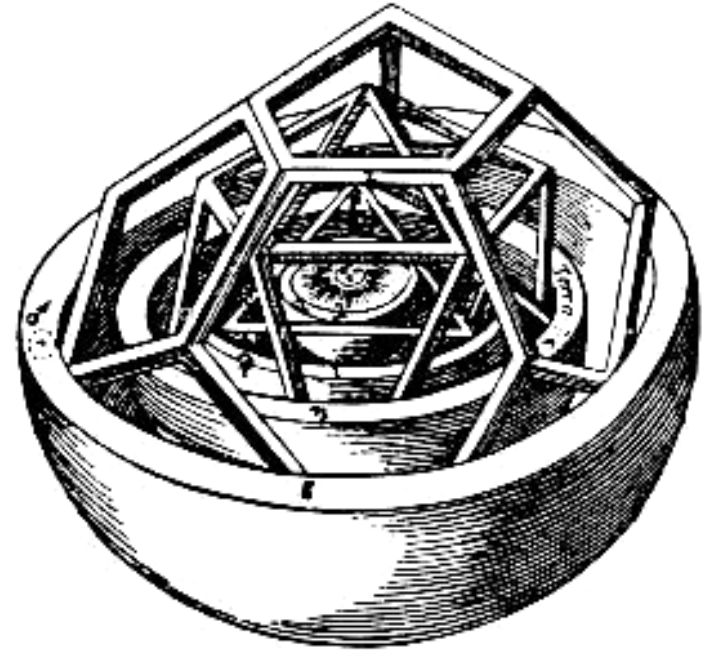
Forerunner of the Cosmological Essays, Which Contains the Secret of the Universe; on the Marvelous Proportion of the Celestial Spheres, and on the True and Particular Causes of the Number, Magnitude, and Periodic Motions of the Heavens; Established by Means of the Five Regular Geometric Solids



Mysterium Cosmographicum

- First published defense of Copernican system
- published 1596 (at age 26 !)
- 2nd ed. 1621 (half as long)
- Book explains Kepler's cosmological theory:
God's Geometrical Plan for the Universe
- based on the Copernican system:
first published defense of Copernican system

- Five Pythagorean regular polyhedra dictate the structure of the universe and reflect **God's plan through geometry.**
- Kepler found that each of the five Platonic solids could be uniquely inscribed and circumscribed by spherical orbs;
- nesting these solids, each encased in a sphere, within one another would produce six layers, corresponding to the six known planets
- **Mercury, Venus, Earth, Mars, Jupiter, and Saturn.**
- By ordering the solids correctly
- **octahedron, icosahedron, dodecahedron, tetrahedron, cube**



Kepler found that circumscribing spheres could be placed at intervals corresponding

(within the accuracy limits of available astronomical observations)

to the relative sizes of each planet's path, assuming the planets circle the Sun

Mysterium Cosmographicum



Mysterium Cosmographicum

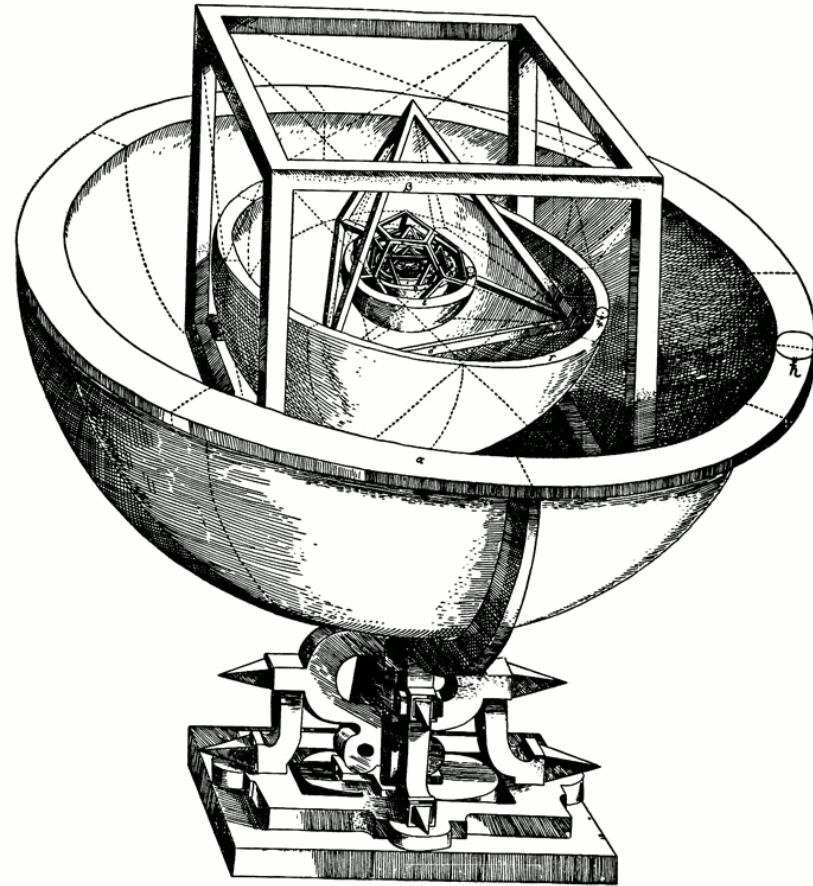
Kepler thought he had revealed

God's geometrical plan for the universe.

Much of Kepler's enthusiasm for the Copernican system stemmed from his theological convictions about the connection between the physical and the spiritual.

The universe itself was an image of God,

- His first manuscript of *Mysterium* contained an extensive chapter reconciling heliocentrism with biblical passages that seemed to support geocentrism.¹
- Kepler never relinquished the Platonist polyhedral-spherist cosmology of *Mysterium Cosmographicum*.
- His subsequent main astronomical works were in some sense only further developments of it,

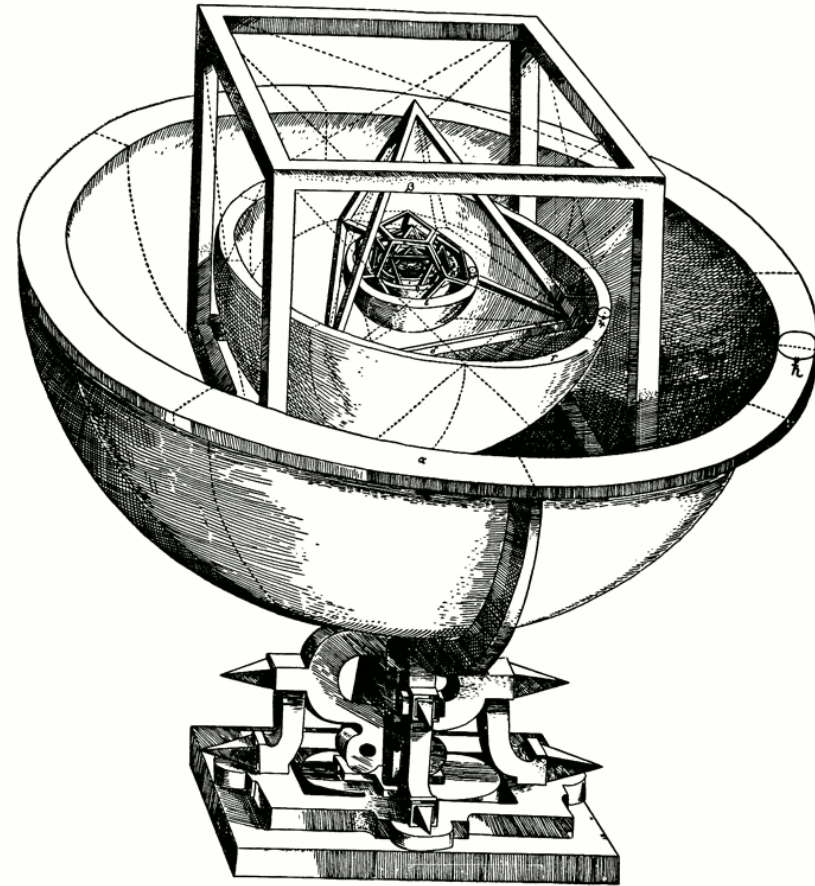


Mysterium Cosmographicum

Modern astronomy owes much to

Mysterium Cosmographicum

- Despite flaws in its main thesis, "since it represents the first step in cleansing the Copernican system of the remnants of the Ptolemaic theory still clinging to it." (Dryer)
- Especially when dealing with the geometry of the universe, Kepler consistently utilizes Platonic and Neo-Platonic frameworks of thought.
- The entirety of the polyhedral idea is based on the same "formal cause" postulated by Plato for the structure of the universe.
- In an argument from design, Kepler postulates the existence and necessity of God the Creator as this "efficient cause"



Astronomia Nova

Full title:

*Astronomia Nova ΑΙΤΙΟΛΟΓΗΤΟΣ seu physica
coelestis, tradita commentariis de motibus
stellae Martis ex observationibus
G. V. Tychonis Brahe*

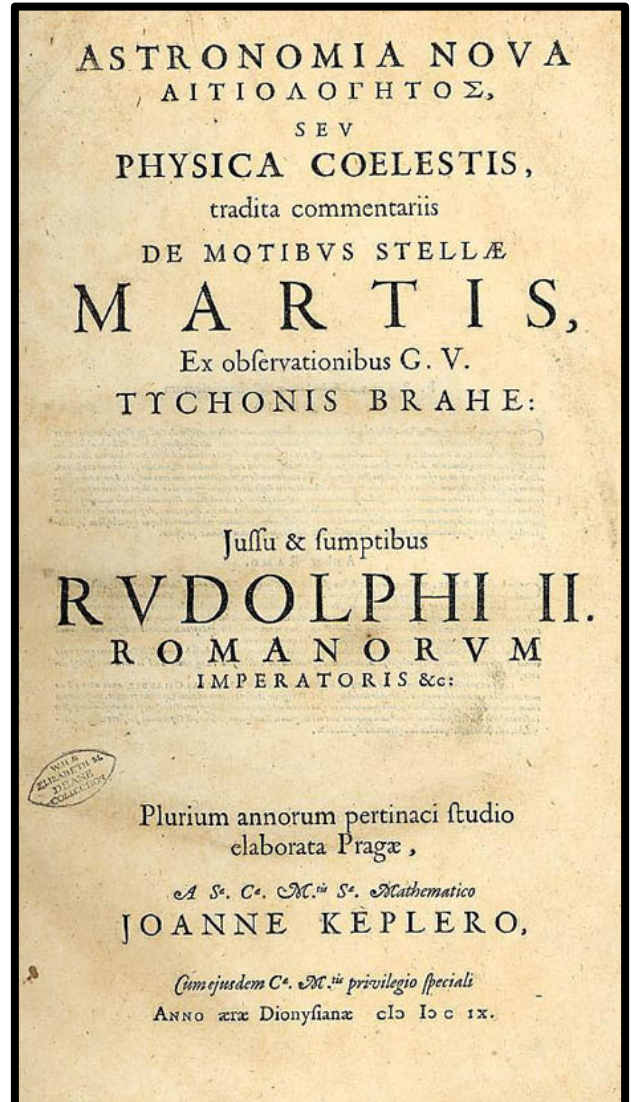
Published 1609

One of the most important works of the
Scientific Revolution

Reports Kepler's 10 year long investigation of
motion of planet Mars.

In addition to providing strong arguments
heliocentrism, it describes the motion of
planets, incl. elliptical shape of orbits

- first 2 laws of Kepler



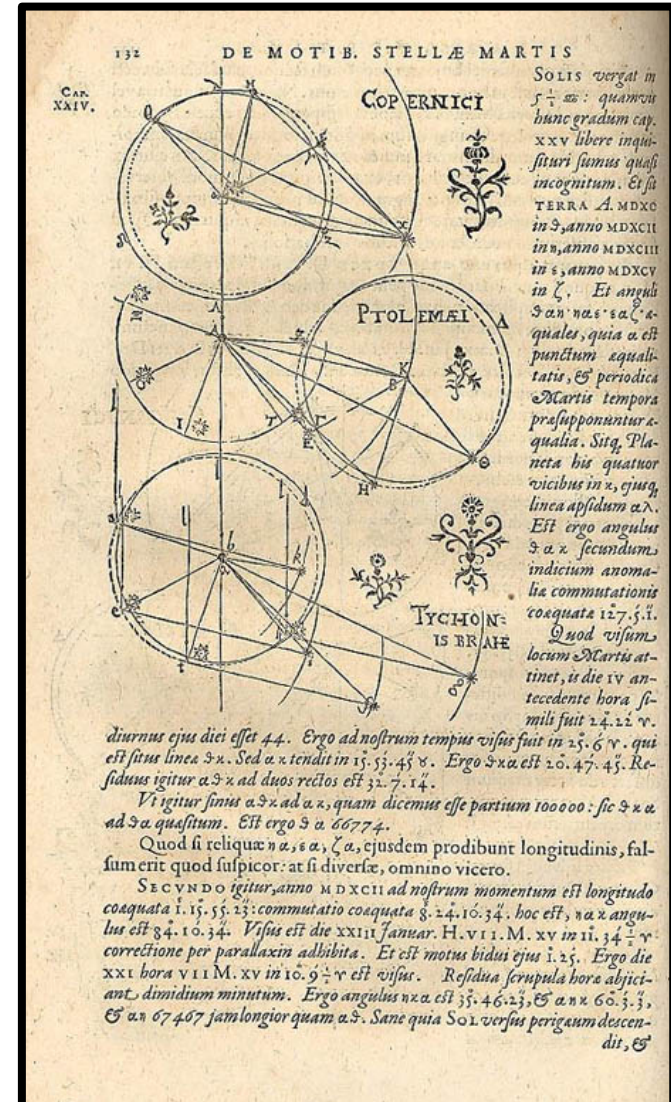
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One of the most important works of the Scientific Revolution

In addition to providing strong arguments heliocentrism, it describes the motion of planets, incl. elliptical shape of orbits:

- first 2 laws of Kepler:
 1. The orbit of a planet is an **ellipse** with the Sun at **one focus**.
 2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.(planets do not move with uniform speed along their orbit).



Harmonices Mundi

- Harmony of the World
- Published 1619
- In a sense return to Pythagoras' "Music of the Spheres". However, not based on numerology, but on Geometry!
- Kepler discovered physical harmonies in planetary motion:
 - difference maximum – minimum angular speeds of a planet approximates harmonic proportion
 - eg. the maximum angular speed of Earth as measured from the Sun varies by a semitone (ratio: 16:15)

Ioannis Keppleri
**HARMONICES
MUNDI**

LIBRI V. QVORVM

Primus GEOMETRICVS, De Figurarum Regularium, quæ Proportiones Harmonicas constituunt, ortu & demonstrationibus.
Secundus ARCHITECTORICVS, seu ex GEOMETRIA FIGVRATA, De Figurarum Regularium Congruentia in plano vel folido:
Tertius proprie HARMONICVS, De Proportionum Harmonicarum ortu ex Figuris; deque Naturâ & Differentiis rerum ad cantum pertinentium, contra Veteres:
Quartus METAPHYSICVS, PSYCHOLOGICVS & ASTROLOGICVS, De Harmoniarum mentali Essentiâ eorumque generibus in Mundo; præsertim de Harmonia radiorum, ex corporibus celestibus in Terram descendentibus, eiusque effectu in Natura seu Anima sublunari & Humana:
Quintus ASTRONOMICVS & METAPHYSICVS, De Harmoniis absolutissimis motuum celestium, ortuque Eccentricitatum ex proportionibus Harmonicis.
Appendix habet comparationem huius Operis cum Harmonices Cl. Ptolemæi libro III. cumque Roberti de Fluctibus, dicti Flud. Medici Oxoniensis speculationibus Harmonicis, operi de Macrocosmo & Microcosmo insertis.



Cum S. C. M^{te}. Privilegio ad annos XV.

Lincii Austriae,

Sumptibus GODOFREDI TAMPACHII Bibl. Francof.
Excudebat IOANNES PLANGVS.

ANNO M. DC. XIX.

1st Edition 1619
6 plates on 5

Harmonices Mundi

- Harmony of the World
- Published 1619
- Musical harmonies for arrangement and motion of heavenly bodies
- Celestial choir:

Mercury	soprano
Venus	alto
Earth	alto
Mars	tenor
Jupiter	tenor
Saturn	bass
- Mercury - large elliptical orbit
- Venus - greatest number of notes
- Venus - orbit nearly a circle
- Venus - only a single note

Ioannis Keppleri
**HARMONICES
MUNDI**

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Harmonices Mundi

Ioannis Keppleri
HARMONICES
MUNDI

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Excudebat IOANNES PLANCVS.

ANNO M. DC. XIX.

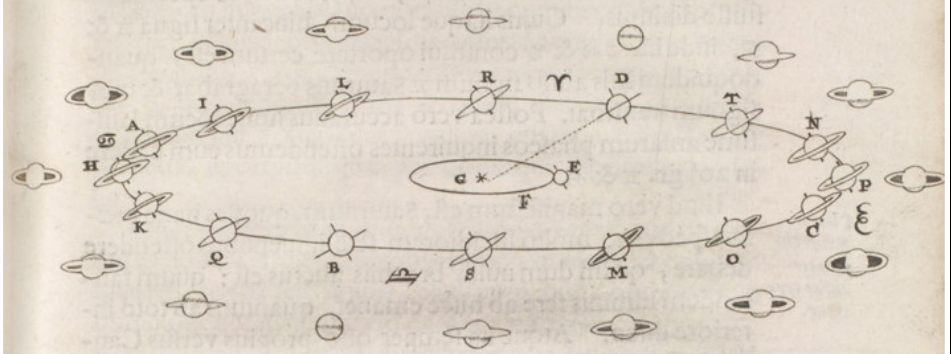
1st Edition 1st 1550
6 plates on 5

Christiaan Huygens

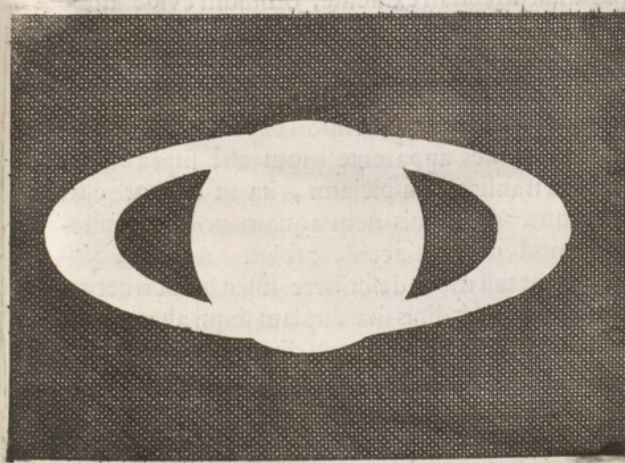
(1629-1695)



Huygens & Saturn

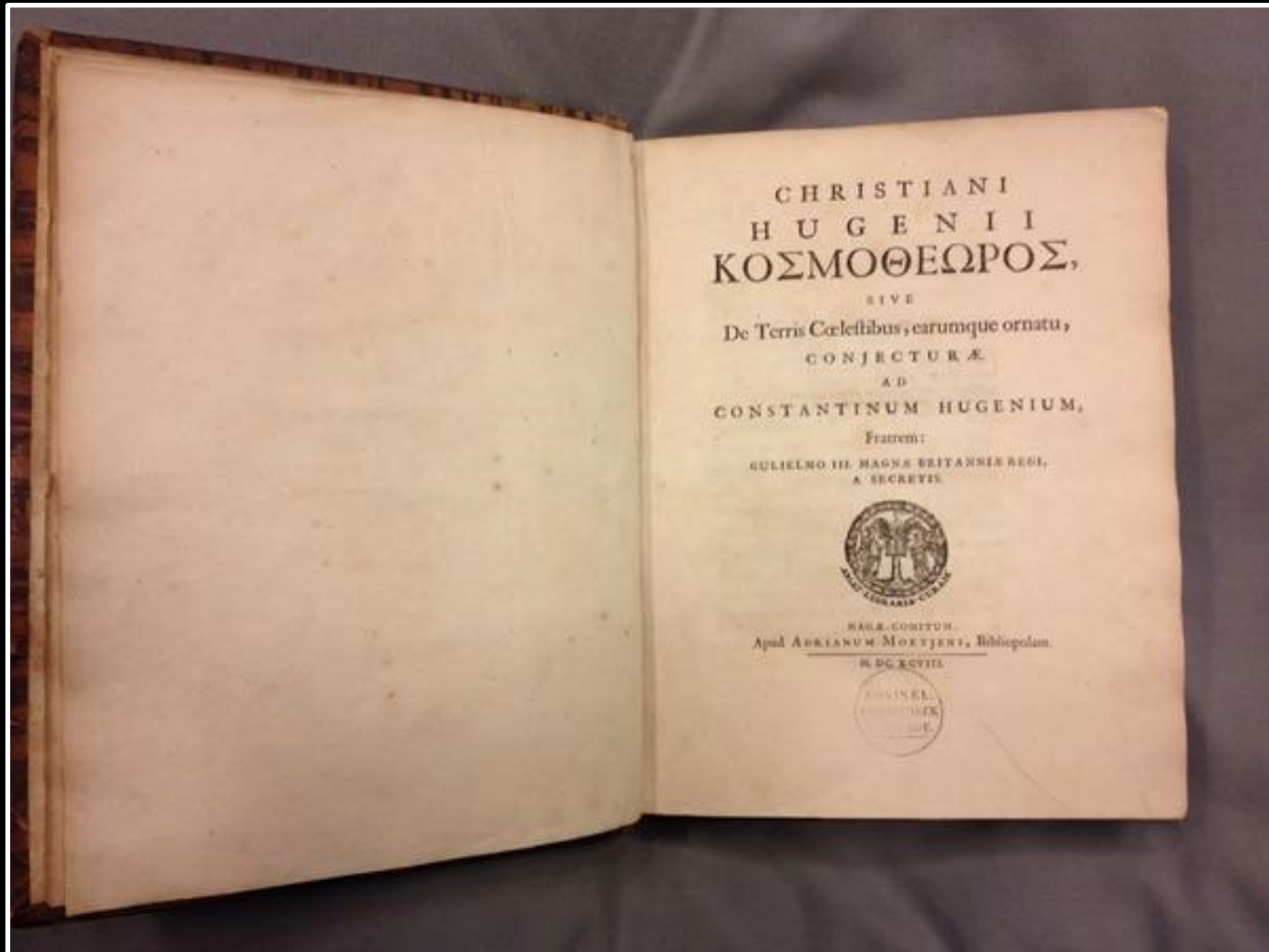


Cujus phaseos vera proinde forma, secundum ea quæ supra circa annulum definivimus, ejusmodi erit qualis hîc delineata cernitur, majori ellipsis diametro ad minorem se habente fere ut 5 ad 2.



Atque

Cosmotheoros



1695-1698:

- Speculation on the existence of extraterrestrial life
- Identification (liquid) water as main condition for the emergence of life
- Method for estimating distances

Galileo Galilei

(1564-1642)

(Pisa-Arcetri)



Galileo Galilei

(1564-1642)

father of observational astronomy
father of modern physics
father of scientific method



Galileo Galilei

(1564-1642)

astronomer, physicist,
engineer,
philosopher, mathematician



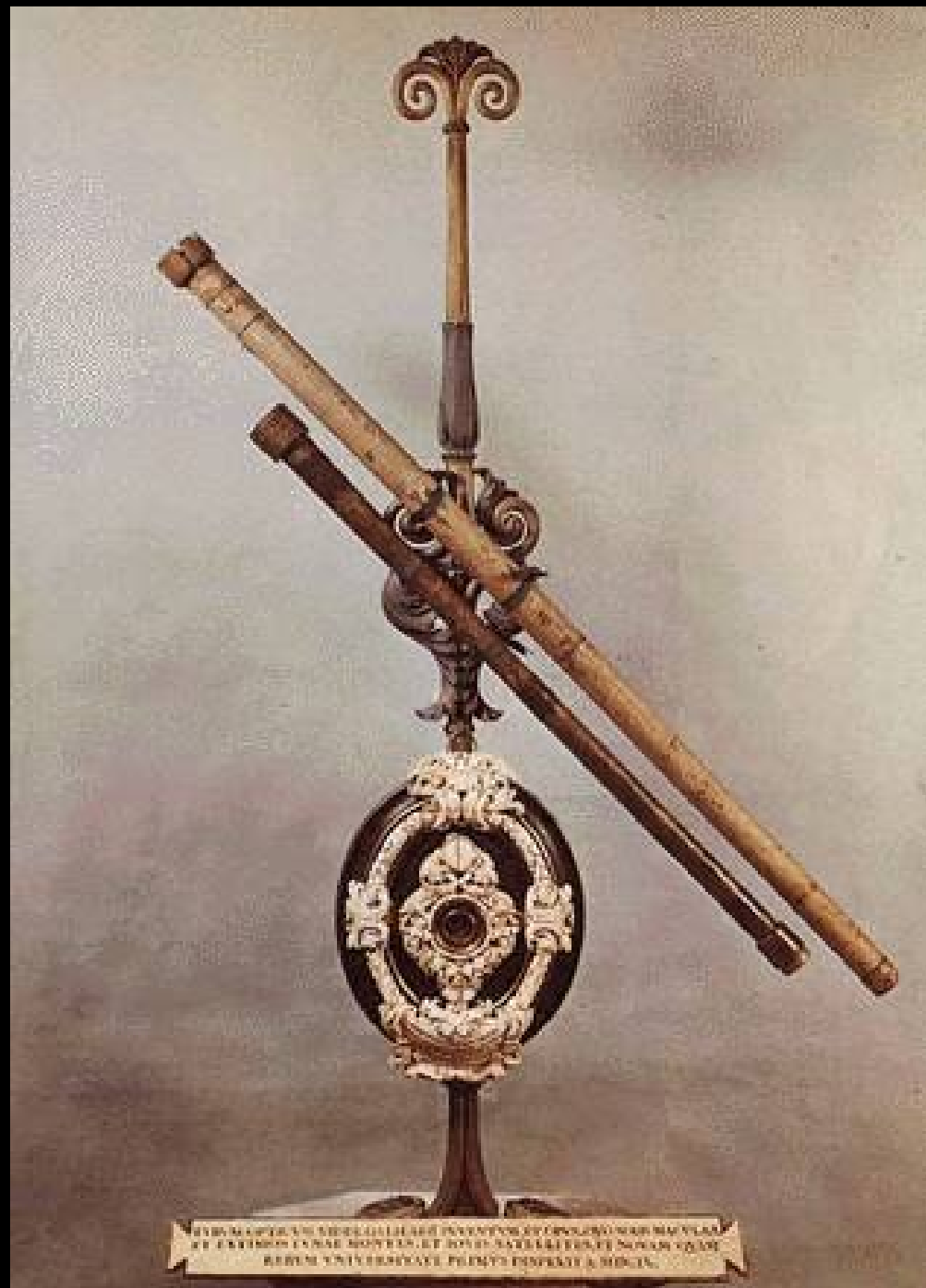
Telescope (1609)

Following vague descriptions of the patent for a telescope by Lippershey in the Netherlands (1608),

basically 2 lenses in line cause a magnification,

Galilei developed his own telescope in 1609:

- 3 x magnification
- 30 x magnification (later).



**Siderius
Nuncius**

1610

**Starry
Messenger**

Publication of initial telescope
astronomical observations.

**S I D E R E V S
N V N C I V S**

MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, praesertim verò

PHILOSOPHIS, atq; ASTRONOMIS, qua à
GALILEO GALILEO
PATRITIO FLORENTINO

Patauini Gymnasij Publico Mathematico

P E R S P I C I L L I

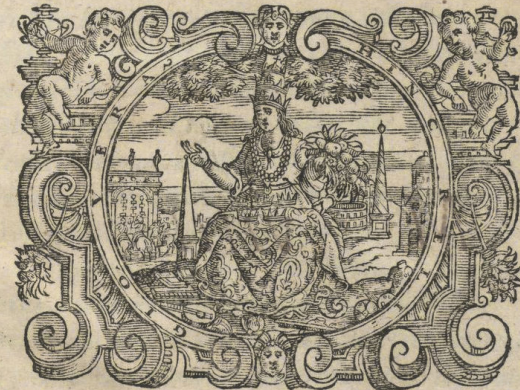
*Nuper à se reperti beneficio sunt observata in LVNÆ FACIE, FIXIS IN
NUMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,*

Apprime verò in

Q V A T V O R P L A N E T I S

Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depra-
hendit primus; atque

M E D I C E A S I D E R A
NVNCVPANDOS DECREVIT.



VENETIIS, Apud Thomam Baglionum. M D C X.

Superiorum Permissu, & Privilegio.

M VIII. 22. 1A.

SIDEREVS NUNCIVS

MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò

PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO

Patauini Gymnasij Publico Mathematico

PERSPICILLI

Nuper à se reperi beneficio sunt obseruata in LVNÆ FACIE, FIXIS IN
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,

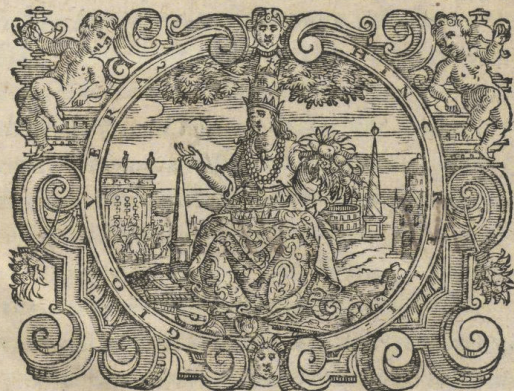
Apprime verò in

QVATVOR PLANETIS

Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque

MEDICEA SIDERA

NVNCVPANDOS DECREVIT.



VENETIIS, Apud Thomam Baglionum. M DC X.

Superiorum Permissu, & Privilegio.

M VIII. 12. 14.

Contents:

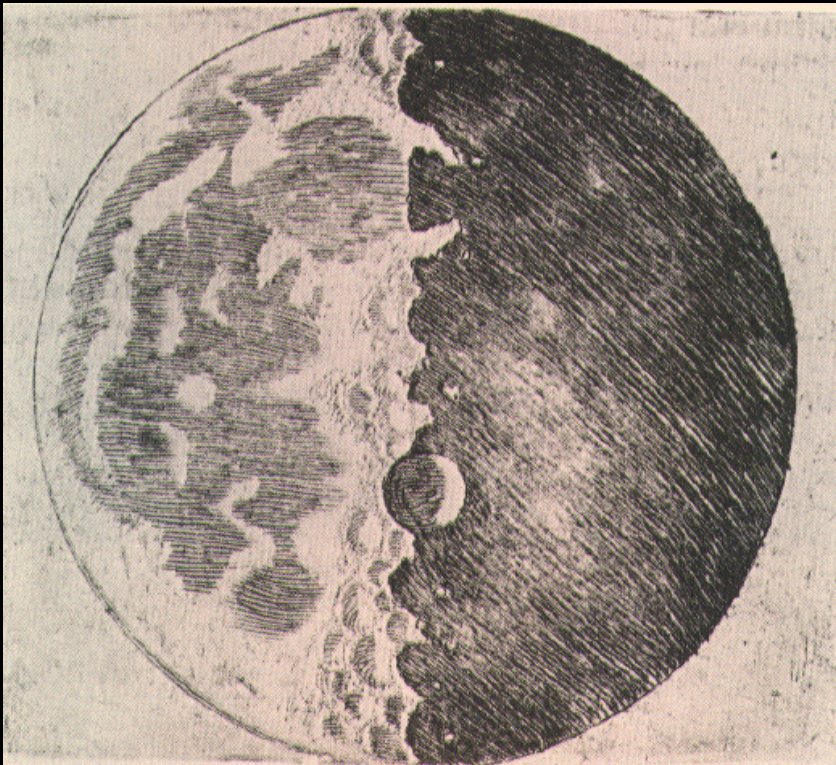
- 70 drawings of
 - Moon: real world of valleys & mountains
 - Orion
 - Pleiades: > 10 x number of stars than visible by eye
 - Taurus
 - Milky Way: congeries of innumerable stars grouped in clusters
 - Galilean Moons (Medicean stars):
 - illustrations of relative positions between Jan. 1610 – Mar. 1610
 - remain on same line: orbiting Jupiter
 - in conflict with Aristotelean cosmology (which states everything orbits Earth)
 - Phases of Venus:
 - solid evidence for Venus and Earth orbiting the Sun
 - Planet Saturn:
 - did not realize he saw rings, and thought Saturn was 3 objects
 - Neptune
 - Galilei did see Neptune, but did not realize it was a planet
 - would take another 236 years before it was discovered as planet by Le Verrier
 - Sunspots

the Moon

Galilei's telescopic study of the Moon revealed it was a real world of its own,

with valleys, mountains, etc.

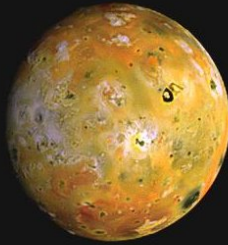
- Directly conflicting serene & perfect Aristotle's & Ptolemaic cosmology



Moon:
surface valleys & hills

Galilean Moons of Jupiter:

Ganymedes, Io,
Callisto, Europa



Astronomical Journal
1610

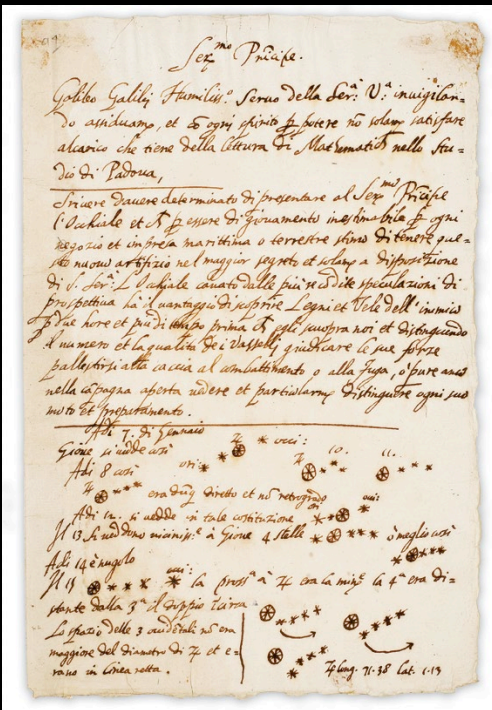
2. J. Jovis mond H. 12	○ ● ●
30. mond	● ● ○ *
2. Jovis	○ ● ● *
3. mond	○ * *
3. H. 1.	* ○ *
4. mond	* ○ ● *
6. mond	● ● ○ *
8. mond H. 17.	* * * ○
10. mond	* * * ○ *
11.	* * ○ *
12. H. 4. mond	* ○ *
17. mond	* ● ● *
14. Jovis	* * ● *
15.	* * ○
16. Jovis	* ○ ● ● *
17. Jovis	* ○ * *
18.	* ○ * * *
21. mond	* * ○ * *
24.	* * ○ *
25.	* * ○ *
29. mond	* * ○
30. mond	* * ○ *
January 4. mond	* * ○ *
4. mond	* * ○ *
5.	* * ○ *
6.	* ○ ● *
7	* ○ ● * * nicht mehr in reiner Form.
7. Jovis	* ○ ● *
11.	* * * ○

Galilean Moons

Ganymedes, Io, Callisto & Europa:

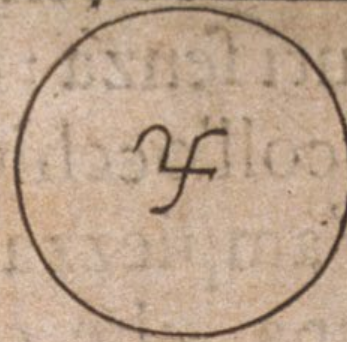
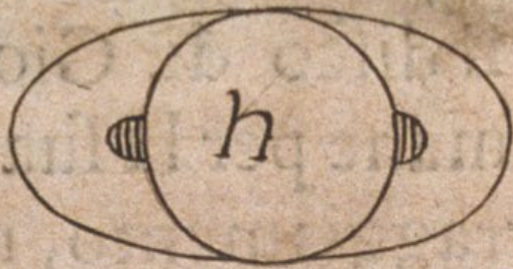
discovery of their orbital motion, demonstrated that Earth was not the only center in the Universe

directly conflicting Ptolemaic and Aristotle's cosmology

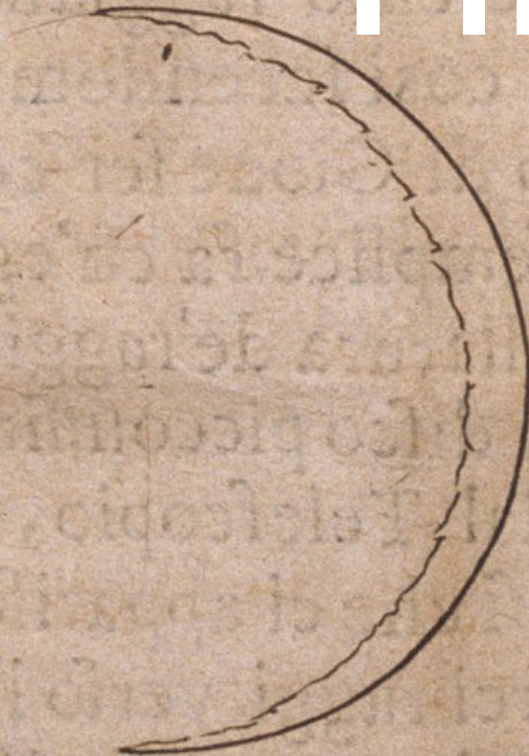


Observationes Januariae 1610

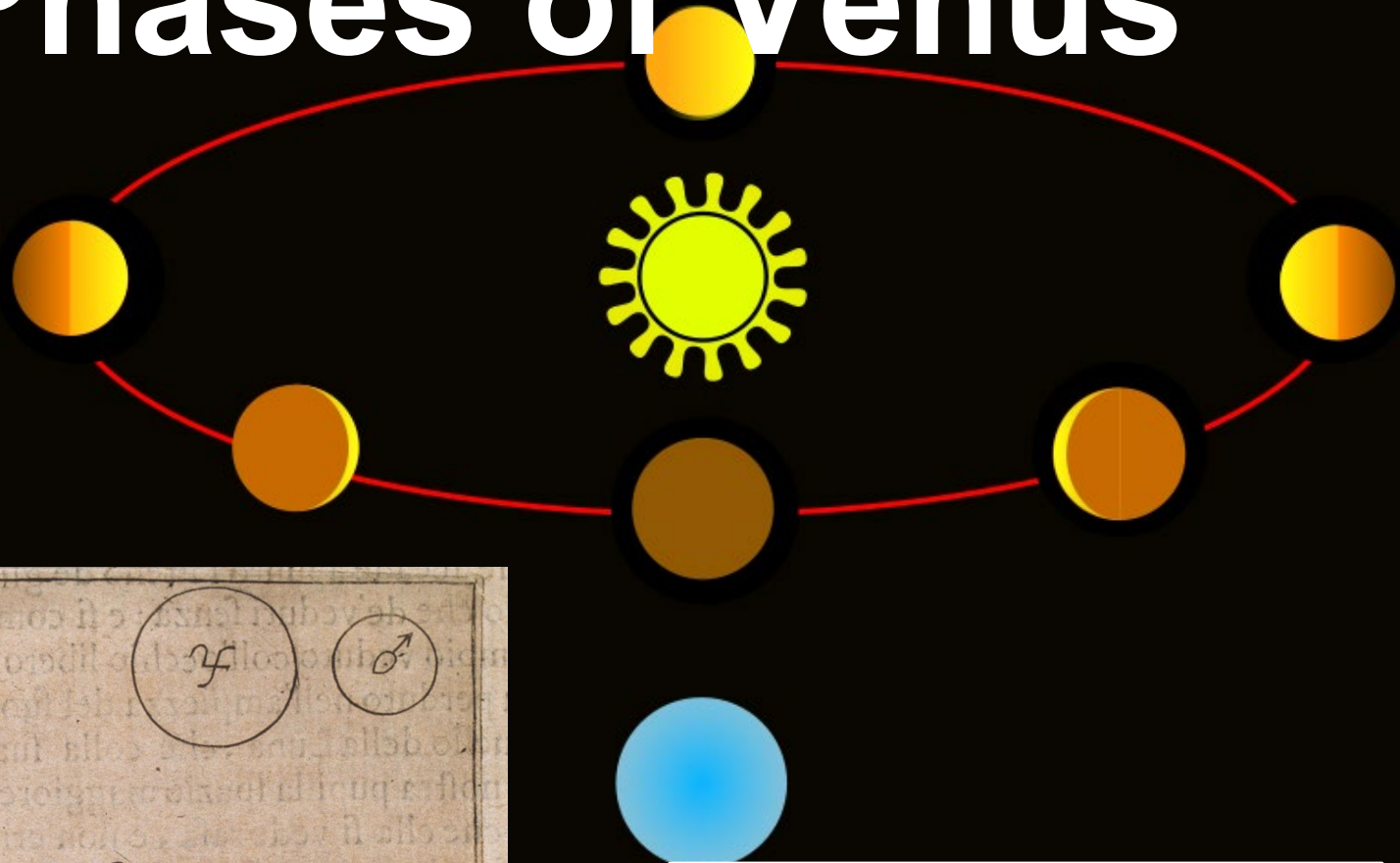
20. Janis	mand. H. 12	0 **
30. mand	** 0 *	
2. Janis	0 ** *	
3. mand	0 * *	
3. H. 1.	* 0 *	
4. mand	* 0 **	
6. mand	** 0 *	
8. mand H. 17.	* * * 0	
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12. H. 4. mand	* 0 *	
17. mand	* ** 0 *	
14. Janis	* * * 0 *	
15.	* * 0	
16. Janis	* 0 ** *	
17. Janis	* 0 * *	
18.	* 0 * *	
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24.	* * 0 *	
25.	* * 0 *	
29. mand	** 0	
30. mand	** 0 *	
January 4. mand	* * 0 *	
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5.	* * 0 *	
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7. * 0 **	* mand. mand. no. offerunt in	reth. d. mand.
7. mand	* 0 **	
11.	* * * 0	



Phases of Venus



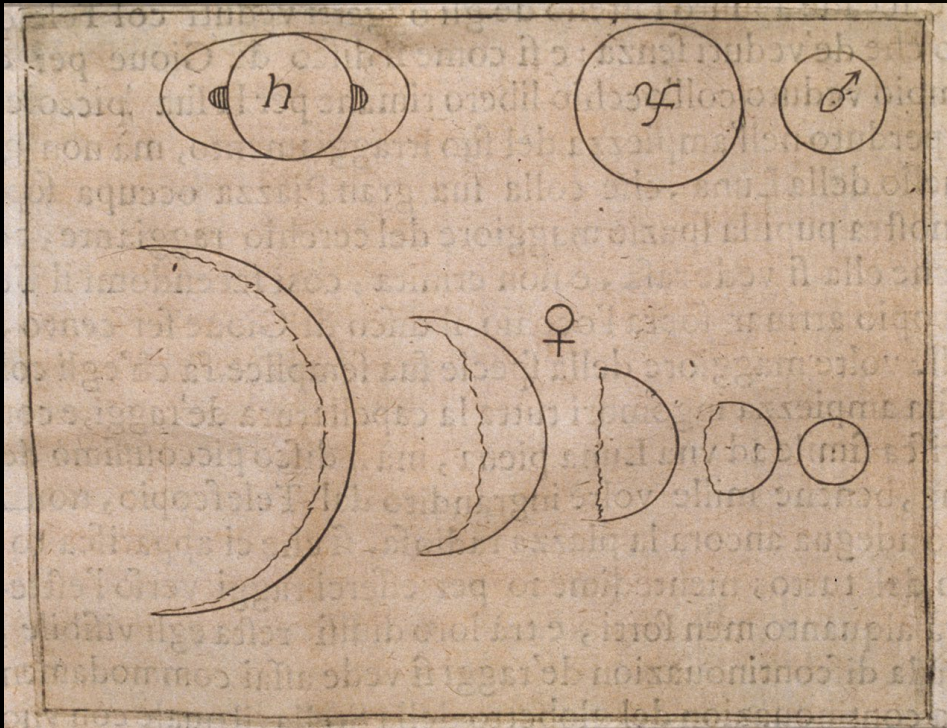
Phases of Venus



EARTH

Evidence for heliocentric Universe:

- Phases of Venus correlated with size of Venus' disk
- Full Venus: small disk
- New Venus: large disk



Dialogue concerning the two chief world systems

(1632)

Latin: **Systema Cosmicum**

book comparing the
Copernican system with traditional Ptolemaic system

- Stated intention was to be objective.
- However, could not hide Galilei's conviction that Copernican system represented the physical reality
- book considered attack on Aristotelian geocentrism
- also insulted the pope

1633:

- Galilei accused of heresy
- Dialogo on Index of Forbidden Books (until 1835)
- Galilei narrowly escapes torture
- house arrest for the rest of his life.





DIALOGO

DI
GALILEO GALILEI LINCEO
MATEMATICO SOPRAORDINARIO

DELLO STUDIO DI PISA.

E Filosofo, e Matematico primario del
SERENISSIMO

GR. DVCA DI TOSCANA.

Due ne i congressi di quattro giornate si discorre
sopra i due

MASSIMI SISTEMI DEL MONDO
TOLEMAICO, E COPERNICANO;

*Proponendo indeterminatamente le ragioni Filosofiche, e Naturali
tanto per l'una, quanto per l'altra parte.*

CON PRI



VILEGI.

IN FIORENZA, Per Gio:Batista Landini MDCXXXII.

CON LICENZA DE' SUPERIORI.



Galilei facing the Roman inquisition

Galileo Galilei

Scientific significance stretches to at least 2 other main aspects:

- Physics
- Scientific Method

Physics

- velocity & speed, gravity,
- free fall
- principle of relativity
- inertia

- Pendulums &
- Hydrostatic balances
- Thermoscope



tower of Pisa:
heavy objects fall equally fast as
light objects



Galileo Galilei

Scientific significance stretches to at least 2 other main aspects:

- Physics
- Scientific Method

Scientific Method

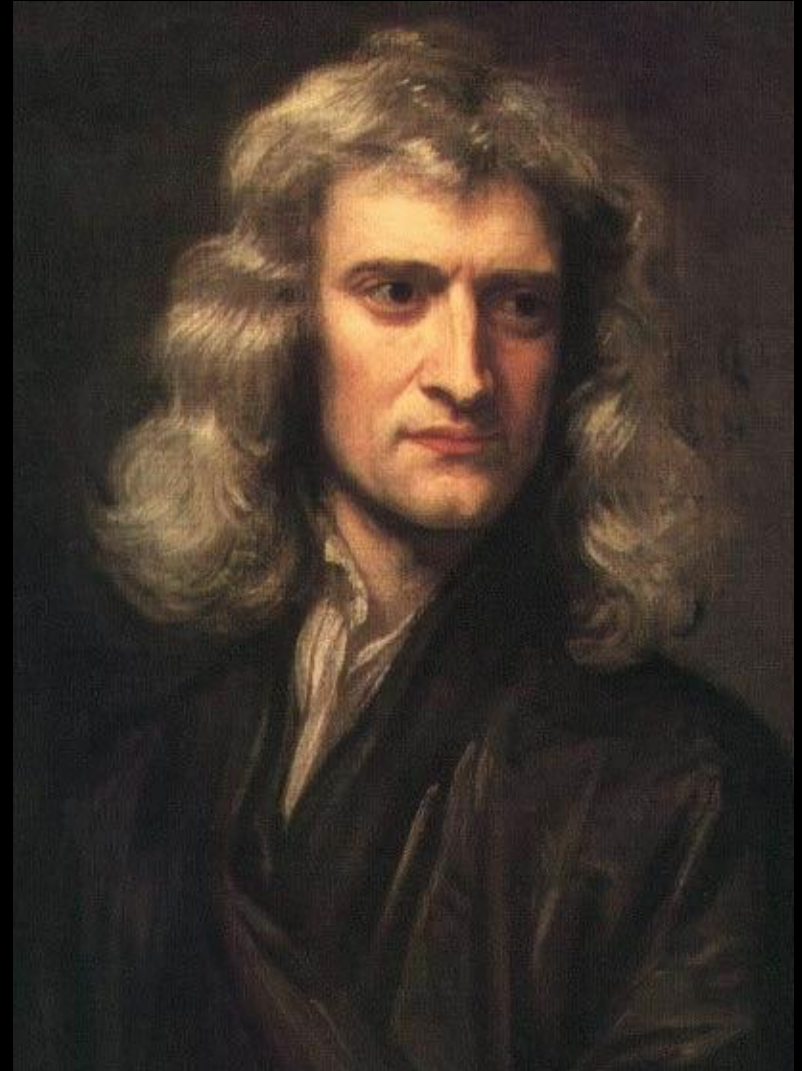
- Innovative combination Experiment – Mathematics
- Laws of Nature are mathematical
- in book “The Assayer”:
 - “Philosophy is written in this grand book, the universe ... It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures;...”
- Appreciation proper relationship mathematics, theoretical physics & experimental physics



Isaac Newton

(1643-1727)

**“If I have seen further
it is by standing on the
shoulders of giants “**



Isaac Newton



Birthplace
Woolsthorpe



Philosophiae Naturalis Principia Mathematica (1687)

... Rational Mechanics will be the sciences of motion resulting from any forces whatsoever, and of the forces required to produce any motion, accurately proposed and demonstrated ... And therefore we offer this work as mathematical principles of his philosophy. For all the difficulty of philosophy seems to consist in this—from the phenomenas of motions to investigate the forces of Nature, and then from these forces to demonstrate the other phenomena ...

Principia is considered one of the most important works in the history of science

PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

^{auto} Autore ^{Equite Publico,} J. S. NEWTON ^{Trin. Coll. Cantab. Soc. Matheseos}
^{Professore} ^{Lucasiano,} & Societatis Regiæ Sodali.
^{et Societatis Regiæ Societatis præside.}

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

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

Principia

(1687)

Philosophiae Naturalis Principia Mathematica (1687)

Newton's 3-volume work:

- Newton's laws of motion
 - forming the foundation of classical mechanics
- Newton's law of universal gravitation
 - in essence, the discovery of the force of gravity
- Derivation of Kepler's laws of planetary motion
 - ie. the laws that Kepler had found empirically
- Integral and Differential Calculus
 - however, language of calculus as we know it is from Leibniz
 - Newton gave the proofs in a geometric form of infinitesimal calculus

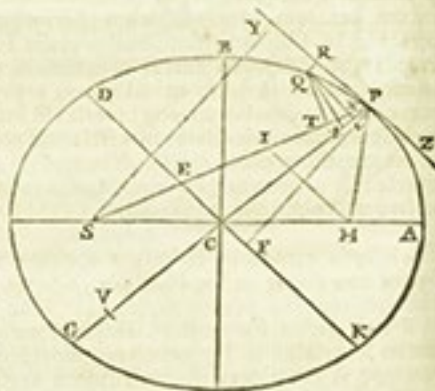
SECTIO III.

De motu Corporum in Conicis Sectionibus excentricis.

PROPOSITIO XI. PROBLEMA VI.

Revolvatur corpus in Ellipsi: requiritur Lex vis centripeta tendentis ad umbilicum Ellipseos.

Est Ellipseos umbilicus S . Agatur SP secans Ellipseos tum diametrum DK in E , tum ordinatim applicatam Qv in x , & compleatur parallelogrammum $QxPR$. Patet EP æqualem esse semixi majori AC , eo quod acta ab altero Ellipseos umbilico H linea HI ipsi EC parallela, (ob æquales CS, CH) æquantur ES, EI , adeo ut EP semisumma sit ipsarum PS, PI , id est (ob parallelas HI, PR & angulos æquales IPR, HPZ) ipsarum PS, PH , quæ conjunctim axem totum AC adæquant. Ad SP demittatur perpendicu-



laris QT , & Ellipseos latere recto principali (seu $\frac{2BC}{AC}$ quad.) dicto L , erit $L \times QR$ ad $L \times Pv$ ut QR ad Pv , id est ut PE seu AC ad PC ; & $L \times Pv$ ad GvP ut L ad Gv ; & GvP ad Qv quad. ut PC quad. ad CD quad., & (per Corol. 2 Lem. vii) Qv quad. ad Qx quad. punctis, Q & P coeuntibus, est ratio æqualitatis; & Qx quad. seu Qv quad. est ad QT quad. ut EP quad. ad PF quad., id est ut CA quad. ad PF quad. live (per Lem. xii.) ut CD quad. ad CB quad. Et conjunctis his omnibus rationibus, $L \times QR$ fit ad QT quad. ut $AC \times L \times PCq. \times CDq.$ seu $2CBq. \times PCq. \times CDq.$ ad $PC \times Gv \times CDq. \times CBq.$ live ut $2PC$ ad Gv .

Sed,

Sed, punctis Q & P coeuntibus, æquantur $2PC$ & Gv . Ergo & his proportionalia $L \times QR$ & QT quad. æquantur. Ducantur hæc æqualia in $\frac{SPq.}{QR}$ & fiet $L \times SPq.$ æquale $\frac{SPq. \times QTq.}{QR}$. Ergo (per Corol. 1 & 5 Prop. vi.) vis centripeta reciproce est ut $L \times SPq.$ id est, reciproce in ratione duplicata distantie SP . $Q.E.I.$

Idem aliter.

Cum vis ad centrum Ellipseos tendens qua corpus P in Ellipsi illa revolvitur potest, sit (per Corol. 1 Prop. x) ut CP distantia corporis ab Ellipseos centro C ; ducatur CE parallela Ellipseos tangenti PR ; & vis qua corpus idem P , circum aliud quodvis Ellipseos punctum S revolvitur potest, si CE & PS concurrant in E , erit ut PE cub. $\frac{SPq.}{QR}$ (per Corol. 3. Prop. vii.) hoc est, si punctum S sit umbilicus Ellipseos, adeoque PE detur, ut $SPq.$ reciproce. $Q.E.I.$

Eadem brevitate qua traduximus Problema quintum ad Parabolam, & Hyperbolam, liceret idem hic facere: verum ob dignitatem Problematis & usum ejus in sequentibus, non pigebit casus ceteros demonstratione confirmare.

PROPOSITIO XII. PROBLEMA VII.

Moveatur corpus in Hyperbola: requiritur Lex vis centripeta tendentis ad umbilicum figuræ.

Sunt CA, CB semi-axes Hyperbolæ; PG, KD diametri conjugatæ; PF, Qt perpendicularia ad diametros; & Qv ordinatim applicata ad diametrum GP . Agatur SP secans cum diametrum DK in E , tum ordinatim applicatam Qv in x , & compleatur parallelogrammum $QR Px$. Patet EP æqualem esse semixi transversæ AC , eo quod, acta ab altero Hyperbolæ umbilico H linea HI ipsi EC parallela, ob æquales CS, CH , æquantur ES, EI ; adeo ut EP semidifferentia sit ipsarum PS, PI , id est (ob parallelas HI, PR & angulos æquales IPR, HPZ) ipsarum PS, PH , quarum differentia axem totum AC adæquat. Ad SP demittatur perpendicularis QT . Et Hyperbolæ latere recto principali (seu $\frac{2BC}{AC}$ quad.) dicto L , erit $L \times QR$ ad $L \times Pv$ ut QR ad Pv , id est, ut PE seu AC ad PC ; Et $L \times Pv$ ad GvP ut L ad Gv .

Philosophiae Naturalis Principia Mathematica (1687)

1687	Volume 1 (Latin)
1713	Volume 2
1726	Volume 3
1728	Published in English

Newton's Laws of Motion

Newton's 1st Law:

zero force - body keeps constant velocity

$$\vec{F} = 0 \quad \Rightarrow \quad \vec{v} = cst.$$

Newton's 2nd Law:

force = acceleration x mass = change of velocity x mass

$$\vec{F} = m\vec{a} = m \frac{d\vec{v}}{dt}$$

Newton's 3rd Law:

action = reaction

$$\vec{F}_a = -\vec{F}_b$$

(the apple incident, 1666)



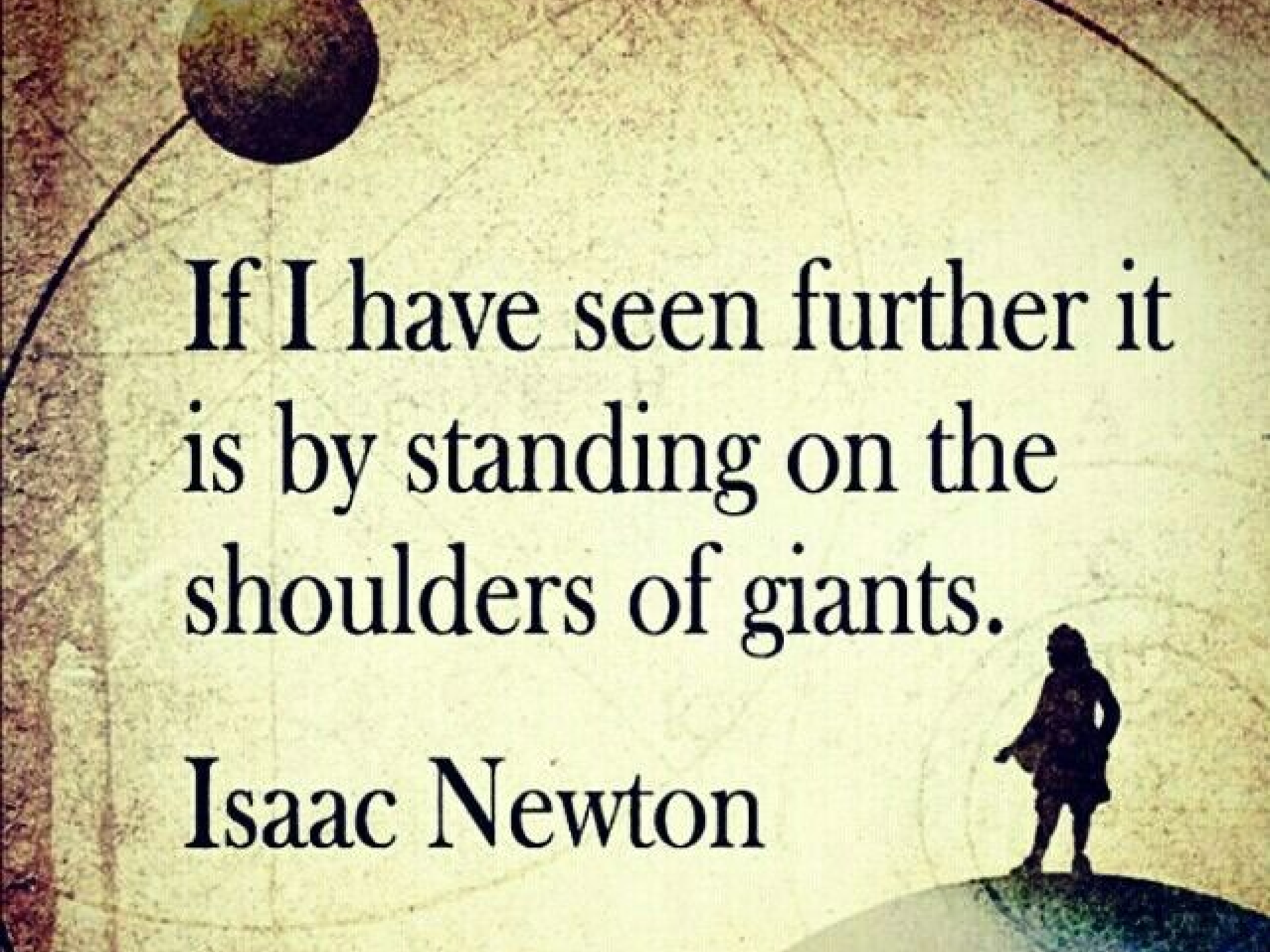
Newton's Gravity

$$\vec{F}_g = -G \frac{mM}{r^2} \vec{e}_r$$



Newton Telescope

(1st mirror telescope)



If I have seen further it
is by standing on the
shoulders of giants.

Isaac Newton