



# the Scientific Revolution:

the Cosmos Mechanized

- **1543**

***Nicolaus Copernicus***

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

- **1609-1632**

***Galileo Galilei***

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

- **1609/1619**

***Johannes Kepler***

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

- **1687**

***Isaac Newton***

- 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)

- **1755**

***Immanuel Kant***

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

- **1785**

***William Herschel***

- proposes theory that our Sun is at or near the center of our Galaxy (Milky Way)



**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

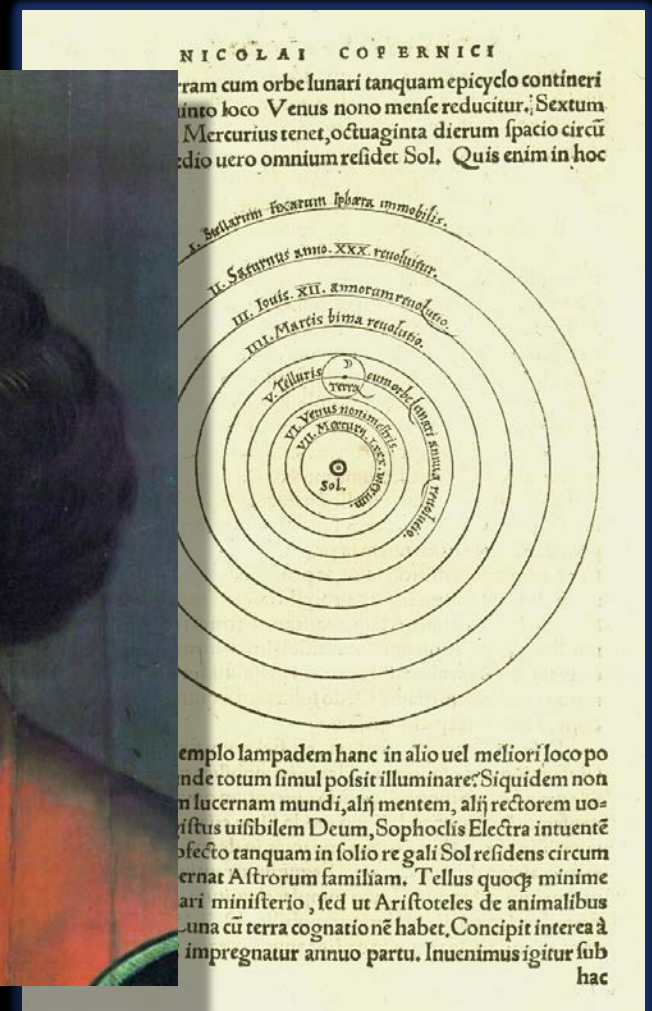
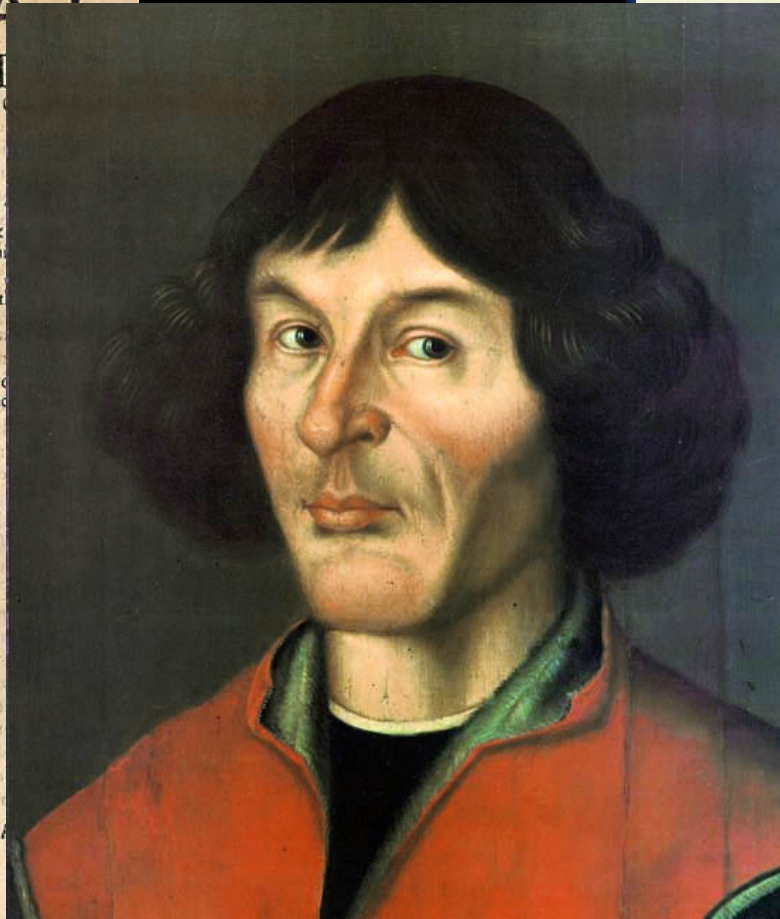
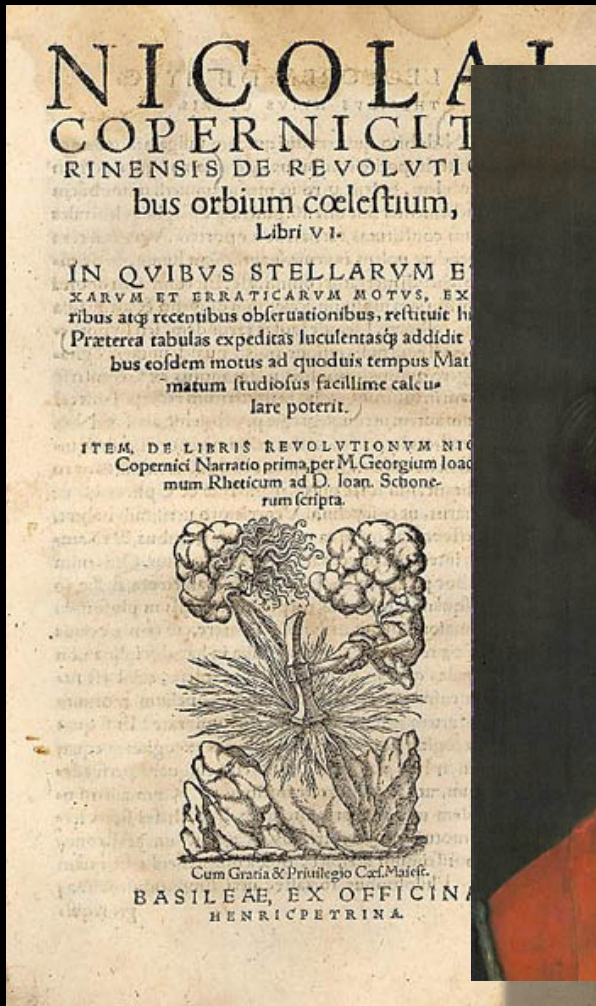


# Commentariolus



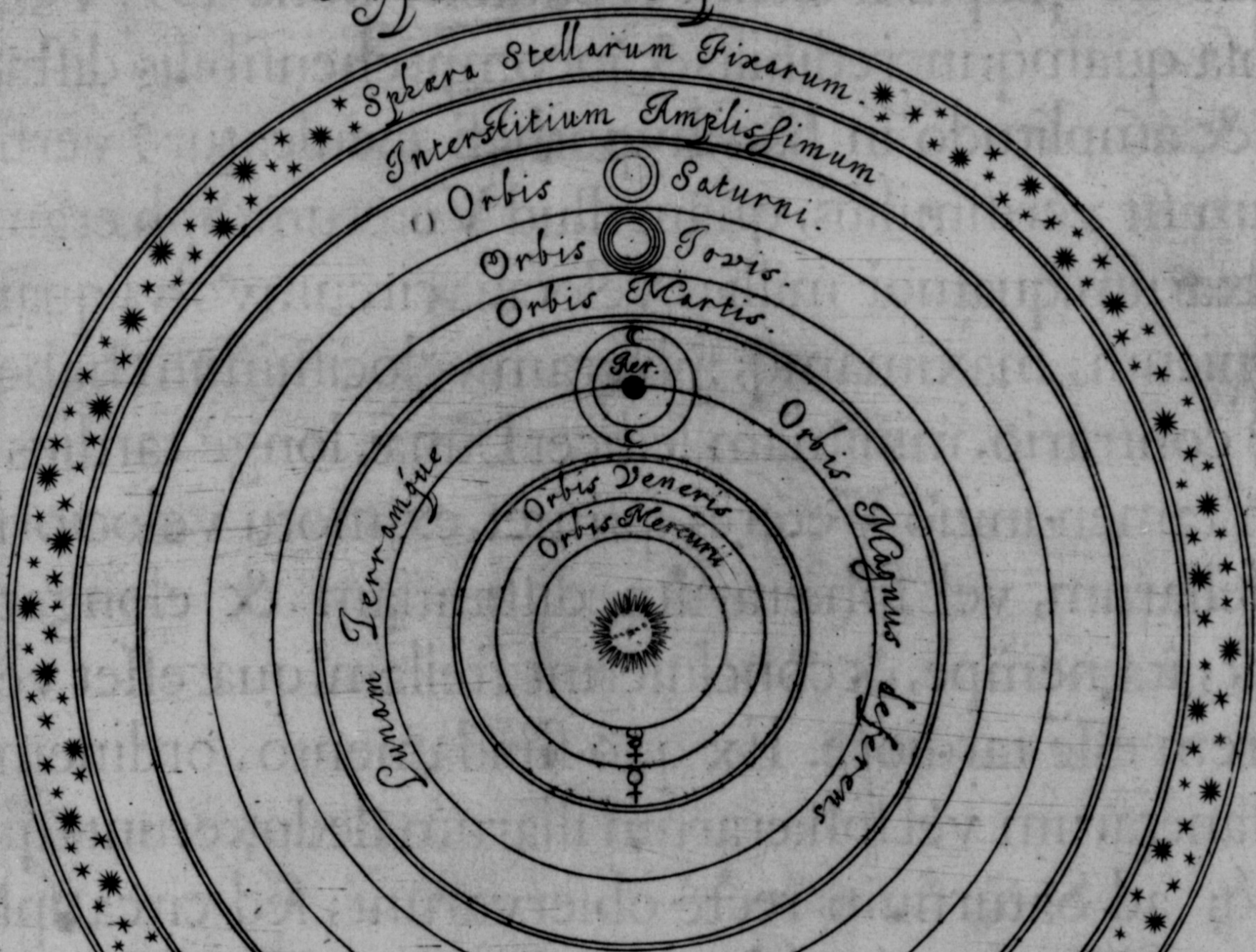
1. There is no one center of all the celestial circles or spheres.
2. The center of the earth is not the center of the universe, but only of gravity and of the lunar sphere.
3. All the spheres revolve about the sun as their midpoint, and therefore the sun is the center of the universe.
4. The ratio of 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)

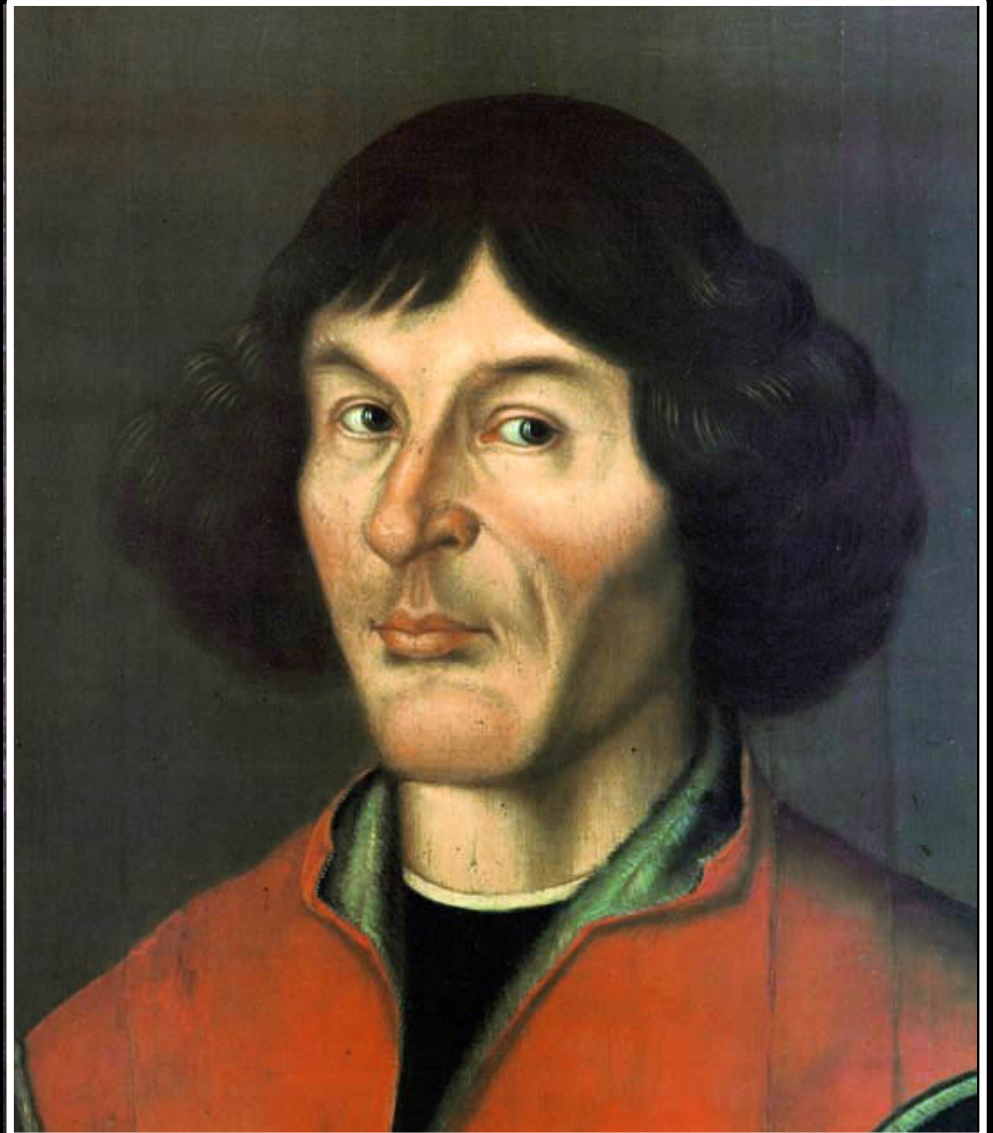
1514- **Commentariolus (Little Commentary)**  
1532 – finished work on Revolutionibus

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

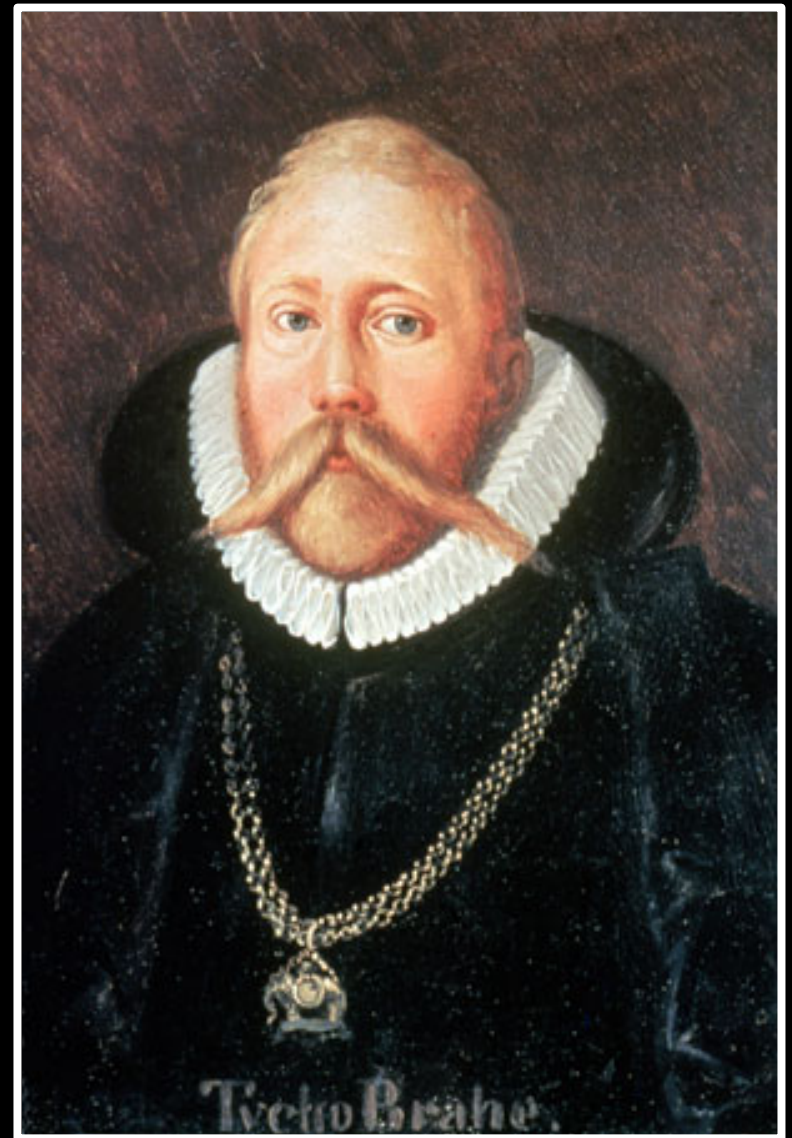
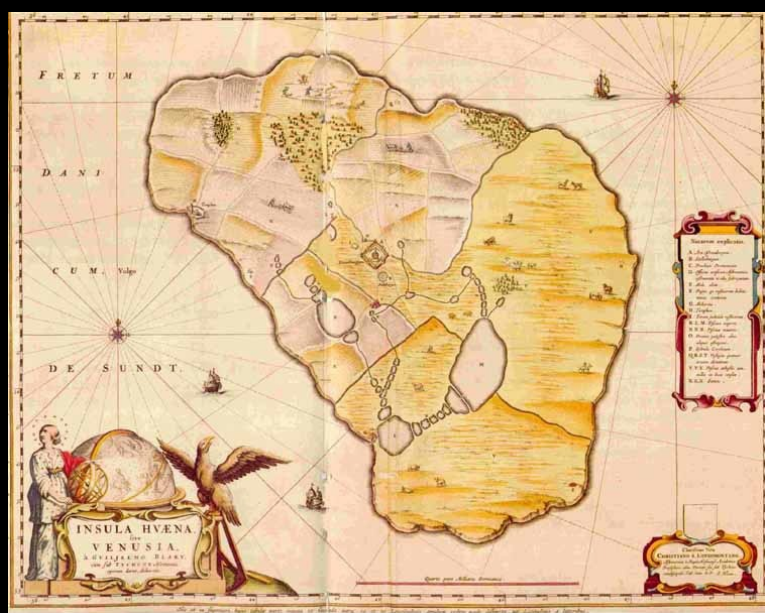
- printed by  
Johannes Petreius, Nuremburg

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.







# Tycho Brahe (1546-1601)

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

# Tycho Brahe (1546-1601)

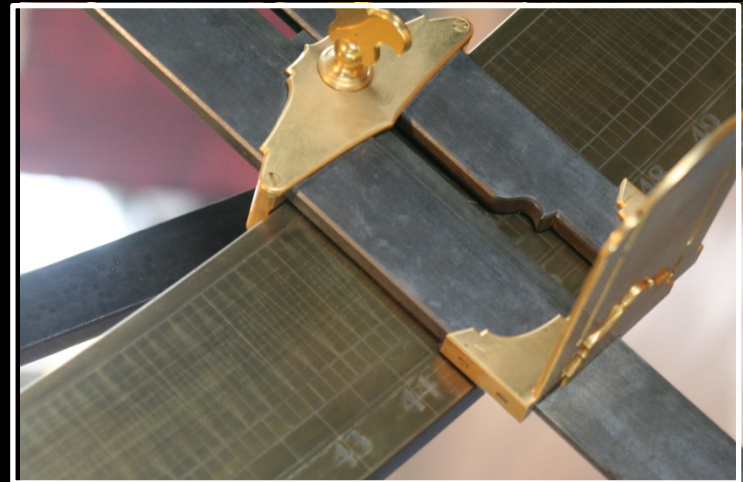


- Danish nobleman
- astronomer, astrologer, alchemist
- Observatory Uraniborg on island Hven
- Hven was his fiefdom
- entire island Hven devoted to exploitation for observatory
- Brahe famous for high  
+ accuracy  
+ quantity  
astronomical and  
planetary observations
- before telescope
- Key to Scientific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



Quadrant

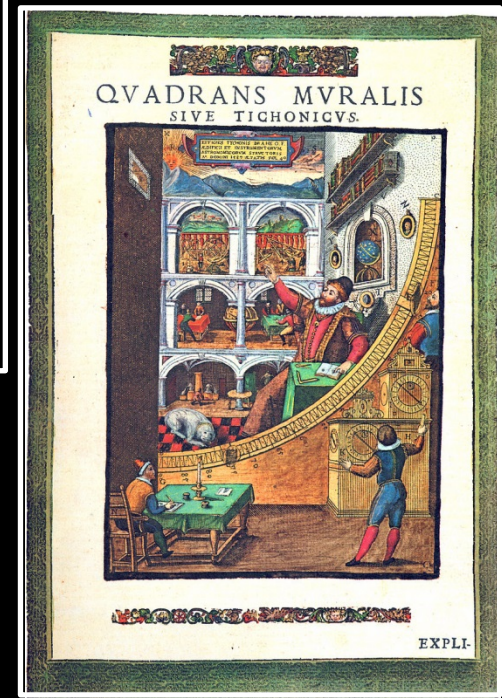
Achieved  
Accuracy  
~1'-2'



# Uraniborg

## Uraniborg

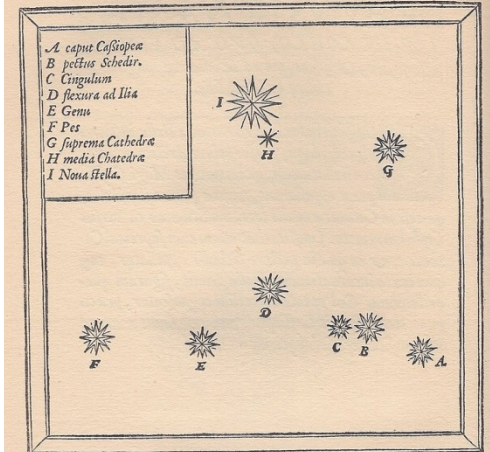
- Island Hven given to Tycho by Danish king Frederik II
- 1576:  
building of Uraniborg
- 1581:  
building of annex,  
Stjerneborg
- cellar Uraniborg:  
alchemy experiments
- 1576-1597  
~ 100 students & assistants
- research community in  
Research Center &  
Institution of Education



# 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

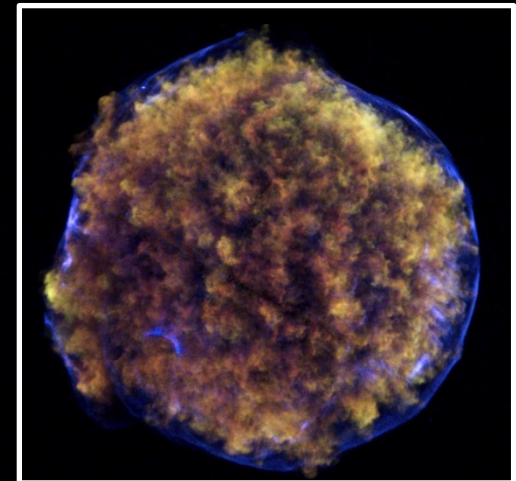


*Distantiam verò huius stelle à fixis aliquibus  
in hac Cassiopeie constellatione, exquisito instrumento,  
& omnium minorum capacj, aliquoties observaui. In-  
veni autem eam distare ab ea, quæ est in pectore, Schediv  
appellata B, 7. partibus & 55. minutis: à superiori  
verò*

Supernova remnant

SN<sub>1572</sub>  
Tycho's SNR (1572)

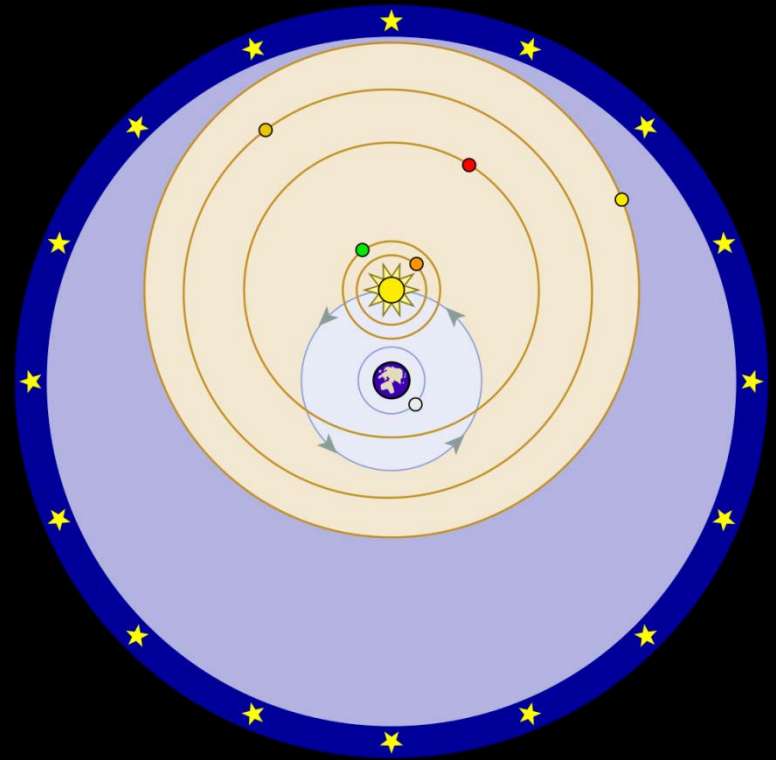
Exploding star



# Geo-Heliocentric Model

**Tycho did not accept the heliocentric view of Copernicus:**

- Observational data in 16th century were not good enough to prove it.
- 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

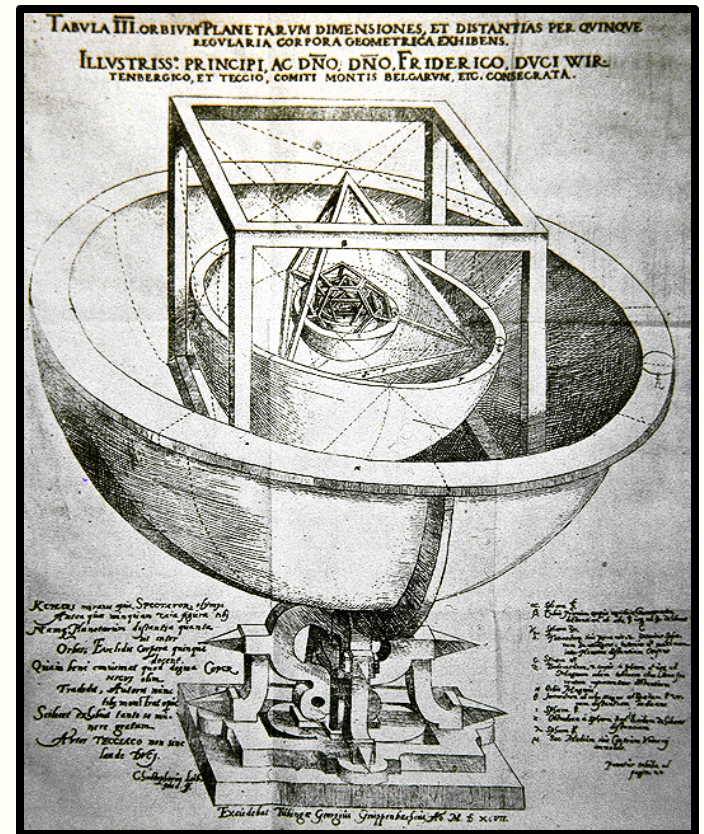


The analytical genius of Kepler gained access to the state of the art accurate observations of Tycho Brahe, opening up the path towards unravelling the laws of motion in the solar system.



# Johannes Kepler

(1571-1630)



Mysterium Cosmographicum



# Johannes Kepler (1571-1630)

## **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",<sup>1</sup>**

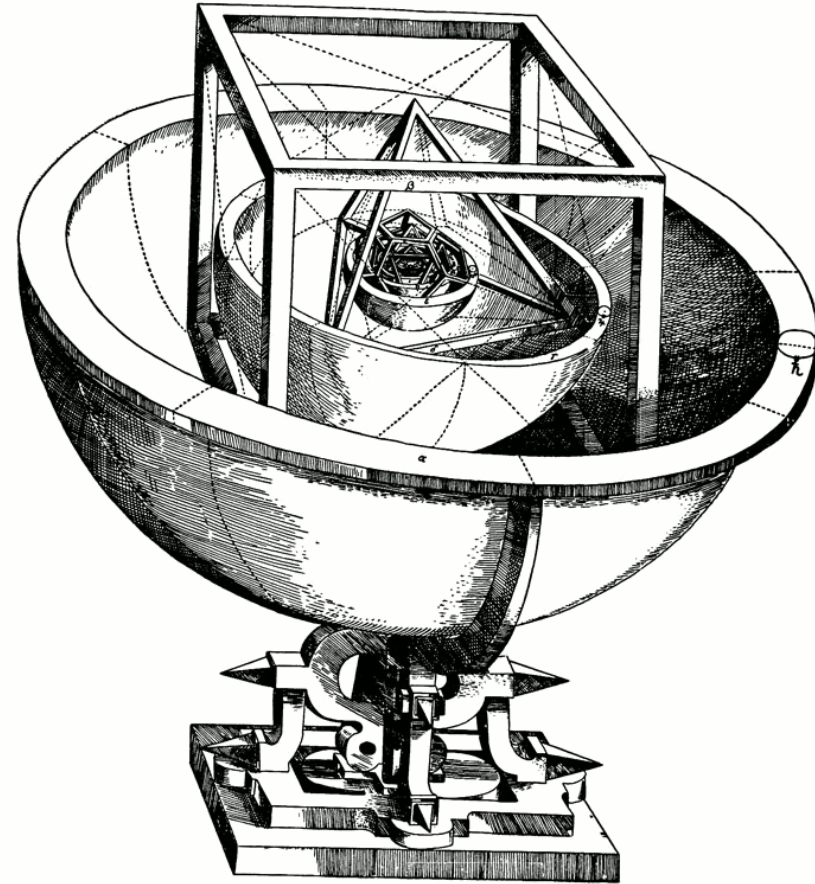
**transforming the ancient tradition of  
physical cosmology by treating astronomy  
as part of a universal mathematical physics.**



# Mysterium Cosmographicum

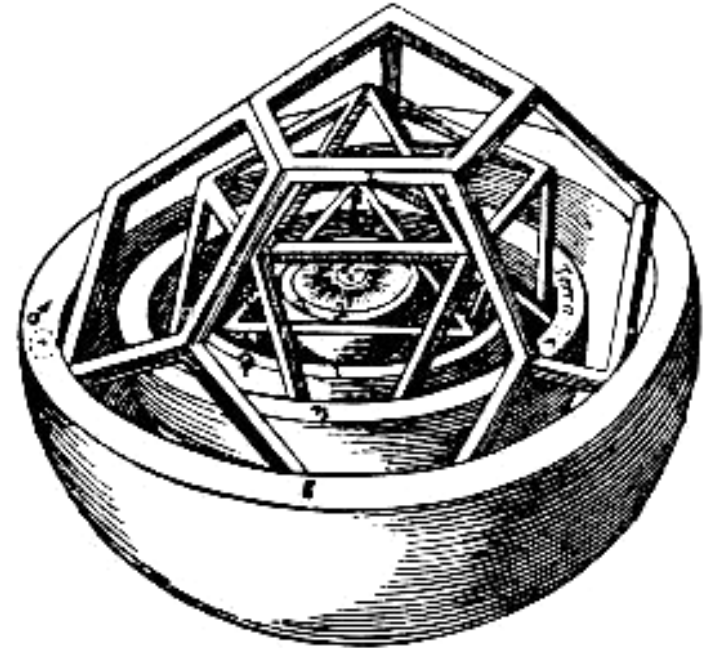
*Prodromus dissertationum cosmographicarum, continens mysterium cosmographicum, de admirabili proportione orbium coelestium, de que causis coelorum numeri, magnitudinis, motuumque periodicorum genuinis & proprijs, demonstratum, per quinque regularia corpora geometrica*

*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 Copernican system
- Published 1596
- Book explains Kepler's cosmological theory, based on the 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 the 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

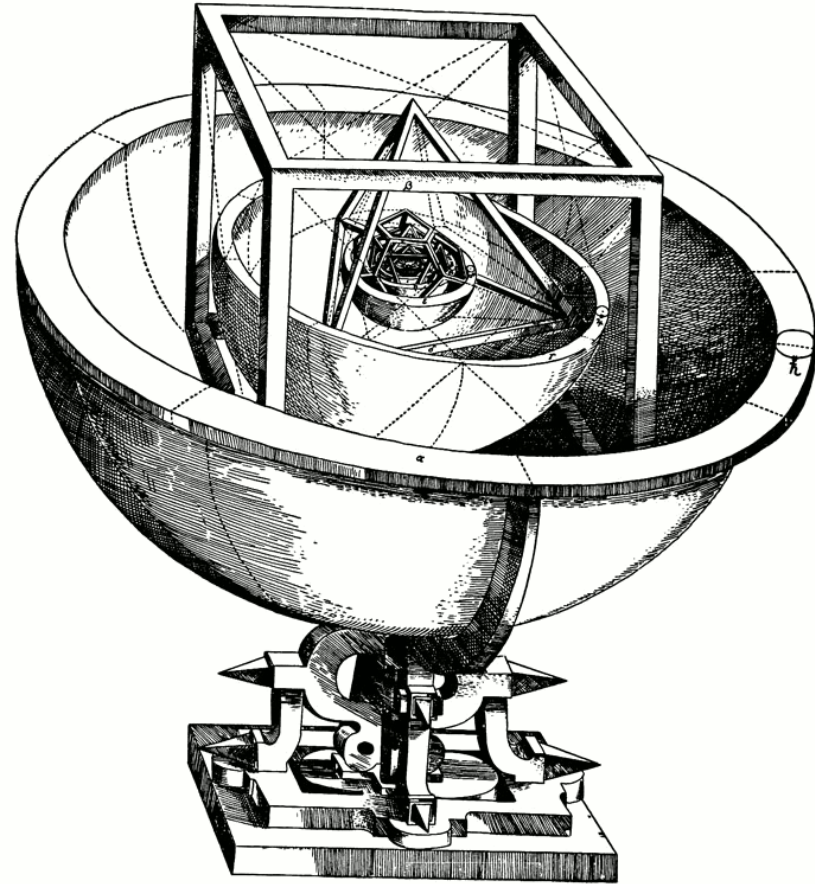
Kepler thought he had revealed

**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.<sup>1</sup>
- 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,

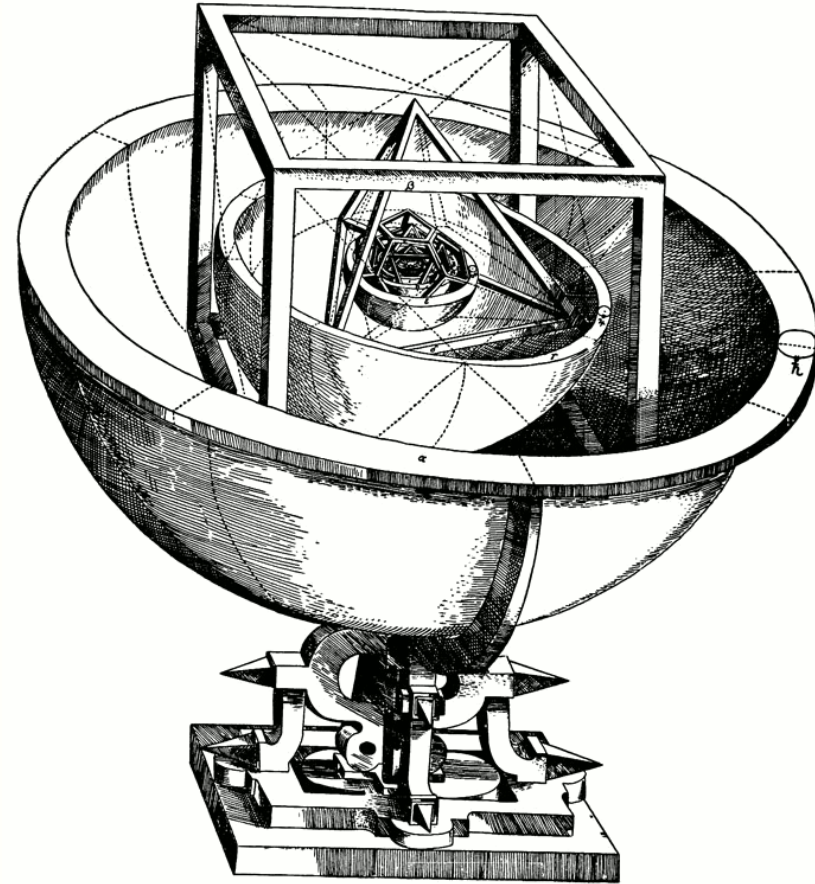


# Mysterium Cosmographicum

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*

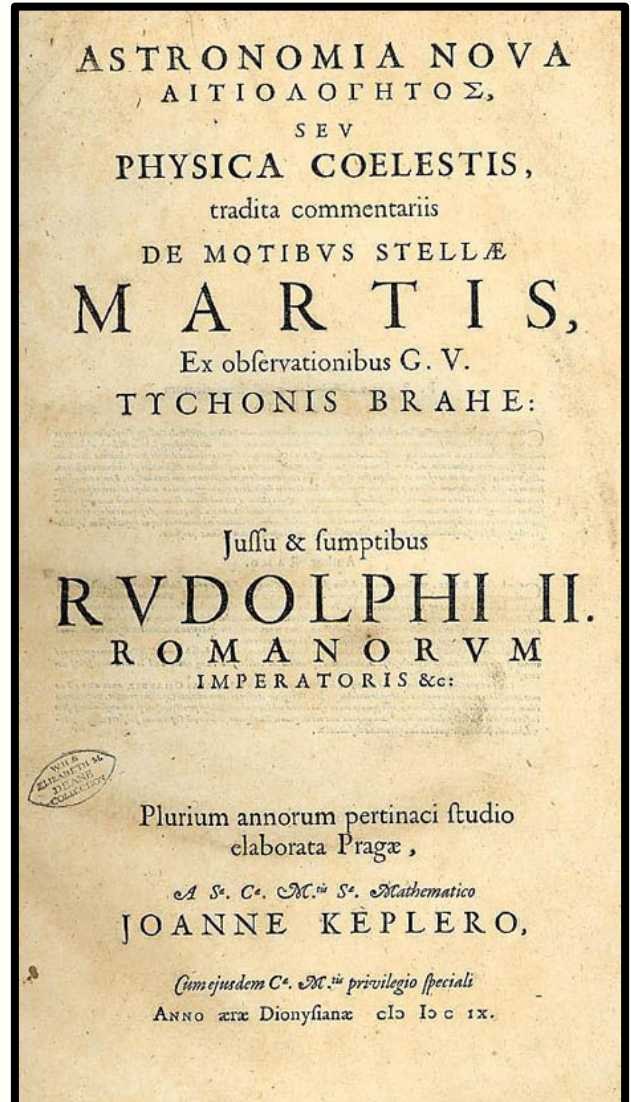
Published 1609

One of the most important works of the  
Scientific Revolution

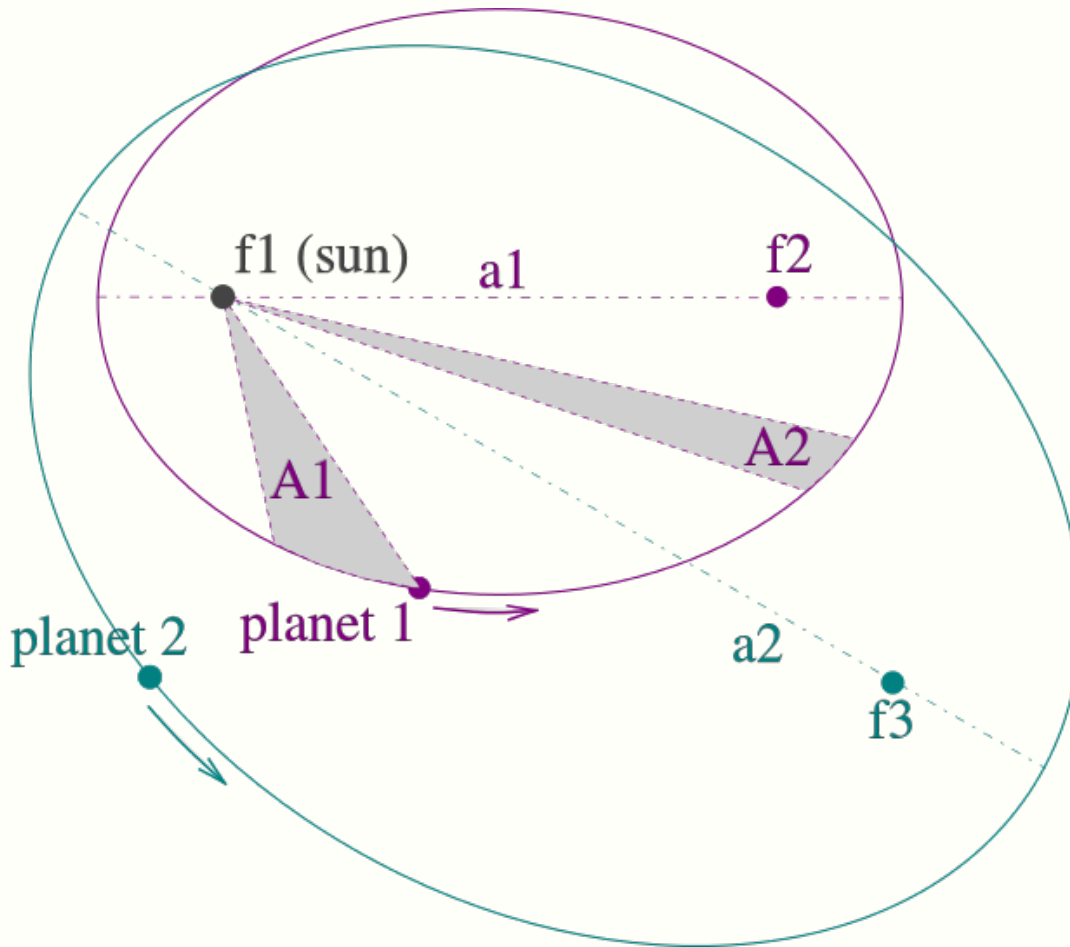
Reports Kepler's 10 year long investigation of  
motion of planet Mars.

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

- first 2 laws of Kepler



# Kepler Laws



## Kepler laws of planetary motion

1. *The orbit of a planet is an ellipse with the Sun at one of the two foci.*
2. *A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.*
3. *The **square of the orbital period** of a planet is proportional to **the cube of the semi-major axis** of its orbit.*

# Harmonices Mundi

- Harmony of the World
- Published 1619
- discusses harmony and congruence in geometrical forms and physical phenomena.
- Musical harmonies for arrangement heavenly bodies
- Final section: discovery of "third law of planetary motion."

Ioannis Kepleri  
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 solido:

Tertius proprie HARMONICVS, De Proportionum Harmonicarum ortu ex Figuris; deque Naturâ & Differentiis rerum ad eantum pertinentium, contra Veteres:

Quartus METAPHYSICVS, PSYCHOLOGICVS & ASTROLOGICVS, De Harmoniarum mentali Essentiâ earumque 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 Harmonicis Cl. Ptolemæi libro II I, cumque Roberti de Fluctibus, dicti Flud. Medici Oxoniensis speculationibus Harmonicis, operi de Macrocosmo & Microcosmo insertis.



Cum S. C. M<sup>o</sup>. Priuilegio ad annos XV.

Linçii Austriae,

Sumptibus GODOFREDI TAMPACHII Bibl. Francof.  
Excudebat IOANNES PLANGVS.

ANNO M. DC. XIX.

1<sup>st</sup> Edition 1619  
6 plates on 5

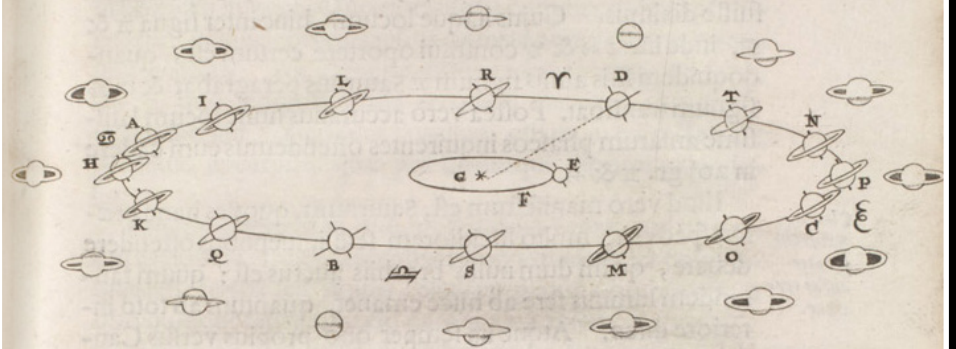
# Christiaan Huygens

(1629-1695)

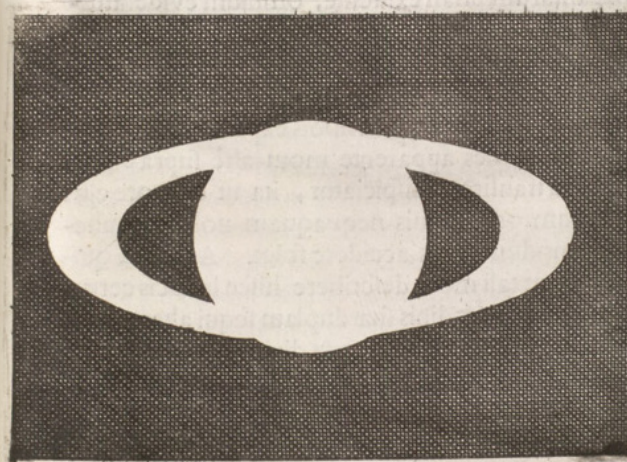




# Huygens & Saturn

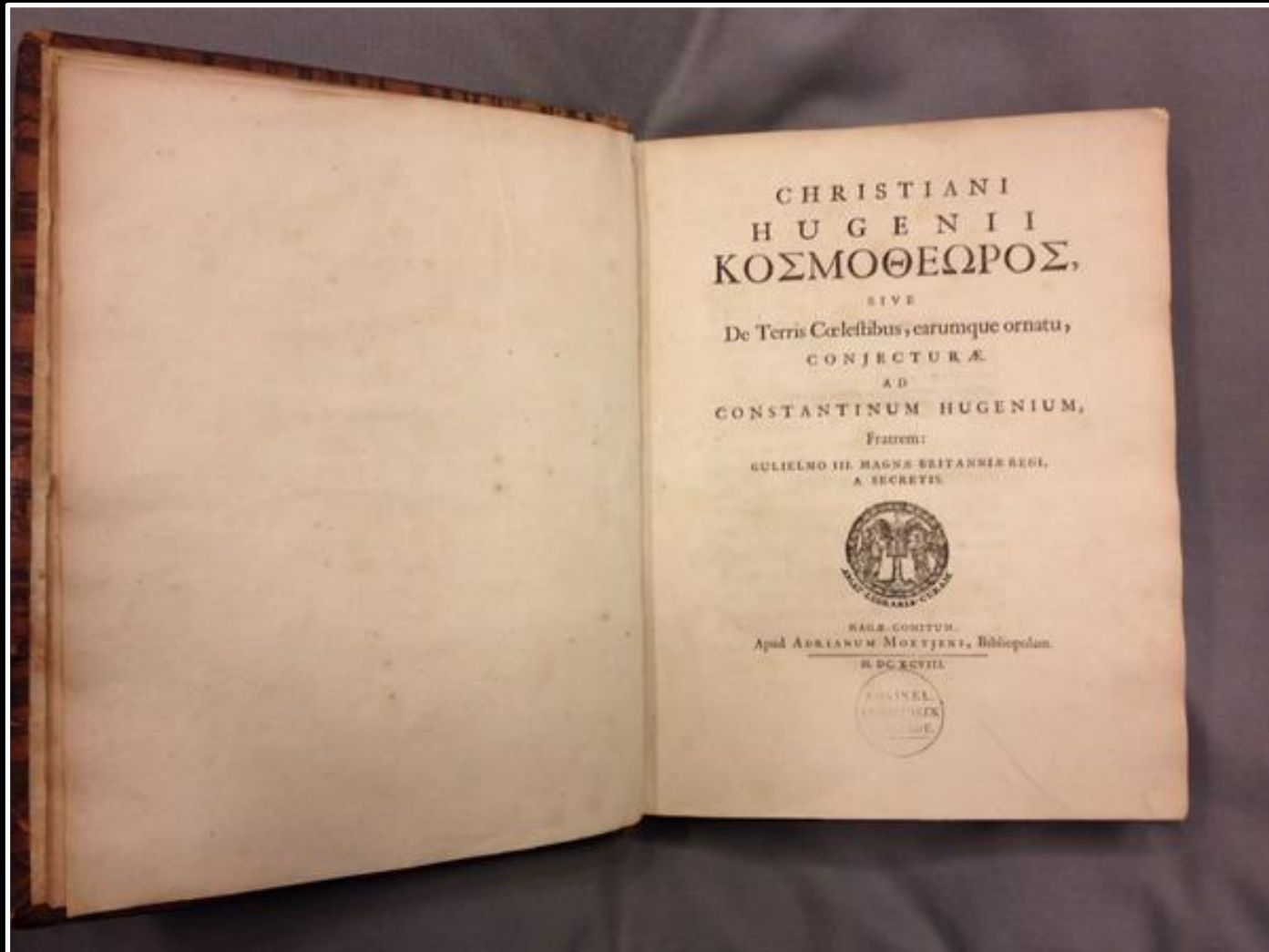


Cujus phaseos vera proinde forma, secundum ea quæ supra circa annulum definivimus, ejusmodi erit qualis hîc delineata cernitur, majori ellipsis diametro ad minorem se habente fere ut 5 ad 2.



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)





# 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



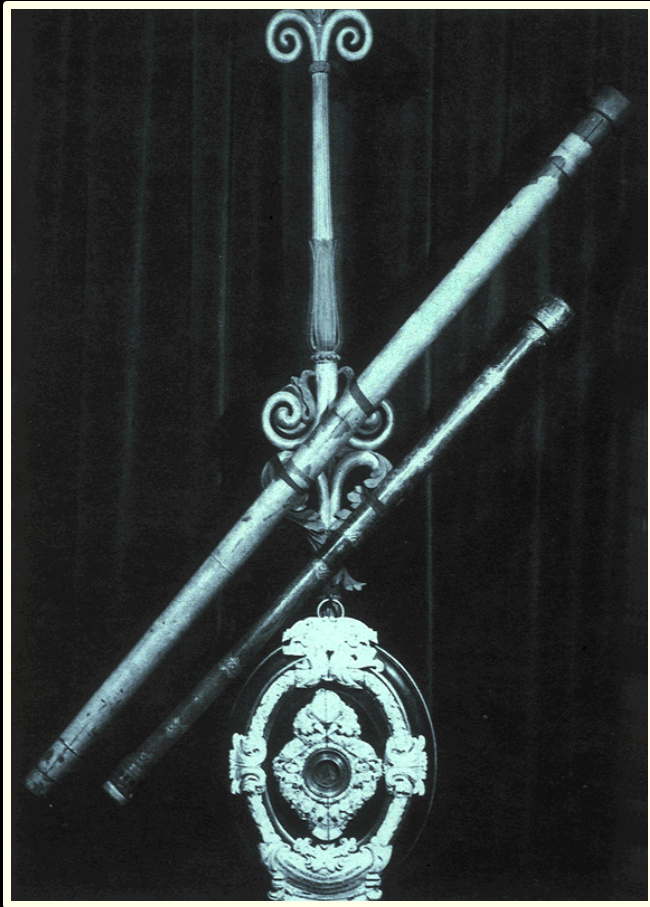
VILEGI.

IN FIORENZA, Per Gio:Batista Landini MDCXXXII.

CON LICENZA DE' SUPERIORI.

# Galileo Galilei

(1564-1642)



Moon:  
surface valleys & hills

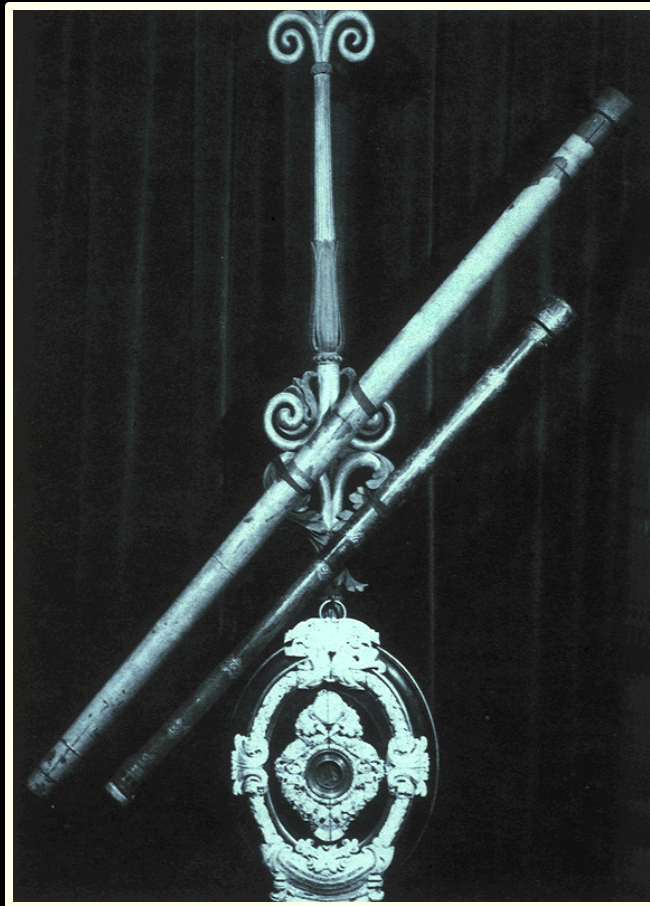


Observations January  
1870

2. J. J. J.	0 **
30. moon	** 0 *
2. J. J. J.	0 ** *
3. moon	0 ** *
3. H. J.	* 0 *
4. moon	** 0 **
6. moon	** 0 *
8. moon H. 17.	* ** 0
10. moon	* * * 0 *
11.	* * 0 *
12. H. J. J.	* 0 *
17. moon	* ** 0 *
14. J. J. J.	* * * 0 *
15.	* * 0
16. J. J. J.	* 0 ** *
17. J. J. J.	* 0 * *
18.	* 0 * * *
21. moon	* * 0 * *
24.	* * 0 . *
25.	* * 0 *
29. J. J. J.	** 0
30. moon	** 0 *
January 4. moon	* * 0 *
4. J. J. J.	** 0 *
5.	* * 0 *
6.	* 0 **
7	* 0 * * * note: note: note: in reach of year.
7. J. J. J.	* 0 **
11.	* * * 0

# Galileo Galilei

(1564-1642)



Galilean  
Moons:

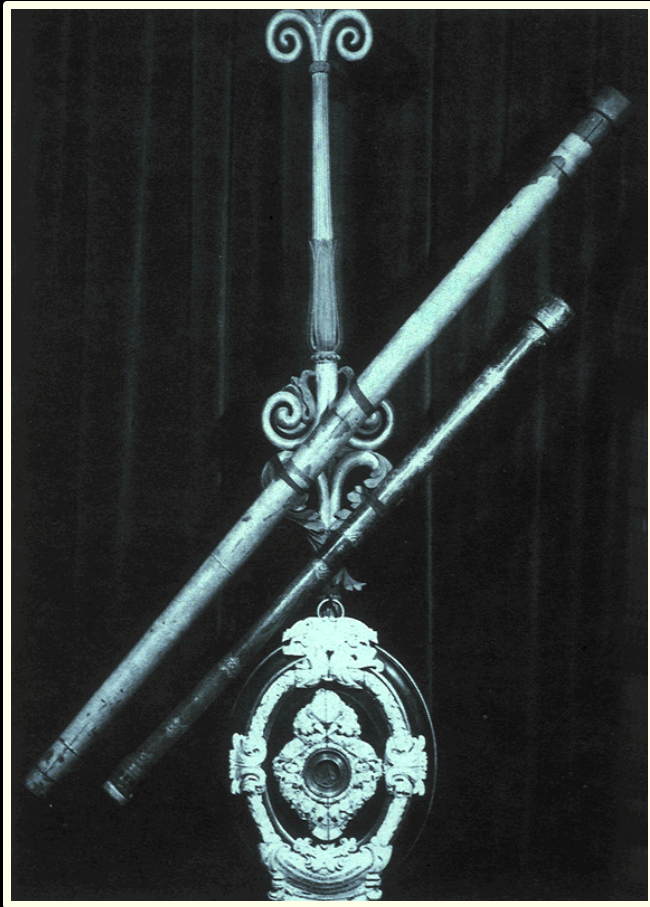
Europa  
Ganymedes  
Callisto  
Io

*Observationes Sidierum*  
1610

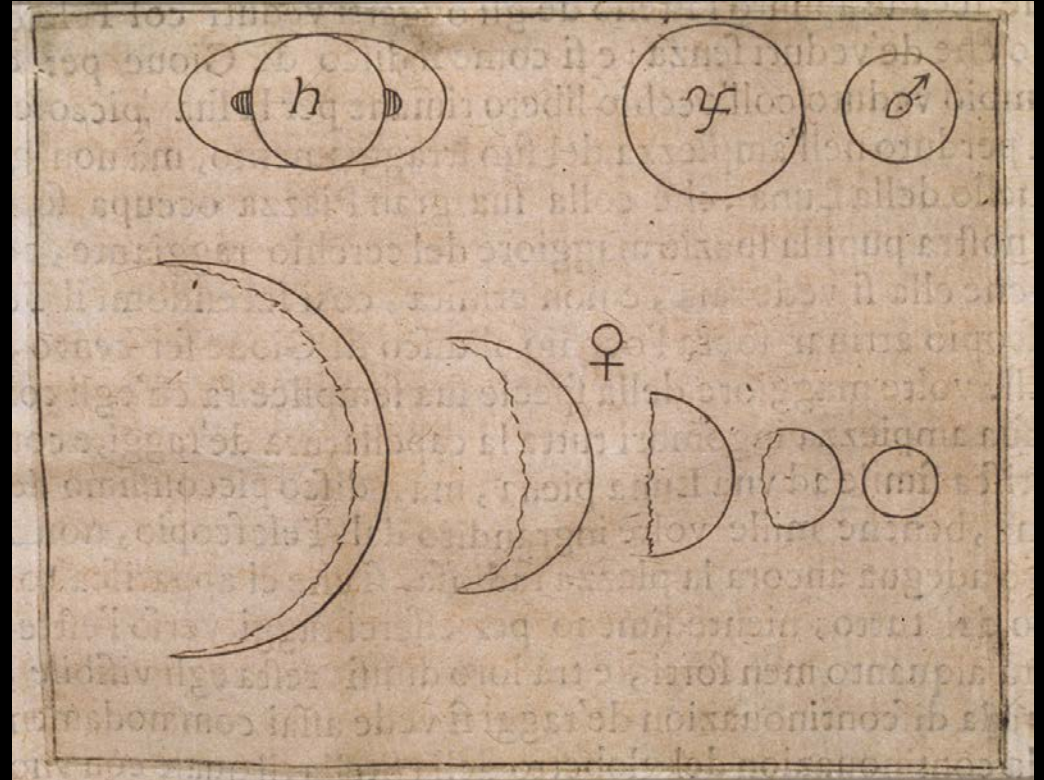
2. Jovis maior H. 12	0 **
30. Jovis	** 0 *
2. Jovis	0 ** *
3. Jovis	0 * *
3. H. J.	** 0 *
4. Jovis	** 0 **
6. Jovis	** 0 *
8. Jovis H. 17.	* * * 0
10. Jovis	* * * 0 *
11.	* * 0 *
12. H. Jovis	* 0 *
17. Jovis	* ** 0 *
14. Jovis	* * * 0 *
15.	* * 0
16. Jovis	* 0 * * *
17. Jovis	* 0 * *
18.	* 0 * * *
21. Jovis	* * 0 * *
24.	* * 0 . *
25.	* * 0 *
29. Jovis	** 0
30. Jovis	** 0 *
January 4. Jovis	* * 0 *
4. Jovis	** 0 *
5.	* * 0 *
6.	* 0 **
7.	* 0 * * * <small>maior motu no. apparent in rebus &amp; rari.</small>
7. Jovis	* 0 **
11.	* * * 0

# Galileo Galilei

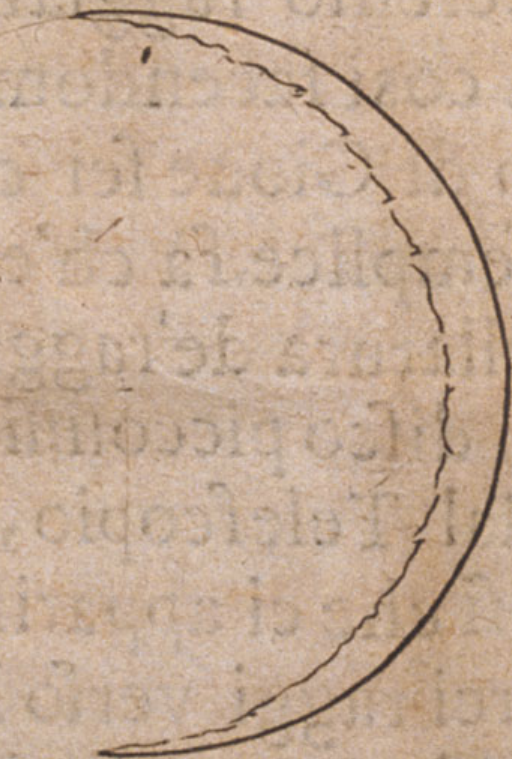
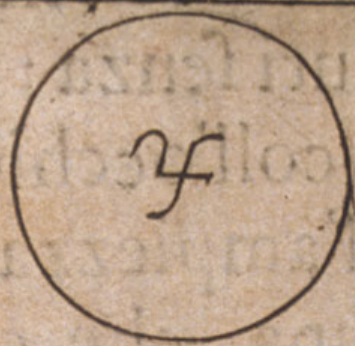
(1564-1642)



Phases of Venus

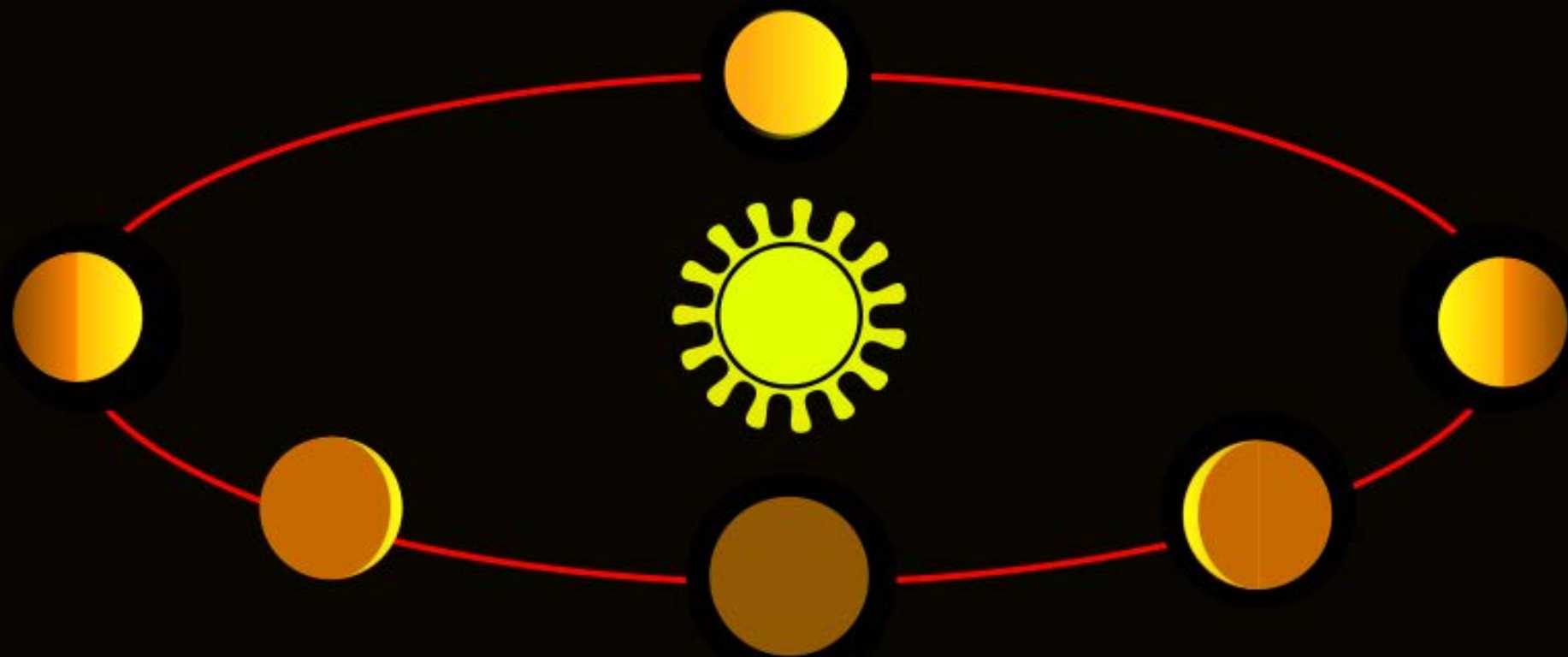






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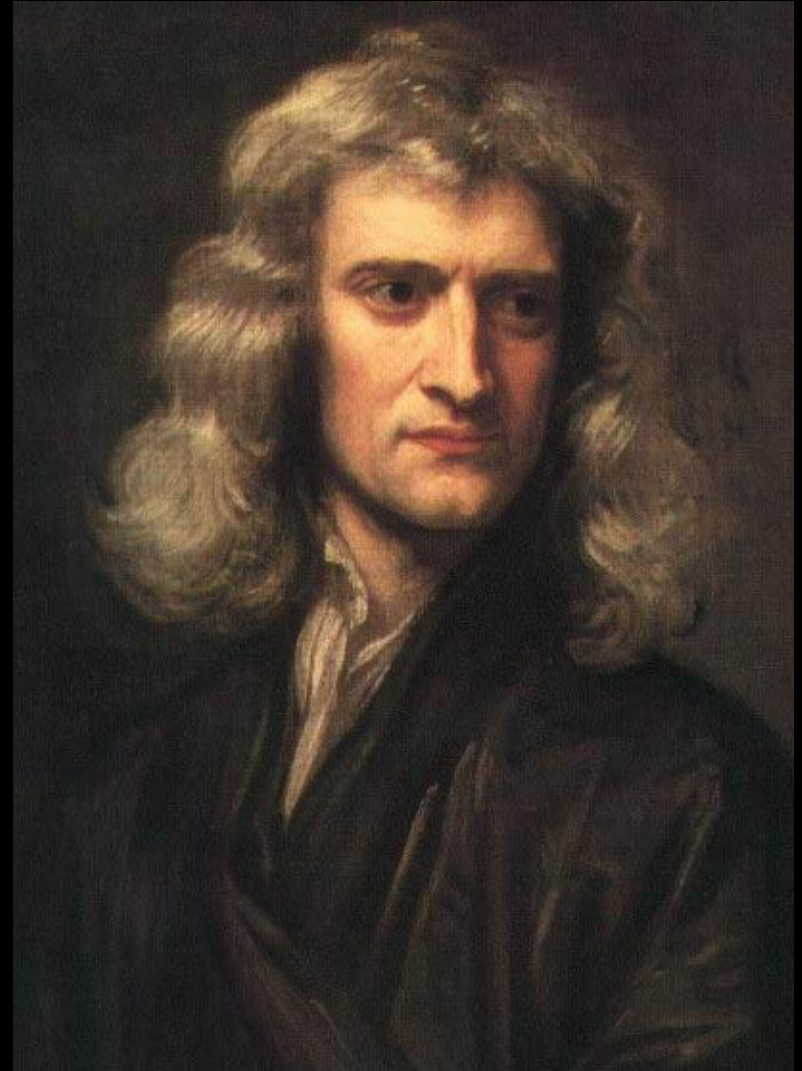


**EARTH**

# Isaac Newton

(1643-1727)

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



PHILOSOPHIÆ  
NATURALIS  
PRINCIPIA  
MATHEMATICA.

<sup>auto</sup> <sup>Equite furoto,</sup>  
Autore J. S. NEWTONI <sup>Trin. Coll. Cantab. Soc. Matheseos</sup>  
<sup>^</sup> Professore <sup>Lucasiano,</sup> & Societatis Regalis Sodali.  
<sup>et Societatis Regie Societatis præsida.</sup>

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

LONDINI,

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

Isaac Newton

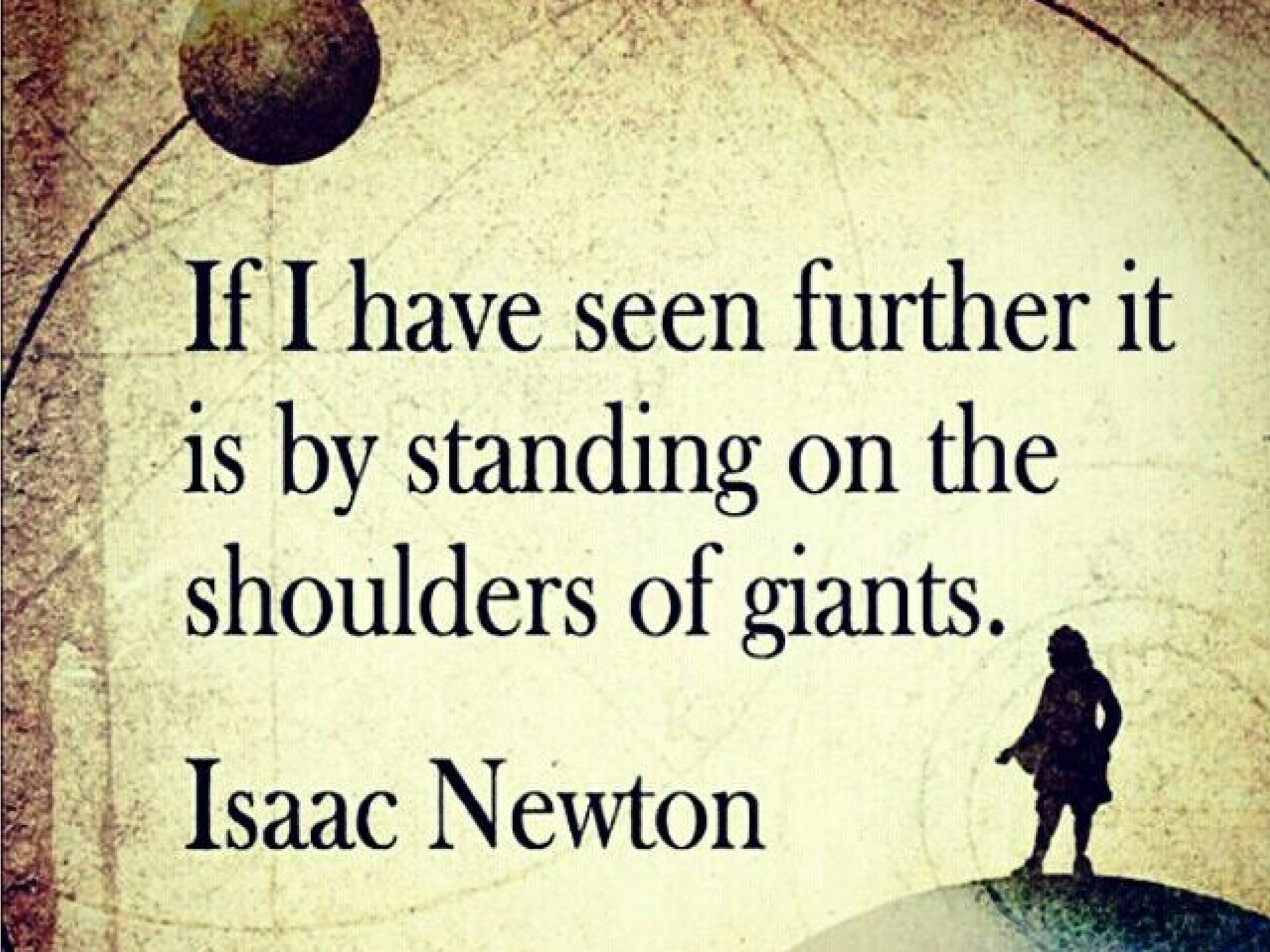
(1642-1726)

# Isaac Newton



**Birthhouse  
Woolshorpe**





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

Isaac Newton