## 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 an studies of Islamic scholars
- most popular astronomical tables for 300 years (incl. Copernicus)

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### 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."

#### • 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 Ptolemiac geocentric model.

### The Scientific Revolution:

### Mechanization of the Universe

1609/1619
 Johannes Kepler

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- 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)

•	<ul> <li>1576</li> <li>Thomas Digges</li> <li>Following his statement of an infinite universe, filled with an infinite number of stars, Digges is the first to identiy the "dark night sky paradox".</li> </ul>
•	<ul> <li>1610</li> <li>Johannes Kepler</li> <li>Letter to Galilei (1610)</li> <li>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.")</li> </ul>

#### • 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 Copepnicus (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

. There is no one center of all the celestial circles or spheres.

6.

- 2. The center of the earth is not the center of the universe, but only of gravity and of the lunar sphere.
  - All the spheres revolve about the sun as their midpoint, and therefore the sun is the center of the universe.
    - 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.
    - 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.
    - 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.
    - 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

NICOLAT COPERNICI T RINENSIS DE REVOLVTIO bus orbium cœleftium, Libri VI

IN QVIBVS STELLARVM E KARVM ET ERRATICARVM MOTVS, EX ribus atg recentibus obferuationibus, refittuic h Præterea tabulas expeditas luculentasig addidit bus eofdem motus ad quoduis tempus Mat matum frudiofus facillime calcus lare poterit.

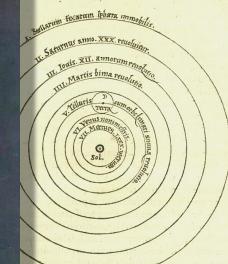
ITEM, DE LIBRIS REVOLVTIONVM NIC Copernici Natratio prima, per M. Georgium Ioac mum Rheticum ad D. Ioan. Schonerum Cripta.



Cum Gratia & Privilegio Carl Maieft. BASILEAE, EX OFFICINA HENRICPETRINA

#### NICOLAI COFERNICI

ram cum orbe lunari tanquam epicyclo contineri into loco Venus nono menfe reducitur. Sextum Mercurius tenet, octuaginta dierum fpacio circu idio uero omnium refidet Sol. Quis enim in hoc



emplo lampadem hanc in alio uel meliori loco po nde totum fimul polsit illuminare: Siquidem non n lucernam mundi, ali mentem, ali rectorem uoiftus uifibilem Deum, Sophoclis Electra intuente ofecto tanquam in folio re gali Sol refidens circum ernat Aftrorum familiam. Tellus quocp minime ari minifterio, fed ut Ariftoteles de animalibus una cu terra cognatione habet, Concipit interea à impregnatur annuo partu, Inuenimus igitur fub hac

# **Orbium Coelestium**



# Nicolaus Copernicus

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

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

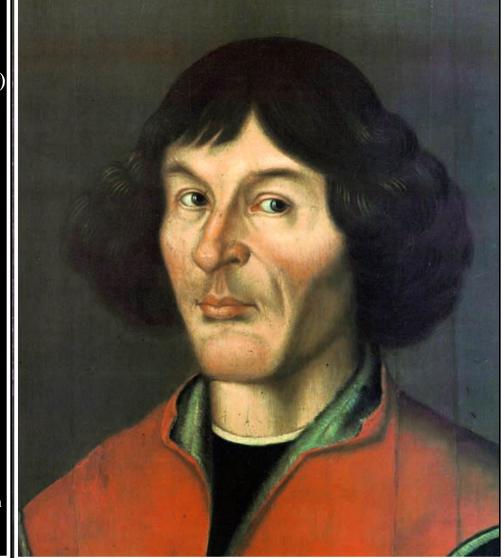
1543 - publication pushed and processed by George Joachim Rheticus (mathematician Wittenberg)

- printed by Johannes Petreius, Nuremburg

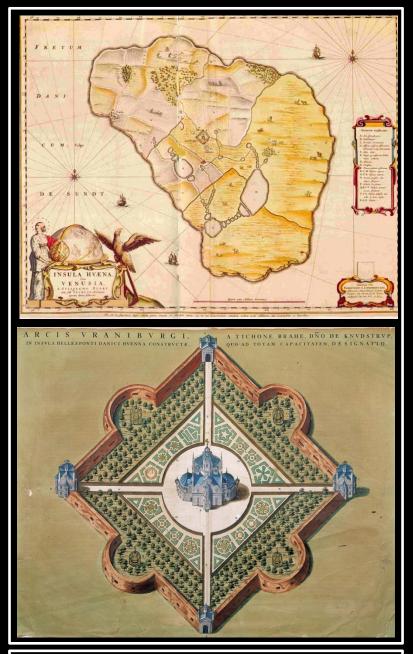
May 24, 1543 - death Copernicus - legend: presentation last pages printed Revolutionibus

Note:

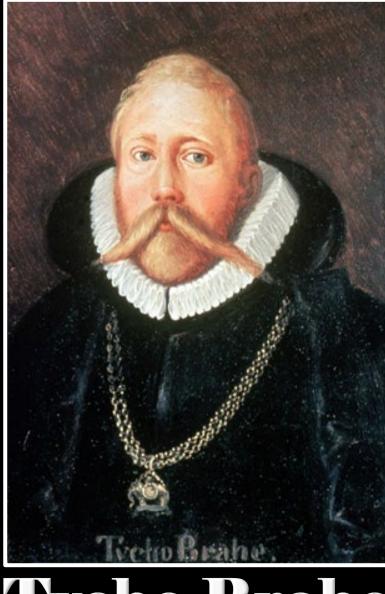
Copernicus cited Aristarchus of Samos in an early (unpublished) manuscript of De Revolutionibus (which still survives), though he removed the reference from his final published manuscript.



### Nikolaus Copernicus (1473-1543)



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



### **Tycho Brahe** (1546-1601)



### 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
   + acccuracy
   + quantity
   astronomical and
   planetary observations
- before telescope
- Key to Scientific Revolution

Quadrant Achieved Accuracy ~1'-2'





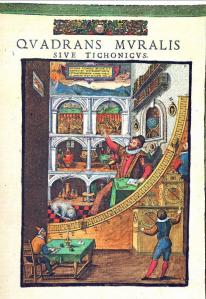


### Uraniborg

#### 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





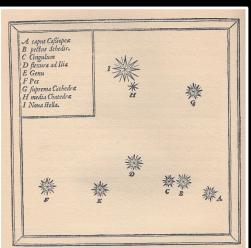
EXPLI-



### 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 hindisight 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

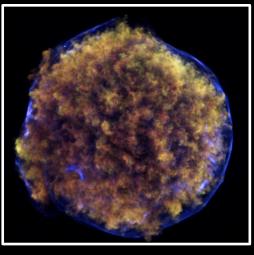


Distantiam verò huius Stelle à fixis aliquibus in hac Cassiopeie constellatione, exquisito instrumento, & omnium minutorum capaci, aliquoties observaui. Inueni autem eam distare ab ea, quæ est in pectore, Schedir appellata B, 7. partibus & 55. minutis : à superiori verò

Supernova remnant

SN1572 Tycho's SNR (1572)

**Exploding star** 

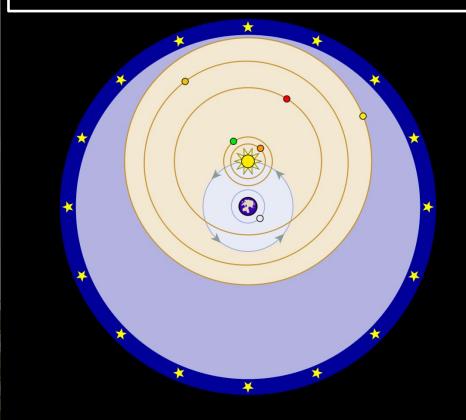




### **Geo-Heliocentric Model**

### Tycho's Geo-Heliocentric Model:

- Sun circles the Earth
- Planets circle the Sun

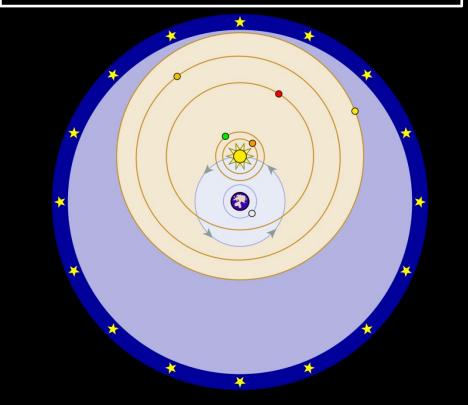




### **Geo-Heliocentric Model**

#### 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 eliminited the ancient (Aristotelean) idea of heavely 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:

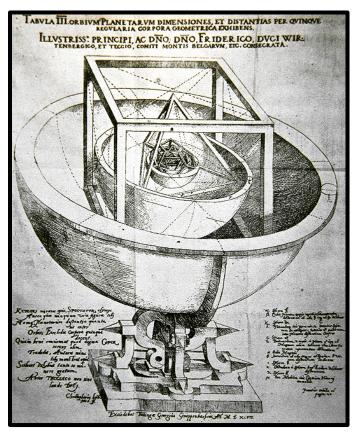
- move to the German imperial court in Prague (following tensions with new Danish king Christian IV)
- meeting up with (young) Johannes Kepler



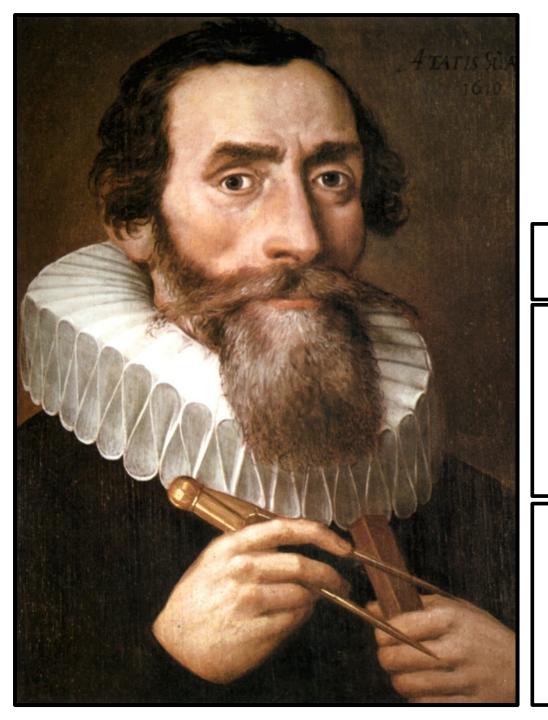
The analytical genius of Kepler gained access to the state of the art accurate observations of Tycho Brahe, opening up the path towards unravelling the laws of motion in the solar system.



## Johannes Kepler (1571-1630)



### Mysterium Cosmographicum



## Johannes Kepler (1571-1630)

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

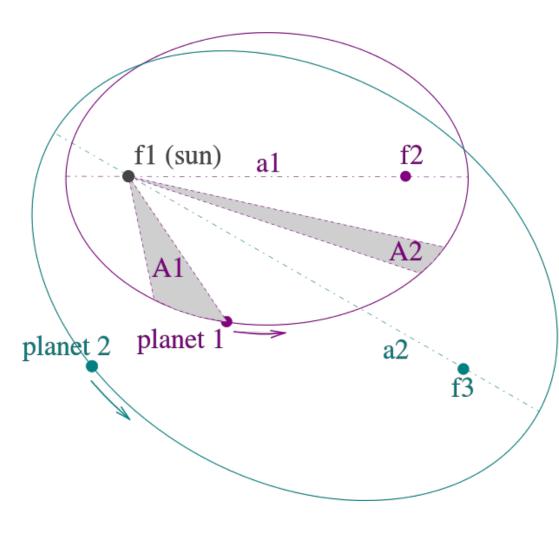
In his 3 books he established an entirely new, revolutionary, look on the workings of the Universe, the cosmology of Kepler,

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.

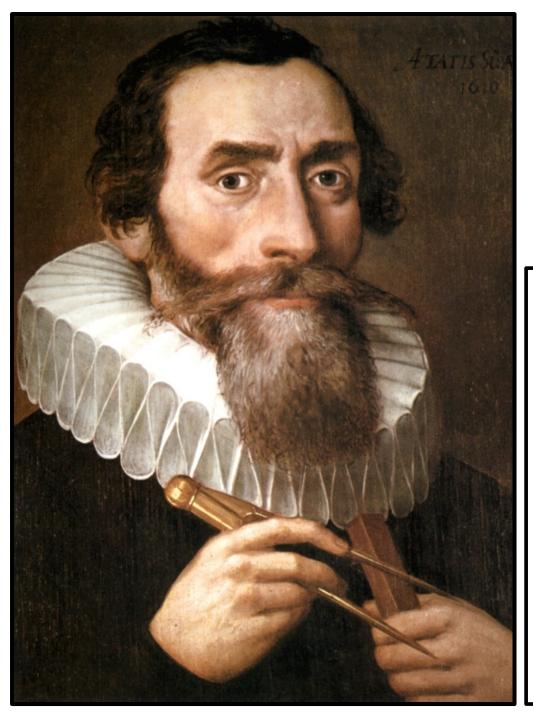
2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of ime.

(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

 $T^2/a^3=const.$ 



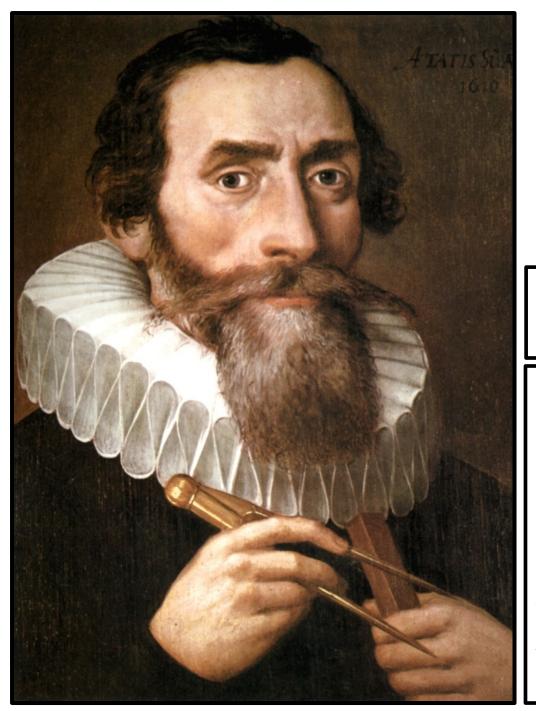
## Johannes Kepler (1571-1630)

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",

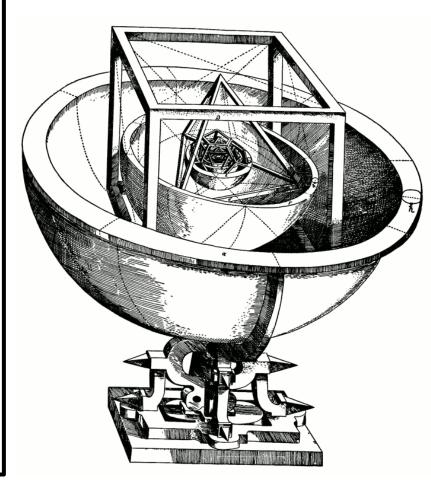
as "an excursion into Aristotle's Metaphysics", and as "a supplement to Aristotle's On the Heavens",<sup>[</sup>

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

# **Mysterium Cosmographicum**

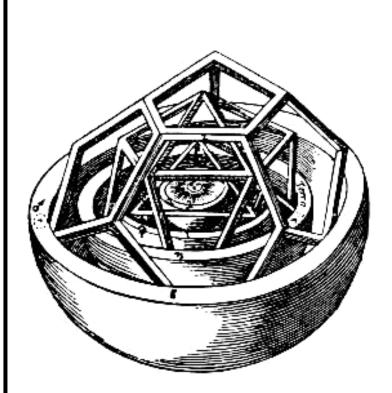
Prodromus dissertationum cosmographicarum, continens mysterium cosmographicum, de admirabili proportione orbium coelestium, de que causis coelorum numeri, magnitudinis, motuumque periodicorum genuinis & proprijs, demonstratum, per quinque regularia corpora geometrica

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 of Copernican system
- published 1596 (at age 26 !)
   2<sup>nd</sup> 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

### <u>Mysterium Cosmographicum</u>



# **Mysterium Cosmographicum**

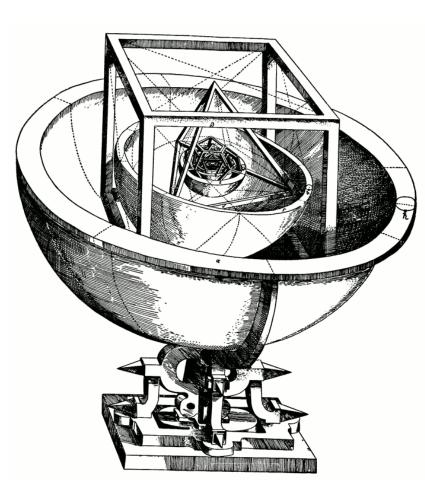
### Kepler thought he had revealed

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>[</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,

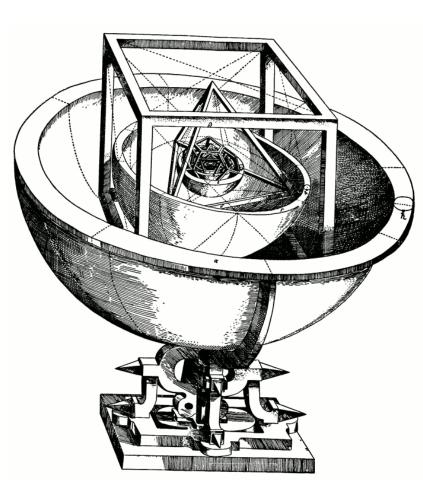


# **Mysterium Cosmographicum**

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 AITIOΛΟΓΗΤΟΣ seu physica coelestis, tradita commentariis de motibus stellae Martis ex observationibus G.V. Tychonis Brahe

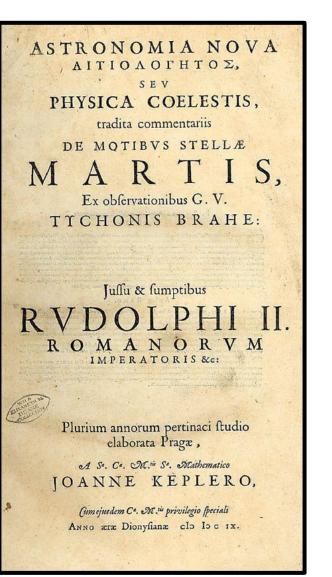
Published 1609

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



## Astronomia Nova

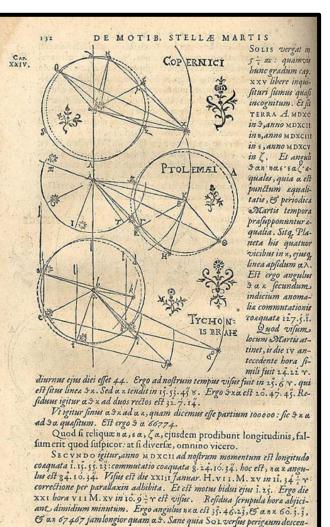
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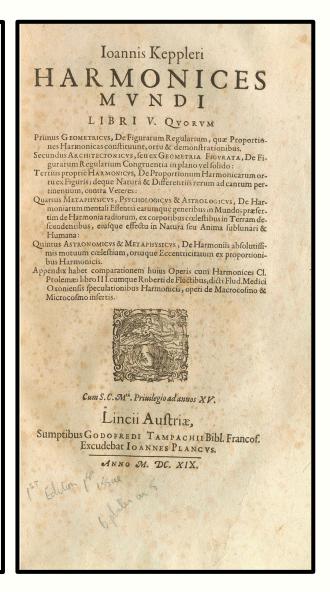
(planets do not move with uniform speed along their orbit).



dit , ET

## 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)

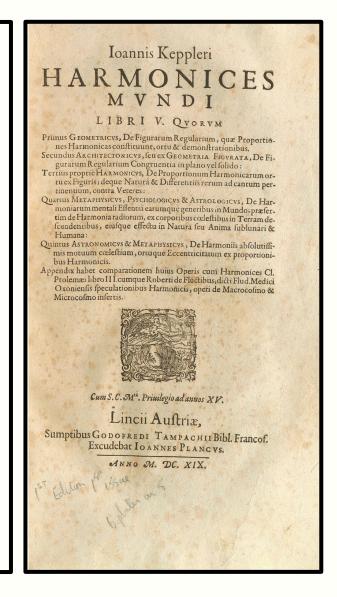


## Harmonices Mundi

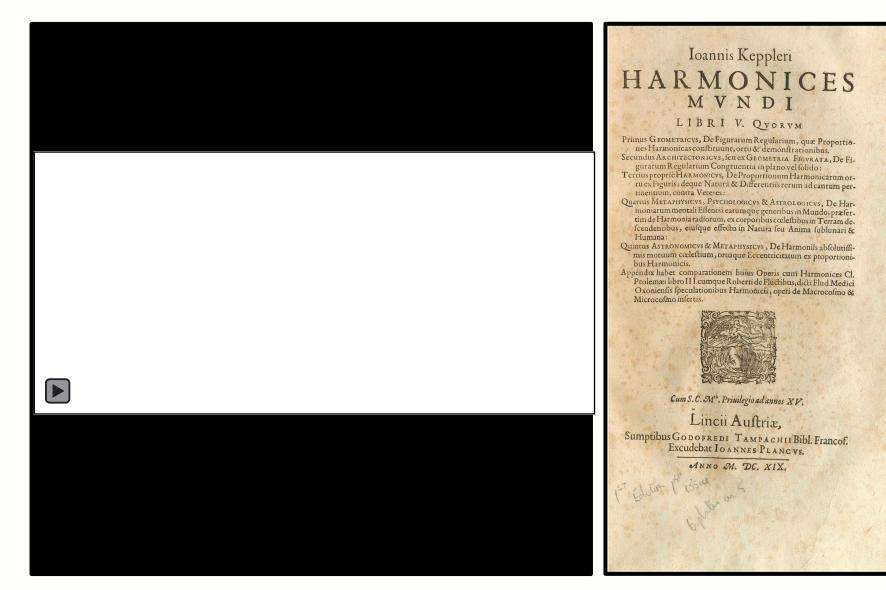
- Harmony of the World
- Published 1619
- Musical harmonies for arrangement and motion of heavenly bodies
- Celestial choir:

soprano	
alto	
alto	
tenor	
tenor	
bass	

- Mercury large elliptical orbit
  - greatest number of notes
- Venus orbit nearly a circle
  - only a single note



## Harmonices Mundi

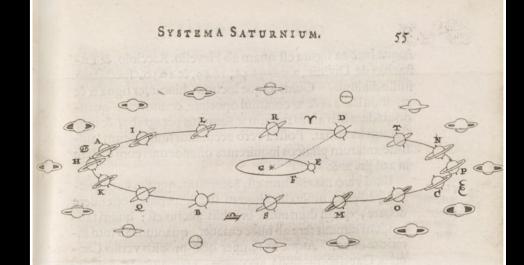


## Christiaan Huygens

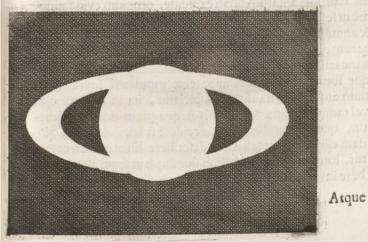
#### $(16\overline{29}-1695)$



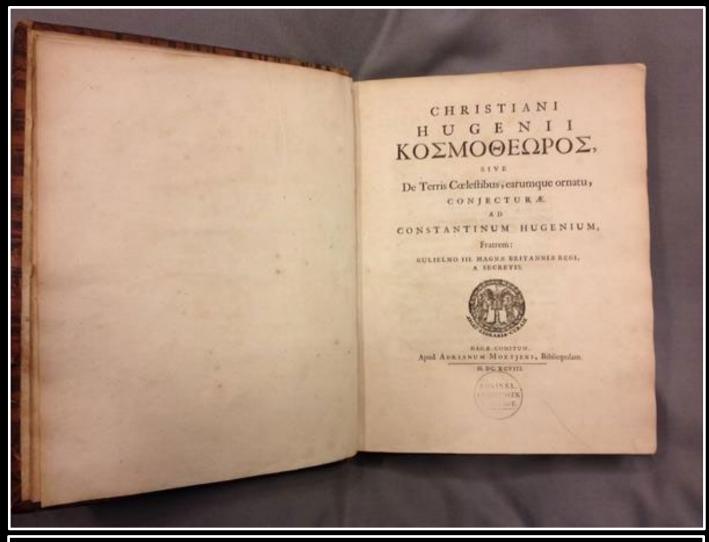




Cujus phaseos vera proinde forma, secundum ea quæ supra circa annulum definivimus, ejus modi erit qualis hîc delineata cernitur, majori ellipsis diametro ad minorem se habente fere ut 5 ad 2.



## Cosmotheoros



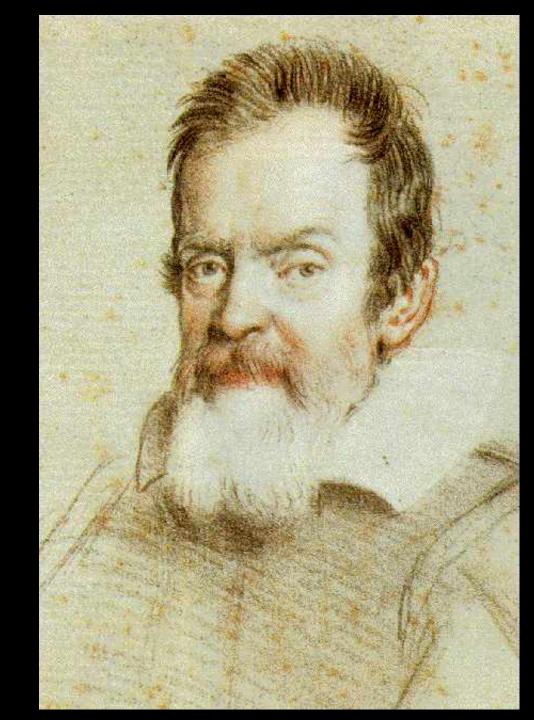
#### 1695-1698:

- 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)

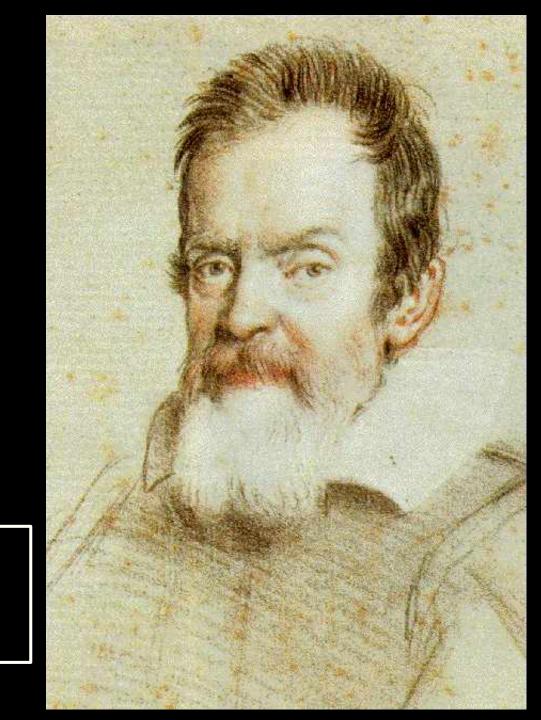
## (Pisa-Arcetri)



# Galileo Galilei

## (1564-1642)

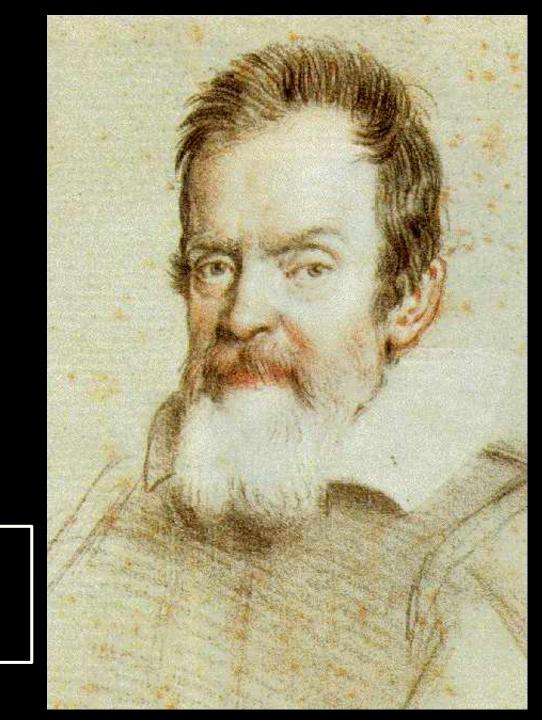
father of observational astronomy father of modern physics father of scientific method



# Galileo Galilei

## (1564-1642)

astronomer, physicist, engineer, philosopher, mathematician



## Telescope (1609)

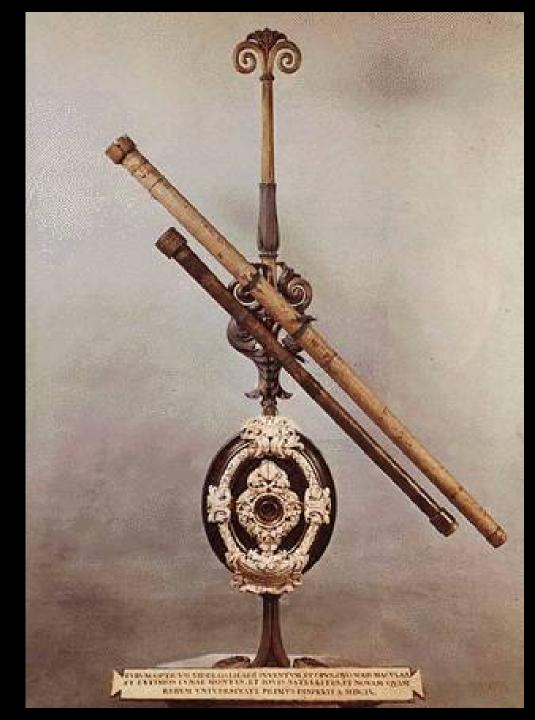
Following vague descriptions of the patent for a telescope by Lippershey in the Netherlands (1608),

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.

SIDEREVS NVNCIVS

MAGNA, LONGEQVE ADMIRABILIA Spectacula pandens, sufpiciendaque proponens vnicuique, præsertim vero

PHILOSOPHIS, atá ASTRONOMIS, qua à GALILEO GALILEO PATRITIO FLORENTINO Patauini Gymnafij Publico Mathematico

PERSPICILLI Nuper à se reperti beneficio sunt observata in UNAFACIE, FIXIS IN-NUMERIS, LACTEO CIRCULO, STELLIS NEBULOSIS, Apprime verd iu

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MEDICEA SIDERA NVNCVPANDOS DECREVIT.



VENETIIS, Apud Thomam Baglionum. M DC X. Superiorum Permilju, & Prinilegio. M VIIII: 22.14.

#### SIDEREVS NVNCIVS MAGNA, LONGEQVE ADMIRABILIA Spectacula pandens, suspiciendaque proponens vnicuique, præsertim vero PHILOSOPHIS, atg. ASTRONOMIS, que à GALILEO GALILEO PATRITIO FLORENTINO Patauini Gymnafij Publico Mathematico PERSPICILLI Nuper à se reperti beneficio sunt observata in LVN & FACIE, FIXIS IN-NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS, Apprime verò in OVATVOR PLANETIS Circa IOVIS Stellam disparibus internallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc víque diem cognitos, nouifime Author depræhendit primus; atque VPANDOS DECRE

VENETIIS, Apud Thomam Baglionum. M D C X. Superior nm Permilju, & Prinilegio.

VIII. 12. 14.

#### Contents:

- 70 drawings of
- Moon: real world of valleys & mountains
- Orion
  - Pleiades: > 10 x number of stars
    - Taurus than visible by eye
- 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:
  - soid 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









## Galilean Moons of Jupiter:

Ganymedes, lo, Callisto, Europa

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## **Galilean Moons**

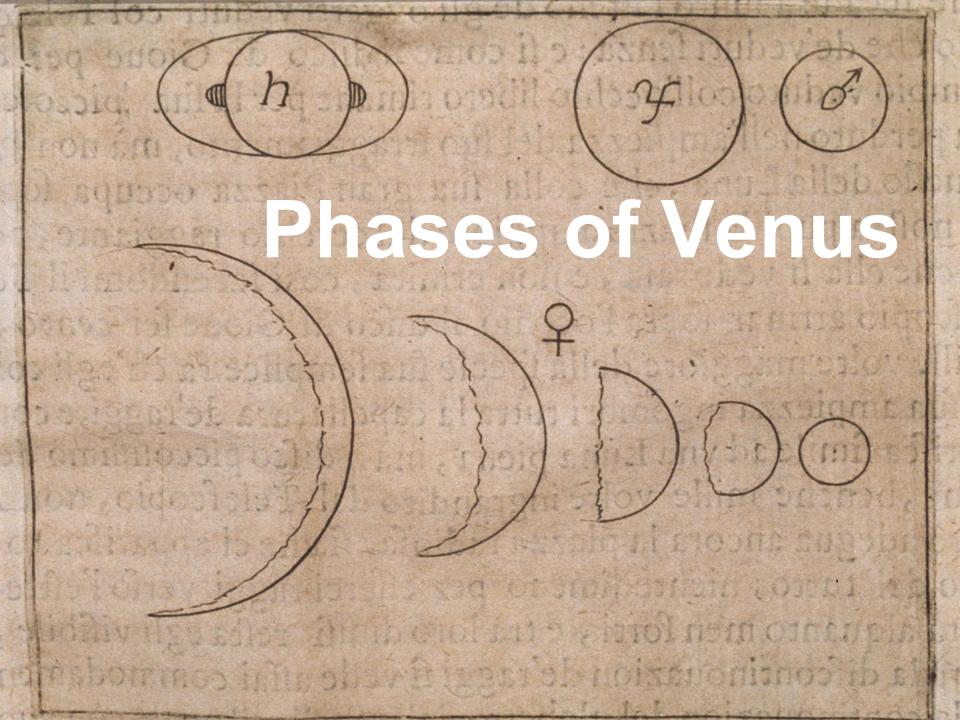
#### Ganymedes, Io, Callisto & Europa:

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

directly conflicting Ptolemaeic and Aristotle's cosmology



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## 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)

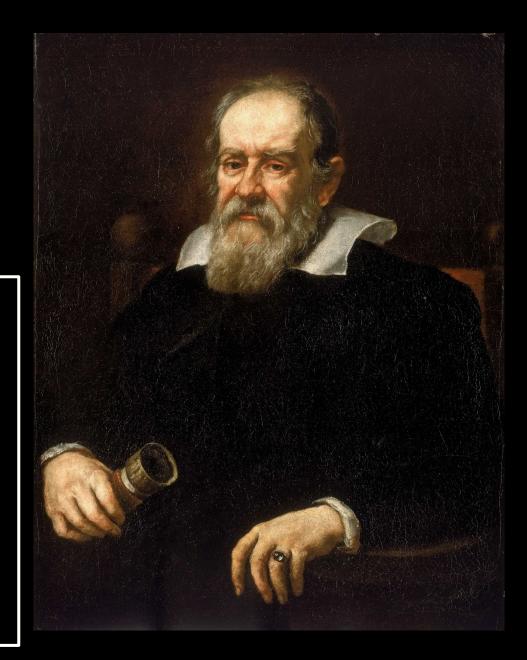
#### Latin: Systema Cosmicum

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 STVDIO DI PISA.

E Filosofo, e Matematico primario del

SERENISSIMO

GR.DVCA DI TOSCANA.

Doue ne i congressi di quattro giornate fi discorre fopra 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:Batifta Landini MDCXXXII.

CON LICENZA DE' SVPERIORI.

Galilei facing the Roman inquisition

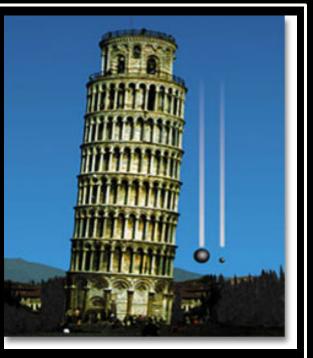
#### Galileo Galilei

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

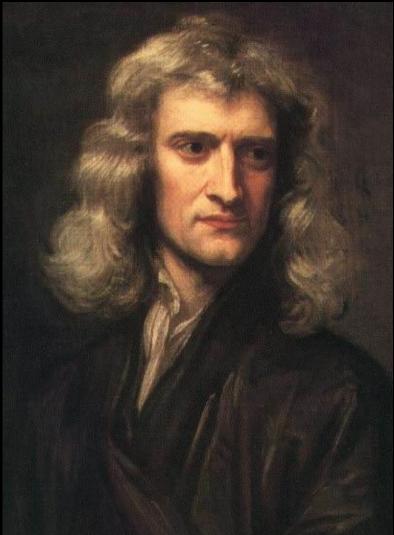
#### Scientific Method

- 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

**m**s

TH

Birthhouse Woolshorpe



## 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

Autore J S. NEWTONOTrin Coll. Cantab. Soc. Mathefeos Professore Lucasiano, & Societatis Regain Sodali. el Societatis Regin Societatis preside

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

#### LONDINI, ·

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

CIDIA

## 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 empiricially
- 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

De Moru Corrozum

#### PHILOSOPHIÆ NATURALIS

#### SECTIO III.

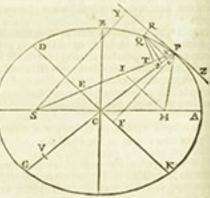
De motu Corporum in Conicis Sectionibus excentricis.

#### PROPOSITIO XI. PROBLEMA VI.

#### Revolvatur corpus in Ellipfi: requiritur Lex vis centripete tendentis ad umbilicum Ellipfeos.

Efto Ellipfeos umbilicus S. Agatur S P fecans Ellipfeos tum diametrum  $\mathcal{D}$  K in E, tum ordinatim applicatam  $\mathcal{Q}$ v ia x, & compleatur parallelogrammum  $\mathcal{Q} \times \mathcal{P}$  R. Patet E P æque

lem effe femiaxi majori AC, co quod acta ab altero Ellipfeos umbilico H linea HI ipfi E C parallela, (ob æquales CS, CH) æquentur ES, EL, adco ut EP femifumma fit iplarum PS, PI, id eft ( ob parallelas HI, PR& angulos aquales IPR. HPZ)ipfarum PS, PH, quæ conjunctim axem totum 1 ACadacquant. Ad S P demittatur perpendicu-



laris QT, & Ellipfeos latere recto principali (feu  $\frac{2BCquad}{MC}$ ) dicto

L. erit  $L \times Q$  R ad  $L \times P v$  ut Q R ad Pv, id eft ut PE fea AC ad  $PC_1 & \&L \times P v$  ad Gv P ut L ad Gv; & Gv P ad Qv quad. ut PC quad. ad CD quad, & (per Corol. 2 Lem. vn.) Qv quad. ad Qx quad. punctis, Q& P cocuntibus, eft ratio requalitatis; & Qx quad. feu Qv quad. eft ad QT quad. ut EP quad. ad PFquad. id eft ut CA quad. ad PF quad. five (per Lem. x11.) ut CDquad. ad CB quad. Et conjunctis his omnibus rationibus,  $L \times QR$ fit ad QT quad. ut  $AC \times L \times PCq \times CDq$ , feu a CBq.  $\times PCq \times CDq$ , ad  $PC \times Gv \times CDq \times CBq$ .

#### PRINCIPIA MATHEMATICA 4

Sed, punctis  $\mathcal{Q} \& \mathcal{P}$  cocuntibus, æquantur  $3 \mathcal{P} C \& G v$ . Ergo & his Lizez proportionalia  $L \times \mathcal{Q} R \& \mathcal{Q} T$  quad. æquantur. Ducantur hæc æqua-Primos. lia in  $\frac{S \mathcal{P} q}{\mathcal{Q} R} \&$  fiet  $L \times S \mathcal{P} q$ .æquale  $\frac{S \mathcal{P} q}{\mathcal{Q} R} \times \mathcal{Q} T q$ . Ergo (per Corol. t & 5 Prop. vt.) vis centripeta reciproce eft ut  $L \times S \mathcal{P} q$ . id eft, reciproce in ratione duplicata diffantiz  $S \mathcal{P}$ .  $\mathcal{Q} E. I$ .

#### Idem aliter.

Cum vis ad centrum Ellipfeos tendens qua corpus  $\mathcal{P}$  in Ellipfi illa revolvi poteft, fit (per Corol. 1 Prop. x) ut  $C\mathcal{P}$  diftantia corporis ab Ellipfeos centro  $C_1$  ducatur CE parallela Ellipfeos tangenti  $\mathcal{P}R$ : & vis qua corpus idem  $\mathcal{P}$ , circum aliud quodvis Ellipfeos punctum S revolvi poteft, fi CE &  $\mathcal{P}S$  concurrant in E, erit ut

 $\frac{PE \ cub}{S \ P \ q}$  (per Corol. 3. Prop. vit.) hoe eff, fi punctum S fit umbili-

cus Ellipfeos, adeoque PE detur, ut SP q reciproce. Q.E.I.

Eadem brevitate qua traduximus Problema quintum ad Parabolam, & Hyperbolam, liceret idem hic facere: verum ob dignitatem Problematis & ufum ejus in fequentibus, non pigebit cafus ceteros demonfiratione confirmare.

#### PROPOSITIO XIL PROBLEMA VIL

#### Moveatur corpus in Hyperbola : requiritur Lex vis centripete tendentis ad umbilicum figura.

Sunto CA, CB femi-axes Hyperbolx; PG, KD diametri conjugate: PF, QI perpendicula ad diametros; & Qv ordinatim applicata ad diametrum GP. Agatur SP fecans cum diametrum D K in E, tum ordinatim applicatam Qv in x, & compleatur parallelogrammum QRP x. Pater EP aqualem elle femiaxi tranfverfo AC, co quod, acta ab altero Hyperbolæ umbilico H linea HI ipfi EC parallela, ob æquales CS, CH, æquentur ES, EI; adeo ut EP femidilferentia fit ipfarum PS, PI, id eft ( ob parallelas IH, PR & angulos æquales IPR, HPZ) ipfarum PS, PH, quarum differentia axem totum zAC adæquat. Ad SP demittatur perpendicularis QT. Et Hyperbolæ latere recto principali (feu  $\frac{zBCq}{AC}$ ) dicto L, crit L × QR ad L×Pv ut QR ad Pv, id eft, ut PE feu AC ad PC; Et L×Pv ad Gv P ut L ad G Gv;

40

## 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

$$\vec{F} = 0 \implies \vec{v} = cst.$$

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

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

### **Newton Telescope**

(1<sup>st</sup> mirror telescope)

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

Isaac Newton