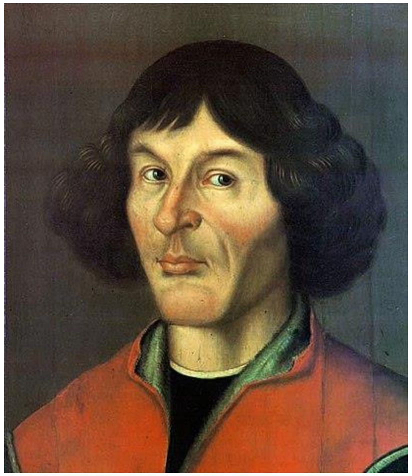
The Copernican Revolution,
and how it almost became unnoticed and forgotten

Leszek Roszkowski

Astrocent at
Nicolaus Copernicus Astronomical Center of PAS
and
National Centre for Nuclear Research
Warsaw, Poland



Astrocent: Particle Astrophysics Science and Technology Centre

- new centre in the field, first in Central-Eastern Europe
- dark matter (DarkSide, DEAP-3600), gravitational waves (Virgo, Einstein Telescope), neutrinos (Hyper-Kamiokande, KM3Net), experiment and theory…
- this Autumn: will be hiring: physicists, engineers, programmers, management, …

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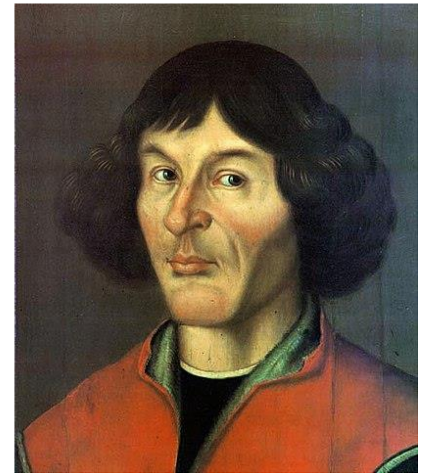

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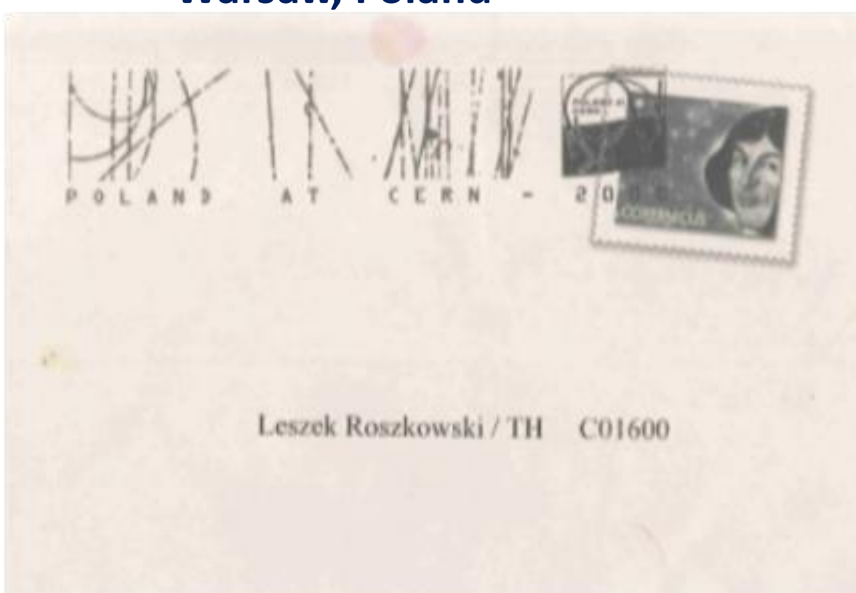
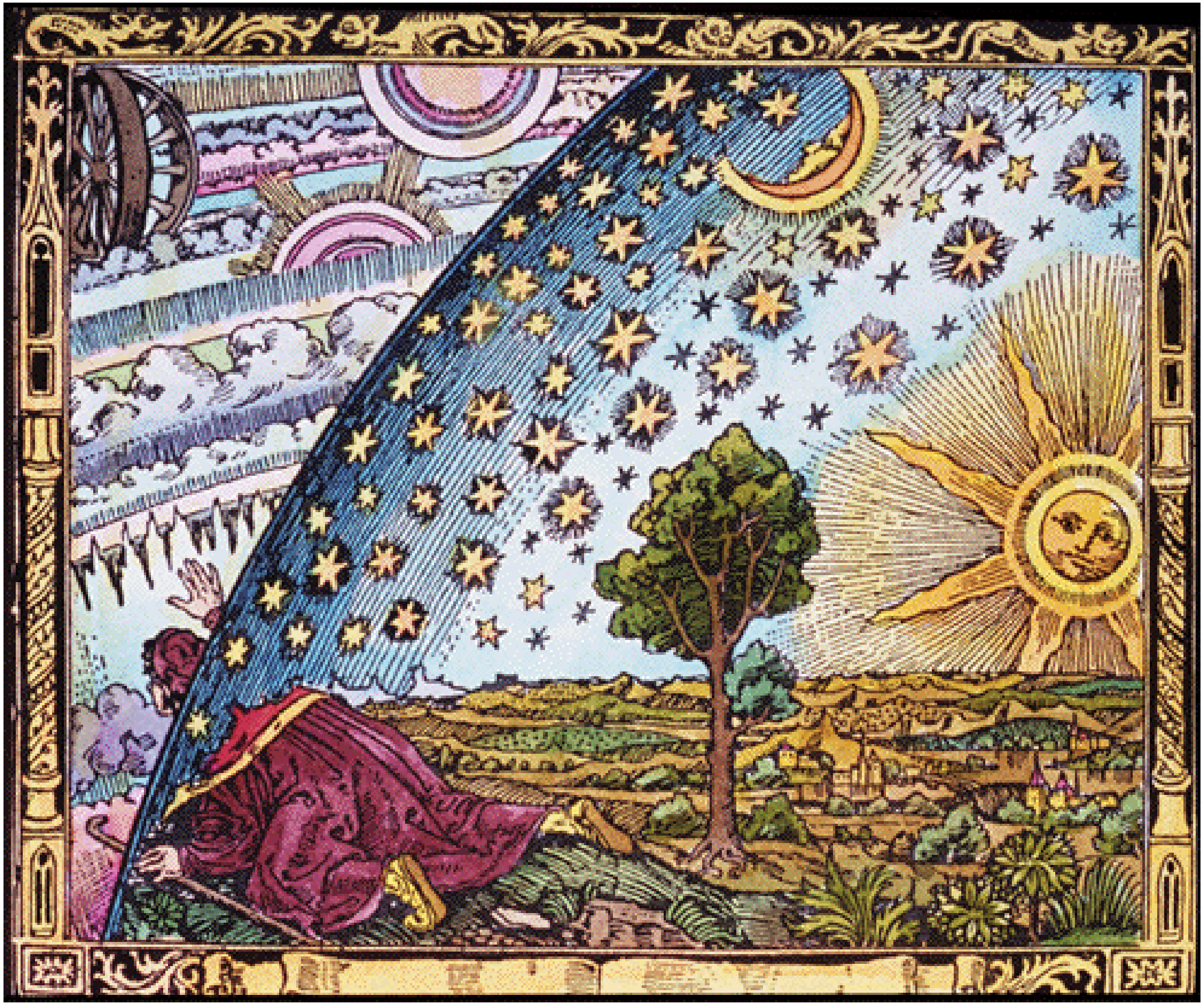


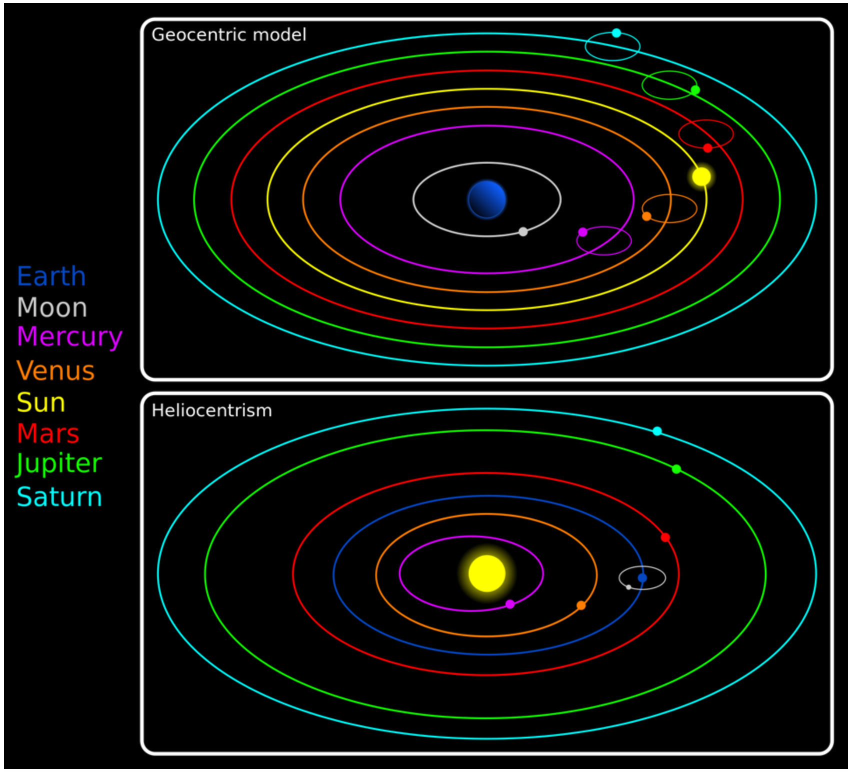
The Science Frontier



wikipedia

Two models of the Universe

Claudius Ptolemy
(~100 - ~170)
Alexandria, Egypt



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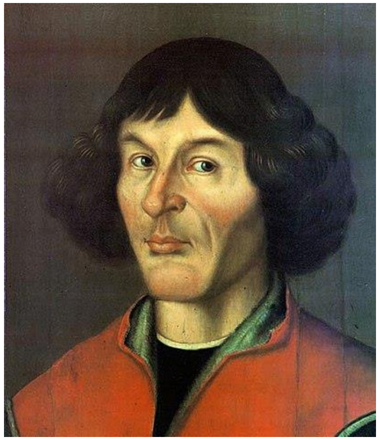
Nicolaus Copernicus
(1473 – 1543)
Poland



Generally accepted paradigm…

Consistent with:

- **Observations of the sky**
- **Aristotle's model of the Universe**
- **Bible/Book of Torah**
- **Common sense**

Insane!

Two models of the Universe

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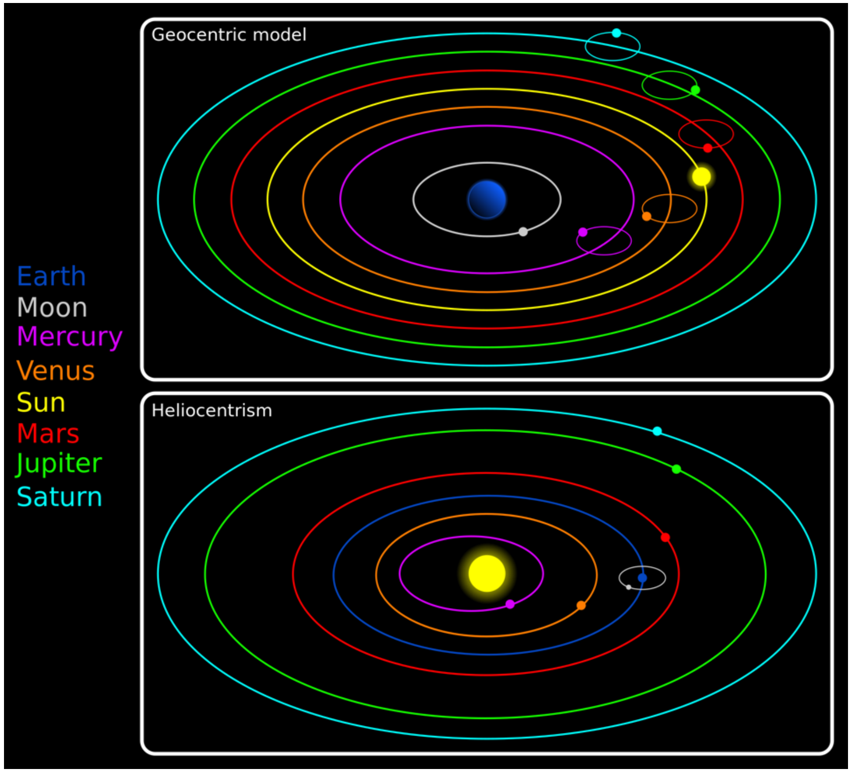

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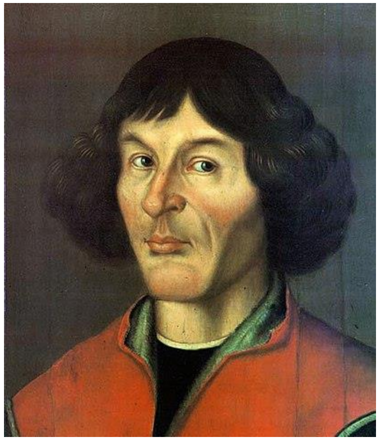

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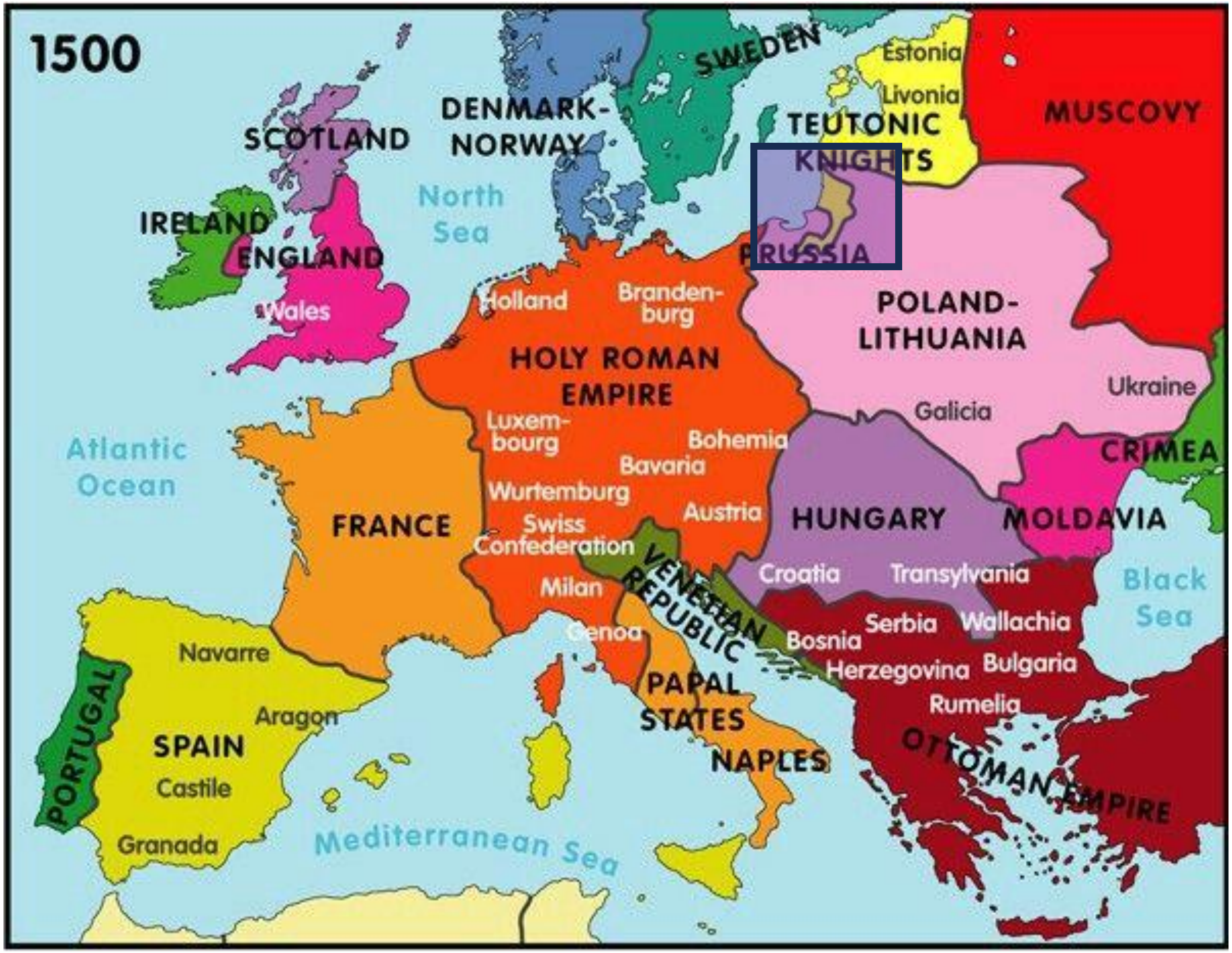


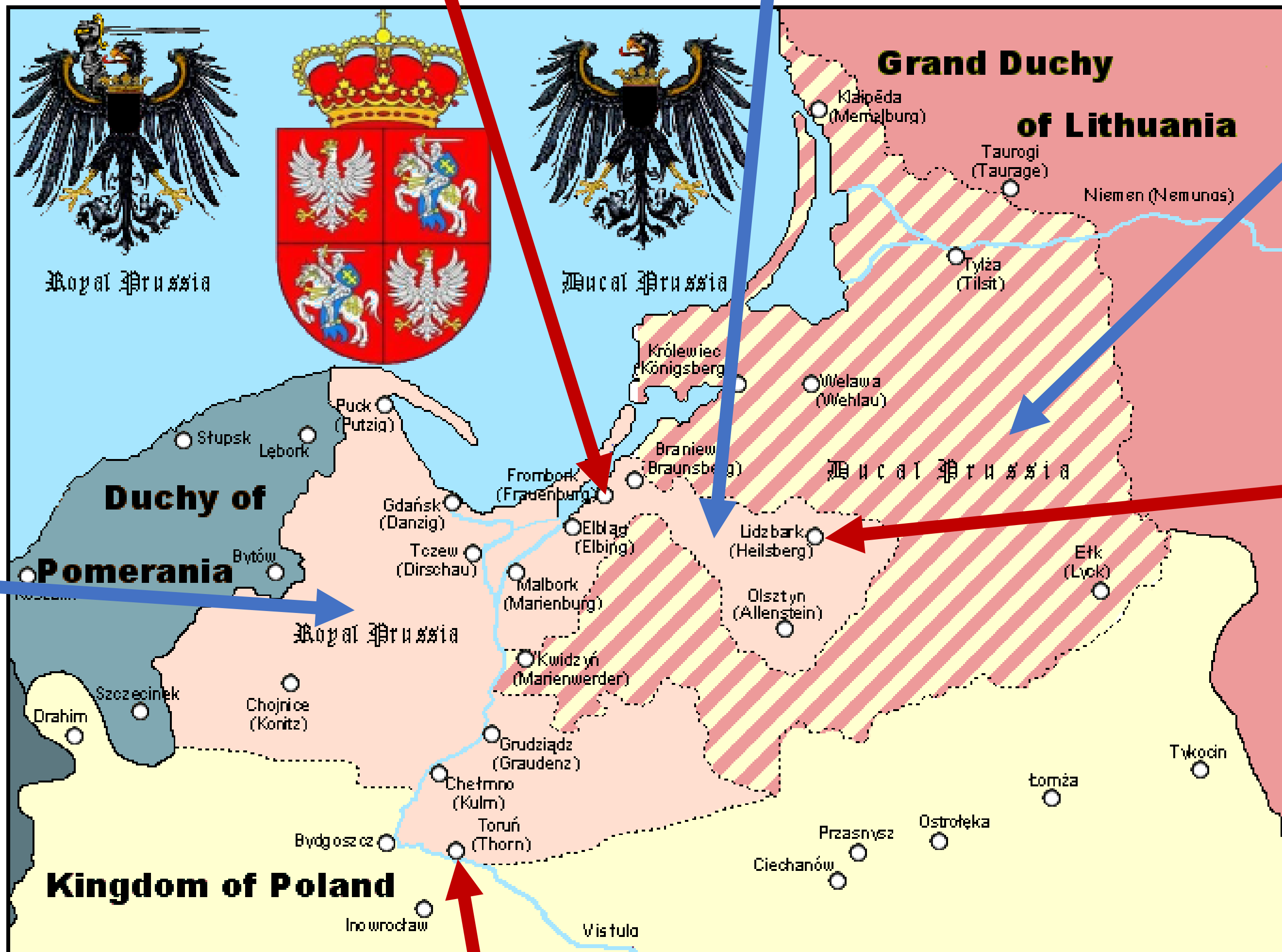
pinterest.com

Warmia

Frombork

Ducal Prussia (under Teutonic Knights Order, subordinate to Poland)

Royal Prussia (regained from the Teutonic Order in 1466)



Lidzbark (site of Warmia diocese & capital)

Toruń

wikipedia

Nicolaus Copernicus

(Mikołaj Kopernik)

(1473 – 1543)

wikipedia

Family and background:

- **Born 19 February 1473 in Toruń, Poland**

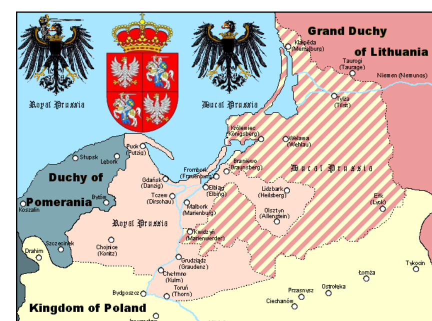
- **Father:** Nicolaus Copernicus Sr –
  a merchant from Kraków
- **Mother:** Barbara Watzenrode –
  daughter of a wealthy Toruń patrician and Toruń city councillor
- **Nicolaus** (Jr) the third (?) of four children

- His father died about 1483

- His uncle **Lucas Watzenrode** Jr offered to pay for his (and his brother Andrzej) education

Lucas Watzenrode
1447 – 1512

Since 1489
Prince-Bishop
of Warmia



Nicolaus Copernicus -- education

➢ **Kraków** (Cracow) – then capital of the Polish-Lithuanian Union

One of the top European intellectual centres

called ``new Athens”

wikipedia

➢ **1491 – 1495: University of Kraków**
(founded 1364, **now** Jagiellonian University)

- **N.Copernicus studied several subjects, including (?) astronomy**
  … but received no degree

➢ **Astronomy in Kraków was very strong, with world-class scholars**

Wojciech of Brudzewo (Albert Brudzewski), many others, …

N. Copernicus: I was born in Toruń, Kraków shaped my thoughts.

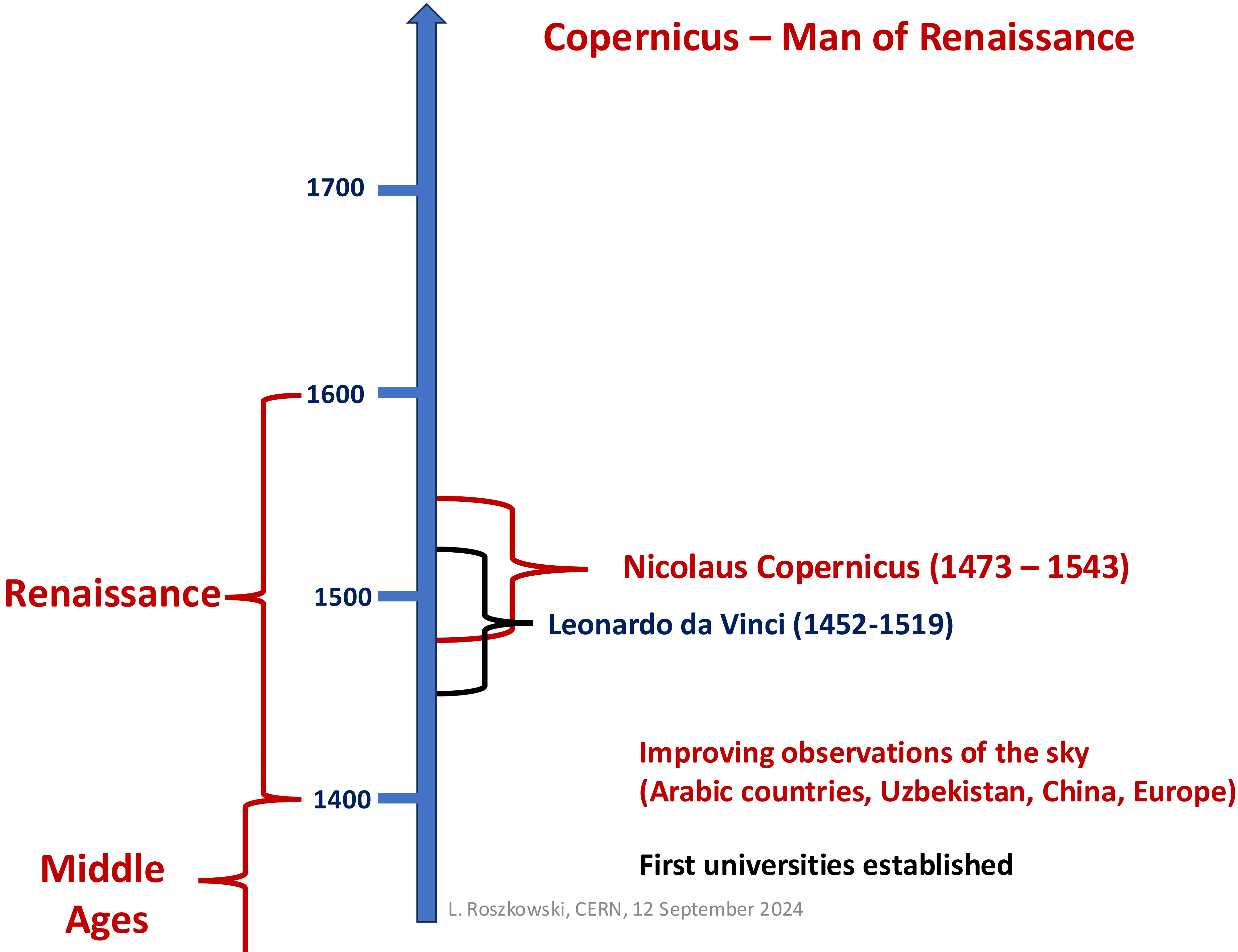
Nicolaus Copernicus -- education

- **1496 – 1500: University of Bologna**
  - law,
  - art (master's)
  - medicine
  - astronomy
- **1500: visit to Rome**
- **1501 – 1503: University of Padua**
  - medicine (Bachelor's degree?)
  - law
  - Greek philology
- **1503: University of Ferrara**
  - doctorate in Canon Law

coblaith.net

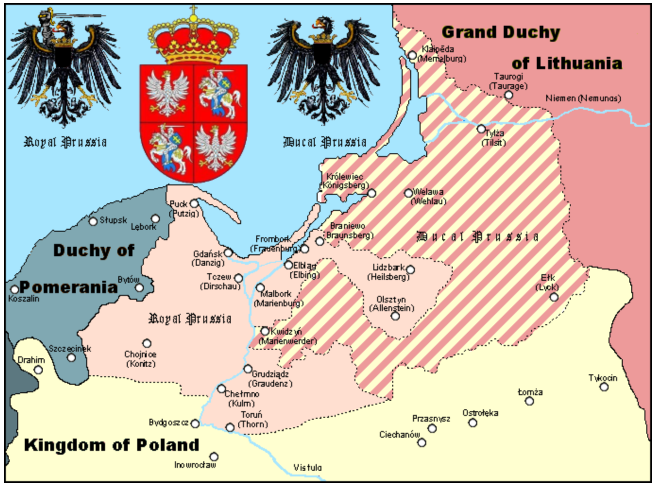
<u>Copernicus had no degree in astronomy</u>

Copernicus – Man of Renaissance



Return to Poland

- In 1503 N. Copernicus moved to Warmia as a canon of Frombork
- His main occupation: personal secretary (and physician) of Lucas Watzenrode in Lidzbark
- In 1510: he moved to Frombork for the rest of his life where he set up an observatory
- …
- He was making sky observations and working on his model in his ``free time" (and hiding it)



Cathedral in Lidzbark

Double life of Dr Copernicus ….

Copernicus -- a man of Renaissance

www.npg.org.uk

- **Polymath:**
  - Astronomy
  - Mathematics
  - Medicine
  - Economy*
  - Law
  - Philosophy and theology

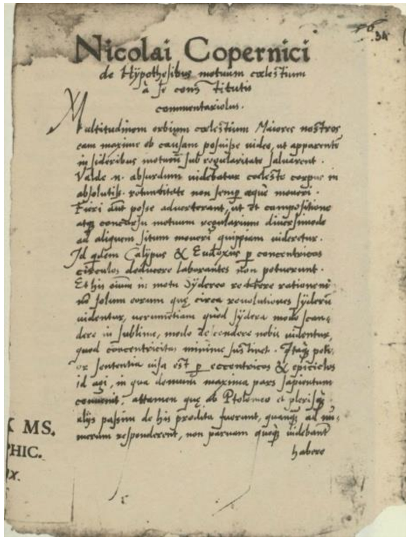
- **Polyglot:**
  - Latin
  - German
  - Polish
  - Greek
  - Italian?

He was also:
- Diplomat
- Governor
- Administrator
- Accountant
- Translator
- ...

* **1517:** quantity theory of money
1519: (Copernicus-)Gresham's law

The *Commentariolus* (*Little Commentary*)

- **~1508 to ~1514 – a brief outline of an early version of Copernicus' heliocentric theory**

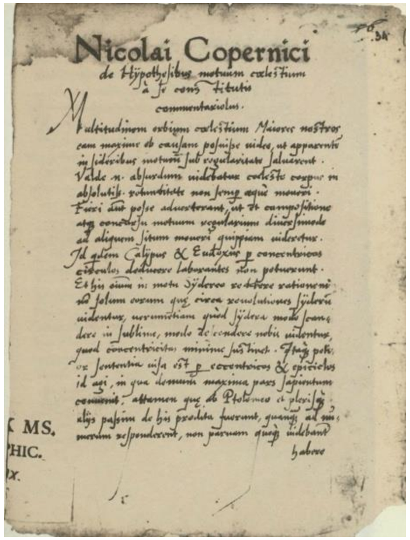

Nicolai Copernici

Wien, Österreichische Nationalbibliothek

The seven postulates:

1. **Celestial bodies do not all revolve around a single point.**
2. **The centre of the Earth is the centre, not of the Universe, but only of *gravity* and of the lunar sphere.**
3. **All the spheres encircle the Sun, which is near the centre of the Universe.**
4. **The distance between the Earth and the Sun is *an insignificant fraction* of the distance from the Earth and the Sun to the stars.**
5. **The stars are immovable; their apparent daily motion is caused by the daily rotation of the Earth.**
6. **The Earth is moved in a sphere around the Sun, causing the apparent annual migration of the Sun; the Earth has more than one motion.**
7. **What appears in the planets as retrograde and direct motion is due not to their motion but to the Earth's.**

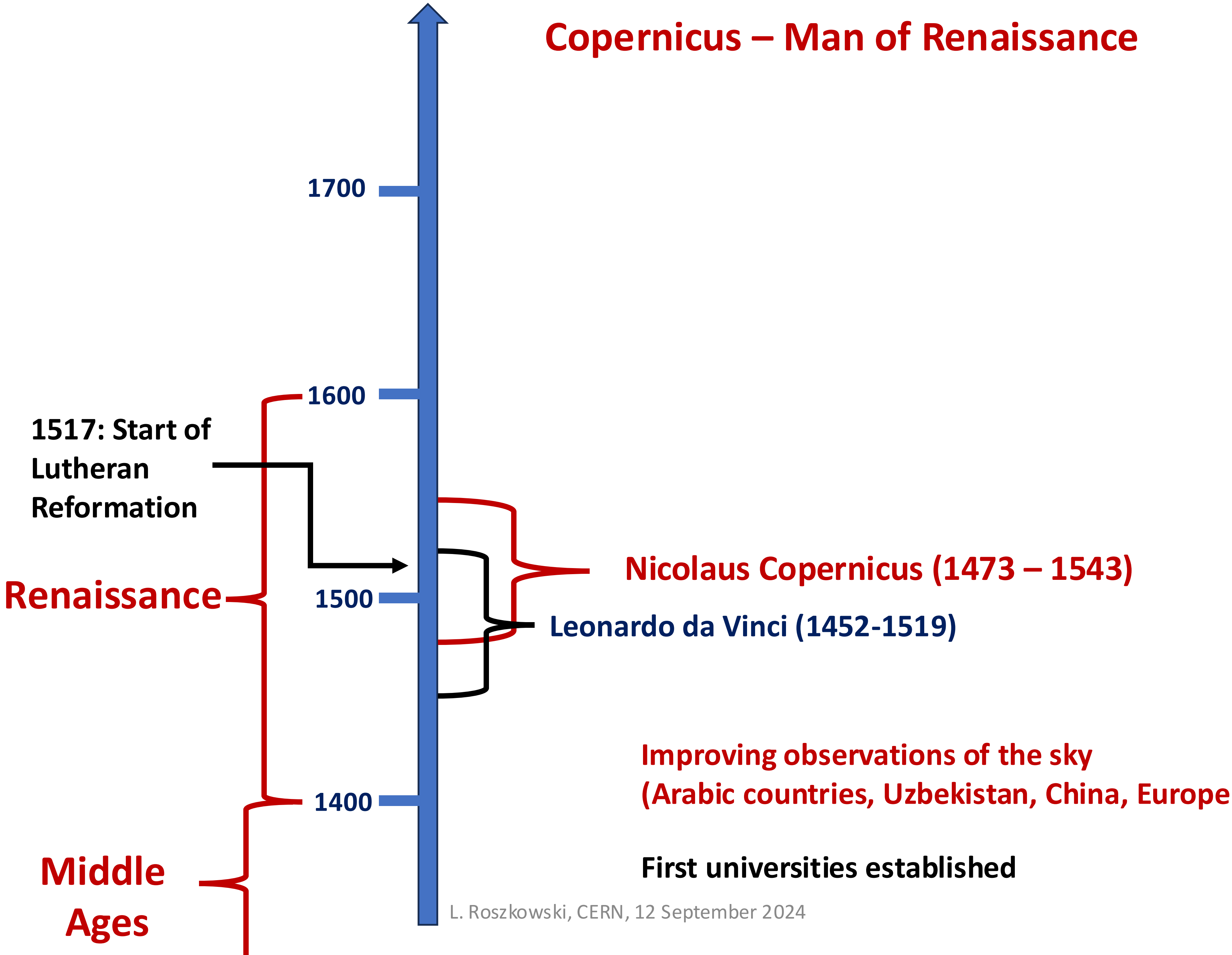
In the follow-up of The *Commentariolus*



- It received relatively little attention, perhaps contrary to Copernicus' expectations
- 1514: Copernicus was invited by Pope Leo X to take part in early works on reform of the calendar
- In 1533, the Copernican system was presented to Pope Clement VII (who reportedly liked it) and to some cardinals
- On 1 November 1536, Cardinal Schonberg (Vatican, Pope's advisor) wrote a letter to Copernicus urging him to publish his results. He offered to cover the costs involved.
- Several top intellectuals, clergy and laity, showed increasing interest in the Copernican model

Yet, Copernicus remained reluctant to publish his main book that he finalised by ~1535

Copernicus – Man of Renaissance

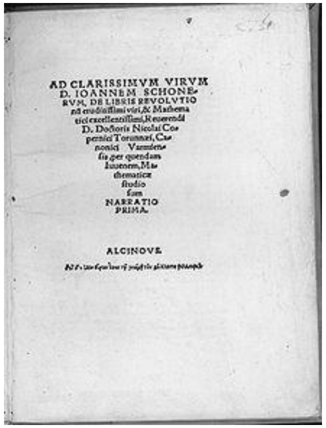


Rheticus

Georg Joachim de Porris,
also known as Rheticus
of Austria
(1514 – 1574)

- a young mathematics professor at the Univ. of Wittemberg
  - May 1539: Rheticus arrived in Frombork
  - He stayed there for over two years

- In 1540 Rheticus published his own first account (Narratio prima, or Report) of Copernicus's cosmology, according to which earth is a planet rotating on its axis and revolving annually about a central Sun.

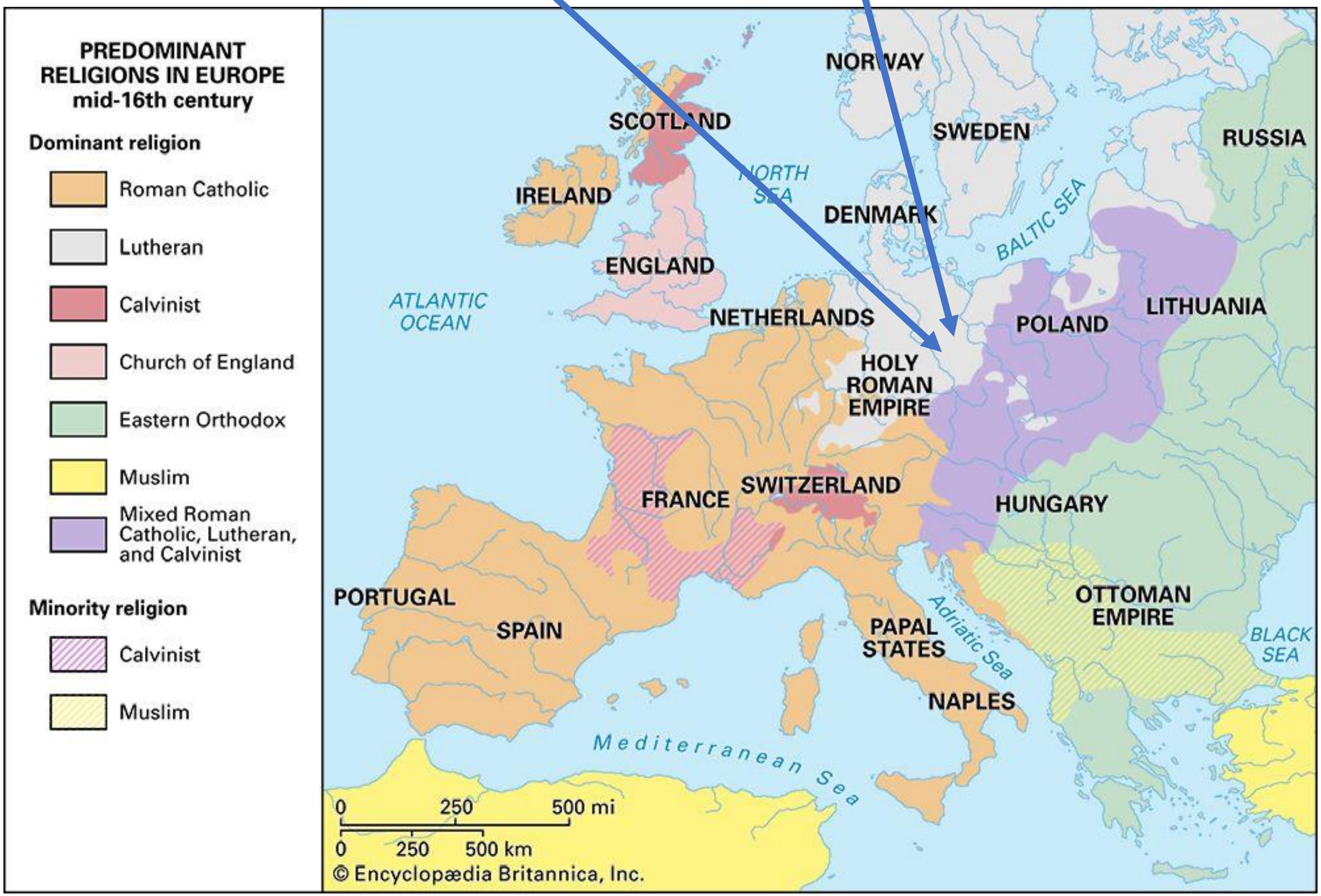


AD CLARISSIMVM VIRVM
D. IOANNEM SCHONE-
RVM, DE LIBRIS REVOLVTIO
NARRATIO
PRIMA.
ALCINOVS

- 1541: Copernicus finally agreed to publish his Opus Magnum.

- in October 1541 Rheticus returned to the Univ. of Wittenberg with the charge to publish the book of Copernicus in Nuremberg.

Nuremberg Wittenberg



Nicolaus Copernicus

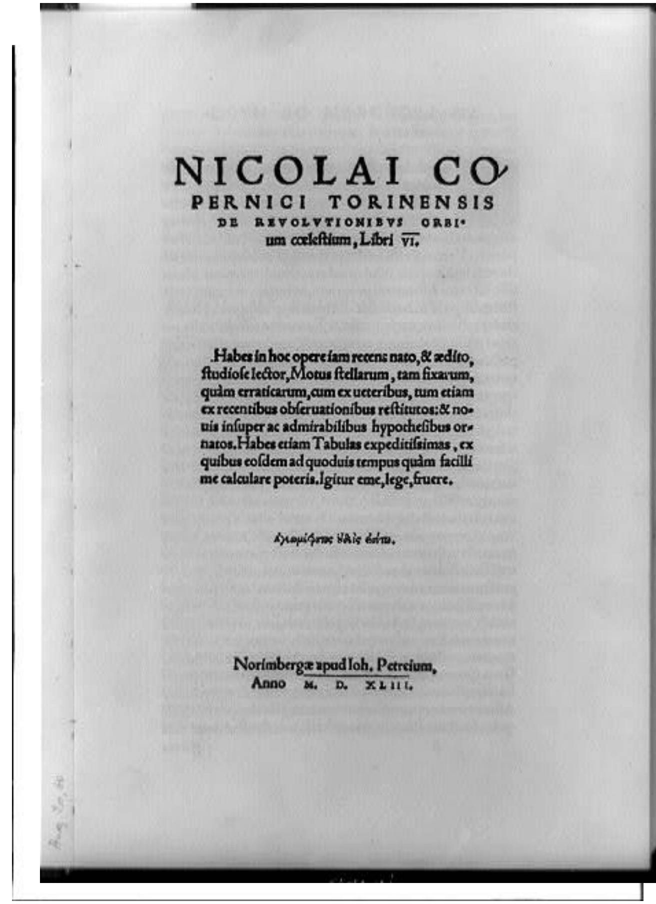
De Revolutionibus Orbium Cœlestium, Libri VI

On the Revolutions of the Celestial Spheres, Six Books

Original edition: March 1543, Nuremberg

<u>Content</u>:

- Preface by Johannes Petreius – publisher
- Unsigned note ``To the Reader, Concerning the Hypotheses of this Work”
- Letter of Nicholas Schonberg, Cardinal of Capua, to N. Copernicus (Rome, 1 November 1536)
- Letter of N. Copernicus to Pope Paul III (Nicolaus Copernicus’ preface to his Books on the Revolutions)
- Six books



NICOLAI CO
PERNICI TORINENSIS
DE REVOLVTIONIBVS ORBI-
um cœlestium, Libri VI.

.Habes in hoc opere iam recens nato, & ædito, studiose lector, Motus stellarum, tam fixarum, quàm erraticarum, cum ex ueteribus, tum etiam ex recentibus obseruationibus restitutos: & nouis insuper ac admirabilibus hypothesibus ornatos. Habes etiam Tabulas expeditissimas, ex quibus eosdem ad quoduis tempus quàm facillime calculare poteris. Igitur eme, lege, fruere.

Ἀγεωμέτρητος οὐδεὶς εἰσίτω.

Norimbergæ apud Ioh. Petreium,
Anno M. D. XLIII.

Copernicus received its copy just before his death on 24 May 1543.

De Revolutionibus Orbium Cœlestium, Libri VI

In the first edition of 1543 in Nuremberg, the publisher made some key changes:

- **An unsigned note ``To the Reader, Concerning the Hypotheses of this Work" was added (without the consent of Copernicus nor Rheticus).**

  It was written by Andreas Osiander (Lutheran theologian and Protestant reformer).

- **It stated that the model should be treated as a mere hypothesis and useful mathematical platform to compute the trajectories of the Sun, Moon and the planets.**

…reports about the novel hypotheses of this work, which declares that the earth moves whereas the sun is at rest in the center of the universe.

… ***these hypotheses need not be true nor even probable. On the contrary***, …

So far as hypotheses are concerned, let no one expect anything certain from astronomy…

- **The main text was modified changing most definitive statements to sound like hypotheses.**

- **In the title ``bodies" were replaced by ``spheres".**

Why was Copernicus reluctant to publish his book?

Quotes from Copernicus' letter to Pope Paul III

- He was fully aware that his model would be considered crazy

Those who know that the consensus of many centuries […] would […] regard it as an insane pronouncement if I made the opposite assertion that the earth moves.

- He was afraid of being ridiculed by non-experts

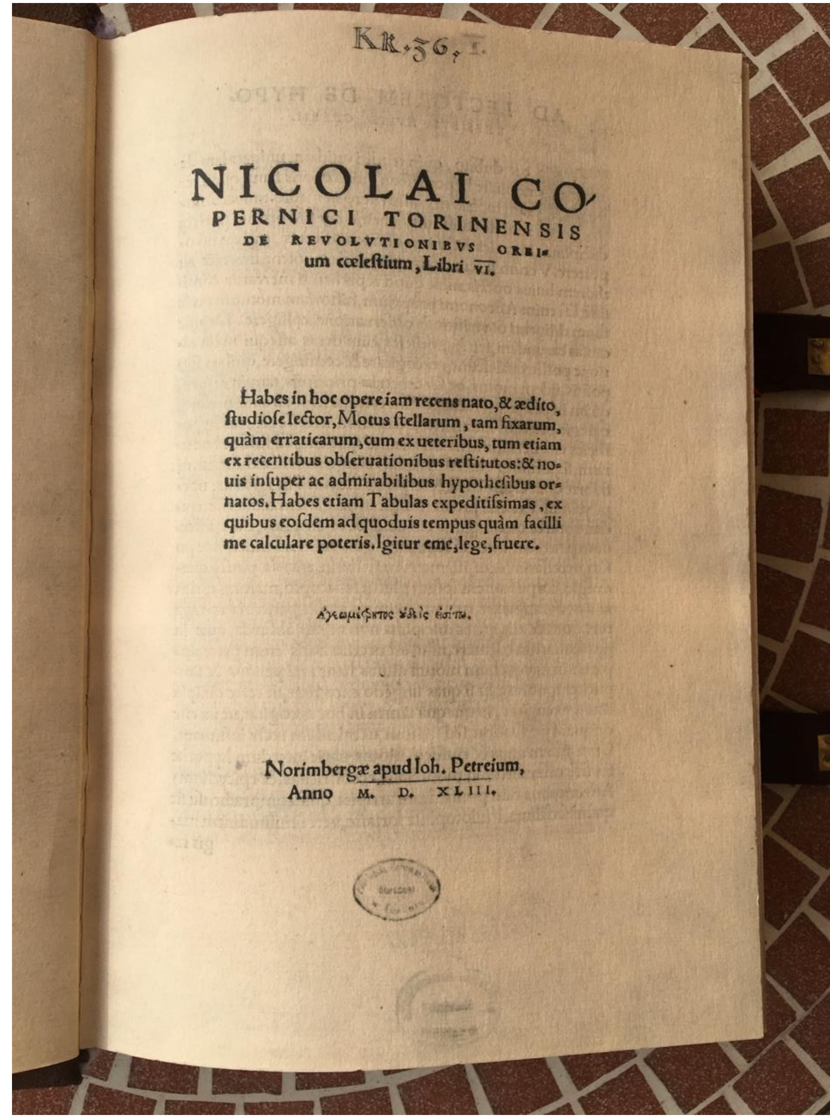
Perhaps there will be babblers who claim to be judges of astronomy although completely ignorant of the subject and, badly distorting some passage of Scripture to their purpose, will dare to find fault with my undertaking and censure it.

The scorn that I had to fear on account of the newness and absurdity of my opinion almost almost drove me to abandon a work already undertaken.

- He preferred instead to present his work only to friends and scholars

Therefore I debated with myself for a long time whether to publish the volume which I wrote to prove the earth's motion or rather to follow the example of the Pythagoreans and certain others, who used to transmit philosophy's secrets only to kinsmen and friends, not in writing but by word of mouth…

Nicolaus Copernicus
De Revolutionibus Orbium Cœlestium, Libri VI



The six books of Copernicus' De Revolutionibus…

- The first is a general vision of the heliocentric theory, and a summarized exposition of his idea of the World.

- The second is mainly theoretical, presenting the principles of spherical astronomy and a list of stars
(as a basis for the arguments developed in the subsequent books).

- The third is mainly dedicated to the apparent motions of the Sun and to related phenomena.

- The fourth is a description of the Moon and its orbital motions.

- The fifth is a concrete exposition of the new system, including planetary longitude.

- The sixth is further concrete exposition of the new system, including planetary latitude.

Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/entries/copernicus/)

Book One

1. **The universe is spherical.**
2. **The earth too is spherical.**
3. How earth forms a single sphere with water.
4. **The motion of the heavenly bodies is uniform, eternal, and circular or compounded of circular motions.**
5. Does circular motion suit the earth? What is its position?
6. The immensity of the heavens compared to the size of the earth.
7. Why the ancients thought that the earth remained at rest in the middle of the universe as its center.
8. The inadequacy of the previous arguments and a refutation of them.
9. **Can several motions be attributed to the earth?** The center of the universe.
10. The order of the heavenly spheres.
11. Proof of the earth's triple motion.
12. Straight lines subtended in a circle.
13. The sides and angles of plane rectilinear triangles.
14. Spherical triangles.

Book Two

1. The circles and their names.
2. The obliquity of the ecliptic, the distance between the tropics, and the method of determining these quantities.
3. The arcs and angles of the intersections of the equator, ecliptic, and meridian; the derivation of the declination and right ascension from these arcs and angles, and the computation of them.
4. For every heavenly body situated outside the ecliptic, provided that the body's latitude and longitude are known, the method of determining its declination, its right ascension, and the degree of the ecliptic with which it reaches mid-heaven.
5. The intersections of the horizon.
6. The differences in noon shadows.
7. How to derive from one another the longest day, the distance between sunrises, and the inclination of the sphere; the remaining differences be- tween days.
8. The hours and parts of the day and night.
9. The oblique ascension of the degrees of the ecliptic; how to determine what degree is at mid-heaven when any degree is rising.
10. The angle at which the ecliptic intersects the horizon.
11. The use of these tables.
12. The angles and arcs of those circles which are drawn through the poles of the horizon to the ecliptic.
13. The rising and setting of the heavenly bodies.
14. The investigation of the places of the stars, and the arrangement of the fixed stars in a catalogue.

Book Three

1. The precession of the equinoxes and solstices.
2. History of the observations proving that the precession of the equinoxes and solstices is not uniform.
3. Hypotheses by which the shift in the equinoxes as well as in the obliquity of the ecliptic and equator may be demonstrated.
4. How an oscillating motion or motion in libration is constructed out of circular [motions].
5. Proof of the nonuniformity in the precession of the equinoxes and in the obliquity.
6. The uniform motions of the precession of the equinoxes and of the incli- nation of the ecliptic.
7. What is the greatest difference between the uniform and the apparent precession of the equinoxes?
8. The individual differences between these motions, and a table exhibiting those differences.
9. Review and correction of the discussion of the precession of the equinoxes.
10. What is the greatest variation in the intersections of the equator and ecliptic?
11. Determining the epochs of the uniform motions of the equinoxes and anomaly.
12. Computing the precession of the vernal equinox and the obliquity.
13. The length and nonuniformity of the solar year.
14. The uniform and mean motions in the revolutions of the earth's center.
15. Preliminary theorems for proving the nonuniformity of the sun's apparent motion.
16. The sun's apparent nonuniformity.
17. Explanation of the first and annual solar inequality, together with its particular variations.
18. Analysis of the uniform motion in longitude.
19. Establishing the positions and epochs for the sun's uniform motion.
20. The second and twofold inequality imposed on the sun by the shift of the apsides.
21. How large is the second variation in the solar inequality?
22. How the solar apogee's uniform and nonuniform motions are derived.
23. Determining the solar anomaly and establishing its positions.
24. Tabular presentation of the variations in the uniform and apparent [solar motions].
25. Computing the apparent sun.
26. The nuchthemeron, that is, the variable natural day.

Book Four

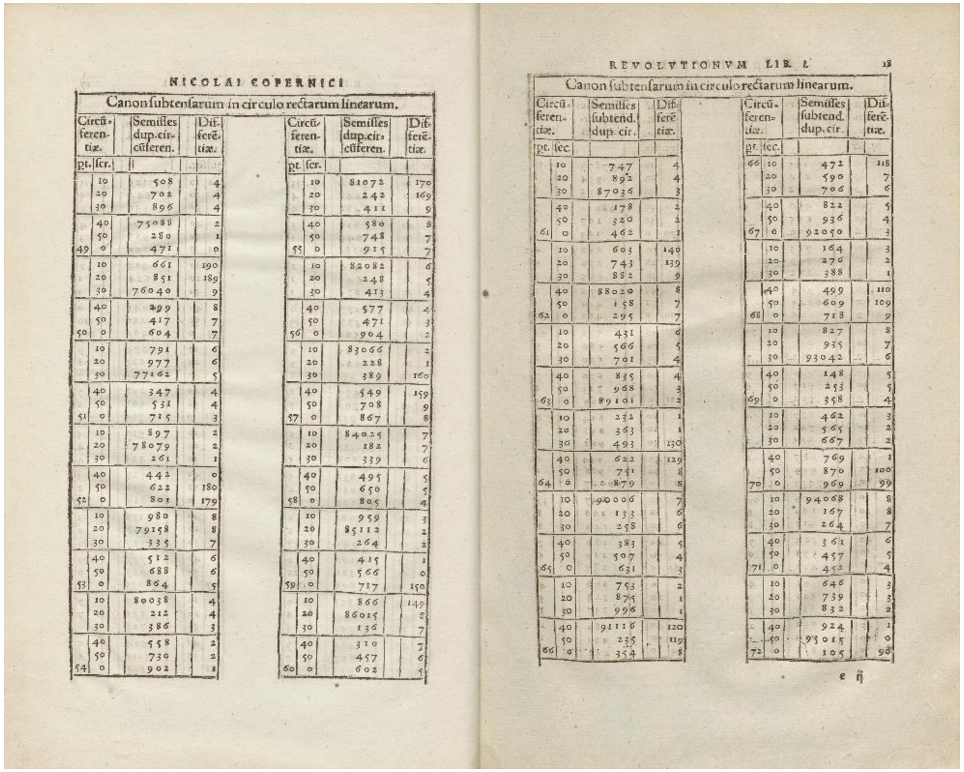
1. The hypotheses concerning the lunar circles, according to the belief of the ancients.
2. The defect in those assumptions.
3. A different opinion about the moon’s motion.
4. The moon’s revolutions, and the details of its motions.
5. Exposition of the first lunar inequality, which occurs at new and full moon.
6. Verification of the statements about the moon’s uniform motions in longitude and anomaly.
7. The epochs of the lunar longitude and anomaly.
8. The moon’s second inequality, and the ratio of the first epicycle to the second.
9. The remaining variation, in which the moon is seen moving nonuniformly away from the [first] epicycle’s higher apse.
10. How the moon’s apparent motion is derived from the given uniform motions.
11. Tabular presentation of the lunar prosthaphaereses or normalizations.
12. Computing the moon’s motion.
13. How the moon’s motion in latitude is analyzed and demonstrated.
14. The places of the moon’s anomaly in latitude.
15. The construction of the parallactic instrument.
16. How the lunar parallaxes are obtained.
17. A demonstration of the moon’s distances from the earth, and of their ratio in units of which the earth’s radius equals one.
18. The diameter of the moon and of the earth’s shadow at the place where the moon passes through it.
19. How to demonstrate at the same time the distances of the sun and moon from the earth, their diameters, the diameter of the shadow
20. The size of these three heavenly bodies, sun, moon, and earth, and a com- parison of their sizes.
21. The apparent diameter and parallaxes of the sun.
22. The moon’s varying apparent diameter and its parallaxes.
23. To what extent does the earth’s shadow vary?
24. Tabular presentation of the individual solar and lunar parallaxes in the circle which passes through the poles of the horizon.
25. Computing the solar and lunar parallax.
26. How the parallaxes in longitude and latitude are separated from each other.
27. Confirmation of the assertions about the lunar parallaxes.
28. The mean conjunctions and oppositions of the sun and moon.
29. Investigating the true conjunctions and oppositions of the sun and moon.
30. How conjunctions and oppositions of the sun and moon at which eclipses occur may be distinguished from others.
31. The size of a solar and lunar eclipse.
32. Predicting how long an eclipse will last.

Book Five

1. The revolutions and mean motions [of the planets].
2. The planets' uniform and apparent motion, as explained by the theory of the ancients.
3. General explanation of the apparent nonuniformity caused by the earth's motion.
4. In what ways do the planets' own motions appear nonuniform?
5. Derivations of Saturn's motion.
6. Three other more recently observed oppositions of Saturn.
7. Analysis of Saturn's motion.
8. Determining Saturn's places.
9. Saturn's parallaxes arising from the earth's annual revolution, and Saturn's distance [from the earth].
10. Expositions of Jupiter's motion.
11. Three other more recently observed oppositions of Jupiter.
12. Confirmation of Jupiter's uniform motion.
13. Determining the places of Jupiter's motion.
14. Determining Jupiter's parallaxes, and its height in relation to the earth's orbital revolution.
15. The planet Mars.
16. Three other recently observed oppositions of the planet Mars.
17. Confirmation of Mars' motion.
18. Determining Mars' places.
19. The size of Mars' orbit in units whereof the earth's annual orbit is one unit.
20. The planet Venus.
21. The ratio of the earth's and Venus' orbital diameters.
22. Venus' twofold motion.
23. Analyzing Venus' motion.
24. The places of Venus' anomaly.
25. Mercury.
26. The place of Mercury's higher and lower apsides.
27. The size of Mercury's eccentricity, and the ratio of its circles.
28. Why Mercury's elongations at about the side of a hexagon look bigger than the elongations occurring at perigee.
29. Analysis of Mercury's mean motion.
30. More recent observations of Mercury's motions.
31. Determining Mercury's places.
32. An alternative account of approach and withdrawal.
33. Tables of the prosthaphaereses of the five planets.
34. How to compute the longitudinal places of these five planets.
35. The stations and retrogradations of the five planets.
36. How the times, places, and arcs of retrogression are determined.

Book Six

1. General explanation of the five planets' deviation in latitude.
2. The theory of the circles by which these planets are moved in latitude.
3. How much are the orbits of Saturn, Jupiter, and Mars inclined?
4. General explanation of any other latitudes of these three planets.
5. The latitudes of Venus and Mercury.
6. Venus' and Mercury's second latitudinal digression, depending on the inclination of their orbits at apogee and perigee.
7. The size of the obliquation angles of both planets, Venus and Mercury.
8. The third kind of latitude, which is called the "deviation," in Venus and Mercury.
9. Computing the latitudes of the five planets.



Astronomer Copernicus, or Conversations with God

Jan Matejko, Polish painter, in 1873 on the 400th anniversary of Copernicus' birth

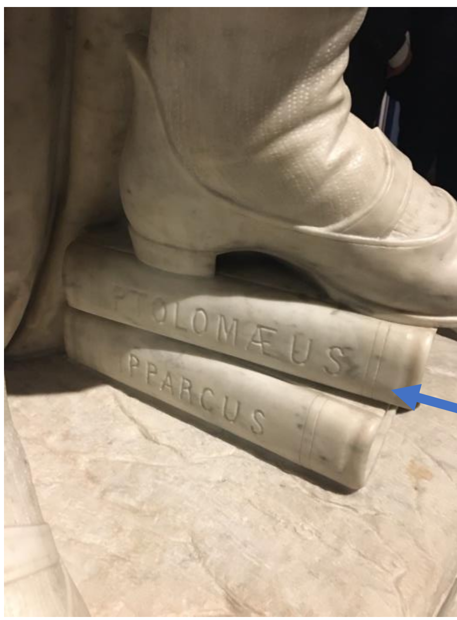
And what's more beautiful then the sky which envelops everything that is beautiful?

Nicolaus Copernicus
De Revolutionibus Orbium Cœlestium

Exhibition on Copernicus, Royal Castle, Warsaw, 20 June 2023

Exhibition on Copernicus, Royal Castle, Warsaw, 20 June 2023

Astrolabe



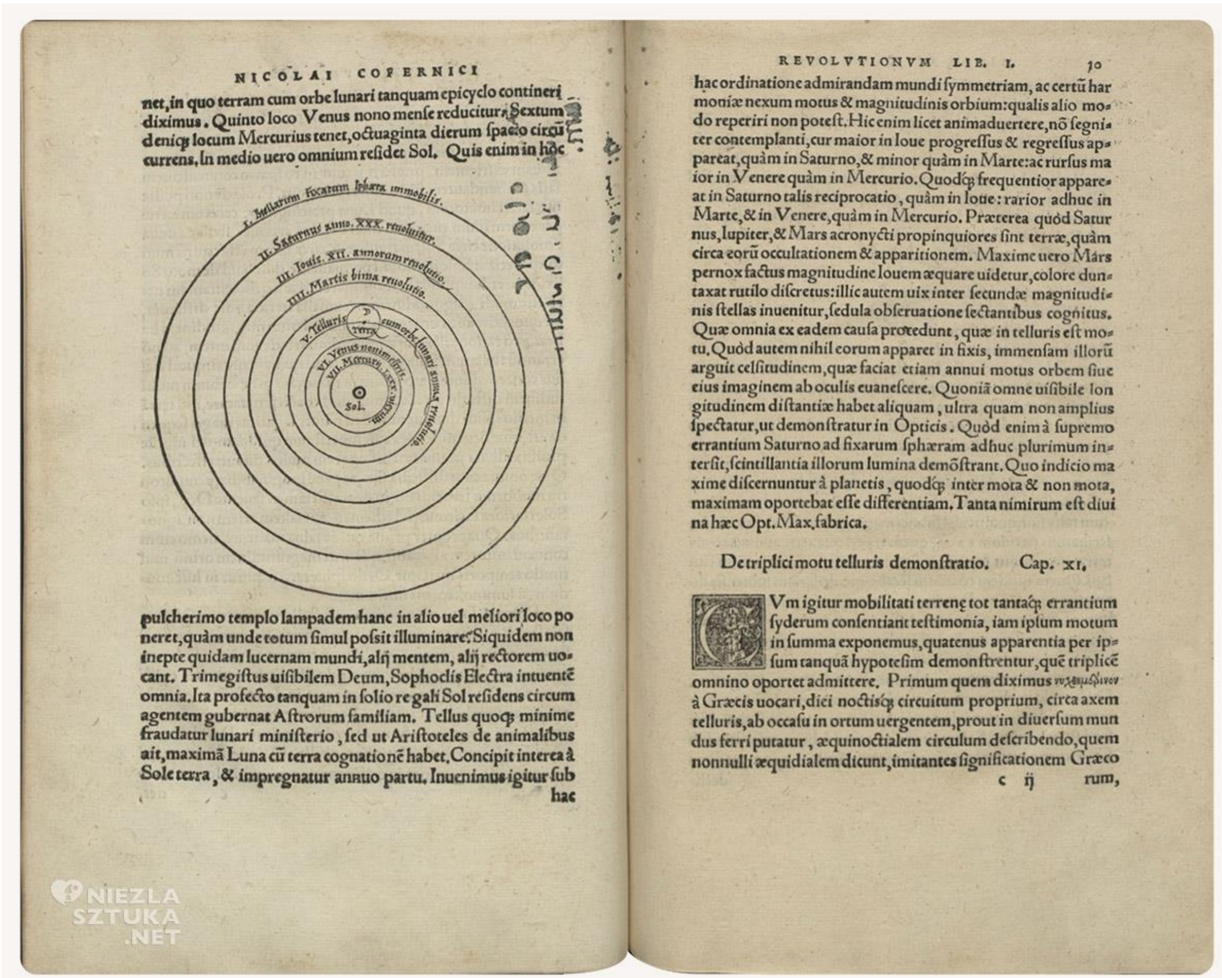
Ptolemy
Hipparchus

Nicolai Copernici

De revolutionibus orbium coelestium

(On the Revolutions of the Heavenly Spheres)

1543


NICOLAI COPERNICI
net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc

pulcherimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentē omnia. Ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoque minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximã Luna cũ terra cognationē habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

REVOLVTIONVM LIB. I. 30
hac ordinatione admirandam mundi symmetriam, ac certũ harmoniæ nexum motus & magnitudinis orbium: qualis alio modo reperiri non potest. Hic enim licet animaduertere, nõ segniter contemplanti, cur maior in Ioue progressus & regressus appareat, quàm in Saturno, & minor quàm in Marte: ac rursus maior in Venere quàm in Mercurio. Quodque frequentior appareat in Saturno talis reciprocatio, quàm in Ioue: rarior adhuc in Marte, & in Venere, quàm in Mercurio. Præterea quòd Saturnus, Iupiter, & Mars acronycti propinquiores sint terræ, quàm circa eorũ occultationem & apparitionem. Maxime uero Mars pernox factus magnitudine Iouem æquare uidetur, colore duntaxat rutilo discretus: illic autem uix inter secundæ magnitudinis stellas inuenitur, sedula obseruatione sectantibus cognitus. Quæ omnia ex eadem causa procedunt, quæ in telluris est motu. Quòd autem nihil eorum apparet in fixis, immensam illorũ arguit celsitudinem, quæ faciat etiam annui motus orbem siue eius imaginem ab oculis euanescere. Quoniã omne uisibile longitudinem distantiæ habet aliquam, ultra quam non amplius spectatur, ut demonstratur in Opticis. Quòd enim à supremo errantium Saturno ad fixarum sphæram adhuc plurimum intersit, scintillantia illorum lumina demõstrant. Quo indicio maxime discernuntur à planetis, quodque inter mota & non mota, maximam oportebat esse differentiam. Tanta nimirum est diuina hæc Opt. Max. fabrica.

De triplici motu telluris demonstratio. Cap. XI.

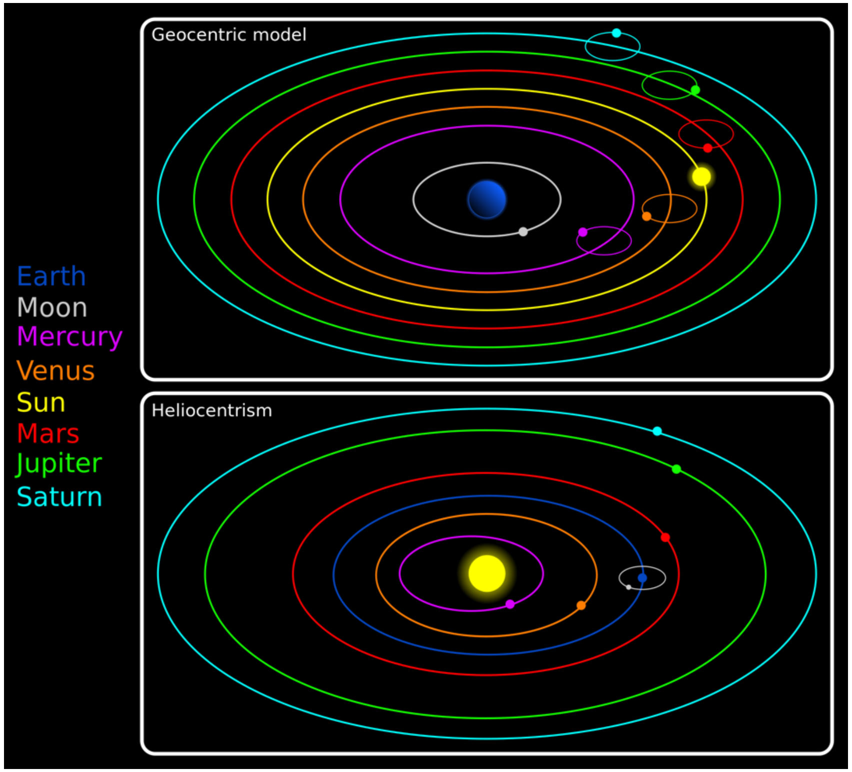
CVm igitur mobilitati terrenę tot tantaque errantium syderum consentiant testimonia, iam ipsum motum in summa exponemus, quatenus apparentia per ipsum tanquã hypotesim demonstrentur, quē triplicē omnino oportet admittere. Primum quem diximus νυχθημερινὸν à Græcis uocari, diei noctisque circuitum proprium, circa axem telluris, ab occasu in ortum uergentem, prout in diuersum mundus ferri putatur, æquinoctialem circulum describendo, quem nonnulli æquidialem dicunt, imitantes significationem Græco
c ij rum,

Monument in Warsaw

The Copernican Revolution

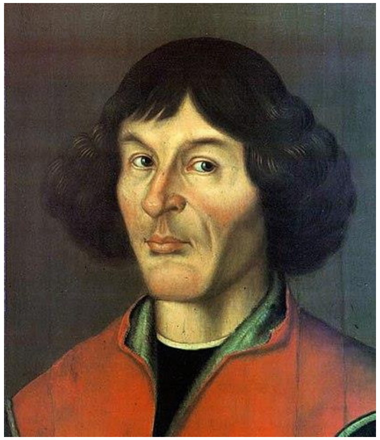
Two models of the Universe

Claudius Ptolemy
(~100 - ~170)
Alexandria, Egypt



https://upload.wikimedia.org/wikipedia/commons/

Nicolaus Copernicus
(1473 – 1543)
Poland



Consistent with:

- **Observations of the sky**
- **Aristotle's model of the Universe**
- **Bible/Book of Torah**
- **Common sense**

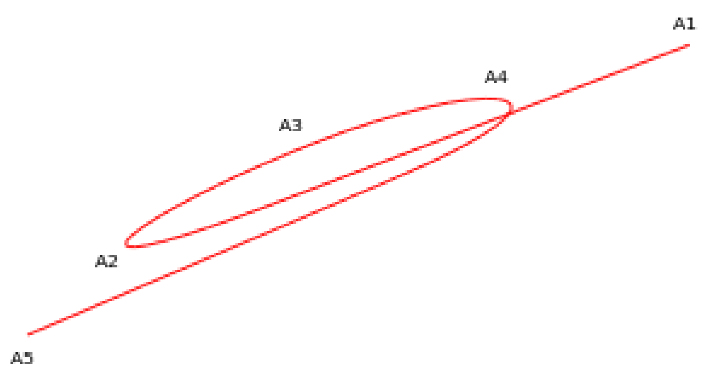
Generally accepted paradigm

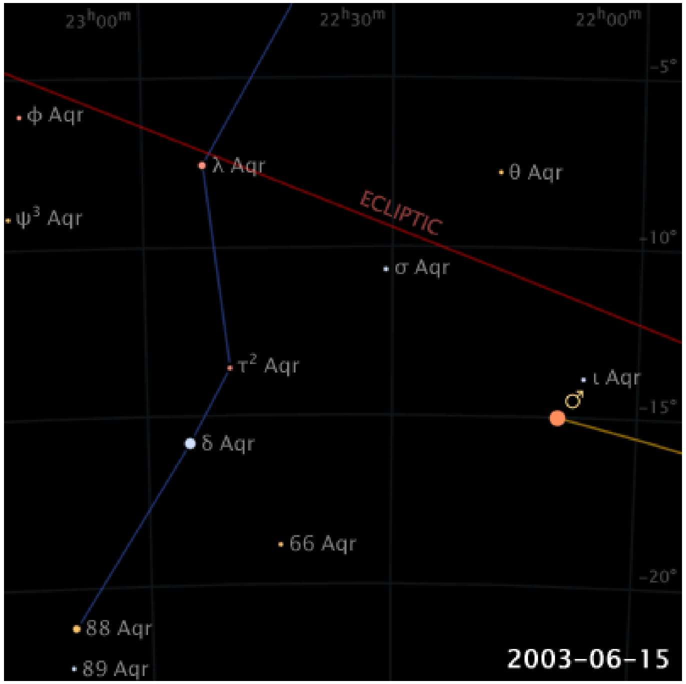
…

How does the solar system look like from the Earth?

The Sun, the Moon and the planets appear to orbit the Earth.

- The Sun, the Moon move from east to west.
- The planets (Mars, Jupiter, Saturn,…) move from east-to-west at *varying speeds*,
- from time to time they appear to temporarily move backwards (**retrograde motion**) before resuming their normal motion.





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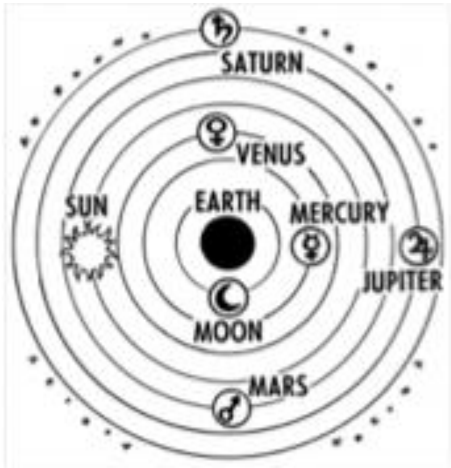
Almagest (2nd c.)

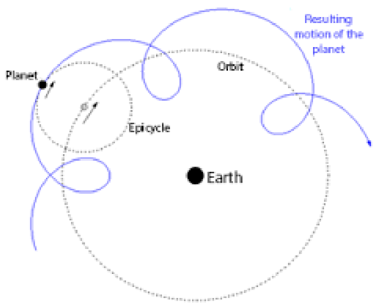
The Ptolemaic model



wikipedia

- the Earth is at rest
- the Sun, Moon, planets and (fixed) stars rotate <u>uniformly</u> in <u>circular</u> orbits around the Earth

- all celestial bodies move along spheres
- the stars are fixed to their sphere
- the spheres rotate daily around the centre

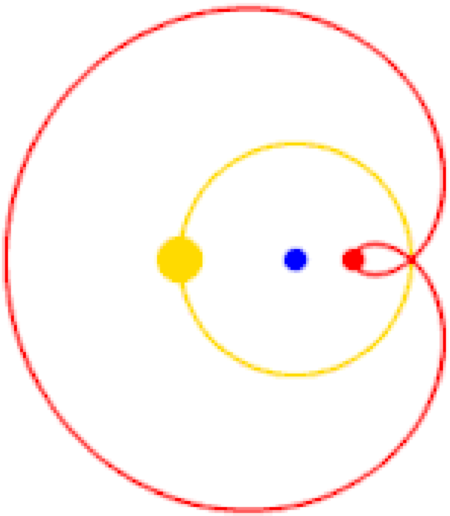


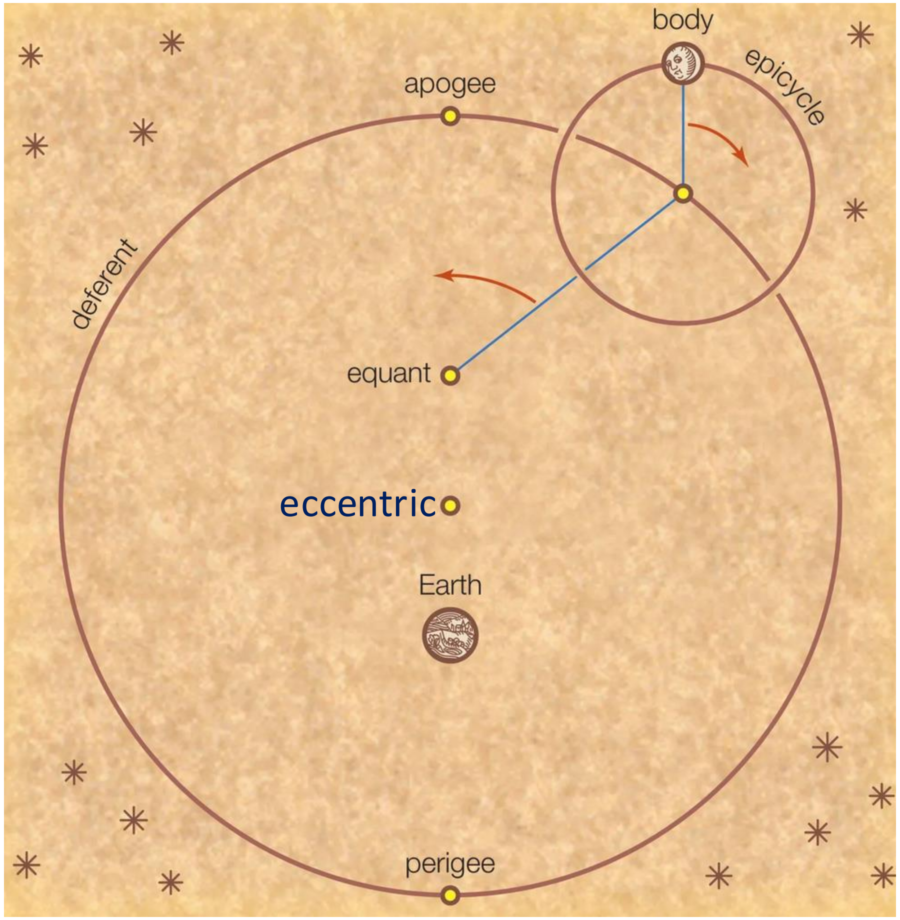
Principles hitting reality check:

To explain the motion of the planets, for *each of them* *epicycles, equants* and *eccentrics* were introduced.

Epicycles, deferents, equants, eccentrics, …

epicycles: retrograde motion





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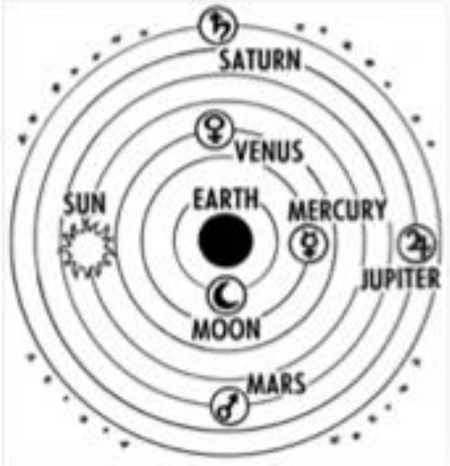
Almagest (2^{nd} c.)

The Ptolemaic model



wikipedia

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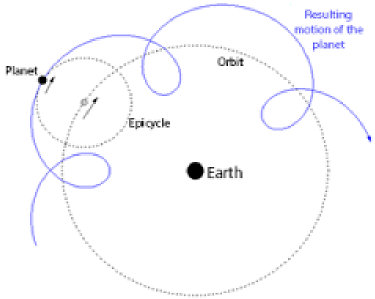
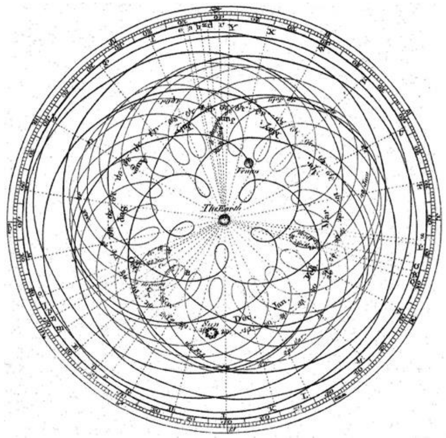


Principles hitting reality check:

To explain the motion of the planets, for *each of them* *epicycles, equants and eccentrics* were introduced.

As such, the model *successfully* described planets motions and was used to compute their positions.



- with improving observations the model got more and more complicated and started running into problems

Copernicus' starting point?

Key question 1:
What prevents the Earth from moving?

Copernicus: nothing as a principle. So it can move.

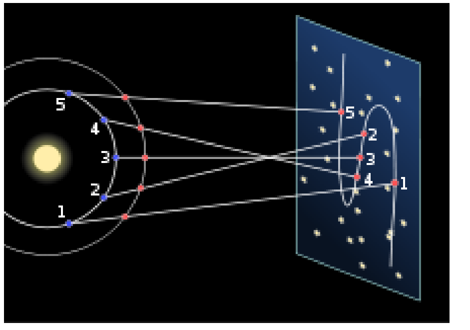
Key question 2:
Can the Earth be a planet?

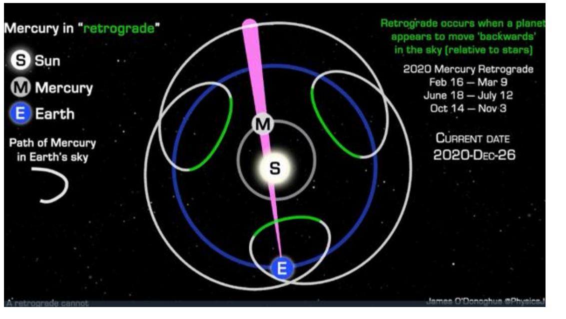
Copernicus realised the Earth is just one of celestial bodies.

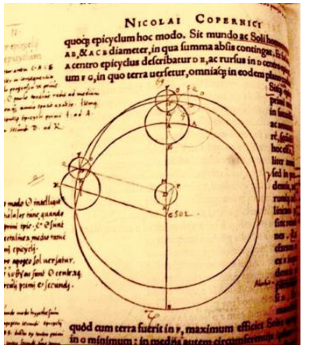
Key question 3:
How does the motion of the Sun, the Moon and the planets look like to an observer on Earth?

Copernicus developed a detailed mathematical description of the motion of the Sun, the Moon and the planets ***as seen by*** **an observer on Earth.**

…including the
retrograde motion







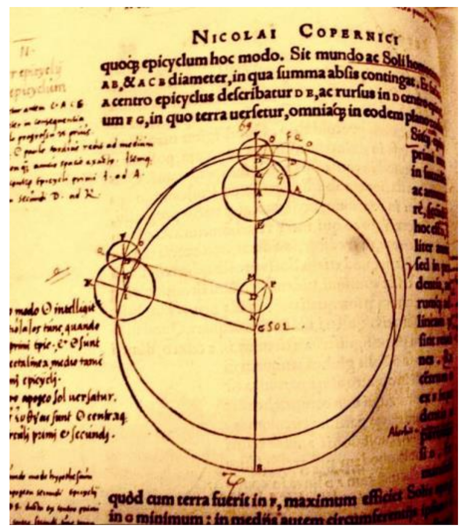
Copernicus and his heliocentric model

He created a full-scale, detailed geometrical model of a heliocentric system:

- **The Earth and the other planets move around the stationary Sun.**
- **The apparent retrograde motion of the planets is caused by the Earth's motion.**
- **The Earth has three motions: annual revolution about the Sun, daily rotation and annual tilting of its axis.**

His model had:

- **mathematical structure,**
- **parameters,**
- **predictions.**



He described the celestial motion in terms of a "pure combination of circles."

Owen Gingerich,
The Book Nobody Read

The model of Copernicus had all the features of a first modern theory.

Jim Peebles (Nobel Prize 2019)

In this sense it marked the beginning of modern science.

Some less well-known great contributions of Copernicus

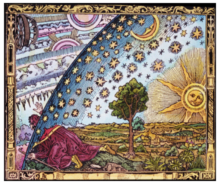
➢ the Universe is MUCH larger than previously thought

From Saturn*, the highest of the planets****,*** ***to the sphere of the fixed stars there is an additional gap of the largest size****.* *This is shown by the twinkling lights of the stars. By this token in particular they are distinguished from the planets, for* ***there had to be a very great difference between what moves and what does not move****. So vast, without any question, is the divine handiwork of the most excellent Almighty.* (The Revolutionibus…)

➢ gravity as universal property of bodies

I believe that ***gravity is nothing but a certain natural desire****,*
which the divine providence of the Creator of all things has implanted in parts,
to gather as a unity and a whole by combining in the form of a globe*.*
This impulse is present*, we may suppose,* ***also in the sun, the moon, and the other brilliant planets, so that through its operation they remain in that spherical shape*** *which they display. (*The Revolutionibus, Book I, Sec. 9*)*

A bit of heliocentric (pre)history



- **Pythagoras of Samos** (570 BC - c. 495 BC): believed **the Earth is spherical**

- **5th – 4th c. BC: some Pythagoreans** (e.g., Philolaus)
  the Earth to be one of several planets going around a central fire

- **3rd c. BC, Aristarchus of Samos: first real heliocentric model (or hypothesis?)**
  - **the Sun and the fixed stars do not move**
  - **the Earth rotates around the Sun in a circle and revolves around its axis**
  - **the Universe is many times greater than believed**

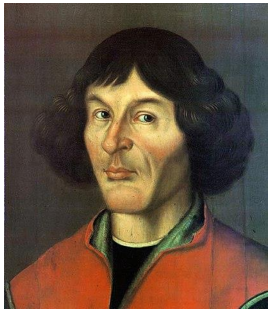
  His work was lost but was cited by Archimedes in *The Sand Reckoner*

- **...**
- **Aryabhata** (499 AD, India): **(geocentric) planetary model with Earth rotating around its axis and elliptical orbits of the planets**

- **~12th c.: Islamic and Persian astronomers** (e.g. Al-Sijzi, Averroes, ...):
  criticised the Ptolemaic model, some claimed the Earth moves and spins

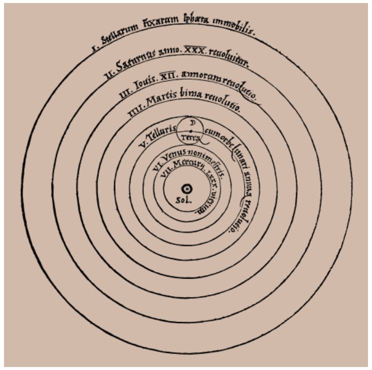
- **~>13th c.: European astronomers, philosophers, etc, joined the debate...**

The Copernican model was a great achievement…



… but it was not fully correct

- **assumed circular orbits and constant speeds**
  - **Mainly because of this, the model did not fully agree with the astronomical observations.**
  - **To correct for this, Copernicus still had to use epicycles (but not equant).**

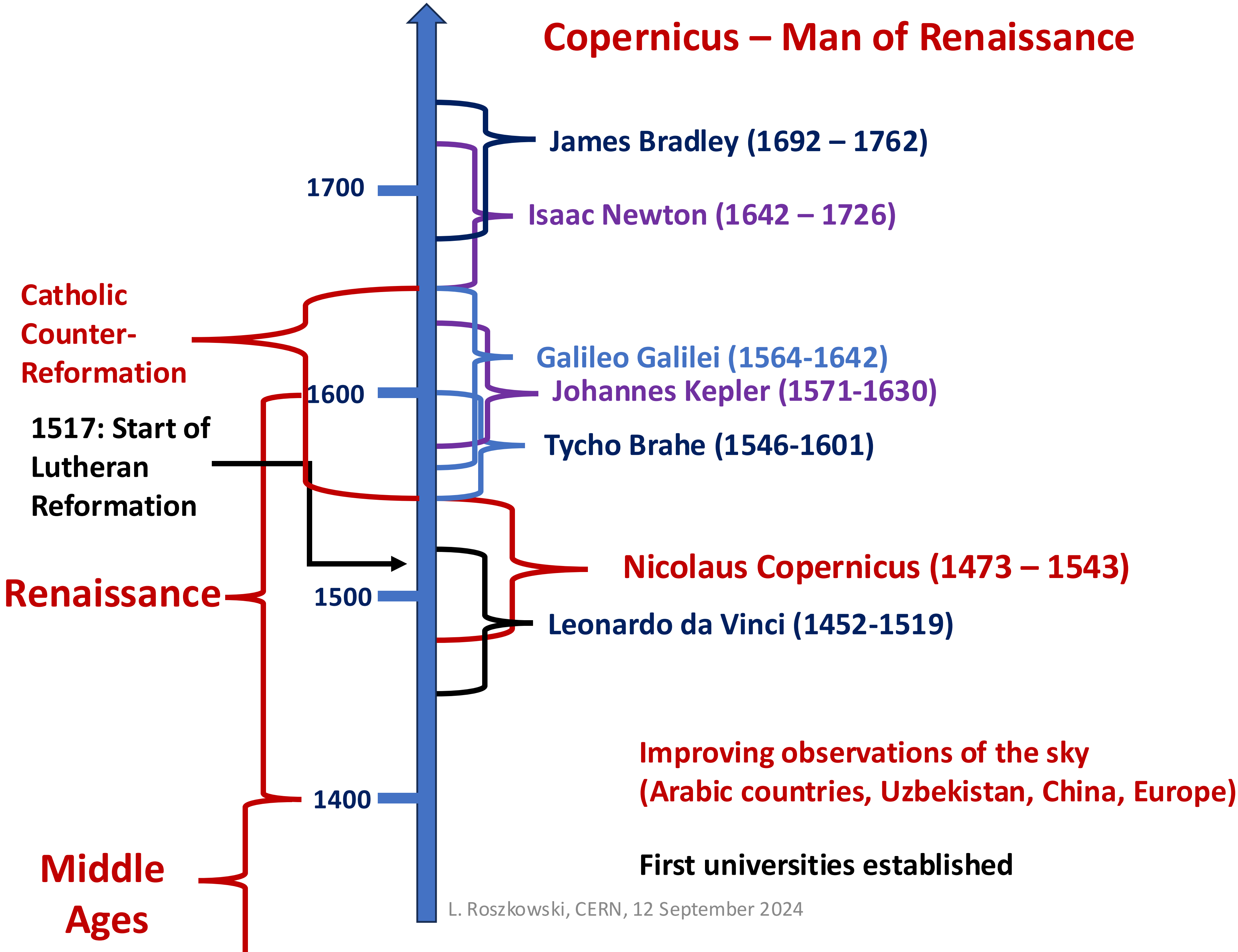


- **it did not give more accurate results**

- **It had no <u>immediate</u> ``smoking-gun" prediction!**

The model was met with much interest…
…but also scepticism.

Copernicus – Man of Renaissance

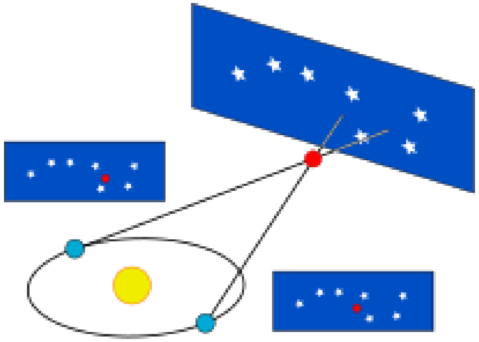


Tycho Brahe

(1546 – 1601)

Danish astronomer

- ➢ **Brahe attempted to measure a stellar parallax**



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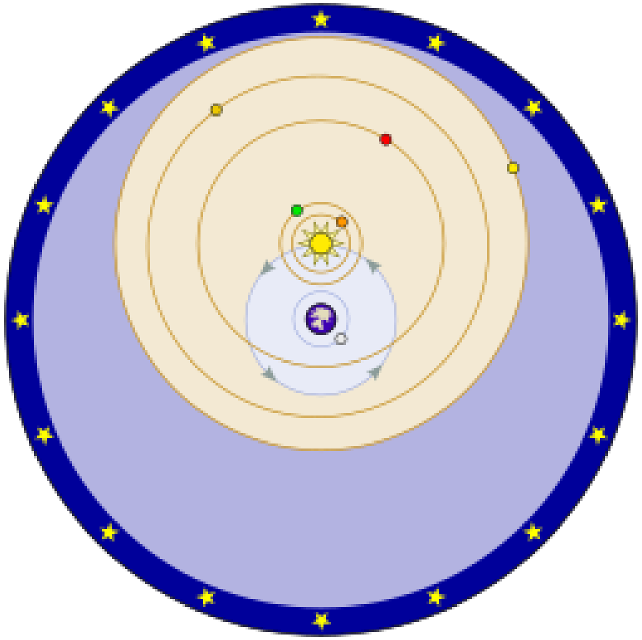


Brahe then favoured an alternative system.

The model was criticised even by his assistant J. Keppler.

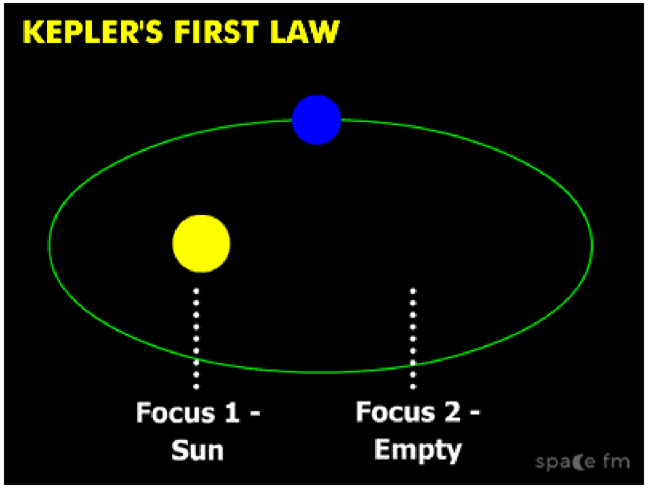
- ➢ **Failing to see it, he rejected the Copernican model.**

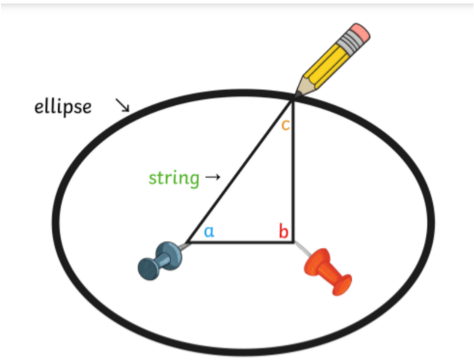
Johannes Kepler

(1571 – 1630)

~1604:

- **Orbits: circle → ellipse**
- **Speed: constant → varying**
- **No more epicycles!**





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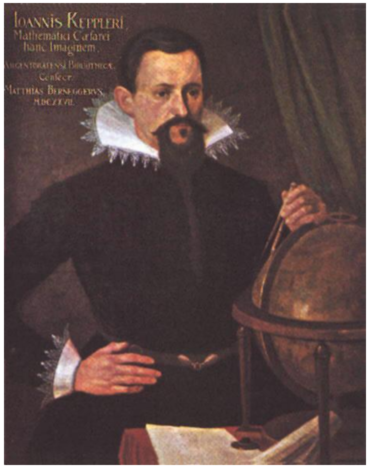


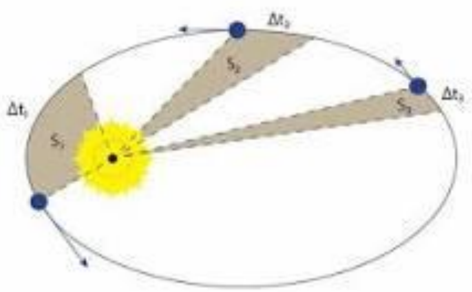
German astronomer, mathematician, astrologer, natural philosopher and music writer

Kepler's Laws:

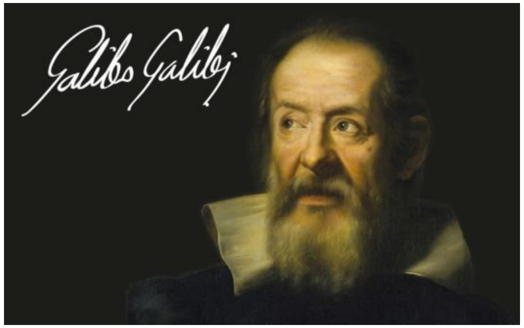
Law 1: **Planets move in elliptical orbits around the Sun.**

Law 2: Planets move faster the nearer they are to the Sun.

Law 3: There is a relationship between the distance of a planet and the time it takes to orbit the Sun.

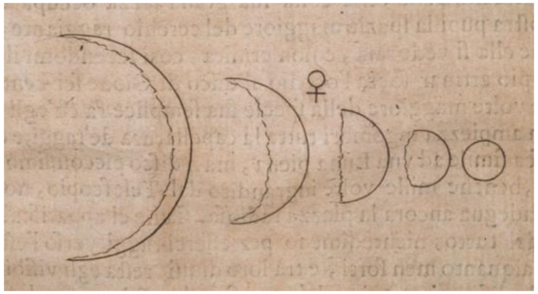


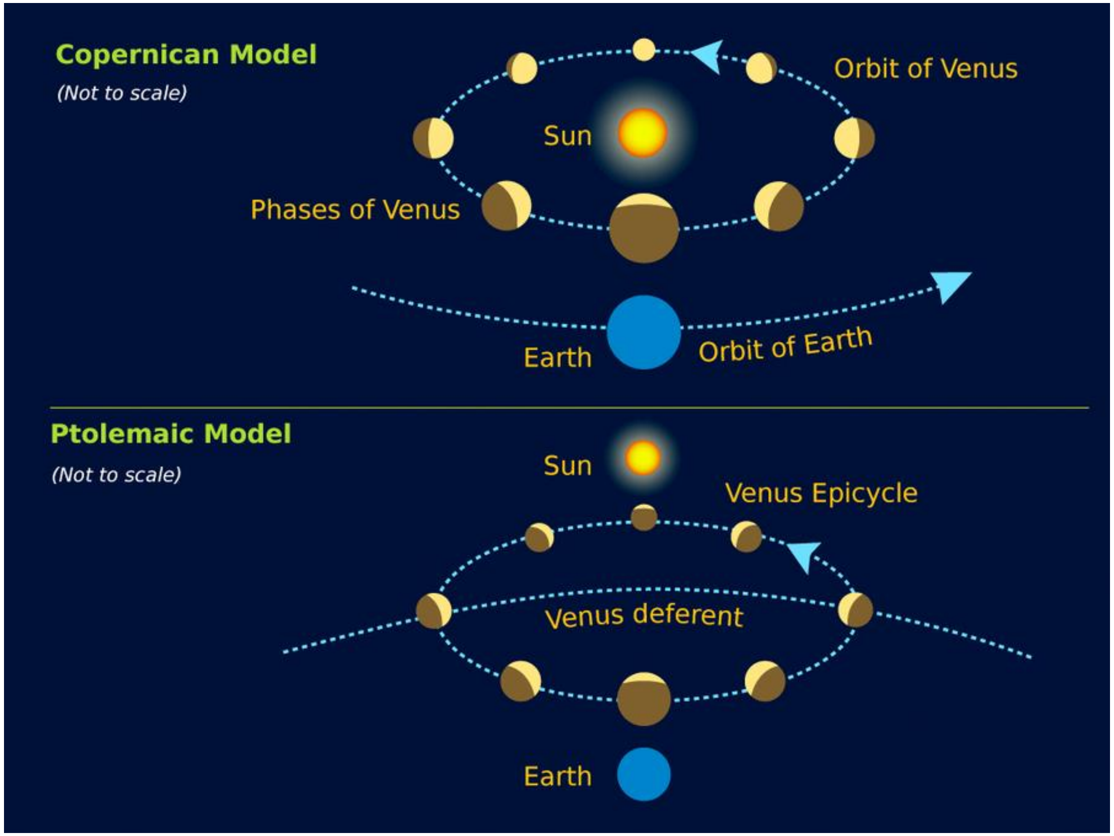
Galileo Galilei
(1564 – 1642)



Italian astronomer, physicist and engineer

- Galileo was first to use a telescope to observe the sky
- 1610: He saw the phases of Venus

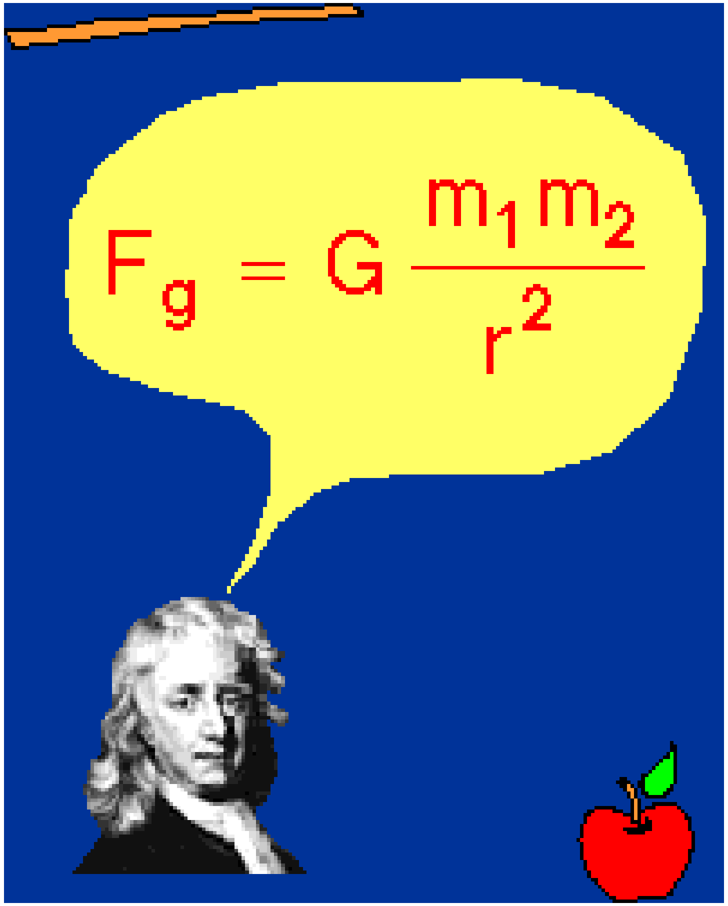


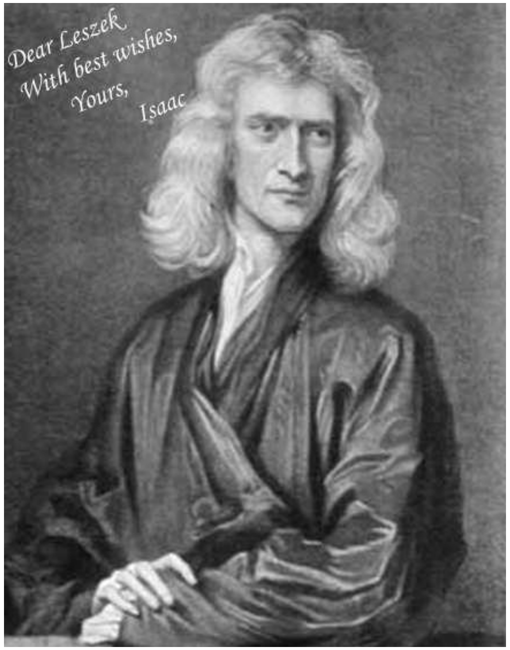


This provided a very strong argument for the Copernican model

Isaac Newton
(1642 – 1726)

➢ **Newton formulated a universal law of gravity.**





English mathematician, physicist, astronomer, alchemist, theologian, and natural philosopher

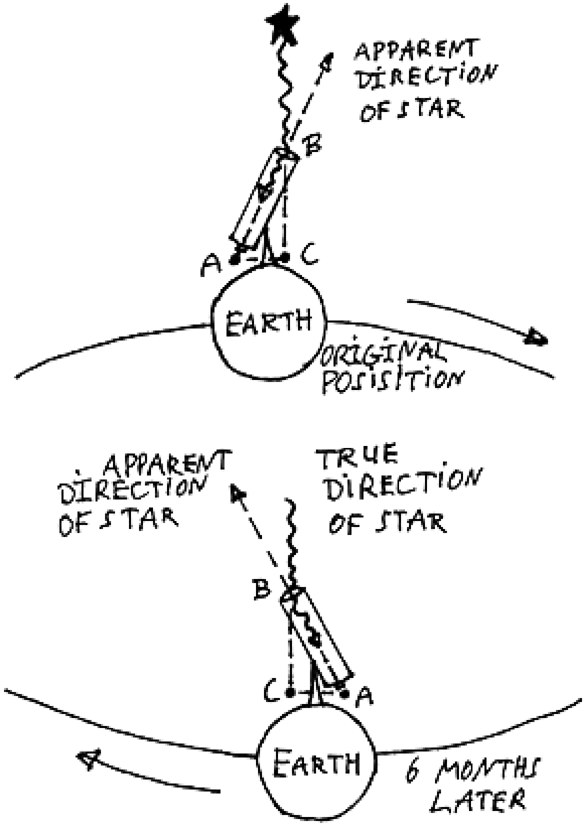
The motion of the planets can be understood in terms of simple universal law of gravity.

James Bradley
(1692 – 1762)

English astronomer and priest

- **1727: discovery of aberration of light of stars**

Bradley noticed that annually stars make small ellipses in the sky

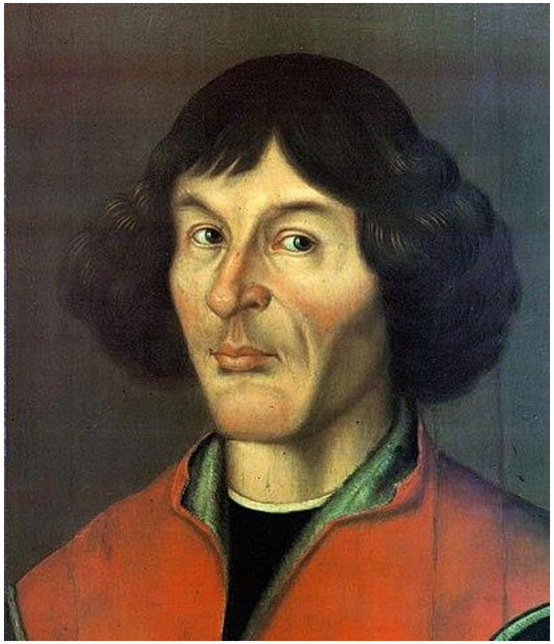


eitgaastra.nl

aberration of light:
apparent motion of a star about its true positions in the sky

CV

- Worked most of his life away from the academic environment
- Did not have a degree in astronomy
- Had to spend most of his time on admin, legal, other duties
- Never had a research grant
- Had only one student
- Had only one publication in astronomy
- Gave no invited talks
- …



Copernican Revolution

…or progression?

➢ Ideas against paradigm	➢ Starting from antiquity
➢ Concrete, detailed model	➢ Copernicus (<1543)
➢ Attempts at verifying it	➢ e.g. Brahe (>~30 yrs)
➢ Correcting it	➢ Keppler (>~100 yrs)
➢ Strong arguments in its support	➢ Galileo (>~100 yrs), Bradley (~>200 yrs)
➢ Understanding it: how → why!	➢ Newton (>~170 yrs)

Science often advances through many unexpected twists, accidental events, wrong assumptions or motivations, sometimes errors…

but…
It DOES advance

The story of Copernicus and his heliocentric theory is a prominent and dramatic illustration of this general experience!