Philosophy of Science Survey

Week 10

PHIL 2160. Ohio University. Spring 2021.

Chapter 14: The Copernican System

Nicolaus Copernicus (1473–1543)

- Polish mathematician, astronomer, and Catholic canon
- Studied humanities and astronomy at the University of Bologna (1496–1501)
  - Studied Regiomontanus's *Epitome of the Almagest*
- Studied canon law at the University of Padua (1501–1503)
  - Received doctorate in canon law
- Worked as his uncle Lucas Watzenrode's secretary.
  - Watzenrode was a prince-bishop of Warmia, where Copernicus is from.
- Continued to work on heliocentric ideas until his death.

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

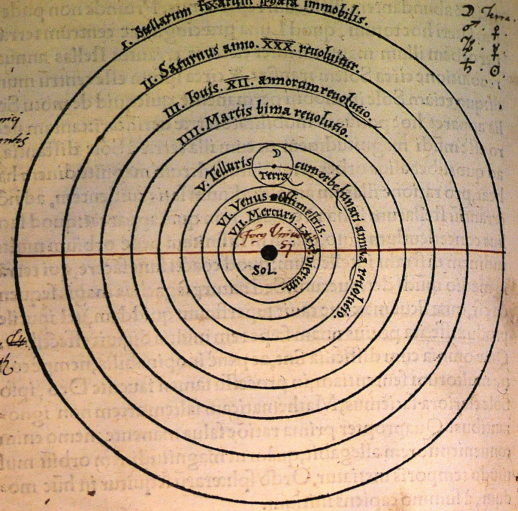
Habes in hoc opere iam recens nato, & ædito, ſtudioſe lector, Motus ſtellarum, tam fixarum, quàm erraticarum, cum ex ueteribus, tum etiam ex recentibus obſeruationibus reſtitutos: & nouis inſuper ac admirabilibus hypotheſibus ornatos. Habes etiam Tabulas expeditiſsimas, ex quibus eoſdem ad quoduis tempus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

Ἀγεωμέτρητος μηδεὶς εἰσίτω.

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

De revolutionibus orbium coelestium (On the Revolutions of the Celestial Spheres) (1543)

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 circumcurrens. In medio uero omnium residet Sol. Quis enim in hoc



pulcherimo templo lampadem hanc in alio uel meliori loco ponere, 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 quoq; minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximā Luna cū terra cognationē habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

hac ordinatione admirandam mundi symmetriam, ac certū harmoniæ nexum motus & magnitudinis orbium: qualis alio modo reperiri non potest. Hic enim licet animaduertere, nō segniter contemplanti, cur maior in Ioue progressus & regressus appareat, quàm in Saturno, & minor quàm in Marte: ac rursus maior in Venere quàm in Mercurio. Quodq; frequentior apparet 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 eorū 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 illorū arguit celsitudinem, quæ faciat etiam annui motus orbem siue eius imaginem ab oculis euanescere. Quoniā 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 interfit, scintillantia illorum lumina demōstrant. Quo indicio maxime discernuntur à planetis, quodq; inter mota & non mota, maximam oportebat esse differentiam. Tanta nimirum est diuina hæc Opt. Max. fabrica.

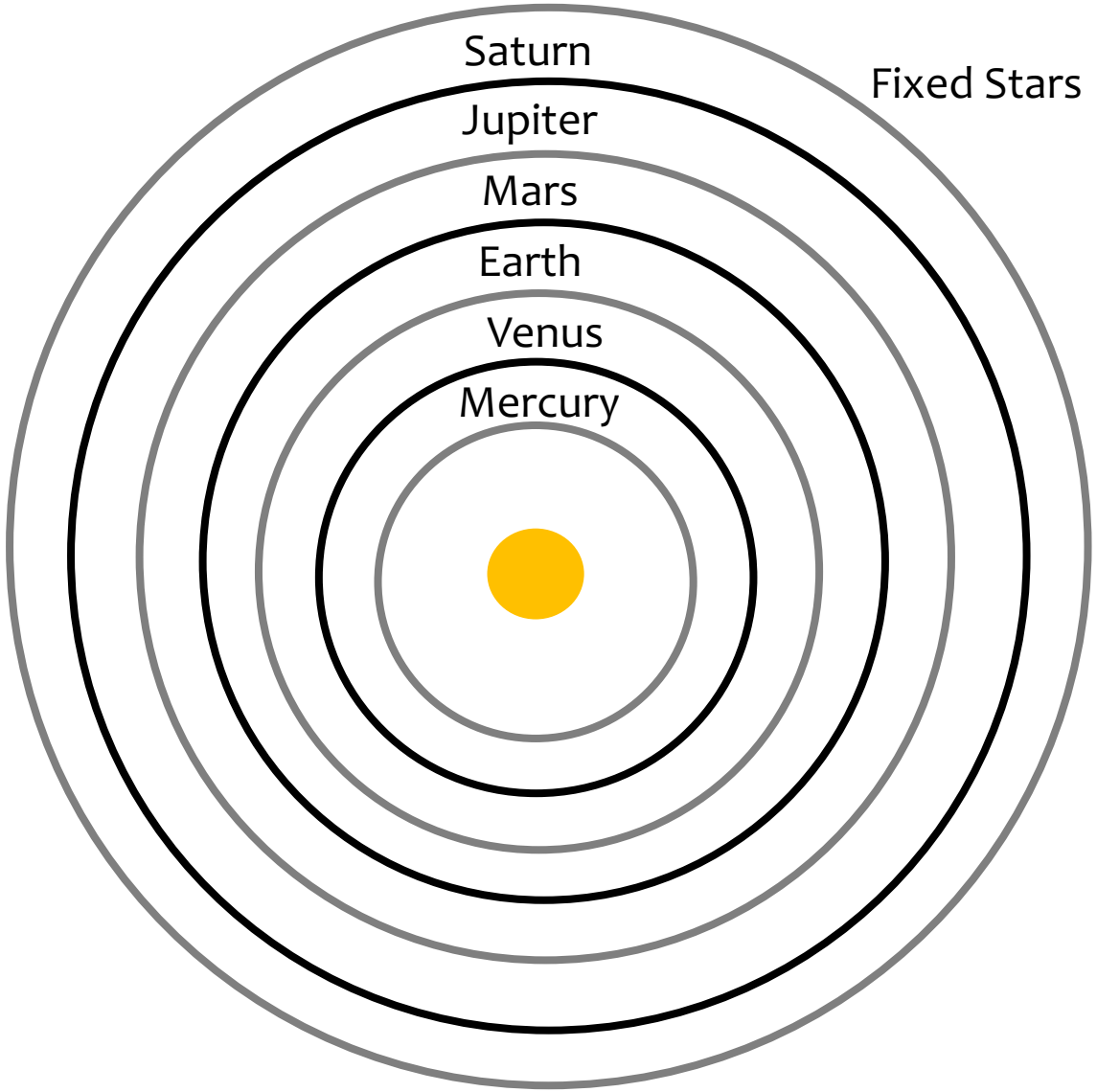
De triplici motu telluris demonstratio. Cap. XI.

CVm igitur mobilitati terrenę tot tantaq; errantium syderum consentiant testimonia, iam ipsum motum in summa exponemus, quatenus apparentia per ipsum tanquā hypothesim demonstrentur, quē triplicē omnino oportet admittere. Primum quem diximus ΝΥΧΘΗΜΕΡΟΝ à Græcis uocari, diei noctisq; 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,

Copernicus's Sun-centered universe

Copernican Universe

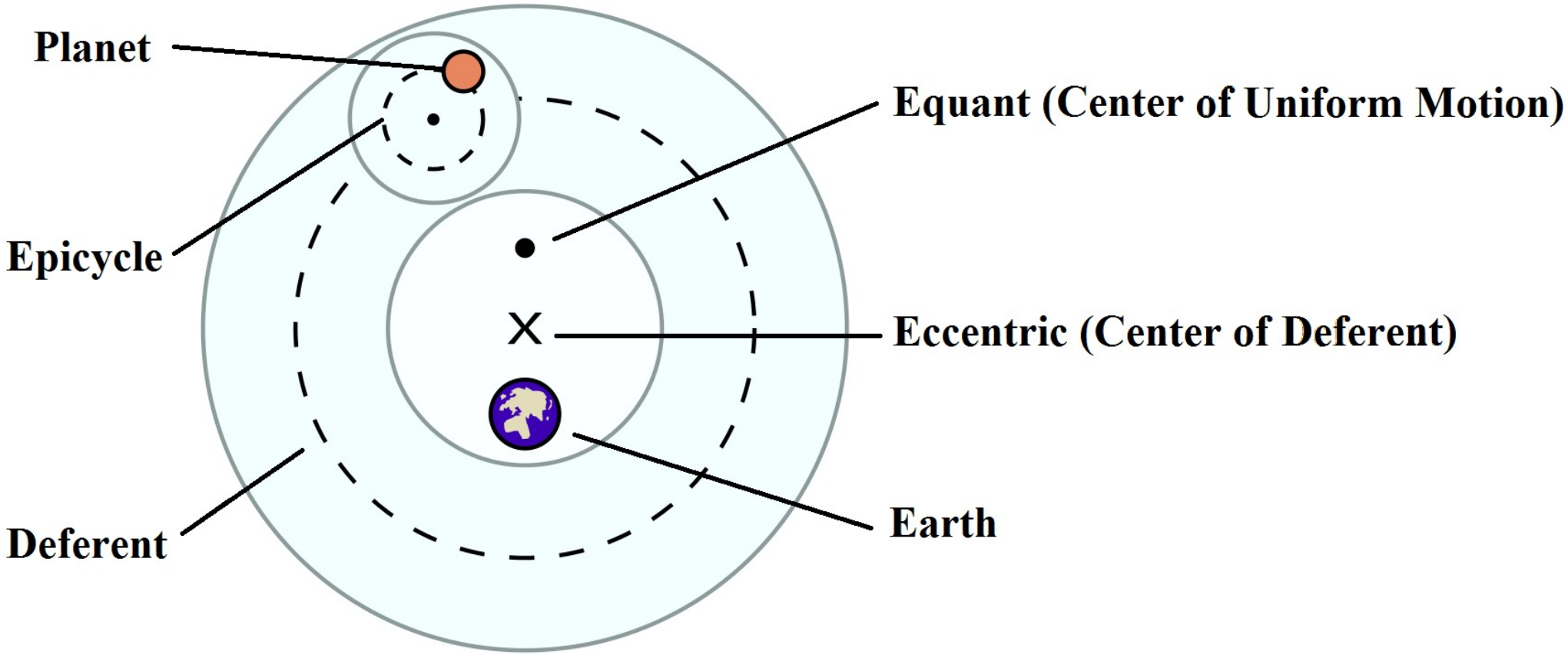


Order of celestial bodies
Sun is at the center of the universe.
Moon (not shown) goes around the Earth.

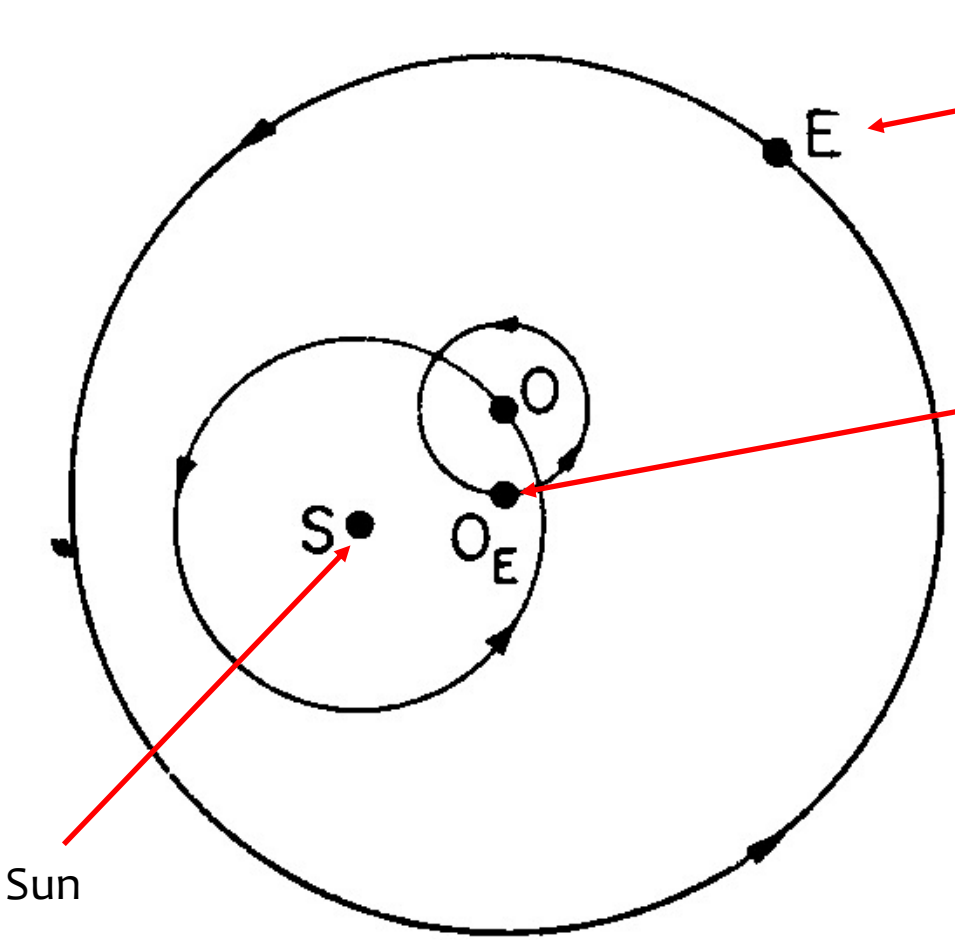
The Copernican System

- Like the Ptolemaic system, which was a mathematical theory for the Aristotelian universe, the Copernican system was a mathematical theory for the Copernican universe.
- Like the Ptolemaic system, the Copernican system *is* an **epicycle-deferent system**.
- Let's compare how each system treats planetary motion.

The Ptolemaic System



The Copernican System (for Earth)



Earth

Center of Earth's deferent

Sun

Earth moves on its deferent. The center of Earth's deferent (O_E) moves on its own epicycle, whose center is O. The point O in turn moves on its own deferent, whose center is the Sun.

There is no equant point in this system.

The Copernican System (for Mars)

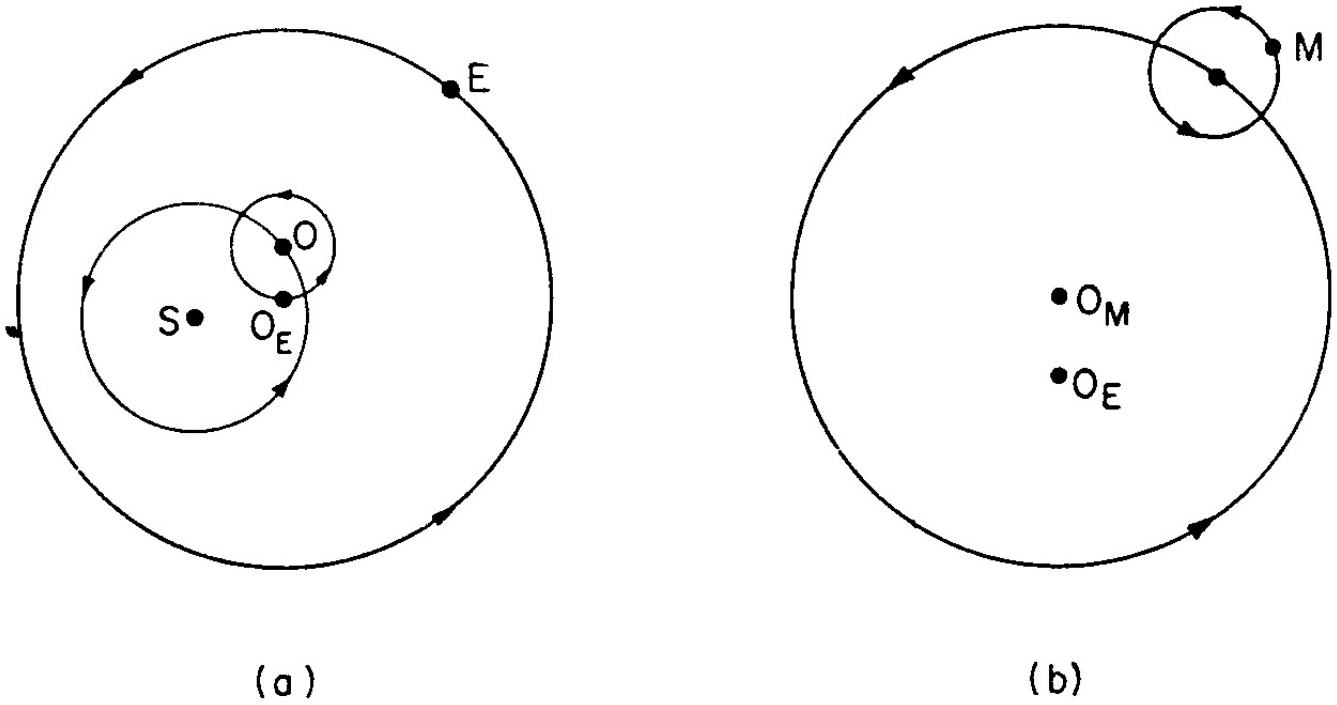
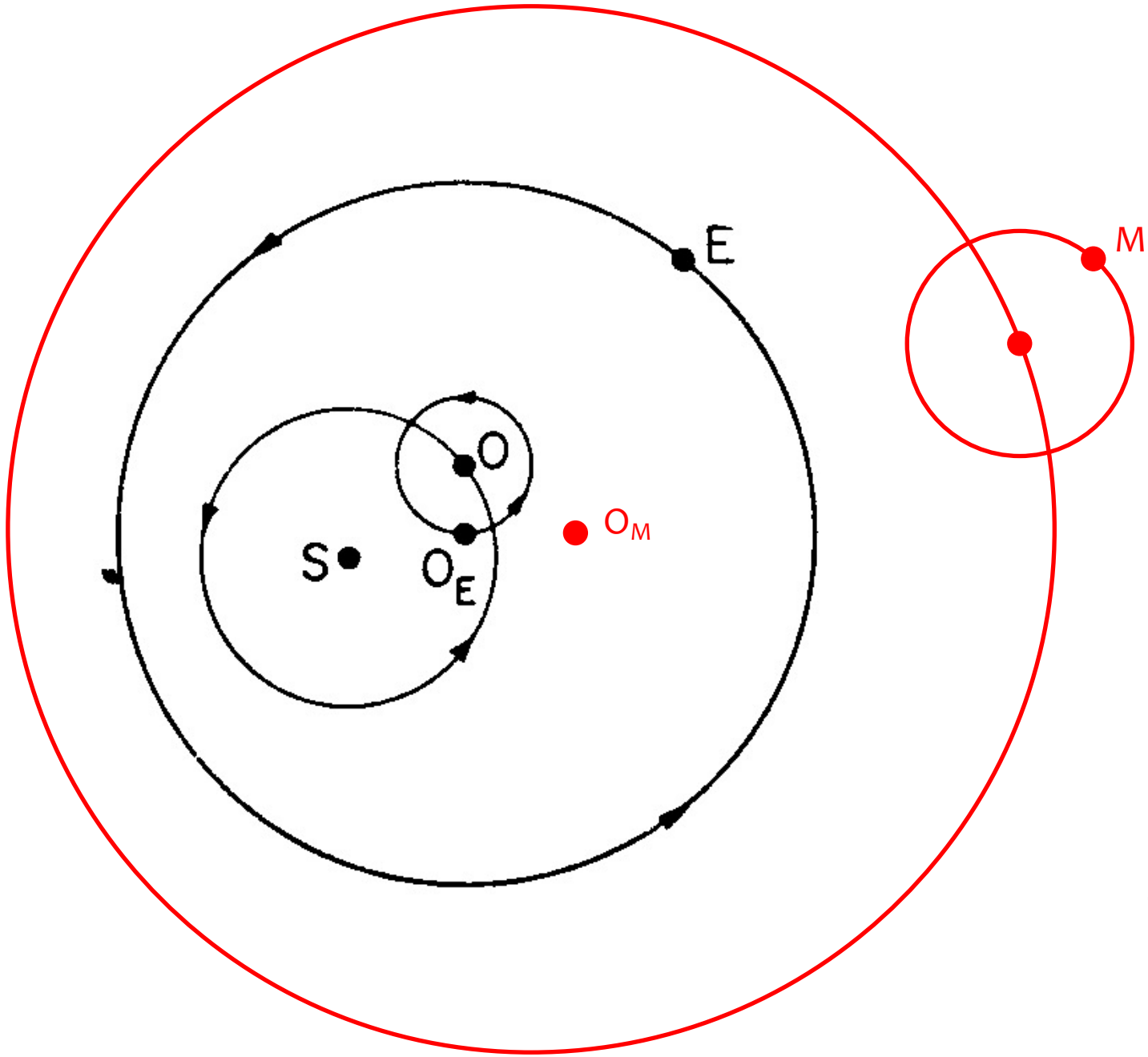


Figure 34. Copernicus' account of the motion of (*a*) the earth and (*b*) Mars. In (*a*) the sun is at S, and the earth, *E*, revolves on a circle whose center, O_E, revolves slowly about a point *O*, which in turn revolves on a sun-centered circle. In (*b*) Mars is placed on an epicycle revolving on a deferent whose center, O_M, maintains a fixed geometric relation to the moving center O_E of the earth's orbit.

The left (a) is the same as the last slide. On the right (b), M is Mars. It moves on its own deferent, whose center is O_M.

O_M moves while keeping a fixed relation to O_E, which is the same O_E on the left (a).

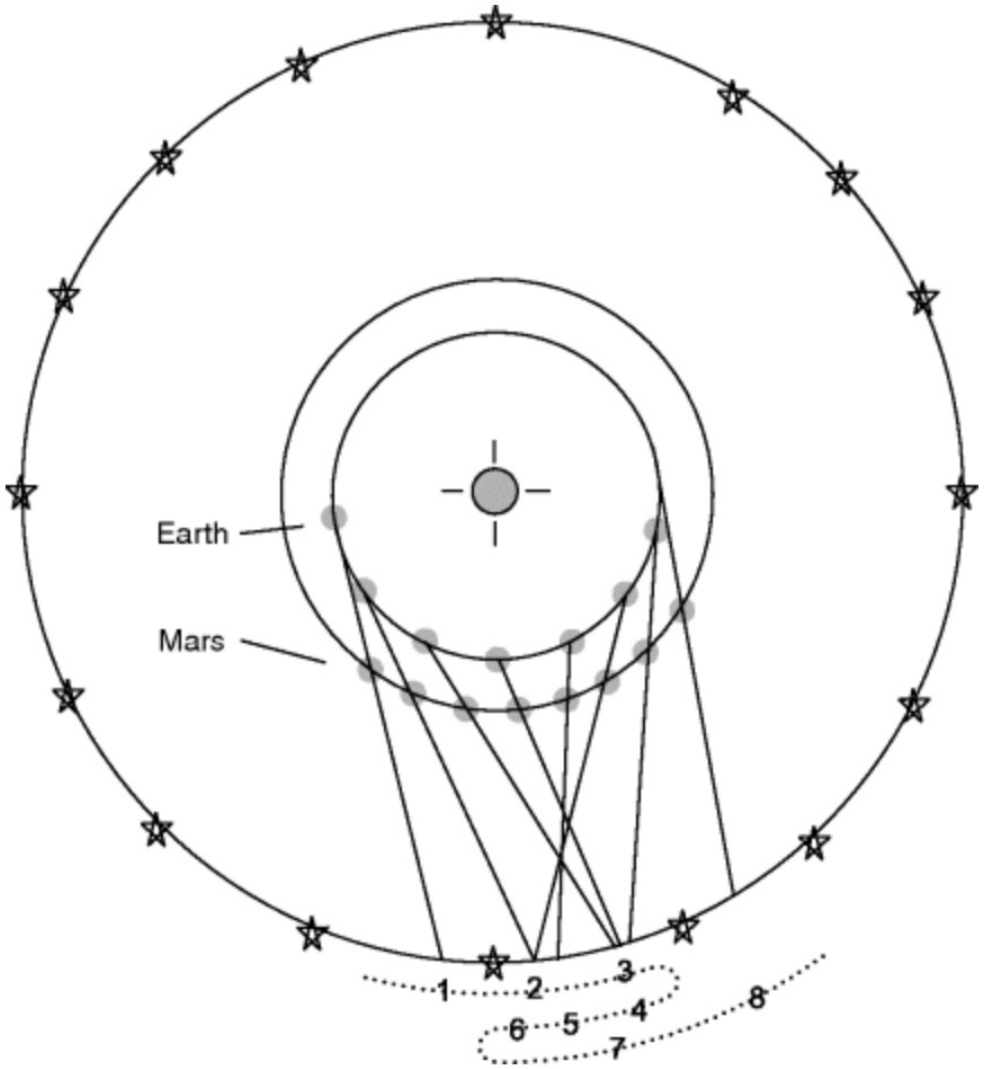
As you can see figure (b) is simplified. It should actually be superimposed on (a) (see an example next).



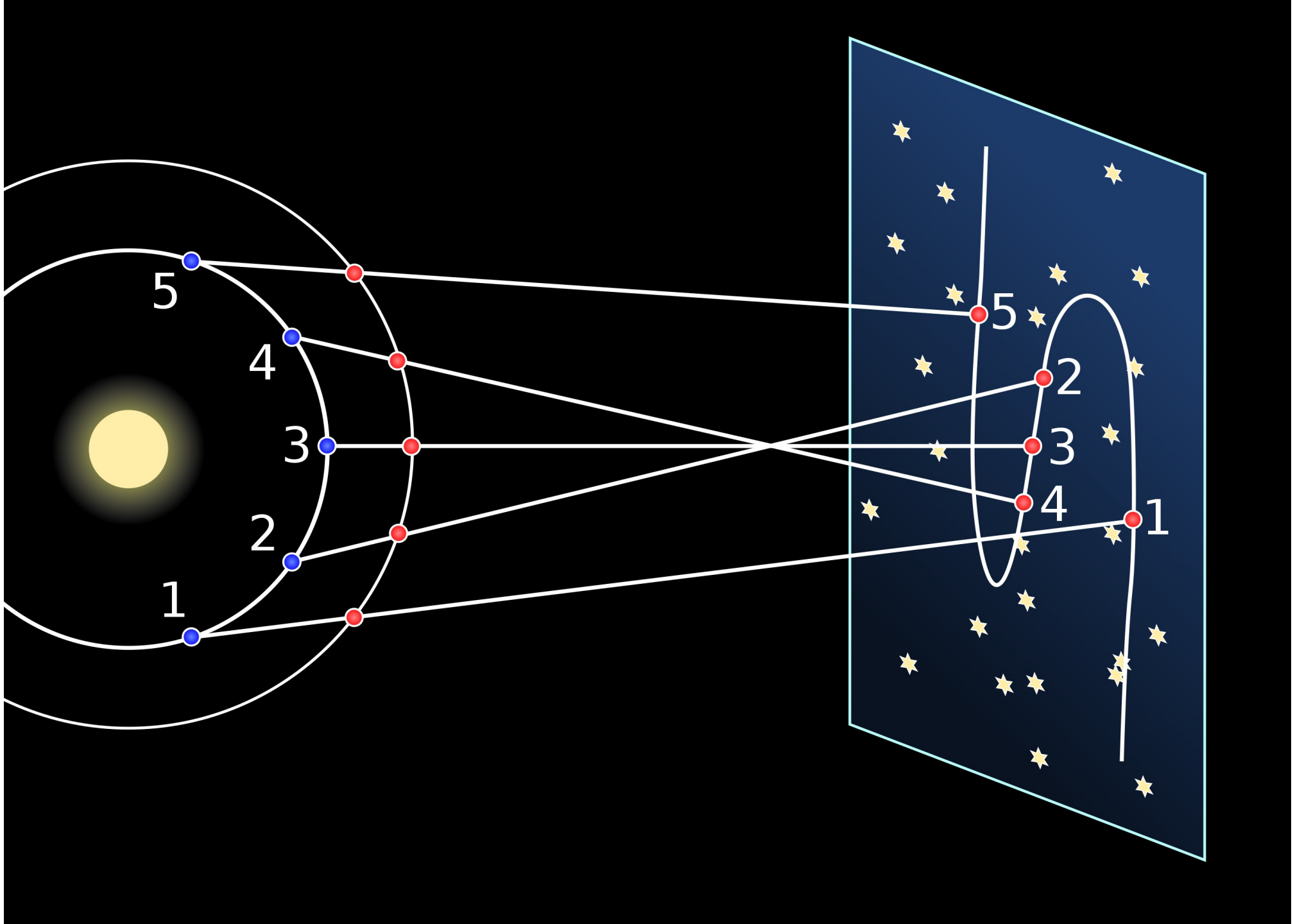
Even this diagram does not show circles necessary to account for the movement of O_M with O_E.

The Copernican System

- The Copernican epicycle-deferent system is designed to make accurate prediction and explanation of the available data.
  - Just like the Ptolemaic epicycle-deferent system
  - In this respect, the Copernican system is as complex as the Ptolemaic system (contrary to what people often say).
- But the Copernican system does not use epicycles to explain retrograde motion.
  - The Copernican explanation comes from the basic structure of the Copernican universe (see next).



The Copernican explanation of retrograde motion. It is explained as a result of perspective shift when the Earth overtakes Mars. (See next few slides)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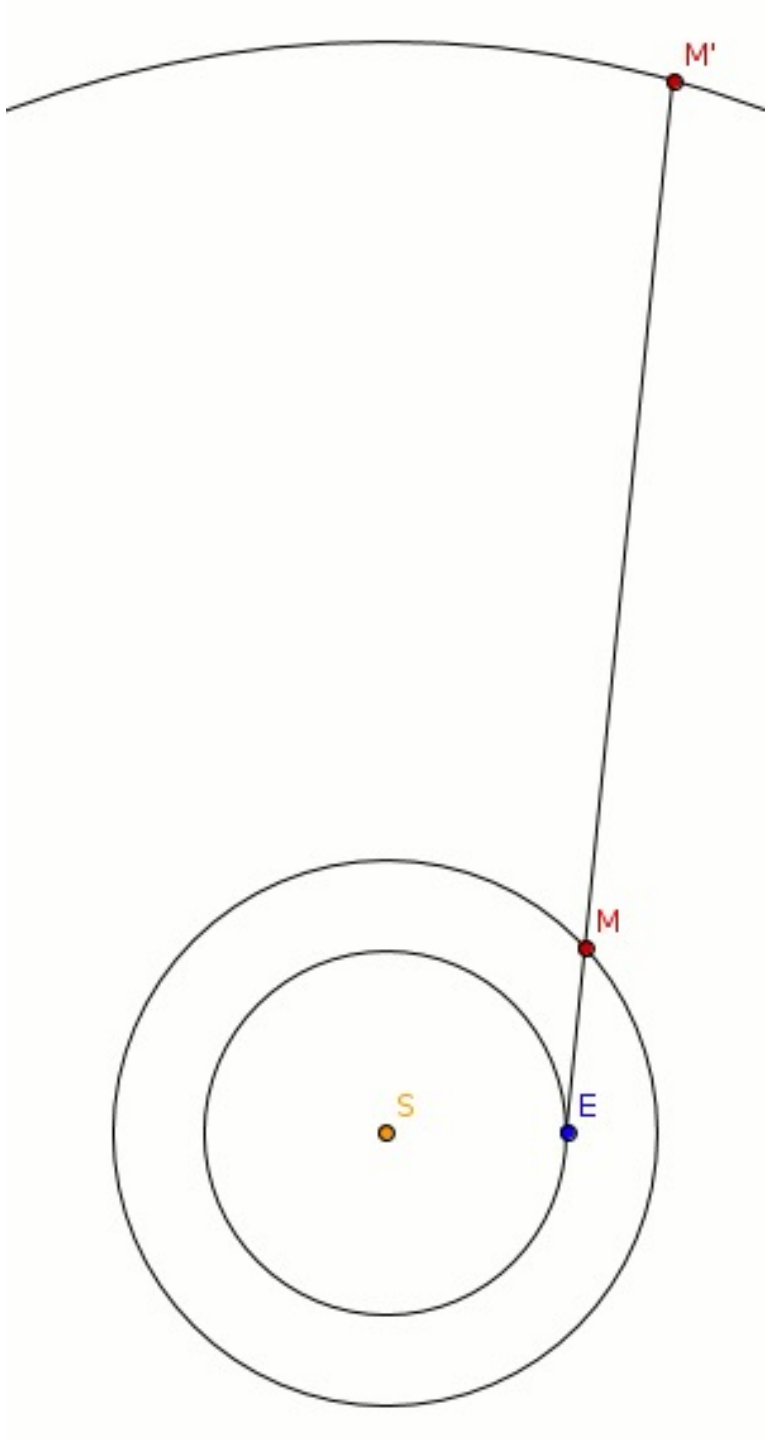


https://upload.wikimedia.org/wikipedia/commons/b/b3/Mars_Loop.gif

- https://foothillastrosims.github.io/planetary-config-react/

Copernicus's Motivations

- The Ptolemaic and Copernican systems are comparable in terms of prediction, explanation, and complexity.
- Then why did Copernicus develop his system? What motivated him?
- We'll address this question in two parts:

1. Commitment to uniform circular motion
2. Influence of Neoplatonism

Copernicus's Motivations

- Recall the problem of the planets (from Week 8): ***to predict and explain the planets' drifting motion and retrograde motion***.
- And this problem comes with certain **constraints on an acceptable solution**:

1. Invoke only uniform circular motions
2. Accurately predict and explain observed motions of the planets
3. Cohere with other, especially core, beliefs of the Aristotelian worldview.

- The Copernican system meets (2) just as well as the Ptolemaic system. But (1) and (3) play a major role in Copernicus's work.

Copernicus's Motivations

1. Invoke only uniform circular motions

- We saw that Ptolemy introduced an equant point to satisfy the requirement of *uniform* motion.
- As a result, the Ptolemaic system meets this constraint in a rather weak way.
- Copernicus was more strongly committed to uniform circular motion and wanted to develop a system that is successful at prediction and explanation but which eliminates an equant point.

Copernicus's Motivations

1. Invoke only uniform circular motions

- Copernicus was more strongly committed to uniform circular motion and wanted to develop a system that is successful at prediction and explanation but which eliminates an equant point.
- The Copernican system meets this constraint.

Copernicus's Motivations

3. Cohere with other, especially core, beliefs of the Aristotelian worldview.

- Recall Copernicus inherited the Christianized version of the Aristotelian worldview.
- In addition to Ptolemy's arguments for the claim that the Earth is at the center of the universe (review Week 6), in the Christianized version, this claim coheres with the Christian worldview.
  - The center of the universe is an important place (it's the unique point of a sphere), and God created humans, whom he loves, and put them there.

Copernicus's Motivations

- The Copernican system sacrifices this particular coherence between the Earth-centered view and the Christianized Aristotelian worldview.
- What motivated him to give up this coherence?
  - Recall he was a Catholic canon, so his reason was not likely to be a rejection of Catholic doctrines.

Copernicus's Motivations

- To answer this question, some (distinguished) historians of science have argued that Copernicus was influenced by Neoplatonism.
  - Recent historical work suggests that this hypothesis lacks support (as DeWitt notes).
  - But here we'll see how a Neoplatonic influence could explain what Copernicus did.
- Neoplatonism first developed between the 3rd and 7th century CE and had significant influence on Christian theology.
- In Copernicus's time, there was a revival of Neoplatonism.

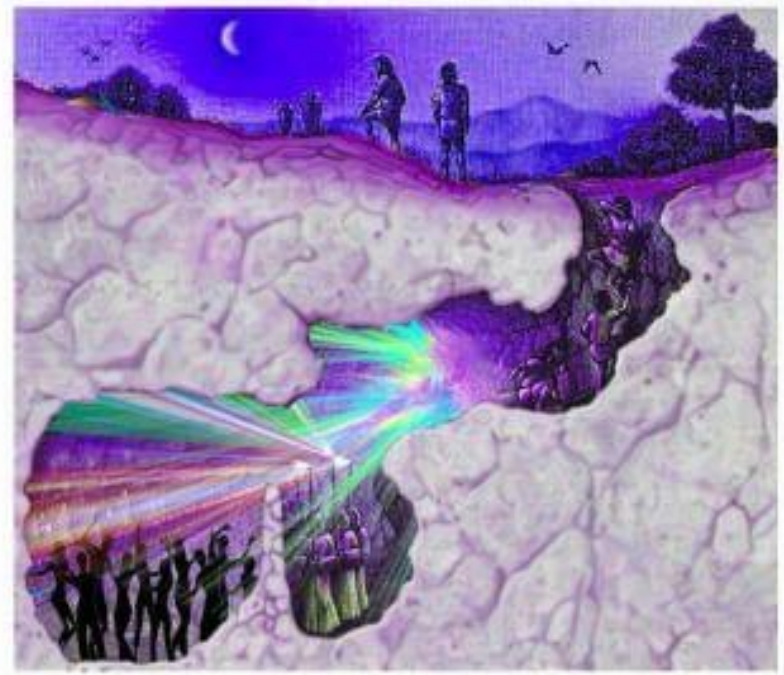
Copernicus's Motivations

- A key figure in this revival of Neoplatonism was the Italian priest and humanist scholar Marsilio Ficino (1433–1499).
- Ficino translated Plato's works into Latin, which Copernicus read.
- One aspect of Neoplatonism is the importance of the sun.
  - In Plato and a pre-Christian version of Neoplatonism, the sun is a metaphor for the Good, the highest principle of the universe.
  - Plato often analogized learning the importance of the sun with learning the truth about the universe. See the allegory of the cave (next).

Plato's Cave, 1604, by Jan Saenredam after Cornelis van Haarlem.
National Gallery of Art (https://www.nga.gov/collection/art-object-page.62542.html)

Plato's Cave

Plato's Rave



Copernicus's Motivations

- In the Christian version of Neoplatonism, the Good was interpreted to be God.
- So the sun, in turn, became a metaphor for God.
- It was also common among Neoplatonists to glorify the sun.
- Now ***if*** *Copernicus was a Neoplatonist*, it would make sense for him to put the sun at the center of the universe and see the result to be coherent with the Christian worldview.

Copernicus's Motivations

- But this historical hypothesis seems to miss some important facts about Copernicus and his work.

(a) Copernicus feared the hostility of theologians against his system, because his system abolished the traditional distinction between heaven and earth. (The traditional distinction is that earth is below us and heaven is above us.)

  - His fear would not make sense if he were Neoplatonist.

Copernicus's Motivations

(b) Book I of Copernicus's *De revolutionibus* is mostly about the Earth's motion (Knox, "Ficino and Copernicus").

- Book I presents his heliocentric universe.
- 4 chapters of Book I concern Earth's motion.
- Just 5 lines in Book I concern the sun's position (see next).

Copernicus's Motivations

"In the middle of all, however, resides the sun. For in this most beautiful temple, who would place this lamp in any other or better place than this, from where it can illuminate the whole universe all at once? Not unjustly, then, some call the sun the lamp of the cosmos, others its mind and others still its governor."

(Copernicus, *De revolutionibus*, I.10. trans quoted from Knox, "Ficino and Copernicus" in *Marsilio Ficino: His Theology, His Philosophy, His Legacy.*)

- Unlike for Copernicus, Neoplatonist influence is stronger and better documented for Kepler.

Chapter 15: The Tychonic System

Tycho Brahe (1546–1601)

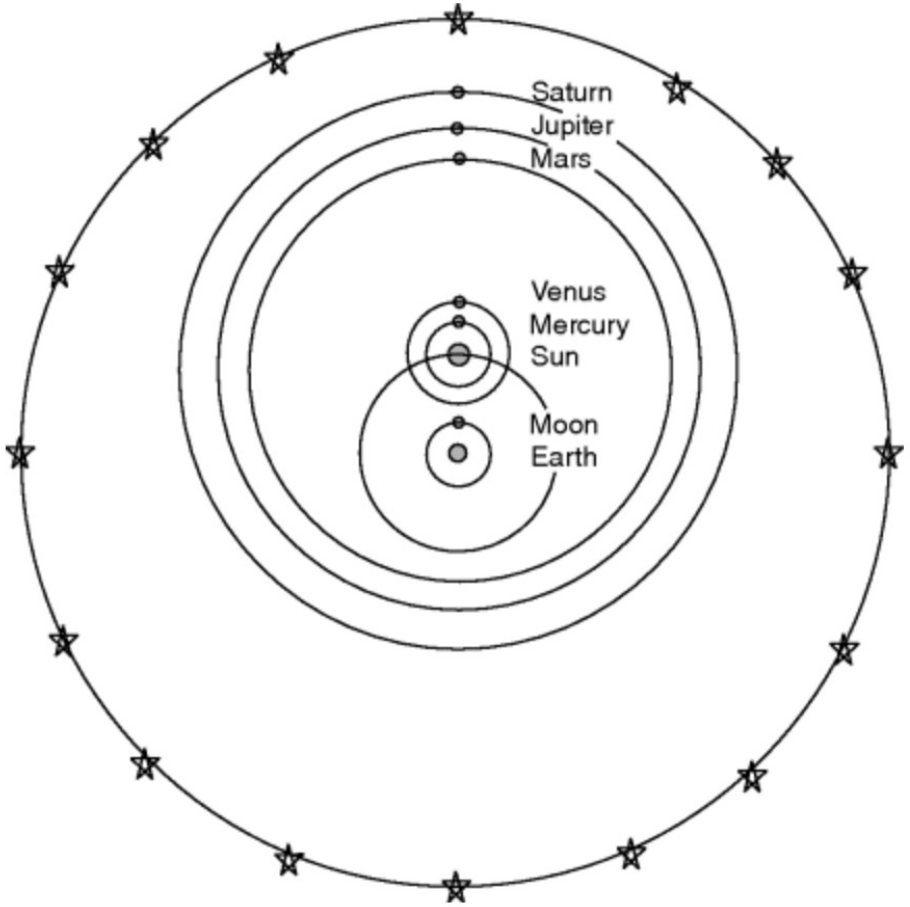
- Danish nobleman and astronomer
- Founded Uraniborg, an astronomical observatory on the island of Hven (off the coast of Copenhagen)
  - Construction began in 1576, with the support of King Frederick II
- Moved to Prague in 1599 to become court astronomer to Rudolf II
  - This move was motivated by the loss of Tycho's influence in the Danish court after Frederick's death
- In Prague, Tycho hired Kepler as his assistant.

Tycho Brahe (1546–1601)

- We'll focus on two of Tycho's contributions to astronomy.

1. The Tychonic system
2. Collection of accurate astronomical observations

The Tychonic System



The Earth is at the center of the universe. Moon, the Sun, and the stars move around the Earth. The five planets move around the Sun.

This system is mathematically equivalent to the Copernican system.

Reception of Copernicus and Tycho's Motivations

- To understand why Tycho proposed his system, we need to look at some reactions to Copernicus's *De revolutionibus*.
- Copernicus's mathematics was generally admired, and Copernicus was hailed as "a second Ptolemy."
  - Elimination of the equant point was considered a major achievement
- But Copernicus's heliocentrism was criticized on scientific and religious grounds. (see next)

Reception of Copernicus and Tycho's Motivations

Scientific Criticisms of Copernicus

- In the Copernican universe, the Sun and the stars are stationary, and the Earth revolves and orbits.
- In the 16th century, all the empirical arguments that Ptolemy and other astronomers used for movement of celestial bodies (especially the stars and the sun, in this case) were considered commonsense arguments against the Copernican universe.
- Moreover, all the arguments in favor of the stationary Earth were considered arguments against the Copernican universe.

Reception of Copernicus and Tycho's Motivations

Religious Criticisms of Copernicus

- Luther said:

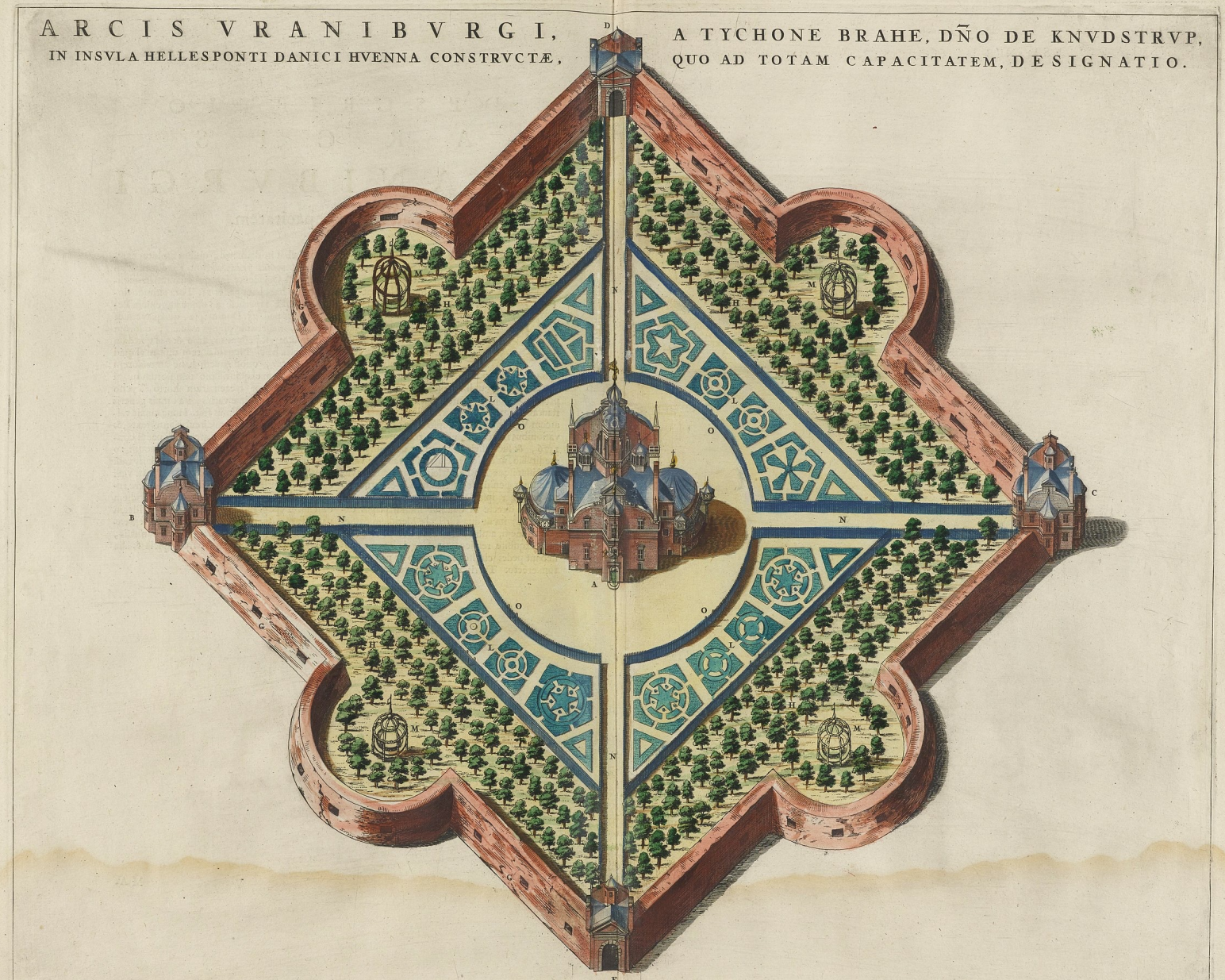
"[Copernicus] wants to prove that the earth moves and goes around instead of the sky, the sun, the moon, just as if somebody were moving in a carriage or ship might hold that he was sitting still and at rest while the earth and the trees walked and moved. But that is how things are nowadays: when a man wishes to be clever he must [. . .] invent something special, and the way he does it must needs be the best! The fool wants to turn the whole art of astronomy upside-down. However, as Holy Scripture tells us, so did Joshua bid the sun to stand still and not the earth."

Reception of Copernicus and Tycho's Motivations

- Tycho consistently admired Copernicus's mathematical theory, but rejected heliocentrism on both scientific and religious grounds.
- In the 16th century, this was a very common response to Copernicus's work.
- So Tycho developed a system that combined geocentrism and the parts of the Copernican system he admired.

Tycho's Observational Astronomy

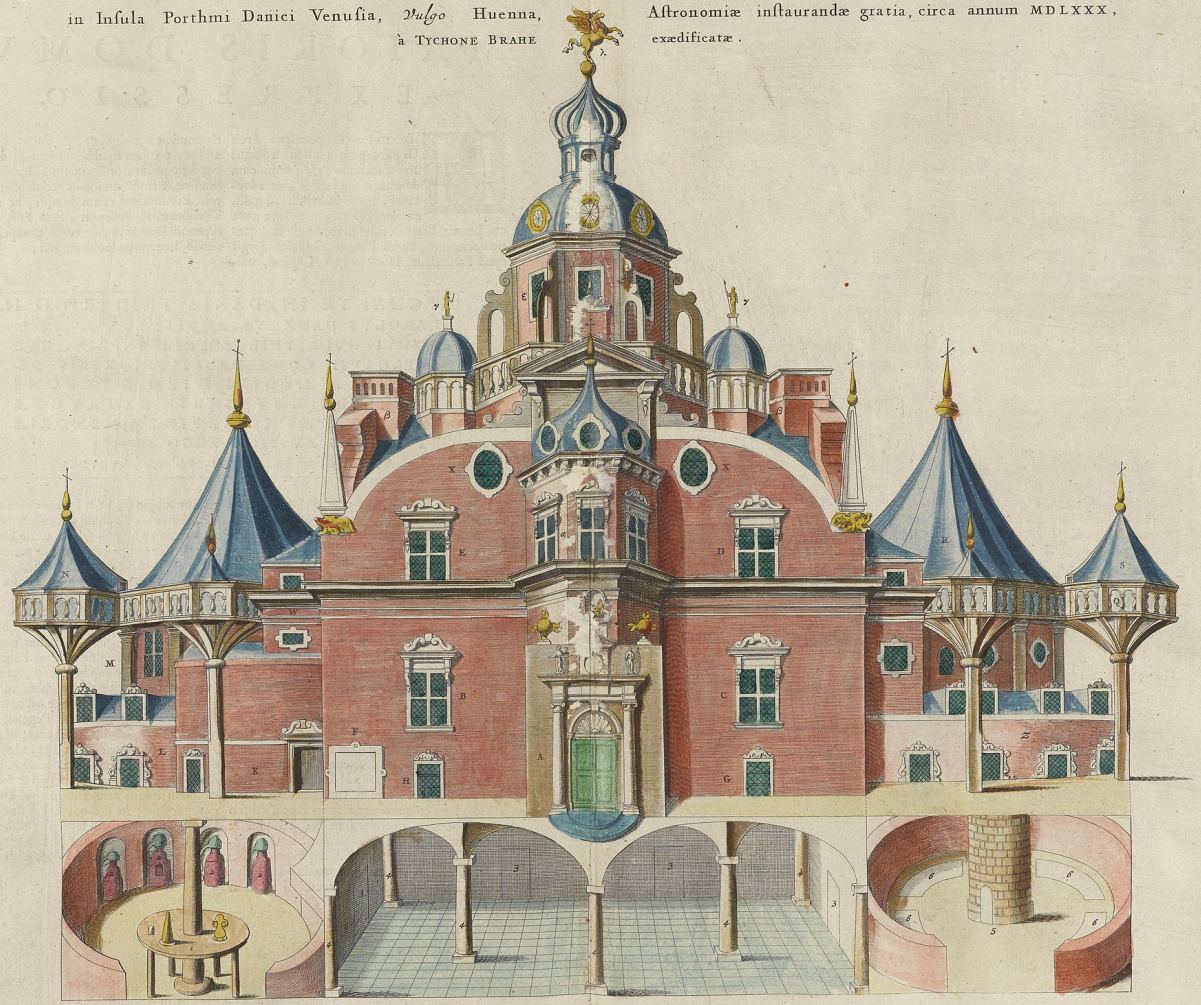
- Tycho's observational work at Uraniborg produced highly accurate naked-eye observations.
  - Probably the most accurate humans could ever make, since some of Tycho's observations reached the limit of the resolving power of human eyes.
- Tycho made accurate observations possible by improving astronomical instruments.
  - He didn't do observations by himself alone. There was a group of assistants who made observations independently of each other, and Tycho carefully compared their data to correct observational errors.



Uraniborg, Tycho's observatory built in the 1570s on the island of Hven

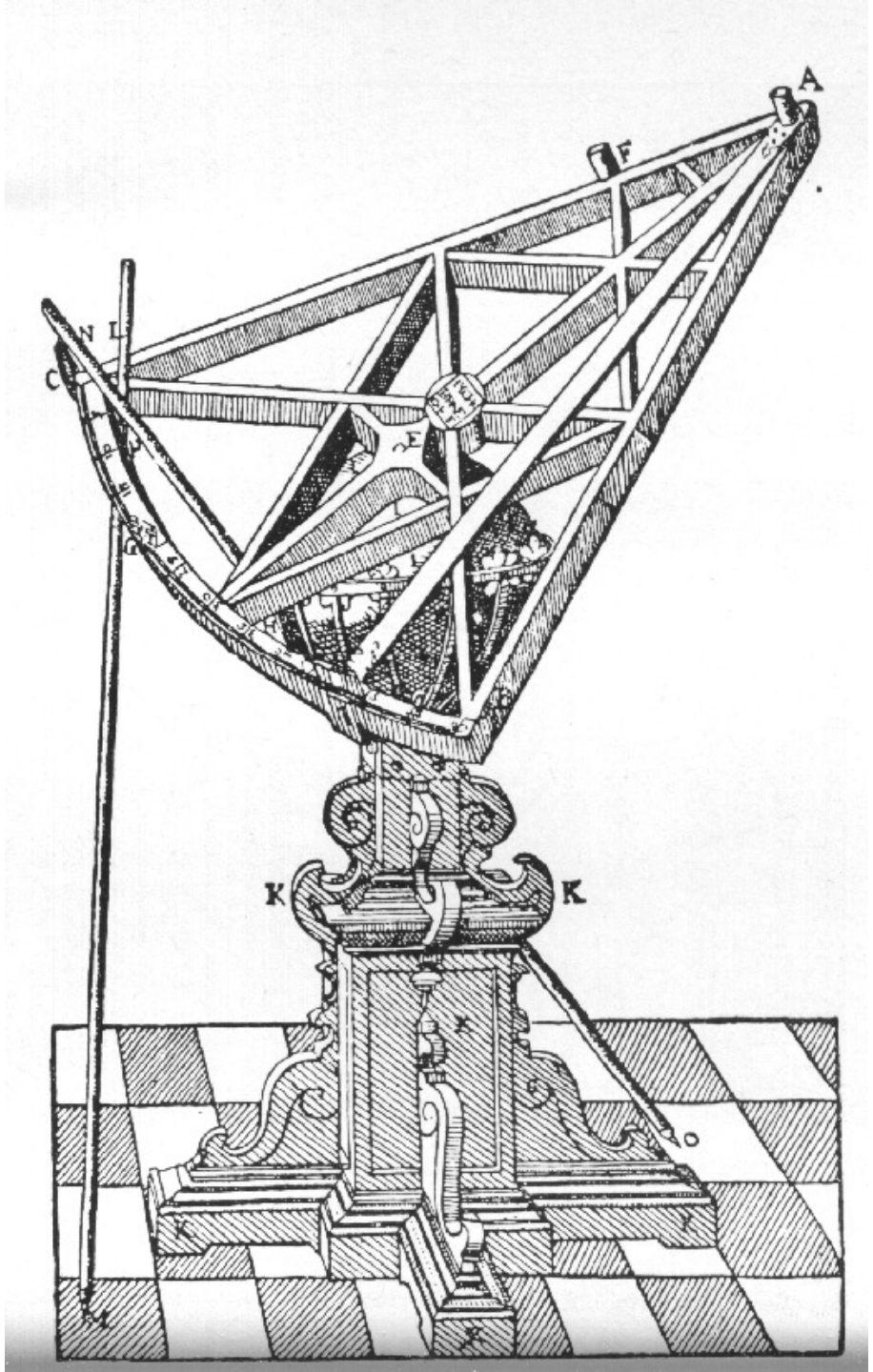
ORTHOGRAPHIA PRÆCIPVÆ DOMVS ARCIS VRANIBVRGI

in Insula Porthmi Danici Venusia, *vulgo* Huenna, Astronomiæ instaurandæ gratia, circa annum MDLXXX, à TYCHONE BRAHE exædificatæ.



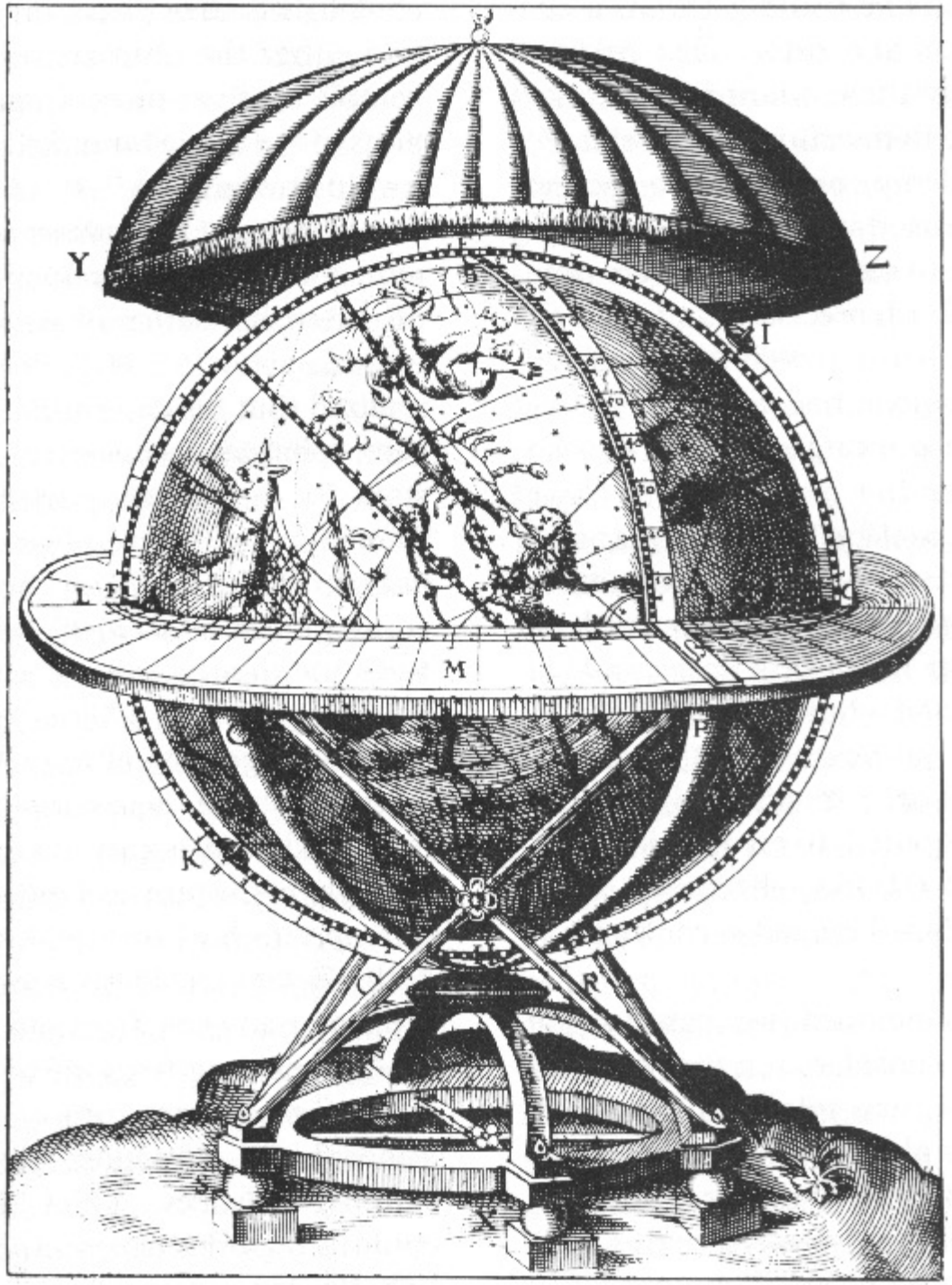
Tycho’s mural quadrant

Mural quadrant made by John Bird in 1773



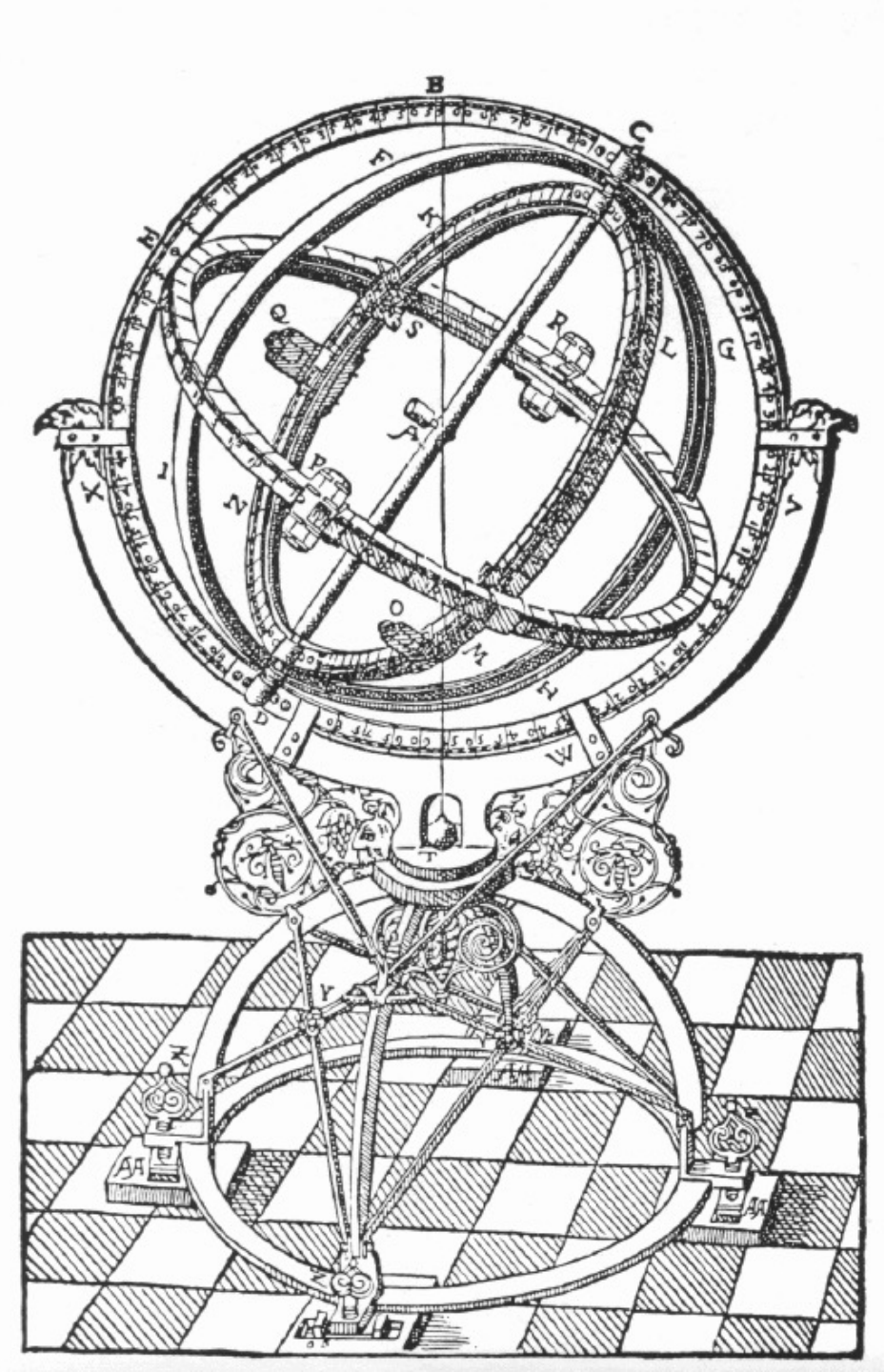
Tycho's sextant

About 1.6m in radius, built in 1582



Tycho's Great Globe

The globe was completed in 1580 and had the radius of about 1.6m. It was used to record the observed positions of stars. By 1595 Tycho had 1000 accurately observed stars inscribed on the globe.



Tycho's Armillary Sphere

Built in 1581. It had the radius of about 1.6m. It was used to record the observed positions of stars.

An armillary sphere is a model of celestial bodies, and it was used as an analog computer to solve astronomical problems.

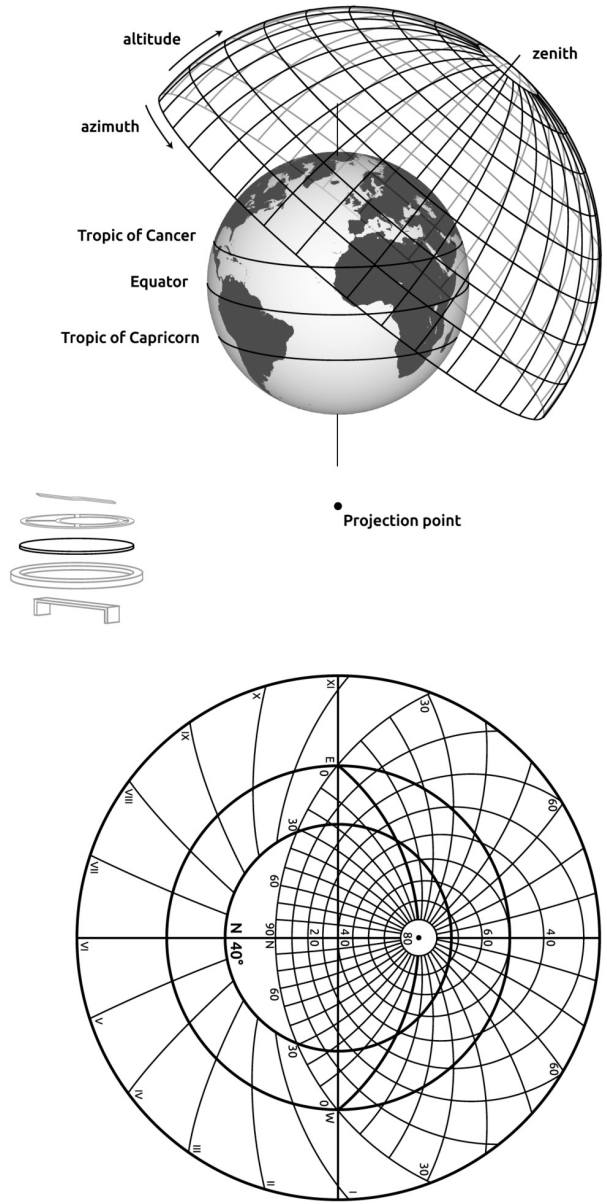
A Note on Technology

- It is commonly thought that the ancient and medieval scientists did not have any technology.
- This impression is plausible *only if* we think "technology" as referring to what we have today.
- But in general, technology means application of scientific knowledge for the purpose of solving problems.
- In this sense, ancient and medieval scientists did have sophisticated technology.
- For example, Tycho's instruments we just saw are improvements of *ancient* instruments.
  - See images next (they are all from instruments of Islamic astronomy)

Astrolabe (dated 1282)

This is a portable analog computer, and it’s related to an armillary sphere.

An astrolabe is an ancient instrument.


altitude
zenith
azimuth
Tropic of Cancer
Equator
Tropic of Capricorn
Projection point

N 40°
E
W
N
S
30
60
90
10
20
40
60
80

Spherical Astrolabe (dated 1480)

Globe (1144)

Ulugh Beg Observatory in Samarkand, Uzbekistan (15th century)

The trench with the lower section of the meridian arc

This is a **mural sextant** (describing 1/6 of a circle). It had the radius of 40m!

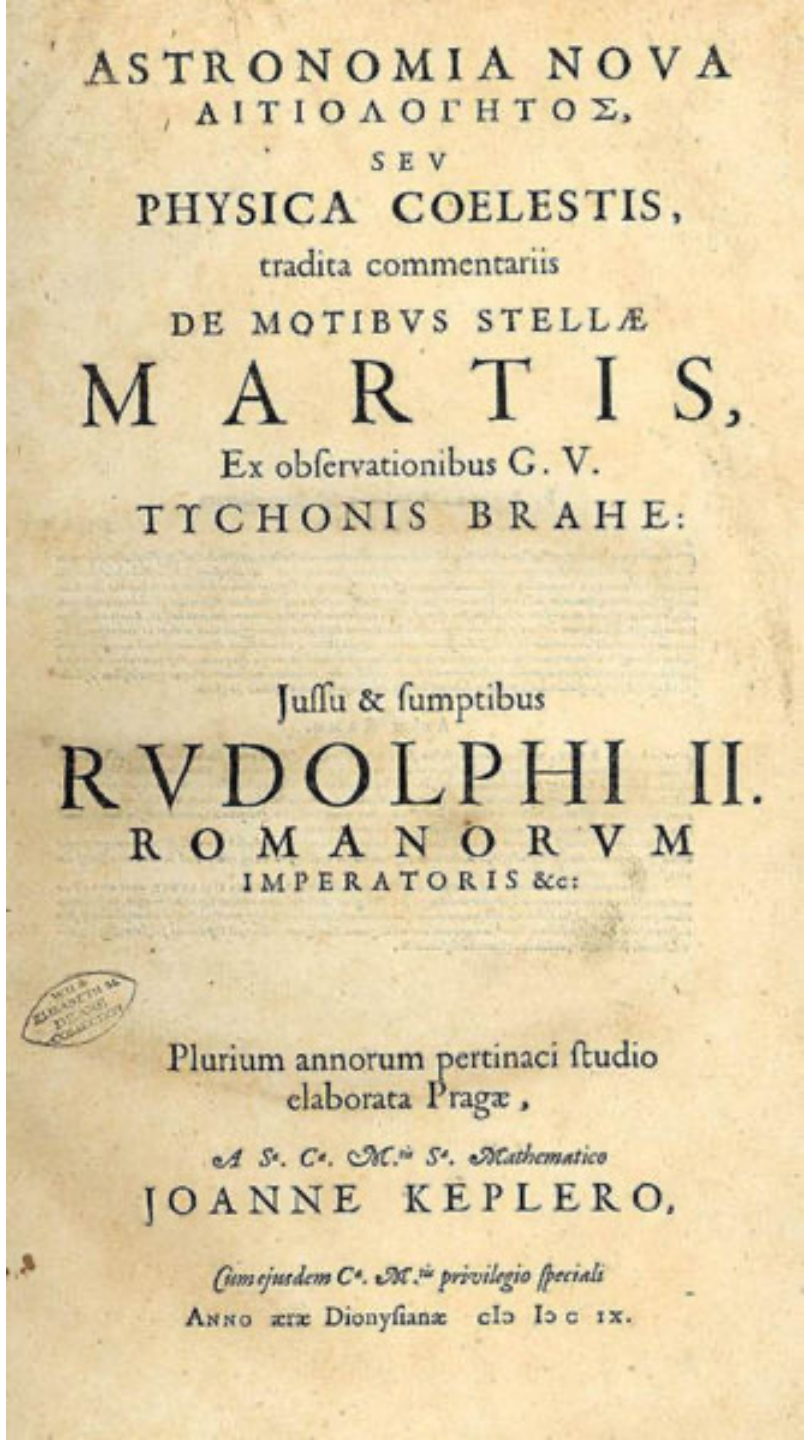
Tycho's Observations

- Tycho's instruments were larger and more precisely designed to improve accuracy of observations.
  - Observations of the positions of celestial bodies
- His most accurate observations are accurate to *1 arcminute*.
  - 1 arcminute is 1/60 of a degree.
  - 1 arcminute is 1/30 of the diameter of Moon (as seen from the Earth).
  - The resolution of the human eye is about 1 arcminute.
- Tycho's other observations are accurate to 4 arcminutes.
- The accuracy of his observations was superseded only after the invention of a telescope. (Galileo built a telescope in 1609.)

Chapter 16: Kepler's System

Johannes Kepler (1571–1630)

- German mathematician and astronomer
- After assisting Tycho, Kepler became the imperial mathematician to Holy Roman Emperor Rudolf II and his successors.
- Publications include:
- *Astronomia nova* (*New Astronomy*), 1609
  - This book presented what is known as Kepler's first and second laws of planetary motion
- *Harmonices Mundi* (*The Harmony of the World*), 1619
- *Epitome of Copernican Astronomy*, 3 volumes, 1618–1621
  - Textbook; popularized heliocentrism



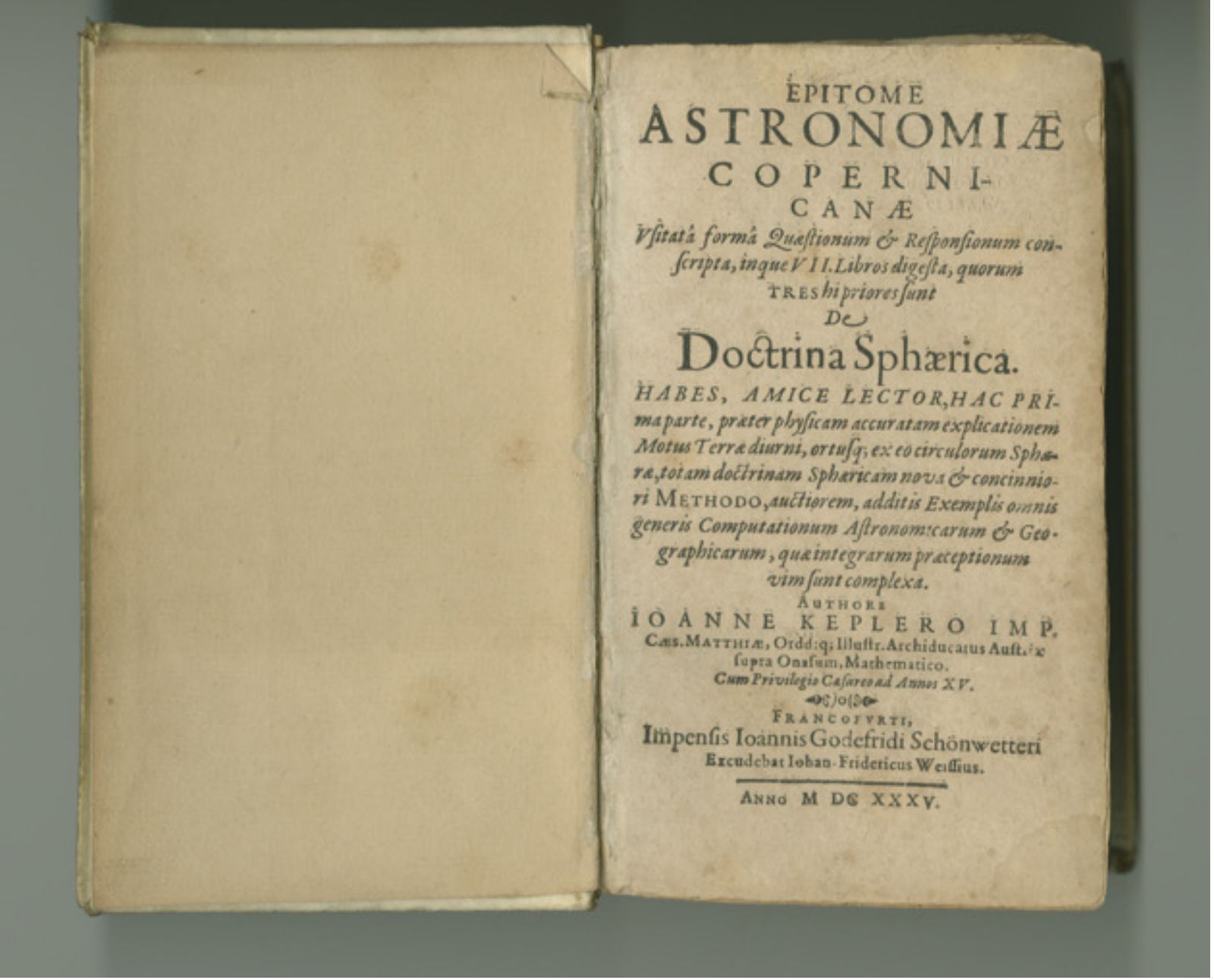
ASTRONOMIA NOVA
ΑΙΤΙΟΛΟΓΗΤΟΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex obſervationibus G. V.
TYCHONIS BRAHE:

Juſſu & ſumptibus
RVDOLPHI II.
ROMANORVM
IMPERATORIS &c:

Plurium annorum pertinaci ſtudio
elaborata Pragæ,
A S. C. M.ti S. Mathematico
JOANNE KEPLERO,
Cum ejuſdem C. M.ti privilegio ſpeciali
Anno æræ Dionyſianæ cIↃ IↃ c ix.

Kepler's *Astronomia nova* (1609)

Full title reads: "New Astronomy, reasoned from Causes, or Celestial Physics, Treated by Means of Commentaries on the Motions of the Star Mars, from the Observations of the noble Tycho Brahe"



EPITOME
ASTRONOMIÆ
COPERNI-
CANÆ
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TRES *hi priores sunt*
De
Doctrina Sphærica.
HABES, AMICE LECTOR, HAC PRIma parte, præter physicam accuratam explicationem Motus Terræ diurni, ortusq; ex eo circulorum Sphæræ, totam doctrinam Sphæricam nova & concinniori METHODO, *auctiorem, additis Exemplis omnis generis Computationum Astronomicarum & Geographicarum, quæ integrarum præceptionum vim sunt complexa.*
AUTHORE
IOANNE KEPLERO IMP.
Cæs. MATTHIÆ, Ordd: q; Illustr. Archiducatus Aust. ex
supra Onasum, Mathematico.
Cum Privilegio Cæsareo ad Annos XV.
FRANCOFVRTI,
Impensis Ioannis Godefridi Schönwetteri
Excudebat Iohan-Fridericus Weissius.
ANNO M DC XXXV.

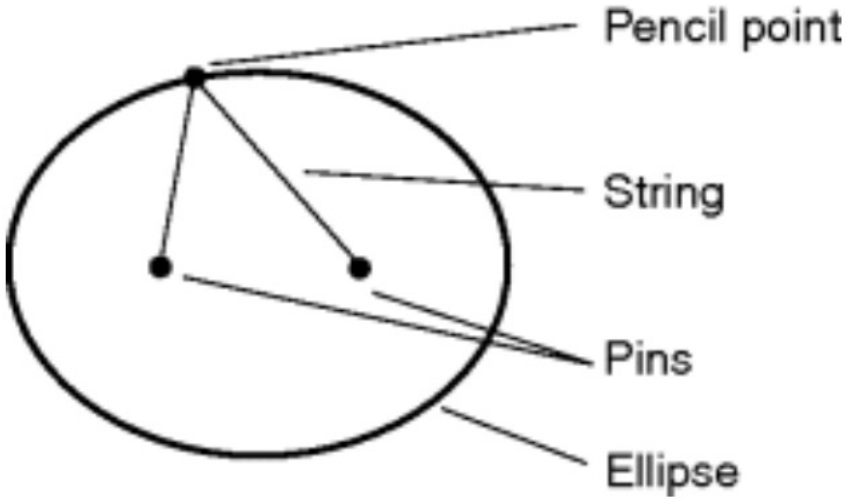
Kepler's *Epitome of Copernican Astronomy*

Kepler's Laws

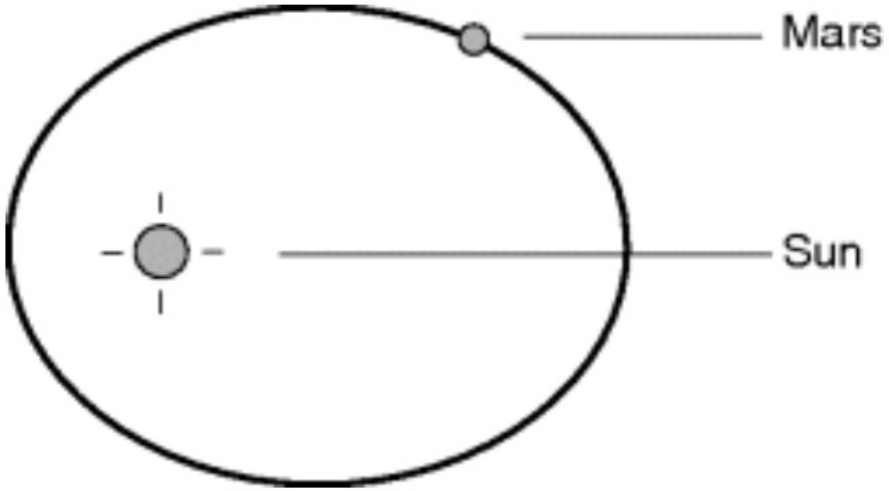
First Law:

The planets move in ellipses with the Sun at one focus.

- A "focus" refers to a particular point in an ellipse (see next).



If you draw an ellipse using a string and a pen like the figure on the top, then we say that pins are the foci of an ellipse.



In Kepler's treatment of Mars, Mars is on an ellipse, and the Sun is at one of the foci.

Kepler's Laws

Second Law:

The line joining the Sun and the planet sweeps out equal areas in equal times.

- https://ophysics.com/f6.html
- See also DeWitt's Figure 16.3

Kepler's Laws

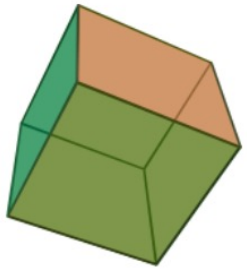
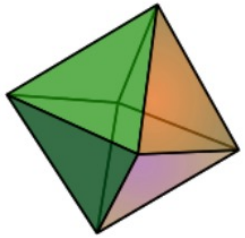
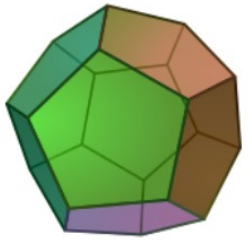
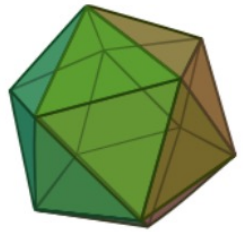
- Kepler's laws replaces uniform circular motion.
- But since uniform circular motion was a constraint on astronomical problem solving, Kepler couldn't simply propose an alternative.
- Instead, he had to show that *no* system based on uniform circular motion can explain Tycho's data on Mars's motion.
  - Remember there can be any number of systems based on uniform circular motion (we already saw three), and they can be (and in fact they *were*) successful at prediction and explanation.

Kepler's Motivations

- Kepler's own motivation in mathematical and astronomical work was to discover God's plan when he created the universe.
- And God's plan, he believed, was mathematically regular and precise.
- So Kepler was strongly interested in (or we might say obsessed with) discovering mathematical or geometrical regularities in the world.

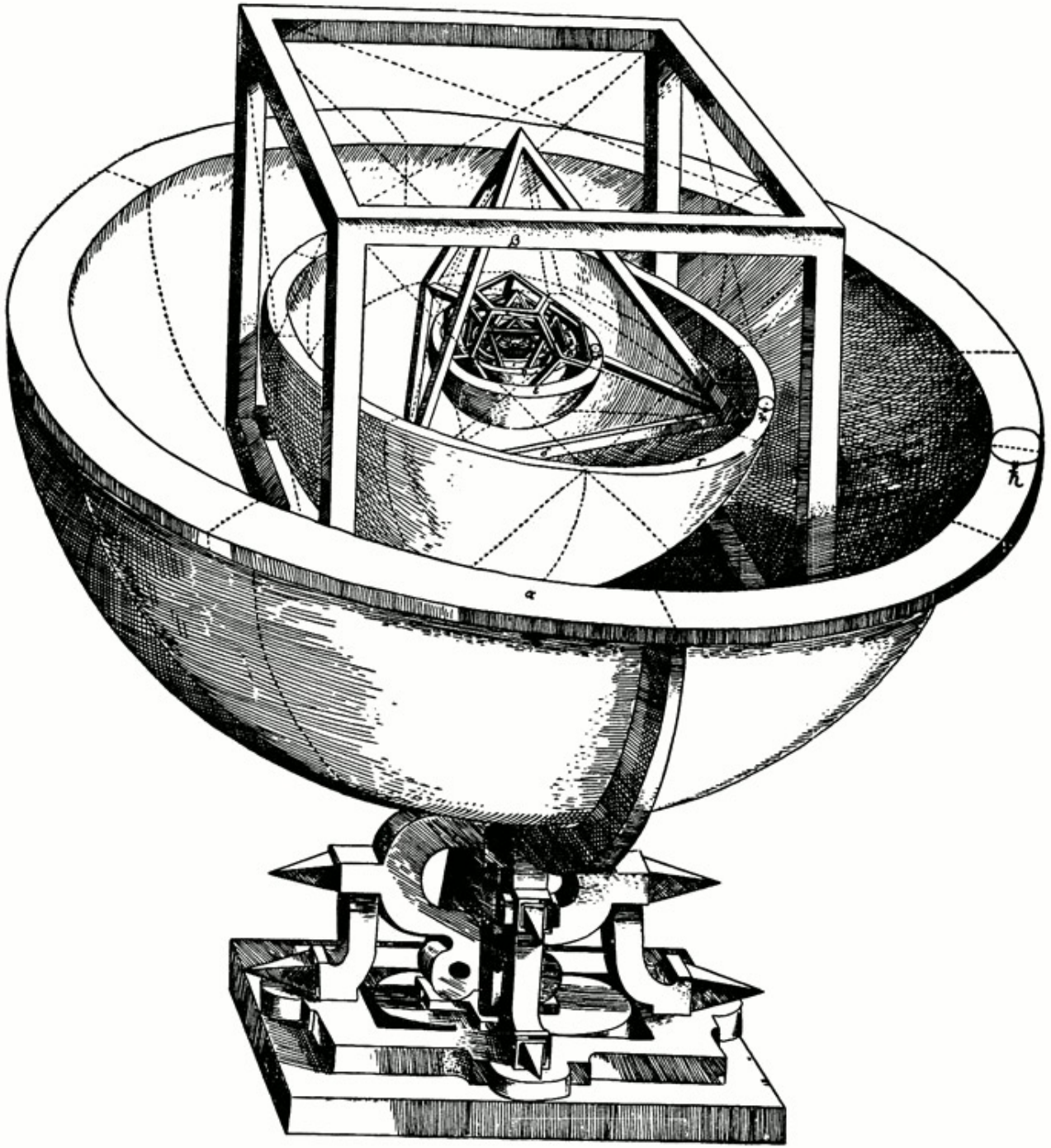
Kepler's Motivations

- The idea that the universe is built around mathematical and geometrical regularities can be found in Plato's works.
- In *Timaeus*, Plato describes a hypothesis about the structure of the universe, and he uses the perfect solids (also called Platonic solids) as the building blocks of the universe.

Tetrahedron	Cube	Octahedron	Dodecahedron	Icosahedron
Four faces	Six faces	Eight faces	Twelve faces	Twenty faces
				

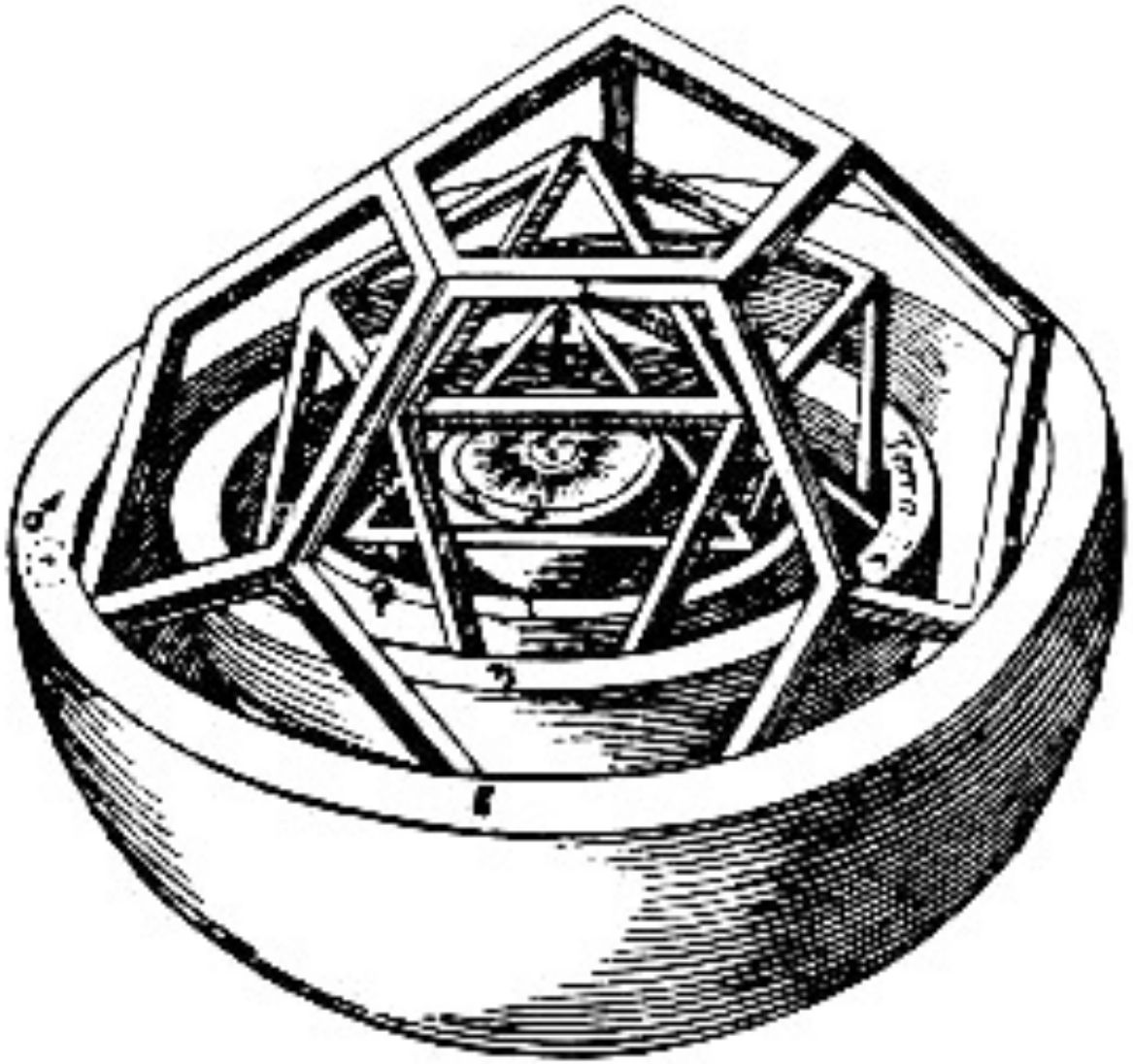
Kepler’s Motivations

- Kepler was influenced by Neoplatonism of his day.
- This explains why Kepler was fascinated by the relationship between the perfect solids and the planetary spheres. (See next)



From Kepler's *Cosmographic Mystery* (1597)

This is the work DeWitt refers to when he talks about what Kepler did before working with Tycho and why Kepler wanted to work with Tycho.



From Kepler's *Cosmographic Mystery* (1597)

Inner spheres