

Nicolaus Copernicus and the motion of the Earth

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The *De revolutionibus*, published in 1543 by Nicolaus Copernicus, is one of the most important works in the entire history of science. This is the book which argued that the Sun lies in the center of the universe, while the Earth flies through the heavens, contrary to common sensory perception, revolving around the Sun once each year. We will call it the *De rev* for short.

Intro	Front Matter
Two Themes	System
Early Life	Problems
Celestial Spheres	Reception
Publication	Revolutions

- We will explore the story of Copernicus in 10 parts.
- First, a brief Introduction.

“Geocentric”

“Heliocentric”


First, a note on terminology: we will use the terms “Geocentric” and “heliocentric” for ancient Earth-centered and Sun-centered conceptions of the universe. While roughly true, yet, strictly speaking, in terms of working mathematical models, neither the ancient nor the Copernican model were precisely Earth-centered nor Sun-centered. For physical purposes, yes, but not in terms of the exact mathematics. This will be illustrated later, but it might be confusing if we didn’t pause to point it out.

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- Copernicus quotations, *De revolutionibus* (1543)
1. Andreas Osiander, anonymous letter “to the reader on the hypotheses of this work”: “Since [the astronomer] cannot in any way attain true causes, he will adopt whatever suppositions enable the motions to be calculated.... For hypotheses need not be true nor even probable. On the contrary, if they provide calculations consistent with the observations, that alone is enough.... Different hypotheses are sometimes offered for one and the same motion (for example, either an eccentric or an epicycle model will explain the Sun’s motion). The astronomer will adopt whichever hypothesis is easier to grasp.... So as far as hypotheses are concerned, let no one expect anything certain from astronomy... lest he accept as truth ideas conceived for another purpose, and depart from this study a greater fool than when he entered it.”
 2. Letter from Cardinal Schönberg, 1536: “Some years ago... I began to have a very high regard for you. For I learned that you had not merely mastered the discoveries of the ancient astronomers uncommonly well but had also formulated a new cosmology. In it you maintain that the Earth moves; that the Sun occupies the lowest, and thus the central, place in the universe; that the eighth [starry] heaven remains perpetually motionless and fixed; and that, together with the [four] elements included in its sphere, the Moon... revolves around the Sun in the period of a year. I have also learned that you have written an exposition of this whole system of astronomy, and that the planetary motions and set them down in tables, to the greatest admiration. I entreat you, most learned sir, unless I inconvenience you, to send me your work, which I will treasure most earnestly. Moreover, I have given you my thanks, and am, Sir, most faithfully and humbly, your servant, who is already

There are handouts with quotations from Copernicus, translated by Dennis Danielson. The quotations are numbered. Some slides have little round numbers in the upper left corner, like this one. Whenever you see a number like this, look for the quotation of the same number on the handout. Download the handout from the indicated url. The handout contains notes, names of people mentioned, resources for further reading, and question prompts for discussion and reflection. A script of this talk is also available.

History of Science Collections



In this video, I will speak as the curator who cares for these rare books.

History of Science vault



Imagine that you are there with me in the vault. You're wearing a sweater because it's 55 degrees, and you can sense the smell of old books. We will take some of these works off the shelves and explore them together.

Nicolaus Copernicus De revolutionibus (1543)



Copernicus published *De revolutionibus*, *On the revolutions of the heavenly spheres*, in 1543. A recently auctioned copy sold for 2.1 million dollars, although the copy we are about to examine is of far greater interest and historical value.

Nicolaus Copernicus De revolutionibus (1566)



The book on the bottom here is the second edition from just 23 years later.

Nicolaus Copernicus De revolutionibus (1617)



The volume bound in brown calf leather is the first 17th century edition.

Nicolaus Copernicus De lateribus (1542)



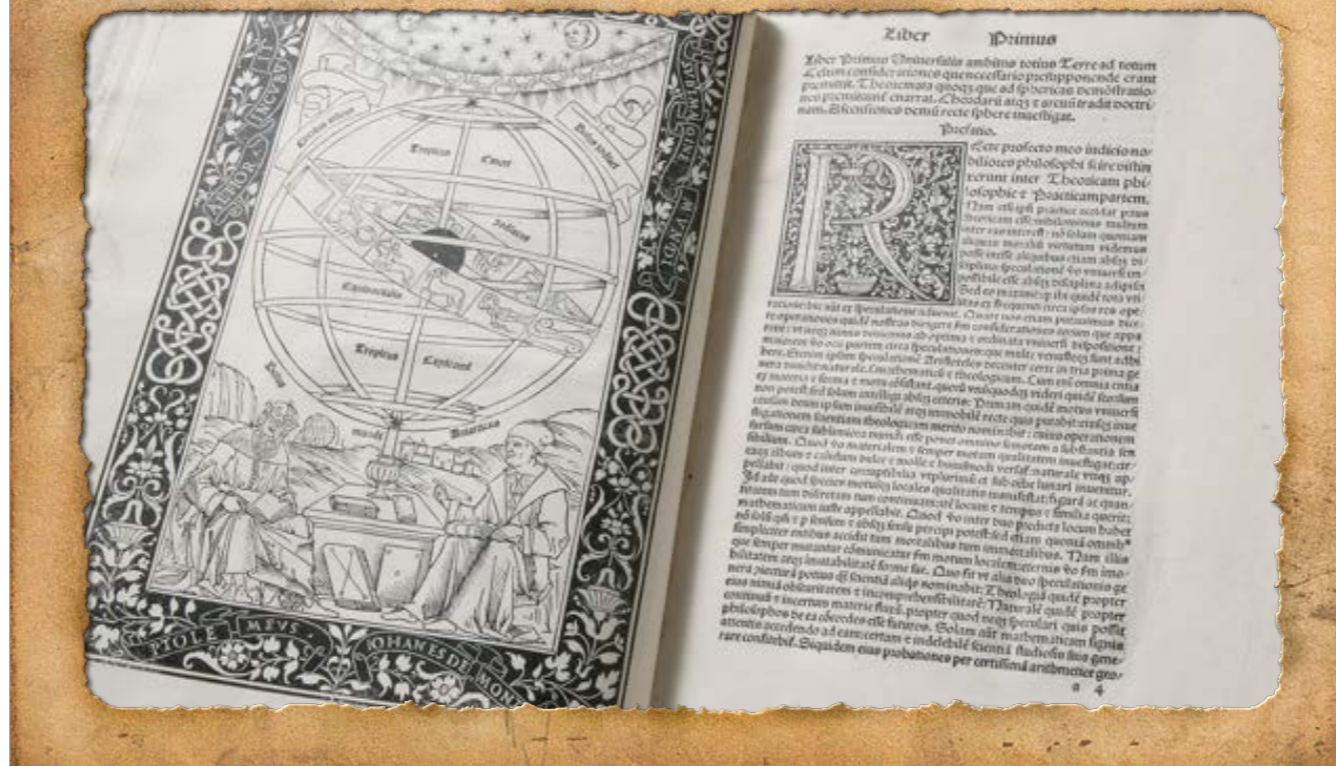
The little book on top here is easily overlooked. The tiny De lateribus is the rarest of Copernicus' works and therefore the priciest of them all.



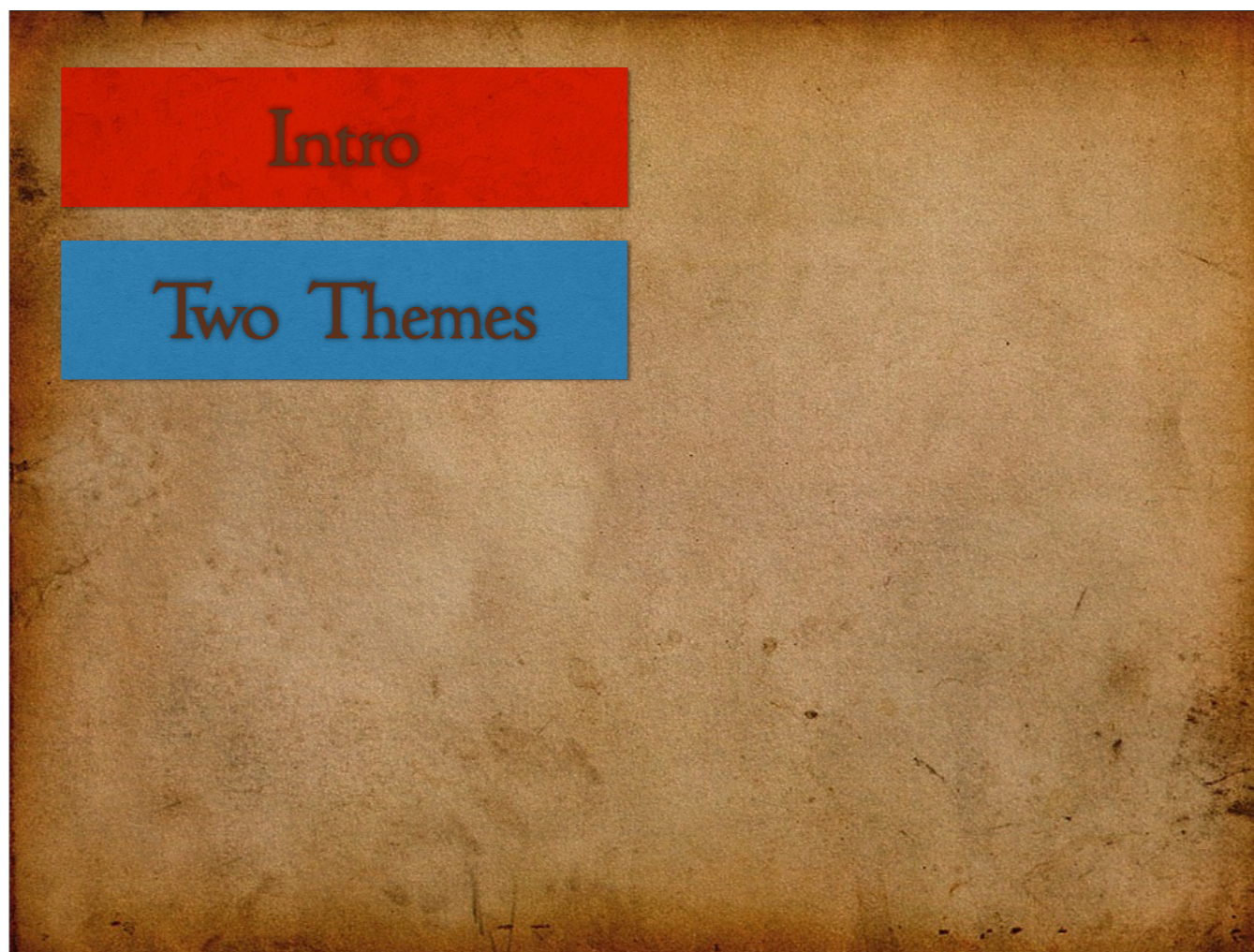
There are only a handful of places on Earth where you may examine all four of these books together. For the rest of this talk we will act as if we are in the vault at the OU History of Science Collections, open them up, turn through their pages, and explore the stories that lie behind them.

Regiomontanus

Epitome of Ptolemy's Almagest



In addition to the books of Copernicus himself, we will note some of the works of his contemporaries and predecessors, including this book by Regiomontanus, perhaps the greatest European astronomer of the Renaissance.



When I teach an undergraduate course in the history of science, I like to begin with Copernicus in order to illustrate two themes that emerge from any large-scale historical overview of the development of science.



We will look at the contents of the De rev for its own sake in just a few minutes. But right now, before diving in, let's use it to illustrate two general themes in the history of science.

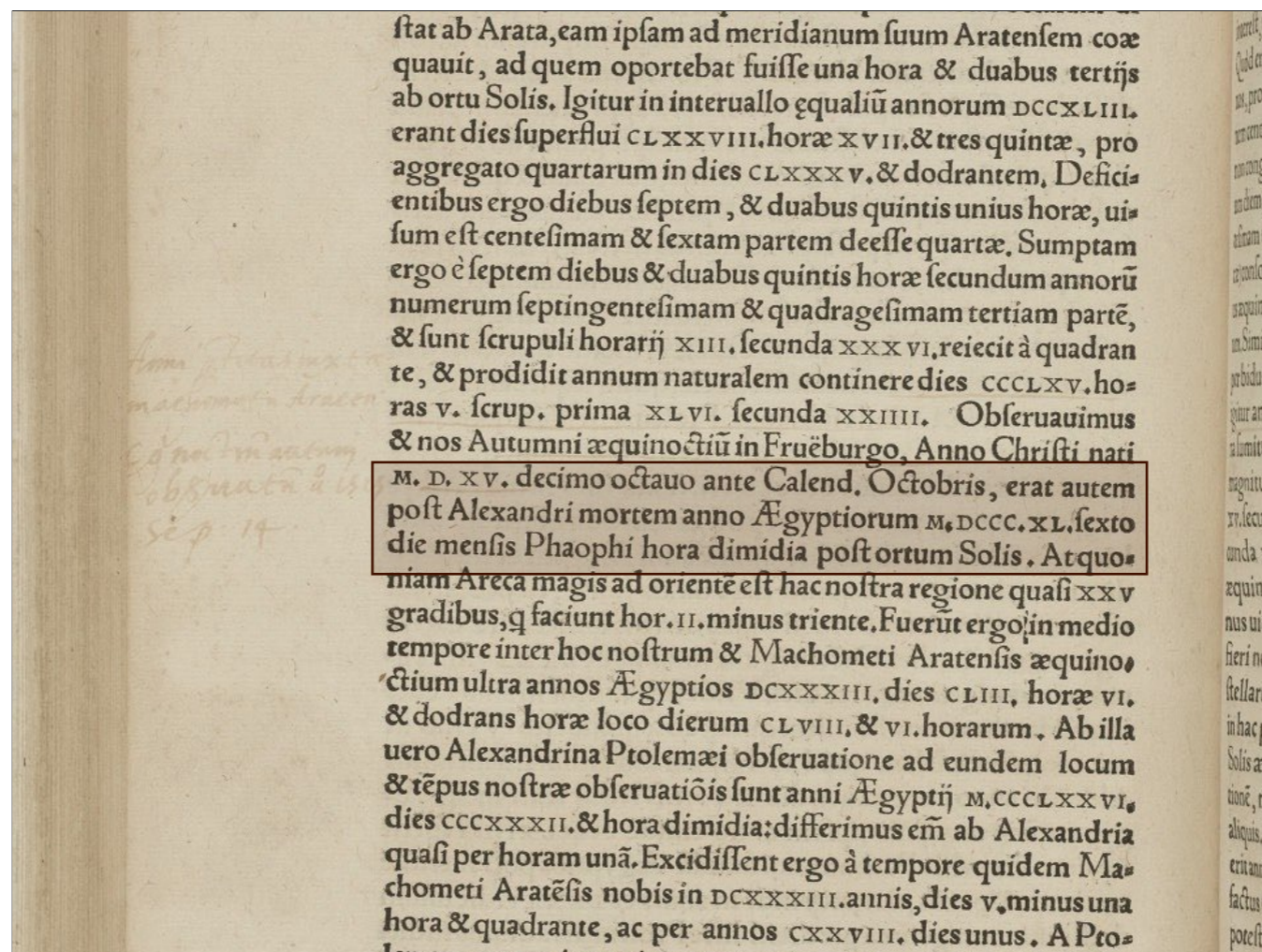
Crossing Cultures

The first major theme is “crossing cultures.”

Is omnibus sic expeditis, superest, ut ipsorum motu
um æquinoctij uerni loca constituamus, quæ ab ali
quibus radices uocantur, à quibus pro tempore quo-
cuncq; proposito deducuntur supputationes. Huius
rei supremum scopum constituit Ptolemæus, principium regni
Nabonassarj Caldeorum, quod apud historiographos in Sal-
manassar Caldeorum regem cadit. Nos autem notiora tempora
secuti, satis esse putauimus, si à prima Olympiade exoriri fueri-
mus, quæ xxviii. annis Nabonassarios præcessisse reperitur,
ab æstiuâ conuersione sumpto auspicio, quo tempore Canicula
Græcis exortum faciebat, & Agon celebrabatur Olympicus, ut
Censorinus ac alij probati autores prodiderunt. Vnde secundum
exactiorem supputationem temporum, quæ in motibus cæle-
stibus calculandis est necessaria, à prima Olympiade à meridie
primæ diei mensis Ecatonbæonos Græcorum ad Nabonassar
ac meridiem primæ diei mensis Thoth, secundum Ægyptios
sunt anni xxvii. & dies ccxlvii. Hinc ad Alexandri decessum
anni Ægyptij ccccxxiiii. à morte autem Alexandri ad initium
annorū Iulij Cæsaris, anni Ægyptij cclxxviii. dies cxviii. s.
ad mediam noctem ante Kal. Ianiuarij. unde Iulius Cæsar anni à
se constituti fecit principium, Qui Pont. Max. suo tertio, & M.
Æmylij Lepidi cōsulatu annū ipsum instituit. Ex hoc anno ita
à Iulio Cæsare ordinato cæteri deinceps Iuliani sunt appellati.

This page contains records of lunar eclipses observed in ancient Babylonia as far back as the reign of Nabonassar in the 700's BCE. Simply put, the growth of western science cannot be understood apart from rich and sustained interactions between multiple cultures.

Copernicus, De rev, Bk III, ch. XI, p. 76v.
Copernicus-1543-076v.tiff



On this page, Copernicus writes that he observed the Autumn equinox in 1515: “according to the Egyptian calendar it was the 1,840th year after the death of Alexander on the 6th day of the month of Phaeophi, half an hour after sunrise.” Instead of using the Julian calendar that was in use in his own day, Copernicus converted tables for planetary motions into the calendar developed in ancient Egypt 3,000 years before.

Copernicus, De rev, Bk III, ch. XIII, p. 79v. Just below the middle of the page, look for MDCCCXL and the name "Phaophi" on the following line.
Copernicus-1543-079v.tiff

cessum Alexandri Magni, anno CLXXVII. tertio intercalarium
 die secundū Ægyptios in mediā nocte, quam sequebatur quar-
 tus intercalariū. Deinde subiungit Ptolemæus idē æquinoctiū
 à se obseruatum Alexandriæ anno tertio Antonini, qui erat à
 morte Alexandri annus CCCCLXIII. nona dies mensis Athyr
 Ægyptiorū, tertij una hora ferè post ortum Solis. Fuerunt inter
 hāc ergo, & Hipparchi cōsiderationē anni Ægyptij CCLXXXV
 dies LXX, horæ VII. & quinta pars unius horæ, cū debuissent
 esse LXXI. dies, & sex horæ, si annus uertens fuisset ultra dies in-
 tegros quadrāte diei. Defecit igitur in annis CCLXXXV. dies u-
 nus minus uigesima parte diei. Vnde sequitur, ut in annis CCC.
 intercidat dies totus. Similem quoq; ab æquinoctio Verno su-
 mit coniecturā. Nam quod ab Hipparcho annotatū meminit
 Alexandri anno CLXXVIII. die XXVII. Mechir sexti mēsis Æ-
 gyptiorū in ortu Solis, ipse in anno eiusdē CCCCLXIII. reperit
 septimo die mēsis Pachon noni secundū Ægyptios post meridiē
 una hora, & paulo plus, atq; itidē in annis CCLXXXV. diē unum
 deesse minus uigesima pte diei. Hisce Ptolemæus adiutus indicē
 is, definiuit annū uertentē esse dierū CCCCLXV. scrup. primorū
 XIII, secundorū XLVIII. Post hęc Machometus in Areca Syriæ,
 u iij non

On the previous page, Copernicus discussed the length of the year as determined by Hipparchos on the island of Rhodes in the mid-2nd century BCE. Hipparchos' length of the year was transmitted beyond Mesopotamia and Persia to ancient India. In the Islamic period, astronomers inherited this remarkable cross-cultural heritage of Mesopotamian, Indian, Greek, and Roman astronomy.

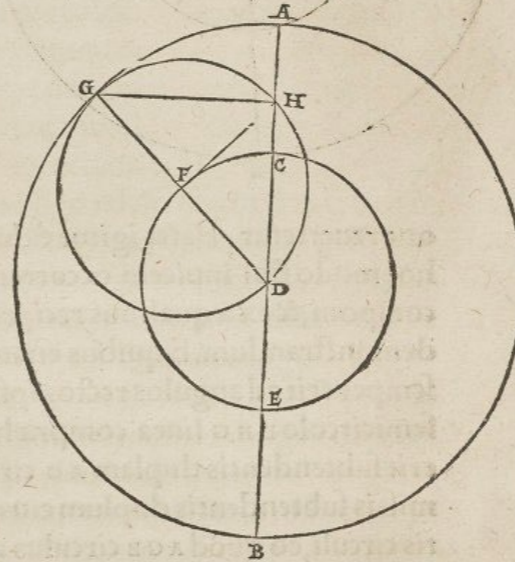
Copernicus, De rev, Bk III, ch. XIII, p. 79r.
 Copernicus-1543-079.tiff

Quomodo motus reciprocus siue librationis ex
circularibus constet. Cap. IIII.



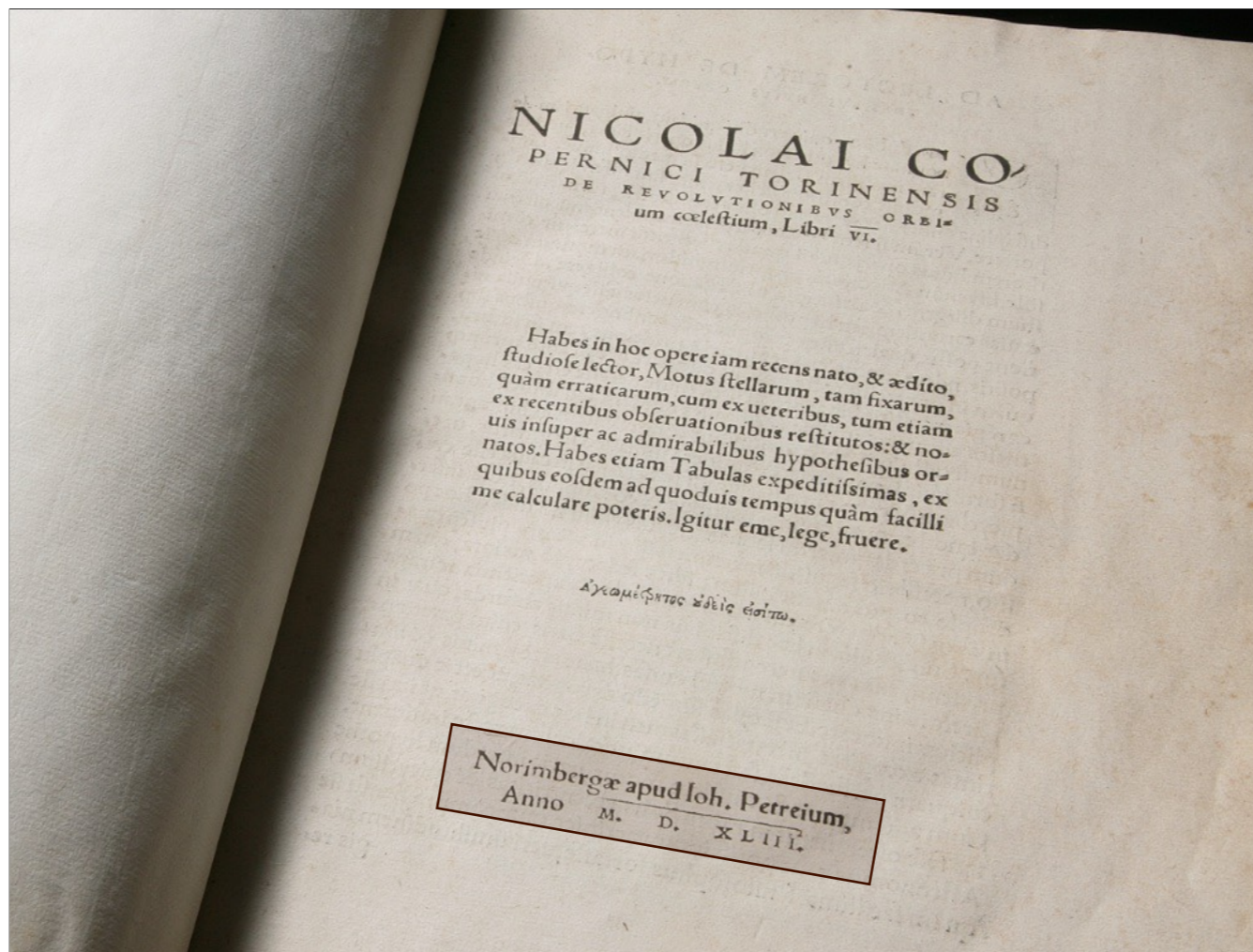
Vodigitur iste motus apparentijs consentiat am-
modo declarabimus. Interim uero quæret aliquis,
quo nam modo possit illarum librationum æquali-
tas intelligi, cum à principio dictum sit, motum cele-
stem æqualē esse, uel ex æqualibus ac circularibus cōpositum.

Hic aut utrobicq; duo motus
in uno apparēt sub utrisq; ter-
minis, qbus necesse est cessa-
tionē interuenire. Fatebimur
quidem geminatos esse, at ex
æqualibus hoc modo demon-
strant. Sit recta linea AB, quæ
quadrifariā secetur in CDE si-
gnis, & in D describatur circu-
li homocentri, ac in eodē pla-
no ADB, & CDE, & in circūfe-
rentia interioris circuli assu-
mat utcūq; F signū, & in ipso
F cētro, interuallo uero FD cir-
culus describatur GHD, qui
secet AB rectā lineā in H signo, & agat dimetiēs DFG. Ostēdendū
est, q̄ geminis motibus circularū GHD & CFE cōcurrētibus in-



This page shows Copernicus' model for the motion of the Moon. It depended upon a remarkable technical innovation called the Tusi couple, named after Nasr al-Din al-Tusi, who worked in modern-day northwest Iran in the mid-1200's. We'll say more about this device later.

Copernicus, De rev, Bk III, ch. IIII, p. 67r.
Copernicus-1543-067r.tiff



The title page of Copernicus shows that it was printed in Nuremberg in 1543. Less than 30 years earlier, in 1517, Martin Luther nailed his 95 theses to the Wittenberg cathedral door, launching the Protestant Revolution. Nuremberg was a leading center of Reformation Europe. Copernicus at the time was a Catholic administrator, working in a cathedral in northern Poland. So we have seen in just these few quick examples that this European book, published as a collaboration between Catholics and Protestants in the middle of the Reformation, incorporated the astronomical knowledge of many pre-modern cultures.

Copernicus, De rev, title page.
Copernicus-1543-000-tp.tiff

Crossing Cultures

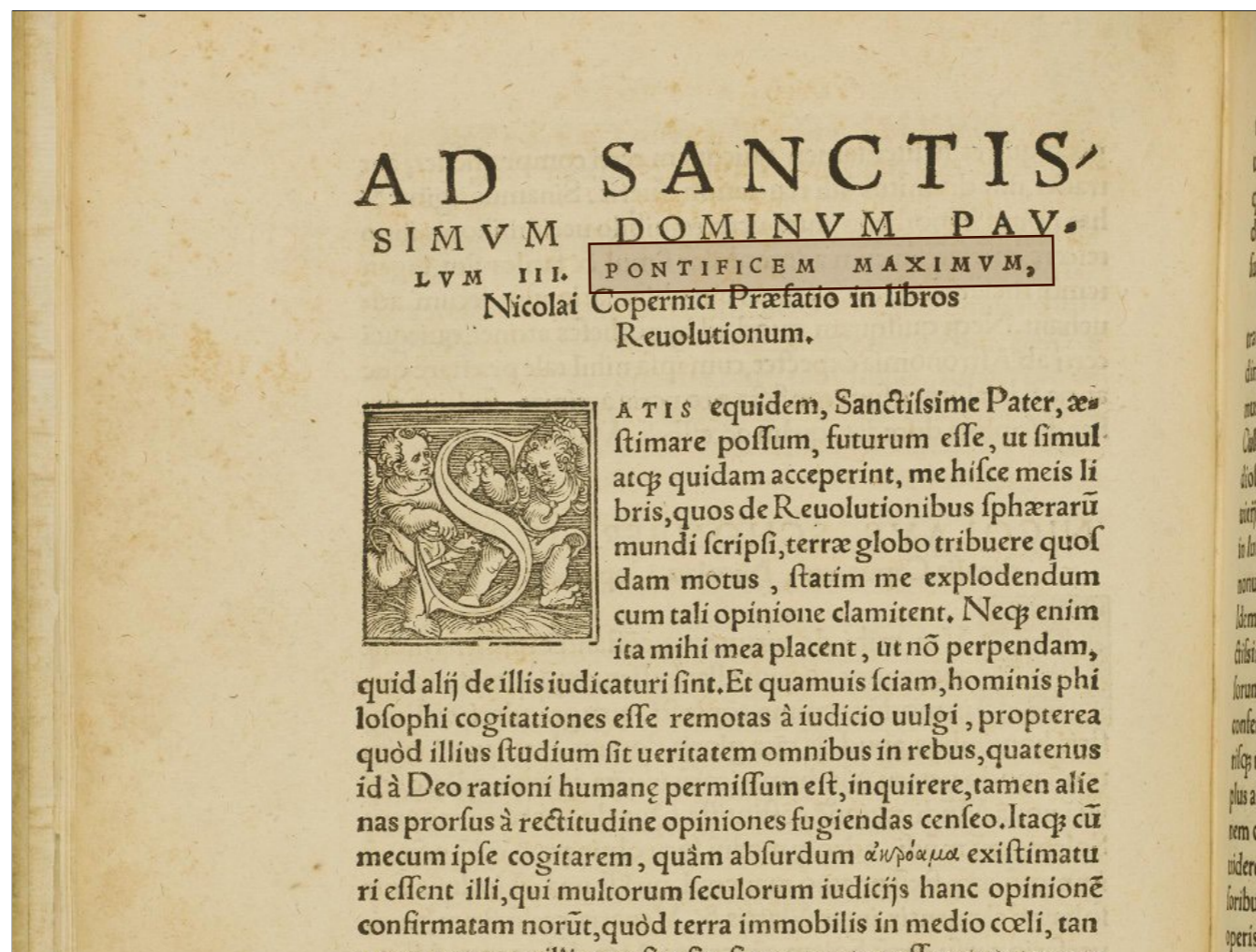
So by opening the De rev of Copernicus you are invited to go on a journey, a time-travel tour spanning more than 4 millennia across a half dozen major civilizations: Mesopotamian, Egyptian, Greek, Roman, Byzantine, Indian, Chinese, Islamic, medieval, and early modern cultures.



Crossing Cultures

Crossing Disciplinary Boundaries

If the first major theme of the history of science is “crossing cultures,” the second is “crossing disciplinary boundaries.” One of the most pressing questions for science today is how to facilitate interdisciplinary collaboration. The history of science offers a continuous account of case studies, pro and con, for how disciplines emerge, collaborate, compete, and adapt to new problem sets and methodologies.



It is of interest that Copernicus dedicated this book to none other than the pontificem maximum, Pope Paul III, who was sympathetic to mathematical methods. In his dedication, Copernicus wrote that astronomy is a branch of mathematics, and that mathematics is for mathematicians. Why would he say this? At the time, physicists were trained more in logic than mathematics, yet physicists were granted more authority and credibility than astronomers in their statements about the universe. The greatest resistance to Copernicus came from physicists and others who underestimated the power of new mathematical methodologies. Not only physicists, but also theologians, were unprepared to recognize the potential of mathematical arguments for the motion of the Earth. So this book as a whole was a challenge from mathematics to the established and reputable domains of physics and theology, both of which had to learn to adapt to the knowledge claims of the new mathematical science. More than a battle of science versus religion, Copernicus was a mathematician battling for the unexpected reach of mathematics compared with traditional methodologies.

Copernicus, De rev, dedication page.
Shows "Pontificem maximum."
Copernicus-1543-000-z02v.tiff

NICOLAUS SCHONBERGIUS CAR
dinalis Capuanus, Nicolao Copernico, S.



Vm mihi de uirtute tua, cōstanti omniū sermone
ante annos aliquot allatū esset, coepi tum maiorem
in modū te animo cōplecti, atq; gratulari etiā no-
stris hominibus, apud q̄s tāta gloria floreret. Intellexerā enim
te nō modo ueterū Mathematicorū inuēta egregie callere, sed
etiā nouā Mūdi rationē cōstituisse. Qua doceas terrā moueri:
Solem inū mūdi, adeoq; mediū locū obtinere: Coelū octauū
immotū, atq; fixū ppetuo manere: Lunā se unā cū inclusis suae
sphærae elementis, inter Martis & Veneris coelū sitam, anni-
uersario cursu circū Solem cōuerrere. Atq; de hac tota Astro-
nomiae ratione cōmentarios à te cōfectos esse, ac erraticarum
stellarū motus calculis subductos in tabulas te cōtulisse, maxi-
ma omniū cum admiratione. Quamobrem uir doctissime, ni-
si tibi molestus sum, te etiā atq; etiā oro uehementer, ut hoc
tuū inuentū studiosis cōmunices, & tuas de mundi sphæra lu-
cubrationes unā cū Tabulis, & si quid habes præterea, qd ad
eandem rem pertineat, primo quoq; tempore ad me mittas.
Dedi autem negotiū Theodorico à Reden, ut istis meis sum-
ptibus omnia describantur, et per te ad me deferantur.

On the preceding page, we find the only signed piece of front matter, a letter from Cardinal Nicholas Schoenberg, who asked Copernicus to publish his great work. The relations between science and religion confronts anyone studying science in the early modern period, because religion and culture were thoroughly intertwined in premodern cultures. So here's a piece of advice for how to handle the intertwining of science and religion: think of their relationships, now in harmony and now in conflict, as analogous to the relations between different disciplines today. The modern scientific disciplines demonstrate complex relations equivalent to those of religion and science at this time.

Copernicus, De rev, letter from Cardinal Schönberg.
Copernicus-1543-000-z02.tiff



Crossing Cultures

Crossing Disciplinary
Boundaries

So the first major theme that emerges from the pre-modern history of science is “crossing cultures,” and the second is “crossing disciplinary boundaries.” Both themes form part of the story of Copernicus’ *De revolutionibus* of 1543.

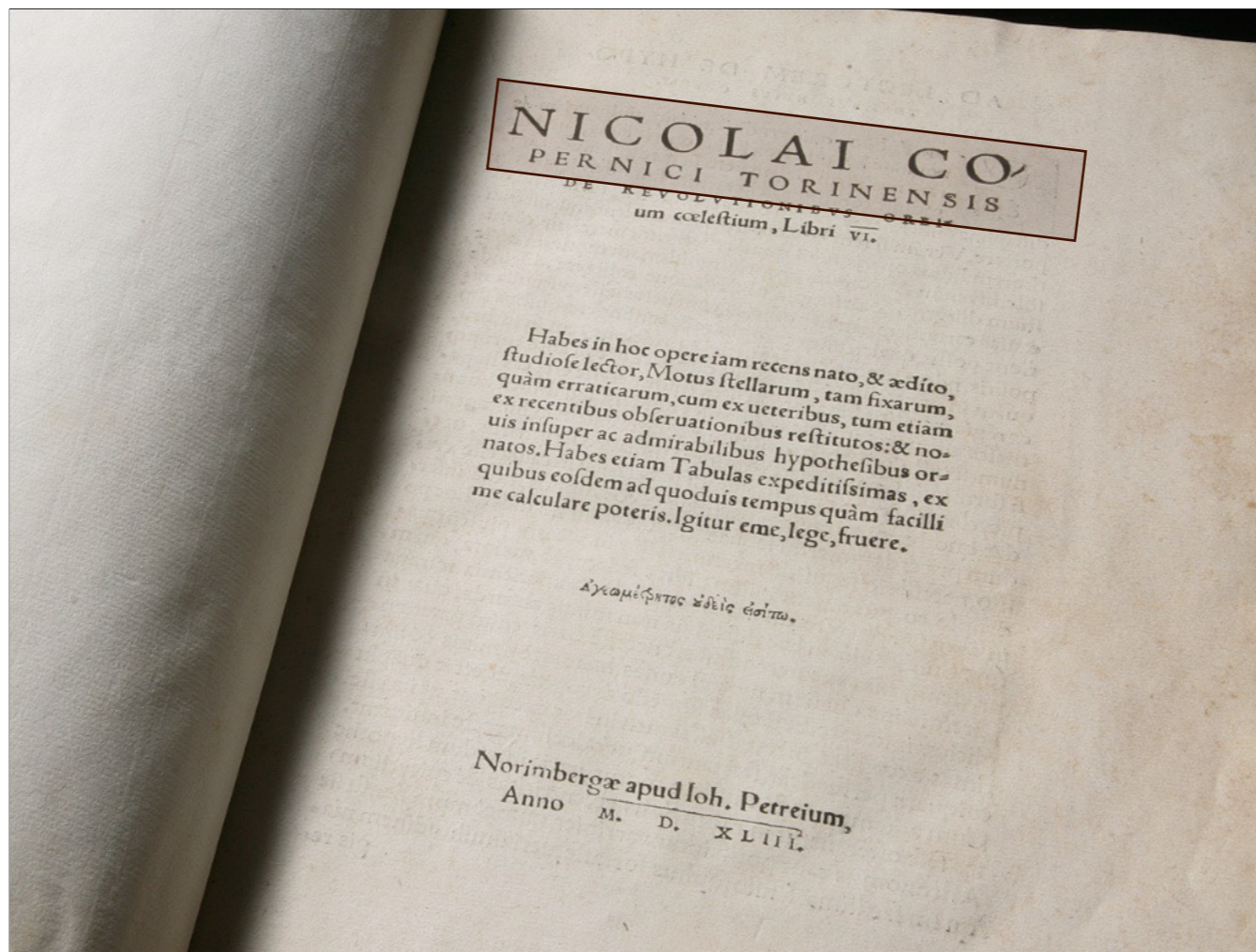


Intro

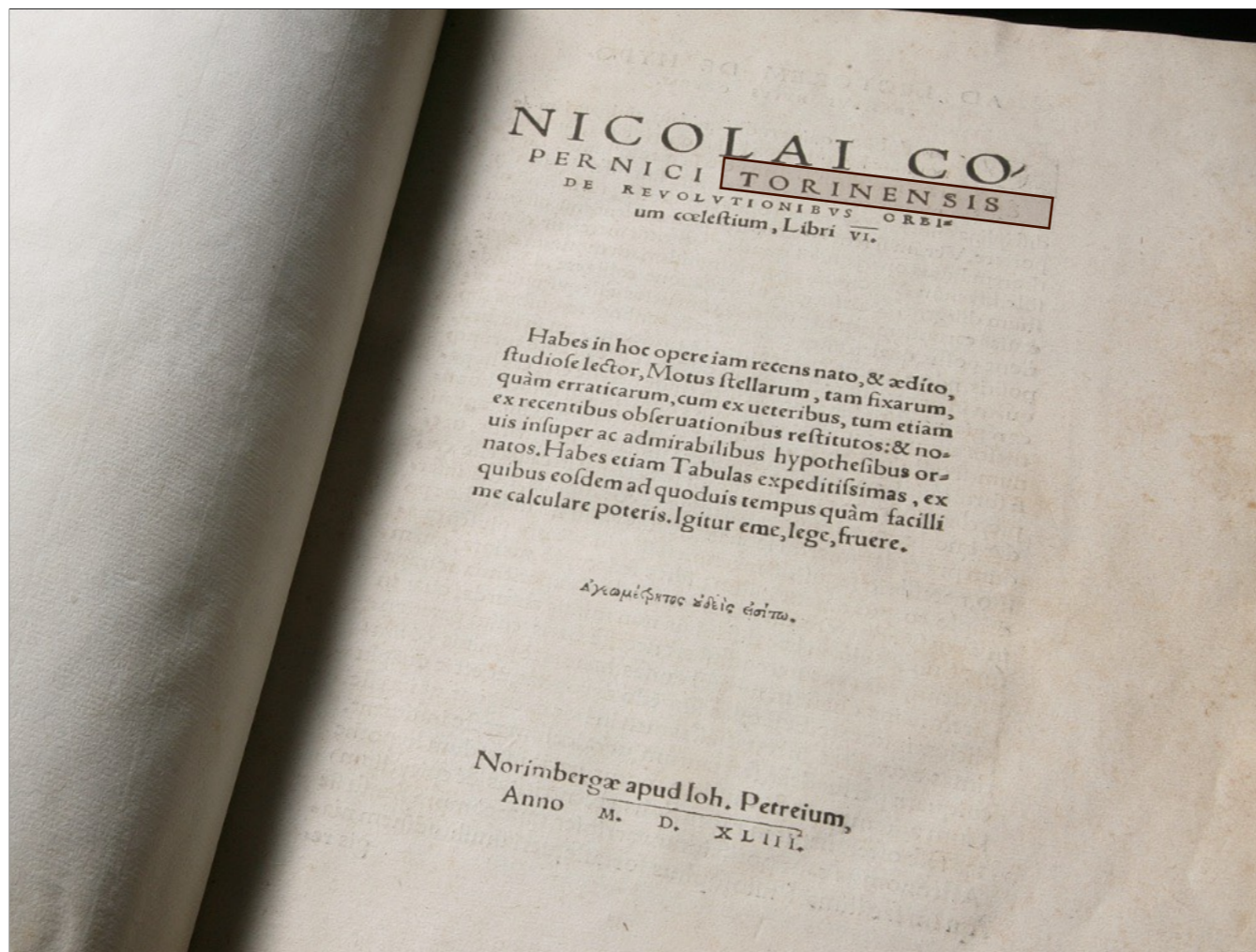
Two Themes

Early Life

Let's turn to Copernicus' early life.



So let's open the De rev to the title page and see what stories it may have to tell us. At the top of the page is the name "Nicolai Copernici" — early printers didn't worry about hyphenation rules!



Copernicus was born in Torun, Poland.



The village of Torun lies on the banks of the Vistula river, which drains into the Baltic.



Copernicus, born in this house, though the son of a merchant, was the nephew of an Archbishop, Lucas Waczenrode.



Bishop Lucas took Copernicus under his wing and set him on the path of financial security, funding his education for the church hierarchy through study of law and medicine.



When he was 18, Copernicus went to Cracow, the capital of Poland, to the university where Bishop Lucas likewise had studied. In Cracow Copernicus studied the liberal arts, which included mathematics and astronomy.



In 1496 Copernicus traveled to study canon law at the University of Bologna, again at his uncle's instigation. Bologna was the most famous school of law in the world.



At Bologna Copernicus assisted the Platonist astronomer Dominico di Novara (with whom he observed a lunar occultation of Aldebaran in 1497).



di Novara was taught by Luca Pacioli of Florence who was a friend of Leonardo da Vinci.



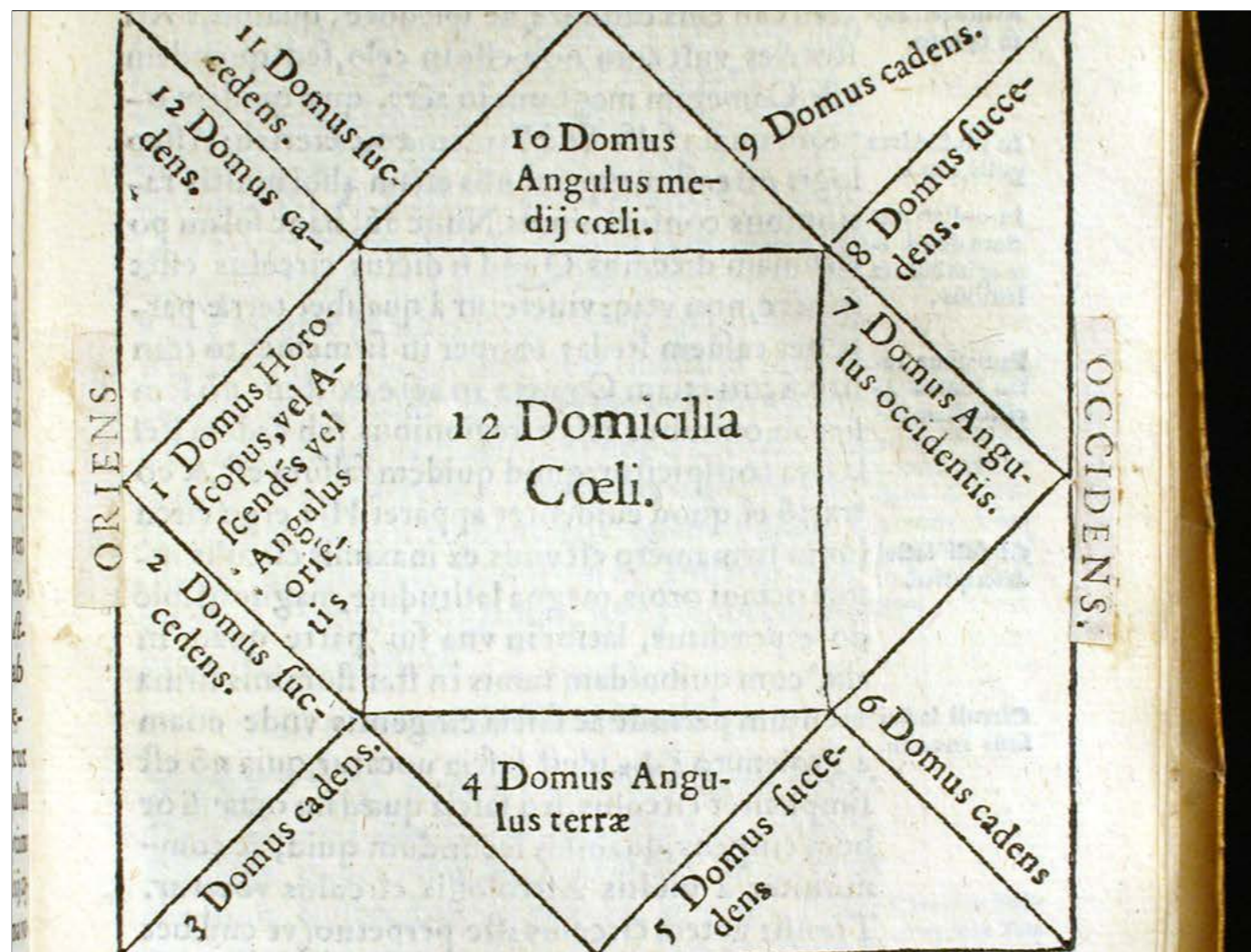
After his study of law at Bologna, Copernicus turned to medicine at the University of Padua in 1501.



In medicine, the University of Padua was pre-eminent—the school attended by founders of modern medicine like Andreas Vesalius and, later, William Harvey. These images from Vesalius show me lecturing at OU, on the left, and on the right the students' reaction when I try to tell a joke.



It was not at all unusual to study astronomy in the context of medicine. Have you caught the flu recently? That is, have you caught the phlegmatic influenza of Saturn? Educated people believed that a planetary influence, or influenza, caused disease. This image of a zodiac man shows how different regions of the heavens, or macrocosm, influenced corresponding regions of the human body, or microcosm.



University-educated physicians depended upon their ability to prognosticate planetary positions. They used mathematical astrology to prescribe the appropriate times for administering medicines and other therapeutic measures.



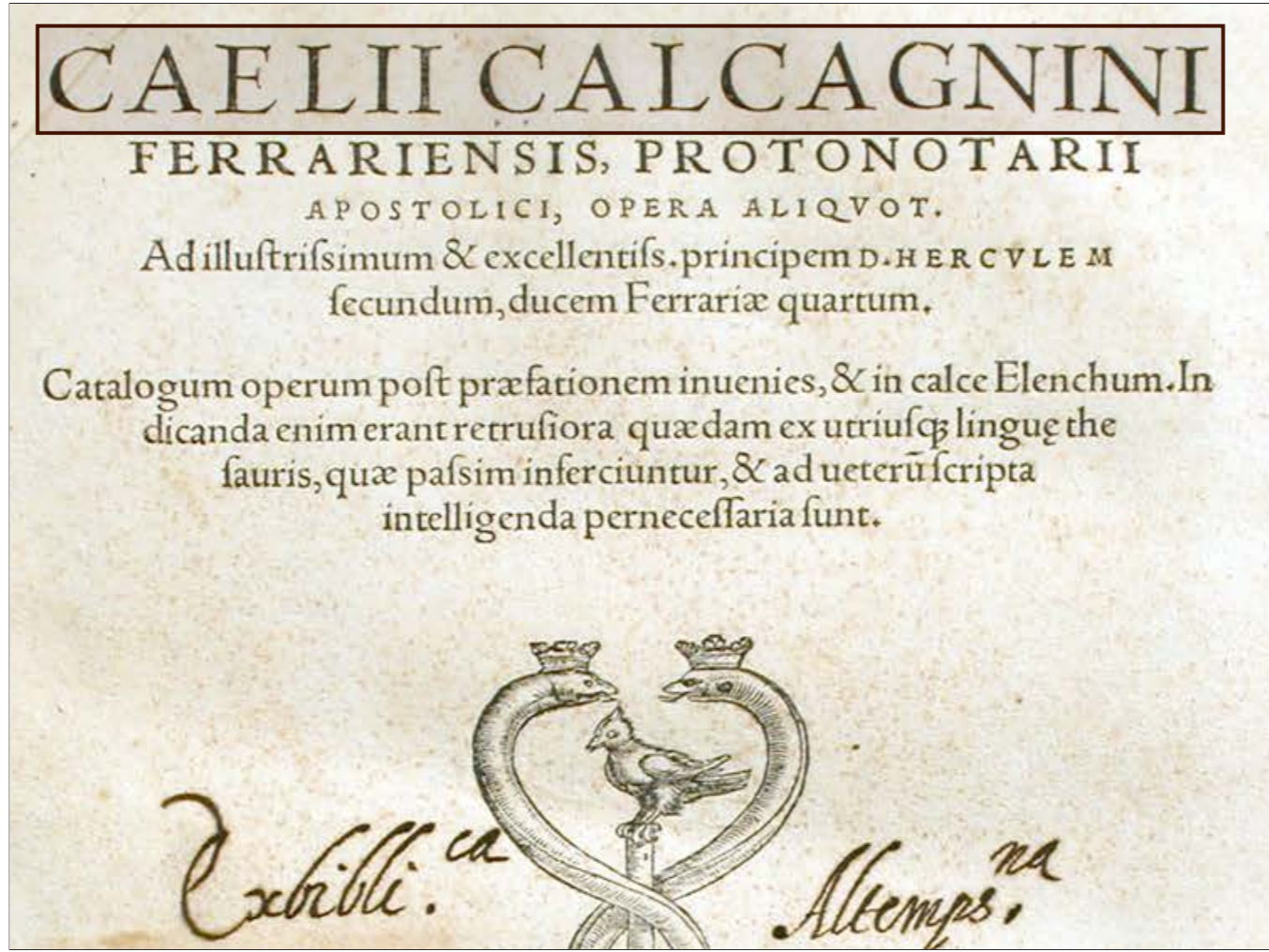
In this portrait of Copernicus, the lily signifies a practitioner of the medical profession.* (pause) By this time, with the support of Bishop Lucas, Copernicus had been appointed as Canon of the Cathedral of Frauenburg, in Poland. Upon his return, Copernicus would serve as the physician of Archbishops and Dukes.

* Marian Biskup and Jerzy Dobrzycki, Copernicus: Scholar and Citizen (Warsaw: Interpress Publishers, 1972), 48.



Copernicus did not graduate from Padua, but transferred to the University of Ferrara. Here Copernicus received a Doctorate in Canon Law in 1503. Foreigners were known to favor the University of Ferrara, particularly if they wished to study Greek.*

—————
William Harrison Woodward, *Studies in Education during the Age of the Renaissance, 1400–1600* (1906; rpt. New York: Teachers College Press, Columbia University, 1967), 168.



Copernicus' interests in law and astronomy were shared in Ferrara by his friend Celio Calcagnini, who became a jurist and professor of astronomy at Ferrara. As an astronomer, Calcagnini's renown extended to England and the court of young Henry VIII.*

*Von Chledowski, 146. This fact is perhaps less surprising given the longstanding relations between England and the University of Ferrara. For example, Reginald Chichele, the Rector of the University of Ferrara in 1446, was the nephew of the Archbishop of Canterbury (Powicke and Emden, 2: 55). Calcagnini is hardly ever cited in the literature on Copernicus, but Chledowski compared the fame of Calcagnini with that of the contemporary Ferraran poet Ludovico Ariosto, claiming that he was known throughout Europe as a jurist and astronomer; Casimir von Chledowski, *Der Hof von Ferrara* (München: Georg Müller, 1921), 145–146: “Calcagnini gehört zu den Universalgenies der Renaissance, als Jurist und Astronom war er in ganz Europa berühmt.” Note the congruence of these two areas of interest with those of Copernicus (who took his degree from Ferrara in law).

QVOD CAELVM STET, TERRA MOVEATVR.

VEL DE PERENNI MOTV TER-

rae, Caelij Calcagnini com-
mentatio.

N T V non audisti academiam ueterem ita de rebus ac to-
ta natura statuisse, ut nihil certò intelligi aut comprehendì
posse arbitretur: quod genus disciplinæ aut mera ignora-
tio est, aut certe quid ignorationi proximū. Id Græci meli-
us quàm nos ἀναπαύσιον dixere, Cicero incomprehen-
sibilitatem interpretatur. Ob id Socratem introduxisse di-
sceptationem in utranq; partem ferunt: quasi hæc una so-
ret aptissimum instrumentū rerū indagini. Nec alia pro-
fecto de causa Arcesilaus collum illud suum columbinum
contemplari solebat, nisi ut uarietate colorum oculos fallente intelligeretur quàm
difficile ac periculosum foret in rebus etiā perspicuis quippiam affirmare. Epicu-
rus bipedalem solem aut certè non multo maiorem arbitrabatur. Solent etiā philo-
sophi remi palmulam solidam ac sartam tectam (ut dicitur) intra aquā quasi fractam
ostendere. Aristoteles probatuim illam intellectus, qua formæ & spectra recipiuntur,
corruptā ac peruersam offerre oculis miras imagines, atq; omnino ueritati rebelles.
Ob id atrahile laborantes sese mirabiliter affectos pro morbi inæqualitate imaginan-

Like Copernicus, but for different reasons, Calcagnini asserted that the Earth moves,

- and the sphere of fixed stars stands still.*

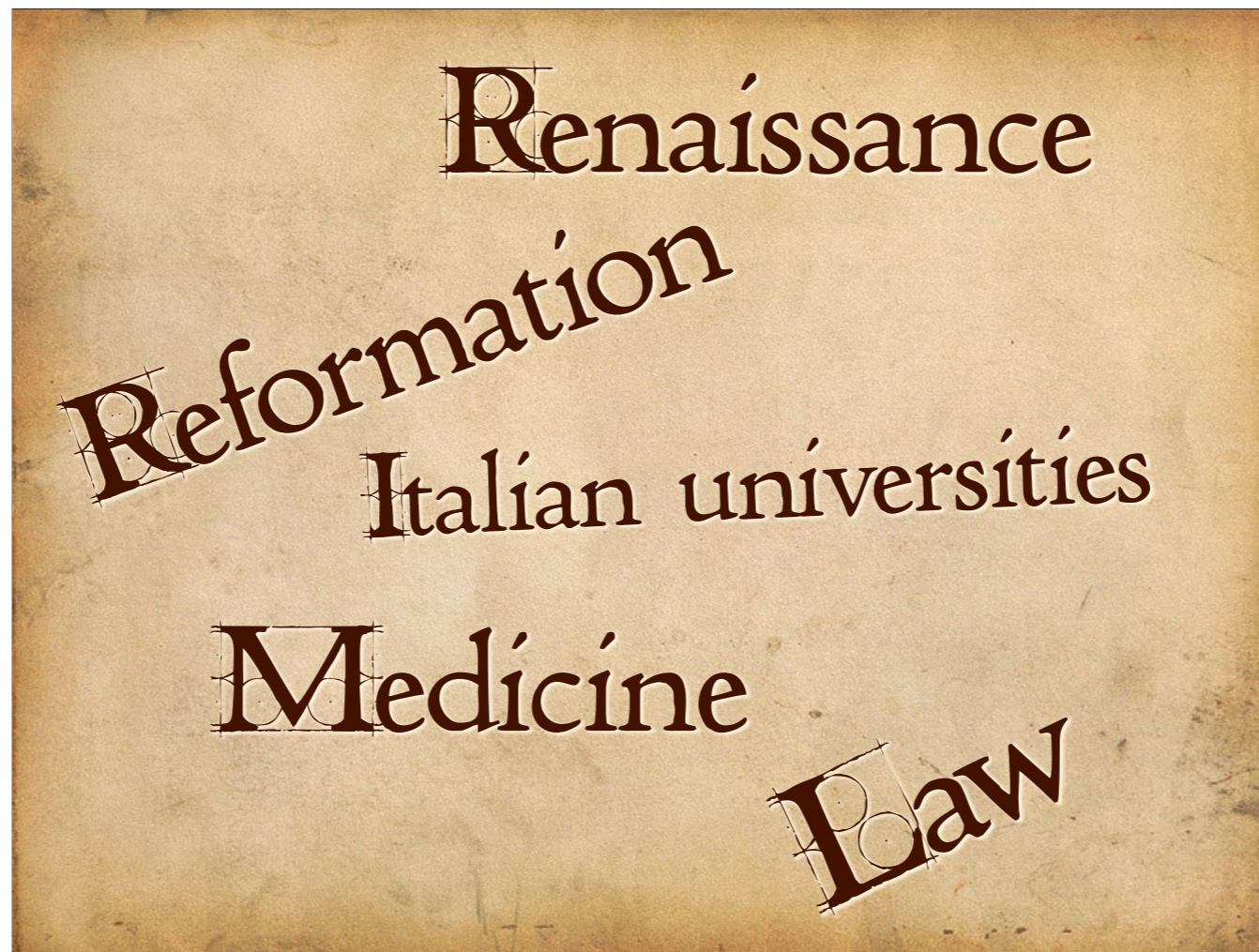
* Celio Calcagnini (1479–1541), “Quod caelvm stet, terra moveatvr, vel de perenni motv ter,” in Caelii Calcagnini, ferrariensis, protonotarii apostolici, opera aliquot: ad illustrissimum & excellentiss principem D. Hercvlem secundum,... (Basileae, 1544).



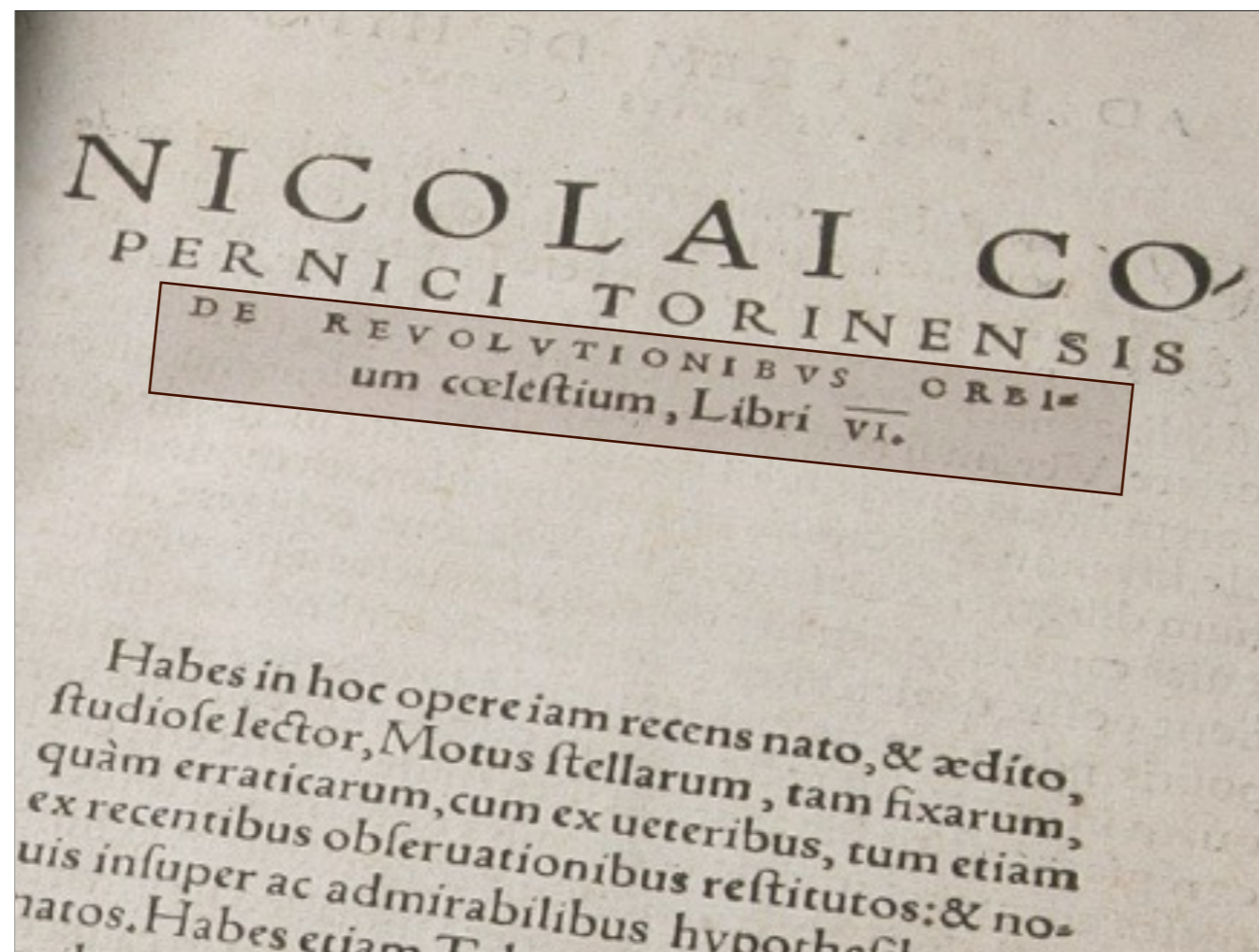
By early 1506, Copernicus had returned to his homeland. In later years, Calcagnini traveled across the Alps to Poland in order to visit his friend. At first Copernicus worked as a cathedral administrator and as a personal physician for his Uncle Lucas, the Archbishop. When Lucas died in 1512, Copernicus took up a position as canon at the cathedral of Frauenburg, now Frombork, Poland.



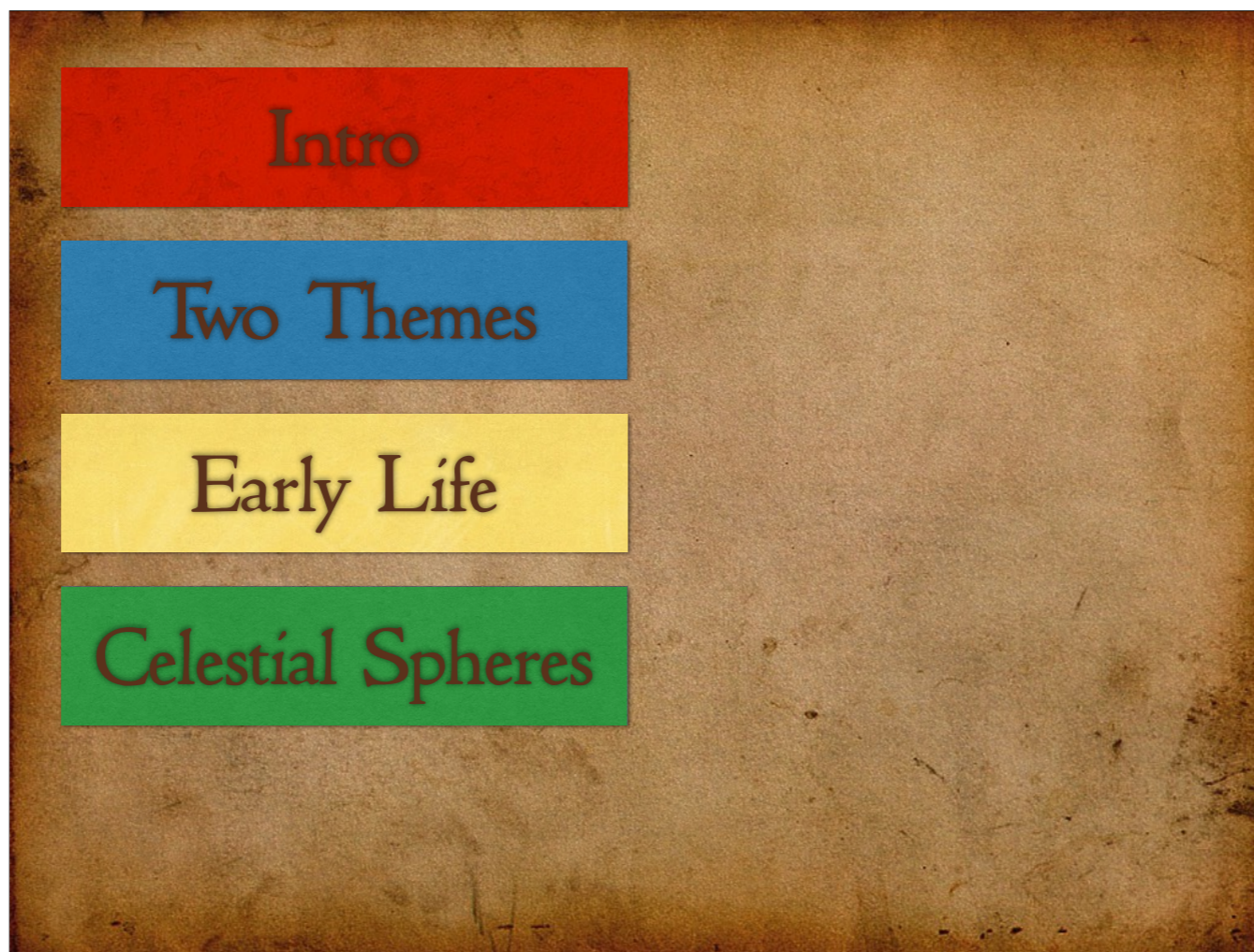
Five years later word arrived that Martin Luther posted 95 theses upon the door of the Wittenberg Cathedral, the symbolic end of the Renaissance and beginning of the Reformation.



To summarize, Copernicus' life spanned the eras of the Renaissance and Reformation. He was educated in Italian universities, and he prepared himself for service to the church as a physician and, by studying law, as a religious administrator.



Now back to the first page, where we read the title *De revolutionibus orbium coelestium*, On the revolutions of the heavenly spheres or orbs [organized in six books or major parts].



What were these celestial spheres? To understand Copernicus, we must consider the celestial spheres, or heavenly orbs.*

Through out this section, I have depended extensively upon the classic study of C. S. Lewis, *The Discarded Image* (see Further Reading)

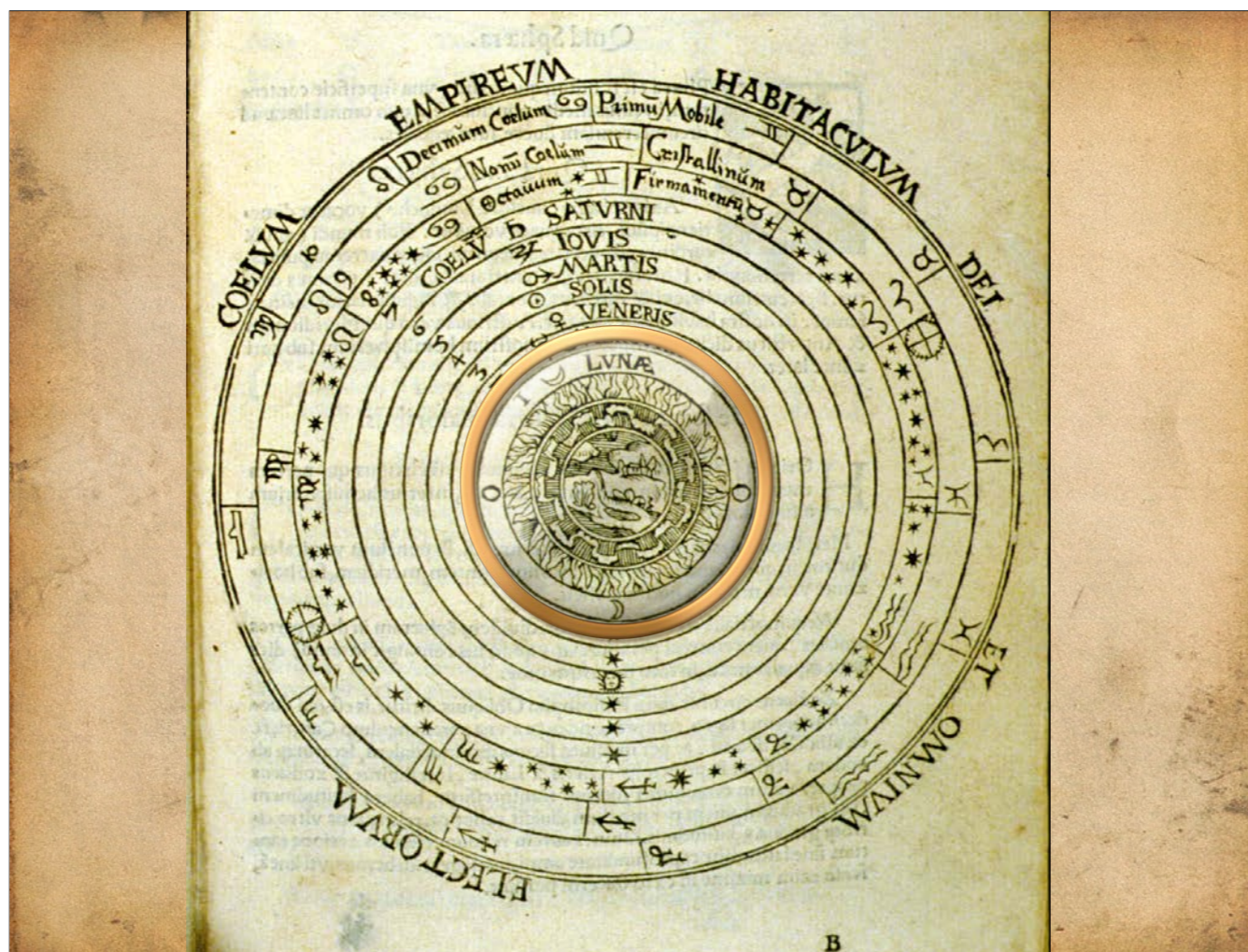


The spheres were a common sense idea that had been accepted from the time of the ancient Greeks. Renaissance scholars, theologians, and astronomers shared a common-sense view of the universe as comprised of solid celestial spheres. Although Copernicus shifted the position of the Earth out of the center, he still accepted the reality of the solid spheres.

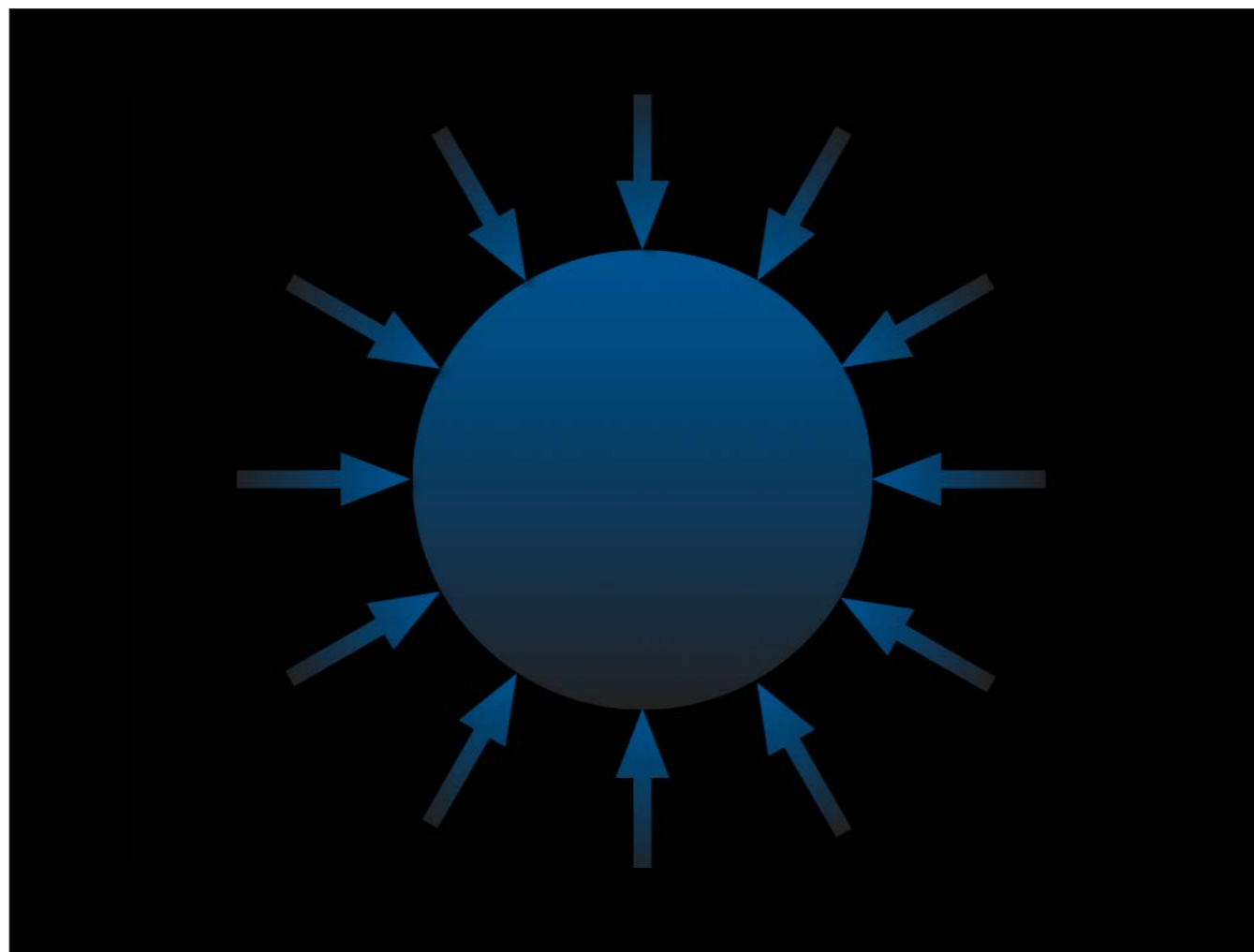
Sacrobosco, De sphaera



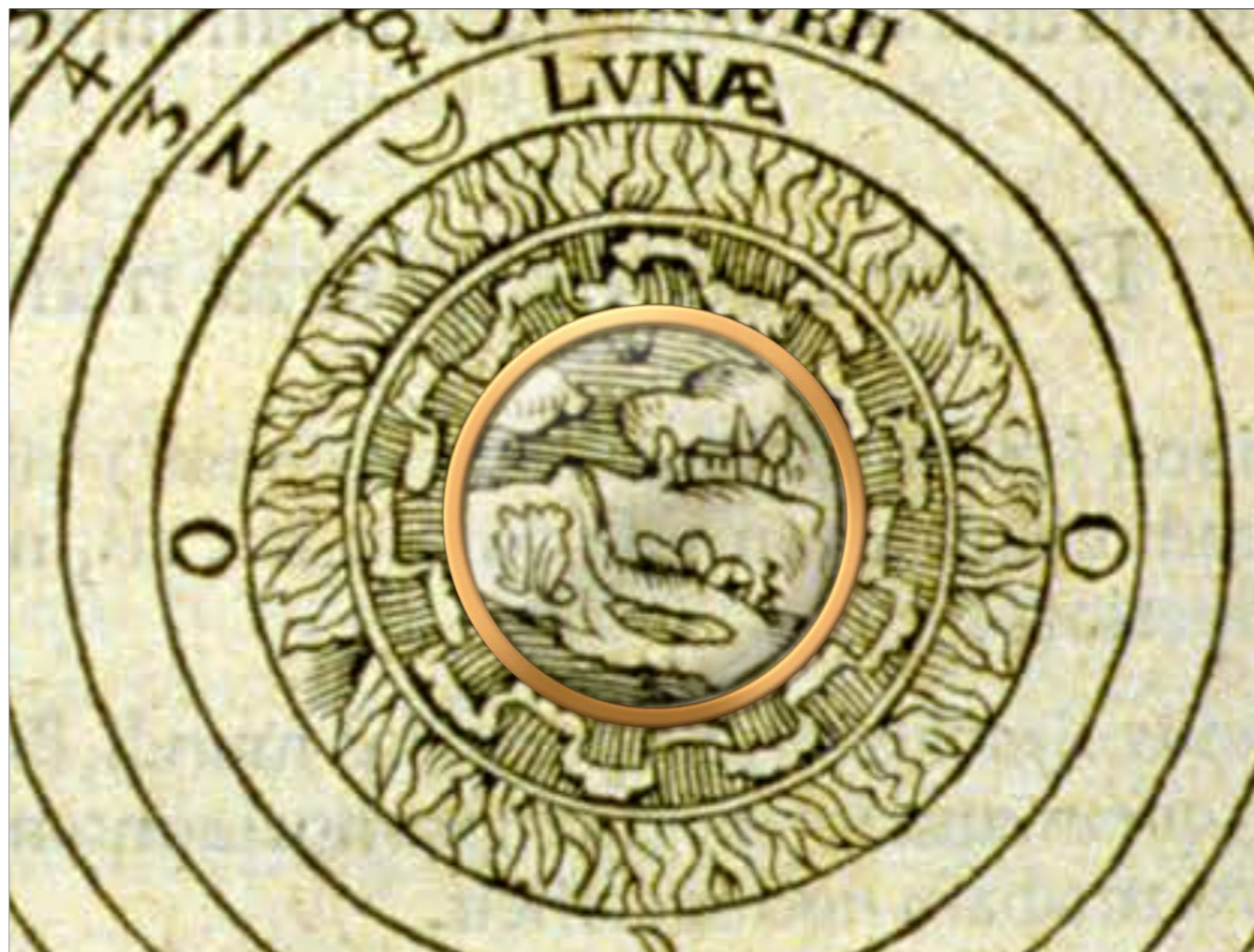
In university study, the most popular introduction to the cosmos was On the Spheres, a medieval work by Sacrobosco first printed in Ferrara in 1472. What was it like to believe in this universe composed of solid spheres and centered upon the Earth? Let's travel back in time, and try to imagine what it feels like to go out at night under these heavenly orbs...



Four elements comprise all that exists below the Moon: earth, water, air and fire.



Just as a rock falls to the ground, so earthy material strives naturally to move toward the center of the universe. Therefore by gravity, earth congregates in a spherical body at the center.



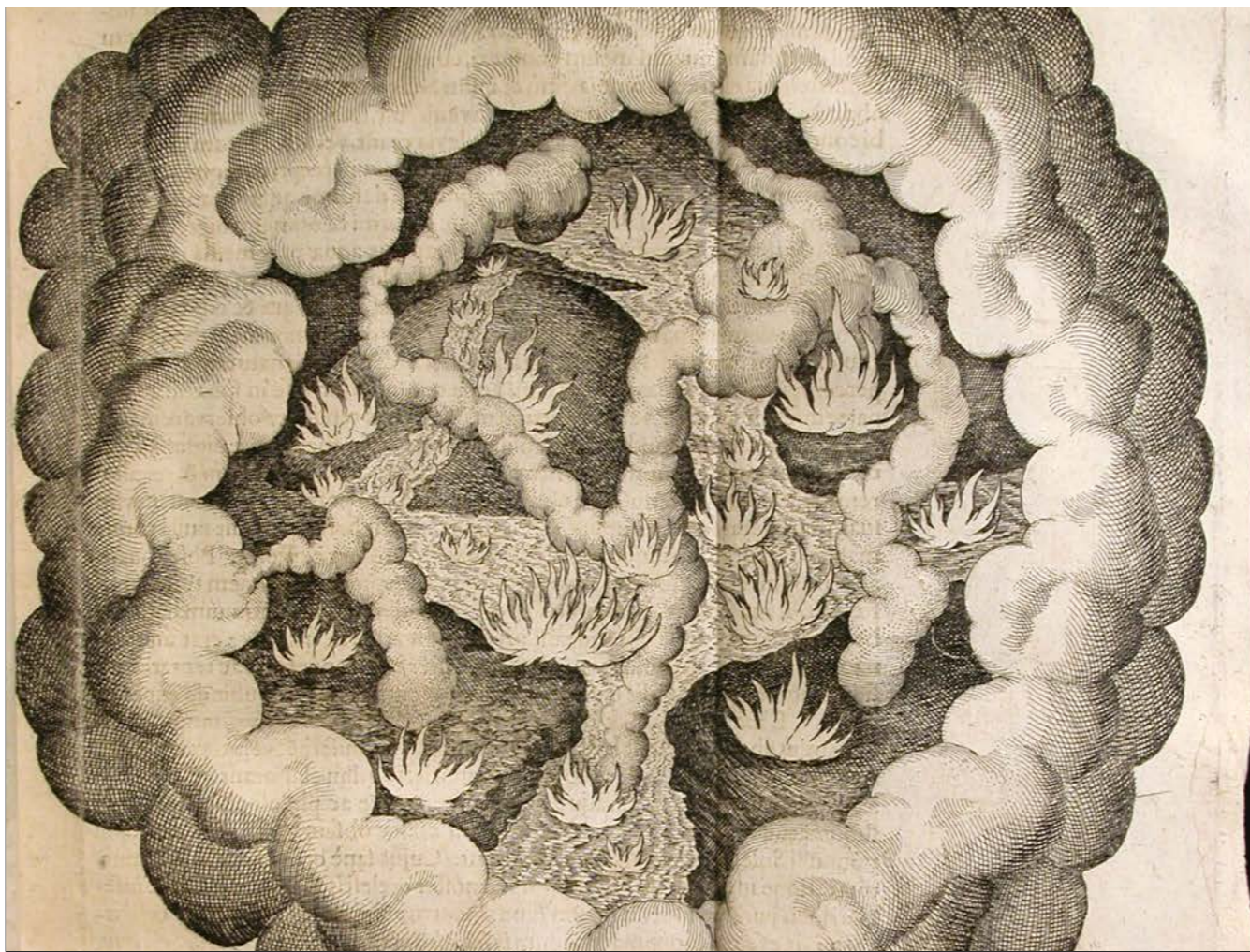
Water mixes with earth to form the seas upon a habitable globe;



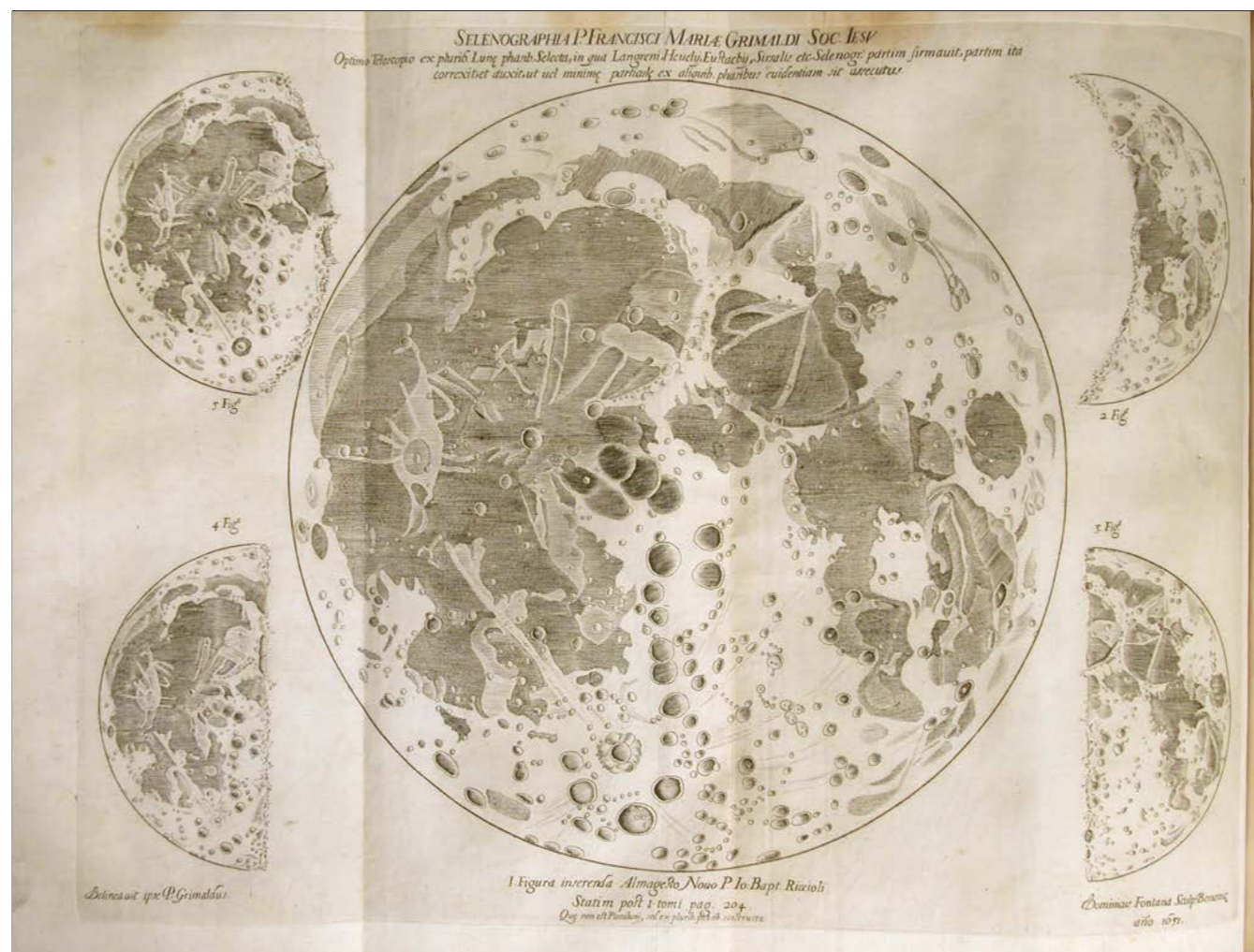
Clouds churn in the region of air;



and just as fire strives naturally to move upward, so exhalations from volcanos and earthquakes rise to the region of fire, just below the Moon, causing fiery phenomena such as meteors and comets.



The four elements of these sublunar regions constantly mix together in unceasing processes of generation and corruption.



As the Moon revolves around the Earth, we see only one familiar side. This observation confirms that the Moon lies embedded within a giant solid transparent sphere that carries it around us once a month.



On the boundary between heaven and Earth, the Moon patrols the great frontier between the regions of corruption below and the pure celestial spheres above.



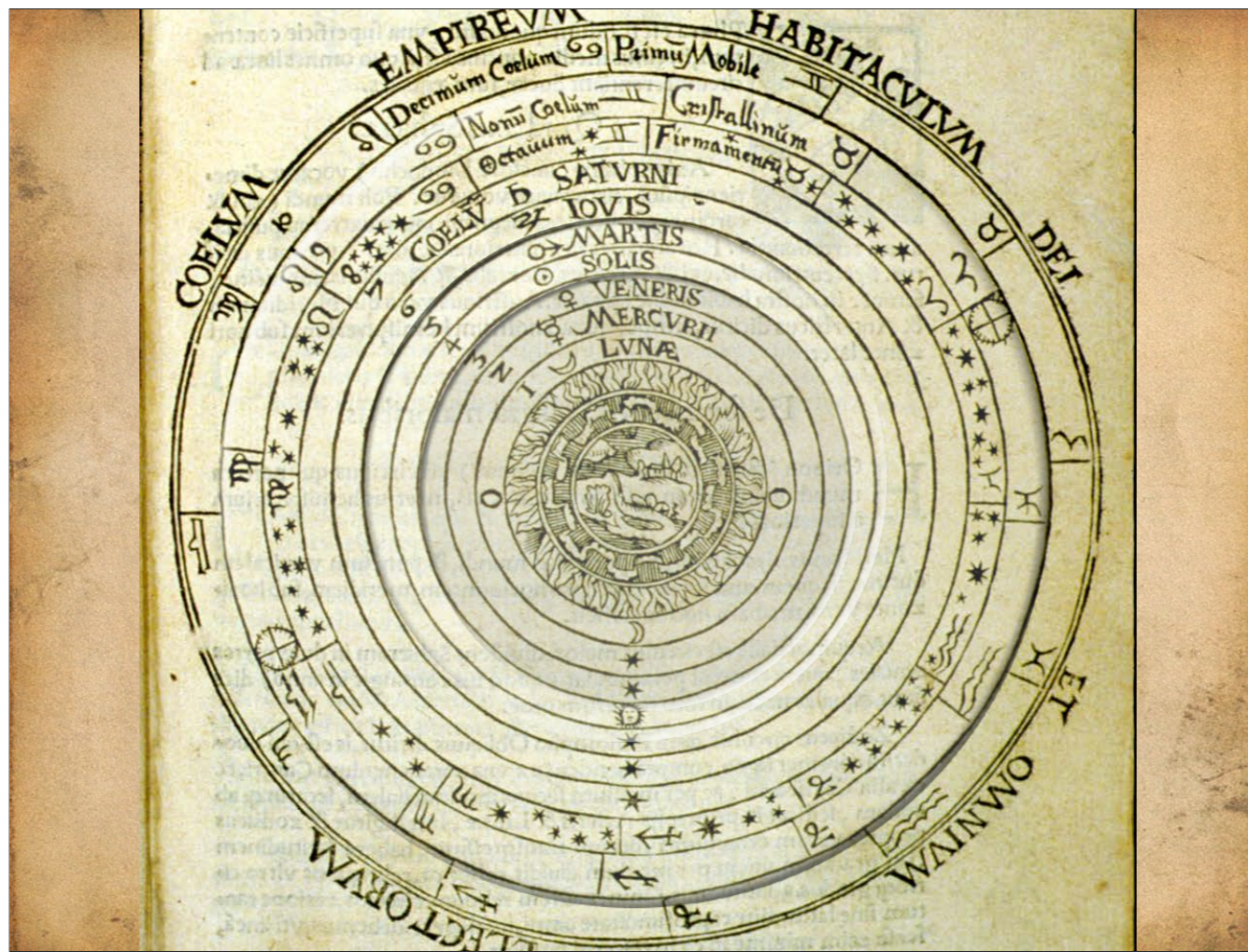
High overhead the stars of the firmament appear fixed in the patterns of the constellations, as if they were bright points of light embedded within their own transparent celestial sphere.



In its daily or diurnal motion, the firmament of fixed stars turns once around the Earth every day. Each star traces one full circle every 24 hours. This makes sense of common experience and natural observations. And if the hypothesis of solid spheres so easily explains the motion of the Moon and of the fixed stars, then why not use them for the other celestial bodies as well?



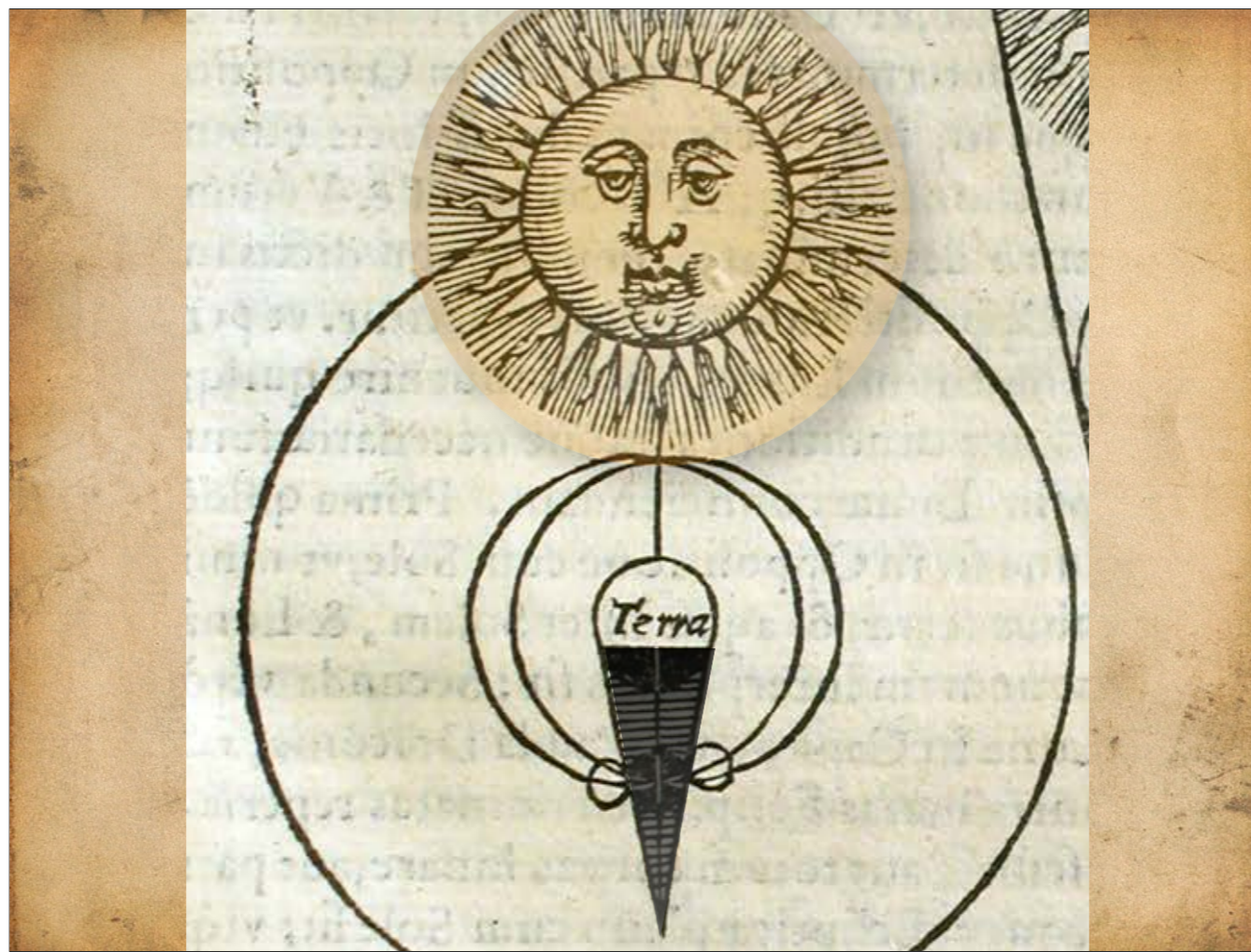
In addition to the Moon and stars, the Sun also has its own sphere. With an annual motion, the sphere of the Sun carries it around the Earth once each year.



For astronomers from the ancient Greeks through the generation of Copernicus, celestial spheres, made of a fifth element called ether or the quintessence, explained the obvious motions of the Sun, Moon and stars. They also can account for the planets. Exalted far above the Earth and the sublunar elemental regions, the solid spheres, incorruptible, effortlessly turn in place, creating a harmony of motions known as the music of the spheres. Aristotle taught that the spheres turn by eternal desire. Dante wrote of “the love that moves the Sun and other stars.”



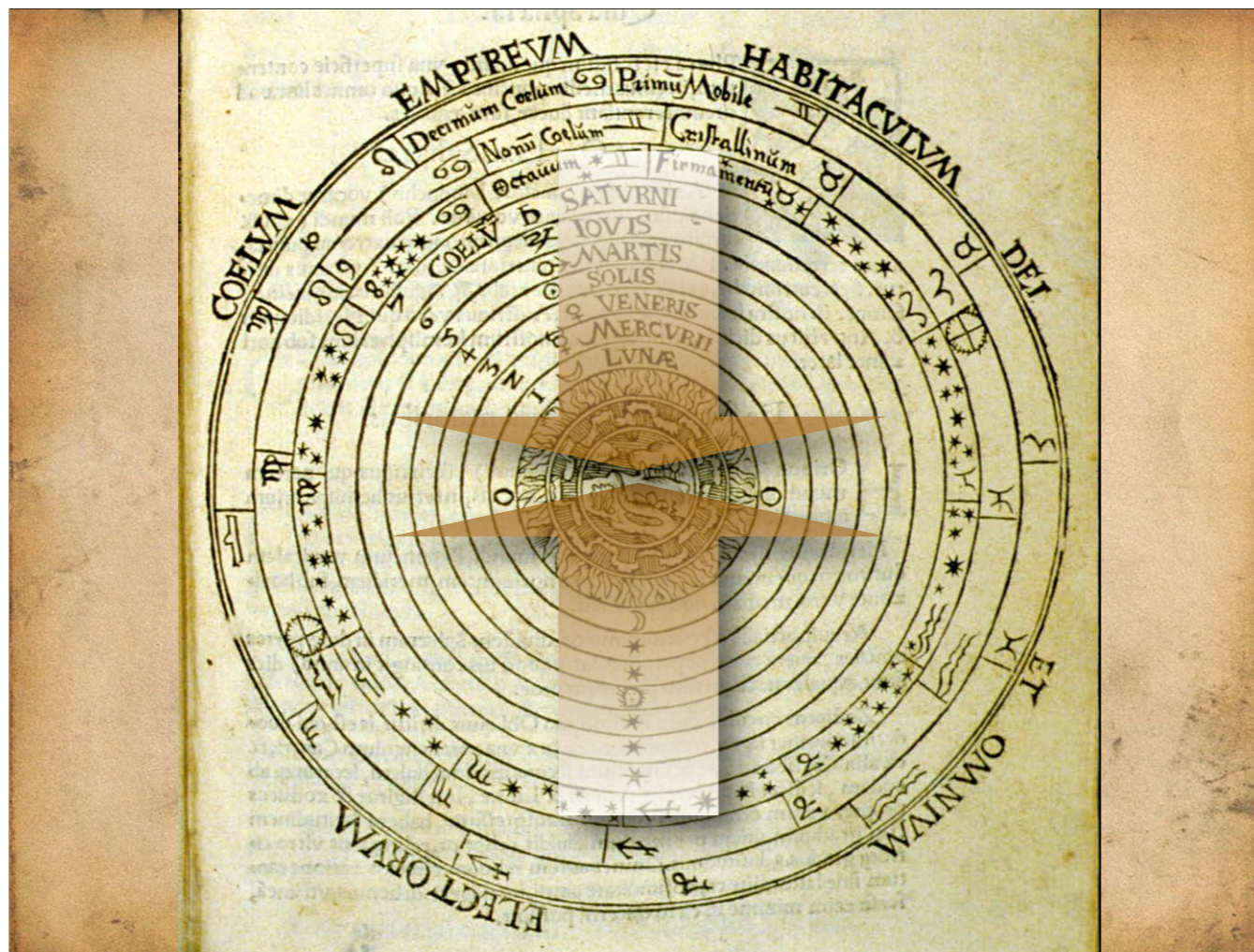
In this geocentric cosmos, the Sun occupies a privileged position in the middle of the heavens, from which it illumines the entire universe, pervading the spheres above and below with light,



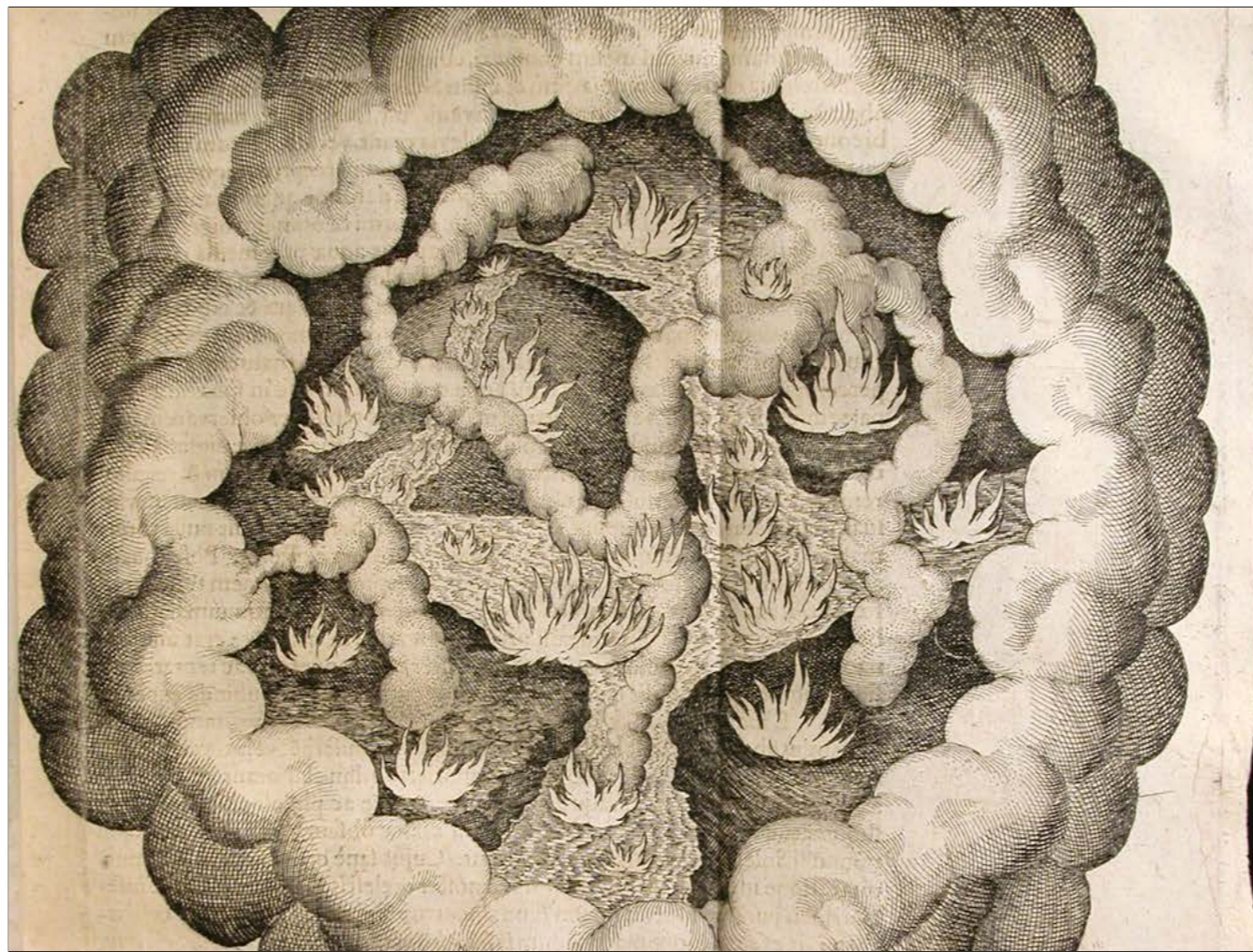
except where that light is obscured by the small conical shadow of our darkened Earth.



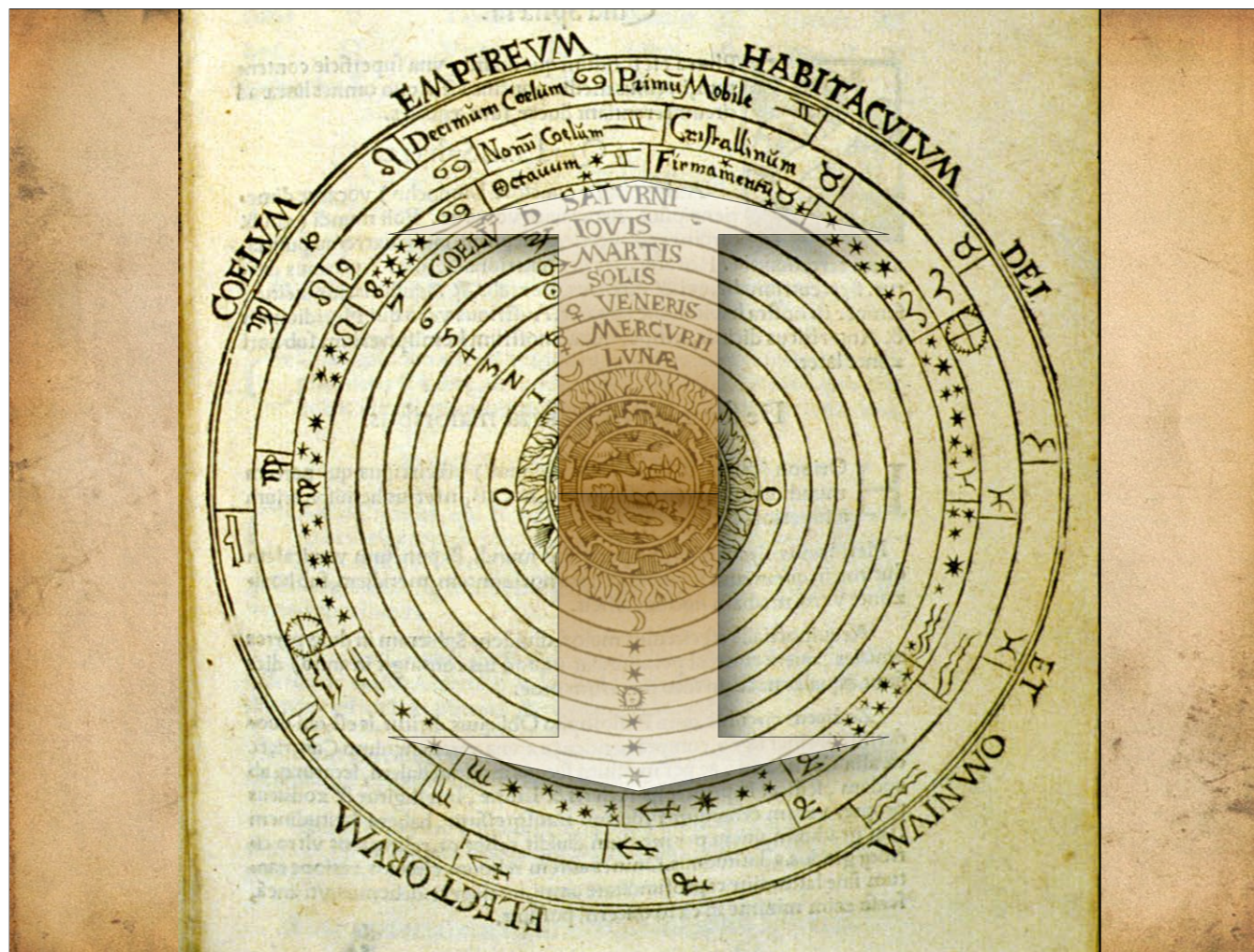
Across our nighttime sky, within a silent shadow of mortality, we gaze upon distant spheres brightly illumined, filled with joy and life.



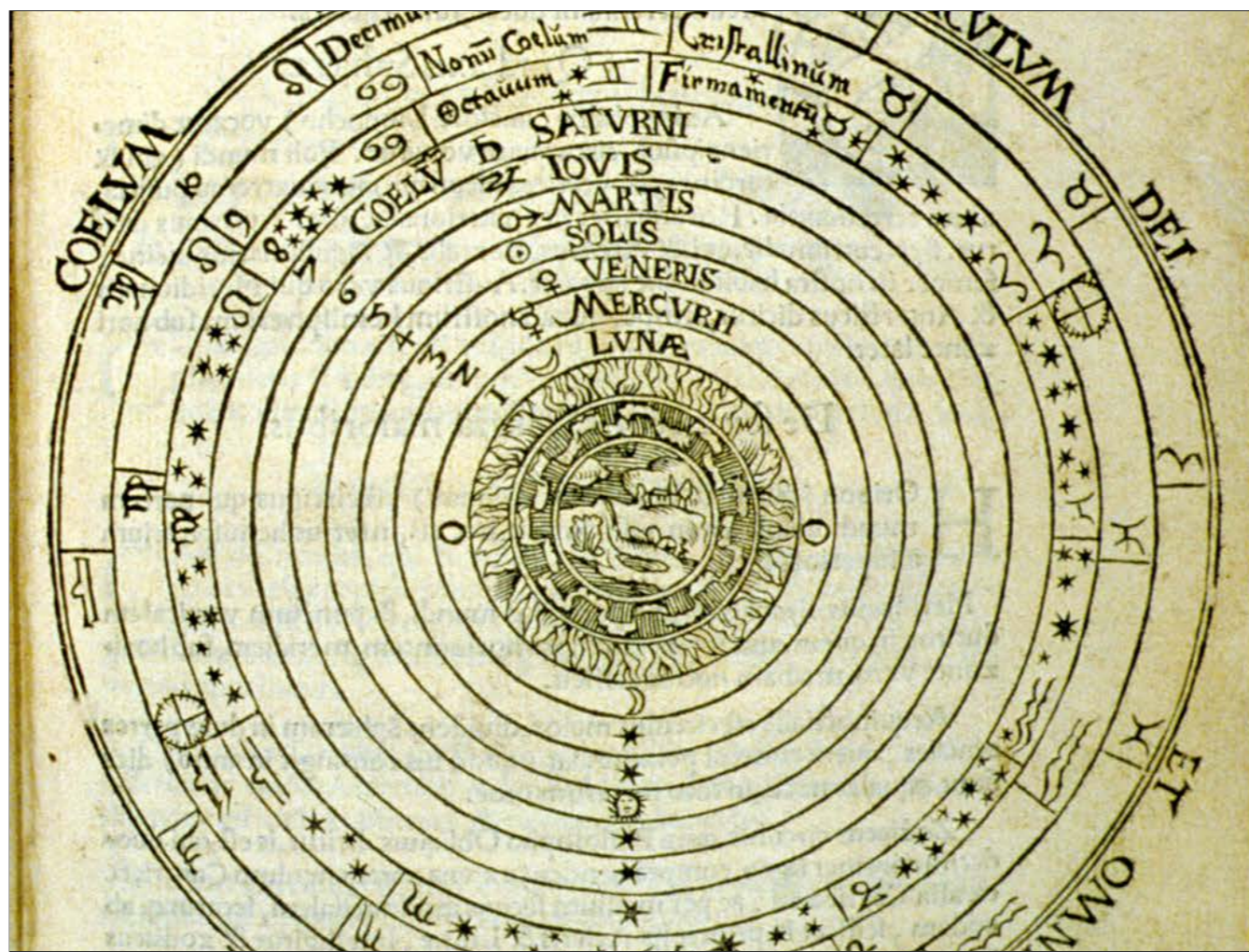
The vigor, power and dignity of the spheres diminish as one descends from the breathtaking daily pace of the outer sphere of fixed stars.



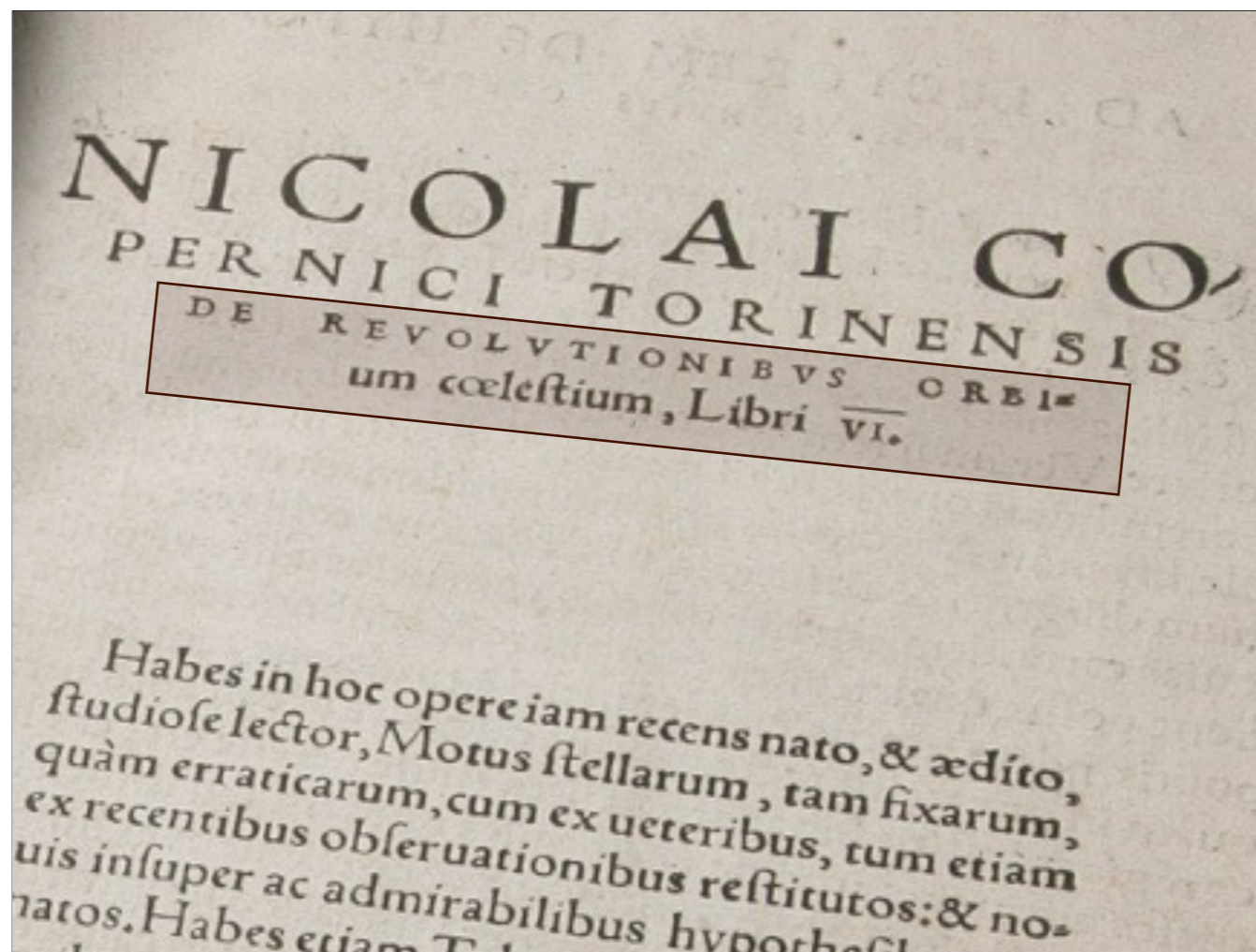
To lie at the center was not a place of privilege, but a cosmic reminder of human insignificance. The greatest king on Earth rules only the gutter of the universe, the theater of corruption and decay, in contrast to the glories of the unspoiled heavens. In this sense, the cosmos was earth-centered, but not human-centered.



In terms of significance, the geocentric universe was centered on its circumference.



From Dante to Chaucer to Shakespeare, this vision of perfect celestial spheres rotating effortlessly around the central globe of mortality was the common conception of the cosmos, ...

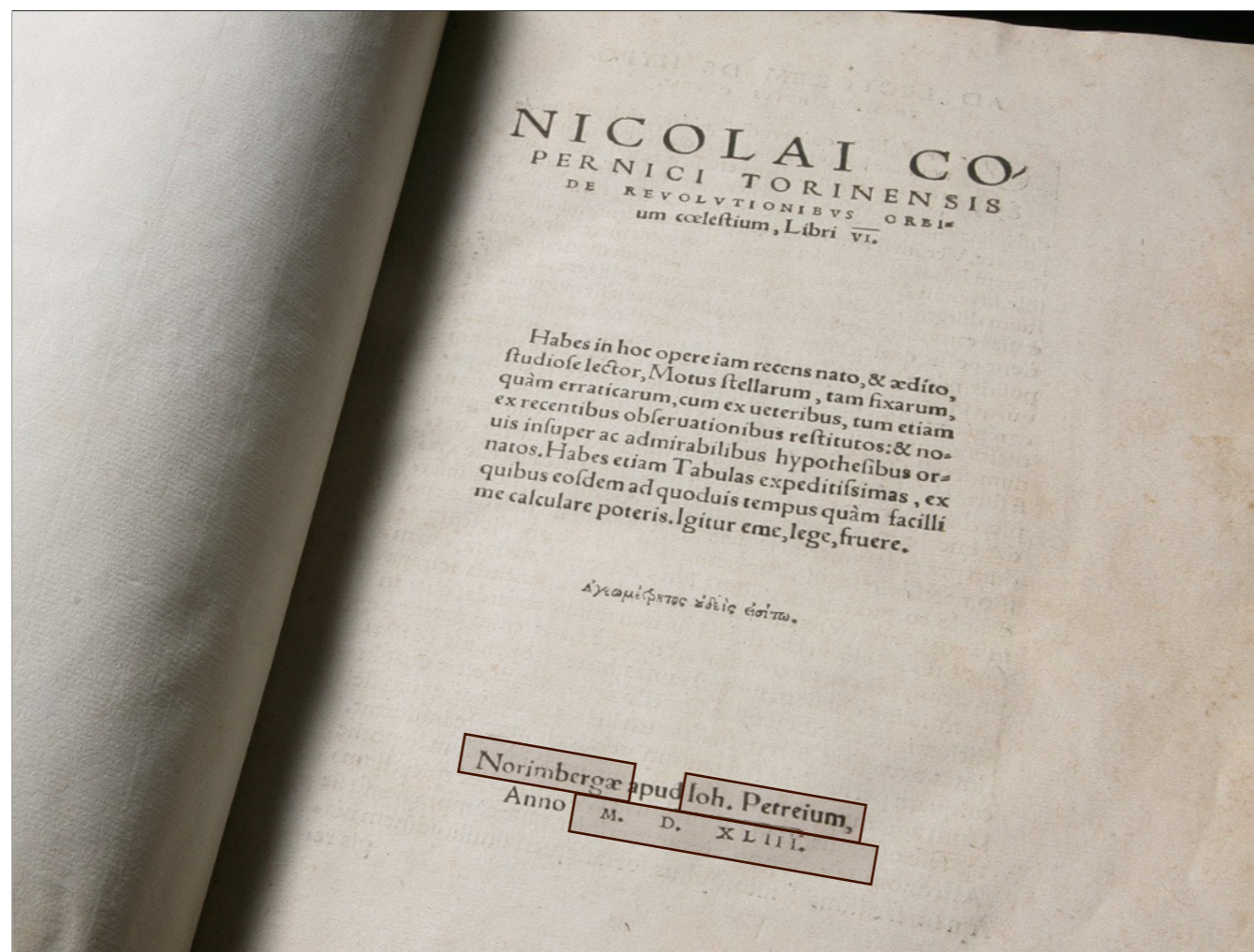


Now we may better understand Copernicus' title: On the revolutions of the celestial spheres. Copernicus did not question the reality of the solid spheres, but lived and moved and had his being within this ancient conception of the cosmos. (pause) Now that we've looked at the top of the title page, let's shift our focus to the lower part of the title page.



What were the circumstances surrounding the publication of the De rev?*

Throughout this section, I have depended entirely upon the pathbreaking study of Peter Barker and Bernard Goldstein (see Further Reading)



At the bottom of the title page, we see that Copernicus' great work was printed in 1543

- in Nuremberg
- by the printer Johann Petreius. This information tells another story, one that relates Copernicus to contemporary events on the European scene. 1543 falls right in the middle of the Reformation. Copernicus was a Catholic who worked in a cathedral in Poland. So why did he publish his work in Nuremberg, which was a Lutheran city? Why did he use Petreius, a Lutheran printer?



For an answer to these questions we must go back to Regiomontanus, the greatest European astronomer of the previous generation. We will have more to say about Regiomontanus later. Yet among his many efforts, Regiomontanus set up a printing press in Nuremberg to bring about a reformation in astronomy. He left as his legacy a lively circle of Lutheran astronomers...



- Bernhard Walther, an associate of Regiomontanus, carried out systematic observations for 30 years, some of which appear in the *De revolutionibus*.*
- Johann Schöner, a student of Walther, edited Regiomontanus' manuscripts for printing. His name appears in the *De revolutionibus*, as we shall see.
- Andreas Osiander, a leading Lutheran theologian, became the anonymous editor of the *De rev.*
 - Petreius, an influential printer, actively searched for worthy titles in astronomy, ancient or modern, to publish with his press. So this is how the *De rev* came to be published in Nuremberg by Petreius.
 - Even the papal astronomer Luca Guarico, in Rome, was known to visit Nuremberg, and Petreius published some of his books. Remember that Copernicus, like Guarico, was Catholic. In a tumultuous century, astronomy remained one endeavor in which Catholics and Protestants might still collaborate.

* According to Swerdlow, Copernicus used three of Walther's observations of Mercury in *De revolutionibus* (p. 53).



Now let's turn past the title page to the Front Matter of the De rev.



Word of Copernicus had spread, largely due to the *Commentariolus*, a little manuscript Copernicus circulated privately among a few friends. In Rome, Johann Albrecht Widmanstadt, the secretary* of Pope Clement VII, presented a lecture on Copernicus' new astronomical ideas. The Pope himself invited Copernicus to join the Church's effort to reform the calendar.

AD LECTOREM DE HYPO.
THEOREMATA HYPO. OPERA.

Non dubito, quin eruditū quidam, uulgatim de nouitate hypotheseon huius operis factū, quidē tam mobilem, Solem uero in medio uniuersi immobilē constituit, uehementer sint offensi, pueris disciplinas liberales recte iam olim constitutas, turbati nō esse portere. Verum si rem exacte perpendere uolent, inueniunt in theorema huius operis, nihil quod reprehendi mereatur cōuenisse. Est enim Astronomi proprium, historiam motuum celestium diligenti & artificiosa observatione colligere, Deinde causas earundem, seu hypotheses, cum ueras adē qui nulla ratione possit, qualescūq; excogitare & coningere, quibus suppositis, eundem motus, ex Geometriæ principijs, tam in futurū, quā in præteritū recte possint calculari. Horū autē utriusq; egregie præstitit hic artifex. Neq; enim necesse est, eas hypotheses esse ueras, imō ne uerisimiles quidem, sed sufficere huiusmodi, si calculum observationibus congruentem exhiberent, si fortē quis Geometriæ & Optices ulpadeo sit ignarus, ut opticydium Veneris pro uerisimili habeat, seu in causa esse credat, quod ea quadraginta partibus, & eo amplius, sese interdum præcedat, interdū sequatur. Quis enim nō uidet, hoc posito, necessario sequi, diametrum stellæ in sesquialtero plus, quam in duplo, corpus autem ipsum plusq; sedecuplo, maiora, quā in æquali apparere, cui tamen omnis æui experientia relinquitur? Sunt & alia in hac disciplina non minus absurda, quæ si præsentiarum excutere, nihil est necesse. Sanis enim patet, apparentiū inæqualium motuū causas, hanc artem præmiti & simpliciter ignorare. Et si quas fingēdo excogitat, ut certe quāplurimas excogitat, nequaquā tamen in hoc excogitat, ut ita illi cuiquam persuadeat, sed tantum, ut calculum recte instituant. Cum autem unus & eundem motus, uarie interdum hypotheses sese offerant, ut in motu Solis, eccentricitas, & epicycliarum Astronomus eam potissimum arripit, quæ comprehensione sit quā facillima, Philosophus fortasse, ueri similitudinem rege

523.2
1543
gis requireret, itē tamen quicquam certi comprehendere, aut tradere, nisi diuinitus illi reuelatum fuerit. Sinamus igitur & has nouas hypotheses, inter ueteres, nihilo uerisimiliores immo relecte, præterea cum admirabiles simul, & faciles sint, ingenio thelaurum, doctissimarum observationum secum aduehant. Neq; quisquam, quod ad hypotheses attinet, quicquid certi ab Astronomia expectet, cum ipsa nihil tale præstare queat, ne si in alium usum confecta pro ueris arripiat, stultior ab hac disciplina discorde, quā accesserit. Vale.

NICOLAUS SCHONBERGIUS CAR.
dudis Capuanus, Nicolao Copernico, S.

Vni mihi de uirtute tua, cōstanti omnium sermone ante annos aliquot allatū esset, cepti tum maiorem in modū te animo cōplecti, atq; gratulari etiā nostris hominibus, apud quos tūa gloria florescit. Intellexi enim te nō modo uerū Mathematicorū inuēta egregie callere, sed etiā nouā Mūdi rationē cōstituisse. Quæ doceas terrā moueri: Solem in uicū mundi, adeoq; mediū locū obtinere: Cœlū octauū planetarū atq; fixarū ppetuo manere: Lunā se unā cū inclusis suæ sphaeræ elementis, inter Martis & Veneris cœlū sitam, anni uerticū cū Solē cōuolueret. Atq; de hac tota Astronomiæ ratione cōmentarios à te cōscriptos esse, ac erraticarum stellarū motus calculis subductos in tabulas te cōstitisse, maxime omnium cum admiratione. Quamobrem uir doctissime, mihi mihi molestus sum, te etiā atq; oro uehementer, ut hoc tuū inuēntū studiosa cōmunice, & tuas de mundi sphaera elaborationes unā cū Tabulis, & si quid habes præterea, qd ad eandem rem pertineat, primo quoq; tempore ad me mitas. Dedit autem negotiū Theodorico à Reden, ut istis meis summi prout omnia desinbantur, atq; ad me transferantur. Quod si tui morem in hac re gesseris, inuelliges te cum homine nouis mihi studio, & caritatis uirtuti satis facere cupiente rem habuisse. Vale, Romæ, Calend. Nouembris, anno M. D. XXXVI.

This may explain why the first signed material in the front matter of the De revolutionibus...

2

NICOLAUS SCHONBERGIVS CAR

dinalis Capuanus, Nicolao Copernico, S.



Vm mihi de uirtute tua, cōstanti omniū sermone ante annos aliquot allatū esset, cœpi tum maiorem in modū te animo cōplecti, atq; gratulari etiā nostris hominibus, apud q̄s tāta gloria floreres. Intellexerā enim te nō modo ueterū Mathematicorū inuēta egregie callere, sed etiā nouā Mūdi rationē cōstituisse. Qua doceas terrā moueri: Solem inū mūdi, adeoq; mediū locū obtinere: Cœlū octauū immotū, atq; fixū ppetuo manere: Lunā se unā cū inclusis suæ sphæræ elementis, inter Martis & Veneris cœlū sitam, anni uersario cursu circū Solem cōuertere. Atq; de hac tota Astronomiæ ratione cōmentarios à te cōfectos esse, ac erraticarum stellarū motus calculis subductos in tabulas te cōtulisse, maxima omniū cum admiratione. Quamobrem uir doctissime, nī si tibi molestus sum, te etiā atq; etiā oro uehementer, ut hoc tuū inuentū studiosis cōmunices, & tuas de mundi sphæra lucubrationes unā cū Tabulis, & si quid habes præterea, qd ad

is by Nicolaus Schönberg, a cardinal. In 1536, Cardinal Schönberg invited Copernicus to publish his views at the Cardinal's expense. Copernicus was not yet ready to publish. Seven years later the Cardinal's letter would be placed near the beginning of De rev. Read an excerpt in Quote #2 on your handout. I won't take time to read every handout quote aloud, but they are alluded to by the little round numbers in the upper left corner of slides like this one.

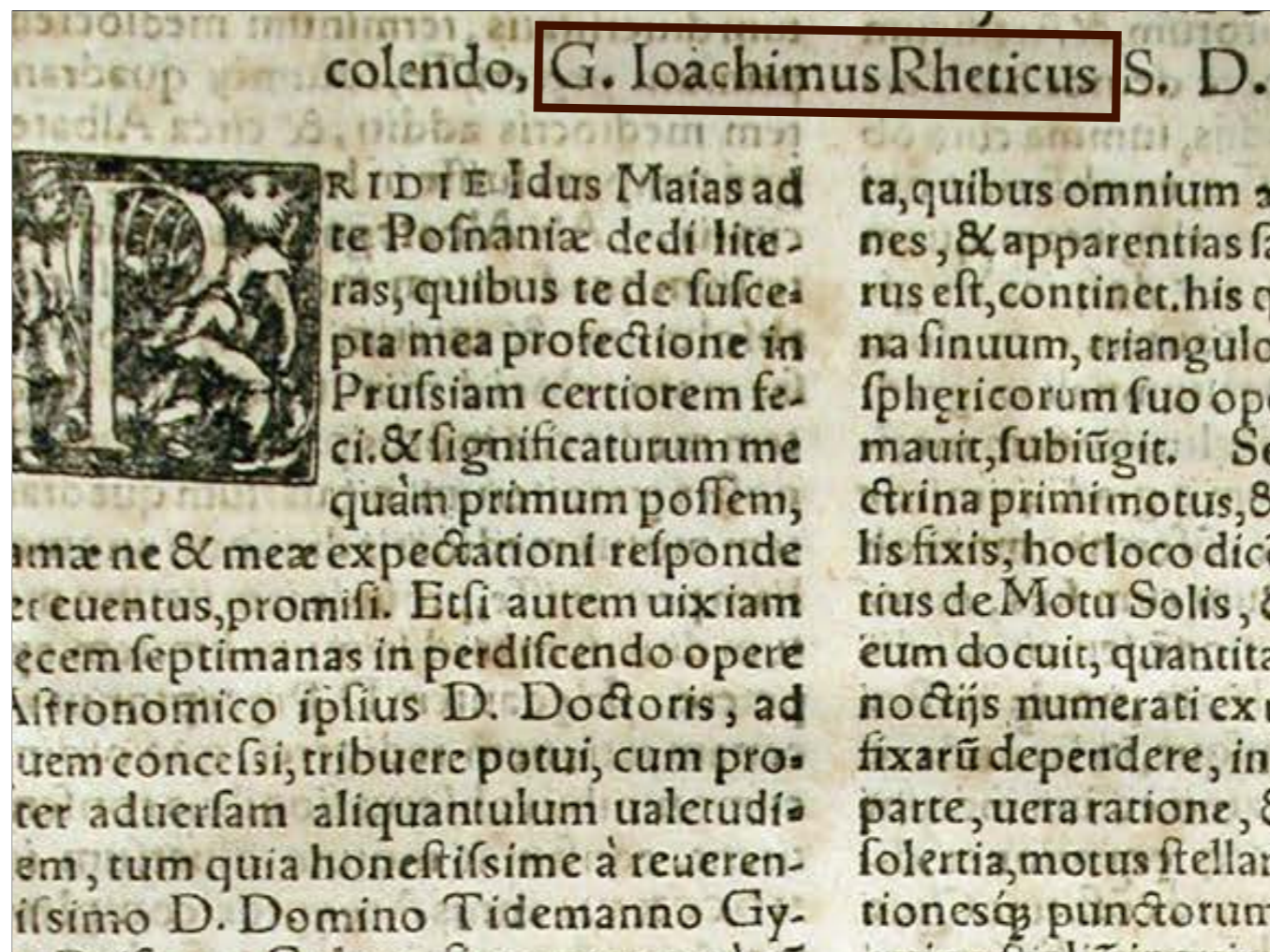


As in Rome so in Nuremberg; the Lutherans also became interested in Copernicus' astronomical reforms.*

—————
*Luther was perceived as a revolutionary despite regarding himself as a conservative attempting only to reform the Church. Similarly, Copernicus sought to cleanse astronomy of corruptions such as the equant, in order to restore fundamental principles such as uniform circular motion. It is no coincidence that in the 16th century, Lutherans proved most receptive to Copernicus' new astronomy.



Charged with reforming the University of Wittenberg, Luther's designated assistant, Philip Melanchthon, appointed



the 22-year old Georg Joachim Rheticus as professor of mathematics.



Rheticus left Wittenberg to join the Nuremberg circle who were committed to advancing the legacy of Regiomontanus:



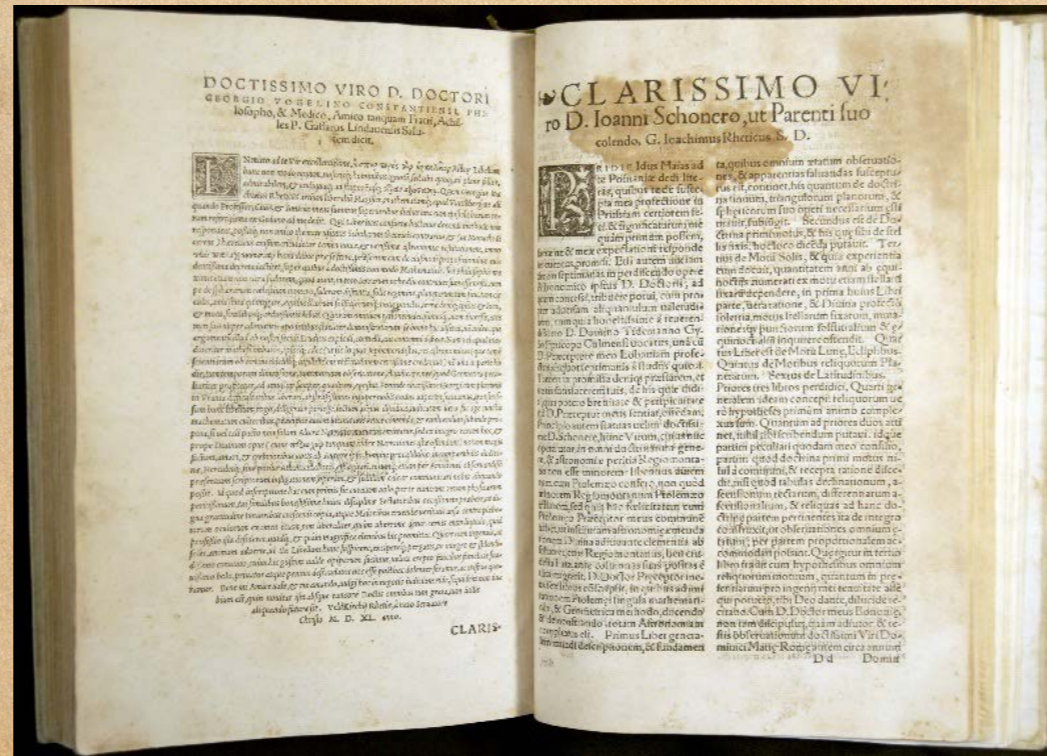
In the spring of 1539 the Nuremberg circle sent the young Rheticus to visit Copernicus in Frauenburg to report on the progress of Copernicus' work. Rheticus took Copernicus a gift of several books, including an edition of the complete Greek text of Ptolemy's *Almagest*. Impressive editions printed by Petreius showed that the Nuremberg circle stood ready and capable to publish Copernicus' own work as soon as it might be ready.



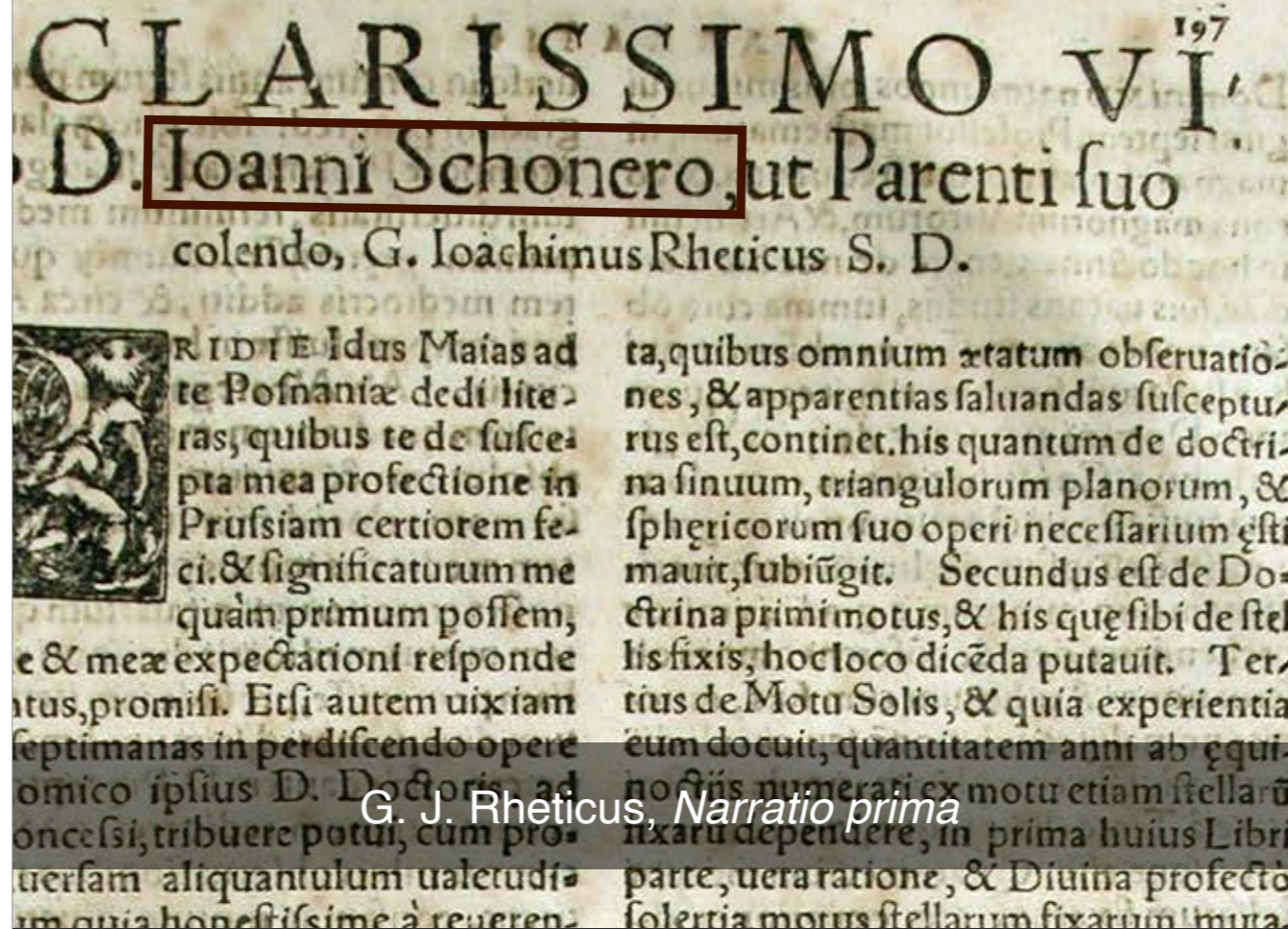
Rheticus, seeking the great astronomer in Frauenburg, instead found a churchman in trouble. At the time, it was not uncommon for church canons with the type of administrative position Copernicus held to have a mistress. Yet Copernicus had fallen out of favor with the

- new Bishop, Dantiscus, because of a long-term mistress. Peter Barker and Bernard Goldstein have shown how Rheticus, working with Tiedemann Giese, bishop of a nearby city, conceived a plan to outmaneuver Dantiscus.

Rheticus, Narratio prima

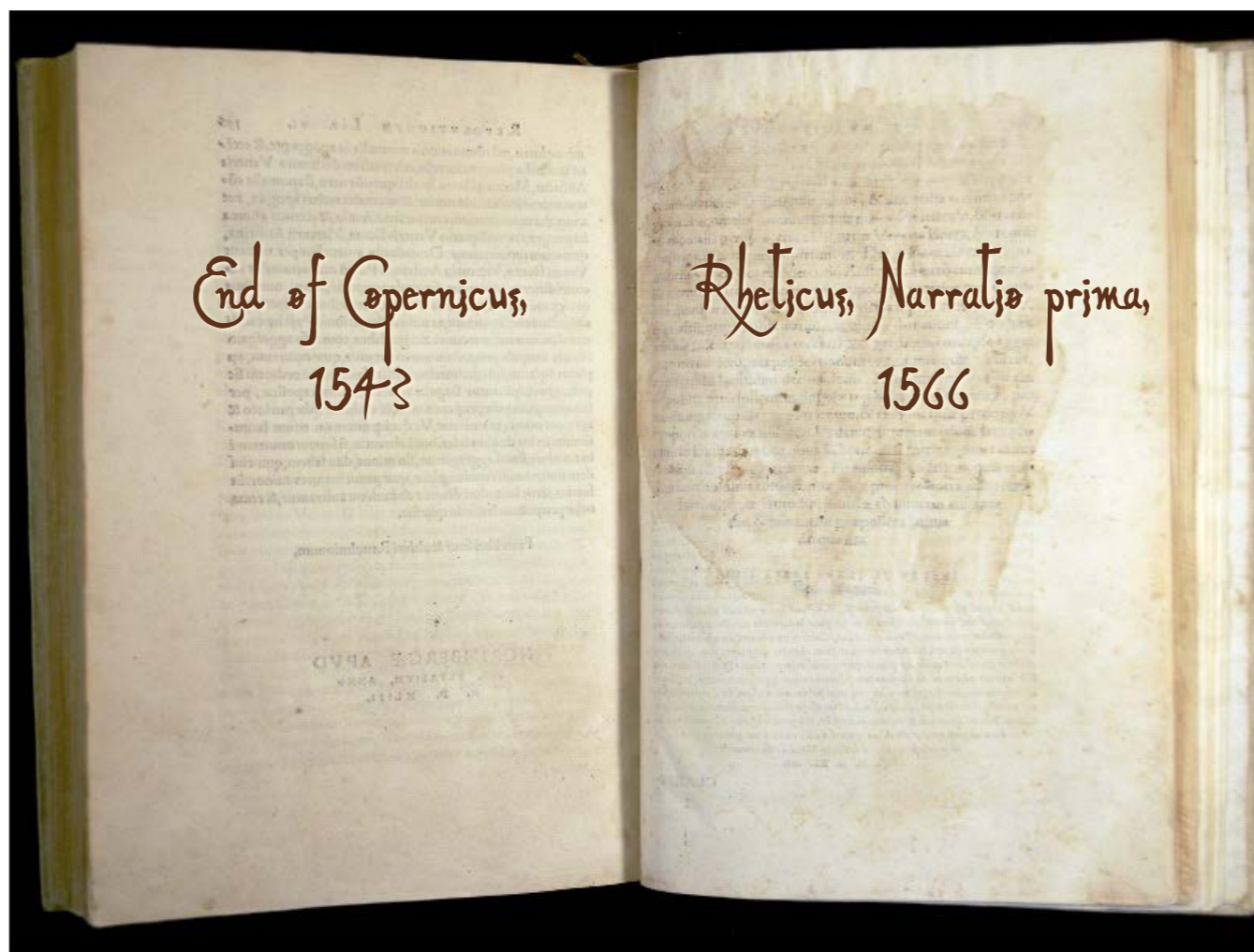


To attract attention to Copernicus' ideas, Rheticus composed a short treatise outlining Copernicus' new astronomy, published in Poland in 1540.

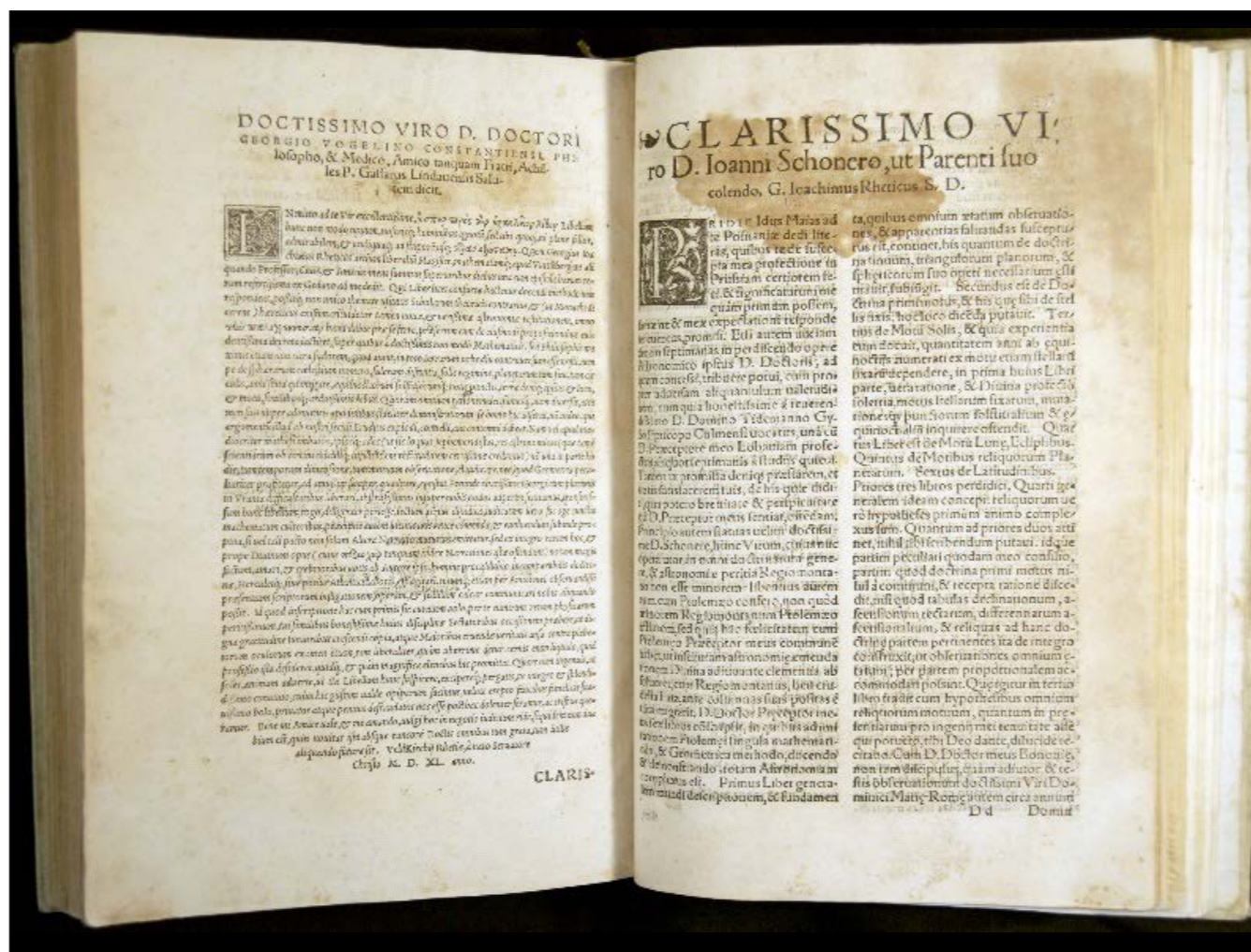


Rheticus wrote the *Narratio prima*, or First Account, as an open letter to Johann Schöner, one of the Nuremberg circle whom we have already mentioned. The *Narratio prima* offered a readable, accessible, non-mathematical summary of the system of Copernicus. Rheticus even touted the contributions the Copernican system would offer to astrology! The *Narratio prima* was a resounding success, and heightened anticipation among both Catholics and Lutherans for the promised great work by Copernicus himself.

[1540, Gdansk]



Rheticus' first account was not rendered obsolete by publication of the *De rev*, but remained popular. The Oklahoma copy of the *De rev*, published in 1543, contains the narratio prima edition of 1566 bound immediately after it within the same binding. If we turn the page,



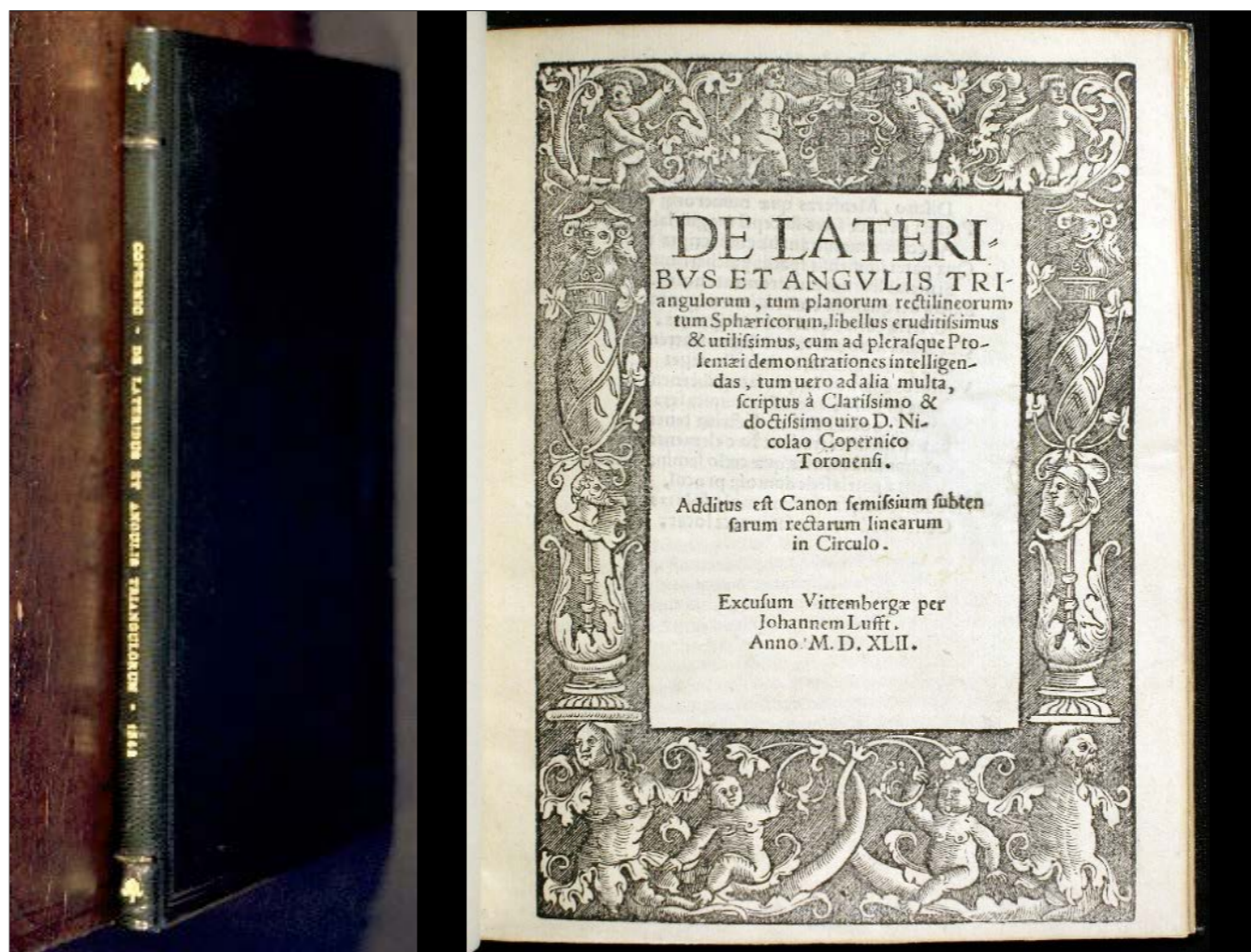
we have the 1566 edition of Rheticus' narratio prima, as shown before, which was routinely bound with second edition copies of the De rev. In our case, the owner added the 1566 Narratio prima to his own 1543 first edition De rev, which he had specially rebound for the occasion.



Rheticus dedicated the Narratio prima to Albrecht, Duke of Prussia. Duke Albrecht ruled Lutheran lands to the west of Frauenburg. Because the Narratio prima aroused such keen interest in Copernicus, Duke Albrecht arranged for Copernicus to serve as his personal physician until the dispute with Dantiscus cooled off.

Has artes teneris annis studiosa Iuuentus
Discito, Mensuras quæ numerosq; docent.
Premia nanque feres suscepti magna laboris,
Ad cœlum monstrant hæc tibi scripta uiam.
Qua patet immensis spatijs pulcherrimus orbis,
Si metas horum cernere mente uoles.
Sidera uel quam cœli regione uagentur,
Æterni cursus quas habeantq; uices.
Cur Luna inuoluat cæca caligine fratrem,
Cur Lunæ usuram lucis & ille neget
Venturos etiam casus quæ fata gubernent
Quas populis clades astra inimica ferant
Hæc si nosse uoles, prius est doctrina tenenda,
Quam breuiter tradunt hæc elementa tibi.
Cumq; hominū mentes, quæ cœlo semina ducunt,
Errent a patria sede domoq; procul,
Hæc doctrina ipsas terrena mole solutas
Cœlesti reduces rursus in arce locat.

Faced with the Duke's support for Copernicus, Dantiscus made a complete about face, writing a poem in praise of Copernicus which he hoped Copernicus would publish. Copernicus did publish it, but not in the De rev!



Instead, Copernicus published De Lateribus in 1542, the year before the De rev. De Lateribus is that very rare little book we mentioned at the beginning. It consists of some

Has artes teneris annis studiosa Iuuentus
 Discito, Mensuras quæ numerosq; docent
 Premia nanque feres suscepti magna laboris,
 Ad cælum monstrant hæc tibi scripta uiam.
 Qua patet immensis spacijs pulcherrimus orbis,
 Si metas horum cernere mente uoles.
 Sidera uel quam cœli regione uagentur,
 AEterni cursus quas habeantq; uices.
 Cur Luna inuoluat cæca caligine fratrem,
 Cur Lunæ usuram lucis & ille neget
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 Cunctq; hominū mentes, quæ cœlo semina ducunt,
 Errent a patria sede domoq; procul,
 Hæc doctrina ipsas terrena mole solutas
 Cœlesti reduces rursus in arce locat.

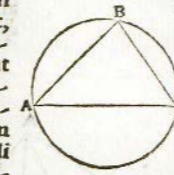
DE LATRIBVS

ET ANGLVLIS TRIANGV

lorum planorum rectilineorum.

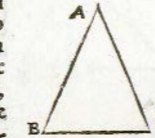
I.

TRIANGVLI datorum angulorum dan-
 tur latera. Sit, inq, triangulum a b c,
 cui per quintum problema quarti Eu-
 clidis circumscribatur Circulus. Erunt
 igitur & a b, b c, c a circumferentiæ da-
 tæ, eo modo, quo cœlx. partes sunt duo-
 bus rectis æquales. Datis autem circum-
 ferentijs dantur etiam latera trianguli
 inscripti circulo tanquam subtensæ, per expositum Cano-
 nem, in partibus, quibus dimetiens assumpta est 2000000.



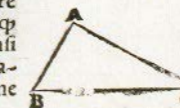
II.

Si uero cum aliquo angulorum duo trianguli latera fue-
 rint data, & reliquum latus cum reliquis angulis cognosce-
 tur. Autem latera data æqualia sunt aut inæqualia, Sed
 angulus datus aut rectus est, aut acutus, uel obtusus. Acru-
 sus latera data datum angulum uel comprehendunt, uel
 non comprehendunt. Sint ergo primum in triangulo
 a b c duo latera a b & a c data æqualia, quæ angulum a
 datum comprehendunt. Cæteri igitur, qui ad basim b c
 cum sint æquales, etiam dantur, uti dimidia residui ipsius a,
 & duobus rectis. Et si qui circa basim angulus primitus fue-
 rit datus, datur mox ipsi compar, atque ex his duorum re-
 storam reliquus. Sed datorum angulorum trianguli dan-
 tur latera, datur & ipsa b c basim, ex Canone in partibus
 quibus a b uel a c tanquam ex centro fuerit, 1000000 partium
 siue demetiens 2000000 partium.



III.

Quod si angulus, qui sub b a c rectus fuerit datis cōpre-
 hensus laterib; idem eueniet. Quoniam liquidissimū est, qd
 quæ ex a b & a c fiunt quadrata, æqualia sunt ei, quod a basi
 b c, datur ergo longitudine b c, & ipsa latera inuicem ra-
 tione



mathematical techniques and tables excerpted from his manuscript, dedicated to his newly reconciled bishop Dantiscus. Barker and Goldstein suggest that to reconcile with his bishop seems to have been the only reason for this publication. The contents, without the poem, were included a year later in the De rev.

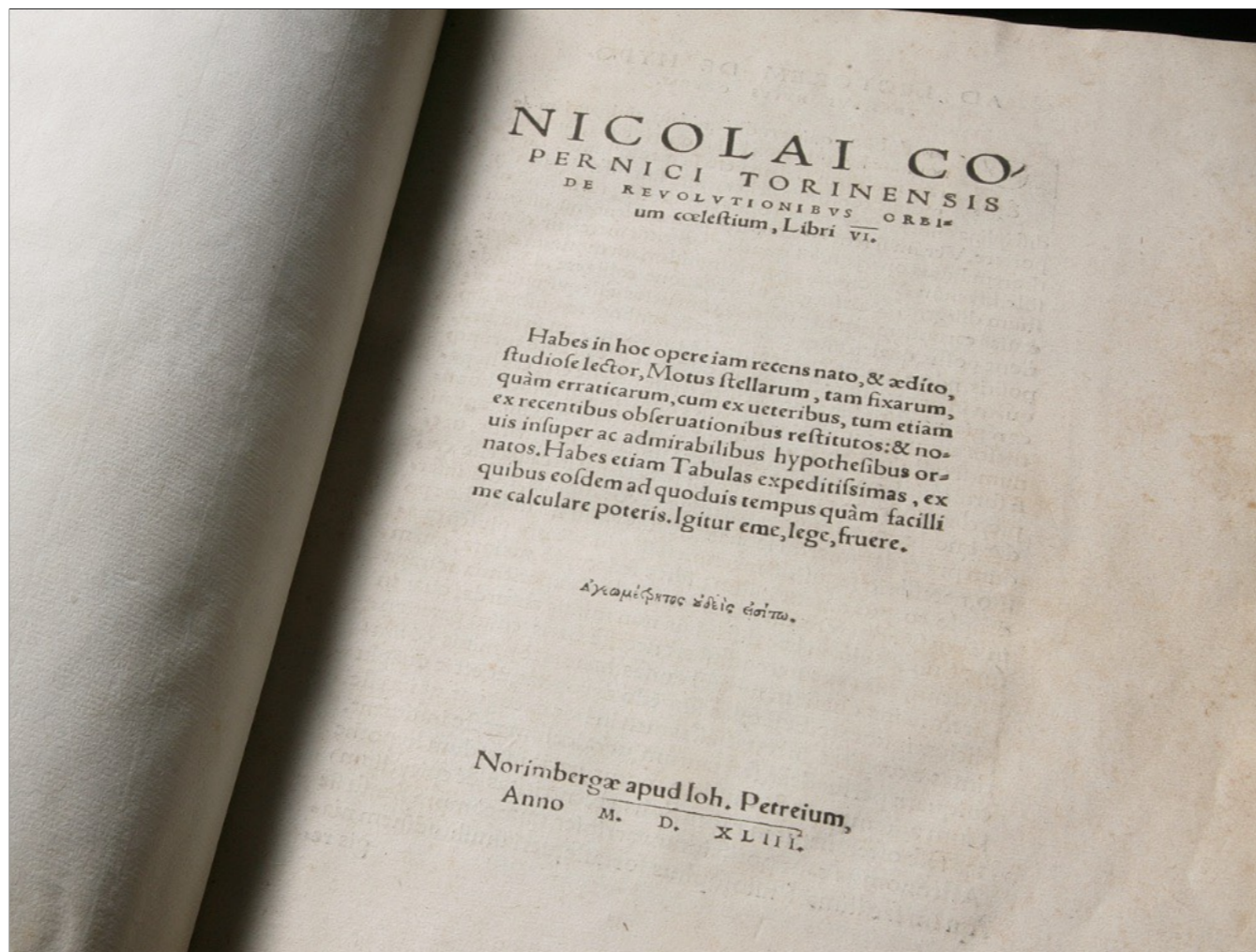
Peter Barker and Bernard R. Goldstein, "Patronage and the Production of De Revolutionibus," Journal for the History of Astronomy 34, (2003): 345–368.



Thus in the middle of the Reformation, Rheticus and Albrecht, a traveling young Lutheran professor and a Lutheran Duke, intervened to ensure the security of a minor Catholic churchman in a neighboring territory, with the result that Copernicus was thereafter free to publish his great work.



During his stay in Frauenburg, Rheticus edited Copernicus' manuscript. When it was nearly complete in the autumn of 1542, Rheticus left to take up responsibilities as professor of astronomy at Leipzig. On the way, Rheticus took the manuscript to Nuremberg for final editing by Osiander, after which it was printed by Petreius.



And that brings us back to where we left off in the De rev. Just the title page suggests many stories, but...



Let's turn the pages to find Copernicus' own dedication in the De rev. Copernicus had larger patrons in mind for the De rev than his local bishop:

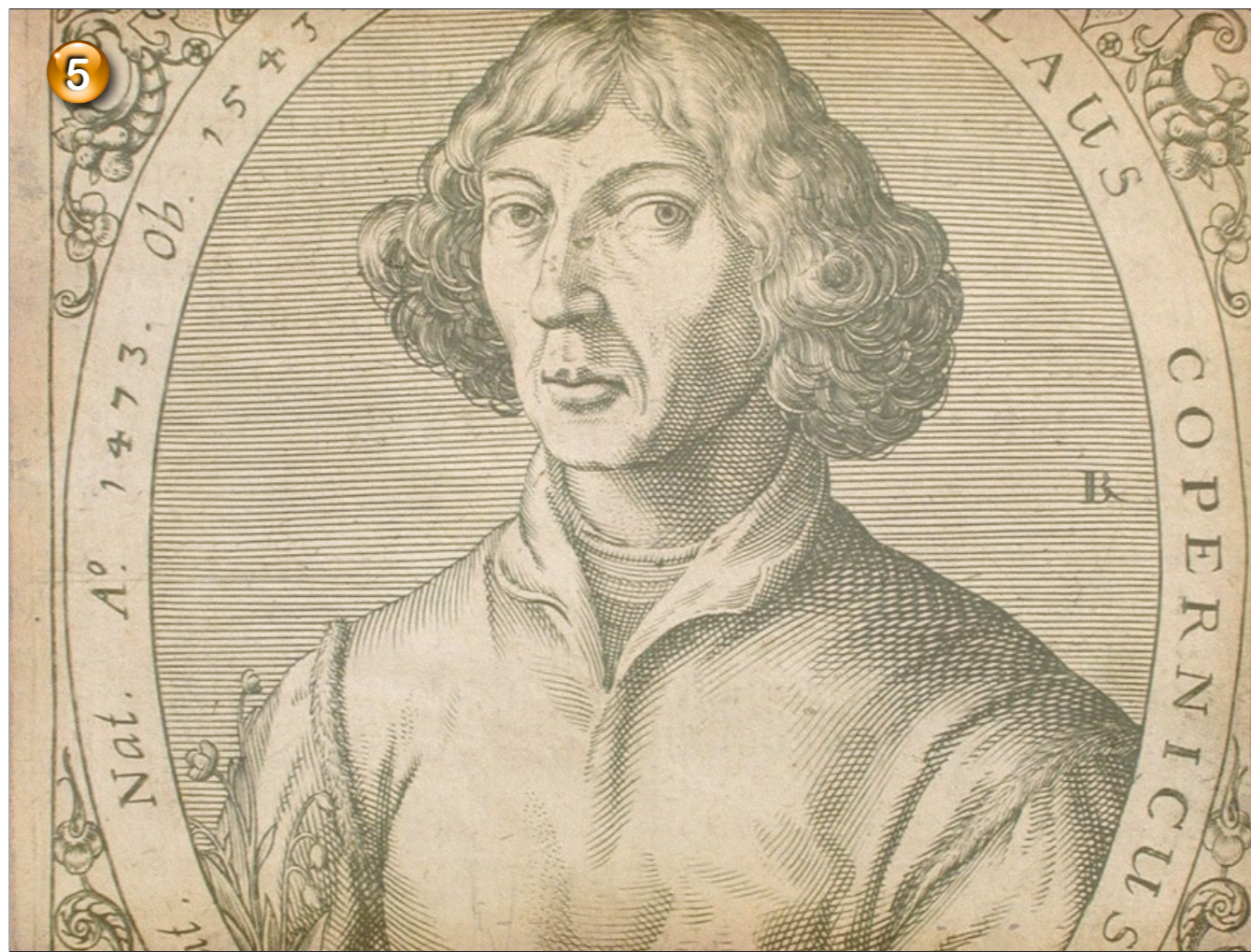
AD SANCTIS-
SIMVM DOMINVM PAV-
LVM III. PONTIFICEM MAXIMUM,
Nicolai Copernici Prælatio in libros
Reuolutionum.



ATIS equidem, Sanctissime Pater, æ-
stimare possum, futurum esse, ut simul
atq; quidam acceperint, me hisce meis li-
bris, quos de Reuolutionibus sphærarū
mundi scripsi, terræ globo tribuere quos-
dam motus, statim me explodendum
cum tali opinione clamitent. Nec; enim
ita mihi mea placent, ut nō perpendam,
quid ali; de illis iudicaturi sint. Et quamuis sciam, hominis phi-
losophi cogitationes esse remotas à iudicio vulgi, propterea
quòd illius studium sit ueritatem omnibus in rebus, quatenus

As we noted earlier, he dedicated it to none other than the pope, pontificem maximum! Interestingly, Osiander and Petreius, although Lutherans, were not averse to including the dedication. Pope Paul III was known for his humanist interests, as Copernicus explained: “I have preferred dedicating these late-night studies to you, Your Holiness, rather than to anyone else. For even in this very remote corner of the Earth where I live you are considered the highest authority by virtue of your exalted office and your love for all literature, even astronomy.” Copernicus, Preface. Danielson, 107.

Some of the works of Paul’s astronomer, Luca Guarico, were published by Petreius.



In the dedication, Copernicus noted that while some theologians might mistakenly regard his system as contrary to the Bible, his arguments rested on mathematics, and those with no expertise in mathematics should not rush to judge: "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 criticize and censure my teaching. I shall not waste time on them; I have only contempt for their unfounded criticism.... Astronomy is written for astronomers." Copernicus, Preface. Danielson, 107.



Revolutionaries in every age cite ancient precedents for their own novel claims. This tactic appealed to the heart and soul of Renaissance humanism.

Ad fontes

Philolaos of Kroton

Herakleides of Pontos

Aristarchos of Samos

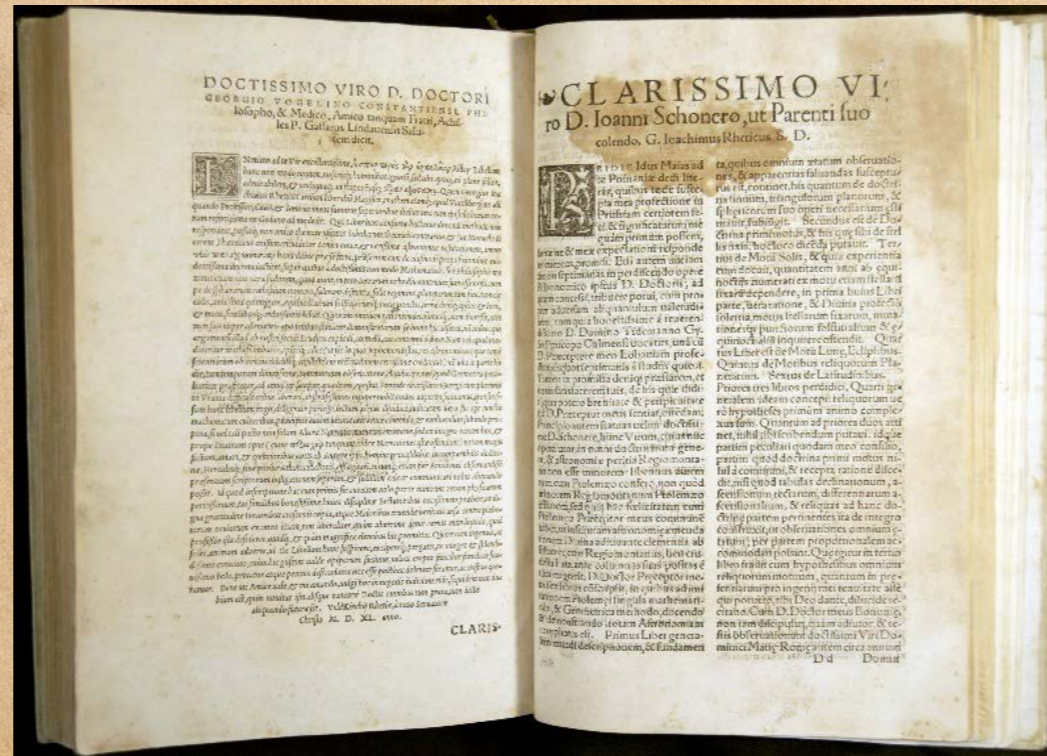
With regard to scholarship, humanism stood for the principle of “ad fontes,” to the sources, a return to ancient texts.

- In his papal dedication, Copernicus justified his novel claims by citing ancient advocates of the motion of the Earth including Philolaos the Pythagorean, Herakleides and Aristarchos, stipulating that “Therefore, having obtained the opportunity from these sources, I too began to consider the mobility of the Earth.”

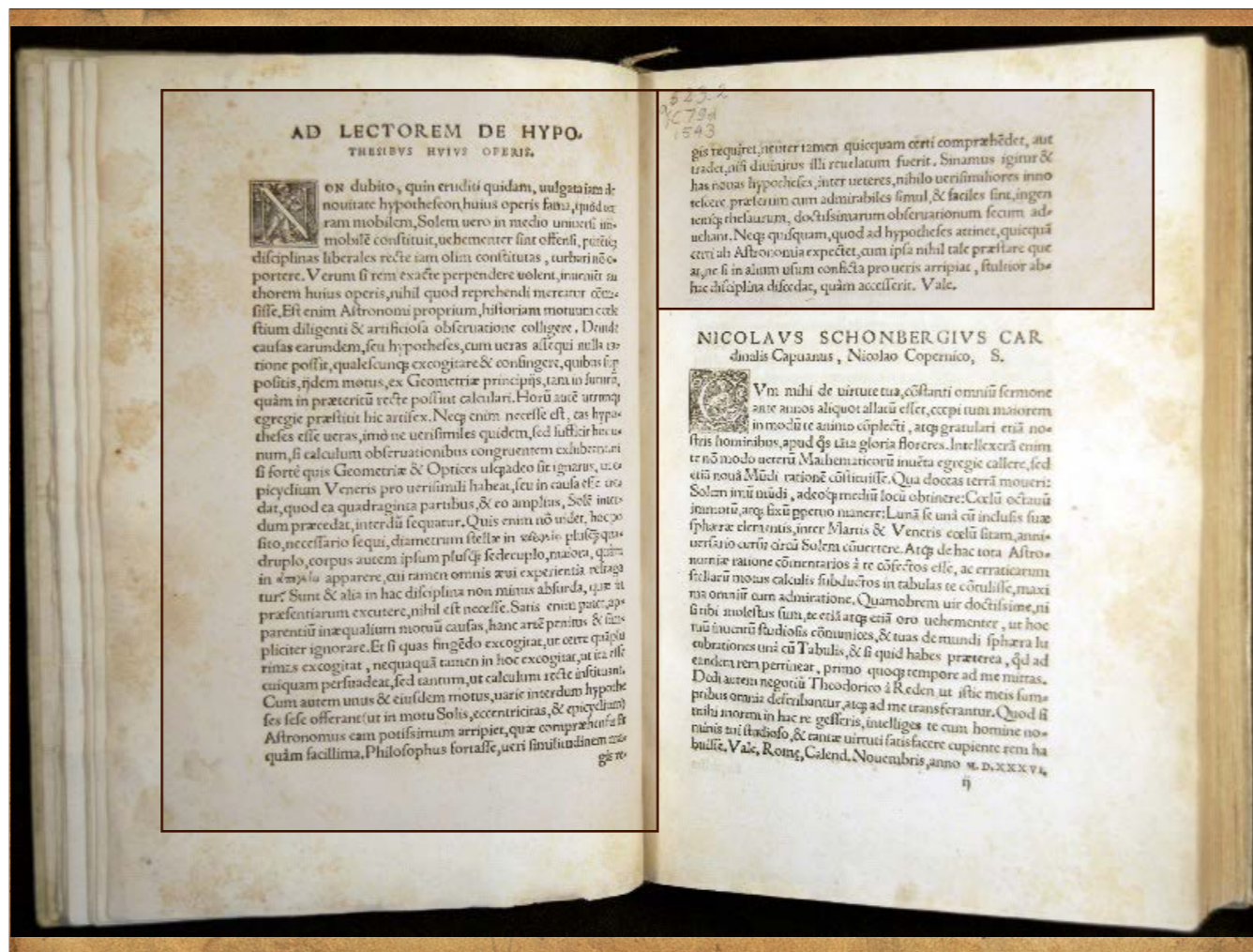


On May 24, 1543, Copernicus died. It is said that on his deathbed he awakened from a coma long enough to recognize proof pages for the work, now in press after so many long years of preparation.

Where is Rheticus?



Consider the contributions of Rheticus: Rheticus encouraged Copernicus to complete the great work, and he edited the manuscript before handing it off to Osiander in Nuremberg. With the Narratio prima, Rheticus awakened widespread interest in its imminent publication. However, despite the crucial roles Rheticus played in bringing the project to completion, the first edition of Copernicus' book nowhere mentions Rheticus by name, unless you happen to have a copy bound with the 1566 narratio prima. To offer deference to the Roman Catholic Church, the front matter only mentions Catholic supporters such as Cardinal Schönberg as well as the papal dedication.

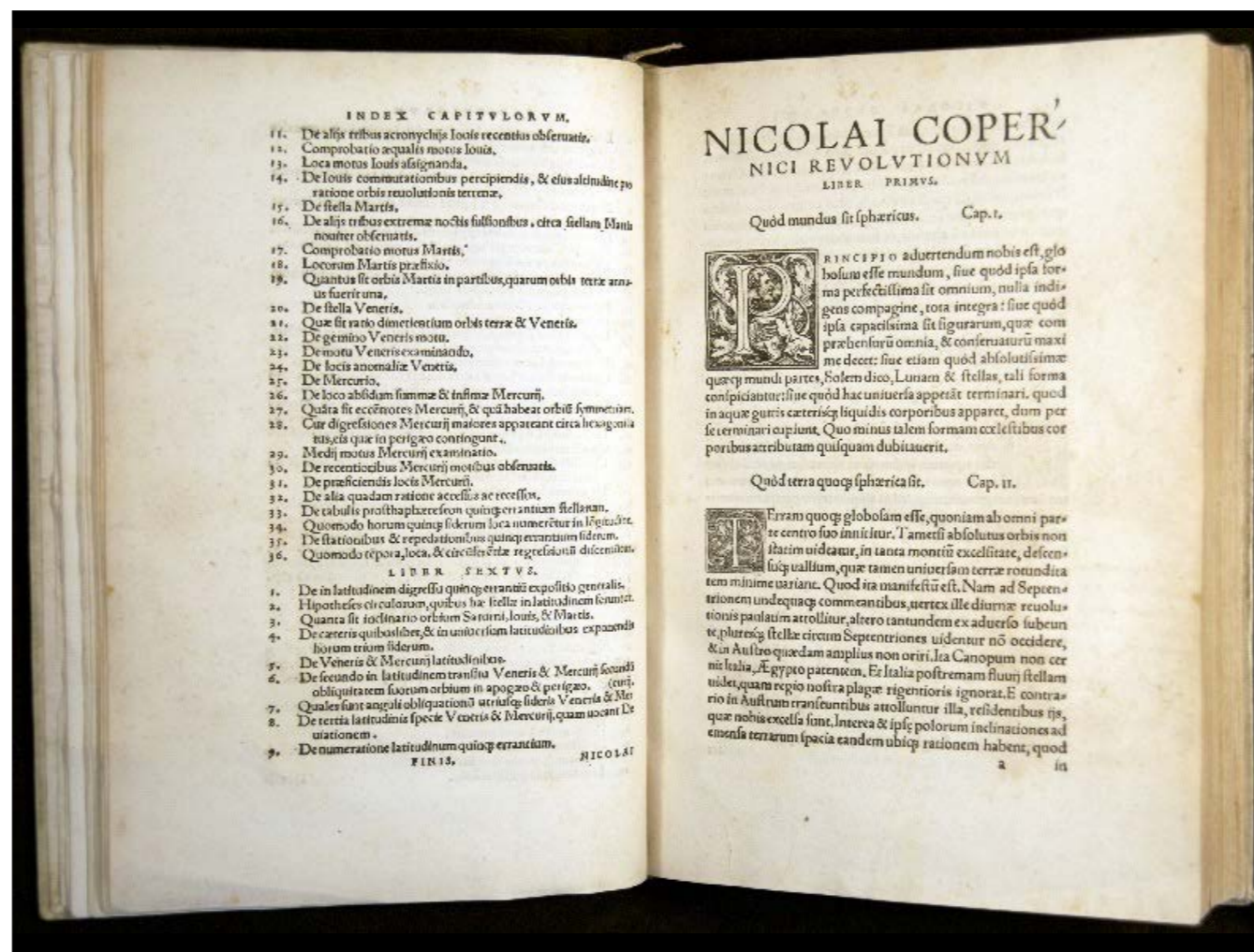


Actually, we skipped over another sign of religious deference found on the very first two pages of the front matter. Andreas Osiander, the final editor in Nuremberg, inserted an anonymous foreword before the letter from Cardinal Schönberg.

AD LECTOREM DE HYPO-
THESIS HVIVS OPERIS.

NON dubito, quin eruditi quidam, uulgata iam de nouitate hypotheseon huius operis fama, quod terram mobilem, Solem uero in medio uniuersi immobile constituit, uehementer sint offensi, putetque disciplinas liberales recte iam olim constitutas, turbari non oportere. Verum si rem exacte perpendere uolent, inueniet auctorem huius operis, nihil quod reprehendi mereatur commississe. Est enim Astronomi proprium, historiam motuum coelestium diligenti & artificiosa obseruatione colligere. Deinde causas earundem, seu hypotheses, cum ueras assequi nulla ratione possit, qualescunque excogitare & confingere, quibus suppositis, eodem motus, ex Geometriæ principijs, tam in futurum, quam in præteritum recte possint calculari. Horum autem utrumque

In this anonymous letter “to the reader, on the hypotheses of this work,” Osiander noted that mathematical works were often regarded as hypothetical, because one may “save the phenomena” with successful predictions using various mathematical models, even with false ones. To ward off controversy, Osiander praised Copernicus not for discovering true causes, not for discovering the physical truth of the universe, but merely for providing calculations that more accurately “save the phenomena.” From a tactical viewpoint Osiander’s letter successfully neutralized the potential for religious controversy, particularly in the Lutheran universities where the *De rev* indeed became attentively studied. Indeed, Osiander’s approach to the *De rev* is now known as the “Wittenberg Interpretation” due to the many Lutheran professors at the University of Wittenberg who adopted it. However, Osiander inserted this preface on his own initiative, without Copernicus’ knowledge, and Rheticus was outraged that Copernicus’ claims for his system were misrepresented.



That concludes the front matter; now let's turn to the body of the work.



Let's take a closer look at the Copernican System.

NICOLAI COPERNICI
REVOLUTIONVM
LIBER PRIMVS.

Quòd mundus sit sphæricus.

Cap. i.



INCIPIO aduertendum nobis est, globum esse mundum, siue quòd ipsa forma perfectissima sit omnium, nulla indigens compagine, tota integra: siue quòd ipsa capacissima sit figurarum, quæ comprehensurū omnia, & conseruaturū maxime decet: siue etiam quòd absolutissimæ quæcūq; mundi partes, Solem dico, Lunam & stellas, tali forma conspiciantur: siue quòd hac uniuersa appetāt terminari, quod in aquæ guttis cæterisque liquidis corporibus apparet, dum per se terminari cupiunt. Quo minus talem formam cœlestibus corporibus attributam quisquam dubitauerit.

Quòd terra quoque sphærica sit.

Cap. ii.

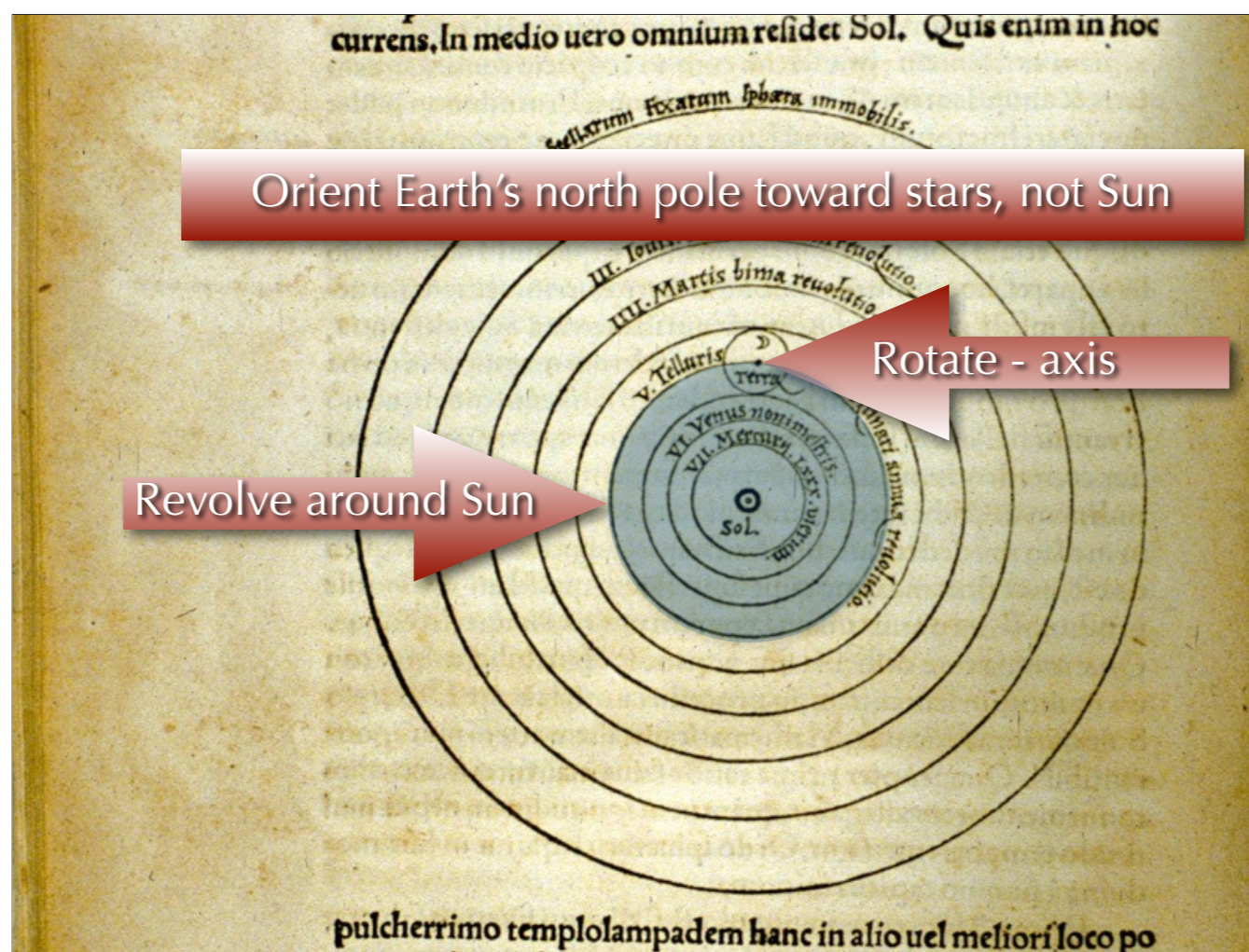


Erram quoque globosam esse, quoniam ab omni parte centro suo innititur. Tametsi absolutus orbis non

In Book I Copernicus laid out his basic assumptions, including that the universe is spherical and that the Earth is spherical. Ptolemy began the Almagest in the same way. Copernicus follows the organizational scheme of the Almagest.



Although the Almagest established the template, Copernicus departed from Ptolemy in Chapter 10 by switching the positions of the Sun and the Earth. To do this, Copernicus had to attribute three different kinds of motion to the Earth.



First, the Earth rotates around its axis once each day. □ Second, it revolves in orbit around the Sun once each year. □ Because Copernicus accepted the reality of the solid spheres, he had to postulate a third motion of the Earth's axis (not needed today), to orient the north pole toward the stars instead of the Sun.

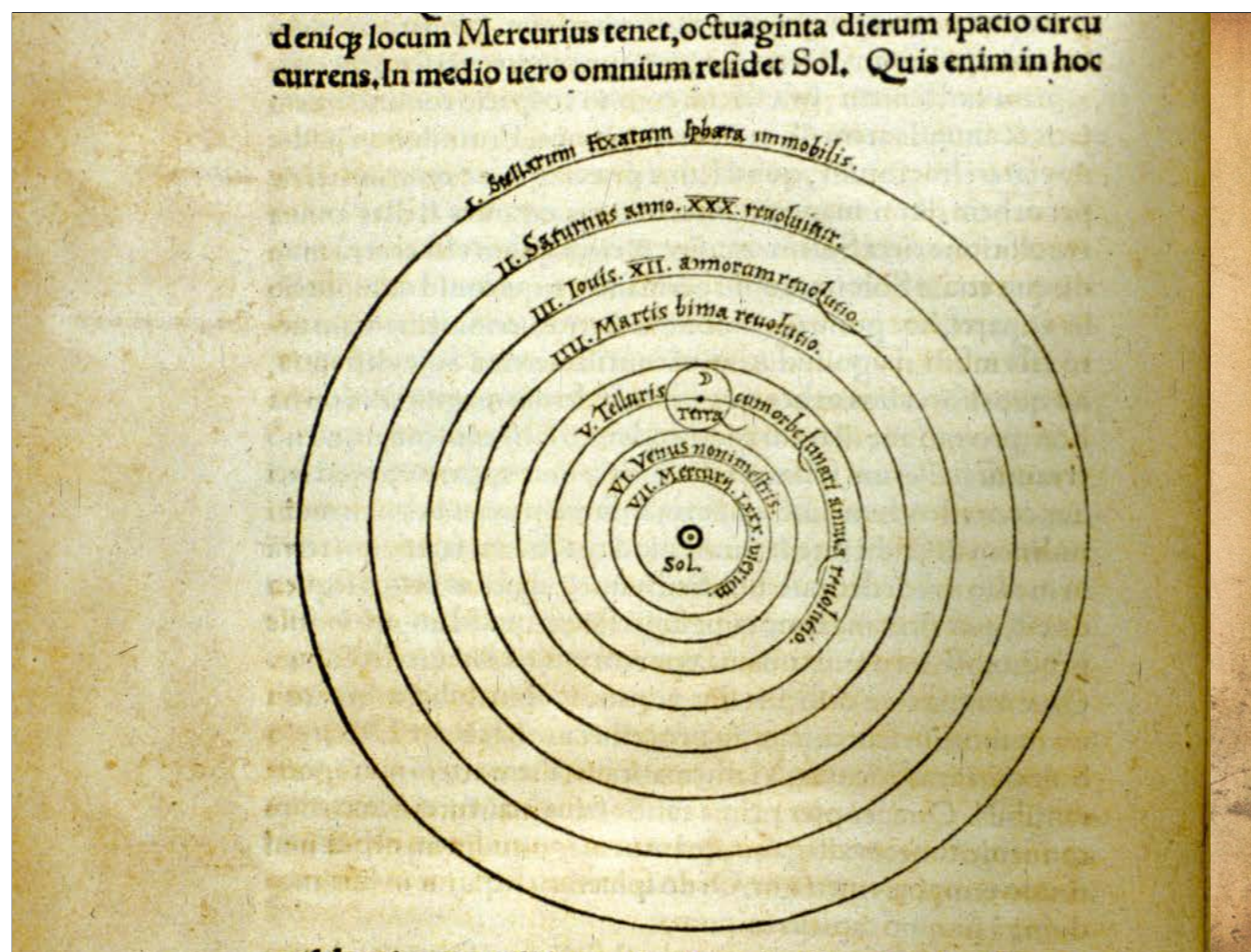
ſpectatur, ut demonſtratur in Opticis. Quòd enim à ſupremo errantium Saturno ad fixarum ſphæram adhuc plurimum interſit, ſcintillantia illorum lumina demõſtrant. Quo indicio maxime diſcernuntur à planetis, quodq; inter mota & non mota, maximam oportebat eſſe differentiam. Tanta nimirum eſt diuina hæc Opt. Max. fabrica.

De triplici motu telluris, et eius demonstratione.
De triplici motu telluris demonſtratio. Cap. xi.



Um igitur mobilitati terre tot tantaq; errantium ſyderum conſentiant teſtimonia, iam iplum motum in ſumma exponemus, quatenus apparentia per ipſum tanquã hypoteſim demonſtrentur, quẽ triplicẽ omnino oportet admittere. Primum quem diximus *παραμυρσινον* 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

In the following chapter, Copernicus deſcribed theſe three motions. Chapter 11 is titled: “demonſtration of the triple motion of the Earth.”



The ancient texts may have provided an opportunity to consider the possibility of a heliocentric system, but what compelled Copernicus actually to adopt this almost universally rejected theory?



The answer is NOT observations. Contrary to widely shared misconceptions on this point, Copernican scholars now agree that the tradition of Ptolemaic astronomy was neither overly complex nor inaccurate. There was no sudden crisis in astronomy, but rather an ongoing reformation from the medieval Islamicate critique of Ptolemy to the new foundation laid by Regiomontanus. Consider three facts:



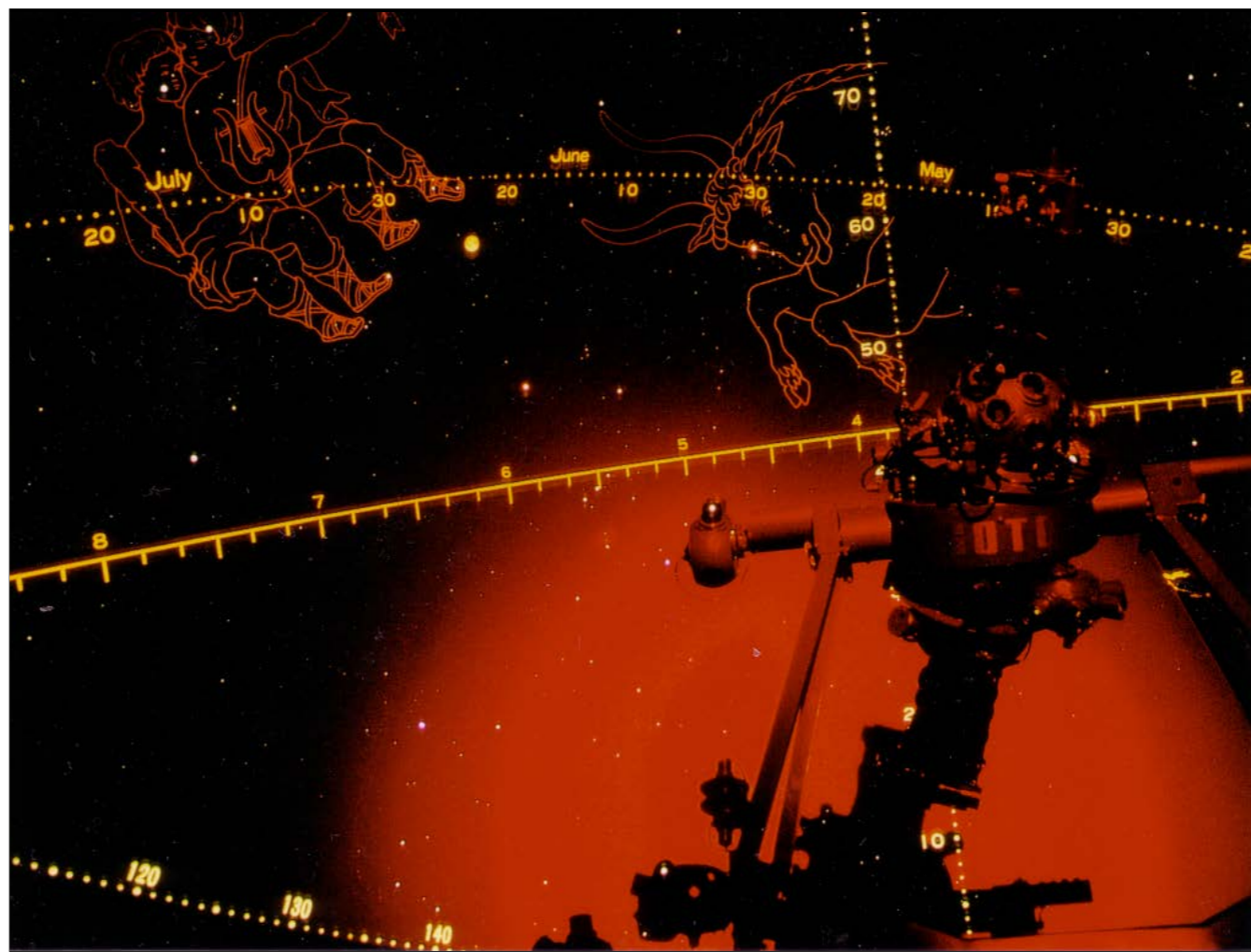
First, Copernicus used about the same total number of circles as Ptolemy.



Second, the 16th century tables based on the Copernican system were not much more accurate than the Ptolemaic tables they replaced.

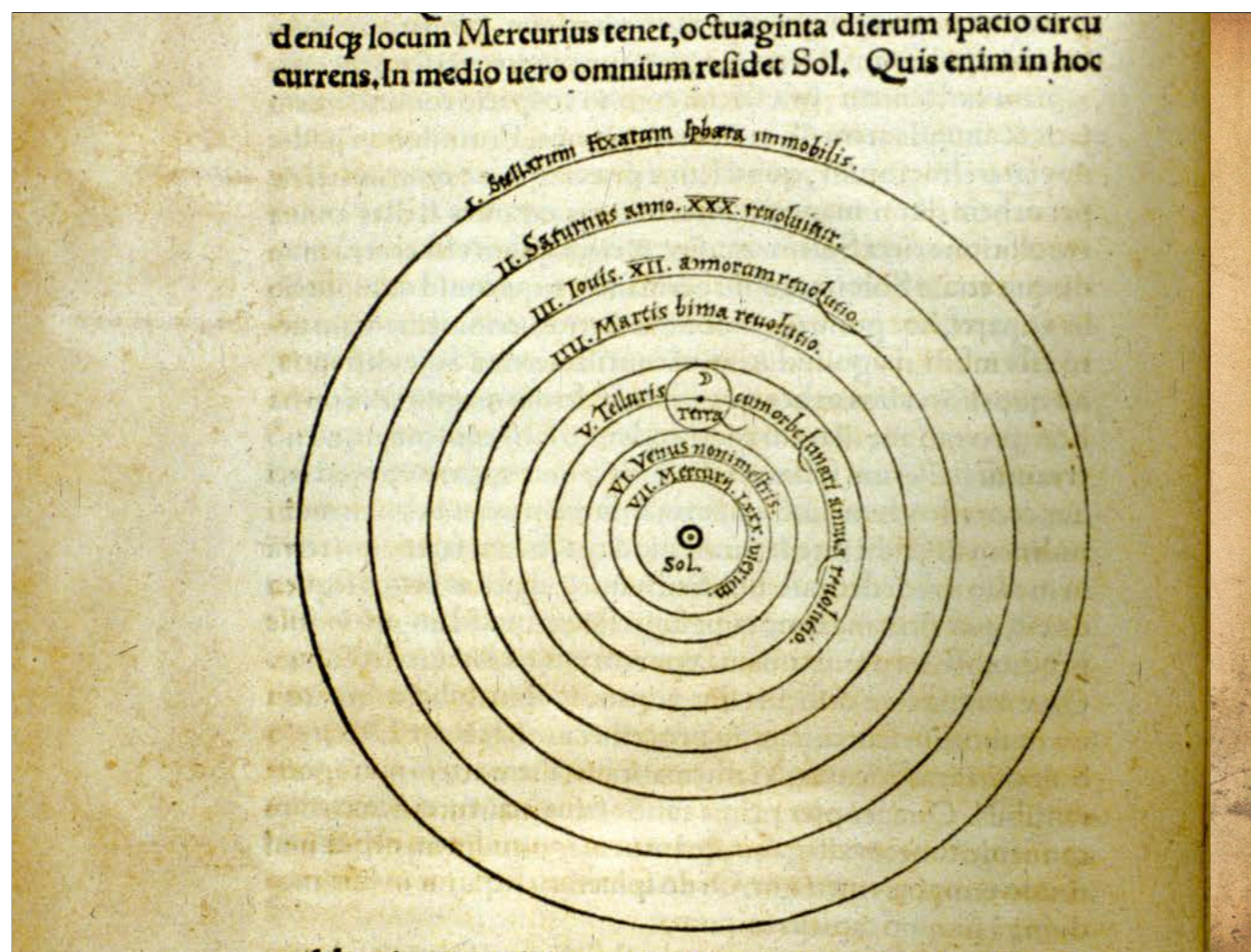


And third, in theory, a geocentric system may be updated to yield accurate predictions for any epoch.



Just this kind of updating is actually performed by engineers of planetarium equipment. A mechanical-optical star projector such as this one (in a university planetarium I once directed) accurately projects the positions of the planets using an observer-centered system. I remember as we assembled this instrument how amazed I was to see etched into the gears and moving parts of the star projector the familiar devices of earth-centered astronomical systems, updated for the 20th century.

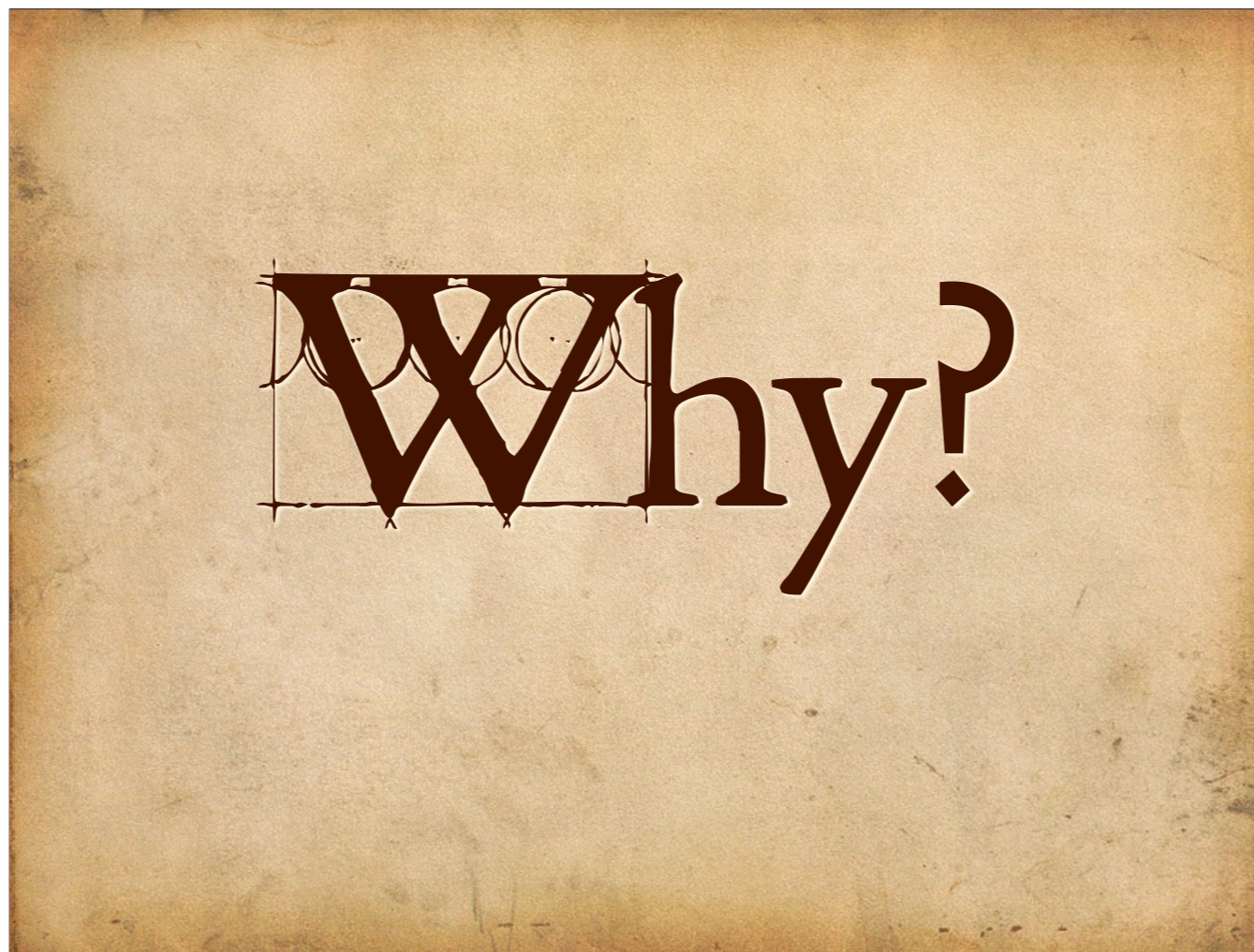
The OBU Planetarium, photograph by Bill Pope.



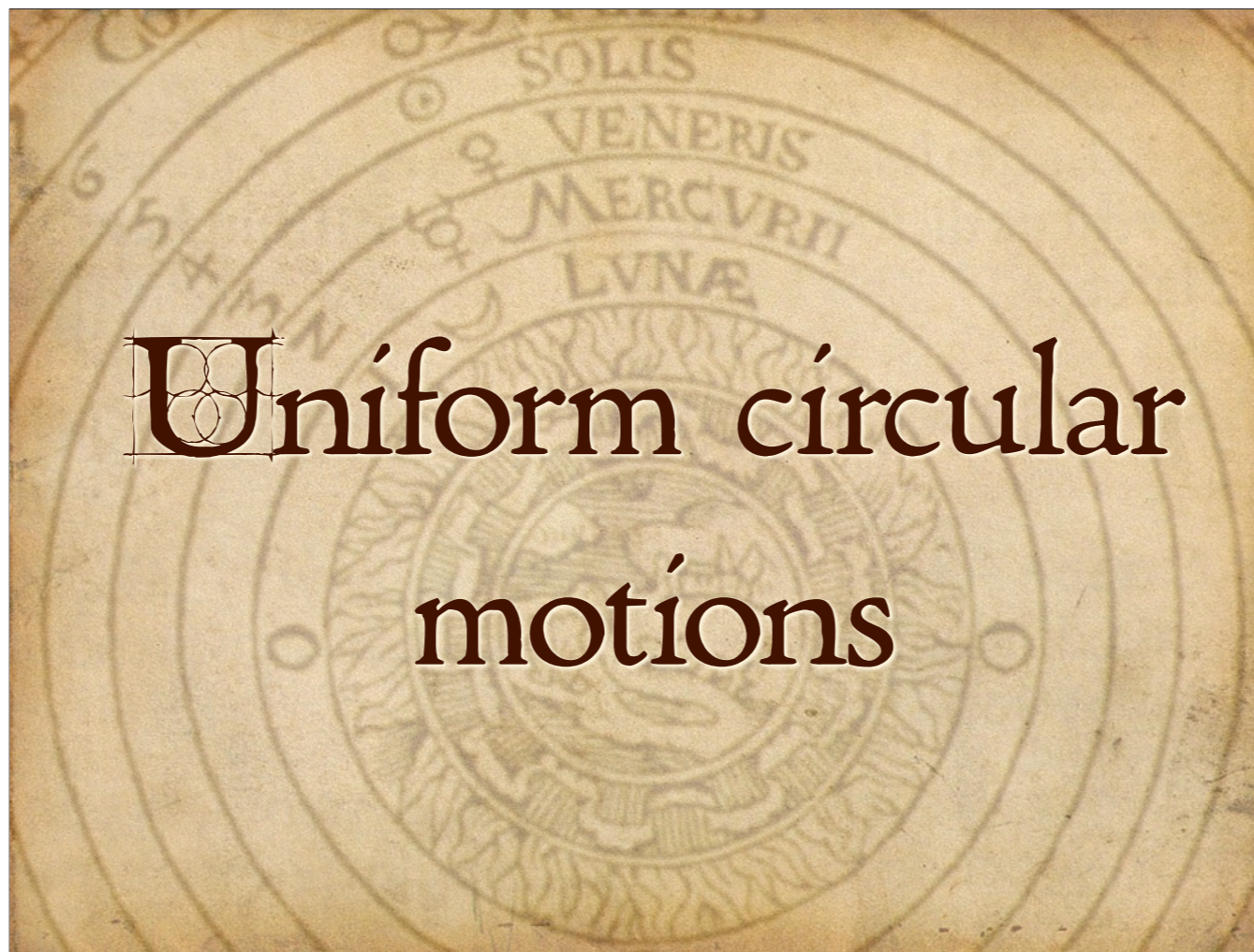
So, simplicity and accuracy do not explain why Copernicus rejected an Earth-centered system. When he conceived the heliocentric cosmos, Copernicus' aim was not to surpass the explanatory power of Ptolemy, but merely to equal it. Kepler dryly noted that Copernicus "represented Ptolemy rather than Nature." Observations did not compel Copernicus to hurl the Earth into the heavens or switch the Sun into the center.



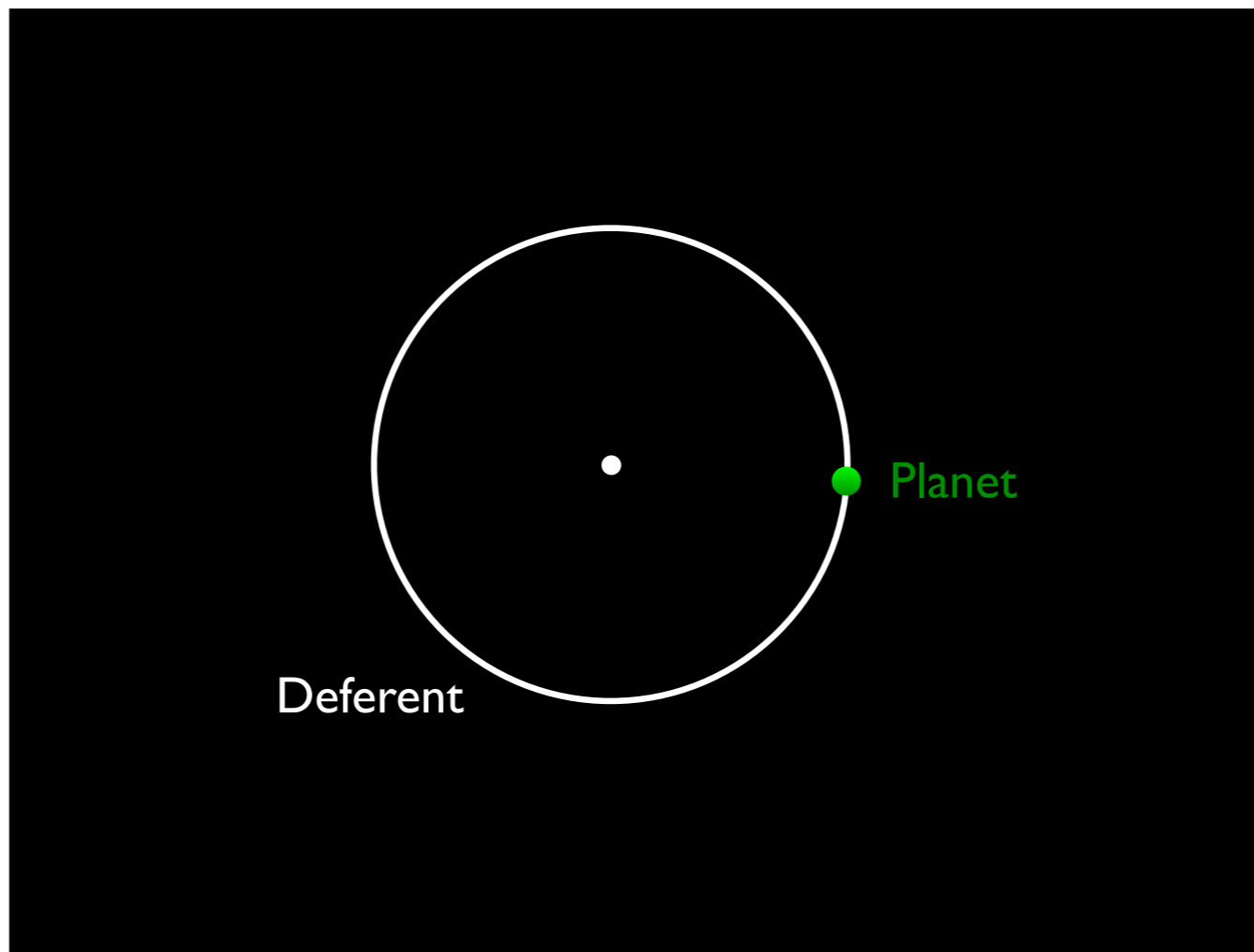
Yet observations were important to Copernicus. To make his case as compelling as possible, Copernicus devoted most of his adult life to a thorough re-determination of the numerical parameters used in the models. This ambition, rather than fear of the Church, explains the *De rev.*'s long-delayed publication. If he could pull it off, this remarkable feat would make his system the basis for future work in mathematical astronomy. Copernicus would become nothing less than the Ptolemy of his time. He would complete the reformation of astronomy called for by Regiomontanus.



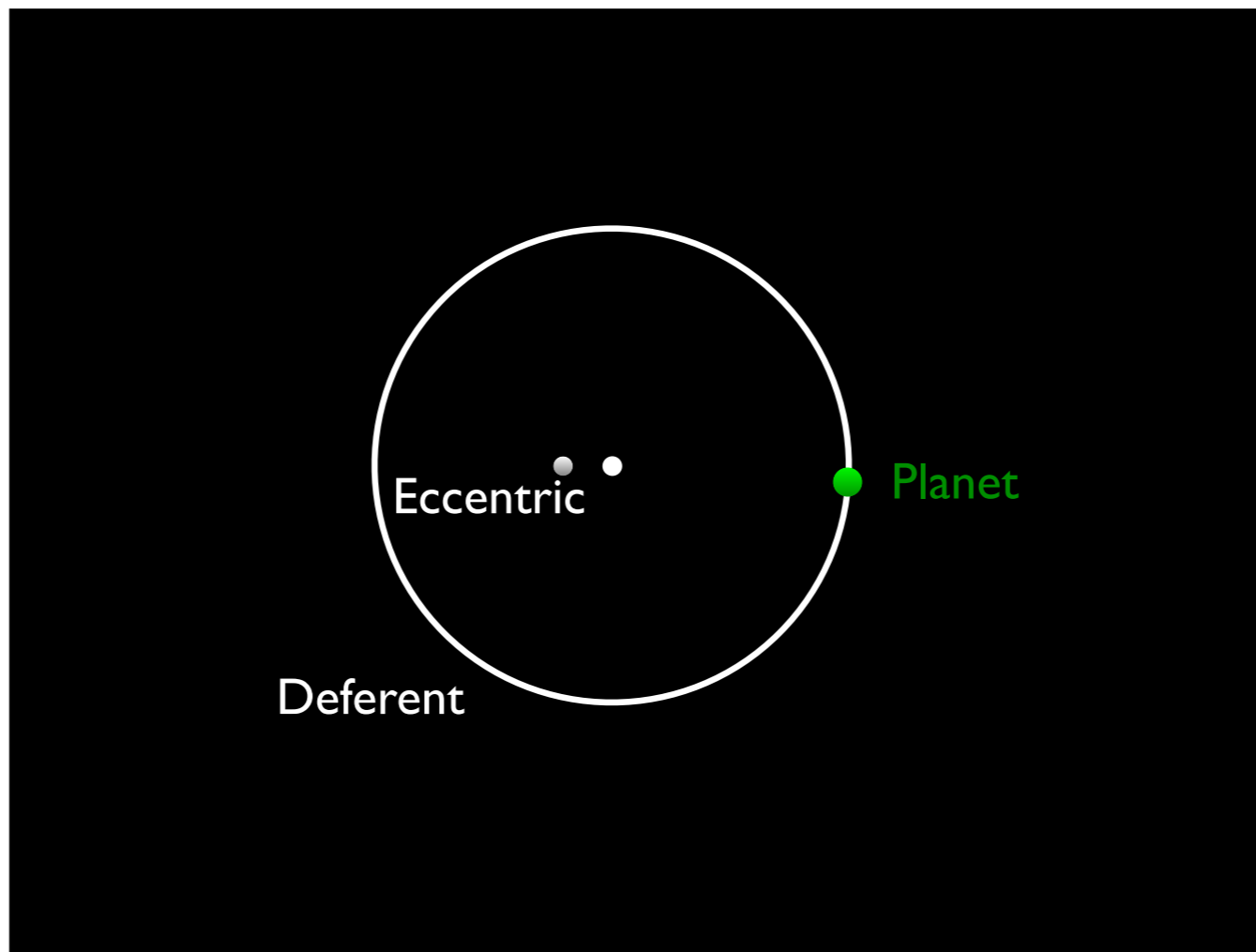
(Pause) Why, then, did Copernicus choose a Sun-centered theory as the foundation for his reform of astronomy? To answer this question, we need to appreciate an innovative tradition in astronomy that began several hundred years prior to Copernicus.



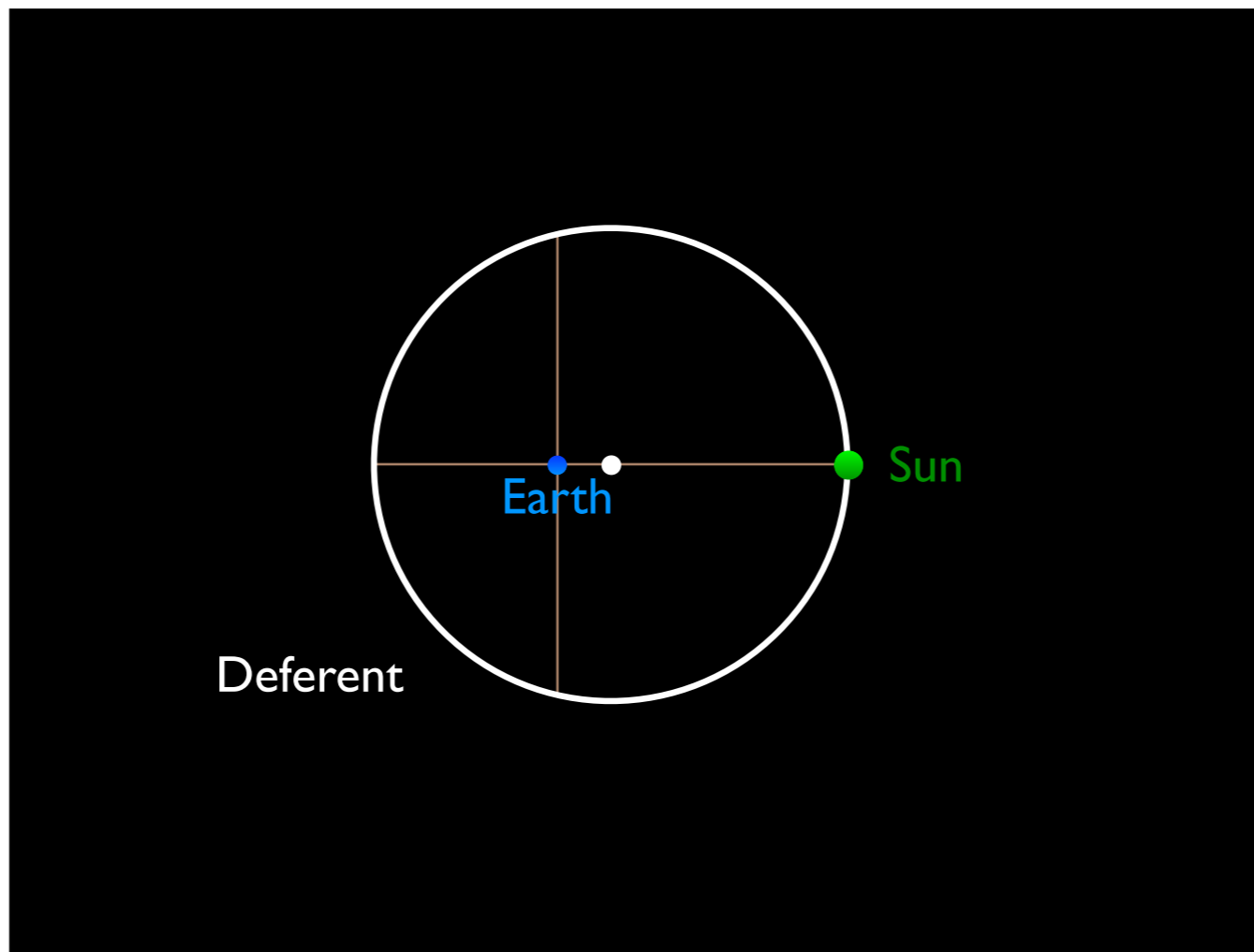
Let's start even farther back. Ever since Plato, ancient astronomers assumed that planets move with combinations of uniform circular motions.



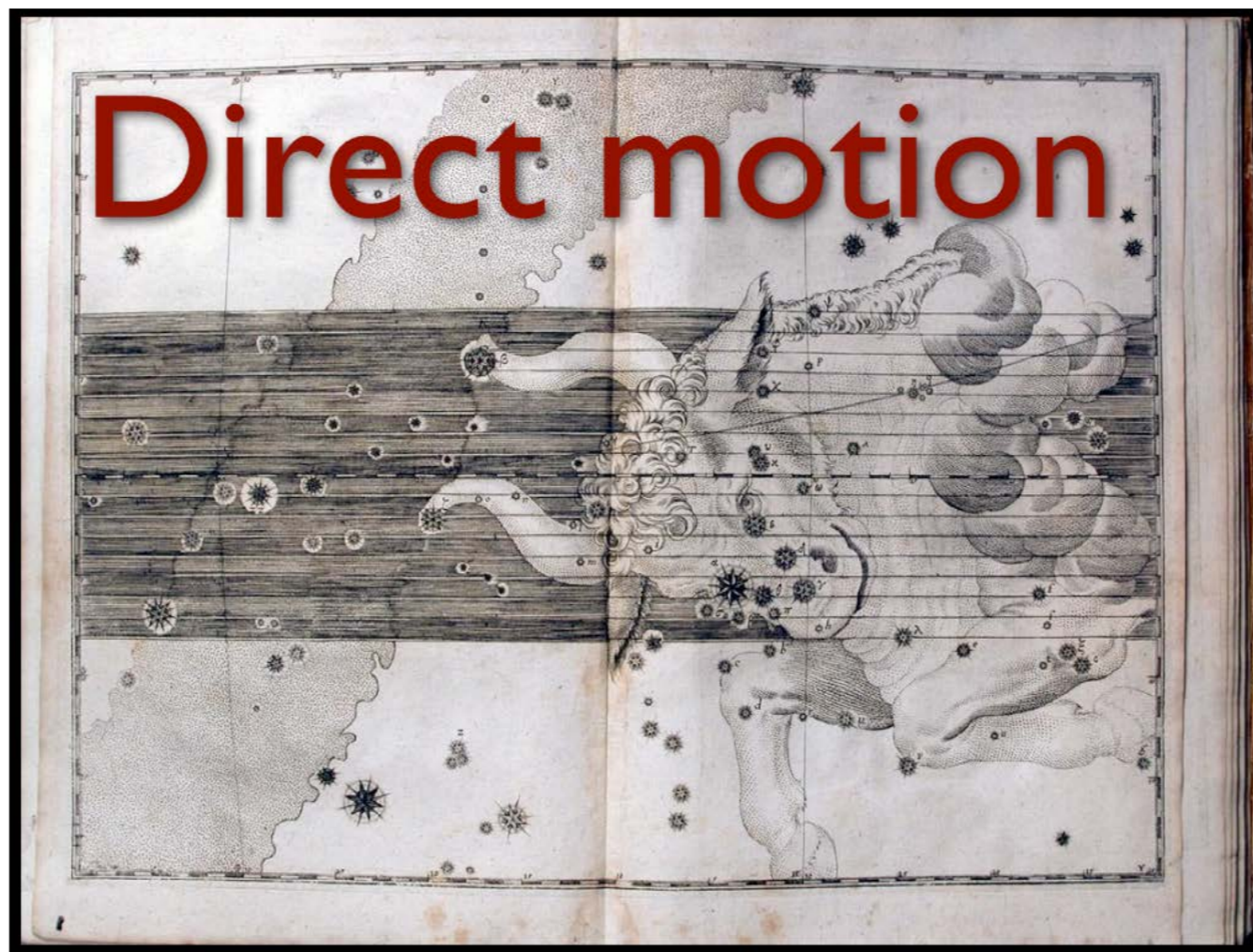
For example, one model might show a planet or even the Sun moving at a constant speed on a large circle, called the deferent.



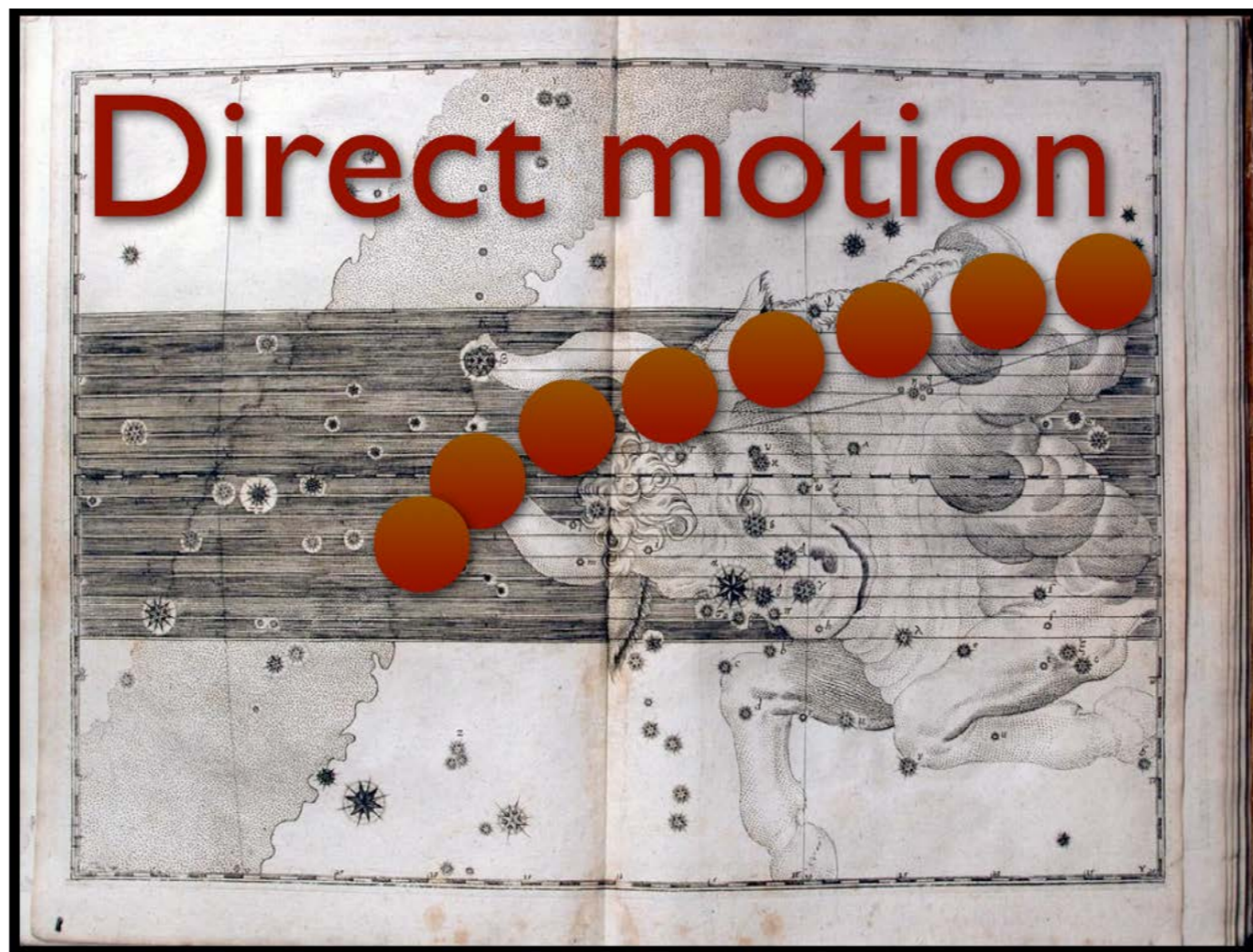
If the Earth is placed just off-center or eccentric to the deferent,



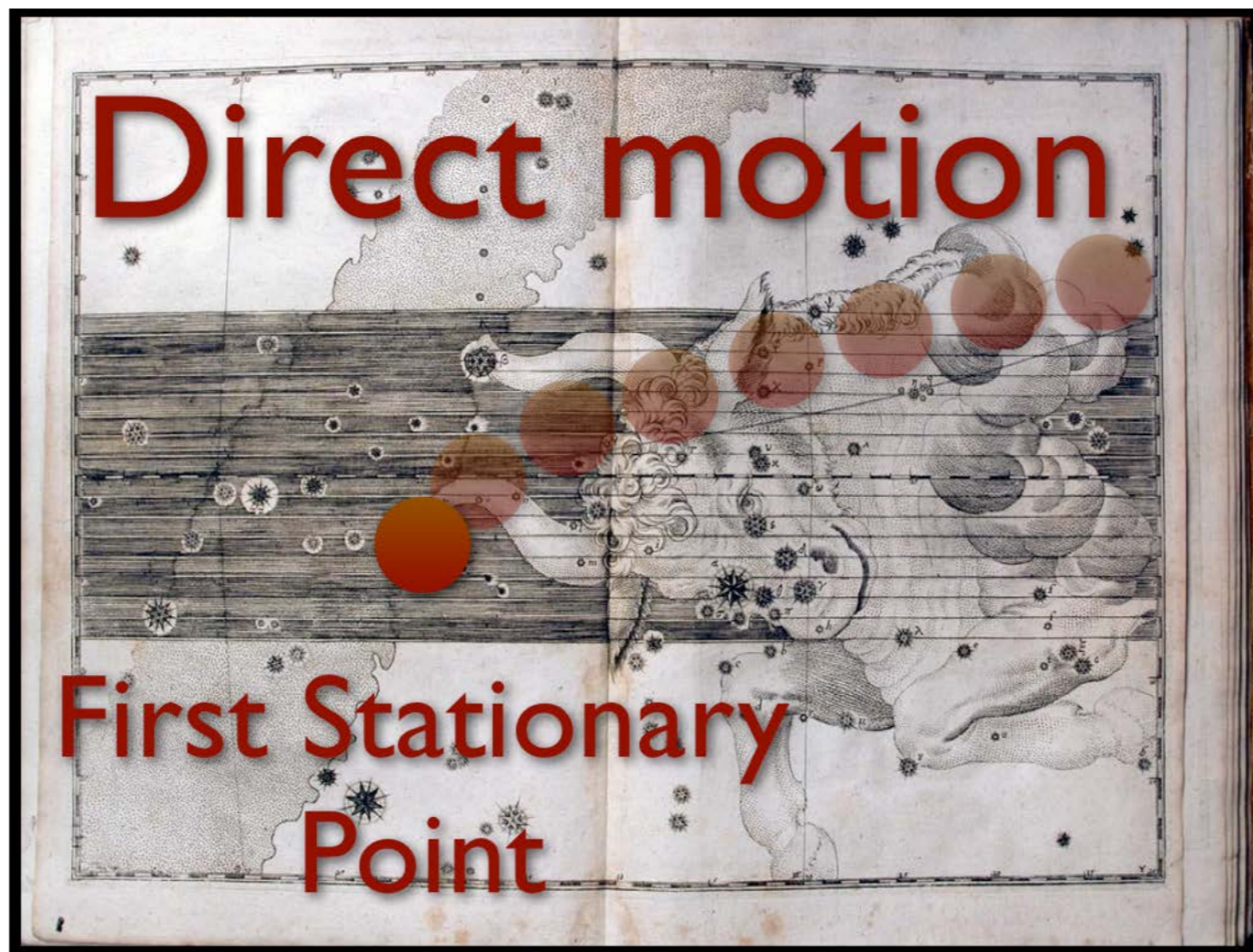
then this kind of eccentric model can account for the unequal lengths of the seasons. The Sun moves on the deferent with constant speed around the center, but as seen from the eccentric Earth, its motion does not appear uniform. This model explains the different lengths of the seasons.



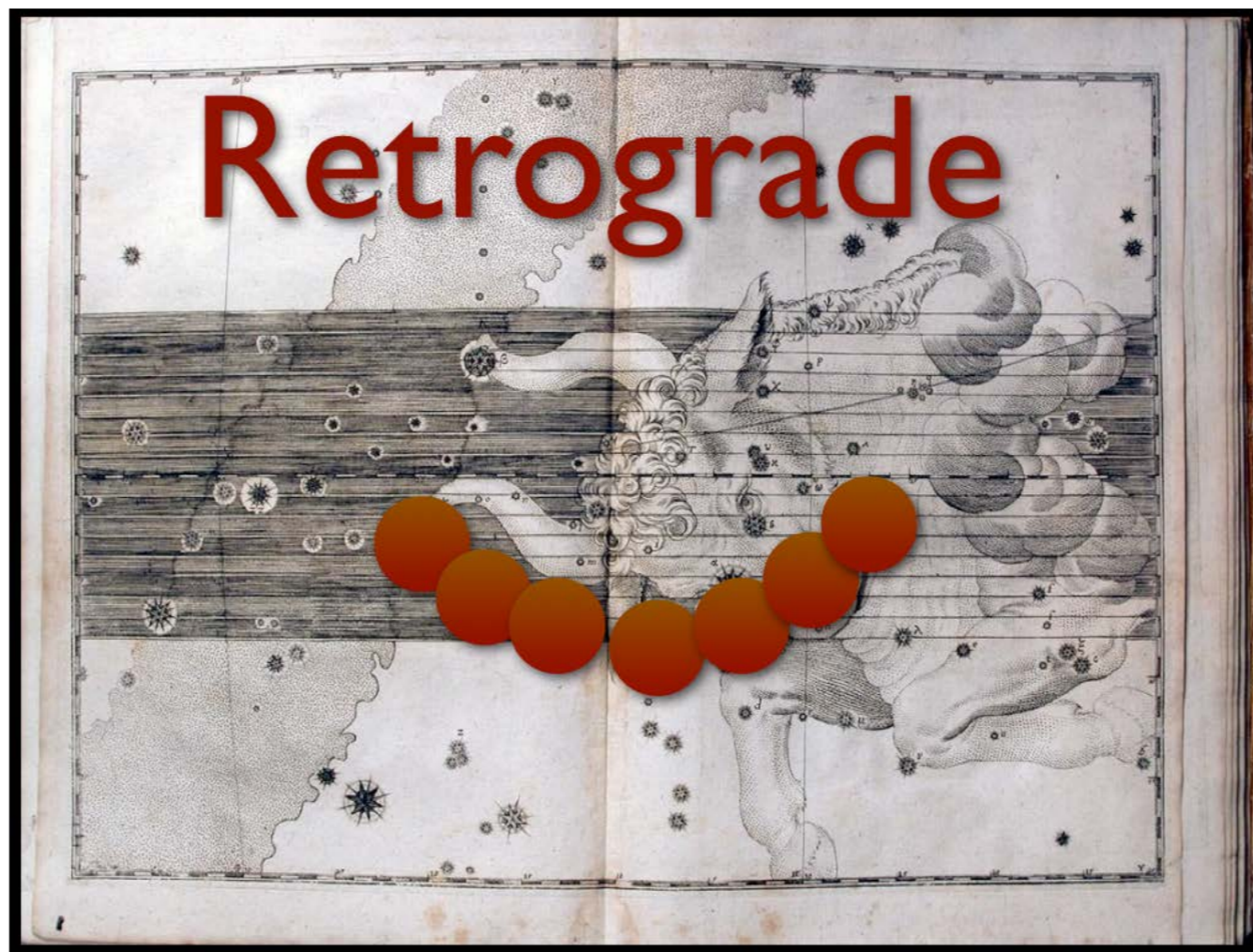
Outer planets such as Mars pose another kind of problem, because at times they appear to move in loops.



From night to night, an outer planet usually moves roughly eastward against the background of fixed stars.



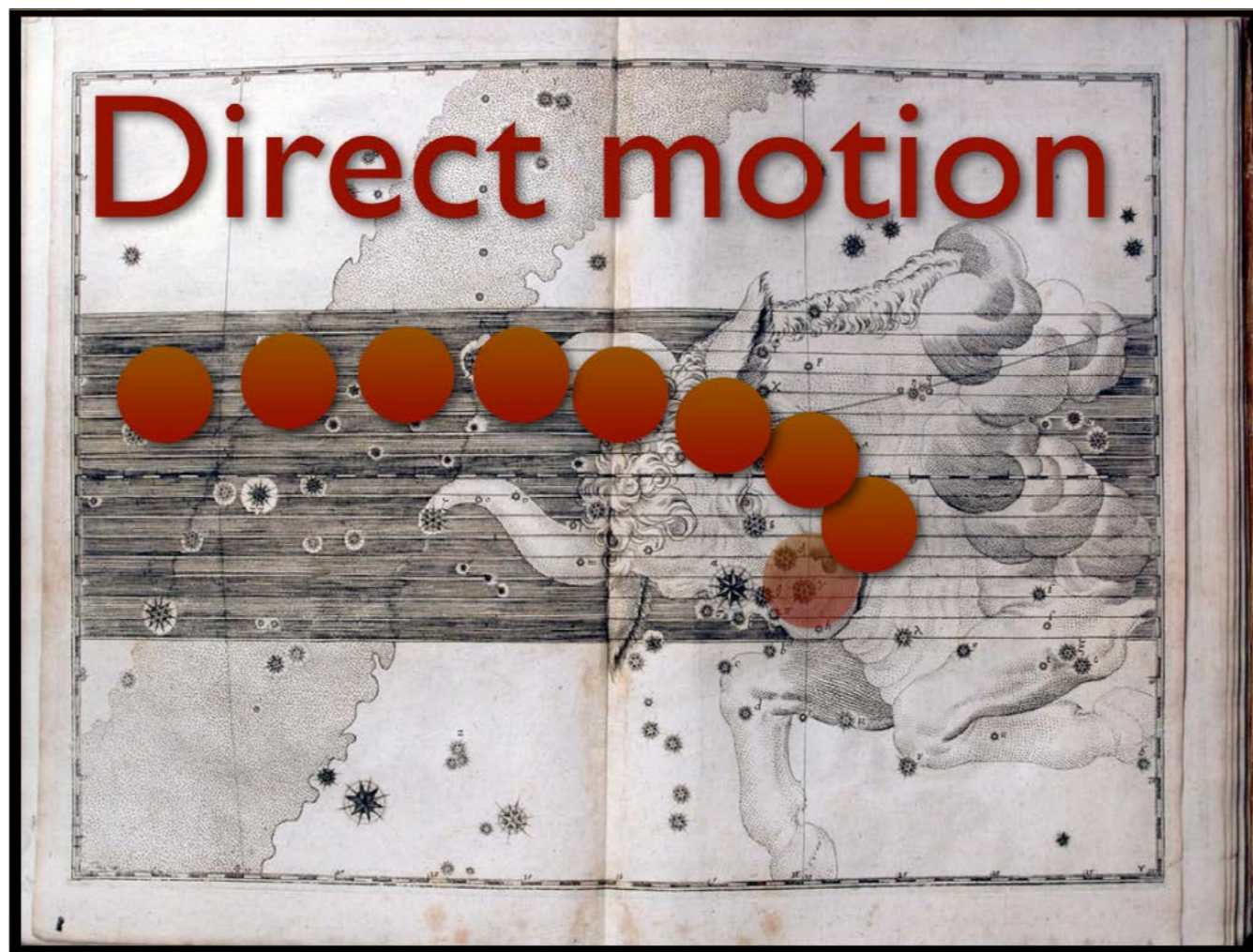
But sometimes it stops, rising several nights in a row near the same star.



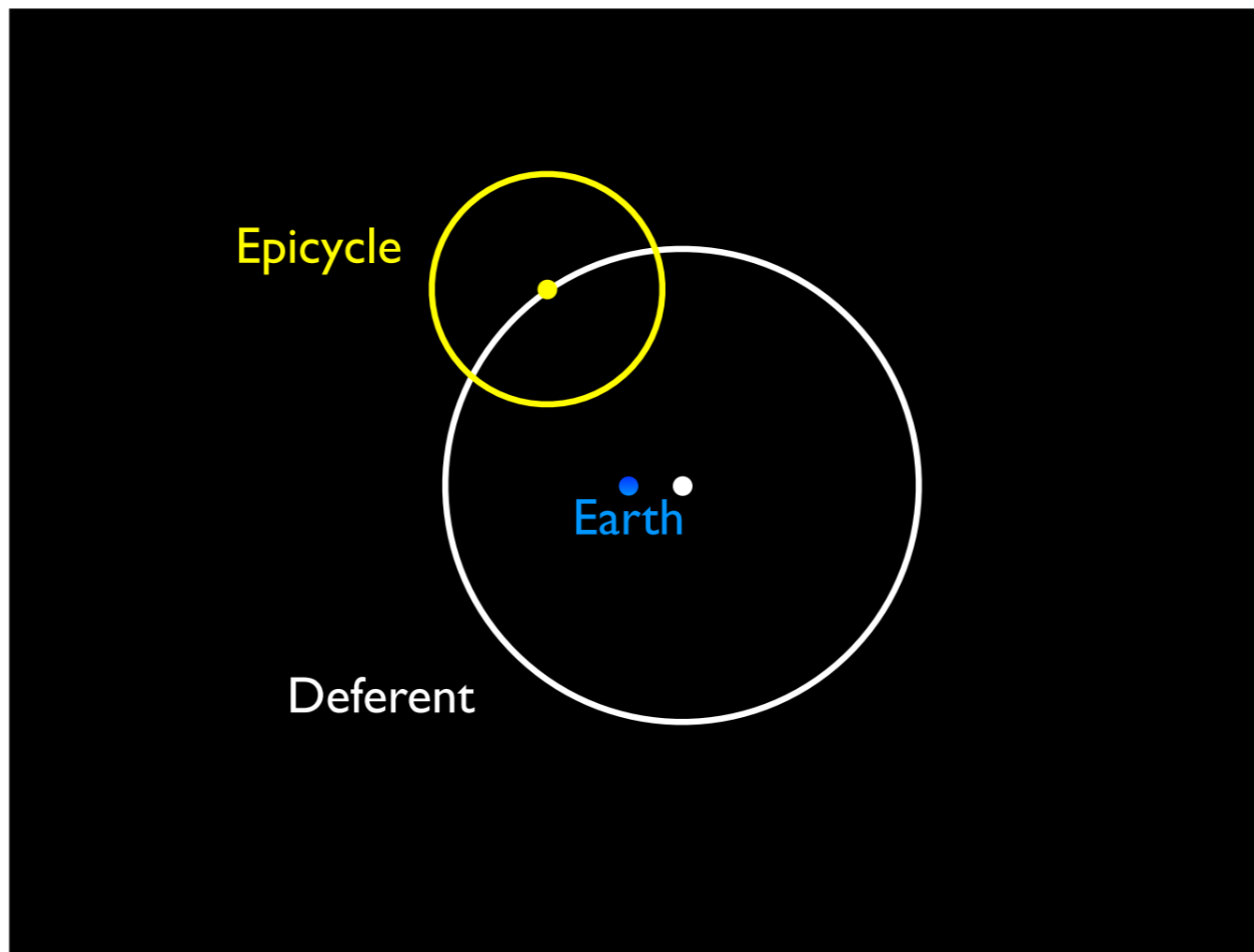
Then it moves backwards, reversing its path in the sky. Mysteriously, the planet appears much brighter during this backward or retrograde motion.



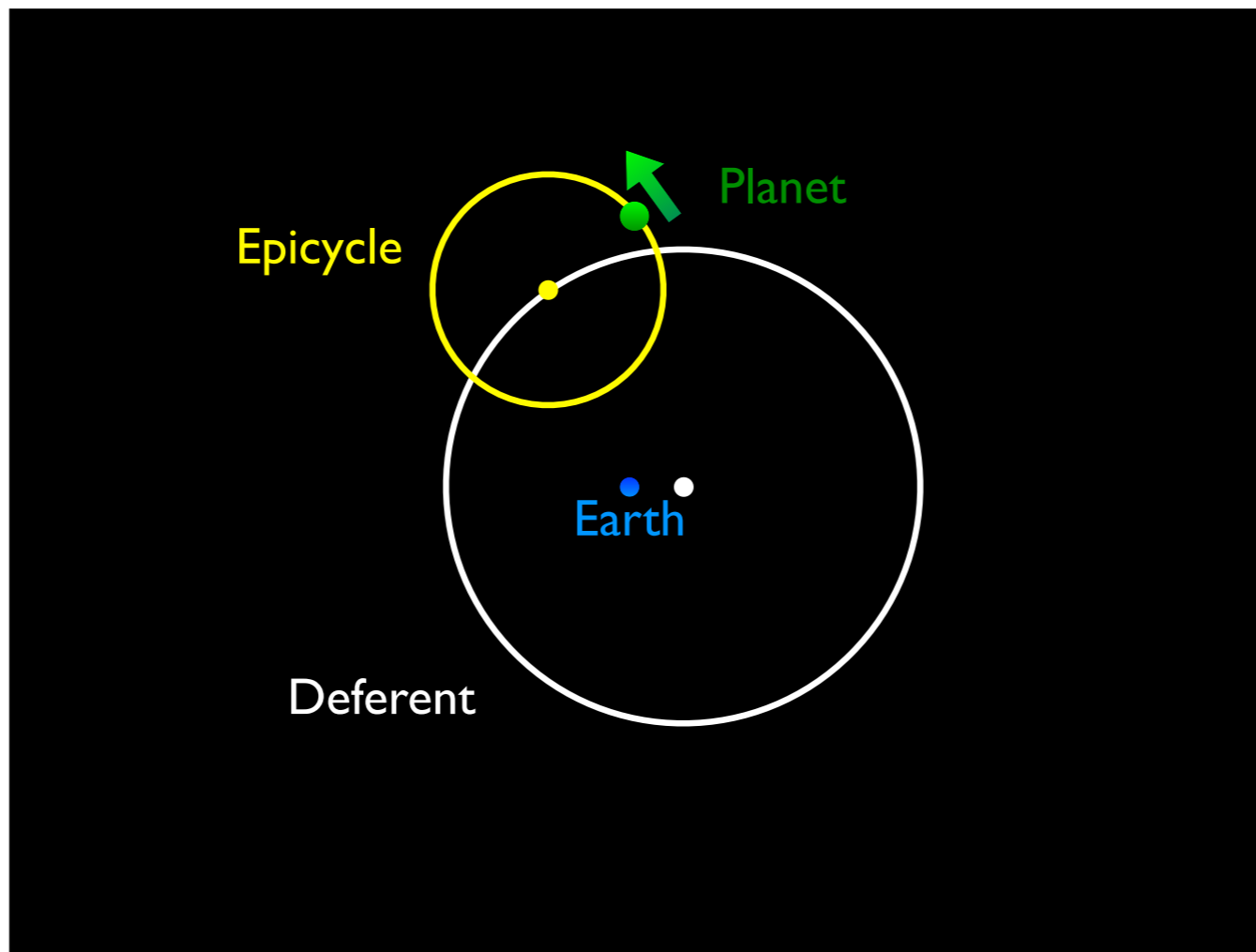
Eventually, the planet comes to another halt,



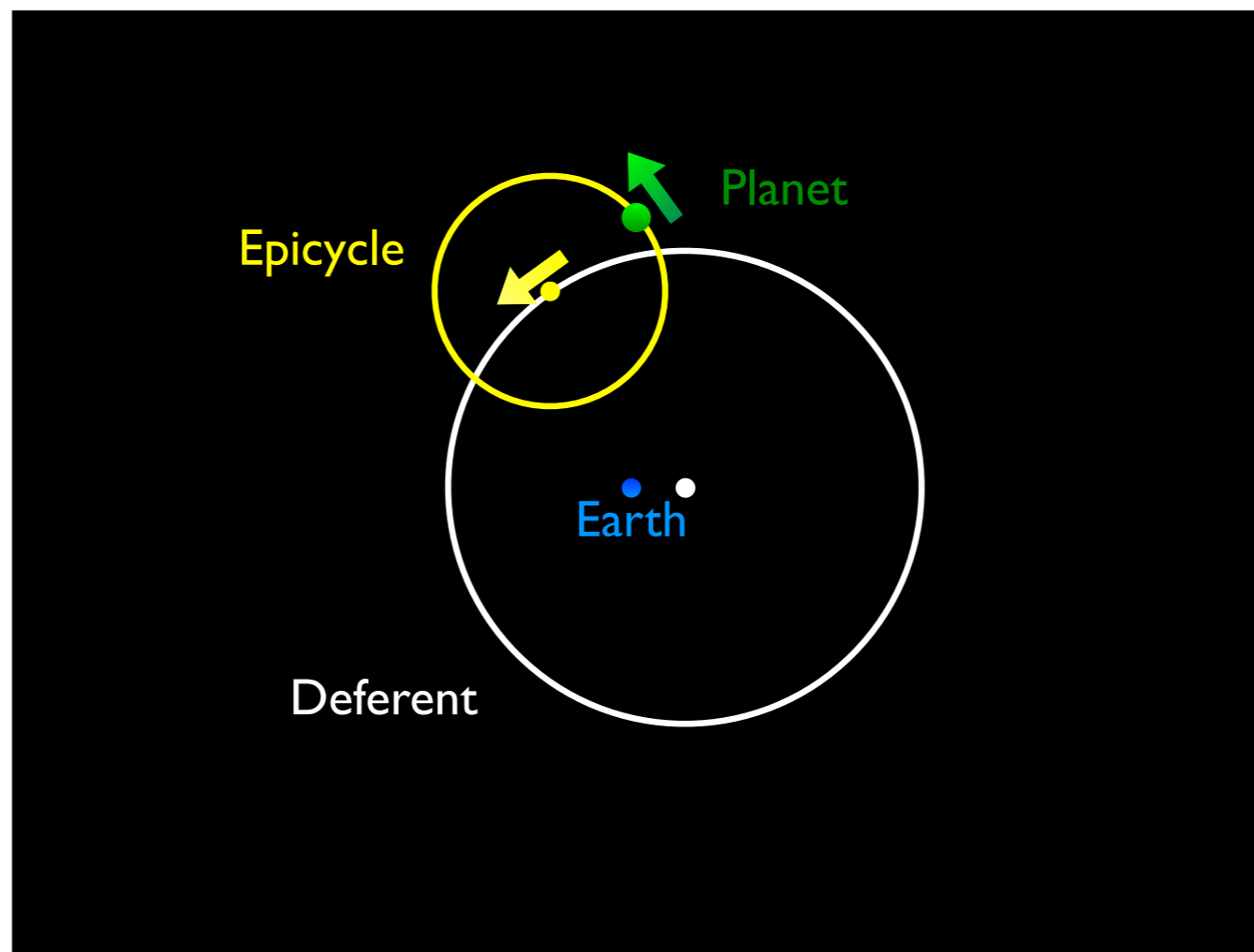
after which it resumes its ordinary eastward motion. Eccentric models alone do not explain these retrograde loops of the planets, nor do they explain why planets are brightest when they are retrograding.



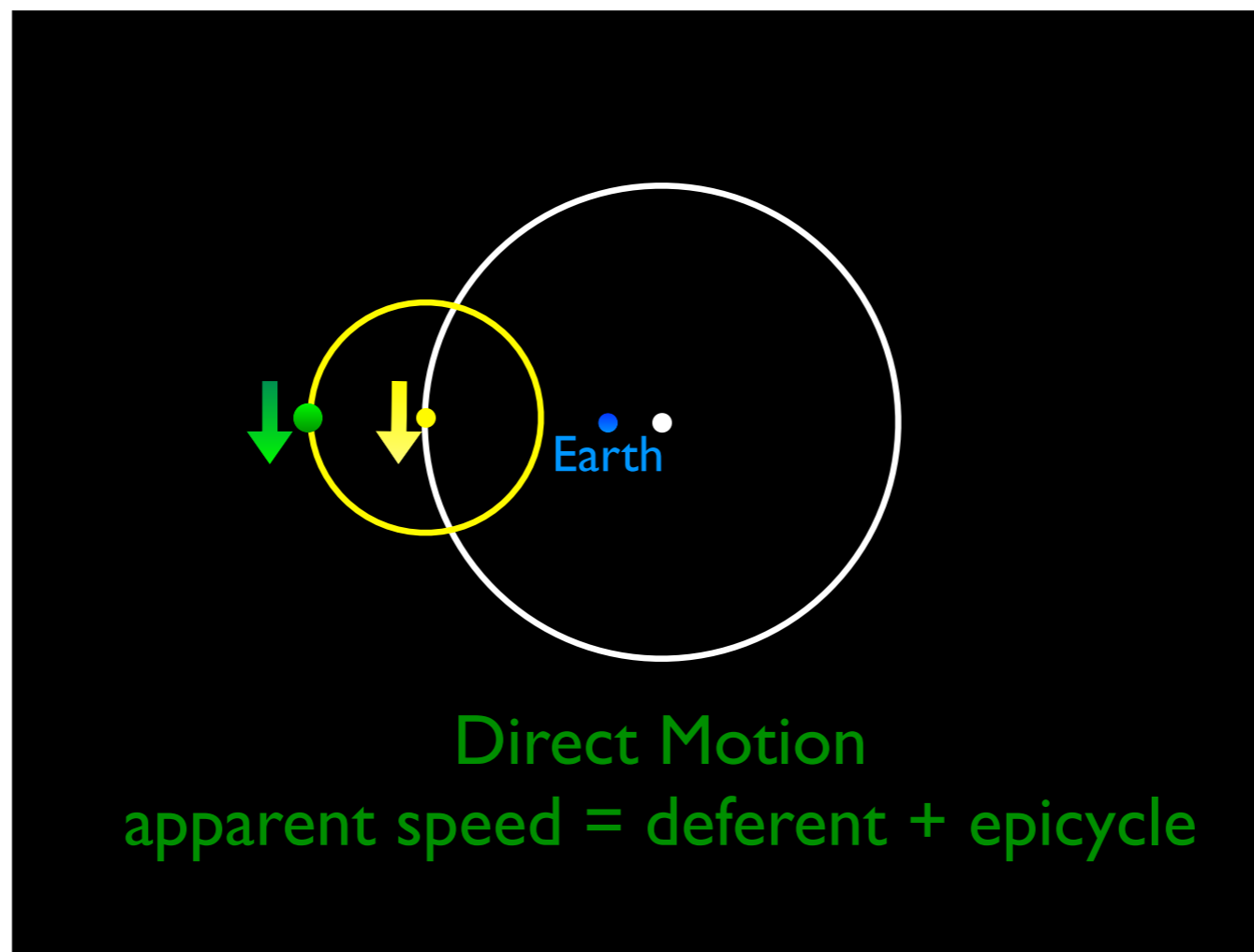
To explain retrograde motion, astronomers since Hipparchos of Nicaea in the second century BCE developed planetary theories using epicycle models.



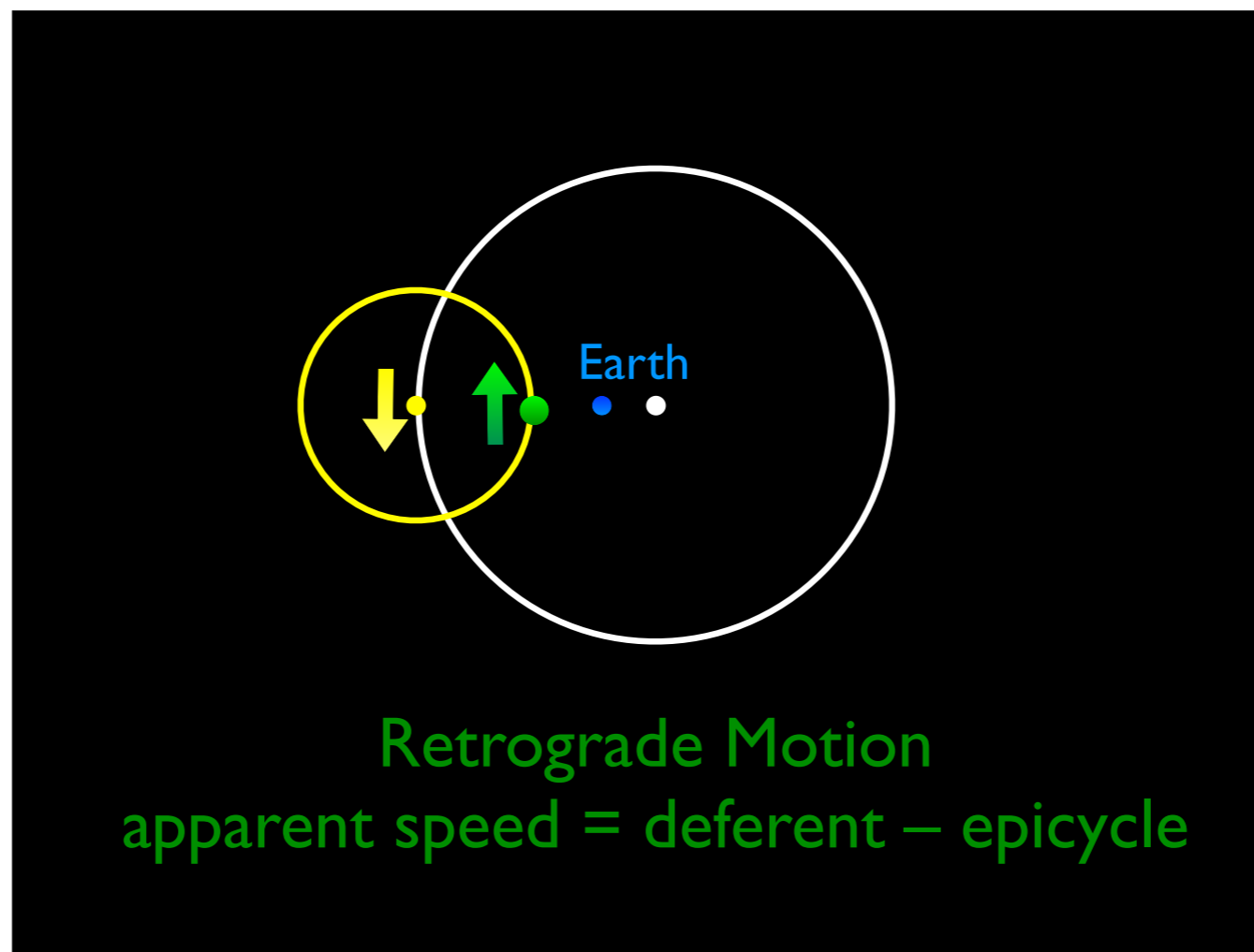
In an epicycle model, the planet does not ride directly on the large deferent circle. Rather, it moves with constant speed on a second circle, or epicycle.



At the same time the planet moves with constant speed around the epicycle, the center of the epicycle moves with constant speed around the large deferent circle. The planet is moving with a combination of uniform circular motions.

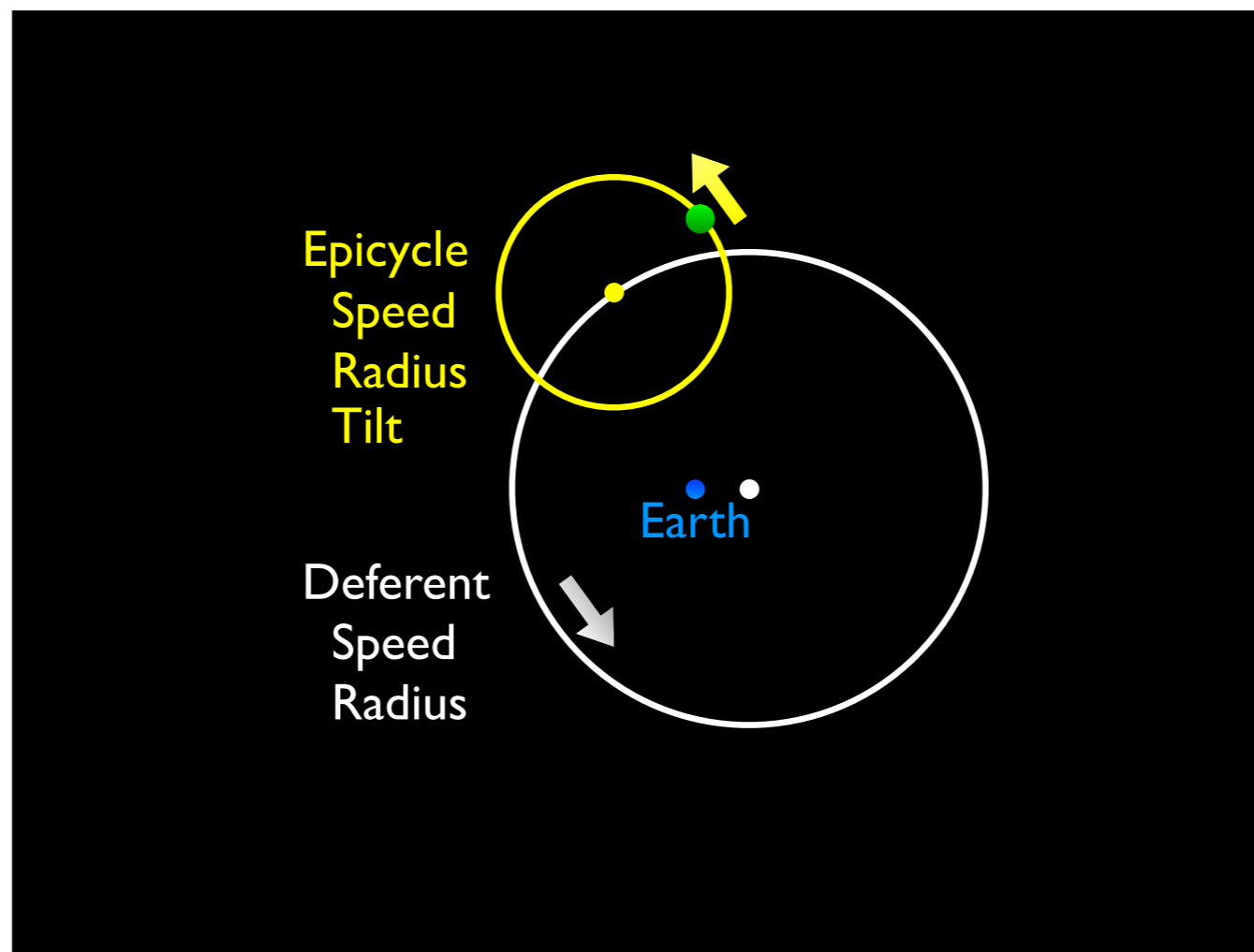


When the planet is on the outermost point of the epicycle it moves roughly eastward with a speed equal to the motion of the deferent circle plus the motion of the epicycle.



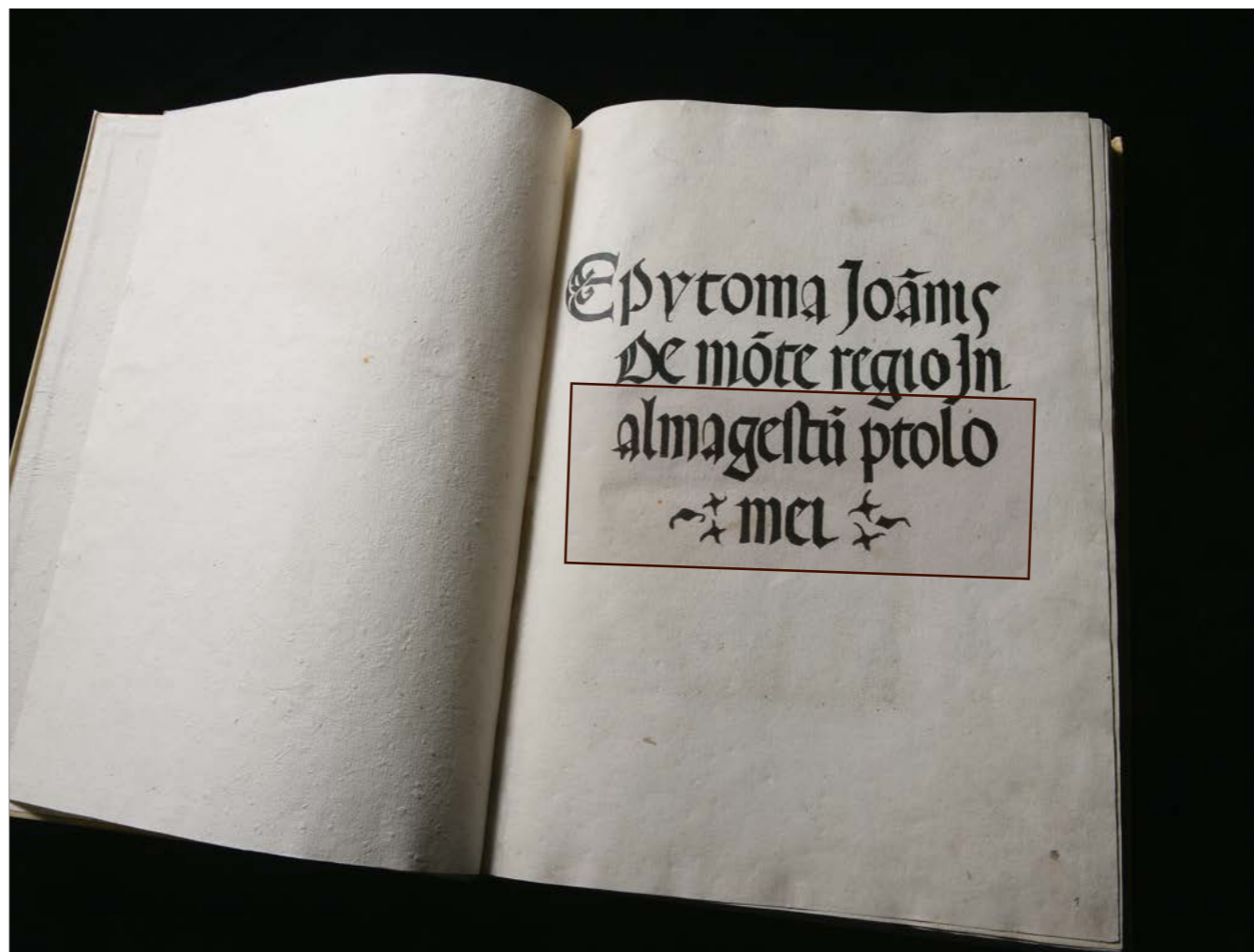
When the planet lies inside the deferent circle, the planet retrogrades with the speed of the deferent minus the epicycle. All that is necessary to have the planet move backwards is to set the speed of the epicycle greater than the speed of the deferent.

- Epicycle models easily account not only for retrograde motion, but also for the changing apparent brightness of a planet, because the planet is closer to the Earth during retrograde motion, and so becomes brighter at the same time that it retrogrades.

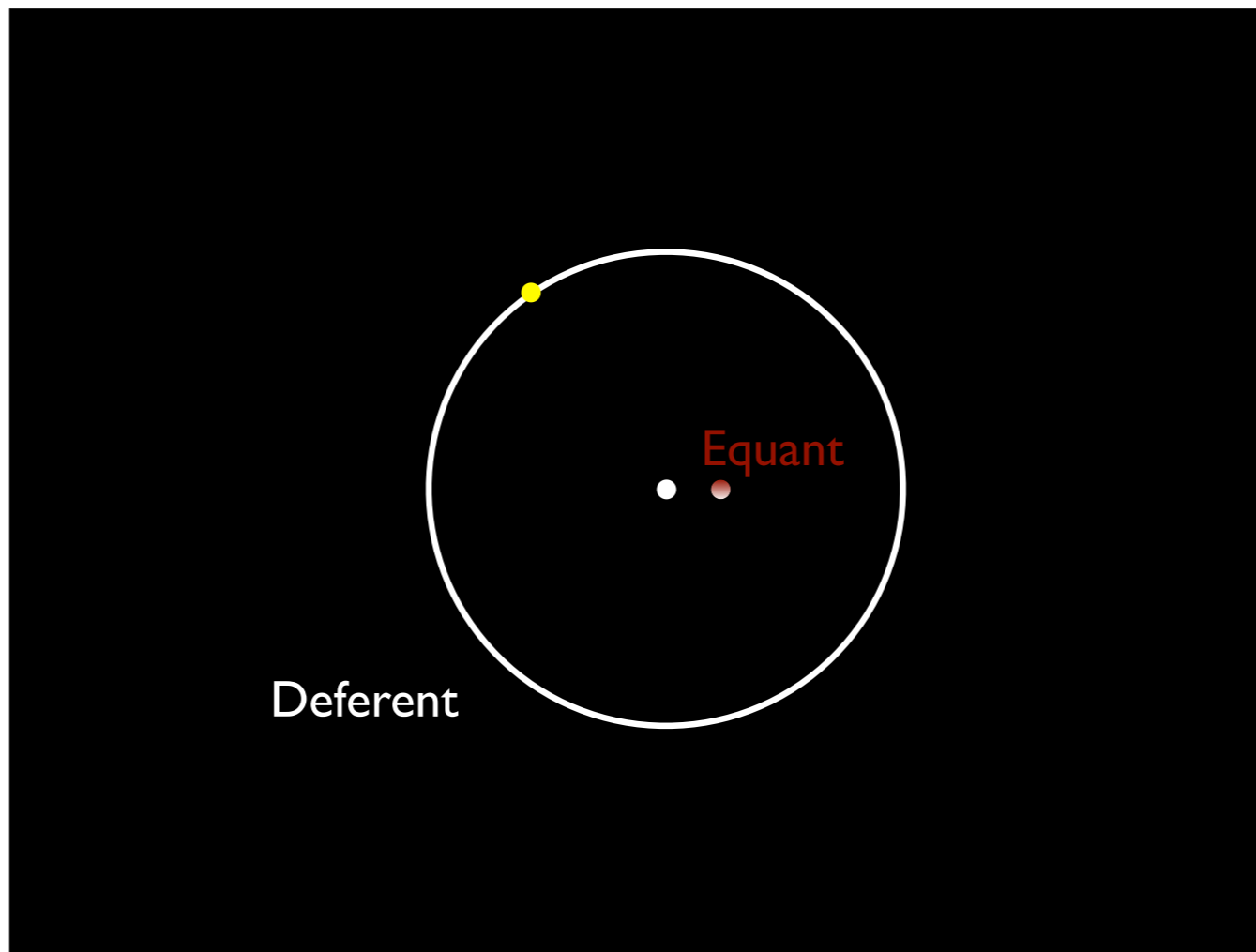


These models are quite versatile: In order to make planetary models more accurately conform to observations, the astronomer may adjust the speed and radius of the epicycle;

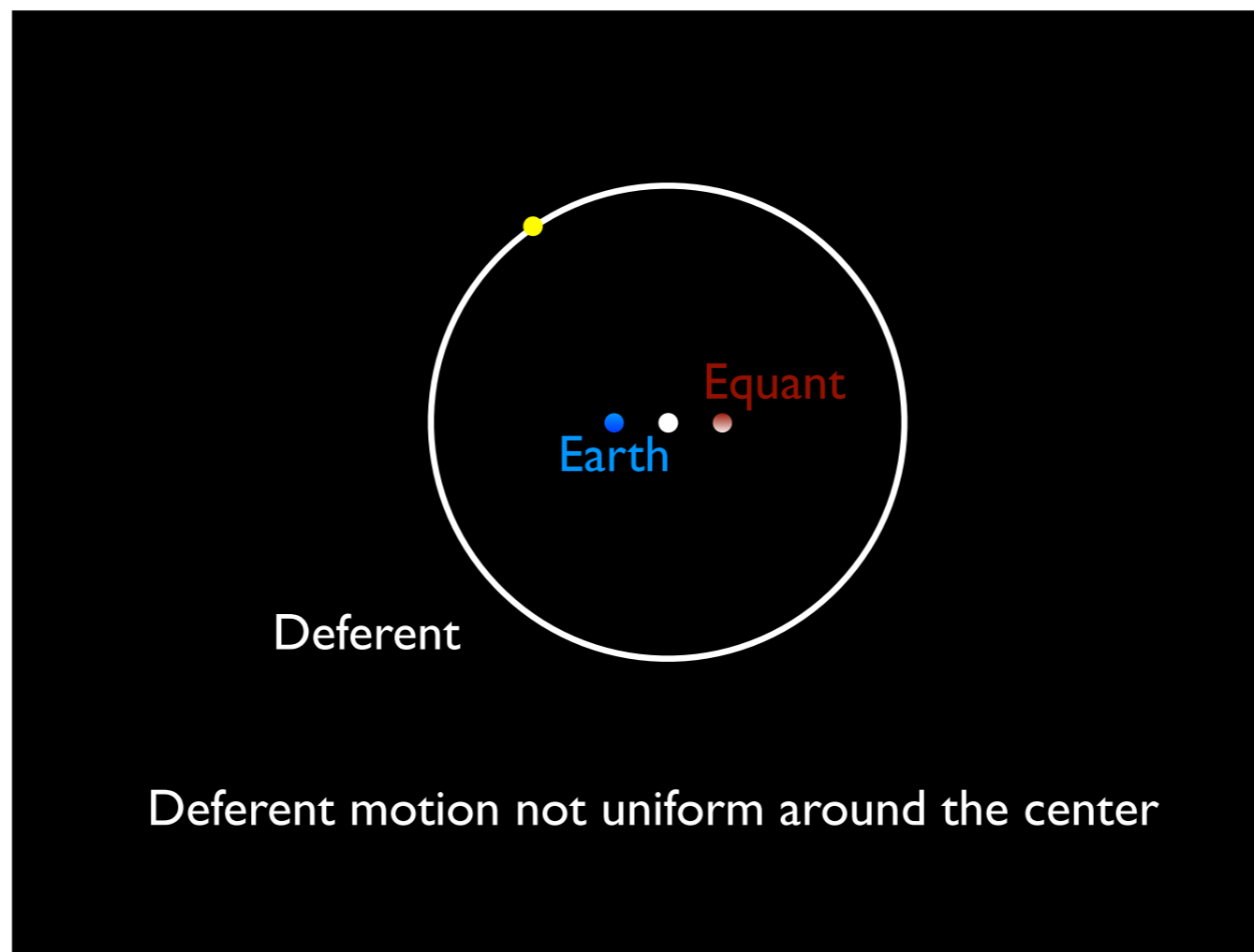
- the speed and radius of the deferent,
- and the degree of tilt of the epicycle to the plane of the deferent.



In the 2nd century, Claudius Ptolemy composed a thorough and systematic account of geocentric astronomy. Later Islamic astronomers called Ptolemy's book Almagest, or "The Greatest."

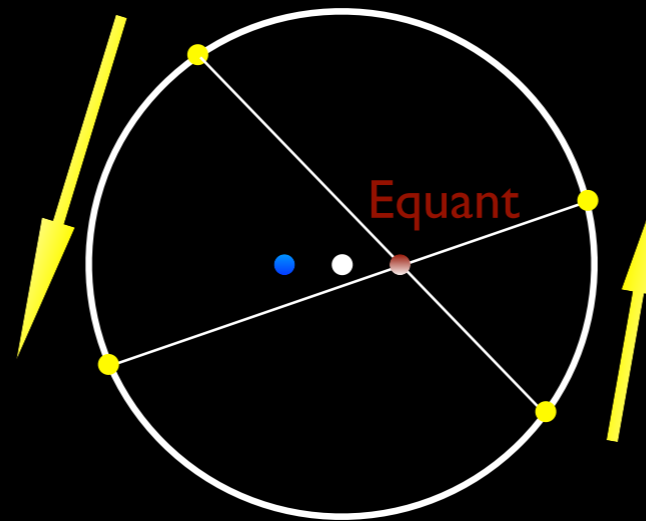


In the Almagest, Ptolemy added a third geometrical device, the ECK WANT equant, in order to predict the positions of the planets even more accurately.



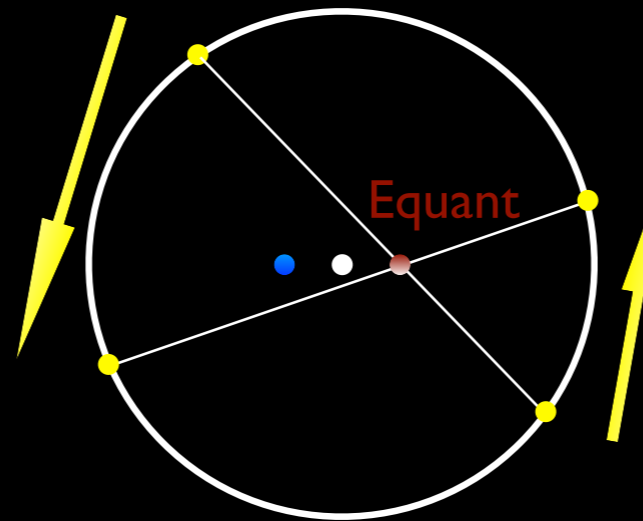
In Ptolemy's models the Earth is eccentric to the deferent, as before. However, for Ptolemy the deferent circle turns uniformly not around its center but around another point, the equant, located off-center an equal distance opposite the Earth.

- In an equant model, deferent motion is not uniform around the center. That is, a point on the circumference of the deferent circle appears to speed up and slow down even as seen from the center, rather than moving with uniform motion.



Uniform motion as seen from the
equant, but not from the center

In other words, with Ptolemy's equant, planets move with uniform motion in equal times as seen from the equant, but not as seen from the center.

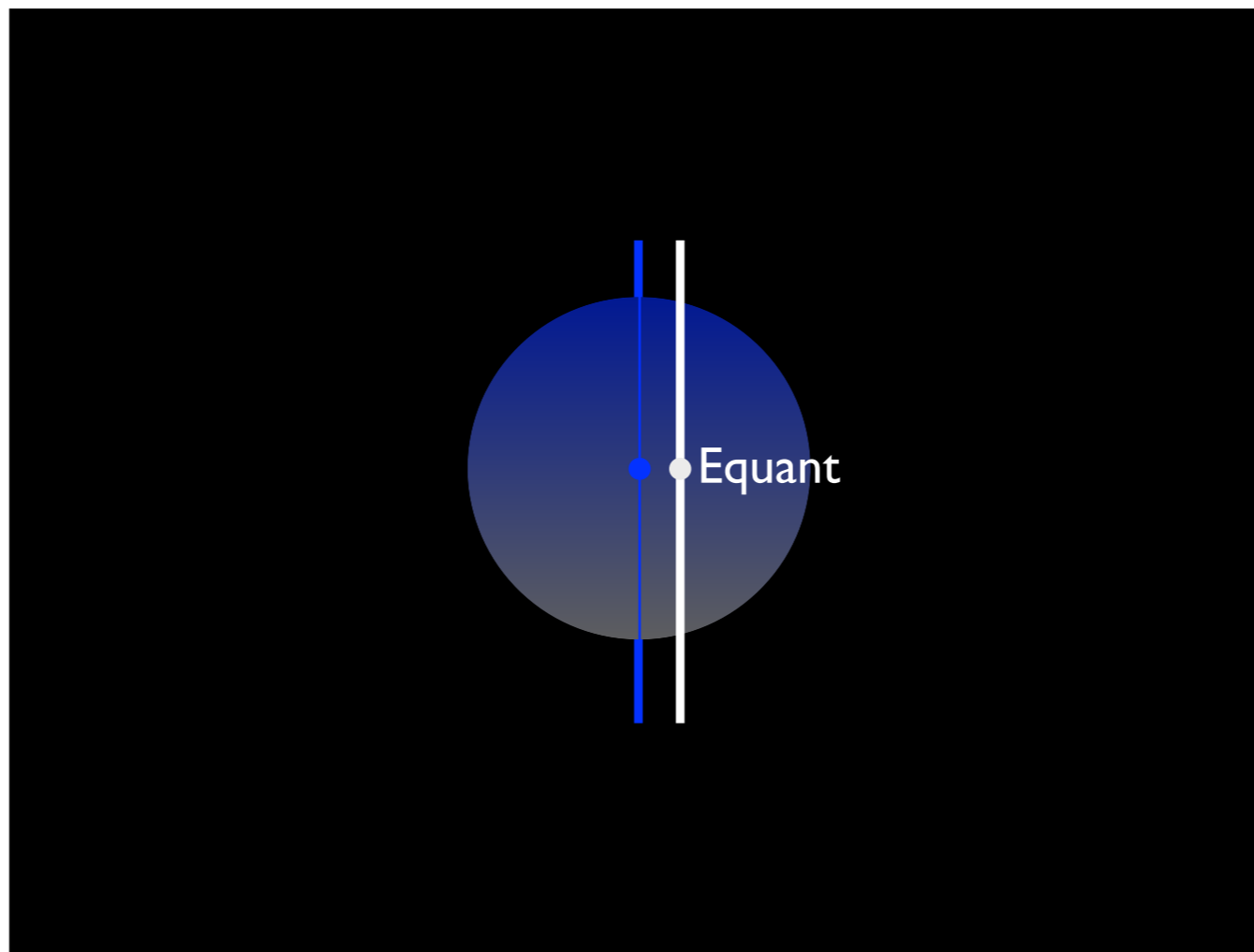


Uniform motion as seen from the
equant, but not from the center

Like other astronomers in the Ptolemaic tradition, Copernicus wanted to eliminate the equant. In the *Commentariolus* manuscript, Copernicus scorned Ptolemy's equant, calling it "not sufficiently pleasing to the mind." Ptolemy believed the equant was necessary to achieve agreement with observations, but for Copernicus, accurate predictions were not the only aim of theory. For Copernicus, one must in principle be able to construct physical models of the revolutions of the spheres. The equant was incompatible with solid spheres, as had been argued for several centuries by Islamicate astronomers.



Contrary to an unfortunately still widespread misunderstanding, the Ptolemaic tradition was anything but stagnant in the middle ages. Ibn al Haytham in the early 11th century founded an innovative Islamicate, or Arabic-language, tradition of astronomers who criticized Ptolemy for geometrical devices like the equant that could not be represented by physical models.



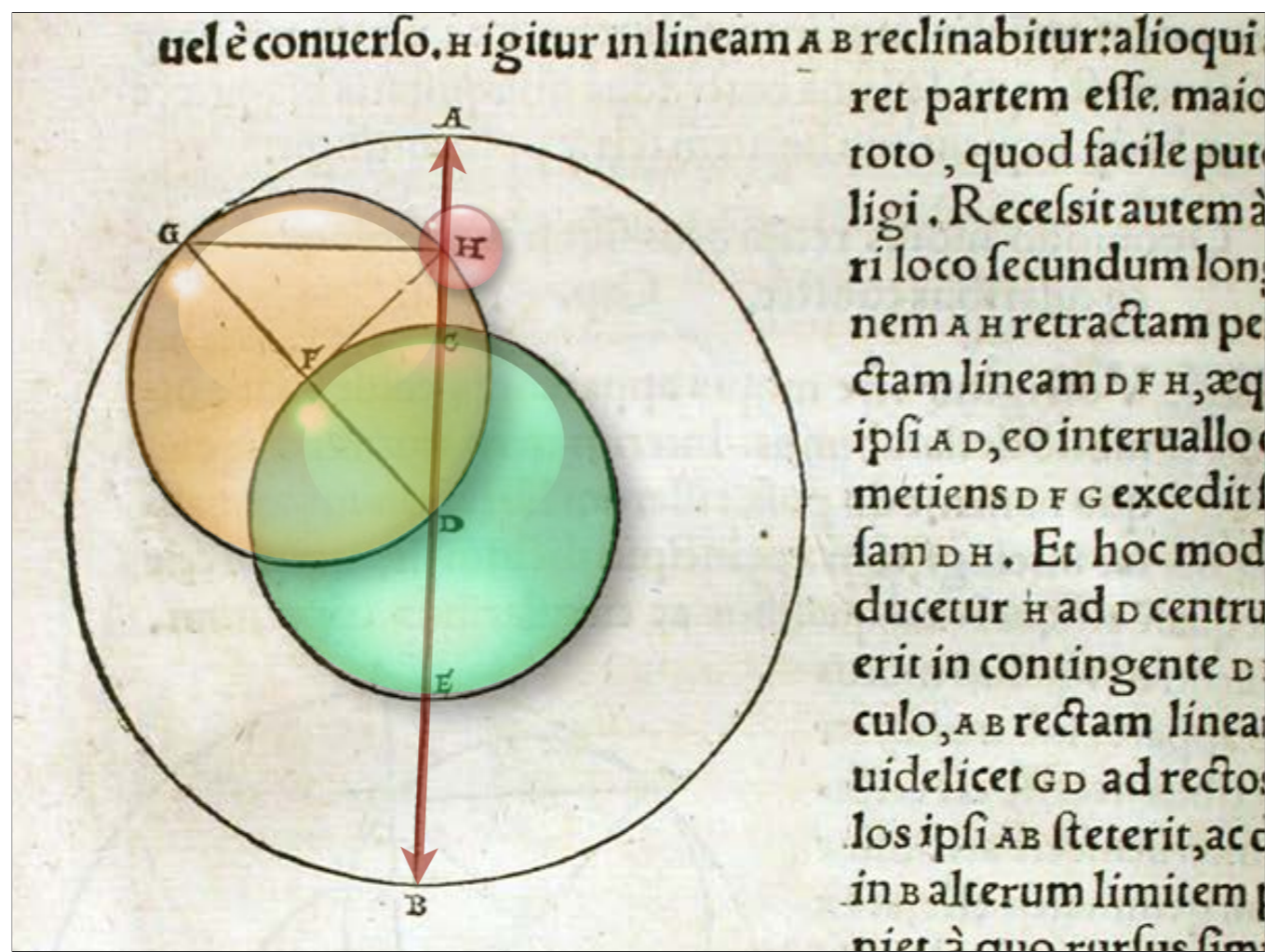
In a rotating sphere, the axis of rotation runs through the center of the sphere. Yet Ptolemy's equant requires a sphere to rotate uniformly around a point not on its axis, which is mechanically impossible for a rigid sphere turning in place. For this reason, Islamicate astronomers insisted that the equant must be avoided at all costs. Copernicus' reform of astronomy built upon this Islamicate critique.



Ibn al H
11th ce

Maragha
al Tusi & ash Shirazi,
13th century

- In the 13th century at the Observatory of Maragha in northwest Iran, Nasir al-Din al-Tusi (1201–1274) and Qutb ad-Din ash-Shirazi (1236–1311) developed astronomical models that dispensed with the equant,
- as did Ibn ash-Shatir (1305–1375) the following century in Damascus.
 - This page from an edition of Euclid attributed to al-Tusi represents the degree to which the history of astronomy throws light on cross-cultural communication. Copernicus relied upon Islamicate discoveries and methods in mathematical astronomy as well as Babylonian, Greek and Roman achievements, and to an expert eye even Indian mathematics makes its appearance in the De revolutionibus. Chinese astronomers were also present at the Maragha observatory. Just as with Catholics and Protestants in Europe, astronomy has always been a cross-cultural, collaborative production.



This diagram from the *De rev* (III.4) shows the famous Tusi couple which the Maragha school used to eliminate equants from their models. Copernicus' diagram is nearly identical to one found in al-Tusi's work.

- Notice the two circles centered on F and D . If circle F rotates twice as fast as D and in the opposite direction, then point H on its circumference will oscillate along line AB . In this way rectilinear motion results, surprisingly, from the combination of uniform circular motion. There is much more to say about this device, which may be employed in a variety of ways,
- but the bottom line is that Copernicus' *De rev* was a sun-centered version of the Maragha models.



Nearly a century before Copernicus, in the 1400's or 15th century, at the University of Vienna, Georg Peurbach tried to reconcile medieval planetary models with the assumption of solid spheres in his

- Novae theoricæ planetarum—the New Theory of the Planets.



Peurbach began to prepare an edition of Ptolemy's Almagest using Gerard of Cremona's Latin translation.

Gerardi cremonensis viri clarissimi
Theorica planetarū feliciter incipit.

Capitulum figure Solis.



Irculus eccentricus uel egressæ
cuspidis: uel egredientis cen-
tri: est qui nō habet centrū suū
cum centro mundi. Pars eccen-
trici: quæ maxime remouetur a
centro mundi/ dicitur aux: uel longitudo lon-
gior. Sed pars que maxime accedit ad infimū

A humanist scholar from Byzantium named Cardinal Bessarion scorned Gerard of Cremona's text as a worthless version, obtained through Syriac, Persian, Arabic, Hebrew and Castilian intermediates.



Bessarion urged Peurbach to go with him back to Rome, to learn Greek, and to read a manuscript of the *Almagest* Bessarion had brought with him from Byzantium—a Greek text that, in Bessarion’s eyes, was “worth more than a province.”

- Peurbach was unable to go, but when he died, his student Regiomontanus accepted the offer. In Italy, Regiomontanus learned Greek, studied Bessarion’s Greek manuscript of the *Almagest*, and became the first Latin-speaking European to fully master both ancient and Islamicate mathematical astronomy. Regiomontanus completed his Latin epitome of the *Almagest* just seven years after Gutenberg printed the Bible in Germany with movable type.



Regiomontanus returned to Nuremberg, and set up his own printing press to further the project of reforming astronomy.



With his printing press in Nuremberg, Regiomontanus hoped that the same hammer that lit the fires of the Protestant Reformation would spread the word of the coming restoration of astronomy.

1475.

1476.

CON. OPPO.

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KL

IVNIVS.

SOLIS
GEMINI

LVNAE
S. G. S. G.

1 c Ncomedis martyris

2 f 4 non Marcellini & Petri

3 g 3 non Erafmi episcopi

4 A 2 non

5 b Non Bonifacii pape

6 c 8 id

7 d 7 id

8 e 6 id

9 f 5 id Primi & Feliciani

10 g 4 id

11 A 3 id Barnabe apostoli

12 b 2 id

13 c Idus

14 d 18 kal Iulij

15 e 17 kal Viti martyris

16 f 16 kal

17 g 15 kal

18 A 14 kal Marci & Marcelliani

19 b 13 kal Geruasii & Protasii

20 c 12 kal

21 d 11 kal Albani martyris

22 e 10 kal Achacii & socorum eius

23 f 9 kal

24 g 8 kal Iohannis baptiste

25 A 7 kal

26 b 6 kal Iohannis & Pauli

27 c 5 kal Septem dormientium

28 d 4 kal Leonis pape

29 e 3 kal Petri & Pauli apostolorum

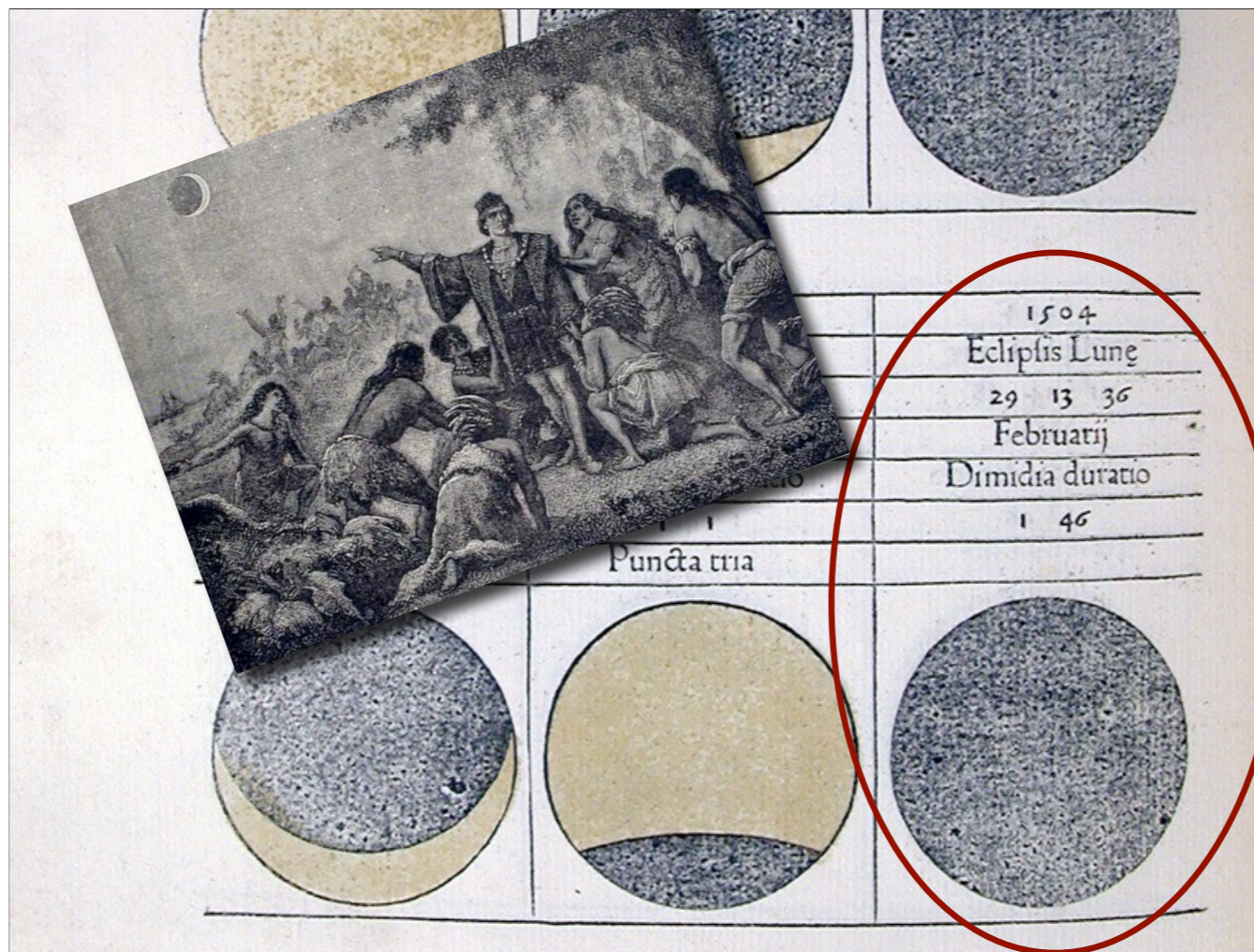
30 f 2 kal Comemoratio s. Pauli

CANCER

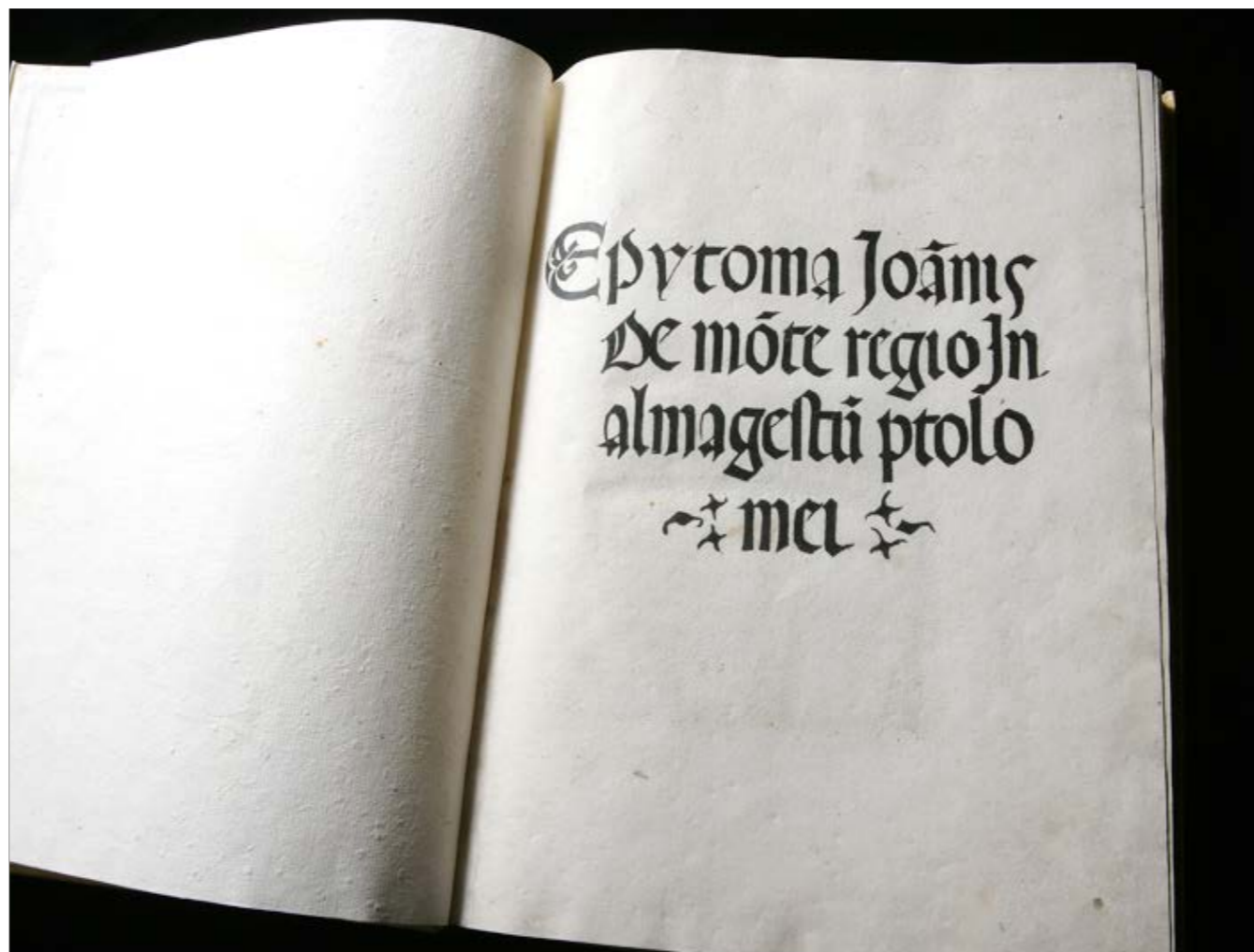
Vigilia

Vigilia

In the Kalendarium, published in 1476, Regiomontanus recorded predictions of the positions of the Sun and Moon for 30 years, based on his updated Ptolemaic geocentric models.



Columbus took a later German edition of the Kalendarium with him on his 4th voyage and used its prediction of the 1504 lunar eclipse to frighten his Jamaican hosts. These were successful predictions, based in part upon Cremona, Peurbach and the Greek Almagest.



Regiomontanus hoped to publish the Latin Epitome of Ptolemy's Almagest, but his premature death delayed its appearance for twenty years. Finally published in 1496, it was the first printed edition in any form of Ptolemy's Almagest, and its only printing in the fifteenth century.

Amplius duobus arcibus in medietate eccentrici equalibus: qui longitudini propiorum fuerit vicinior: maiorem in centro terre subcedit angulum. Et hoc constat: quod quanto planeta longitudini propiorum vicinior fuerit: tanto motus eius appareat maior erit.

Sit eccentricus a. b. g. d. cuius centrum e. diametrum per longitudinem longioris et propiorum transitio sit a. c. g. in qua centrum terre s. duo arcus a. b. b. g. sunt equaliter. unde angulus b. e. t. qualiter erit angulus k. e. b. Dico angulum k. s. b. maiorem esse angulo b. s. t. propterea quod arcus k. b. longiorum propiorum sit vicinior: s. e. t. b. s. continuatur occurrant periferie eccentrici in l. et d. duobus lineis b. l. et k. d. perpendicularibus super cao. s. p. et s. q. quia angulus b. l. e. est equalis angulo k. d. b. per 25. tertij. et angulus s. p. l. equalis angulo s. q. d. igitur per quartam igitur propiorum s. d. ad s. l. sicut s. k. ad s. p. Sed s. d. maior est s. l. per septimam tertij. ergo s. q. maior est s. p. Lineam autem b. s. maior est linea k. s. per eandem septimam tertij. ergo per octavam quinti propiorum b. s. ad s. k. maior est quam propiorum k. s. ad s. q. et per eandem b. s. ad s. p. maior est quam b. s. ad s. q. igitur propiorum b. s. ad s. p. maior est proportionem k. s. ad s. q. quare ex ratione finium seu chordarum angulus s. k. q. maior est angulo s. b. p. Ideoque duo anguli s. k. q. et s. l. q. simul maiorem sunt duobus b. s. p. et s. l. p. Siquis per s. p. primi angulus k. s. b. maior est angulo b. s. t. quod fuit ostendendum. Quedam manifestum est.

Propositio vi.

Amplius duobus arcibus in medietate epicycli superioris equalibus: qui longitudini longiorum vicinior fuerit: maiorem in centro terre subcedit angulum.

Sit epicyclus a. b. g. super centro e. diametrum a. c. g. transitum per longitudinem longiorum a. p. propiorum g. e. centrum terre s. Sumpti sunt in parte superiori duo arcus b. t. et b. k. equaliter. b. t. quidem vicinior ad longitudinem longiorum. Dico angulum b. s. t. maiorem esse angulo b. s. k. Secundo enim t. s. et k. s. epicyclum inferius in l. e. m. et super continuatur b. l. et b. m. cadit perpendicularis s. p. et s. q. Sunt itaque b. l. et b. m. k. anguli equaliter per 25. tertij. adeo quod eorum contrapositioni s. l. p. et s. m. q. sunt equaliter. p. autem t. q. sunt recti: ergo per quartam igitur m. s. ad l. s. propiorum est sicut s. q. ad s. p. Sed m. s. est maior l. s. per octavam tertij. igitur s. q. est maior s. p. Sed s. b. est maior s. b. per eandem octavam tertij. quare per octavam quinti b. s. ad s. q. propiorum maior est quam b. s. ad s. p. autem ad s. p. maior est b. s. ad s. q. per eandem igitur b. s. ad s. p. maior est quam b. s. ad s. q. igitur ex ratione finium angulus s. b. q. maior est angulo s. b. p. Sed extrinseci eorum b. m. k. et b. l. l. sunt equaliter: igitur residui duo intrinseci sunt inaequaliter: k. s. angulus b. s. t. maior angulo b. s. k. quod est intentum. Ex his manifestum est tam per modum eccentrici quam epicycli stellam in temporibus equalibus in eodem signorum inaequaliter arcibus describere.

Propositio vij.

Secundum modum eccentrici maxima differentia inter motum equalem et apparentem continget in puncto transitus medij: quem determinat linea motus apparentis super diametro per ambo centra eintellano perpendiculariter.

Sit eccentricus a. b. g. d. per cuius centrum e. et per centrum mundi s. e longiorum longioris a. t. propiorum g. transitio diametrum a. g. Linea motus apparentis flans super a. g. orthogonaliter sit s. b. ducta q. s. b. e. angulus d. ueritatis inter motum equalem et apparentem est e. b. s. Dico enim equaliter sit est angulus a. e. b. Sed apparetur est angulus a. s. b. Si autem duo alij anguli d. ueritatis apud duo puncta t. et k. qui sunt e. s. t. e. k. s. Dico angulum b. maximam bonum esse. Continetur enim b. d. an. d. e. d. ueritatis angulus t. s. d. maior angulo t. d. s. Sed e. d. t. equalis est angulo e. t. d. per eundem nem circuli: quinta primi igitur residuum s. d. e. maior est residuo e. t. s. sed e. d. s. equalis est angulo e. b. s. igitur angulus e. b. s. maior est angulo e. t. s. Similiter probabitur e. b. s. maior est e. k. s. Quid sit ostende. Sint b. t. p. ducta in arcu a. b. ducta e. k. z. e. l. perpendicularibus super b. s. et t. s. per nullitatem primi patet e. s. longiorum esse e. k. et e. k. longiorum e. l. Sed e. b. e. b. et e. t. sunt equaliter: ergo per octavam quinti propiorum e. t. ad e. l. maior est proportionem b. e. ad e. k. et b. e. ad e. k. propiorum maior proportionem b. e. ad e. s. Ideoque et ratio finium angulus b. e. t. maior angulo b. e. s. angulus b. maior angulo t. igitur e. c.

Et hoc inferitur quanto linea motus apparentis puncto transitus medij vicinior fuerit: tanto differentia inter motum apparentem et equalem maior est.

Idem ostendere poteris de punctis inter b. et g.

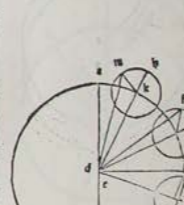
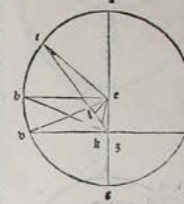
Hinc etiam constat arcum a longitudinem longiorum: est puncto motus minoris ad punctum transitus medij esse maiorem arcum a puncto transitus medij ad longitudinem propiorum in punctum motus maioris in duplo maxime ueritatis.

Quam quanto angulus a. e. b. est maior angulo a. s. b. tanto etiam angulus g. s. b. maior est angulo g. e. b. Ideo angulus a. e. b. maior est angulo g. e. b. in duplo anguli e. b. s. quod est intentum.

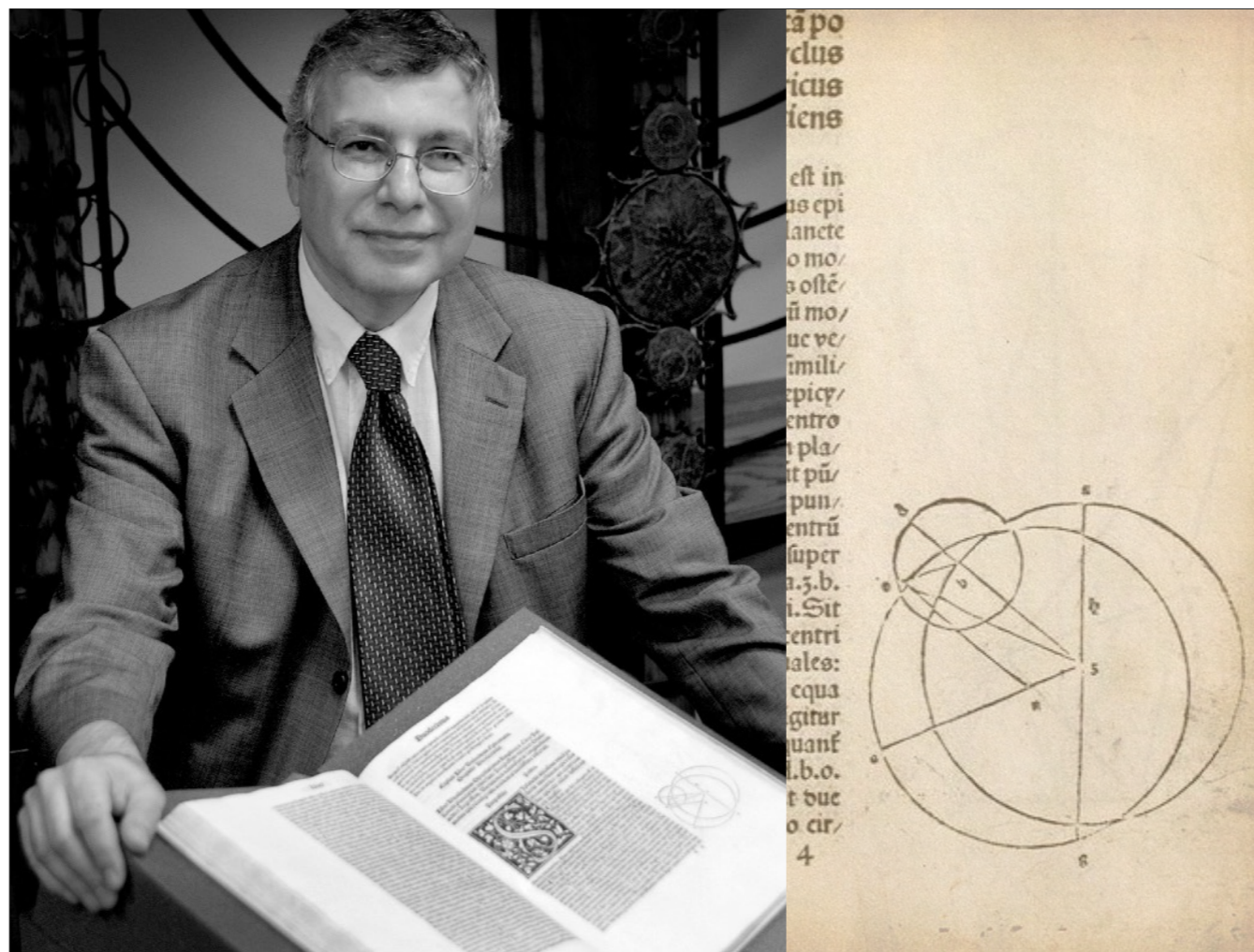
Propositio viij.

Secundum modum epicycli dum centrum epicycli in concentrico planetaque in epicyclo eque cito circueat: fueritque motus minor in longitudine longiorum: maxima differentia inter motum equalem et apparentem continget dum linea motus apparentis a puncto longitudinis longiorum quarta circuli disluerit.

Sit concentricus a. b. g. d. super centro e. sitque a. locus centri epicycli dum planeta fuerit in longitudine longiorum epicycli s. non sit punctum centri epicycli dum linea e. n. motus apparentis ueritatis ab a. per quartam circuli sit

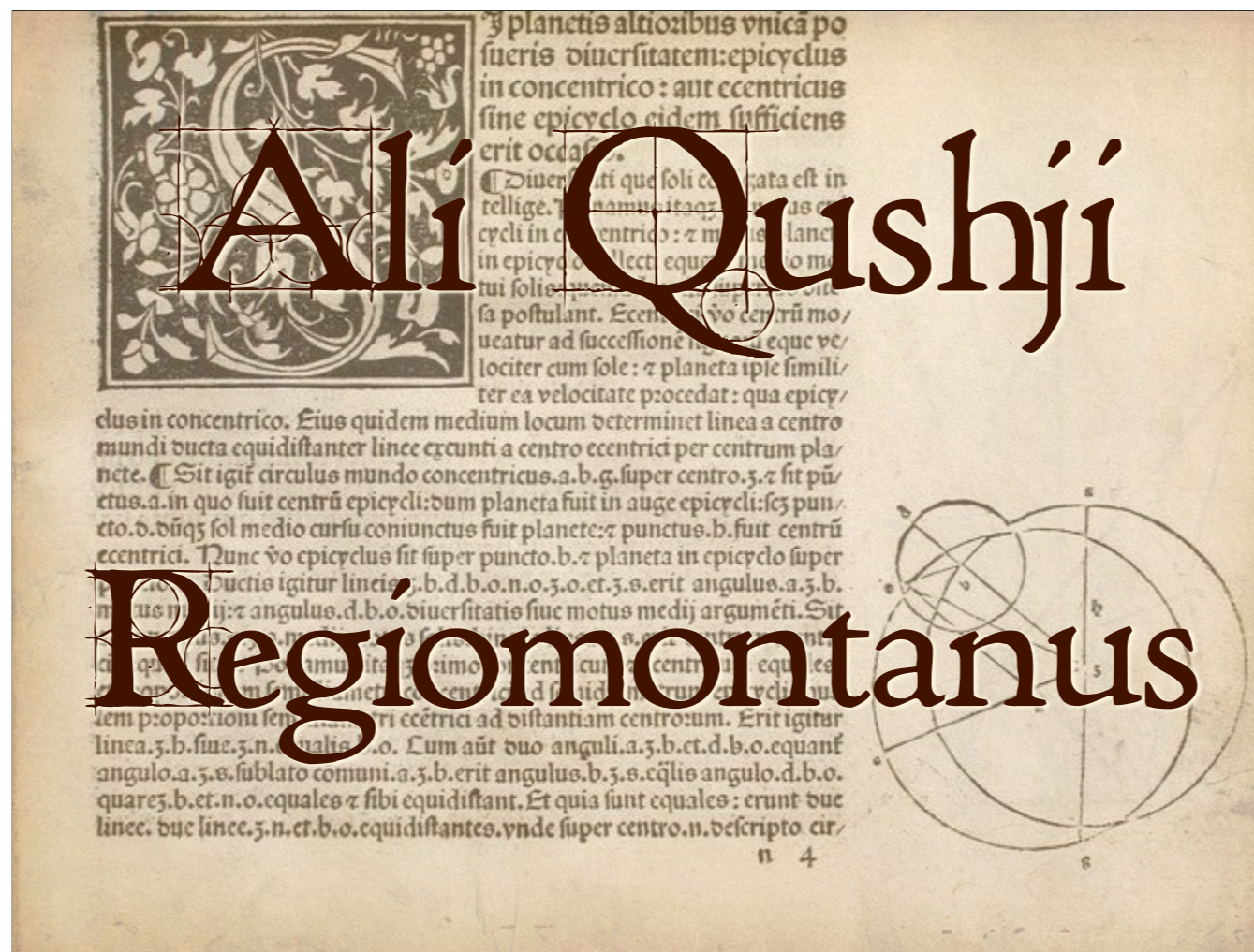


Far from merely abridging the Almagest, the Epitome was a major contribution to Renaissance astronomy, containing new techniques, methods, observations and critical reflections.



For example, Jamil Ragep has shown that the 15th century Islamicate astronomer Ali Qushji, a generation before Regiomontanus, proved that eccentric models could be used for all of the planets instead of epicycle models, except for retrograde motion. This proof, sought after unsuccessfully by Ptolemy himself, was then included by Regiomontanus in his *Epitome of the Almagest*. Here Jamil is holding the Oklahoma copy of Regiomontanus open to the diagram shown on the right, which is identical to that used by Ali Qushji. Noel Swerdlow has argued that this diagram provided the major step in the transformation to a Sun-centered model.

F. Jamil Ragep, "Ali Qushji and Regiomontanus: Eccentric Transformations and Copernican Revolutions," *Journal for the History of Astronomy* 36, (2005): 359–379.



In other words, Ali Qushji and Regiomontanus opened the door for anyone to actually transpose the positions of the Earth and Sun. One might now choose any point one wished for the center, and all the mathematics would work out to the same result. Copernicus picked up where Islamicate and Renaissance astronomers left off. Indeed, Ali Qushji himself considered the possibility and commented that a moving Earth is impossible to disprove.

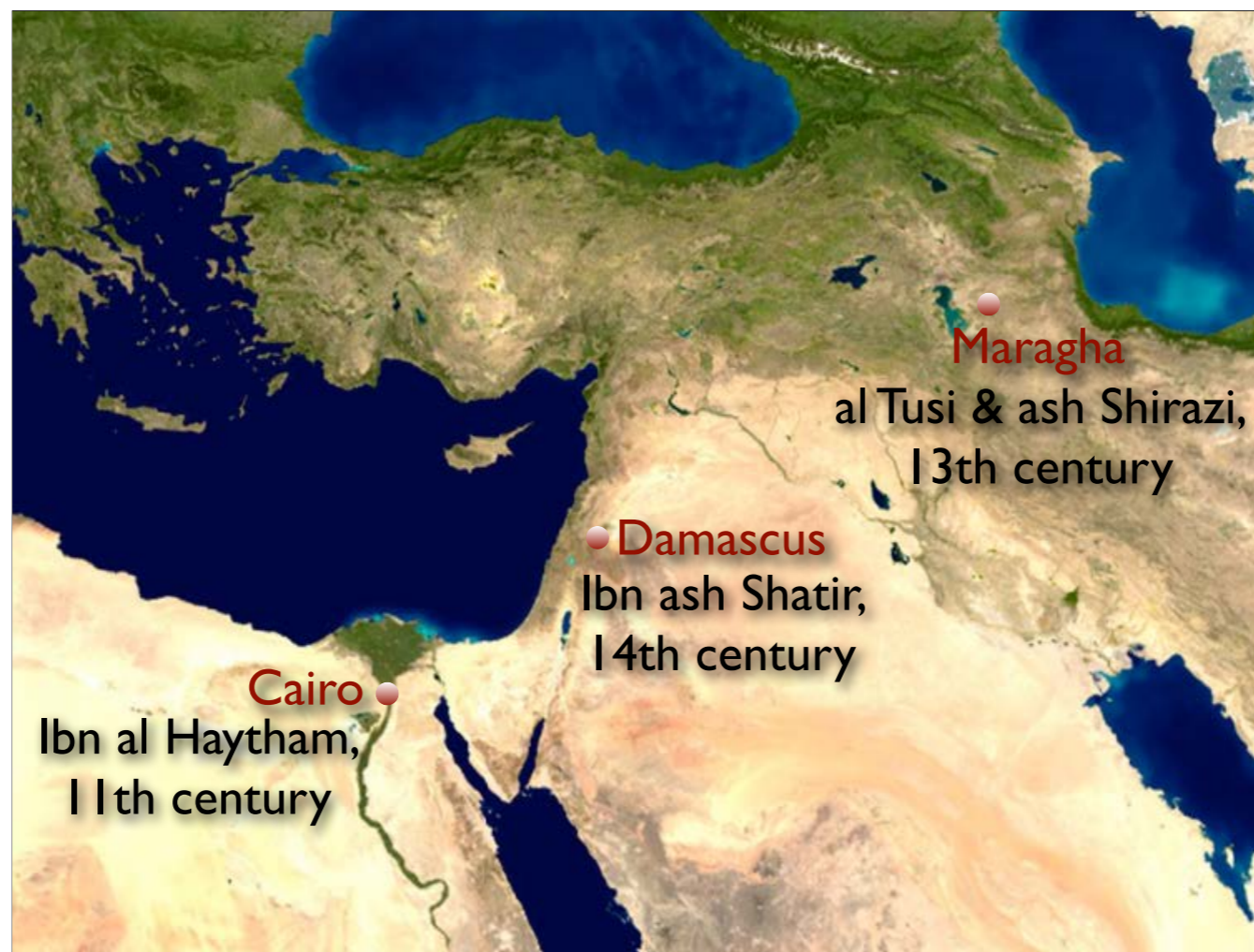
epicycli. ex n. v. et. v. r. que est equalis. d. g. reperies an
mi. ii. secun. **Sed mirum est:** q in quadratura luna in c
cli existente nō tanta appareat: cū tamen si integra lucet
tet apparere ad magnitudinē suam: que apparet in op
auge epicycli. Habet ⁊ alij modū alium: semidiametro
que in auge ⁊ in opposito per obseruationem reperte si
dicetur in sexta sexti.

Propositio xxiiij.



E data solis aut lune a centro ter
gatione eius a polo horizontis: d
ctus in circulo altitudinis inuestig
Repetatur figura. 16. hui⁹. ex angulo. q
querimus arcum. b. t. Nota enim erit pro

Here is another page of the Epitome. On this page Regiomontanus exclaimed, “Sed mirum est....” What a marvel! At the end of Book V, Section 22, Regiomontanus called attention to the astonishing fact that Ptolemy’s lunar theory required the Moon occasionally to appear four times its usual size. This impossible wonder arrested the attention of Copernicus. To correct for this astonishing anomaly, Copernicus used a crank mechanism identical to that which the Maraghan astronomer ash-Shatir developed in the 14th century.



How did Regiomontanus and Copernicus learn Islamicate astronomy? No one knows how Ali-Qushji's eccentric models, the Tusi couple, or ash-Shatir's lunar theory reached Copernicus.



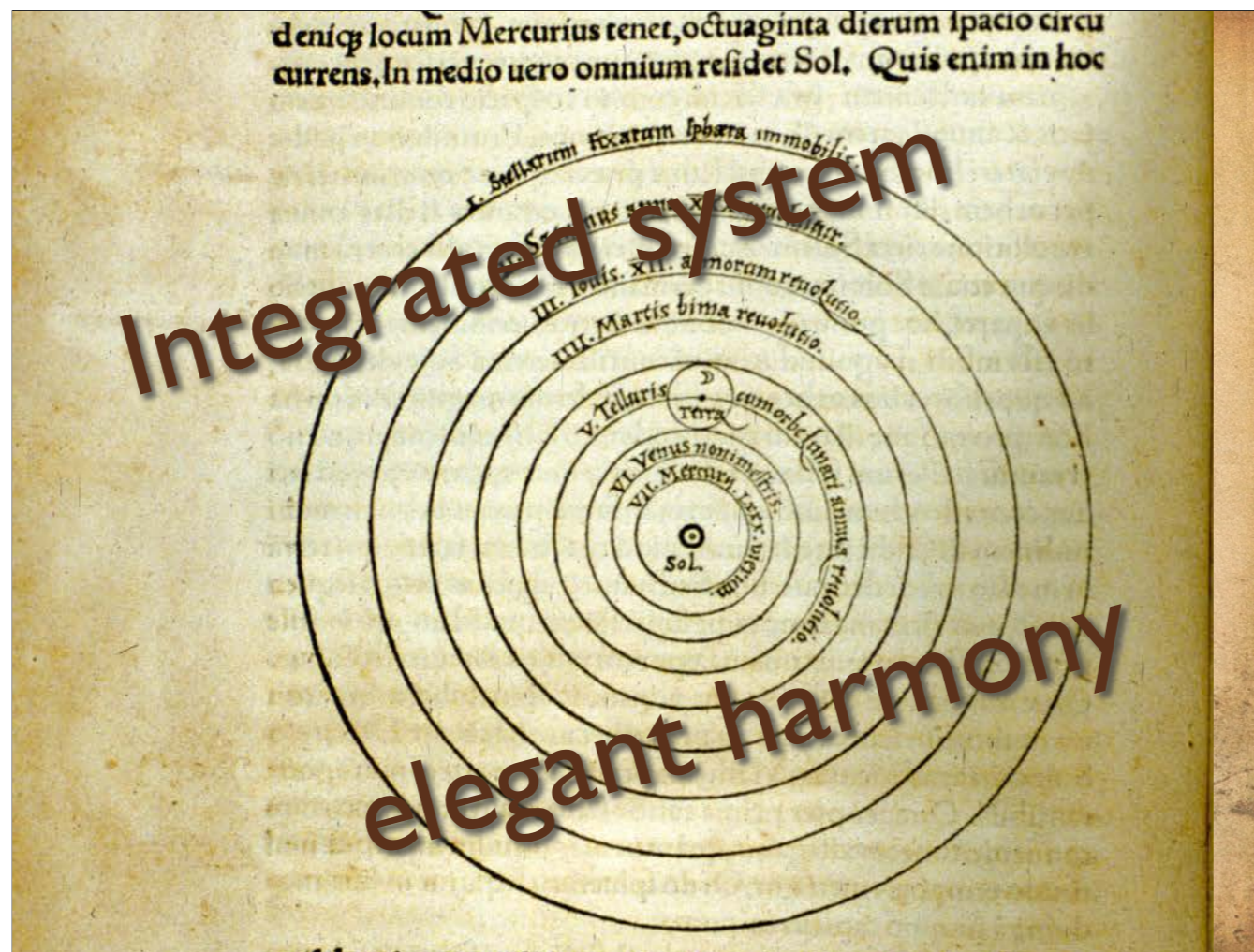
Maragha models of al-Tusi and ash-Shirazi reached Constantinople by the mid-1400s, and northern Italy by the mid-1500s, whether through a hundred Greek visitors to the Council of Ferrara, including Cardinal Bessarion, or by some other route. Perhaps Copernicus encountered them during his university years in Padua and Ferrara. And perhaps Regiomontanus encountered the work of Ali Qushji during his stay in Hungary.



In the Epitome of the Almagest a magnificent full-page woodcut depicts Ptolemy and Regiomontanus seated beneath an armillary sphere.

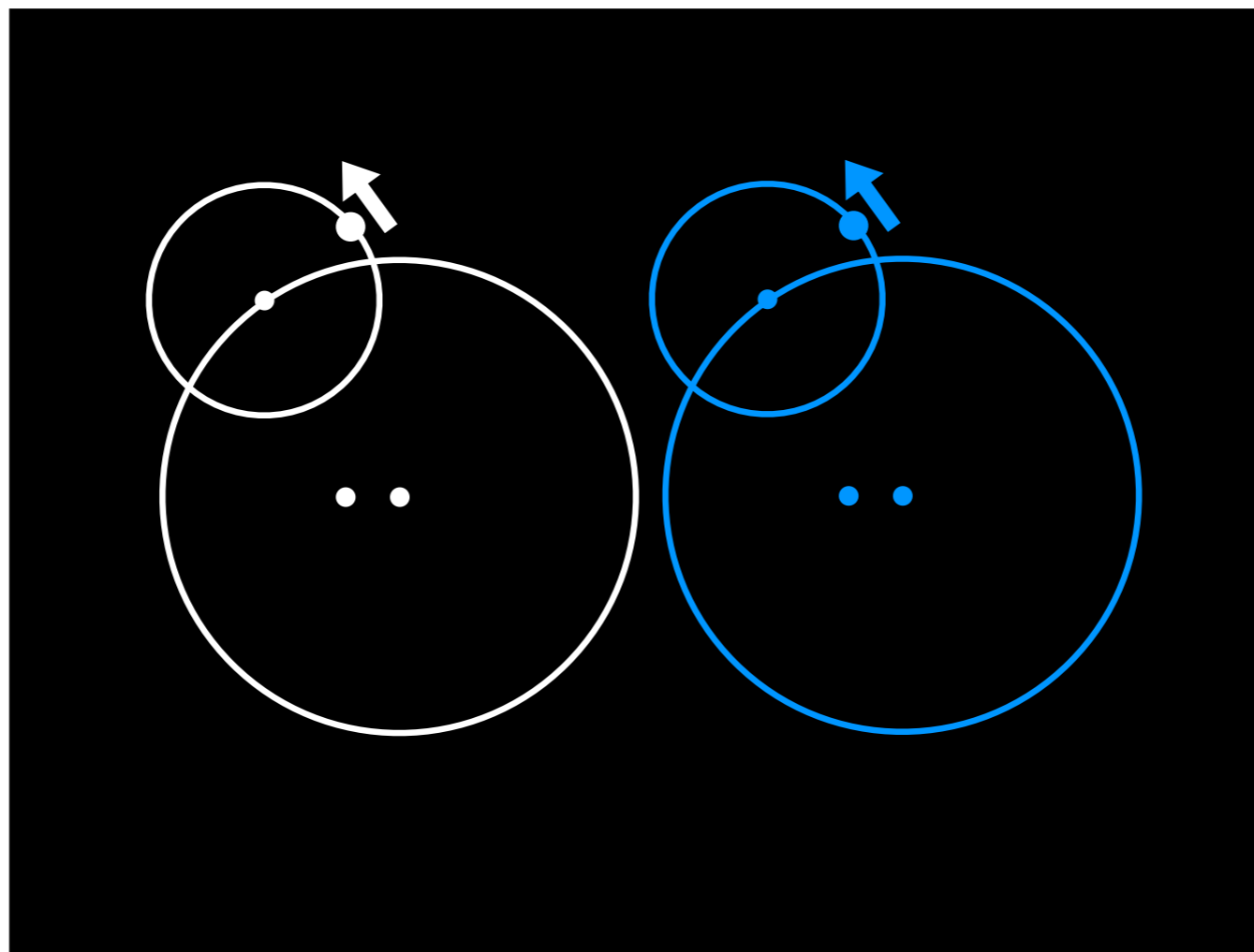


Together they epitomize the tradition of mathematical Earth-centered astronomy, from its ancient culmination in Ptolemy and its Islamicate invigoration to its rebirth in Latin Europe with Regiomontanus.

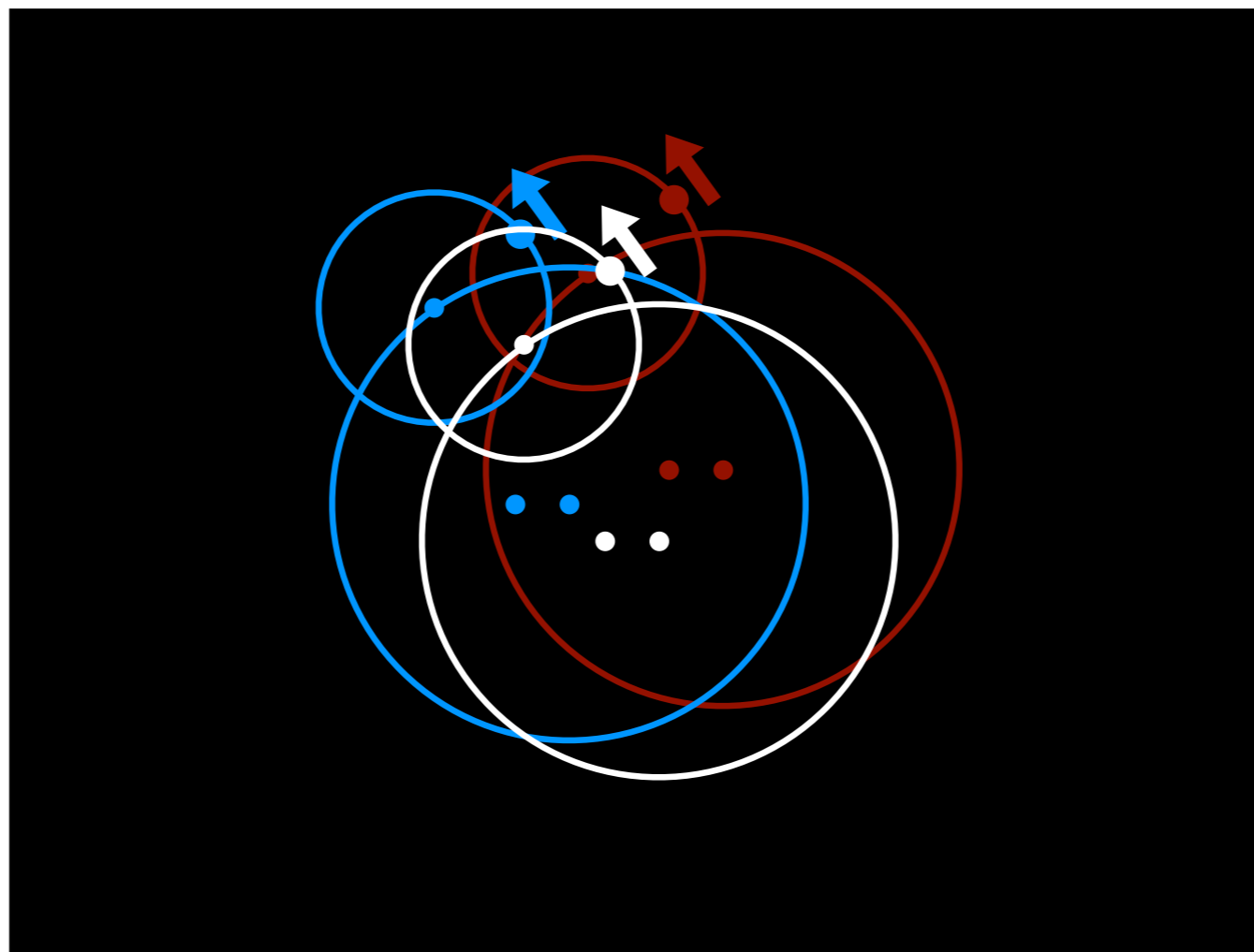


Thus, by building on a long-standing Islamicate astronomical tradition to rid astronomy of the corruptions introduced by Ptolemy's equant, Copernicus sought to recover a pure astronomy consistent with the classical ideal of uniform circular motion. (Pause) But why would any reader believe Copernicus had achieved the truth so long sought-after in the Ptolemaic tradition? The answer is that the most important advantage offered by Copernicus was a vision of the universe

- as a coherent and integrated system, where all the planets move together in elegant harmony.



Ptolemy considered each planet in isolation. In the geocentric cosmos, each planet was explained separately by its own individual model.



Ptolemaic models for the various planets did not even share the same center. So not only did Ptolemaic models fail to be precisely centered on the Earth, but they each fell off-center by slightly different amounts. Copernicus compared this fragmented portrait of the cosmos with a sculpture assembled piece-meal, more like a monster than the balanced form of a man. As Copernicus explained:

7

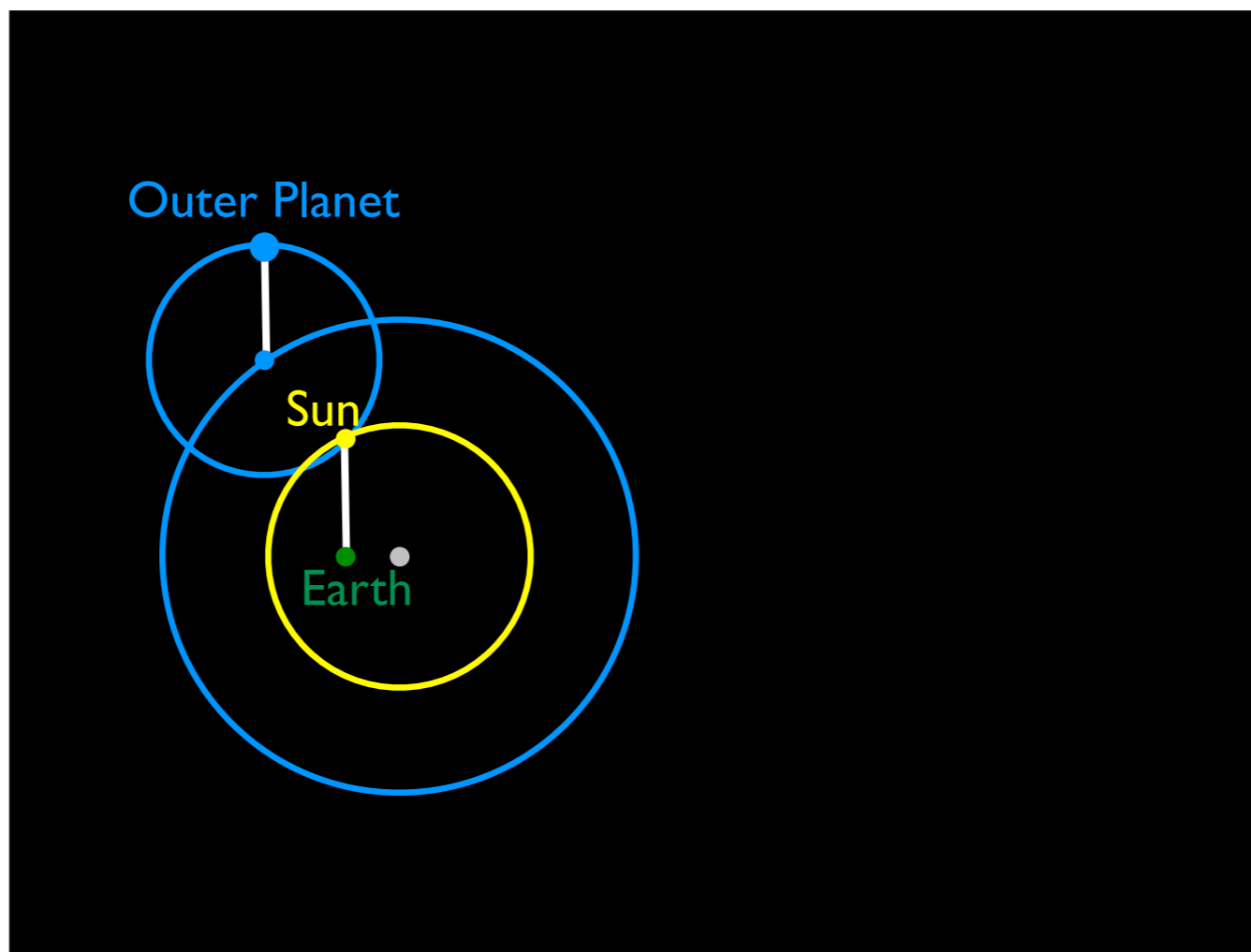
[Astronomers have not] “deduced... the main point, that is, the structure of the universe and the true symmetry of its parts. On the contrary, they have been like someone attempting a portrait by assembling hands, feet, a head and other parts from different sources. These several bits may be well depicted, but they do not fit together to make up a single body. Bearing no genuine relationship to each other, these fragments, joined together, produce a monster rather than a man.”

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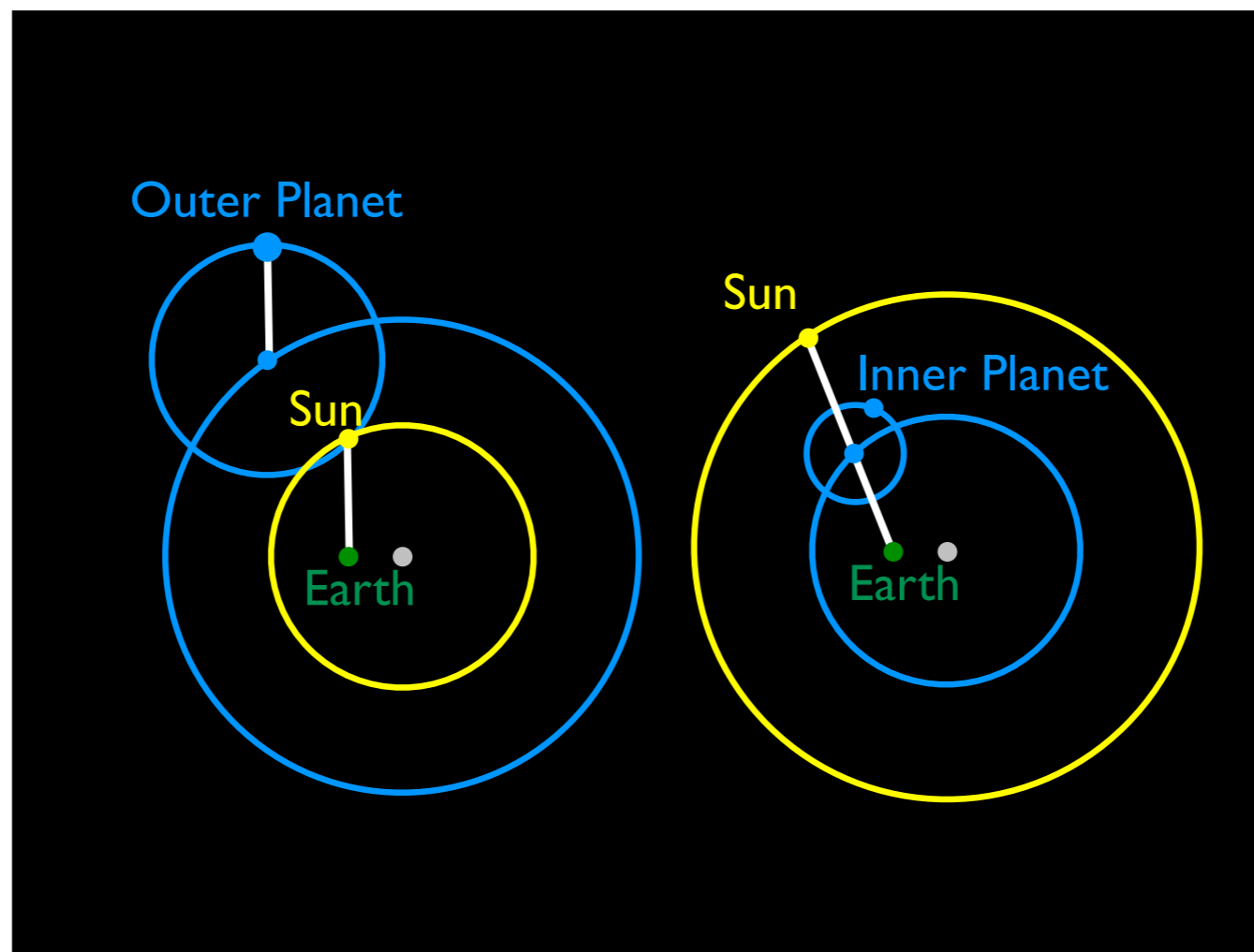
Copernicus, Preface. Danielson, 106.



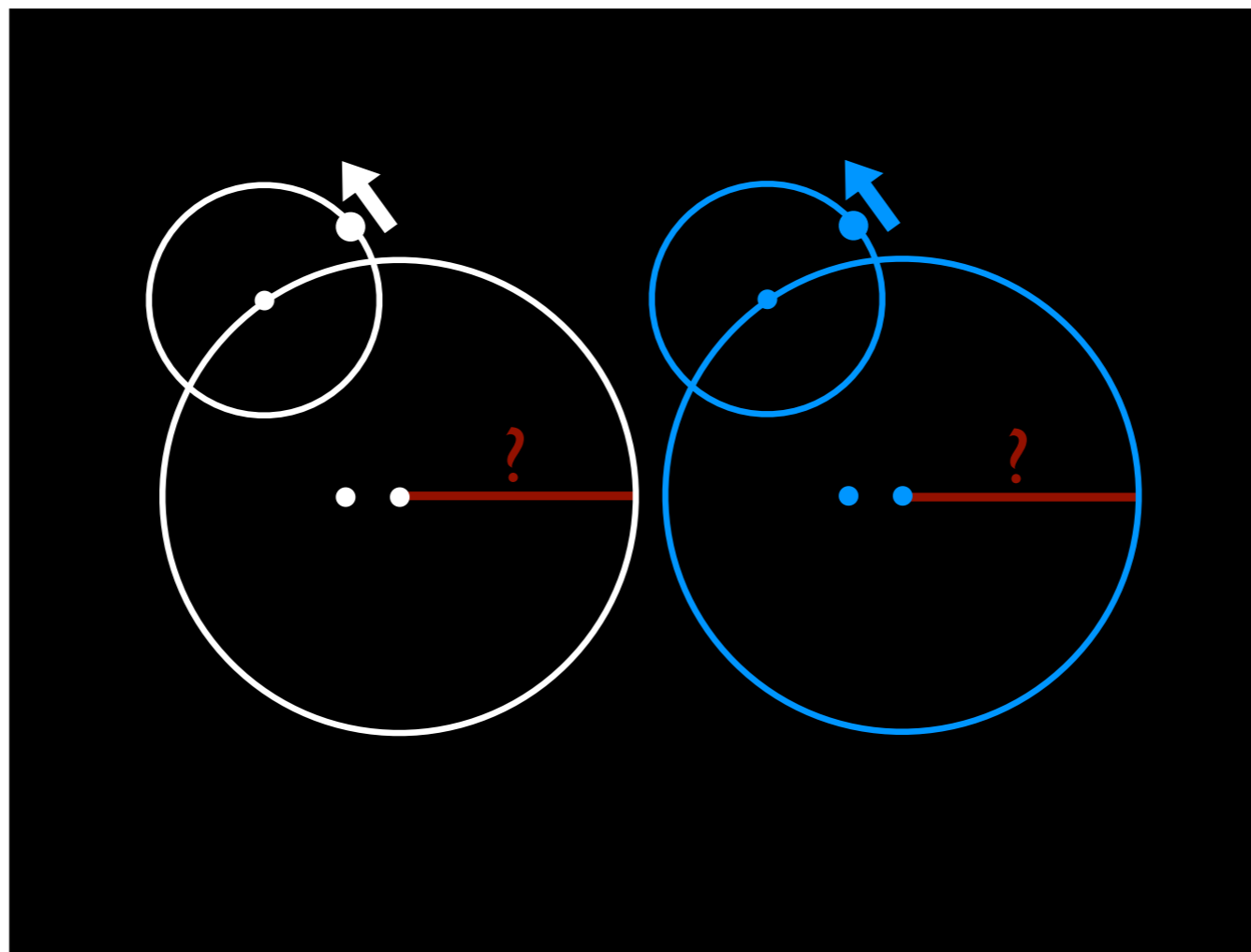
Monster or Man? If the parts of the cosmos do not fit together there is no telling what kind of creature astronomers might come up with. To Copernicus, the Ptolemaic cosmos was a Mr. Potato Head.



Here's another point of comparison: In Ptolemaic planetary models for the outer planets, radius lines in each large epicycle always remain parallel to the line from the Earth to the Sun. In other words, the line from the Earth to the Sun was inexplicably linked to the motions of the planets

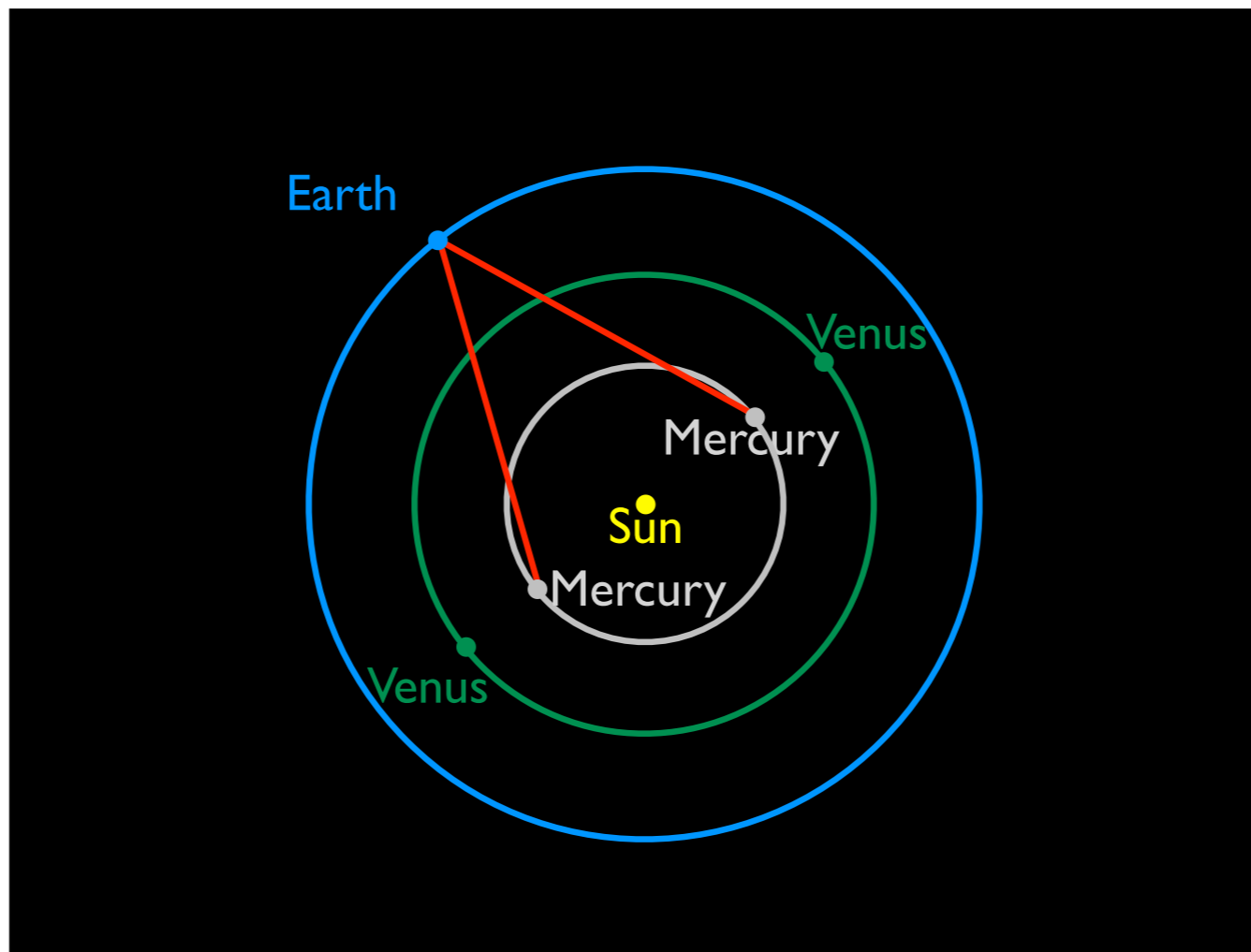


For the inner planets, the centers of the epicycles at all times remain on the line from the Earth to the Sun. (pause) There was no inherent reason why the Earth–Sun line should be linked to the motions of the planets in these ways. In the Ptolemaic system it was merely an odd coincidence. On the other hand, Copernicus explained, if one accepts the motion of the Earth, then all of these linkages are naturally explained; instead of an unexpected coincidence, the reasons become clear. In the Copernican system, all the planets become naturally linked in an intricately choreographed cosmic dance.

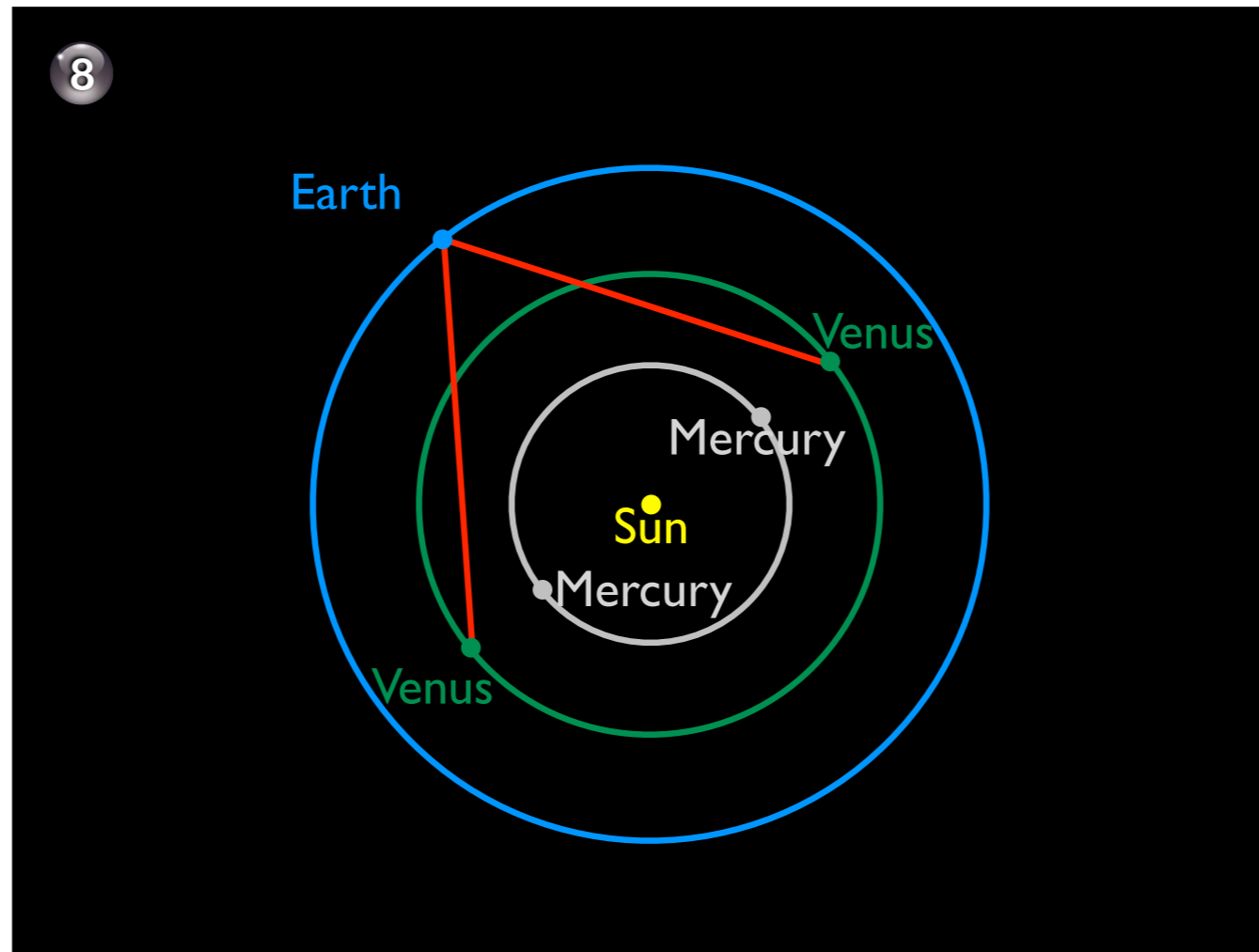


Another open question was the distances of the planets. In the Ptolemaic system, it was impossible to measure the relative sizes of planetary deferent circles. Therefore, the distances to the planets could not be calculated directly, apart from the assumption of nesting solid spheres. As a result, one could not determine the order or sequence of the planets. For example, in the Ptolemaic system, Mercury might lie closer to the Sun than Venus, or perhaps Venus lies closer to the Sun than Mercury; it is impossible to be sure.

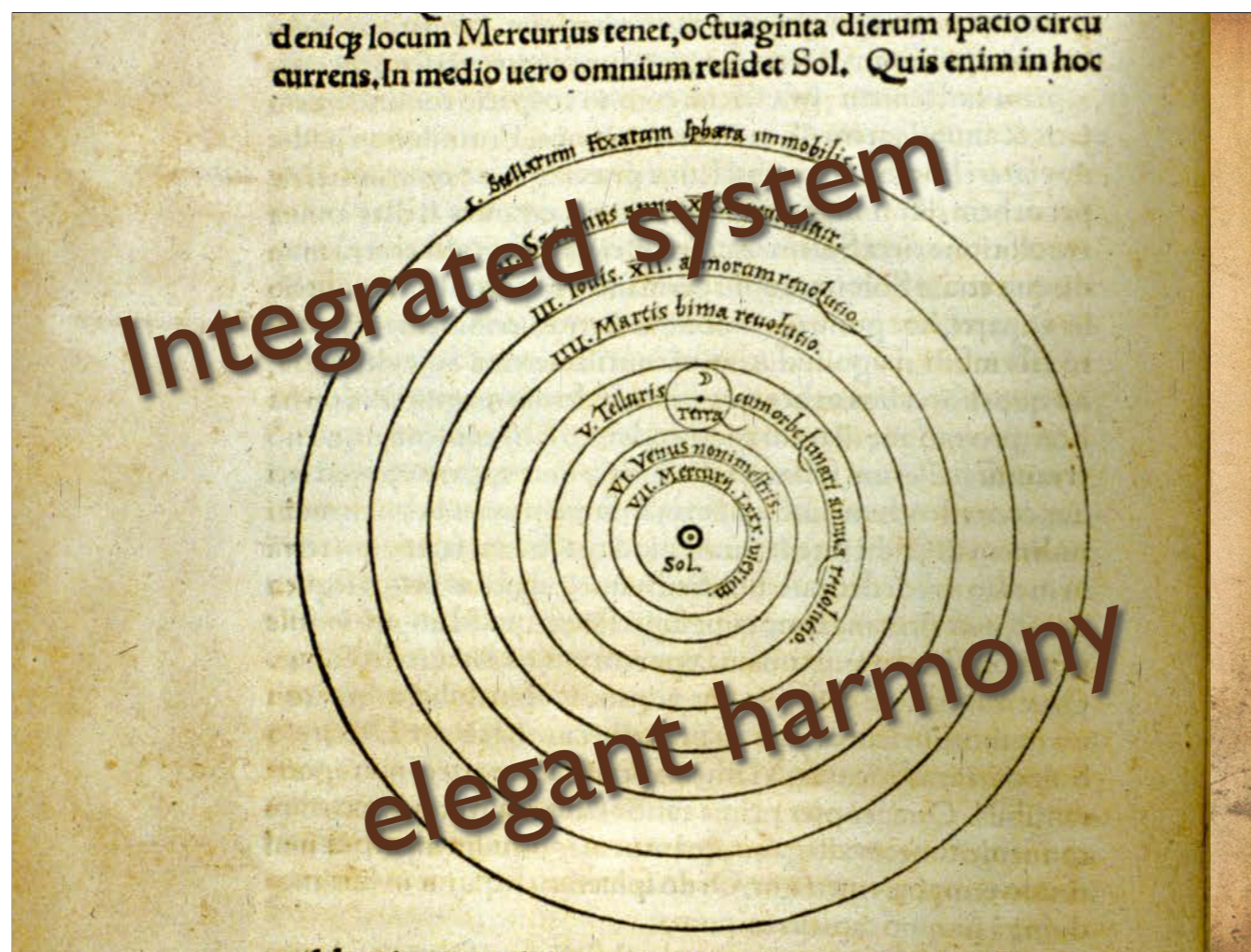
Copernicus, *De revolutionibus*, 1.10 (f. 8v).



On the other hand, in the Copernican system, the ORDER of all of the planets is fixed. The Copernican system specifies, for example, that Mercury must be closer to the Sun than Venus.



The Copernican system also specifies the DISTANCES of the planets, triangulating the sizes of the planetary deferents. Copernicus explained: “if the motion of the other planets is viewed in relation to the circular motion of the Earth... then... the order and sizes of all the orbs and spheres and heaven itself are so interconnected that in no portion of it can anything be shifted without disrupting the remaining parts and the entire universe.” Copernicus, Preface. Danielson, 107.



So the Ptolemaic system had no fixed scale determining the relative proportions of the universe. Copernicus showed that the Earth's motion relates the parts of the cosmos into a unified whole, a coherent and integrated system explaining the harmonies between the planetary motions, their distances and order. Similarly,...

Planet	Period
Fixed stars	Infinite (immobile)
Saturn	30 years
Jupiter	12 years
Mars	2 years
Earth	1 year
Venus	9 months
Mercury	80 days

In contrast to the Ptolemaic system, where there was no relationship between the planetary periods and their distances, the Copernican order of the planets corresponds with the lengths of their periods.

- The farther the planet from the Sun, the longer its period of revolution. This trend continues without interruption from Mercury's period of 80 days up to Saturn's period of 30 years. The infinite period of the now immovable fixed stars completes a perfectly consistent sequence. Copernicus insisted: "No one can propose a more fitting first principle than that the magnitude of a planet's sphere is proportionate to its period of revolution." [Copernicus, Book I, Chapter 10. Danielson, 116.] He concluded: Thus we discover in this orderly arrangement the marvelous symmetry of the universe and a firm harmonious connection between the motion and the size of the spheres...." [Copernicus, Book I, Chapter 10. Danielson, 117.]

Table of Copernican planetary periods: Mercury: 80 days; Venus: 9 months; Earth: 1 year; Mars: 2 years; Jupiter: 12 years; Saturn: 30 years; Fixed stars: immobile. Copernicus used two different sets of planetary distances. This table is taken from his famous diagram. He used a different set of values in the technical part of the book. I thank Katherine Tredwell for calling this and many other details to my attention.

AD SANCTIS-
SIMVM DOMINVM PAV-
LVM III. PONTIFICEM MAXIMUM,
Nicolai Copernici Præfatio in libros
Reuolutionum.



ATIS equidem, Sanctissime Pater, æ-
stimare possum, futurum esse, ut simul
atq; quidam acceperint, me hisce meis li-
bris, quos de Reuolutionibus sphaerarū
mundi scripsi, terræ globo tribuere quos-
dam motus, statim me explodendum
cum tali opinione clamitent. Neq; enim
ita mihi mea placent, ut nō perpendam,
quid alij de illis iudicaturi sint. Et quamuis sciam, hominis phi-
losophi cogitationes esse remotas à iudicio vulgi, propterea
quòd illius studium sit ueritatem omnibus in rebus, quatenus
id à Deo rationi humane permissum est, inquirere, tamen aliē-
nas prorsus à rectitudine opiniones fugiendas censeo. Itaq; cū
mecum ipse cogitarem, quā absurdum ἀνθρώπων existimatu-
m illi quidam seculorum iudicis hanc opinionē

There were symbolic advantages to the Sun-centered system as well. In the papal dedication, Copernicus infused the center of the cosmos with new dignity, describing it as the center of a Temple, fit only for a lamp as noble as the Sun. He wrote: “Behold, in the middle of the universe resides the Sun. For who, in this most beautiful Temple, would set this lamp in another or a better place, whence to illumine all things at once? For aptly indeed do some call him the lantern—and others the visible god, and Sophocles’ Electra, the Watcher of all things. Truly indeed does the Sun, as if seated upon a royal throne, govern his family of planets as they circle about him.” Copernicus, Book I, Chapter 10. Danielson, 117.



Copernicus elevated the Earth's status by transforming it into a planet that moves in the heavens.

- In the geocentric cosmos, the Earth was located at the unworthy center of death and corruption. In contrast, for Copernicans such as Galileo, the Earth "is not the sump where the universe's filth and ephemera collect," but rather participates in the dance of the stars.

Intro	Front Matter
Two Themes	System
Early Life	Problems
Celestial Spheres	
Publication	

So if these considerations of integration and harmony might persuade one to accept Copernicus' ideas, what were the problems with his views? Why did most people remain unpersuaded?

A diagram of Copernicus' heliocentric model of the universe. At the center is a small circle labeled 'Sol' (the Sun). Concentric circles around it represent the orbits of the planets. From the inside out, the orbits are labeled: 'Mercurius', 'Venus', 'Telluris' (Earth), 'Luna' (Moon), 'Mars', 'Jovis' (Jupiter), and 'Saturnus'. The outermost circle is labeled 'I. Stellarium fixarum sphaera' (the sphere of fixed stars). The diagram is a historical manuscript page with Latin text and a large, ornate initial 'P' at the top left.

Problems

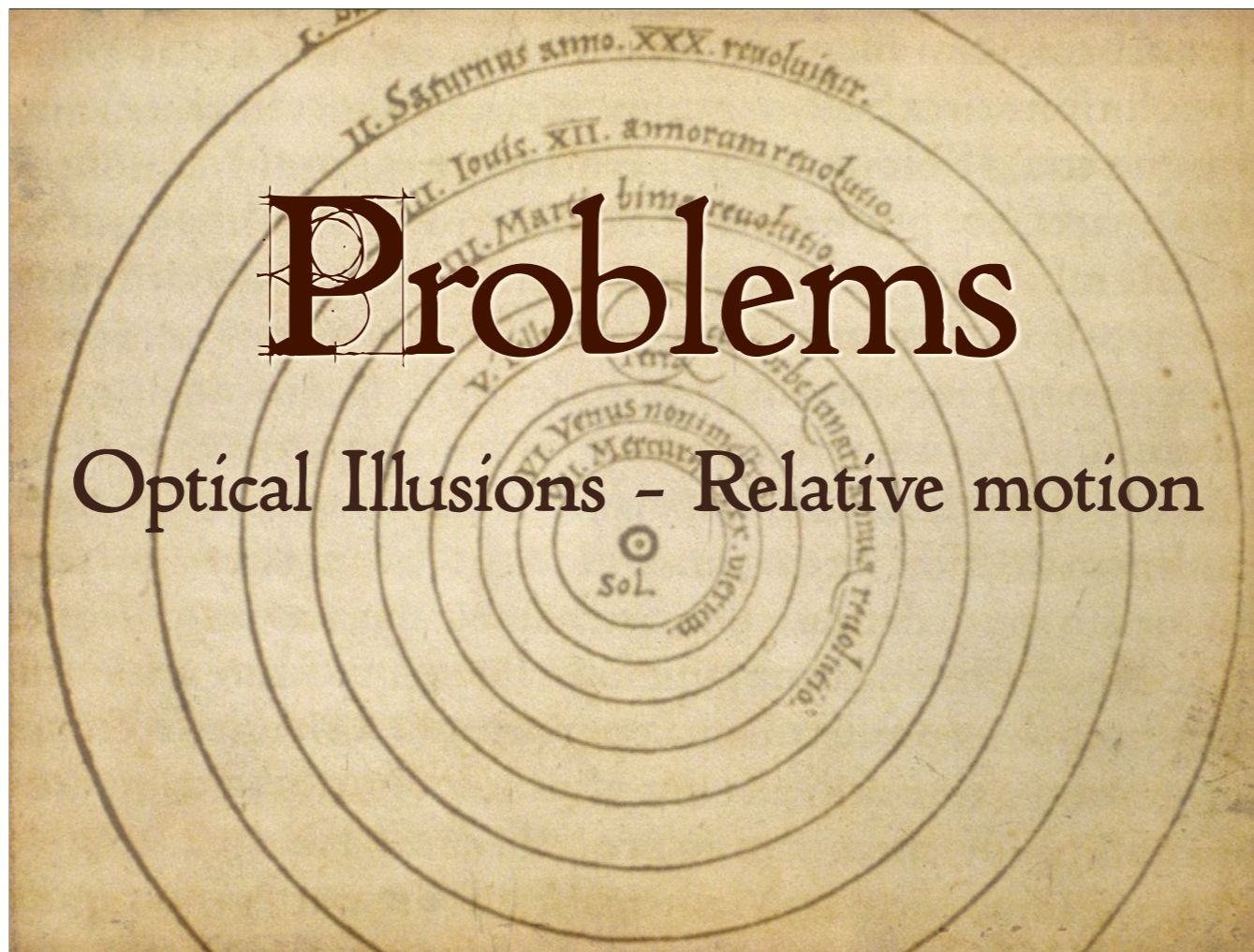
Optical Illusions - Relative motion

Physics

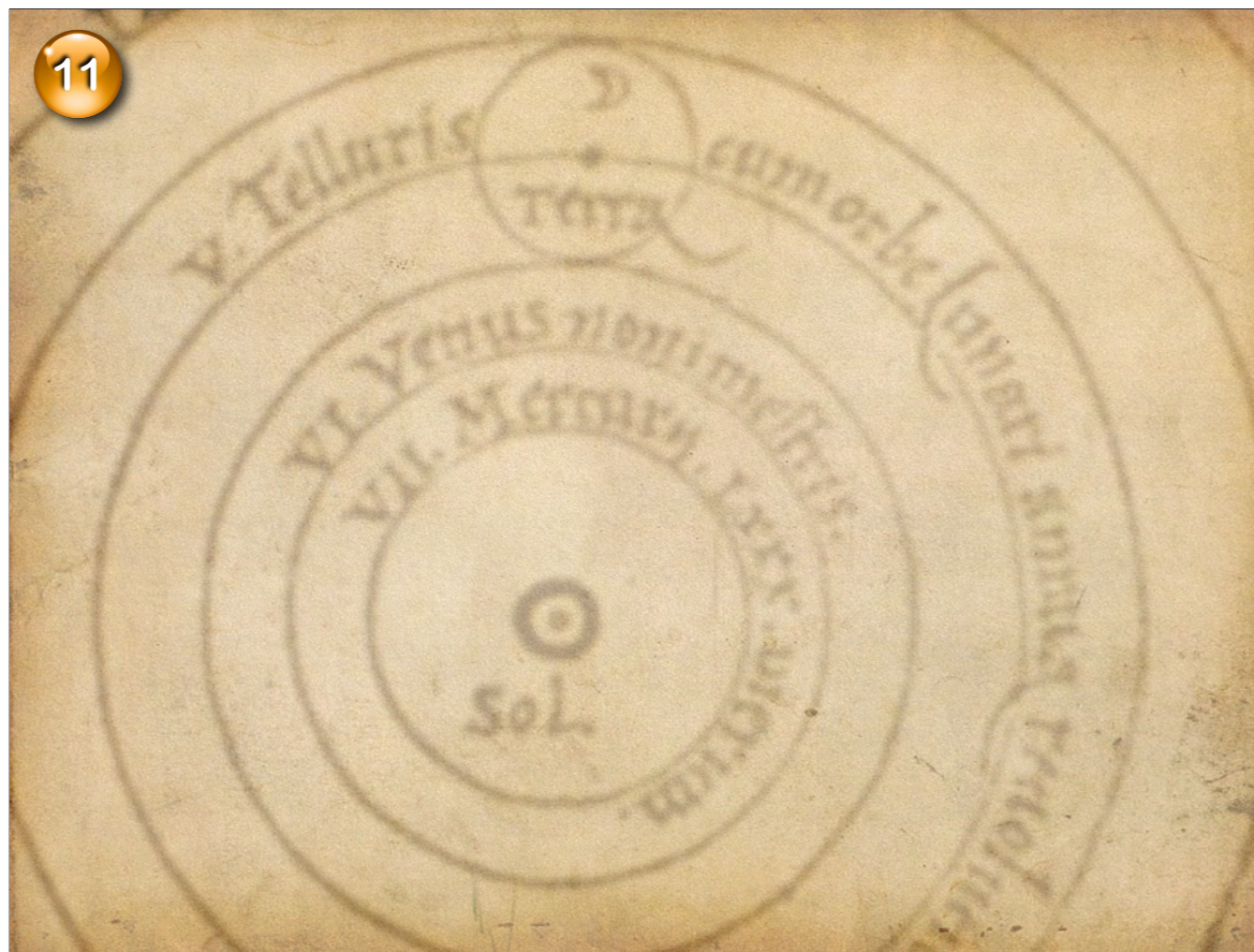
Astronomy

Aesthetics

In 1543 little proof was available that the Earth moves; there were many reasons not to accept it. How did Copernicus surmount these common objections?

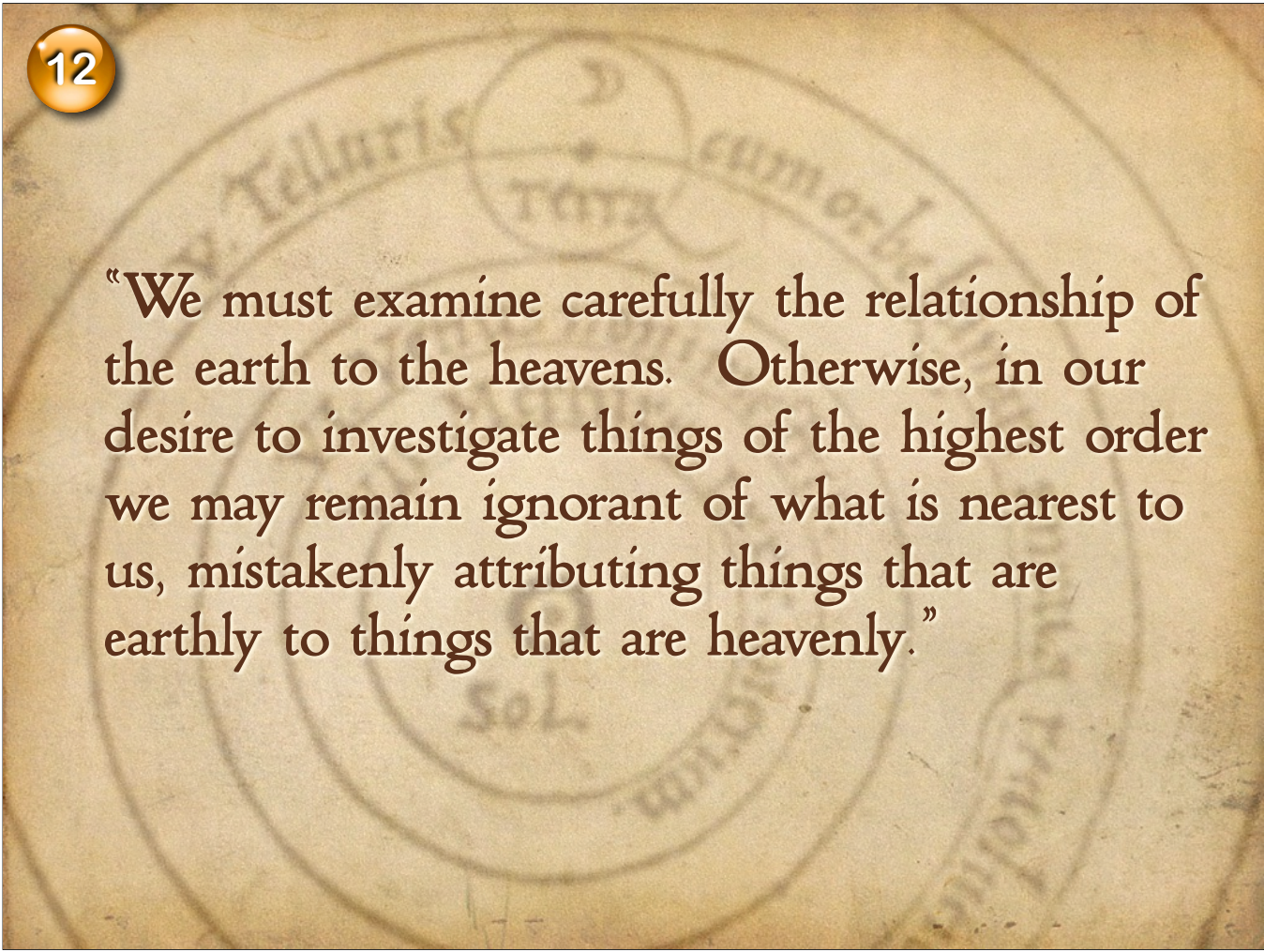


Let's first consider problems of optics, perspective, and optical illusions that arise due to relative motion.



Of course, the motion of the Earth cannot be directly observed. The evidence of our senses often deceives us, yet we naturally give weight to common sense and ordinary observation. According to optics, to overcome the prejudices of common sense, one begins by considering the perspective of the observer:

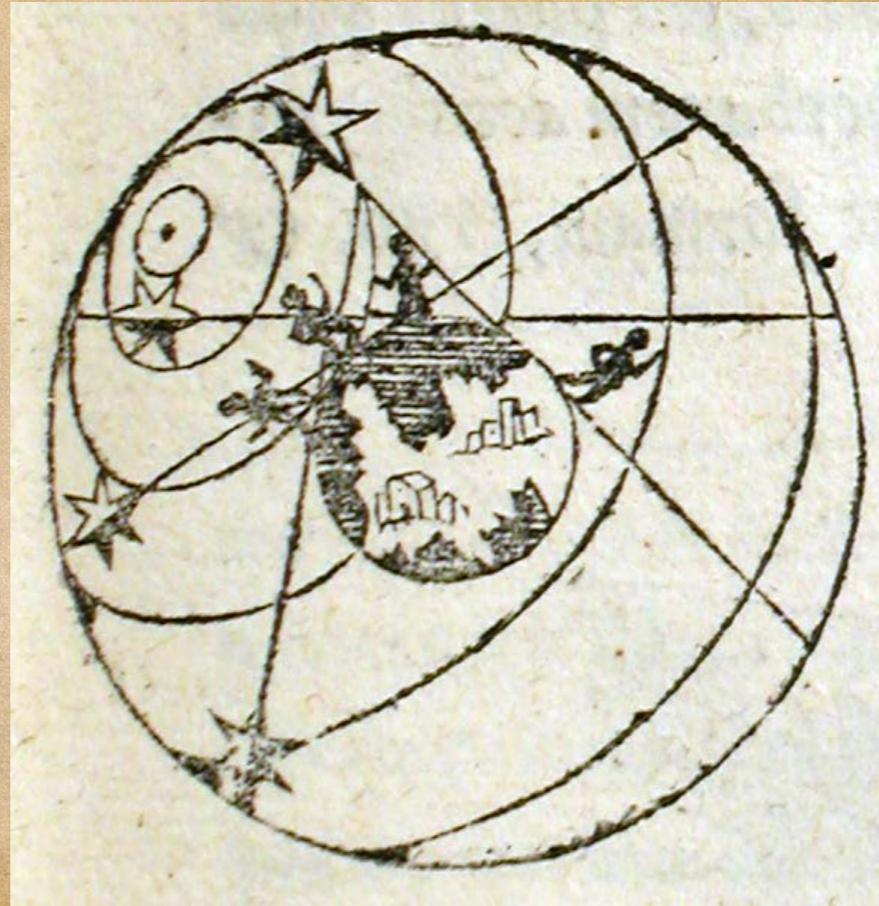
[“This whole matter is difficult, almost paradoxical, and certainly contrary to many people’s way of thinking.... God helping me, I shall make these things clearer than sunlight, at least to those not ignorant of the art of astronomy.” Copernicus, Book I, Chapter 10. Danielson, 116.]



“We must examine carefully the relationship of the earth to the heavens. Otherwise, in our desire to investigate things of the highest order we may remain ignorant of what is nearest to us, mistakenly attributing things that are earthly to things that are heavenly.”

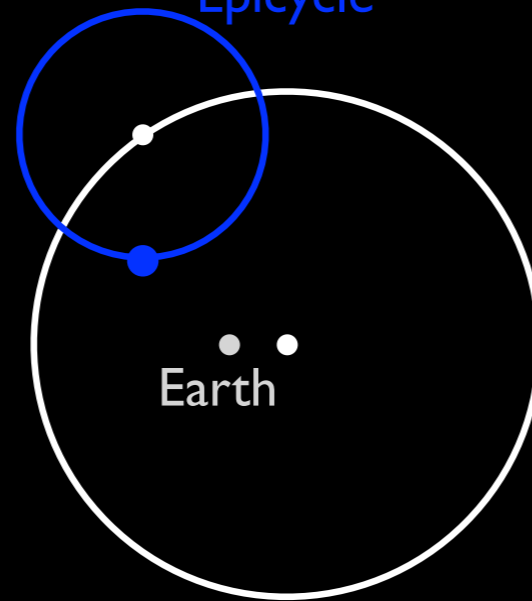
“We must examine carefully the relationship of the earth to the heavens. Otherwise, in our desire to investigate things of the highest order we may remain ignorant of what is nearest to us, mistakenly attributing things that are earthly to things that are heavenly.” [Copernicus, Book I, Chapter 4. Danielson, 111.]

Because of relative motion, what we observe as the apparent motion of the heavens is largely due to the motion of the Earth. We ride a boat sailing through space, and what we observe is not a true movement of the planets but a combination of their movement and our own.

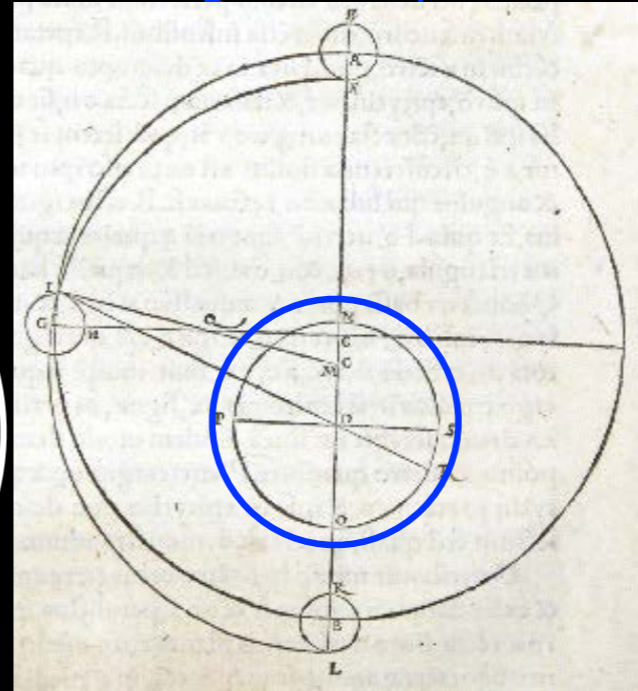


This principle of relative motion applies to the motions of the stars and the planets. With respect to the daily motion of the stars, relative motion explains why the stars appear to rotate around the Earth once each day. The same diurnal motion of the stars results whether the heavens spin around the Earth, or whether the Earth spins in the opposite direction. Copernicus explained: "It is like the case spoken of by Virgil's Aeneas: 'We sail forth from the harbor, and lands and cities draw backwards.' For when a ship glides along smoothly, its passengers see its motion reflected by everything outside of the ship and, by contrast, suppose themselves and everything else on board to be motionless. No wonder, then, that the movement of the Earth makes us think the whole universe is turning round." Copernicus, Book I, Chapter 8. Danielson, 115.

Ptolemy:
Retrograde
Epicycle

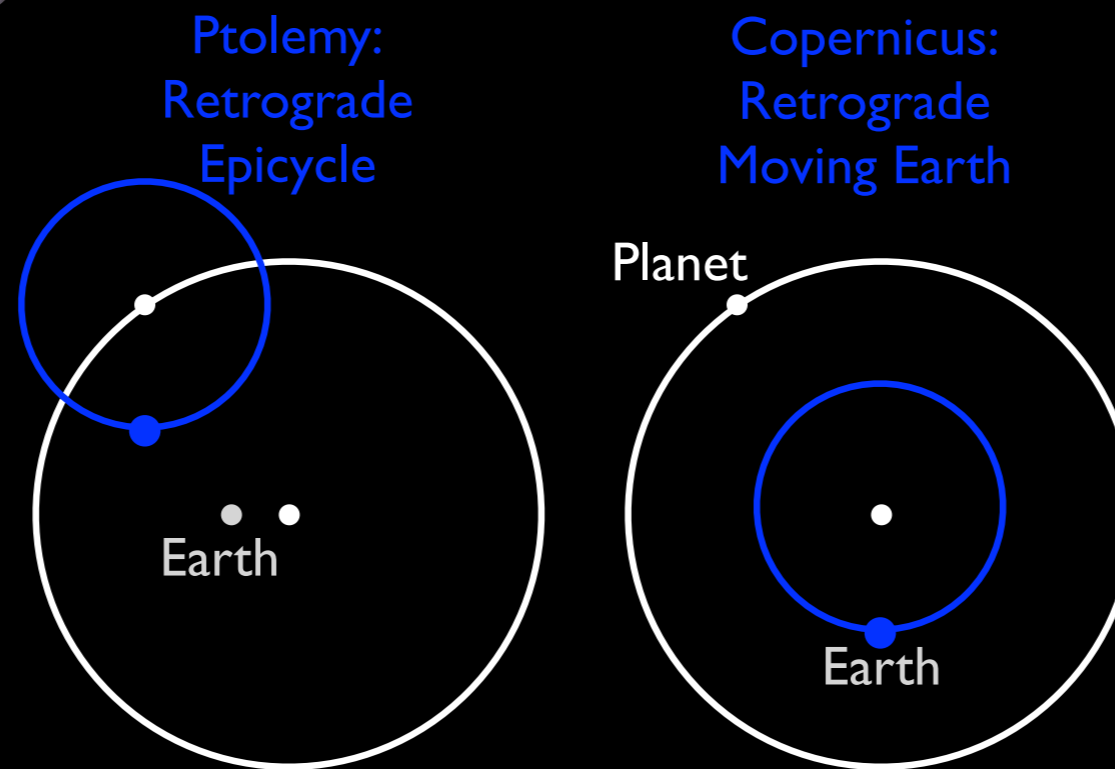


Copernicus:

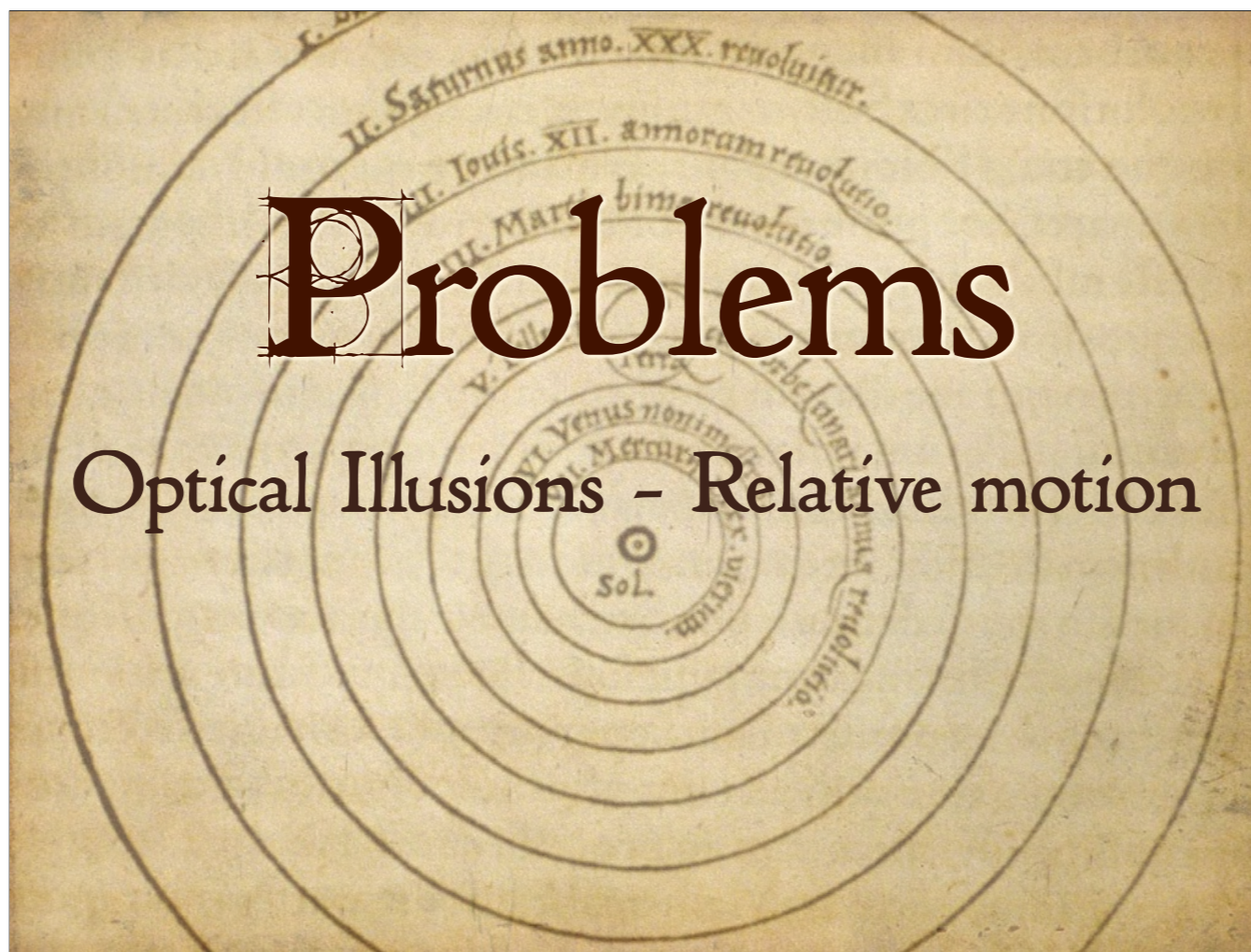


Relative motion also explains why the planets appear to reverse direction and trace retrograde loops in the sky.

- The large blue epicycle that accounts for the retrograde motion of the outer planets in the geocentric system is no longer needed when the center is shifted to the Sun, for in the Copernican model these epicycles are replaced by the circle of the annual motion of the Earth. Copernicus explained: "If the Earth moves [instead of the Sun]... then the risings and settings of the constellations and fixed stars... will appear just as they do. Furthermore, the stations and retrograde motions of the planets will be seen not as their own motions but as earthly motion transmuted into apparent planetary motions." Copernicus, Book I, Chapter 9. Danielson, 115.



Because of the relativity of motion, the models of Ptolemy and Copernicus produce equivalent observations. There is no way to prove one versus the other on the basis of the apparent motions of the stars and planets.



So the first problem, that a moving Earth seems to violate common sense, was addressed by the principle of relative motion.

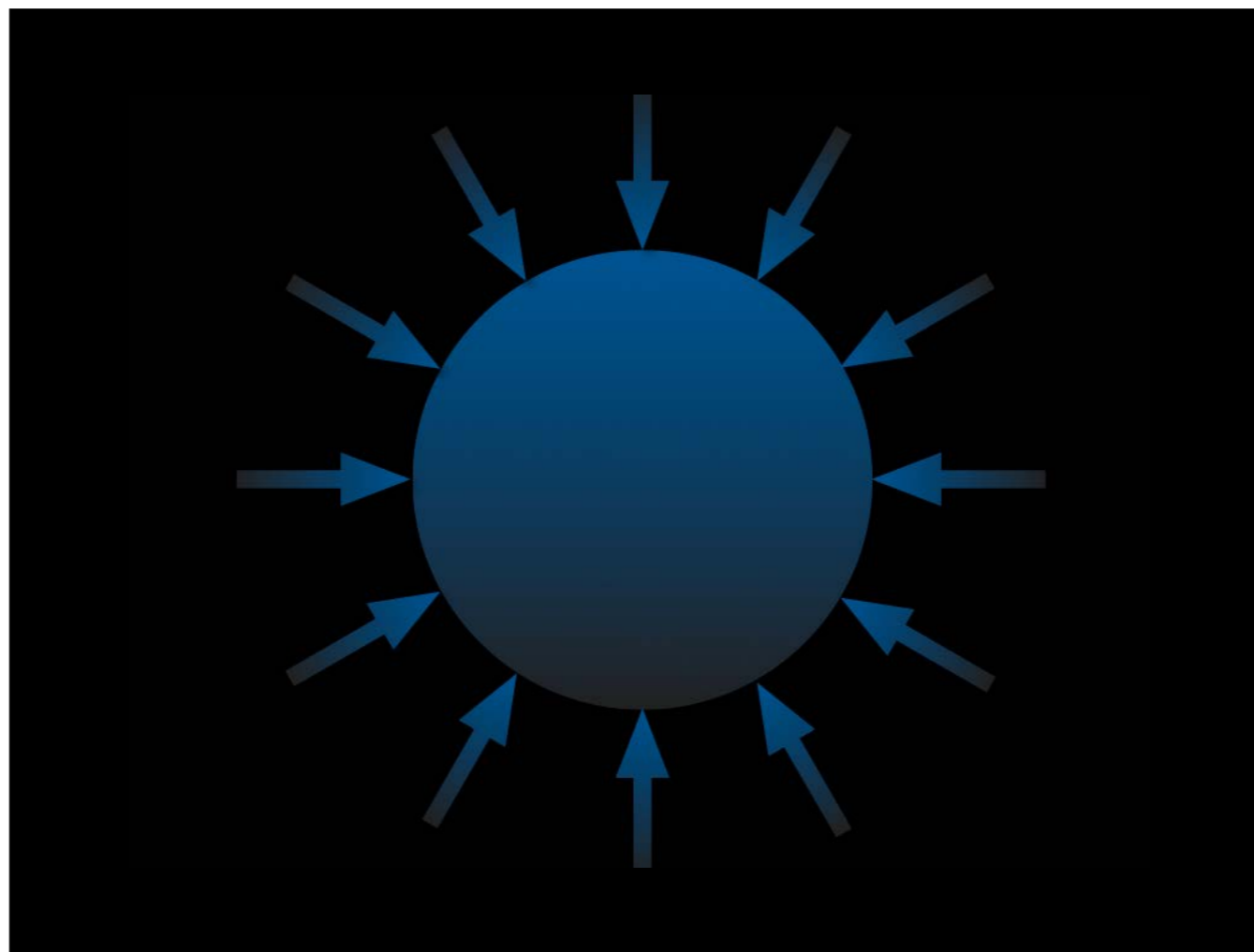
A diagram of Copernicus's heliocentric model of the universe. At the center is a small circle labeled 'SOL' (the Sun). Concentric circles represent the orbits of the planets, labeled from the center outwards: 'Mercurius', 'Venus', 'Telluris' (Earth), 'Mars', 'Iovis' (Jupiter), and 'Saturnus'. Each planet's orbit is accompanied by text indicating its orbital period: 'Mercurius. LX. dies', 'Venus. octiduum', 'Telluris. annus', 'Mars. biennis', 'Iovis. XII. annorum', and 'Saturnus. XXX. annorum'. The diagram is drawn on aged, yellowed paper.

Problems

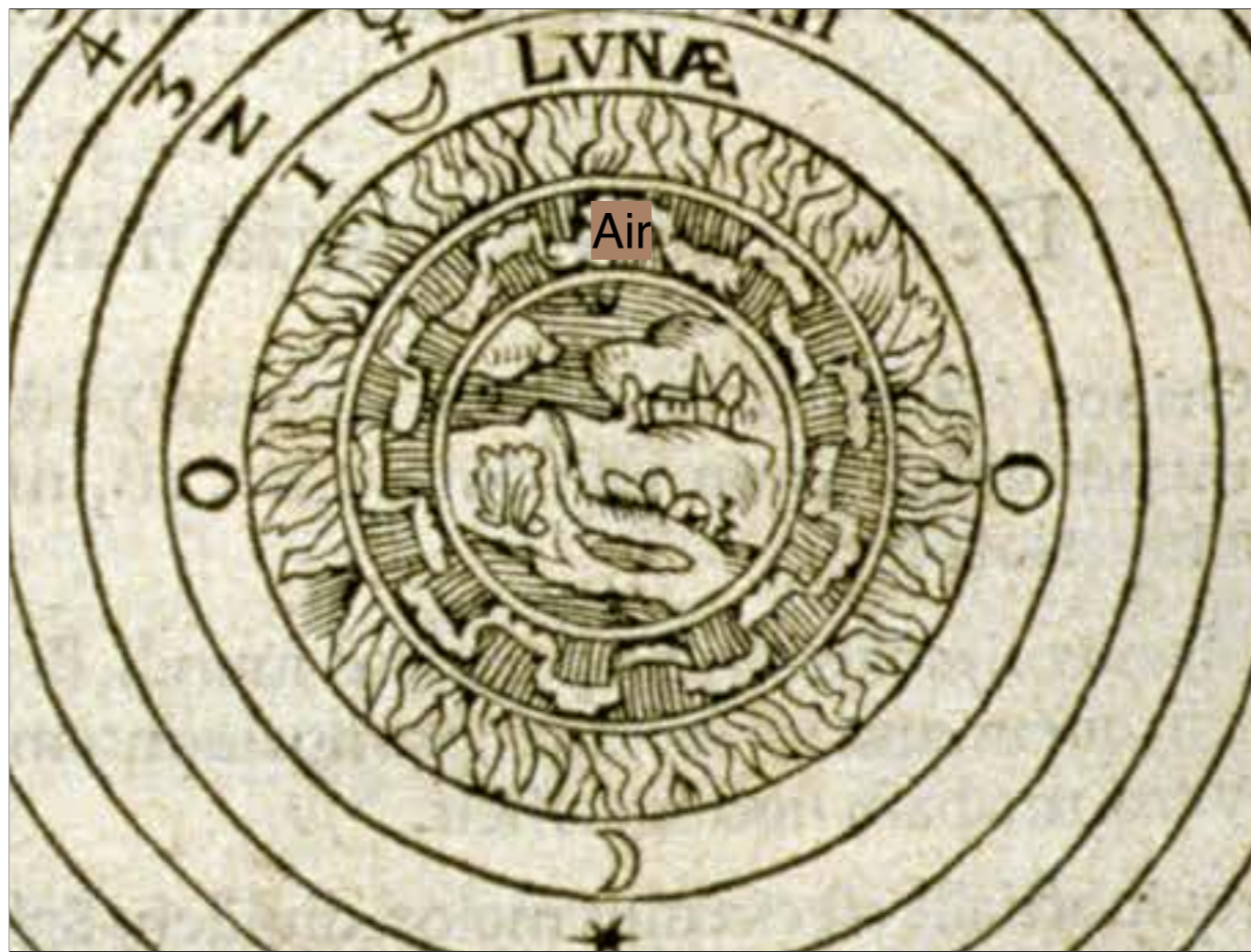
Optical Illusions - Relative motion

Physics - Natural place

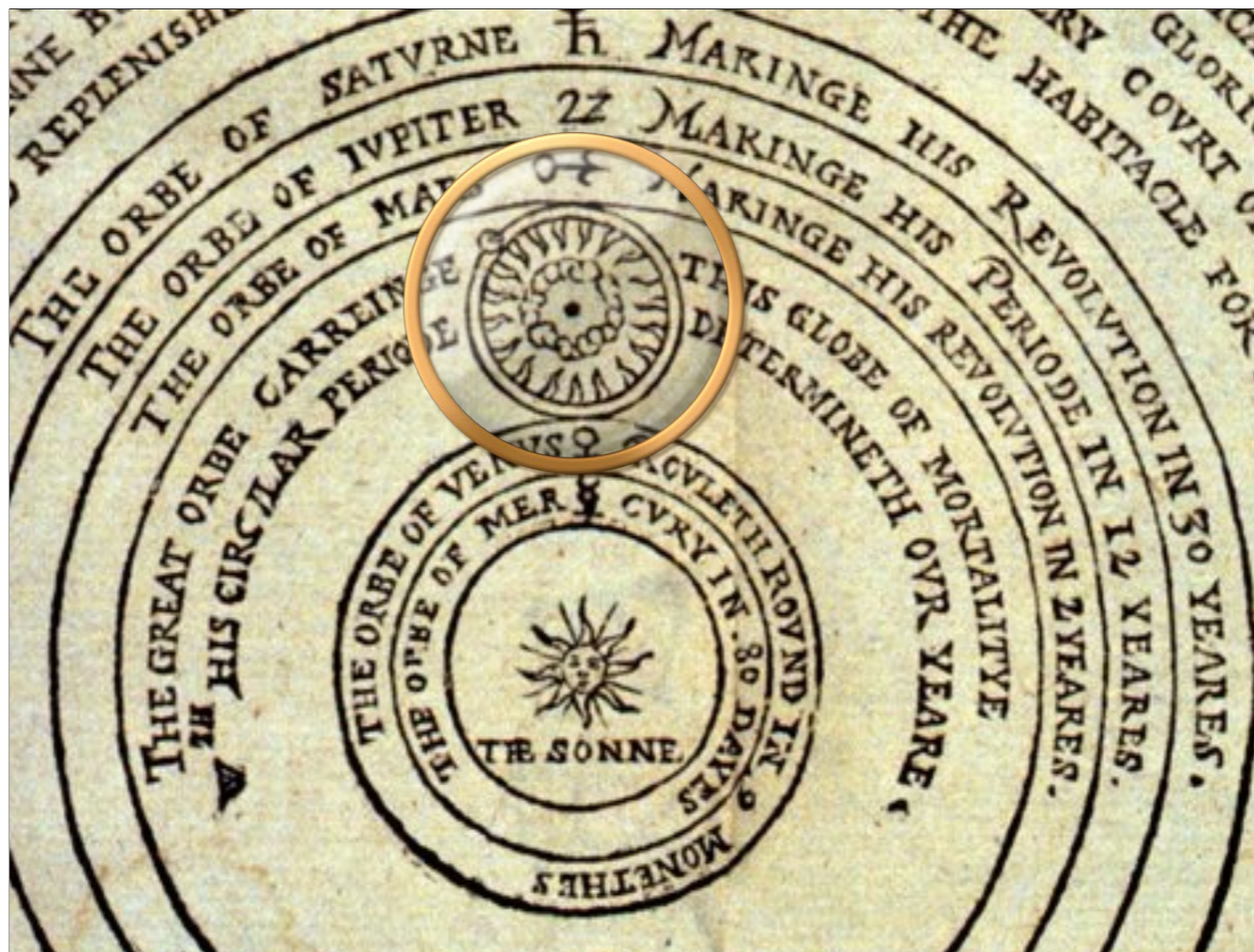
Another problem was that the Copernican cosmos flatly contradicted the physics of natural place.



According to Aristotle, every element seeks its natural place; an earthy body falls toward the center of the universe. If earthy matter falls from all sides, then the Earth as a body must be a globe at rest in the center of the universe.



The natural place of air, also, is downward, resting on top of water and earth. So one might question: if the Earth is moving, why doesn't the Earth leave its atmosphere behind? Wouldn't the loss of wind be felt in a single great rush as the Earth moves away? How could the atmosphere endure intact around a moving Earth?



To answer this objection, Copernicus suggested that the Earth and its circumjacent elements move together. If it is natural for the Earth to move, then it will also be natural for the water and air to move with it. This was a huge redefinition of natural place. Many medieval physicists, including Jean Buridan, Nicole Oresme, and William Ockham, were willing to take this step. However, to those who did not share this belief that earth could have a natural motion other than toward the center of the universe, Copernicus seemed to beg the question.

A diagram from Copernicus' 'De revolutionibus' showing a heliocentric system with the Sun at the center and concentric orbits for the planets. The orbits are labeled with Roman numerals and the names of the planets in Latin. The text 'I. Sol' is at the center, followed by 'II. Mercurius', 'III. Venus', 'IV. Terra', 'V. Mars', 'VI. Iovis', and 'VII. Saturnus'. The orbits are labeled with their respective periods: 'I. Sol', 'II. Mercurius. annorum. VIII. revolutio.', 'III. Venus. annorum. VII. revolutio.', 'IV. Terra. annorum. VI. revolutio.', 'V. Mars. annorum. II. revolutio.', 'VI. Iovis. annorum. XII. revolutio.', and 'VII. Saturnus. annorum. XXX. revolutio.'.

Problems

Optical Illusions - Relative motion

Physics - Natural place

So the theory of natural place in physics required rethinking.



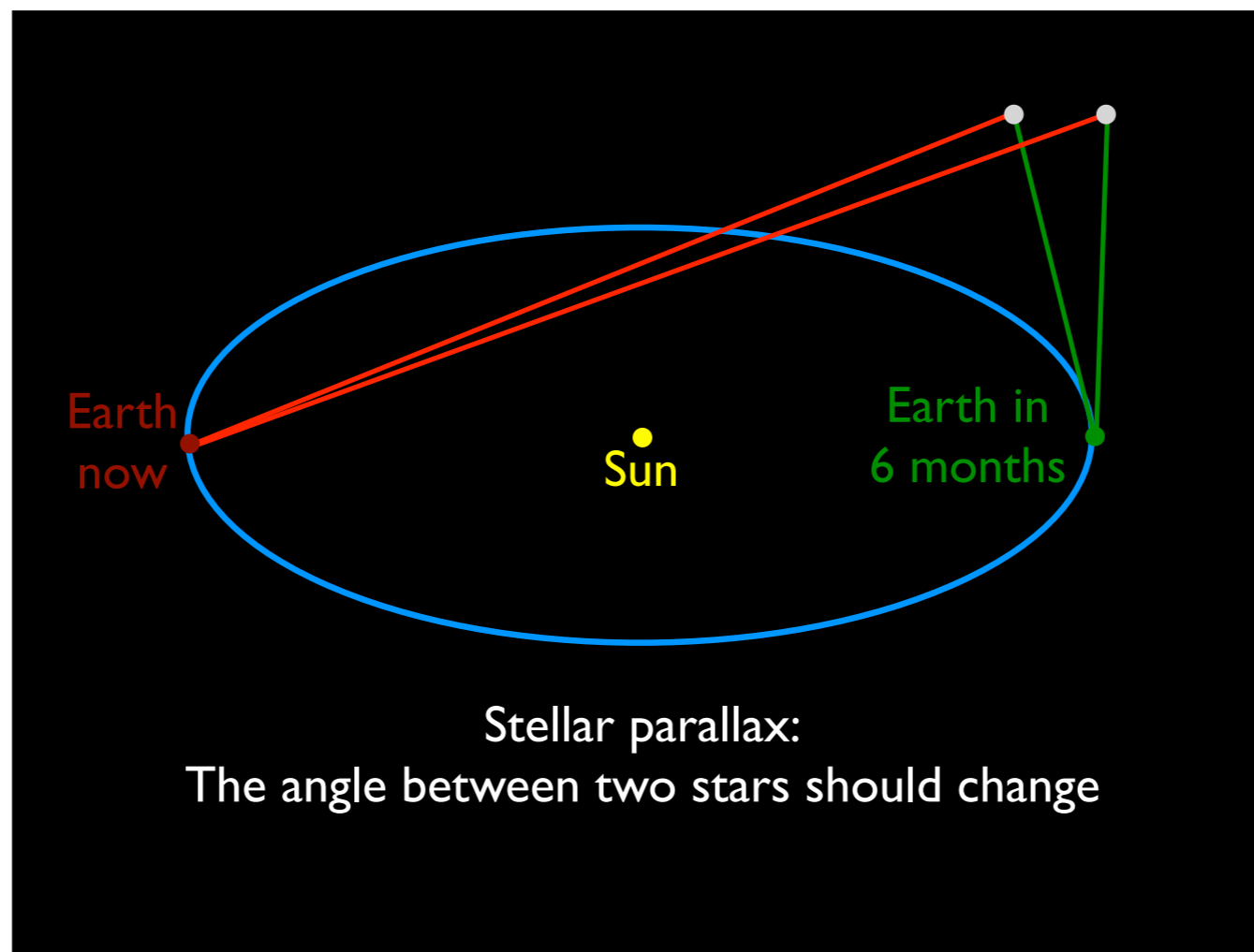
Problems

Optical Illusions - Relative motion

Physics - Natural place

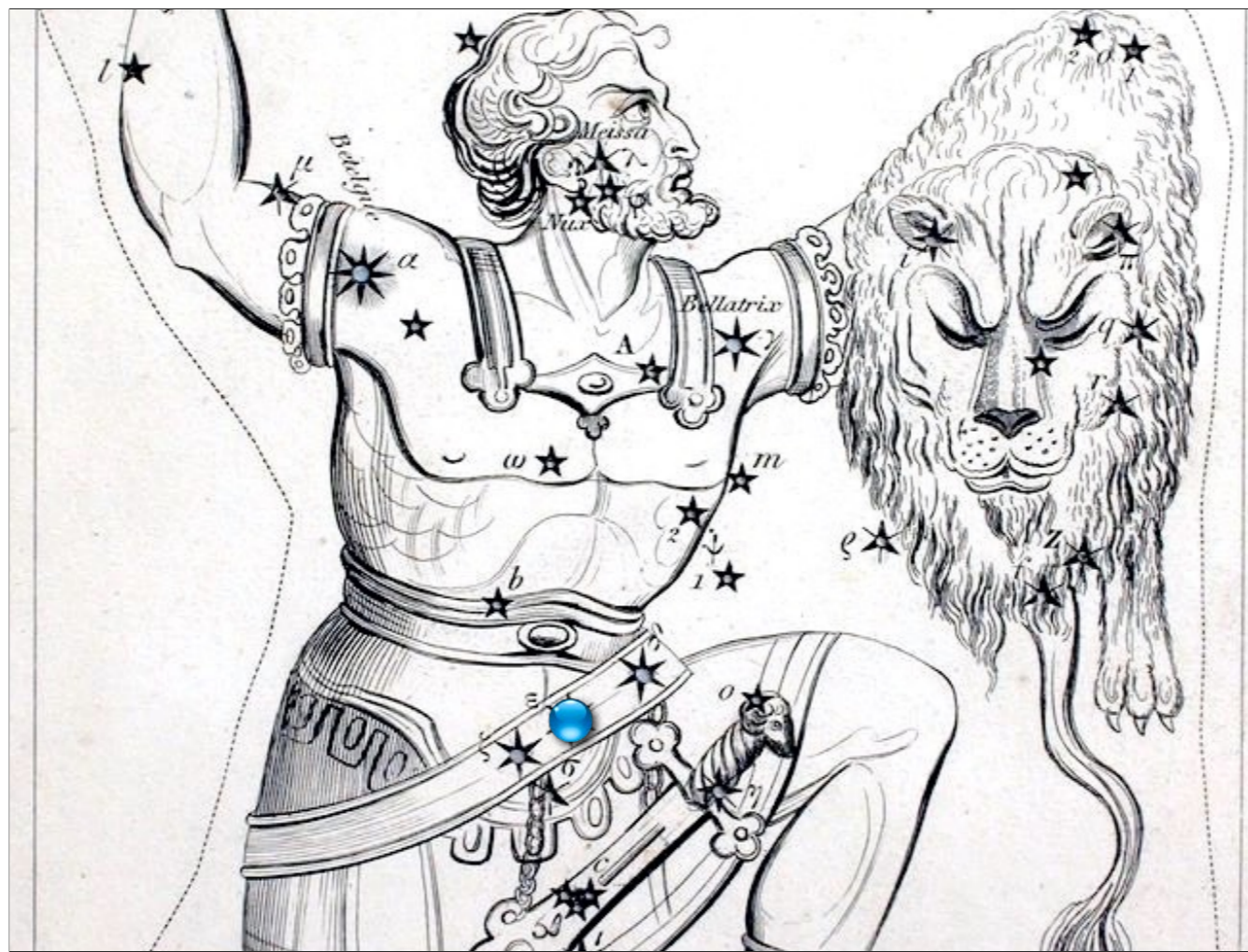
Astronomy

There were also objections from astronomy.

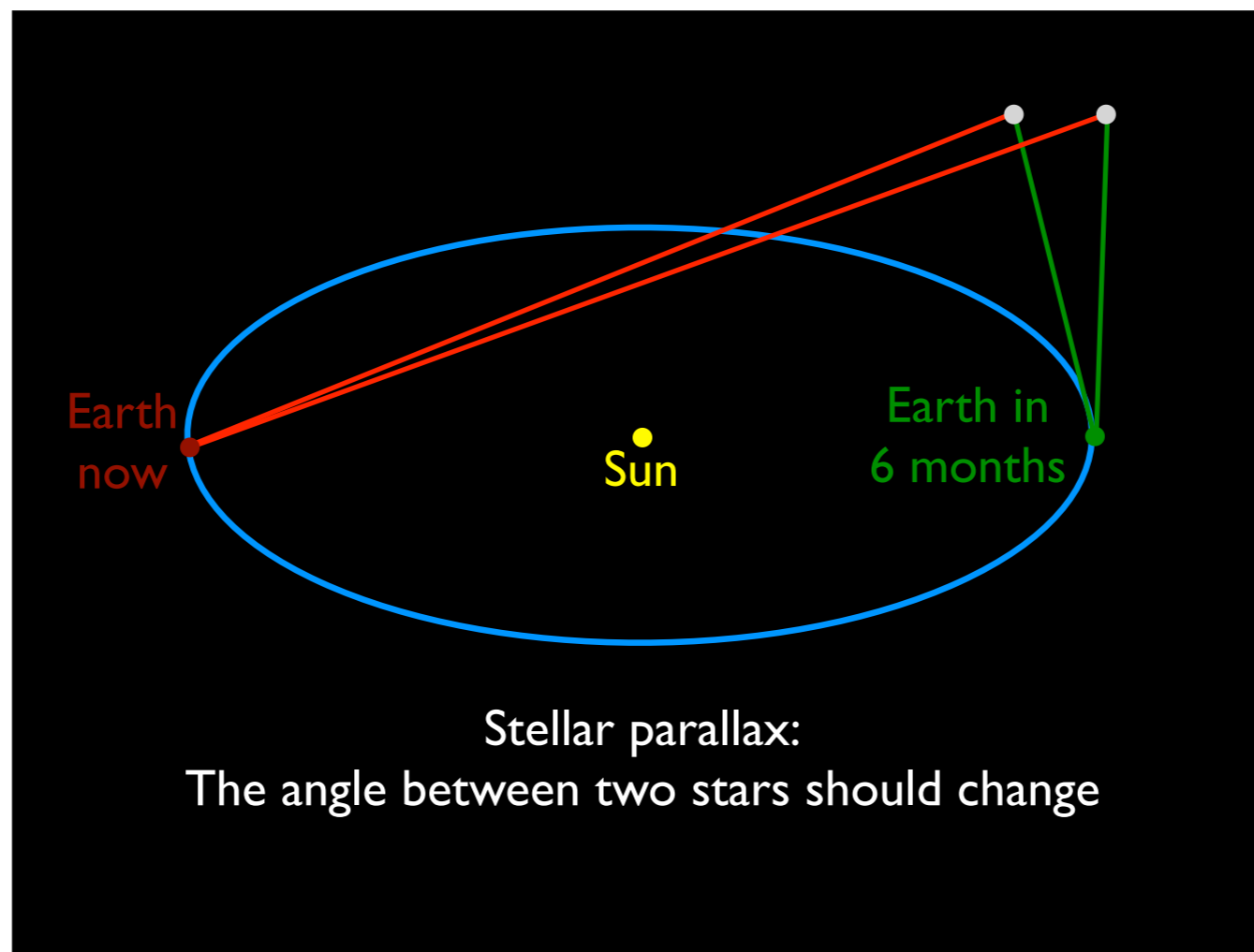


One problem from astronomy was that if the Earth moves, one should observe stellar parallax, or a shifting in the angles between stars over time.

- That is, if we measure the angle between any two stars today,
- then if the Earth is traveling around the Sun, there should be a slight change in the same angle six months from now.



Consider the constellation of Orion the Hunter. Focus on the middle star of Orion's belt. Close your right eye, and hold up your thumb so that it aligns with this star. Without moving your thumb, close your left eye and open your right. When you switch back and forth between eyes, does the position of your thumb appear to shift along the belt of Orion? This is parallax, and something like it should be observed if the Earth shifts its position in space every six months as it moves around the Sun.



From antiquity, stellar parallax was not observed, and this failure disproved the heliocentric model. Most people took this observation as a decisive refutation of the theory. Persuaded on other grounds, however, Copernicus insisted upon the deficiency of human observation. Setting aside the evidence of the senses, Copernicus argued that the fixed stars must lie at such immense distances that the parallax caused by the Earth's motion is too small to be observed.*

*Copernicus, Book I, Chapter 10.



Others were troubled by the idea of planetary satellites. In the Ptolemaic system, the Moon was a planet. Yet in the Copernican system, the Moon is no longer a planet, but a satellite of planet Earth. So one might ask: as a satellite revolves around a planet, or as the Moon revolves around the Earth, how could the Moon keep up if the Earth is moving at the same time?



Problems

Optical Illusions - Relative motion

Physics - Natural place

Astronomy

In addition to these problems,



Problems

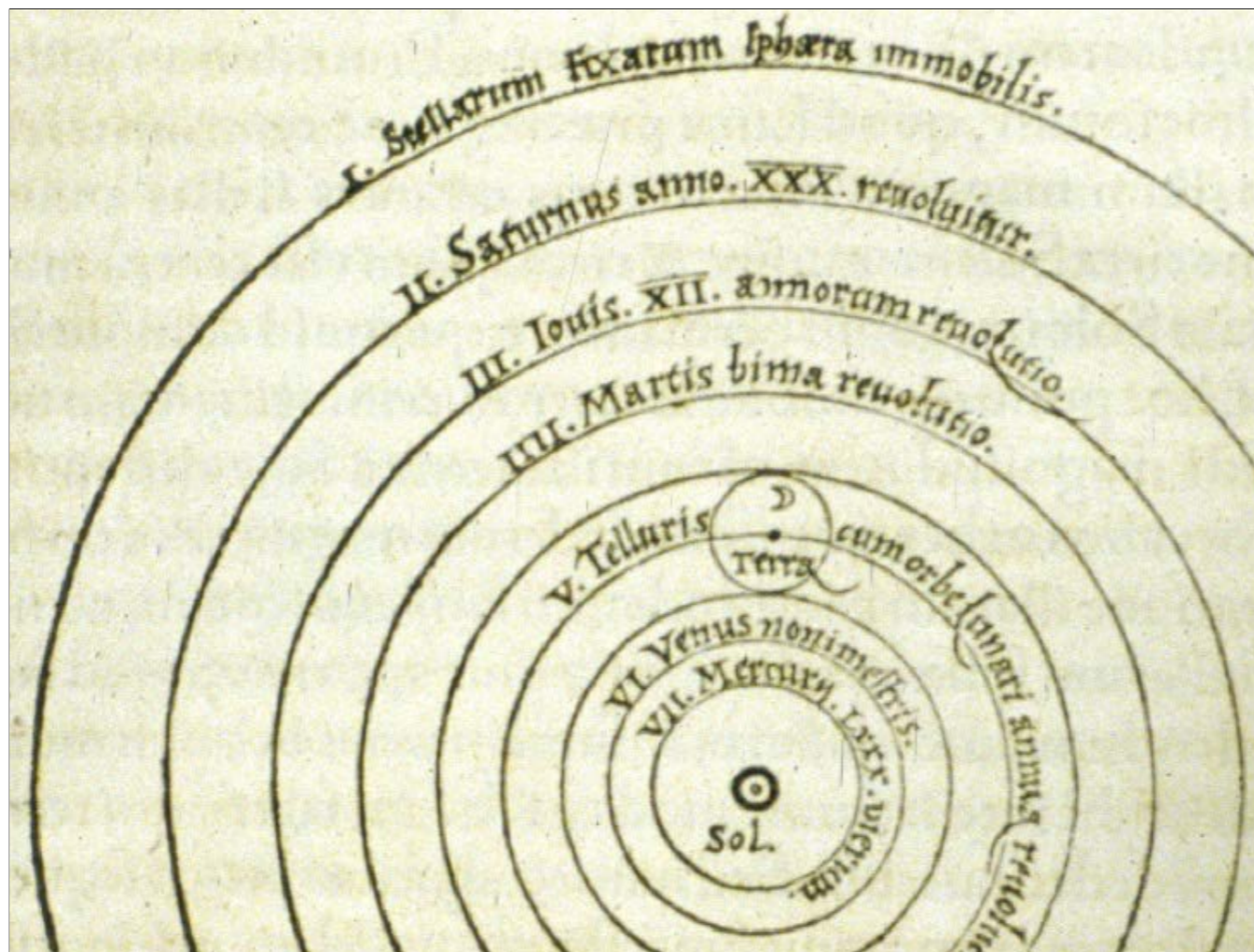
Optical Illusions - Relative motion

Physics - Natural place

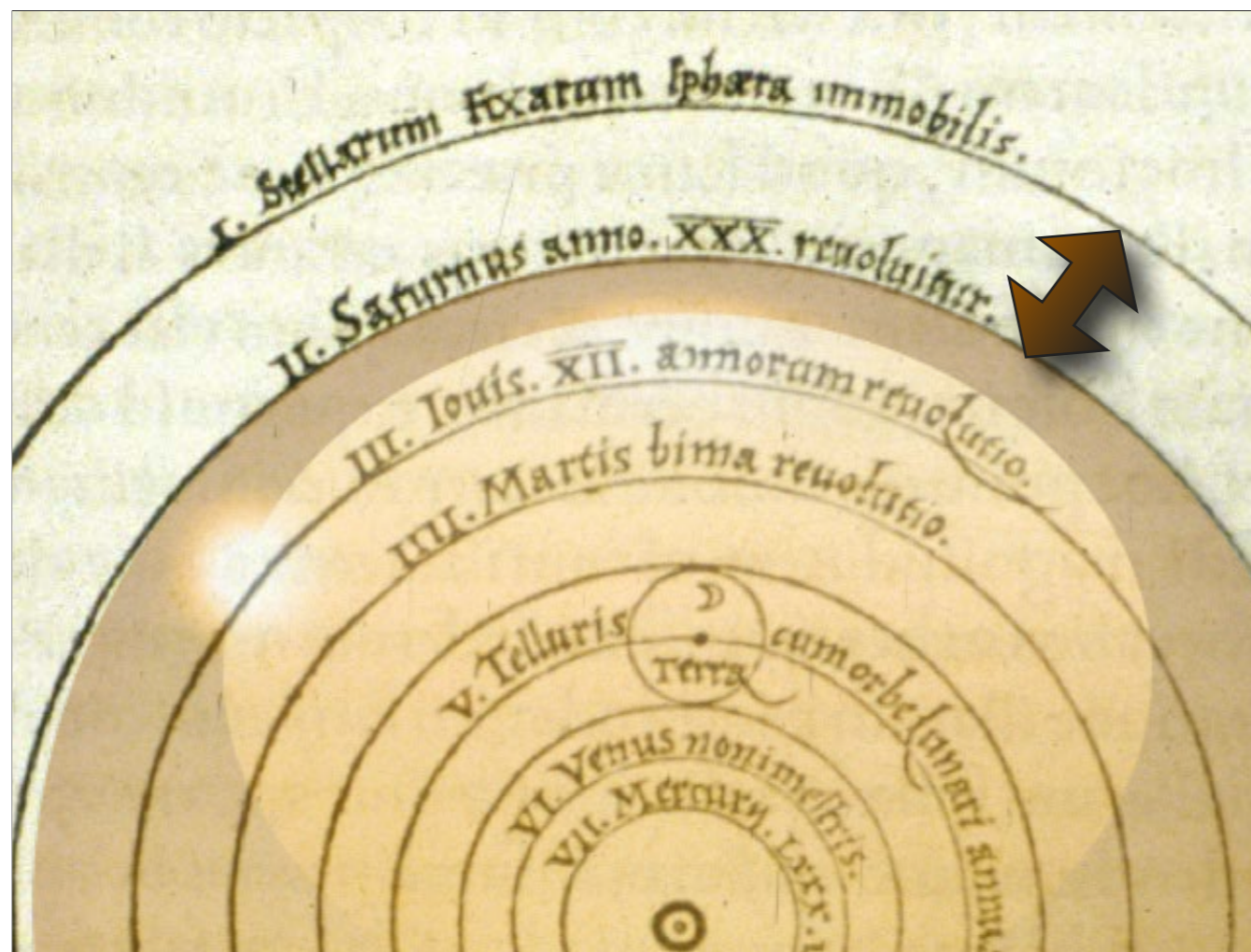
Astronomy

Aesthetics

There were also objections arising from aesthetics. Among aesthetic criteria, simplicity is pre-eminent. But how is simplicity defined? If it consists simply of counting the number of circles, then Copernicus did not represent a significant improvement. When one gets down to the details of the models, Copernicus added many smaller epicycles, so his total number of circles was about the same as for Ptolemy.



Copernicus showed how the motions of the planets are linked in many elegant ways. Yet critics did not admire the needless proliferation of centers of revolution. In the Ptolemaic system all planets revolved around a single body, the Earth. In the Copernican system not every body revolves around the center, because the Moon, no longer a planet, revolves around the Earth instead of the Sun. Why should there be multiple centers of revolution in a single universe?



Although Copernicus insisted upon the solid spheres of the planets, to explain the absence of stellar parallax he required a vast distance between the planetary spheres and the fixed stars.

- This giant gap was conspicuous by its absence in the famous Copernican section. What might fill that gap? One might wonder if the universe were actually infinite in size...

Quæ omnia ex eadem causa procedunt, quæ in telluris est motus. Quod autem nihil eorum apparet in fixis, immensam illorum arguit cellitudinem, quæ faciat etiam annui motus orbem siue eius imaginem ab oculis euanescere. Quoniã omne uisibile longitudinem distantie habet aliquam, ultra quam non amplius spectatur, ut demonstratur in Opticis. Quod enim à supremo errantium Saturno ad fixarum sphaeram adhuc plurimum inter sit, scintillantia illorum lumina demonstrant. Quo indicio maxime discernuntur à planetis, quodque inter mota & non mota, maximam oportebat esse differentiam. Tanta nimirum est diuina hæc Opt. Max. fabrica.

De Hypothesi Copernici motus terre, et eius demonstratione.

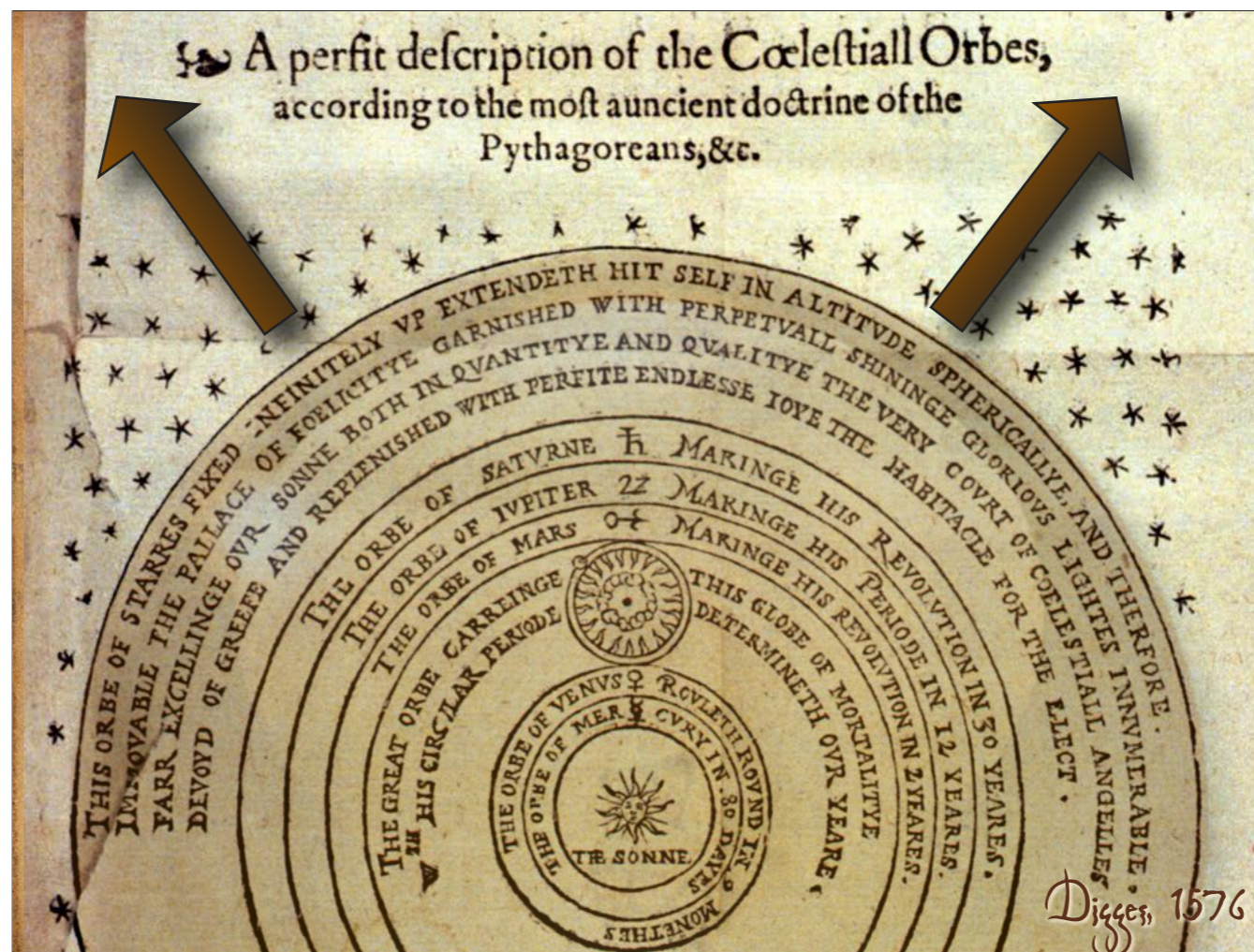
De triplici motu telluris demonstratio. Cap. xi.



Um igitur mobilitati terre tot tantaque errantium syderum consentiant testimonia, iam ipsum motum in summa exponemus, quatenus apparentia per ipsum tanquam hypotesim demonstrantur, quæ triplicem omnino oportet admittere. Primum quem diximus *πῶς ἡ γῆ περιεγύρει τὸν ἑαυτῆς ἀξονα* à Græcis uocari, diei noctisque circuitum proprium, circa axem telluris, ab occasu in ortum uergentem, prout in diuersum mundum fertur, ut patet ex antiquis sphaericis circulis describenda, quem

As Copernicus wrote, “So vast, without any doubt, is the handiwork of the Almighty Creator.”*

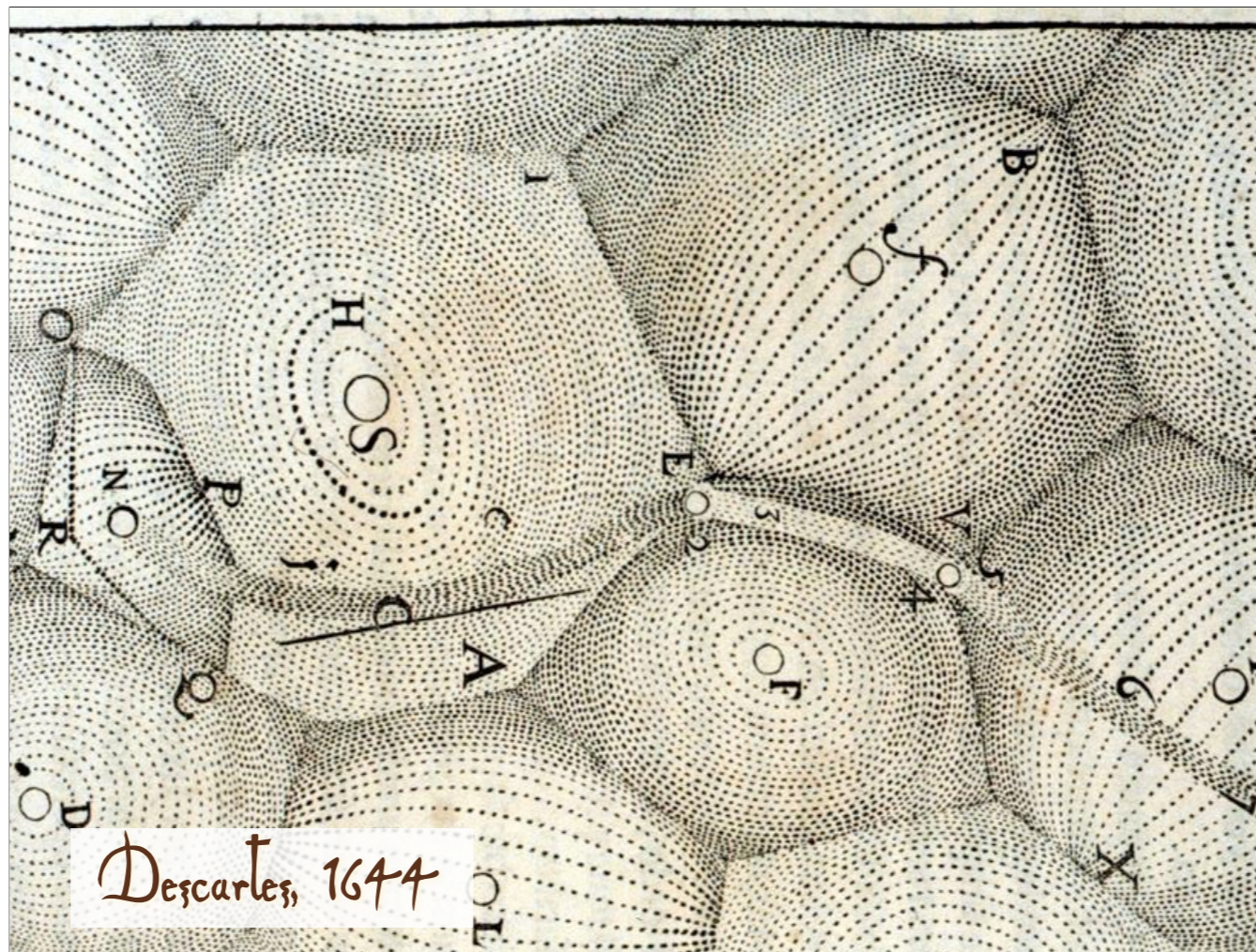
*Copernicus, Book I, Chapter 10. Danielson, 117.



Copernicus echoed medieval speculations that the universe might continue outward to an indefinite extent, containing a hollow sphere at its center for the planets.* The English Copernican Thomas Digges portrayed the Copernican system in this way in 1576.

- On the other hand, Copernicus and Digges did believe in solid planetary spheres in a determinate, hierarchical order.

*Copernicus, Book I, Chapter 8. Danielson, 114. For medieval debates on the infinity of the universe and the possibility of extracosmic void space see Grant (Further Reading).



Descartes, 1644

Theirs was not the randomly structured cosmos of the ancient atomists nor the dynamic, ever-transforming universe of the Stoics. The latter found expression in the endless impermanent vortices of Descartes, where worlds upon worlds continually form and dissolve in the flux of time.

A diagram of Copernicus' heliocentric model of the universe. At the center is the Sun (Sol). Concentric circles represent the orbits of the planets. From the inside out, the orbits are labeled: Mercurius (Mercury), Venus, Telluris (Earth) with the Moon, Mars, Iovis (Jupiter), and Saturnus (Saturn). Latin text around the orbits describes the revolutions of each planet. The word 'Problems' is superimposed in a large, dark red, serif font over the diagram.

Problems

Optical Illusions - Relative motion

Physics - Natural place

Astronomy

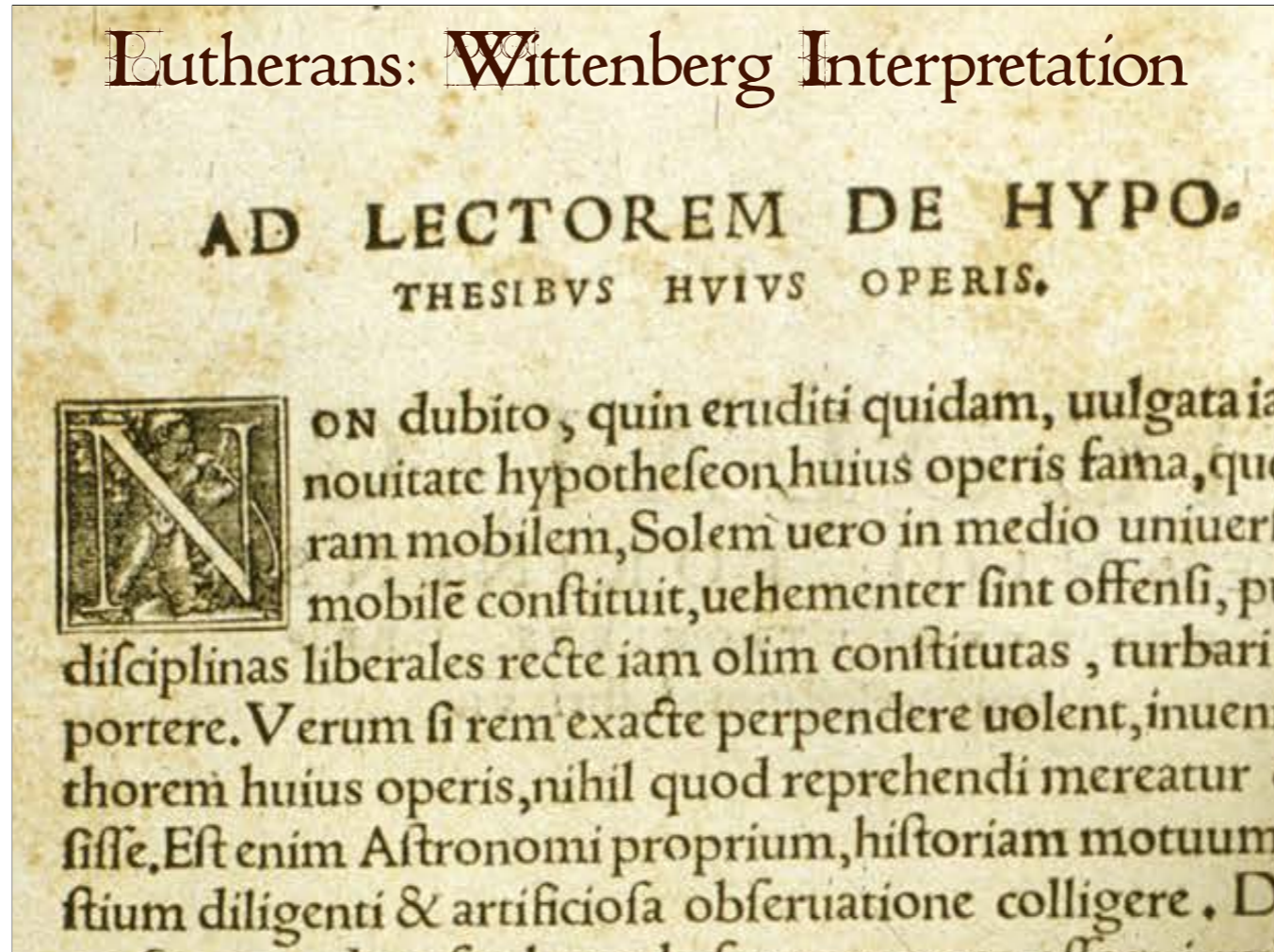
Aesthetics

Because of these and other problems, no more than a dozen mathematicians accepted the physical truth of Copernicus' system in its first half-century.

Intro	Front Matter
Two Themes	System
Early Life	Problems
Celestial Spheres	Reception
Publication	

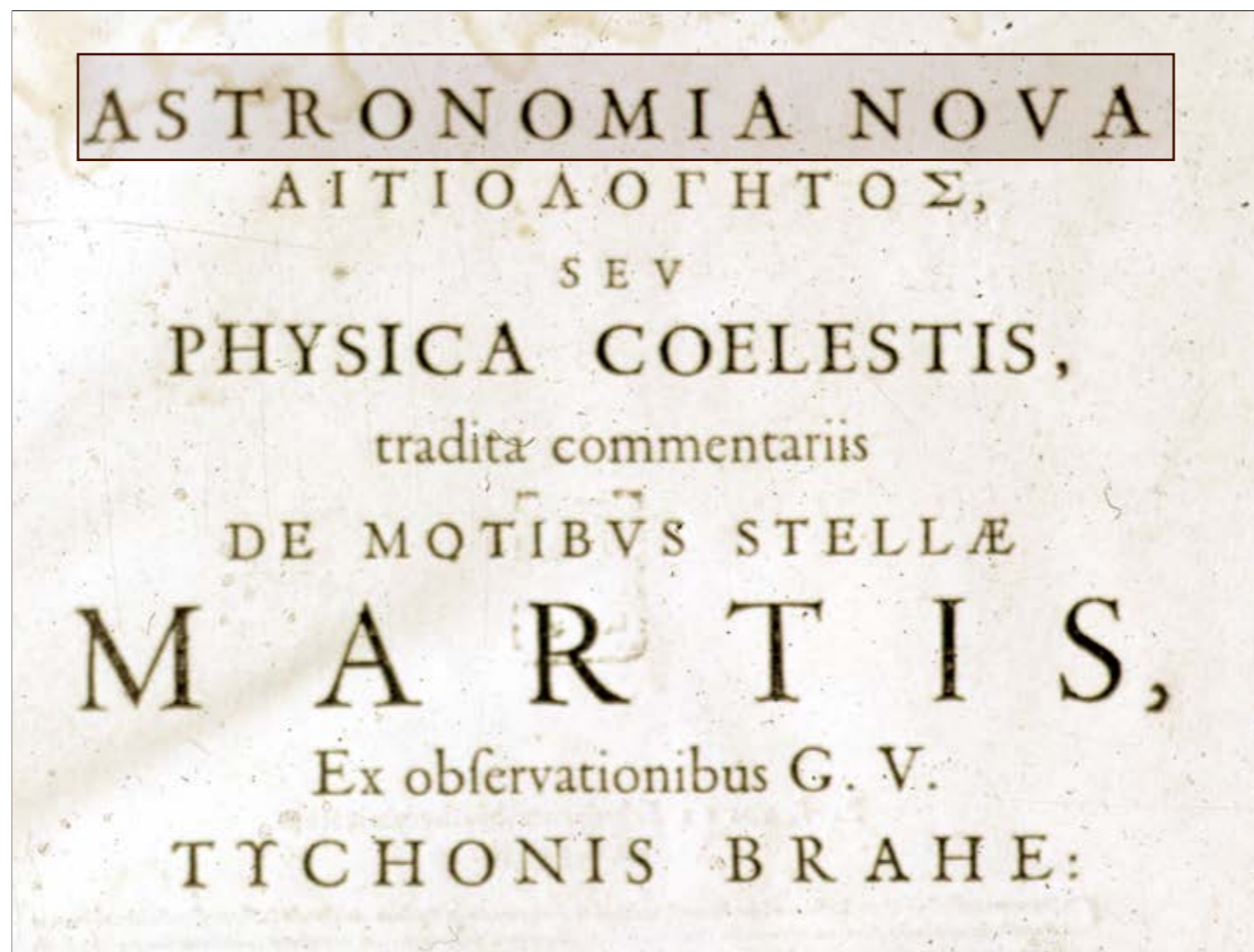
So let's consider the immediate Reception of Copernicus.

Lutherans: Wittenberg Interpretation



In what we earlier called the “Wittenberg Interpretation,” most astronomers immediately following Copernicus followed the suggestion of Osiander’s preface that one might interpret Copernican models hypothetically, as intended merely to “save the phenomena,” rather than to present a realist account of the universe. This instrumentalist interpretation is typical of the immediate Lutheran reception of Copernicus. No sense of crisis compelled them to undergo a revolutionary paradigm shift. They adopted Copernicus’ work selectively, piecemeal, accepting his mathematical system while often rejecting or suspending judgment on its physical implications.*

*The classic scholarship on the Wittenberg Interpretation is by Robert Westman.



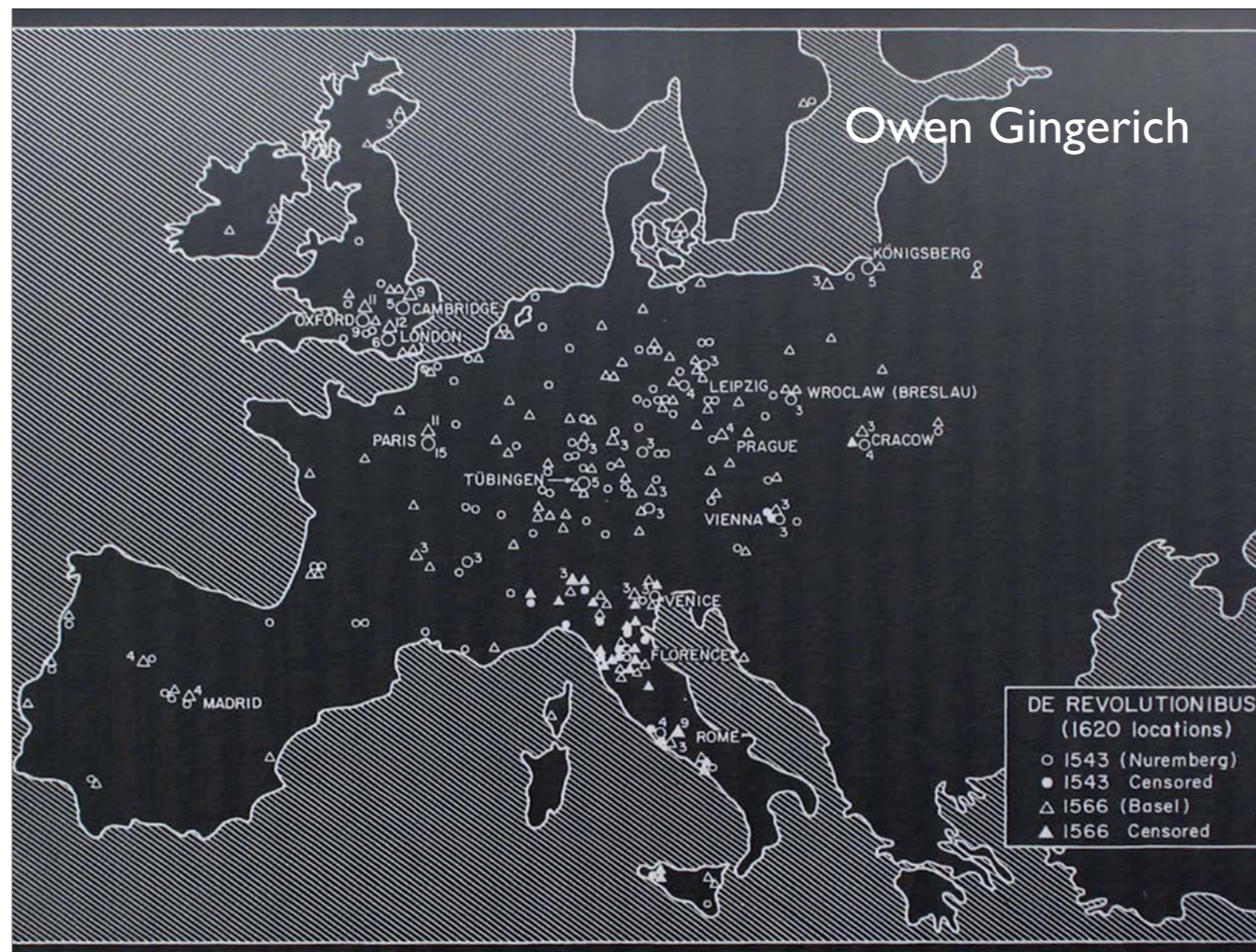
In the aptly named *Astronomia nova*, or *New Astronomy*, where Kepler put forward what are now regarded as his first two laws...



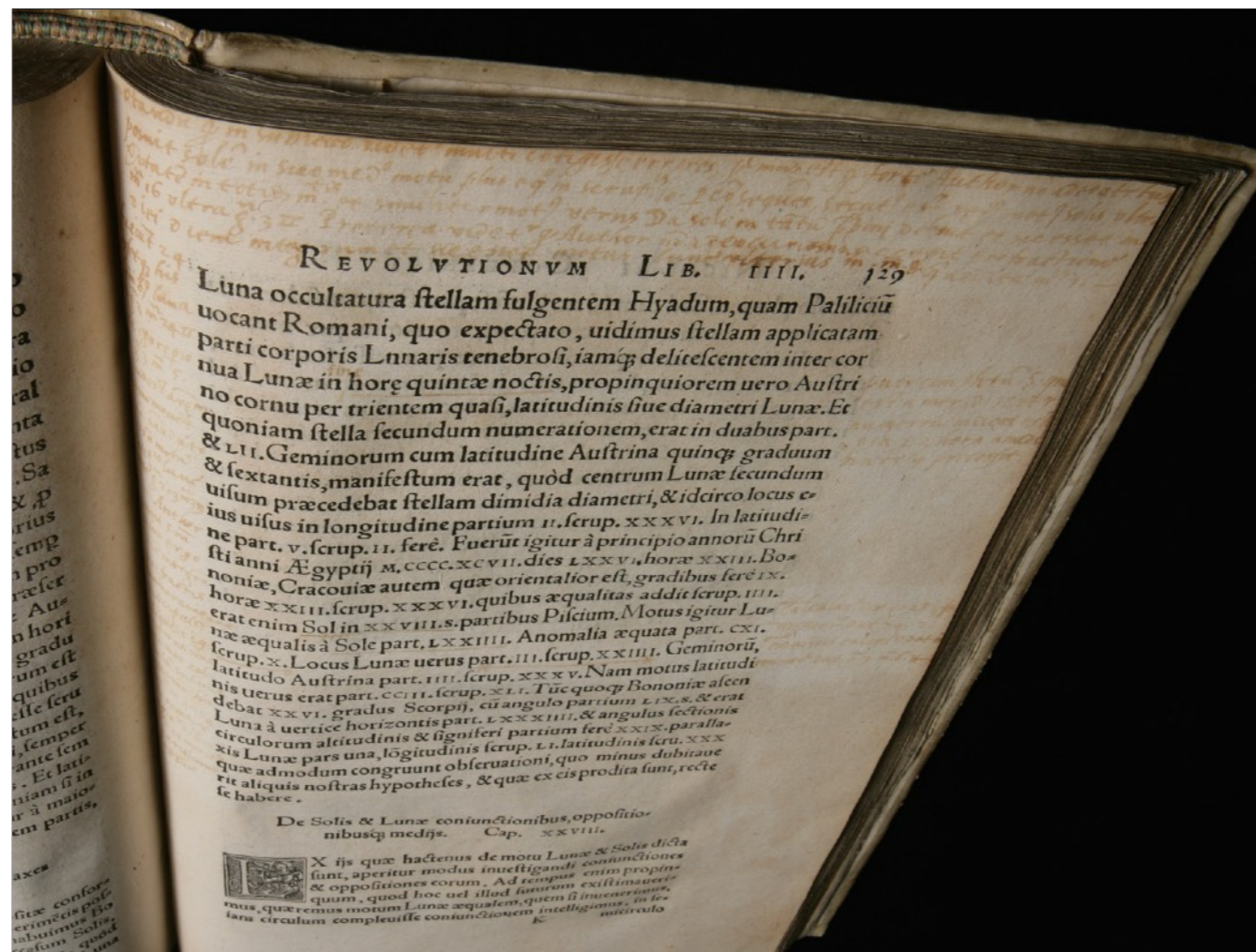
In a magisterial survey of contemporary readers of Copernicus, Harvard astronomer and historian Owen Gingerich shows that Lutherans were not the only sixteenth century astronomers sympathetic to Copernicus.*

—————

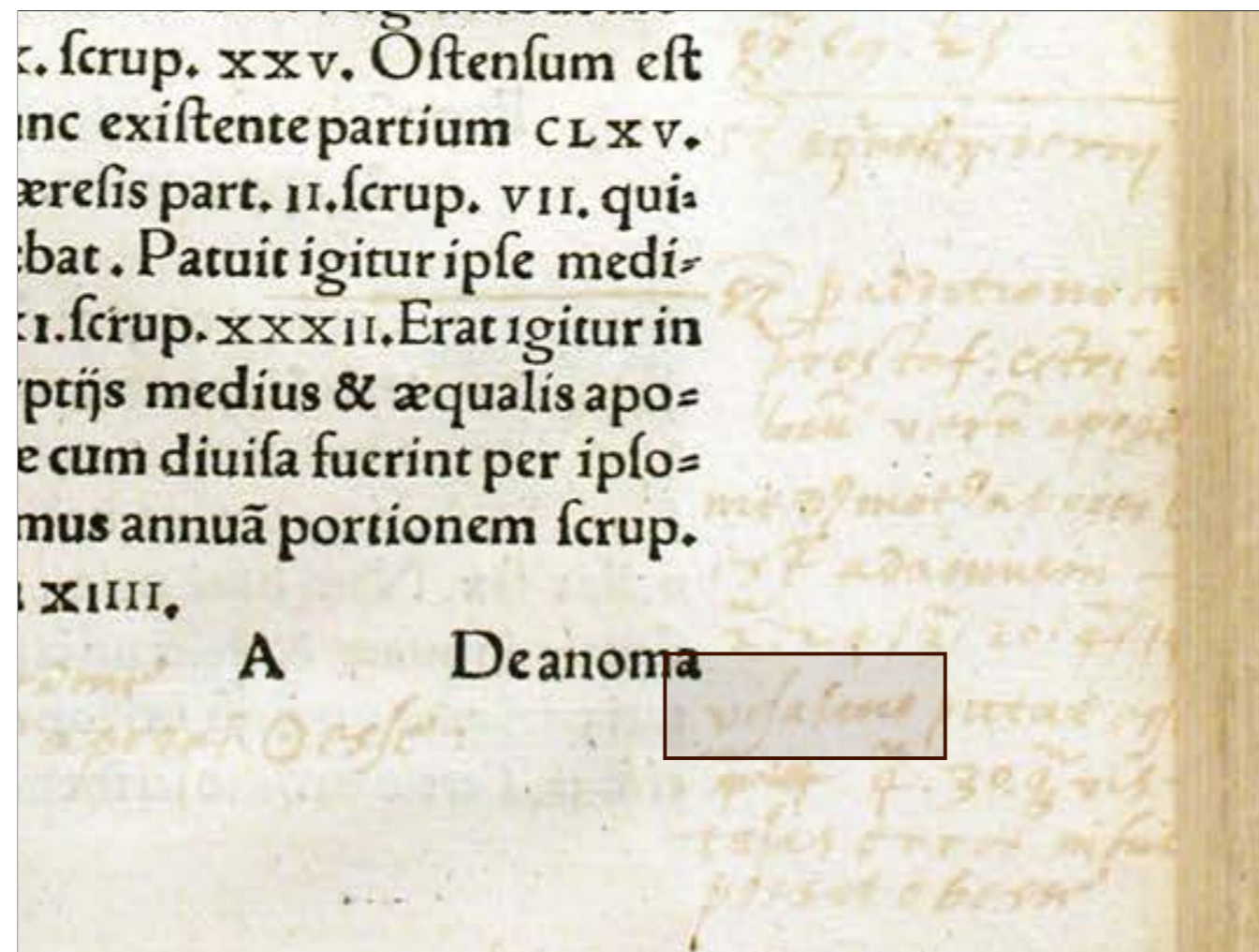
*See Gingerich, *Census*. A very interesting account of the writing of the *Census* is *The Book Nobody Read* (see Further Reading). The following account of Offusius relies entirely upon Gingerich's analysis; see Gingerich, *Book Nobody Read*, ch. 11.



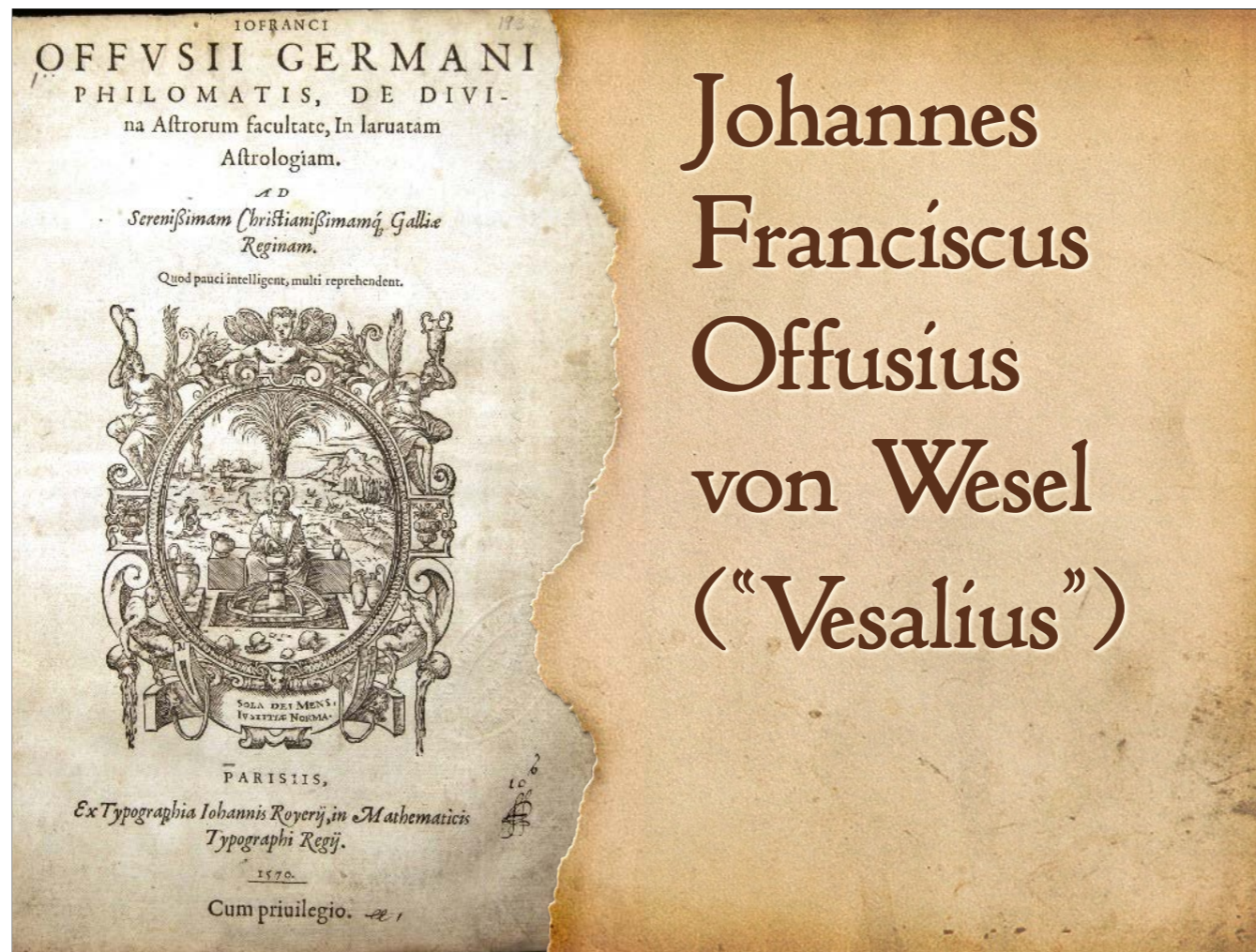
By examining the annotations in every surviving copy of the *De rev*, Gingerich shows that copies of Copernicus were avidly studied all across Europe.



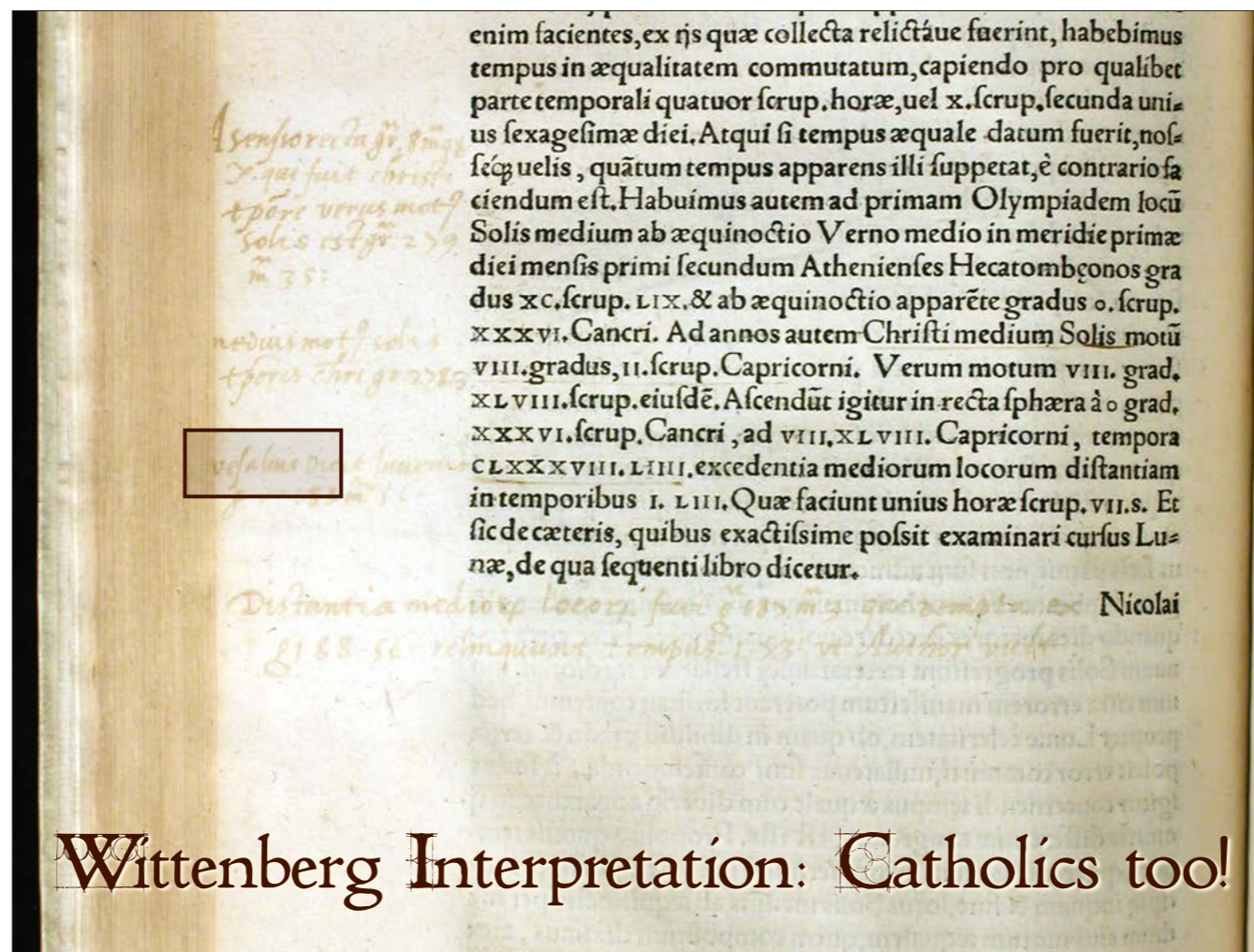
For example, within only a decade of its publication, a circle of astronomers located in Catholic Paris worked through the *De revolutionibus*. Their comments are disseminated in eight surviving copies. The existence of this circle was unknown before Gingerich completed his census.



The Oklahoma copy of *De revolutionibus* enabled Professor Gingerich to identify the leader of this Parisian circle as Vesalius. But who was Vesalius? Gingerich embarked on a long Copernicus chase, as he put it, to solve the mystery of this previously unknown Vesalius (who was not the famous anatomist).

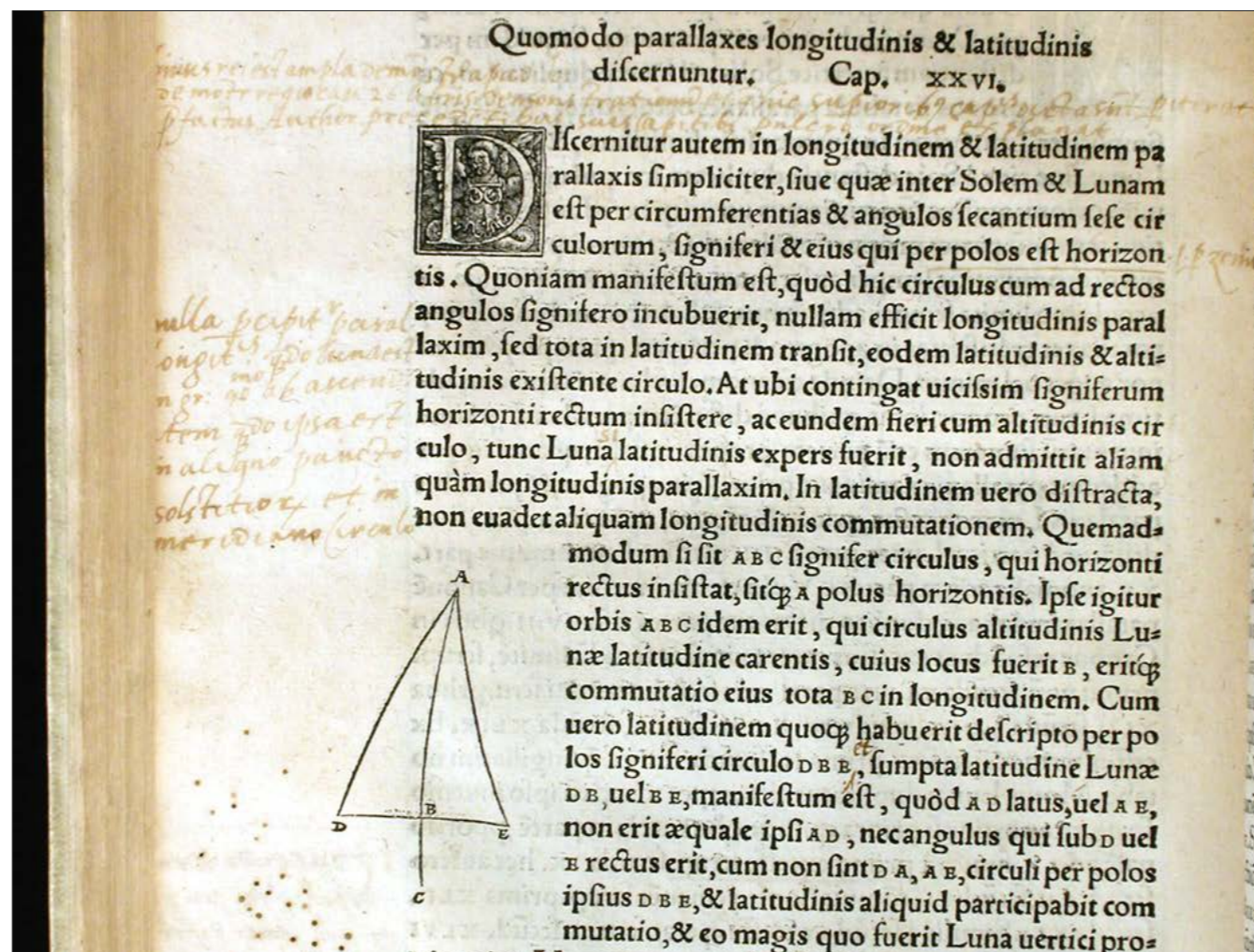


The Vesalius who was the leader of the Parisian circle turns out to be Johannes Franciscus Offusius von Wesel. This title page is from a work by Offusius. The name Vesalius is derived from the name of his hometown, Wesel, a village on the Rhine river near the Dutch–German border.



Wittenberg Interpretation: Catholics too!

Offusius and his Catholic circle in Paris admired the accomplishments of Copernicus in much the same way as their Lutheran counterparts. That is, Offusius praised the elegance of Copernican models, but was not fully persuaded that they were physically true.



Gingerich has rewritten our understanding of the early reception of Copernicus by showing that, even in the early decades, the *De revolutionibus* was far from a book that nobody read. In both Protestant and Catholic territories, astronomers recognized its significance and subjected it to serious technical study, admiring it as the point of departure for future work.

Nicolaus Copernicus

De revolutionibus (1543, 1566, 1617)



This avid and sustained interest helps explain why there were two subsequent editions in 1566 and 1617.

INDEX
LIBRORUM
PROHIBITORUM
SANCTISSIMI DOMINI NOSTRI
GREGORII XVI
PONTIFICIS MAXIMI

Nevertheless, in 1616 Galileo was instructed to hold to Copernicanism only hypothetically, and the *De revolutionibus* of Copernicus was put on the Index of Prohibited Books until it could be corrected.

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 circū currens, in medio uero omnium residet Sol. Quis enim in hoc



pulcherrimo templo lampadem hanc in alio uel meliori loco poneret, quam 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, 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 harmoniae nexum motus & magnitudinis orbium: qualis alio modo reperiri non potest. Hic enim licet animaduertere, nō segnitē contemplanti, cur maior in Ioue progressus & regressus appareat, quam in Saturno, & minor quam in Marte: ac rursus maior in Venere quam in Mercurio. Quodque frequentior appareat in Saturno talis reciprocatio, quam in Ioue: rarior adhuc in Marte, & in Venere, quam in Mercurio. Præterea quod Saturnus, Iupiter, & Mars acronycti propinquiores sint terræ, quam 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. Quod autem nihil eorum apparet in fixis, immensam illorū arguit celsitudinem, quæ faciat etiam annui motus orbem siue eius imaginem ab oculis euanescere. Quoniam omne uisibile longitudinem distantiae habet aliquam, ultra quam non amplius spectatur, ut demonstratur in Opticis. Quod enim à supremo errantium Saturno ad fixarum sphaeram adhuc plurimum interstit, scintillantia illorum lumina demonstrant. Quo indicio maxime discernuntur à planetis, quodque inter mota & non mota, maximam oportebat esse differentiam. Tanta nimirum est diutina hæc Opt. Max. fabrica.

De huiusmodi triplici motu terre, et eius demonstratione.
Detriplici motu telluris demonstratio. Cap. xi.

Cum igitur mobilitati terræ tot tantaque errantium siderum consentiant testimonia, iam ipsum motum in summa exponemus, quatenus apparentia per ipsum tanquam hypotesin demonstrantur, quæ triplicem omnino oportet admittere. Primum quem diximus *peripheticum* 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 æquidiale dicunt, imitantes significationem Græcorum,

Four years later, a total of ten corrections were issued, which Catholic readers at the time wrote into their copies of the book.

tu. Quod autem nunc coram apparet in axis, minimum motu
arguit celsitudinem, quæ faciat etiam annui motus orbem siue
eius imaginem ab oculis euanescere. Quoniã omne uisibile lon-
gitudinem distantiae habet aliquam, ultra quam non amplius
spectatur, ut demonstratur in Opticis. Quod enim à supremo
errantium Saturno ad fixarum sphaeram adhuc plurimum in-
ter sit, scintillantia illorum lumina demonstrant. Quo indicio ma-
xime discernuntur à planetis, quodq; inter mota & non mota,
maximam oportebat esse differentiam. Tanta nimirum est diui-
na hæc Opt. Max. fabrica.

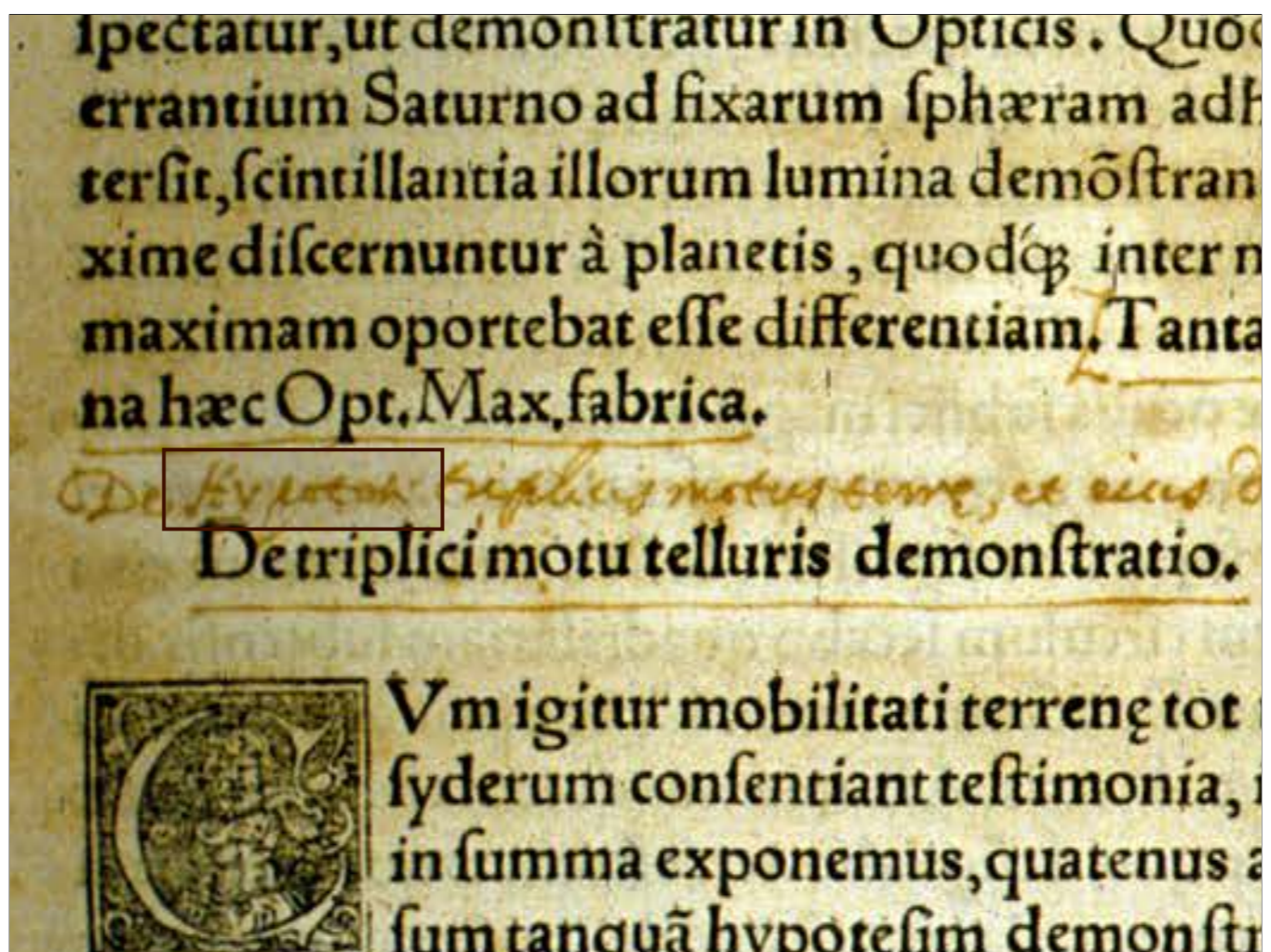
De huiusmodi triplici motu terre, et eius demonstratione.

De triplici motu telluris demonstratio. Cap. xi.



Um igitur mobilitati terre tot tantaq; errantium
syderum consentiant testimonia, iam ipsum motum
in summa exponemus, quatenus apparentia per ip-
sum tanquã hypotesim demonstrantur, quẽ triplicẽ
omnino oportet admittere. Primum quem diximus *ὑποστροφικόν*
à Græcis uocari, diei noctisq; circuitum proprium, circa axem

In this example, where Copernicus presented a “Demonstration of the triple motion of the Earth,” the censors corrected it to



“Demonstration of the hypothesis of the triple motion of the Earth.” For the Inquisitors as for Osiander, Copernicus’ work was admired and respected, but not necessarily accepted as physically true. The censors took for granted the instrumentalist view of the role of mathematics in physical science.

æ omnia ex eadem causa procedunt, quæ in telluris est mo-
 Quod autem nihil eorum apparet in fixis, immensam illorū
 arguit cellitudinem, quæ faciat etiam annui motus orbem siue
 eius imaginem ab oculis euanescere. Quoniā omne uisibile lon-
 gitudinem distantiae habet aliquam, ultra quam non amplius
 spectatur, ut demonstratur in Opticis. Quod enim à supremo
 errantium Saturno ad fixarum sphaeram adhuc plurimum in-
 ter sit, scintillantia illorum lumina demōstrant. Quo indicio ma-
 xime discernuntur à planetis, quodq; inter mota & non mota,
 maximam oportebat esse differentiam. Tanta nimirum est diui-
 na hæc Opt. Max. fabrica.

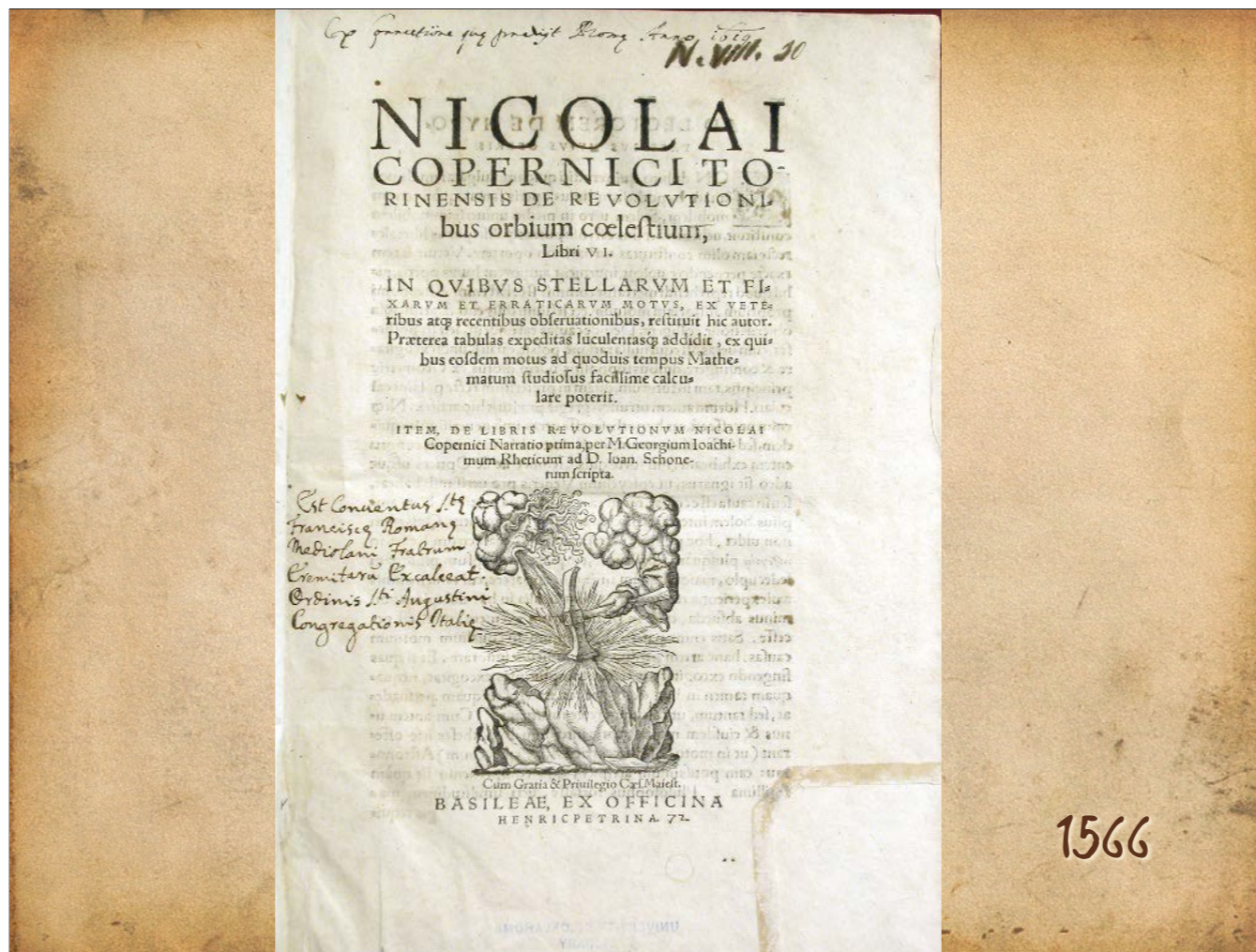
De Hypothesi Copernici motus terre, et eius demonstratione.

De triplici motu telluris demonstratio. Cap. xi.

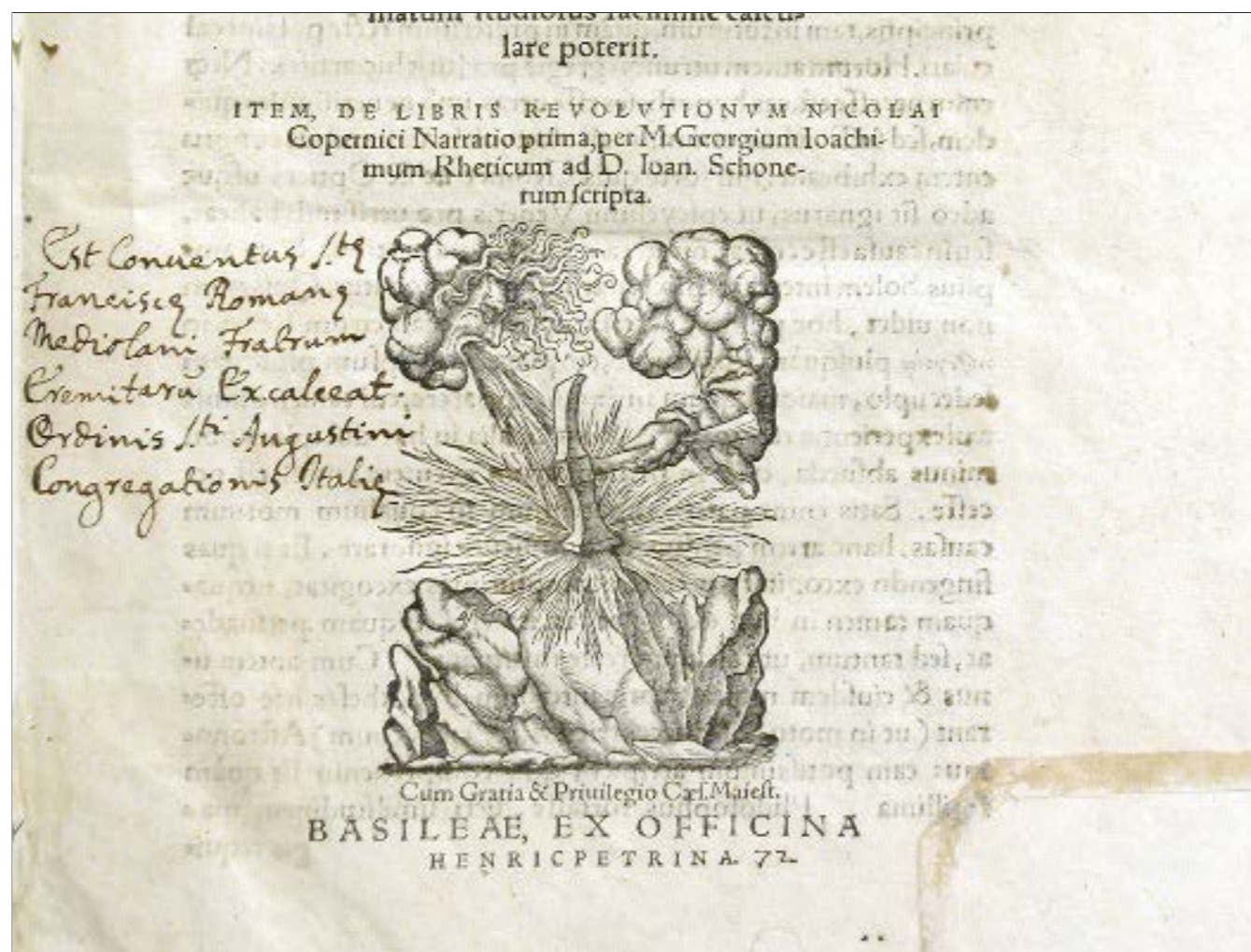


Um igitur mobilitati terre tot tantaq; errantium
 syderum consentiant testimonia, iam ipsum motum
 in summa exponemus, quatenus apparentia per ip-
 sum tanquā hypotesim demonstrantur, quæ triplicē
 omnino oportet admittere. Primum quem diximus *υποστροφικον*
 à Græcis uocari, diei noctisq; circuitum proprium, circa axem
 telluris, ab occasu in ortum uergentem, prout in diuersum mun-
 dum fertur, ut patet ex antiquis stellarum circulis describenda, quem

In addition, the censors instructed readers to delete the line, “So vast, without any doubt, is the handiwork of the Almighty Creator,” lest it be read as implying that the universe is infinite.



On this title page of the second edition,



printed in Basil by Heinrich Petri,

Ex functione que prodit Long. Anno 1519.
N. VIII. 20

NICOLAI
COPERNICIT O-
RINENSIS DE REVOLUTIONI-
bus orbium coelestium,

Libri VI.

IN QVIBVS STELLARVM ET FI-
XARVM ET ERRATICARVM MOTVS, EX VETE-
ribus atq; recentibus obseruationibus, restituit hic autor.
Præterea tabulas expeditas luculentasq; addidit, ex quib;
bus eisdem motus ad quoduis tempus Mathe-
maticum studiosus facillime calcu-
lare poterit.

ITEM, DE LIBRIS REVOLUTIONVM NICOLAI
Copernici Narratio prima, per M. Georgium Ioachi-
mum Rheticum ad D. Ioan. Schone-
rum scripta.

the annotation at the top of the page reads



“Corrected as provided by Rome in the year 1619.”



And sure enough, if we turn to the corresponding page, we see this is a censored copy.

autem nihil eorum apparet in fixis, immensam illorum arguit
celitudinem, quæ faciat etiam annui motus orbem siue eius ima-
ginem ab oculis euanescere. Quoniam omne uisibile longitudi-
nem distantie habet aliquam, ultra quam non amplius specta-
tur, ut demonstratur in Opticis. Quod enim à supremo erranti-
um Saturnio ad fixarum sphaeram adhuc plurimum inter sit, scin-
tillantia illorum lucina demonstrant. Quo indicio maxime di-
scernuntur à planetis, quodque inter mota & non mota, maximam
oportebat esse differentiam. ~~Tanta nimirum est diuina hæc~~
~~Opt. Max. fabrica.~~

De Hypothesi triplicis motus terre eiusque demonstratione
~~De triplici motu telluris demonstratio.~~

Cap. XL

CUm igitur mobilitati terrenæ tot tantaque errantium sy-
derum consentiant testimonia, iam ipsum motum in sum-
ma exponemus, quatenus apparentia per ipsum tan-
quam hypotesin demonstrantur, quem triplicem omnino oportet
admittere. Primum quem diximus *πλάνησις* à Græcis uoca-
ri, diei noctisque circuitum proprium, circa axem telluris, ab occa-
su in ortum uergentem, prout in diuersum mundus ferri puta-
tur, æquinoctialem circulum describendo, quem nonnulli æ-

The sentence about the vastness of the universe has been crossed out, and the demonstration of the triple motion of the earth has been made hypothetical in this copy also.

nec repugno. At nostro ævo usu tubi optici non una macula, sed complures in sole conspiciuntur, pleraque forma orbiculari, nonnulla forma variæ abeuntes ac redeantes. Idem tubus etiam plura in cælo detexit ignorata Copernico & toti antiquitati.

** [Stellarum fixarum sphaera] Notandum est, Sphaeram attribui stellis fixis extimum ac summum in mundo locum occupantibus, nullam autem Sphaeram nominari planetarum. Magnus ille cæli observator Tycho Brahe constanter asseverat, sibi certis experimentis constare nullos esse in cælo orbis reales sive solidos, sed cælum esse rarissimum ac liquidissimum. Pag. 92. & 575 operis Astronomici. Idem tamen terram moveri pernegat.

†† [Sol gubernat astrorum familiam] Keplerus Solem præditum esse vult vi magnetica, quæ omnium planetarum motu regat ac gubernet in æthere liquido. Vim magneticam appellat interiorum formarum sympathiam ac consensum, qualis cernitur inter magnetem & ferrum. Similis quoque formarum similitudo videtur esse inter terram & lunam.

† [Acronycti] Id est, vesperi orientes, Solique e diametro oppositi.

CAPUT XI.

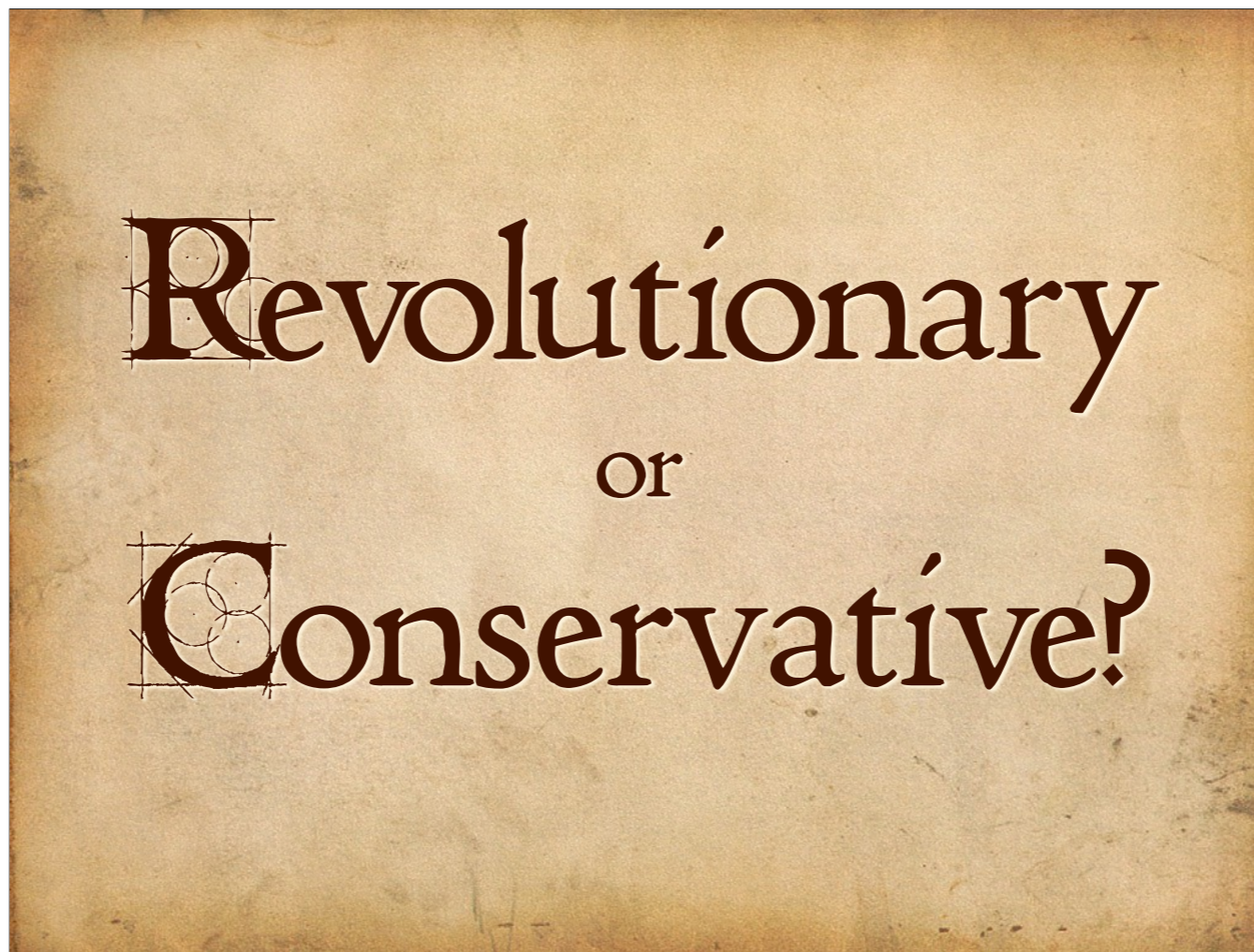
De triplici motu telluris demonstratio.

CUM igitur mobilitati terrenæ tot tantaque errantium fide-
rum consentiant testimonia, iam ipsum motum in summa ex-
ponemus, quatenus apparentia per ipsum tanquam hypothe-
sim

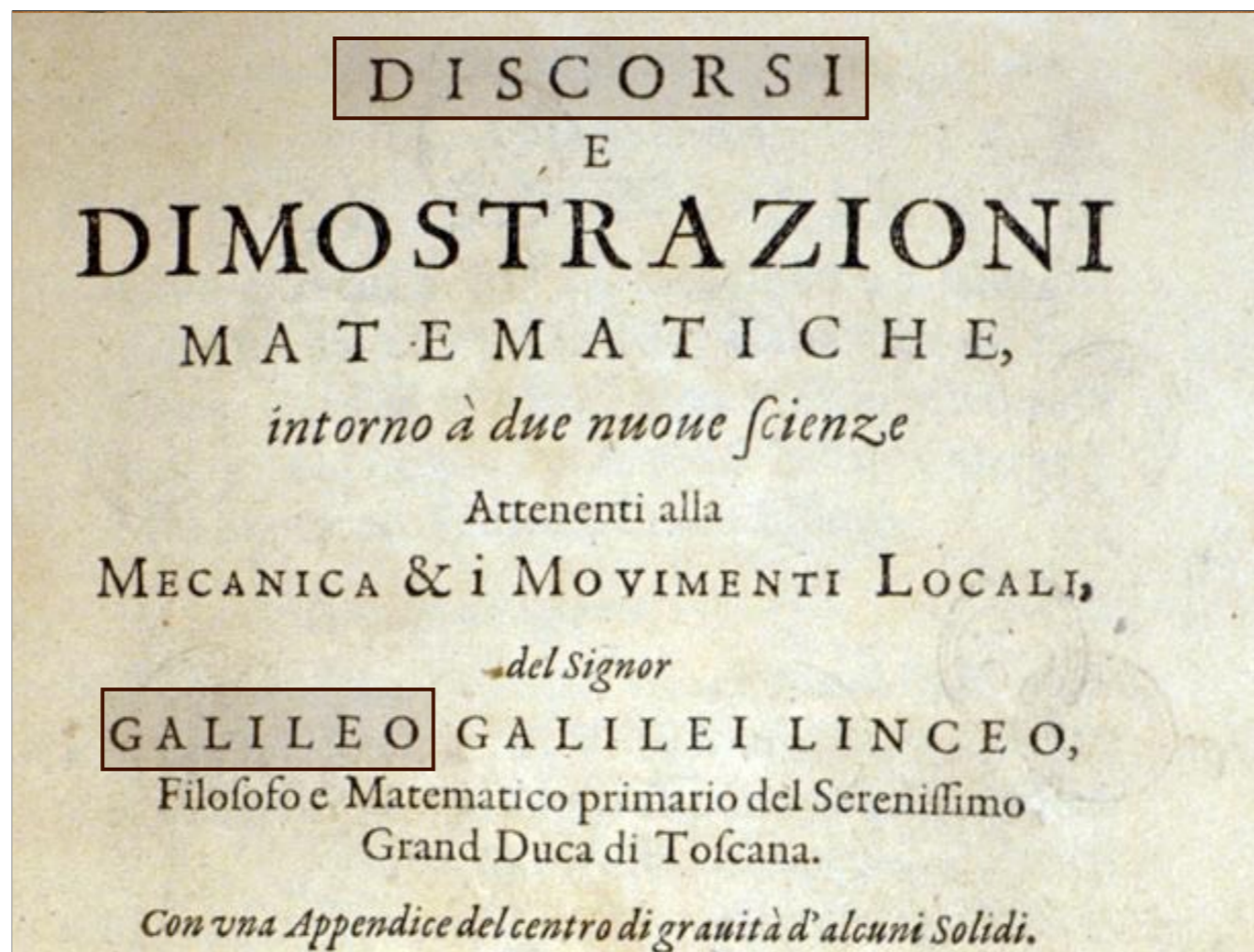
no corrections have been made. Presumably this copy remained in Protestant hands.

Intro	Front Matter
Two Themes	System
Early Life	Problems
Celestial Spheres	Reception
Publication	Revolutions

So where does this leave the Copernican Revolution?

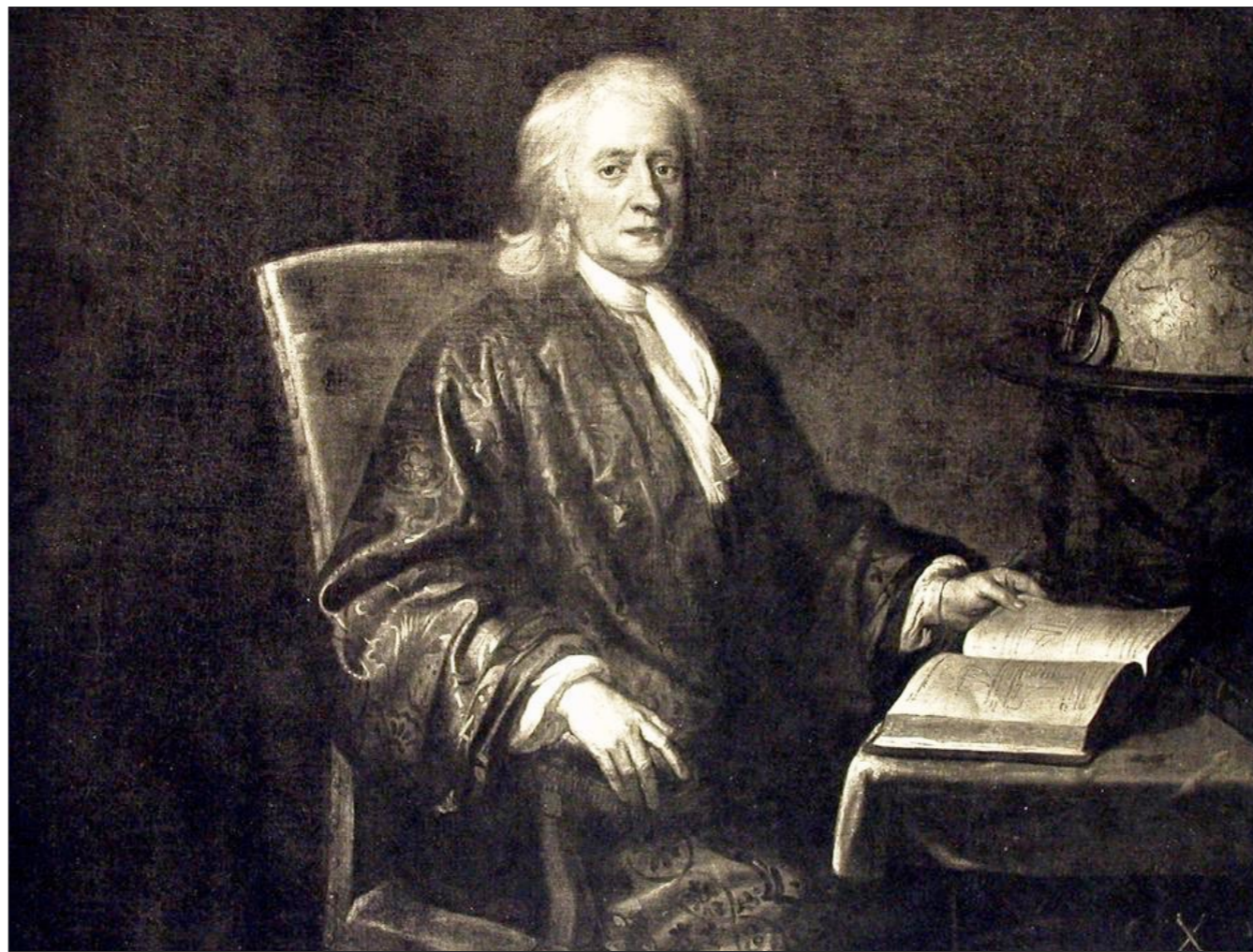


Was Copernicus a revolutionary, or a conservative? I hope I have shown that he was both.



The visionary Copernican idea that the Earth moves as a planet sparked a revolution in physics. Widespread adoption of the Copernican system required a thorough revision of the physics of natural place, which

- Galileo completed in his Discorsi, published over 80 years after Copernicus' De revolutionibus.



Once Newton unified the terrestrial physics of Galileo with the celestial mechanics of Kepler's laws, Copernicus became a symbol of a Scientific Revolution, a complete overthrow of Aristotelian physics and cosmology.

IV. *A Letter from the Reverend Mr. James Bradley Savilian Professor of Astronomy at Oxford, and F.R.S. to Dr. Edmond Halley Astronom. Reg. &c. giving an Account of a new discovered Motion of the Fix'd Stars.*

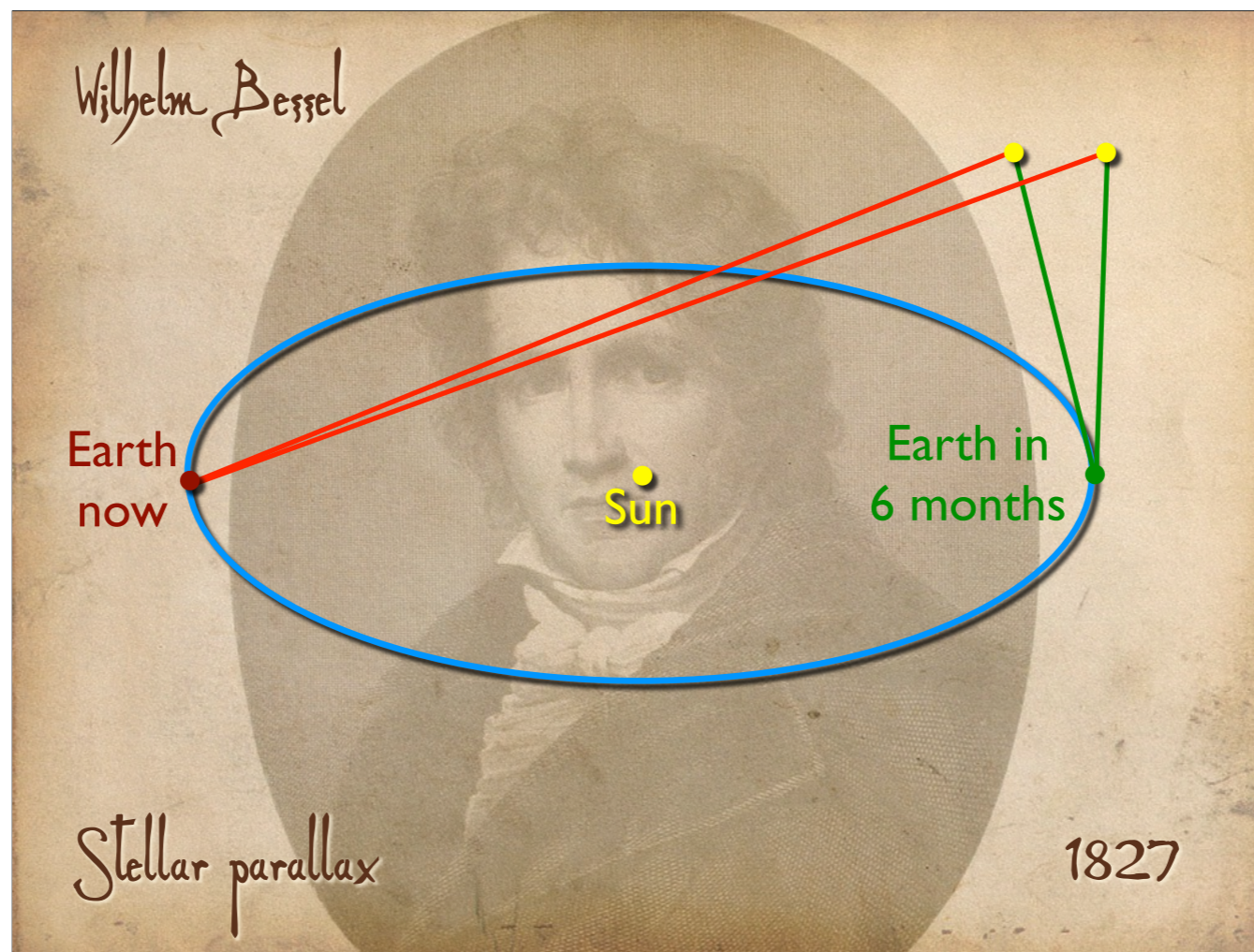
S I R,

YOU having been pleased to express your Satisfaction with what I had an Opportunity sometime ago, of telling you in Conversation, concerning some Observations, that were making by our late worthy and ingenious Friend, the honourable *Samuel Molyneux* Esquire, and which have since been continued by my self, in order to determine the *Parallax of the fixt Stars*; I shall now beg leave

Stellar aberration

1725

Still, direct observational proof of the motion of the Earth was hard to find. The first direct evidence of the annual revolution of the Earth came in 1725, when James Bradley detected stellar aberration, a shifting of light from distant stars.

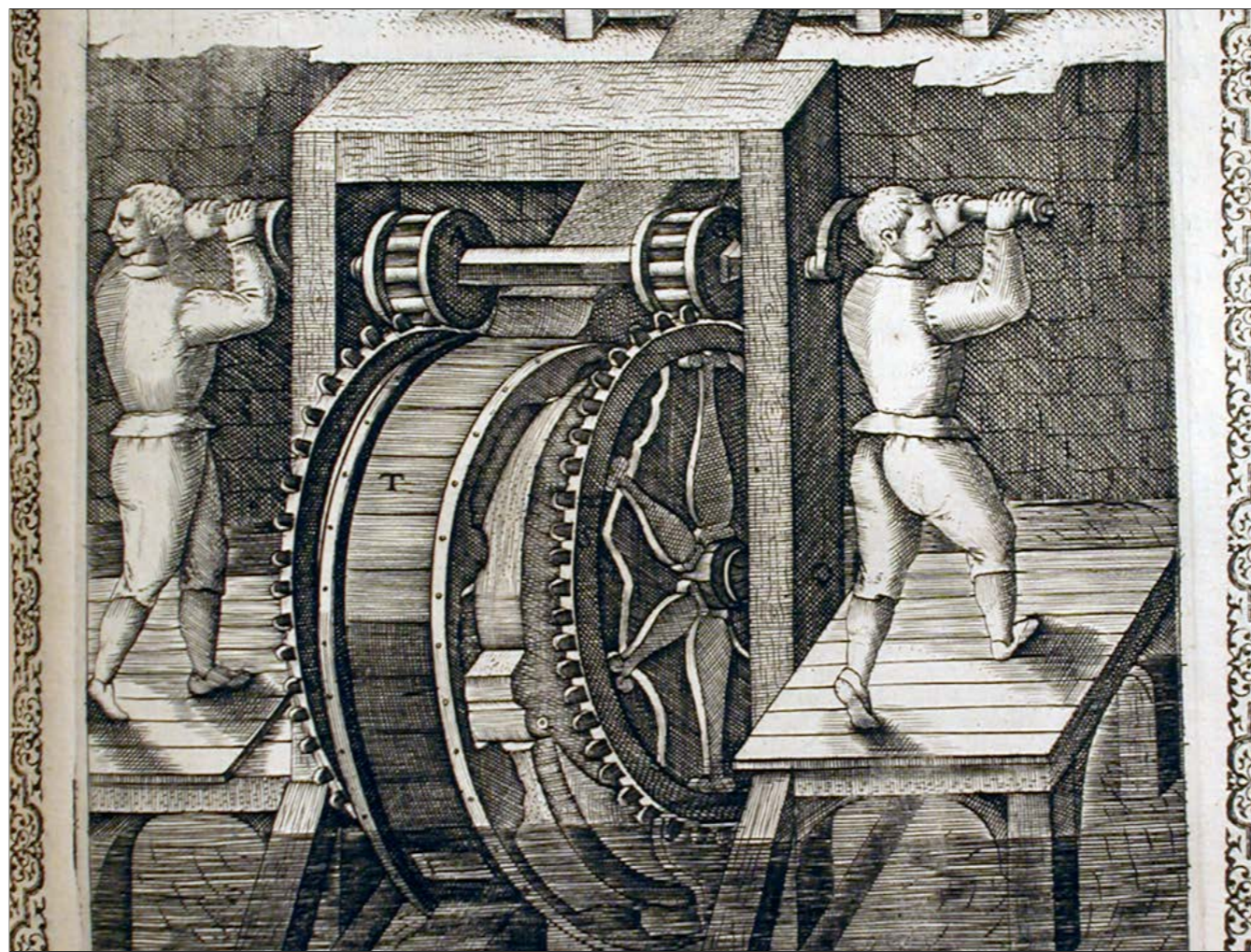


Stellar parallax was not confirmed until 1827, when Wilhelm Bessel found a shift in the position of double star 61 Cygni.

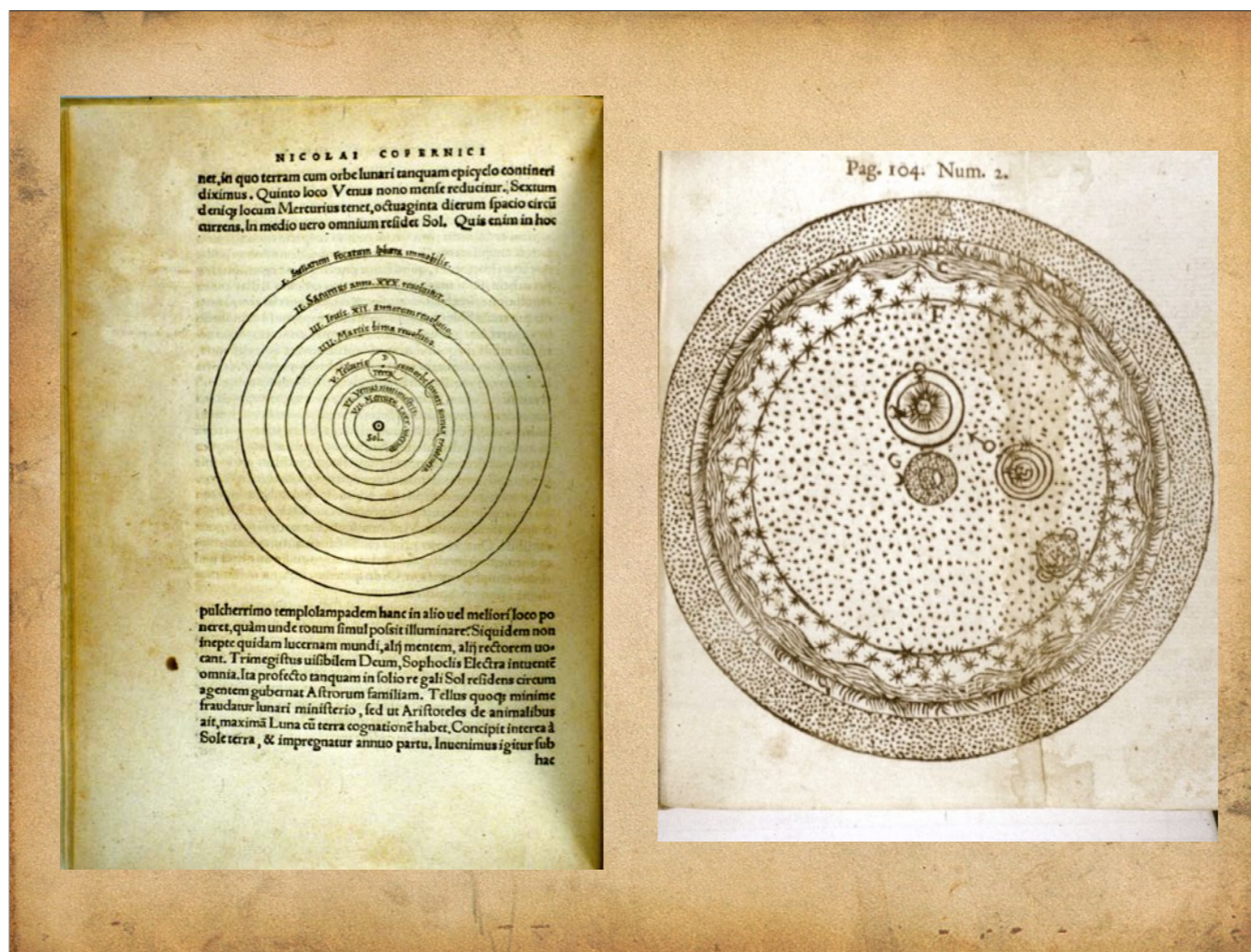


The Foucault pendulum swings in a constant direction, and thus reveals the rotation of the Earth turning underneath. It is a physical proof of the rotation of the Earth.

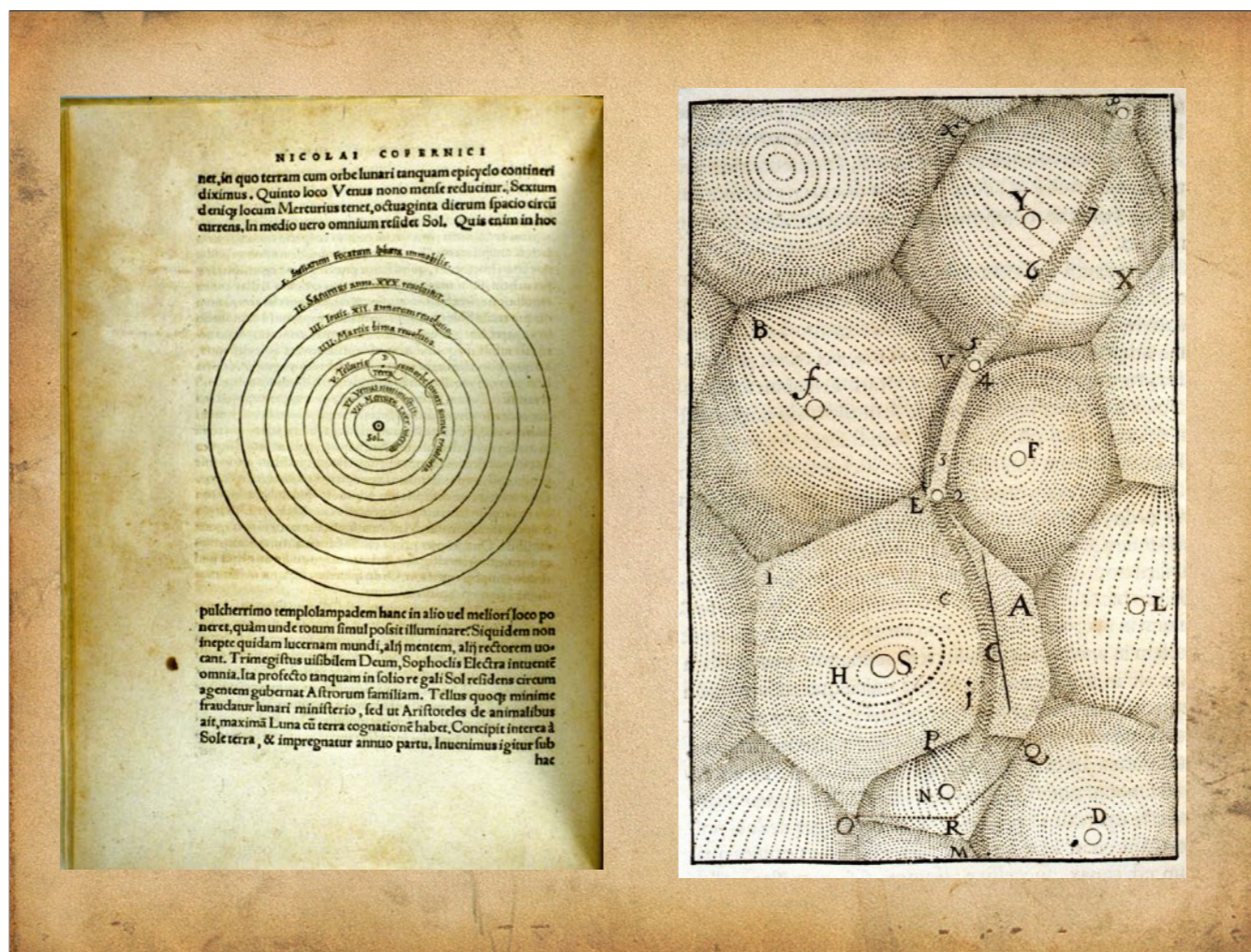
- Yet the Foucault pendulum was not conceived until 1851, three centuries after Copernicus. Three centuries seems like evolution, not revolution.



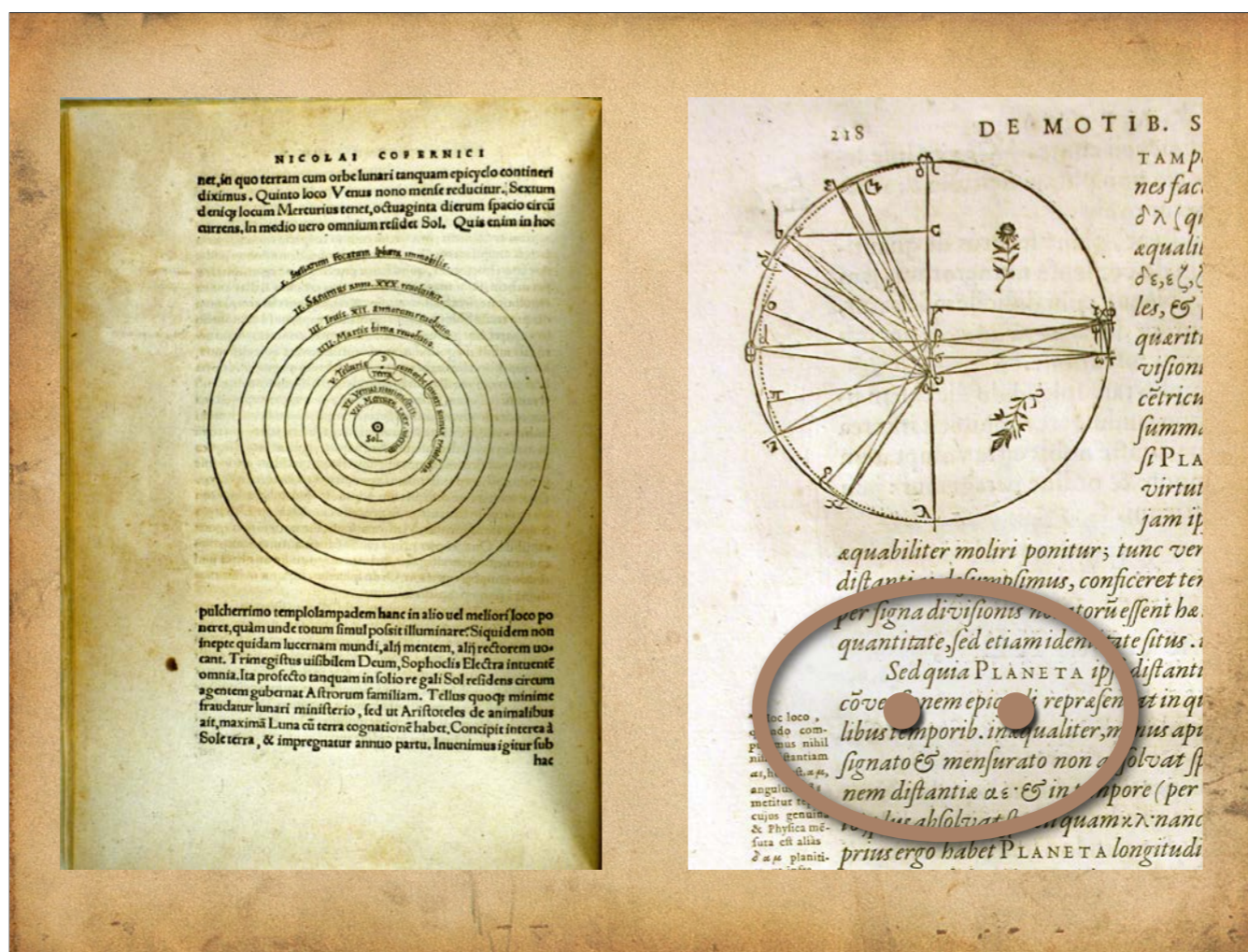
Yet revolutionaries do not always intend their own revolutions. Even the word “revolution” contains ambiguities: a revolution may refer to one complete turn of a wheel, a significant repetition, as Copernicus described the “revolutions” of the celestial spheres. In this sense, Copernicus’ contemporaries regarded him as a great reformer who *restored* a tradition rather than defying or overthrowing it. In many ways the astronomy of Copernicus was *not* revolutionary, but continuous with a vigorous Ptolemaic tradition. In this way Copernicus’ conservative astronomy contrasts with its radical implications for physics.



As a conservative in astronomy, Copernicus defended the ancient notion of solid spheres, in contrast to the fluid heavens of later astronomers. Tycho and Kepler, not Copernicus, melted the cosmic spheres.

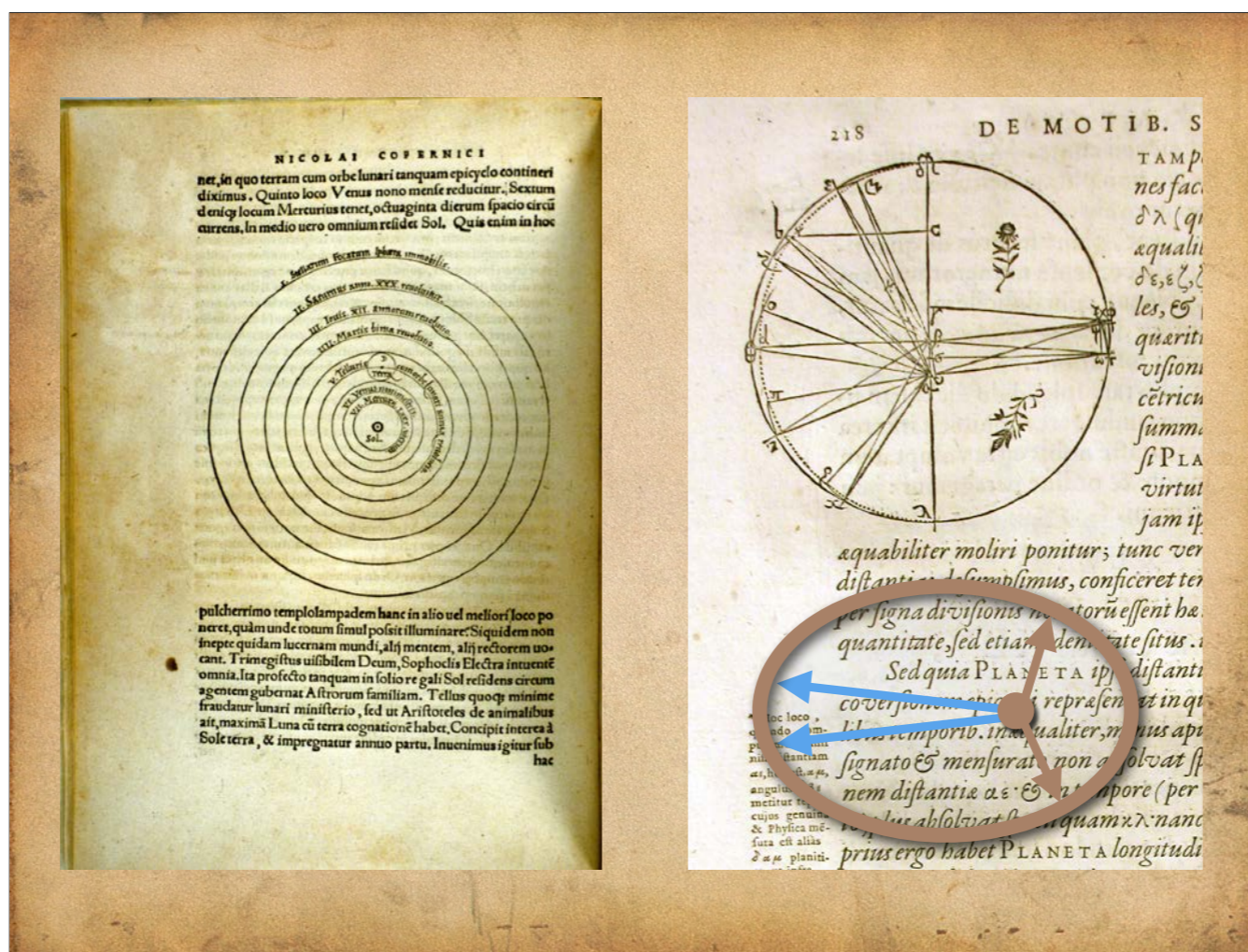


Copernicus envisioned a hierarchical cosmos,
unlike the endless vortices of Descartes.



The geometric devices of Copernicus remained the circles, deferents, epicycles, and eccentrics of the ancient and medieval astronomers. The Copernican achievement was in many ways a natural extension of the tradition of al-Tusi, ash-Shatir, and Regiomontanus.

- Kepler with his ellipses, not Copernicus, broke away from the hold of the fundamental axiom of ancient astronomy that the heavens move only with combinations of circular motions.



While Copernicus, like Islamicate astronomers before him, rejected Ptolemy's equant because it compromised the ancient ideal of uniform circular motion, Kepler appears to be the revolutionary one, for he reintroduced non-uniform motion with his equal-areas law.*

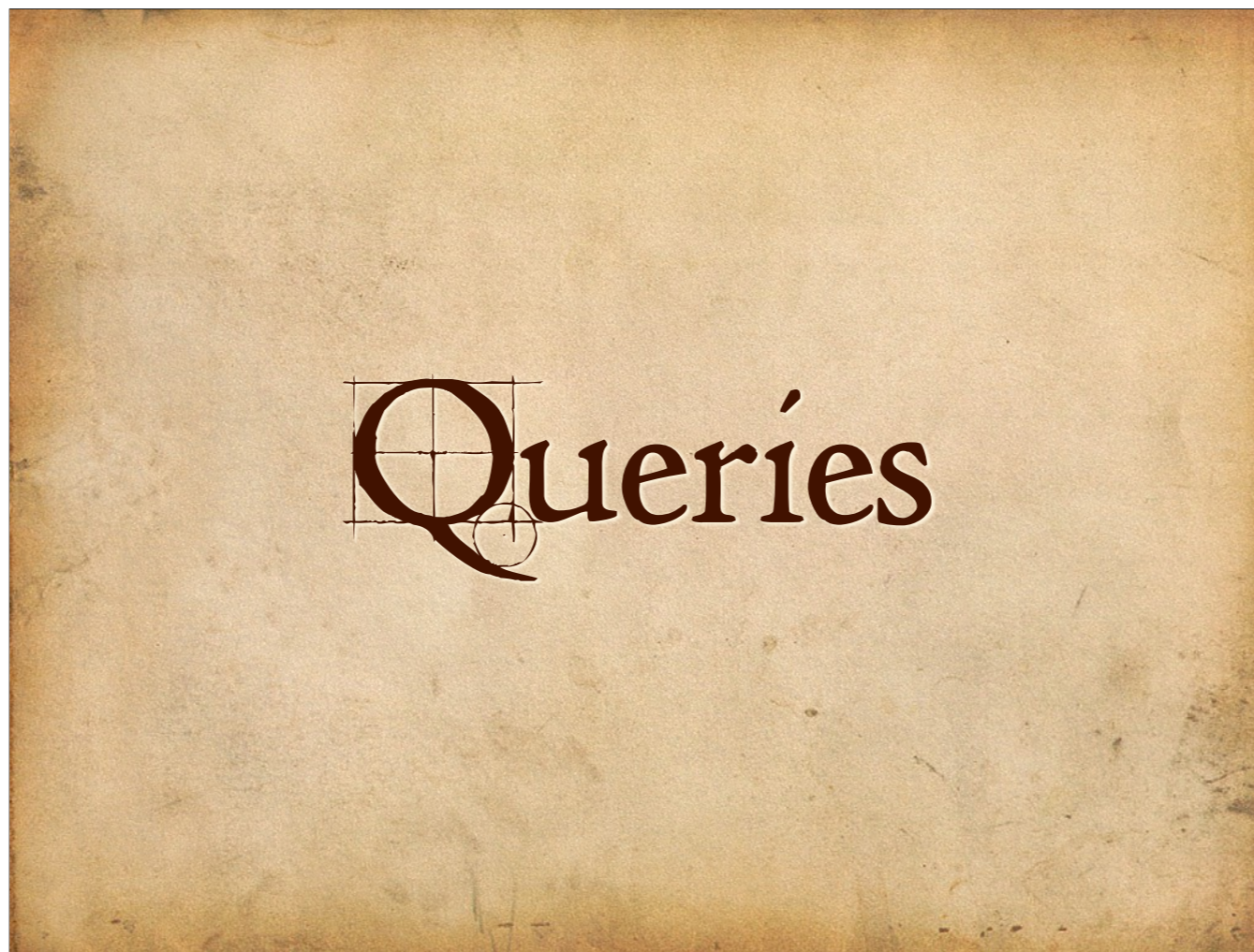
*Swerdlow and Neugebauer (p. 38): "The point E, called in the middle ages the 'equant point,' corresponds to the empty focus of the ellipse in Kepler's model for planetary motion.... Ptolemy's model, in both direction and distance, was the best earlier approximation to Kepler's first two laws of planetary motion."



- Copernicus achieved renown as a mathematician rather than an observer, in contrast to contemporary Wittenberg astronomers.
- Tycho Brahe, the greatest observer of the century, rejected the Copernican cosmos.



And Copernicus died nearly sixty years before Galileo trained the telescope on the circling moons of Jupiter and the distant stars of Orion. Although contemporary readers were largely unable to accept all that Copernicus believed, the post-Copernican achievements in astronomy were more revolutionary than the *De Revolutionibus*. One may describe Copernicus as radical or as conservative, as you wish, yet what is certain is that Copernicus stood on the brink of greater changes than even he could imagine.



It's now time to put on our thinking caps and interpret the significance of what we've been exploring! If this presentation has been successful, then you are now doing some real thinking. I hope your mind is spinning. Here are some queries for your reflection.

- ♦What two themes evident from the De rev are described as relevant to the history of science generally? Do they make sense to you?
- ♦Why is it problematic to refer to Copernicus as a professional astronomer? What other occupational roles did he have or train for?
- ♦Were the celestial spheres a common sense idea, capable of explaining a multitude of celestial phenomena?
- ♦In the ancient Earth-centered system, was the Earth's position a place of privilege?

- ♦How did the Reformation affect Copernicus and his work? How did publication of the *De rev* reflect cooperation between Catholics and Protestants across sectarian lines?
- ♦In his dedication to the pope, Copernicus argued that, while some theologians might mistakenly regard his system as contrary to the Bible, his arguments rested on mathematics, and those with no expertise in mathematics should not rush to judge. Is this principle one of the implications of the story of Copernicus?

- ♦ Does this story display characteristics of the Renaissance, such as humanist scholarship or the printing revolution?
- ♦ If Copernicus believed that mathematical methods enabled one to better understand reality, why did Andreas Osiander insert the preface to the *De rev* which argued that Copernicus could be interpreted only instrumentally, or hypothetically? Is realism vs. instrumentalism a recurring point of disagreement in science? How did this preface affect the immediate reception of the *De rev*?

- ♦It is often said that Copernicus refrained from publishing his views until his death because of fear of suppression by the Roman Catholic Church. Discuss the historical evidence pertinent to this claim.
- ♦It is often said that by removing the Earth from the center of the universe, Copernicus rejected the anthropocentric orientation of the medieval cosmos. Discuss the historical evidence pertinent to this claim.

- ♦ What is retrograde motion of the planets?
How does it appear to the eye in the night sky?
- ♦ Evaluate the following explanations for the superiority of Copernican astronomy: (1) The Ptolemaic system was unable accurately to predict the positions of the planets. (2) The Ptolemaic system had no explanation of retrograde motion. (3) The Ptolemaic system was too complex.

♦The geometrical devices of deferent, epicycle, eccentric, and equant, as used in geocentric astronomical models, proved quite versatile and effective in combination to explain astronomical motions in terms of underlying "uniform circular motions." How does Copernicus represent continuity and discontinuity with this ancient and medieval tradition? (Did he use the same geometrical devices? Did he affirm uniform circular motion? Did he accept solid spheres?)

- ♦ Did Copernicus represent an abrupt discontinuity from the religious cultures of the Middle Ages, both Christian and Islamic, to the Scientific Revolution?
- ♦ What advantages did Copernicus point to in favor of his system over that of Ptolemy's?
- ♦ Does Copernicus represent the rejection of medieval anthropocentrism?
- ♦ How does the shift from geocentrism to heliocentrism illustrate the importance one's perspective makes?

- ♦ What compelled Copernicus actually to adopt a heliocentric system? Observations? Simplicity? What does this imply for our understanding of science?
- ♦ What objections posed to Copernicus seem most powerful to you? If you had read the *De rev* in 1543, would you have been persuaded? What if you had read it in 1615? Would you have interpreted it hypothetically? At what point in history would you have been willing to defend it as physically true?

- ♦What would it be like to live through a time of major change in the human understanding of the cosmos?
- ♦Was Copernicus a revolutionary, or a conservative, or both?
- ♦In this story of Copernicus, did you discover anything new, surprising, or unexpected?
What was most meaningful to you?

Further reading

Background

- ♦C.S. Lewis, *The Discarded Image*
- ♦Dennis R. Danielson, *The Book of the Cosmos*
- ♦Michael J. Crowe, *Theories of the World from Antiquity to the Copernican Revolution*
- ♦James Evans, *The History & Practice of Ancient Astronomy*

Background

For a classic interpretation of medieval and Renaissance sensibilities about the cosmos, see C. S. Lewis, *The Discarded Image: An Introduction to Medieval and Renaissance Literature* (Cambridge: Cambridge University Press, 1994).

Many primary sources, accompanied by brief, judicious comments, may be found in Dennis R. Danielson, *The Book of the Cosmos* (Perseus Books Group, 2002).

An introductory survey of mathematical astronomy from antiquity to Copernicus is Michael J. Crowe, *Theories of the World from Antiquity to the Copernican Revolution* (Dover Publications, 2001), which includes excerpts from Book I of Ptolemy's *Almagest*.

A more advanced survey text is James Evans, *The History & Practice of Ancient Astronomy* (Oxford University Press, 1998), and

Background

- ♦ Otto Neugebauer, *History of Ancient Mathematical Astronomy*
- ♦ Edward Grant, *Planets, Stars, and Orbs: The Medieval Cosmos, 1200-1687*
- ♦ F. Jamil Ragep, *Nasir Al-Din Al-Tusi's Memoir on Astronomy*
- ♦ F. Jamil Ragep, "Ali Qushji and Regiomontanus," *Journal for the History of Astronomy* 36, (2005): 359-379.

the standard study is Otto Neugebauer, *History of Ancient Mathematical Astronomy* (Springer Verlag, 1975).

The standard study of Renaissance scholastic cosmology is Edward Grant, *Planets, Stars, and Orbs: The Medieval Cosmos, 1200-1687* (Cambridge: Cambridge University Press, 1996).

A representative figure of the Islamic tradition that influenced Copernicus is introduced in Nasir Al-Din Muhammad Ibn Muhammad Tusi, and F. Jamil Ragep, *Nasir Al-Din Al-Tusi's Memoir on Astronomy* (Springer, 1993).

F. Jamil Ragep, "Ali Qushji and Regiomontanus: Eccentric Transformations and Copernican Revolutions," *Journal for the History of Astronomy* 36, (2005): 359-379.

The De revolutionibus

- ♦Owen Gingerich, The Book Nobody Read
- ♦Owen Gingerich, An Annotated Census of Copernicus' De Revolutionibus
- ♦Nicholas Copernicus, On the Revolutions (Johns Hopkins University Press, 1992)
- ♦Noel M. Swerdlow, and Otto Neugebauer, Mathematical Astronomy in Copernicus's De Revolutionibus, 2 vols.

De rev

Owen Gingerich's personal account of his endeavor to examine every surviving copy of De Revolutionibus provides a very readable and delightful introduction to Copernicus and his era: Owen Gingerich, The Book Nobody Read: Chasing the Revolutions of Nicolaus Copernicus (Walker & Company, 2004).

The scholarly account is Owen Gingerich, An Annotated Census of Copernicus' De Revolutionibus (Brill Academic Publishers, 2002).

For the text of Copernicus' De Revolutionibus, excerpts are available in the two works mentioned above by Crowe and Danielson. There is no widely acclaimed English translation of the complete work, but one is Nicholas Copernicus, On the Revolutions (Baltimore and London: The Johns Hopkins University Press, 1992).

The standard study of Copernicus' mathematical astronomy is Noel M. Swerdlow, and Otto Neugebauer, Mathematical Astronomy in Copernicus's De Revolutionibus (Springer, 1984), 2 vols. The first part of this work is the best available biographical account of Copernicus.

Publishing and Reception

- ♦Peter Barker, and Bernard R. Goldstein, "Patronage and the Production of De Revolutionibus," *Journal for the History of Astronomy*, 34 (2003): 345-368.
- ♦Dennis Danielson, "Achilles Gasser and the birth of Copernicanism," *Journal for the History of Astronomy*, 35 (2004): 457-474.
- ♦Kerry Magruder and Brent Purkale, *Galileo's World*: lynx-open-ed.org/galileo

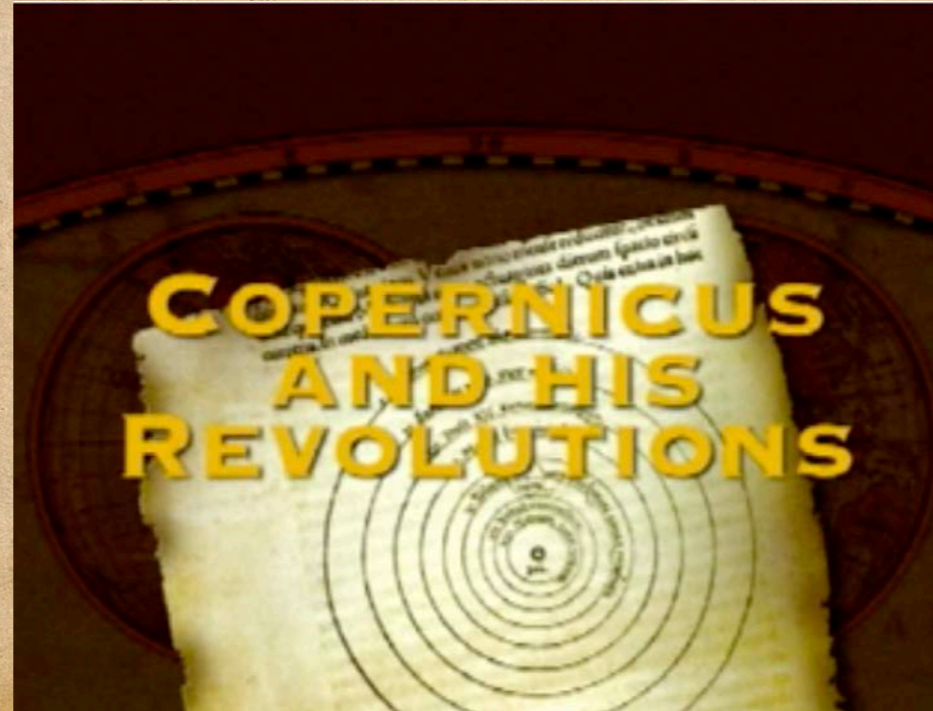
Publishing

This section of the show is based on the recent scholarship of Peter Barker and Bernard Goldstein, particularly Peter Barker, and Bernard R. Goldstein, "Patronage and the Production of De Revolutionibus," *Journal for the History of Astronomy*, 34 (2003): 345.. See also Dennis Danielson, "Achilles Gasser and the birth of Copernicanism," *Journal for the History of Astronomy*, 35 (2004): 457-474.

Reception

The 16th- and 17th-century reception of Copernicus is far too broad a topic to cover here, but one accessible starting point, with more detail about Tycho, Kepler and Galileo, is Kerry Magruder and Brent Purkale, *Galileo's World*: lynx-open-ed.org/galileo.

- ♦Written and produced by Kerry Magruder for the Cosmology and Cultures Project of the OBU Planetarium, August 2005



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This presentation incorporates much material from “Copernicus and His Revolutions,” a planetarium show written and produced by Kerry Magruder for the Cosmology and Cultures Project of the OBU Planetarium, August 2005, CC-by-nc-sa. While today’s presentation is organized as if we were paging through the De rev, the planetarium show is organized chronologically. It includes additional content about the background before Copernicus and about the reception after Copernicus. The two videos are complementary; each contains material not in the other.

<https://kerrysloft.com/history-of-science/copernicus-and-his-revolutions/>
<http://www.kerrymagruder.com/mov/Copernicus.pdf>

Thank you

- ♦Images courtesy the History of Science Collections, University of Oklahoma



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