Philosophy of Science Survey

Week 9

PHIL 2160. Ohio University. Spring 2021.

Chapter 13: The Ptolemaic System (cont’d)

The Problem of the Planets (review)

- For the Aristotelian astronomers, the scientific problem about the planets was ***to predict and explain their drifting motion and retrograde motion***.
  - Explaining in the minimal sense (retrodicting the observed data).
- **The constraints on an acceptable solution to this problem** are:

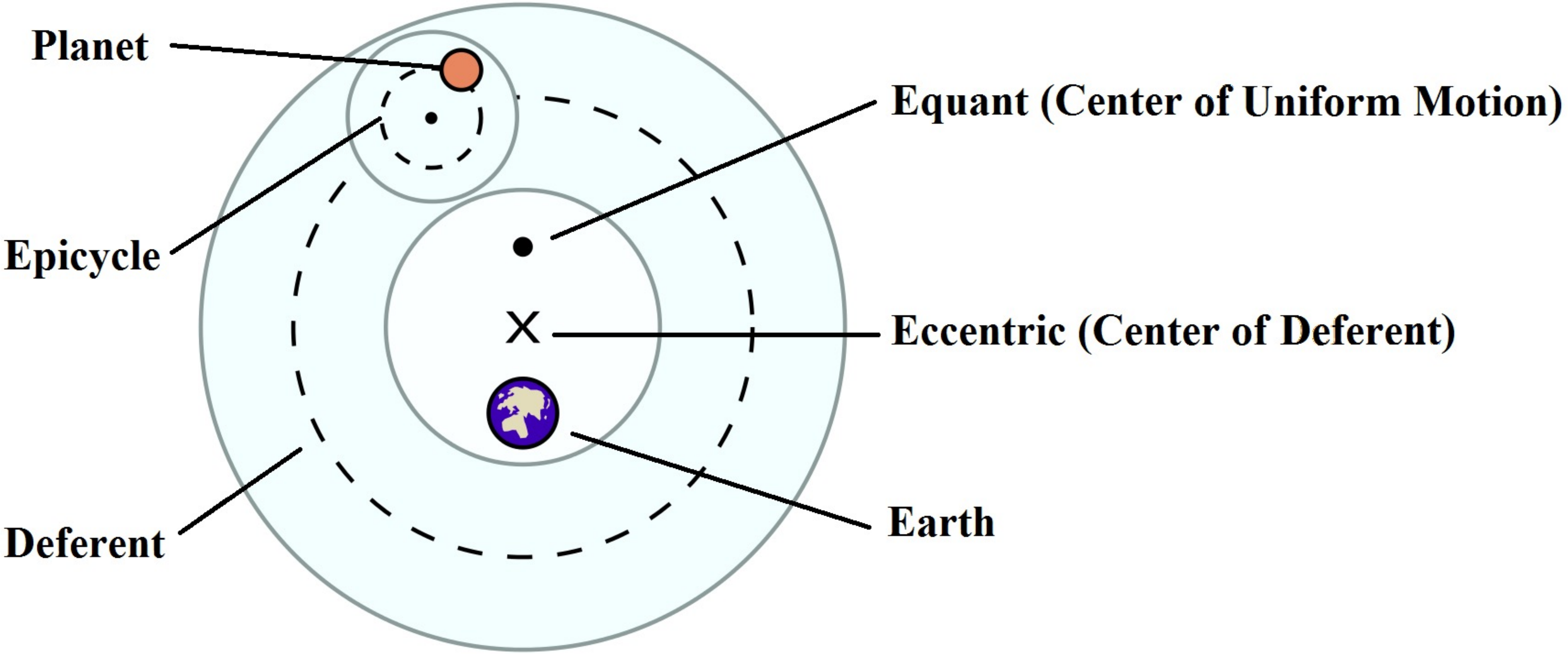
1. Invoke only uniform circular motions
2. Accurately predict and explain observed motions of the planets
3. Cohere with other, especially core, beliefs of the Aristotelian worldview.

- (1) and (2) play a major role in the development of Ptolemy's solution.

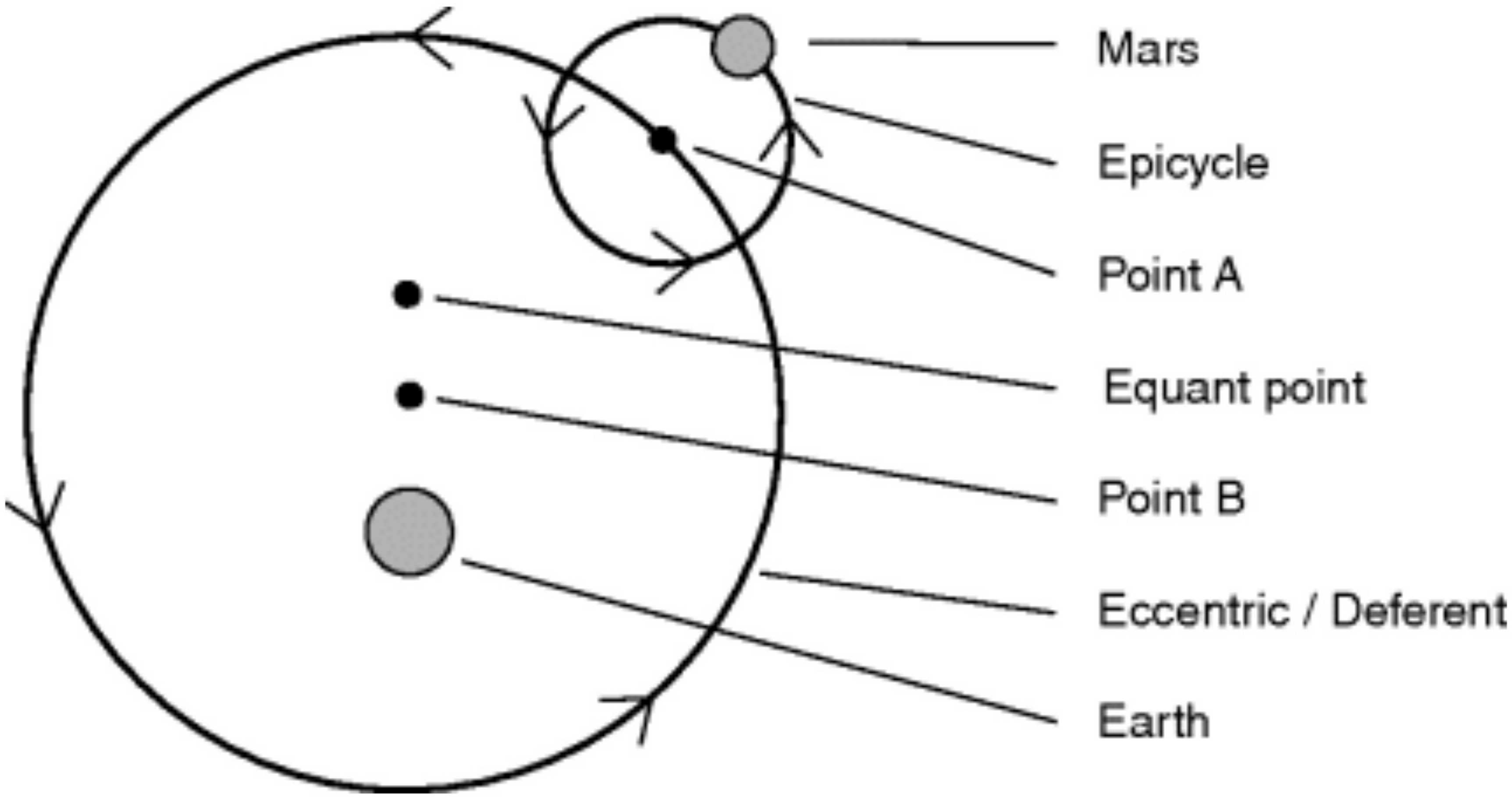
Solving the Problem of the Planets

- Ancient astronomers responded by adjusting and adding peripheral beliefs rather than rejecting the core Aristotelian beliefs.
- Before Ptolemy (100–170 CE), Apollonius (240–190 BCE) and Hipparchus (190–120 BCE) proposed an adjustment to the simple Aristotelian system.
- This is **the epicycle-deferent system**.

Solving the Problem of the Planets



The epicycle-deferent system



Mars
Epicycle
Point A
Equant point
Point B
Eccentric / Deferent
Earth

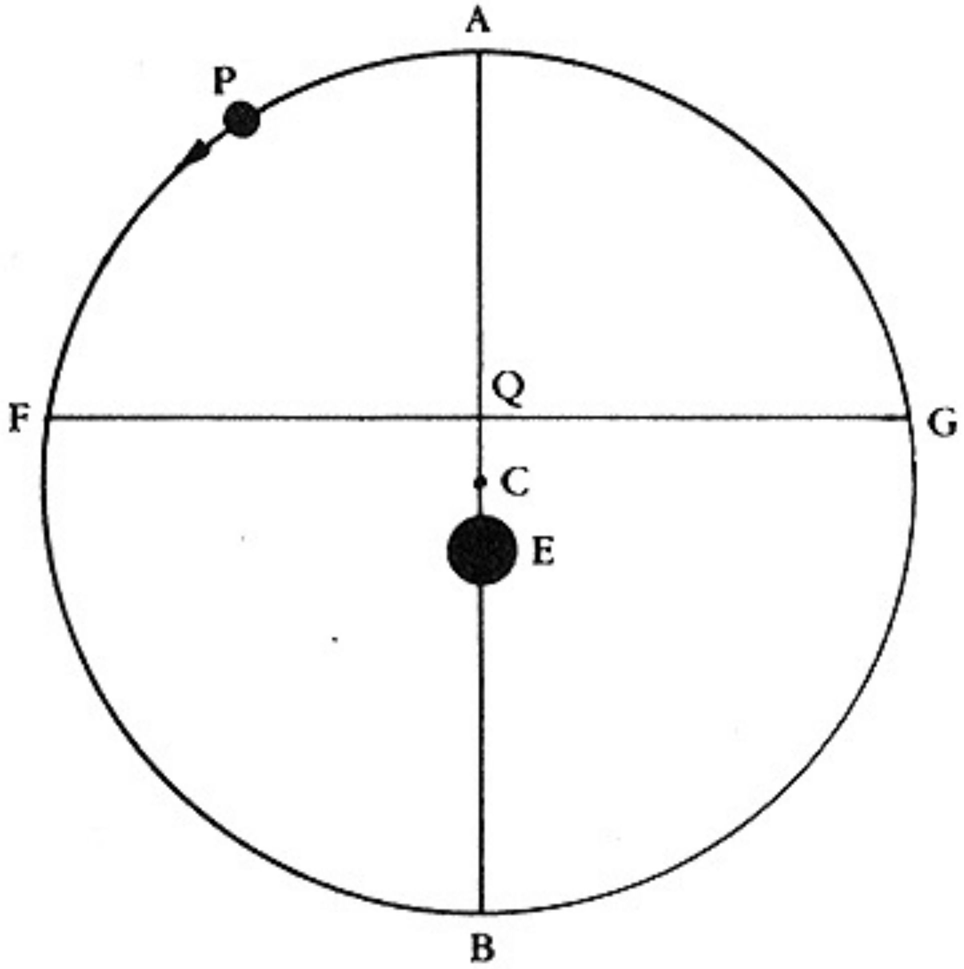
Solving the Problem of the Planets

1. Invoke only uniform circular motions

- All the epicycles and deferents are perfect circles.
- But planetary motion is *not uniform* with respect to the eccentric (the center of a deferent).
- Ptolemy tried to solve this discrepancy with an equant point.
- We didn’t talk about this last point yet. Let’s start with the definition of an equant point.

Solving the Problem of the Planets

- In Ptolemy’s epicycle-deferent system, a planet (or the center of its epicycle) moves uniformly about its deferent as viewed from an equant point.
- Let’s unpack this with a simple, deferent-only system (next).



P = planet; E = Earth; C = center of the deferent; Q = equant point

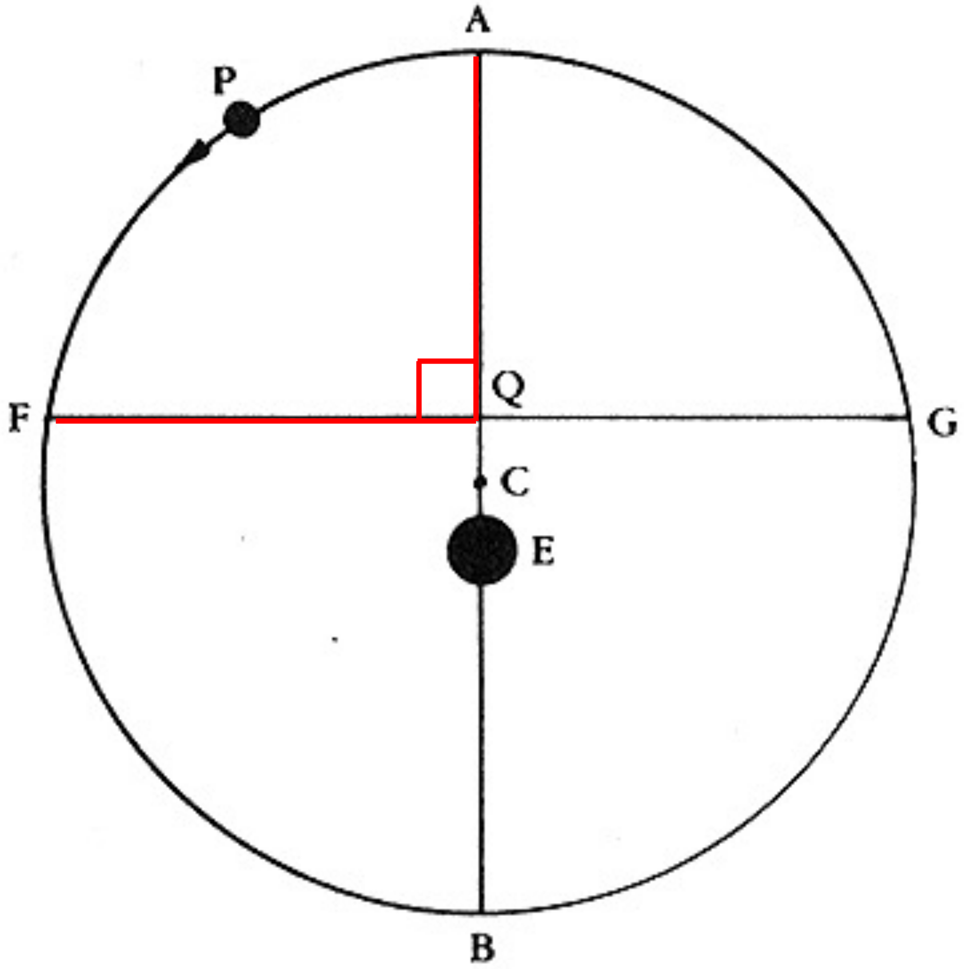
Let's say that the planet (P) travels from A to F in 3 years and from F to B in another 3 years.

Is the motion uniform?

The answer depends on how we measure speed.

Suppose we use our usual notion of **linear speed** (speed = distance/time). Is P moving uniformly?

No, because the circumference FB is longer than AF. In order to cover FB in the same time it did cover AF, P must move faster along FB.



P = planet; E = Earth; C = center of the deferent; Q = equant point

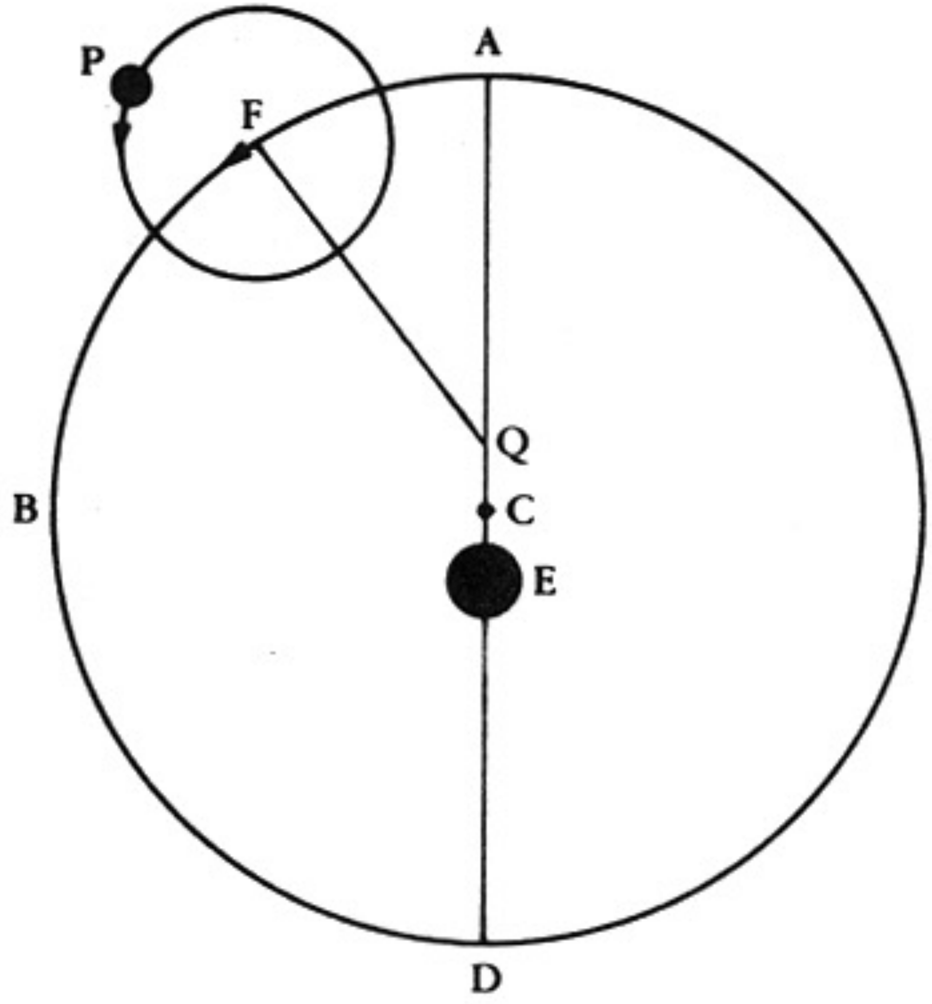
Suppose we use the notion of **angular speed** (speed = angle swept/time)

As the planet (P) travels from A to F in 3 years, it sweeps out the right angle AQF.

As the planet (P) travels from F to B in 3 years, it also sweeps out the right angle FQB.

So the angular speed with respect to the equant point Q is uniform.

Ptolemy’s epicycle-deferent model with an equant point



P = planet; E = Earth; C = center of the deferent; Q = equant point; F = center of the epicycle

Solving the Problem of the Planets

- Why did Ptolemy introduce an equant point?
- We can say two things about this question.

1. The role of conceptual facts.
2. The role of empirical facts.

- DeWitt only mentions (1).

Solving the Problem of the Planets

1. The role of conceptual facts.

- Conceptual facts constrain acceptable solutions.
- Ptolemy’s constraint was to invoke only uniform circular motion.
- The epicycle-deferent system invokes only circular motion.
- But the planet, if viewed from the Earth, does not move uniformly (in linear speed).
  - This is an observed fact (recall retrograde motion).

Solving the Problem of the Planets

- So to meet the constraint of uniform motion, Ptolemy introduced an equant point.
  - The plant moves uniformly (in angular speed) with respect to an equant point.
- Note that in Ptolemy's system, uniformity of motion is diluted: only a hypothetical observer located at an equant point will see planets moving uniformly.

Solving the Problem of the Planets

2. *The role of empirical facts.*

- An acceptable solution needs to accurately predict and explain empirical facts.
- The planet, if viewed from the Earth, does not move uniformly (in linear speed).
- Ptolemy's epicycle-deferent system predicts and explains this and other empirical facts.

Solving the Problem of the Planets

- If Ptolemy enforced uniform motion without an equant point, his system would be less successful at prediction and explanation of the data.
- For Ptolemy, the predictive and explanatory success of the epicycle-deferent system was *more important* than enforcing uniform motion.
- So, as a compromise, Ptolemy introduced an equant point, even though uniformity is now diluted.

Solving the Problem of the Planets

- In the 16th century, Copernicus questioned whether Ptolemy's system adequately meets the constraint of uniform motion.
- Since we know Copernicus broke with Ptolemy's system, we might expect that he also gave up the commitment to uniform circular motion.
- Not so!
- In fact, Copernicus was even more committed to uniform circular motion than Ptolemy. And this commitment motivated Copernicus to develop an alternative system. (More on this in the next chapter)

Solving the Problem of the Planets

- https://www.foothill.fhda.edu/astronomy/astrosims/ptolemaic-system/index.html
- Try turning on “Show Equant Vector”

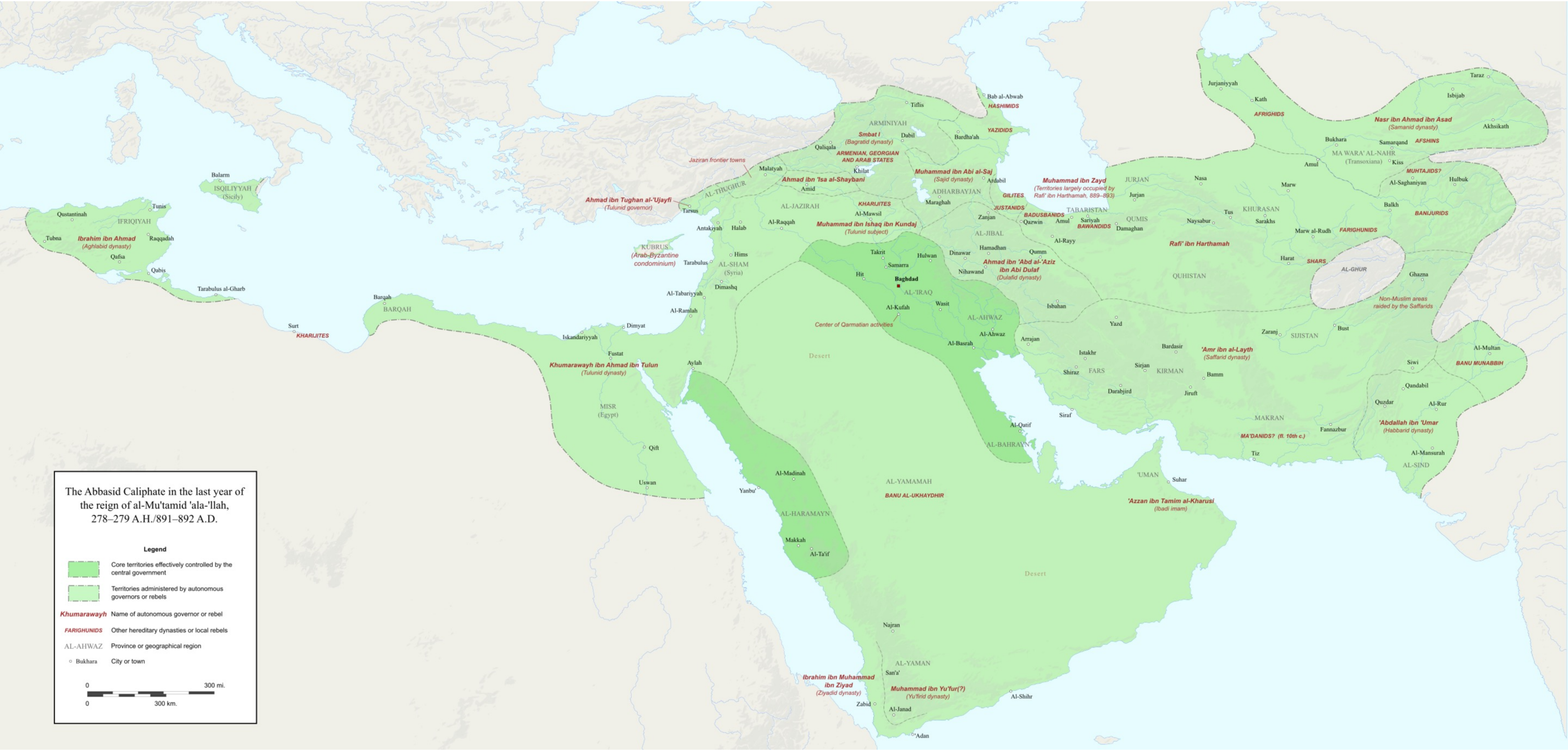
Chapter 14: The Copernican System (Historical Background)

Transmission of Greek Science

- This chapter is about the Copernican system and Copernicus's own motivations.
- But the *Almagest* is a 2nd century work, and Copernicus worked in the 16th century.
- What happened in 1400 years?

Transmission of Greek Science

- After the fall of Western Roman Empire in 480, the study of science and philosophy declined in Europe.
  - The scholarly interest shifted to Christian theology.
- In the 750s, the Abbasid dynasty took over the Muslim empire and founded its new capital, Baghdad. Soon Baghdad would become the largest metropolitan city in the world.



The Abbasid Caliphate in the last year of the reign of al-Mu'tamid 'ala-'llah, 278–279 A.H./891–892 A.D.
Legend
Core territories effectively controlled by the central government
Territories administered by autonomous governors or rebels
Khumarawayh Name of autonomous governor or rebel
FARIGHUNIDS Other hereditary dynasties or local rebels
AL-AHWAZ Province or geographical region
Bukhara City or town
0 300 mi.
0 300 km.
Balarm
ISQILIYYAH (Sicily)
Qustantinah
Tunis
IFRIQIYAH
Tubna
Ibrahim ibn Ahmad (Aghlabid dynasty)
Raqqadah
Qafsa
Qabis
Tarabulus al-Gharb
Surt
KHARIJITES
Barqah
BARQAH
Iskandariyyah
Dimyat
Fustat
Khumarawayh ibn Ahmad ibn Tulun (Tulunid dynasty)
MISR (Egypt)
Qift
Uswan
Aylah
KUBRUS (Arab-Byzantine condominium)
Ahmad ibn Tughan al-'Ujayfi (Tulunid governor)
Tarsus
AL-THUGHUR
Jaziran frontier towns
Malatyah
Antakiyah
Halab
Hims
Tarabulus
AL-SHAM (Syria)
Dimashq
Al-Tabariyyah
Al-Ramlah
Desert
Tiflis
ARMINIYAH
Smbat I (Bagratid dynasty)
Dabil
Qaliqala
ARMENIAN, GEORGIAN AND ARAB STATES
Khilat
Ahmad ibn 'Isa al-Shaybani
Amid
AL-JAZIRAH
Al-Raqqah
KHARIJITES
Al-Mawsil
Muhammad ibn Ishaq ibn Kundaj (Tulunid subject)
Takrit
Samarra
Hit
Baghdad
AL-'IRAQ
Al-Kufah
Wasit
Center of Qarmatian activities
Al-Basrah
AL-AHWAZ
Al-Ahwaz
Hulwan
Bab al-Abwab
HASHIMIDS
YAZIDIDS
Bardha'ah
Muhammad ibn Abi al-Saj (Sajid dynasty)
Ardabil
ADHARBAYJAN
Maraghah
GILITES
JUSTANIDS
Zanjan
BADUSBANIDS
Qazwin
Amul
Sariyah
BAWANDIDS
TABARISTAN
Damaghan
QUMIS
Muhammad ibn Zayd (Territories largely occupied by Rafi' ibn Harthamah, 889–893)
JURJAN
Jurjan
AL-JIBAL
Al-Rayy
Dinawar
Hamadhan
Qumm
Nihawand
Ahmad ibn 'Abd al-'Aziz ibn Abi Dulaf (Dulafid dynasty)
Isbahan
Arrajan
Yazd
Istakhr
Shiraz
FARS
Darabjird
Siraf
Sirjan
KIRMAN
Bardasir
Jiruft
Bamm
Al-Qatif
AL-BAHRAYN
Jurjaniyyah
Kath
AFRIGHIDS
Taraz
Isbijab
Nasr ibn Ahmad ibn Asad (Samanid dynasty)
Akhsikath
Bukhara
Samarqand
AFSHINS
MA WARA' AL-NAHR (Transoxiana)
Kiss
Amul
MUHTAJIDS?
Al-Saghaniyan
Hulbuk
Nasa
Marw
KHURASAN
Tus
Naysabur
Sarakhs
Balkh
BANIJURIDS
Marw al-Rudh
FARIGHUNIDS
Rafi' ibn Harthamah
Harat
SHARS
AL-GHUR
Ghazna
QUHISTAN
Non-Muslim areas raided by the Saffarids
Zaranj
SIJISTAN
Bust
'Amr ibn al-Layth (Saffarid dynasty)
Al-Multan
BANU MUNABBIH
Siwi
Qandabil
Quzdar
Al-Rur
MAKRAN
Fannazbur
'Abdallah ibn 'Umar (Habbarid dynasty)
MA'DANIDS? (fl. 10th c.)
Tiz
Al-Mansurah
AL-SIND
'UMAN
Suhar
'Azzan ibn Tamim al-Kharusi (Ibadi imam)
Al-Madinah
Yanbu'
AL-HARAMAYN
Makkah
Al-Ta'if
AL-YAMAMAH
BANU AL-UKHAYDHIR
Desert
Najran
AL-YAMAN
San'a'
Ibrahim ibn Muhammad ibn Ziyad (Ziyadid dynasty)
Muhammad ibn Yu'fur(?) (Yu'firid dynasty)
Al-Shihr
Zabid
Al-Janad
'Adan

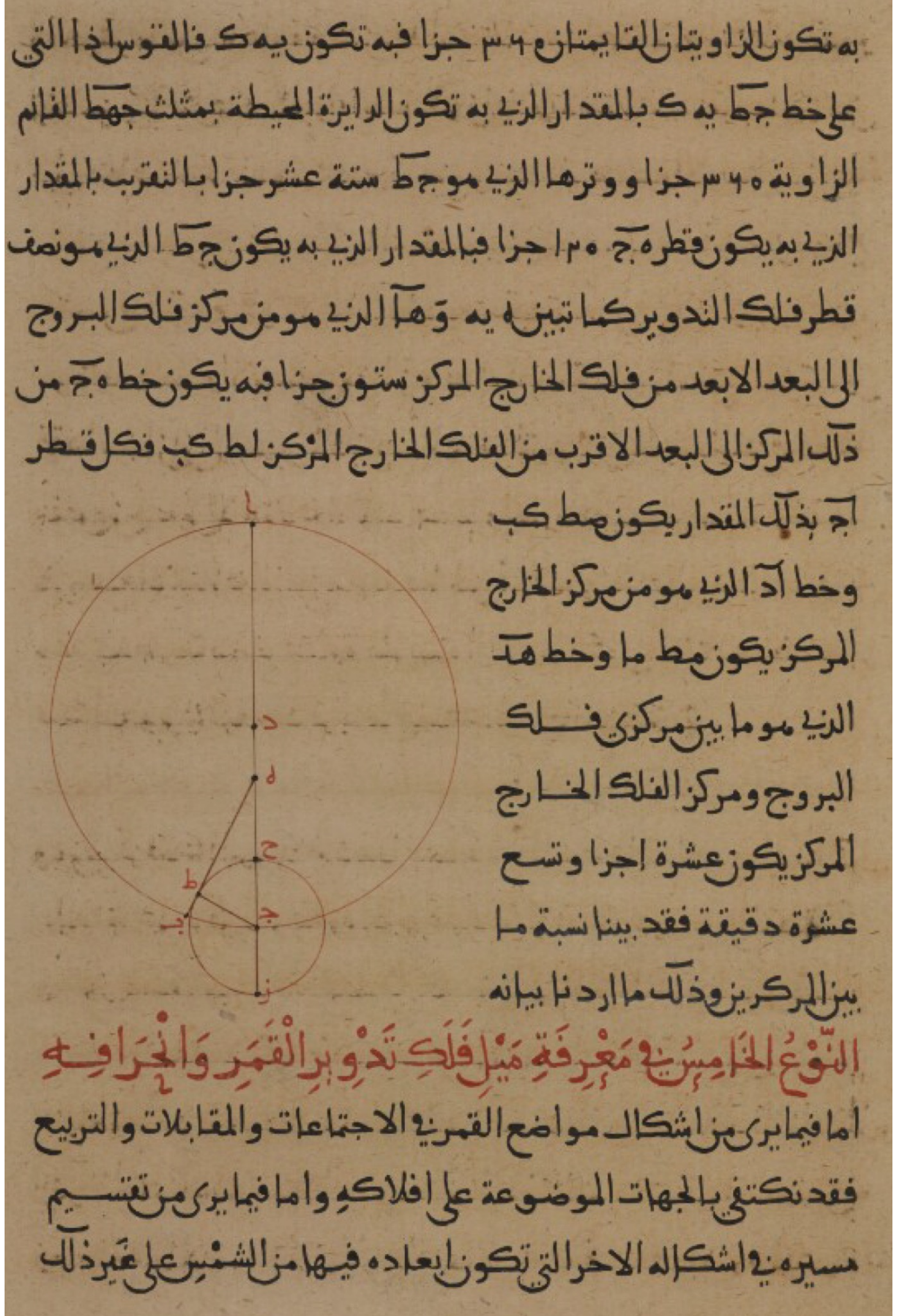
Transmission of Greek Science

In Baghdad, the Abbasids established the House of Wisdom.

It was like a research center: it had groups of scientists, philosophers, and other academics, and there was a large library.

Transmission of Greek Science

- One of the most important activities of the House of Wisdom was its translation department.
- Scholars translated all the Greek texts available to them into Arabic.
- This is known as the Translation Movement.
    - Ptolemy's *Almagest* is the Arabic title given by these translators (it means "the greatest.")
- It would make an important impact on the European (Western) science and philosophy when these texts and commentaries were later translated into Latin.



به تكون الزاويتان القايمتان ٣٦٠ جزا فبه تكون يه ك فالقوس اذا التي
على خط جط يه ك بالمقدار الذي به تكون الدايرة المحيطة بمثلث جهط القايم
الزاوية ٣٦٠ جزا و وترها الذي هو جط ستة عشر جزا بالتقريب بالمقدار
الذي به يكون قطره جه ١٢٠ جزا فبالمقدار الذي به يكون جط الذي هو نصف
قطر فلك التدوير كما تبين له يه وها الذي هو من مركز فلك البروج
الى البعد الابعد من فلك الخارج المركز ستون جزا فبه يكون خط هج من
ذلك المركز الى البعد الاقرب من الفلك الخارج المركز لط كب فكل قطر
اج بذلك المقدار يكون قط كب
وخط اد الذي هو من مركز الخارج
المركز يكون مط ما وخط هد
الذي هو ما بين مركزي فلك
البروج ومركز الفلك الخارج
المركز يكون عشرة اجزا وتسع
عشرة دقيقة فقد بينا نسبة ما
بين المركزين وذلك ما اردنا بيانه

النوع الخامس في معرفة ميل فلك تدوير القمر وانحرافه

اما فيما يرى من اشكال مواضع القمر في الاجتماعات والمقابلات والتربيع
فقد نكتفي بالجهات الموضوعة على افلاكه واما فيما يرى من تقسيم
مسيره في اشكاله الاخر التي تكون ابعاده فيها من الشمس على غير ذلك

Arabic translation of Ptolemy's *Almagest* (8th or 9th century)

Islamic Astronomy

- In addition to the translation movement, Islamic scholars made their own contributions to science.
- We'll briefly look at Islamic astronomy.

Islamic Astronomy

- Islamic astronomy engaged in three activities:

1. Mastering Ptolemy’s *Almagest* and correcting the parameters of Ptolemy’s epicycle-deferent system.
2. Developing new astronomical systems that better predict and explain the data.
3. Establishing astronomical observatories.

- Let’s look at quick examples of each.

Islamic Astronomy

1. Mastering Ptolemy's Almagest and correcting the parameters of Ptolemy's epicycle-deferent system

Al-Battani (c. 858–929) (**Albategni** in Latin)

- Corrected and greatly improved Ptolemy's measurements
- E.g., al-Battani's measurement of the length of a year is only a little more than 2 minutes off from our current measurement.
- In the 16th and 17th centuries, the Latin translations of al-Battani's works were cited by Copernicus, Kepler, and others.

Latin translation of al-Battani's work (1645)

Islamic Astronomy

2*. Developing new astronomical systems that better predict and explain the data*

Ibn al-Haytham (c. 965–c. 1040) (**Alhazen** in Latin)

- Focused on the problem of reconciling Ptolemy's mathematical system with the Aristotelian structure of the universe.
  - Recall the Aristotelian structure is concentric crystalline spheres. It is a physical model of the universe.
  - Ptolemy's system is a geometrical (non-physical) model.
  - The question is how epicycles are physically realized.
- Ibn al-Haytham revived Ptolemy's physical-sphere version of the epicycle-deferent model (see next).

Physical-sphere version of the Ptolemaic epicycle-deferent system

This model was included in Georg von Peuerbach's *Theoricae novae planetarum* (first printed in 1454), which contributed to a revival of astronomy in Europe.

This text formed the basis of the astronomical education of Copernicus.

Islamic Astronomy

2. Developing new astronomical systems that better predict and explain the data

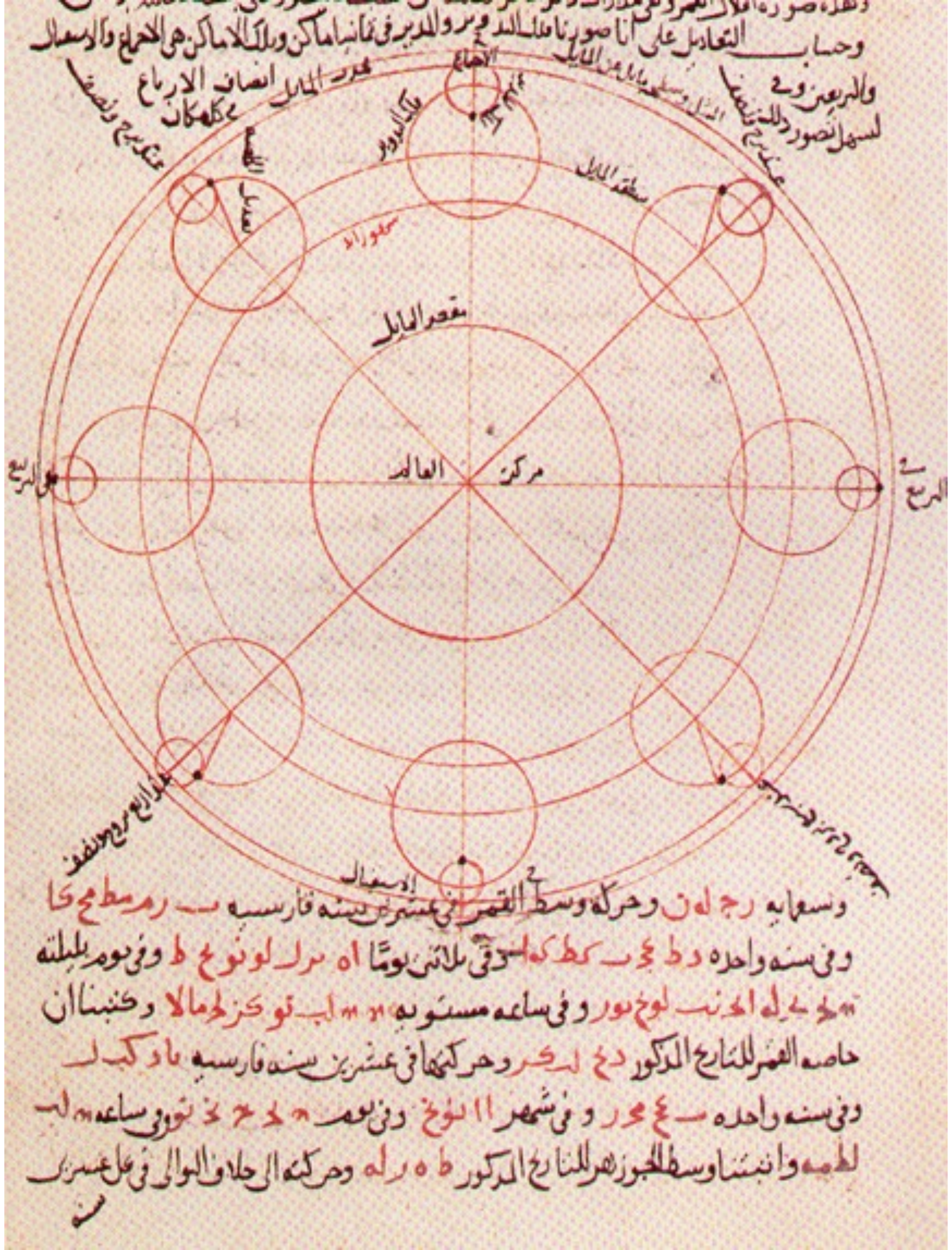
- Islamic astronomers since Tusi (1201–1274) debated
  - the possibility of separating mathematical astronomy from Aristotelian physics.
  - the possibility of Earth's motion.
- Copernicus followed Tusi's objection to Ptolemy's argument for stationary Earth.
- They also developed astronomical systems that departed from Ptolemy's.
  - E.g., systems without an equant point

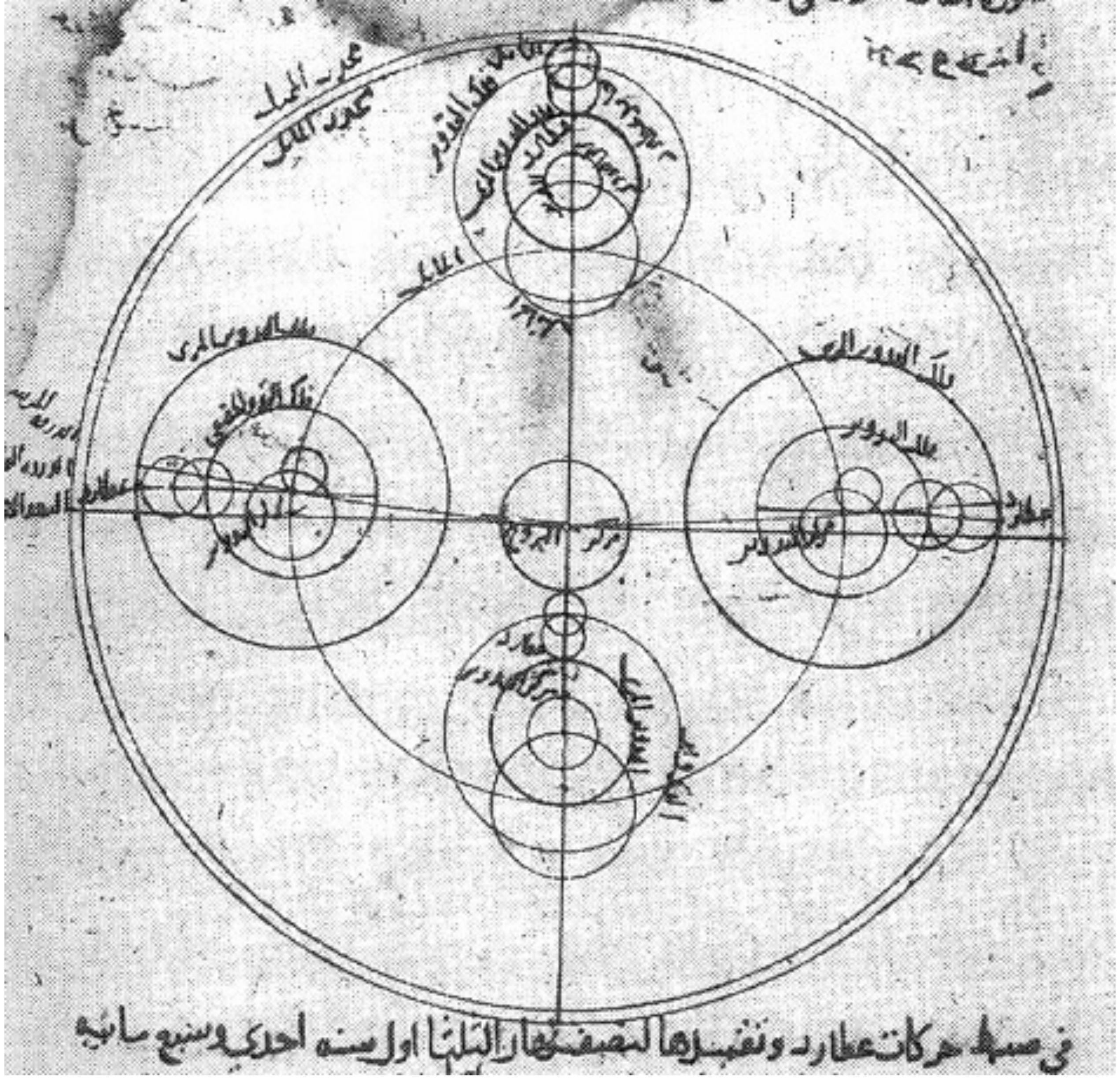
Islamic Astronomy

2. Developing new astronomical systems that better predict and explain the data

Ibn al-Shatir (1304–1375)

- Eliminated Ptolemy’s equant point and developed a system with an extra epicycle.
- Ibn al-Shatir’s system is mathematically equivalent to Copernicus’s.





Moon (left) and Mercury (right) according to Ibn al-Shatir

Islamic Astronomy

2. Developing new astronomical systems that better predict and explain the data

Ali Qushji (1403–1474)

- Argued that astronomy should be independent of Aristotelian physics.
  - This means that Aristotelian conceptual facts (e.g., beliefs about motion and elements) should not constrain problem solving in astronomy.
- Argued that an astronomical system with moving Earth is *possible* and looked for empirical evidence for the Earth's rotation.

Islamic Astronomy

2. Developing new astronomical systems that better predict and explain the data

- Qushji's ideas were very likely to be transmitted to Europe through Regiomontanus's *Epitome of the Almagest* (published in 1496).
  - Regiomontanus (1436–1476) was a German astronomer.
  - His *Epitome of the Almagest* is the first printed edition of Ptolemy's *Almagest*.
  - In 1496, which this was published, Copernicus was 23.

Regiomontanus's *Epitome of the Almagest* (1496)

Primus

Prefationē aūt ptolemei ad litterā exprimere libuit: tum propter crebras in ea sentētias scitu dignissimas: tum propter auctoritatē Ptolemei: quo etiam imitatio nr̄a fidelior redderet. Nūc ad sciētiā chordarū feliciter descēdam⁹

Propositio Prima.

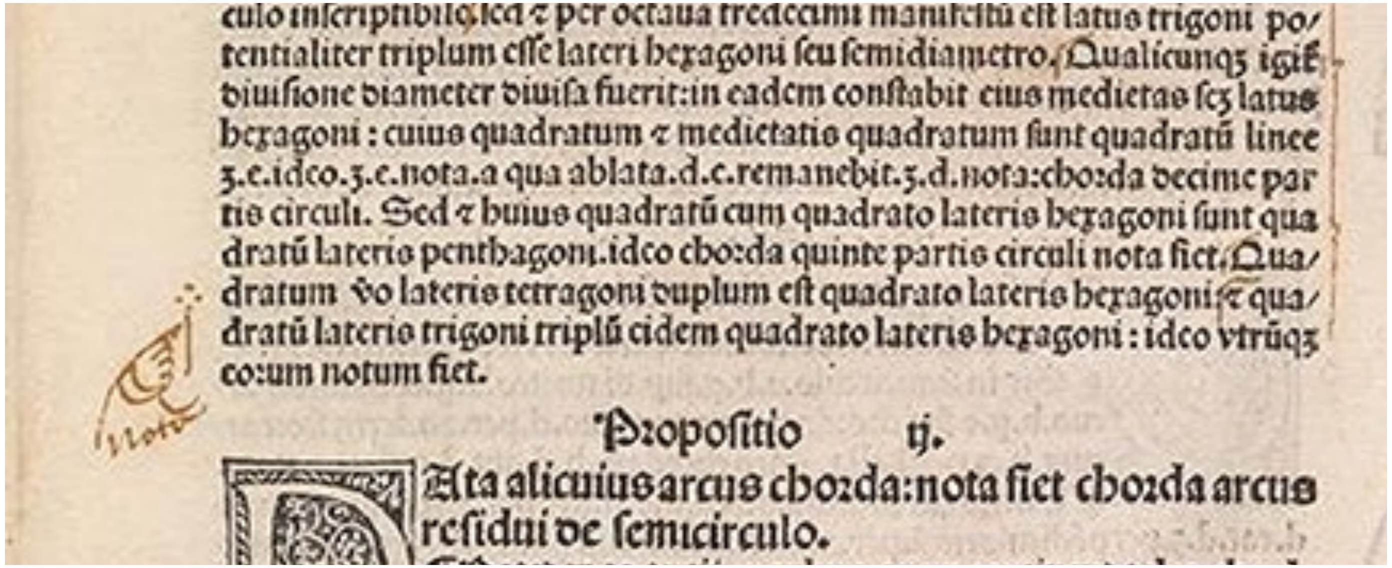
Data circuli diametro: latera decagoni: hexagoni: pentagoni: tetragoni: atq3 trianguli isopleurorum eidem circulo inscriptorum reperire.

Sit semicirculus.a.b.g.supra diametrum.a.d.g.et centrum.d.erectus. Protrobā.d.b.perpendicularem super.a.g.per.11.primi euclidis. lineamq3.d.g.diuidam per duo equalia super puncto.e.et ducam lineā.e.b.huic equalem faciam.e.z. productaq3.b.z.dico.z.d. esse equale lateri decagoni: et.b.z.equale lateri penthagoni. Quod sic ostendam: Quia g.d.diuiditur in duo equa super.e.et addita est ei in longum.d.z.ergo per sextam secūdi quadrangulum quod fit ex.g.z.in.d.z.cum quadrato.d.e.equū est quadrato linee.e.z.sed.e.z.est equalis.e.b.et per penultimā primi quadratum.e.b.equū est duobus quadratis.b.d.et.d.e.quod igitur fit ex.g.z.in.z.d cum quadrato.d.e.equale erit duobus quadratis.b.d.et.d.e.ablato cōmuni quadrato.d.e.erit quod fit ex.g.z.in.z.d.equale quadrato.b.d.ideo etiā eq̄le quadrato.d.g.ergo per secundā partē.16.sexti.g.z.ad.d.g.proportio fiet sicut.d.g.ad.z.d.proportio.ideo per principium sexti linea.z.g.est diuisa in puncto.d.sm̄ proportionē habentem medium et duo extrema.sed maior ei⁹ portio scz.d.g.est latus hexagoni per correlariū.16.quarti.ideo per cōuersionē tredecimi minor eius portio scz.d.z.est latus decagoni: quod est primū. Et quoniā per penultimā primi quadratū.b.z.est equale duobus quadratis.b.d.et.d.z.et.b.d.est latus hexagoni: et.d.z.latus decagoni.ideo per conuersam decime tredecimi.b.z.erit latus penthagoni: quod est secūdū. Et si duxeris lineam.a.b.constabit ipsam ex sexta quarti esse latus quadrati circulo inscriptibilis.sed et per octauā tredecimi manifestū est latus trigoni potentialiter triplum esse lateri hexagoni seu semidiametro. Qualicunq3 igitur diuisione diameter diuisa fuerit: in eadem constabit eius medietas scz latus hexagoni: cuius quadratum et medietatis quadratum sunt quadratū linee z.e.ideo.z.e.nota.a qua ablata.d.e.remanebit.z.d.nota: chorda decime partis circuli. Sed et huius quadratū cum quadrato lateris hexagoni sunt quadratū lateris penthagoni.ideo chorda quinte partis circuli nota fiet. Quadratum vo lateris tetragoni duplum est quadrato lateris hexagoni: et quadratū lateris trigoni triplū eidem quadrato lateris hexagoni: ideo vtrūq3 eorum notum fiet.

Propositio ij.

Data alicuius arcus chorda: nota fiet chorda arcus residui de semicirculo.

Patet ex.30.tertij angulum quem continent tales chorde rectum esse.ideo per penultimā primi quadratū diametri circuli equū erit quadratis duobus ipsarum chordarum: igit et c. Sic ex latere decagoni inuenies chordam arcus.144.graduū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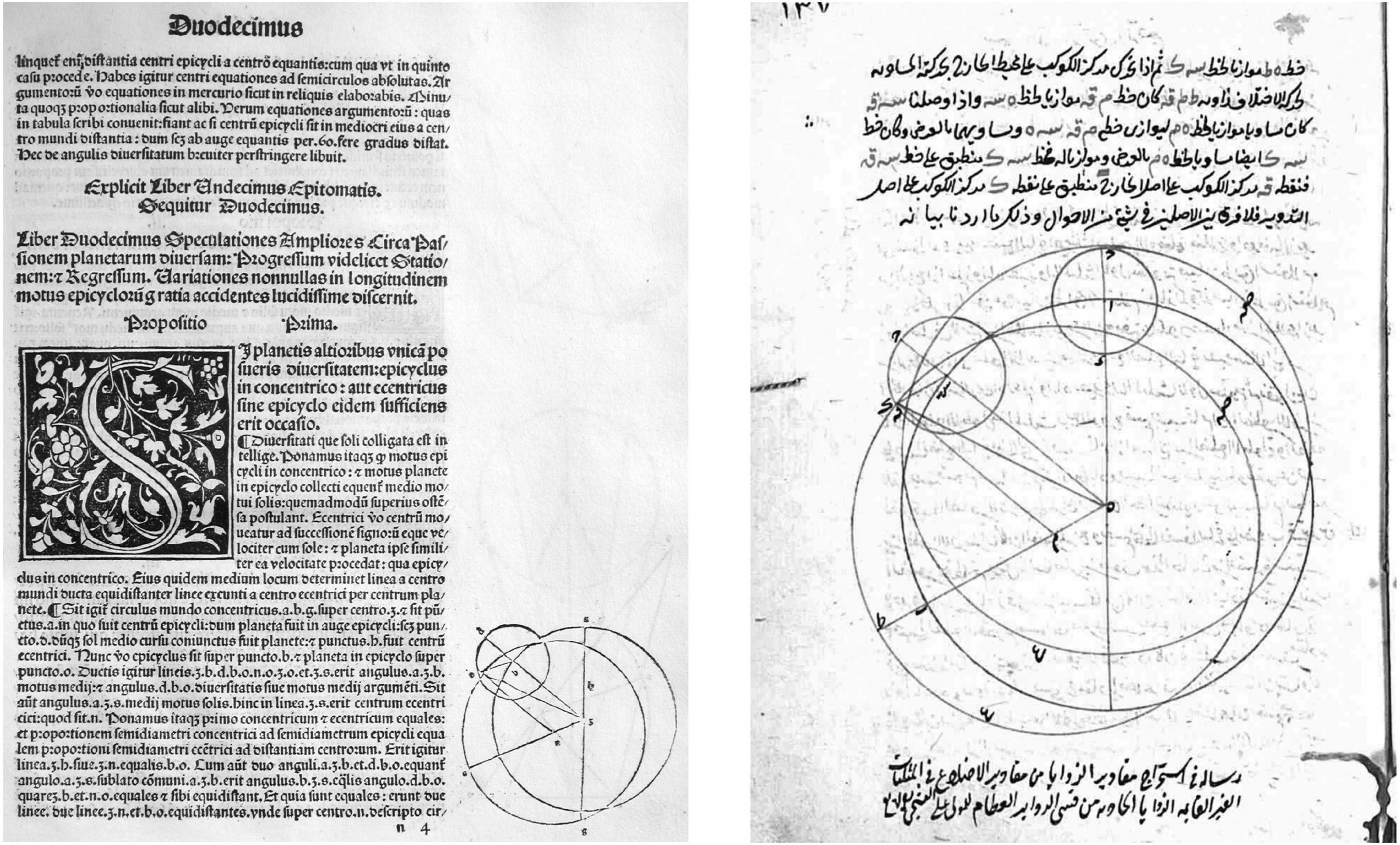
Propositio ij.

Data alicuius arcus chorda: nota fiet chorda arcus residui de semicirculo.

Regiomontanus's *Epitome of the Almagest* (1496). Annotated in Latin by a reader. Note the diagram with "noto" above.


Duodecimus

linquet enī distantia centri epicycli a centrō equantis: cum qua vt in quinto casu procede. Habes igitur centri equationes ad semicirculos absolutas. Argumentorū vō equationes in mercurio sicut in reliquis elaborabis. Minuta quoqȝ proportionalia sicut alibi. Verum equationes argumentorū: quas in tabula scribi conuenit: fiant ac si centrū epicycli sit in mediocri eius a centro mundi distantia: dum scȝ ab auge equantis per.60.fere gradus distat. Hec de angulis diuersitatum breuiter perstringere libuit.

Explicit Liber Undecimus Epitomatis.
Sequitur Duodecimus.

Liber Duodecimus Speculationes Ampliores Circa Passionem planetarum diuersam: Progressum videlicet Stationem: et Regressum. Uariationes nonnullas in longitudinem motus epicyclorū gratia accidentes lucidissime discernit.

Propositio Prima.

SI planetis altioribus vnicā posueris diuersitatem: epicyclus in concentrico: aut ecentricus sine epicyclo eidem sufficiens erit occasio.

¶ Diuersitati que soli colligata est intellige. Ponamus itaqȝ ꝙ motus epicycli in concentrico: et motus planete in epicyclo collecti equent medio motui solis: quemadmodū superius ostēsa postulant. Ecentrici vō centrū moueatur ad successionē signorū eque velociter cum sole: et planeta ipse similiter ea velocitate procedat: qua epicyclus in concentrico. Eius quidem medium locum determinet linea a centro mundi ducta equidistanter linee exeunti a centro ecentrici per centrum planete. ¶ Sit igit circulus mundo concentricus.a.b.g.super centro.ȝ.et sit pūctus.a.in quo fuit centrū epicycli: dum planeta fuit in auge epicycli: scȝ puncto.d.dūqȝ sol medio cursu coniunctus fuit planete: et punctus.b.fuit centrū ecentrici. Nunc vō epicyclus sit super puncto.b.et planeta in epicyclo super puncto.o. Ductis igitur lineis.ȝ.b.d.b.o.n.o.ȝ.o.et.ȝ.s.erit angulus.a.ȝ.b. motus medij: et angulus.d.b.o.diuersitatis siue motus medij argumēti. Sit aūt angulus.a.ȝ.s.medij motus solis. hinc in linea.ȝ.s.erit centrum ecentrici: quod sit.n. Ponamus itaqȝ primo concentricum et ecentricum equales: et proportionem semidiametri concentrici ad semidiametrum epicycli equalem proportioni semidiametri ecētrici ad distantiam centrorum. Erit igitur linea.ȝ.b.siue.ȝ.n.equalis.b.o. Cum aūt duo anguli.a.ȝ.b.et.d.b.o.equant angulo.a.ȝ.s.sublato cōmuni.a.ȝ.b.erit angulus.b.ȝ.s.eq̄lis angulo.d.b.o. quareȝ.b.et.n.o.equales et sibi equidistant. Et quia sunt equales: erunt due linee. due linee.ȝ.n.et.b.o.equidistantes. vnde super centro.n.descripto cir

n 4

FIG. 1. Comparison of diagrams of Regiomontanus and Qūshjī. (*Left*) J. Regiomontanus and G. Peurbach, *Epytoma Joannis de monte regio In almagestum ptolemaei* (Venice, 1496), n4r, and (*right*) ᶜAlī Qūshjī, *Fī anna aṣl al-khārij…*, Carullah MS 2060, f. 137a. Reproductions courtesy of the History of Science Collections, University of Oklahoma Libraries, and of the Süleymaniye Library, Istanbul, respectively.

Islamic Astronomy

3. Establishing astronomical observatories

- An observatory is a research institution. It needs:
  - A building
  - Observational instruments
  - A library
  - A staff of professional astronomers
- See images next

The observatory of Taqi ad-Din (16th century)

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

The trench with the lower section of the meridian arc

Qushji worked here.

Revival of Science in Europe

- Before the end of 11th century, Arabic texts (Arabic translations of Greek originals and original Arabic works) as well as Greek originals (which had been lost in Europe) entered Europe through Spain.
- European scholars began translating them. This effort continued into the 13th century.
- By the end of 12th century, Europeans recovered major parts of Greek and Islamic philosophy and science.
- This recovered learning continued in newly founded universities (see next).

Medieval universities and dates of founding

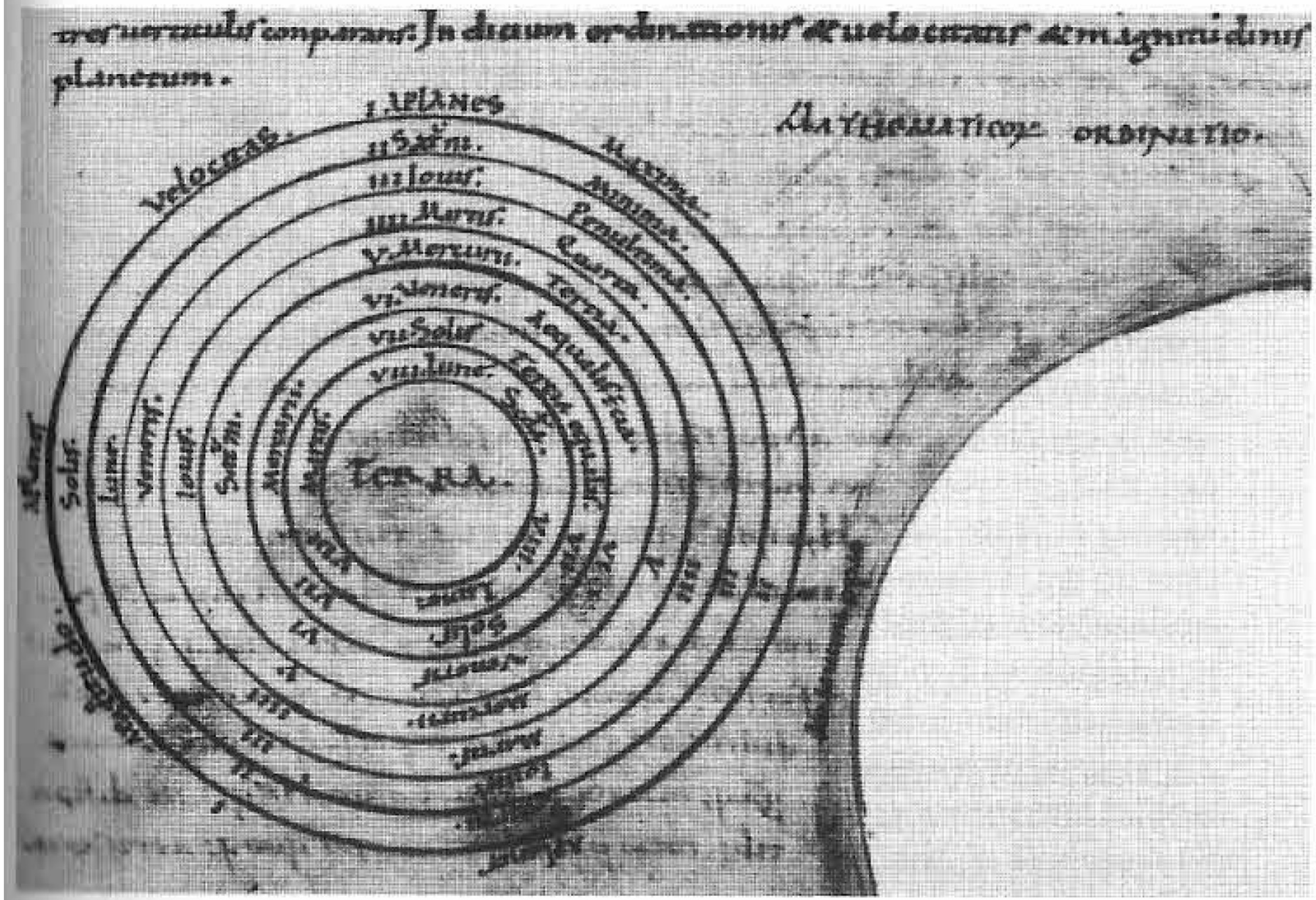
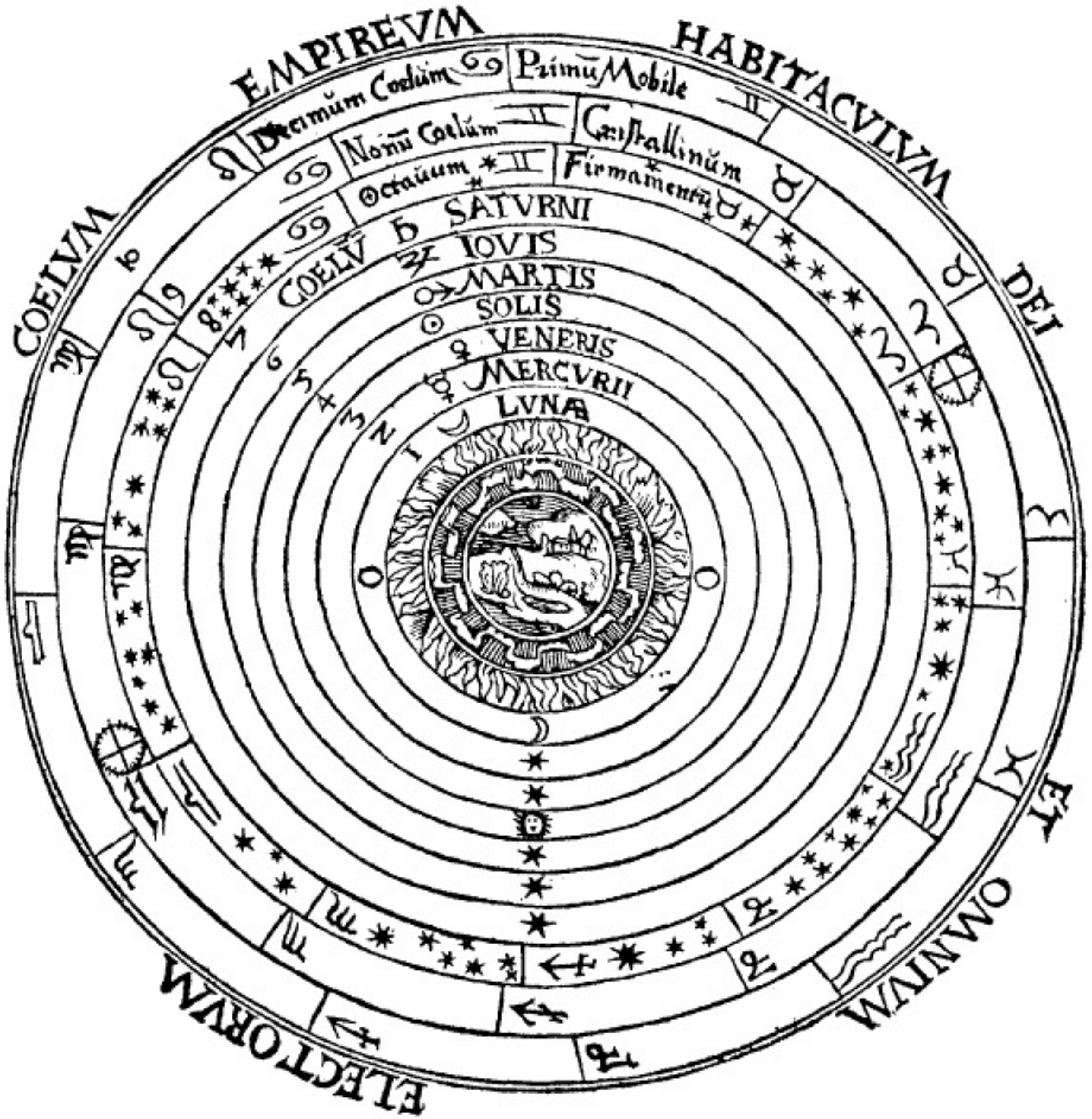


Fig. 11.1. The simplified Aristotelian cosmology popular in the Middle Ages. Paris, Bibliothèque Nationale, MS Lat. 6280, fol. 20r (12th c.).

Schema huius præmissæ diuisionis Sphærarum.



Peter Apian’s representation of the universe from his *Cosmographia* (1524) (https://en.wikipedia.org/wiki/Petrus_Apianus)

Note the Christianization of the Aristotelian universe: the outermost part is the empire of God.

Revival of Science in Europe

- Christians in Europe now had to assimilate Greek and Islamic science and philosophy into their already Christian worldview.
- This resulted in a Christianized Aristotelian universe we have seen before.
- It also resulted in a ban on teaching certain Aristotelian ideas.
  - The Condemnations of 1270 and 1277 at the University of Paris
- When Copernicus started his astronomical study, what he inherited was this Christianized version of Greek and Islamic science and philosophy.
  - DeWitt talks about Neoplatonism, which is a Christianized version of Plato's philosophy.

Chapter 14: The Copernican System