Aristotelian Physics and Chemistry

Terrestrial Series

Fi Fire

Ai Air

Wa Water

Ea Earth

Celestial Series

Et Ether

(A pure, transparent, luminous substance found only in the heavens)

"Gravity" = tendency of Earth and Water to sink toward the center of the universe (opposite of "levity")

Claudius Ptolemy (AD 100-170)

Almagest

- star catalogue
- instruments
- motions & **model** of planets, Sun, Moon

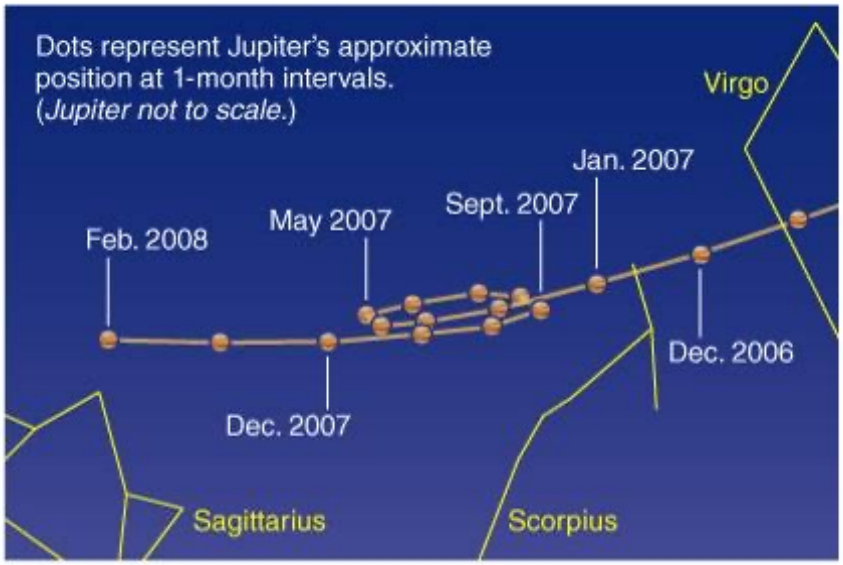
His model fit the data, made accurate predictions, but was horribly contrived – especially for retrograde motion!

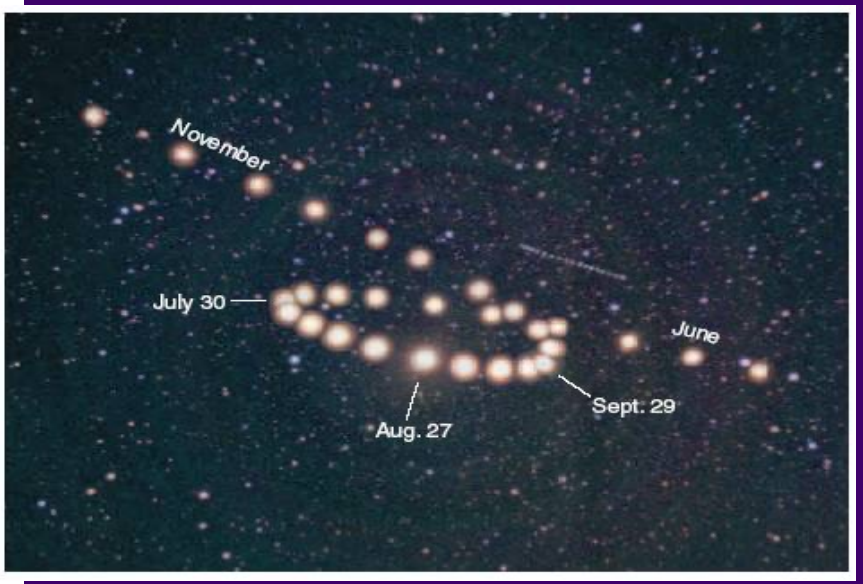
How does one explain *retrograde* motion?

Over a period of 10 weeks, Mars appears to stop, back up, then go forward again.

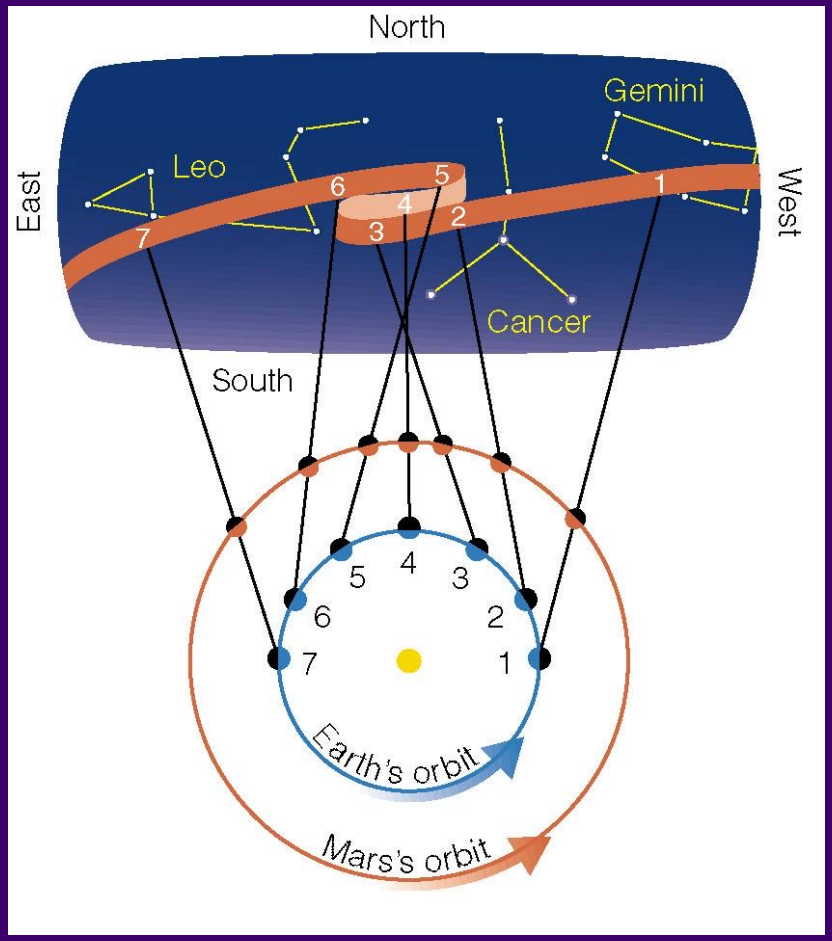
What was once so mysterious about the movement of planets in our sky?

- Planets usually move slightly *eastward* from night to night relative to the stars.
- But, sometimes they go *westward* relative to the stars for a few weeks: **apparent retrograde motion.**





We see apparent retrograde motion when we pass by a planet in its orbit.



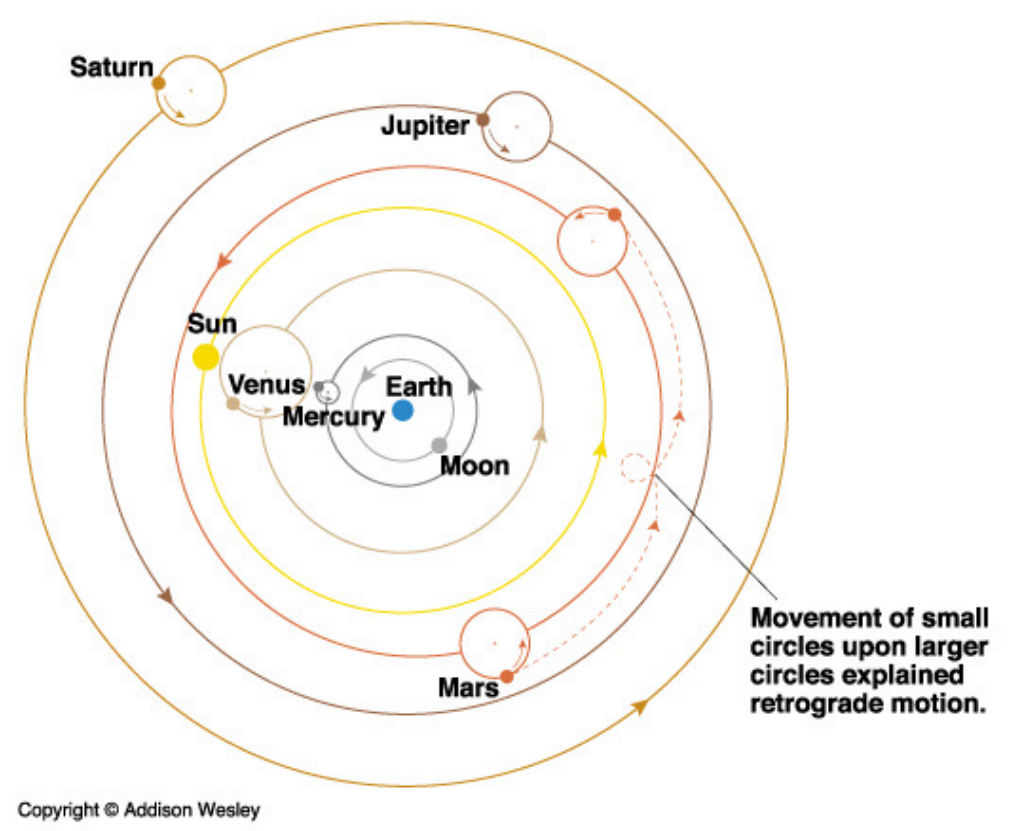
PLAY Mars Retrograde Motion

Explaining Apparent Retrograde Motion

- Easy *for us* to explain: occurs when we "lap" another planet (or when Mercury or Venus lap us)
- But very difficult to explain if you think that Earth is the center of the universe!
- *In fact, the Greeks considered but rejected the correct explanation…*

Ptolemy's Geocentric Model

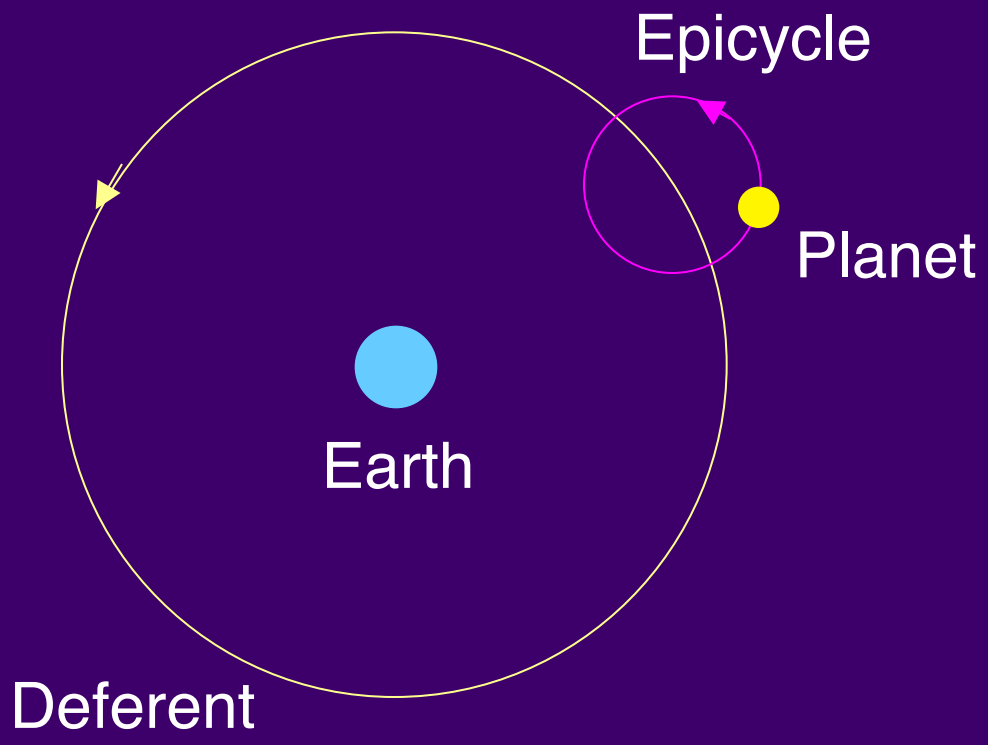
- Earth is at center
- Sun orbits Earth
- Planets orbit on small circles whose centers orbit the Earth on larger circles
  - – [the small circles are called **epicycles**]



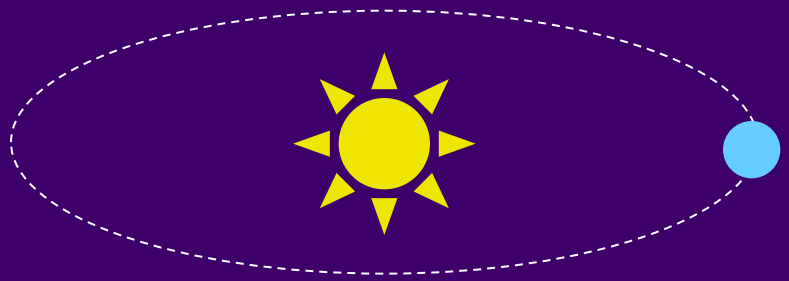
Ptolemy's Geocentric Model

- This explained retrograde motion
- Inferior planet epicycles were fixed to the Earth-Sun line
- This explained why Mercury & Venus never strayed far from the Sun!

Epicycles to explain retrograde motion



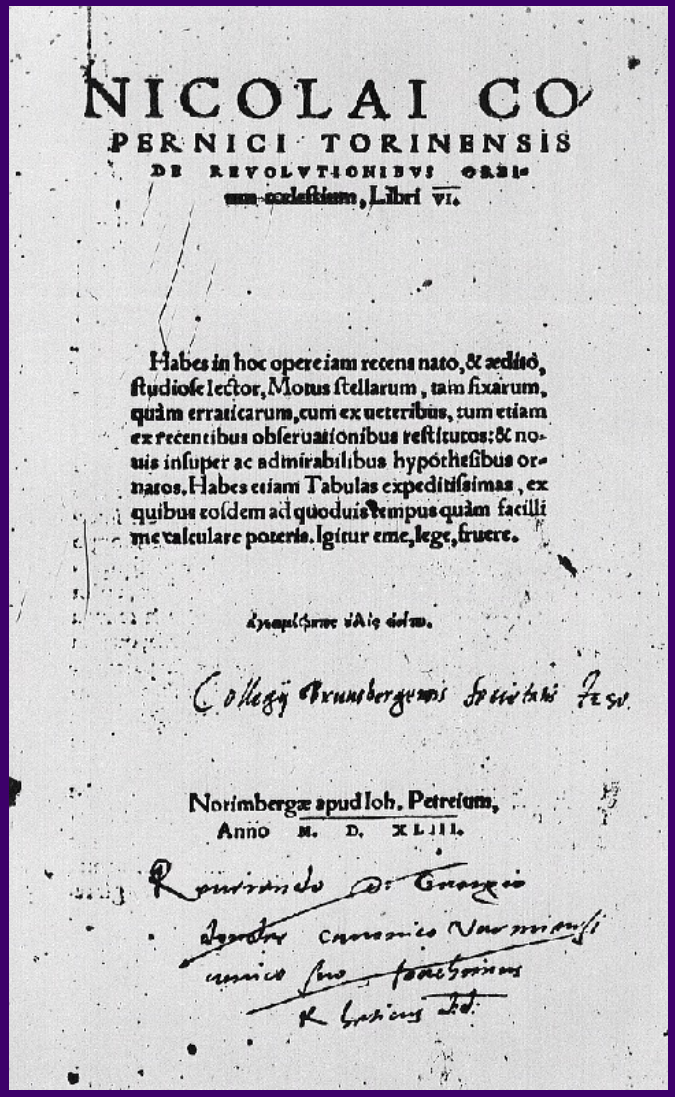
Ptolemy also used minor epicycles, off-center circles, and other geometrical tricks to explain details of planetary motion.



The Copernican Revolution

Nicolaus Copernicus (Mikolaj Koppernigk) 1473-1543

De Revolutionibus (“Revolutions”) (published 1543)

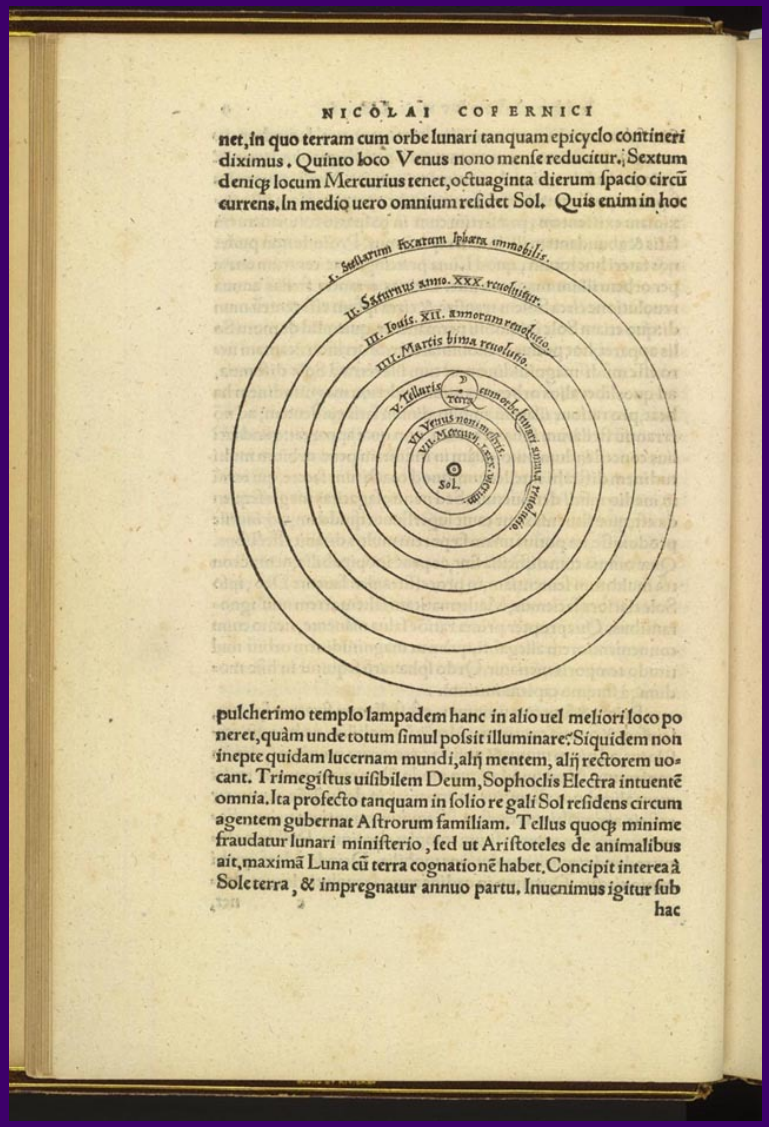


NICOLAI CO
PERNICI TORINENSIS
DE REVOLVTIONIBVS ORBI-
um coelestium, Libri VI.

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

Collegij Norumbergensis Societatis Jesu

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

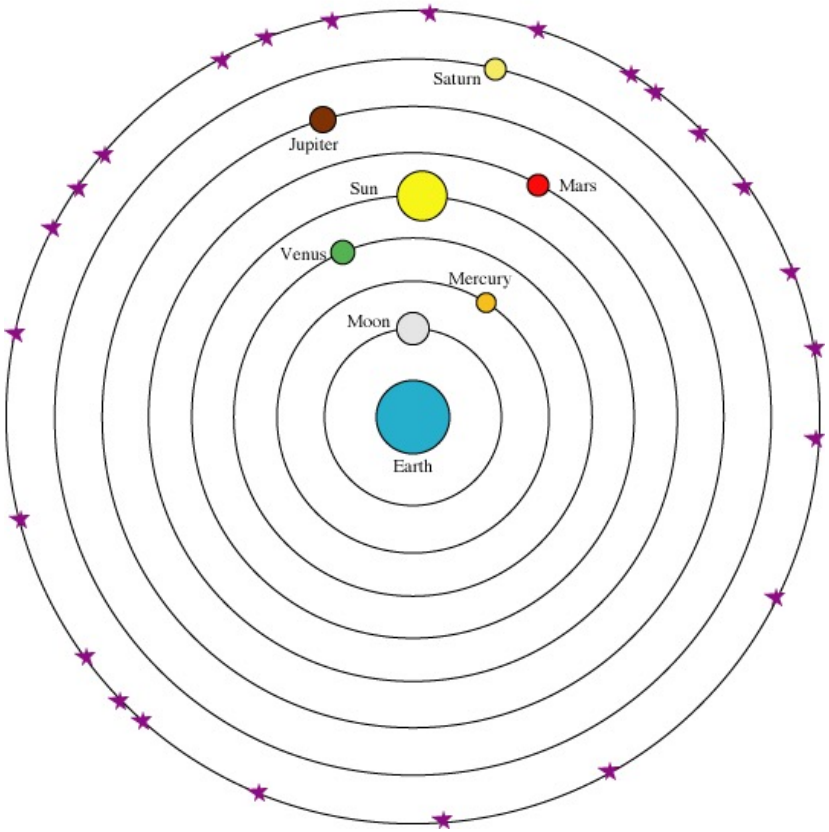


NICOLAI COPERNICI

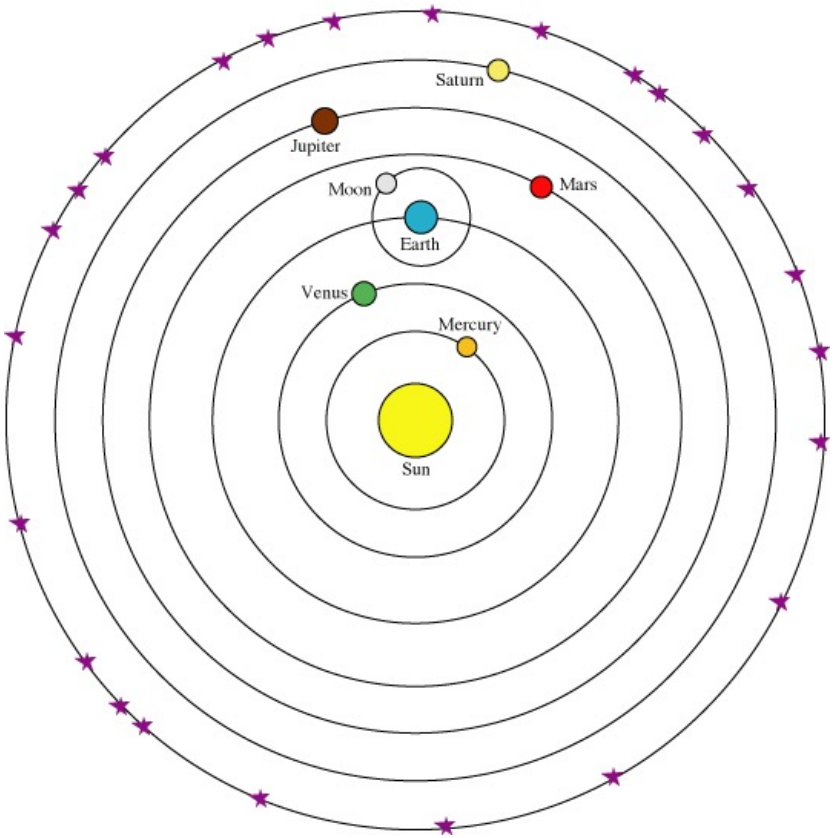
net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc

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

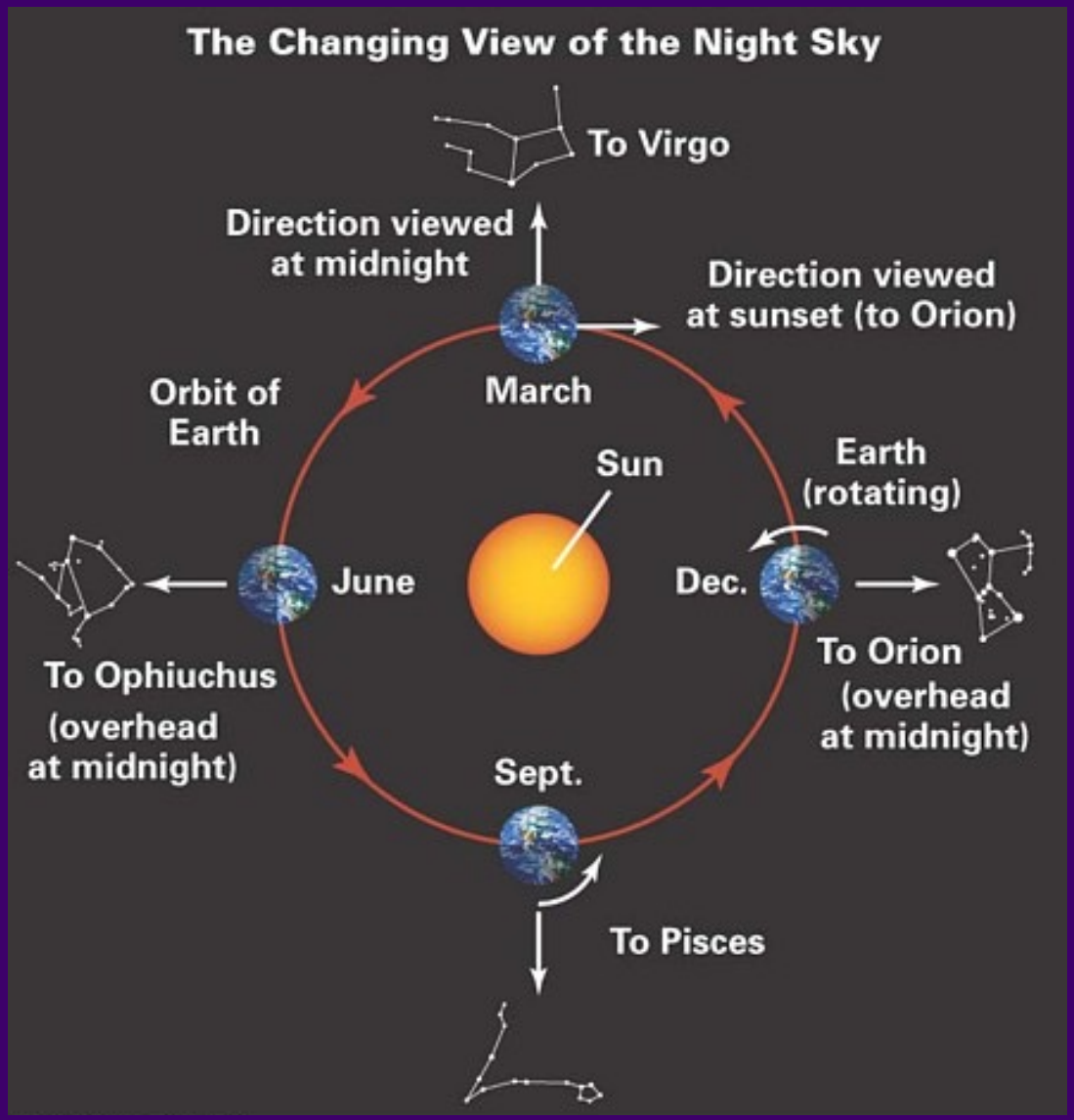
The Aristotelian Universe



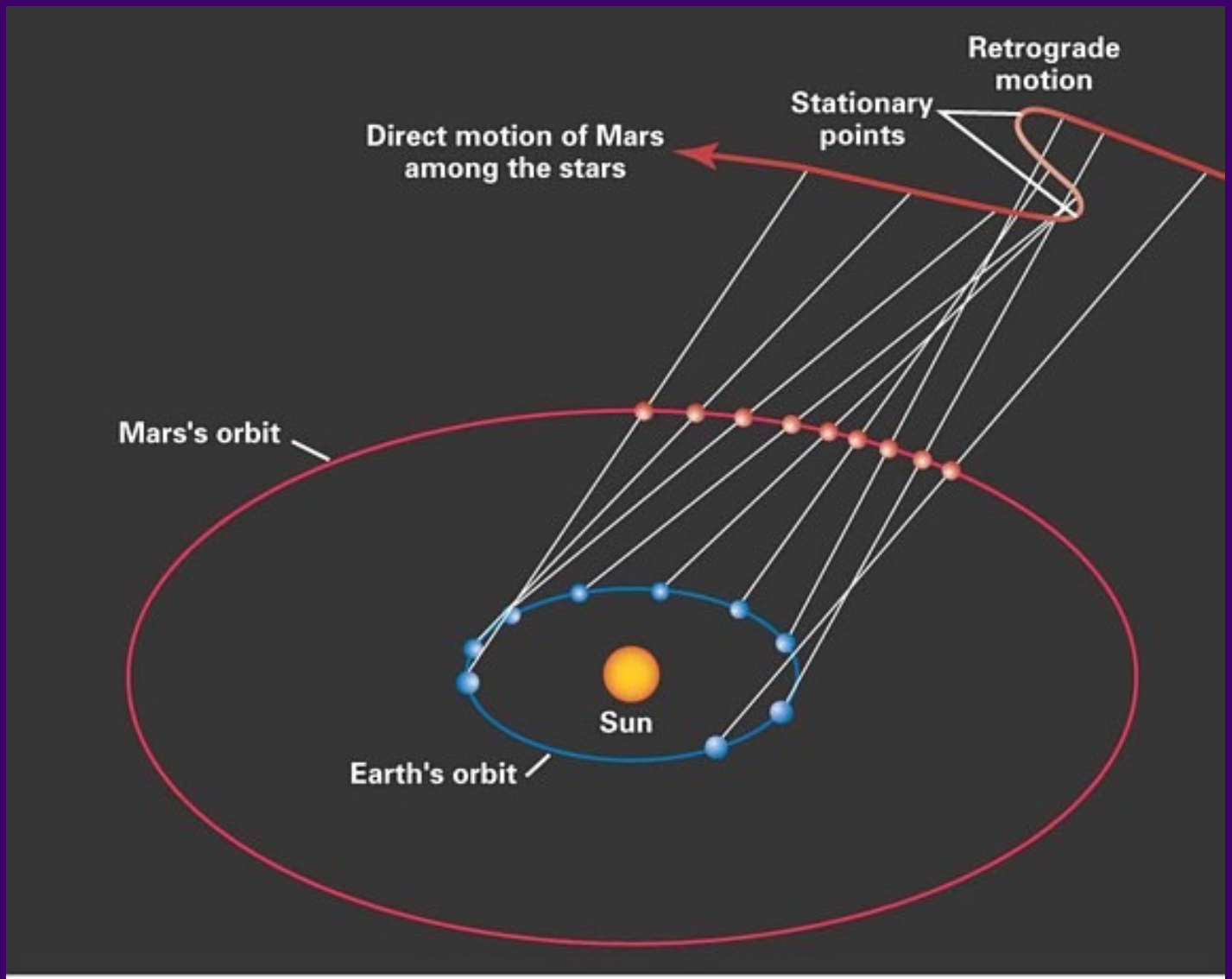
The Copernican Universe



Motion of Stars and Sun
(according to Copernicus)



Motion of Planets
(according to Copernicus)



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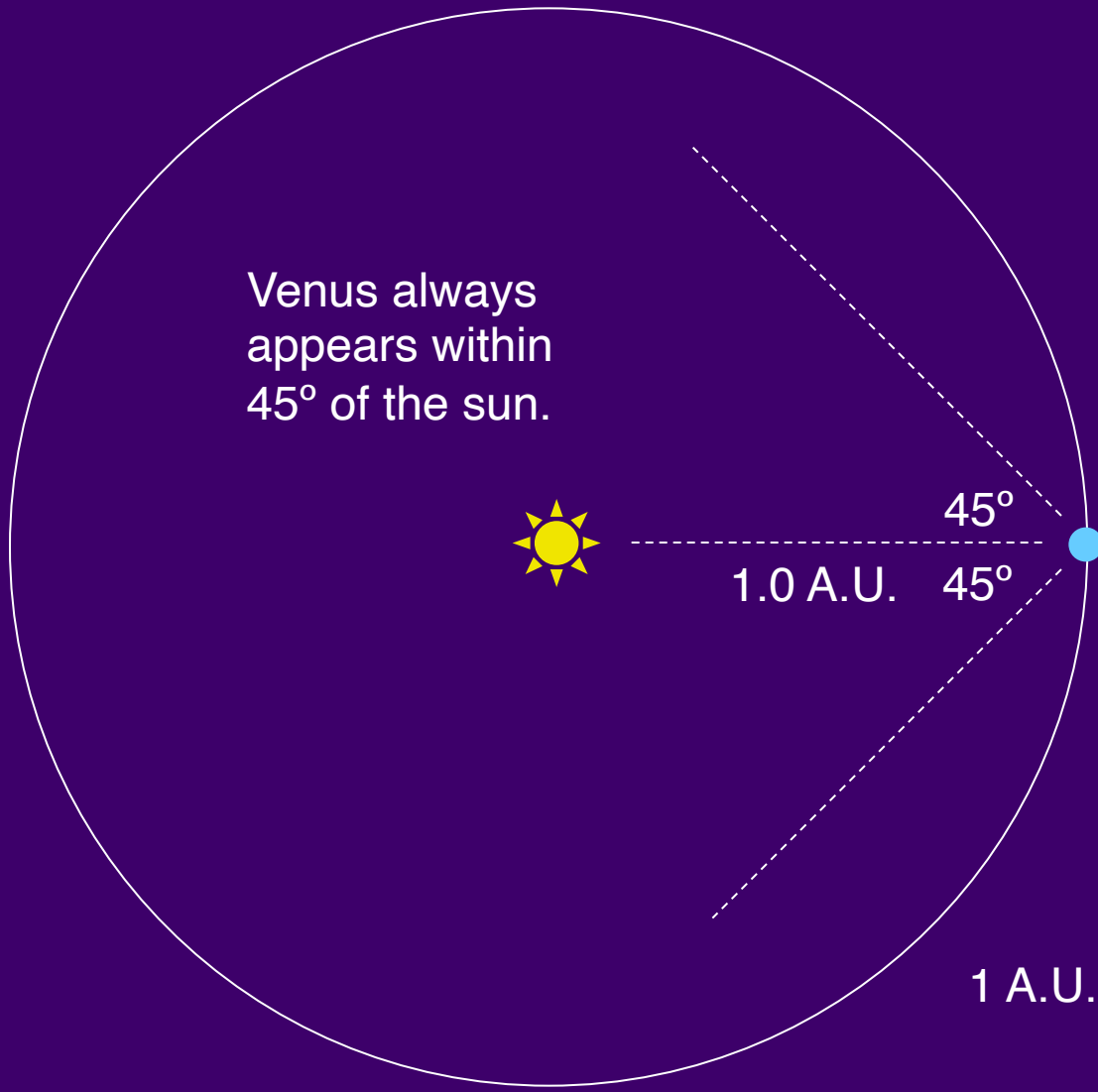
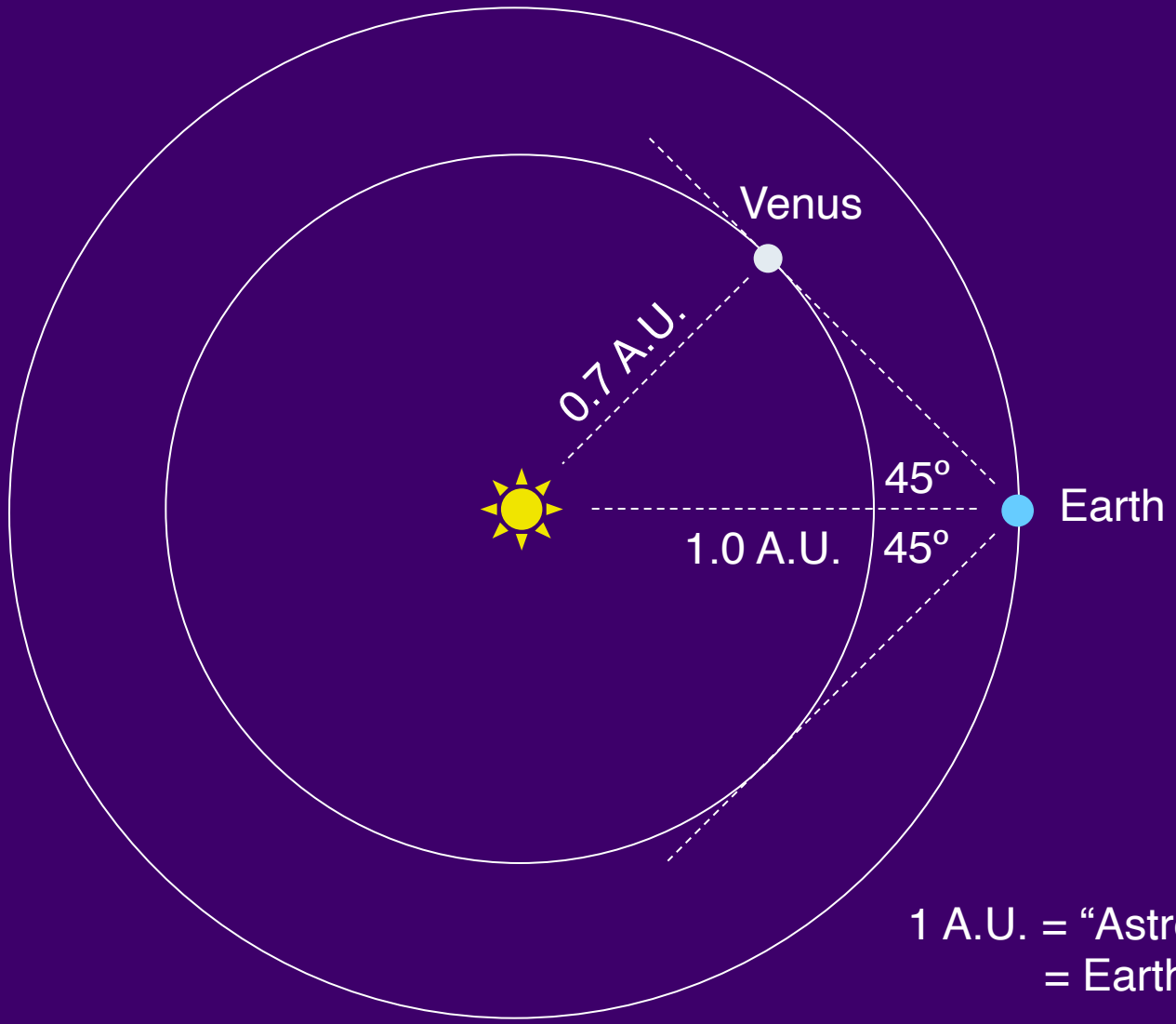
Sizes of Planetary Orbits



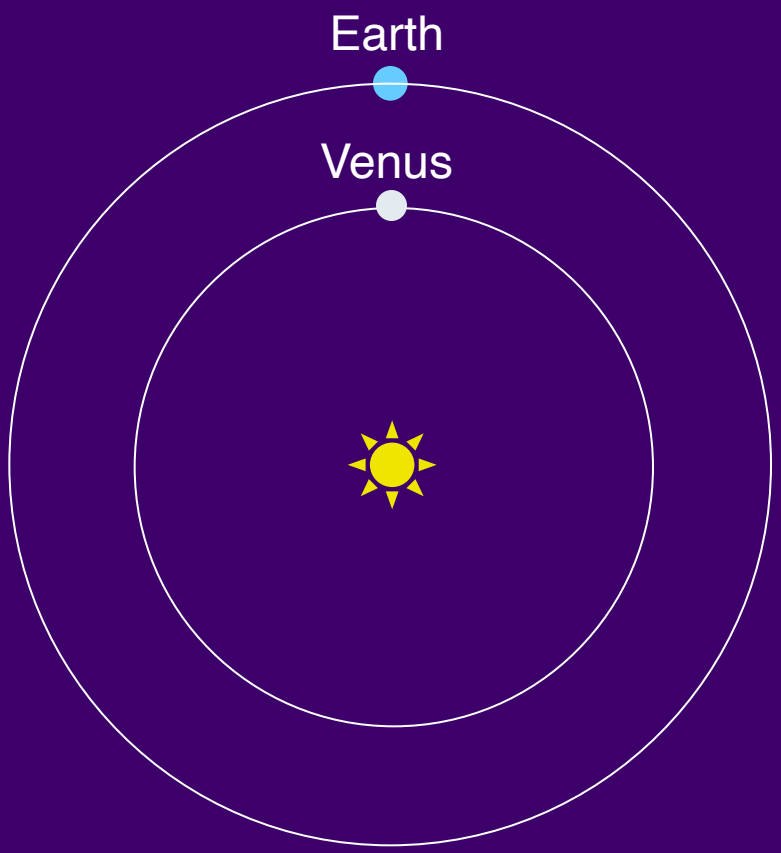
1 A.U. = “Astronomical Unit”
= Earth-Sun distance

Sizes of Planetary Orbits



1 A.U. = “Astronomical Unit”
= Earth-Sun distance

Speeds of Planetary Orbits



- Venus crosses in front of the sun every 1.6 years.
- During this time, Venus must orbit 2.6 times.
- Set up a ratio to find time for one orbit:

$$\frac{1.6 \text{ years}}{2.6 \text{ orbits}} = \frac{x \text{ years}}{1 \text{ orbit}}$$

$$\longrightarrow \quad x = 1.6/2.6 \text{ years}$$

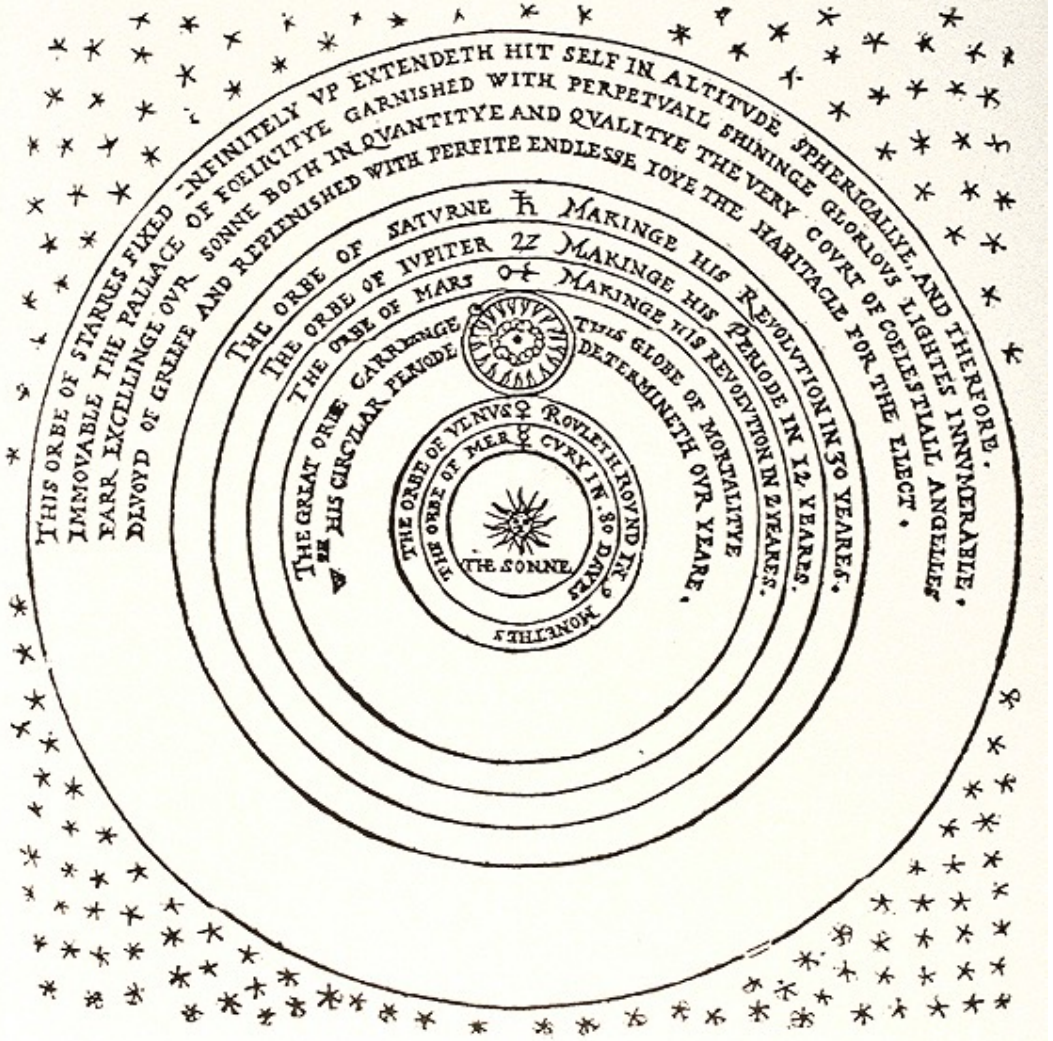
$$= 0.62 \text{ years}$$

Advantages of the Copernican model

- Explained motions of stars, sun, moon just as well as the Ptolemaic model
- More natural explanation of planetary motion (no major epicycles)
- Allowed calculation of sizes, speeds of planetary motion
- Predicted positions more accurately (because more up to date)
- Sphere of the stars no longer necessary!

A perfit descriptiõ of the Cœlestiall Orbes,

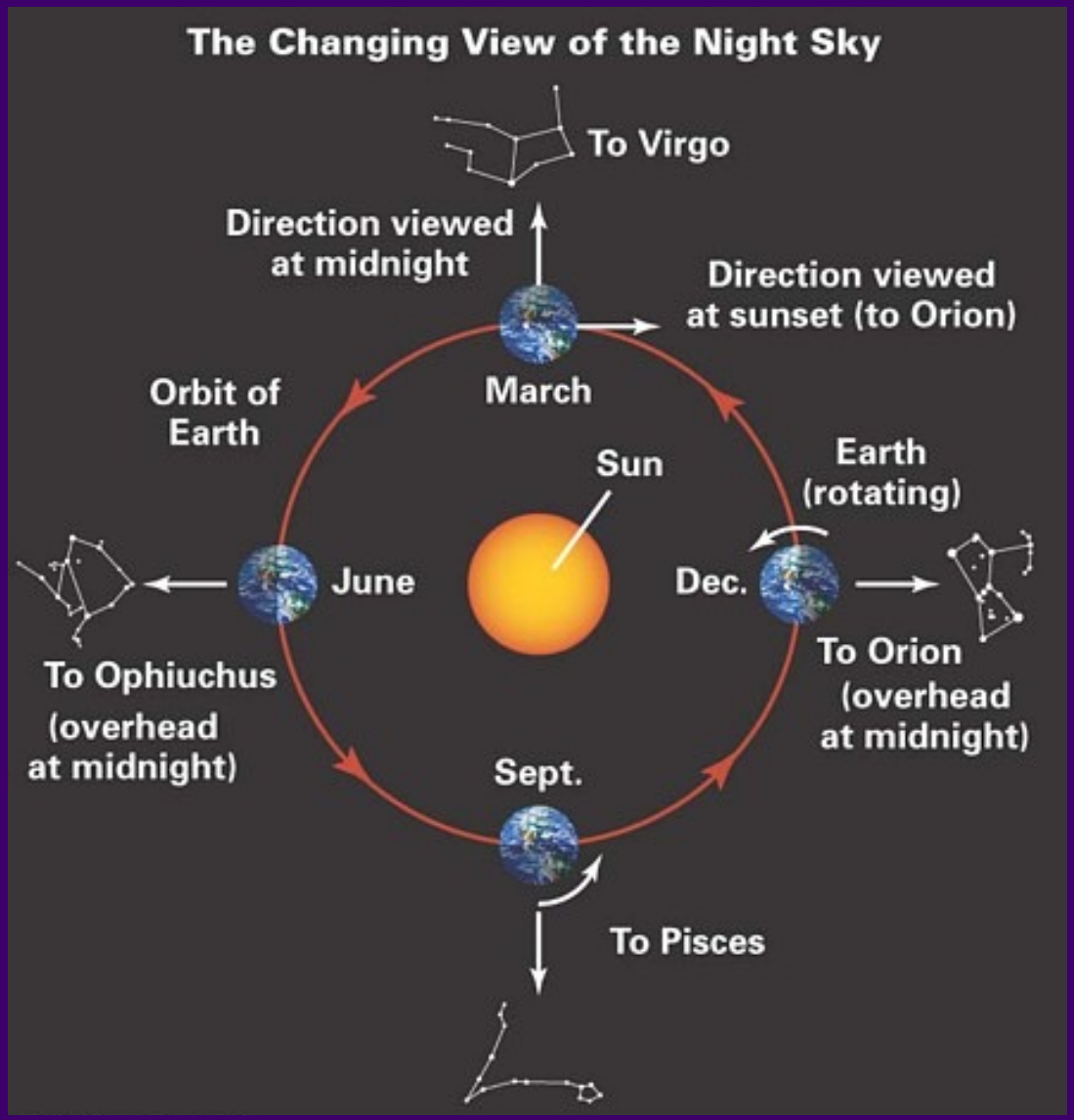
according to the most auncient doctrine of the Pythagoreans, &c.



Disadvantages of the Copernican model

- Still used minor epicycles (and other complications) to predict exact planetary positions
- Not inherently more accurate than Ptolemaic scheme
- All motions still based on circles (made of “ether”?)
- Stars must be at *huge* distances, since otherwise we’d see sizes of constellations change during the year.
- If the earth is moving so fast, why don’t we feel it?
- What about Aristotelian physics, gravity, etc.?
- If earth isn’t the center of the universe, does that make us less important?
- If earth is part of the heavens, does this mean that the heavens are made of ordinary stuff?
- Isn’t it simply ridiculous to turn the whole universe inside out, just to help astronomers better understand the obscure details of planetary motion?

If earth moves, why don't constellations seem to change size?



Reactions to Copernicus

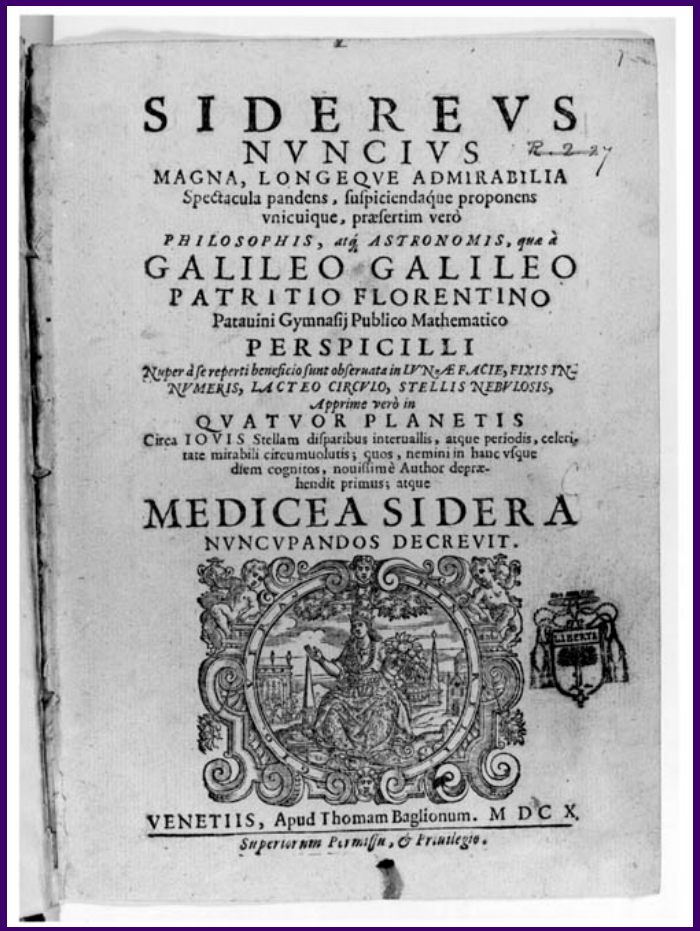
- A few denunciations and rebuttals, mostly on religious grounds (and mostly from Protestants, not Catholics)
- Mostly ignored until around 1600
- Meanwhile, astronomers used his book, whether they believed the central hypothesis or not
- Gradually, more and more astronomers became convinced
- “Victory by infiltration”

Galileo Galilei

Italian scientist, 1564 - 1642

Made one of the first telescopes, and pointed it at the heavens . . .

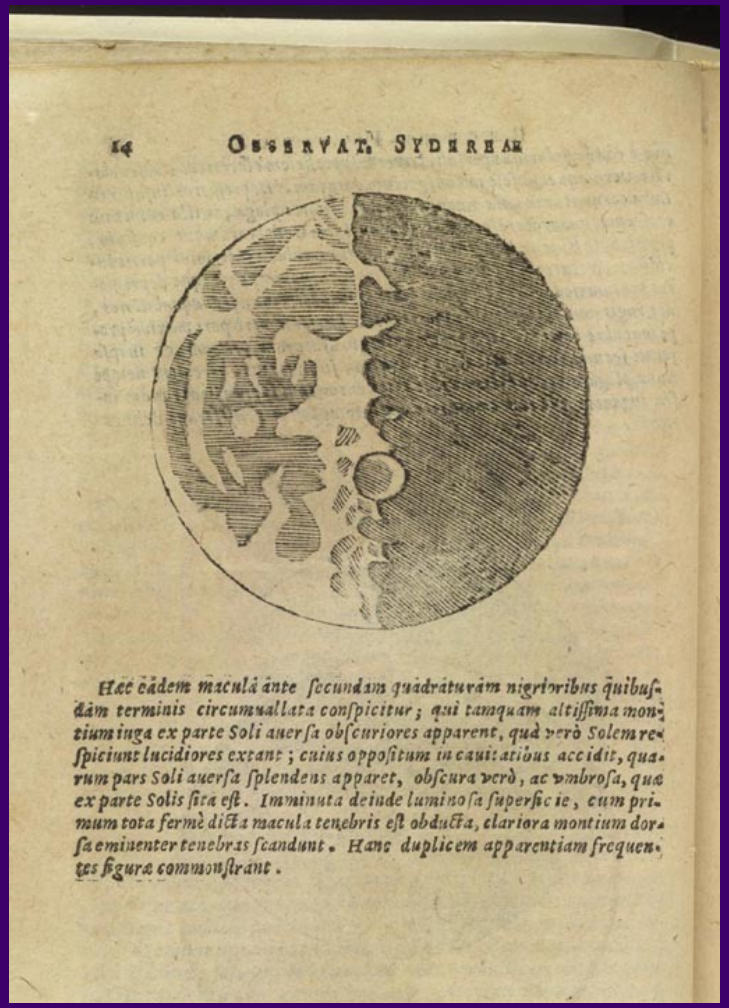
Siderius Nuncius (*The Starry Messenger*) Venice, 1610



SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in VVLNÆ FACIE, FIXIS INNVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc vsque diem cognitos, nouissimè Author deprehendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

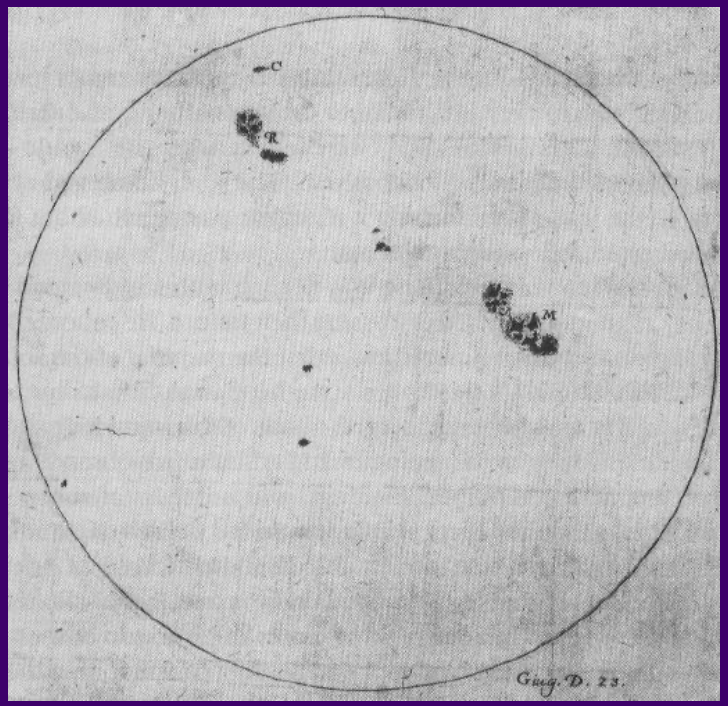
(Written in Italian, not Latin!)

Lunar topography . . . Sunspots . . .

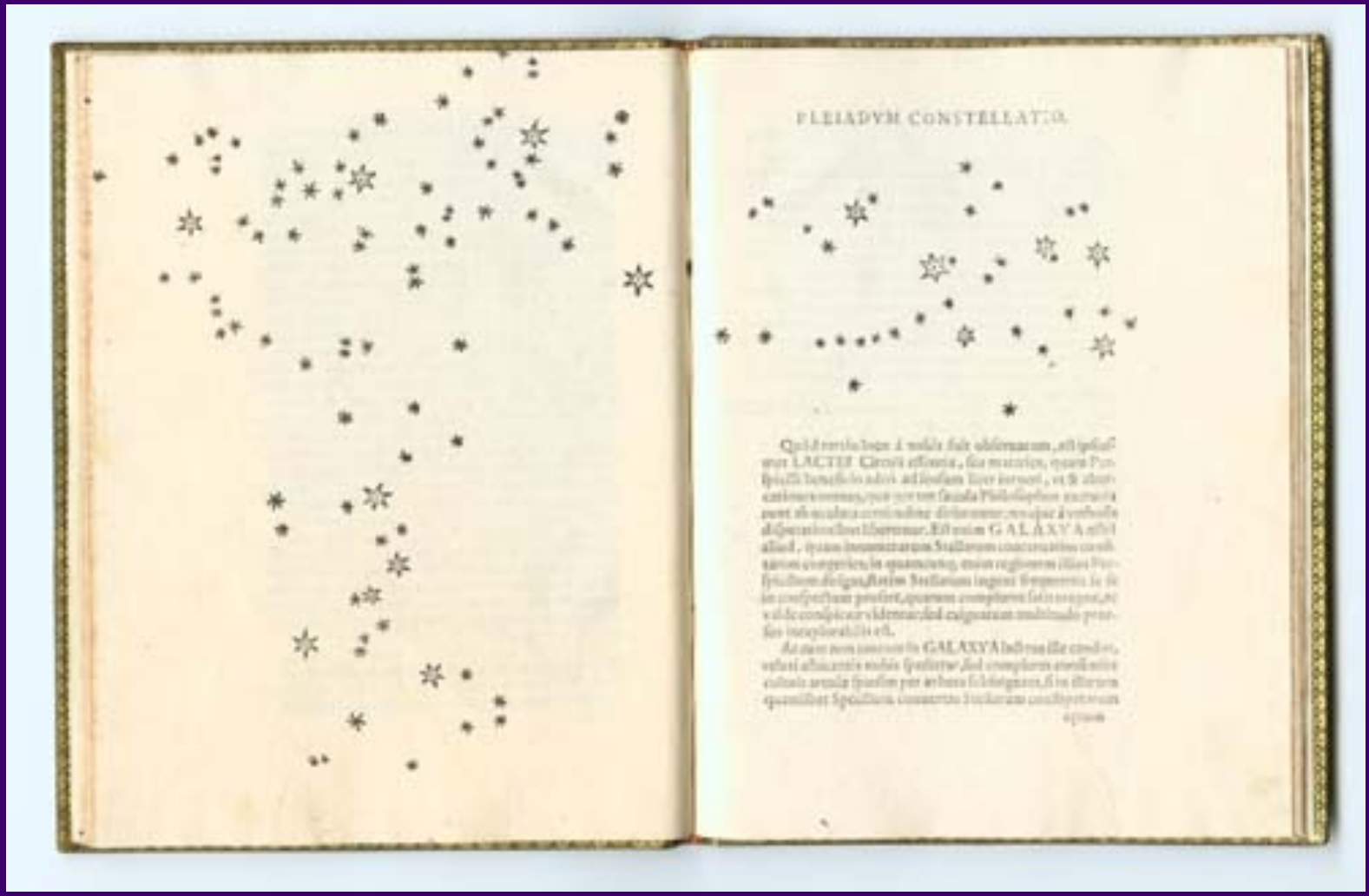


14 OBSERVAT. SYDEREAE

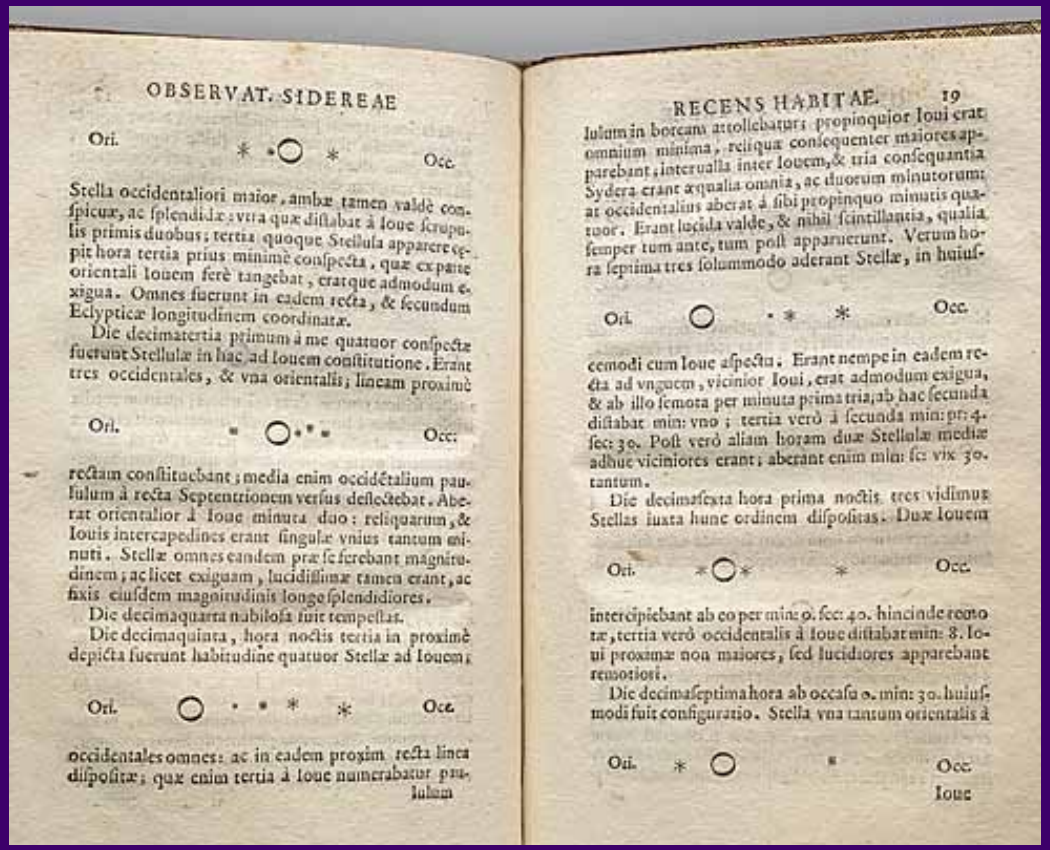
Hæc eadem macula ante secundam quadraturam nigrioribus quibusdam terminis circumuallata conspicitur; qui tamquam altissima montium iuga ex parte Soli auersa obscuriores apparent, quod verò Solem respiciunt lucidiores extant; cuius oppositum in cauitatibus accidit, quarum pars Soli auersa splendens apparet, obscura verò, ac vmbrosa, quæ ex parte Solis sita est. Imminuta deinde luminosa superficie, cum primum tota fermè dicta macula tenebris est obducta, clariora montium dorsa eminenter tenebras scandunt. Hanc duplicem apparentiam frequentes figuræ commonstrant.



Many new stars . . .



New “planets” orbiting Jupiter . . .



OBSERVAT. SIDEREAE

Ori. * ○ * Occ.

Stella occidentaliori maior, ambæ tamen valdè conſpicuæ, ac ſplendidæ; vtra quæ diſtabat à Ioue ſcrupulis primis duobus; tertia quoque Stellula apparere cepit hora tertia prius minimè conſpecta, quæ ex parte orientali Iouem ferè tangebat, eratque admodum exigua. Omnes fuerunt in eadem recta, & ſecundum Eclypticæ longitudinem coordinatæ.

Die decimatertia primum à me quatuor conſpectæ fuerunt Stellulæ in hac ad Iouem conſtitutione. Erant tres occidentales, & vna orientalis; lineam proximè

Ori. * ○ * * Occ.

rectam conſtituebant; media enim occidentalium paululum à recta Septentrionem verſus deflectebat. Aberat orientalior à Ioue minuta duo: reliquarum, & Iouis intercapedines erant ſingulæ vnius tantum minuti. Stellæ omnes eandem præ ſe ferebant magnitudinem; ac licet exiguam, lucidiſſimæ tamen erant, ac fixis eiuſdem magnitudinis longe ſplendidiores.

Die decimaquarta nubiloſa fuit tempeſtas.

Die decimaquinta, hora noctis tertia in proximè depicta fuerunt habitudine quatuor Stellæ ad Iouem;

Ori. ○ * * * Occ.

occidentales omnes: ac in eadem proxim recta linea diſpoſitæ; quæ enim tertia à Ioue numerabatur paululum

RECENS HABITAE. 19

Iulum in boream attollebatur; propinquior Ioui erat omnium minima, reliquæ conſequenter maiores apparebant; interualla inter Iouem, & tria conſequantia Sydera erant æqualia omnia, ac duorum minutorum: at occidentalius aberat à ſibi propinquo minutis quatuor. Erant lucida valdè, & nihil ſcintillantia, qualia ſemper tum ante, tum poſt apparuerunt. Verum hora ſeptima tres ſolummodo aderant Stellæ, in huiuſ-

Ori. ○ * * Occ.

cemodi cum Ioue aſpectu. Erant nempe in eadem recta ad vnguem, vicinior Ioui, erat admodum exigua, & ab illo ſemota per minuta prima tria; ab hac ſecunda diſtabat min: vno; tertia verò à ſecunda min: pr: 4. ſec: 30. Poſt verò aliam horam duæ Stellulæ mediæ adhuc viciniores erant; aberant enim min: ſc: vix 30. tantum.

Die decimaſexta hora prima noctis tres vidimus Stellas iuxta hunc ordinem diſpoſitas. Duæ Iouem

Ori. * ○ * * Occ.

intercipiebant ab eo per min: 9. ſec: 40. hinc inde remotæ, tertia verò occidentalis à Ioue diſtabat min: 8. Ioui proximæ non maiores, ſed lucidiores apparebant remotiori.

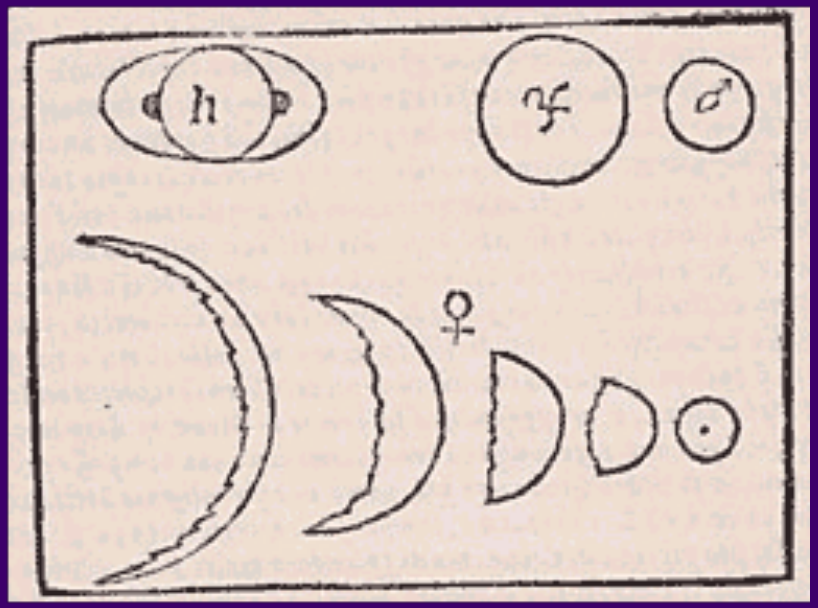
Die decimaſeptima hora ab occaſu 9. min: 30. huiuſmodi fuit configuratio. Stella vna tantum orientalis à

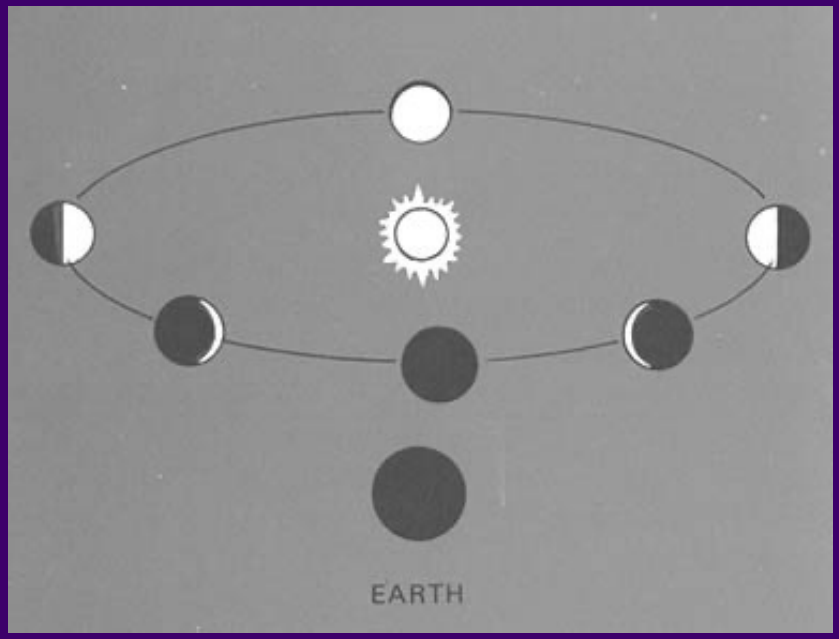
Ori. * ○ * Occ.

Ioue

At least *some* planets don’t orbit the earth; and earth isn’t the only planet with a “moon”!

Phases of Venus . . .





Venus, at least, must orbit the sun, not the earth.

What happened to Galileo?

- He became famous (not just among astronomers)
- He started advocating Copernicanism (and ridiculing those who disagreed)
- Condemned by the Church, placed under house arrest

A final thought . . .

Copernicus was Polish, Tycho Danish, Kepler German, Galileo Italian, Newton English.

So what?

Science belongs to everyone.