Copernican Astronomy

Nicolaus “gets the ball rolling”

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

pulcherrimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentẽ omnia. Ita profecto tanquam in solio regali Sol residens circum

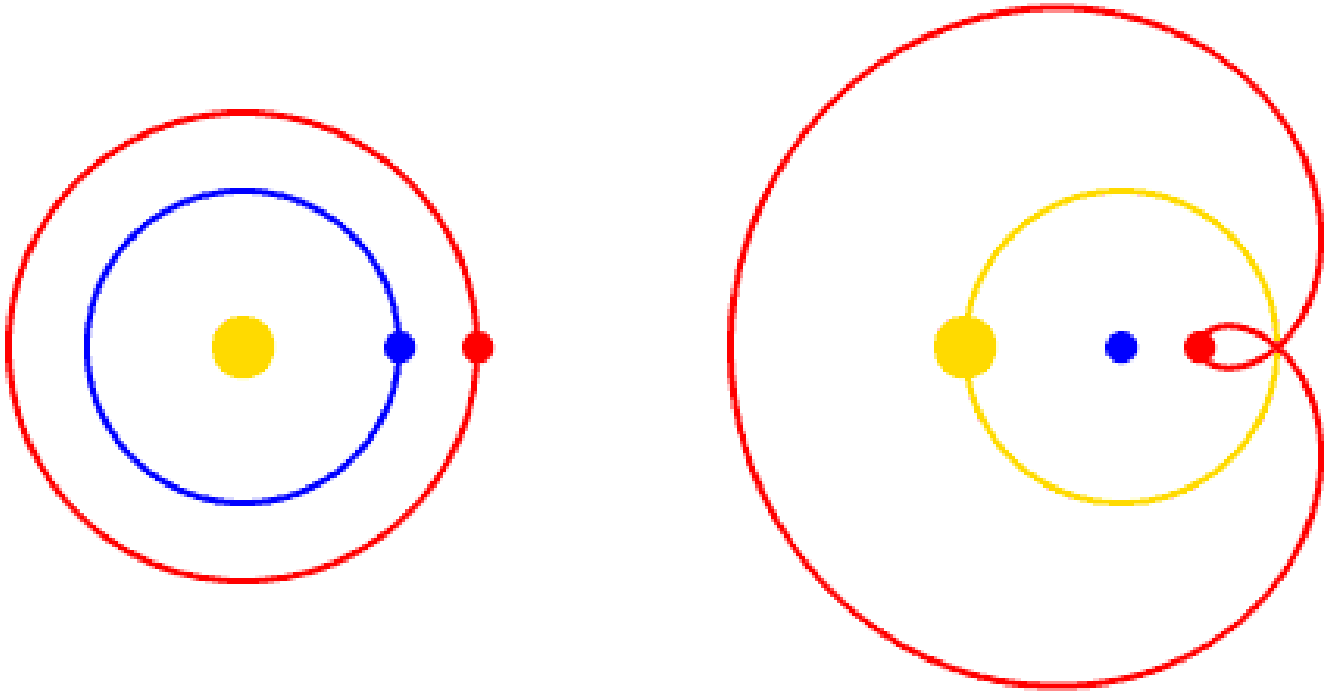
Recap: Problems for Ptolemy

- In Ptolemy's model the sun's orbit (around the earth) is rather special.
  - The sun has no epicycle, just a deferent
  - The epicycles of the superior planets (Mars, Jupiter, Saturn) each exactly duplicate the sun's orbit.
  - The deferents of the inferior planets (Mercury, Venus) exactly duplicate the solar orbit.
- These aspects of Ptolemy's model were purely *ad hoc*.

Copernican solutions

- Concerning the sun's special role in the universe, Copernicus had an elegant solution.

- Putting the sun at the centre, and making the earth a planet, explained all of the relevant data.
  - The inferior planets are always close to the sun.
  - The superior planets undergo retrograde motion when (and only when) in opposition to the sun.
- Also, (major) epicycles were not needed by Copernicus. Effectively, the earth's orbit replaced the deferent of an inferior planet, and the epicycle of a superior planet.



- Copernicus (left) vs. Ptolemy (right) on the orbit of Mars (from Wikipedia)

Copernicus can determine the order + orbit radii of the planets

- Why did Ptolemy put Mercury closer to the earth than Venus is? I.e. why the order: Mercury, Venus, Sun, rather than (say) Venus, Mercury, Sun?

"In the Ptolemaic system the deferent and epicycle of any one planet can be shrunk or expanded at will without affecting either the sizes of the other planetary orbits or the position at which the planet, viewed from a central earth, appears against the stars." (Kuhn, p. 175)

Ptolemy just had to *assume* that Mercury is closer to us than Venus, since it travels more quickly from one side of the sun to the other.

"There is no similar freedom in the Copernican system. If all the planets revolve in approximately circular orbits about the sun, then both the order and the relative sizes of the orbits can be determined directly from observation without additional assumptions." (Kuhn, p. 175)

- Is this a big advantage?

Orbital Radii in A.U.

Planetary Distances: Copernicus' Values versus Today's Values

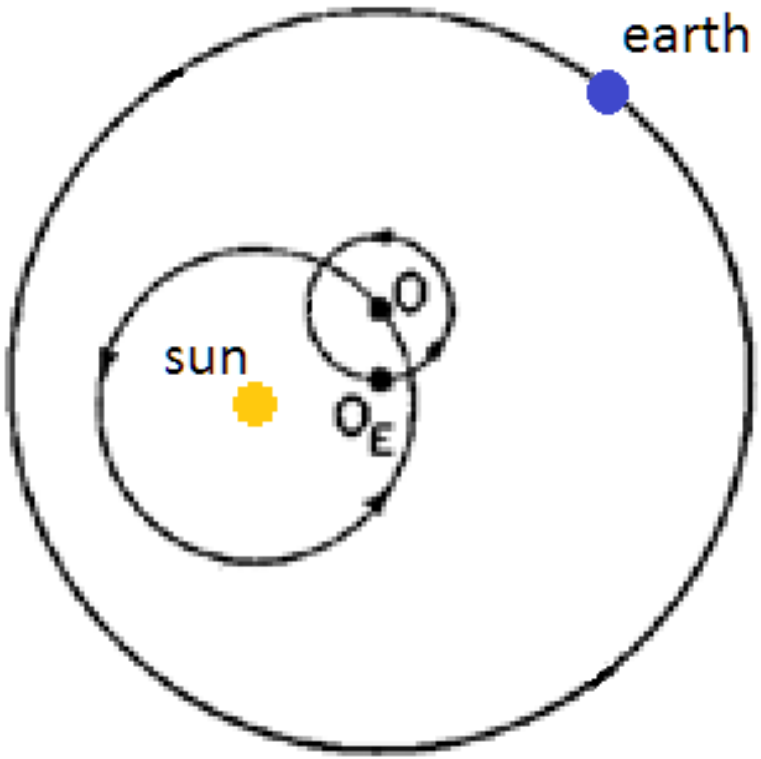
	Sun-to-Planet Distances	
Planet	Copernicus' Values (AU)	Today's Values (AU)
Mercury	0.38	0.387
Venus	0.72	0.723
Earth	1.00	1.000
Mars	1.52	1.524
Jupiter	5.2	5.204
Saturn	9.2	9.582

A.U. = "Astronomical Unit" = radius of earth's orbit (about 93 million miles)

Problems for Copernicus

- But Copernicus's model was still based on circular orbits, and so shared the empirical inaccuracies of Ptolemy's model.
- Copernicus didn't like eccentrics and equants, and so used "minor" (small) epicycles instead.
- These were just as messy and arbitrary as eccentrics and equants, however, and no more accurate on the whole.

E.g. minor epicyles for the earth



- Whoa! Complicated!

Problems for Copernicus

The planets all follow (roughly) the same path through the celestial sphere, the "ecliptic". This path includes the famous twelve constellations of the zodiac, used in astrology.

Copernicus can't explain this.

Problems for Copernicus

- There is no *stellar parallax* observable with the naked eye (or even with Galileo's telescopes).
- How did Copernicus explain this?
- He said that the stars are very far away, at least *hundreds* of times further than Saturn.
  - (Since there's no theoretical reason for this, it's an *ad hoc* hypothesis.)

"... But that there are no such appearances [i.e. annual parallax] among the fixed stars argues that they are at an immense height away, which makes the circle of annual movement or its image disappear from before our eyes since every visible thing has a certain distance beyond which it is no longer seen, as in optics. For the twinkling of their lights shows that there is a very great distance between Saturn the highest of the planets and the sphere of the fixed stars. By this mark in particular they are distinguished from the planets, as it is proper to have the greatest difference between the moved and the unmoved. How exceedingly fine is the godlike work of the Best and Greatest Artist!" [pp. 26-27]

The “Copernican abyss”

- The Copernican universe therefore had an enormous gap, or ‘abyss’ of apparently empty space between Saturn’s orbit and the celestial sphere. The stars had to be at least 700 times higher than Saturn’s orbit, or roughly 4,200 AU, or 34 *million* earth radii.

- This seemed *absurdly* large to most people.

"Indeed, those distances that we have hitherto considered for the new star are child's play, so long as we abide by the usual opinion of the motionlessness of the Earth. Yet if we should lay bare the Copernican abysses of immensity, good God, to how great an altitude will this star be raised? ... For many, the mind tires from observing the immeasurability of the world ..."

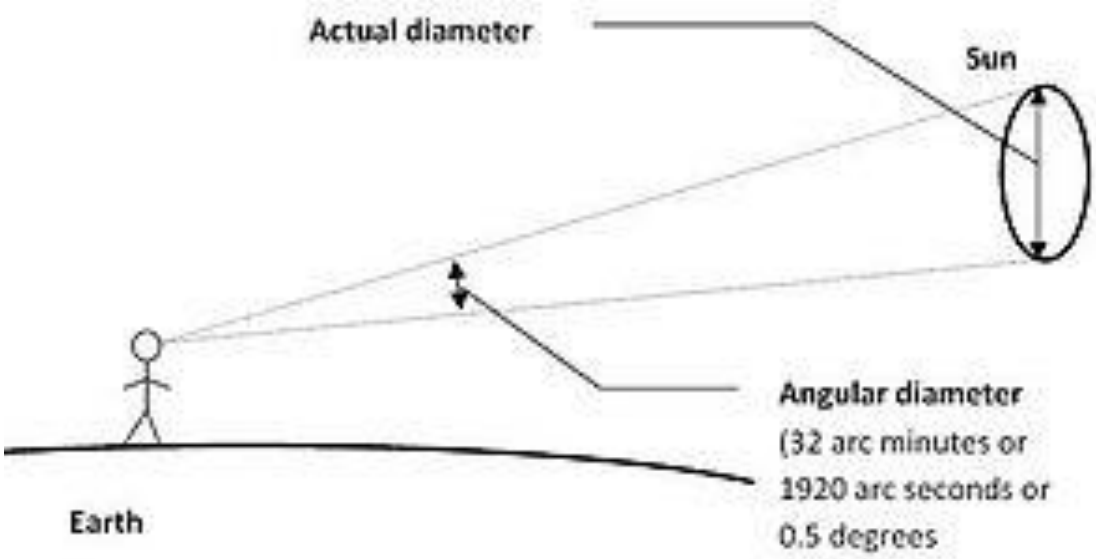
- Kepler, *De Stella nova in pede Serpentarii*, 1604.

The Problem of Star Sizes

- Whether viewing a star with the naked eye, or through a telescope, it appeared to be a small disc, rather than an infinitesimal point.
- (About 1-2 arc-minutes across with the naked eye, and 5 arc-seconds with Galileo's telescope.)

Apparent Diameter

- The *apparent* size of a sphere, for a given viewer, is its “angular diameter”, measured in degrees, or fractions of a degree, as shown in the diagram below.



Giant Stars?

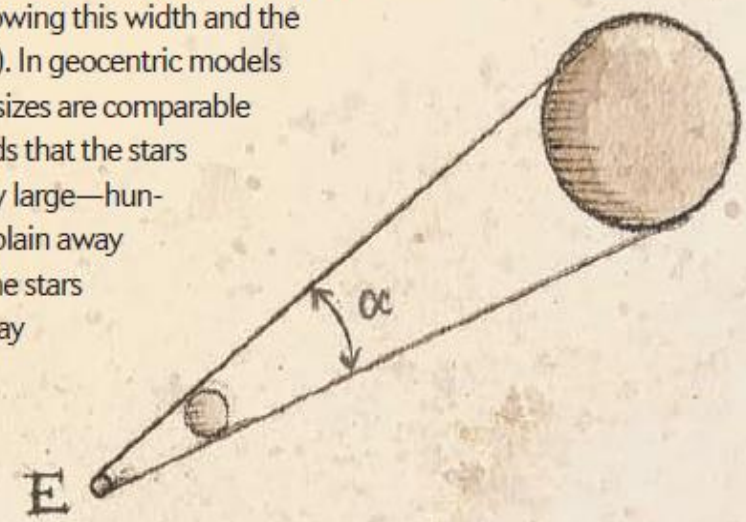
- Let's do the math. If a star has an angular diameter of 2 arc-minutes, and it is 4000 AU above us, then its real diameter is about

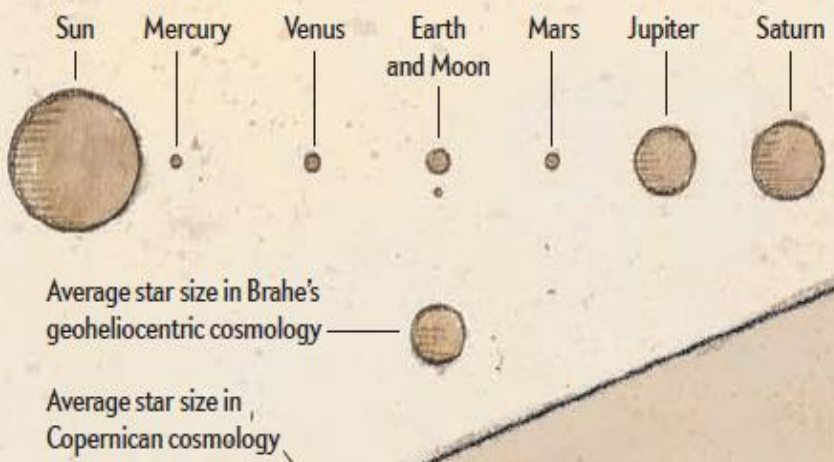
  4000 x *tan*(1/30) = 2.3 AU.

- OMG! The star is bigger than the sphere of the earth's *orbit*!!

The Problem with Star Sizes

The most devastating argument against the Copernican universe was the star size problem. When we look at a star in the sky, it appears to have a small, fixed width. Knowing this width and the distance to the star, simple geometry reveals how big the star is (*right*). In geocentric models of the universe, the stars lie just beyond the planets, implying that star sizes are comparable to that of the sun (*below*). But Copernicus's heliocentric theory demands that the stars be extremely far away. This in turn implies that they should be absurdly large—hundreds of times bigger than the sun (*bottom*). Copernicans could not explain away the anomalous data without appeals to divine intervention. In reality, the stars are far away, but their apparent width is an illusion, an artifact of the way light behaves as it enters a pupil or telescope—behavior that scientists would not understand for another 200 years.





- Copernicus had said, talking about astronomers using ugly and arbitrary eccentrics and equants:

  With them it is as though an artist were to gather the hands, feet, head, and other members for his images from diverse models, each part excellently drawn, but not related to a single body, and since they in no way match each other, the result would be monster rather than man.

Tu Quoque

- Tycho Brahe agreed that Copernicus's model was better in certain ways. But he was really bothered by the "Copernican abyss" and the massive stars.

- The Copernican system is grossly disfigured, Tycho said, like a human body in which

  "... a finger or a nose should surpass in size the many parts of the entire rest of the body".

Grossly disfigured

A Copernican reply

"… whatever size you concede to the Vastness and Magnitude of the World, it will still have no measure compared to the infinite Creator. The greater the King, the larger and more spacious a palace he deems fitting to his Majesty. And what will you think of God?"

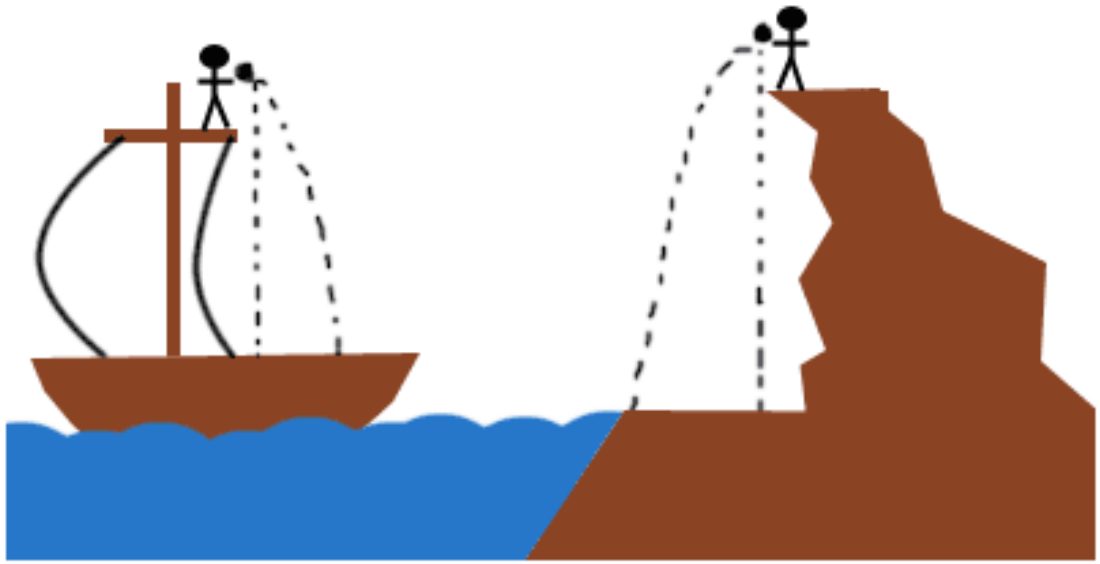
- Christoph Rothmann, letter to Tycho, 1589.

Why can't we *feel* the earth's motion?

- Even astronomers who supported and used the Copernican model in their work mostly regarded it as a mere mathematical trick, a useful fiction, rather than literally true.
- The idea of a moving earth seemed ridiculous, in large part because we can't feel any such motion at all.

Political philosopher Jean Bodin

No one in his senses, or imbued with the slightest knowledge of physics, will ever think that the earth, heavy and unwieldy from its own weight and mass, staggers up and down around its own center and that of the sun; for at the slightest jar of the earth, we would see cities and fortresses, towns and mountains thrown down. A certain courtier Aulicus, when some astrologer in court was upholding Copernicus' idea before Duke Albert of Prussia, turning to the servant who was pouring the Falernian, said: "Take care that the flagon is not spilled."



- A ball dropped from the top of the mast on a moving ship would move toward the stern as it fell (wouldn’t it?)
- So, similarly, a ball dropped on a moving earth would move to the side.

- In other words, Copernican astronomy was at odds with Aristotelian *mechanics*.
- A new mechanics would have to be developed, and was – by Descartes, Galileo and Newton. But this didn’t come till later.

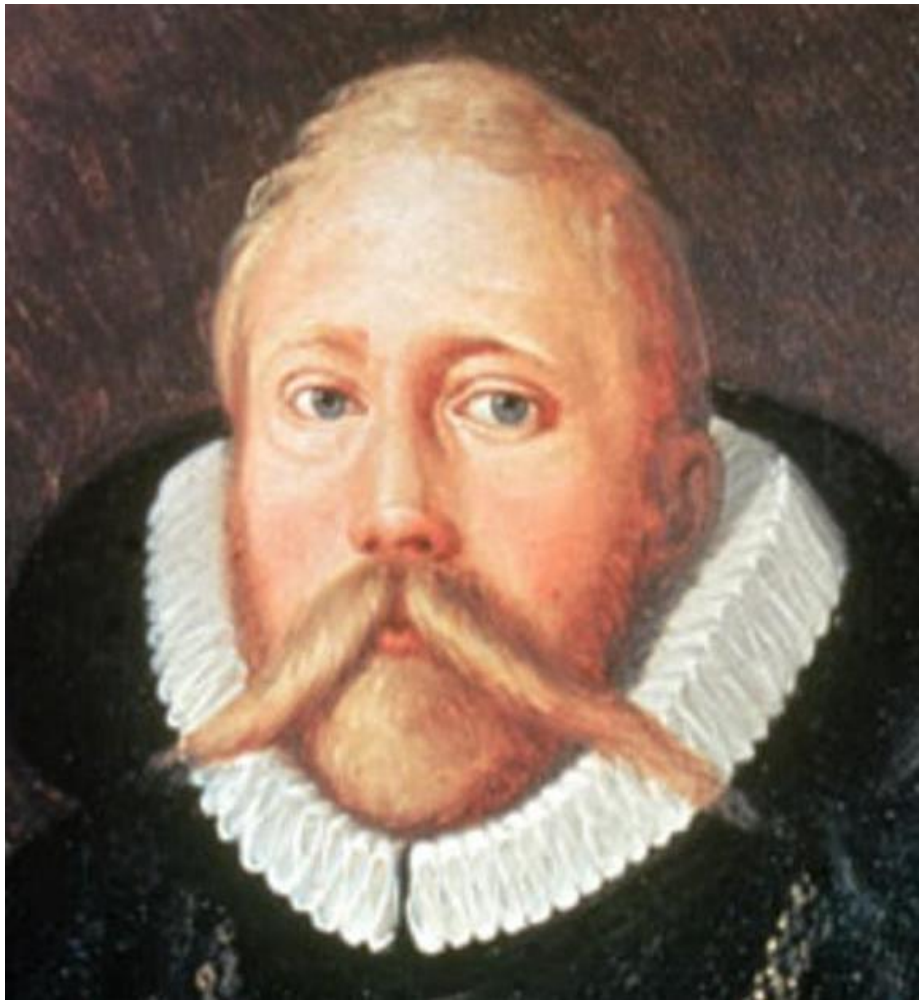
The Protestant Reaction

Citation of Scripture against Copernicus began even before the publication of the *De Revolutionibus*. In one of his "Table Talks," held in 1539, Martin Luther is quoted as saying:

> People gave ear to an upstart astrologer who strove to show that the earth revolves, not the heavens or the firmament, the sun and the moon. . . . This fool wishes to reverse the entire science of astronomy; but sacred Scripture tells us [Joshua 10:13] that Joshua commanded the sun to stand still, and not the earth.[4]

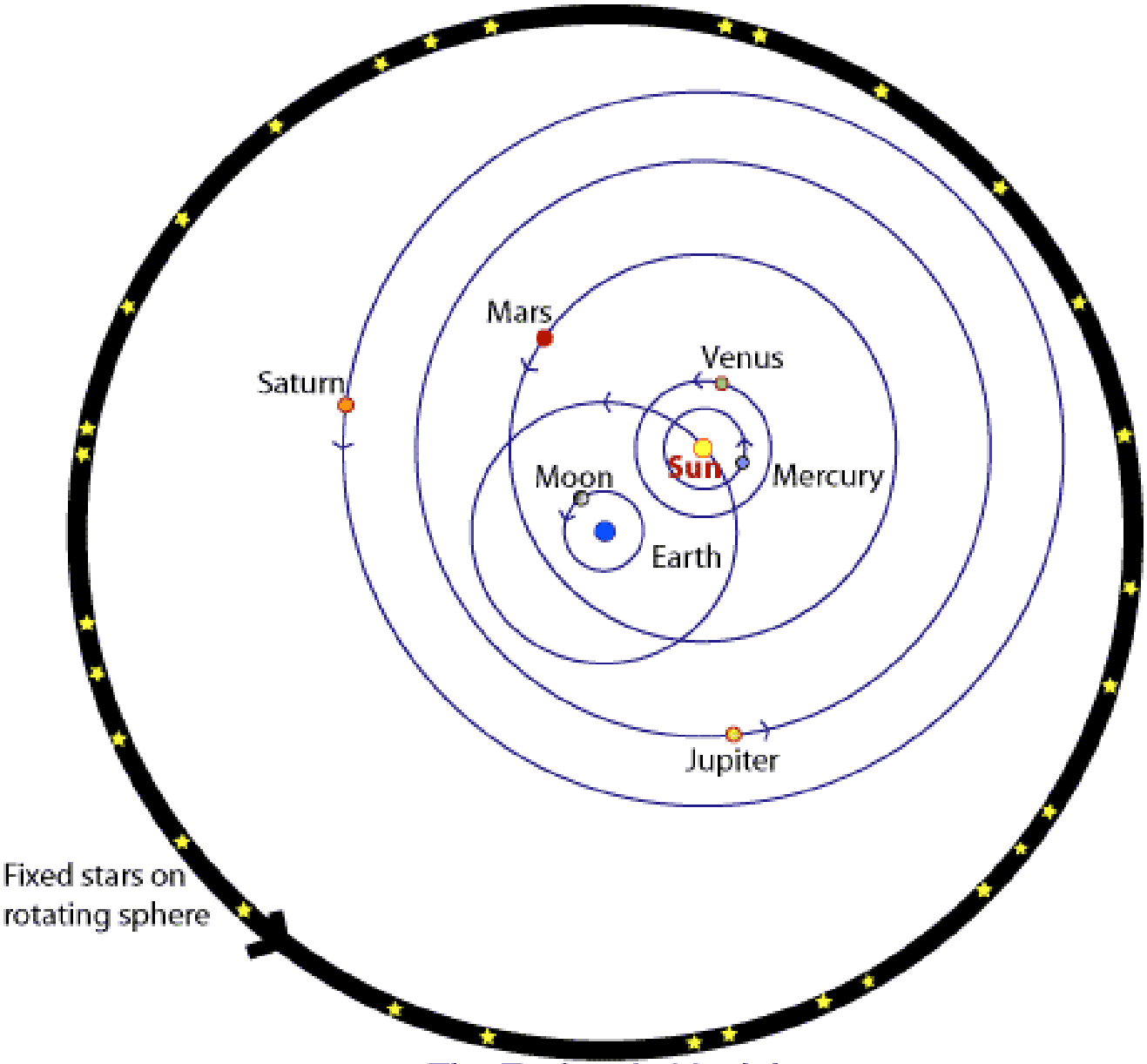
Tycho Brahe

- 1546-1601
- Danish astronomer
- Had a brass nose

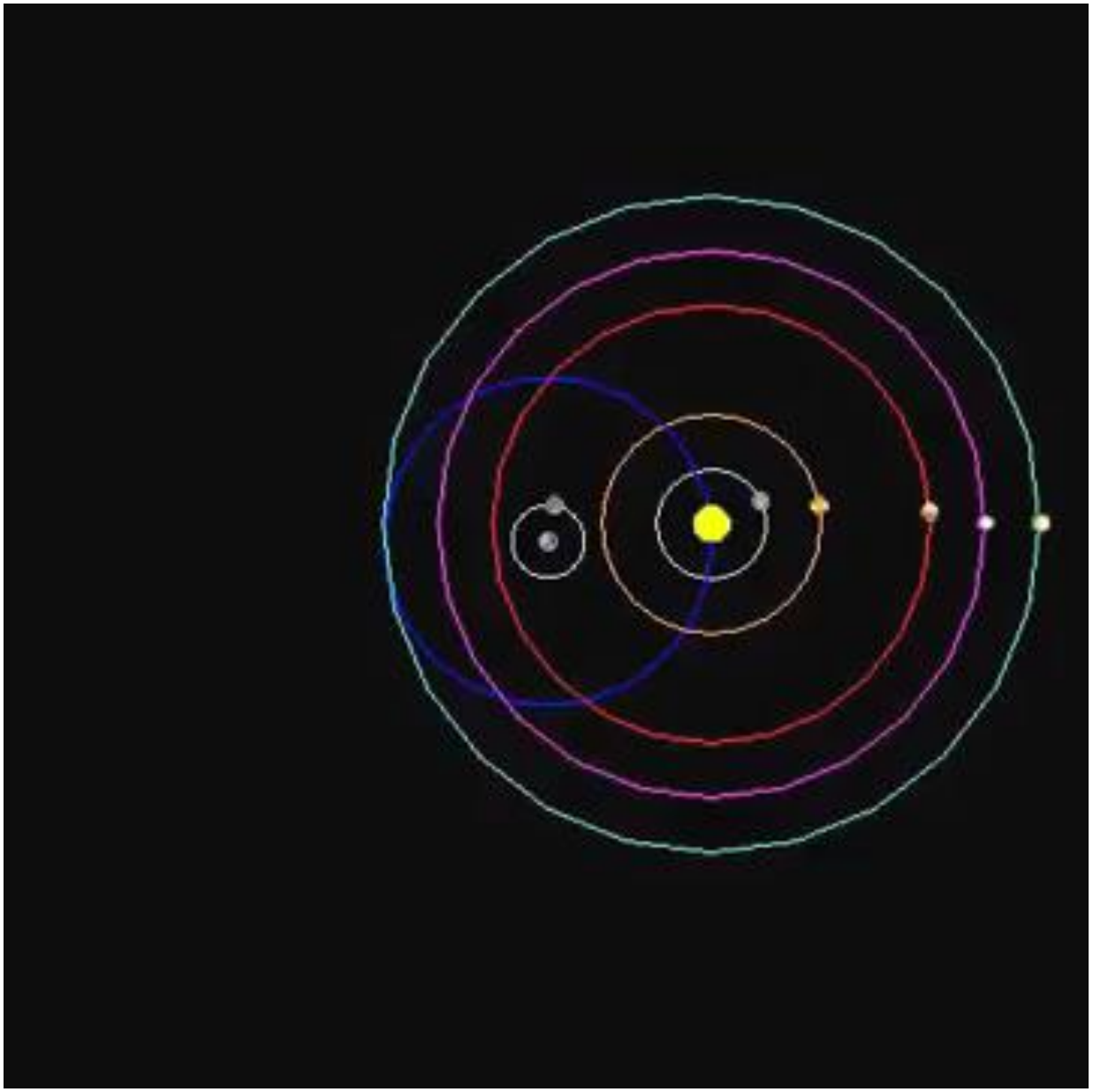


Tycho's 3rd model

- Tycho Brahe made the best, most accurate, measurements of the planetary motions yet achieved.
- He found Copernicus's arguments from mathematical harmony compelling
- But the moving earth seemed impossible, so he proposed a *compromise* model that seemed to combine the best of both.



The Tychonic Model



- This was quite a popular theory, in the first half of the 17th century (around 1600-1640).
- The Jesuits liked it, in particular.
- It's a mistake to view the debate about the earth's motion in 1600-1640 as "Ptolemy vs. Copernicus"

The impact of Tycho's model

- Tycho's model was wrong, of course, and has been largely forgotten.

- However, in the early 17th century, when the battle between Copernicus and Ptolemy was raging, Tycho's model had a huge impact.
- *Why would that be?*

- It made it virtually impossible for Galileo to *prove* the earth's motion, for Tycho's (stationary earth) model would predict virtually all the same things as Copernicus's.

- Moreover, Tycho’s model avoided many of the objections that were aim at heliocentrism:
  - the “Copernican abyss”
  - Huge stars (the universe is grossly disfigured)
  - We can’t feel the earth’s motion

- How does Tycho’s model avoid these?

Kepler

- Kepler used Tycho's data to support his elliptical orbit theory of the planetary motions.
- This was far more accurate than Copernicus's model. (predictions matched the data better)
- He made new astronomical tables, based on his model, which were quickly recognised as vastly superior to the old ones. Thus everyone who used astronomical tables was forced to use "heliocentric technology".

Kepler

- Kepler was rather obsessed with finding mathematical patterns in nature.
- E.g. when Galileo discovered that Jupiter has 4 satellites, he combined this with the fact that earth has one satellite to infer that Mars has two.
- Was he right?

Mysterium Cosmographicum
(secret of the universe)

Kepler

- Kepler was a strong supporter of Galileo's work, although Galileo didn't return the favour.

- (E.g. Kepler never reviewed Kepler's *New Astronomy*, and never even used Kepler's improved telescope.)

Galileo’s telescope

- Galileo made a telescope and pointed it at the night sky. What did he see?

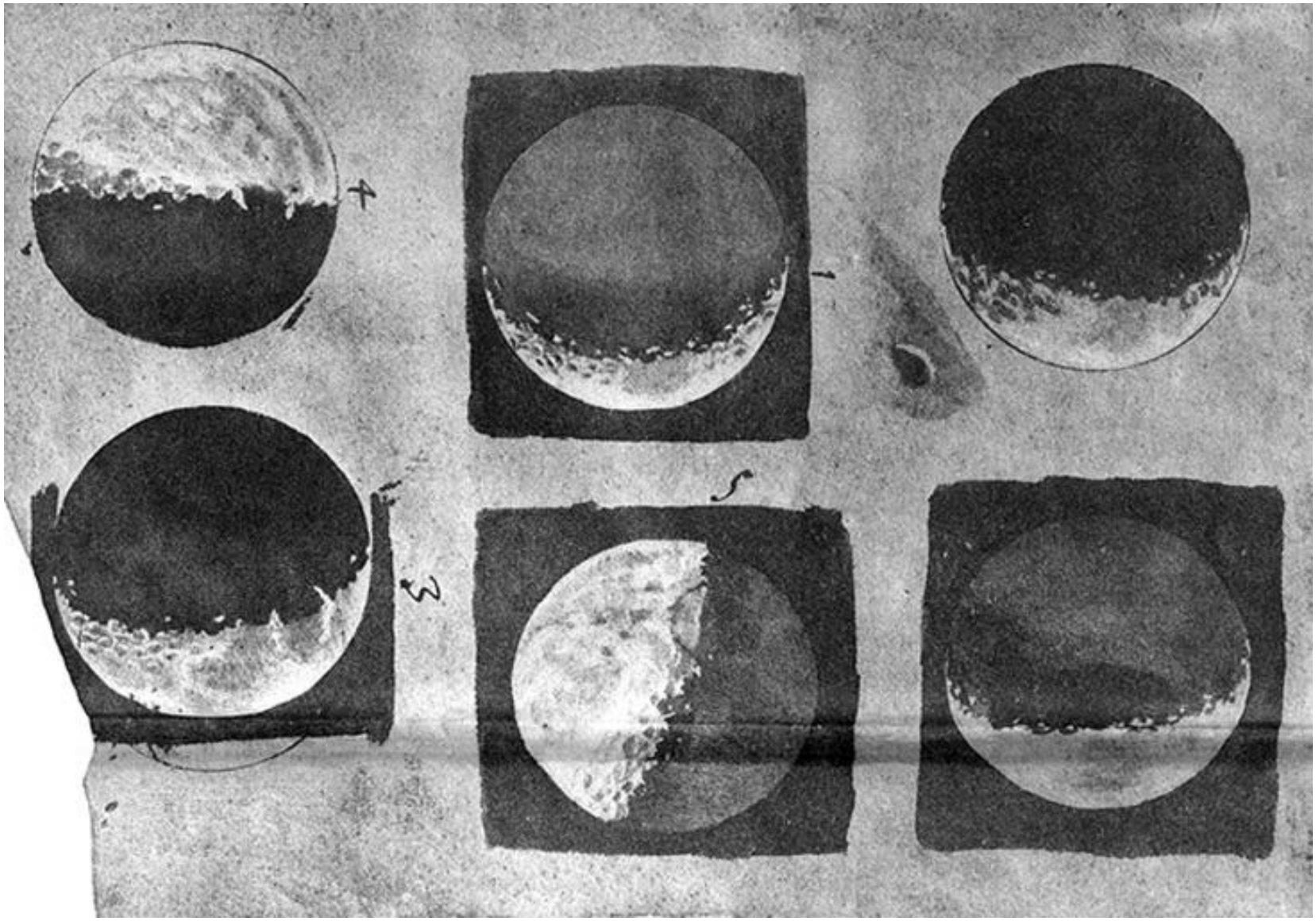
Observations with a Telescope

1. Imperfections in the heavens, e.g. spots on the sun, craters on the moon.
2. “Planets” orbiting Jupiter.
3. Venus in full phase (like a full moon, not crescent).
4. A lot more stars. E.g. the milky way was shown to consist of closely-spaced dim stars.

Sun spots

- Are they really *on* the sun, or in front of it?

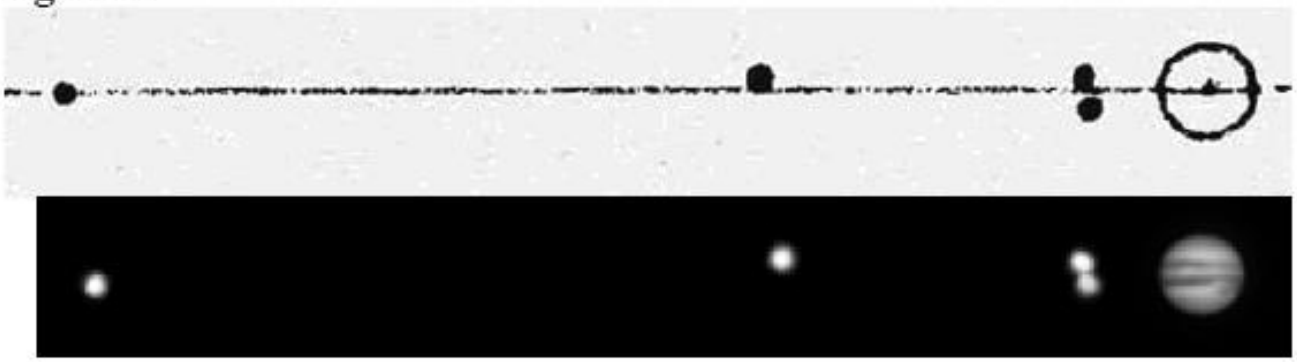
Galileo’s drawings of a bumpy moon



Photograph of the moon

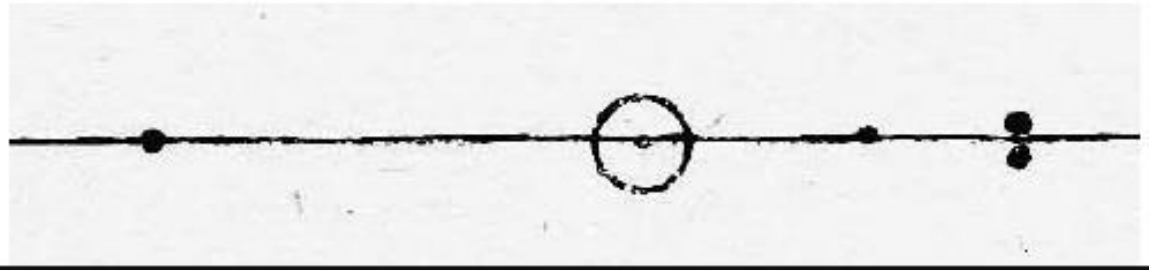
Galileo's drawings of Jupiter's moons

Figure 1



Galileo
25 March 1613 H 0.5
(*Opere* Vol. 5 p. 241)

Stellarium
25 March 1613
12:56:00 EST
FOV 0.367°



Galileo
12 March 1613 H 5
(*Opere* Vol. 5 p. 241)

Stellarium
12 March 1613
4:52:00 PM EST
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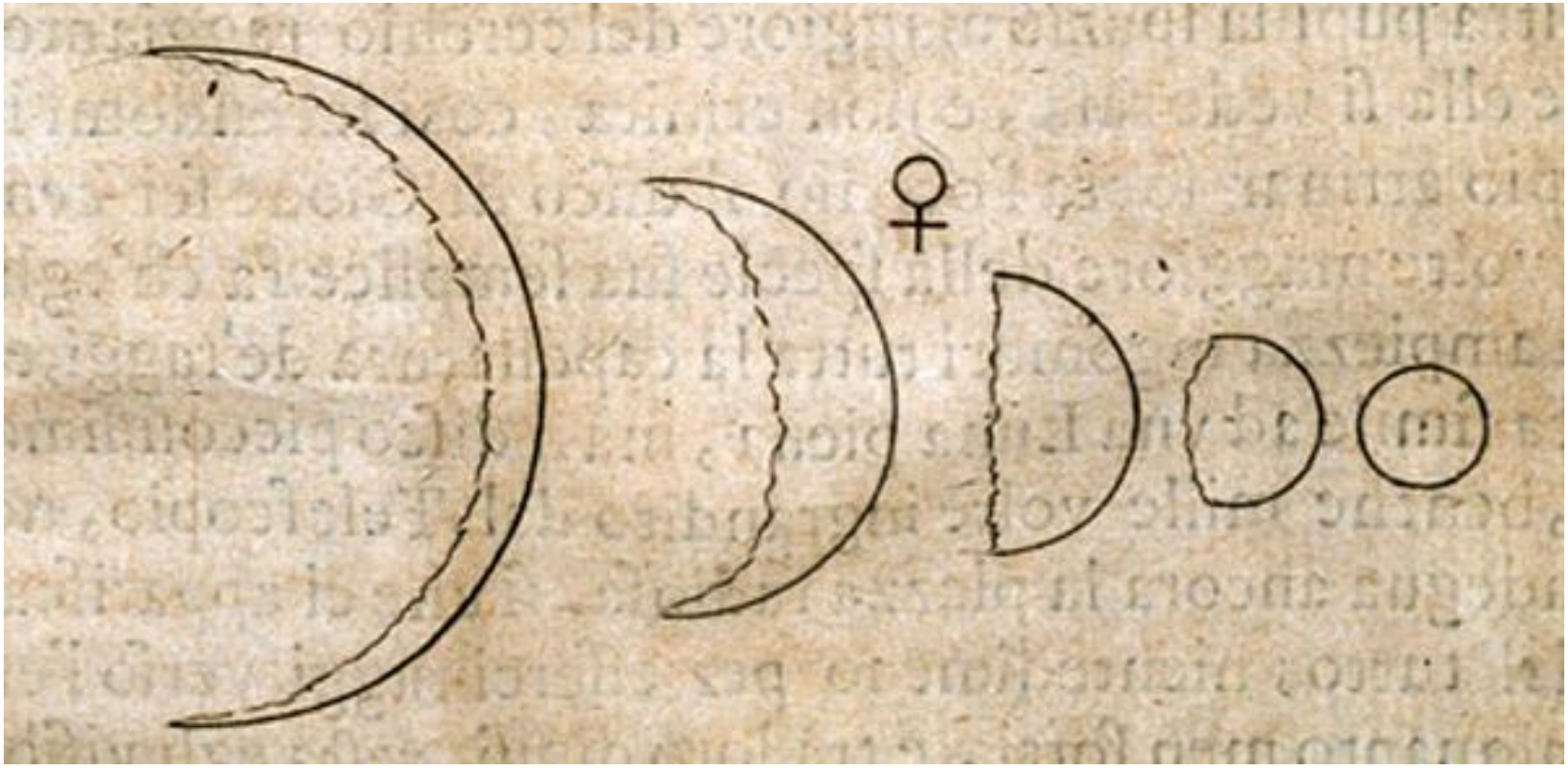
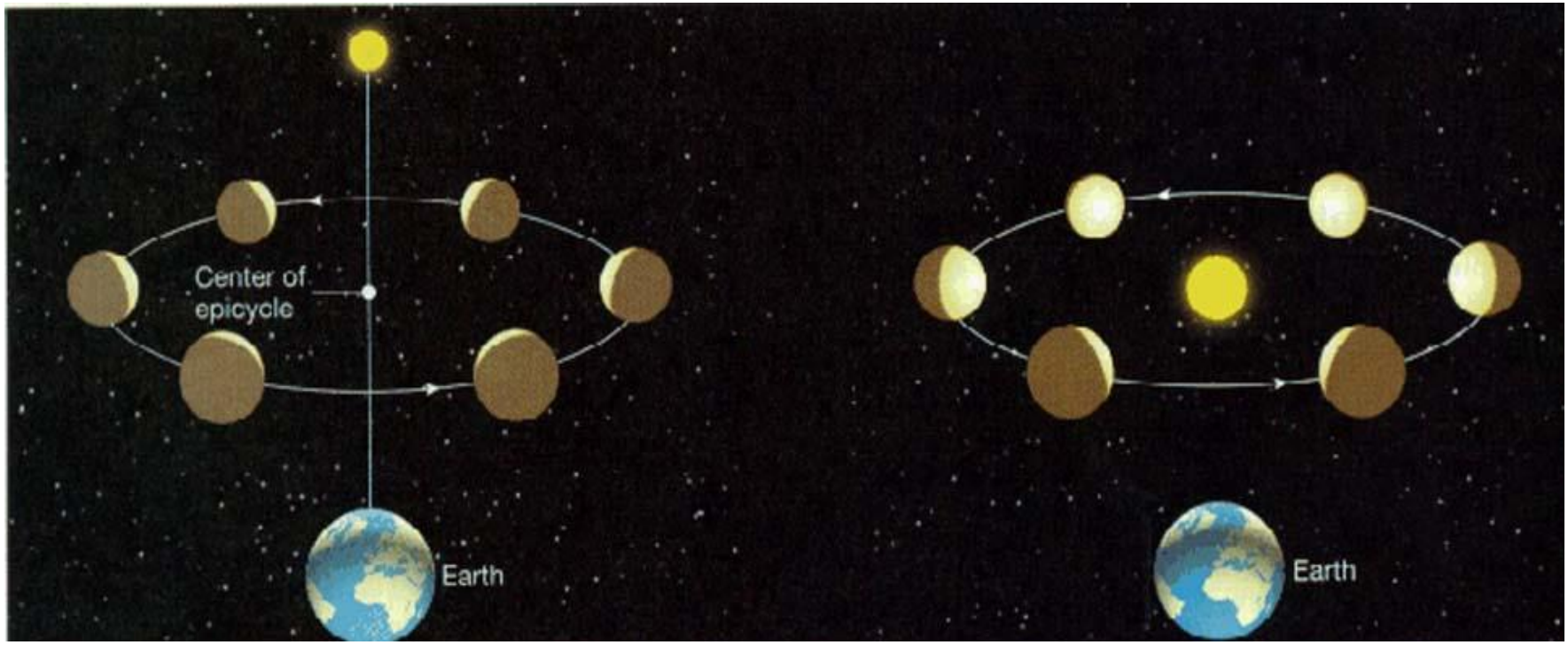
The observed phases of Venus



The ***predicted*** phases of Venus according to Ptolemy (left) and Copernicus (right)



What did all this show?

- In a nutshell:
  - Sunspots, bumpy moon refuted Aristotle's view of the heavens as perfect and unchanging.
  - Moons of Jupiter refuted Aristotle's view that all planets orbit the earth.
  - Phases of Venus refuted Ptolemy's model, where Venus's epicycle lies between the earth and sun.
- But *all these data were predicted by Tycho's model as well*, so they didn't prove that the earth moved.

Many possible causes

- For any observed data, we can imagine many possible causes of it.
- If two hypotheses both predict the observed data, then which hypothesis do you (inductively) infer *from* the data?