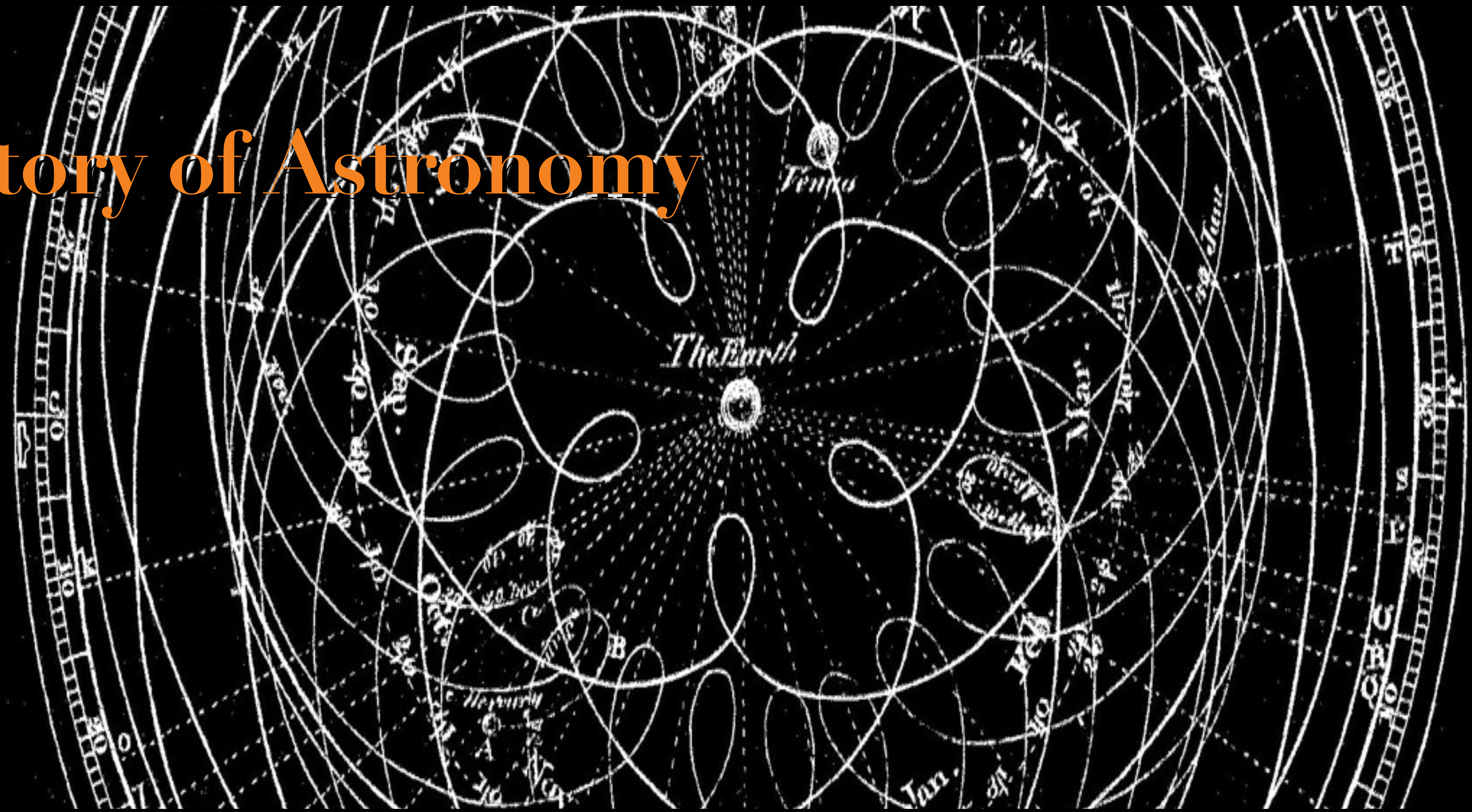
History of Astronomy



Archaeoastronomy

The Calendar

When should you plant your crops? When does the cold weather start?

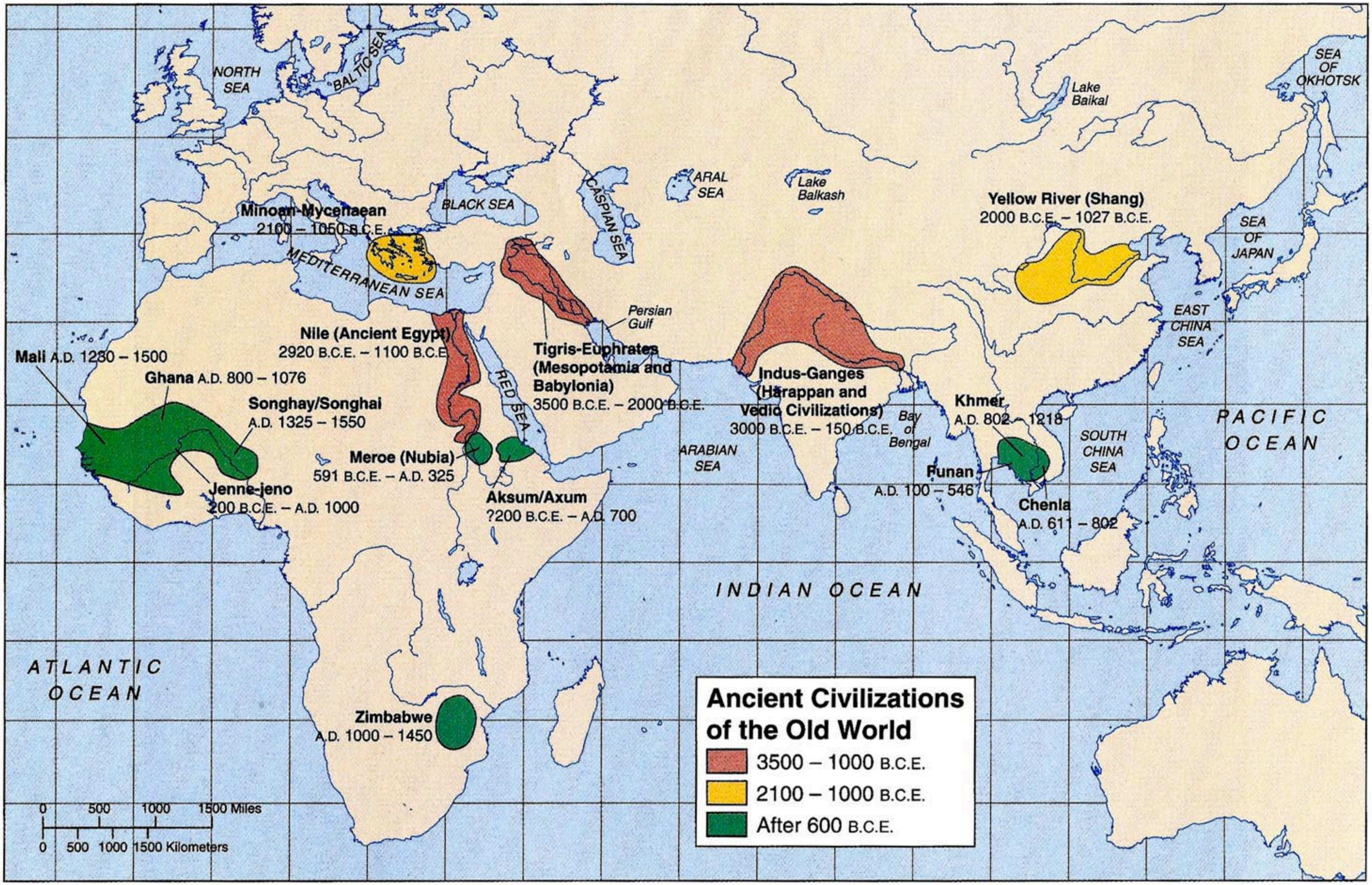
How long is a year?

In what direction should I travel if I am lost on the ocean?

If you woke up on an unknown planet, how would you figure these out?

What did ancient people do?

Ancient Civilizations of the Old World

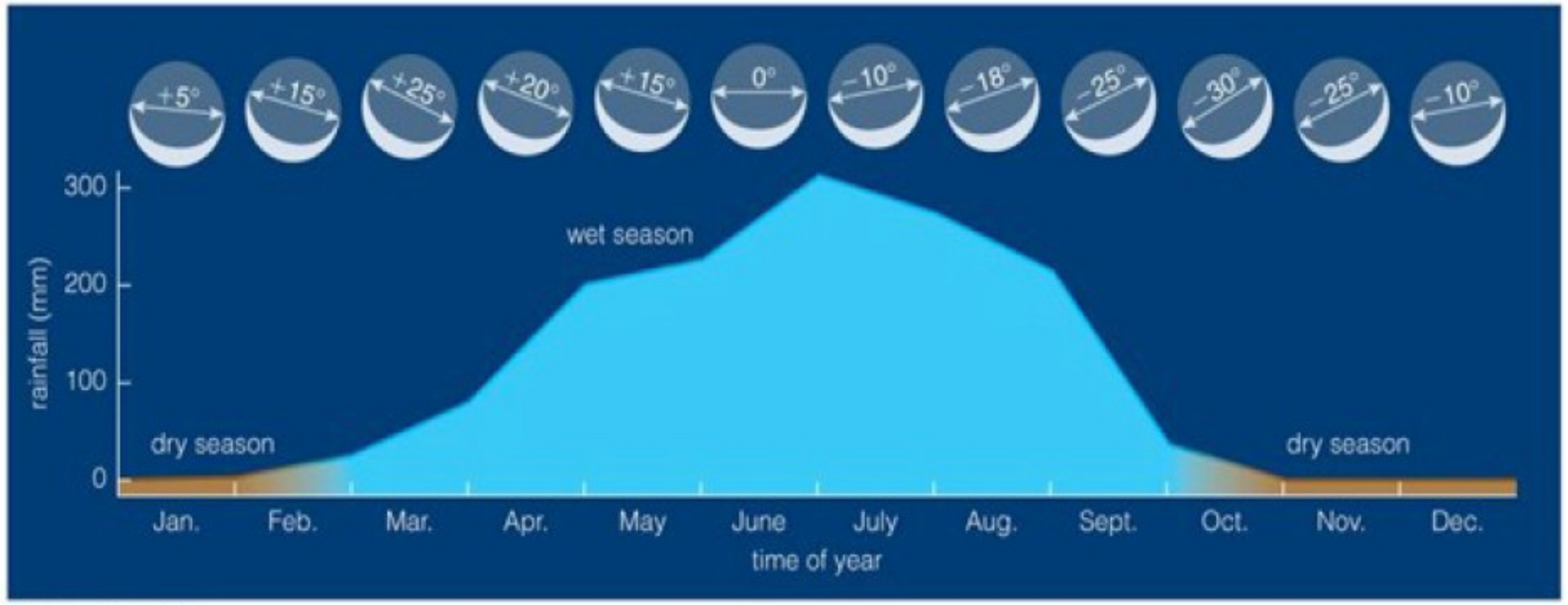


Purposes of ancient astronomy

1. Predict weather patterns

The seasons are tied into our orbit and axial tilt.

Ancient peoples recognized that recurring weather patterns matched celestial events.



Ancient people of central Africa (6500 B.C.) could predict seasons from the orientation of the crescent moon.

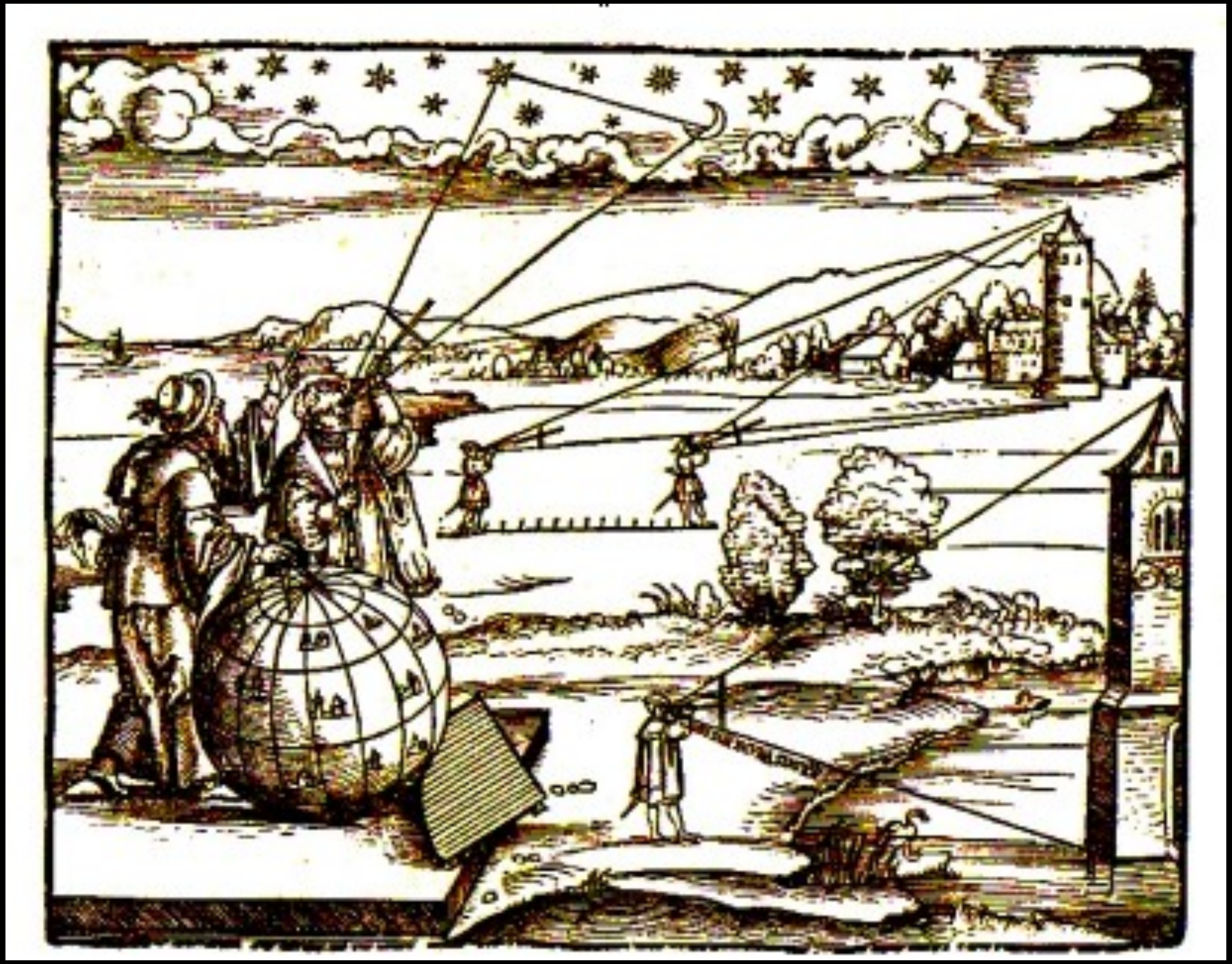
Some used the position of the Sun, some used position of stars, others used the orientation of the Moon.

Purposes of ancient astronomy

2. Assist travellers

Unless you know the time of day or the North direction, the Sun is not a good key to direction.

The North Star and the constellations can orient a traveler much better!



Tools of ancient astronomy

Many cultures built structures to make astronomical measurements.

These structures usually marked important celestial alignments, such as soltices.

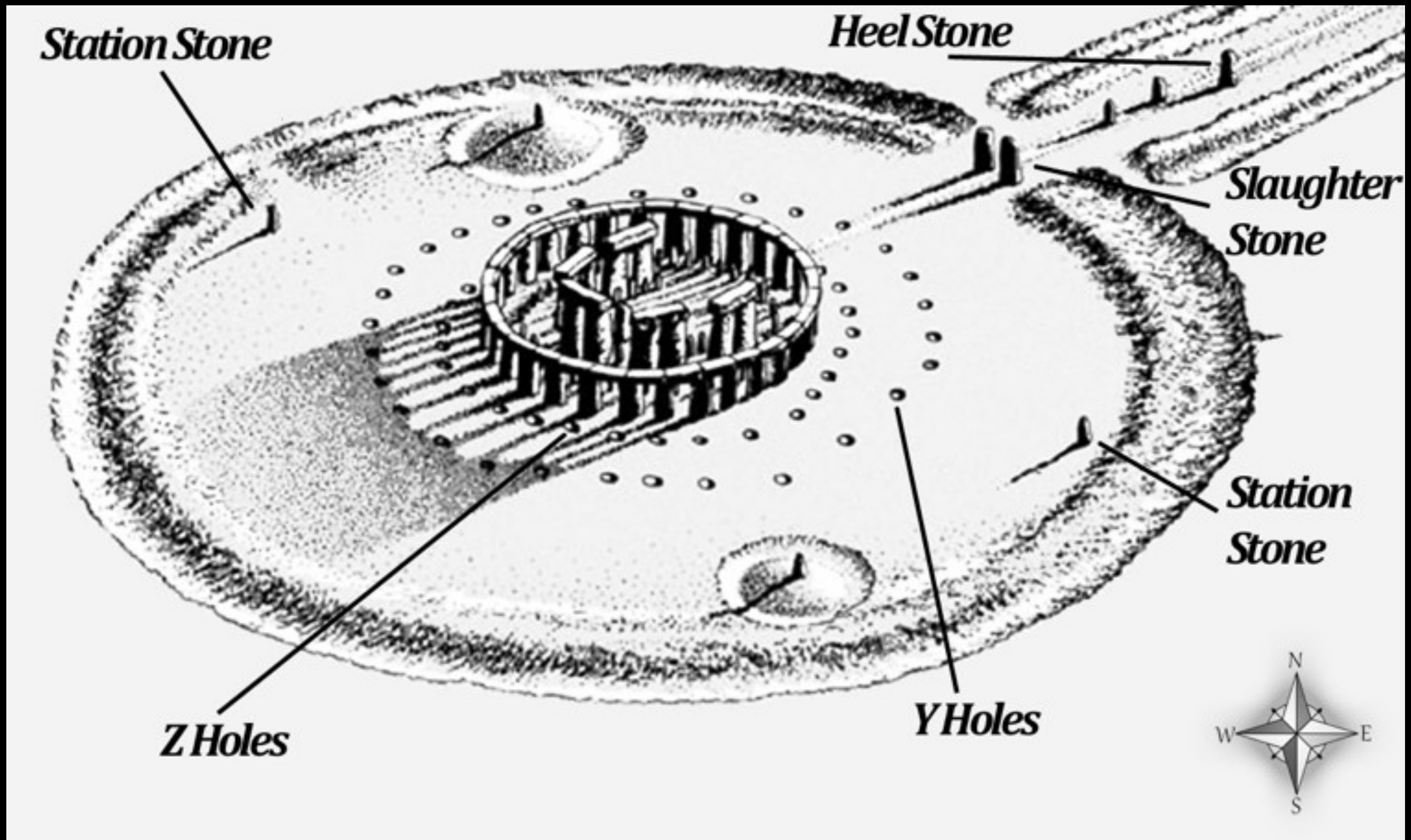
They served as giant calenders, and were often the sites of rituals, probably related to the annual cycles.

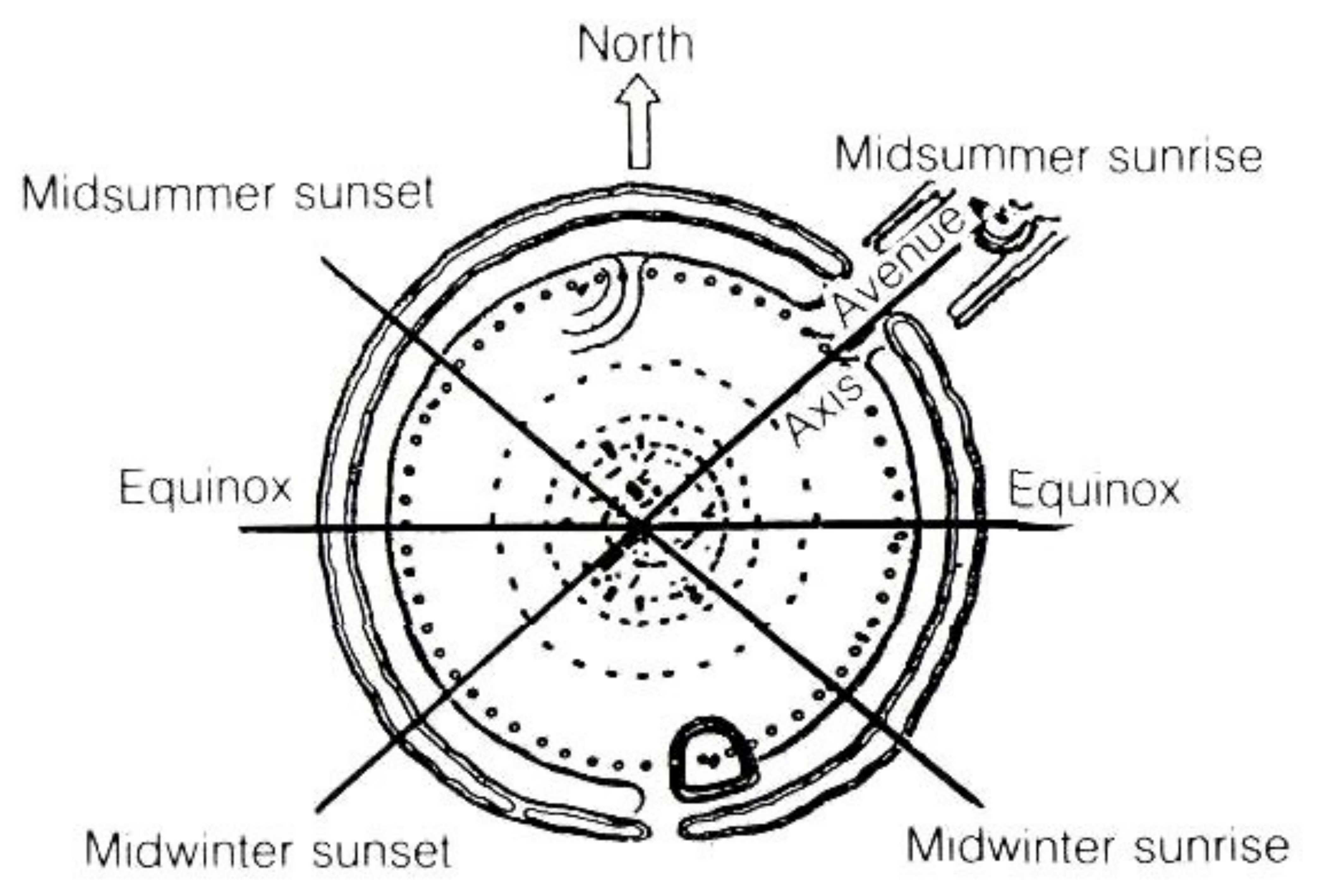
Stonehenge

Built/modified over 1700 years
(2800 BC - 1100 BC)

50 tonne stones moved 200 km to construct.

Summer solstice sunrise aligns with heel stone. Equinox and winter solstice alignments also evident.





Other ancient calendars

Babylonian Astronomy

The Babylonians had complex mathematical models to describe the motions of the Moon and other planets.

Their clay tablets provide us with the earliest written astronomical observations, dating from around 3500 BC. The earliest known star charts are from 1200 BC.

Babylonian Astronomy

Babylonians used a base 60 number system. This is the origin of 360 degrees in a circle and 60 minutes in an hour, etc.

The Babylonians developed an accurate lunar calendar, that consisted of 12 or 13 month years, in an 19 year cycle.

They discovered the "Saros cycle" in which solar and lunar eclipses repeat every 18 years 11 days.

Western astronomy is directly descended from Babylonian astronomy.

Mayan Astronomy

The Mayan culture had an advanced mathematical understanding of astronomy.

They had models to predict the motions of the Sun, Moon and planets, especially Venus.

Many Mayan buildings, including temples and ball courts, had astronomical alignments or other significance.

El Caracol in Chichén Itzá, Mexico, has many windows that are aligned with astronomical events.

Mayan Astronomy

El Castillo at Chichen Itza has 91 steps per side, plus the platform on top, giving 365 for the number of days in a year.

The pyramid is built so the shadows appear to form a slithering snake on the equinoxes.

They had many astronomical texts, almost all of which where burned by the Spanish.

Dresden Codex: Earliest known written text in the Americas dating from the 11th century. The codex, written by the Mayans contains detailed astonomical tables describing the Lunar and Venus cycles

Dresden Codex

Ancient Indian Astronomy

Indian astronomy has long history dating back to 1500 BCE (Indus Valley Civilization).

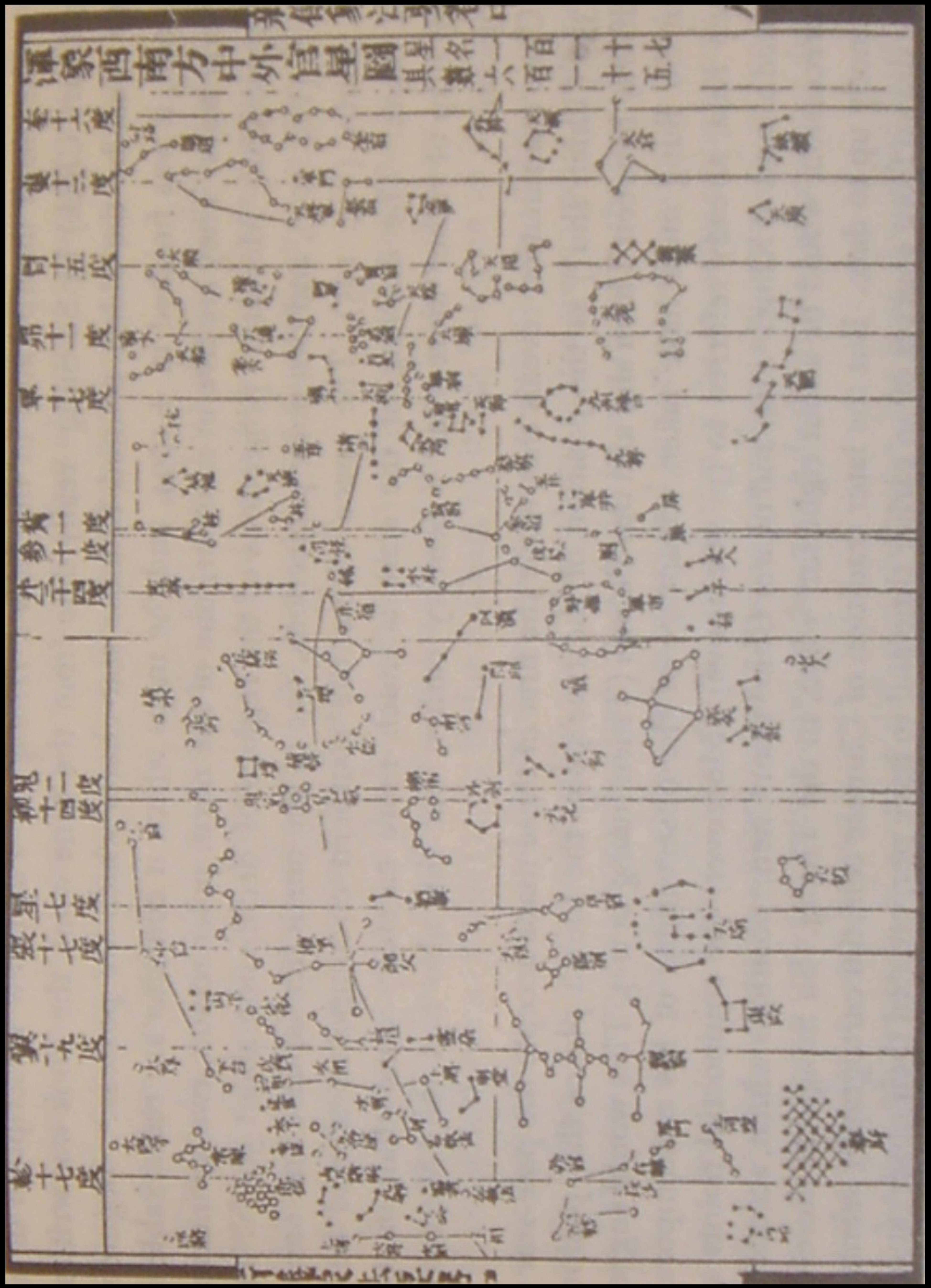
Vedanga Jyotisha, the oldest known text dates back to 1400 BCE

Indian astronomers had a detailed understanding of time, positions of planets and other celestial events, and greatly influenced Chinese and Arabic astronomy later.

Ancient Chinese Astronomy

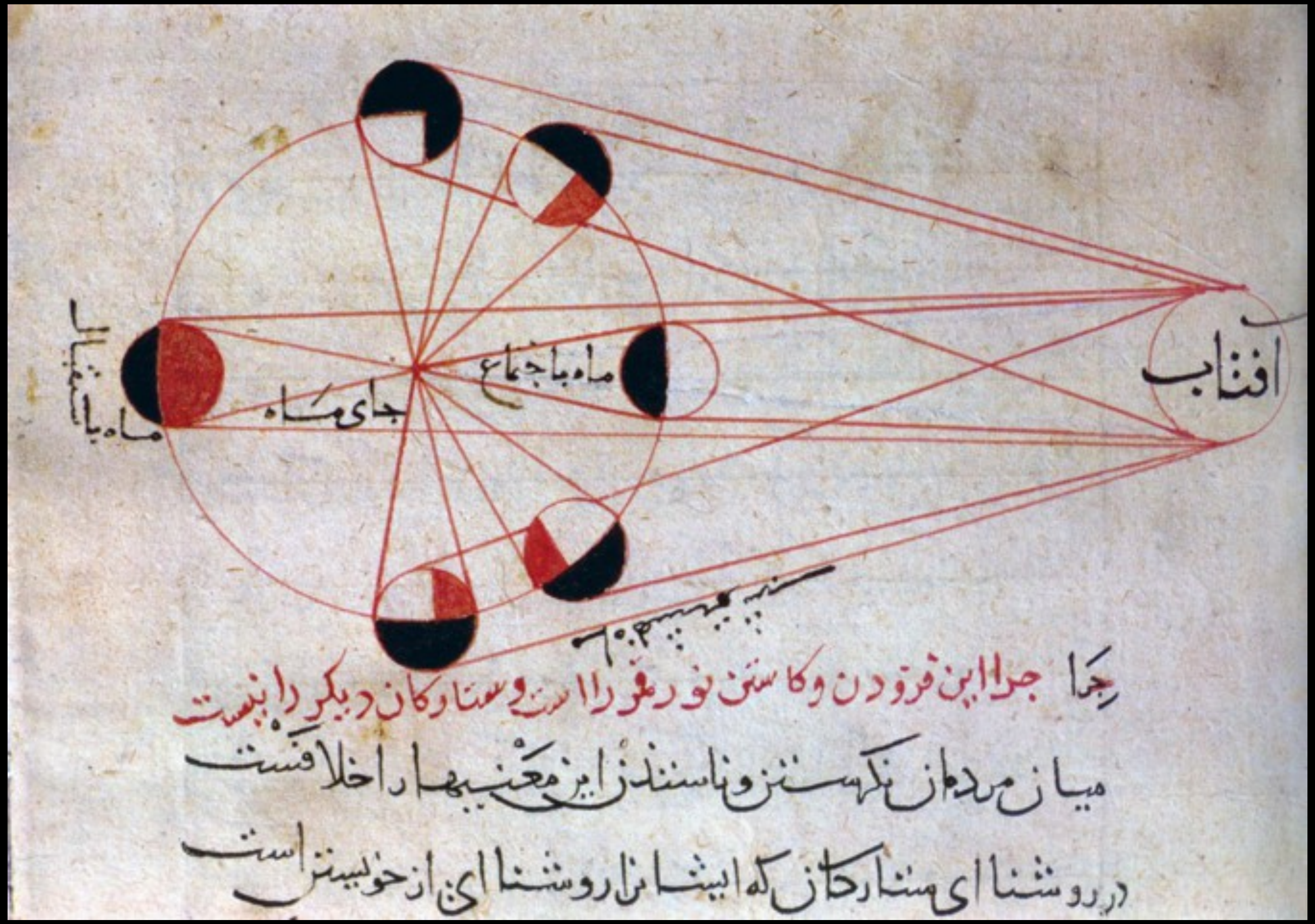
Chinese astronomers created detailed maps of the stars - used for prophetic purposes also.

Chinese astronomers noted "guest stars" such as SN-1054. After a thousand years, it now appears to us as the Crab Nebula.

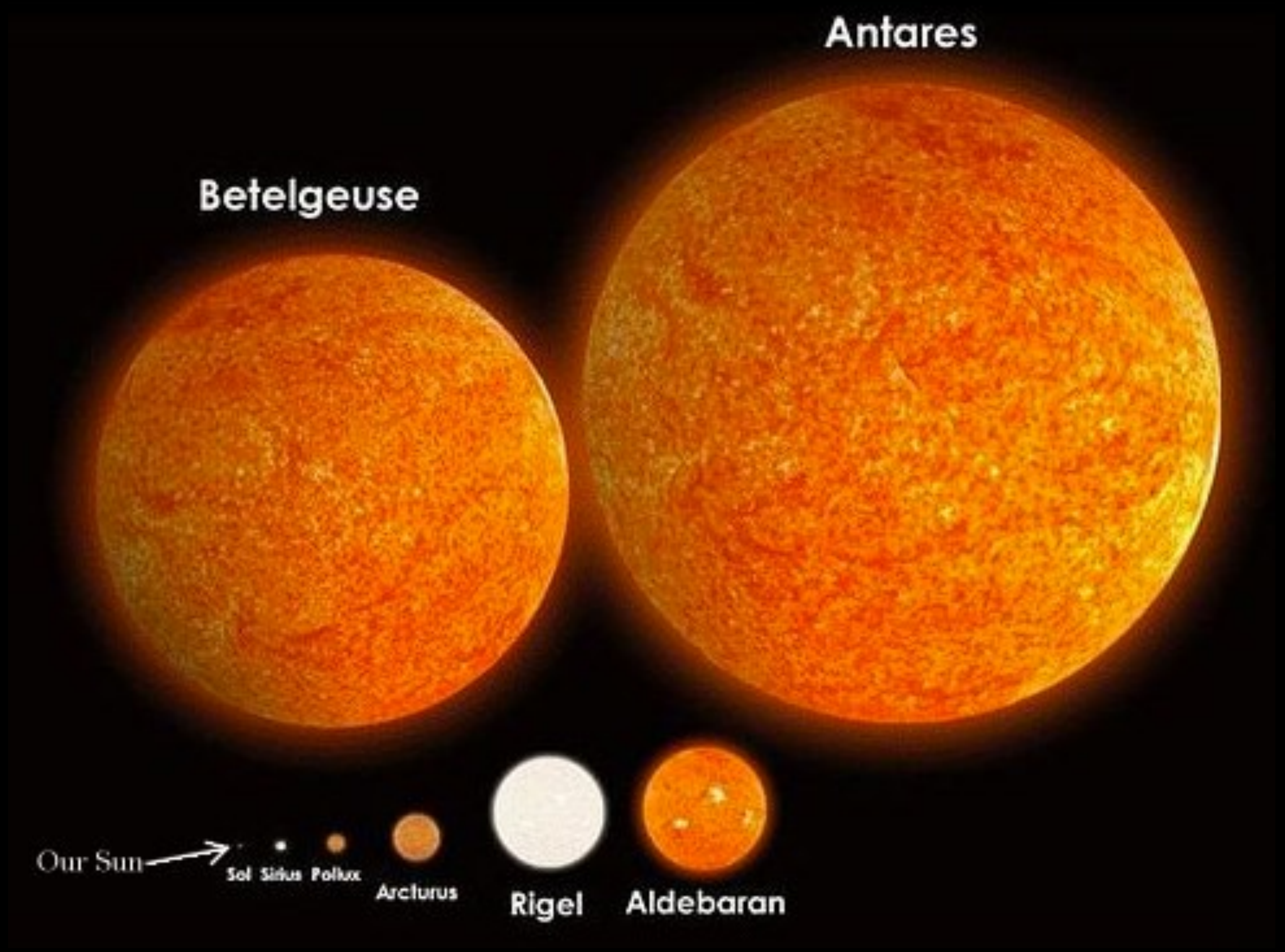


Arabic Astronomy

Astronomers in the Middle East were the most advanced at one point, building upon the understanding of the Greeks.



Terms such as "Zenith" and "Azimuth" as well as the naming of many stars come from Arabic astronomers.



Arabic Astronomy

Elaborate devices called Astrolabs were built to predict celestial motions.

This example was built by Abu Bakr Ben Yusuf, year 613 of the Hegira (1216-1217).

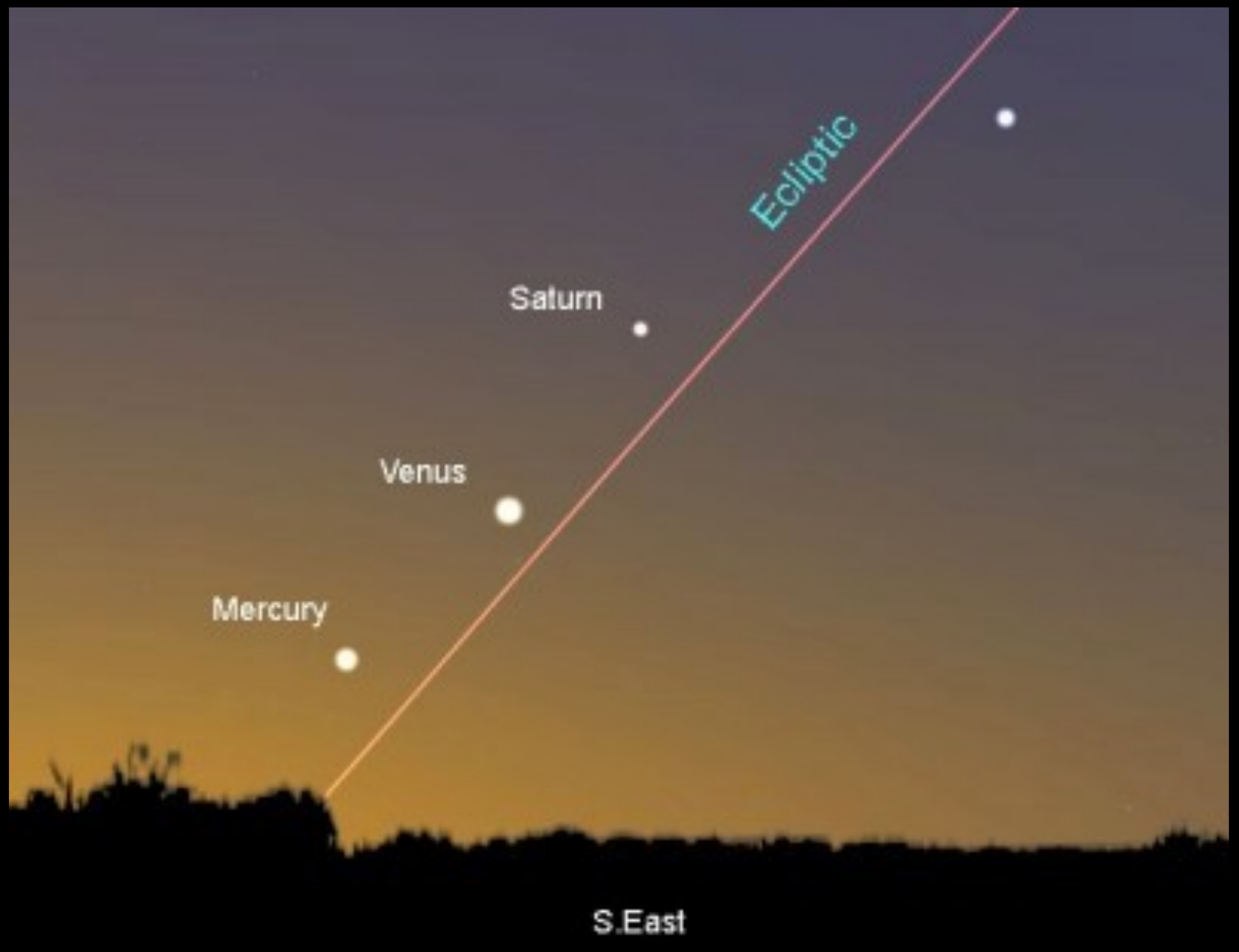
Origins of Geocentric Model

Ancient Greece

Greeks distinguished Sun, Moon, planets and stars as distinct types of objects.

The Sun and Stars move from East to West in the night sky.

Planets follow the ecliptic (the path of the Sun) but sometimes move in **retrograde**.



The motion of Mars against the background of stars, as observed from Earth over a period of several months. Moves from W to E, then reverses direction for several days, then reverses direction again

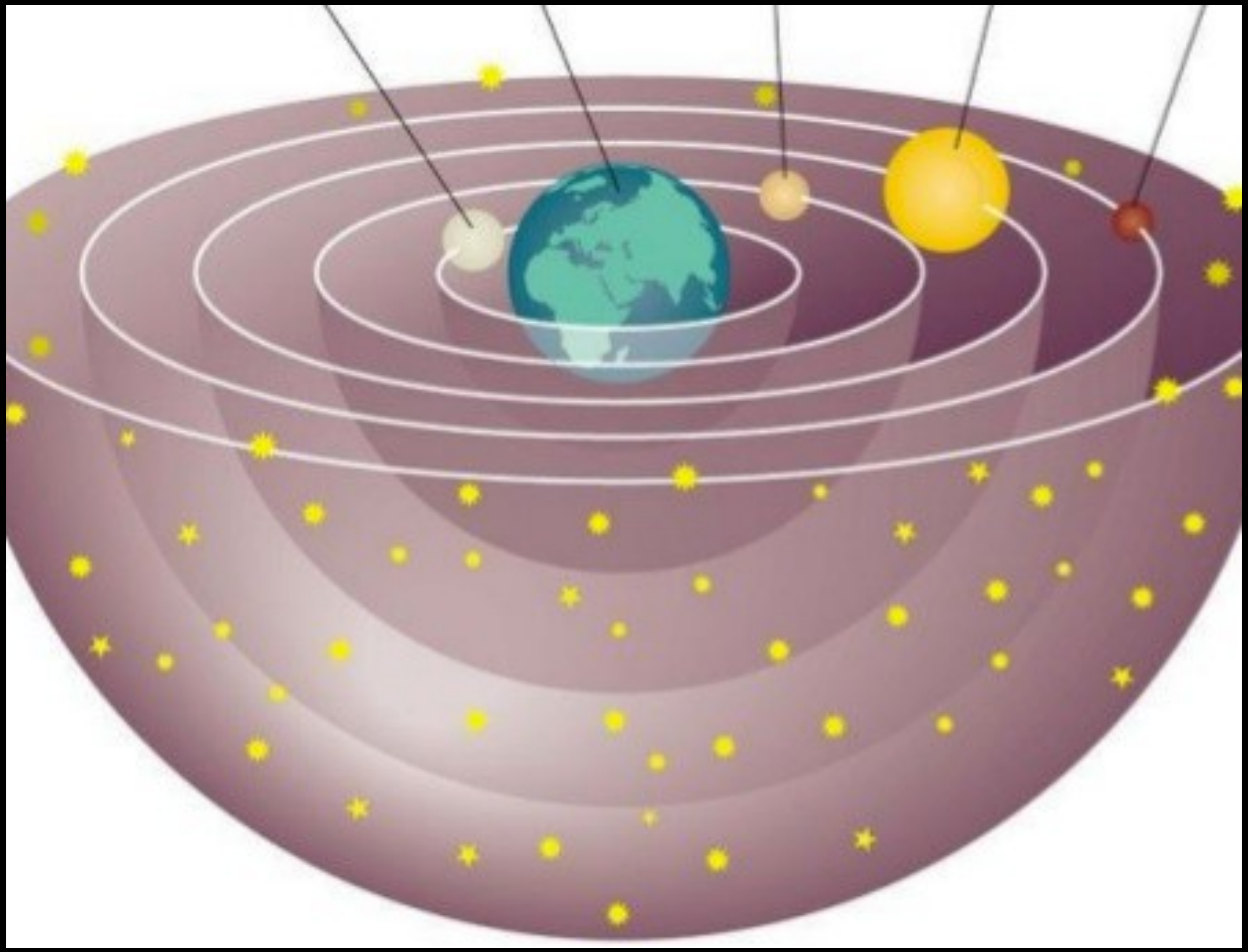
Ancient Greece

Plato (424-347 BCE): Path to truth through pure thought (not experiment!)

Perfection of the Heavens:
all heavenly objects must be perfect circles, traveling in perfect paths.

No beginning, no end, no change.

Plato's student, Eudoxus, developed system of 27 spheres to describe motion of heavens.



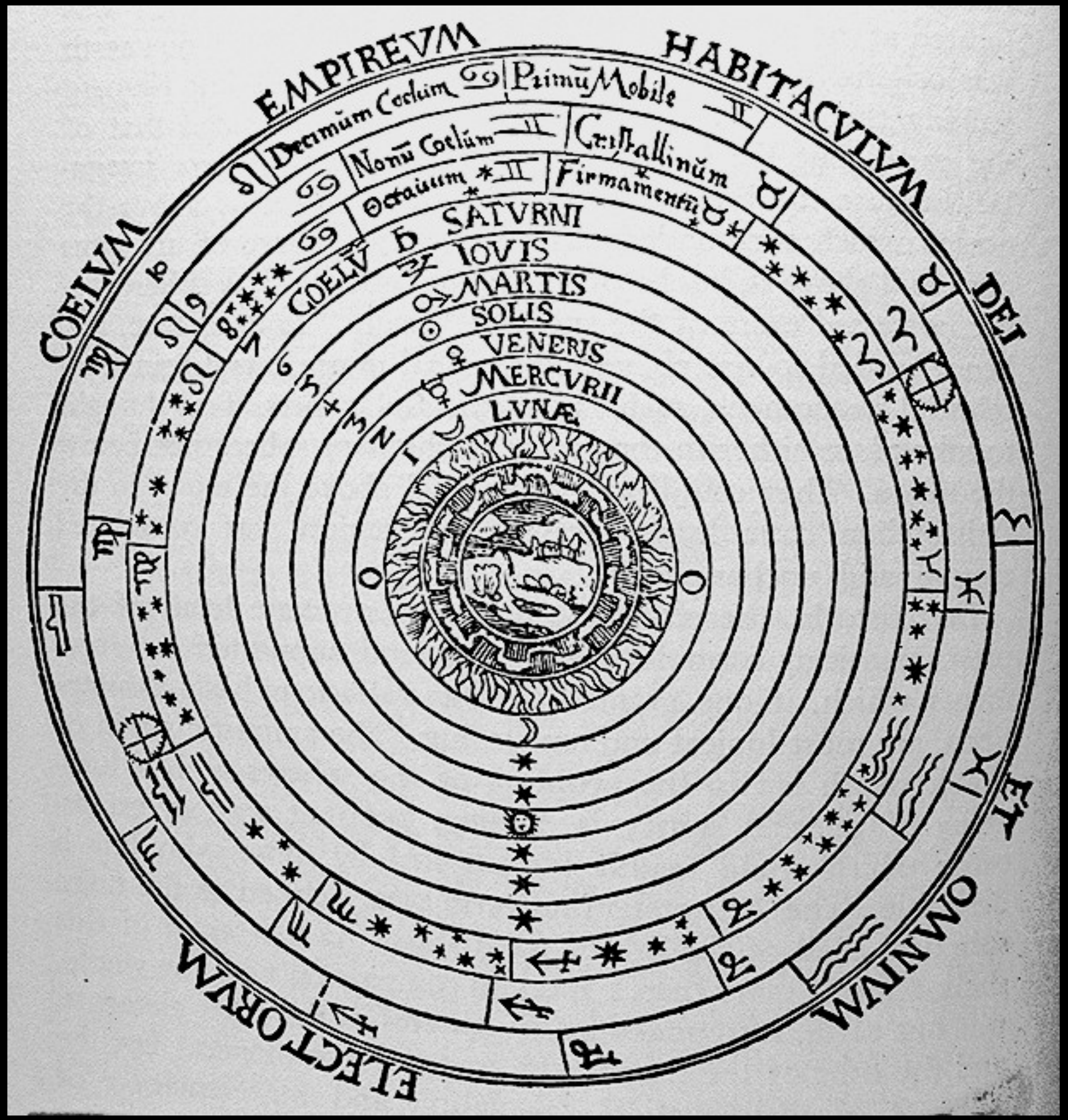
Ancient Greece

Aristotle (384-322 BCE): greatest authority in antiquity, expert on philosophy, politics, ethics, poetry, drama...

All arguments stem from “first principles” - beliefs that are obviously true.

Perfection of heavens was a “first principle”. Natural state of all objects is to be *at rest*, motion of Earth could not be seen (parallax).

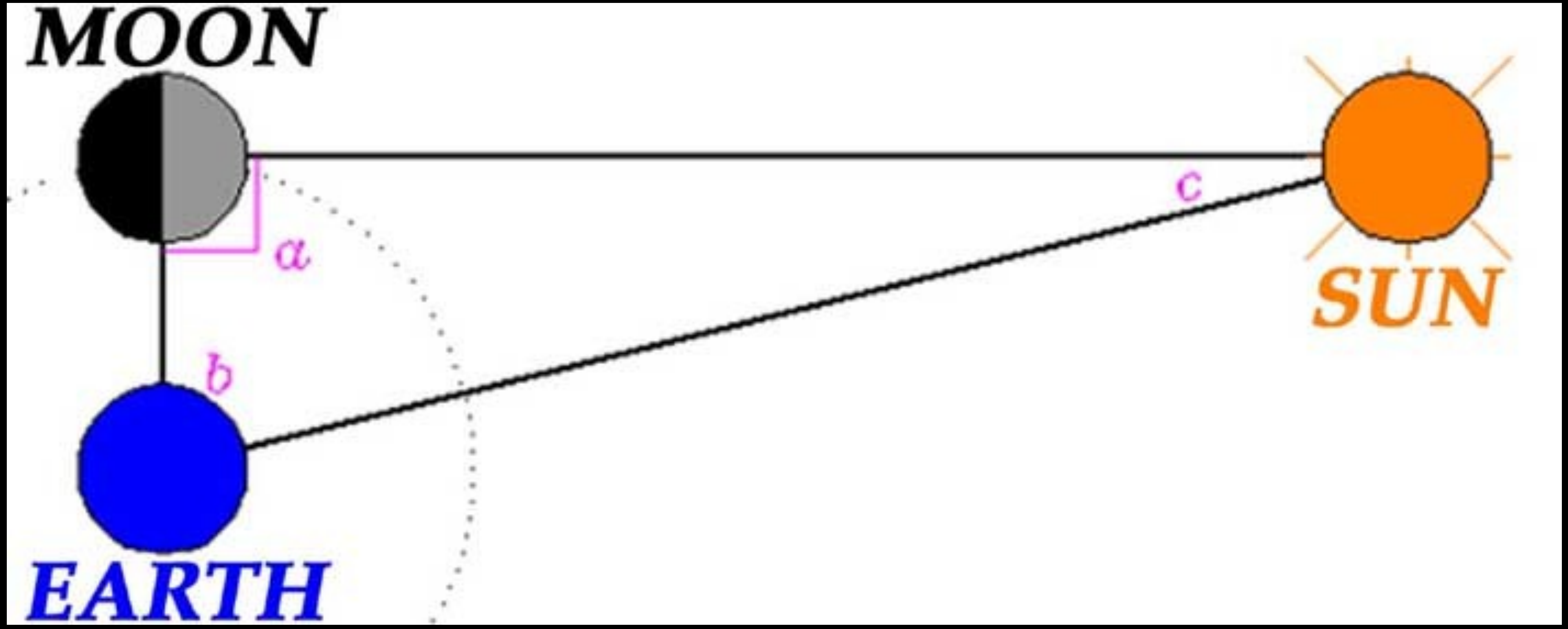
Modified Eudoxus model to 55 spheres.



Ancient Greece

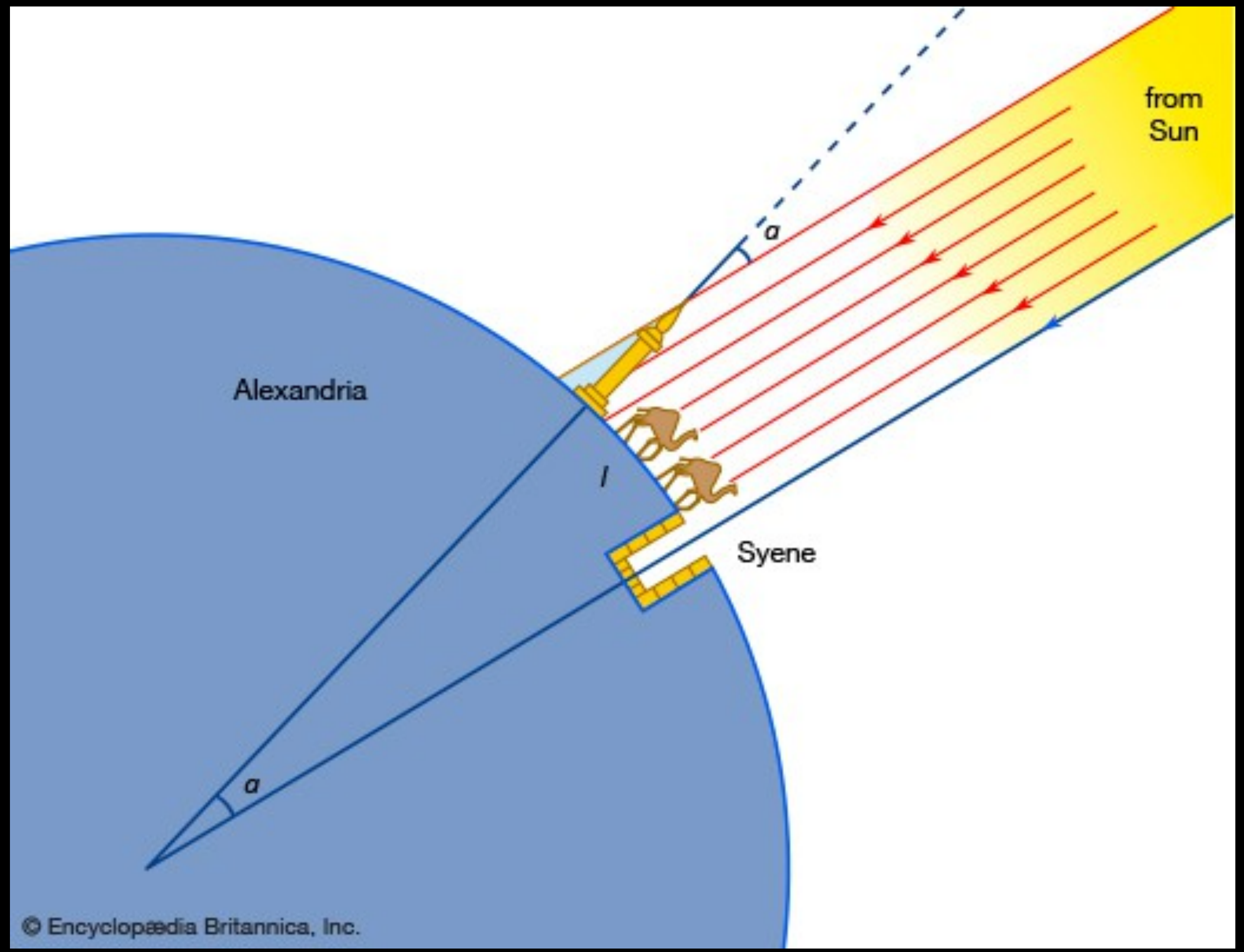
Aristarchus (~310-230 BCE): Proposed idea that Earth rotates around the Sun

He used triangulation to estimate distance to the Sun. He calculated 19x Earth-Moon dist, but its actually ~400x.



Ignored due to Aristotle's authority.

Eratosthenes (276-195 BCE): Calculated radius of Earth by measuring angle of shadow in two different cities. (Accurate to ~10%)



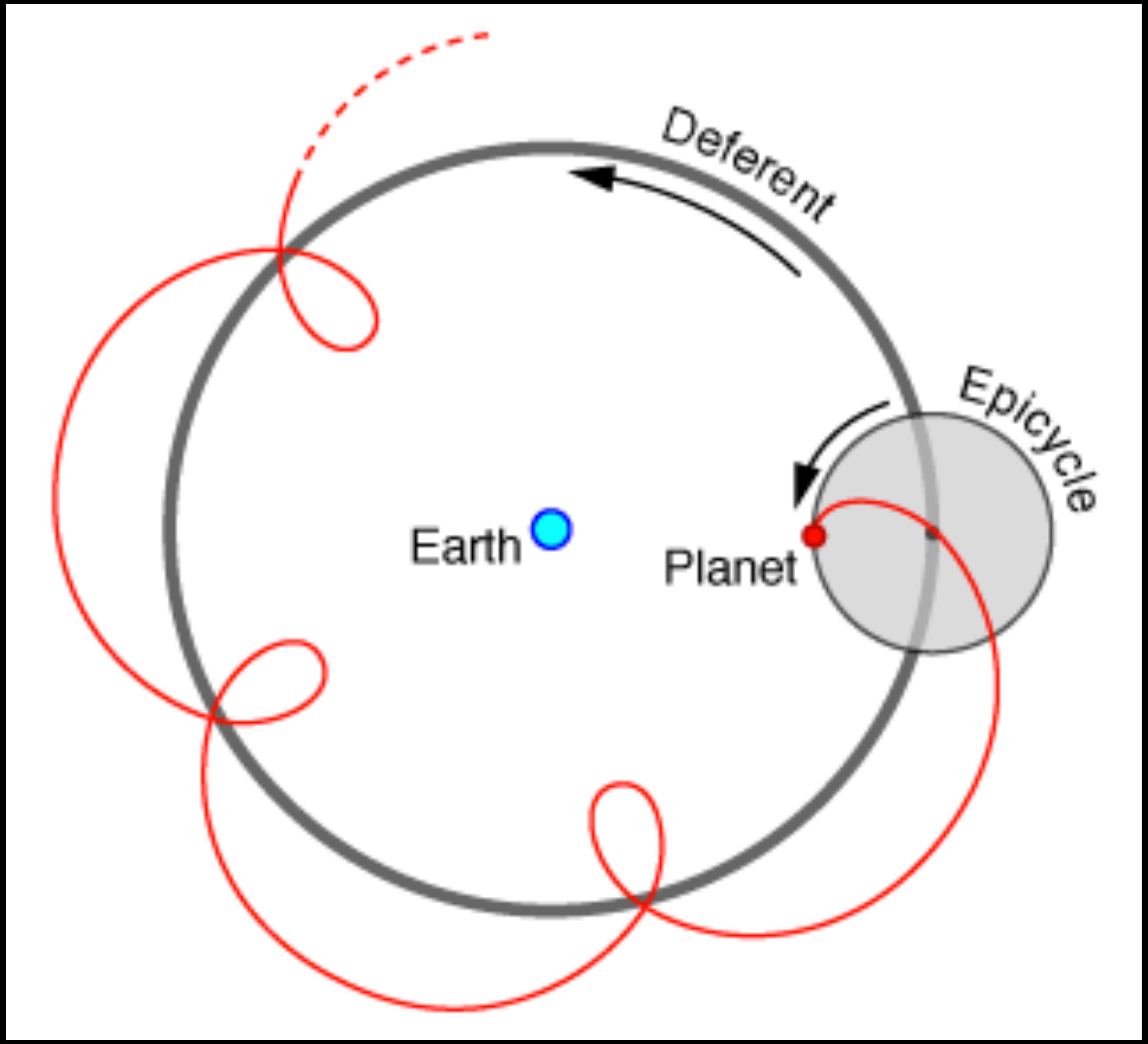
Ancient Greece

Ptolemy (~140 CE): Developed advanced mathematical model of geocentric universe in *Almagest*.

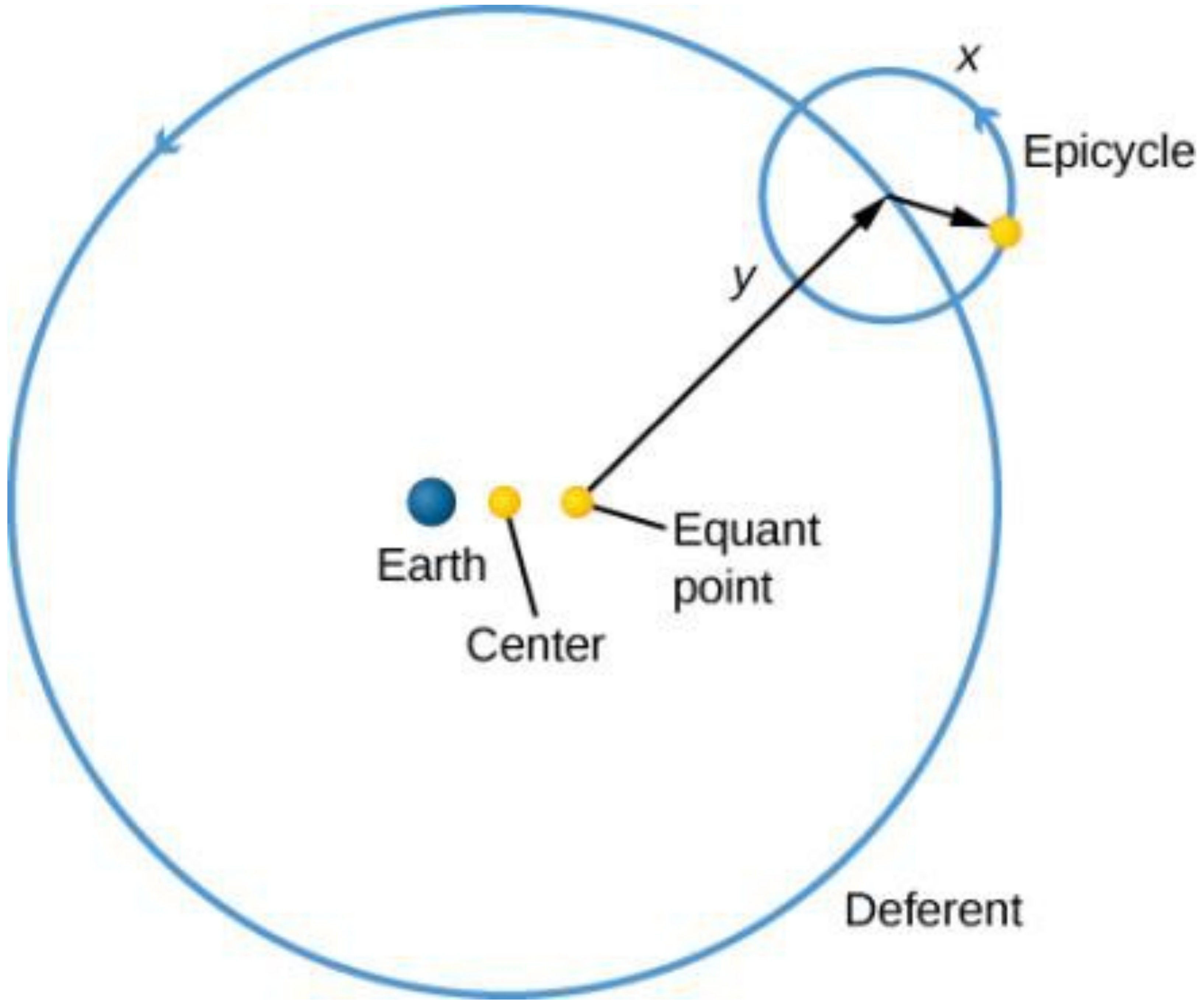
All objects had a primary path: Deferent

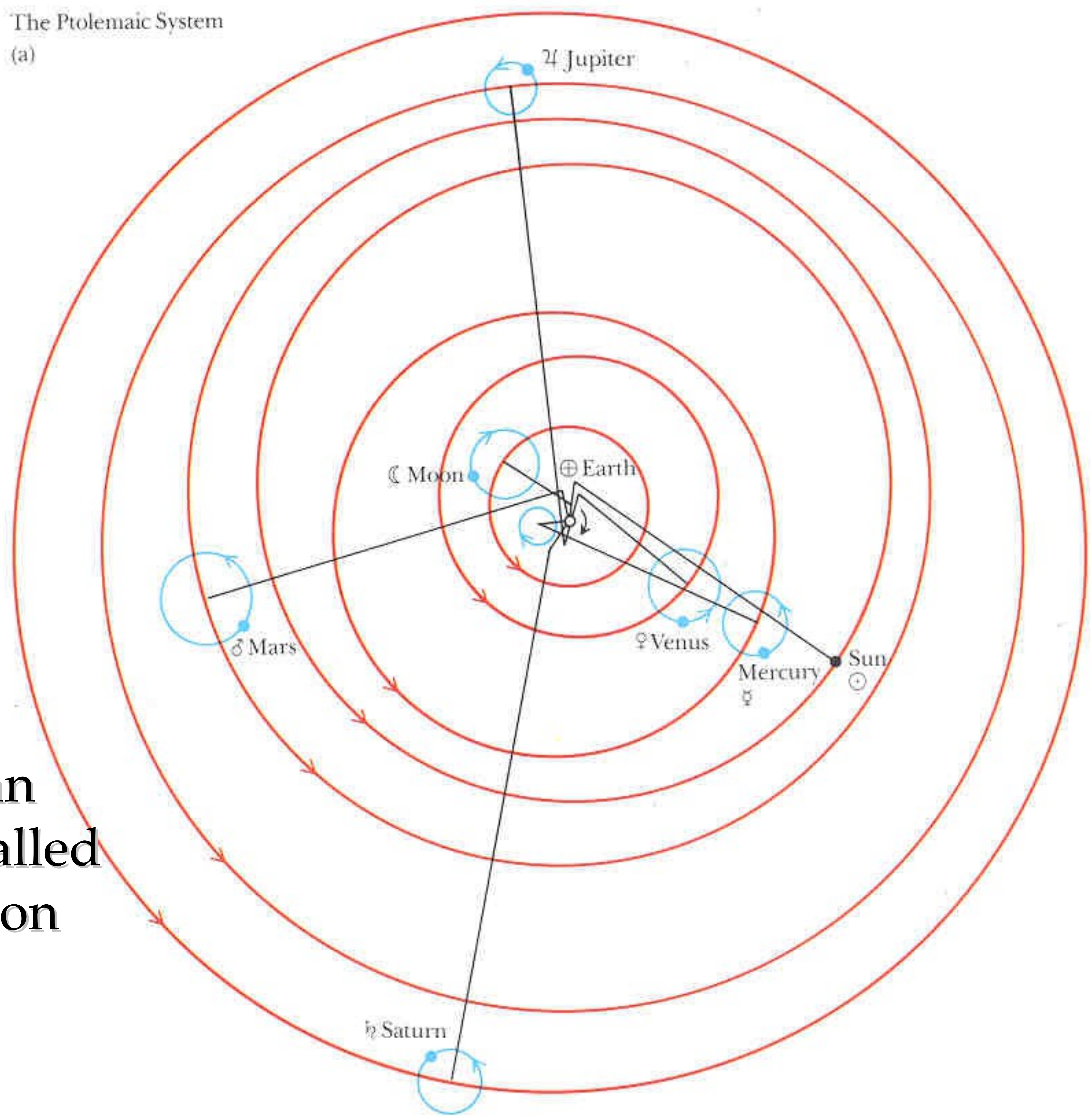
Planets moved on epicycles to account for retrograde motion.

Needed 80 spheres to describe motion of the heavens.



Ptolemy's Complicated Cosmological System





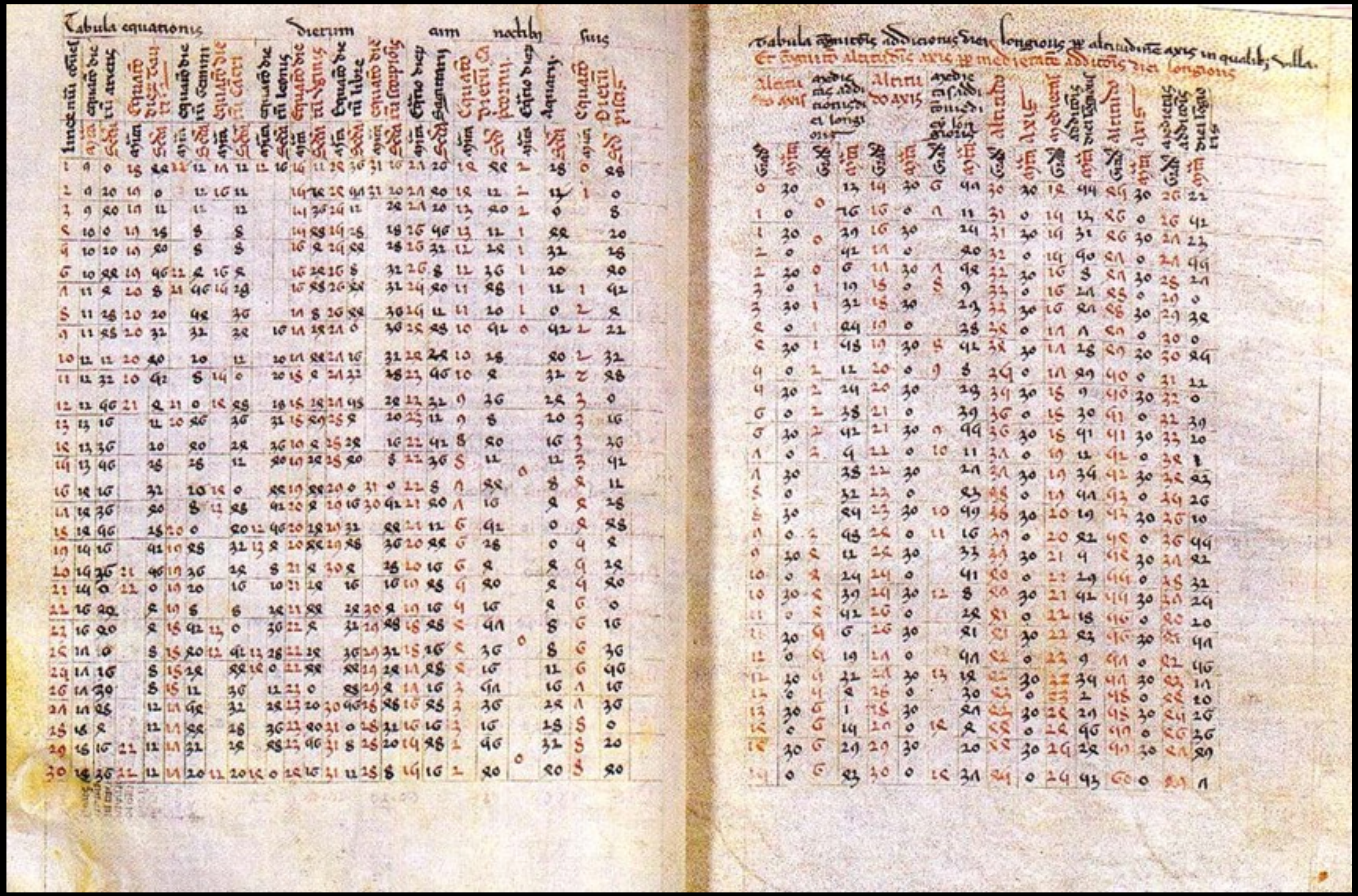
Each planet orbits around a small circle called an *epicycle*. Each epicycle orbits on a larger circle called the *deferent*. This system is not centered exactly on Earth but on an offset point called the *equant*.

Ptolemaic Model

Ptolemaic model was successful for centuries, but eventually its errors became clear.

If your watch is off by 1 second per day, how long does it take for you to miss a job interview by 5 minutes?

Alfonsine Tables (13th c.) - last attempt to fix model.

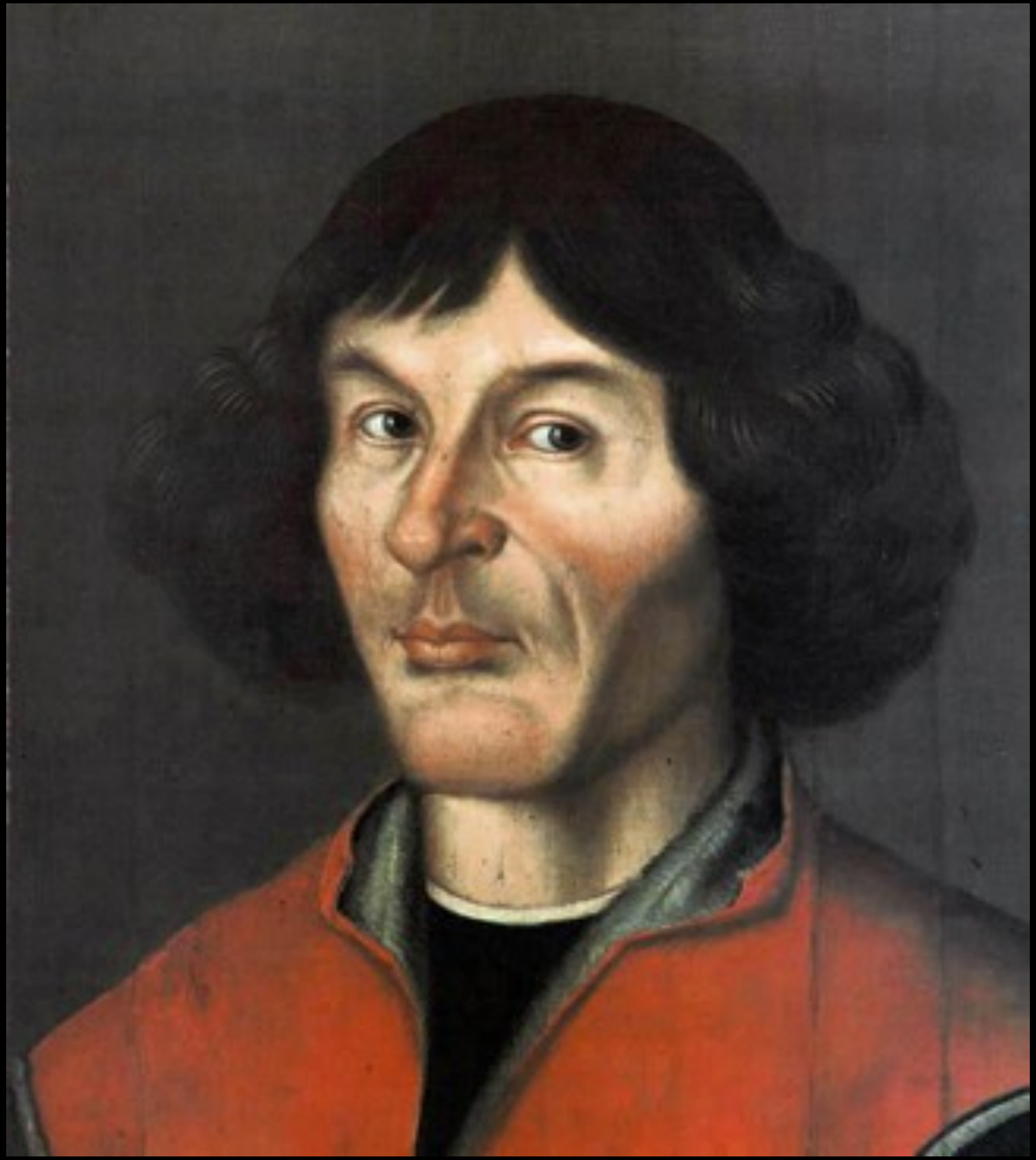


Transition to Heliocentric Model

Nicolaus Copernicus (1473–1543)

Copernicus was a Polish cleric and scientist who played a leading role in the emergence of modern science.

Although he could not prove that Earth revolves about the Sun, he presented such compelling arguments for this idea that he turned the tide of cosmological thought and laid the foundations upon which Galileo and Kepler so effectively built in the following century.



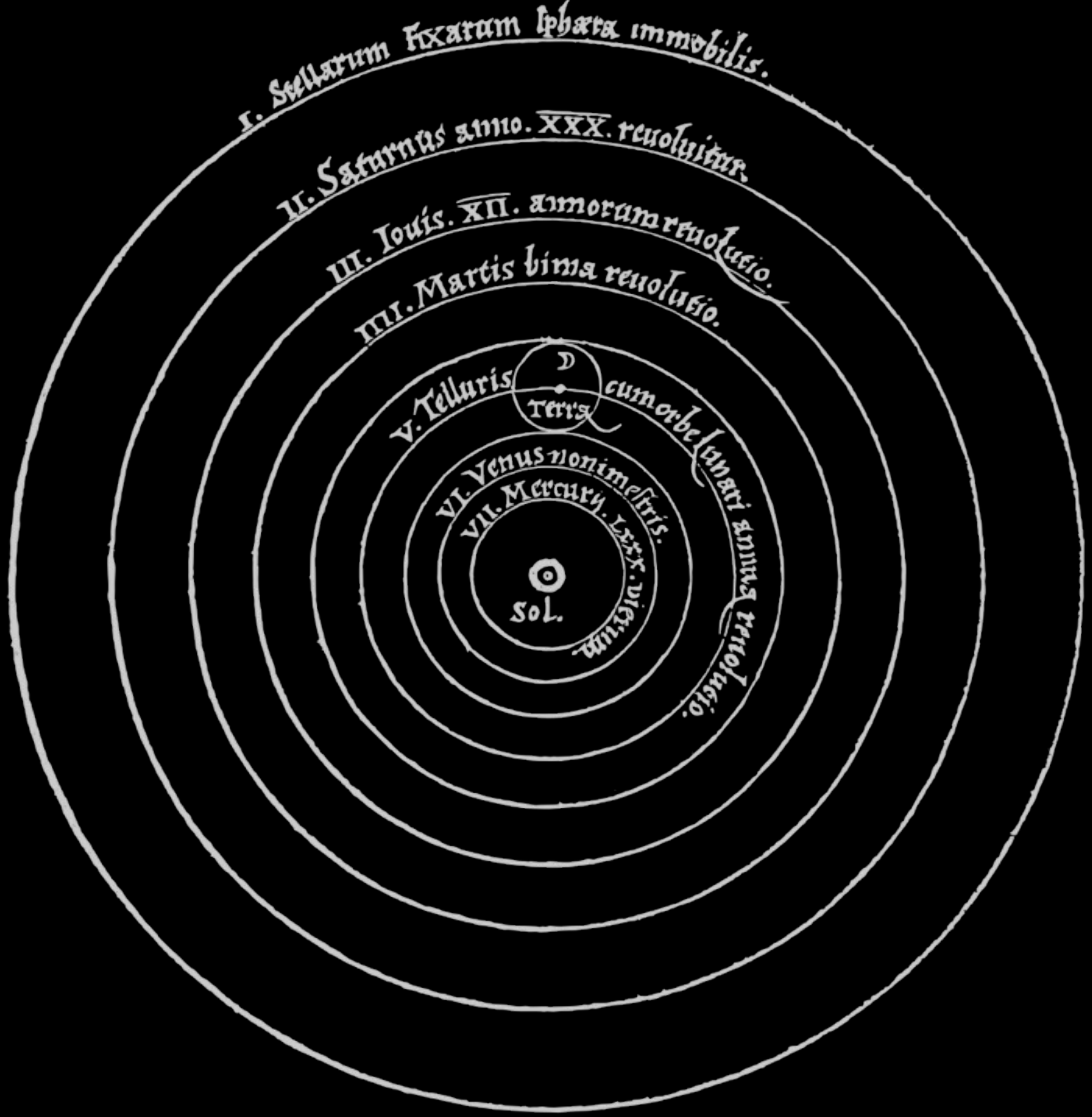
Copernicus

Copernicus (1473-1543) worked as a Church administrator, mathematician and astronomer.

Developed heliocentric (Sun-centred) model

Could not predict planetary motion

Ptolemaic model was still superior, but Copernican model did not need epicycles to explain retrograde!



Principles of Copernican Model

1. All orbits are circular, the perfect form.

2. There isn't one common centre of orbit.

3. The Earth is centre of the Moon's orbit. The planets orbit the Sun.

4. The stars are much, much further away.

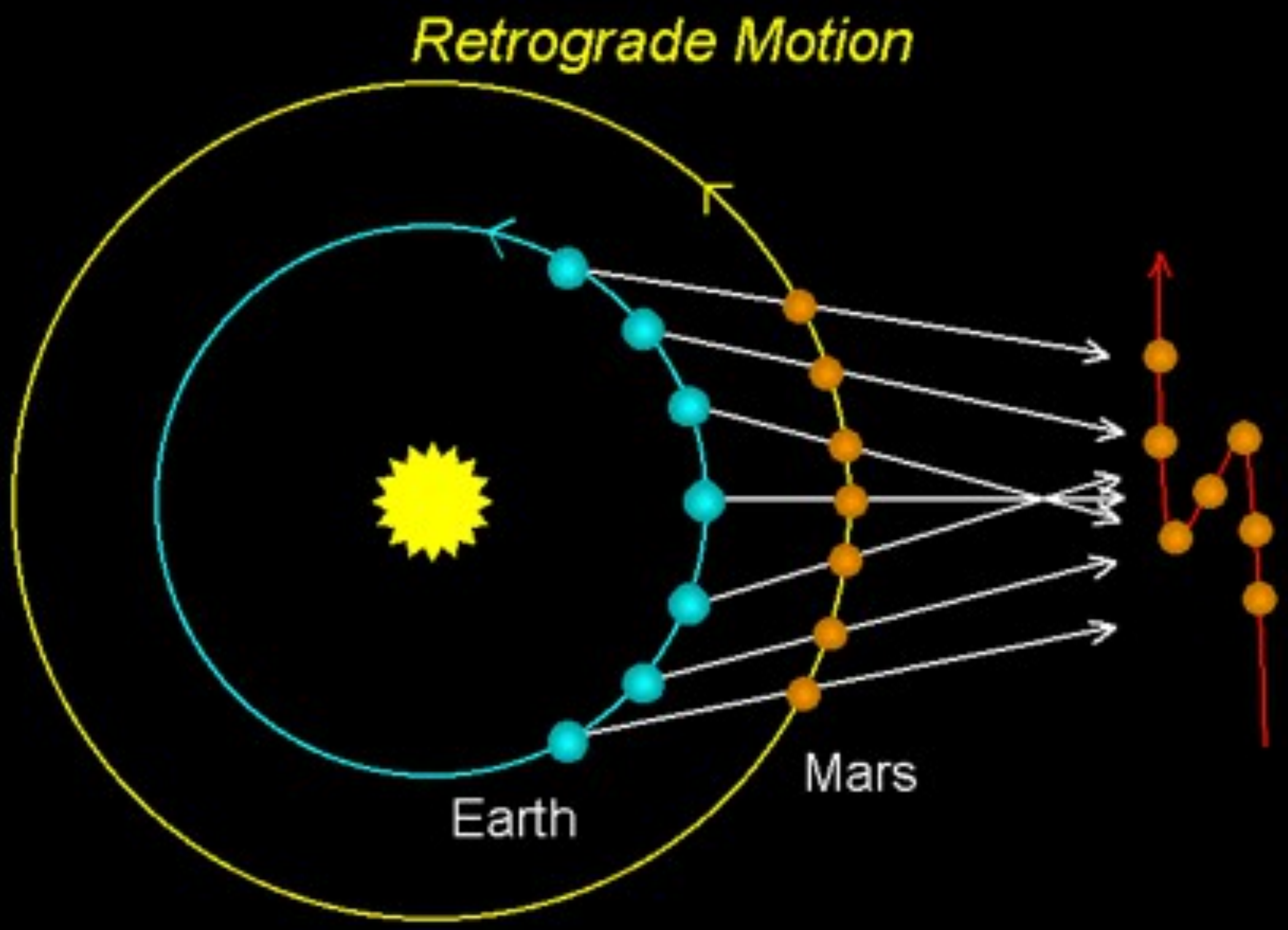
5. The motion of the stars and Sun is due to rotation of Earth on its own axis.

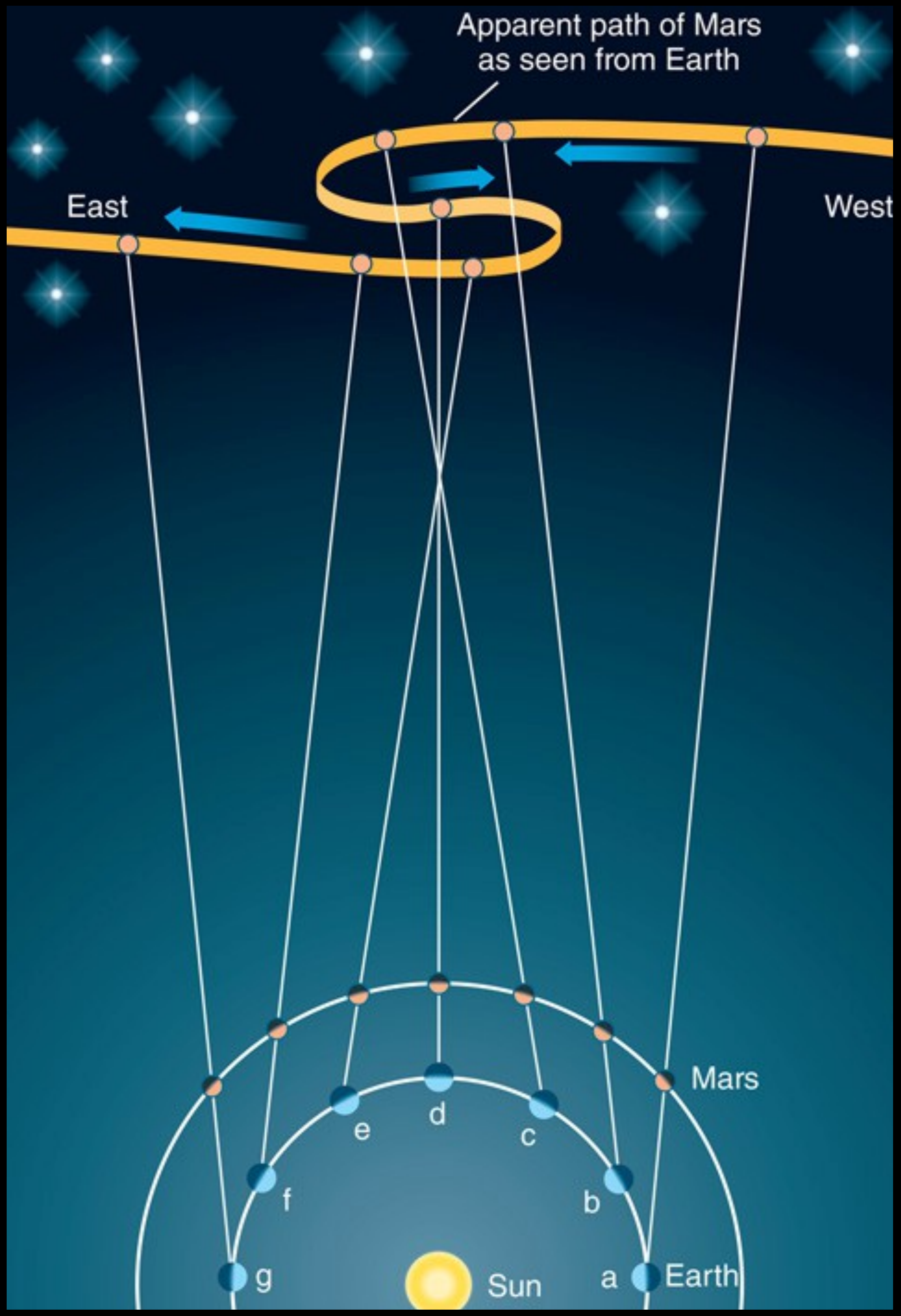
6. The **retrograde** motion of the planets is due to Earth's orbit.

Copernican Retrograde Motion

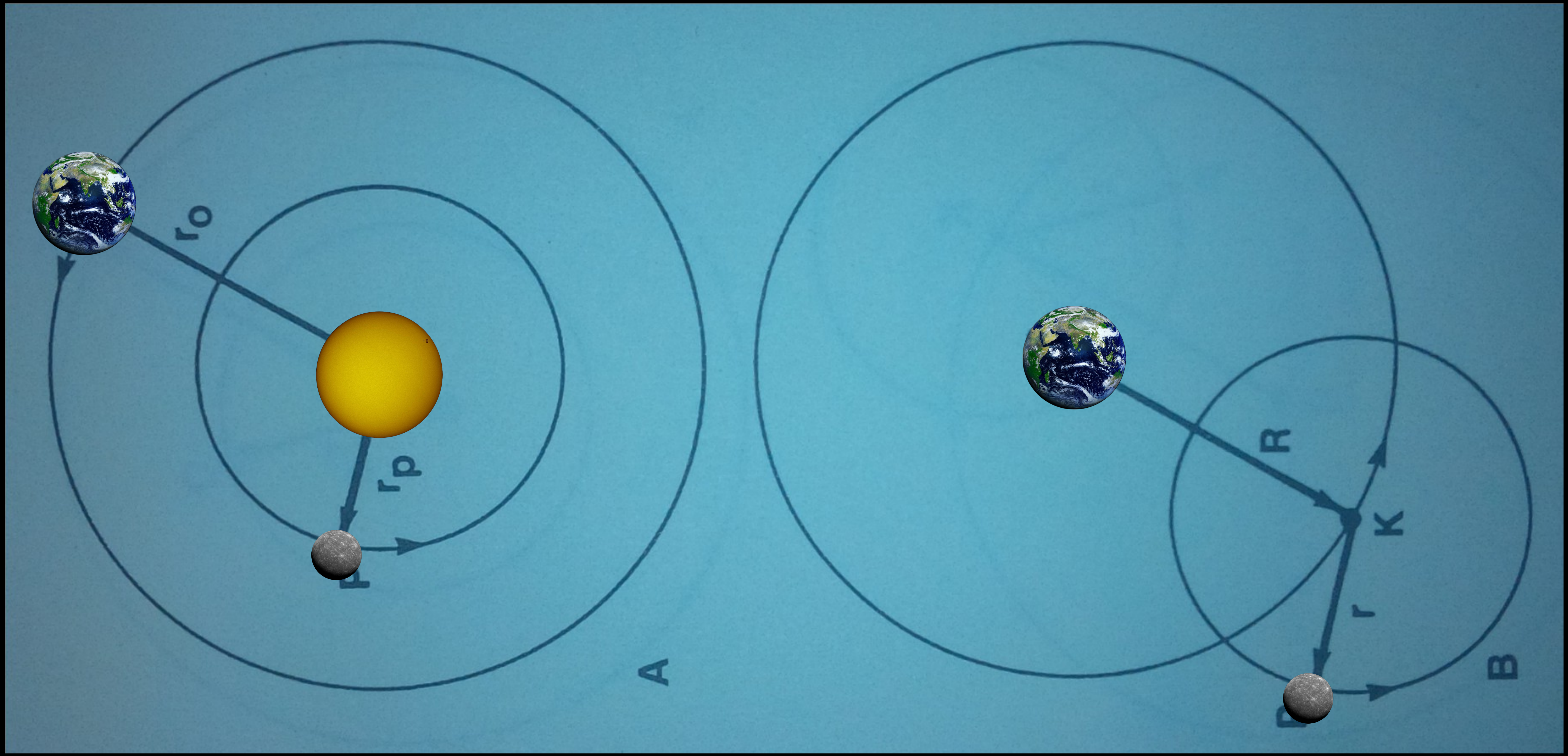
80 spheres needed for Ptolemaic model, most of which account for retrograde motion

Copernican model could use 9 spheres!





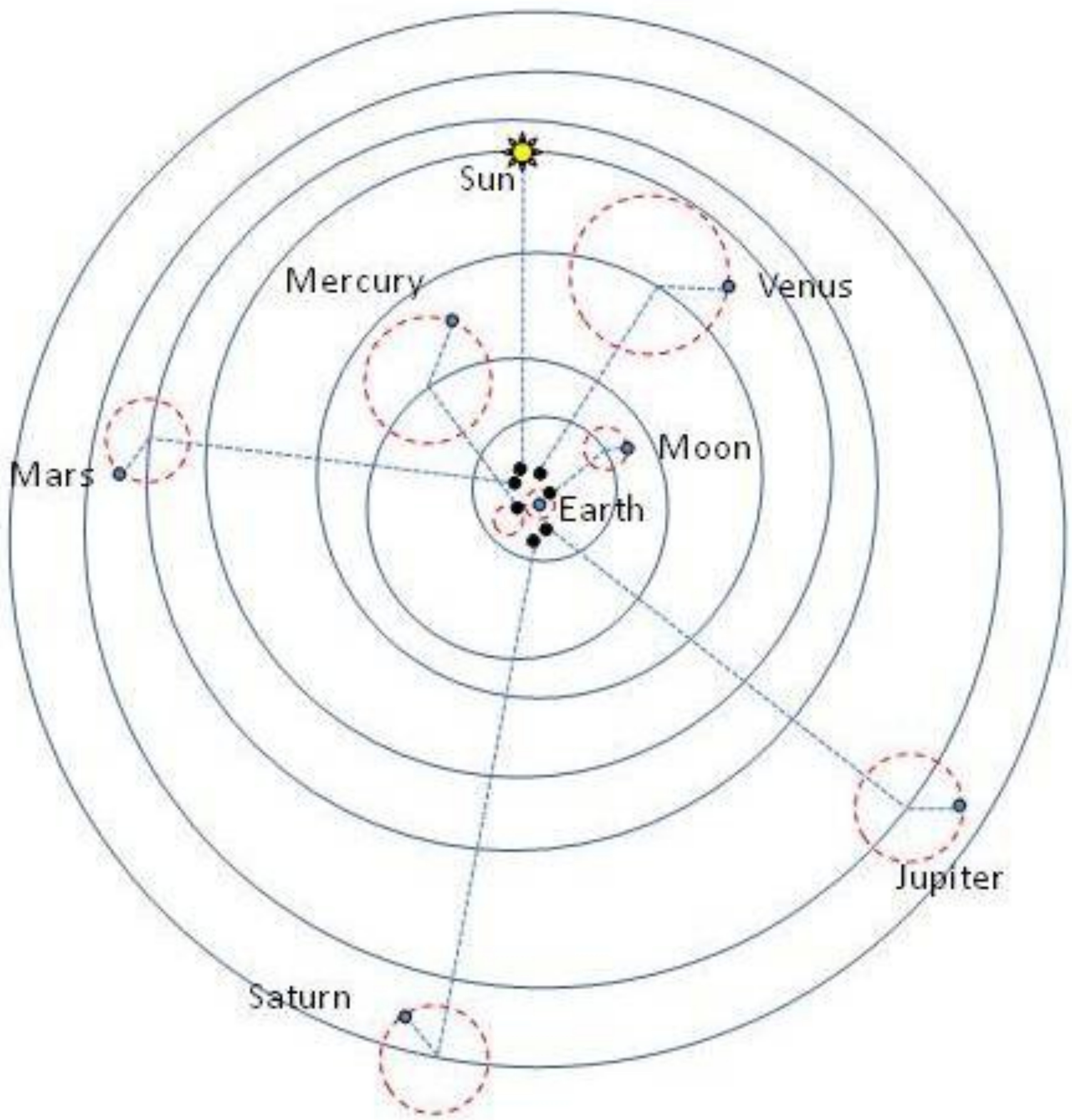
Heliocentric vs. Geocentric models



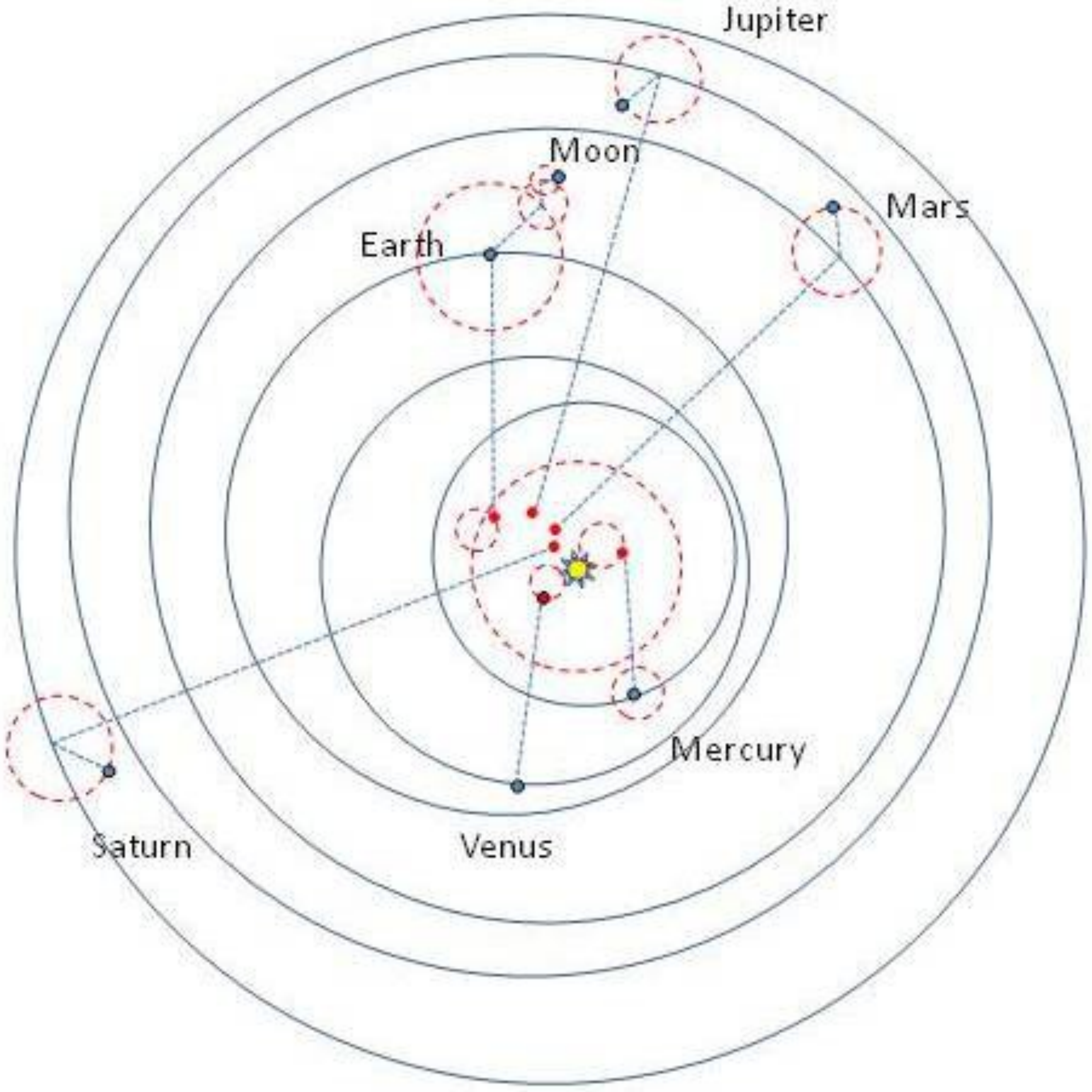
The heliocentric model explained observed phenomenon in a much more logical and elegant manner.

The heliocentric model of Copernicus was still mathematically equivalent to Ptolomy's geocentric model, due to both being based on circles.

Heliocentric vs. Geocentric models



Ptolemaic Model



Copernican Model

Galileo Galilei (1564–1642)

Galileo advocated that we perform experiments or make observations to ask nature its ways.

When Galileo turned the telescope to the sky, he found things were not the way philosophers had supposed.

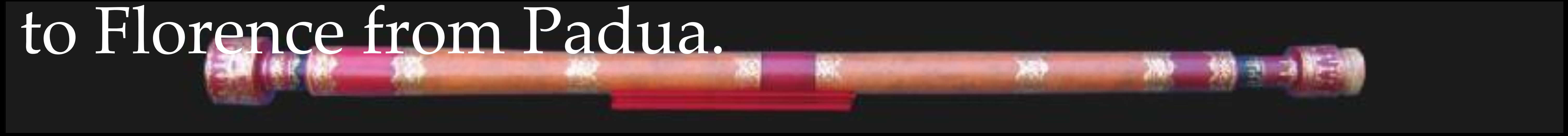
Telescope Used by Galileo

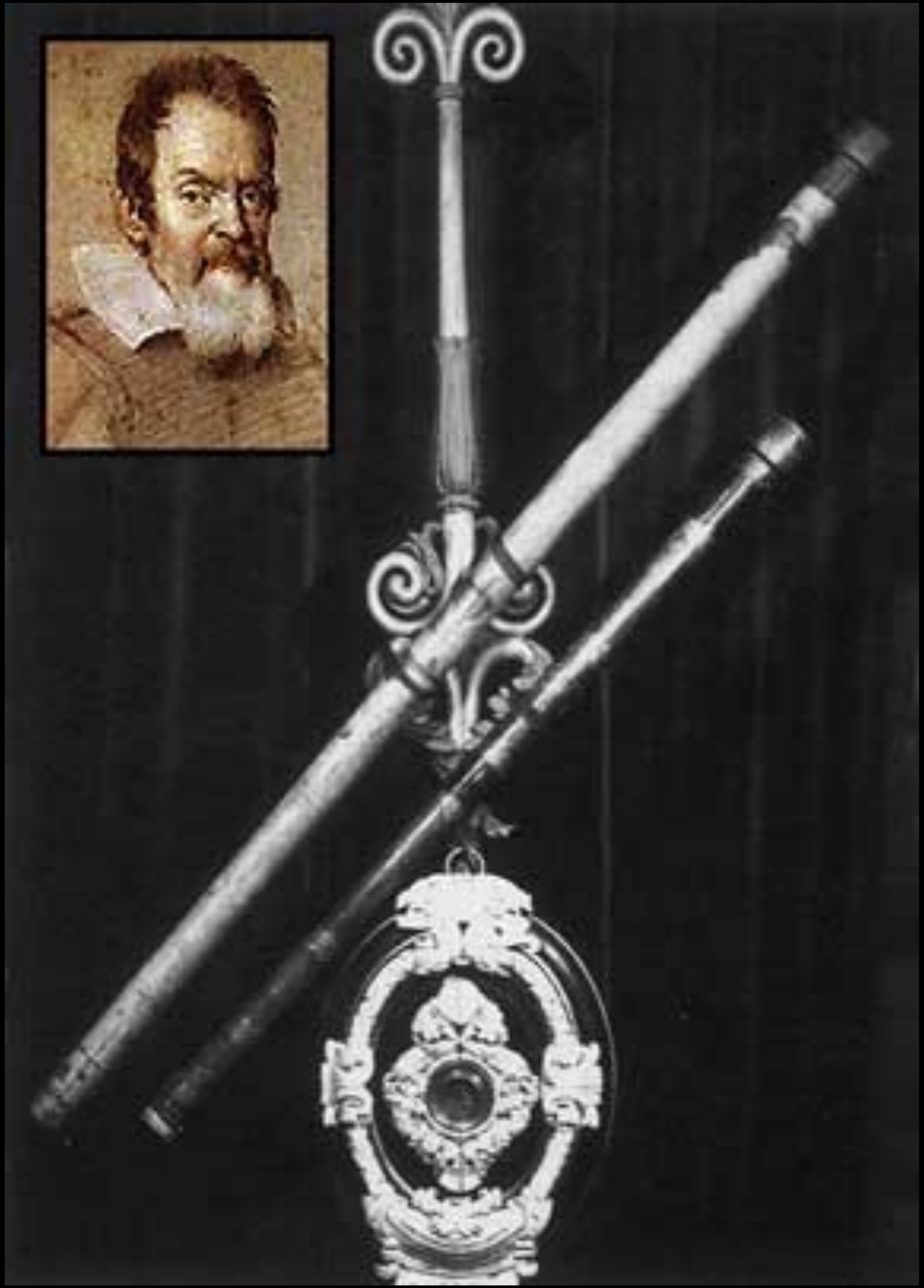
Telescope invented around 1608 by German-Dutch lensmaker Hans Lippershey.

Galileo built his own in 1609, and made the first astronomical observations, which disagreed with the geocentric model.

His telescope had a wooden tube covered with paper and a lens 26 millimeters across.

Allowed Galileo to become influential and to move to Florence from Padua.





Galileo's Observations

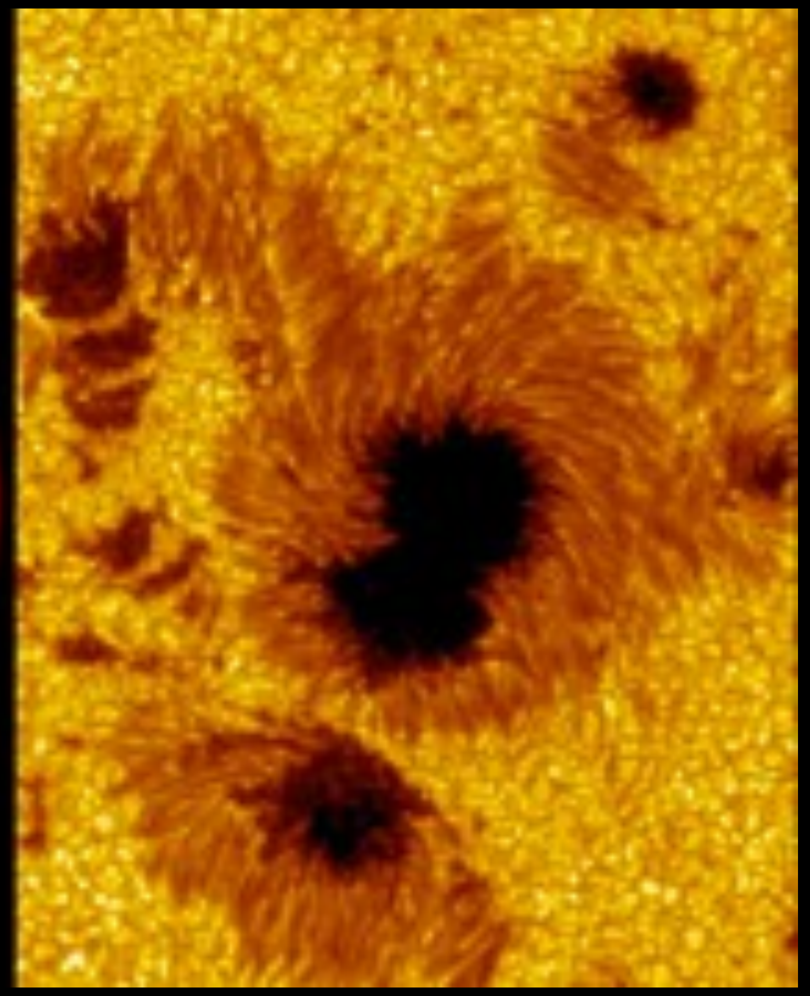
Galileo (1564-1642) - first to use a telescope to increase accuracy of astronomical measurements

Made a series of revolutionary observations:

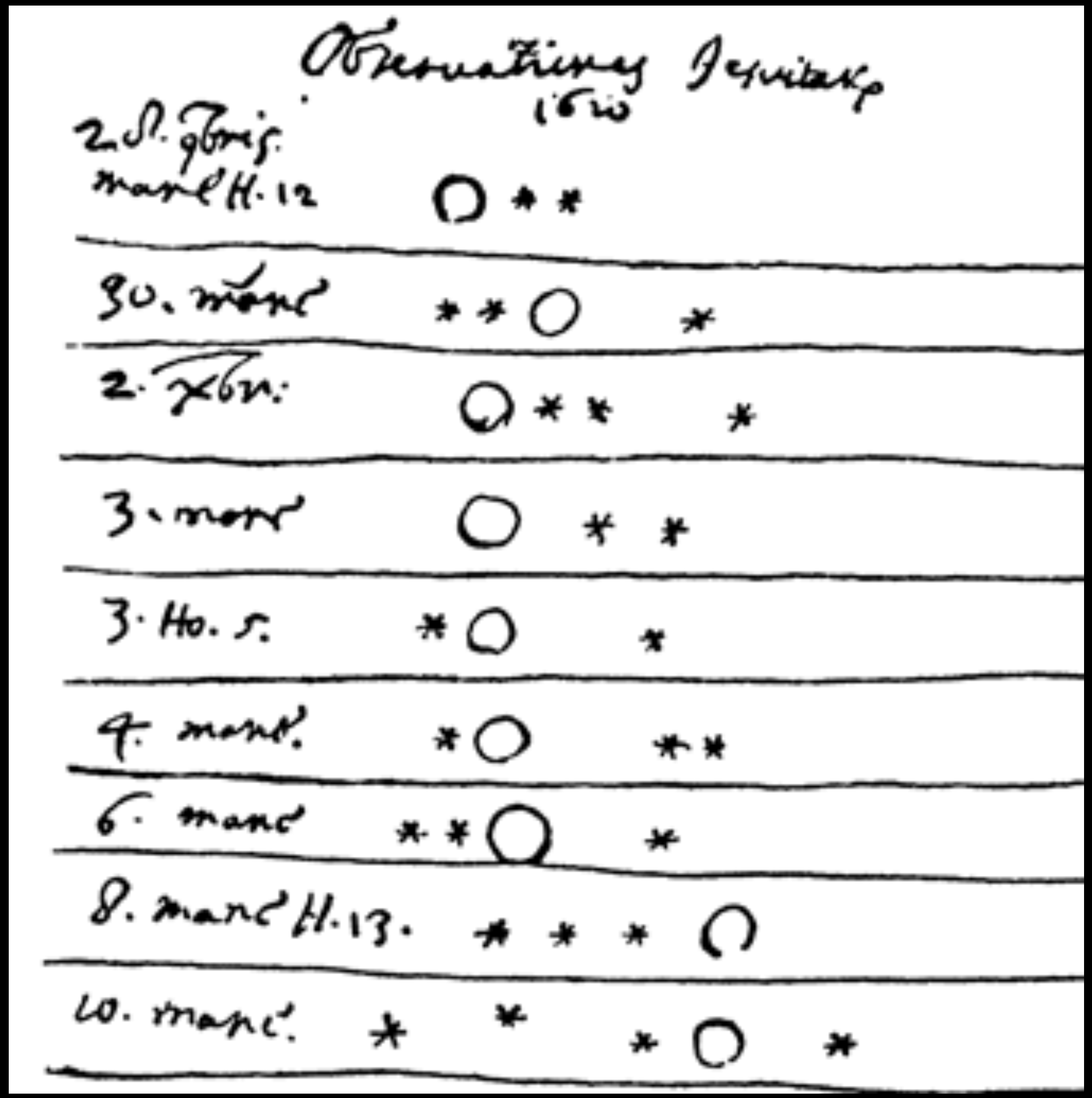
1. Moon had craters

2. Sun had spots (observed using smoked glass)

(Undermined the "perfection" of Aristotle)

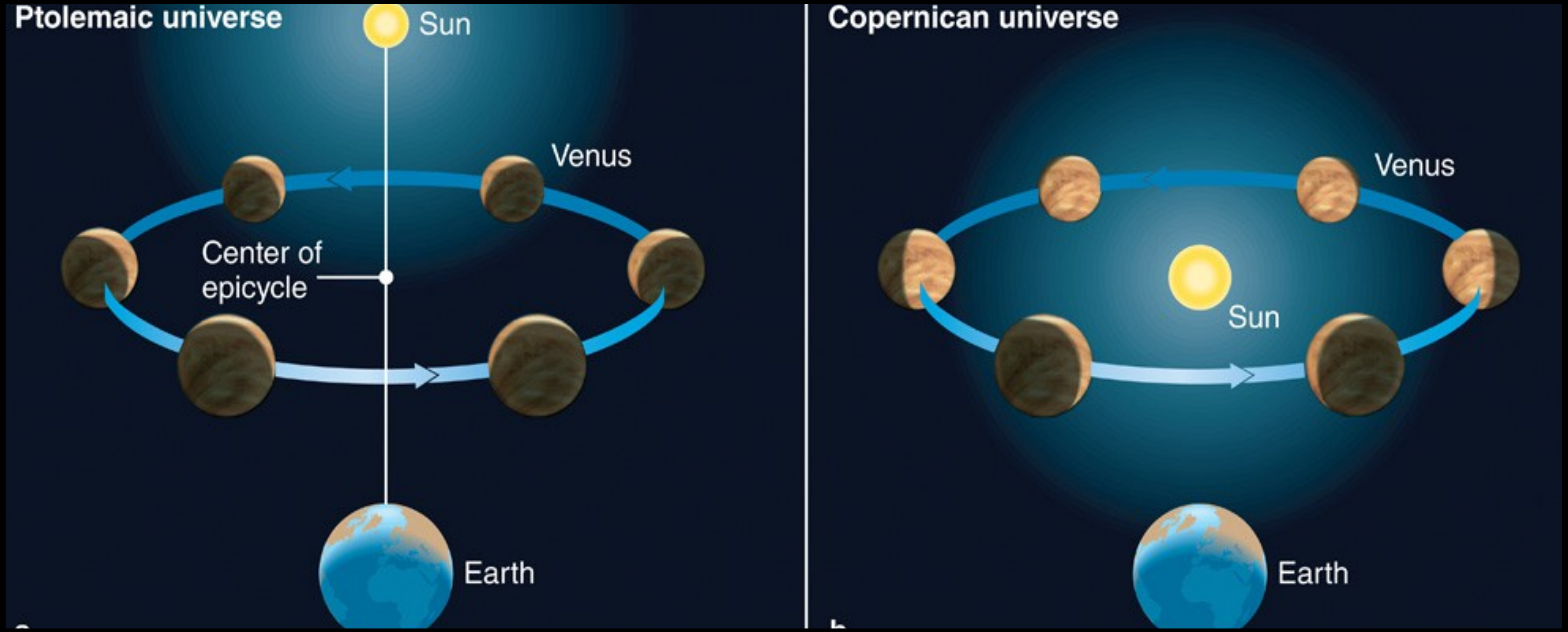


Galileo's Observations



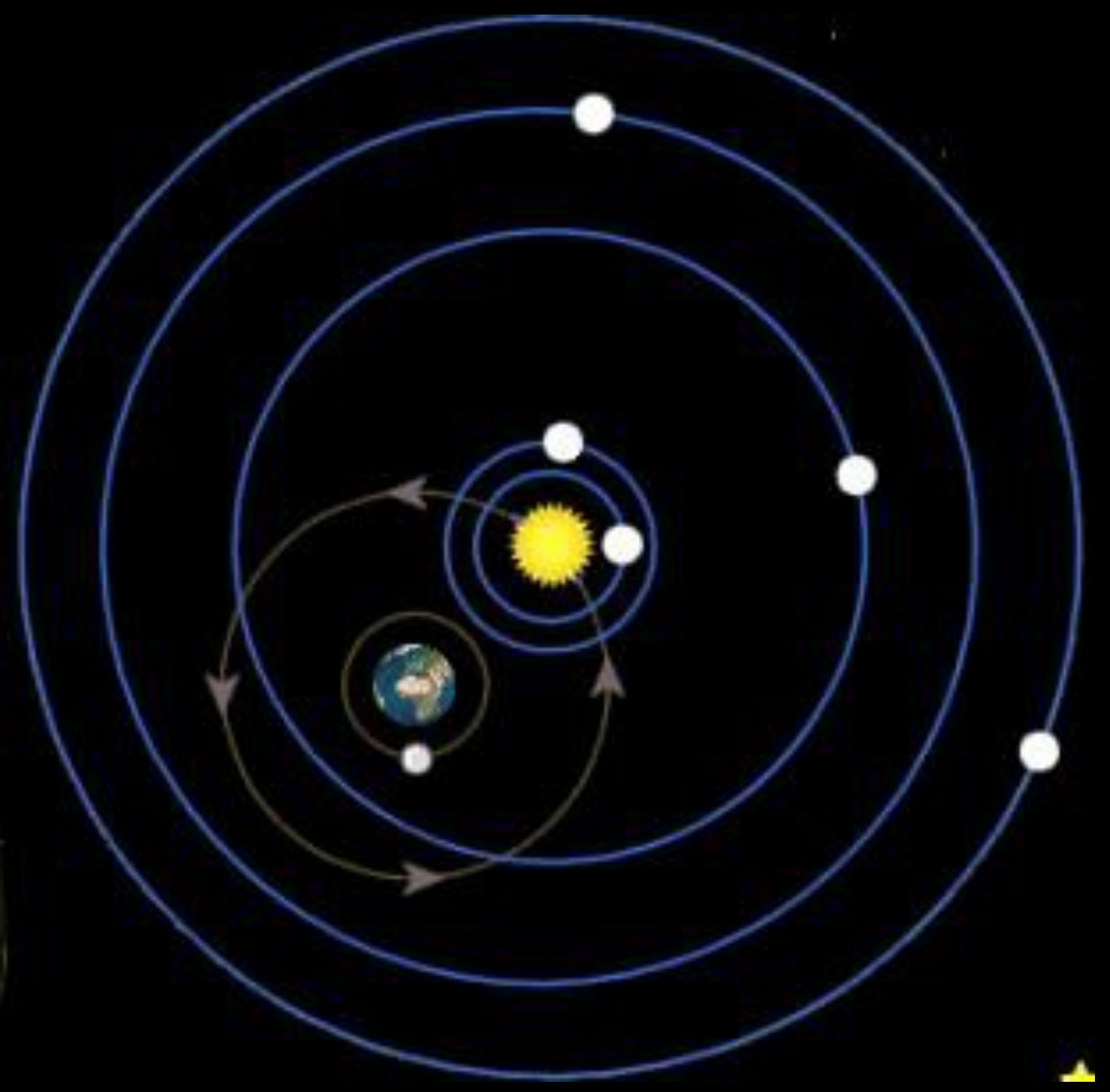
3. There were 4 dots of light that moved back and forth across Jupiter - moons that clearly orbit something OTHER than Earth.

4. Venus's phases do not match a geocentric model



Tycho Brahe (1546-1601)

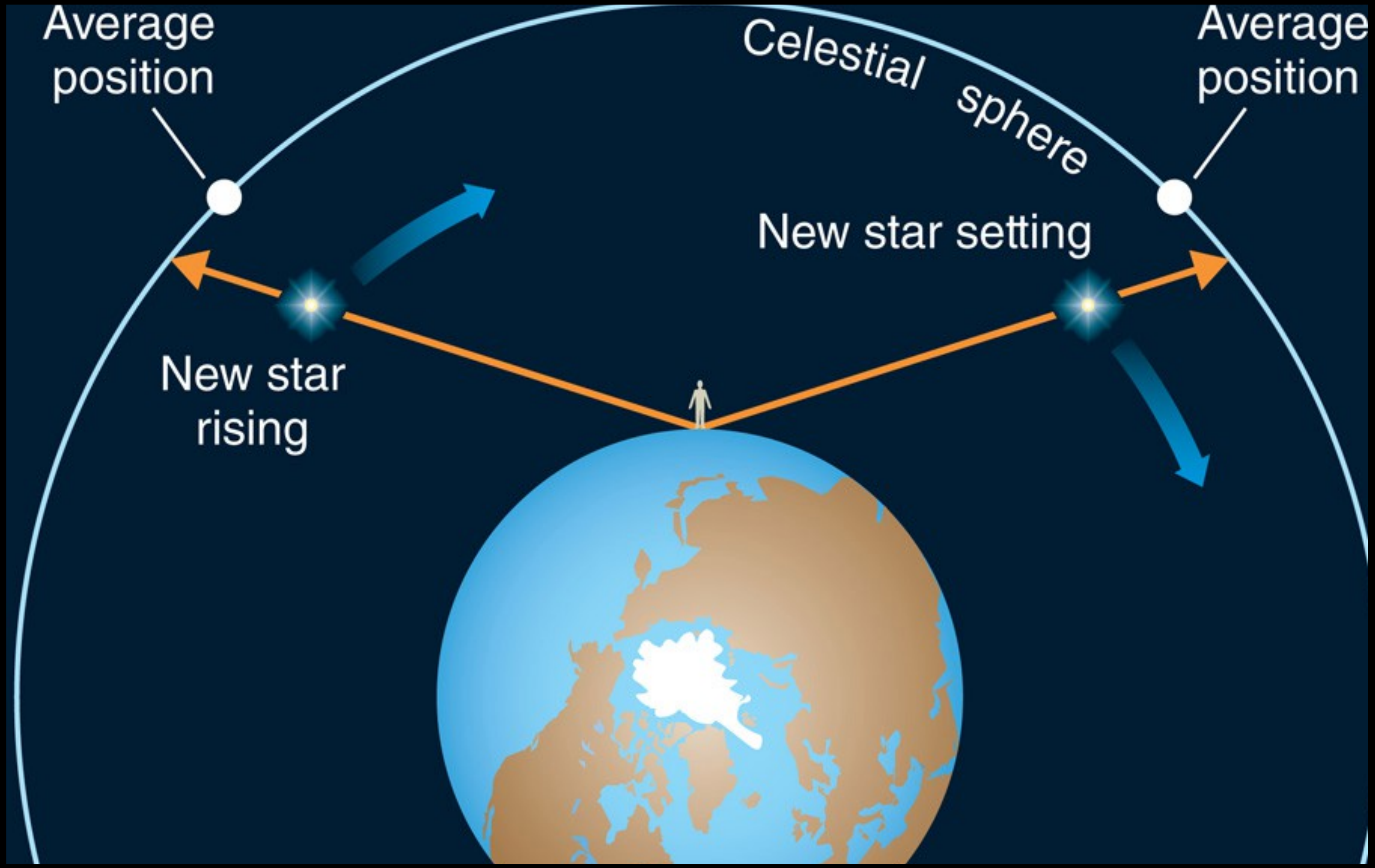
Tried to develop a new geocentric model to replace Ptolemaic model. His model was geocentric, but all other planets orbited the Sun.



Observed a guest star (supernova) that showed no parallax.

Thus, it had to be part of the celestial sphere.

Thus, the celestial sphere was NOT unchanging, as Aristotle said!



Tycho Brahe's Legacy

Built giant equipment to measure angular positions of celestial objects.

Recorded date - time - positions of planets, stars, comets, and a supernova; accurate to 1′ (most accurate to date).

Invited Johannes Kepler to join him in study a year before he died.

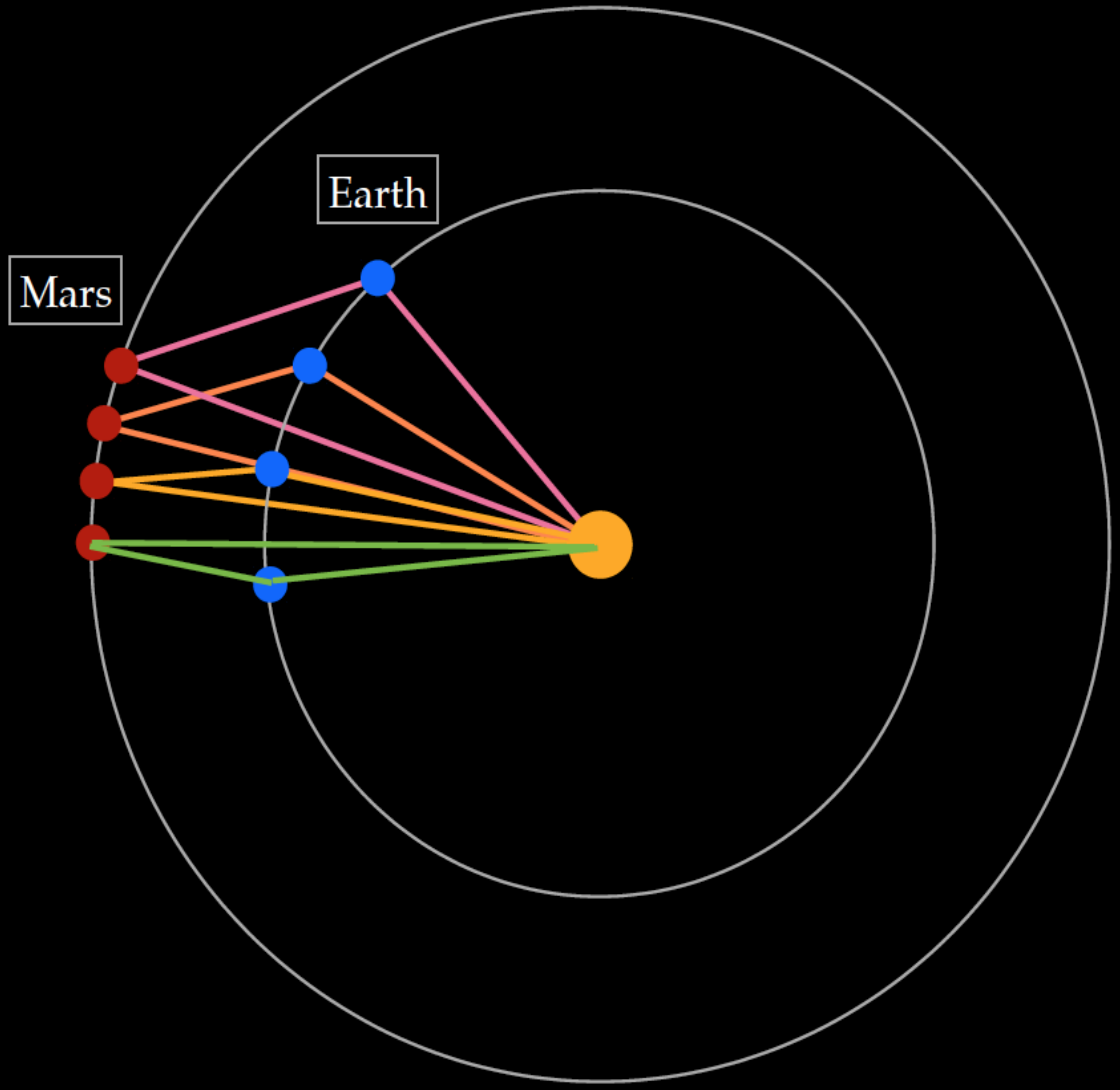
Kepler's Works

Kepler (1572-1630) spent 29 years using triangulation techniques to find patterns among Tycho's data.

Kepler's key technique:

1. All distances referenced as multiples of Earth's orbit.

2. Accounted for the Sun moving about Earth at 360/365º per day (Tycho's model).



Determining the AU

With Kepler's Laws, only one distance needs to be determined in Earth-based units (km, miles, etc) to determine ALL orbital distances in that unit.

Various attempts had been made since the time of Aristarchus.

Shortly after Kepler's death, a parallax measurement was performed as Venus transited the Sun. This was off by 50%.

It wasn't until 1896 that a decent measurement was made.

Descriptive Laws

Kepler's Laws work for the planets in our solar system - they need to be modified to work for our Moon, Jupiter's moons.

Copernicus, Kepler and Galileo ***described*** what they saw, but did not explain why it was like that.

Prescriptive Laws

Why do the planets orbit with those periods?

Why does the Moon orbit as it does?

Recall that planetary orbits can be >150y long! If we found a planet orbiting very distantly from a star, how can we determine the orbital period without having to wait that long?

These questions can be answered with prescriptive laws that explain ***why*** and ***how*** all orbits work, without reference to our solar system.

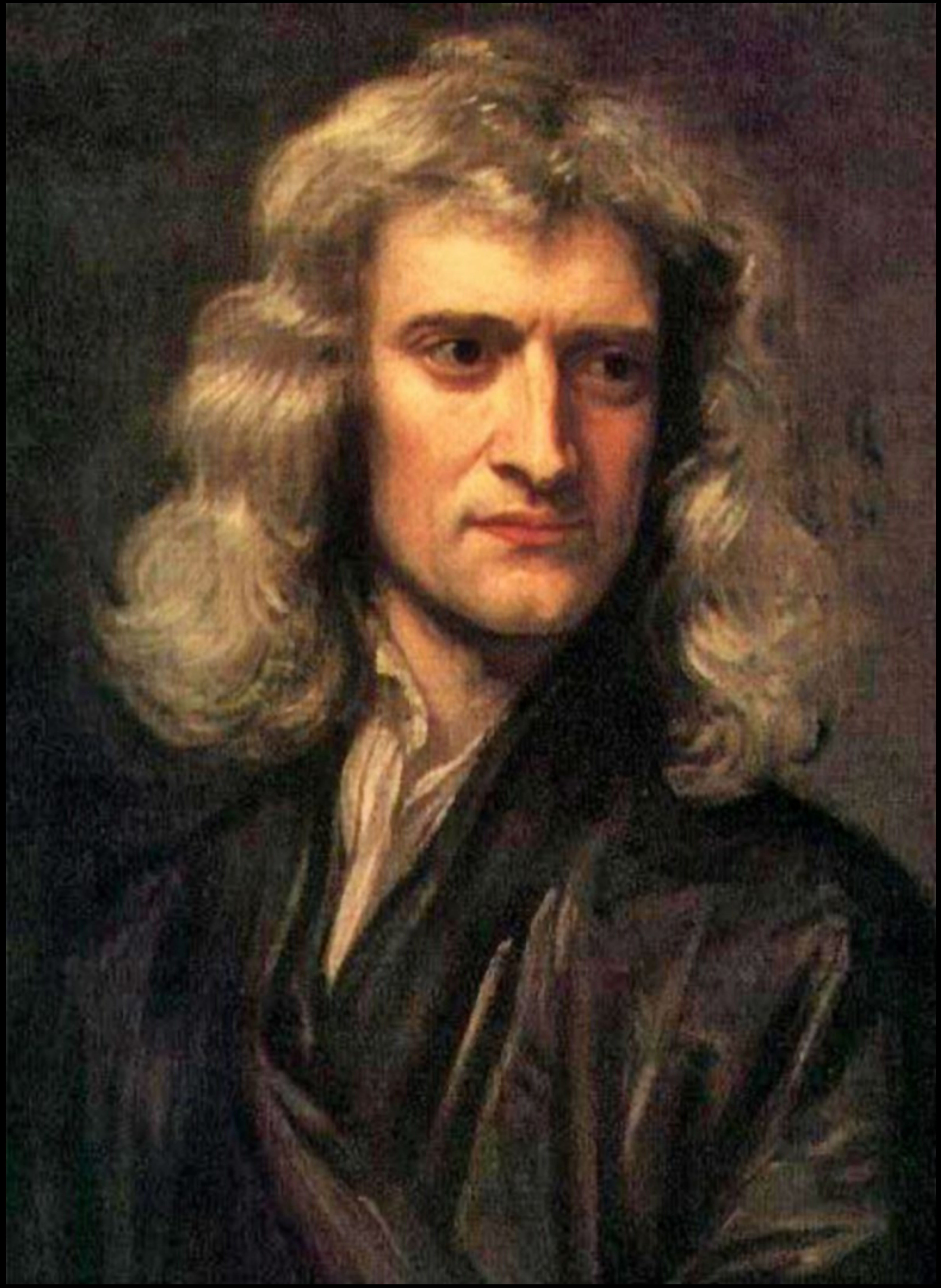
Birth of modern Astronomy

Isaac Newton (1643-1727)

Published *Philosophae Naturalis Principia Mathematica*

Natural science was secondary - searched for philosopher's stone (alchemy) and studied biblical interpretation (apocalypse).

"Newton was not the first of the age of reason, he was the last of the magicians."
- John Maynard Keynes



Next lecture: Astronomy Today