Cosmological Models

I. Planetary Motion
II. Aristotle and Ptolemy
III. Copernicus
IV. Galileo
V. Kepler's Laws
VI. Newton's Laws
VII. Einstein

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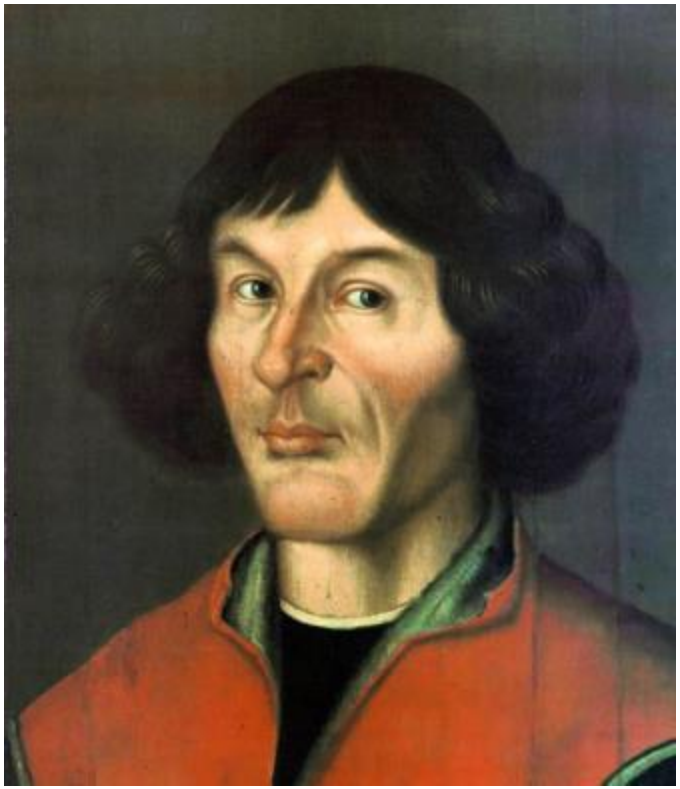


Copernicus
1473 – 1543 AD

Nicolaus Copernicus was the first to develop a complete and detailed heliocentric model of the heavens. He was a Polish cleric, physician, and part-time astronomer.

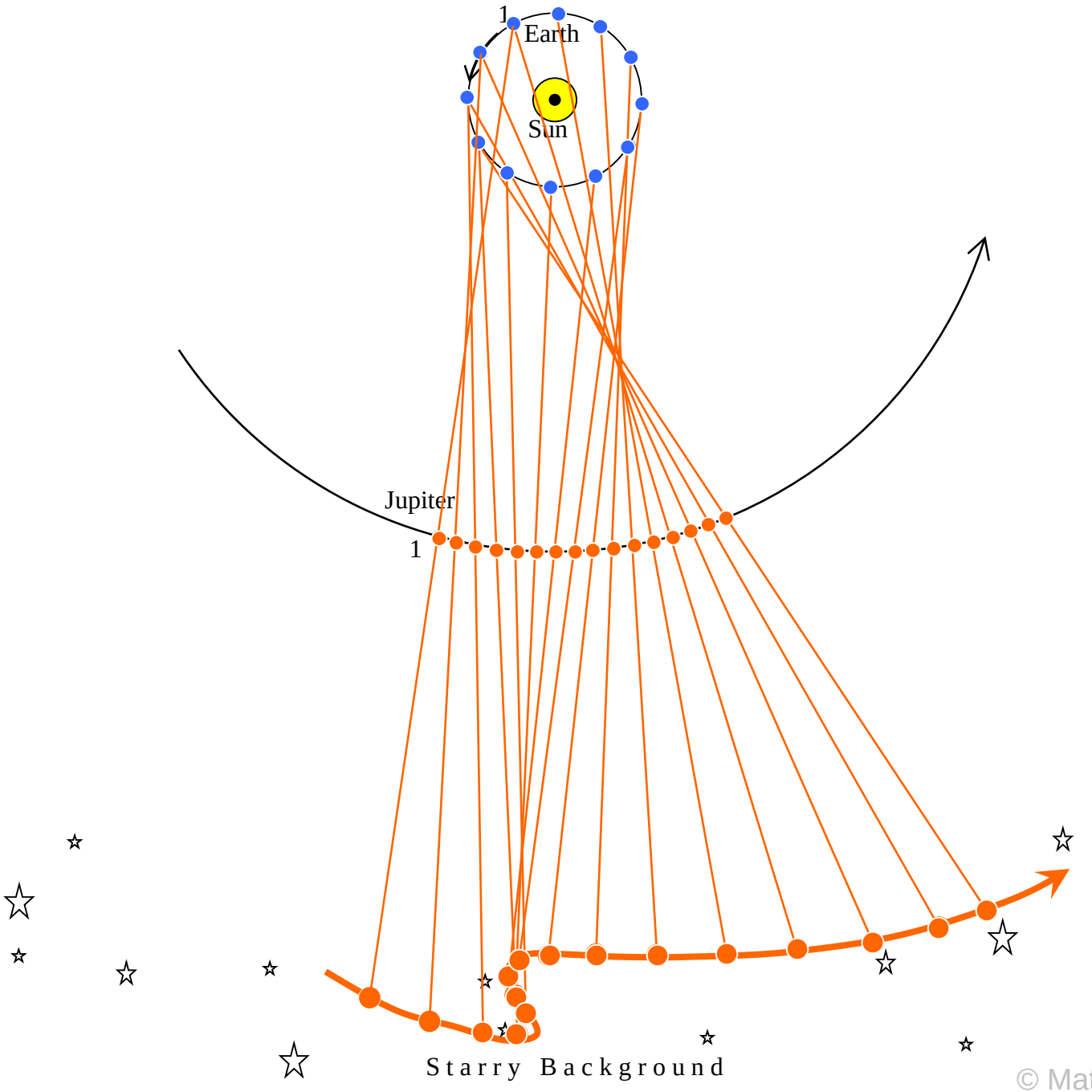
His work, *De Revolutionibus Orbium Celestium* (On the Revolutions of the Celestial Spheres), published in 1543, was a seminal scientific treatise that changed the way we think!

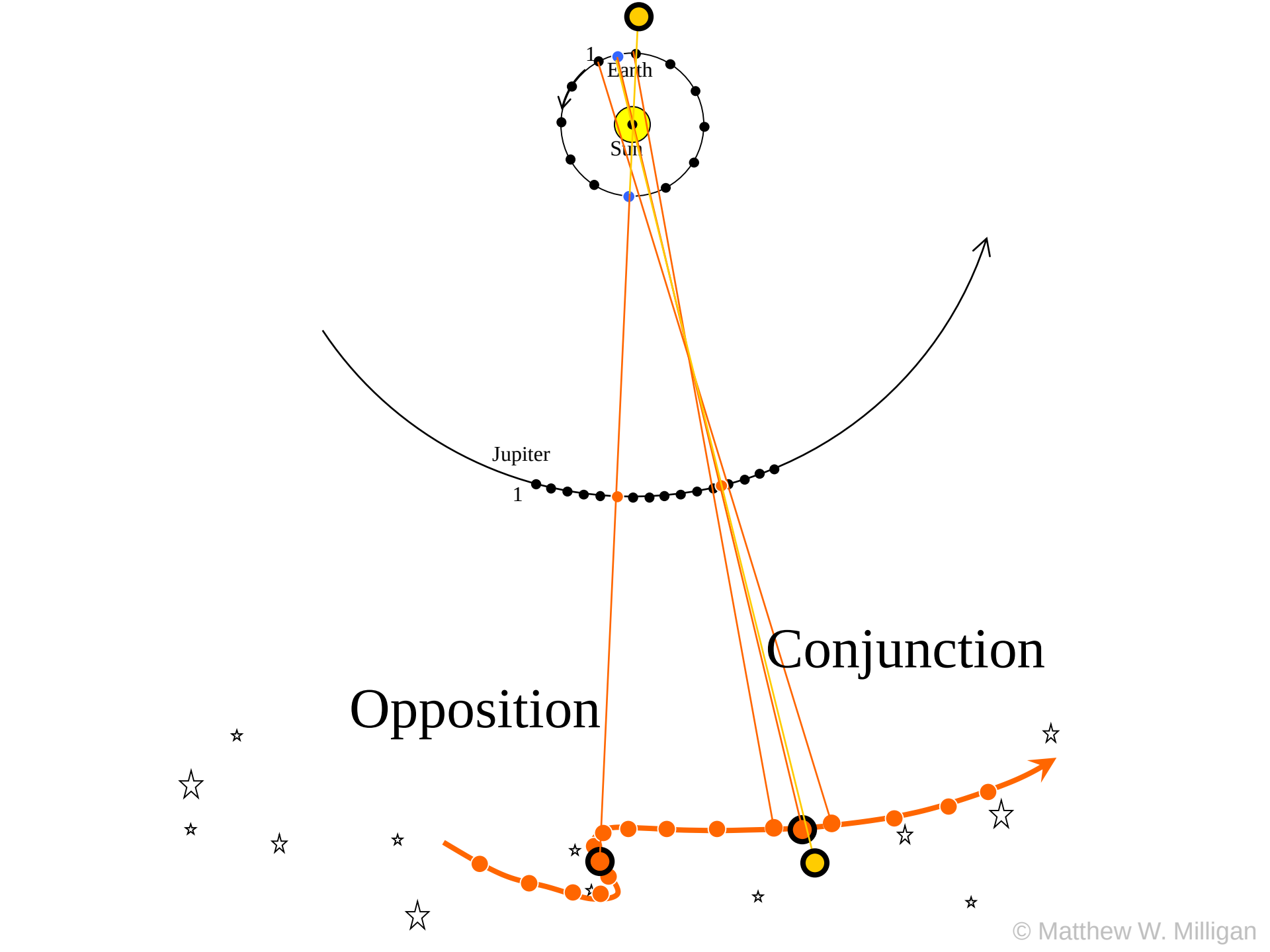
7 Key Ideas of Copernicus

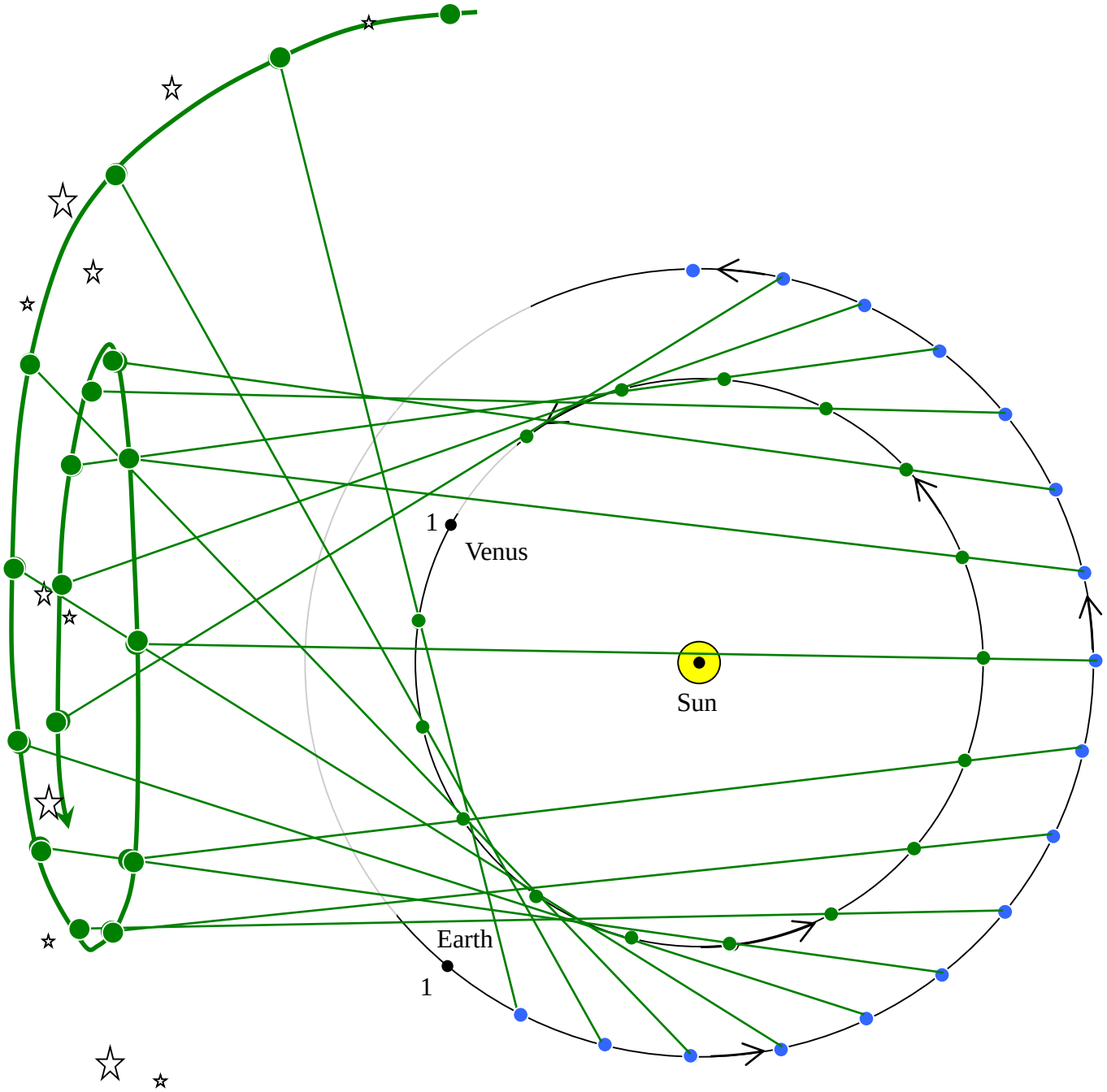
1. There is no one center of the celestial spheres.
2. The Earth is not the center of the universe, but only of gravity and Moon's orbit.
3. All of the planets revolve around the Sun.
4. The distance from Earth to the stars is much greater than the distance from Earth to the Sun.
5. The celestial sphere of stars does not move, rather it *appears* to move due to Earth's rotation on its axis.
6. The Sun does not move, rather it *appears* to move due to Earth's revolution in its orbit about the Sun.
7. The planets do not actually move retrograde, rather it *appears* that way due to Earth's motion.

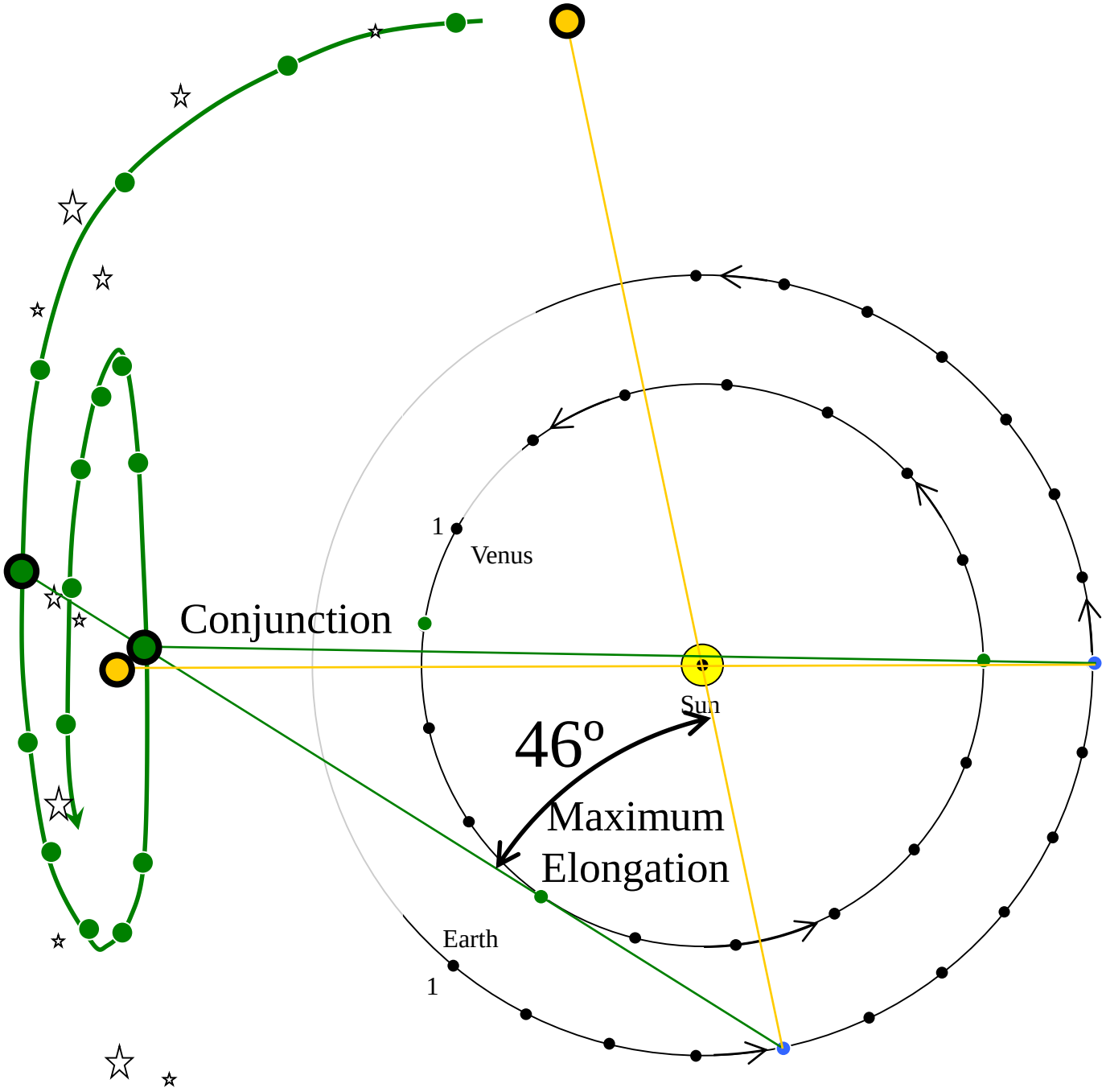
Importance of Copernicus

- Copernicus sought a more natural and logical explanation for the appearance of the heavens.
- He disregarded religious dogma and preconceived notions.
- He humbled and redirected mankind's viewpoint by displacing us from the center of the universe.
- His work signaled the beginning of the Scientific Revolution.





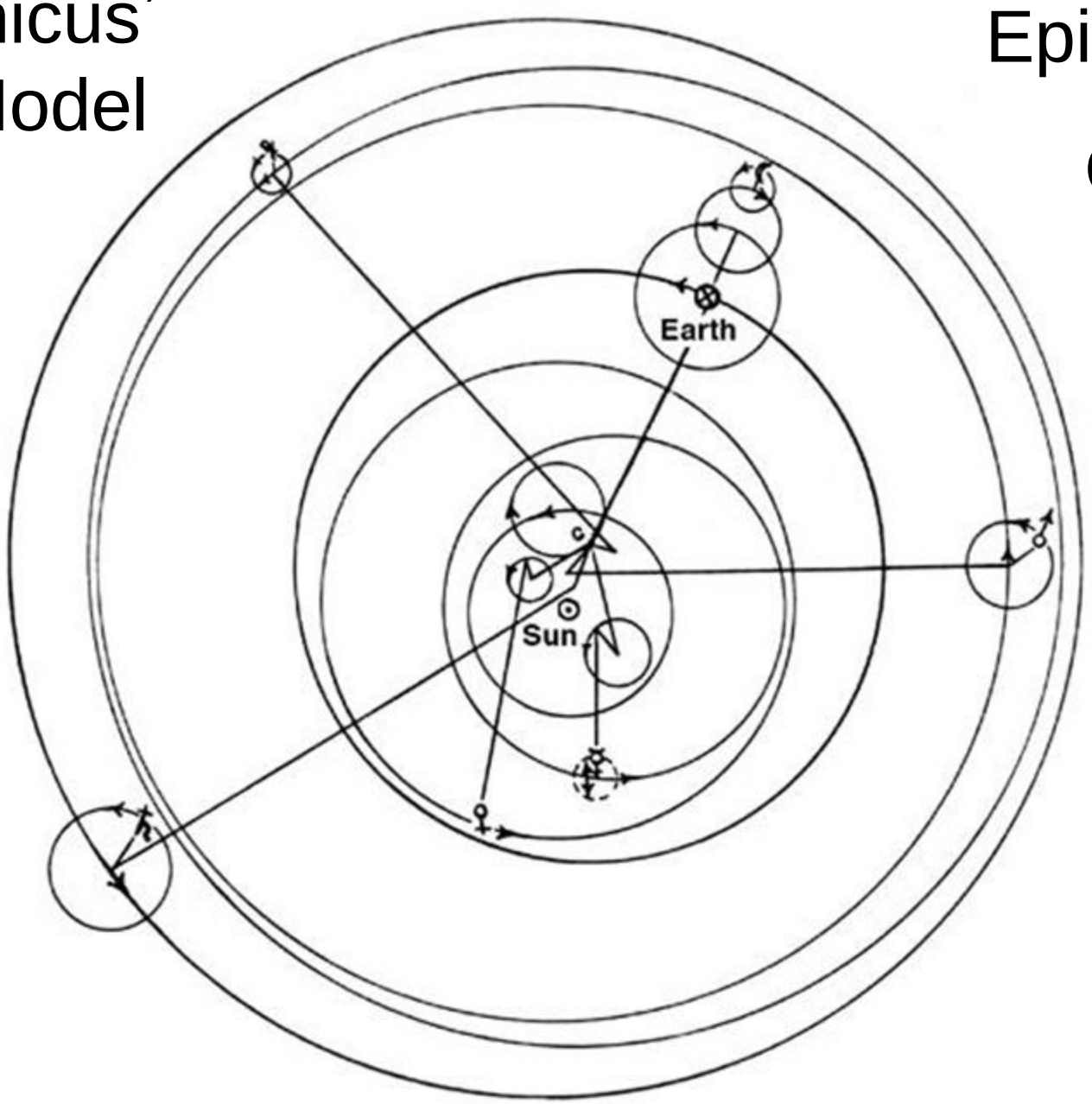




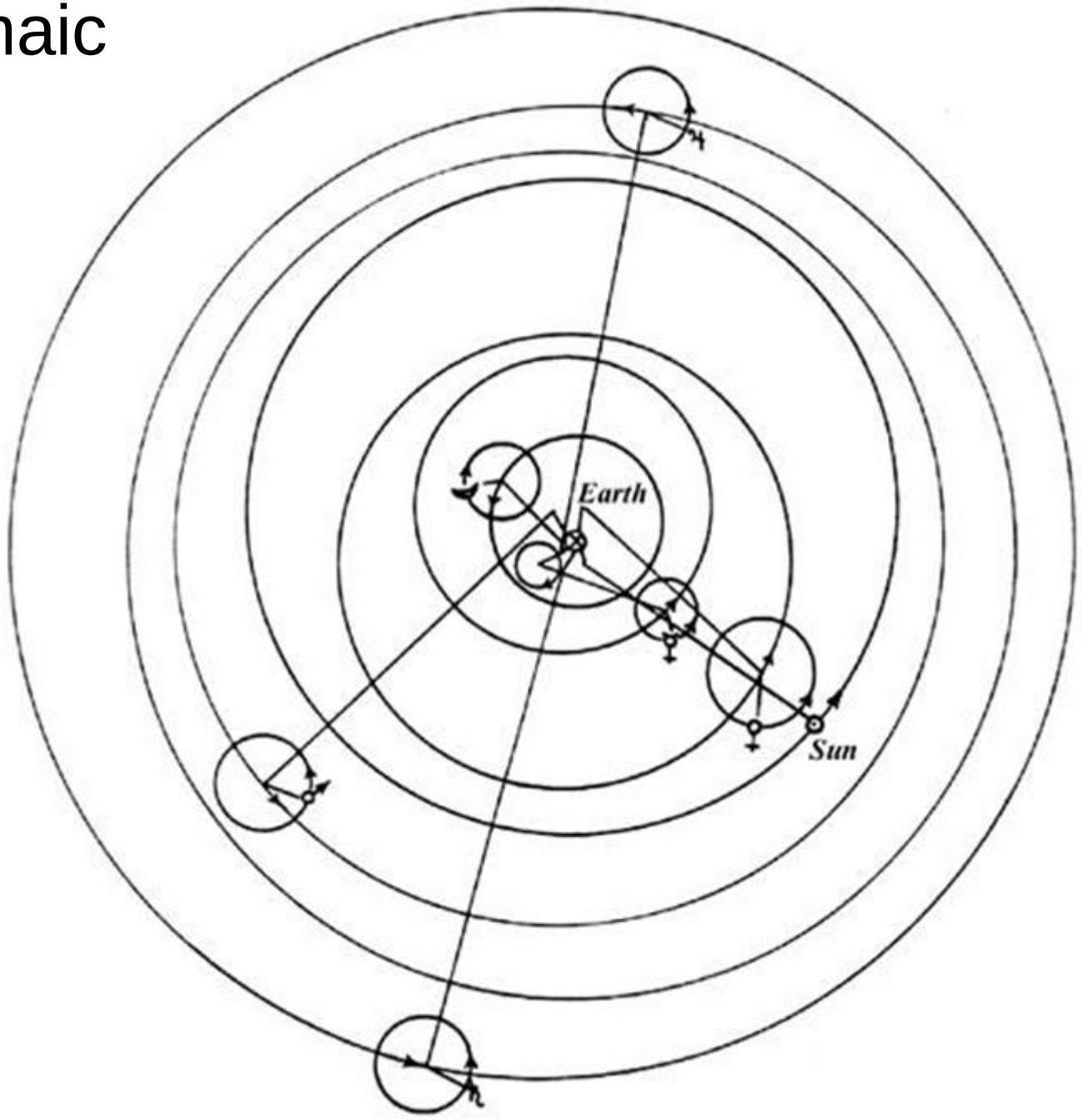
Copernicus' Final Model

Epicycles!

Oh No!



Ptolemaic Model



Sadly, Copernicus found it necessary to retain the idea of epicycles in order to create a model capable of giving the apparent positions of Moon, Sun, and planets with as much accuracy as the Ptolemy's model, the *Almagest*.

~ sigh ~

Old habits die hard…

However, it should be stressed that Copernicus did not use epicycles as a means to explain retrograde motion.

Did Copernicus *prove* that Earth is not a stationary object at the center of the universe?

No, he did not! Nevertheless, he came up with a logical and reasonable explanation that allowed for Earth to *not* be at the center – and of course, in the end, we know that he was correct on many of his ideas.

The Copernican Principle

- In spite of resorting to epicycles in his model, Copernicus is still credited with getting the important parts right, especially the notion that Earth is not the center of the universe.
- In fact, the notion that the Earth does not hold *any* special place in the Universe is called the “Copernican Principle”.
- The Copernican Principle is found in many aspects of science…

The Copernican Principle

- As applied to Earth – it is just a somewhat average planet among the other planets – "the 3rd rock from the Sun".
- How would the Copernican Principle apply to the Sun?
- In the 1920's Edwin Hubble discovered that there is more to the universe than just the Milky Way Galaxy (in which we live). What did he find?

The Copernican Principle

- In the 1920's Edwin Hubble discovered that galaxies are moving away from us in all directions. This would seem to indicate we are at the center of an expanding universe. What would the Copernican Principle tell us about this observation?

The Copernican Principle

- Are we alone in the universe?

- Apply the Copernican Principle to this question and discuss with a classmate.

The Copernican Principle

- By the Copernican Principle it was expected that there were other planets orbiting other stars. But only since 1995 astronomers have been able to actually detect these planets that orbit other stars. These are now called exoplanets.
- Astronomers expect to find “another Earth” orbiting “another Sun”. And it stands to reason life may be present on such a world.

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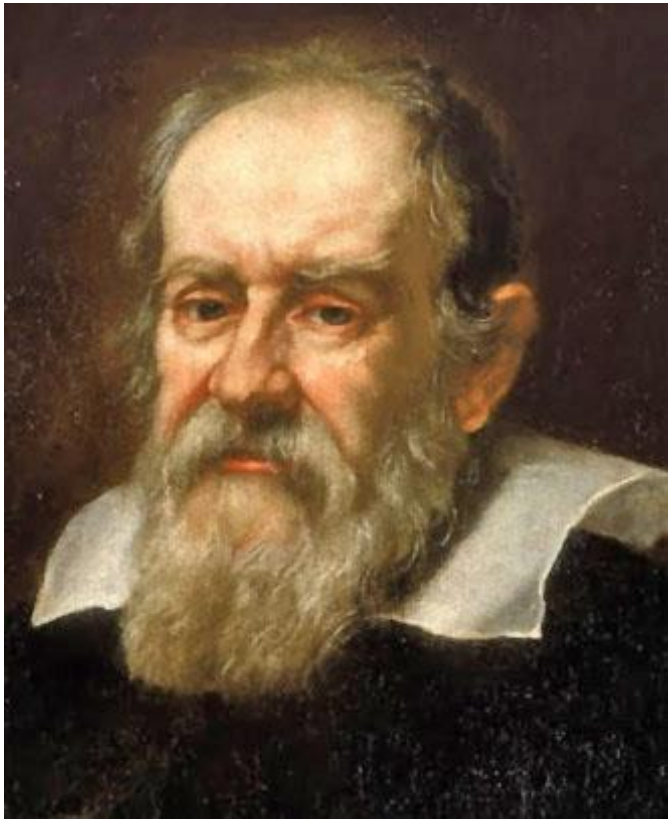
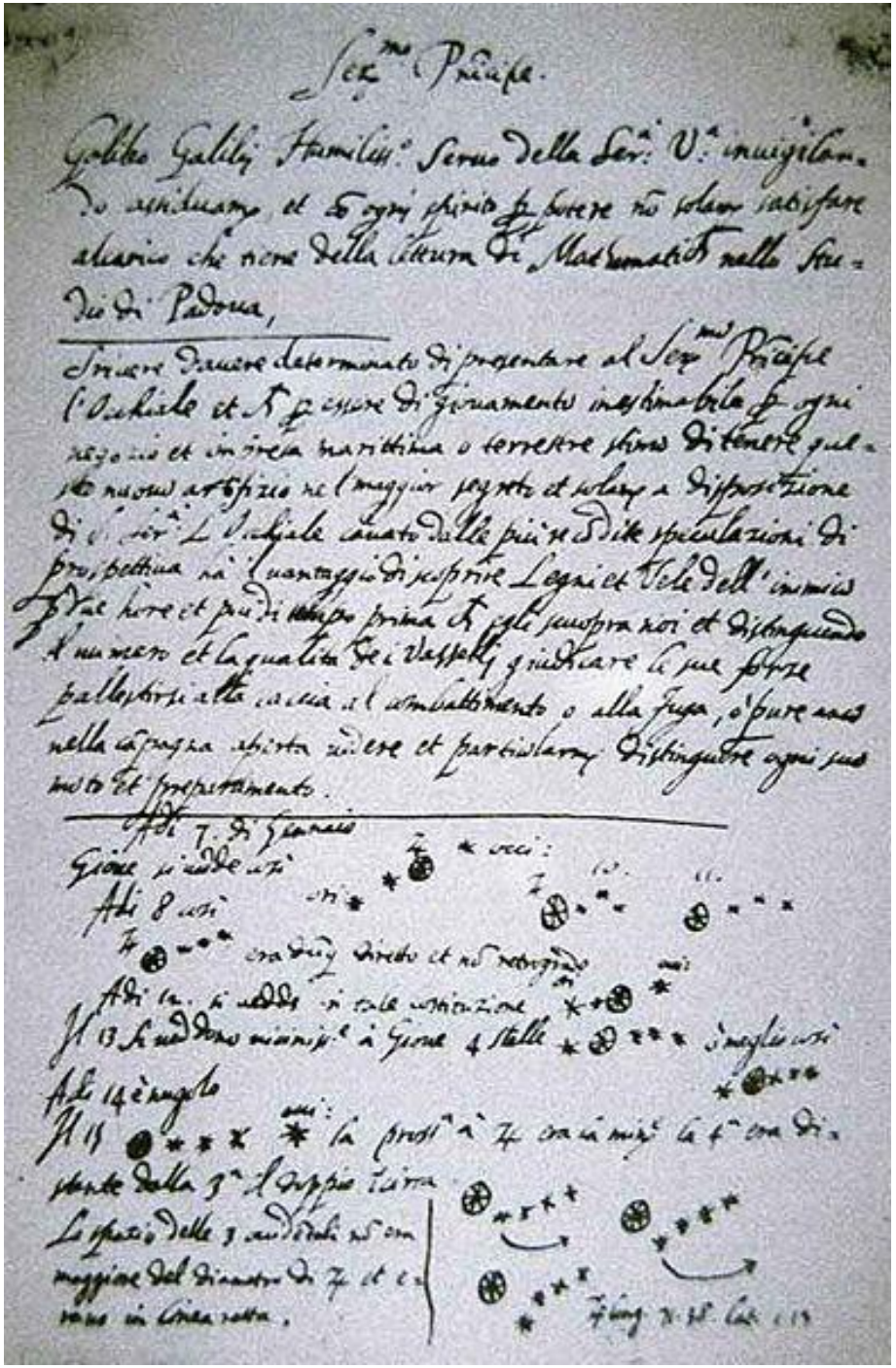


Galileo
1564 – 1642 AD

Galileo Galilei is regarded as the “Father of Modern Science” and pioneered ways of thinking and experimenting in physics and astronomy.

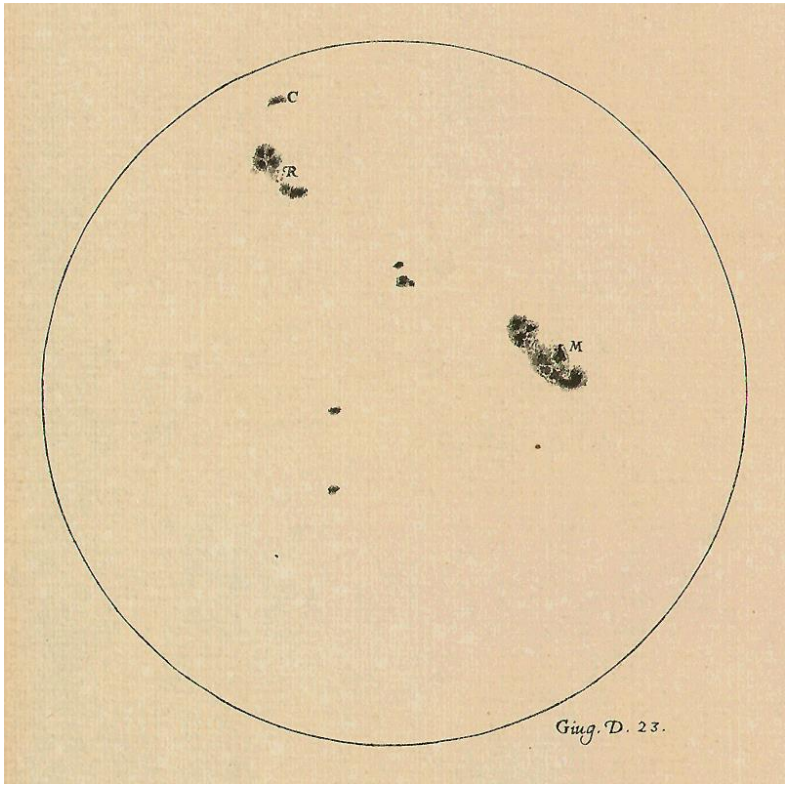
Although he did not invent the telescope, he made his own in 1609. He was the first to use a telescope to systematically observe celestial bodies such as the Moon, the planets, the stars, and the Sun.



This is a page from Galileo's observation journal.

Galileo pioneered the concept of developing theory based on careful observation and collection of data.
i.e. He established the "scientific method".

What did Galileo observe with the telescope?



He saw that the Sun had “dark blemishes” (now called sunspots).

Based on these surface features he could tell that the Sun rotates.

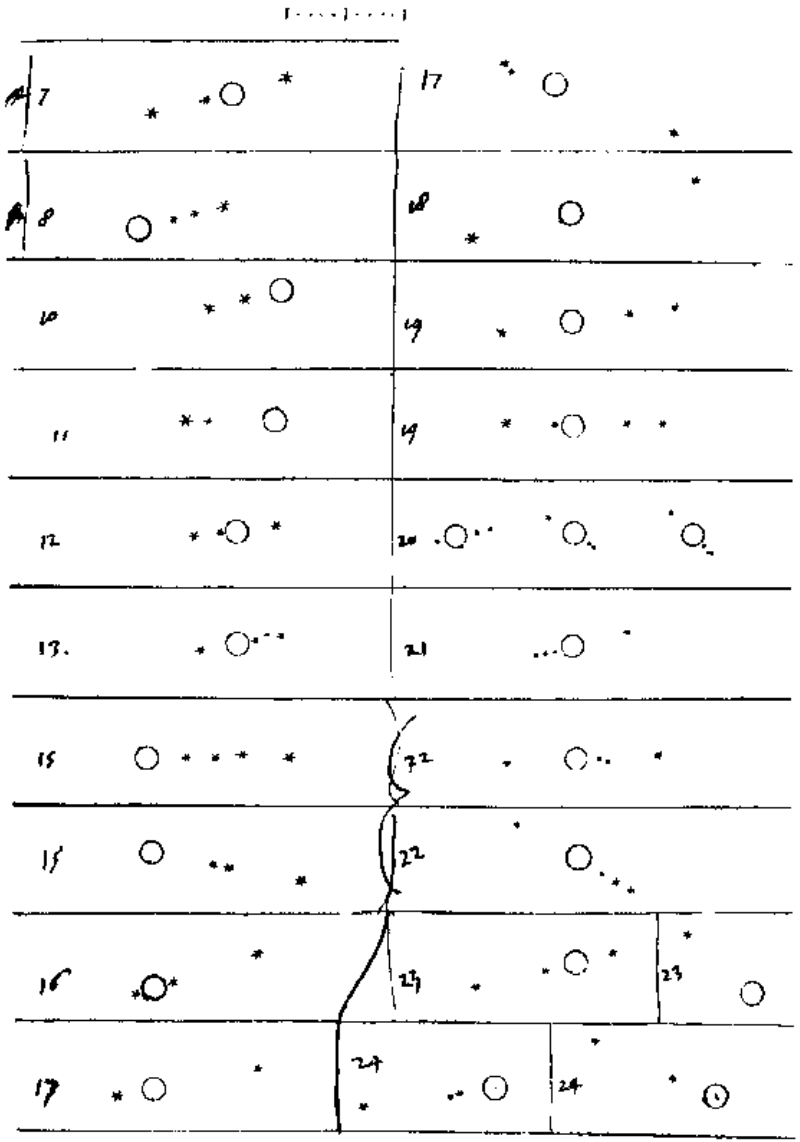
the Sun

What did Galileo observe with the telescope?

He saw that Moon has features similar to those on Earth: craters, mountains, valleys, and smooth “seas”.

(The “seas” were eventually found <u>not</u> to be bodies of water).

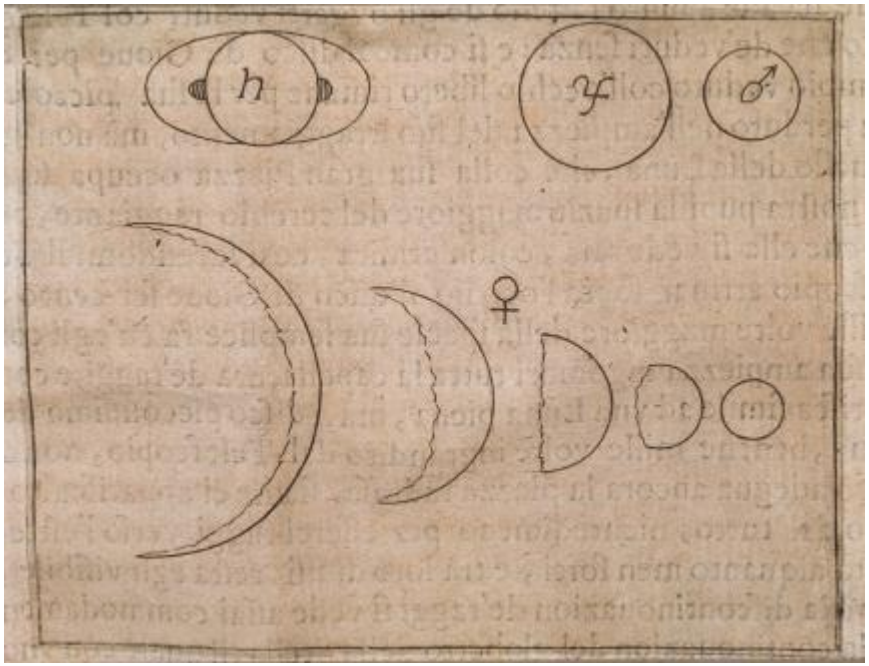
What did Galileo observe with the telescope?



He saw that Jupiter was accompanied by four bright objects that moved about it.

He determined that these were moons orbiting Jupiter. (These moons are now referred to as the Galilean Moons.)

What did Galileo observe with the telescope?



He saw that the planet Venus exhibited phases like the Moon. These phases included crescent, “quarter”, gibbous. At some points it appeared nearly “full”.

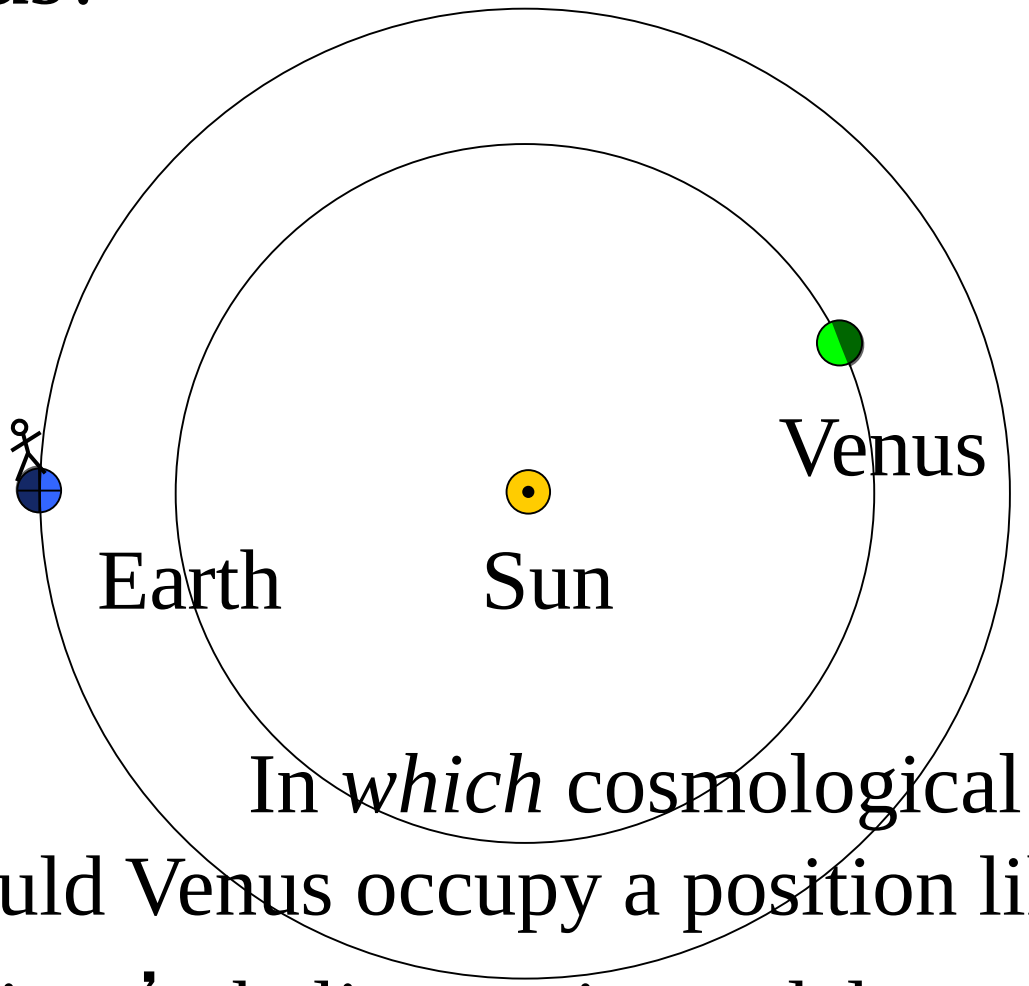
Galileo's Writings

- 1610 – Sidereus Nuncius (Starry Messenger) – in which he detailed telescopic observations
- 1613 – The Letters on Sunspots – suggested the heavens were "corruptable"
- 1632 – Dialogo Dei Due Massimi Sistemi (Dialogue Concerning the Two Chief World Systems) – in which he championed the Copernican viewpoint (For this he was tried by the Inquisition and punished. In 1992 the church "forgave" him.)

How did Galileo’s observations support the heliocentric model of Copernicus and cast doubt on the geocentric ideas of Aristotle and Ptolemy?

And is there a “smoking gun”?

Where would Venus have to be located in order to appear ***gibbous***?

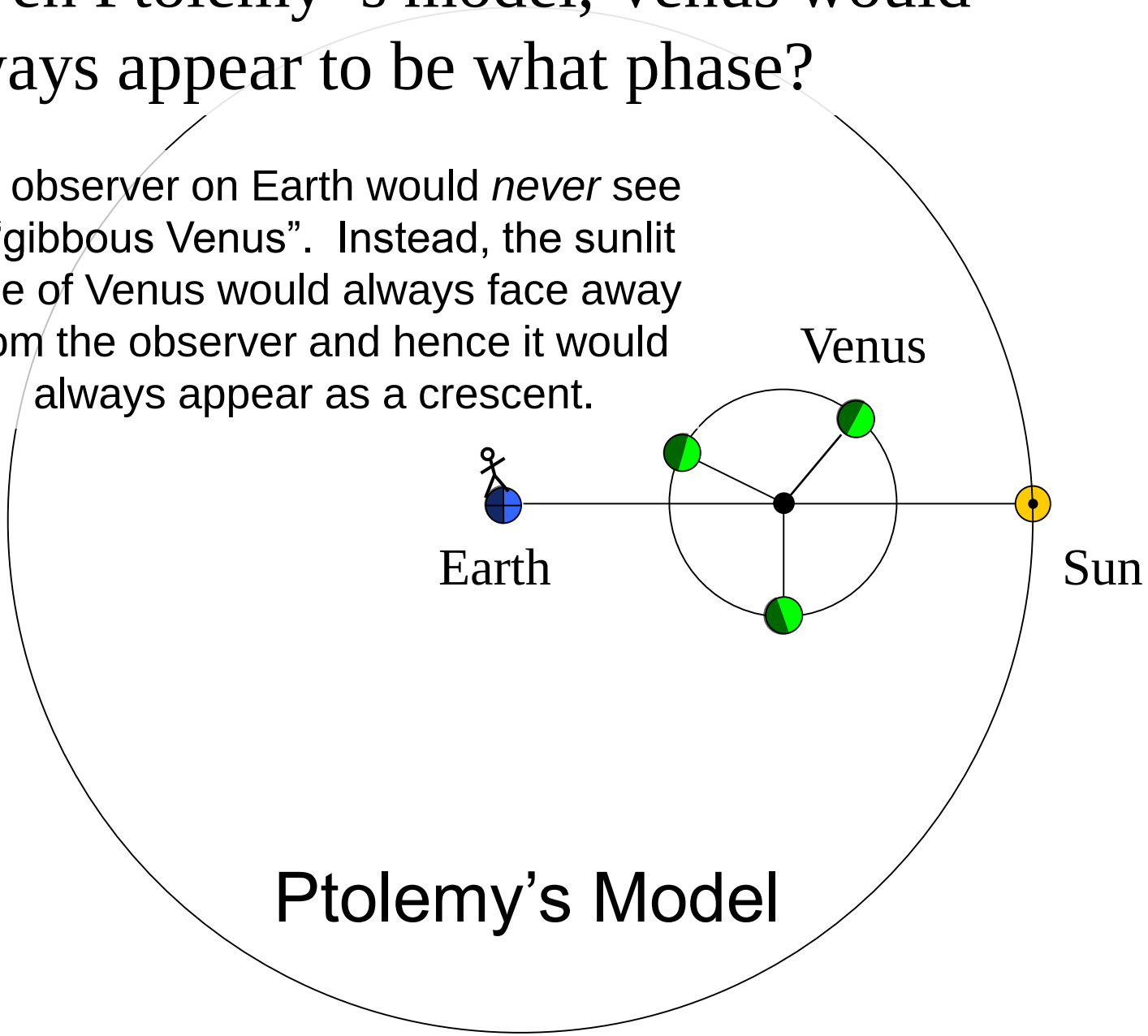


In *which* cosmological models would Venus occupy a position like this?

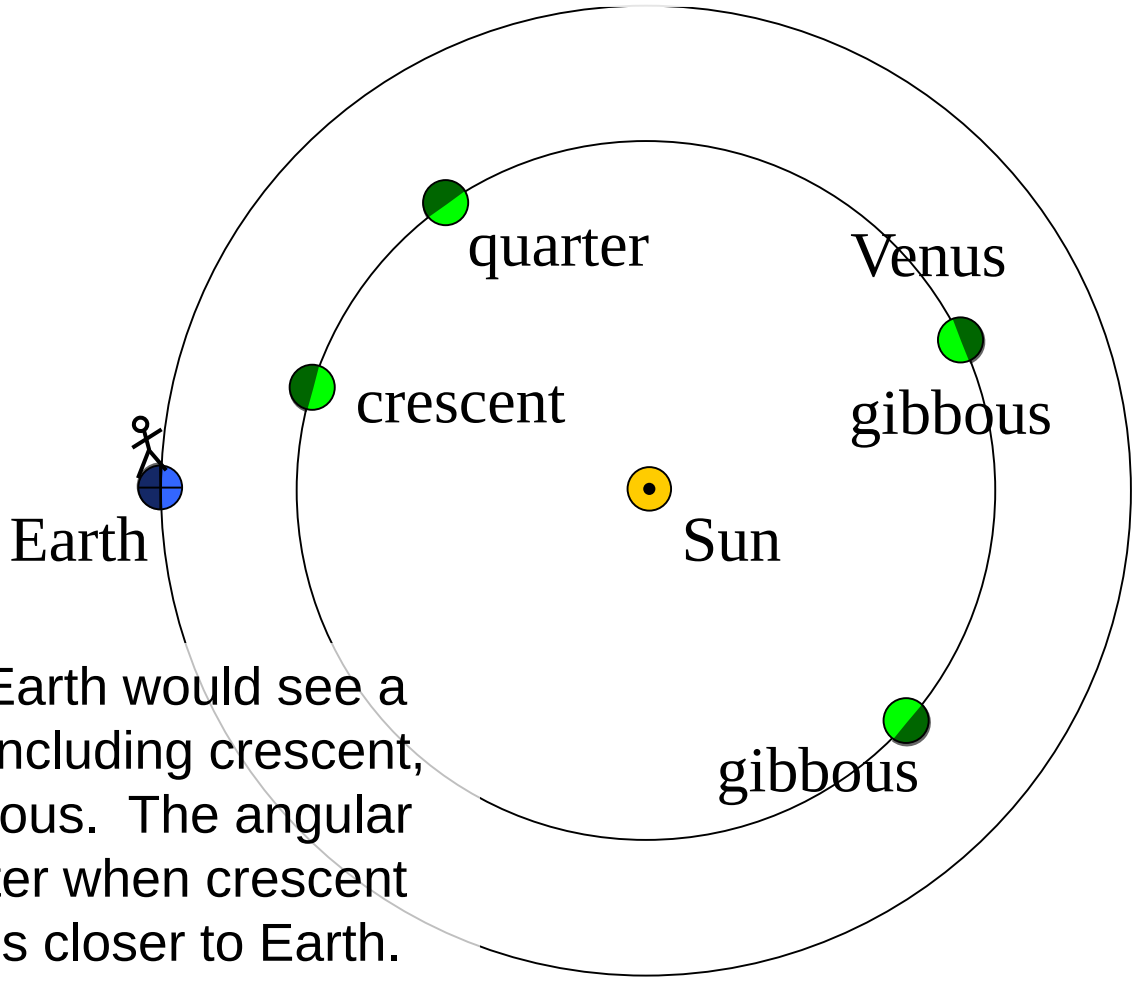
Only in Copernicus's heliocentric model would this happen – *NOT* in Ptolemy's geocentric model.

Given Ptolemy's model, Venus would always appear to be what phase?

An observer on Earth would *never* see a "gibbous Venus". Instead, the sunlit side of Venus would always face away from the observer and hence it would always appear as a crescent.



Given Copernicus's model, Venus would appear with what variety of phases?



An observer on Earth would see a range of phases including crescent, quarter, and gibbous. The angular diameter is greater when crescent because Venus is closer to Earth.

Copernicus's Model

The gibbous and nearly full phases of Venus showed that Ptolemy's geocentric model could not be correct! This was the "smoking gun" – solid evidence that Ptolemy's Almagest could not possibly be correct.

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Tycho Brahe
1546 – 1601 AD

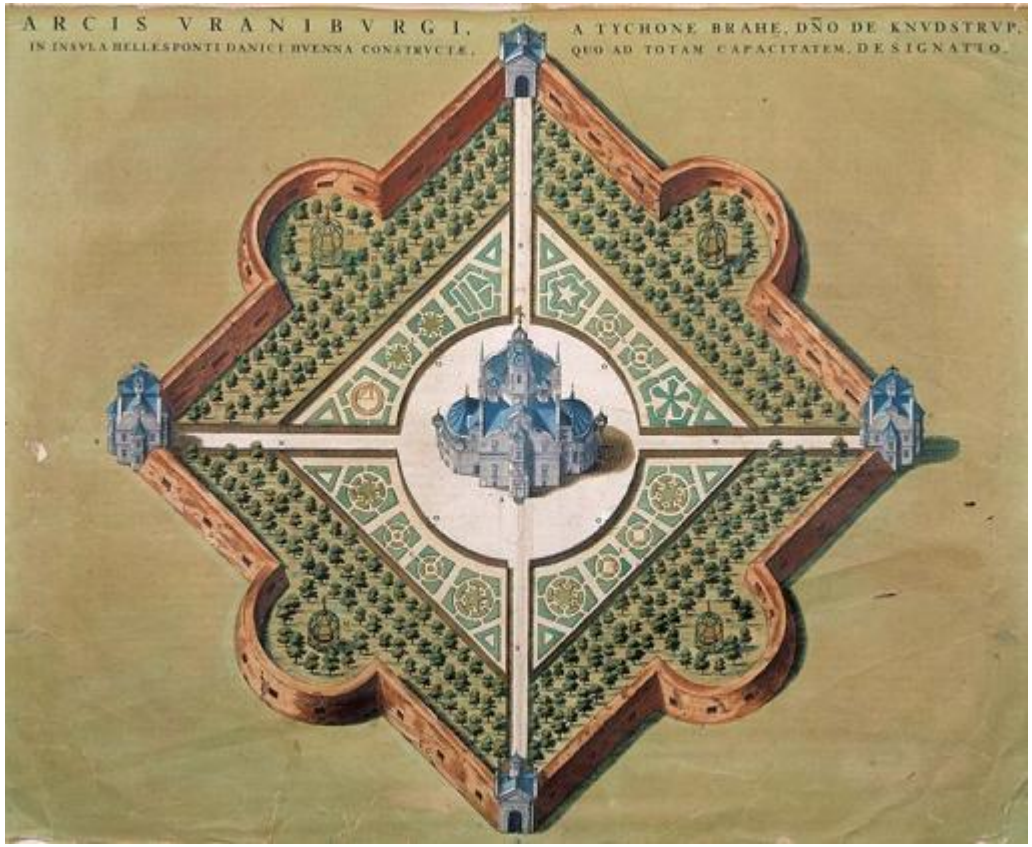
Tycho Brahe was a Danish astronomer. King Frederick II gave him an island and funding to build an observatory, Uraniborg.

Tycho made extremely careful measurements of stellar and planetary positions, accurate to 1 arc minute.

He also developed his own unique geocentric model.

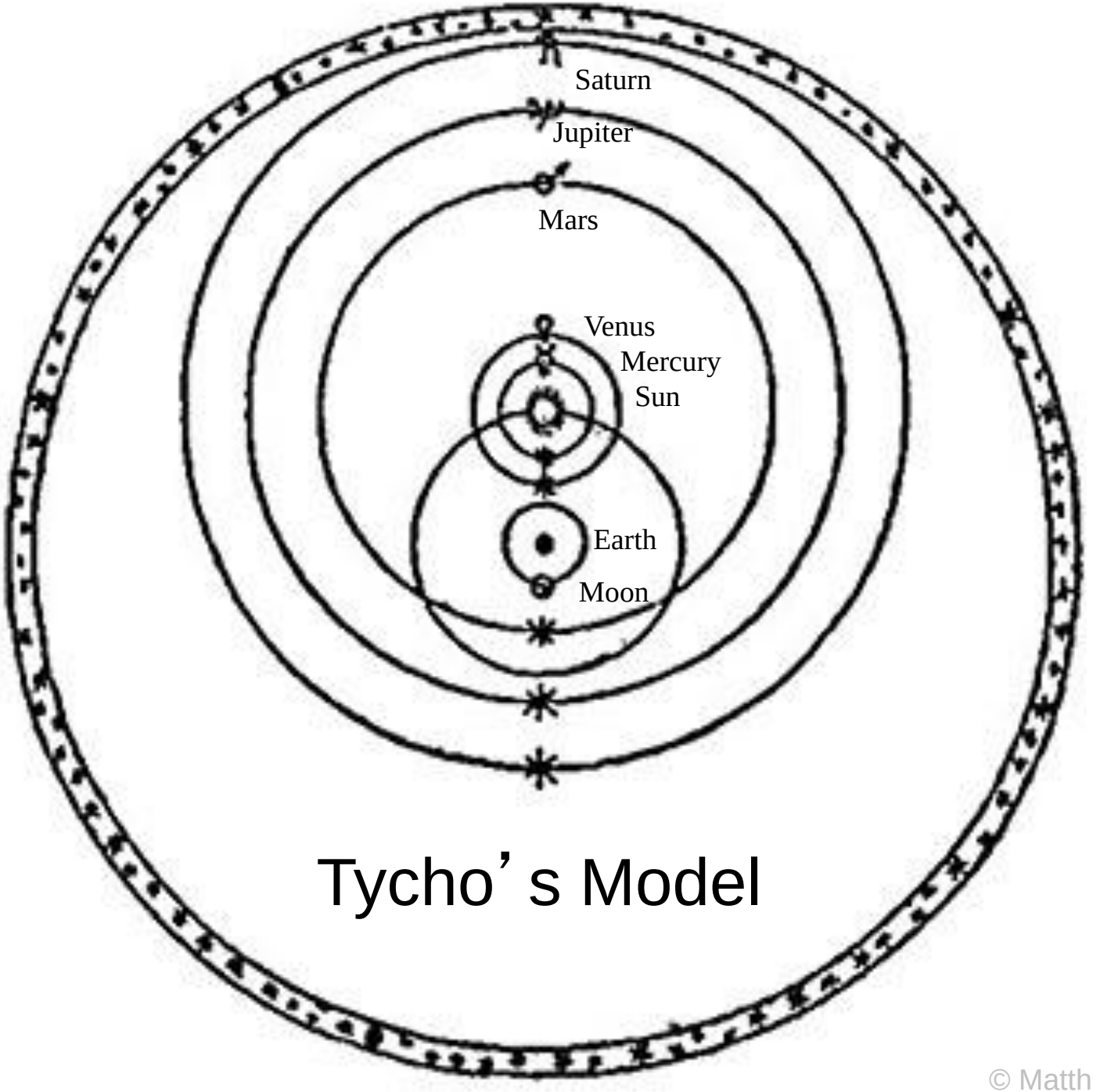
Tycho Brahe
1546 – 1601 AD

Observations of Comet of 1577 – it lacked apparent parallax, whereas the Moon had discernable parallax based on simultaneous observations from Uraniborg near Copenhagen and Prague (by Thadaeus Hagecius).



Uraniborg

Tycho's quadrant:



Tycho's Model

Tycho Brahe
1546 – 1601 AD

Tycho Brahe's ideas:

Earth does not move, and it is at the center of the orbits of the Moon, Sun, and stars.

The moving Sun is the center of the planets orbits.

In *his* geocentric model, Venus *would* have a gibbous phase! The world would have to wait for "rock solid proof" that Earth orbits the Sun…