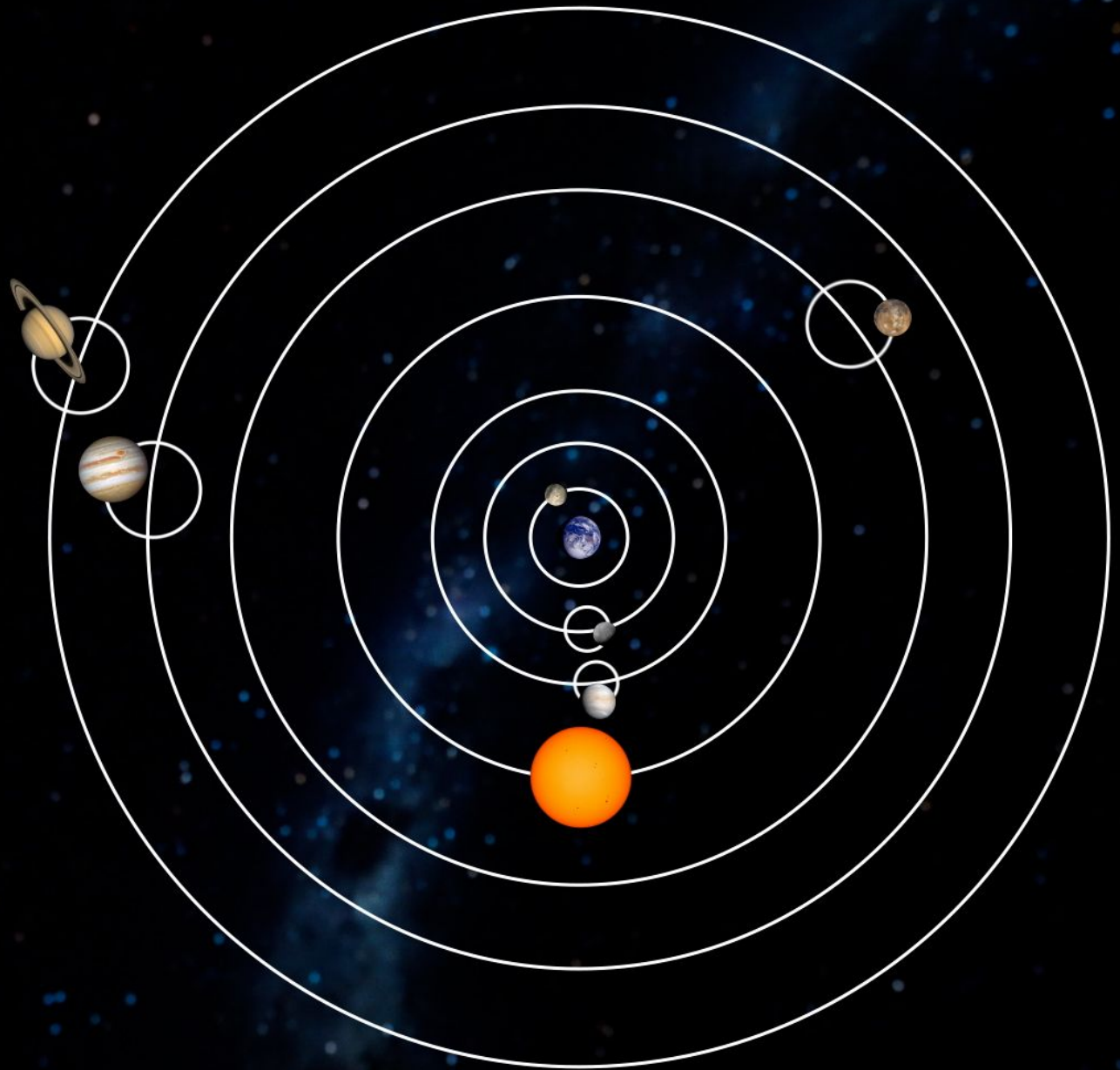


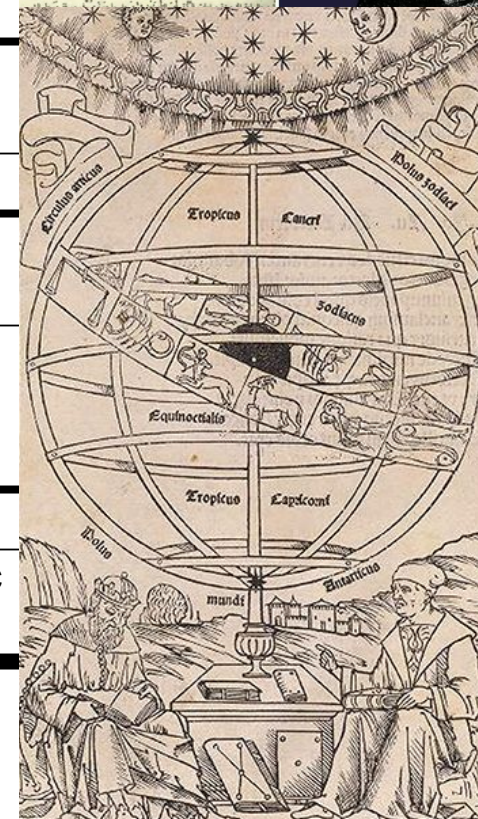
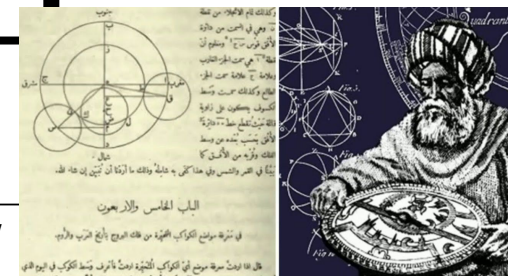
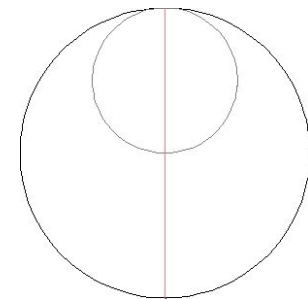
Ptolemy of Alexandria



150 CE

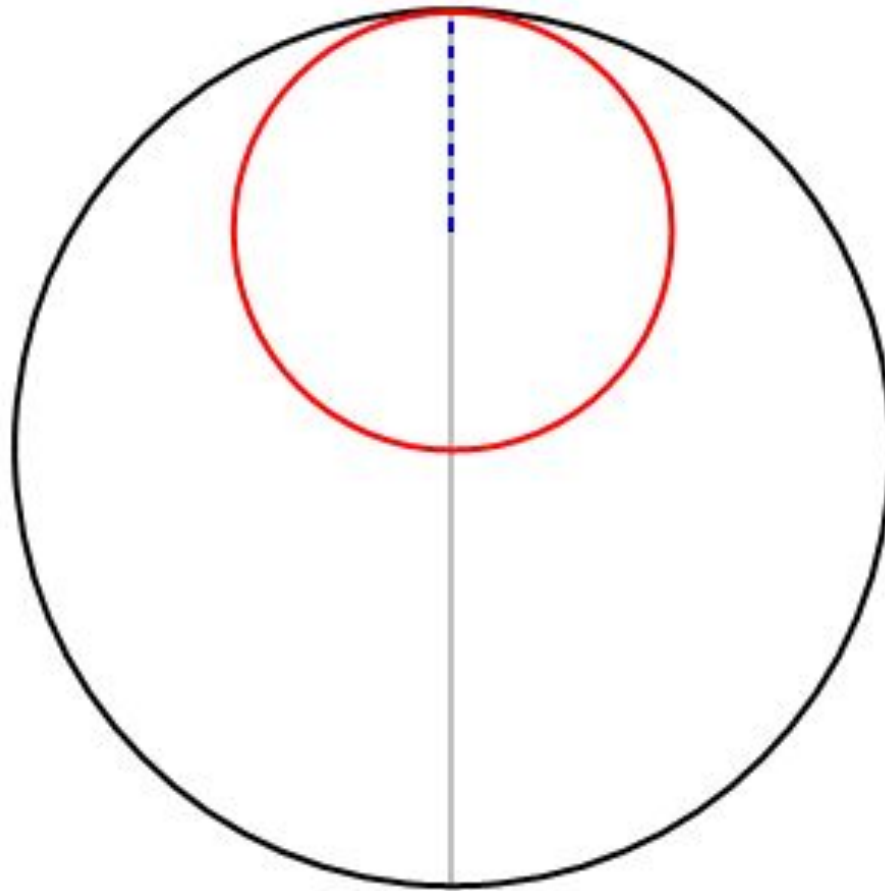
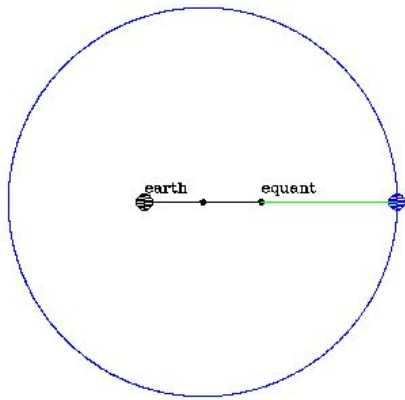


	Key	
Period	Development	People and Contribution
c. 150 CE	Synthesis	Ptolemy
		Geocentric model codified in the <i>*Almagest*</i> .
9th-13th C.	Islamic Golden Era: Preservation & Critique	Al-Battani, Ibn al-Haytham, Al-Tusi, Ibn al-Shatir
		Refined data, criticized physical models, created new devices (Tusi-couple), model predates Copernicus.
12th-13th C.	Translation	European Translators
		Ptolemy's refined work returned to Europe via Latin.
15th Century	Renewed Scrutiny	Peuerbach & Regiomontanus
		Produced mathematical and widely read textbook critique of the <i>Almagest</i> . Showed Ptolemaic Model incorrect (specifically the moon orbit)
1543	Revolution	Nicolaus Copernicus
		Published <i>De revolutionibus</i> , proposing a heliocentric universe and igniting the Scientific Revolution.



Tusi Couple: Solved the problem of the Equant (Nasir al-Din al-Tusi) 1245 CE

Equant rotation



Copernicus (1473-1543)

Published
outline of ideas
first in 1514
("Little
Commentary")



***Astronomer Copernicus, or Conversations
with God by Jan Matejko (1873)***

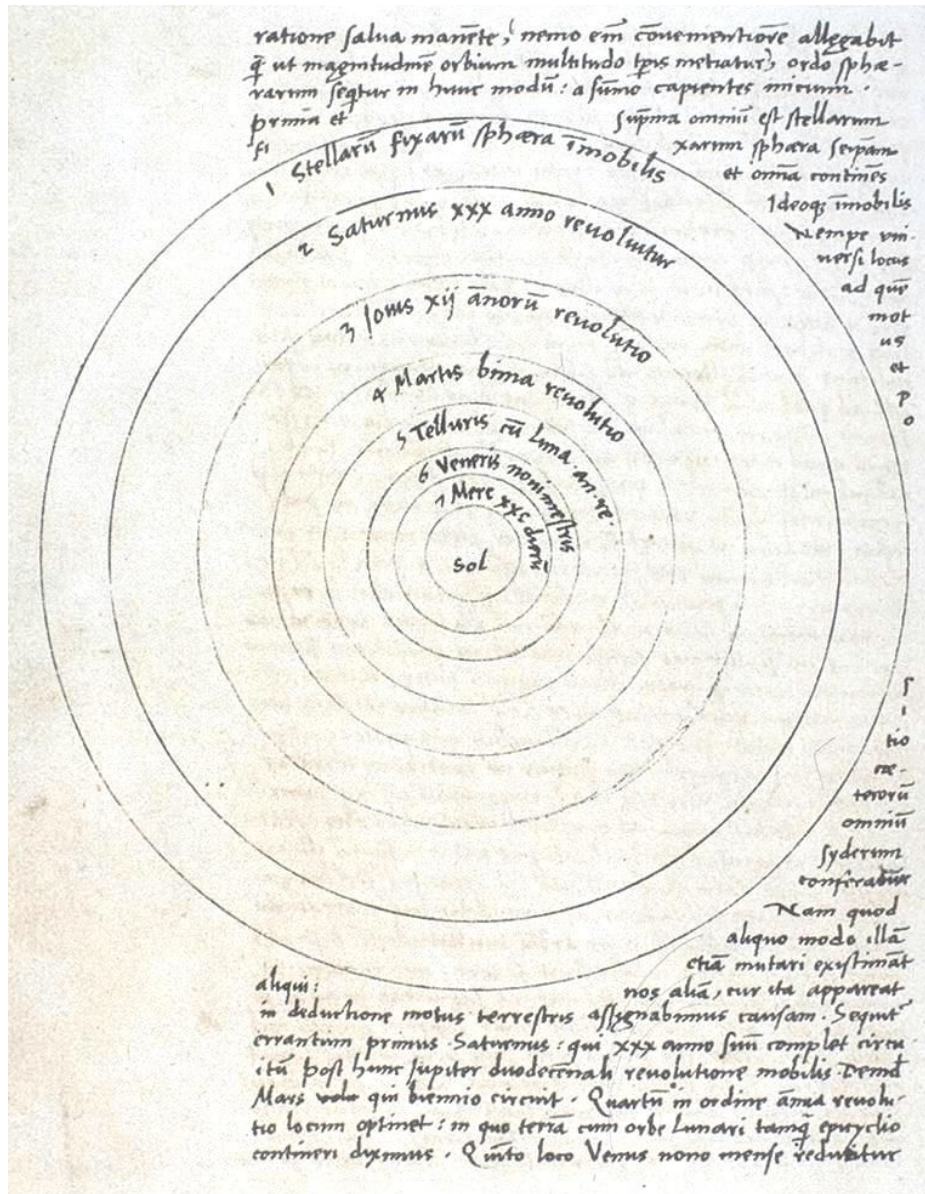
The Path to Revolution: Copernicus

- Published heliocentric model in *De revolutionibus orbium coelestium* (On the Revolutions of the Heavenly Spheres)



Astronomer Copernicus, or Conversations with God by Jan Matejko (1873)

The Path to Revolution: Copernicus



Astronomer Copernicus, or Conversations with God by Jan Matejko (1873)

Why Copernicus' model was not complete

- Heliocentric but as still bound by an ancient Greek philosophical dogma: all celestial motion must be uniform and perfectly circular
- Still very complex, relied on Tusi circles to explain the equant problem, more epicycles and deferents than Ptolemy
- Not better at prediction than the Ptolemaic model
- No direct physical proof



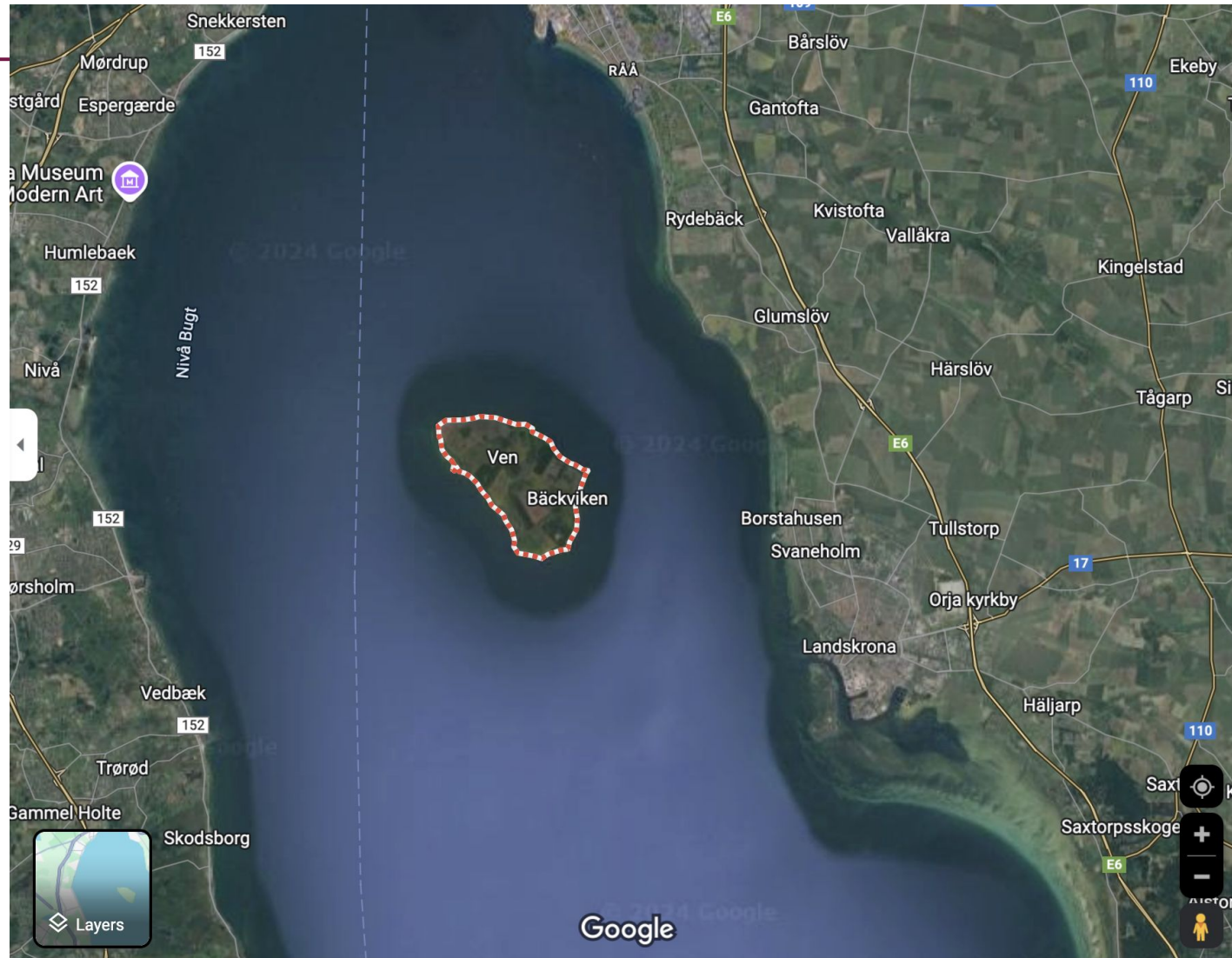
Tycho Brahe (1546-1601)

Danish nobleman
was surveying the
sky, without a
telescope.



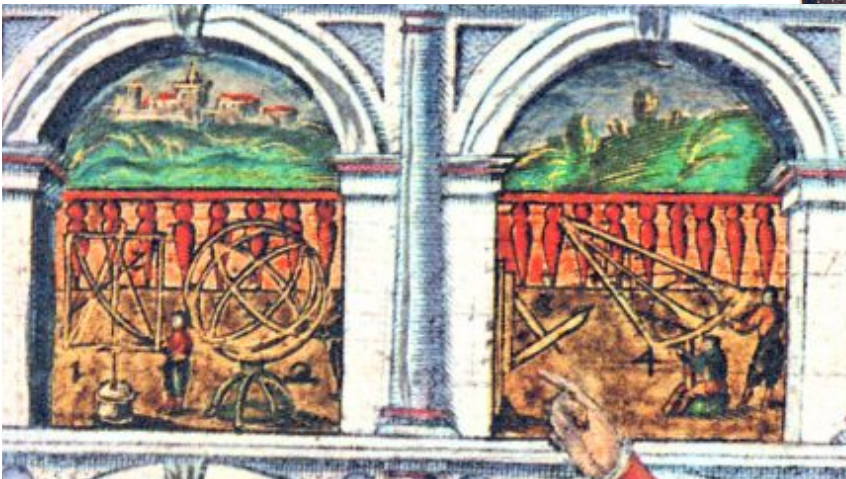
Tycho Brahe

Observatory
and highly
accurate
instruments
on his own
island, Hven.



Tycho Brahe

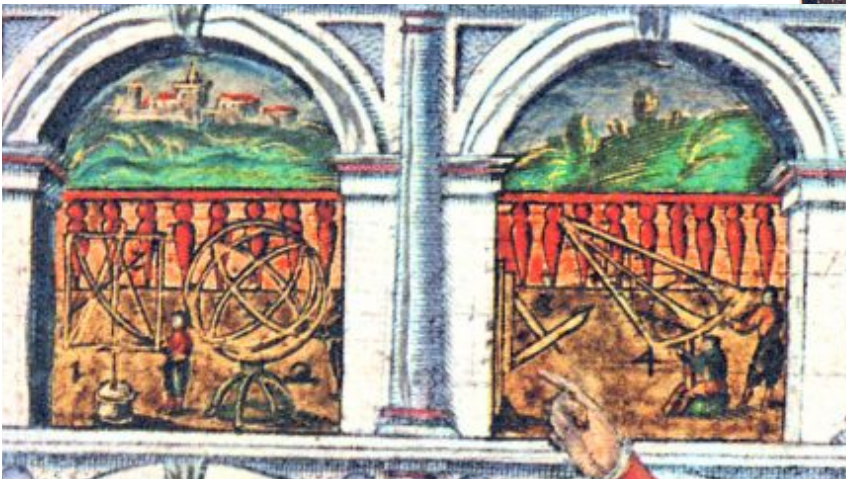
After observing a supernova (Tycho's Star) in 1572, he was given funds for an observatory and highly **accurate** instruments on his own island, Hven.



Tycho Brahe

Ultra precise data and observation were needed to test and fine-tune various models

Brahe got the data!



Tycho Brahe

Alchemy!

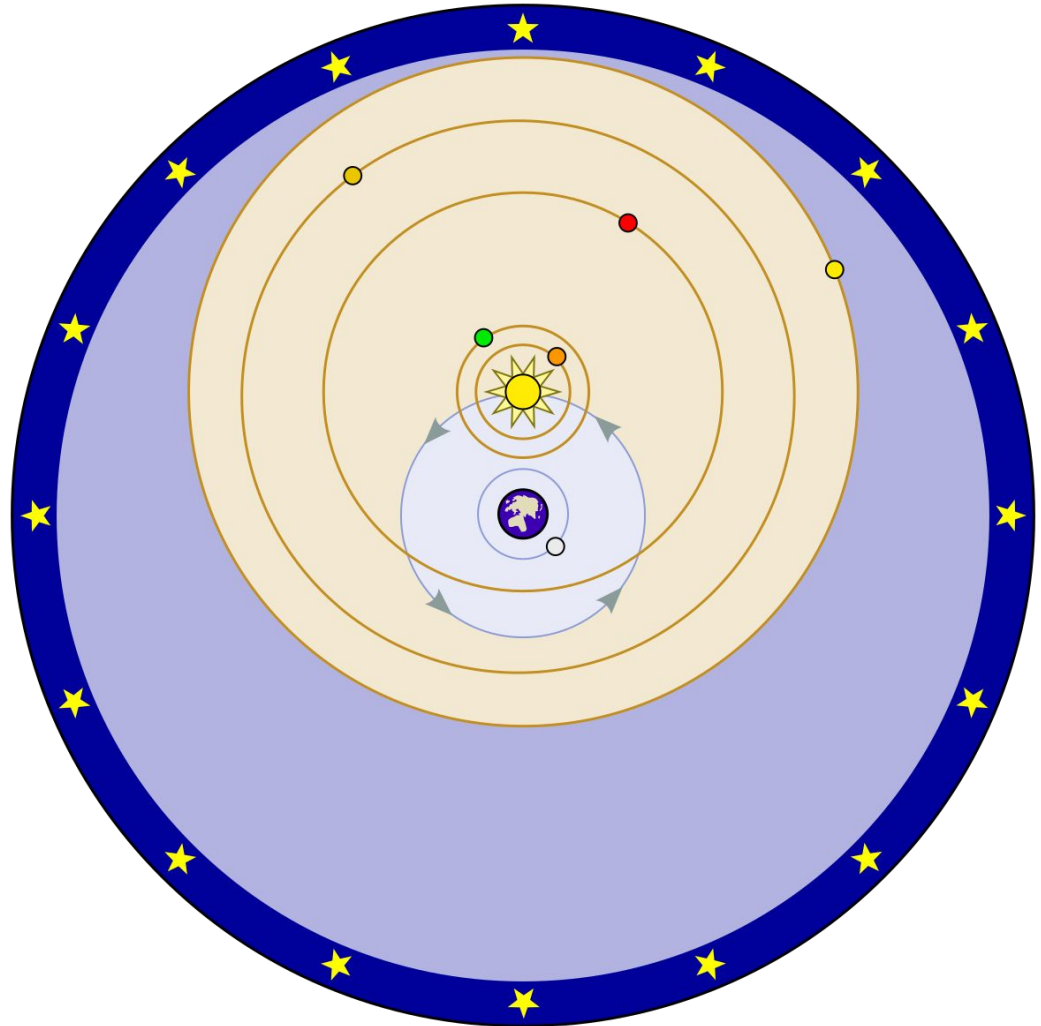
Not as well known of
Brahe:

16 furnaces in
basement, lots of
equipment for
distillations and
purifications



Tycho Brahe's Geoheliocentrism Model of the Solar System

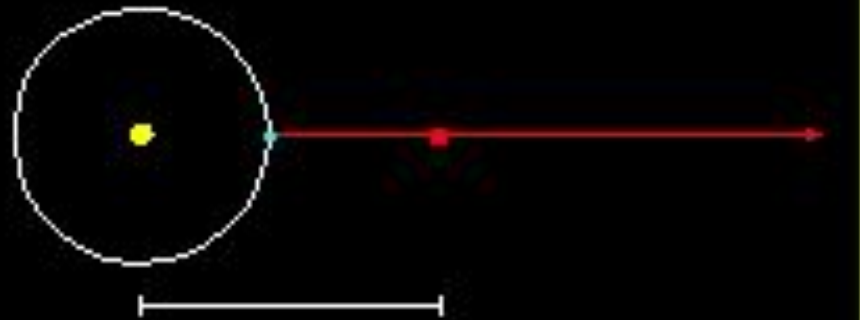
- A geo-heliocentric system for the solar system
- Earth is stationary at the center
- The Sun and Moon revolve around the Earth
- The other planets (Mercury, Venus, Mars, Jupiter, Saturn) revolve around the Sun
- A hybrid of the Ptolemaic and Copernican systems, was a compromise that allowed for the planets' observed motions
- While conceptually different, the Tychonic model is mathematically equivalent to the heliocentric Copernican system



Tycho Brahe: Does not see Stellar Parallax



1998 Dec 31

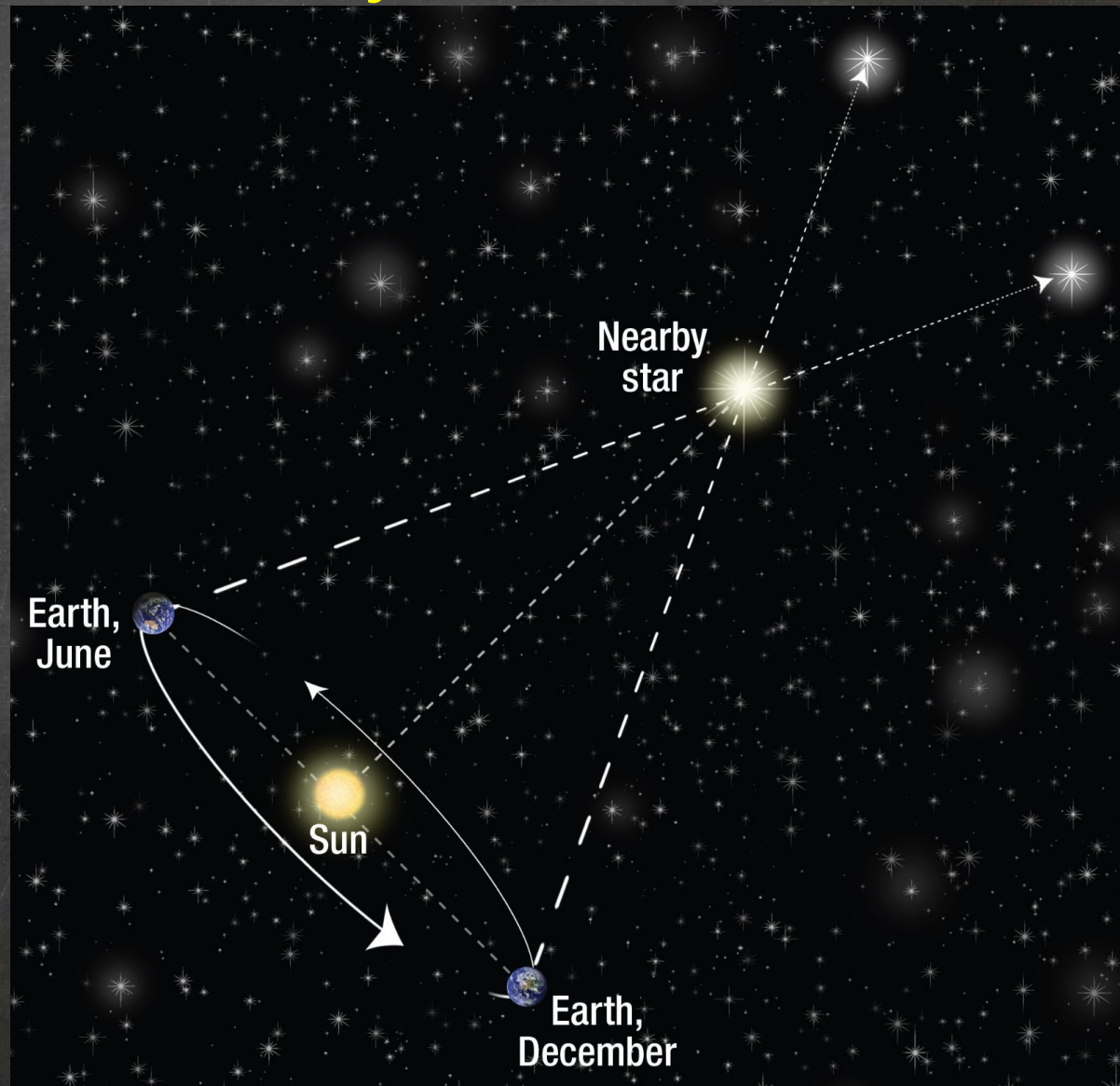


Grab a Sheet of Paper, Close your Computer and Put Away Your Devices ...

Tycho made his hybrid model because he did not see any evidence of Stellar Parallax.

Handwrite your answer to this question:

Speculate on what was Copernicus' answer to the problem of Stellar Parallax?



Tycho Brahe and Johannes Kepler

Brahe was exceptionally good at gathering data, but his interests did not include the difficult mathematical analysis of observations.

Brahe hired Johannes Kepler as an assistant, but kept most data to himself. Only after Brahe died was Kepler able to do a full mathematical analysis on the orbits of the planets.

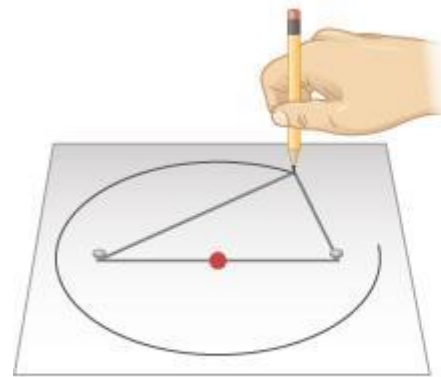
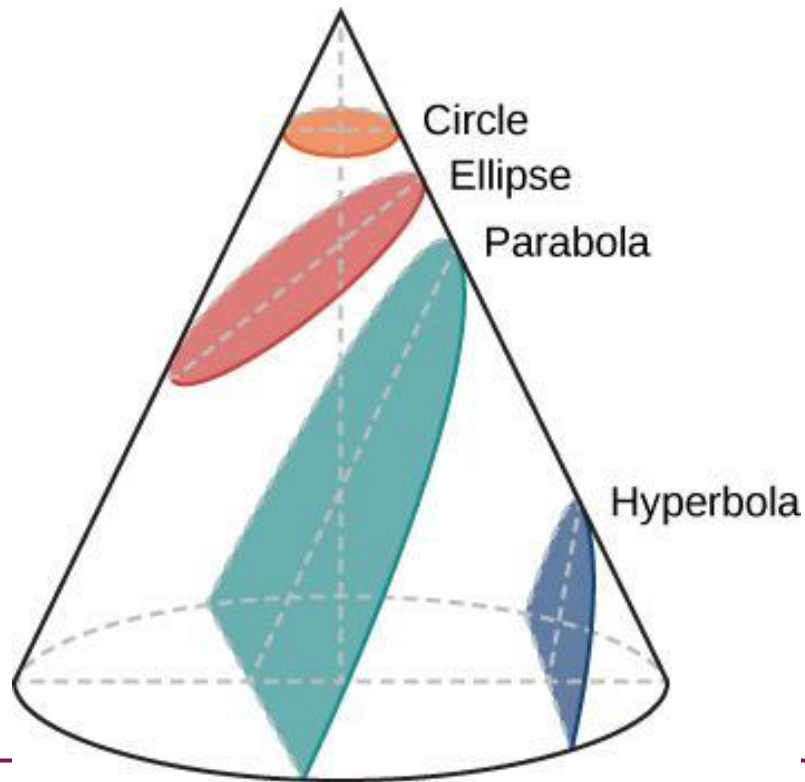
Spent years with Brahe data trying to “Save the Appearances”

Kepler’s analysis led to his **three laws of planetary motion**.

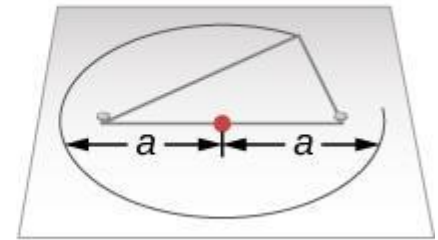


Kepler's Laws of Planetary Motion

Since Kepler determined circles could not fit the orbital data, he tried a different “conic section” shape, called an **ellipse**.



(a)



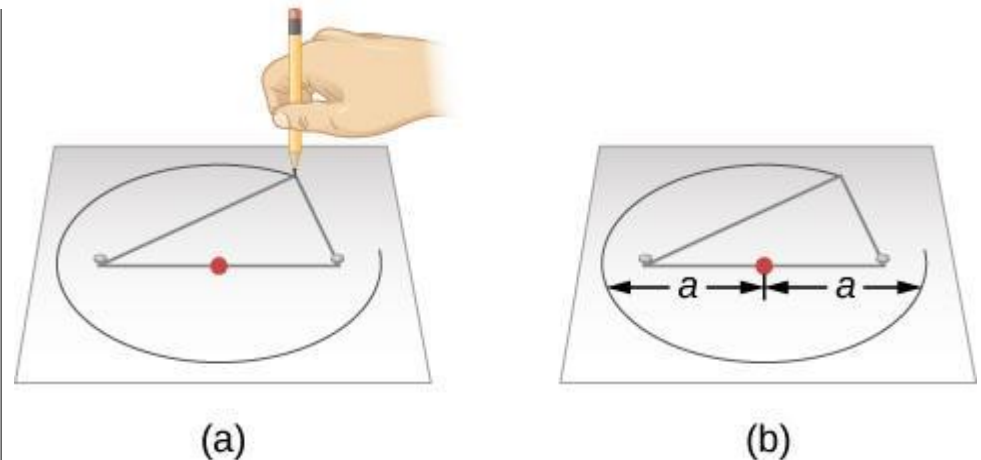
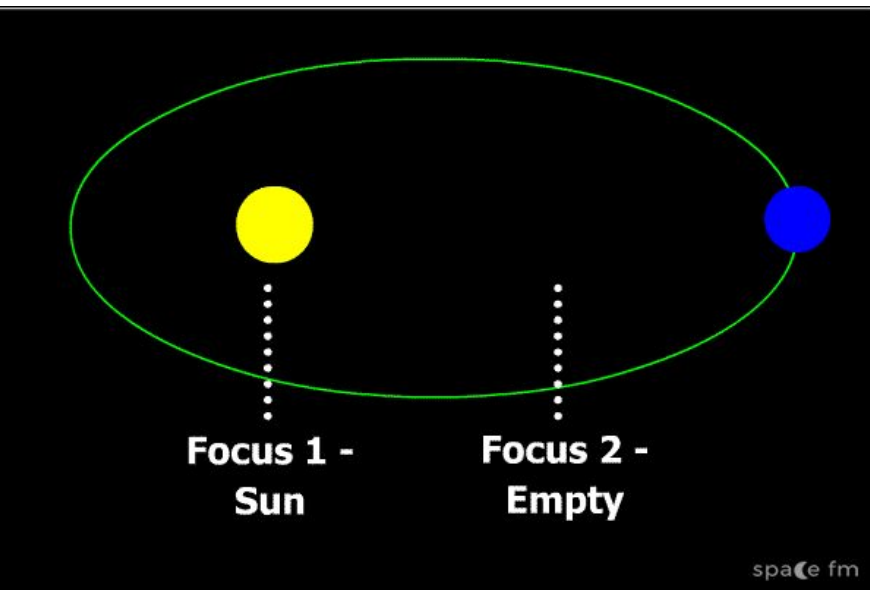
(b)

Kepler's First Law

Unlike a circle, an ellipse is not defined by a single central point, but rather two **foci** (singular: focus).

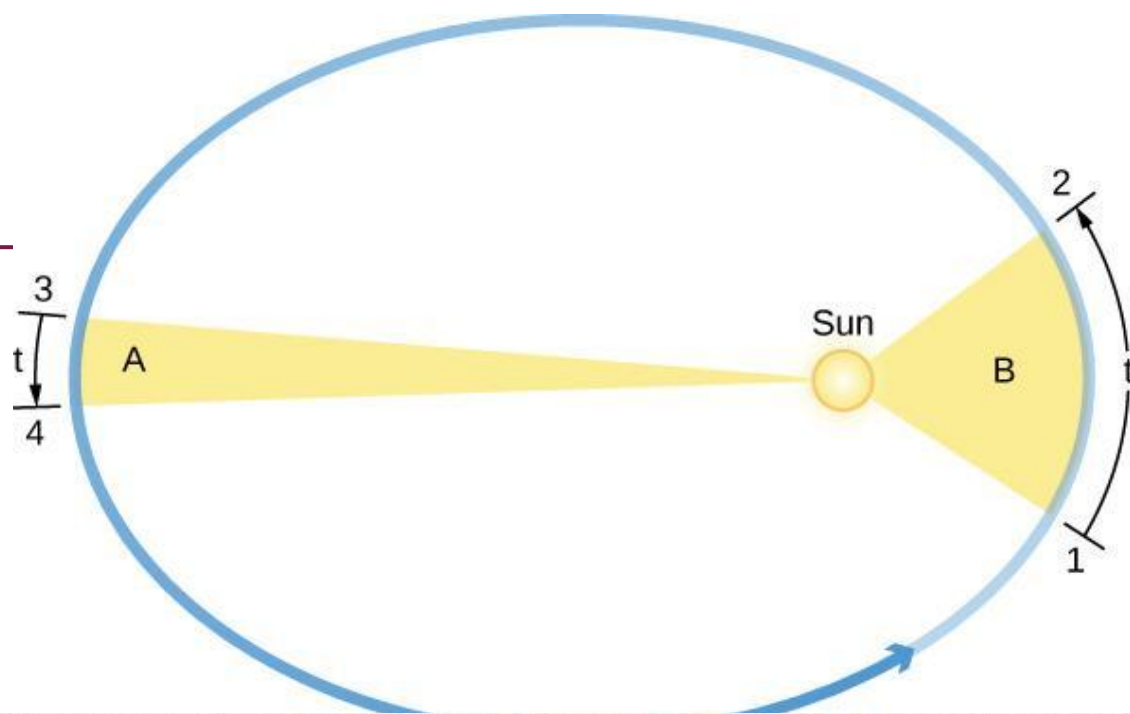
The planet to Sun distance is always changing

Kepler's First Law states that each planet moves around the Sun in an orbit that is an ellipse, with the Sun at one **focus** of the ellipse.



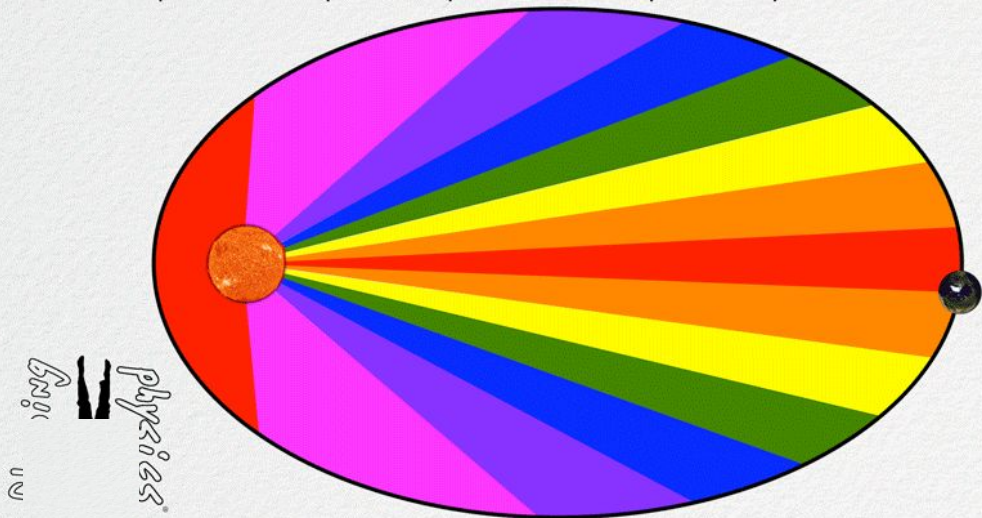
Kepler's Second Law

Kepler's Second Law states that the straight line joining a planet and the Sun sweeps out equal areas in space in equal intervals of time.



Kepler's Second Law of Planetary Motion:

"Each planet moves such that an imaginary line drawn between the sun and the planet sweeps out equal areas in equal time periods."



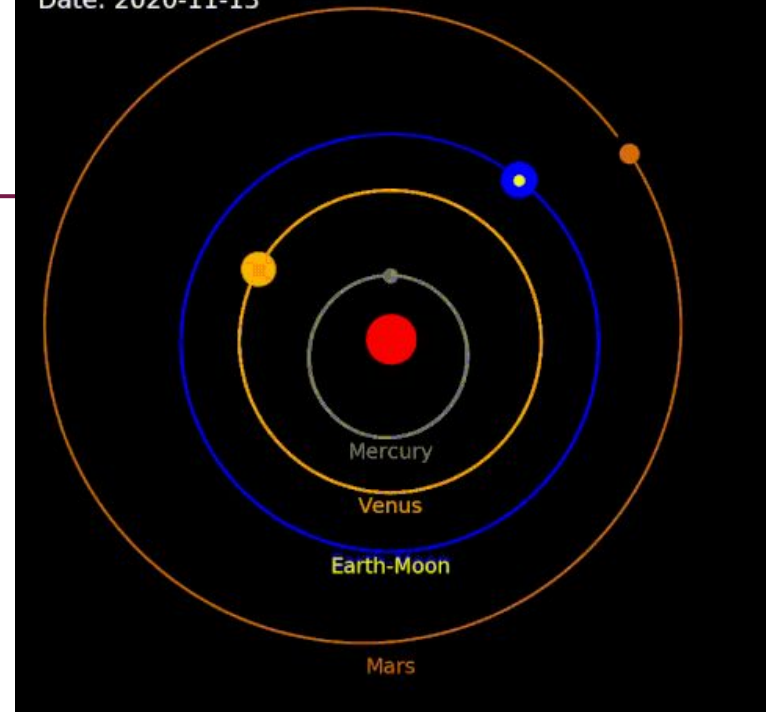
Kepler's Third Law

Kepler's Third Law is the most mathematical:

$$P^2 = a^3$$

The square of a planet's orbital period is directly proportional to the cube of the semimajor axis of its orbit.

Date: 2020-11-13

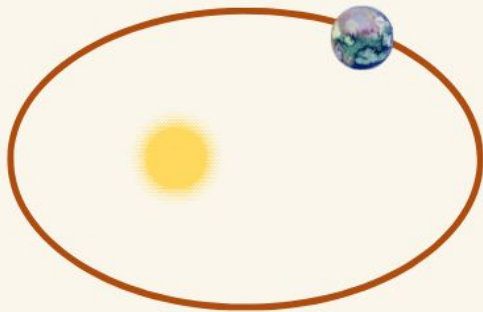


Planet	P(yr)	a(A.U.)	P ²	a ³
Mercury	0.241	0.387	0.058	0.058
Venus	0.615	0.723	0.378	0.378
Earth	1	1	1	1
Mars	1.881	1.524	3.537	3.537
Jupiter	11.862	5.203	140.7	140.8
Saturn	29.456	9.534	867.7	867.9

Kepler's Laws of Planetary Motion



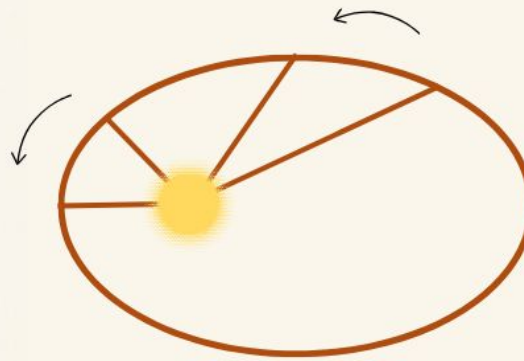
First Law



ellipse

Planets orbit in ellipses with the Sun at one focus.

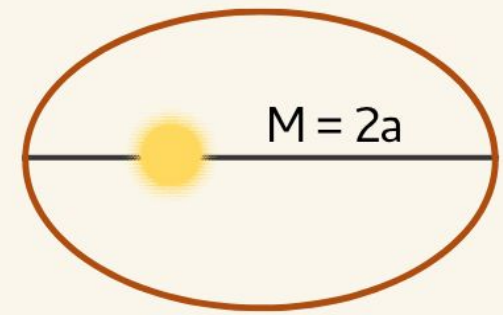
Second Law



Planets sweep out equal areas in equal times.

Third Law

P: period (time for one cycle)
2a: length of major axis



$$P^2 \propto a^3$$

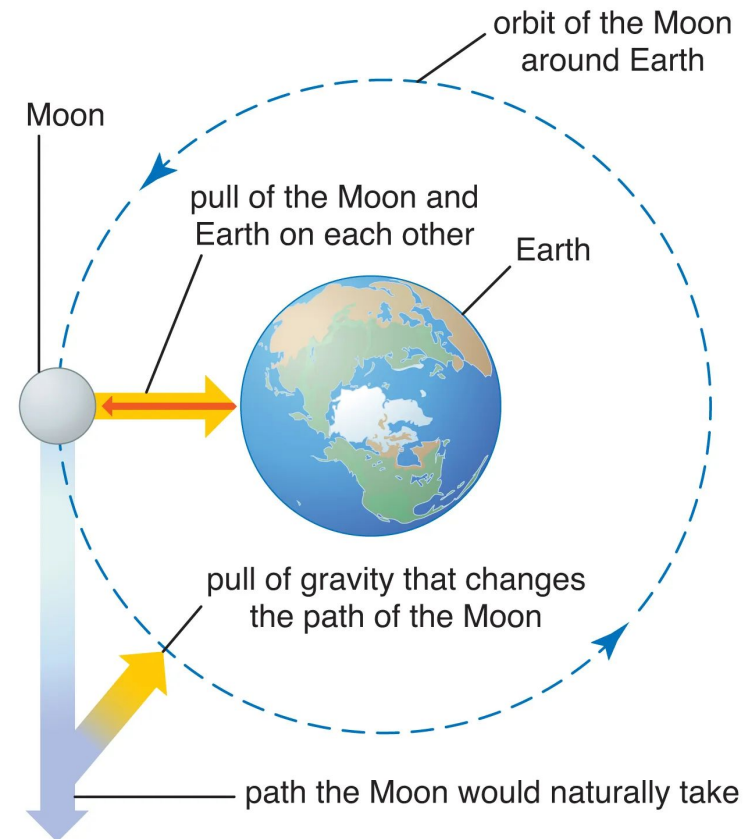
The square of the orbital period is proportional to the cube of the semi-major axis

Kepler's Third Law

Kepler's Laws of Planetary Motion have stood up to all scientific evidence of the past 500 years.

Even though he didn't understand **why** (This is Newton's Law of Universal Gravitation) the planets acted this way, he showed that they did.

Planet	P(yr)	a(A.U.)	P ²	a ³
Mercury	0.241	0.387	0.058	0.058
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Galileo Galilei, Father of Modern Science

Galileo is responsible for the modern view of science and the transition from authority-based “science” to an observation-based science (empiricism).

Galileo developed experiments to study:

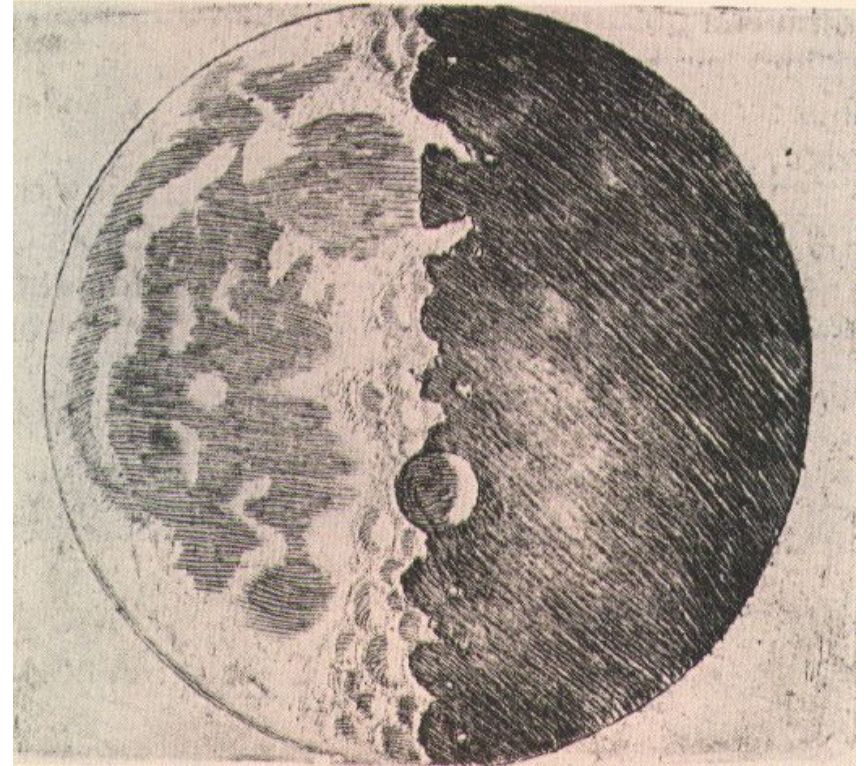
- How objects would move without friction (the basis of the law of inertia)
- How objects accelerate (the basis of the law of gravity)

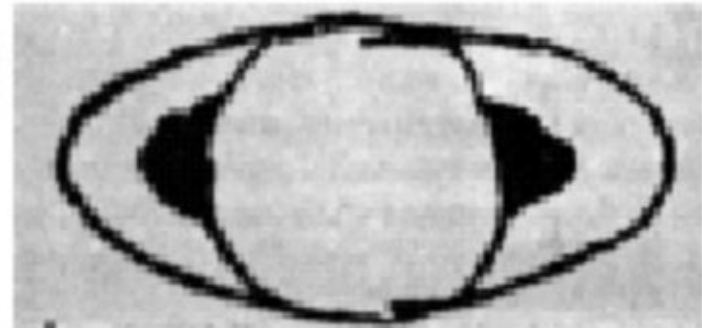
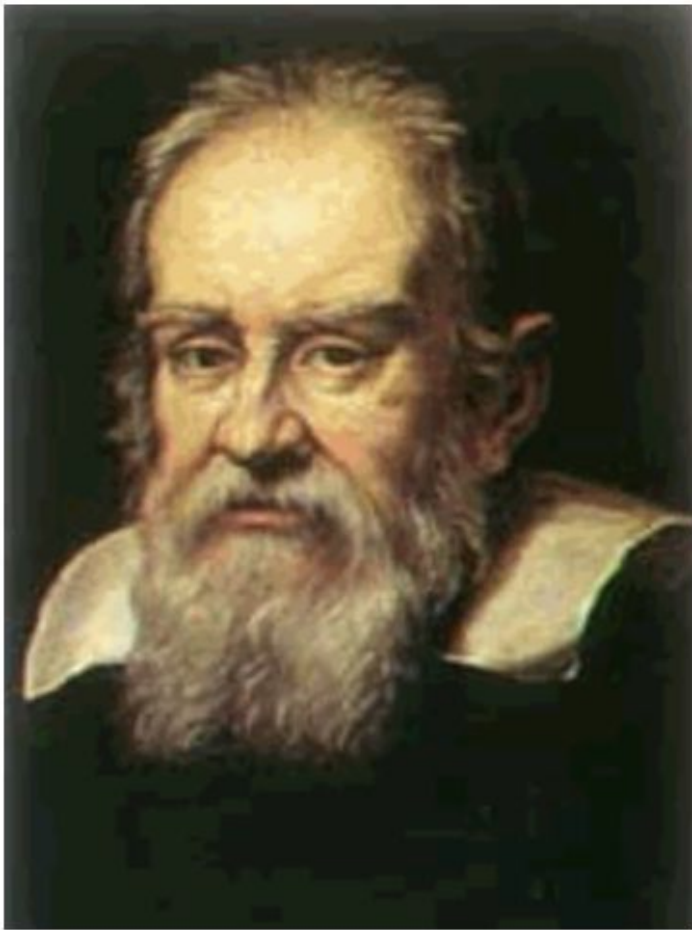


Galileo Galilei, Father of Modern Science

The telescope was invented in Holland around 1608, and Galileo improved the design in his workshop. His first few observations at amazed him:

1. **Craters, peaks on the moon**
2. Stars too faint to see by eye
3. Moons around Jupiter
4. Rings around Saturn
5. Spots on the Sun





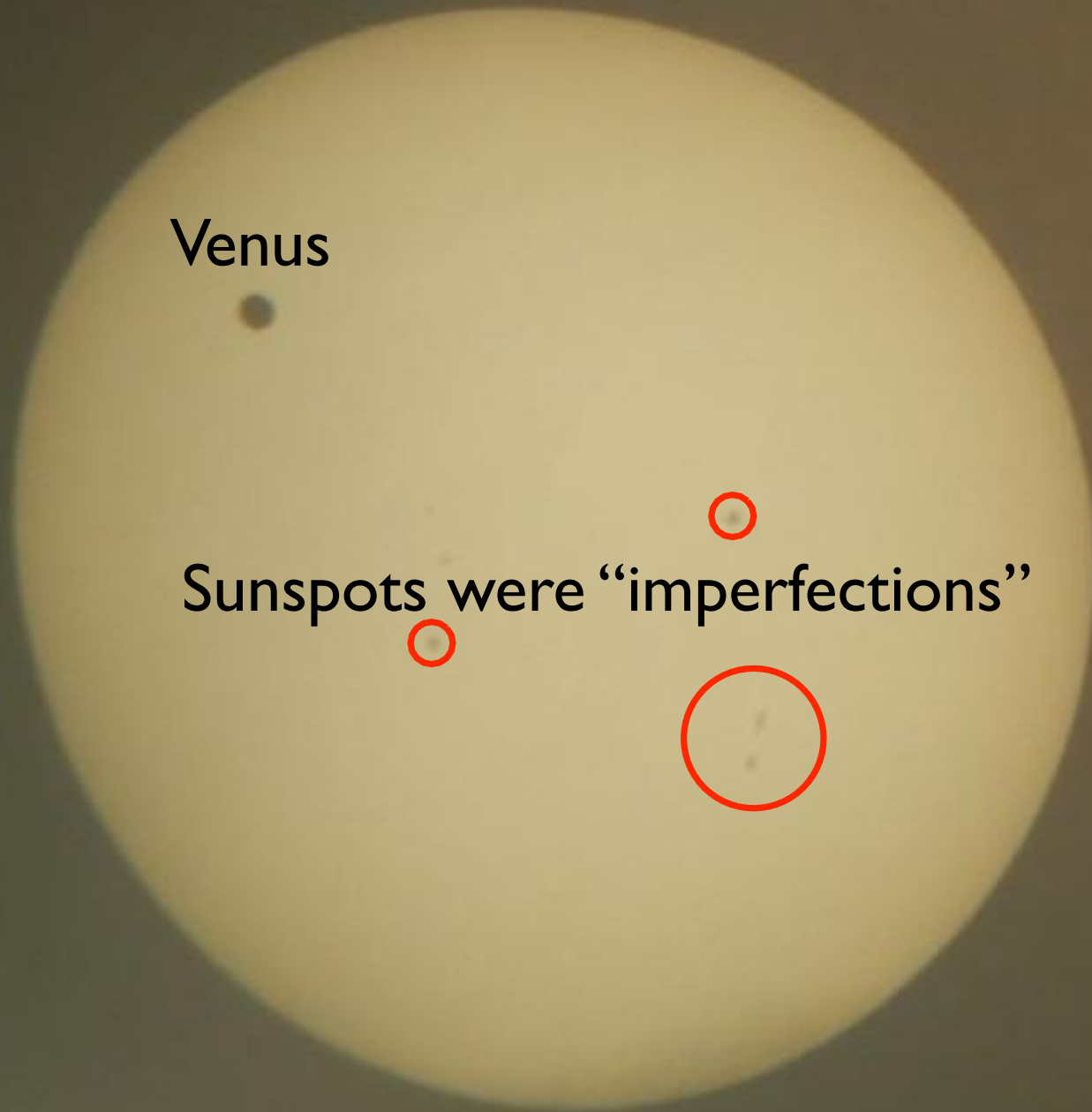
Galileo & his drawings

Top drawing: Galileo's drawing of Saturn, 1610

Bottom drawing: Galileo's drawing of Saturn, 1616

Venus

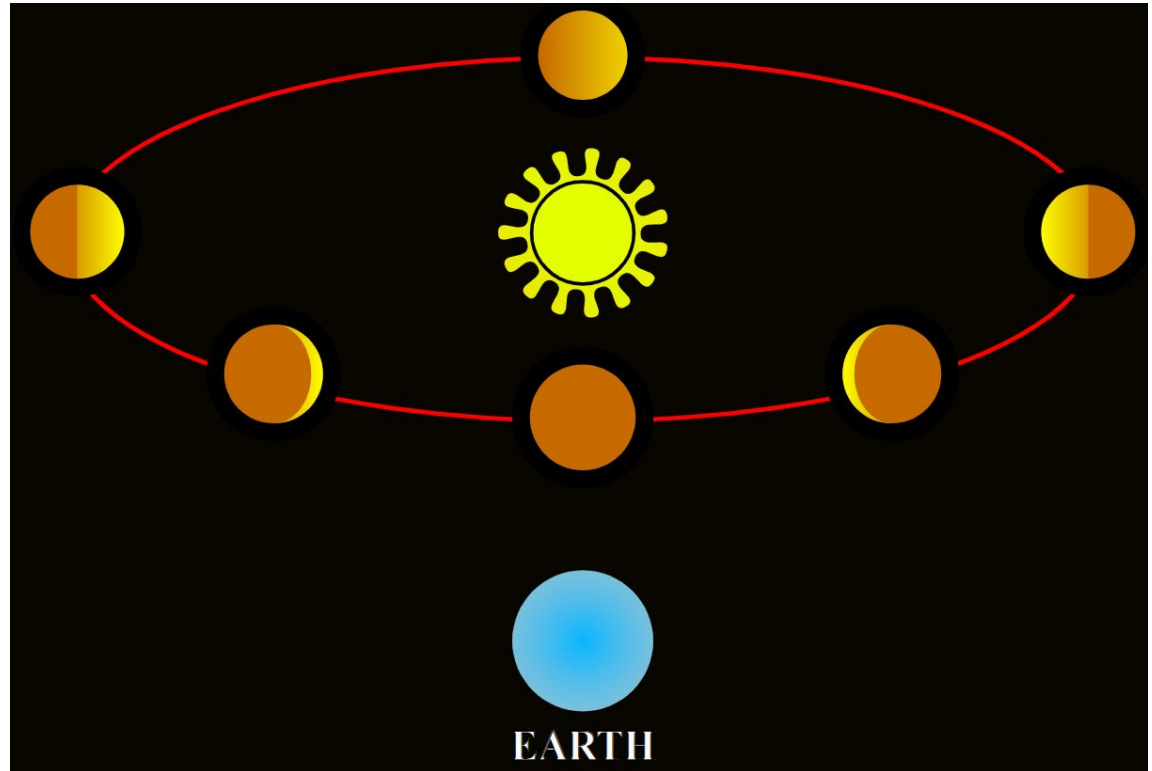
Sunspots were “imperfections”



Galileo Galilei, Father of Modern Science

Beyond this initial list, the definitive proof that the Earth **could not** be at the center of the solar system was Galileo's observation of the **phases of Venus**.

<http://astro.unl.edu/classaction/animations/renaissance/venusphases.html>



The observations of Venus's phases was the final nail in the coffin of all of the geocentric “universe” models.

Galileo Galilei, Father of Modern Science



Within 40 years of the observations, only the heliocentric “universe” was taught. This was not without pushback from the Roman Catholic Church.

Galileo published *Dialog Concerning the Two Chief World Systems* with permission from local censor in Florence and the head censor at the Vatican in 1630. However, he was charged with disobeying the papal decree from 1616 (not heresy) and convicted in 1632.

He was sentenced to spend the rest of his life under house arrest. His work became a foundation of the Newtonian revolution in science.

His books were on the Church’s forbidden list until 1836. He was “found innocent” in 1992 by a special commission (i.e. they admitted they were wrong).
