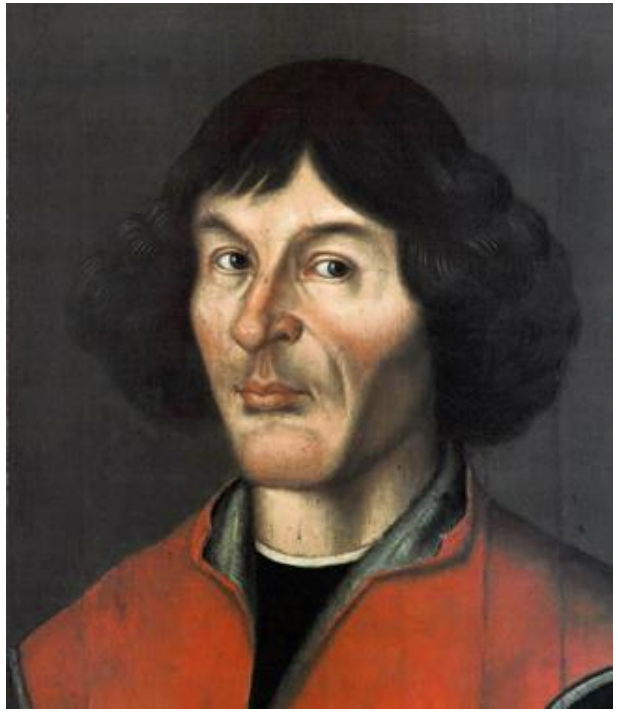
Astronomy of the Solar System – Module 2: Observing The Sky – Birth of Astronomy Part 2

GEORGIA STATE UNIVERSITY
WITH RESOURCES FROM

Galileo Galilei (1564–1642), father of observational Astronomy, the first to point a telescope at the sky, revolutionary discoveries to support heliocentric model, persecuted by the Catholic Church for heresy. (Credit: OpenStax)



Nicolaus Copernicus (1473–1543), cleric and scientist, proposed heliocentric model, the foundation of future work by Johannes Kepler & Galileo Galilei. (Credit: OpenStax)

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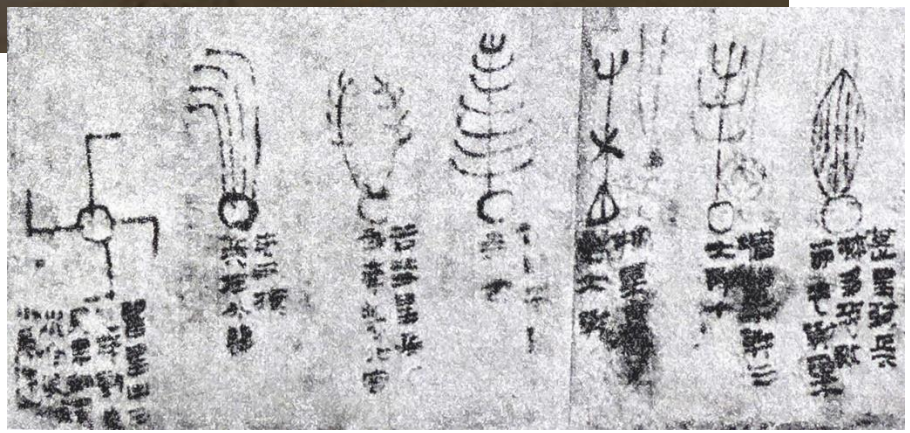
Who started Astronomy & when?

OpenStax Astronomy: 2.2

- **People all over the world invented calendars & navigation based on sky**
  - ***Egyptians (Babylonians, Assyrians):*** 365 day calendar, used star Sirius to predict seasonal flooding of river Nile
  - ***Chinese:*** 365 day calendar, recorded comets & dark spots on the Sun
  - ***Mayans:*** Venus based long & short calendars ending 2012, used Venus for cultural events
  - ***Polynesians:*** navigated vast open ocean to colonize pacific islands using night sky
  - ***Ancient British:*** tracked motion of Sun & Moon with intricate stone structures
- **Modern Astronomy** comes from ***Greek/Roman line*** which had absorbed Babylonian concepts
  - 2500 yrs ago, mathematician Pythagoras: gods made sphere "perfect forms", Moon is a sphere, so ***Earth must also be a sphere***

Logo for the *Sun in Time* program at NASA's Marshall Space Flight Center. Foreground: famous **Mayan/Aztec** calendar. Background: image of the solar corona taken from the ISAS/NASA Yohkoh spacecraft. (Credit: NASA Marshall Space Flight Center)

Facing east on July 15, 3000 BC from the ancient city of Memphis in **Egypt**. (Credit: Stellarium)



Recordings of Comet sightings, Astrology Manuscript, ink on silk, BCE 2nd century, Han. (Credit: Hunan Province Museum, China, public domain)

What did the ancient Greeks figure out? OpenStax Astronomy: 2.2

- **Aristotle's (300's BCE) advances**
  - ***Moon's phases*** – different portions of the Moon's sunlit hemisphere as it orbits Earth
  - ***Sun farther than Moon*** – Moon can block Sun when passing in front of it **("solar eclipse")**
  - ***Earth is round***
    - Different constellations come into view when traveling long distance southward (would keep seeing same on flat Earth)
    - Earth's round shadow seen on Moon when Moon passes through it **("lunar eclipse")**

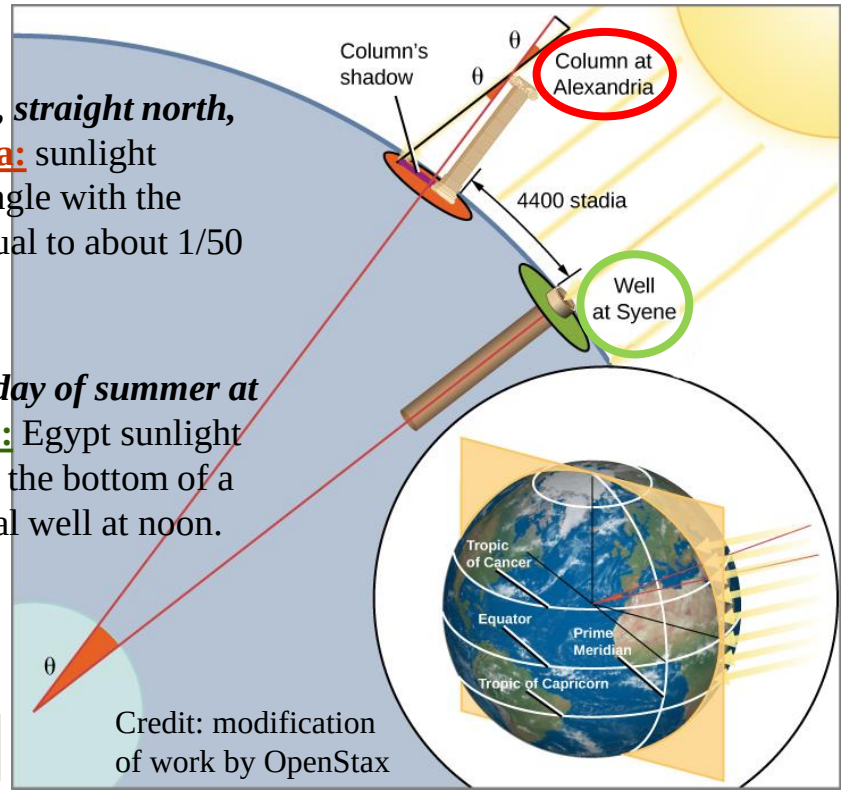
Lunar eclipse: Earth casts its round shadow on full Moon as it passes through. The faint, deep red orange while completely inside Earth's shadow is due to refracted sunlight by Earth's atmosphere (Credit: OpenStax, modification of work by Brian Paczkowski)

Greek scholars & scientific reasoning: Aristarchos & Eratosthenes (200s BCE)

- ***Hypothesis,* Aristarchos*: Earth orbits Sun***
- ***Prediction,* fellow scholars:** Near stars shift relative to background stars **("stellar parallax")** seen from Earth's orbit
- ***Test:*** observed stars 6 months apart – ***no stellar parallax!***
- ***Analysis: either*** stars are incredibly far away ***or*** Earth is at rest
- ***Conclusion:*** Cosmos not that huge so Earth rests at center

***Same time, straight north,* Alexandria:** sunlight made an angle with the vertical equal to about 1/50 of a circle.

***First day of summer at* Syene:** Egypt sunlight struck the bottom of a vertical well at noon.

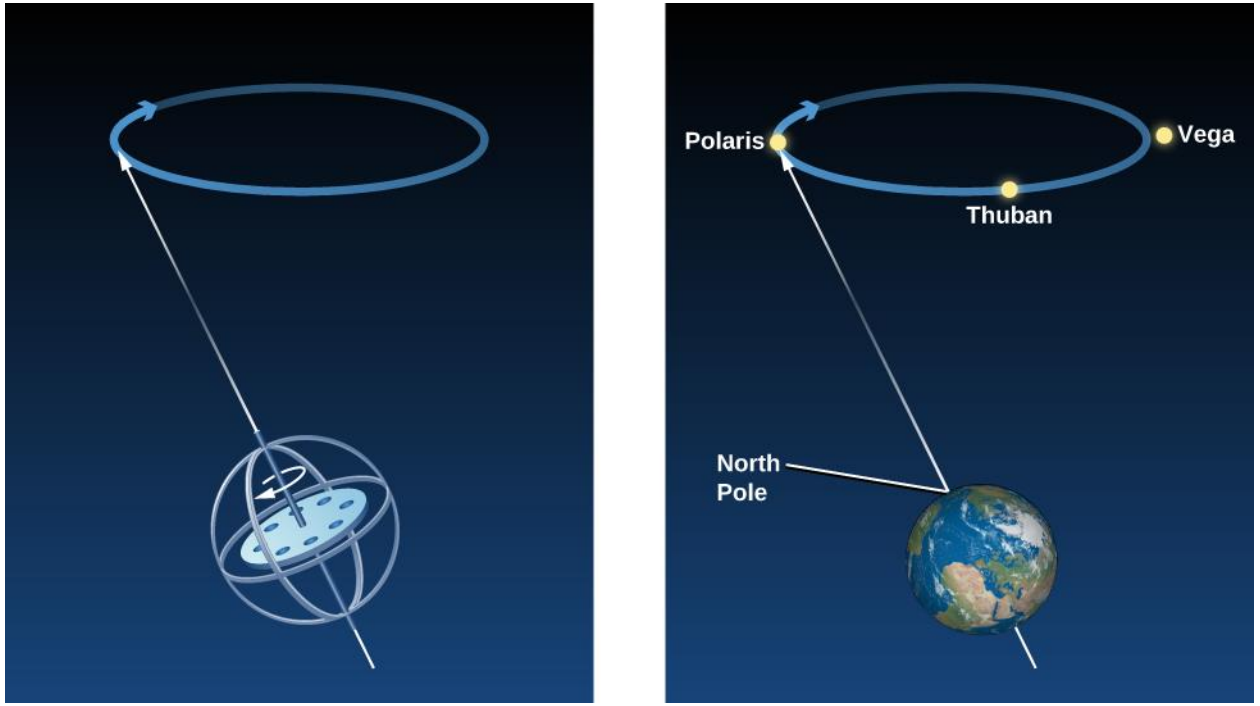


Credit: modification of work by OpenStax

Eratosthenes: distance between cities (5000 stadia) subtended 1/50 of Earth's circumference, C. So, C = 50 x 5000 stadia = 250,000 stadia. If 1 stadium = 1/6 km, then C ~ 40,000 km. **Close to current value!**

How well did the ancient Greeks know the stars? OpenStax Astronomy: 2.2

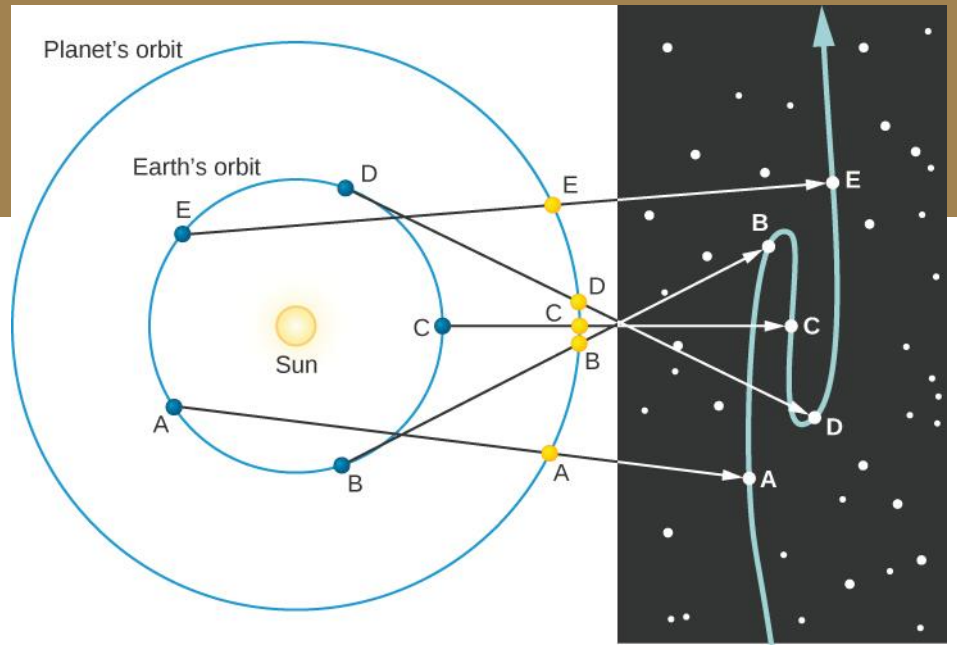
- **Hipparchus (150 BCE): *pioneered star catalog***
  - Celestial coordinates of 850 stars similar to longitude/latitude system
  - Brightness bins of stars **– apparent magnitude**
    - Brightest star = first magnitude, ½ as bright = second magnitude, ¼ as bright = third magnitude, etc.
    - Brightness judged by eyesight, arbitrary
  - Compared his to older measurements of stellar positions: direction around which sky rotates, ***north celestial pole, changes very slowly and continuously***!
    - ***Today:*** Earth's axis wobbles like that of a spinning top that got bumped – **precession**
    - Caused by gravitational tug of Moon & Sun on Earth's slight equatorial bulge
    - ***Today:*** Polaris is North Star, Vega in 14,000 yrs, back to Polaris in 26,000 yrs



Precession: spinning ***top on the left***, spinning ***Earth on the right***. Earth's axis wobbles in a 26,000-year cycle. It always points to the north celestial pole. The star closest to it is called "North Star". Today, it is Polaris. 5,000 years ago, it was Thuban. Precession also shifts the ecliptic among the constellations which changes the zodiac – remember Ophiuchus! (Credit: OpenStax)

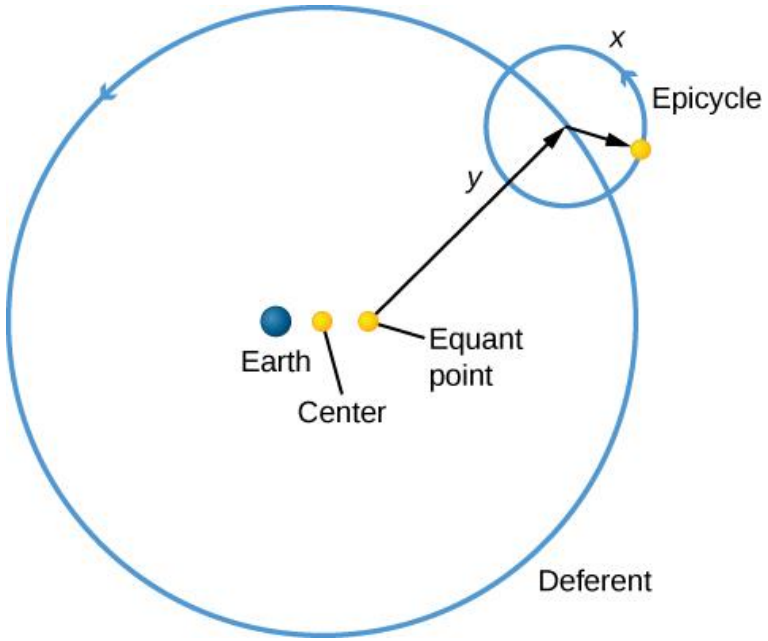
How well did the ancient Greeks know the planets? OpenStax Astronomy: 2.2

- **Ptolemy (year 140):** ***formed geocentric model***
  - Used Hipparchus and his own data of a couple of centuries of planetary positions
  - predicted the positions of the planets for any desired date and time with ***Earth at the center of the solar system***
- **Challenge:** ***planets' apparent motion in sky is complicated*** – eastward most of the time **("prograde")**, reverse to westward occasionally **("retrograde")**
  - **Simple explanation in Sun-centered model:** Earth, planets orbit Sun like race cars. When we on Earth overtake slower planets/are overtaken by faster planets, they ***appear to us to move backward*** relative to background.
- Need **complex geometry** to explain retrograde motion with circular orbits and Earth at center!



Retrograde motion: outer planet (Mars) moves among fixed stars as seen from Earth. Letters for Earth's & Mars' positions on left correspond to the locations we see Mars against background stars while both planets orbit the Sun. (Credit: OpenStax)

Ptolemy's Geocentric Cosmology: planet orbits around a small circle, ***epicycle***, which orbits on a larger circle, ***deferent***, centered on an offset point called the ***equant*** (not exactly Earth). Greeks: Earth must be stationary and orbits circular. (Credit: OpenStax)

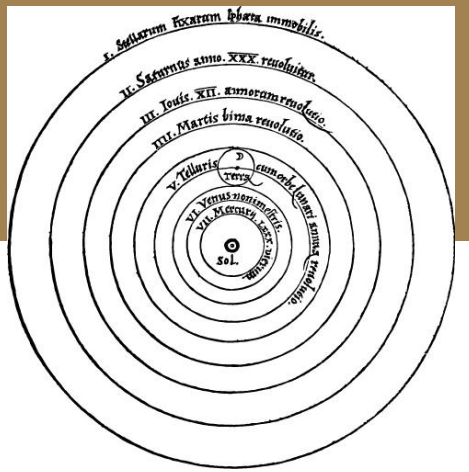


What led to the conclusion that the Sun is at the center?

OpenStax Astronomy: 2.4

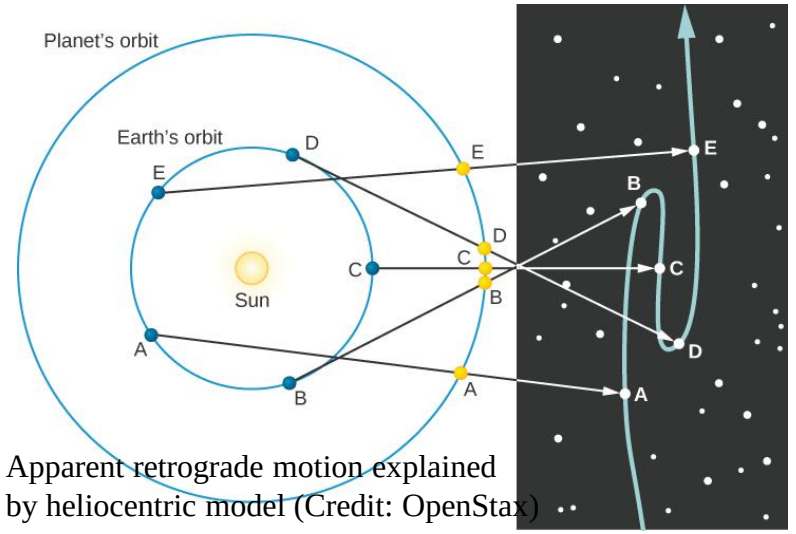
- **Arab & Jewish cultures: *expanded Greek Astronomy with advent of Islam in 7th century***
  - Most of the brightest stars have Arab names
  - Meanwhile in Europe (middle ages): centuries of strife and warfare prevented pursuit of knowledge
- 16th century Europe (Renaissance or "Rebirth" in French): **Polish cleric, Nicolaus Copernicus**, re-examined planetary position data
  - After several centuries: more complicated to predict planetary conditions
  - ***Hypothesis:*** Sun at center (heliocentric), Earth a planet only orbited by Moon
  - ***Strengths***: explained apparent retrograde planetary motion without epicycles, greatly simplifies planetary position predictions
  - ***Weakness***: kept requirement of circular orbits
- After 100+ years heliocentric model fully accepted

Reasoning: Geocentric vs. Heliocentric Model

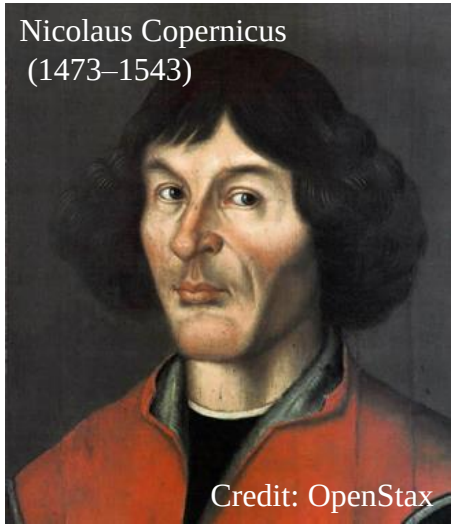


Copernicus' own drawing of the heliocentric model (Credit: OpenStax, Copernicus)

1. ***Geo:*** if Earth were moving, we would all sense or feel this motion
   Helio: not if everything moves along with it (carriage, train)
2. ***Geo:*** if Earth rotated about an axis it would fly into pieces
   Helio: so would celestial sphere if it rotated instead of Earth
3. ***Geo:*** adjusted geocentric model predicts just as accurately
   Helio: heliocentric model is much simpler, more elegant



Apparent retrograde motion explained by heliocentric model (Credit: OpenStax)



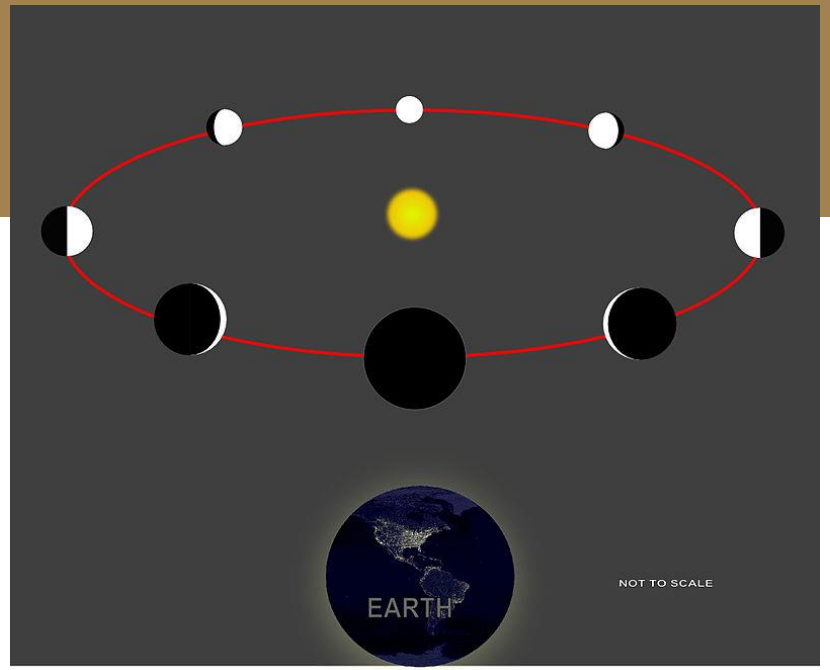
Nicolaus Copernicus (1473–1543)

Credit: OpenStax

How was the geocentric model disproved? OpenStax Astronomy: 2.4

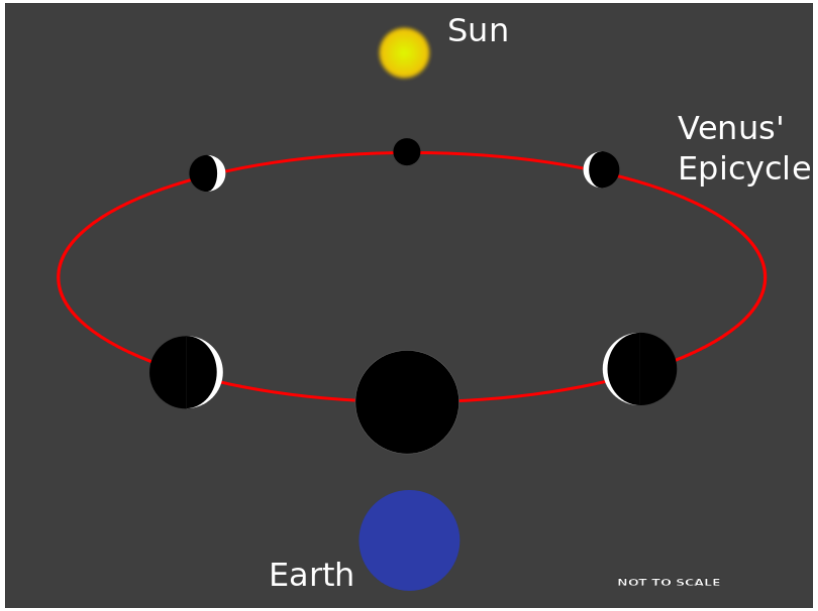
- ***Geocentric & heliocentric models existed in parallel for ~ 50 yrs, hotly debated***
  - Science was rooted in philosophy: pure human thought + divine revelation reveals truth. Human sensory perception of nature is inferior.
- **Apply scientific method to test both hypotheses**
  - ***Step 1: must explain all known phenomena***
    - Both predict planetary positions accurately
  - ***Step 2: devise observational testing where hypotheses predict different outcomes***
    - Example: Phases of Venus
    - Heliocentric prediction: If Venus orbits Sun then it has full set of phases like Earth's Moon
    - Geocentric prediction: If Venus orbits Earth then it only has new and crescent phases
  - ***Step 3: Observe Venus with a telescope***
    - Had to wait ~ 100 yrs for Galileo Galilei
    - Galileo observed Venus' full set of phases

Disproved geocentric model, supported heliocentric model!



Phases of Venus predicted by heliocentric model. Credit: By Nichalp09:56, 11 June 2006 (UTC) modified by Sagredo - Based on PD raster image Image:Phasesofvenus.jpg, http://history.nasa.gov/SP-424/p4.jpg , Public Domain, https://commons.wikimedia.org/w/index.php?curid=3237558

Phases of Venus predicted by geocentric model. Credit: By Astrobryguy Derivative work of en:File:Phases-of-Venus2.svg (released to public domain). - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=16680420



Why was Galileo Galilei so important?

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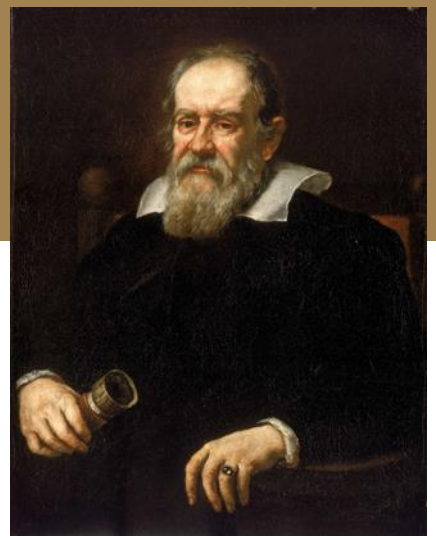
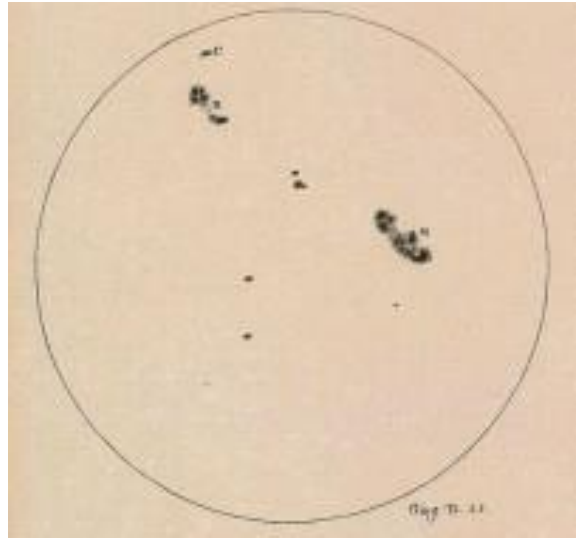


Galileo Galilei (1564–1642): First to turn the telescope to the sky where he made discoveries that contradicted the model of the cosmos constructed by philosophical reasoning. (Credit: OpenStax)

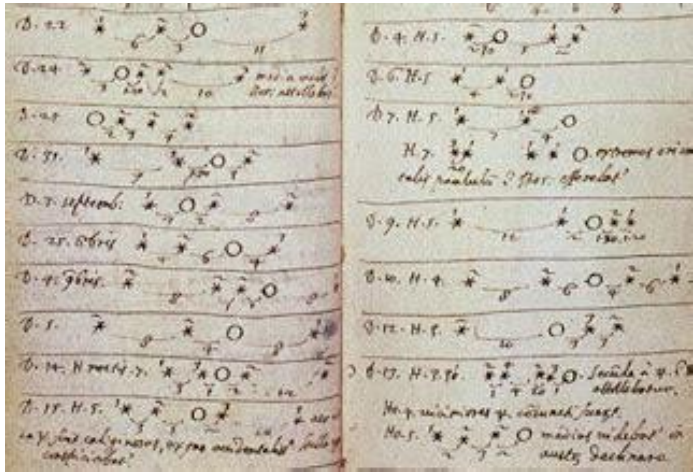
Telescope used by Galileo: wooden tube covered with paper and a lens 26 mm lens.

Pioneer of scientific method (*observ., exper. & testing of hypotheses with quantitative measurements)*

- Professor at the University of Padua, Italy, & mathematician to the Grand Duke of Tuscany
- Studied motion of objects acted on by applied forces, friction & gravity
  - Dropped objects from Tower of Pisa
  - Developed laws for linear motion
- Built own telescope after hearing about its invention by Dutchman **Hans Lippershey**
  - Milky Way made of individual stars
  - Tiny dark spots on Sun ***(NOT perfect)***
  - Mountains, craters, valleys, plains on Moon ***(like Earth, could Earth be celestial too?)***
  - Saturn has lobes (turned out to be rings)
  - **Jupiter has four large moons *(Earth NOT only center of revolution)***
  - **Venus has full set of phases *(must orbit Sun)***



Sunspots, by Galileo Galilei: https://skyandtelescope.org/astronomy-news/seeing-sunspots-as-the-ancients-did/ , Public Domain, https://commons.wikimedia.org/w/index.php?curid=92624296



Moons of Jupiter, by Galileo Galilei: https://commons.wikimedia.org/wiki/File:Galileo_Galilei_(1564_-_1642)_-_Manuscipt_observations_of_Jupiter,_its_four_moons_and_stars.jpg# public domain

Was there any fallout for Galileo with his heliocentric evidence?

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Galileo before Inquisition (modified work, public domain)**:** https://commons.wikimedia.org/wiki/File:Galileo_before_the_Holy_Office.jpg#/media/File:Galileo_before_the_Holy_Office.jpg

- 1632: The Roman Catholic Church dragged Galileo ***before the Inquisition*** accusing him of heresy (assault of common belief).
- He was ***sentenced to house arrest*** until he passed.
- His books on Church's ***forbidden list*** until 1836.
- The Catholic Church only ***admitted 1992*** that ***Galileo was right.***

How can I see the planets?

Mercury, Venus, Mars, Jupiter, Saturn

- Night sky apps for smartphones, reputable media & Astronomy websites; google upcoming events
- ***Brighter than most stars***, don't twinkle; ***along zodiac***
  - **Mercury:** closest to Sun, rises/sets just before/after Sun
    - ***Hard to see:*** only during twilight, close to horizon
  - **Venus:** brightest planet, close to Sun
    - ***"morning star"***, east, shortly before sunrise
    - ***"evening star"***, west, shortly after sunset
  - **Mars:** orange color, only bright when close to Earth
  - **Jupiter:** second brightest planet
    - Can see ***Galilean moons*** with small telescope
  - **Saturn:** dimmer, can see ***rings*** with small telescope

Great Conjunction of Saturn (upper right) and Jupiter (lower left), two days before 12/21/2020. (Credit: Bautsch, public domain, Panasonic DC-G9, 0.2s exposure, f/6.3, ISO speed 200, focal length 364 mm)