

## Lecture 4: Geocentric Universe

- Earth was thought to be the center of the universe until only a few centuries ago!
- Man has been around for millions of years
- Our scientific revolution began only a few thousand years ago
- The origins of the Scientific Method are in the Natural Philosophy of the ancient Greeks



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## Scientific Method

- The Greek philosophers were mainly interested in the logical consequences of pure thought
- They studied the properties of an ideal universe
- Observations of imperfect reality were generally thought to be useless
- This changed a bit when Aristotle (384BC – 322BC) first used the Scientific Method: Observation, Theory, Prediction, Testing



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## Aristotle

- He noted that the Earth's shadow (as projected onto the Moon during a lunar eclipse) is curved
- He theorized that the Earth must therefore be round
- He predicted that bright stars would have different positions in the sky depending on the latitude of the observed
- This prediction was confirmed by observations



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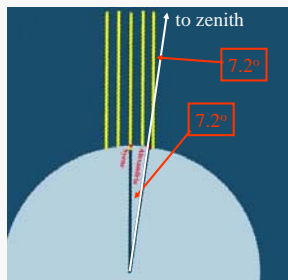
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## Earth's Radius

- Eratosthenes (276BC – 194BC) used Aristotle's geometrical approach to measure the radius of the Earth

- The angle between the zenith and the Sun at noon on June 22 is 7.2 degrees as observed from Alexandria, Egypt
- On the same day, the Sun is exactly at the zenith (at noon) in Syene, which is 5000 stadia to the north of Alexandria



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## Earth's Radius

We can combine the 5000 stadia distance from Syene to Alexandria with the fact that the angle between the zenith and the Sun at noon on June 22 is 7.2 degrees in Alexandria to compute the Earth's radius using the relation

$$\frac{5000 \text{ stadia}}{2\pi R} = \frac{7.2^\circ}{360^\circ}$$

- This yields for the radius of the Earth  $R = 39,789$  stadia
- Converting to kilometers gives the result  $R = 6,366$  km since there are 0.16 km/stadium

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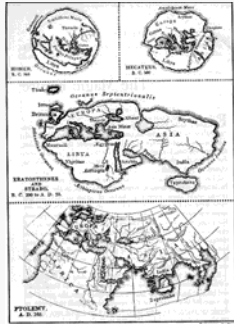
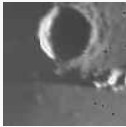
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## Earth's Radius

The calculation yields for the Earth's radius 39,789 stadia, or 6,366 km

Modern satellite observations give 6,378 km, which is extremely close to the value obtained by Eratosthenes



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## Planetary Motions

- To the Greeks, the motions of the stars, Sun, and Moon could be understood in terms of the geocentric universe
- The planets ("wanderers") created some problems with this idea because their motions are complex
- The motion of the planets relative to the stars is usually in the eastward direction each sidereal day

• But sometimes it was retrograde (westward) relative to the background stars



• [Retrograde motion of Mars](#)

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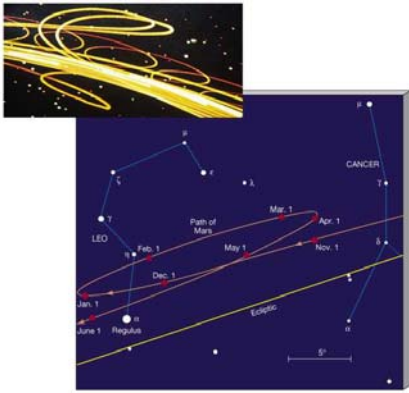
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## Geocentric Universe

- The Earth was assumed to be at the center of the universe, according to the ideas of Aristotle. Why did they believe this?
  - REASON #1: The Earth doesn't feel like it's moving.
  - REASON #2: Wouldn't there be a strong wind if the Earth moved quickly around the Sun?
  - REASON #3: Why do we see no stellar parallax if the Earth moves around the Sun?



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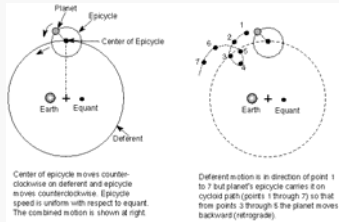
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## Ptolemy's Model

- Following the "perfect universe" ideas of Aristotle, Ptolemy (150AD) constructed an Earth-centered model of the universe using only perfectly circular motions
- To explain planetary motions while keeping Earth at the center and using only circles required epicycles




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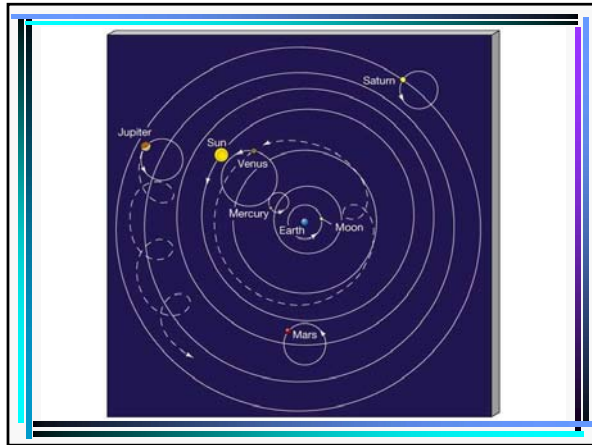
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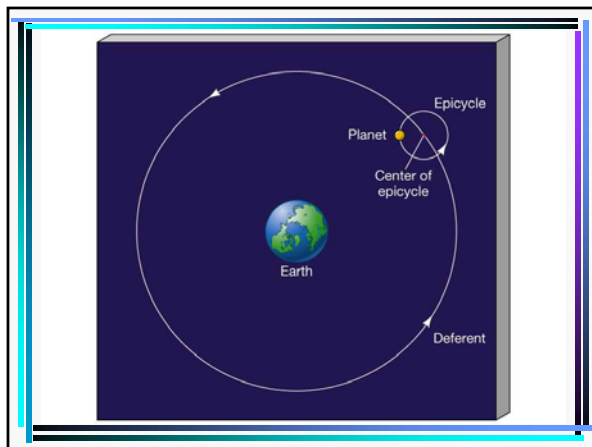
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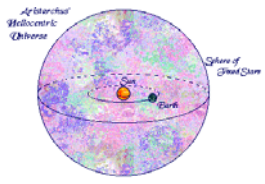
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## Ptolemy's Model

- Aristotle promoted the Earth-centered universe in 350 BC
- Not all Greek philosophers agreed that the Earth was at the center
- Aristarchus thought the Sun was at the center in 250 BC, but was unable to overcome the influence of Aristotle's teachings
- Ptolemy constructed the most detailed geocentric model in 140 AD



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## Ptolemy's Model

- Ptolemy's model had some strengths:
  - Provided a satisfactory description of the motions of the Sun, Moon, and planets
  - Achieved considerable predictive power
  - Was a coherent model with consistent principles
  - In accord with the established scientific doctrine of the time



[Ptolemaic animation](#)

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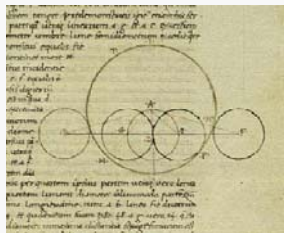
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## Ptolemy's Model

- Ptolemy's model needed to be continually updated and modified by astronomer-priests to maintain agreement with the latest observations of planetary motion
- This ultimately required 80 circles and nested epicycles, which was extremely complex and unwieldy



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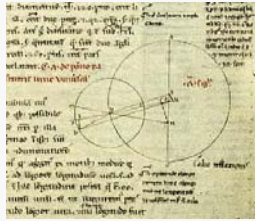
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## Copernican Revolution

- Over time, the observations became more and more precise
- Eventually, it became impossible to “adjust” the model of Ptolemy to maintain agreement with the new observations
- The Ptolemaic model ultimately failed to account for the observed motions of the heavenly bodies...

Detail from Ptolemy's Almagest



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## Copernican Revolution

- The rise of the Scientific Method led to the overthrow of Ptolemy's model
- The Renaissance sparked a transition from the passive acceptance of religious dogma and static beliefs to critical thinking and observational testing
- There was new interest in the nature of the physical world around us, rather than the “perfect universe” of the Greek's
- This is the time of Leonardo da Vinci (1452-1519)



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## Copernican Revolution

- At that time, Nicholas Copernicus was the latest astronomer/priest working on the Ptolemaic model, to improve its agreement with observations
- In 1500 AD, Copernicus was trying to add a few more epicycles to the model...
- He realized, to his horror, that it could not be done!
- This is like “check-mate” in a game of chess
- The scientific method led Copernicus to abandon his geocentric view!



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## Copernicus (1473-1543)



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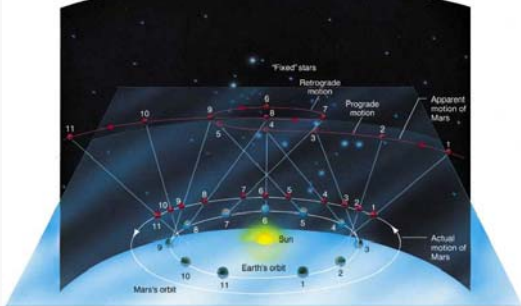
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## Same Sidereal Time



Copernican animation

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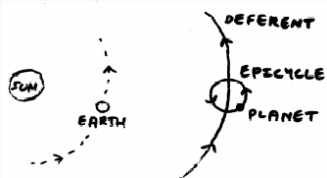
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## Copernican Revolution

- What motivated Copernicus?
  - The Heliocentric (Sun-centered) model is much simpler
  - It agreed better with the observational data
  - The perfect geometry of circles was retained, and there were still a few SMALL epicycles needed
  - But, the epicycles were NOT necessary to explain the retrograde motions of the planets



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### Copernican Revolution

•Foundations of the Copernican Revolution:

- 1. "Celestial Spheres do not have one common center" – the Earth is not at the center of all motions in the heavens
- 2. "The Earth is the center of gravity and of the lunar orbit" -- the Moon clearly orbits around the Earth
- 3. "All the spheres (planets) revolve around the Sun" – including the Earth
- 4. "The stars are much, much farther away from the Earth than is the Sun" – therefore stellar parallax was undetectable, until the invention of the telescope

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### Copernican Revolution

•Foundations of the Copernican Revolution:

- 5. "The stars appear to move, but this is really due to the Earth's daily rotation about its axis" – explains diurnal motion
- 6. "The Sun is motionless, but appears to move due to the Earth's daily and yearly motions" – explains seasonal and daily motions of the Sun
- 7. "The retrograde motion of the planets is due to the motion of the Earth and planets around the Sun" – this is the modern understanding of retrograde motion

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### Direct Motion

• Planetary motion is usually in the eastward sense relative to the stars (viewed every 24 sidereal hours)

• Retrograde (westward) motion was a problem for Ptolemy's model

• Copernicus explains it in a natural way

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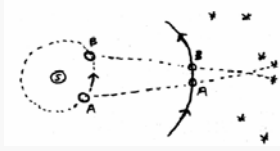
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## Retrograde Motion

- During retrograde motion, planets appear to move westward relative to the stars (viewed every 24 sidereal hours)
- In the model of Copernicus, this happens when inner planets "overtake" outer planets
- The inner and outer planets all show this phenomenon



[Animation of retrograde motion of Venus](#)

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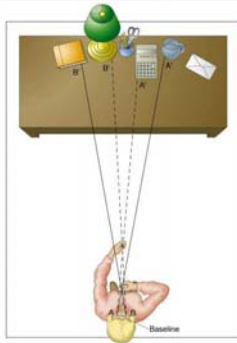
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## What is Parallax?



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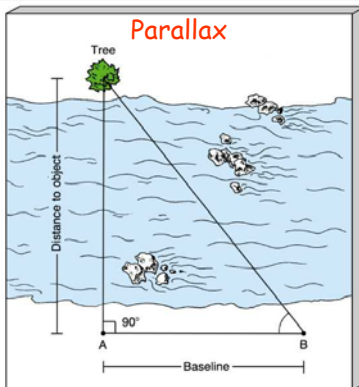
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## Parallax



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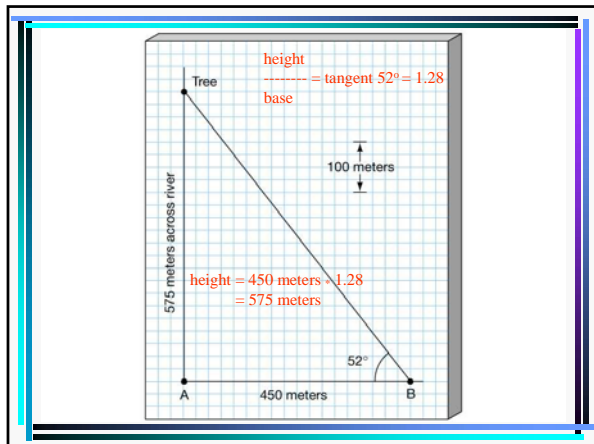
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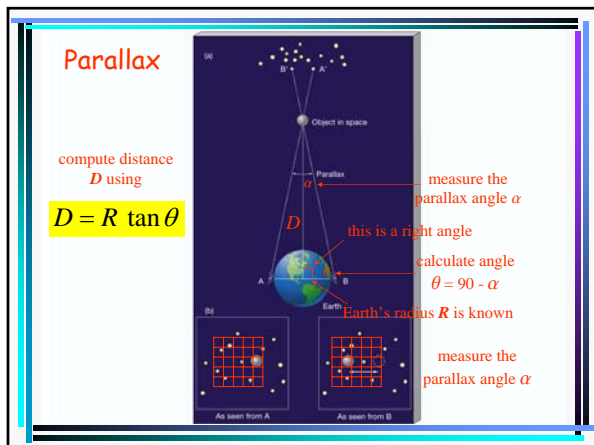
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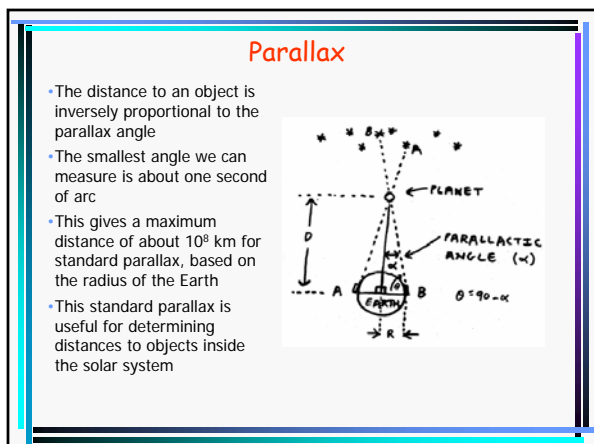
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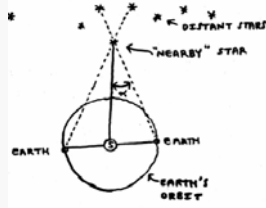
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## Stellar Parallax

- The maximum distance can be increased by increasing the base of the triangle
- This can be accomplished using the orbit of the Earth
- The Stellar Parallax method gives a maximum distance of about  $10^{13}$  km, or a few light years
- A Stellar Parallax of one second of arc gives a distance of one parsec, or about 3.3 light years




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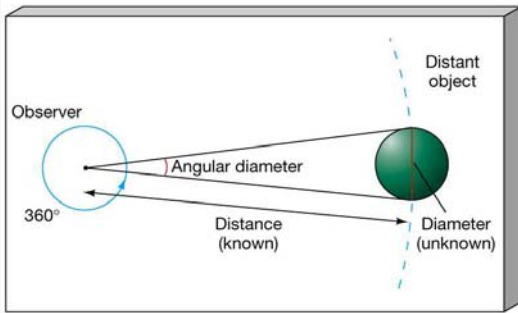
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## Size Determination




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## Copernican Revolution

- Copernicus was published De Revolutionibus in Latin in 1543
- Tycho Brahe (1580) made naked-eye observations of the planetary positions for several decades
- Galileo built the first astronomical telescope in 1609, beginning the era of modern observational astronomy




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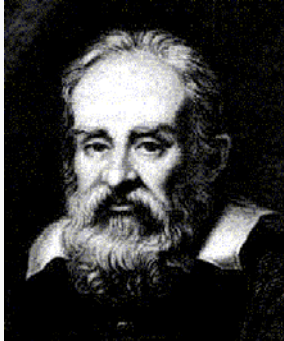
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### Galileo (1564-1642)



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### Galileo's Contributions

- Made first telescopic observations of the sky (1609)
- His observations included the discovery of sunspots:



DARK SPOTS  
ON SUN



IRREGULAR  
LUNAR  
SURFACE

- He used observations of sunspots to discover the rotation of the Sun, with a period of about one month



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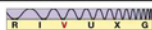
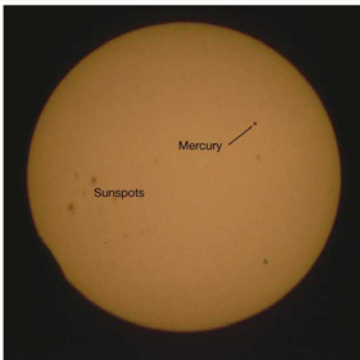
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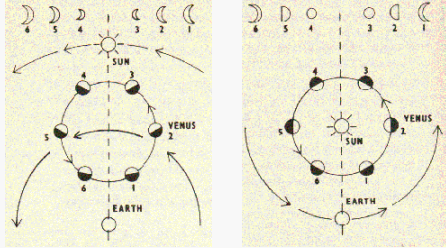
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### Galileo's Contributions

Galileo also observed the phases of Venus, and found that they were inconsistent with the Earth-centered model of Ptolemy



Ptolemaic model

Copernican model

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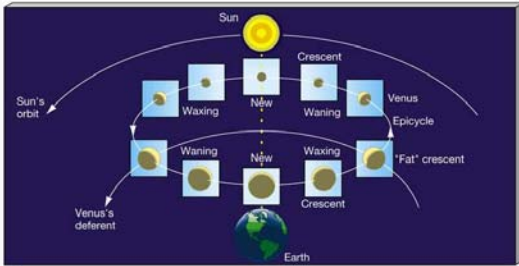
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### Phases of Venus - Ptolemy's Model



(b) [Animated Phases of Venus](#)

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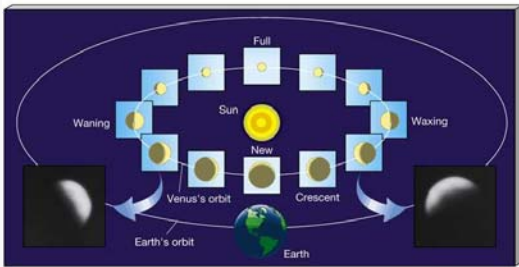
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### Phases of Venus - Copernicus' Model



(a) [Animated Phases of Venus](#)

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### Galileo's Contributions

- Galileo also observed the rough surface of the Moon



*Observatione Siderearum*  
1610

2. Jovis	○ ○ ○
3. Jovis	○ ○ ○
4. Jovis	○ ○ ○
5. Jovis	○ ○ ○
6. Jovis	○ ○ ○

- and the satellites of Jupiter




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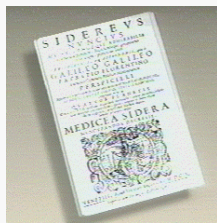
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### Galileo's Contributions

- His observations and ideas, influenced by Copernicus, conflicted with the natural philosophy of Aristotle, which was the basis for the teachings of the Church
- Galileo published his findings in "The Starry Messenger" in 1610
- This was at the time of the Inquisition...not a good time to be opposing the Church
- In 1616, he was judged a heretic, and Copernicus' book was banned!



The Starry Messenger

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### Galileo's Contributions

- Galileo was advised to speak cautiously about the Copernican model, as if it were not actually real
- In 1632, Galileo published "Dialogue Concerning the Two Chief World Systems"
- In this book, a clever person argues for the Sun-centered universe, and a fool argues for the Earth-centered model
- It was written in Italian, and the church was not pleased...



Cardinal Bellarmino



Galileo's book

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### Galileo's Contributions

Galileo faced the Inquisition in 1633, and was forced to drop his claim that the universe was heliocentric...



Upon confessing, he is said to have muttered "eppur si muove" ("and yet it still moves")

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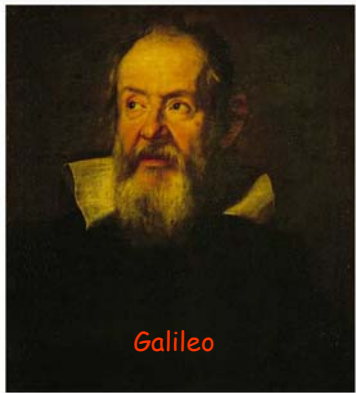
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Galileo

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