
**Astronomy 350L**

**(Spring 2005)**

# The History and Philosophy of Astronomy

**(Lecture 2: Antiquity I)**

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# Astronomy and Cosmology in Antiquity:

## → Two Threads of Thought

- Mainstream (orthodoxy) → Antiquity I (Jan. 20)
  - Plato, Eudoxus, Aristotle, Hipparchus, Ptolemy
  - Two-sphere-universe
  - Earth-centered (geocentric)
  - Planetary motion: in circles, deferent-epicycle

- Dissent (heterodoxy) → Antiquity II (Jan. 25)
  - Pythagoras, Democritus, Epicurus, Stoics, Aristarchus
  - Democritus (atomism) and Aristarchus (Sun-centered)
  - close to modern world view
  - but forgotten (suppressed) for 1,400 years

# Ancient Greece: The Birth of Science


6th cent. BC: Use geometry to address celestial motions

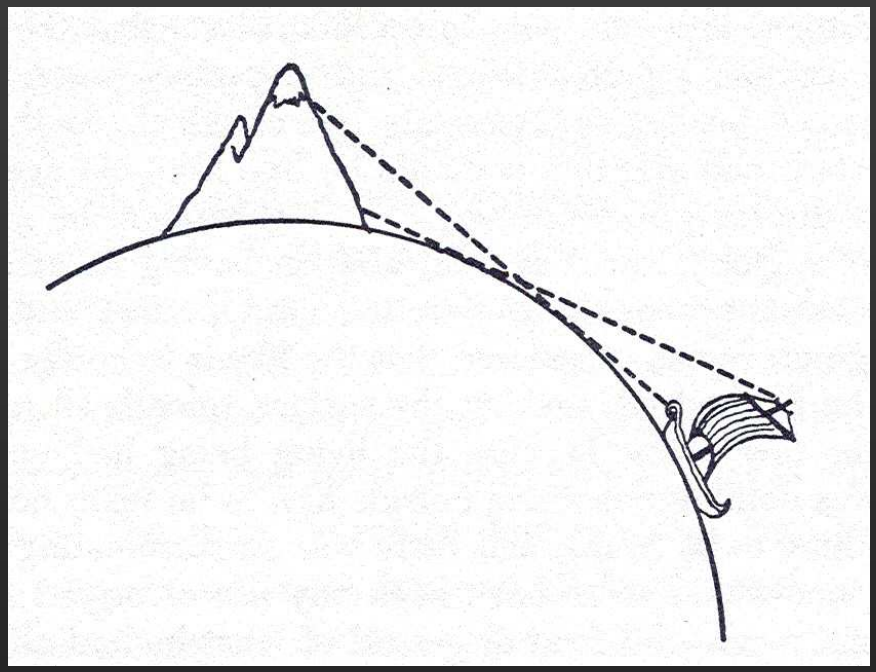
## Observing the Sky: The Basic Facts

(all with the naked eye!)

- Earth is a Sphere
- ***Daily*** motion of celestial sphere (stars)
- Stars don’t change their relative positions
- ***Annual*** motion of Sun with respect to stars
- Moon’ s motion w.r.t. to fixed stars
- Planets motion w.r.t. to fixed stars ***weird***

# Spherical shape of the Earth

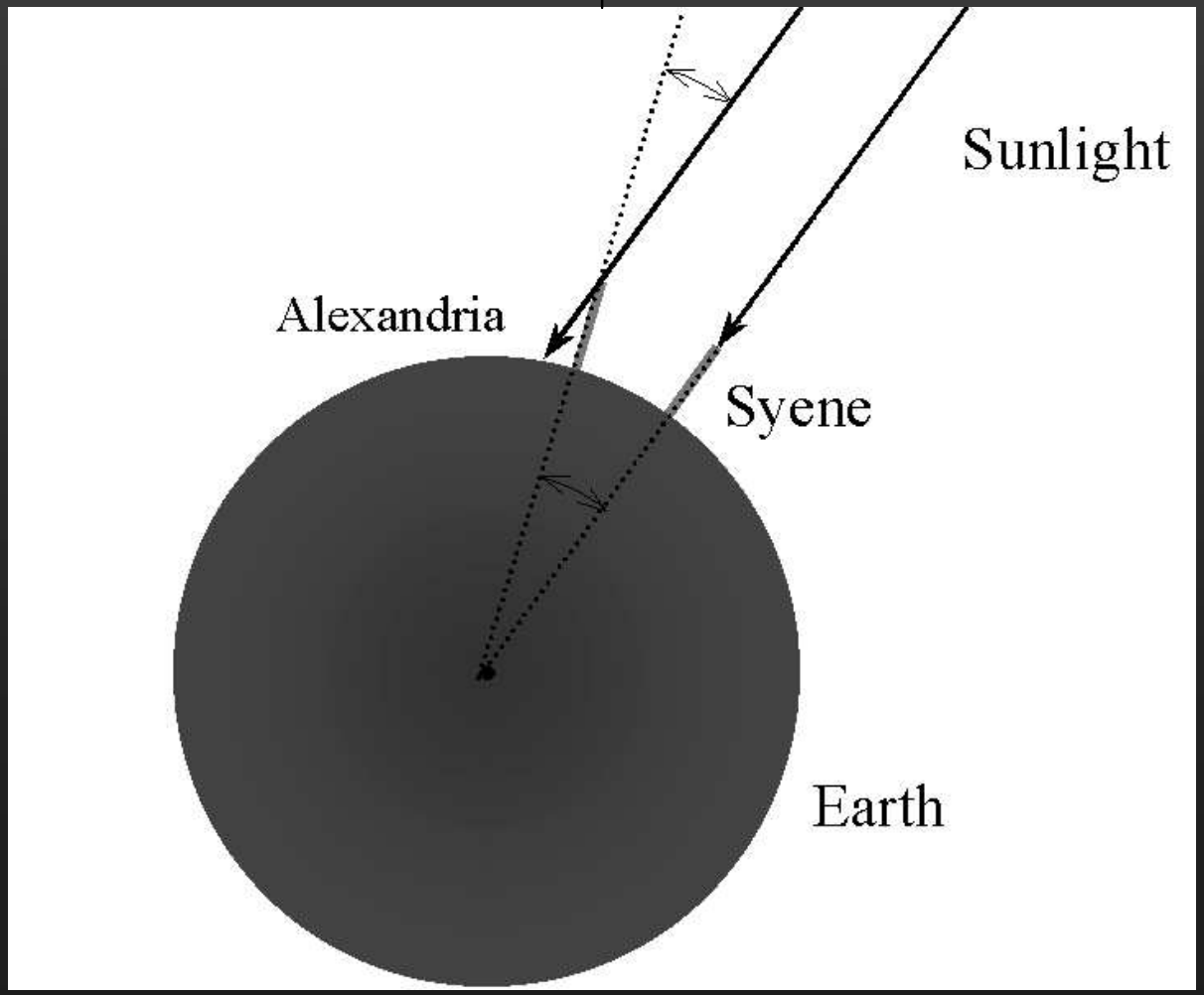
- Ships at sea



- Lunar eclipse: earth’s shadow circular
- Traveler’s Tales (e.g., recorded by Herodotus)

# Size of the Spherical Earth

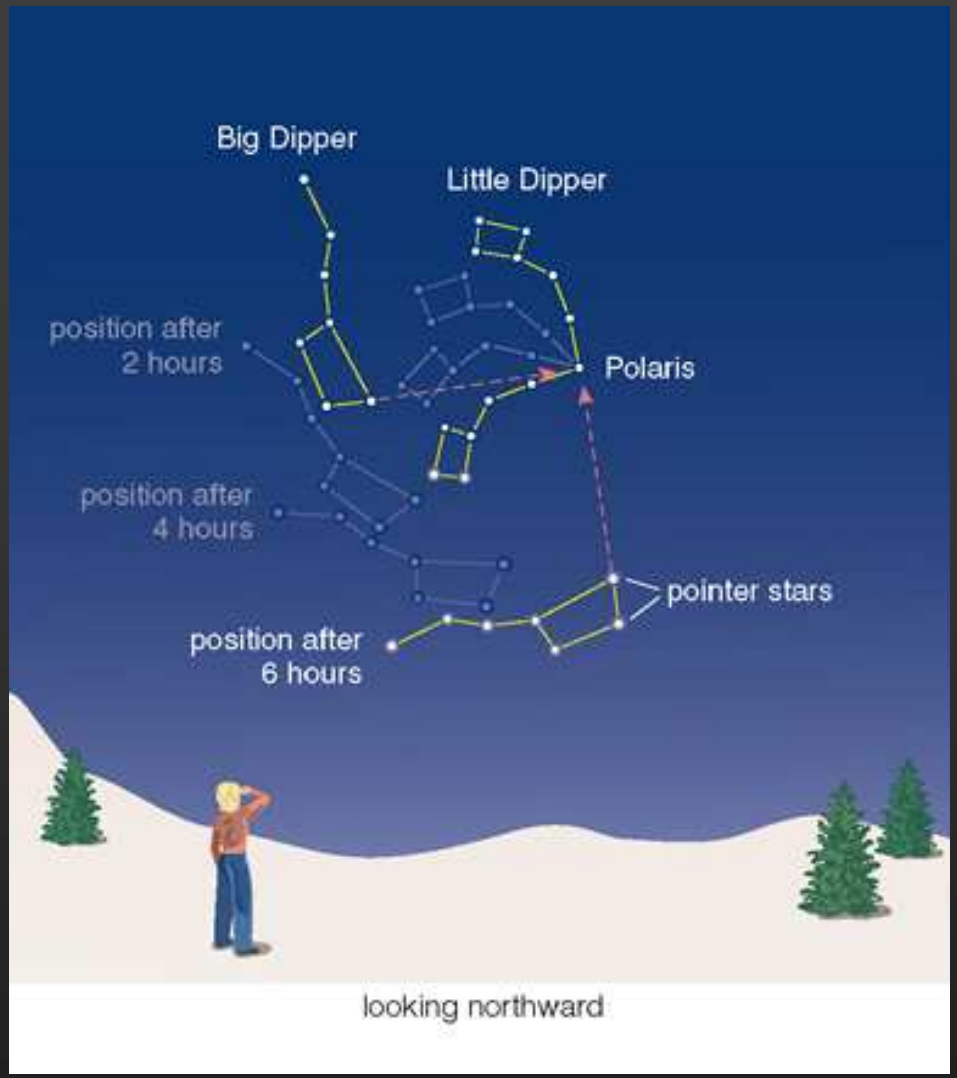
- Use geometry and common sense
  Eratosthenes (3rd cent. BC, Alexandria)




-7° = 800 km

-360° = 40,000 km

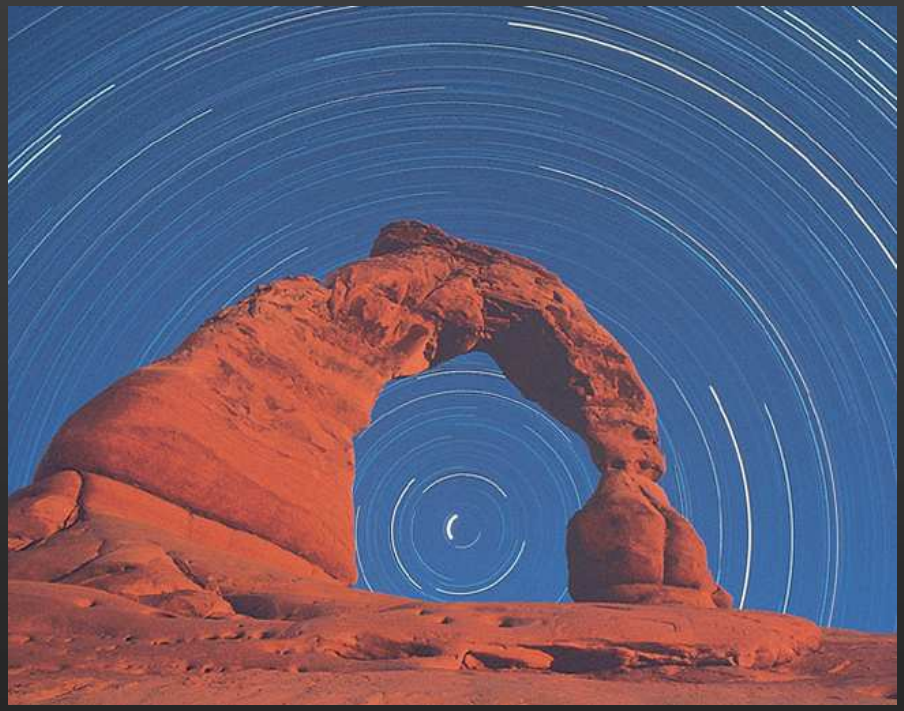
# Daily motion of the stars



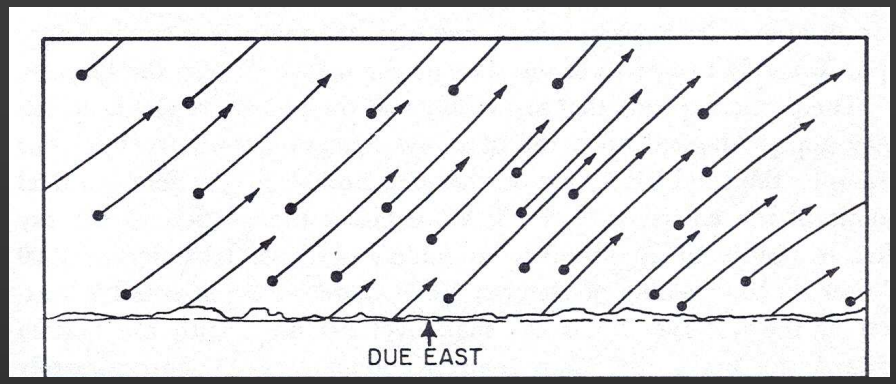

No change in relative positions → fixed stars

**Daily motion of the stars:**

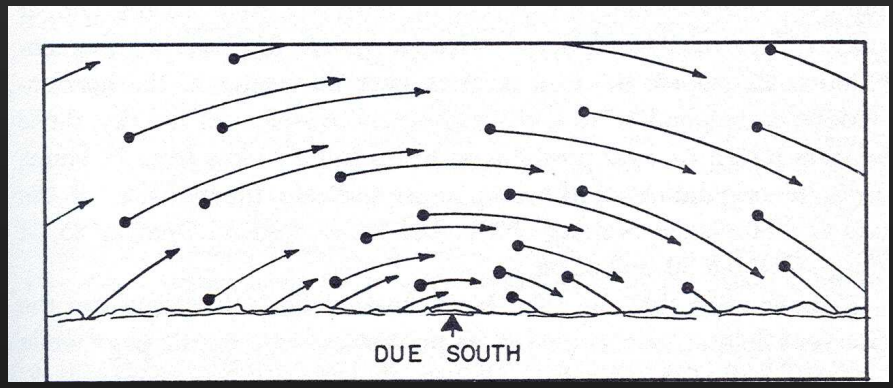
**Looks different in different directions!**



Due North



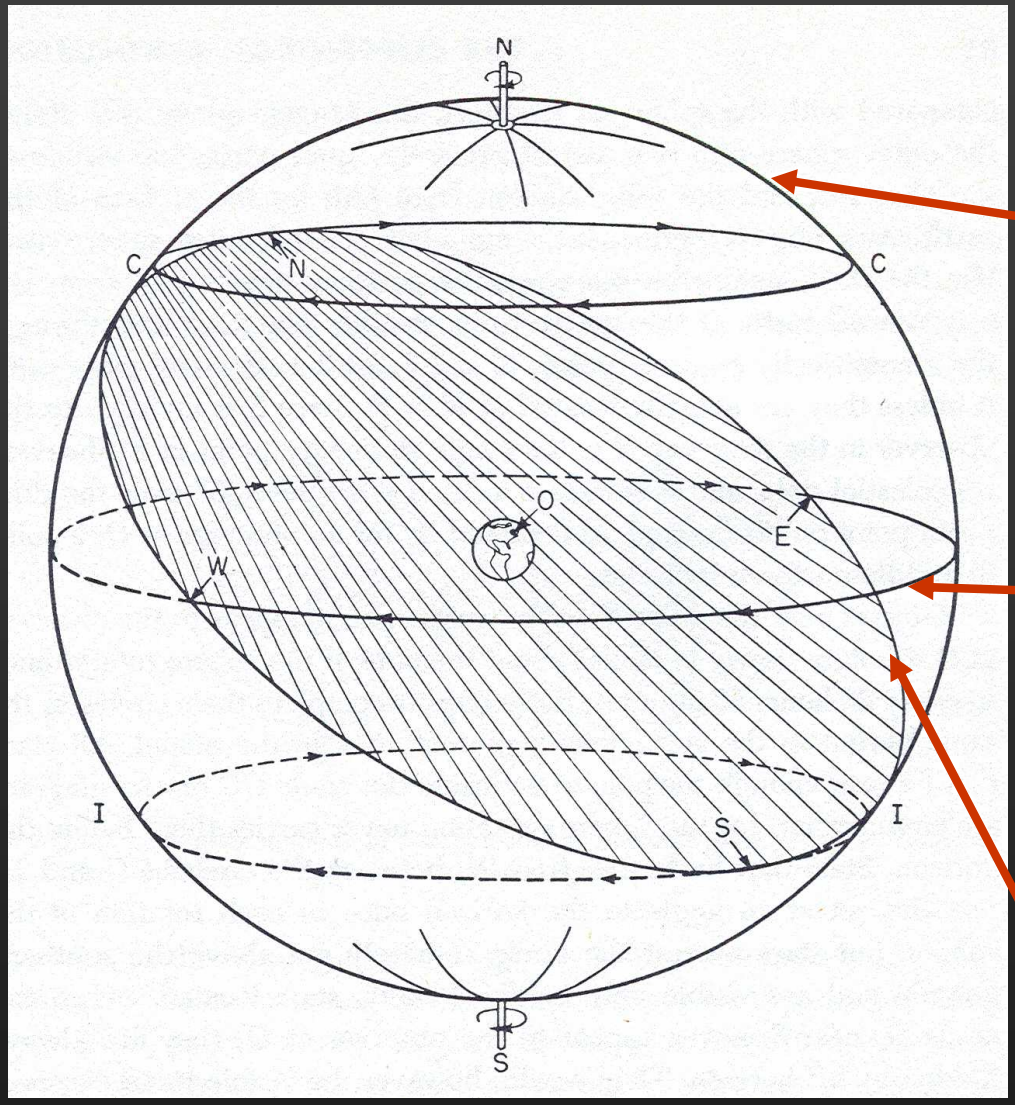

Due East




Due South

- Circumpolar stars

# Q: How to explain daily stellar motion???



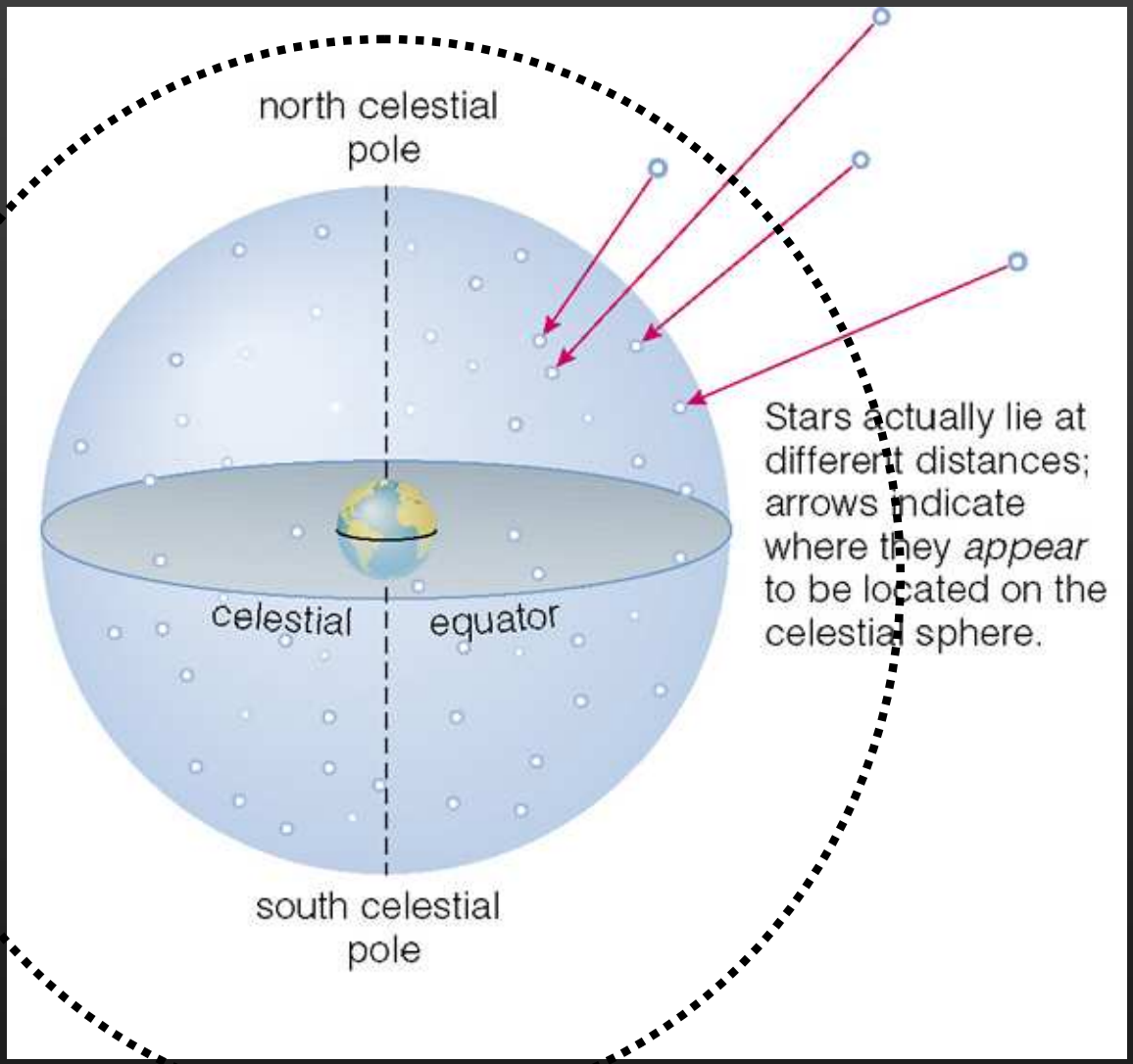

Celestial sphere
(contains fixed stars)

Celestial equator

Local Horizon
(every observer has own one!)

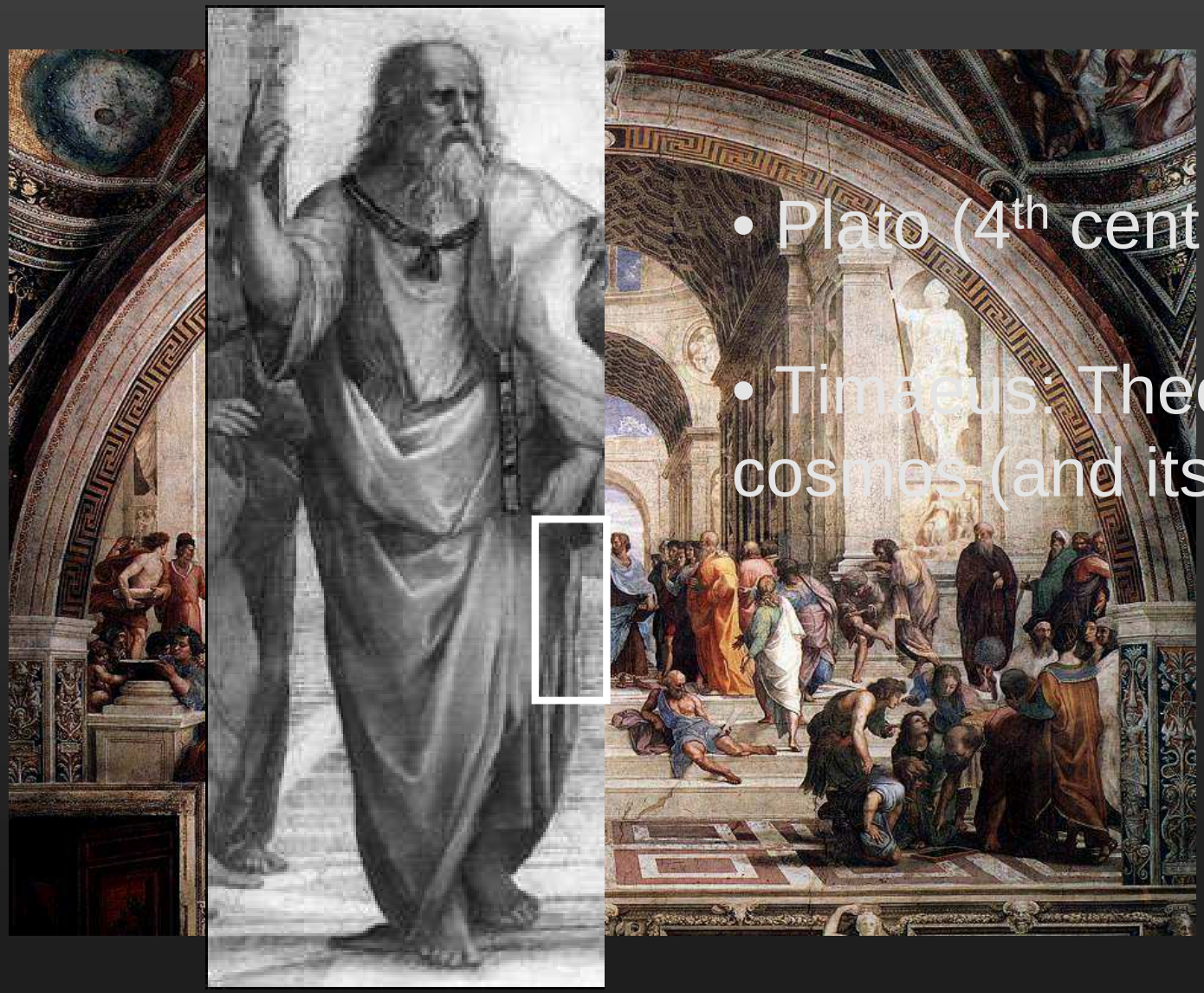
A: The Ancient Two-sphere-universe!

# Quick reminder: Why does concept of celestial sphere work (from our present-day perspective)?



**Ancient Two-sphere-universe:**

- Plato's philosophy demands that universe is spherical!



- Plato (4th cent. BC)
- Timaeus: Theory of the cosmos (and its creation)

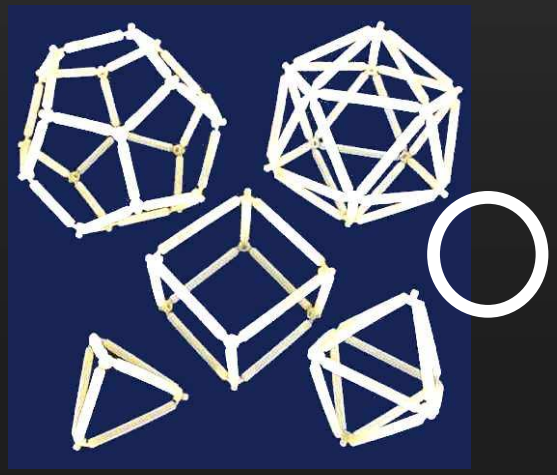
Plato’s philosophy demands that universe is spherical!

Q: How so?

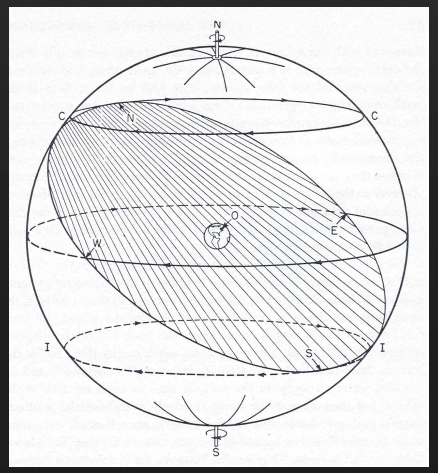
**Divine craftsman (Demiurge)**

(William Blake, 1757-1827)

## Realm of Ideas



## Realm of Experience

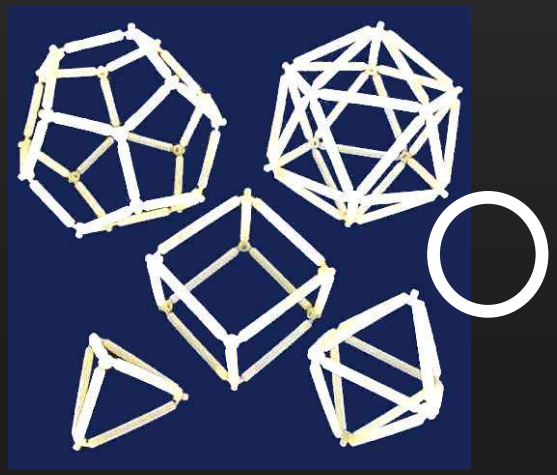


Plato's philosophy demands that all natural motion is uniform along circles!

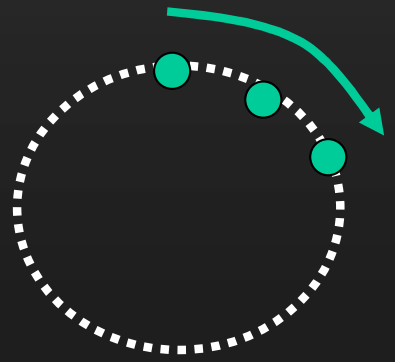
Divine craftsman (Demiurge)

(William Blake, 1757-1827)

Realm of Ideas



Realm of Experience



Uniform, circular motion

**Ancient Two-sphere-universe:**

- Next Q: What is rotating? Earth or Sphere of Fixed Stars???

Hypothesis: The Earth?

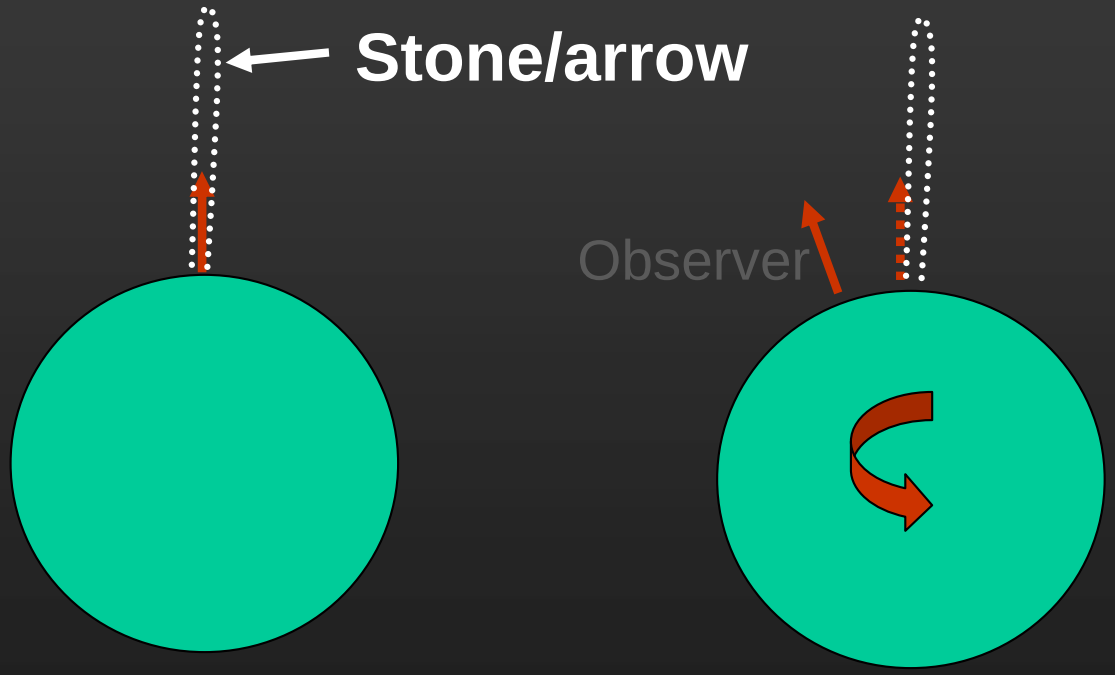
- actually proposed by Heracleides of Pontus (4th cent. BC)
- that obviously can explain observations (and we now know that it is true)

But: Why was this (correct) hypothesis rejected and rediscovered only ~2,000 years later?

## Ancient Two-sphere-universe:

Q: Why was rotating-Earth hypothesis rejected?

A: - Theory of motion (terrestrial physics → Aristotle)
- Common-sense (naïve expectation)




Greeks argued: Stone would be left behind if Earth rotated! (Think about why this argument is wrong!)

# Q: How do we know that Earth rotates?

A: Foucault’s pendulum (1851)!

**Ancient Two-sphere-universe:**

- Q: What is rotating? Earth or Sphere of Fixed Stars???

Greek's (incorrect) Answer: The Celestial Sphere!

Q: How could they have gotten this so wrong?

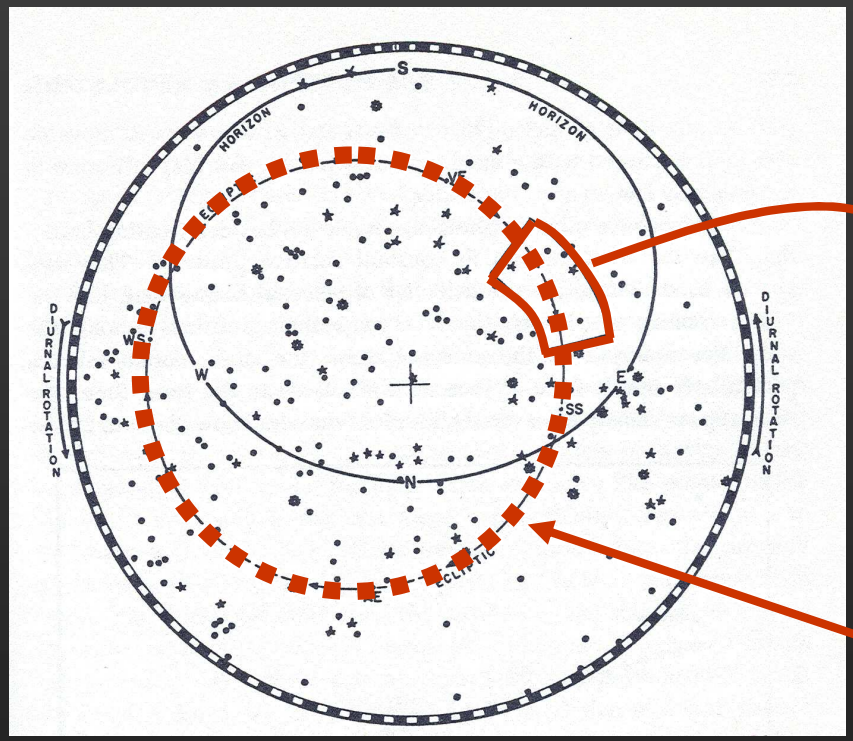
1. Conforms to naïve experience

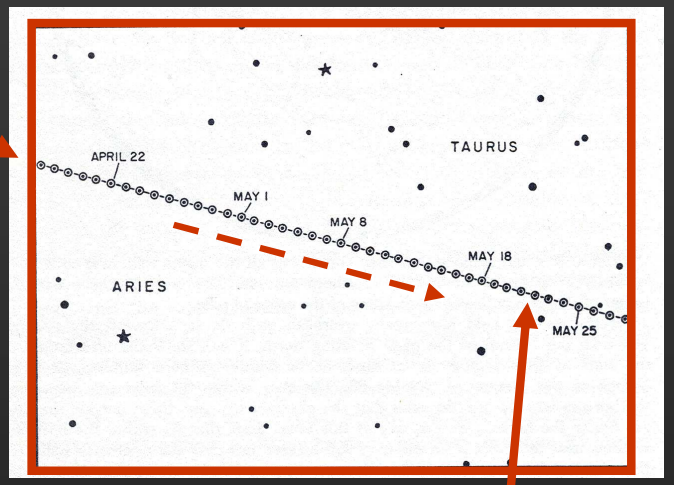
2. Elegantly explains many observations

3. Backed up by Aristotle → greatest authority for 2,000 years (`The Philosopher')

# Two-sphere-universe + stationary Earth:

→ **Nicely accommodates annual solar motion!**




Sun moves w.r.t. fixed stars along *ecliptic*!

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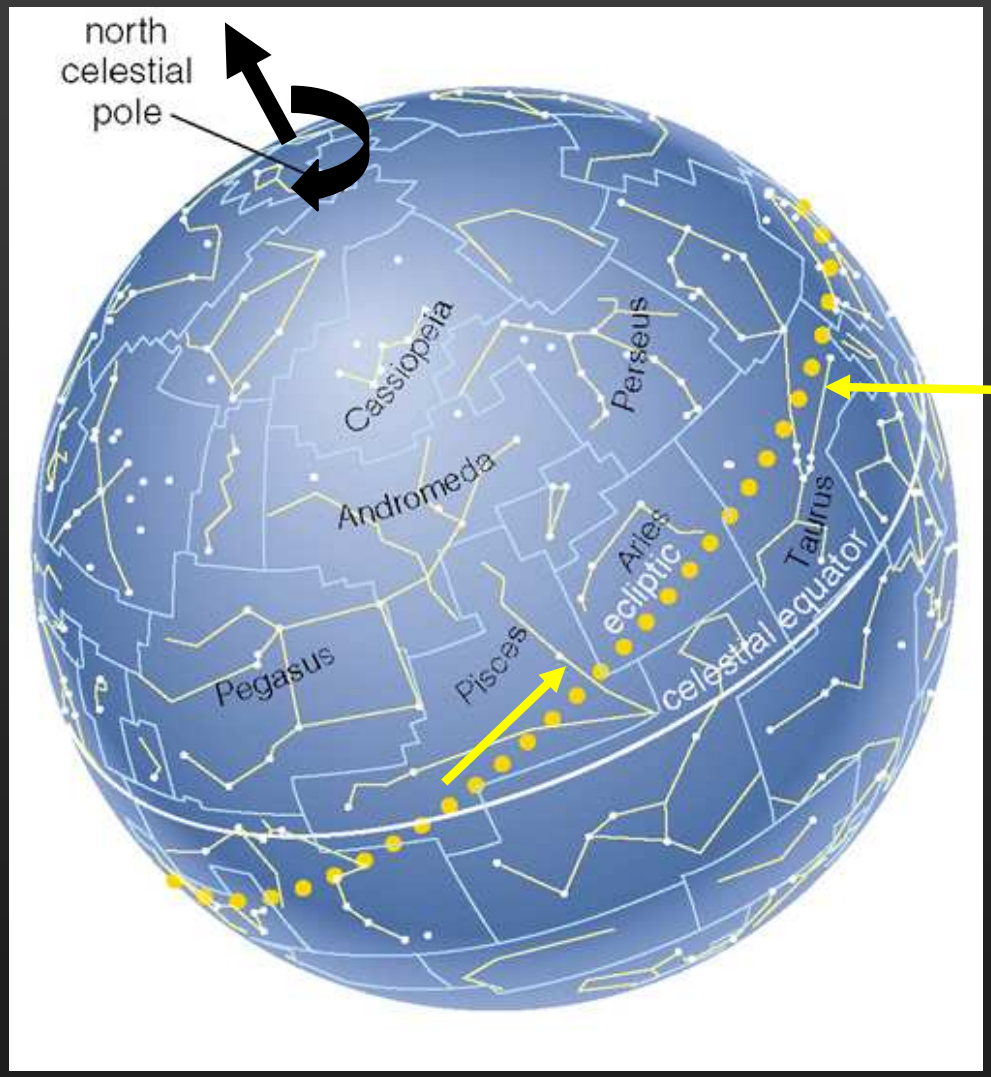


Sun moves along ecliptic once a year!

# Two-sphere-universe + stationary Earth:

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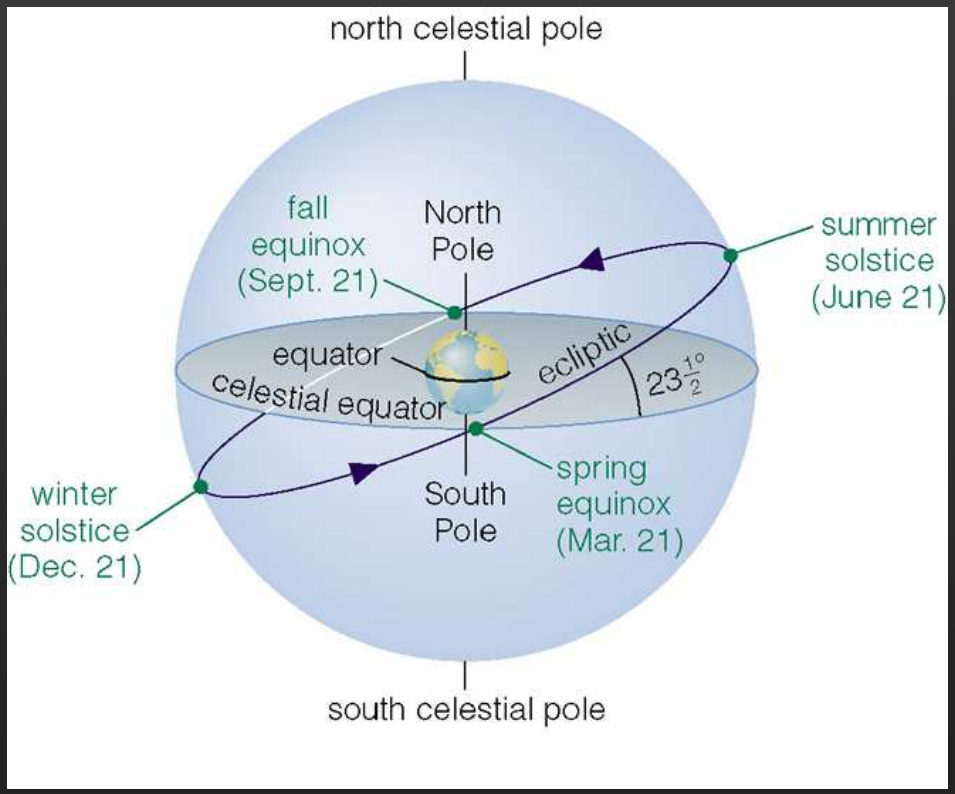
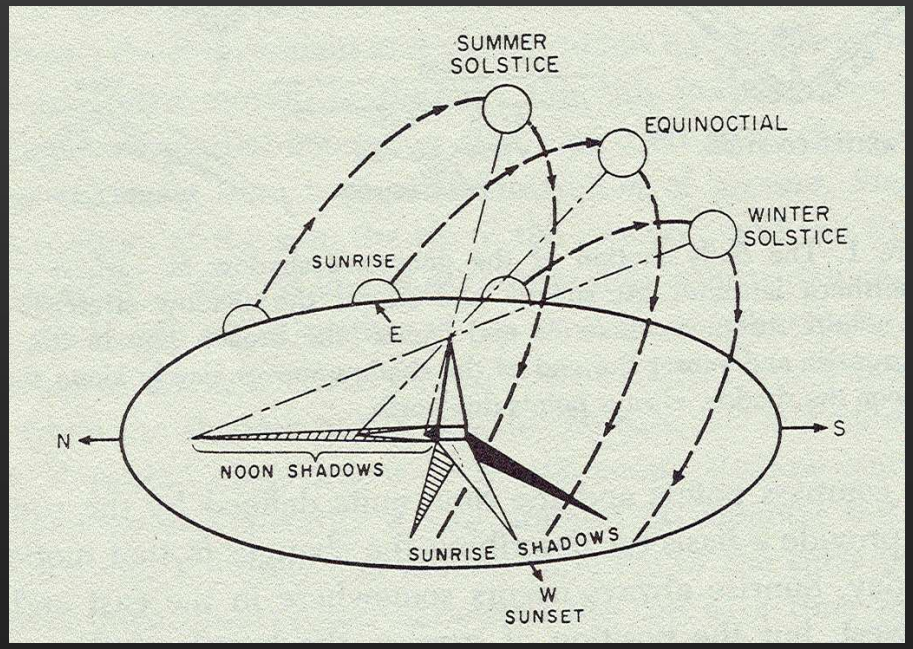
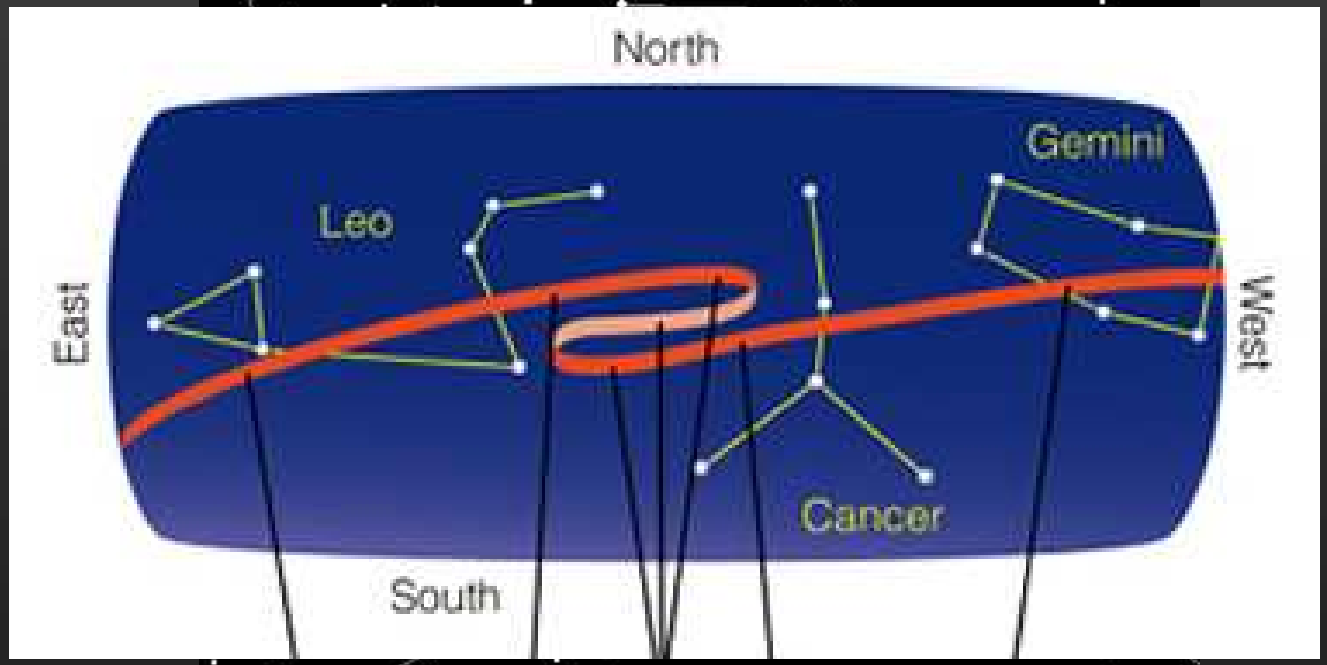


# Plato's Grand Challenge:

## How do planetary motions fit in?

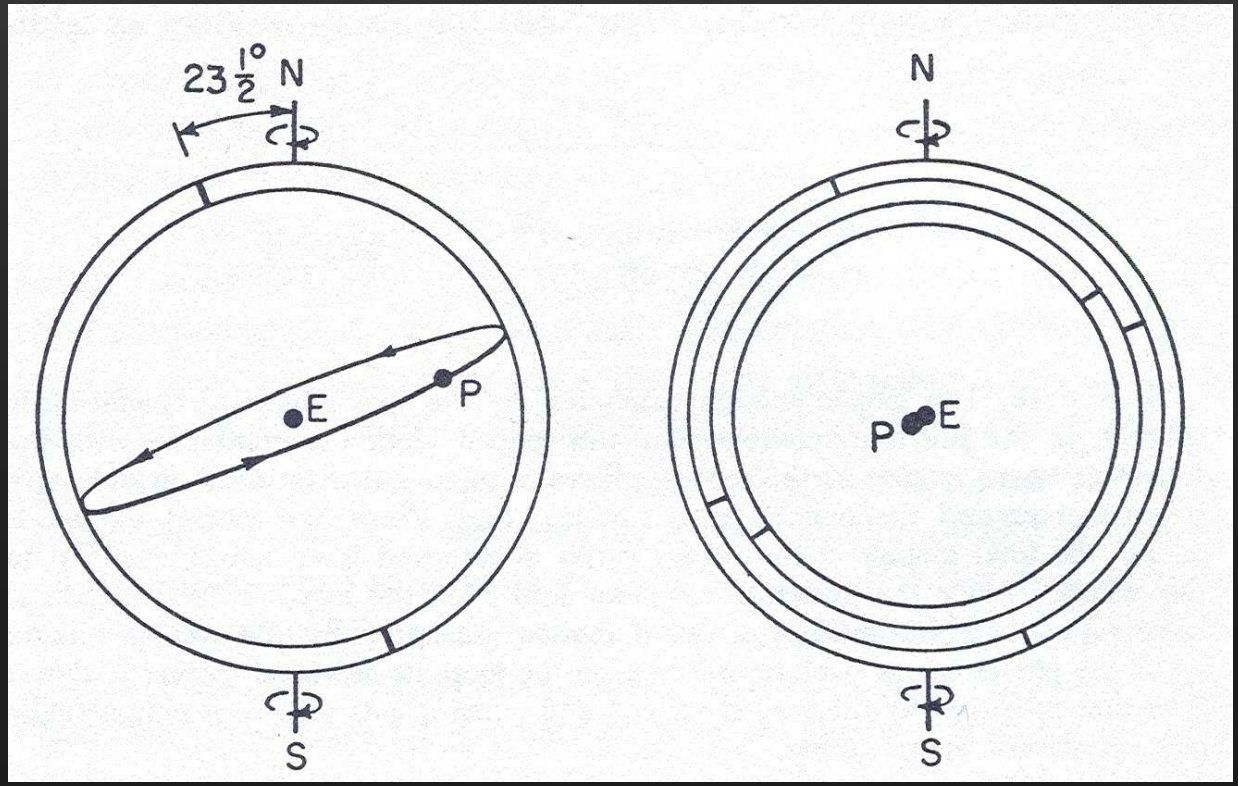



- Retrograde motion of planets, opposite direction to daily motion (E-W) of celestial sphere

# Plato's Grand Challenge:

## How do planetary motions fit in?

- First taken up by his pupil Eudoxus
  → founder of Greek mathematical astronomy
- Theory of homocentric spheres (all spheres have same Center)



## Plato's Grand Challenge:

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  → founder of Greek mathematical astronomy
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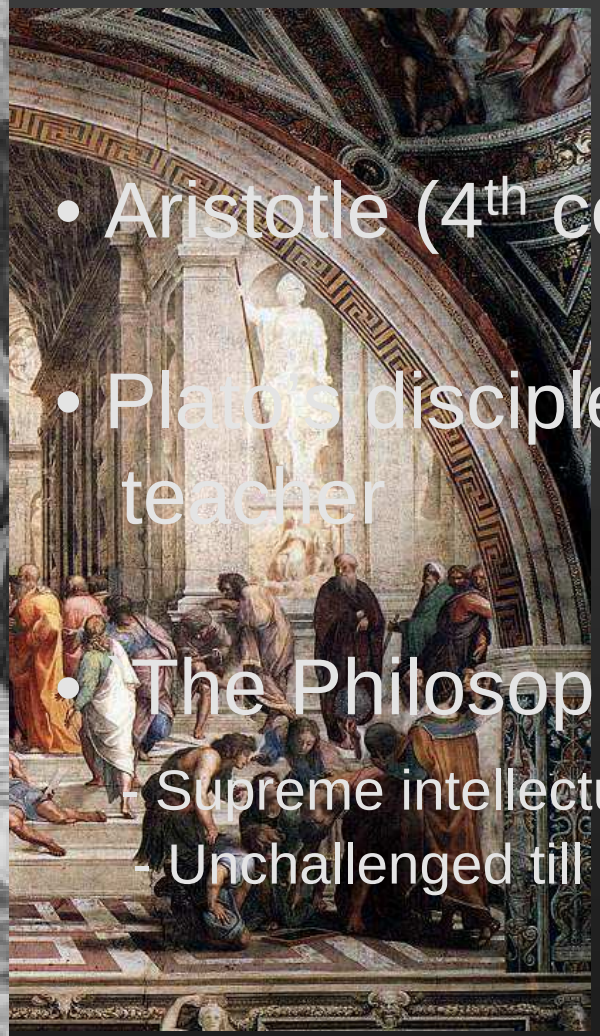
- A many-sphere universe!

- How to establish the order of spheres?
  - Order of planets (Earth, Sun, Moon, Mercury, Venus, Mars…)
  - What object is in the center?

**Ancient Two-sphere-universe:**

- Part of Aristotle's all-embracing, coherent worldview!



- Aristotle (4th cent. BC)
- Plato's disciple, Alexander's teacher
- 'The Philosopher'
  - Supreme intellectual authority
  - Unchallenged till Renaissance

**The Aristotelian Universe:**

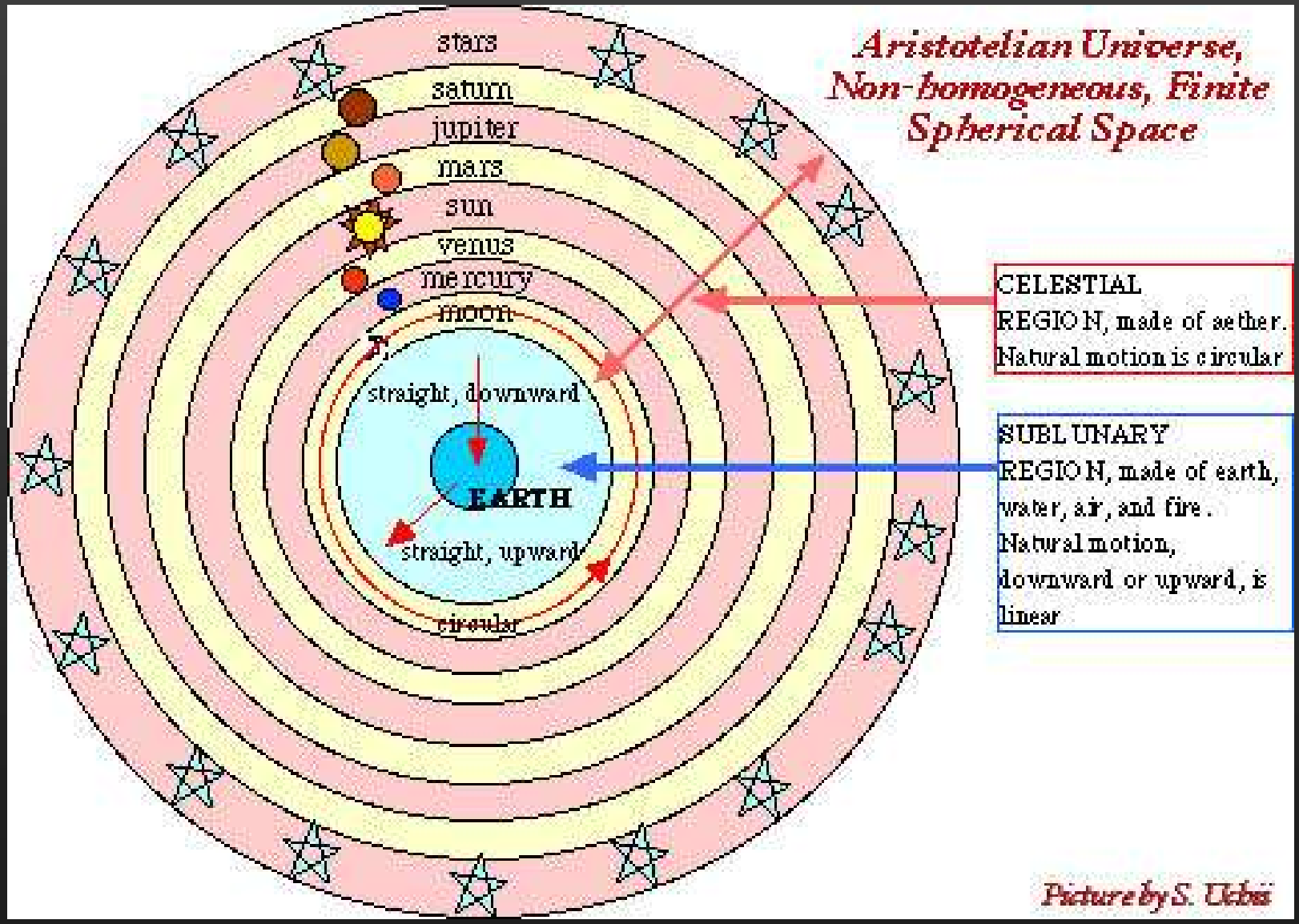
- Earth is in center!
- Planets, including Sun, move around earth, affixed to crystal spheres
- The Universe is finite, has edge
- Two distinct regions of the cosmos:
  (1) The Heavens (supralunar)
  - perfect, no change, circular motions
  (2) Terrestrial (sublunar)
  - change (turmoil), non-circular motions

**Reminder: How do we know that Earth moves?**

- from our modern (heliocentric) perspective


- Not observed (too small) until 1838 (Bessel)!

# The Aristotelian Universe:



**The Aristotelian Universe:**

- A coherent framework of all of nature
- Astronomical concepts tied up with terrestrial physics (theory of motion)
- Theory of gravity depends on Earth being in center of the universe!
- Finite universe, bounded by spherical edge
- There cannot exist a vacuum (plenum theory)
- Cosmos is eternal, guaranteed by spherical motion

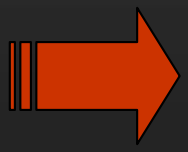
## The Aristotelian universe:

- Qualitative
  planetary m
- Greeks bef 323 BC)
  did not car
- Fundament my
  in the wake enistic Age)

# The Hellenistic Age: Alexander's conquest

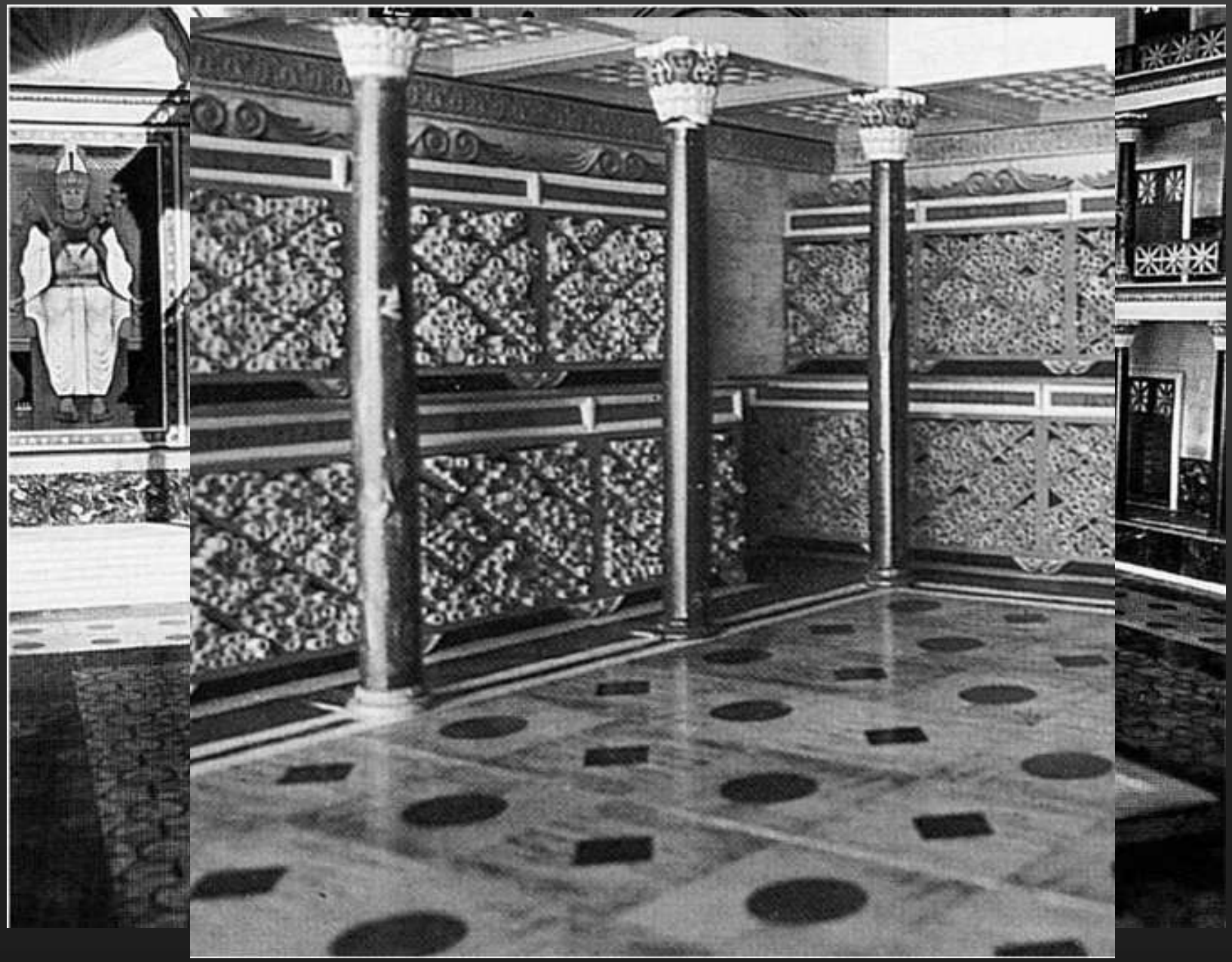
## The Hellenistic Age: Alexander's conquest

- Greece (before Alexander):
  - Science and philosophy
  - Disregard for empirical facts (observations)
- Babylon / Egypt:
  - No Science and philosophy
  - Wealth of data (observations)

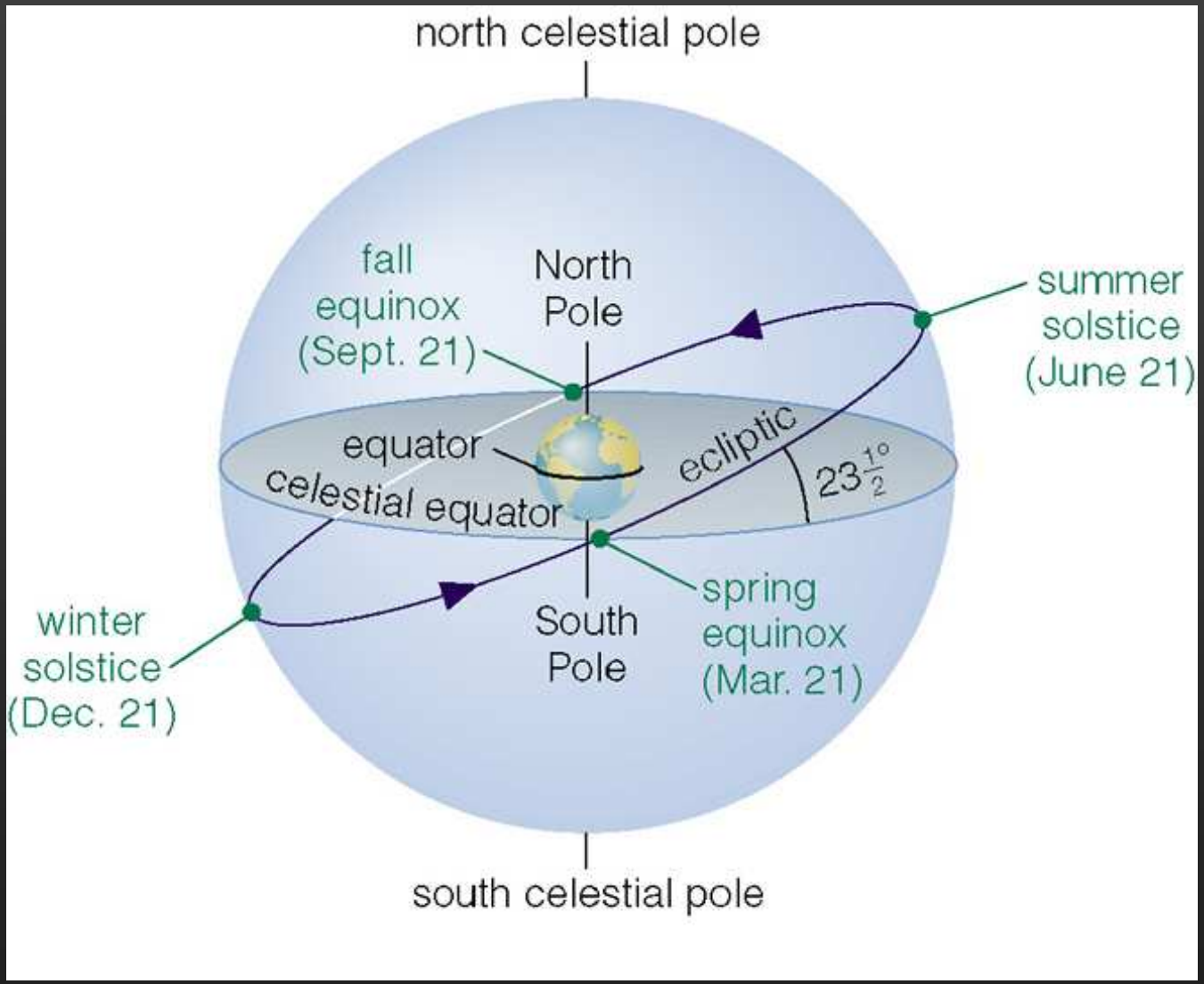


Birth of Hellenistic Astronomy:
- Quantitative, precision-driven
- based in Alexandria (Great library)
- Hipparchus, Eratosthenes, Ptolemy

# The Great Library in Alexandria



# Hipparchus (2nd cent. BC): Precession of the Equinoxes



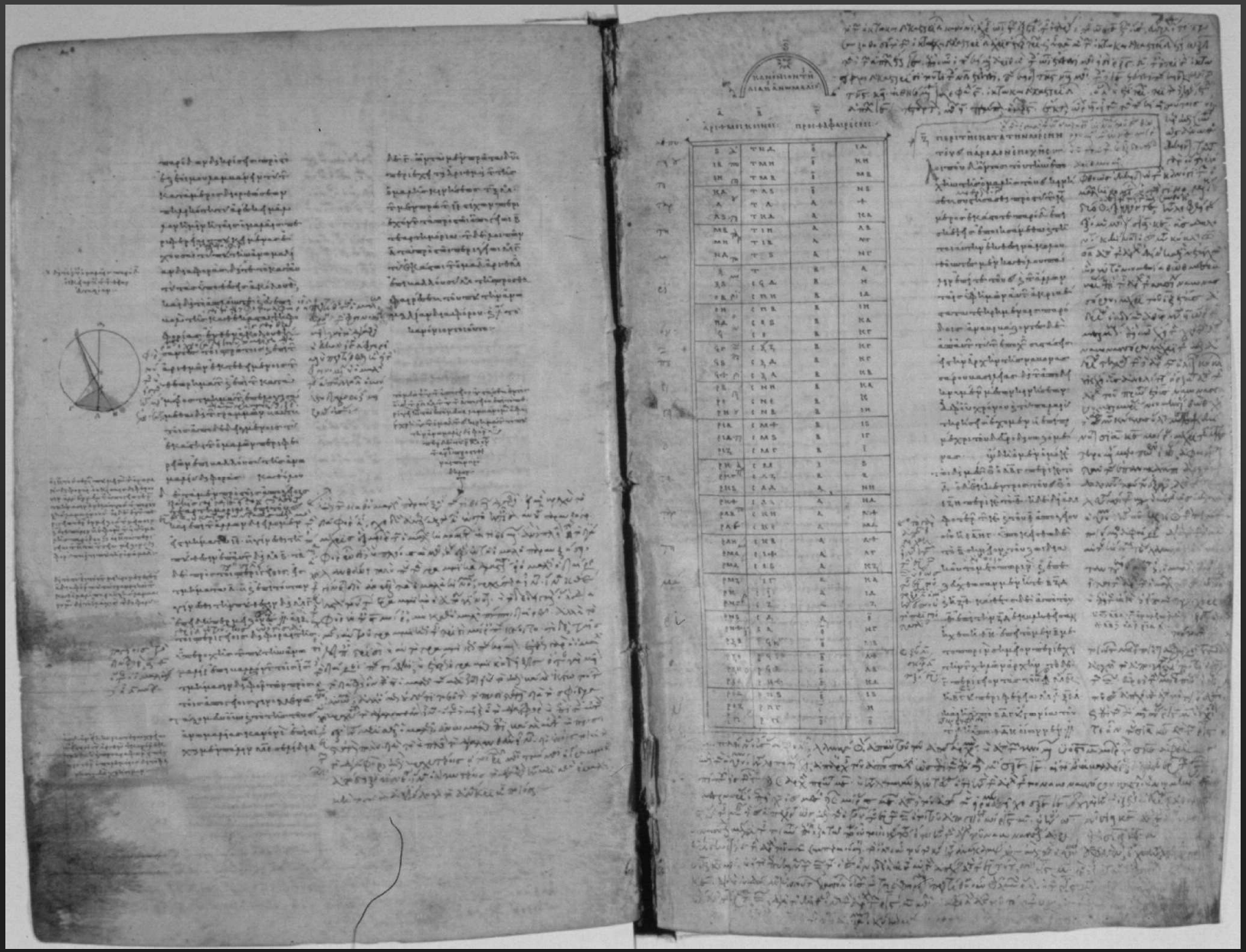

- slow movement (~26,000 yrs) of CE-ecliptic intersection

**The Ptolemaic System:**

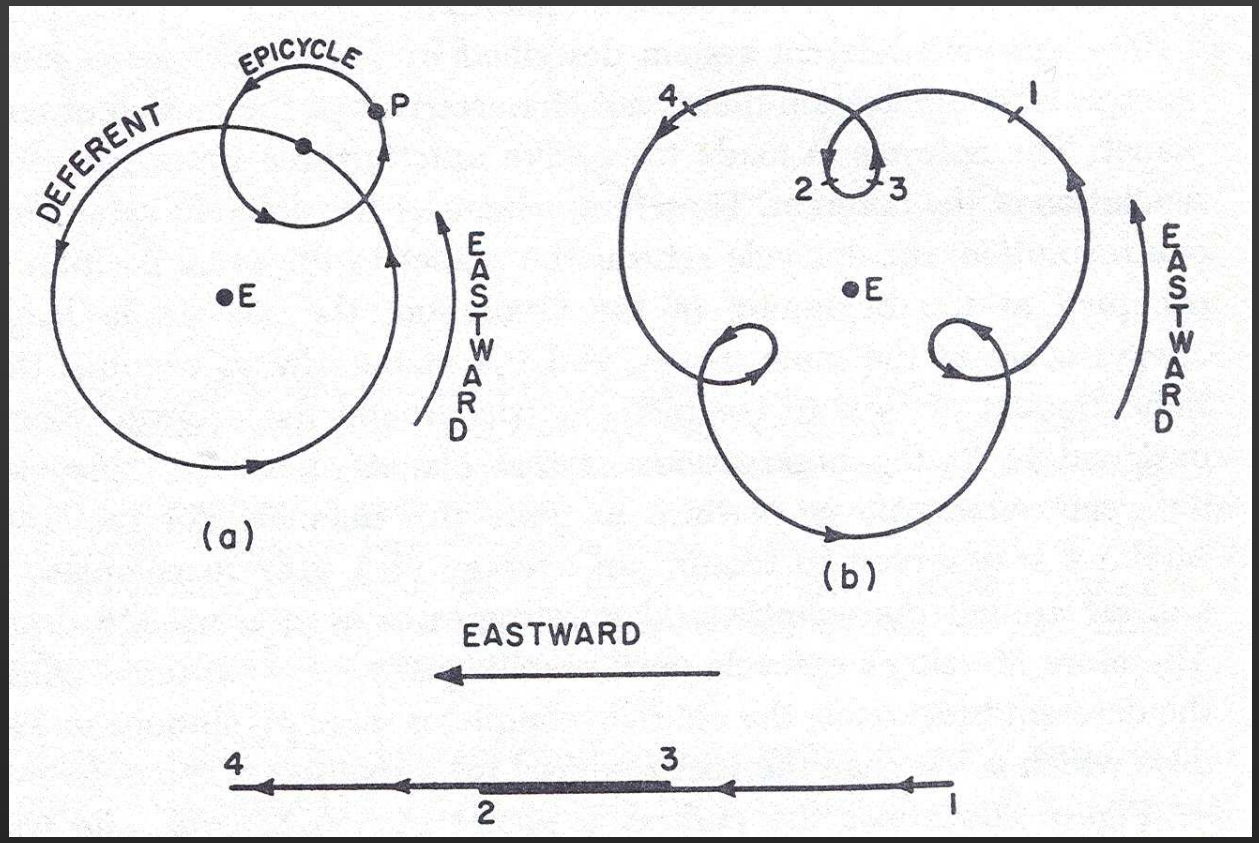
- Aristotelian, but dominated by mathematical precision!

- Ptolemy (2nd cent. AD)
- Greatest astronomer of antiquity
- 'Almagest' (150 AD)

# Ptolemy’s Almagest (Arabic), or Syntaxis:

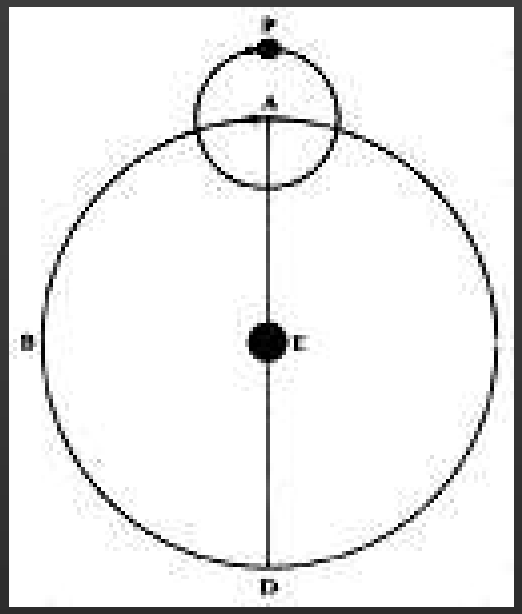


## The Ptolemaic System:

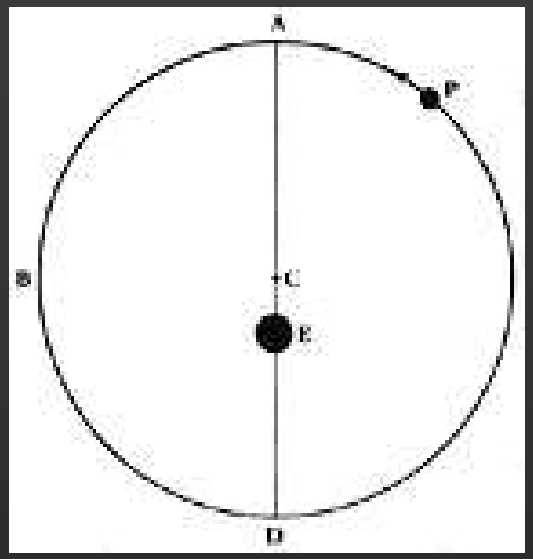



- Circles within circles (deferent/epicycle)
- Designed to *precisely* explain planetary motions

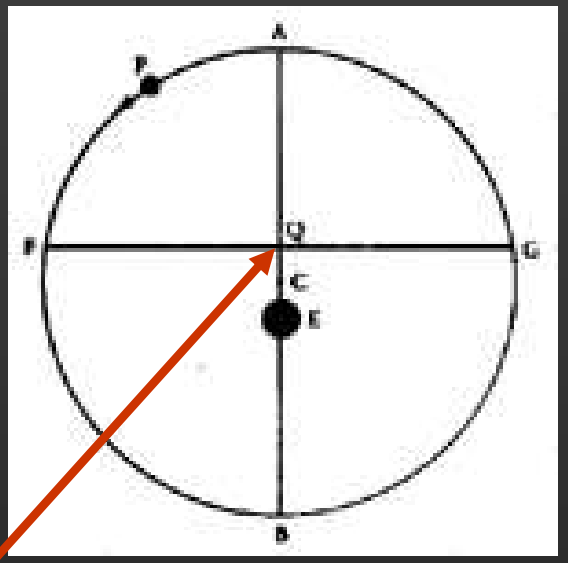
# The Ptolemaic System: Basic Building Blocks




a) deferent/epicycle




b) eccentric

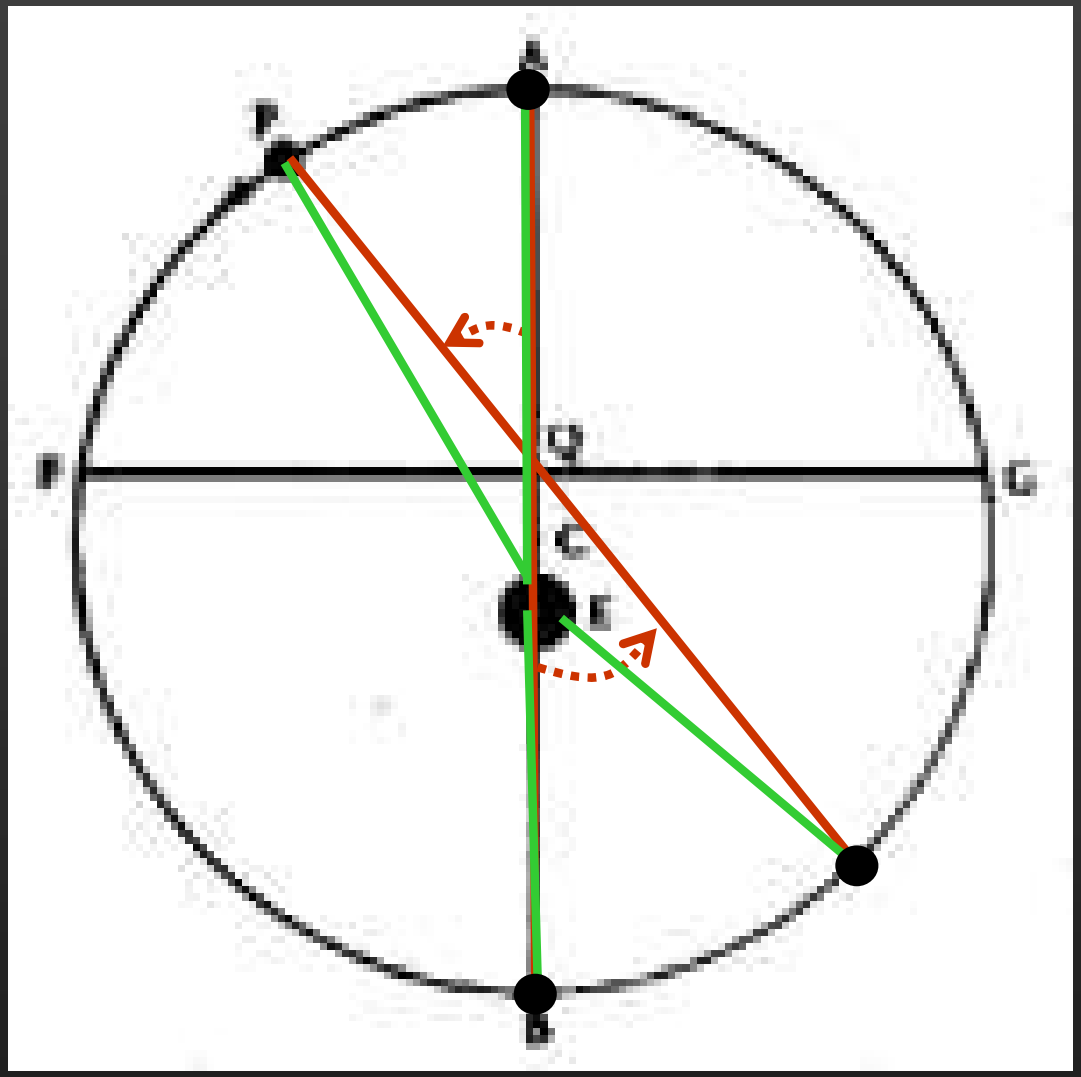



c) equant

E = Earth
P = Planet

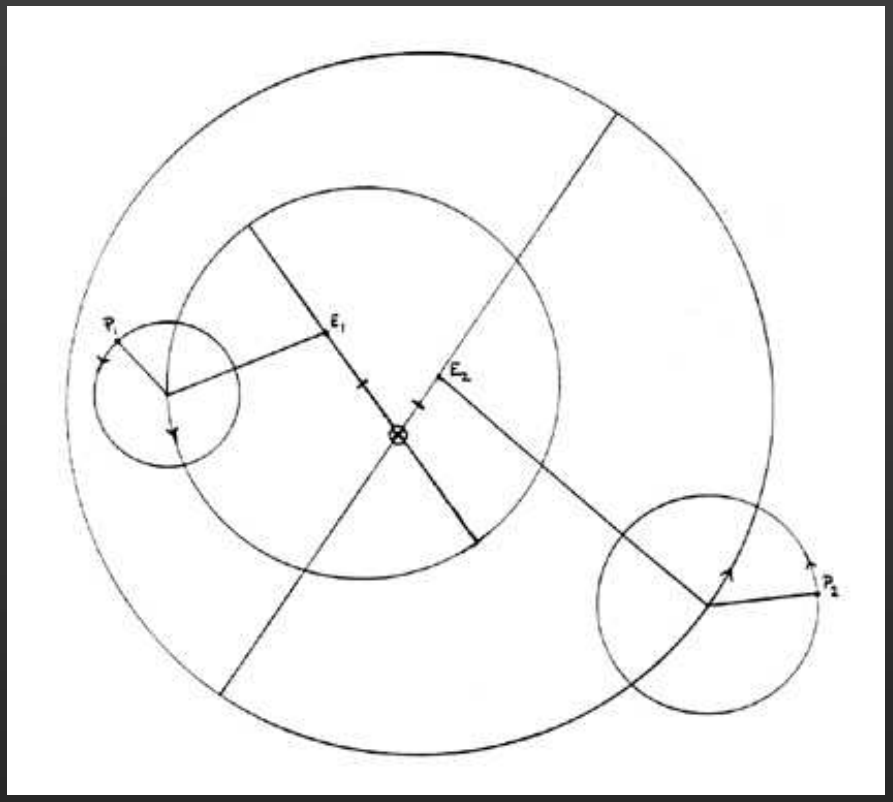
Q = Equant point
C = Center (of universe)

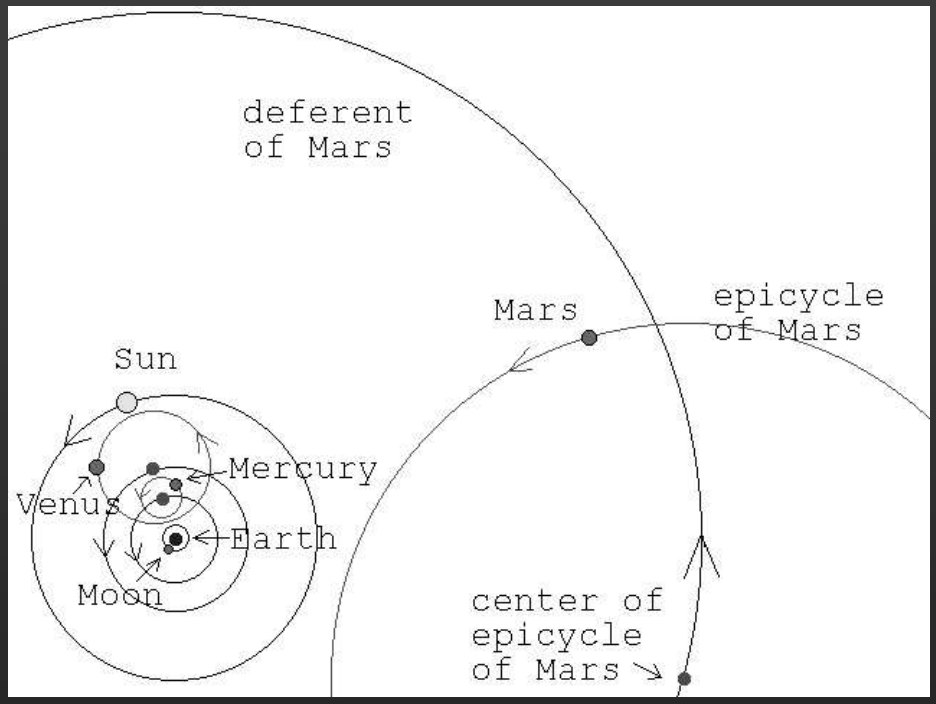
# The Ptolemaic System: The Equant point




- Planet’s motion does not look uniform from Earth
- But it does look uniform from equant point!

# The Ptolemaic System: Proliferating complexity!






- But it never quite worked!
  - it remained patchwork
  - more and more complicated (Copernicus' monster)

**The Ptolemaic System:**

- Ptolemaic-Aristotelian universe completely dominated astronomical thought for 14 centuries (till Renaissance/Copernicus)

- Why was this (wrong) system so long-lived?

  - intricate connection to Aristotelian philosophy
  - it was very successful in explaining data
  - during Middle Ages adopted by Catholic Church as dogma (see trial of Galileo)

- But it never quite worked!

  - it remained patchwork
  - more and more complicated (Copernicus' monster)