

ASTRONOMY 9: HISTORY OF COSMOLOGY

Handout #10

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Cosmology in Ancient Greece: Aristotle and Greek Astronomy

I. Aristotle (384–322 BC)

- Student of Plato’s Academy
- Founded Lyceum
- Worked in almost every field of known science and philosophy!
- Profound influence on development of Western science
- Every effect must have a *cause*
- Important innovation: universe can be described by **natural laws** inferred by rational thought
- Aristotle’s physics: mostly quite wrong, but strong common-sense appeal
 - Founded science of **mechanics** (physics of motion)
 - Developed the idea of “force”, **impetus** theory of motion (wrong, but widely held even today!)
 - Thought force was *required* to keep Earthly objects in motion (didn’t fully understand *inertia*)
- Aristotle applies his physics to the cosmos
 - Basic Earthly elements: air, earth, fire, water
 - Terrestrial and celestial physics are very different!
 - Two types of “natural” motion
 - A) Earth: linear, straight-line, finite motion (air and fire go up, water and earth go down)
 - B) Heavens: perfect, eternal, circular motion
 - Bodies are impelled to move to their “natural” location
 - Can only have one center ⇒ only one world
 - Circular motion must have a corresponding basic element ⇒ 5th element (quintessence): **ether** (heavenly, unchanging)
 - Cosmic division:
 - A) Sub-lunary sphere (inside moon’s orbit): earthly, changing, becoming, imperfect, made of 4 elements (Ionian)
 - B) Celestial realm (moon and beyond): immutable, perfect, made of ether (Eleatic)
 - Objects don’t get “left behind” ⇒ Earth is **fixed at the cosmic center**
 - Earth known to be spherical on *observational* grounds:
 - A) Circular shadow during lunar eclipse
 - B) Different stars become visible when travel north/south
 - Heavens are rotating ⇒ Universe must be **finite!**
 - Space has an unapproachable “edge”
 - Universe is **eternal**, uncreated
 - God rules from outside (primary cause of all motion)
 - Appropriates Eudoxus’ sphere model to explain planetary motion
 - Better observations require more spheres ⇒ 55 total! (Still no explanation for varying brightnesses)
 - Aristotle thinks spheres are *physically real*
 - No “Void” (vacuum), unlike the Atomists

II. Heraclides of Pontus (c. 388–310 BC)

- Proposed **rotating** Earth to explain daily rotation of heavens
- Proposed Mercury and Venus orbit Sun, not Earth
- Ideas rejected by Aristotelians

III. Aristarchus of Samos (approx. 310–230 BC) “The Ancient Copernicus”

- Measuring the size of the cosmos...
- Estimated size of Moon to be $\approx 1/3$ size of Earth (from lunar eclipse shadow)
- Measured angle between Sun and Moon when Moon is half-full (called “first quarter”)
- Concluded Sun is 18–20 \times further away than Moon
- But apparent (angular) sizes of Sun and Moon are the same \Rightarrow Sun is at least 18 times as big as Moon, or 6 times as big as Earth!
- Used inaccurate data (Moon diameter 2° , actually 0.5°), and method doesn’t work well in practice: Sun is actually much bigger still!
- **Heliocentric** model: Sun is at the center!
- Correct but rejected by Aristotelians, forgotten for 1500 years... Science is not a linear progression of ideas!

IV. Eratosthenes of Cyrene (276–194 BC)

- Clever measurement of the circumference of the earth
- Distance between Alexandria and Syene (now Aswan, Egypt) measured to be 5000 “stadia” (Greek unit of length)
- Compare noon shadows at summer solstice, find 7.2° difference
- Assume Sun is far away so that rays are parallel
- Circumference is then

$$C = \left(\frac{360^\circ}{7.2^\circ} \right) \times 5000 \text{ stadia} = 50 \times 5000 \text{ stadia} = 250,000 \text{ stadia}.$$

- Length of stadium is uncertain; result was very accurate if 1 stadium = 157.2 meters:

$$C = (250,000 \text{ stadia}) \times 1 = (250,000 \text{ stadia}) \times \left(\frac{157.2 \text{ m}}{1 \text{ stadia}} \right) \times \left(\frac{1 \text{ km}}{1000 \text{ m}} \right) \approx 40,000 \text{ km}$$

V. Appollonius of Perga (approx. 262–190 BC)

- Back to the geocentric cosmos
- A new answer to Plato’s challenge to “save the phenomena”
- Different from Eudoxus’ “onion” cosmos of spheres, more like a Ferris wheel
- Not totally geocentric: introduced “**eccentric** circle”
 - Earth remains motionless at cosmic center
 - Planets still move in circles at uniform speed
 - But center of circles is now displaced from Earth!
 - Apparent motion as viewed from Earth is of variable speed
- Also invented **epicycle**
 - Wheels upon wheels
 - Allows (complicated) explanation of retrograde motion
- “Theorist”: did not try to apply ideas to observational data

VI. Hipparchus of Rhodes (190–120 BC)

- Great Greek astronomer
- Synthesized Babylonian and Greek data with new Greek geometrical models from Appollonius
 - Model for Sun’s motion (eccentric circle)
 - Model for Moon’s motion (eccentric + epicycle)
- Also made accurate catalog of 850 star positions
- Discovered precession of equinoxes