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)

- $7^\circ = 800$ km
- $360^\circ = 40,000$ km
Daily motion of the stars

No change in relative positions fixed stars
Daily motion of the stars:

Looks different in different directions!

- Circumpolar stars
Q: How to explain daily stellar motion???

A: The Ancient Two-sphere-universe!

Celestial sphere (contains fixed stars)

Celestial equator

Local Horizon (every observer has own one!)
Quick reminder: Why does concept of celestial sphere work (from our present-day perspective)?

Stars actually lie at different distances; arrows indicate where they appear to be located on the celestial sphere.
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)
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 \textit{ecliptic}!
Two-sphere-universe + stationary Earth:

→ Nicely accommodates annual solar motion!

Sun moves along ecliptic once a year!
Two-sphere-universe + stationary Earth:

→ Nicely accommodates annual solar motion!
Plato’s Grand Challenge:
How do planetary motions fit in?

- Retrograde motion of planets, opposite direction to daily motion (E-W) of celestial sphere
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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)
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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
  - Supreme intellectual authority
  - Unchallenged till Renaissance

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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

Stellar Parallax

- Not observed (too small) until 1838 (Bessel)!
The Aristotelian Universe:

- **Stars**
- **Saturn**
- **Jupiter**
- **Mars**
- **Sun**
- **Venus**
- **Mercury**
- **Moon**

**Aristotelian Universe, Non-homogeneous, Finite Spherical Space**

- **Celestial Region**, made of aether. Natural motion is circular.
- **Sublunary Region**, made of earth, water, air, and fire. Natural motion, downward or upward, is linear.

*Picture by S. Uchi*
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, but not precise as far as planetary motion is concerned.
- Greeks before Alexander the Great (356-323 BC) did not care much about observations.
- Fundamental change in the history of astronomy in the wake of Alexander's conquests (Hellenistic Age).
The Hellenistic Age: Alexander’s conquest
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• 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

E = Earth
P = Planet

b) eccentric

Q = Equant point
C = Center (of universe)

c) equant
The Ptolemaic System: The Equant point

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