Lecture #4: Plan

• Eclipses (cont’d)
• Early Ideas of the Heavens:
  — Shape & size of the Earth
  — Size & distance of Moon & Sun
• Geocentric Universe
• Heliocentric Universe
At New Moon, the Moon is between the Earth and the Sun. Sometimes the alignment is just right, allowing the Moon to block the light from the Sun, creating an eclipse.
Solar Eclipses

Romania, August 11, 1999
Regions of visible total eclipses
Lunar Eclipses

As the Moon passes behind the Earth, the Earth can cast a shadow on the surface of the Moon, creating a lunar eclipse.
Why don’t eclipses happen all of the time?

- **Answer:** The Moon orbital plane around the Earth is tilted by 5° from the ecliptic
Everything Must be Just Right!

• For an eclipse to occur, the Moon must be crossing the ecliptic at the same time it passes either in front of the Earth (solar eclipse) or behind the Earth (lunar eclipse) [B&D]

• Otherwise, no eclipses are possible [A&C]

• At least two solar and two lunar eclipses must happen each year (but may be only partial/annular eclipses rather than total eclipses)
Shape of the Earth

Aristotle (Greece, 384 – 322 B.C.)

- During a lunar eclipse, the Earth’s shadow on the Moon is clearly curved
- A traveler moving south sees stars that were previously hidden below the southern horizon
Distance and Size of the Moon

Aristarchus (Greece, 310 – 230 B.C.)

- Lunar eclipse:
  - Aristarchus: \( D_E \approx 3 \ D_M \)
  - Modern: \( D_E \approx 4 \ D_M \)

- Total length of lunar eclipse vs length of Moon’s motion through zodiac
  - Measured: 3 vs 660 hours

\[
\text{Circumference of Moon’s orbit} = \frac{660}{3} \times D_E = 220 \ D_E = 2 \pi \ d_{EM}
\]

\[
\text{Radius of Moon’s orbit} = \frac{220 \ D_E}{2\pi} \approx 35 \ D_E = 70 \ R_E
\]

- Modern value = 60 \( R_E \) !
Distance and Size of the Sun

Aristarchus (Greece, 310 – 230 B.C.)

- At Quarter Moon:
  - \( \cos A \equiv \frac{d_{EM}}{d_{ES}} \)
  - \( d_{ES} = \frac{d_{EM}}{\cos A} \)
  - \( \sim 20 \, d_{EM} \) (Aristarchus)
  - \( d_{ES} \sim 400 \, d_{EM} \) (modern)
Distance and Size of the Sun (cont’d)

Aristarchus (Greece, 310 – 230 B.C.)

- **Solar Eclipse:**
  - $A_M \sim A_S$
  - $D_M / d_{EM} \sim D_S / d_{ES}$
  - $D_S \approx (d_{ES} / d_{EM}) D_M$
    - $\sim 20 \, D_M$ (Aristarchus)
    - $\sim 400 \, D_M$ (modern)

- **Since, according to Aristarchus,**
  - $D_S = 20 \, D_M$ and $D_E \sim 3 \, D_M$
  - $D_S \approx 7 \, D_E$
  - $D_S \approx (400 / 4) \, D_E = 100 \, D_E$ (modern)

\[ \frac{L}{2\pi d} = \frac{A}{360^\circ} \]

Therefore, $L = 2\pi d \times \frac{A}{360^\circ}$
The First Heliocentric Universe!

Aristarchus (Greece, 310 – 230 B.C.)

• Amazingly, he also postulated that the Earth goes around the Sun
• But his critics claimed that if this were true, they would see the positions of the stars change relative to each other

→ But no shift in position observed at the time

→ Model rejected!!!
Parallax

- Shift in an object’s *apparent* position caused by the observer’s motion
Size of the Earth

Eratosthenes (Egypt, 276 – 195 B.C.)

• **Observed:**
  1. In Alexandria, the Sun casts a shadow at noon on the day of summer solstice
  2. In Syene, the Sun is directly overhead at noon on that same day and casts *no* shadow
Size of the Earth

Eratosthenes (Egypt, 276 – 195 B.C.)

• Definitions:
  – $A \equiv$ angle between obelisk and the Sun ($7^\circ$)
  – $d \equiv$ distance between Alexandria and Syene (5000 stadia ~ 500 miles)
  – $C \equiv$ circumference of Earth

• Proportions:
  – $A / 360^\circ = d / C$
  – $7^\circ / 360^\circ = d / C$
  – $C = (360/7) \times d$
    $\sim 50 \times 500$
    $\sim 25,000$ miles

• Modern: $C = 24,662$ miles!
Geocentric Model

- Earth at the center
  - "Natural"
  - "common sense"
  - Don’t feel Earth’s motion
  - No parallax
- All objects move around Earth affixed to crystalline spheres
Geocentric (‘Ptolemaic’) Model

• **Retrograde Motion:**
  - Apparent “backward” (= East-to-West) motion of Mars with respect to stars

• **Ptolemy (~150 A.D.):** explained it with “epicycles” = small spheres attached to larger ones
Heliocentric Universe

• Nicolas Copernicus (Poland, 1473 – 1543)
  — Revived Sun-centered model of the Heavens *(On the Revolutions of Celestial Orbs)*
  — Explained retrograde motion *(circular orbits)*