

Astronomy 350L (Fall 2006)



### The History and Philosophy of Astronomy

(Lecture 3: Antiquity I)

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### Astronomy and Cosmology in Antiquity:

### Two Threads of Thought

### Mainstream (orthodoxy) — Antiquity I (Sep. 7)

- Plato, Eudoxus, Aristotle, Hipparchus, Ptolemy
- Two-sphere-universe
- Earth-centered (geocentric)
- Planetary motion: in circles, deferent-epicycle

### Dissent (heterodoxy) — Antiquity II (Sep. 12)

- 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**



6<sup>th</sup> 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 (3<sup>rd</sup> cent. BC, Alexandria)



### Daily motion of the stars



No change in relative positions —— fixed stars

### Daily motion of the stars:

### Looks different in different directions!



### Due North

- Circumpolar stars



### Due East



### **Due South**

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



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's philosophy demands that universe is spherical! Q: How so?



#### (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 (4<sup>th</sup> 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)

Stone/arrow Observer

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!

### **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

**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 sar



**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)

- 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!

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### Aristotle (4<sup>th</sup> cent. BC)

### i ofisciple, Alexander's

### 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



### 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 did not car
- Fundament in the wake



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### 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 (2<sup>nd</sup> cent. BC): Precession of the Equinoxes



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

### The Ptolemaic System:

### - Aristotelian, but dominated by mathematical precision!

# (2<sup>nd</sup> cent. AD) eatest astronomers agest (150 AD)

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

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### The Ptolemaic System:



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

### The Ptolemaic System: Basic Building Blocks



### 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)