Announcements

- Problem Set #1 due this afternoon at 5pm!
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- TAs are available by appointment, office hours TBA

Read: Chap 3
Announcements

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- TAs are available by appointment, office hours TBA
- Blog?
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Blog?

**Orchard Hill Observing:** 8:00PM on Thursday Sept 13th
http://www.astro.umass.edu/~orchardhill

**Today’s topic:** Motion of Celestial bodies

- Led to modern science
- Philosophy: scientific method
- Discovery of Laws of Motion and Gravity
Problem Set #1 due this afternoon at 5pm!

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Blog?

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Today’s topic: Motion of Celestial bodies

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Questions?
Scientific thinking is based on everyday ideas of observation and trial-and-error experiments.
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Astronomical observations had practical benefit:

- Keeping track of time and seasons
- Agriculture
- Religious and ceremonial purposes
- Aid to navigation

Days of the week named for the Sun, Moon and visible planets
Scientific thinking

Table 3.1 The Seven Days of the Week and the Astronomical Objects They Honor

The correspondence between objects and days is easy to see in French and Spanish. In English, the correspondence becomes clear when we look at the names of the objects used by the Teutonic tribes who lived in the region of modern-day Germany.

<table>
<thead>
<tr>
<th>Object</th>
<th>Teutonic Name</th>
<th>English</th>
<th>French</th>
<th>Spanish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>Sun</td>
<td>Sunday</td>
<td>dimanche</td>
<td>domingo</td>
</tr>
<tr>
<td>Moon</td>
<td>Moon</td>
<td>Monday</td>
<td>lundi</td>
<td>lunes</td>
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<tr>
<td>Mars</td>
<td>Tiw</td>
<td>Tuesday</td>
<td>mardi</td>
<td>martes</td>
</tr>
<tr>
<td>Mercury</td>
<td>Woden</td>
<td>Wednesday</td>
<td>mercredi</td>
<td>miércoles</td>
</tr>
<tr>
<td>Jupiter</td>
<td>Thor</td>
<td>Thursday</td>
<td>jeudi</td>
<td>jueves</td>
</tr>
<tr>
<td>Venus</td>
<td>Fria</td>
<td>Friday</td>
<td>vendredi</td>
<td>viernes</td>
</tr>
<tr>
<td>Saturn</td>
<td>Saturn</td>
<td>Saturday</td>
<td>samedi</td>
<td>sábado</td>
</tr>
</tbody>
</table>

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Read: Chap 3

09/11/12 – slide 4
Egyptian obelisk: Shadows tell the time of day
England: Stonehenge \( \approx 1550 \) B.C.
China: Earliest known records of supernova explosions (1400 B.C.)

"On the Jisi day, the 7th day of the month, a big new star appeared in the company of the Ho star."

"On the Xinwei day the new star dwindled."

Bone or tortoise shell inscription from the 14th century BC.
What have we learned?

- In what ways do all humans use scientific thinking?
  - Same type of trial and error thinking that we use in everyday live, but carefully organized

- How did astronomical observations benefit ancient societies?
  - Keeping track of time and seasons; navigation

- What did ancient civilizations achieve in astronomy?
  - To tell the time of day and year, to track cycles of the Moon, to observe planets and stars.
  - Many ancient structures aided in astronomical observations.
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- Many ancient structures aided in astronomical observations.
Our mathematical and scientific heritage originated with the civilizations of the Middle East.
Key questions:

- How did Copernicus, Tycho, and Kepler challenge the Earth-centered model?
- What are Kepler's three laws of planetary motion?
- How did Galileo solidify the Copernican revolution?

Read: Chap 3
Why does modern science trace its roots to the Greeks?

- Greeks were the first people known to make models of nature.
- They tried to explain patterns in nature without resorting to myth or the supernatural.
- Used mathematics to make ideas precise and predictive.

Greek geocentric model
(≈ 400 B.C.)
How science works . . .

- May be many models that describe apparent reality
- Science chooses the one with predictive power
- Predictive power implies *physical laws*
How science works . . .

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- Predictive power implies *physical laws*

The Scientific Method

- Theories are subject to revision in light of new data
- Simple theories are preferred to complicated theories without additional predictive power

*Occam’s Razor*
Retrograde motion: key problem

Over a period of 10 weeks, Mars appears to stop, back up, then go forward again.

- Planets mean wanderers
- Outstanding problem for Greek astronomers and philosophers
- Example: path of Mars in 2005-2006

Read: Chap 3
How did the Greeks explain planetary motion?

Basic features of Greek *geocentric* model:

- Earth at the center of the Universe
- Heavens must be *perfect*
- Objects moving on perfect spheres or in perfect circles

Plato

Aristotle
Celestial sphere

- Huge rotating sphere, centered on but much larger than the Earth
- All objects in the sky beyond the planets can be thought of as lying upon the sphere
The most sophisticated geocentric model was that of Ptolemy (A.D. 100-170) – the Ptolemaic model:

- Sufficiently accurate to remain in use for 1,500 years (good to about 1 deg of arc)
- Arabic translation of Ptolemy's work named Almagest ("the greatest compilation")
But this theory made it difficult to explain apparent retrograde motion of planets...

- Ptolemaic Geocentric Theory (elaborate mechanism)
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- Ptolemaic Geocentric Theory (elaborate mechanism)
In the Ptolemaic model, the planets really do go backward ...
Retrograde motion

Heliocentric Theory
Simple explanation

Read: Chap 3
Distance to Sun

- Aristarchus of Samos — 280 BC
- Heliocentric theory
Size of Earth

Eratosthenes (≈ 240 BC)

- Measurements:
  - Syene to Alexandria
  - distance ≈ 5000 stadia
  - angle = 7°
Eratosthenes (≈ 240 BC)

- Measurements:
  - Syene to Alexandria
  - distance ≈ 5000 stadia
  - angle = 7°

- Calculate circumference of Earth:
  - $\frac{7}{360} \times \text{(circum. Earth)} = 5000$ stadia
  - circum. Earth = $5000 \times \frac{360}{7}$ stadia ≈ 250,000 stadia

- Compare to modern value (≈ 40,100 km):
  - Greek stadium $\frac{1}{6}$ km $\implies$ 250,000 stadia ≈ 42,000 km
Heliocentric theory predicts stellar parallax

- Viewpoint A: object in front of blue square
- Viewpoint B: object in front of red square
- “Stereo” or 3D vision
Heliocentric theory predicts stellar parallax

- Viewpoint A: object in front of blue square
- Viewpoint B: object in front of red square
- “Stereo” or 3D vision

Stellar parallax was not observed!
Time line: review

Thales (c. 624–546 B.C.)
Proposed the first known model of the universe that did not rely on supernatural forces.

Anaximander (c. 610–546 B.C.)
Suggested the idea of a celestial sphere.

Pythagoras (560–480 B.C.)
Taught that Earth itself is a sphere.

Plato (428–348 B.C.)
Asserted that heavenly motion must be in perfect circles.

Eudoxus (c. 400–347 B.C.)
Used nested spheres to improve agreement between geocentric model and observations.

Aristotle (384–322 B.C.)
Argued forcefully in favor of an Earth-centered universe.

Anaxagoras (c. 500–428 B.C.)
Suggested that Earth and the heavens are made of the same elements.

Democritus (c. 470–380 B.C.)
Proposed that the world is built from indivisible atoms.

Meton (c. 450–?? B.C.)
Identified the Metonic cycle used in some lunar calendars.

Heracleides (c. 388–315 B.C.)
First to suggest that Earth rotates.

Aristarchus (c. 310–230 B.C.)
First to suggest that Earth goes around the Sun.

Eratosthenes (c. 276–196 B.C.)
Accurately estimated the circumference of Earth.

Major steps in the development of the geocentric model
Other milestones of Greek astronomy

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Time line: review

Apollonius (c. 240–190 B.C.)
Introduced circles upon circles to explain retrograde motion.

Hipparchus (c. 190–120 B.C.)
Developed many of the ideas of the Ptolemaic model, discovered precession, invented the magnitude system for describing stellar brightness.

Ptolemy (c. A.D. 100–170)
His Earth-centered model of the universe remained in use for some 1,500 years.

Major steps in the development of the geocentric model
Other milestones of Greek astronomy

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Read: Chap 3

09/11/12 – slide 23
Greek cosmology

Heliocentric model
Greek cosmology

Celestial sphere rotates to the west

- Heliocentric model
- Geocentric model
Which of the following is NOT a fundamental difference between the geocentric and Sun-centered models of the solar system?

1. Earth is stationary in the geocentric model but moves around Sun in Sun-centered model.

2. Retrograde motion is real (planets really go backward) in geocentric model but only apparent (planets don’t really turn around) in Sun-centered model.

3. Stellar parallax is expected in the Sun-centered model but not in the Earth-centered model.

4. The geocentric model is useless for predicting planetary positions in the sky, while even the earliest Sun-centered models worked almost perfectly.
Which of the following is NOT a fundamental difference between the geocentric and Sun-centered models of the solar system?

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4. The geocentric model is useless for predicting planetary positions in the sky, while even the earliest Sun-centered models worked almost perfectly.
How was Greek knowledge preserved through history?

- Library at Alexandria, Egypt
- Muslim world preserved and enhanced the knowledge they received from the Greeks
- Al-Mamuns House of Wisdom in Baghdad was a great center of learning around A.D. 800
- With the fall of Constantinople (Istanbul) in 1453, Eastern scholars headed west to Europe, carrying knowledge that helped ignite the European Renaissance.
How did Copernicus, Tycho, and Kepler challenge the Earth-centered idea?

- Proposed Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU)

Copernicus (1473-1543)
How did Copernicus, Tycho, and Kepler challenge the Earth-centered idea?

- Proposed Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU)

But...

- Model was no more accurate than Ptolemaic model in predicting planetary positions, because it still used perfect circles

Copernicus (1473-1543)
Distance to planets

- Copernicus—1500 AD
- Revival of heliocentric theory
Successes of Copernicus

- Explained retrograde motion
- Explained *inferior* and *superior* planets
- Found a relationship between the orbital period and the distance of a planet from the Sun
## Successes of Copernicus

### Distances to planets inferred by Copernicus

<table>
<thead>
<tr>
<th>Planet</th>
<th>Copernican value (AU*)</th>
<th>Modern value (AU)</th>
</tr>
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<tbody>
<tr>
<td>Mercury</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>Venus</td>
<td>0.72</td>
<td>0.72</td>
</tr>
<tr>
<td>Earth</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Mars</td>
<td>1.52</td>
<td>1.52</td>
</tr>
<tr>
<td>Jupiter</td>
<td>5.22</td>
<td>5.20</td>
</tr>
<tr>
<td>Saturn</td>
<td>9.07</td>
<td>9.54</td>
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<tr>
<td>Uranus</td>
<td>—</td>
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</tr>
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*Distances to planets inferred by Copernicus.*

### Announcements
- Scientific thinking
- Middle East
- Greek roots
- Philosophy of science
- Retrograde motion
- Greek cosmology
- Celestial sphere
- Ptolemy
- Geocentric theory
- Distance to Sun
- Size of Earth
- Stellar parallax
- Time line
- Greek models
- Food for thought
- Flow of knowledge
- Modern Astronomy
- Distance to planets

### Read: Chap 3

09/11/12 – slide 30
### Successes of Copernicus

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<td>39.53</td>
</tr>
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</table>

- Remarkably accurate by today’s standards
- Outer planets not yet discovered
Tycho Brahe [1546-1601] observed supernova (1572)
Very bright must be nearby if Copernicus’ theory is correct
Attempted to measure distance geometrically
No shift or parallax
Parallax

- Tycho Brahe [1546-1601] observed a supernova (1572)
- Very bright must be nearby if Copernicus’ theory is correct
- Attempted to measure distance geometrically
- No shift or parallax

- Concluded that Copernicus must be wrong
- Parallax not observed until the 19th century!

Read: Chap 3

09/11/12 – slide 31
Most of Solar System revolves around Sun

Sun revolves around Earth
Tycho Brahe’s Tools

- Telescope not yet invented
- Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- Still could not detect stellar parallax, and thus still thought Earth must be at center of solar system (but recognized that other planets go around Sun)
- Hired Kepler, who used Tycho's observations to discover the truth about planetary motion
Earth-crossing objects, how dangerous?

- How many objects are there?
  - About 2000 with diameters of 1 km or larger
  - Such objects could cause Tsunamis 300 feet high!
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- How often do they strike Earth?
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See http://www.pibburns.com/catastro/impacts.htm to feel scared.