Announcements

Exam study materials are posted on the course web page, and a practice exam is available in OWL.

- Homework 2 is now available on the OWL
- Due 10/01/08 before midnight
- 1st midterm: 10/2/08
- Midterms will be “pyramid” exams: 75% of grade from in-class exam, 25% from take-home exam (same exam)
- If you don’t do the take-home part, then 100% of the grade will be based on the in-class exam score

PRS is on - please join!

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After Copernicus and Kepler, philosophers still adhered to the Greek model for 3 reasons:

1. Falling objects should be left behind if the Earth moves
2. The heavens must be perfect and unchanging
3. Stellar parallax

Final key scientist in this story: Galileo Galilei
Galileo’s arguments against the Greek objections:

1. Used experiments to show that objects in motion tend to remain in motion

   For example, Galileo argued that objects in motion tend to remain in motion. This explains why falling objects are not left behind when the Earth moves — they are already in motion with the Earth, and they remain in motion with the Earth as they fall.

2. Many observations (with the new-fangled invention called the telescope) showed that the heavens are far from perfect (e.g., spots on the Sun, jagged mountains and valleys on the Moon)

3. The Milky Way indicated that stars are far more numerous than thought, and probably much more distant than appreciated
Galileo’s Observations

- Galileo saw shadows cast by the mountains on the Moon.
- Observed craters.
- The Moon had a landscape; it was a “place”, not a perfect heavenly body.
- The Sun has nasty little spots on it — not a perfect thing!

Galileo’s Observations

- Galileo discovered that Jupiter had four moons of its own.
- Jupiter was the center of its own system.
- Heavenly bodies existed which did not orbit the earth.
Galileo’s observation of the phases of Venus was the final evidence which buried the geocentric model.

**Geocentric**

No gibbous or full phases! All phases are seen!

Galileo observed all phases!

**Heliocentric**

Recent Observations (2004) of Phases of Venus
Why don’t we see solar eclipses more often?

Opportunities to observe a total solar eclipse are rare! The diameter of the umbra is ~270 km; the diameter of the penumbra is ~7000 km.

The umbra sweeps across a relatively small area on the surface of the Earth, and it moves quickly -- the shadow moves across the surface at roughly 1,700 km/hour.
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These diameters depend on the Earth-Moon distance. If the Moon happens to be farther away at the time of the eclipse, the umbra diameter will be smaller (or even zero if the umbra is above the surface of the Earth).

O.K., the Moon casts a small shadow on the Earth. But, the Earth casts a big shadow on the Moon. Why don’t we see lunar eclipses more often?
Why don’t we see eclipses more often?

• Shouldn’t *somebody* see an eclipse at every new moon and every full moon? Solar eclipses seem to be quite rare; why?

• Answer: the Moon’s orbit is tilted by 5° with respect to the Earth’s orbit (the “ecliptic plane”)

• Moon’s orbit tilted 5° to ecliptic plane
  – Crosses ecliptic plane only at the two *nodes*
  – Eclipse possible only when full/new Moons occur near nodes

*When full and new moons occur near nodes, eclipses can happen.*

The plane of the Earth’s orbit around the Sun is the *ecliptic plane*, here represented by the surface of a pond.
Summary: Eclipses

When the Moon’s orbit intersects the ecliptic plane:

- at new moon: solar eclipse
- you must be in Moon’s shadow to see it
  - within umbra: total solar eclipse
  - within penumbra: partial solar eclipse
- at full moon: lunar eclipse

Everyone on the nighttime side of Earth can see it.

Shouldn’t eclipses occur every 6 months?

Additional complication: the Moon’s orbit precesses, i.e., it wobbles like a child’s top.
When the rotation axis of an object slows changes direction, this is called \textit{precession}.  

\textbf{The Earth’s axis of rotation precesses, like the motion of a top.}

The Moon’s orbit also precesses. Due to this precession, the nodes shift, and the eclipse “seasons” occur less than 6 months apart.

The combination of the shifting eclipse seasons and the Moon’s 29.5 day cycle leads to a complicated cycle that repeats every 18 years and 11.5 days. \textbf{The “saros cycle”}
Remarkably, some ancient astronomers were able to recognize the saros cycle and predict eclipse dates. Today, we can predict eclipse times with tremendous precision.

- Note that while the saros cycle predicts the date of an eclipse, the position of the shadow on the Earth shifts

Measuring relations in the sky

We often measure the sky in *angles*, not distances.

- Full circle = 360°
- 1° = 60 arcmin
- 1 arcmin = 60 arcsec
Measuring Angles in the Sky: Some points of reference

For an object with a fixed size (a fixed linear diameter), its *angular diameter* decreases when the object’s distance is increased.

\[
\text{Angle (in radians)} = \frac{\text{linear diameter}}{\text{distance}}
\]

Full circle = 360°

Full circle = \(2\pi\) radians

\(\pi = 3.141592654\)

360° = \(2\pi\) radians
**PRS Question — working with angles**

Jupiter is about 5 times farther from the Sun than the Earth is. If the angular diameter of the Sun is about 0.5 degrees as seen from the Earth, then how many degrees wide is the Sun as seen from Jupiter?

- **Enter a numeric answer into your PRS unit.**

**Answer:** if we move an object five times farther away, its angular diameter will be five times smaller. So, \(0.5/5 = 0.1\) degrees. Viewed from Jupiter, the angular diameter of the Sun is 0.1 degrees.

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**PRS calculation:**

**How Big is the Moon?**

- The **angular diameter** of the Moon is 0.5 degrees.
- In **radians**, the angular diameter is 0.0087 radians. Roughly, \(\text{ang. diameter} = 0.009\)
- The **distance** to the Moon is 384,000 km. For this calculation, use \(\text{distance} = 400,000\) km
- **HOW BIG IS THE MOON?**
**PRS calculation:**
How Big is the Moon?

- Roughly, \( \text{ang. diameter} = 0.009 \)
- Roughly, \( \text{distance} = 400,000 \text{ km} \)
- The linear diameter of the Moon is
  1. 300 km
  2. 3,600 km
  3. 10,000 km
  4. 36,000 km
  5. 100,000 km

\[
\text{Angle (in radians)} = \frac{\text{linear diameter}}{\text{distance}}
\]

\[
(4 \times 10^5 \text{ km}) \times (9 \times 10^{-3} \text{ rad}) = \text{Linear diameter}
\]

\[
\text{Linear diameter} = 36 \times 10^2 \text{ km} = 3,600 \text{ km}
\]
The diameter of the Earth is roughly 13,000 km. Therefore, the diameter of the Earth is roughly 4 times larger than the diameter of the Moon.

But what does big mean? Does this mean that the Earth is 4 times bigger than the Moon?

Volume of sphere = \( \frac{4}{3} \pi R^3 \)

The radius of Jupiter is 10x larger than the radius of Earth. How much larger is the volume of Jupiter compared to Earth?

1. 4/3 \( \pi \) times larger
2. 20 times larger
3. 100 times larger
4. 1000 times larger
5. 10000 times larger

**PRS calculation.**
True or False: We have seasons on Earth because our planet is closer to the Sun in the summertime

1. True
2. False

Angular size of the Sun: Which picture was taken in January?

1. Picture 1
2. Picture 2
Angular size of the Sun in January

Angular size of the Sun in July
Angular size of the Sun: Jan. vs. July:
angular diameter is larger in January.
What does this tell us?
*The Sun is closer to the Earth in January.*

January

July

But, it's colder in January!

Also, when it’s winter in the northern hemisphere, it’s summer in the southern hemisphere (and vice versa).

**CONCLUSION:** the seasons are **NOT** due to the distance from the Earth to the Sun.