Announcements

- **Mid-Term Exam #2, 1 week from Today!**

- **HW #2 was due last Monday at 11pm.**

- **Don’t forget your planetarium visit + the assignment to record your impressions!**
Terrestrial Planets: Mercury, Venus, Earth, Mars (+ the Moon).

Erosion (if you have an atmosphere), plate tectonics (if you have a moving mantle), volcanism (ditto), and cratering shape the geology.

Internal heat drives the geology: Mercury, Mars, and the moon are “dead” (frozen), Earth and Venus still “alive” (molten core and mantle).
Craters get covered over by volcanoes, “subducted” back into the mantle by plate tectonics: crater count tells you the age of the surface!

Venus: objects burn up: few craters
Craters on Venus

- Few small craters
- Small objects burn up in dense atmosphere
- Use large (>30 km) craters to estimate age
- Lava plains 500-600 million years old.
- Vast geologic activity then, not much since
A MISCONCEPTION ABOUT THE MANTLE

- It’s not liquid!
- Very slowly moving, viscous solid.
- Imagine play-dough made from rocks.
A Good Question

Will Earth eventually suffer the fate of Mars: i.e. will it “freeze”, lose its magnetic field, and “die”?

Answer 1: It’s already starting! The inner part of the molten iron core “froze” about 1 billion years ago.

Answer 2: Radioactivity still provides so much heat, that the Sun will destroy the solar system far before the Earth cools completely.
The Giant Planets - Jupiter, Saturn, Uranus & Neptune
A Different Kind of Planet

- Bigger and move massive
- Lower density, and different composition
- Rings and numerous moons
Why are Jovian planets different?

Beyond the “Frost Line” of about 5 AU, planetesimals could accumulate ice (water, ammonia, methane) during the formation of the solar system.

Ice is more abundant than rock/metal so the planetesimals grew larger and accumulated H & He from the Solar Nebula.
**Jovian (Giant) Planets: Basics**

- **Distance:** 5-30 AU
  - Much farther from Sun than terrestrial planets
  - Much colder (50-100 K)

- **Mass:** 10-100 Earth masses
  - Much more massive than terrestrial planets

- **Jupiter & Saturn are similar**
  - Size (about 10 Earth diameters)
  - Composition: mostly hydrogen and helium

- **Uranus & Neptune are similar**
  - Smaller than Jupiter & Saturn
  - Less hydrogen and helium, more methane, ammonia, water. Some metal and rock.
Clouds

Clouds on Jupiter & Saturn
- Composed of ammonia ice ($\text{NH}_3$)
- Different colors: due to differing cloud composition
- Saturn’s clouds deeper; less visible

Clouds on Uranus & Neptune
- Composed of methane ($\text{CH}_4$)
- Produces blue-green color
What causes the differences among the Jovian planets?

The Jovian cores are all very similar in size, roughly 10x Earth masses.

The differences between the Jovian planets is a result of the amount of H/He they accumulated.
What causes the differences among the Jovian planets?

The difference arise from their formation:

- **Timing**: the planets that formed first, capture the most H & He.

- **Location**: the planets that form in the densest regions (nearer to the Sun) form their cores first.
Basic Data

Jupiter
- 318 Earth masses
- 11 Earth diameters
- Density 1.3 g/cm³

Saturn
- 95 Earth masses
- Density 0.7 g/cm³
- Would float!
- Lowest of any planet
**Basic Data**

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Basic Data

- **Uranus**
  - 14 Earth masses
  - Density 1.2 g/cm$^3$
  - Diameter 36% of Jupiter’s

- **Neptune**
  - 17 Earth masses
  - Density 1.6 g/cm$^3$
  - Diameter 35% of Jupiter’s
**Appearance**

- Jovian planets show “banded” appearance
  - Due to atmosphere
  - We see only cloud tops

- Rotation quite fast (hours)
  - Jupiter: 10 hrs
  - Saturn: 11 hrs
  - Uranus: 17 hrs
  - Neptune: 16 hrs
JUPITER’S DENSITY

- At first, stacking pillows on top of each other makes the pile bigger.
- However, at some point, the weight of the extra pillows starts to squish the stack to a smaller size.
- Building a planet is similar.
Jupiter’s Density

- Adding mass to a Saturn-mass object does not make the planet grow as large as fast.
- At some point, the size actually gets smaller as you add mass.
- Jupiter’s higher density is a result of the fact that its size is smaller “than it should be” for its mass.
- Jupiter and Saturn are about the same size but its mass is 3 times that of Saturn.
Jupiter’s Interior Structure

- Phase of hydrogen depends on pressure.
- Metallic hydrogen conducts electricity, but is not solid.
- Core has 10x the mass of Earth in the size of the Earth.

<table>
<thead>
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<th>pressure (bars)</th>
<th>temperature (K)</th>
<th>density (g/cm³)</th>
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<td>125</td>
<td>0.0002</td>
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<tr>
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</tr>
<tr>
<td>2,000,000</td>
<td>5,000</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Core of rock, metals, and hydrogen compounds
**Interior Structures**

- The structure depends on the size of the planet. **Less massive, less gravity, less pressure**
- Boundaries are deeper in less massive planets
- The states of the cores of the smaller planets are less extreme (perhaps liquid)
Like the Earth, Jupiter has a magnetic field that generates a magnetosphere!

Extends past Saturn’s orbit!

Generates Aurora.
Magnetic Fields

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What is the weather like on Jovian planets?

Like on Earth, clouds form in the atmosphere of Jupiter in layers. They give Jupiter its wonderful colors.
What is the weather like on Jovian planets?

- **Ammonia Sulfide clouds reflect red and brown colors**
- **Ammonia clouds reflect white light**
Cloud Motions on Jupiter

Great Red Spot 3 times as large as Earth
Cloud Motions on Jupiter

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Cloud Motions on Jupiter

Great Red Spot 3 times as large as Earth
Saturn has the same type of clouds, but they are deeper. Also, since it is farther away, the colors are more subdued.
Uranus and Neptune are cold enough that methane clouds form. These cloud reflect the blue light transmitted by the methane gas above them.
Uranus & Neptune

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- These cloud reflect the blue light transmitted by the methane gas above them.
Axial Tilt & Seasons

- **Jupiter**
  - Only 3° axis tilt; no real seasons

- **Saturn**
  - 27° tilt; normal seasonal variation

- **Neptune**
  - 29° tilt; similar to Saturn

- **Uranus**
  - 98° tilt (on its side!) [collision?]
  - Extreme seasons! Each 21 years long
Jovian Planets: Summary

- Much larger and more massive than terrestrial planets.
- Composed mostly of Hydrogen & Helium, also large amounts of water, ammonia, and methane ice.
- Formed very differently: gathered ice (cooler temperatures far from sun), then sucked in hydrogen and helium gas.
Jovian Moons

- We know of over 100 Jovian moons!
- More are being discovered still

- Jupiter: 63
- Saturn: 56
- Uranus: 27
- Neptune: 13
These moons have enough self gravity that they are spherical

Are or were geologically active

Have a lot of ice.

Formed in orbit around the Jovian planets

Circular, equatorial orbits in the same direction as the planet rotates
Small Moons

- Many, many more than large moons
- Gravity not strong enough to be circular
- Probably captured asteroids so orbits do not follow a pattern
- Orbits can be tilted, elliptical, or even backwards
Galilean Moons of Jupiter

Io           Europa       Ganymede        Callisto

Unusual?
Changes on Io’s Surface
Io has volcanos!

- No impact craters!
- Must be hot inside!
How can this be?

Io is squished and stretched due to tidal forces as it orbits Jupiter.

- small tidal bulges
- larger tidal bulges when closer to Jupiter
Europa has liquid water oceans!?
Europa has liquid water oceans!?
Ganymede

- Largest moon: about the size of Mercury! larger than Earth's moon
- Surface features include:
  - Fresh craters
  - Evidence of icy flows (water volcanoes?)
  - Mixed terrain, similar to Europa
- Galileo mission also discovered a magnetic field!
Saturn's Titan

- The only moon in the solar system with an atmosphere
- Like Venus, completely covered in clouds
- Atmosphere is mostly nitrogen, like Earth's, with methane.
- Life possible?
Saturn’s Titan

- Atmosphere is mostly nitrogen, like Earth’s. Also has hydrocarbons which produces the haze.

- Looking at Titan in the infrared, we begin to see through the haze, and see surface features.

- Rains liquid methane and other organic compounds

- Has volcanoes of water and ammonia
Landing on Titan
Neptune’s Triton

- Moon of Neptune that orbits backwards!
- Is active: it has a geyser.
All Jovian planets have rings.
Saturn’s Rings (as seen from Earth)
Saturn’s Rings (as seen by Cassini)
Saturn’s Rings (as seen by Cassini)
What is the rings’ composition?

- Composed of ice and dust with sizes ranging from dust particles to large boulders
- Small moons create the rings and gaps
Why do Jovian planets have rings?

- Jovian planet rings form from dust created from impacts on their small moons.

- Cannot be left over from their formation (particles cannot survive 4.6 billion years).

- There must be a source and the most probably is the small moons.
Asteroids, Comets, and Pluto (and “Xena” & “Sedna”, “Eris”, etc.?)
Asteroids

- Small, rocky objects
- Like terrestrial planets
- Size much smaller, not round, no atmosphere
- Also called “Minor Planets”
- Early solar system remnants
- Four largest:
  - Ceres (1000km), Pallas, Vesta, Hygeia
What do they look like?

Asteroids are not round
The Asteroid Belt

The location of the 150,000 known asteroids on July 1, 2004

On this scale, the asteroids are much smaller than the dots used to represent them.
Asteroid Belts in Movies

- Asteroids are actually hundreds of thousands of kilometers apart
Asteroid Eros as seen from NEAR
Crater on surface of Asteroid Eros (seen by NEAR)
Asteroid Ida and its moon Dactyl
What is a meteorite?

- **A meteorite** is a piece of an asteroid, or even the moon or another planet, that has fallen to Earth.

- **A meteor** is the bright tail of hot debris as it falls through the atmosphere (a shooting star!).
What is a comet?

A comet is an icy planetesimal left over from the formation of the solar system.

When it is near the Sun, it also exhibits a coma and two tails.
As a comet approaches the Sun in its orbit, its ices can sublimate into gas and dust, creating a coma and tail.
**Meteor Showers**

- As comets orbit the Sun, large (pea-sized) particles are left behind in the comets orbit.

- If the Earth passes through this trail of dust, we see a meteor shower.
Meteor Showers

Time-lapse photo
Where do comets come from?

Only a tiny fraction of comets come close to the Sun

Kuiper Belt: a disk extending from 30-100 A.U. In roughly orderly orbits, aligned with ecliptic, same direction as orbits (discovered in 1992!)

Oort Cloud: On random orbits extending to 50,000 A.U.
What Happened to Pluto?

- **Not a gas giant planet.**
- **Eccentric, inclined orbit.**
- **Smallest planet.**
In 2005, astronomers discovered an object in the Kuiper Belt larger than Pluto!

Pluto “demoted” to a “dwarf planet”, one of many “trans-neptunian” objects.
Largest known trans-Neptunian objects (TNOs)

- Dysnomia
- Eris
- Pluto (with Charon)
- Makemake
- Haumea
- Sedna
- Orcus
- Quaoar
- Varuna
Sedna: The Most Distant (known) Object in the Solar System

- Smaller than Pluto
- Closest approach to Sun is 75 A.U.
- At its most distant, it is 900 A.U. from the Sun
- Never enters the Kuiper Belt!
- An inner Oort cloud comet?
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Reminders

Read 6.3–6.5 for next time.