The Solar System
• One star
• Planets
• Asteroids
• Comets

Kuiper Belt Objects (KBOs)
• Oort Cloud
• Space Debris

Solar System Today
(Not to Scale)

Inner Planets, Orbits to Scale

Top Row: Earth, Venus
Bottom Row: Mars, Mercury, the Moon

Inner Planets, Sizes to Scale

Planets, Sizes to Scale
• Top Row: Jupiter & Saturn
• Middle Row: Uranus & Neptune
• Bottom Row: Earth, Venus, Mars, Mercury, & the Moon

Planets with the Sun, Sizes to Scale
How should we categorize the objects in the Solar System?

Planets & Dwarf Planets
New “Official” Definition

What exactly is a planet?

1. It orbits the Sun.
2. Has enough mass so that it is round
3. It has “cleared the neighborhood”
   - Pluto & Ceres satisfy #1 and #2, but not #3!
   - Pluto: other Kuiper Belt Objects
   - Ceres: other Asteroids

Planets
The planets of the solar system fall into three categories:
   - Terrestrial Planets  (those like Earth)
     - Mercury
     - Venus
     - Earth & Moon
     - Mars
   - Jovian Planets  (Like Jupiter; gas giants)
     - Jupiter
     - Saturn
     - Uranus
     - Neptune
   - Dwarf Planets, including Pluto and Ceres

Terrestrial Planets
Terrestrial comes from Latin “terra” meaning “earth”

Mercury, Venus, Earth, and Mars have some similar features:
   - Small mass
   - High Density
   - Surface features
   - Fewer moons
   - No ring systems
   - Thinner atmospheres

Mercury
   - Smaller than some moons!
   - About 40% the size of Earth
   - About 5% the mass of Earth
   - No moons, extremely thin atmosphere.
Mercury's Relative Size

Venus: “Earth’s sister planet”

- Diameter: 95% Earth’s diameter
- Mass: 82% Earth’s mass
- Highest albedo (reflectivity) in the solar system
- View from Earth is blocked by cloud cover

Earth

- Largest and most massive of terrestrial planets
- Distance of 1 AU (basis for the AU)
- Point of reference for other terrestrial planets

Mars

- Diameter: 53% of Earth (twice as big as the Moon)
- Mass: 10% of Earth
- Axis is tilted at 25º: seasons!
- One Martian day: 24 hours, 37 minutes
- One Martian year: 687 Earth days

Are Jovian planets all alike?

Jovian planets (not gas giants!)

- Better name: liquid giants (Jupiter & Saturn) or ice giants (Uranus & Neptune)
- Large mass (about 15x-300x mass of Earth)
- Hydrogen-rich composition
- Low density (1/3rd to 1/7th of Earth)
- Lots of moons, ring systems
Jupiter
- Mass: 300x Earth
- Size: 11x Earth
- Orbital distance: 5.2 AU
- Mostly H & He; no solid surface
- 62 moons, thin rings

Saturn
- Giant and gaseous/liquid like Jupiter
- Spectacular rings
- At least 61 moons, including cloudy Titan
- Cassini spacecraft currently in orbit

Uranus
- Mass: 14.4 x Earth
- Size: 4 x Earth
- Temperature: -366º F
- Similar composition to Jupiter & Saturn, but more ammonia & methane
- 30ish moons, rings

Neptune
- Mass: 17x Earth's
- Size: 4x Earth's
- Temperature: -357º F
- Composition like Uranus
- 13 moons, rings
- Discovered in 1846
Orbits in the Solar System

- Planets all revolve (orbit) around the Sun in the same direction
- Planets mostly rotate (spin) in the same direction on their axes
  - Exceptions: Uranus & Venus
- Orbital planes are close: within 5° of Earth’s orbital plane (the ecliptic)
- Spin planes are close: all within 30° of the Sun’s equator (with the exception of Uranus)

Protoplanetary Disks

Clues to Formation

- Patterns of Motion
- 2 types of planets
  - Terrestrial & Jovian
- Asteroids and Comets
- Exceptions to the Rules

Early Solar System

- The young Sun probably had a disk of gas & dust: the Solar Nebula
- Small cores in the disk (planetesimals) grow through accretion
- Temperature is warmer as you get closer to the center (where the Sun is!)
Chemicals in the Planets

- Sun’s composition: about 3/4 Hydrogen, 1/4 Helium, with roughly 2% other stuff
- Earth is very different!
- Jupiter & Saturn are more similar…

Collisions dominated the early solar system

- dust collects together into planetesimals
- planetesimals collect together into protoplanets
- Protoplanets gather up left over debris and became planets

Predictions from the Solar Nebula Theory

- Planet orbits should fall roughly in one plane
- Orbit and spin directions should be mostly the same
- Planets should have roughly the same age as their star

Differentiation in the Solar Nebula

- Material forms clumps according to temperature
- Only high-density elements can form clumps at high temperatures

The planets formed by the accretion of planetesimals and the accumulation of gases in the solar nebula
Temperature and Formation of the Solar System Lecture-Tutorial: Pg. 111-112

- Work with a partner or two
- Read directions and answer all questions carefully. Take time to understand it now!
- Come to a consensus answer you all agree on before moving on to the next question.
- If you get stuck, ask another group for help.
- If you get really stuck, raise your hand and I will come around.

Explanations from Solar Nebula Theory:

- Rocky inner planets, gaseous outer planets
- Common orbital and spin directions
- Common age of planets & star

- Jupiter is very massive, gravitational force prevents a planet forming between Mars & Jupiter: Asteroid belt!
- Comets & Kuiper Belt: leftover planetesimals!

Unsolved Problems:

- How fast do Jovian planets form? How fast does the disk get cleared out?
- Does the disk cool slowly or rapidly?
- What about orbital migration?
- Why does Venus spin backward? Why is Uranus tilted on its side?

Extrasolar Planets

- Over 700 planets confirmed since 1992, 3000+ candidates from Kepler Mission!
- 200+ of the planetary systems found contain more than one planet
- Many of the first planets found are “Hot Jupiters”, high mass & small orbits
- Various detection methods

Planet Search Methods

- Doppler Effect
  - Detect wobble toward or away from us
- Astrometry
  - Detect side-to-side wobble
- Transits
  - Search for “eclipses” as the planet passes in front of the star.
- IR imaging
  - A first glimpse at the light from planets!

Doppler Method

- Planets orbiting other stars “tug” on their star a bit
- The star wobbles when the planet tugs on it
- We can detect that wobble by measuring Doppler shifts
Astrometry

- Like the Doppler method, astrometry searches for wobbling stars.
- The Doppler Effect measures stars coming toward or moving away from us.
- Astrometry measures stars wobbling side to side.

Wobble of our own Sun -->

Eclipsing Planets

A planet might pass right in front of its star, making a small eclipse, or transit.

Transit Method

Most planets have now been discovered using the Transit Method.

If a planet happens to transit its host star:
- We can learn the size of the planet
- We might see the planet’s atmosphere.

The Kepler Mission

Kepler’s search field

Kepler’s Planet Candidates

Radius Relative to Earth

Orbital Period in days