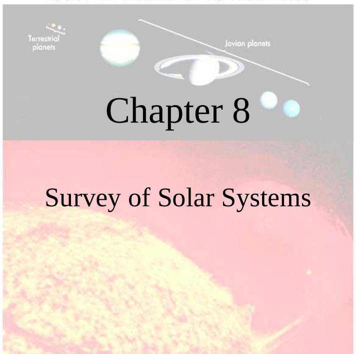


# Chapter 8

Survey of Solar Systems

# Agenda

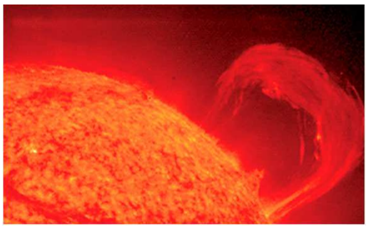
- Announce:
  - Schedule Next Observation...Candidate dates: Tue(11/30), Th (12/2), Th(12/9)
  - Project Part II due today
  - Project Presentations begin in two weeks
  - 4 weeks from today: Final Exam (1:50pm)
- Pass Back Unc/Significant Digits:
  - Some questions on final
  - Not all have been turned in
- Ch. 8 Solar Systems



# The Solar System

- The ***Solar System*** is occupied by a diversity of objects, but shows an underlying order in the dynamics of their movements
- The planets form two main families:
  - solid rocky inner planets
  - gaseous/liquid outer planets
- Astronomers deduce that the Solar System formed some 4.5 billion years ago out of the collapse of a huge cloud of gas and dust

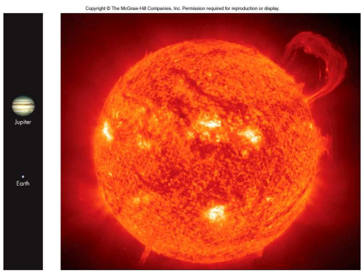
# The Sun



- The Sun is a star, a ball of incandescent gas whose output is generated by nuclear reactions in its core
- Composed mainly of hydrogen (71%) and helium (27%), it also contains traces of nearly all the other chemical elements



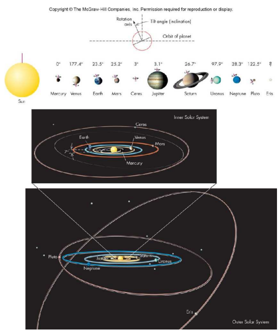
# The Sun



- It is the most massive object in the Solar System – 700 times the mass of the rest of the Solar System combined
- Its large mass provides the gravitational force to hold all the Solar System bodies in their orbital patterns around the Sun



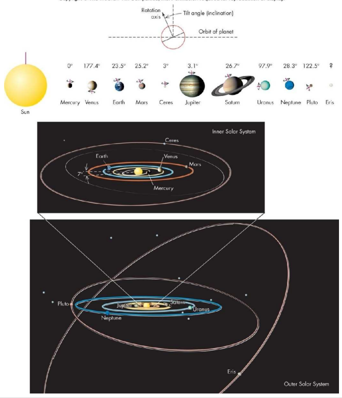
# The Planets



- Orbits are almost circular lying in nearly the same plane – Pluto is the exception with a high (17°) inclination of its orbit

# The Planets

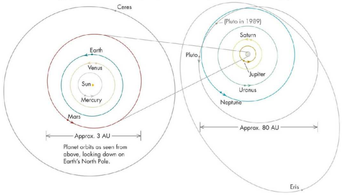




# The Planets

- All of the planets travel counterclockwise around the Sun (as seen from high above the Earth's north pole)
- Six planets rotate counterclockwise; Venus rotates clockwise (retrograde rotation), and Uranus appears to rotate on its side

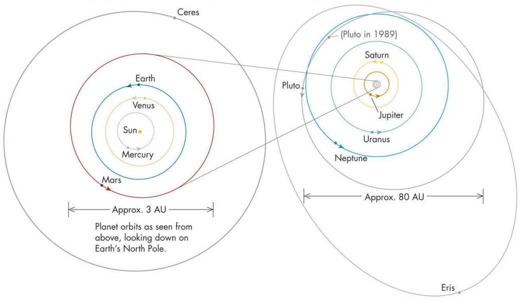






# The Planets

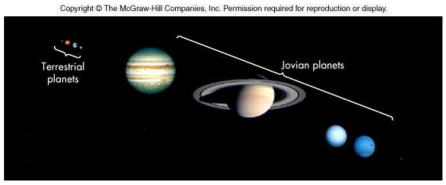







# Inner Planets



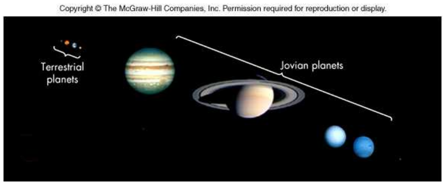


- Mercury, Venus, Earth, Mars
- Small rocky (mainly silicon and oxygen) bodies with relatively thin or no atmospheres
- Also known as ***terrestrial planets***



# Outer Planets





- Jupiter, Saturn, Uranus, and Neptune
- Gaseous, liquid, or icy ($H_2O$, $CO_2$, $CH_4$, $NH_3$)
- Also referred to as ***Jovian planets***
- Jovian planets are much larger than terrestrial planets and do not have a well-defined surface

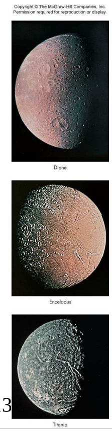


# Dwarf Planets

- Pluto and similar objects fail to fit into either family
- Recently, scientists have discovered more than 200 similar objects orbiting the Sun at the same distance as Pluto
- In 2006, a new family was introduced – the dwarf planets
  - Massive enough to pull themselves spherical
  - Orbits have not been swept clear of debris

# Satellites

- The number of planetary satellites
  changes frequently as more are discovered!
  - Jupiter 63
  - Saturn 60
  - Uranus 27
  - Neptune 13
  - Mars 2
  - Earth 1
  - Mercury and Venus are moonless
  - Even Pluto and Eris have moons!






# Asteroids and Comets

- Composition and size
  - ***Asteroids*** are rocky or metallic bodies ranging in size from a few meters to 1000 km across (about 1/10 the Earth's diameter)
  - ***Comets*** are icy bodies about 10 km or less across that can grow very long tails of gas and dust as they near the Sun and are vaporized by its heat

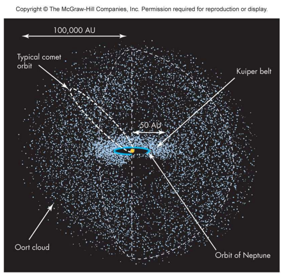


# Asteroids and Comets

- Their location within Solar System
  - Most asteroids are in the ***asteroid belt*** between Mars and Jupiter indicating that these asteroids are the failed building-blocks of a planet
  - Some comets may also come from a disk-like swarm of icy objects that lies beyond Neptune and extends to perhaps 1000 AU, a region called the ***Kuiper Belt***



# Asteroids and Comets



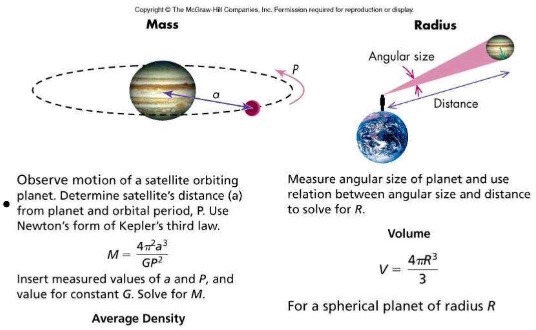

Most comets orbit the Sun far beyond Pluto in the ***Oort cloud,*** a spherical shell extending from 40,000 to 100,000 AU from the Sun



# Measuring Composition

- Since the inner and outer planets differ dramatically in composition, it is important to understand how composition is determined
- A planet's reflection spectrum can reveal a planet's atmospheric contents and the nature of surface rocks
- Seismic activity has only been measured on Earth for the purposes of determining interior composition

# Measuring Composition: Density



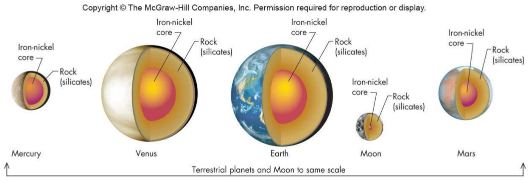
# Measuring Composition: Density

- Once average density known, the following factors are taken into account to determine a planet's interior composition and structure:
  - Densities of abundant, candidate materials
  - Variation of these densities as a result of compression due to gravity
  - Surface composition determined from reflection spectra
  - Material separation by density differentiation
  - Mathematical analysis of equatorial bulges



# Analysis Concludes:



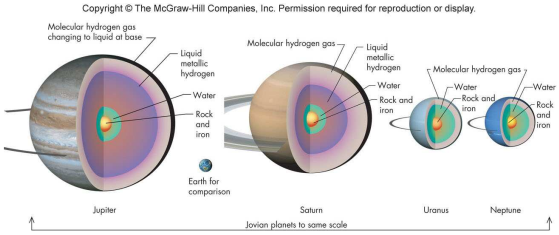



- The terrestrial planets, with average densities ranging from 3.9 to 5.5 g/cm$^3$, are largely rock and iron, have iron cores, and have relative element ratios similar to the Sun except for deficiencies in lightweight gasses



# Analysis Concludes:






- The Jovian planets, with average densities ranging from 0.71 to 1.67 g/cm$^3$, have relative element ratios similar to the Sun and have Earth-sized rocky cores



# Age of the Solar System

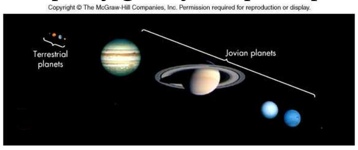
- All objects in the Solar System seem to have formed at nearly the same time, out of the same original cloud of gas and dust
- Radioactive dating of rocks from the Earth, Moon, and some asteroids suggests an age of about 4.5 billion yrs
- A similar age is found for the Sun based on current observations and nuclear reaction rates



# Bode's Law

- First noted in 1766, formalized mathematically by J. E. Bode in 1778
  - 0 3 6 12 24 48 96 192 384
  - 4 7 10 16 28 52 100 196 388
  - 0.4 0.7 1.0 1.6 2.8 5.2 10.0 19.6 38.8
- Does a pretty good job, up to a point






# Origin of the Solar System

- A theory of the Solar System's formation must account for the following:
  - Planets orbit in the same direction and in the same plane
  - Rocky inner planets and gaseous/liquid/icy outer planets
  - Compositional trends in the solar system
  - All Solar System bodies appear to be less than 4.5 billion years old
  - Other details – structure of asteroids, cratering of planetary surfaces, detailed chemical composition of surface rocks and atmospheres, etc.

## The Solar Nebula Hypothesis

- Derived from 18th century ideas of Laplace and Kant
- Proposes that Solar System evolved from a rotating, flattened disk of gas and dust (an ***interstellar cloud***), the outer part of the disk becoming the planets and the inner part becoming the Sun





## The Solar Nebula Hypothesis

- This hypothesis naturally explains the Solar System's flatness and the common direction of motion of the planets around the Sun
- Interstellar clouds are common between the stars in our galaxy and this suggests that most stars may have planets around them





## Interstellar Clouds

- Come in many shapes and sizes – one that formed Solar System was probably a few light years in diameter and 2 solar masses
- Typical clouds are 71% hydrogen, 27% helium, and traces of the other elements





## Interstellar Clouds

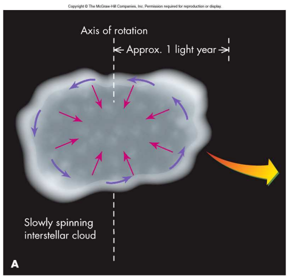
- Clouds also contain tiny dust particles called ***interstellar grains***
  - Grain size from large molecules to a few micrometers
  - They are a mixture of silicates, iron and carbon compounds, and water ice





## In the Beginning…



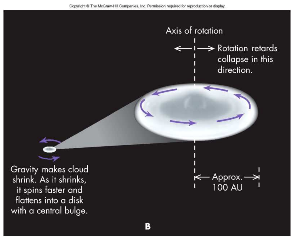



- Triggered by a collision with another cloud or a nearby exploding star, rotation forces clouds to gravitationally collapse into a rotating disk



## The Solar Nebula



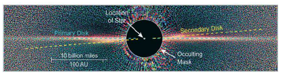



- A few million years pass for a cloud to collapse into a rotating disk with a bulge in the center
- This disk, about 200 AU across and 10 AU thick, is called the ***solar nebula*** with the bulge becoming the Sun and the disk condensing into planets

# Disk Observations









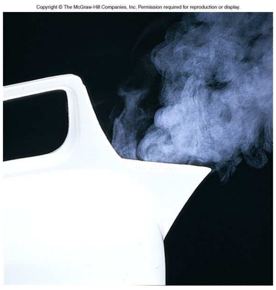
# Temperatures in the Solar Nebula

- Before the planets formed, the inner part of the disk was hot, heated by gas falling onto the disk and a young Sun – the outer disk was colder than the freezing point of water

# Condensation

- ***Condensation*** occurs when gas cools below a critical temperature at a given gas pressure and its molecules bind together to form liquid/solid particles





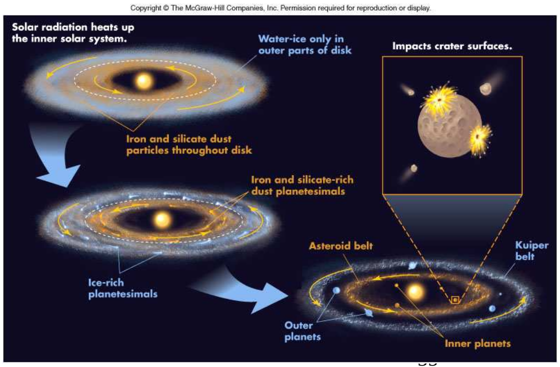


# Condensation in the Solar Nebula

- Iron vapor will condense at 1300 K, silicates will condense at 1200 K, and water vapor will condense at room temperature in air
- In a mixture of gases, materials with the highest vaporization temperature condense first
- Condensation ceases when the temperature never drops low enough
- Sun kept inner solar nebula (out to almost Jupiter's orbit) too hot for anything but iron and silicate materials to condense
- Outer solar nebula cold enough for ice to condense

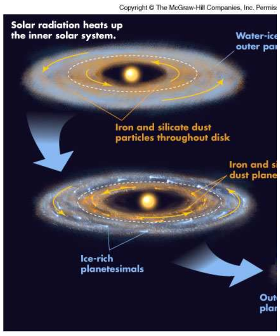
# Formation of Planets



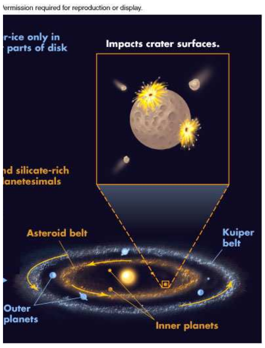



# Accretion

- Next step is for the tiny particles to stick together, perhaps by electrical forces, into bigger pieces in a process called ***accretion***
- As long as collisions are not too violent, accretion leads to objects, called ***planetesimals,*** ranging in size from millimeters to kilometers



## Planetesimals

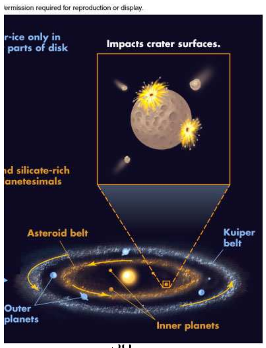



- Planetesimals in the inner solar nebula were rocky-iron composites, while planetesimals in the outer solar nebula were icy-rocky-iron composites
- Planets formed from “gentle” collisions of the planetesimals, which dominated over more violent shattering collisions

37

## Formation of the Planets

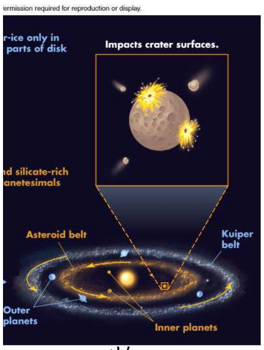
- Simulations show that planetesimal collisions gradually lead to approximately circular planetary orbits
- As planetesimals grew in size and mass their increased gravitational attraction helped them grow faster into clumps and rings surrounding the Sun




38

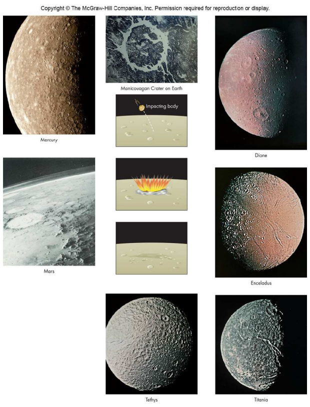
## Formation of the Planets

- Planet growth was especially fast in the outer solar nebula due to:
  - Larger volume of material to draw upon
  - Larger objects (bigger than Earth) could start gravitationally capturing gases like H and He




39

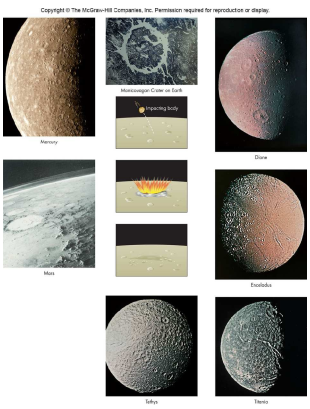
## Continuous Bombardment



- Continued planetesimal bombardment and internal radioactivity melted the planets and led to the density differentiation of planetary interiors

40

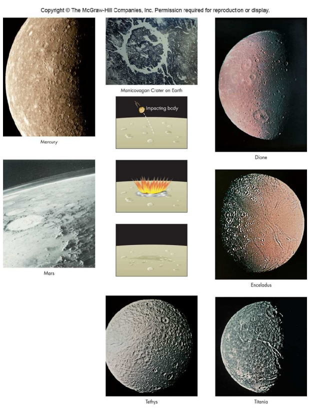
## Formation of Moons



- Moons of the outer planets were probably formed from planetesimals orbiting the growing planets
- Not large enough to capture H or He, the outer moons are mainly rock and ice giving them solid surfaces

41

## Final Stages



- Rain of planetesimals cratered surfaces
- Remaining planetesimals became small moons, comets, and asteroids

42

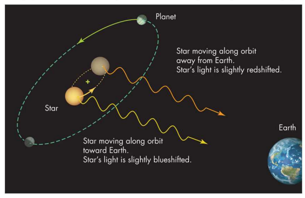
# Formation of Atmospheres

- Atmospheres were the last planet-forming process
- Outer planets gravitationally captured their atmospheres from the solar nebula
- Inner planets created their atmospheres by volcanic activity and perhaps from comets and asteroids that vaporized on impact
- Objects like Mercury and the Moon are too small – not enough gravity – to retain any gases on their surfaces

# Exosolar Planets

- Evidence exists for planets around other nearby stars
- The new planets are not observed directly, but rather by their gravitational effects on their parent star
- These new planets are a surprise - they have huge planets very close to their parent stars

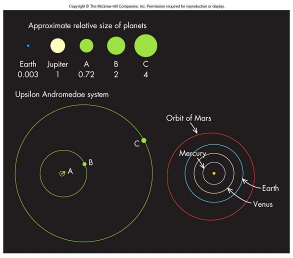







# Exosolar Planets

- Idea: The huge planets formed far from their stars as current theory would project, but their orbits subsequently shrank
- This migration of planets may be caused by interactions between forming planets and leftover gas and dust in the disk






# A Sample of Exoplanets