Lecture #7: Plan

• Solar System:
  — Components
  — Origin

• Other Planetary Systems
Solar System: Components

- **Sun** (~99.9% of the mass!)
- **Planets:**
  - Mercury, Venus, Earth, Mars (inner / terrestrial planets)
  - Jupiter, Saturn, Uranus, Neptune (outer / jovian planets)
  - Pluto (one of many “Trans-Neptunian Objects” = TNOs)
- **Moons** (= satellites) of planets
- **Asteroids** (separates inner and outer planets)
- **Comets** (outer Solar System)
Solar System: Planets

My Very Elegant Mother Just Served Us Nine Pickles!
The Kuiper Belt

- Outside orbit of Neptune (> 40 AU)
  → Trans-Neptunian Objects (TNO’s)
- Many bodies, mostly smaller but also larger than Pluto, have been found here
- So is Pluto really a planet?!? Not anymore…
Comets: The Oort Cloud

- Cloud of comets located ~ 100,000 AU from the Sun
- Gravitational influences from passing stars occasionally send comets into the Solar System
Orbits in the Solar System

• All planets revolve around the Sun in the same direction and in more or less the same plane
  – Mercury’s orbit is tipped by 7 degrees
  – Pluto’s orbit is tipped by 17 degrees
Rotation in the Solar System

- Most of the planets rotate in the same direction
  - Counterclockwise as viewed from above
  - Venus rotates clockwise as viewed from above
  - Uranus’ and Pluto’s rotational axes are tipped significantly!

![Diagram of the solar system with labeled rotation axes and inclination angles for various planets.](image-url)
Calculating a Planet’s Density

Density = Mass / Volume

- Mass: from orbital motion of moons around planet
- Volume = \((4/3) \pi R^3\) where \(R =\) radius of planet
Average Density of Planets

• **Inner planets:**
  - ~ 5 kg/liter
  - Small bodies
  - Mostly rock and iron

• **Outer planets:**
  - ~ 1 kg/liter
  - Larger bodies
  - Gas & ices

Water = 1 kg/liter
Age of Planets

• **Radioactive dating** tells us that:

All bodies in the Solar System whose ages have so far been determined are consistent with having formed about 4.5 billion years ago.
Solar System: Origin

Solar Nebula Theory: The Solar System originated from a rotating, flattened disk of gas and dust, with the outer part of the disk becoming the planets and the inner part becoming the Sun.

4.5 Byr ago
Angular Momentum

• If no external forces are acting on an object:

\[ L = m \cdot V \cdot R = \text{constant} \]

\( L \): angular momentum
\( m \): mass of object
\( V \): rotation speed
\( R \): size of object
Conservation of Angular Momentum

Angular momentum = $mvr = \text{constant}$

As $r$ decreases, $V$ must increase.

- $M \cdot V \cdot R = \text{constant}$
- If $R \downarrow$ then $V \uparrow$
- If $R \uparrow$ then $V \downarrow$
Solar System: Origin

Solar Nebula Theory: The Solar System originated from a rotating, flattened disk of gas and dust, with the outer part of the disk becoming the planets and the inner part becoming the Sun.

4.5 Byr ago
Condensation & Formation of Planets

• Young Sun heats up inner disk
• Gas condenses to form grains:
  – Outer zone: icy grains, silicates, iron-rich grains
  – Inner zone: silicates & iron-rich grains
Planetesimal & Planet Formation

- Accretion of grains to form planetesimals
- These planetesimals collided and gathered over millions of years to form the planets
Formation of Atmosphere on Terrestrial Planets

- **Outgassing**
  - Gas trapped inside planet escapes through volcanoes or other processes

- **Collisions**
  - Gas could have been freed from planet’s crust by collisions or via direct delivery by comets!
Support for Solar Nebula Theory

• Protoplanetary disks: disks of dark, dusty material orbiting young stars
• This one is only around 10 million years old!
Support for Solar Nebula Theory

- Direct views of protoplanetary disks *(by blocking out the light from the young star at the center)*
Support for Solar Nebula Theory

- **Direct views of protoplanetary disks** *(by observing in an energy band where the star is faint)*
Direct Views of Exoplanets

The Brown Dwarf 2M1207 and its Planetary Companion (VLT/NACO)

ESO PR Photo 14a/05 (30 April 2005)
Direct Views of Exoplanets

- Fomalhaut b:
  - 0.5-2 Jupiter masses
  - ~115 A.U. from star
  - ~18 A.U. closer than the debris disk
Detecting Exoplanets: Indirect Methods

- **Transit method (>1000 planets discovered this way!):**
  - Planet partially eclipses central star
  - Look for dimming of light from central star

- **Proper Motion method:**
  - Detect the spatial “wobble” of the central star

- **Doppler Shift method (more on this later):**
  - Detect the kinematic “wobble” of the central star

\[ a = \frac{F}{m} \]
Occurrence of Planets
(circa Jan 2013)