

Lecture 3: Solar System Small Bodies and Exoplanets

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1 Small Bodies in the Solar System

1.1 Comets

- Composition: Ice, rock, dust, and frozen gases
- Structure:
 - Nucleus: Ice, rock, and frozen gases
 - Coma: Gas and dust around nucleus
 - Tail: Material blown by solar wind
- Classification:
 - Short-period comets (< 200 years)
 - Long-period comets (> 200 years)
- Example: Halley's Comet (76-year period)

1.2 Kuiper Belt

- Location: 30-50 AU from Sun
- Contents:
 - KBOs (Kuiper Belt Objects)
 - Dwarf planets including Pluto
 - Source of short-period comets
- Similar to asteroid belt but:
 - Much larger
 - Contains mostly icy bodies rather than rocky bodies

1.3 Oort Cloud

- Distance: 2,000-100,000 AU from Sun
- Spherical shell of icy bodies
- Source of long-period comets
- Contains trillions of objects > 1 km
- Marks outer boundary of Solar System

1.4 Zodiacal Dust

- Source: Asteroid collisions and comet outgassing
- Creates zodiacal light through sunlight scattering
- Constantly replenished

2 Earth's Special Properties

- Location in habitable zone
- Stable atmosphere with oxygen
- Liquid water on surface
- Magnetic field protection
- Plate tectonics for carbon cycle
- Large moon for stability
- Protective ozone layer

3 Exoplanets

3.1 Detection Methods

3.1.1 Radial Velocity

The semi-amplitude K of the radial velocity variation is given by:

$$K = \left(\frac{2\pi G}{P} \right)^{1/3} \frac{M_p \sin i}{(M_s + M_p)^{2/3}}$$

where:

- P = orbital period
- M_p = planet mass
- M_s = stellar mass
- i = orbital inclination
- Measures stellar *wobble* due to planet
- More sensitive to massive, close-in planets
- Current precision: ~ 1 m/s

3.1.2 Transit Method

The fractional flux decrease during transit is:

$$\frac{\Delta F}{F} \approx \left(\frac{R_p}{R_s} \right)^2$$

where:

- R_p = planet radius

- R_s = stellar radius
- Measures stellar brightness drop
- Advantages:
 - Can detect Earth-sized planets
 - Allows atmospheric characterization
 - Can find multiple planets

3.2 Key Space Missions

3.2.1 Kepler Space Telescope (2009-2018)

- Observed $> 530,000$ stars
- Discovered $> 2,600$ confirmed planets
- Key finding: 1.4 planets per star average

3.2.2 TESS (2018-present)

- All-sky survey
- Focus on nearby bright stars
- Optimized for follow-up observations

3.3 Exoplanet Statistics

Size categories:

- Terrestrial: $< 1.6R_{\oplus}$
- Super-Earths: $1.6 - 2R_{\oplus}$
- Mini-Neptunes: $2 - 4R_{\oplus}$
- Gas Giants: $> 4R_{\oplus}$

Current census (2024):

- $> 7,000$ confirmed planets
- > 800 multiplanet systems
- Most common: Super-Earths and Mini-Neptunes
- Several Earth-sized planets in habitable zones

4 Further Reading

- The Extrasolar Planets Encyclopaedia
- "Exoplanets" by Sara Seager (ed.) (2010)
- NASA Exoplanet Archive: <https://exoplanetarchive.ipac.caltech.edu>