Pluto and Beyond

- Pluto
- Kuiper Belt
- Comets
- Asteroids
- Meteors and Meteorites
Pluto

Charon
Pluto and Planet X

• Orbits of Neptune and Uranus suggested that there might be another planet out there – Planet X

• After an exhaustive search, Pluto was discovered by Clyde Tombaugh in 1930.

• However, subsequent mass measurements indicate that Pluto is not massive enough to perturb Uranus and Neptune
  – Original measurements were in error
  – There is no planet X
Orbit and Rotation

• Highly eccentric orbit:
  \[ e = 0.25, \ a = 39.44 \ \text{AU}, \ i = 17.2^\circ \]
  from \( P^2 = 4 \pi^2 \ a^3/GM \), \( P = 248 \ \text{years} \)
  Because of it’s eccentric orbit, Pluto is sometimes closer than Neptune (i.e., 1979-1999)

• Rotation period: \( \sim 6.4 \ \text{days} \)
  – Axis of rotation close to ecliptic (like Uranus) \( \sim 118^\circ \)
Interior

- Hard to tell:
  \[ \langle \rho \rangle = 2060 \ \text{kg/m}^3 \]
- Some surface methane-ice
- Surface temperature \( \sim 40 \ \text{K} \)
- Atmosphere: Methane gas
  - \( P \sim 10^{-8} \ \text{atm} \)
Charon

- Moon discovered in 1978
- Important for mass measurement of Pluto, but orbit truly measures $M_{\text{pluto}} + M_{\text{charon}}$
- $M_{\text{charon}}$ probably ~ 1/6 of $M_{\text{pluto}}$
Origin?

• With bizarre orbit and composition like Jovian moons, where did Pluto come from?
  – Is Pluto a planet at all? [No longer…]  
  – Moon ejected from Neptune’s system after cataclysmic encounter?  
  – Formed in situ?

• Still heavily debated
Orbits
Asteroids, Comets, and other small bodies

• Bode’s “law”
  \[ a_n = 0.4 + 0.3 \times 2^{n-2} \]
  • Where \( n=2 \) (Venus), \( n=3 \) (Earth), etc
  • 0.4, 0.7, 1.0, 1.6, 2.8, 5.2, 10.0, 19.6
  Merc, Ven, Earth, Mars, ?, Jup., Sat., Uranus
  • ? region is close to Asteroid belt
  • “law” fails for Neptune, works for Pluto
    – Probably not fundamental
What are Asteroids?

- Small chunks of rock with orbits between 2.3 – 3.5 AU
- Can have extremely high orbital eccentricities:
  - Most are 0.1 – 0.3
  - Some are as large as 0.83
- Kirkwood gaps at ½, 1/3, ¼, 2/5, ¾, of Jupiter’s orbital period
  - Interactions with Jupiter cleared these regions
Orbits
Composition

- **S-type**
  - Bright (albedo ~ 0.15)
  - Silicate absorption bands
  - Found near Mars
- **C-type**
  - Dark (albedo ~ 0.02 – 0.05)
  - Carbon or magnetite (Fe₃O₄)
  - Found at outer edge of the belt
- **M-type** (5% of total)
  - albedo ~ 0.10
  - Metallic
Gaspra
Ida and Dactyl

\[ \langle \rho \rangle \sim 2200-2900 \text{ kg/m}^3 \]
<\rho> \sim 1400 \text{ kg/m}^3 \rightarrow \text{ porous interior}
<\rho> \sim 2700 \text{ kg/m}^3 \rightarrow \text{solid rock interior}

New result: most rocks strewn across the surface come from a single impact crater
How large is that asteroid?

- We see the reflected light from the asteroid:

\[ F_{\text{incident}} = \frac{L_{\text{sun}}}{(4 \pi D^2)} \]

\[ F_{\text{earth}} = \left[ \frac{F_{\text{incident}}}{(4 \pi d^2)} \right] \times A \times \text{cross section} \]

\[ = \left[ \frac{L_{\text{sun}}}{(4 \pi D^2)} \right] \times A \times \pi r^2 / (4 \pi d^2) \]

\[ = \left( \frac{L_{\text{sun}}}{16 \pi D^2 d^2} \right) (A r^2) \]

At the same time, the incident radiation heats up the asteroid so it emits in the IR:

\[ F_{\text{vis}} / F_{\text{IR}} = A / (1-A) \]  \[[\text{reflected/absorbed}]\]
Earth crossing asteroids

• Most asteroids have eccentricities $\sim 0.05 – 0.3$
  – Orbits between Mars and Jupiter

• Asteroids with eccentricities $> 0.4$ may intersect Earth’s orbit
  – **Apollo** asteroids: semi-major axis $> 1.0$ AU
  – **Aten** asteroids: semi-major axis $< 1.0$ AU
  – **Amor** asteroids: only cross orbit of Mars
Earth crossing asteroids cont.

• Approx 1200 Earth-crossing asteroids are known
  – Most have been discovered in the last couple years with onset of systematic searches
  – Fast moving objects – need all sky coverage in short period of time.
  – Faint objects, so need large telescopes too.
    • Next generation of telescopes being built – LSST will be a 6-8m with large field of view.
  – Most are small, ~ 1 km in diameter (NOTE: explosive power of “small” NEO is still catastrophic)
  – Approximately 300 Earth crossers are designated “potentially dangerous”
    • D > 150 m; distance < 7.5 × 10^6 km
Orbital Resonances

- **Trojan asteroids**: at distance of Jupiter and in 1:1 orbital resonance with Jupiter

All 5 are theoretically good locations for “locked” orbits, but L1, L2, and L3 are unstable to perturbations. L4 and L5 are stable, and asteroids accumulate near these positions.
Comets

• Comets are small bodies moving on highly elliptical orbits.
  – As they near the sun, they warm, brighten, and produce a tail.

• **Nucleus**: a few km in diameter
  – Dirty snowball model
  – Compact, solid bodies of frozen gases embedded in a rocky core
    • Water, CO$_2$, NH$_3$, CH$_4$

• **Coma**: icy surface heats as comet nears sun
  – Evaporated material becomes a diffuse halo of dust and gas

• **Ion tail**: approximately straight, 180º from sun
  – Spectra show numerous ions: radicals of CO, CO$_2$, N$_2$, NH$_3$, CH$_4$

• **Dust tail**: broad, diffuse, and gently curved
  – Microscopic dust particles reflect sunlight
  – Dust tail will eventually follow Keplarian orbit around sun
Comet Structure

- **Dust tail**
- **Ion tail**
- **Hydrogen envelope**
- **Coma**
- **Nucleus**

To Sun: 10^7 km
Comet's motion: 10^6 km

10^8 km
Comets

Comet Hyakutake

Comet Halley
Comet Orbits
Comet Orbits

• **Long period** comets have highly elliptical orbits
  – Beyond the orbit of Pluto
    • At large distances, they move slowly
      → spend most of their time far from sun
    • a ~ 50,000 AU, P ~ 10^7 years
  – **Oort cloud**
    • Source of additional comets after gravitational perturbation by passing star
    • May be as many as 10^{11} – 10^{14} comets in the Oort cloud

• **Short period** comets (P < 200 yrs) come from a flattened ring/belt beyond Neptune
  – **Kuiper Belt** – until a few years ago, this was a theoretical construct
  – Now, we have several detections of TNO/KBO every year and lists are growing.
  – KBOs move in roughly circular orbits ~ 30-100 AU
Meteoroids and Meteroites

• A meteor (shooting star) occurs when interplanetary debris enters the Earth’s atmosphere
  – If material survives, it is a meteroite
  – Most meteoroids crumble quickly when they encounter the atmosphere – bright streak is a result of friction heating and exciting air molecules
Origin of Meteoroids

• Comets – 99% of meteoroids are debris from dust tails
  – If Earth crosses comet’s orbit shortly after comet approaches sun → meteor showers

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<td>Geminid</td>
<td>50</td>
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Types of Meteoroids

• **Irons**: 90% iron, 10% nickel  
  – $<\rho> \sim 7500 – 8000 \text{ kg/m}^3$

• **Stones**: silicate materials (like terrestrial rocks)  
  – $<\rho> \sim 3000 – 3500 \text{ kg/m}^3$
  – Subset have silicate spheres (**chondrules**)  
    • Know as **Chondrites**

• **Stony-irons**: small stone pieces set in iron  
  – $<\rho> \sim 5500 – 6000 \text{ kg/m}^3$

• **Carbonaceous chondrite**: embedded material contains more carbon  
  → dark
Where to Find Meteorites Easily?

Typical Earth location
Where's the meteorite?

Antarctica
Where's the meteorite?