A Little History

- Gerard Kuiper and Kenneth Edgeworth “predicted” a distribution of small bodies in the outer solar system – 1940s
- Real surveys began in early ’90s
  - 70,000 KBOs w/ d > 100 km (estimated)
  - 30 AU < a < 50 AU
  - Range of inclination/eccentricity
- 1st KBO is really Pluto!
Properties of TNOs

- Green stars $\rightarrow$ scattered population
- Red squares $\rightarrow$ classical KBOs
- Lines are different power law fits
- Surface density best fit by two power laws
Basic Orbital Properties

- **“Classical”**
  - Low eccentricity, low inclination
  - $40 \text{ AU} < a < 47 \text{ AU}$

- **“Resonant”**
  - Occupying various resonances with Neptune $\rightarrow 3:2, 4:3, 2:1$ etc
  - $a \sim 40 \text{ AU}$

- **“Scattered”**
  - High eccentricity, high inclination

Distribution of TNOs
Population

- Total mass \(\sim 0.5\) Earth masses
- Total number \(\rightarrow\) unknown
  - \(> 1500\) detected via surveys
  - \(\sim 100\) KBOs with photometry
  - “classical” KBOs are “red” (B-R > 1.5)
  - “scattered” KBOs are “grey”
    - Largely colorless (flat spectrum)
    - Primordial?

Classical KBOs

- Mostly between 42 and 48 AU
- Formed via “quiet accretion”

![Diagram showing distribution of KBOs](image)
Orbital Populations

- Reflect dynamical history of the outer solar system
  - Hahn & Malhotra (2005 AJ 130 2392)
    - N-body simulation
    - Neptune migration → previously heated disk
    - Populates the 5:2 resonance with Neptune
  - “scattered” KBOs largely affected by planet migration

Orbital Populations

- Hahn & Malhotra
Scattered KBOs - orbits


Populations (Hahn & Malhotra 2005)

<table>
<thead>
<tr>
<th>Dynamical Class</th>
<th>Site (AU)</th>
<th>Population</th>
<th>Mass ($M_\oplus$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centaurs ...........</td>
<td>$a &lt; a_N$</td>
<td>$&lt; 80$</td>
<td>$&lt; 4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Trojans ............</td>
<td>$a = a_N$</td>
<td>$&lt; 1.1 \times 10^3$</td>
<td>$&lt; 5 \times 10^{-4}$</td>
</tr>
<tr>
<td>3:2 ..................</td>
<td>$a = 39.5$</td>
<td>$2.7 \times 10^3$</td>
<td>$3.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Main Belt ...........</td>
<td>$40.1 \leq a \leq 47.2$</td>
<td>$1.3 \times 10^5$</td>
<td>0.059</td>
</tr>
<tr>
<td>2:1 ..................</td>
<td>$a = 47.8$</td>
<td>$5.3 \times 10^3$</td>
<td>$2.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>Scattered Disk .......</td>
<td>$50 &lt; a &lt; 150, 28 &lt; q &lt; 40$</td>
<td>$2.5 \times 10^3$</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Note.—Assuming density $\rho = 1$ g cm$^{-3}$ and albedo $\rho = 0.04$. 
**Explanation for Colors?**

- Neptune migrates from 25 AU to 40 AU
- Scatters objects
- Objects at 40 AU are relatively unperturbed → surfaces reflect methane ice

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**KBO colors**

![Graphs and charts illustrating KBO colors](image-url)
KBO Colors vs Dynamics

- 16 years worth of data
- Orbital properties:
  - $a = 67.9$ AU, $e = 0.4378$, $i = 43.99$
  - Aphelion at 97.5 AU, perihelion at 38.2 AU
But are they really planets?

Asteroid Distribution - orbit

- Note concentrations in various regions of the plot
- Each clump is an asteroid “family”
- Major families
  - Main belt (Mars-Jupiter)
  - Trojans
  - Near-Earths

SIZE COMPARISON (DIAMETER)

- Earth: 12,756km
- Moon: 3,475km
- Mars: 6,788km
- Pluto: 2,360km
- Sedna: less than 1,800km
- Charon: 1,250km
- Quaoar: 1,250km
- 2003 UB313: 2,600km
Size Distribution

- Power law
  \[ N(R) = N_0 \left(\frac{R}{R_0}\right)^{-p} \]
- Theory says \( p = 3.5 \) → based on collisionally dominated size distribution
- Ivezic et al. 2000 → \( p = 2.3 \pm 0.05 \) for size distribution of 0.4-5.0km → main belt asteroids
  - Derived from SDSS data

Collisions

- Collisions → numerical simulations
  - 100-200 km diameter progenitors
- Limits?
  - Surface ages
  - Vesta’s surface looks primordial, but it has a large impact crater
Asteroid Composition

- How do you measure asteroid compositions?
  - Reflection spectroscopy
  - Comparison with meteorites
Asteroid Composition - colors
Jedicke et al. 2004  →  results indicate “space weathering”

Comparison with meteorite samples
Points are real data, line is reflection spectrum of samp
Composition-results

- 75% of asteroids are dark
  - Look like “carbonaceous chondrites”
  - Most of these are “hydrated” → heated in past so that minerals mixed with liquid water
- 12% are “stony irons” → Fe silicates
- M-type albedos → pure Ni/Fe, no silicate absorption features