SOLAR SYSTEM SCIENCE

June 16 2008
Science with Giant Telescopes, Chicago

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Outline of the Talk

• Quick Overview of Solar system
• Nature of the Kuiper belt
• Binary KBOs: Science Use Case
• Summary

Style: Sweeping and Accessible
The Three Domains of the Solar System

- Terrestrial planet domain (intensively studied and visited)
- Giant planet domain (exploration just beginning)
- Comet domain (only recently discovered, almost unexplored)
Background:

The Three Domains of the Solar System

- **Terrestrial planet domain** (intensively studied and visited)
- **Giant planet domain**
  (exploration just beginning)
- **Comet domain**
  (only recently discovered, almost unexplored)
Big Picture: The Three Comet Reservoirs

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Identified</th>
<th>Formation Location</th>
<th>T [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oort cloud</td>
<td>1950</td>
<td>5 - 20 AU (Jupiter - Neptune)</td>
<td>120 - 50</td>
</tr>
<tr>
<td>Kuiper belt</td>
<td>1992</td>
<td>≥ 20 AU (beyond Neptune)</td>
<td>≤ 50</td>
</tr>
<tr>
<td>Main-belt</td>
<td>2006</td>
<td>3 AU (Mars - Jupiter)</td>
<td>~150</td>
</tr>
</tbody>
</table>

Oort Cloud: 10^5 AU

Kuiper Belt: 10^2 AU
Big Picture: Primordial Ice in the Solar System

Asteroid Belt
Kuiper Belt
Centaurs
JFC
HFC
LPC
Trojans
Jupiter-Neptune Source Zone
Oort Cloud
Ejection
Defunct Comets
Disintegration
Sun/Planet Impact
MBC

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Kuiper Belt:

- Source of Jupiter-family comets
- Sun’s Debris Disk
- Deep-freeze repository of volatile matter
- Remnant of the accretion epoch
Eccentricities are large: KB is excited
Inclinations are large: KB is a fat doughnut.
Kuiper Belt in Perspective
• Dynamically structured

• Well populated resonances:
  - planet migration

• High mean inclinations and eccentricities:
  - past excitation \( (\Delta V \sim 1.7 \text{ km/s}) \)

• Mass \( (\sim 0.1 \text{ M}[\text{Earth}]) \) too small for accretion:
  - current belt is a 0.1% - 1% remnant

**Intense post-accretion dynamical processing has occurred**
Migration and planet-planet resonance interactions together give the NICE N-Body Model
Tsiganis, Morbidelli, Levison 2005
$T = 877.8 \text{ My}$

![Graph showing semimajor axis (AU) vs. eccentricity with a label from Tsiganis, Morbidelli, Levison 2005.](image)
• Binary formation results from dynamically very cold conditions and overlapping Hill spheres.

• Binary properties tell us about this (early) state, presumably associated with accretion itself.

• Therefore, binaries provide a window onto planet accretion complementary to the one provided by the excited Kuiper belt dynamical structure.
SCIENCE USE CASE

• Optical data (GSMT) give orbit parameters semimajor axis, $a$, and orbital period, $T \Rightarrow$ Mass

[exploits both the sensitivity and the resolution of GSMT]

• Optical and thermal (JWST, ALMA) data give albedo, $p$, and radius, $R$

[exploits the thermal sensitivity of JWST and ALMA]

• Mass and Radius give density, $\rho$, the “first geophysical parameter”
Binaries are abundant [>10%?], most are close
SCIENCE USE CASE

• STEP 1: GSMT survey to identify binaries [to $\theta \sim 0.008''$ and $\Delta m \geq 5$]

• STEP 2: GSMT sampling for orbit and mass determination [periods $\sim$week to $\sim$year]

• STEP 3: JWST/ALMA measurements to determine albedo and size

[STEPS 2 and 3 would run concurrently]
Optical data (GSMT) give orbit parameters \( a \) and \( T \) => Mass

Optical and thermal (JWST) data give albedo, \( p \), and radius, \( R \)

Mass and Radius give density, the “first geophysical parameter”
SCIENCE USE CASE

Thermal Constraint

Optical Constraint

Radius [km]

Geometric Albedo

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SCIENCE USE CASE

Kuiper Belt Objects
Planetary Satellites
Jovian Trojans
Cometary Nuclei

Density $\rho$ [kg m$^{-3}$]

Effective Diameter $D$ [km]

SL9
SW2
Bo
C-G
T1
Wild 2
133P
Hektor
EL61
Eris
Pluto
Charon
Phoebe
Amalthea
Enc
Patroclus
Pandora
Prometheus
QG298
TC36
Varuna
Hyperion

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SUMMARY

1. Kuiper Belt is dynamically hot [$\Delta V \sim 2$ km/s], indicating past violence

2. KB wide-binaries are fragile; formation models suggest $\Delta V \sim 1 - 10$ cm/s

SCIENCE USE CASE

1. Distribution of binaries can test accretion models, frictional-damping, collisional & other capture models

2. Orbits and sizes (and Kepler’s law) will give density. Density opens up “geophysics”.

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The End