The Kuiper Belt

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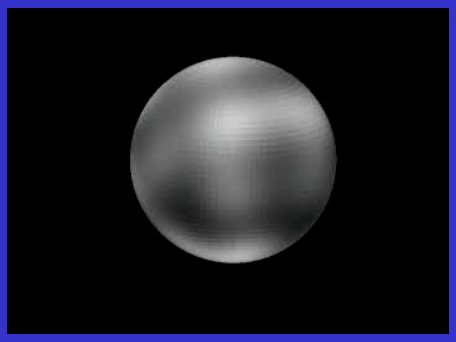
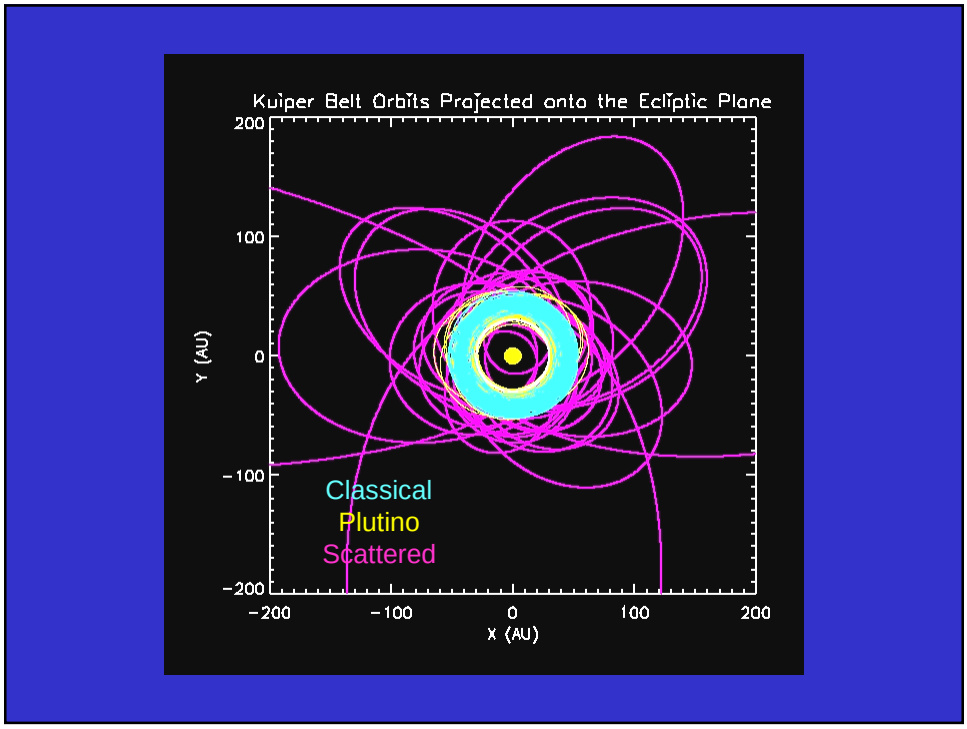
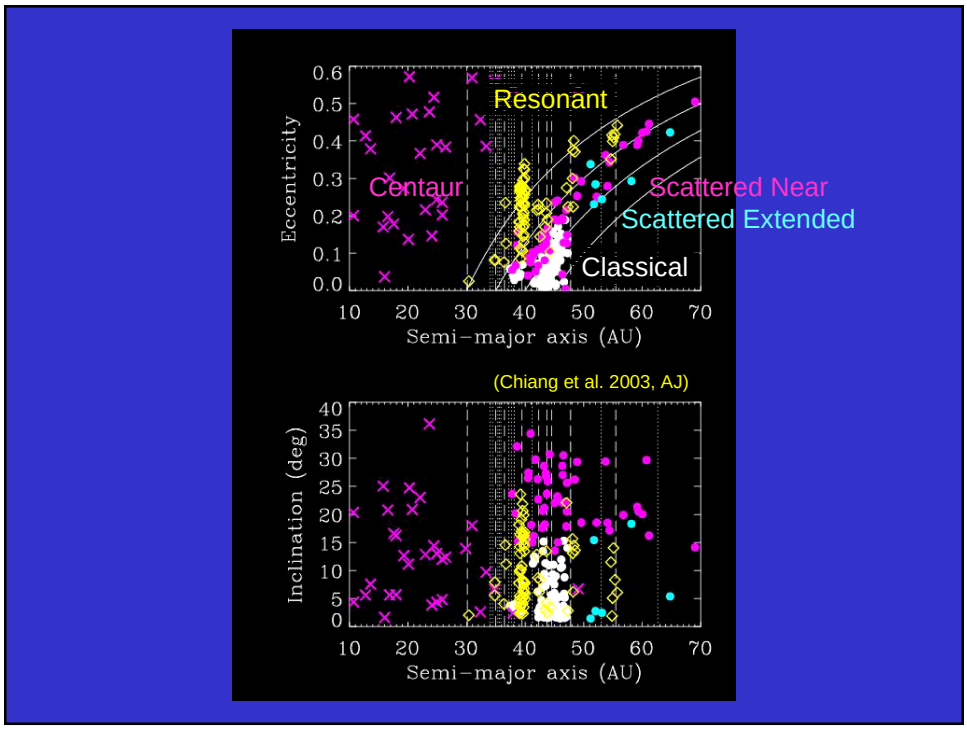


Pluto: Head of the Plutino Family
(M. Buie)

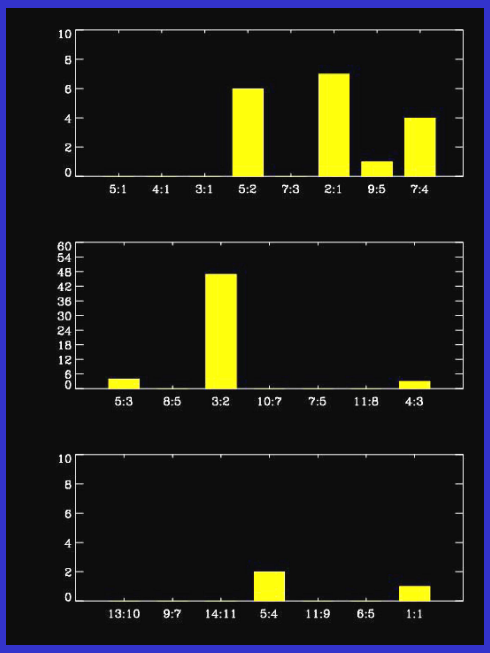
Issues in Kuiper Belt science:

1. Resonance capture
2. Trojans
3. Dynamical heating
4. Edge
5. Colors and inclinations
6. Size distribution
7. Missing mass

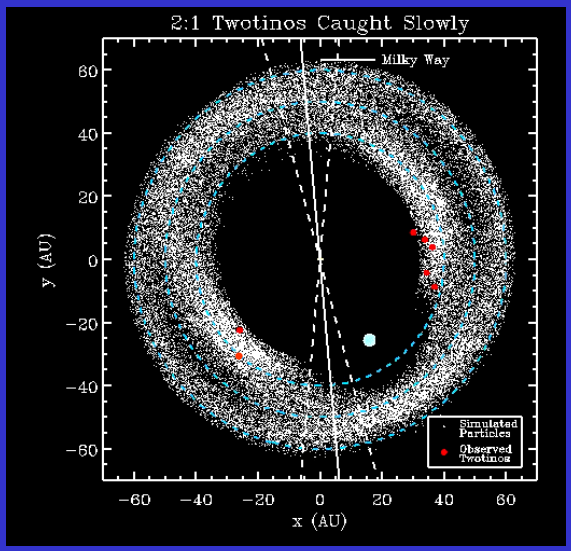

Kuiper Belt Orbits Projected onto the Ecliptic Plane
200
100
0
−100
−200
Y (AU)
−200
−100
0
100
200
X (AU)
Classical
Plutino
Scattered


Eccentricity
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Resonant
Centaur
Scattered Near
Scattered Extended
Classical
10
20
30
40
50
60
70
Semi−major axis (AU)
(Chiang et al. 2003, AJ)
Inclination (deg)
40
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
Semi−major axis (AU)

Breakdown of all Resonant KBOs

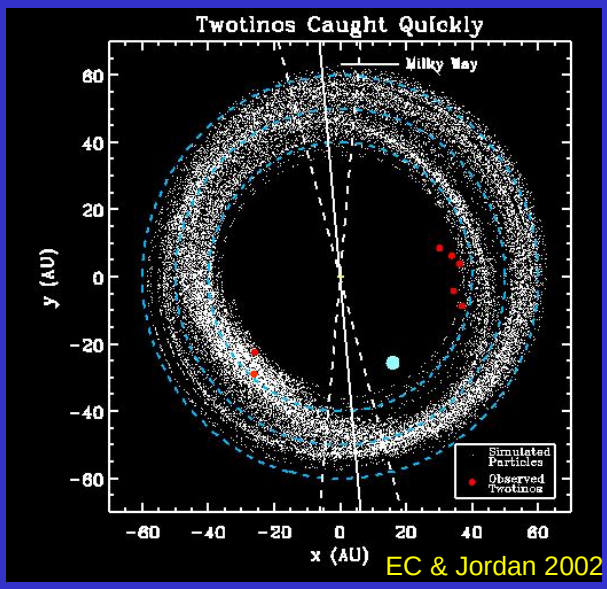


Twotino (2:1) Snapshot



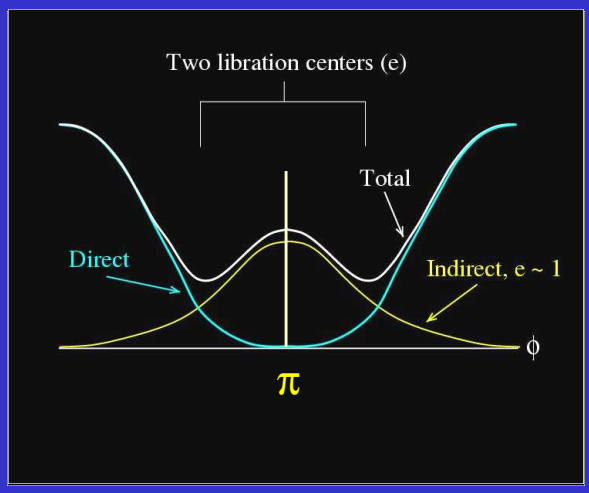
EC & Jordan 02

Faster Migration ($\tau \sim 10^6$ yr): Asymmetric Capture

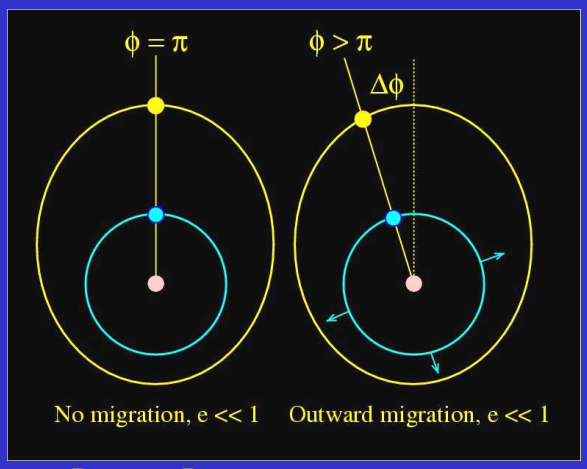


EC & Jordan 2002

Direct + Indirect Effects



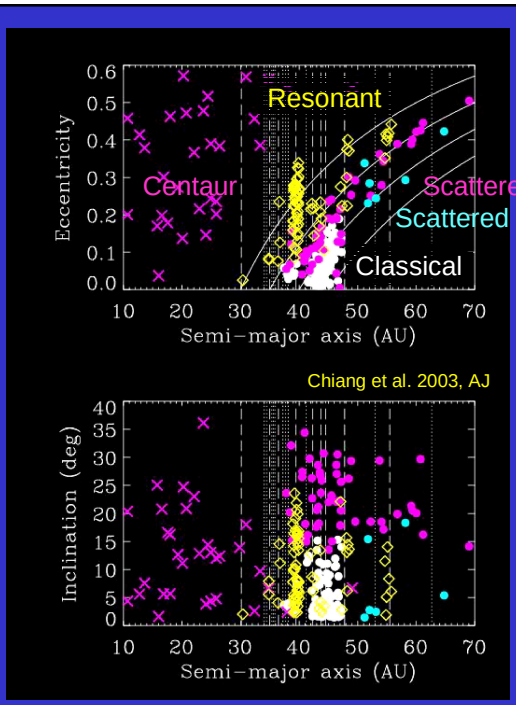
Preference for φ > π set by outward migration



$$\Delta\phi \cong \frac{\tau_{lib}}{\tau_{mig}} \frac{\tau_{lib}}{\tau_{orb}}$$

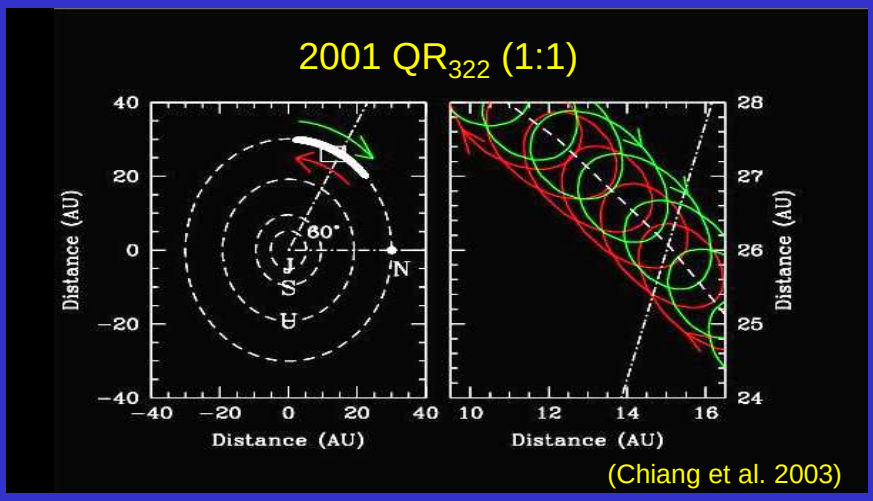
1. Asymmetric capture: Signature for migration

Murray-Clay & Chiang, in prep.



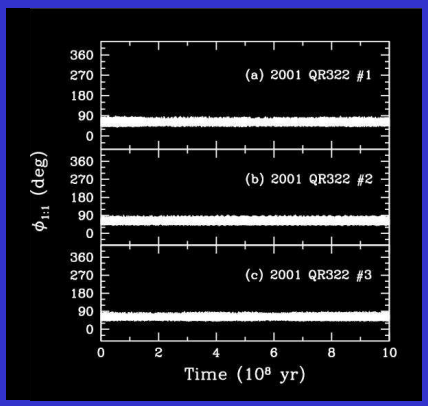
Chiang et al. 2003, AJ

First Discovered Neptunian Trojan

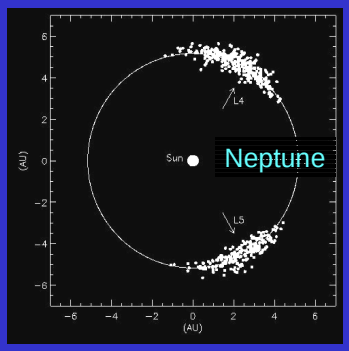


(Chiang et al. 2003)

Long-term stability
⇒ Primordial resident



"Move over Jupiter"

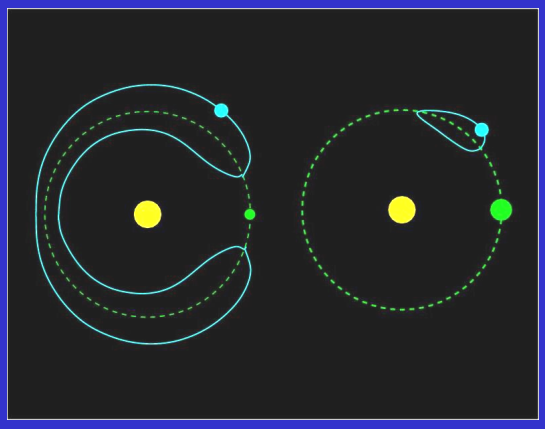


1 "Large" Neptune Trojan in 60 °
⇒ ~20—60 Neptune Trojans
vs. ~10 Jovian Trojans

"Large": 130--230 km diameter
12%--4% visual albedo

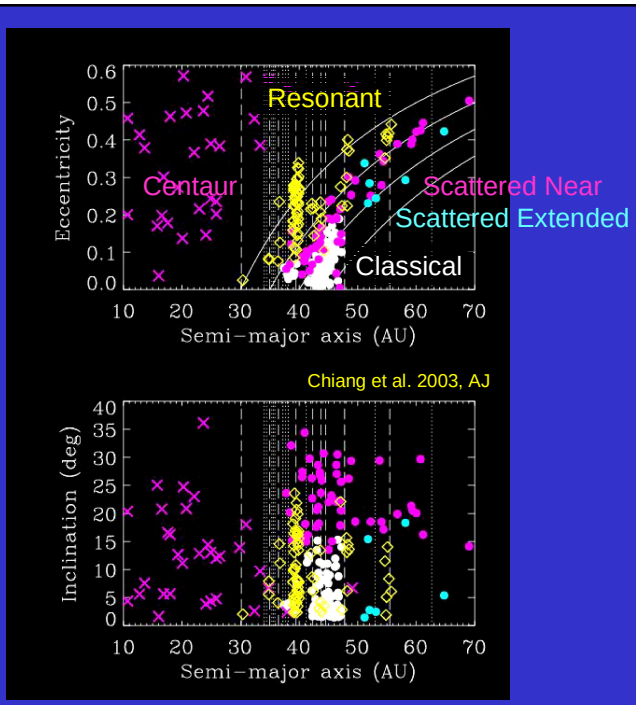
2. How do Trojans constrain host planet formation?

Fleming & Hamilton 2000; Marzari & Scholl 1998

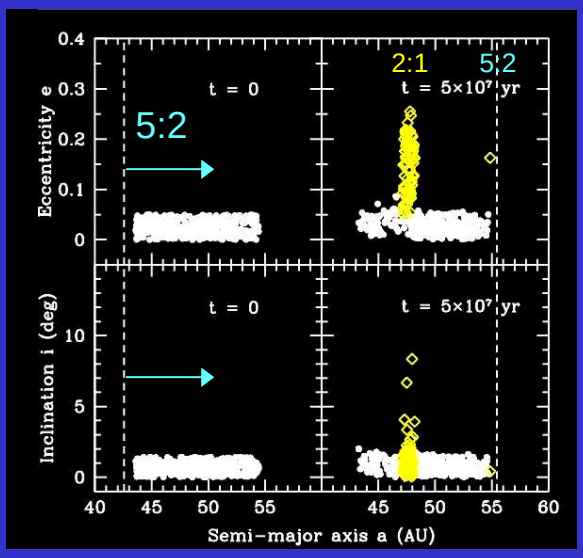


Adiabatic invariant $D = \Delta\Phi_{110000}\, M_N^{1/4}\, a_N^{1/4}$

Argues against violent orbital history for Neptune

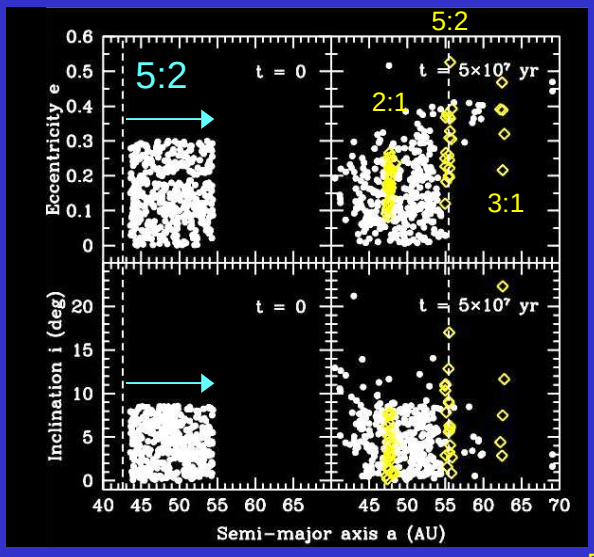


Sweeping 5:2 resonance
Cold initial conditions: low capture efficiency



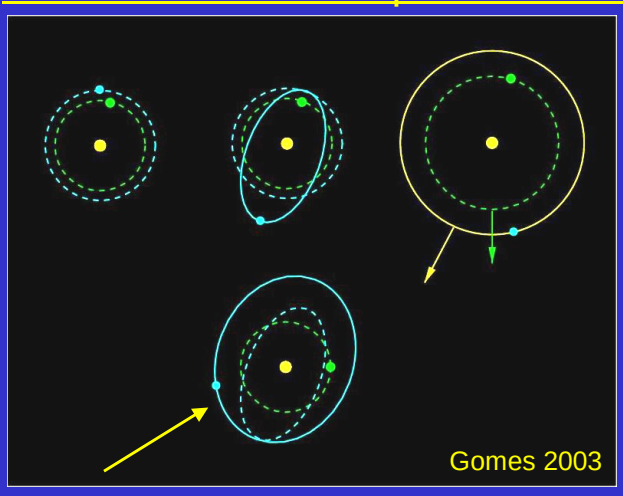
EC et al. 2003

Sweeping 5:2 resonance
Hot initial conditions: high capture efficiency



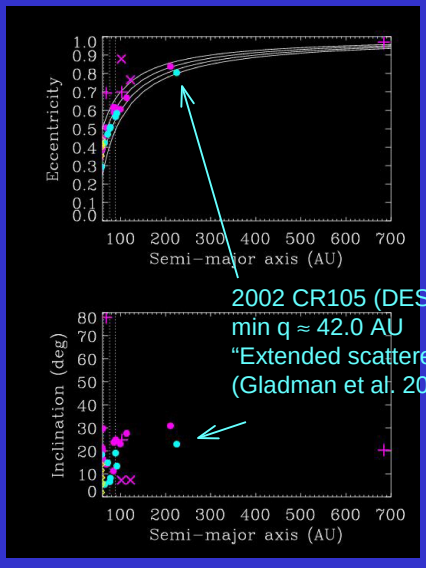
EC et al. 2003

3. How was the Belt pre-heated?



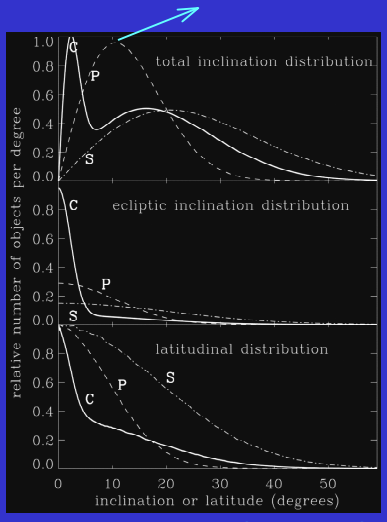
Problem: How to raise the perihelion after scattering

Other lines of evidence for pre-heating:

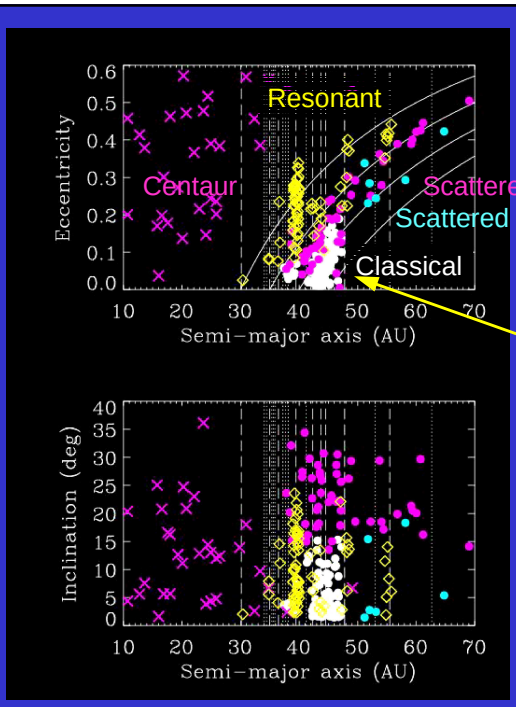


2002 CR105 (DES)
min q ≈ 42.0 AU
"Extended scattered disk"
(Gladman et al. 2002)

Observed resonant inclinations too high



(Brown 01)

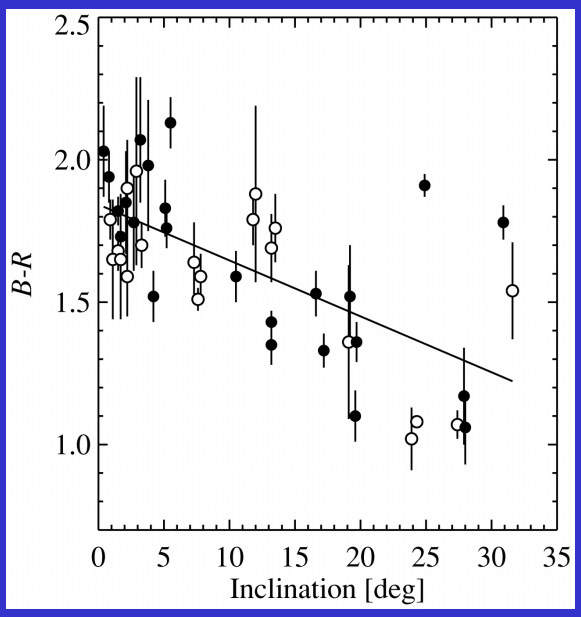


Kuiper Cliff

4. Why is there an edge?

1. Present edge coincides with 2:1
   No coincidence (Levison & Morbidelli 03)

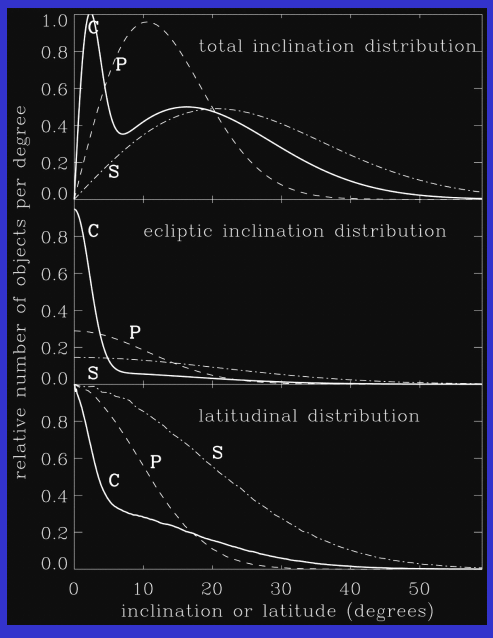
2. Primordial edge inside 2:1
   Radial drift of solids + critical metallicity threshold for planetesimal formation?
   (Youdin & Shu 02; Youdin & Chiang 03)



5. What does the Color-Inclination correlation for Non-Resonant KBOs mean?

(4.1σ)

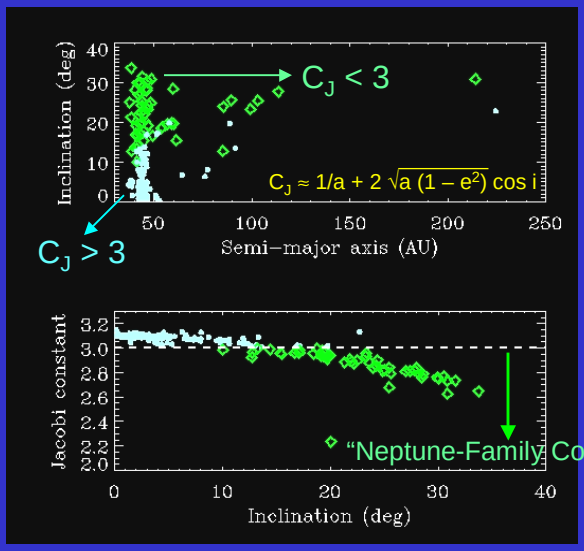
(Trujillo & Brown 02)



Bi-modal inclination distribution for Classical KBOs

(Brown 01)

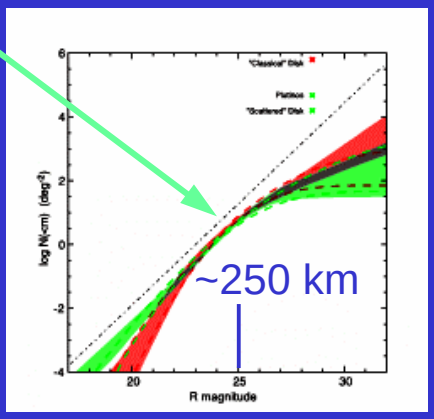
Bolstering the bi-modal inclination distribution



(EC,unpublished)

6. Can one explain the size distribution?

d ln N / d ln R = -4



(Bernstein et al. 04)

7. Where is the missing mass?

1. In the beginning, ~10 $M_\oplus$
   a. form Pluto
   b. form binaries (Goldreich, Lithwick, Sari 02)
2. In the end, ~0.1 $M_\oplus$

and can we get this dynamically rather than by counting objects?