
2004 KITP Conference on Planet Formation
Cometary Reservoirs as Clues to Planet Formation
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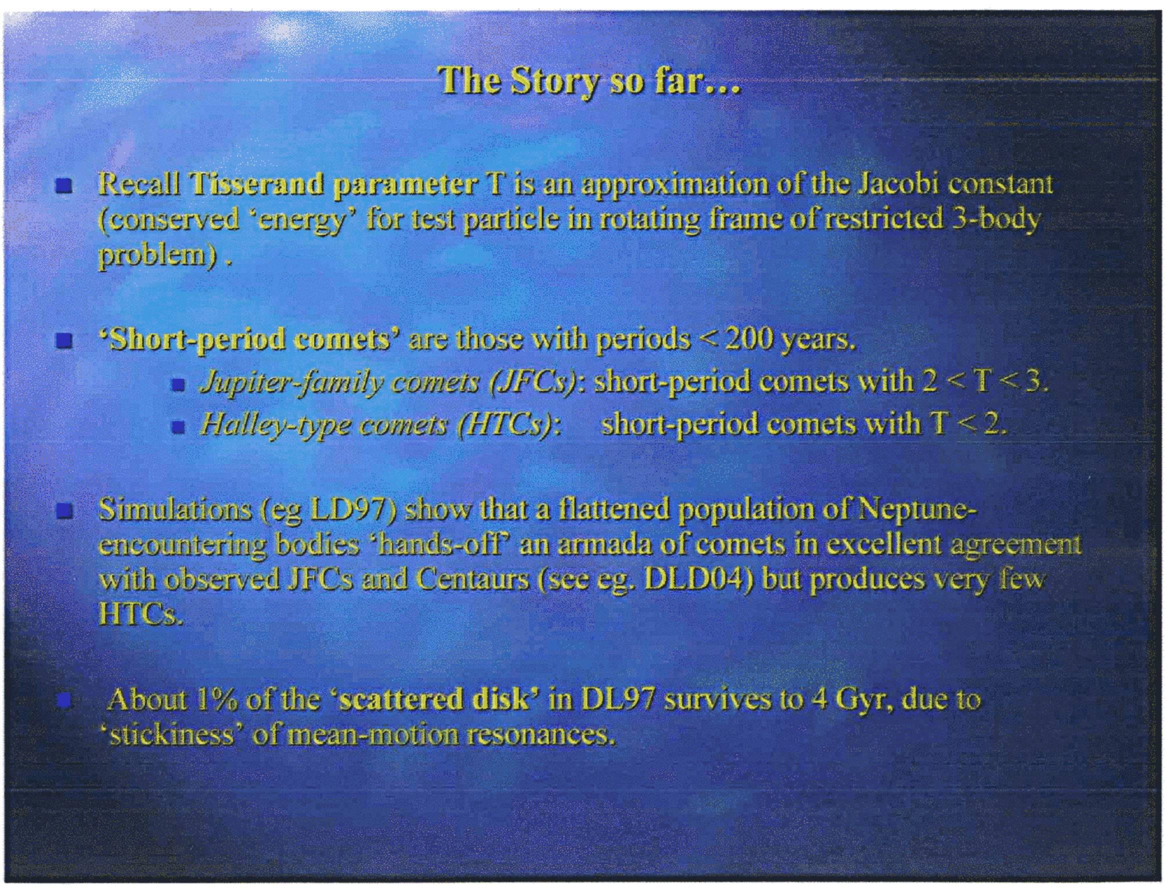
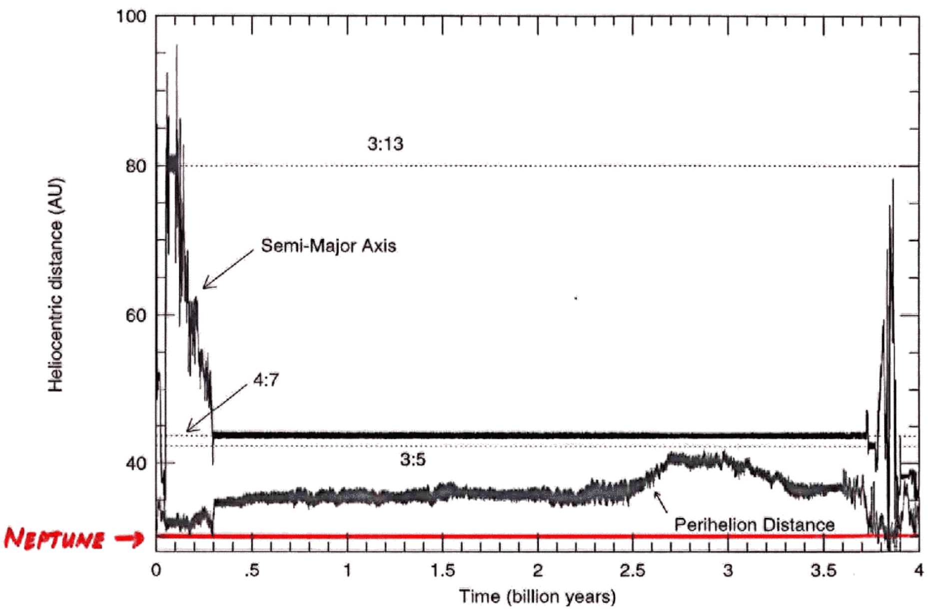
Goals:
• Use dynamics of observed comets as clues to reservoir properties
• Use properties of reservoirs as clues to planet formation processes
*Collaboration with Hal Levison (SouthWest Research Institute).
Some portions also in collaboration with Luke Dones (SwRI),
Paul Weissman (JPL) and Ian Lepage (Queen's)


The Story so far…
Recall Tisserand parameter T is an approximation of the Jacobi constant (conserved 'energy' for test particle in rotating frame of restricted 3-body problem) .
'Short-period comets' are those with periods < 200 years.
Jupiter-family comets (JFCs): short-period comets with 2 < T < 3.
Halley-type comets (HTCs): short-period comets with T < 2.
Simulations (eg LD97) show that a flattened population of Neptune-encountering bodies 'hands-off' an armada of comets in excellent agreement with observed JFCs and Centaurs (see eg. DLD04) but produces very few HTCs.
About 1% of the 'scattered disk' in DL97 survives to 4 Gyr, due to 'stickiness' of mean-motion resonances.

"SCATTERED DISK" – DUNCAN & LEVISON (1997)



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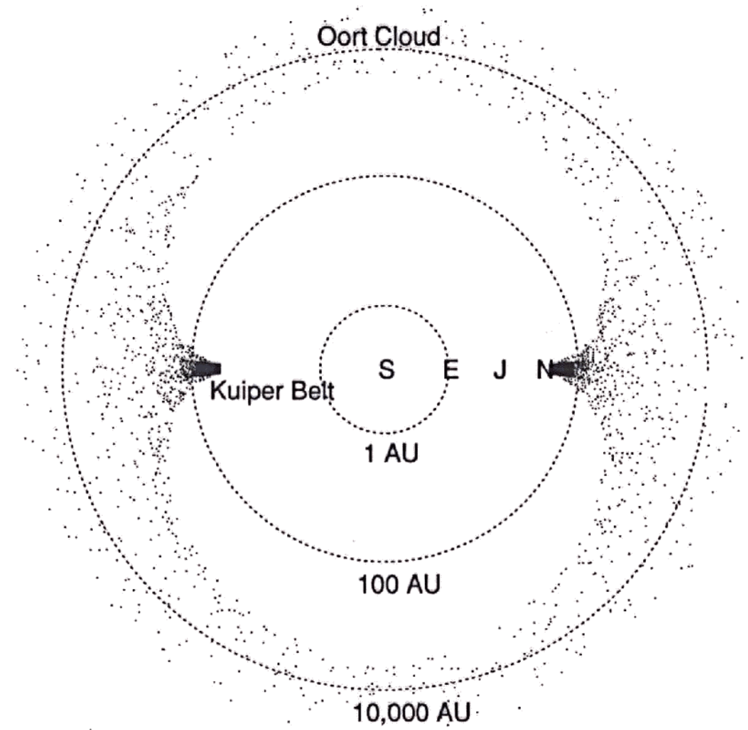
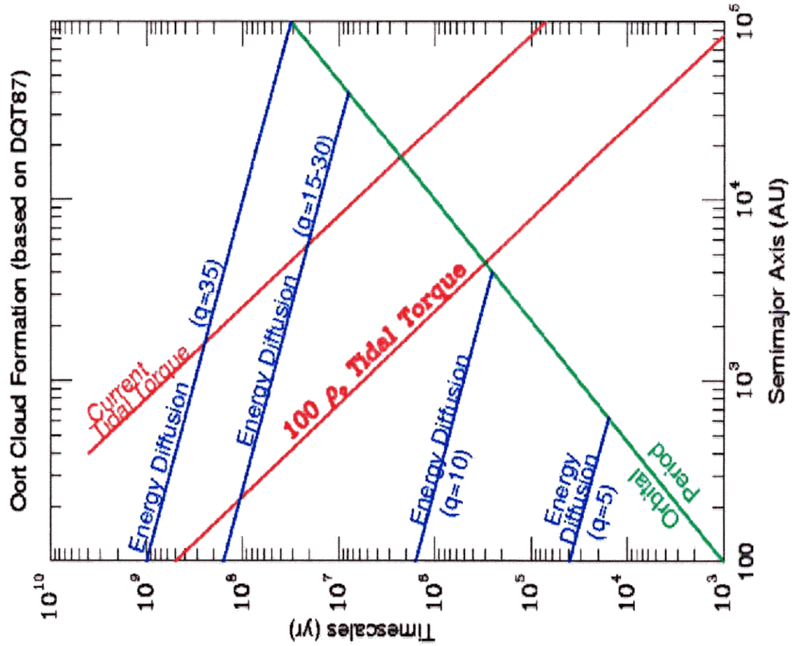




OORT CLOUD FORMATION (DUNCAN QUINN TREMAIRE } 1987)

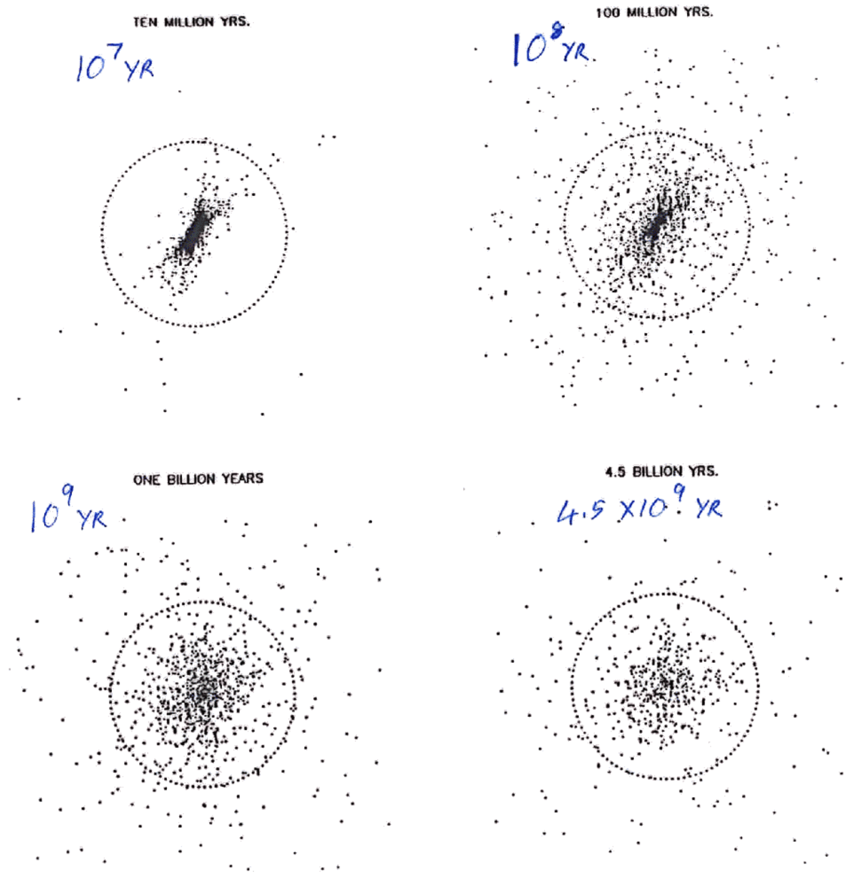
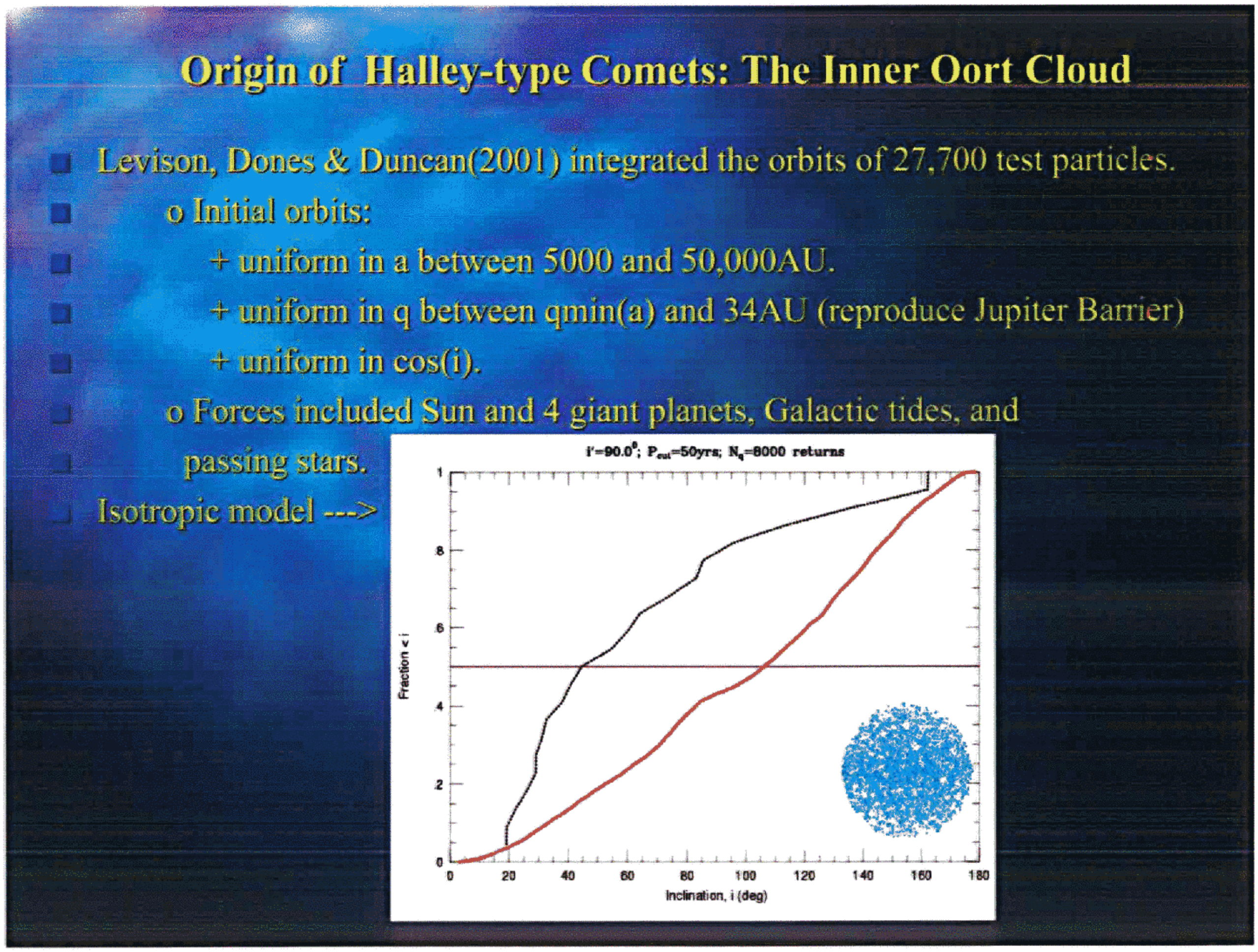
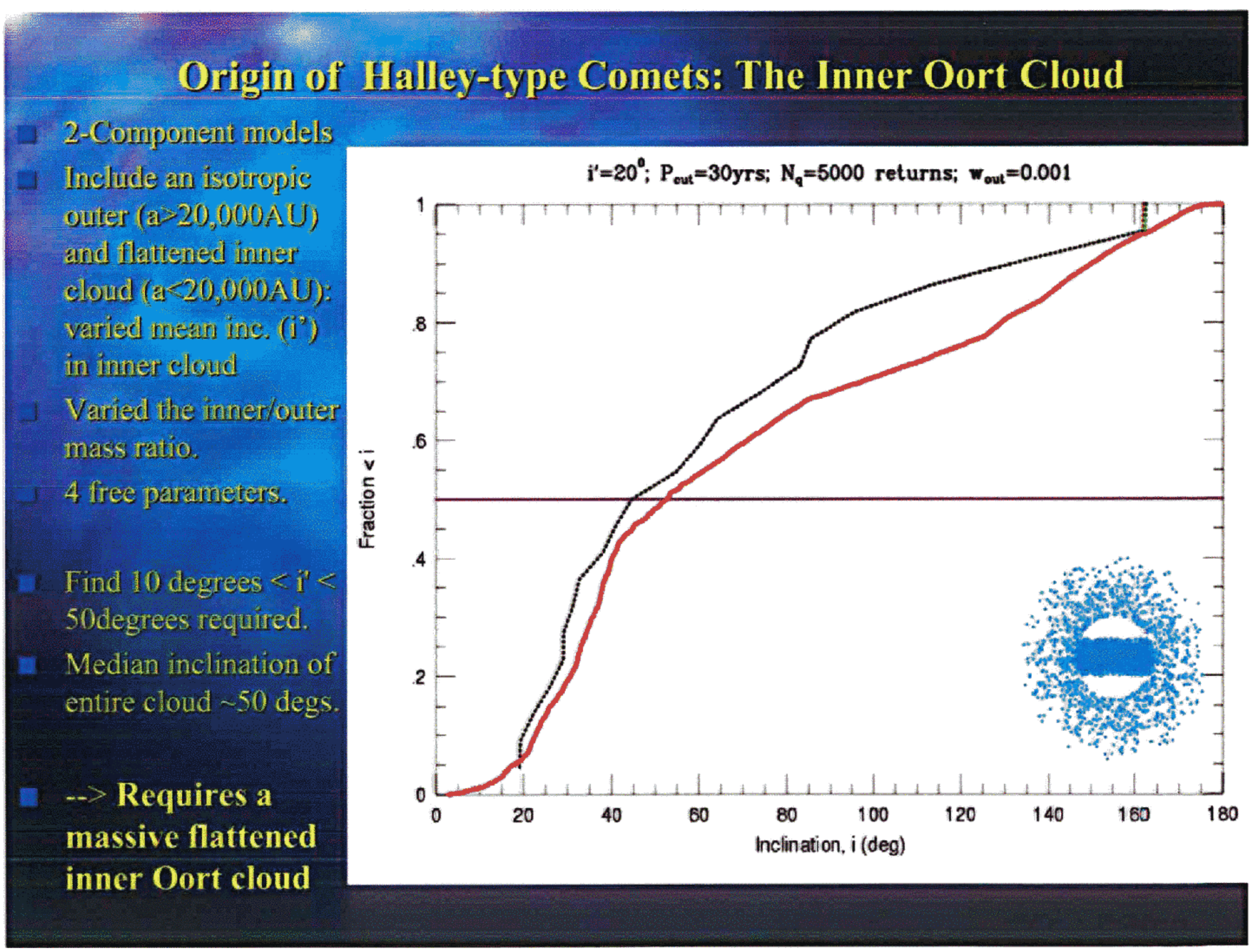
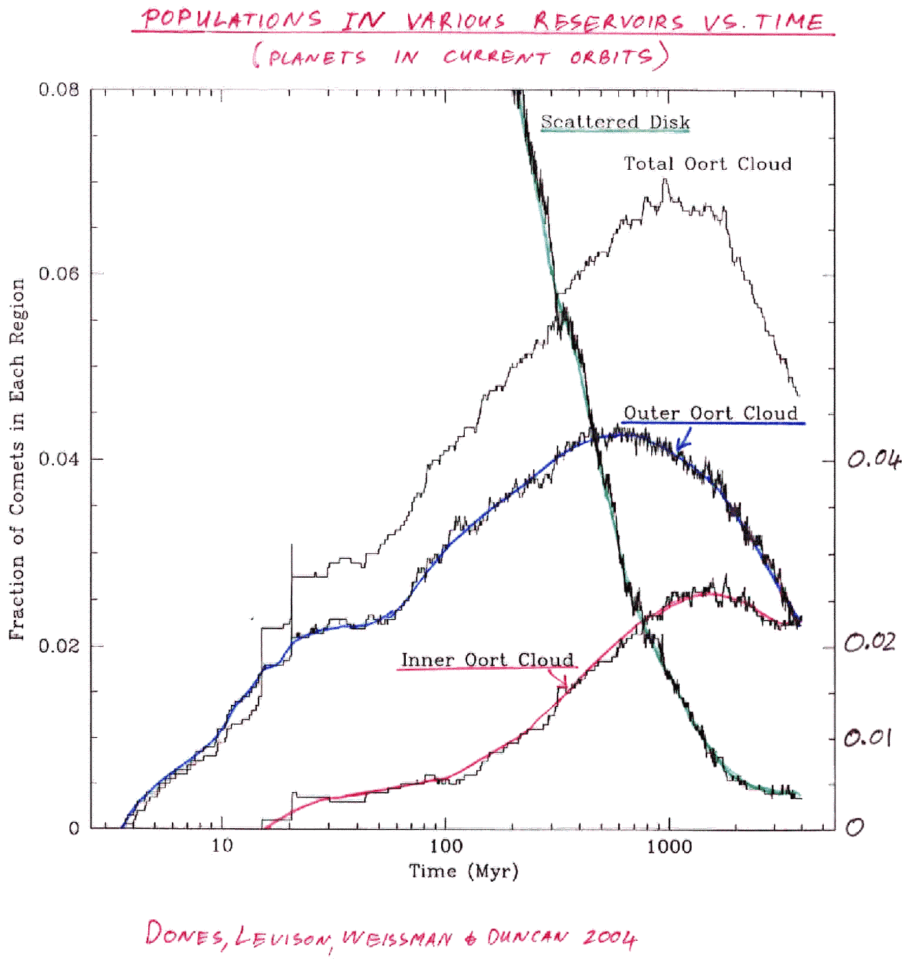


Figure 4 The formation of the Oort comet cloud in the simulation of Duncan et al (1987). The Galactic plane in each snapshot is a horizontal line. The dotted circle denotes a radius of 20,000 AU, indicating the inner edge of the classical Oort Cloud.


Origin of Halley-type Comets: The Inner Oort Cloud
Levison, Dones & Duncan(2001) integrated the orbits of 27,700 test particles.
o Initial orbits:
+ uniform in a between 5000 and 50,000AU.
+ uniform in q between qmin(a) and 34AU (reproduce Jupiter Barrier)
+ uniform in cos(i).
o Forces included Sun and 4 giant planets, Galactic tides, and passing stars.
Isotropic model --->
i'=90.0°; P_out=50yrs; N_q=8000 returns
Fraction < i
Inclination, i (deg)


Origin of Halley-type Comets: The Inner Oort Cloud
2-Component models
Include an isotropic outer (a>20,000AU) and flattened inner cloud (a<20,000AU): varied mean inc. (i') in inner cloud
Varied the inner/outer mass ratio.
4 free parameters.
Find 10 degrees < i' < 50degrees required.
Median inclination of entire cloud ~50 degs.
--> Requires a massive flattened inner Oort cloud
i'=20°; P_out=30yrs; N_q=5000 returns; w_out=0.001
Fraction < i
Inclination, i (deg)


POPULATIONS IN VARIOUS RESERVOIRS VS. TIME
(PLANETS IN CURRENT ORBITS)
Scattered Disk
Total Oort Cloud
Outer Oort Cloud
Inner Oort Cloud
Fraction of Comets in Each Region
Time (Myr)
0.08
0.06
0.04
0.02
0
10
100
1000
0.04
0.02
0.01
0
DONES, LEVISON, WEISSMAN & DUNCAN 2004


2004 KITP Program on Planet Formation
Summary
Our simulations show that dynamical transport of bodies from a relatively low inclination trans-Neptunian disk successfully reproduces the Jupiter Family comet population and the Centaurs but not the Halley-type comets. Simulations starting with an initially excited population are underway.
Roughly 1% of objects encountering Neptune survive for the age of the solar system. A scattered disk of ~10^9 comets left over from planet formation could supply all observed Jupiter Family Comets and is roughly consistent with observations.
Our simulations of capture from the Oort cloud into Halley-type orbits are inconsistent with an isotropic source. Simulations suggest a dominant flattened component must be the main source and current work is focused on the outer scattered disk + Galactic tides.
Planetesimal clearing using existing planetary orbits and Galactic tidal field is very inefficient (~2.5%) at creating the outer Oort Cloud. Preliminary results incorporating simple migration models give similar results. Next steps include growth of planetary masses, damping by gas and collisions and/or denser Galactic environment.