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 (IFCs): 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 IFCs and Centaurs (see eg. DL04) 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 & LEVIISON (1997)

![Graph showing heliocentric distance over time]

![Diagram of solar system with Oort Cloud and Kuiper Belt]

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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.
- Initial orbits:
  - Uniform in eccentricity
  - Uniform in inclination
  - Uniform in argument of perihelion
- Forces included Sun and 4 giant planets, Galactic tides, and passing stars.
- Isotropic model
- Requires a massive flattened inner Oort cloud

24-component models include an isotropic outer cloud ($a=300,000$ AU) and flattened inner cloud ($a=20,000$ AU), varied mean inc. ($i$).
- Varyed the mean inner cloud mass.
- 4 free parameters.
- Found 10 degrees < $i$ < 50 degrees required.
- Median inclination of entire cloud ~ 30 degrees.
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.