Monte Carlo simulation of the cometary contribution to the LHB

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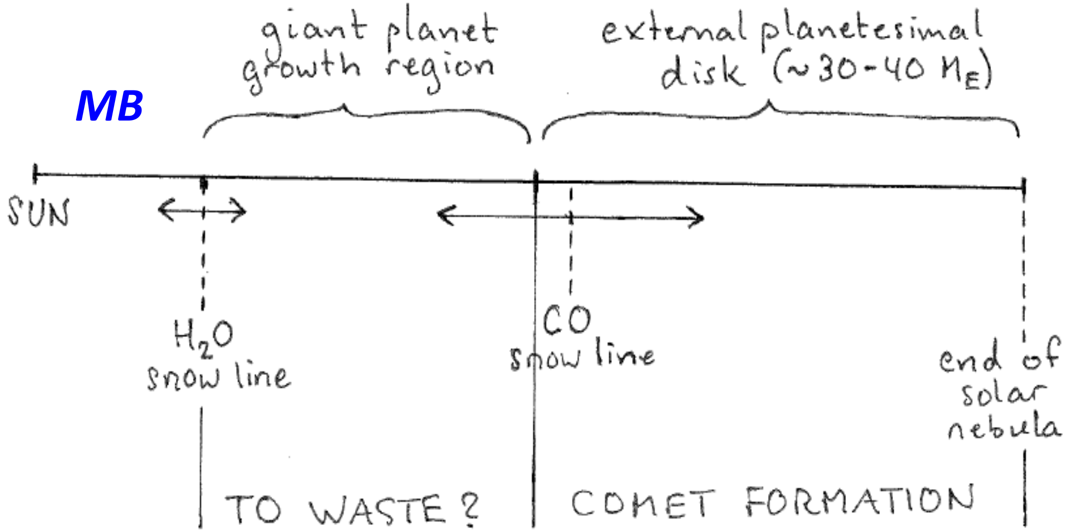
Planetesimal formation



The giant planet growth region was cleared by gas drag and gravitational scattering early on – indications are that this led to ice dumping inside the region

The region inside the H_2O snow line saw the birth of the asteroid Main Belt precursor

The outer disk may be the source of all observed comets!

Transplanetary disk population

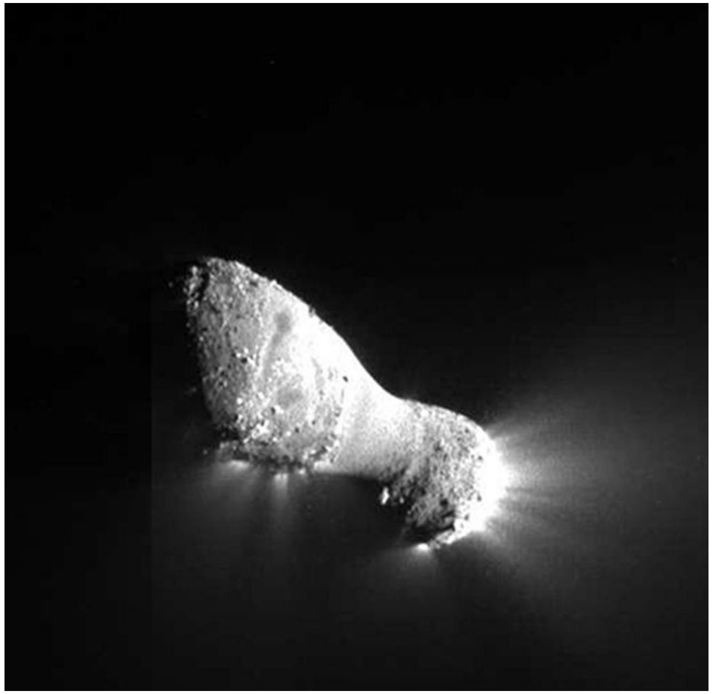
- Mass frequency function: $\phi(M)dM$ = fraction in $[M, M+dM]$
- Average mass: $$\langle M \rangle = \int_{M_{min}}^{M_{max}} \phi(M) M \, dM$$
- If N is the total number of objects in $[M_{min}, M_{max}]$, the total mass is: $$M_{tot} = N \langle M \rangle$$

- $<M>$ is given by $\phi(M)$, M_{min} and M_{max}
- N is then given by M_{tot}

Wide range of sizes

Even smaller do exist!

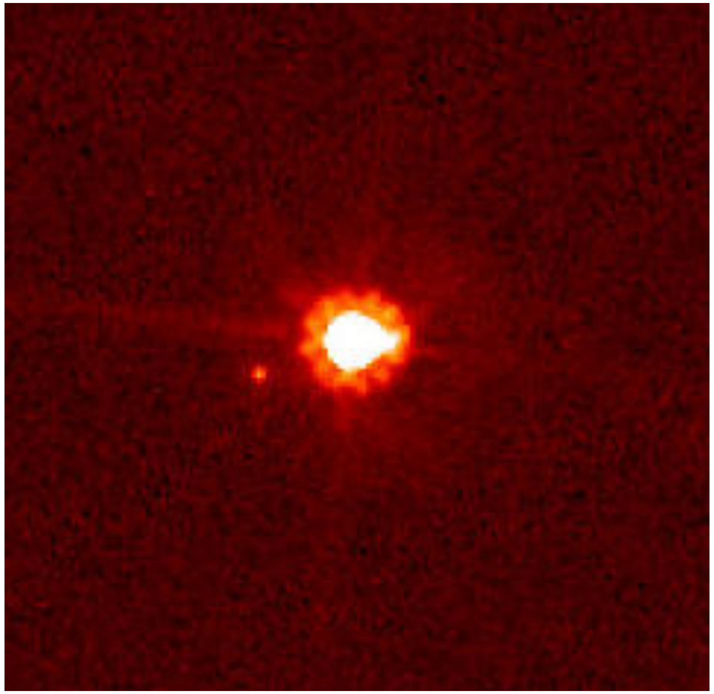
103P/Hartley 2



Diam. ≈ 1.4 km

Larger ones may exist!

Eris + Dysnomia



Diam. ≈ 2300 km

Fixing the parameters

- M_{min} comes from observations: $R_{min} \approx 0.5$ km
- M_{max} may come from: $$N \int_{M_{max}/2}^{M_{max}} \phi(M)\, dM \sim 1$$

or from comet formation theory(?)

- *ϕ(M)* may be modeled on the Main Belt size distribution, checking on the JF at the small end

Comet size distributions

s = cumulative size distribution power-law index

- ***Jupiter Family*** *(diam. 4-10 km)*

  Meech et al. (2004): s ≈ 1.9

  Tancredi et al. (2006): s ≈ 2.7

- ***Jupiter Trojans*** *(diam. 4-40 km)*

  Jewitt et al. (2000): s ≈ 2.0

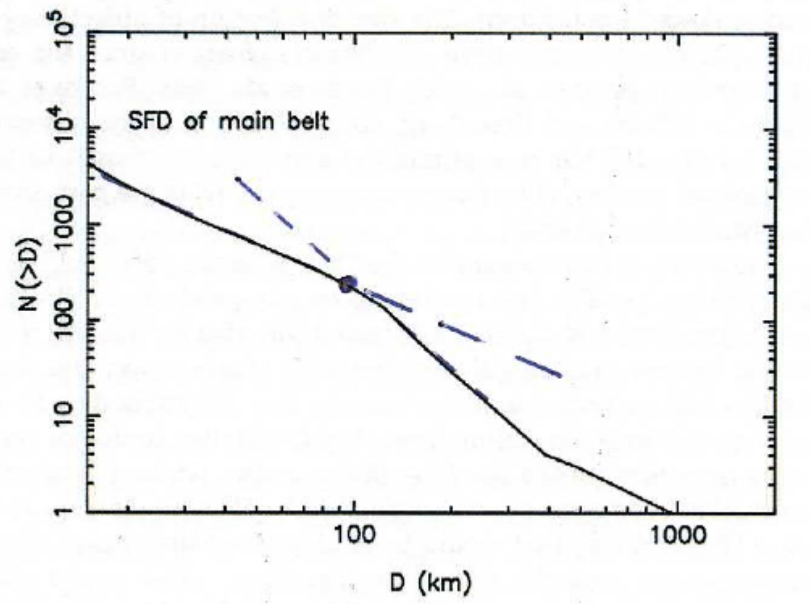
- ***Transneptunians*** *(diam. > 100 km)*

  Gladman et al. (2001): s ≈ 3.4

Bernstein et al. (2004): *much lower at 25 km*

Asteroid size distribution

- Drag-induced orbit drift is a serious barrier to bottom-up planetesimal formation in the Main Belt
- ***Asteroids may have formed big*** (*D > 100* km), according to Morbidelli et al. (2009)
- *Smaller asteroids are then collisional fragments* (LHB-related?)



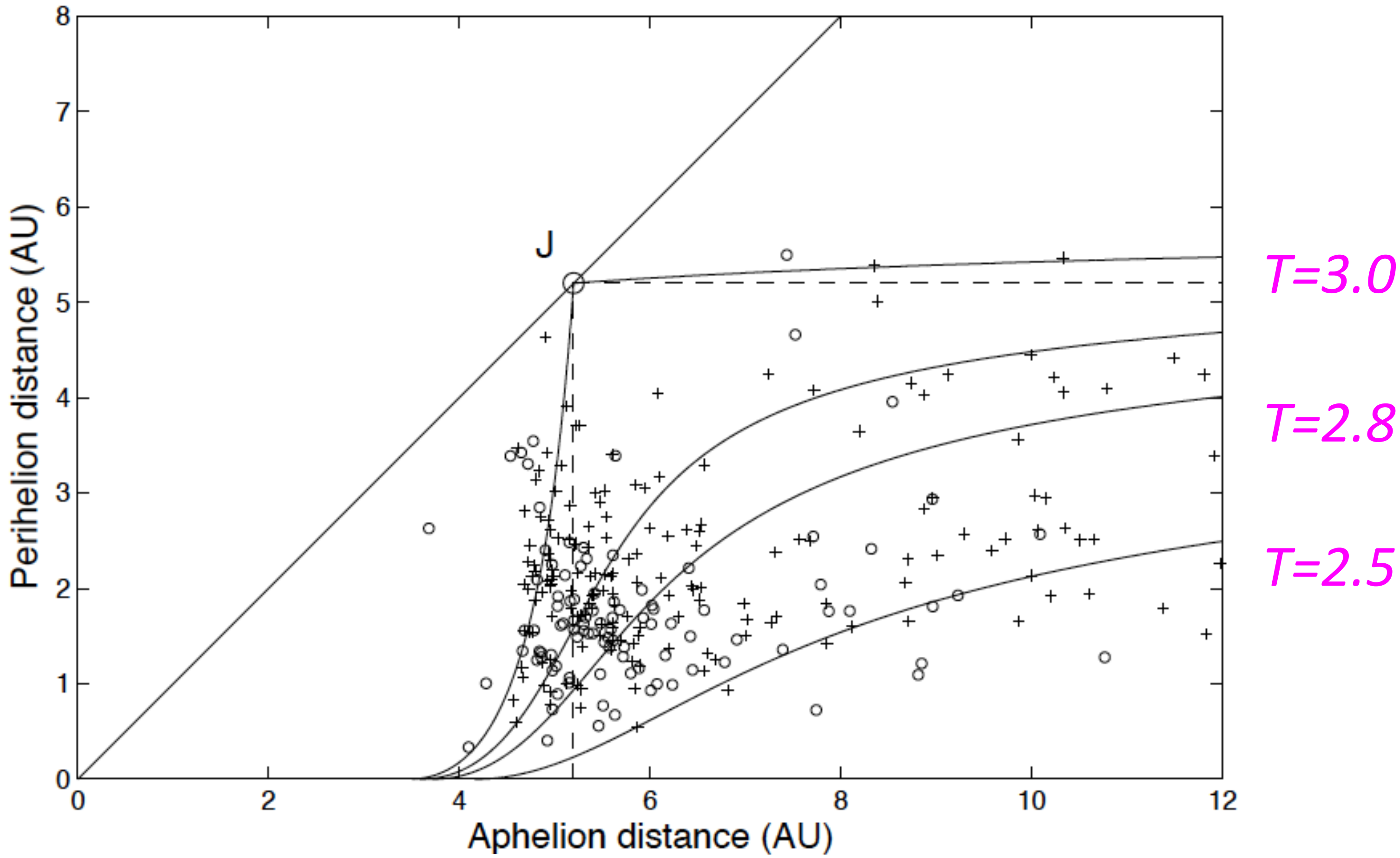
Morbidelli et al (2009)

Would this be similar for comets?

Number of impacts

- If there are ΔN objects entering into JF orbits within a given mass range, the number of impacts onto planet '*i*' will be $\Delta N \times p_c^{(i)}$, where $p_c^{(i)}$ is the *integrated impact probability, averaged over the whole ensemble of possible physical and dynamical evolutions of the entering objects*
- While the dynamics is almost independent of M, the physical evolution is mass dependent (low mass comets may have shorter lifetimes)

The Jupiter Family



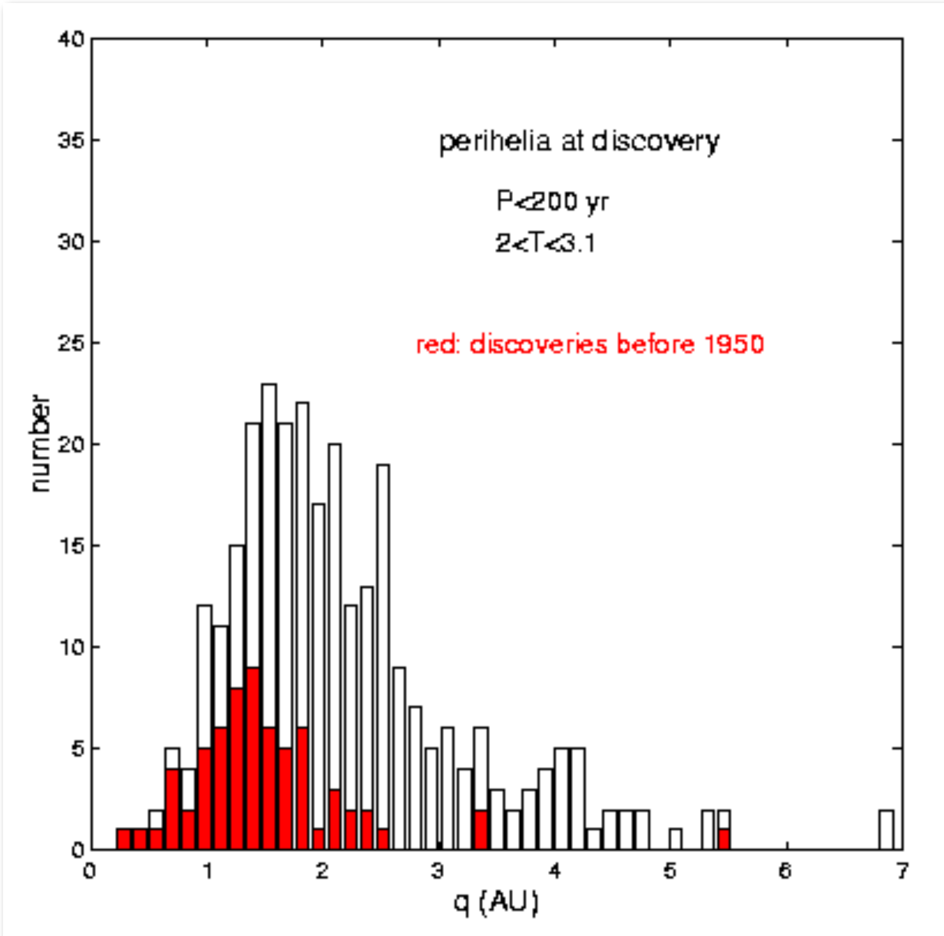
$$T = \frac{a_J}{a} + 2\sqrt{\frac{a}{a_J}(1 - e^2)} \cos i$$

Jupiter Family dynamics

- The main driver is *orbital deflections at close encounters with Jupiter*, causing jumps in *(Q,q)* more or less conserving the value of *T* and keeping cos *i* close to 1
- JF comets tend to be discovered shortly after downward jumps (decreasing *q*)
- A typical visit into the JF, from injection to ejection, lasts for 10^4–10^5 yr and is characterized by a certain q_{min}, which is different for different comets

Discovery bias

- ***Strong discovery bias, typically requiring*** *q<2.5 AU*
- This limit has increased to larger *q* in recent years
- *The role of q is determined by the mechanisms of comet activity (H_2O or CO driven)*
- *The current orbit distribution is an observationally biased shapshot of a relaxed, steady-state population*



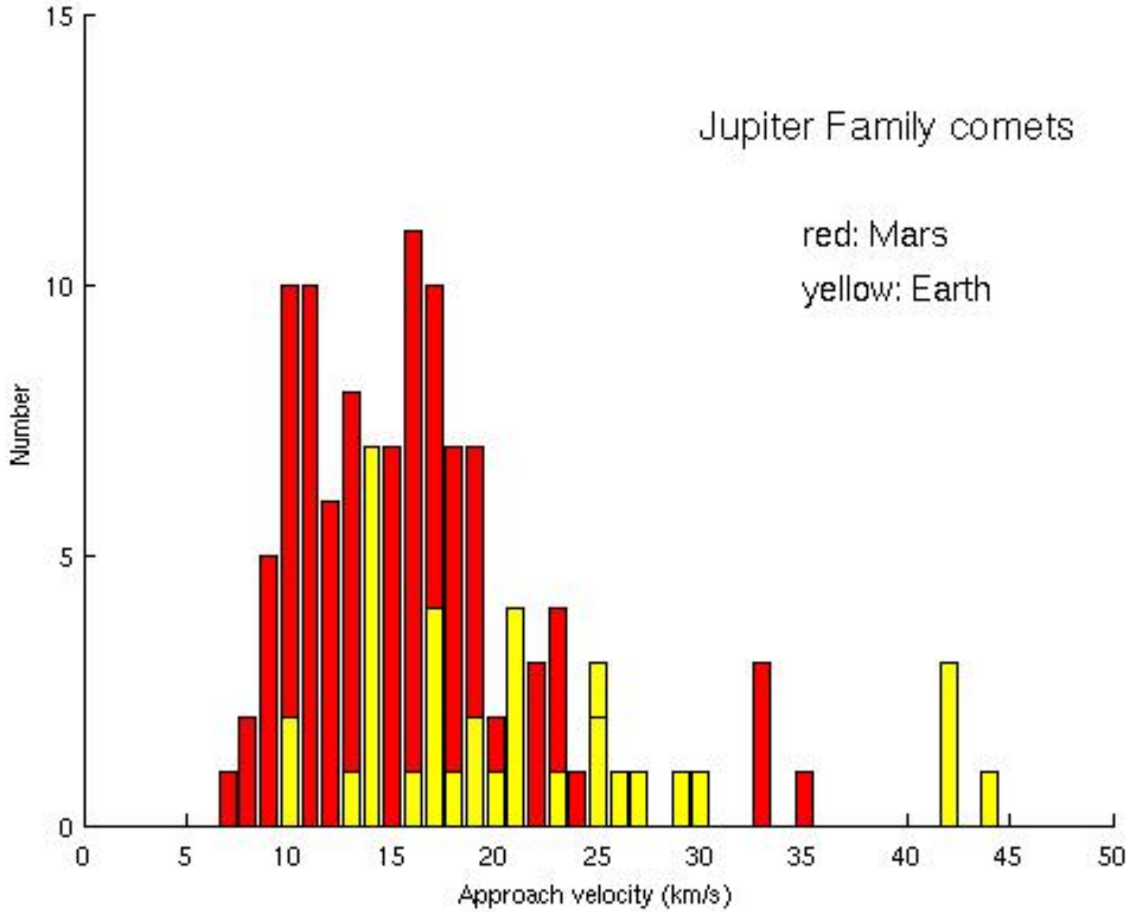
Jupiter Family

Planet-to-planet variations

- All contributions to $p_c^{(i)}$ vanish, when $q > Q^{(i)}$
- The observed q distribution thus indicates a trend for increasing p_c from Mercury to Mars (but this is just one factor)
- We wish not just to count the impacts but also to characterize them in terms of the mass and speed of the impactor
- The mass at impact is less than the entry mass and depends on physical evolution
- The speed is found from the approach velocity:

$$U_i = V_i\sqrt{3 - T_i}$$

JF comet encounter velocities



Escape speeds: ***5 km/s*** resp. ***11 km/s***

Monte Carlo simulation

- Trace the orbital and physical evolutions of a large number of representative objects in a simple dynamical model
- Treat different initial masses *M* separately
- For each revolution, derive all contributions $\Delta p_c^{(i)}$ and mark them by the appropriate mass *m* (after physical evolution) and approach velocity U_i
- At the end of each visit, compute the integrated impact probabilities and the associated distributions of approach velocities
- The total sample of visits is taken to represent the real objects

Special cases

- Comet 2P/Encke is a large contributor to the current impact risk of short-period comets, but it is totally unrepresentative in terms of dynamics – decoupled from Jupiter and likely ending up by colliding with the Sun
- Our MC simulation must not neglect this kind of object!
- We will consider gravitational deflection by terrestrial planets as production mechanism

Gravitational deflection

- Similar to our mapping of $\Delta p_c^{(i)}$, we obtain probabilities of passing close enough to exceed a certain limiting deflection angle
- We pick at random a certain number of orbits based on these probabilities, and let these give rise to a 2nd generation of orbiting objects with deflected orbits – this will likely include Encke-types and predict their expected abundance and contribution to the impacts

Physical evolution

- We intend to model:
  - *Erosion due to sublimation*
  - *Dust mantling influencing the erosion*
  - *Dust mantle blow-offs*
  - *Non-tidal splitting events*
- The aim is to find a model that reproduces the observed statistical features of the JF comets and from this determine the relevant mass loss rates and lifetimes for the MC simulation