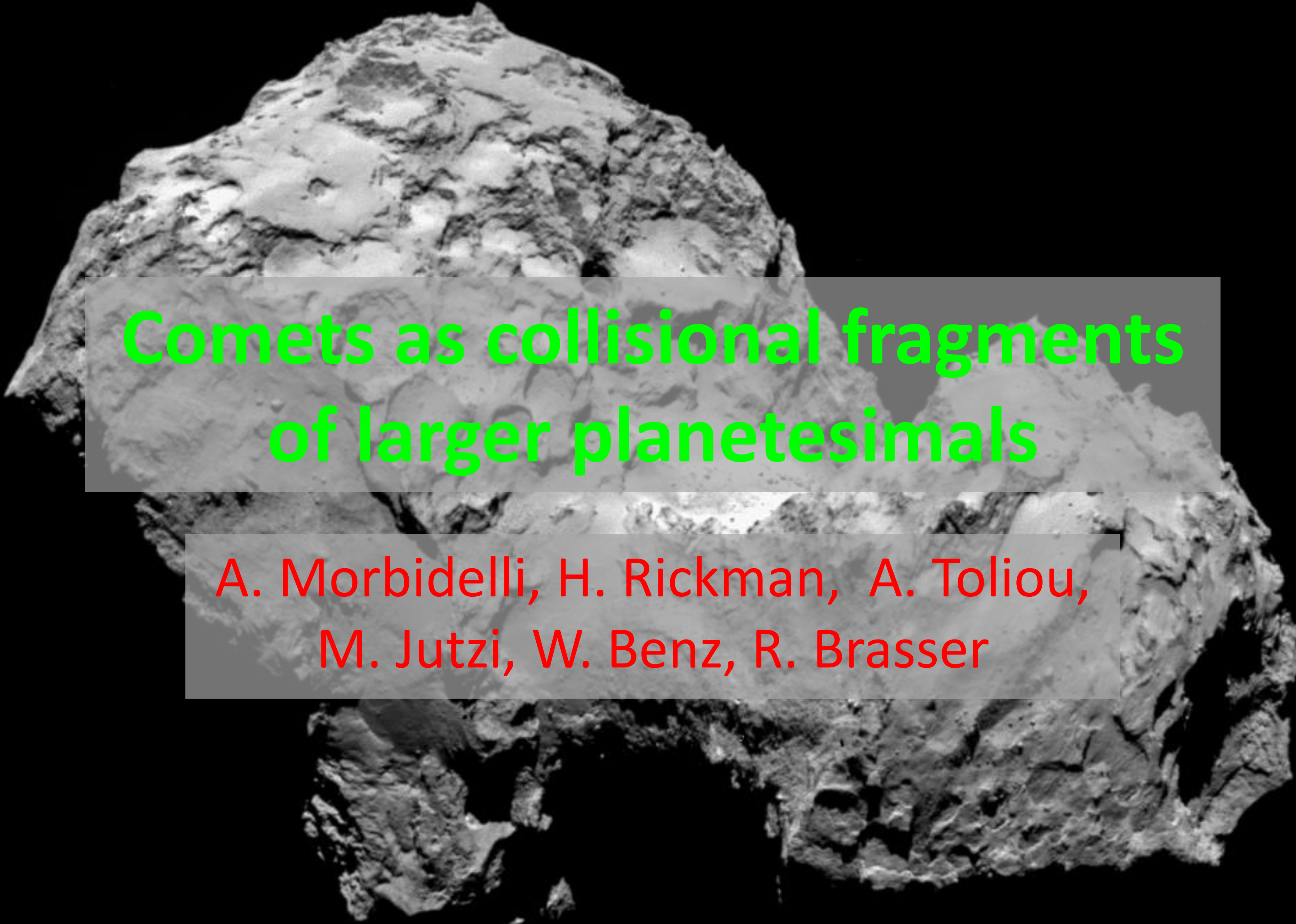

Comets as collisional fragments of larger planetesimals

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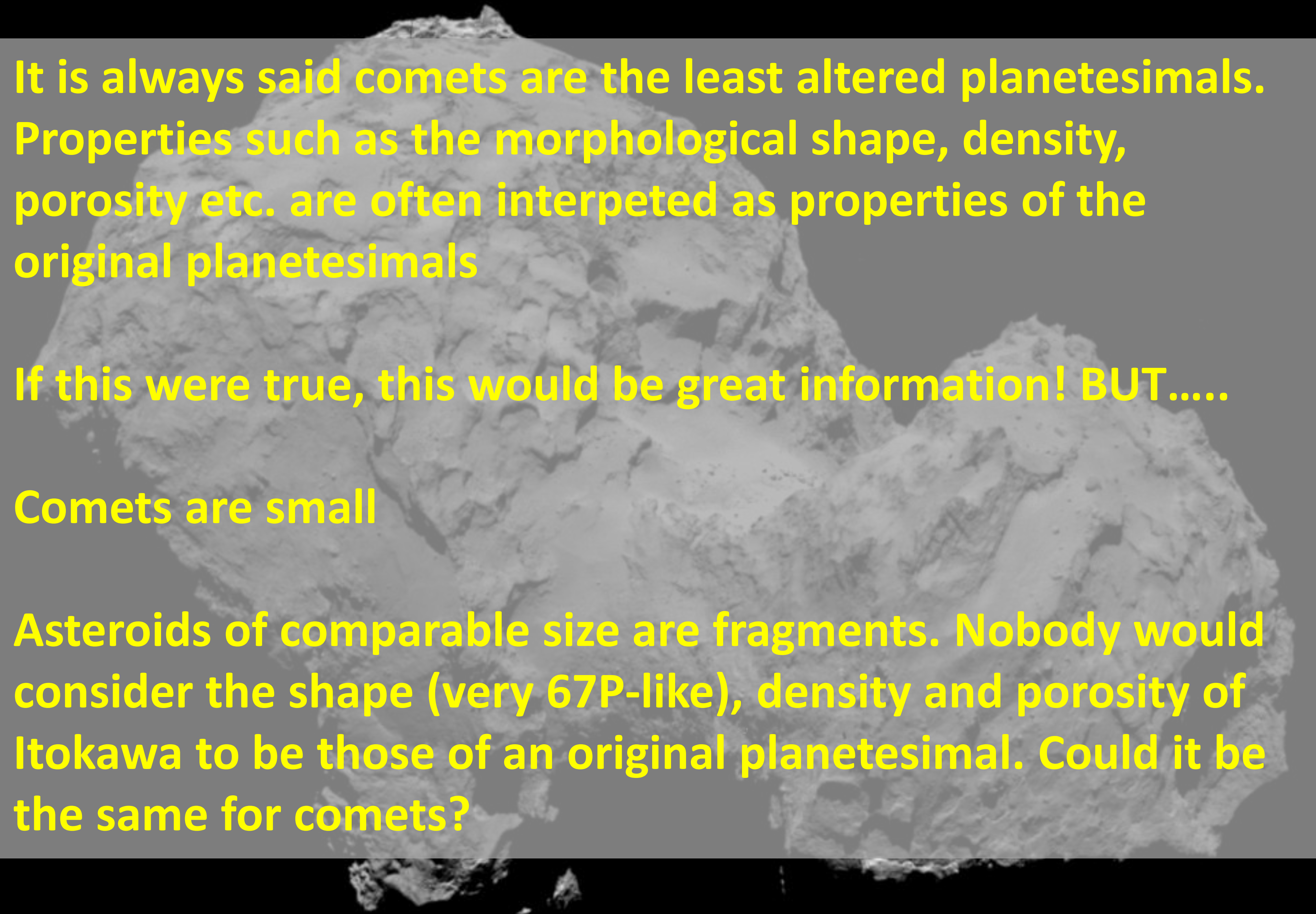


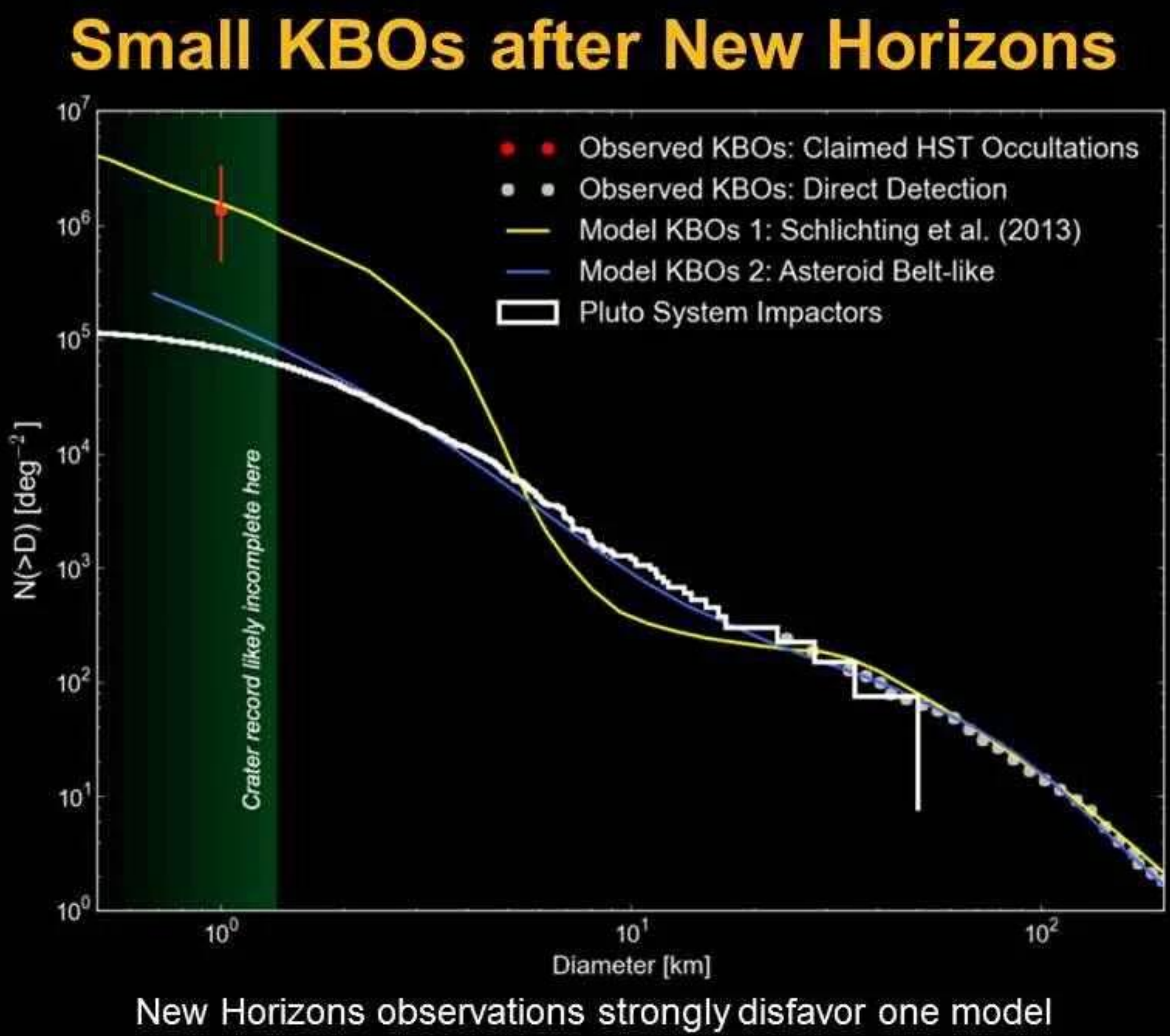
It is always said comets are the least altered planetesimals. Properties such as the morphological shape, density, porosity etc. are often interpeted as properties of the original planetesimals

If this were true, this would be great information! BUT…..

Comets are small

Asteroids of comparable size are fragments. Nobody would consider the shape (very 67P-like), density and porosity of Itokawa to be those of an original planetesimal. Could it be the same for comets?

The KBO SFD deduced from craters on Pluto and Charon is very similar to that of the asteroid belt, which is well known to be at collisional equilibrium for D<100km (Bottke et al., 2005)



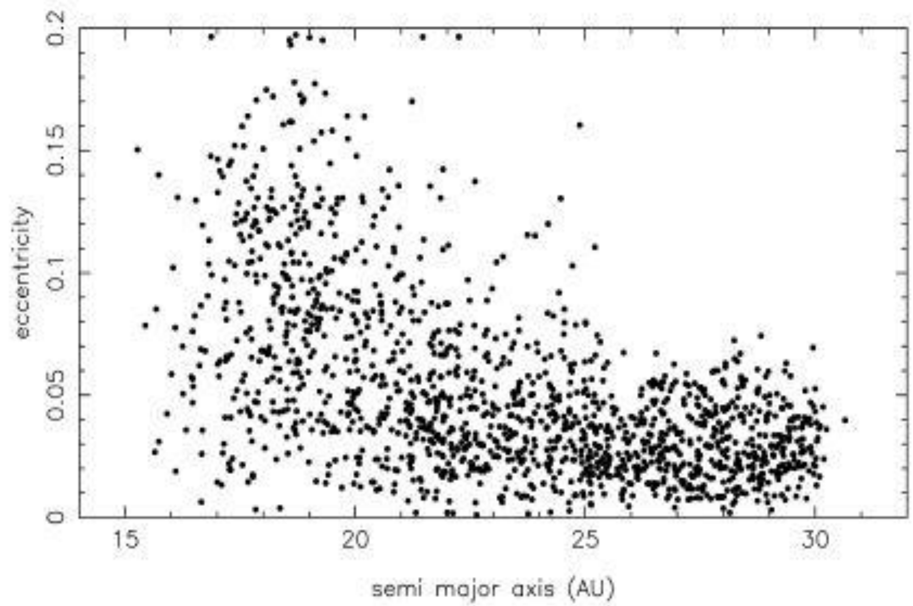
Can a comet of the size of 67P (D~4 km) be a primoridial planetesimal, i.e. can it have avoided catastrophic collisions throughout the history of the Solar System?

We addressed this question in two papers:

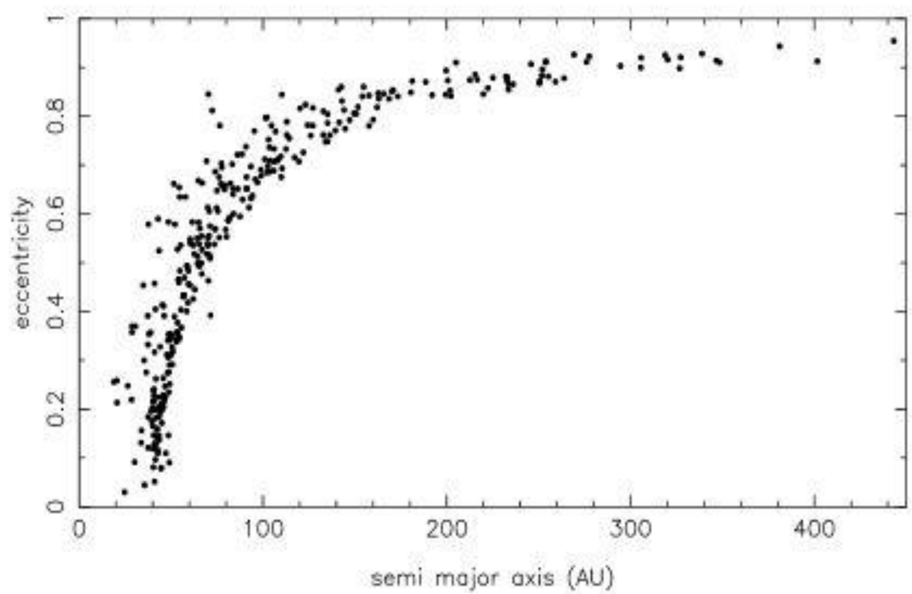
Morbidelli and Rickman 2015, A&A, 583, 43
Jutzi et al., 2016 A&A submitted

Morbidelli and Rickman, 2015

We consider the comet's collision catastrophic probability during 3 phases of Solar System evolution:



1) **The phase during which the comet remained in a massive trans-neptunian disk, moderately excited in e,i due to self stirring (Levison et al., 2011)**



2) **The phase during which the disk is dispersed, and the scattered disk is formed**

3) **The phase in which the comet resides in the Scattered Disk**

The length of phase 1 is unknown. It could be 400My if the dispersal of the disk triggered the LHB (Gomes et al., 2005)

We also took an effective shortcut:

Instead of making a full study of the collisional evolution (with objects disrupted and produced in collisions, with an evolving SFD) we followed a « an absurdum approach »

Assume that all comets are pristine.
Then the SFD did not evolve. It was always like that in the current SFD, just multiplied by a factor (~100) compensating for the dynamical decimation occurring in the process transforming the original planetesimal disk into the current SD.

There are currently $2x10^9$ comets with D>2.3km (Brasser and Morbidelli, 2012), with a differential SFD exponent q=-3.3 (from New Horizons).

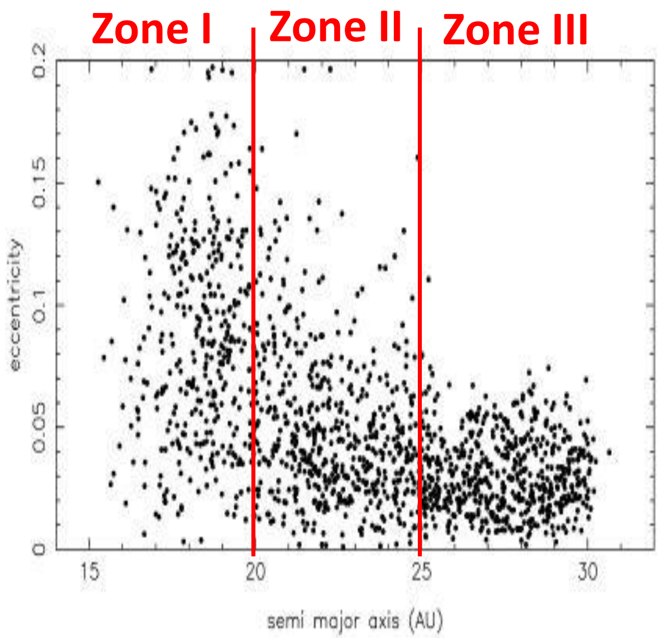
Thus we assume $2x10^{11}$ comets in the original planetesimal disk
If in such a disk a 67P-sized comet cannot avoid catastrophic collisions, then the assumption is wrong and 67P has to be a collisional fragment.

We find that, if the trans-Neptunian disk survived for 400My before being dispersed (LHB hypothesis), there is no chance that 67P could have survived. It should have suffered at least ~10 catastrophic collisions. Thus 67P is likely to be a fragment of a bigger object.

Table 2. Number of disruptive collisions expected for a target of R = 2 km located in each disk zone as a function of the exponent q of the differential size distribution.

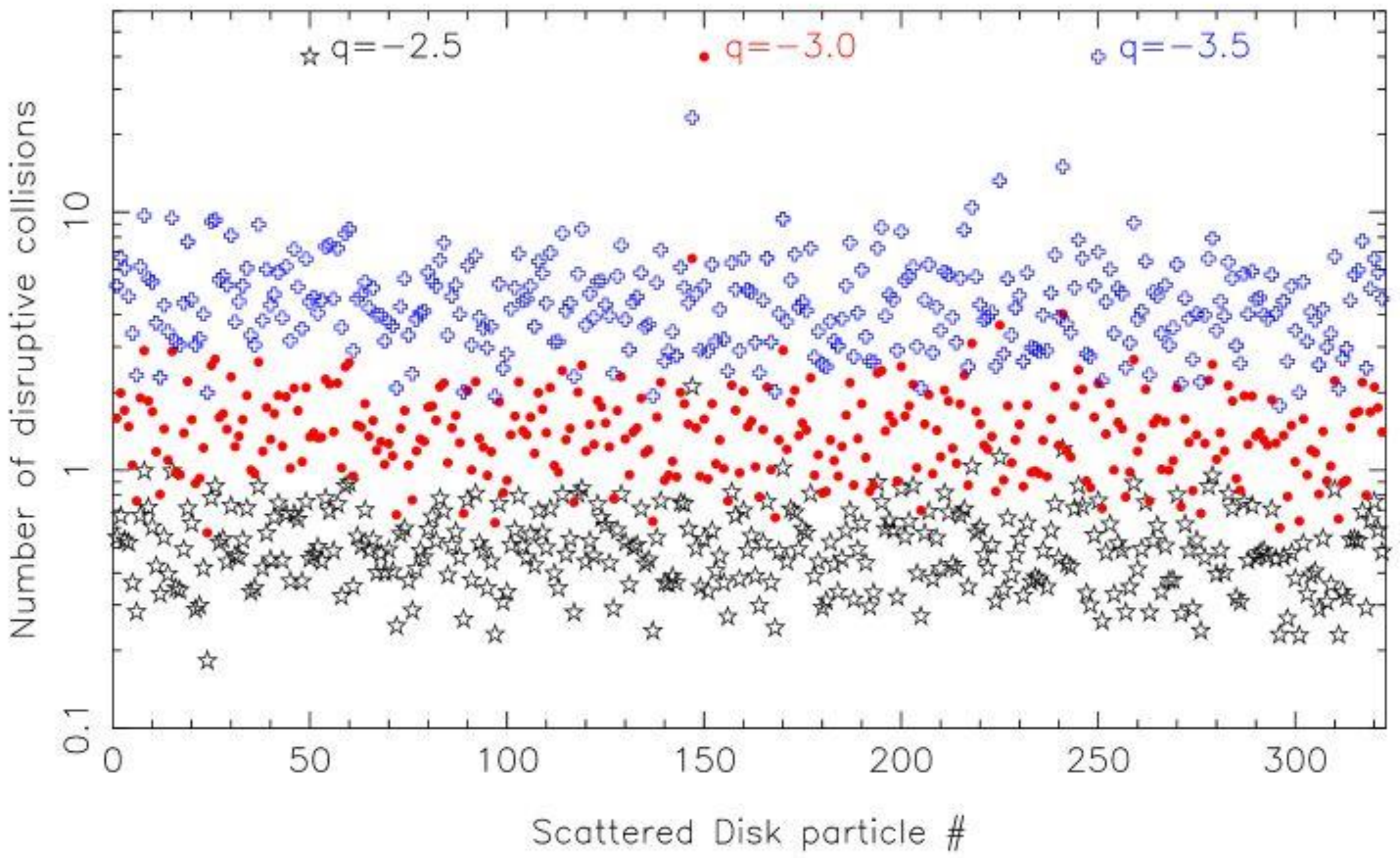
q \ Target zone	I	II	III
−2.5	58.0 (51.2)	28.7 (20.7)	12.3 (9.6)
−3.0	94.5 (75.0)	39.7 (23.7)	12.1 (7.9)
−3.5	190.6 (137.7)	70.2 (35.3)	15.4 (8.2)

Notes. The first row reports the target zone. The first column gives the value of q. Each box reports the number of catastrophic collisions expected over 400 My. In parentheses we report the same quantity estimated by using the dynamical state of the disk after 100 My of evolution, instead of that shown in the top panel of Fig. 1 (300 My). The number of catastrophic collisions is smaller, but it is nevertheless much larger than unity in all cases.



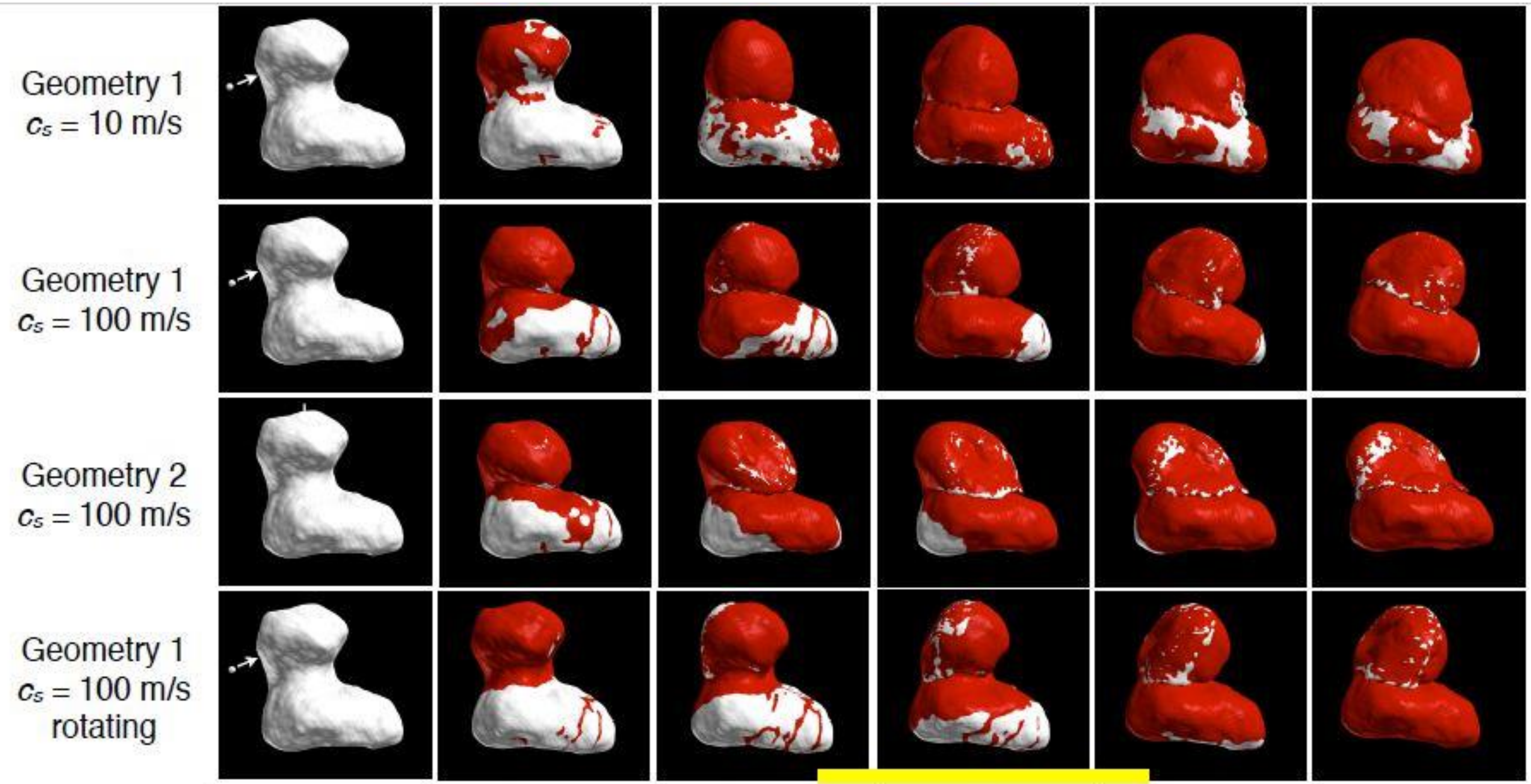
But one could consider this as a good argument agains a LHB

Thus we also considered Phases 2 and 3 only (origin of the SD and residence in it for 4Gy)



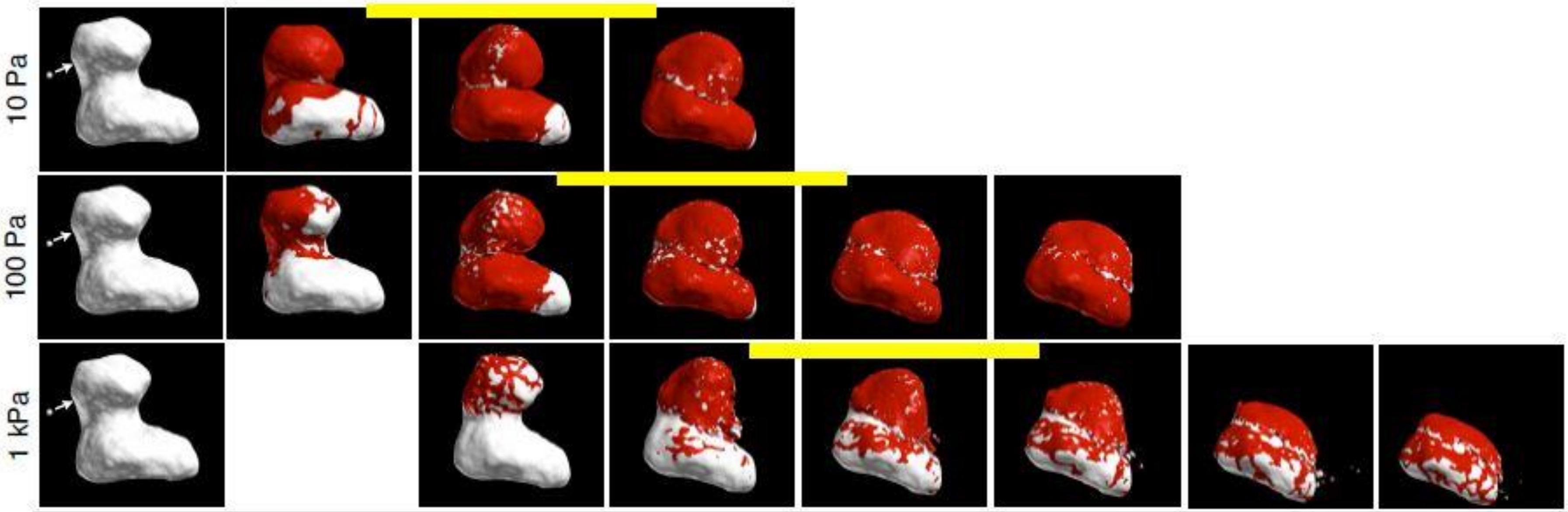
We computed the number of catastrophic collisions that each tracer of our SD population should have had, depending on the SFD exponent q. For -3.5<q<-3.0, all comets with D=4km should have had at least one catastrophic collision. This assumes Q* from Benz and Asphaug, 1999.

Given that the number of catastrophic collisions is close to 1, we reconsidered more precisely the problem in Jutzi et al., 2016



v (m/s	10	30	50	80	100
Q (J/Kg)	0.01	0.08	0.23	0.59	0.92

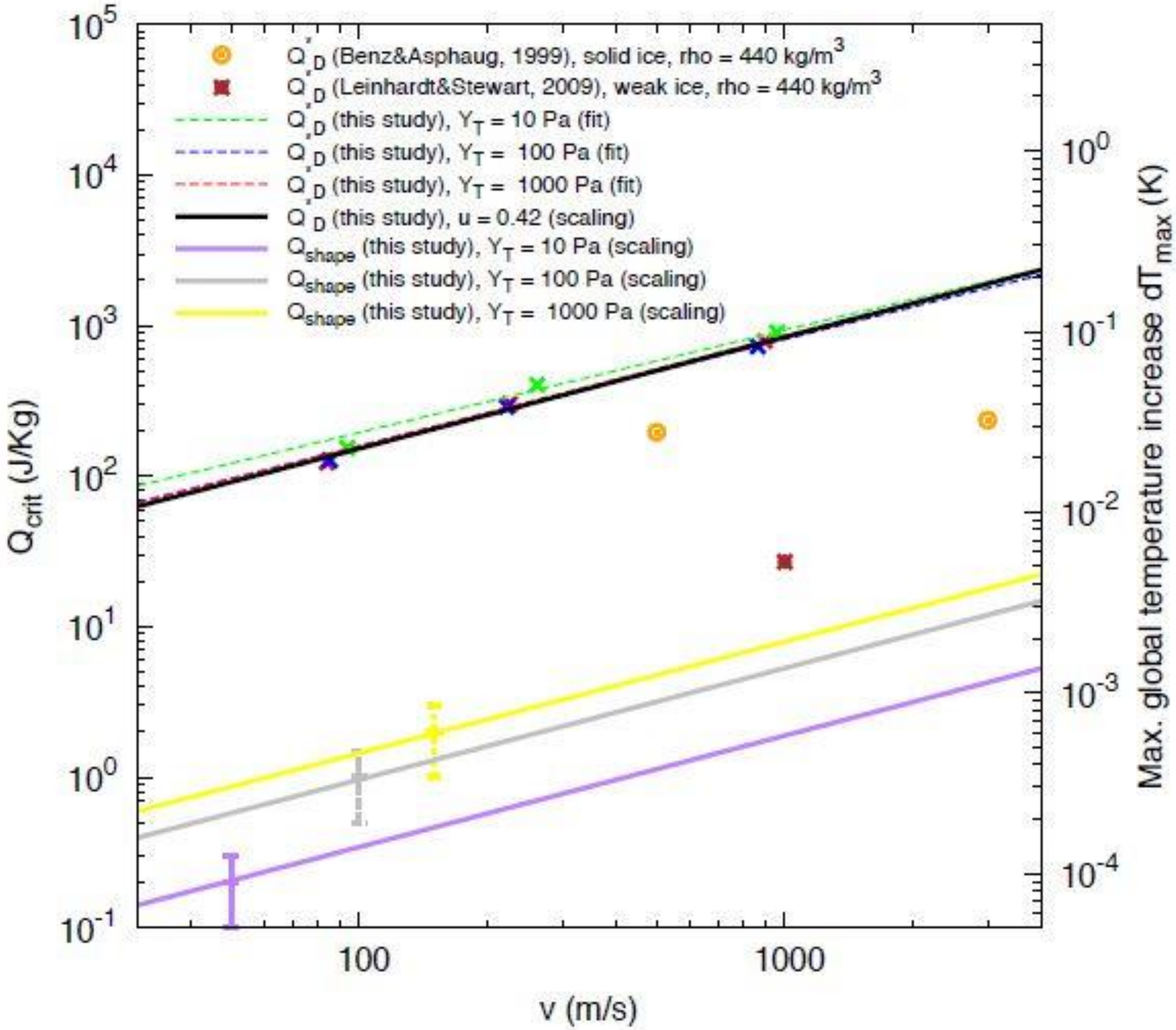
Fig. 1. Shape-changing collisions on comet 67P/C-G. We use SPH to simulate impacts of a R_p = 100 m projectile on the smaller of the two lobes of comet 67P/C-G. The minimal specific energy required to cause a significant change of the comet's shape by such impacts, $Q_{reshape}$, is estimated for different impact geometries and rotation axis. The material strength is the same in all cases shown here (Y_T = 10 Pa). The effect of the material's



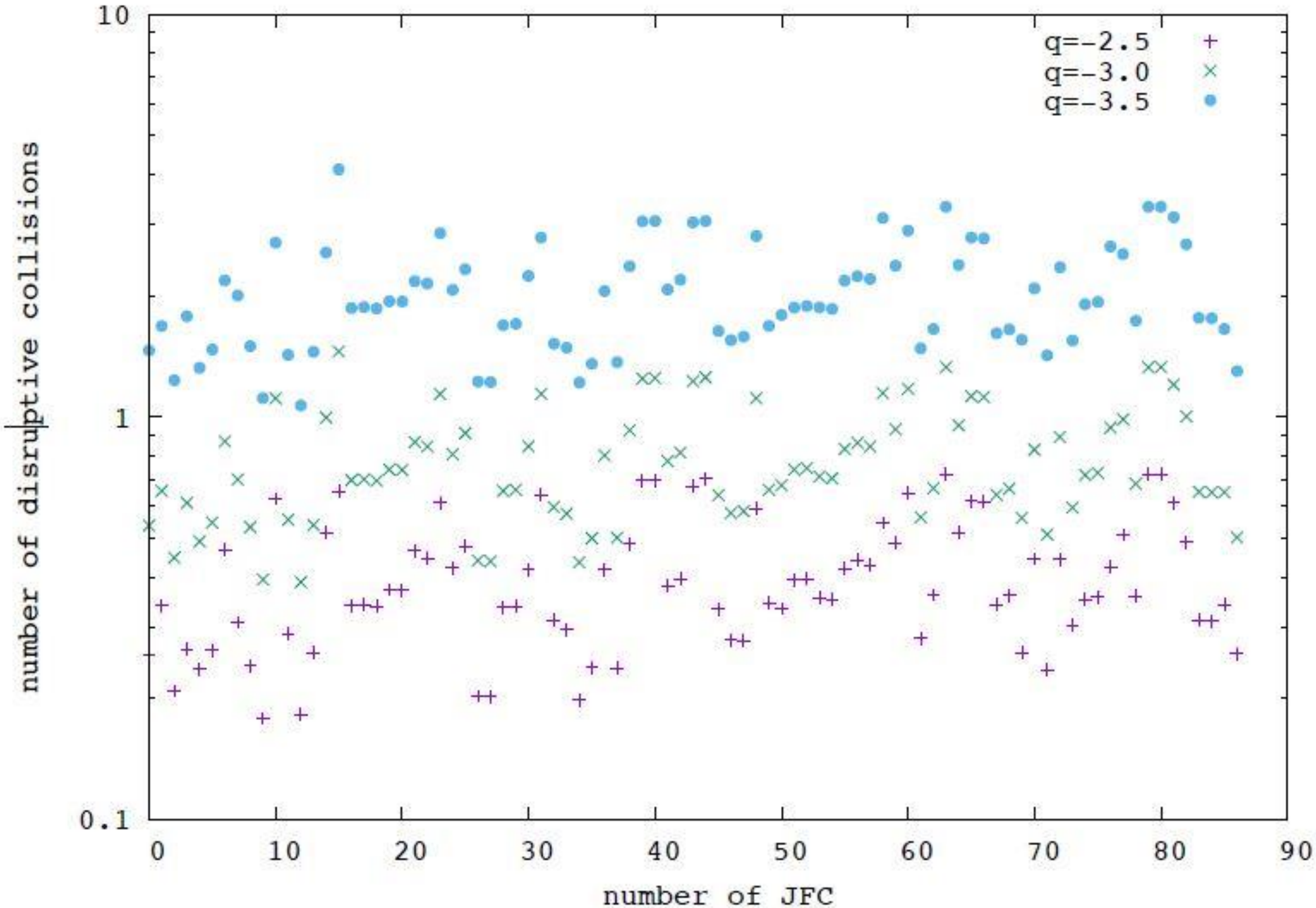
v (m/s	10	50	100	150	200	300	400
Q (J/Kg)	0.01	0.23	0.92	2.07	3.69	8.29	14.74

Fig. 2. Same as Fig. 1 but for different material strength Y_T of the target: $Q_{reshape}$ ~ 0.2±0.1 J/K for Y_T = 10 Pa (corresponds to average in Figure 1); $Q_{reshape}$ ~ 1.0±0.5 J/K for Y_T = 100 Pa; $Q_{reshape}$ ~ 2.0±1.0 J/K for Y_T = 1000 Pa.

Summary of the results of SPH experiments on the specific energy for catastrophic disruption or significant change in shape (bilobed structure)

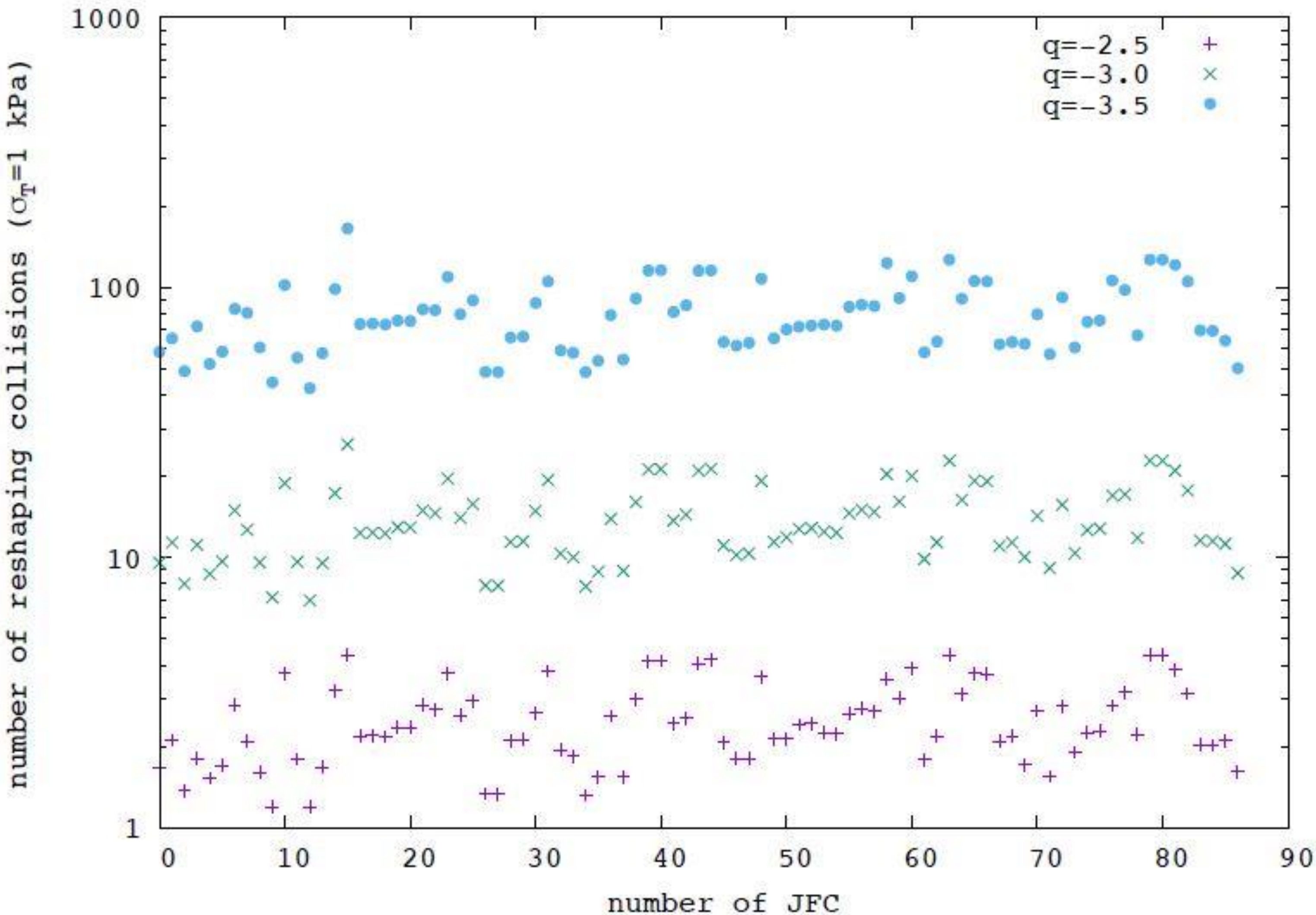


We then redid the same analysis as in Morbidelli and Rickman (2015) for phases 2 and 3, but with the updated Q* and improved dynamical simulations from Brasser and Morbidelli (2012)



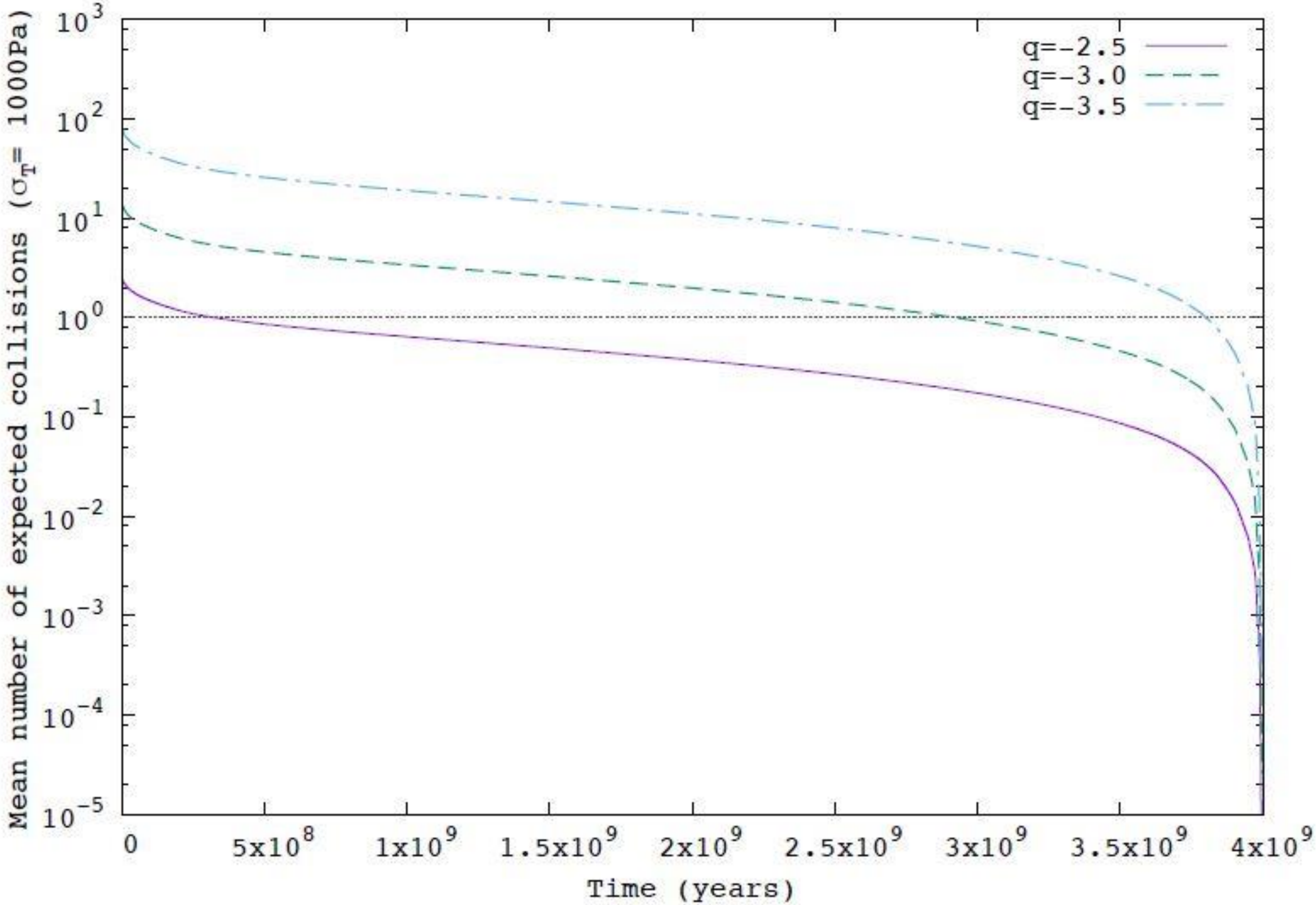
Now the number of catastrophic collisions can be < 1 also for q = -3 or -3.5
This is due to the fact that the new Q* is larger than Benz and Asphag (1999) due to the high porosity of 67P.

So, we considered the probability that 67P survived with its *primordial shape*



67P should have suffered > 10 collisions destroying its shape.
So, its shape cannot be primordial.

When should the last reshaping collision have happened?



Between 250My and 1Gy ago

Thus, 67P should have had at most an age of 1 Gy.

In another paper, Jutzi and Benz show that the shape and porosity of 67P may be obtained as the outcome of both catastrophic and sub-catastrophic collisions of a moderately bigger object (D=6km) – Jutzi and Benz, submitted

CONCLUSIONS

Even assuming that there was no LHB, i.e. the planetesimal disk was immediately dispersed into the Scattered disk at gas-removal time, 67P is unlikely to be a primordial planetesimal.

In fact, its shape is unlikely to have survived intact for ~ 4 Gy

It is more likely that 67P was originated in the collision of a larger body, less than 1 Gy ago

Such collision could be a sub-catastrophic one on a moderately larger parent body (D=6km), but this could also be the last episode of a collisional cascade.

Collisional evolution of a trans-Neptunian disk initially with only D>100km objects in 400My

Notice the generation of bodies of all sizes.

The number of comets with D>2km is ~10^{11} and the slope of the SFD is in agreement with New Horizons crater SFD measurements

Courtesy of W. Bottke