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High velocity collisions between large dust aggregates at the limit for growing planetesimals

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Introduction:

Planetesimals are km-size bodies supposed to be formed in protoplanetary disks as planetary precursors [1]. The most widely considered mechanism for their formation is based on mutual collisions of smaller bodies, a process which starts with the aggregation of (sub)-micron size dust particles. In the absence of events that lithify the growing dust aggregates, only the surface forces between dust particles provide adhesion and internal strength of the objects.

It has been assumed that this might be a disadvantage as dust aggregates are readily destroyed by rather weak collisions. In fact, experimental research on dust aggregation showed that for collisions in the m/s range (sub)-mm size dust aggregates impacting a larger body do show a transition from sticking to rebound and/or fragmentation in collisions and no growth occurs at the large velocities [2, 3]. This seemed to be incompatible with typical collision velocities of small dust aggregates with m-size bodies which are expected to be on the order 50 m/s in protoplanetary disks [4].

We recently found that the experimental results cannot be scaled from m/s to tens of m/s collisions. In contrast to the assumptions and somewhat counterintuitive, it is the fragility of dust aggregates that allows growth at higher collision velocities. In impact experiments Wurm et al. [5] showed that between 13 m/s and 25 m/s a larger compact (target) body consisting of micron-size SiO_2 dust particles accreted 50 % of the mass of a $\sim$1 cm dust projectile consisting of the same dust. For slower impacts the projectile only rebounded or fragmented slightly.

Transitions in aggregate collisions:

Therefore, after the transition from sticking to rebound and fragmentation with increasing collision velocity another transition occurs for still larger collision velocities from fragmentation to partial accretion. Growth at fast collisions is possible as the fragmentation of the projectile dissipates a large fraction of the kinetic energy which allows a part of the projectile to stick. The experiments so far had an upper limit in collision velocity of 25 m/s as the spring launcher used did not provide higher projectile velocities. We therefore constructed another set-up which allows the launch of large cm-size dust projectiles at up to 100 m/s. The experiments are supposed to answer if growth is still possible at velocities larger than 25 m/s or if there is another transition still, where mass loss occurs again instead of growth. In more detail it is also important what size distribution of fragments results at higher collision velocities as these particles are fed back to the particle reservoir of the protoplanetary disk for further evolution.

High velocity impacts:

We currently carry out collision experiments where 1 cm dust projectiles collide with a 10 cm dust target at velocities larger than 25 m/s. Preliminary results indicate that there is indeed another transition from accretion to mass loss at higher velocities, probably somewhere close to 50 m/s, noting that the experiments, so far, were carried out only for one type (morphology) of compact dust targets and for compact projectiles. We will present and discuss these developments and first results at the conference.

The threshold velocity for growth of dusty bodies might be close to the maximum velocities expected in protoplanetary disks. Depending on the exact results but based on a larger variety of targets it might be answered if growth of planetesimals is possible through collisions or if collisional growth gets stalled at sizes below 1 m.

References:

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