Compacted loose particles from numerical simulations compared to Rosetta collected particles I. Maroger[1], J. Lasue[1], R. Botet[2], Ph. Garnier[1], S. Merouane[3], Th. Mannel[4,5], A.C. Levasseur-Regourd[6], M.S. Bentley[7]
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Introduction: The Rosetta space mission included three main instruments for solid dust particle analysis. The combined microscope and mass spectrometer COSIMA (Cometary Secondary Ion Mass Analyser) [1], the atomic force microscope MIDAS (Micro-Imaging Dust Analysis System) [2], and the impact detector GIADA (Grain Impact Analyser and Dust Accumulator) [3]. These three instruments provide complementary insights into dust particles properties over a wide range of sizes/masses (10nm to 1mm). GIADA and MIDAS observed a major contribution from compact dust particles together with a population of porous particles with a low fractal dimension ($D_f \sim 1.7$ for MIDAS [4]) [5, 6]. The fractal dust component of the nucleus and its properties give constraints on the formation of comets in the early solar system [5].
In this work, we analyse results from a simple numerical model of dust aggregates compaction to assess the initial physical properties of the dust populations.

Results from COSIMA images analysis: COSIMA collected and analysed cometary grains ejected by 67P/Churyumov-Gerasimenko on gold black covered targets [1]. The COSISCOPE camera provided images of these targets at a 13.7 microns resolution, which enabled studies of the typology and the flux of collected particles [7]. The images show particles ranging from a few tens to several hundreds of microns, the majority of which appear to be built from micron-sized sub-components (confirmed by MIDAS [8]). Analysis of the particle morphologies identified four families of particles as illustrated on Fig. 1.
A grazing incidence angle of illumination allows COSISCOPE to retrieve both the surface area of the collected particles and their height based on their projected shadow (see Fig. 1). The area is determined from a ratio of bright pixel before and after exposure. An aspect ratio of the compacted particles may be obtained from $\left(\frac{\text{height}}{\sqrt{\text{area}}}\right)$. The aspect ratio density distribution for each type of particles detected is represented in Fig. 2. The compact particles, C, appear unbroken and present the largest aspect ratio values, ranging from 0.4 up to 1 or more. The various aggregated particles present typical aspect ratio around 0.3 with the shattered clusters being the flattest.

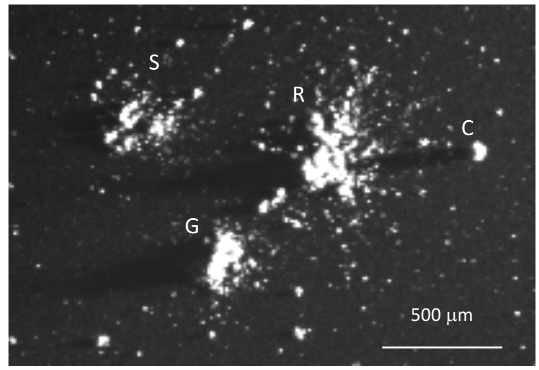

Figure 1: Diversity of particles types detected by COSIMA (compact particle, C; rubble pile, R; shattered cluster, S; and glued cluster, G) (adapted from [7]).

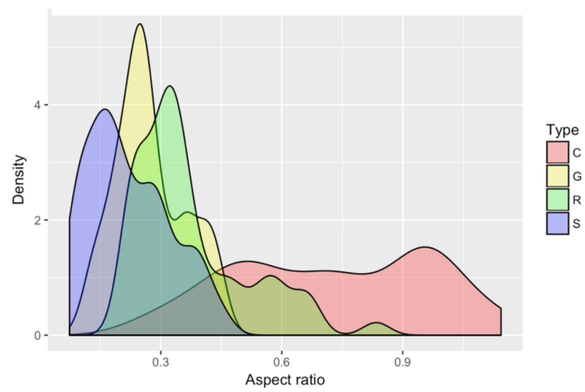

Figure 2: Normalized density of aspect ratio for each type of particles detected by COSIMA (adapted from [7]).

To understand the physical structure of cometary nuclei, it is important to infer, as much as possible, the particles properties prior to their collection.
COSIMA analyses have shown a correlation between the flux of dust particles at various distances from the comet nucleus and their morphology [9]. The fragmenting particles appear to have a mechanical strength of a few 1000 Pa [10] and their morphological diversity could result from different collection speeds in the range from 1 to 6 m.s^{-1} as investigated by laboratory simulations [11].
We further compare the COSIMA measurements with a simple numerical model of aggregates deformation to assess whether their morphologies could also be explained by different initial populations porosity.

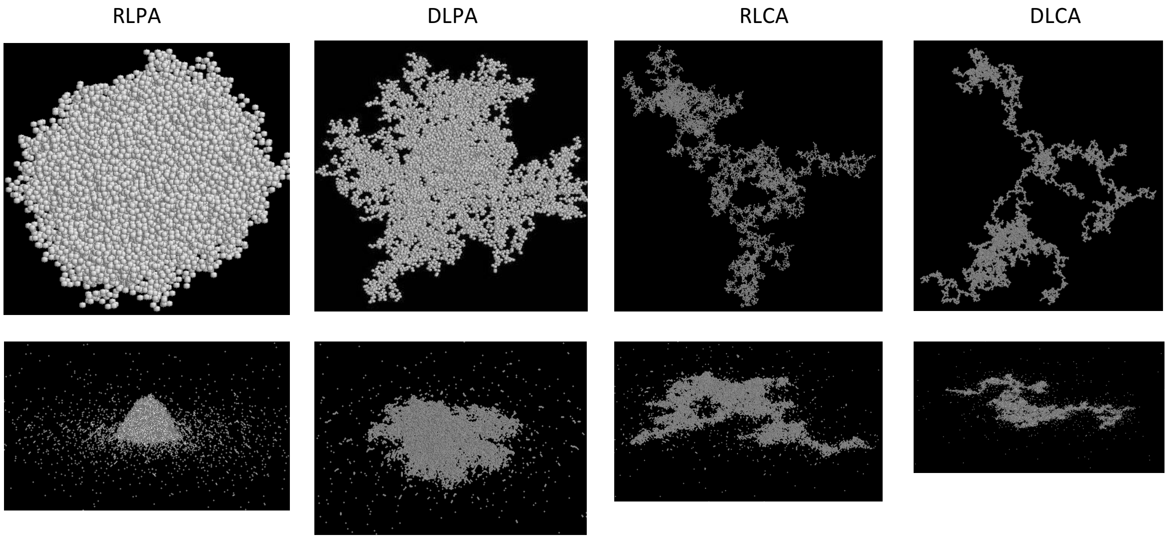

Figure 3: 3D view of four particles representing four different aggregation processes before projection (above) and after projection (below)

Aggregates numerical compaction simulation: Fractal aggregates in the early Solar System form a range of porosities represented by their fractal dimension, D_f, based on their aggregation processes (diffusion limited or reaction limited aggregations, depending on the surface sticking probabilities of the monomers, and particle-cluster or cluster-cluster aggregations) [12-13]. We consider 4 different kinds of fractal aggregates presenting different initial fractal dimensions (Fig. 3): DLCA ($D_f = 1.8$), RLCA ($D_f = 2.1$), DLPA ($D_f = 2.5$) and RLPA ($D_f = 3$). The aggregates are projected particle by particle onto the plane z=0, without considering mass loss. The geometrical parameter $\sin(\theta_0)$ is a threshold above which particles that are projected onto the previous ones may break their bonds and bounce. This parameter is directly linked to the cohesive strength between monomers, or the collection velocity, with values close to 1 corresponding to very cohesive monomer bonds and lower values corresponding to less cohesive bonds.

A statistical distribution of the aspect ratio for particles of each kind is obtained by simulating 1000 particles of 10,000 identical spherical monomers. Fig. 4 illustrates the normalized density of the aspect ratio values for each family of compacted aggregates. Comparing Fig. 2 and 4, we find that the range of aspect ratios observed by COSIMA could be due to either two different initial groups of particles such as the compact one (RLPA) and one with a lower fractal dimension (such as DLPA). Alternatively, it could originate from a single type of aggregation process (such as DLPA) but presenting different cohesive strengths amongst aggregates ($\sin(\theta_0)$ ranging from at least 0.1 to 1). The RLCA and DLCA processes compacted with $\sin(\theta_0)$~0.1 (Fig. 4.a) would appear more consistent with the COSIMA observations of the flattest kind of particles observed (shattered clusters with an aspect ratio of 0.15).

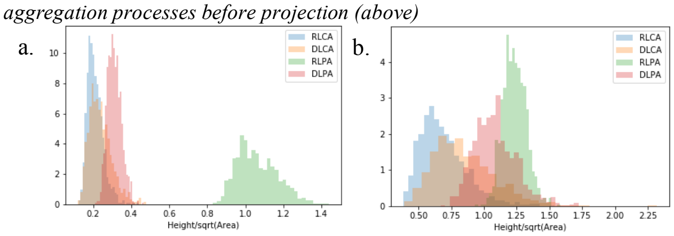

Figure 4: Normalized distribution of aspect ratio for each aggregate type considered (geometrical parameter of a. $\sin(\theta_0)$~0.1 and b. $\sin(\theta_0)$~1)

Conclusion: Aggregate compaction simulations may help to trace back the initial properties of dust particles collected by COSIMA. We find that COSIMA results may be explained either by compacting two different initial families with different fractal dimensions and the same cohesive strength between monomers. Alternatively, a single aggregation process forming not so porous fractal particles (like DLPA) with a large range of internal cohesive strengths, or collection velocities, may also explain most of the observed aspect ratio distribution.

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