Observations of the collisional process between clusters formed in free-falling dust streams

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Introductions:
The critical size in the growth of dust aggregates in protoplanetary disks is important in the formation of planetesimals. Laboratory experiments, in which hundred-micron-sized aggregates consisting of micron-sized dust monomers confined in a container collide with each other under microgravity (e.g., Kothe et al., 2013), and numerical studies (e.g., Wada et al., 2009) have been conducted to study the collisional outcome of dust aggregates. The results of laboratory experiments and numerical simulations are similar in the critical collision velocity for growth but different in occurrence of bouncing. Bouncing sometimes occurs in the laboratory experiments but not in the numerical simulations. Collisions between the container wall and the aggregates may have made the surface of the aggregates more compact than the interior, so that bouncing may have occurred. To avoid such collisions, we designed a new experimental approach of collisions between clusters, that is collisions between the clusters formed in free-falling dust streams. So far, we found that the filling factor of the clusters consisting of 45-μm glass beads was ~0.3. This filling factor corresponds to the coordination number between the beads of 2-6. Since no bouncing occurs in the numerical dust aggregates with this coordination number, we expected no bouncing will occur when the clusters collide with each other. The purpose of this study is to carry out the experiments of collisions between the dust clusters and to observe the collision process to discuss the possibilities of the growth of the clusters.

Experimental methods:
A setup for producing dust streams and a digital camera (960 fps, 32 μm/pixel) are installed at the top of a vacuum chamber. After the dust streams are produced, the digital camera falls along a shaft and images the dust streams. The dust streams are produced from a pair of nozzles with different slopes on the left and the right, and have horizontal velocity and collide with each other. The experiment was performed at 0.1 atm using the 45-μm glass beads.

Results and Discussions:
The width of the cluster formed in this experimental setup is 3 mm, and the number of constituent particles of the clusters with the previously estimated filling factor is 10^5 or so, assuming that the clusters are ellipsoids with 2:1:1 axial ratio. In this experiment, we realized the collision velocity between the clusters of about 9 cm/s and succeeded in imaging the collisional process. The observation duration after the collision was about 0.06 seconds. No "bouncing" occurred in cluster-cluster collision within this time and the clusters coalesced. In fact, it was confirmed that the clusters did not "fragment" at least at this collision velocity. On the other hand, the cohesive force of the glass beads used in this study was ~0.5 μN, which was measured by a centrifugal separation method under atmospheric pressure (Nagaashi et al., 2018). The critical collision velocity of dust aggregate consisting of 45-μm glass spheres with a smooth surface and with that cohesion is expected to be ~1 cm/s (Wada et al., 2009), inconsistent with this experimental result. This may suggest that the clusters in dust streams are more likely to "stick and grow" than predicted by the numerical simulation of dust aggregate for some unidentified reasons. Alternatively, the cohesive force of the glass spheres in the reduced atmospheric pressure (0.1 atm) may have increased

from the value measured under atmospheric pressure. We also found that no change in the cluster volume before and after the collision based on the digital camera images. Since the total number of constituent particles of the clusters were not changed, this means that there was no detectable change in the filling factor of the clusters before and after the collision.

Keywords: protoplanetary disks, dust aggregates, collision