The Particle Accretion in Microgravity Experiment: Protoplanetary Aggregate Formation A. D. Whizin[1], D. D. Durda[2], C. S. Tsang[2], and S. G. Love[3], [1]Southwest Research Institute, [2]NASA JSC. (email:awhizin@swri.edu)

Introduction: Early on during terrestrial planet formation processes in the gravity-less environment of the solar nebula the accretion of dust aggregates occurs, leading to the formation of protoplanetesimals. The exact mechanisms related to their growth poorly understood and in order to better inform planet formation models we need to understand the mechanical properties of the aggregates and which of these controls their growth [1]. The low-gravity mechanical processes and mineralogic composition of this dust need to be characterized as they are important to properties such as cohesion, aggregation, porosity, and coefficient of restitution. The objectives of the experiments are to determine the effects of particle size, number density, and composition on the accretion of dust-scale grains in microgravity conditions. This work enhances and builds upon previous microgravity free-float experiments initially performed by astronaut Don Pettit aboard the International Space Station (Figure 1) [2], and later performed by co-author Durda. In the Pettit experiments bags of finely grained materials like coffee and sugar were agitated
and left to free-float immediately showing the aggregation of the highly cohesive materials.

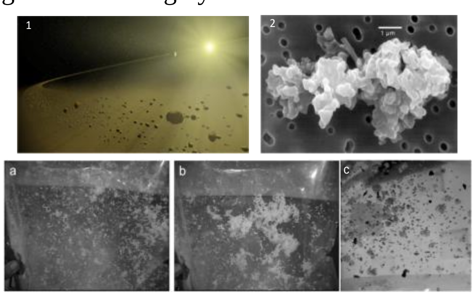

Figure 1: (1) Artist rendering of an early solar nebula. (2) SEM image of IDP dust aggregate of many small sub-micron particles. (a, b) Aggregates and individual particles of sugar and (c) other materials that were allowed to float for several hours aboard the ISS (a, b, c figures from Love et al 2014).

The clusters that formed did so due to surface forces such as van der Waals and electrostatic forces. In a low-gravity environment these and other secondary forces dominate over the self-gravity of the cluster; this is the case in the nascent protoplanetary disk where small mm to cm-sized protoplanetesimals form. We observed the formation of clusters in this size regime and we report their controlling parameters.

Materials: In this experiment, we used carefully crushed and sieved dust powders made up of olivine (San Carlos peridot gems), UCF-1 CI simulant [3], enstatite, crushed Allan Hills 83100 CM2 carbonaceous chondrite and Northwest Africa 869 L3-6 ordinary chondrite. We sieved the samples to three size distributions each (0.125 – 0.5 mm, 0.5 – 1.0 mm, and 0.5 – 2.0 mm), covering masses (i.e. number densities) of 3 g, 10 g, and 20 g.

Experiment: We built and flew a parabolic flight experiment to study the dependence of fundamental properties of different relevant analog minerals on the growth of porous clusters (aggregates) in microgravity (Figure 2). Each frame has two camera arms mounted with wing nuts for easy assembly during the zero-g flight, and has a GoPro camera mounted on each end to collect data.

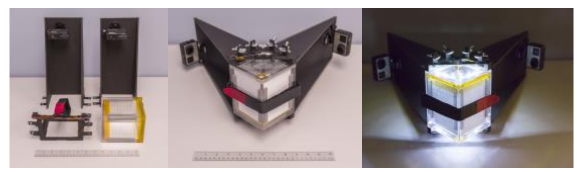

Figure 2: The experiment frame and camera arm mounts used in the parabolic flight experiments. GoPro's are mounted on each arm for a stereoscopic view. LED lights are activated during flight for extra illumination to observe the fine-grained dust's behavior.

In each flight (4 so far completed) we fly nine 10 x 10 x 12 cm Plexiglas boxes, each filled with one of the samples. During each parabola a single box is removed from the storage case and allowed to free-float for the ~20 seconds of microgravity. The boxes are then shuffled between the three flyers for a streamlined and rehearsed rotation method so that all boxes fly equal time Experiments on the ground and aboard the ISS have shown that this is more than enough time to allow for the rapid formation of aggregates of the dust [4], and this was indeed the case as observed during our ~17 second free-float times. The formation of the aggregates were observed and recorded and the aggregation's characteristics and behavior then analyzed.

Results: Using the open source tracking software ImageJ, we tracked the particles and clusters (Figure 3). The aggregate pixel areas were determined and plotted for each frame, and for each of the experiment boxes. Interestingly, we observed the greatest aggregation in the smallest particle size boxes and the CI simulant and ALH 83100 meteorite. The olivine at the smallest size fraction has relatively sparse number density but readily formed clusters. Boxes containing higher number densities saw larger and more abundant aggregate formation.

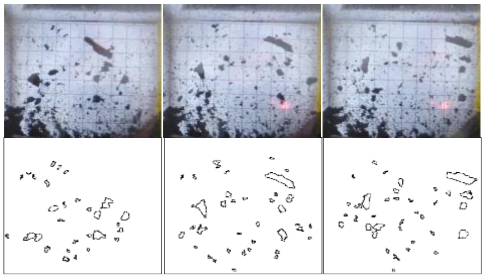

Figure 3: Using ImageJ tracking software we analyzed short continuous clips of data during the weightless portion of the parabolic flight shown here. The frames were analyzed to isolate the clusters of particles that formed in the low-gravity environment as shown by the lower series of B&W images.

Conclusions: We find that the composition of the dust was not as important to aggregate formation as the particle size distribution, and to lesser degree, the number density in the initial cloud (Figure 4-6). Such behavior was evident in nearly all boxes, indicating the ease to with which small dust grains adhere in a reduced-gravity environment such as the solar nebula or asteroid surface. This perhaps indicates a lower floor to the bouncing regime threshold for aggregates such as these, which could possibly enhance the planet formation process, but more work is needed here. Future analysis of this data will include dependencies on number density and composition and power law models.

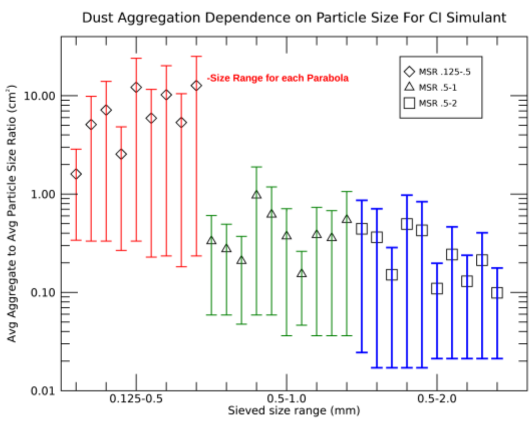

Figure 4: The average aggregate sizes obtained from the tracked clip image sequences and plotted in three bins according to their respective particle size distributions.

Due to meticulous planning by our team we were able to accomplish all of the Flight #1-4 objectives. Our final flight is in March 2020 and we plan to fly our final missing samples from our phase space, which will include some of the larger number densities we ran out of material to include.

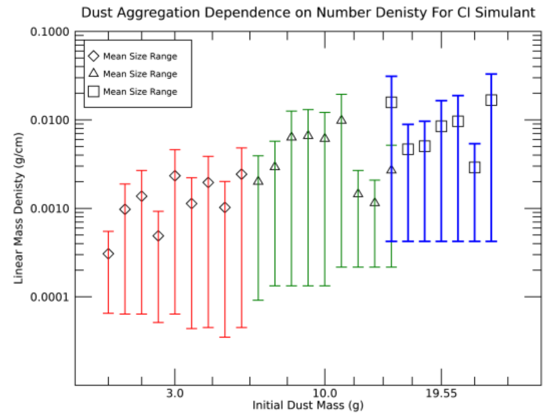

Figure 5: The aggregation of CI simulant and olivine as the number density was varied. Greater density equaled greater aggregation.

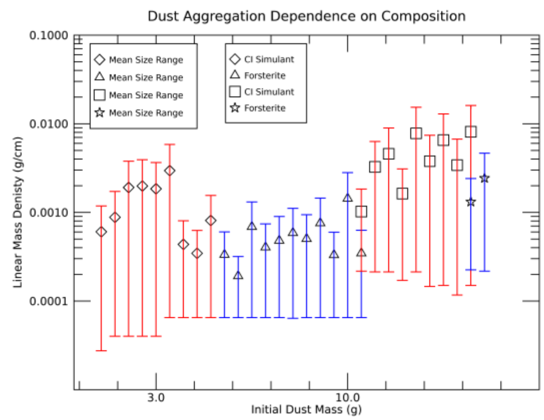

Figure 6: The aggregation of dust particles as we varied composition. The CI simulant adhered to itself far easier than olivine did in zero-gravity.

References: [1] Blum and Wurm (2008) *Annu. Rev. Astron. Astrophys*, 46:21-56; [2] Love, S. G., Pettit, D. R., Messenger, S. R. (2014) *Met & Plan. Sci.*, 49, 5, 732-739; [3] Metzger, P. T., Britt, D. T., Cannon, K. M., Schultz, C. D., Landsman, Z., Peppin, M., and Covey, S. D. (2018), *LPSC* #2926; [4] Poppe and Schräpler (2005) *Astron. & Astrophys.*, 438, 1, 1-9.

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