Dust cloud manipulation in microgravity: positioning, squeezing and trapping

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Interaction in Cosmic and Atmospheric Particle Systems (ICAPS) is one of the main projects of the European Space Agency in physical sciences (Boon at al., 2008, Blum at al., 2008). Its part related to astrophysical experiments in microgravity deals with investigation of dust particle interaction, kinetics of agglomeration, formation of extended extremely fluffy agglomerates and their detailed microstructure. Microgravity is a necessity for these experiments because of relatively low gas pressure. Even individual micrometer size particles fall down too quickly in a rarefied gas at normal gravity to form agglomerates by Brownian mechanisms. Extended agglomerates, would they appear in such conditions, will not sustain their own weight.

After formation in microgravity conditions, the dust cloud requires different manipulations, most important are positioning, squeezing and trapping. First of all, one has to counterbalance external perturbations – residual gravity, thermophoretic force and gas flow driven by thermal creep. Two latter effects arise as a result of temperature differences along the chamber walls. Tiny temperature gradients as low as about 1mK/cm sweep away the cloud from the observation area. Solution of this problem is rather straightforward using static three- dimensional force with active feed back: a Cloud Positioning System analyzes regularly cloud images and works out a force that moves the whole cloud in such a way that the reference group of particles stays around the same fixed position in the chamber.

Cloud trapping and/or squeezing are more challenging tasks for a cloud containing millions of particles per cubic centimeter in a volume of tens of cubic centimeters. Trapping (without squeezing) assumes creation of a flat potential well with steep enough walls preventing a cloud from dispersion due to Brownian motion or sweeping away by external perturbation forces. Cloud squeezing requires extended central potential. Ideally the gradient should be high enough to move most of the cloud particles to a fixed point in the chamber to form single agglomerate within a reasonable time interval. Modeling and microgravity experiments showed that cloud trapping and squeezing can not be provided by known instrumentation based on electro dynamic balancing of the Paul trap type (Davis, 2002).

In the Microgravity Research Centre we develop a set of new approaches and instruments for cloud positioning, trapping and squeezing, which for simplicity termed “traps” – thermophoretic, photophoretic, diffusiophoretic, gas density variation, fluid velocity profiling, and magnetic. The thermophoretic trap passed the first tests in microgravity conditions (Vedernikov et al., 2007 and 2009). Its advantage is in the fact that positioning, trapping and squeezing properties do not require electrical charge on the particles and all these “trap” functions in the free molecular regime are much less sensitive to particle sizes as compared to the electro dynamic balancing. Such property is particularly interesting for agglomeration experiments. The progress in the development of the efficient thermophoretic traps bases on appropriate geometry of the trap and rapid temperature variation. We developed rapid thermoelectric heaters (Vedernikov et al., ICT & ECT 2009) making more than 500 K/s on the working surface that allows using the thermophoretic trap at frequencies up to about 20 Hz.

The traps under development have different properties: stabilized temperature or on the contrary highest possible temperature variation in the trapping volume (up to about hundred degrees), particle preferential trapping based on particle size, optical, magnetic or other properties, formation of intensive three-dimensional periodic shear flow or three-dimensional gas density pulsations of the contraction-expansion type with minimal shear flow intensity, etc. Their choice and/or combination (also including electro dynamic balancing) depends upon the task for dust cloud manipulation system. Their use at normal gravity is also possible.

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