First tests of thermophoretic trap in short duration microgravity conditions

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Keywords: aerosol dynamics, cloud dust, dynamic balancing, instrument development, microgravity

The European Space Agency’s scientific program Interactions in Cosmic and Atmospheric Particle Systems (ICAPS) is aimed at increasing our knowledge about dust agglomeration in astrophysical processes mostly related to proto-planetary matter formation (Blum et al., 2008). Microgravity conditions are needed to suppress sedimentation, which in the laboratory considerably reduces the experimentation time, thus Brownian motion driven agglomeration can be performed over a much-extended period of time. However, grain diffusion to the walls (at which all dust grains inevitably stick) and residual forces, like e.g. thermophoresis, impose limits to the maximum achievable agglomerate size and the agglomeration rate. The reduction of these adverse effects demands an efficient trapping mechanism for dust ensembles with the following requirements: particle sizes – from monomers of ~1μm to agglomerates of up to ~1mm; particle concentration up to 10^6-10^7 cm^-3; total chamber volume about 1 liter; cloud volume in the ‘area of interest’ – 1 to 40 cm^3; room temperature (about 300K); cloud volume in the ‘area of interest’ – 1 to 40 cm^3; total chamber volume about 1 liter. Prevention of grain diffusion or drift to the walls of the experiment chamber allows long-duration agglomeration studies for the investigation of aggregate morphologies, aggregation rate, aggregate mass distribution, and temporal behavior of the mean aggregate mass for a variety of grain sizes, shapes, compositions and gas pressures.

To meet the requirements of the project, the experimental instrumentation should provide 1) squeezing of such a dense cloud (mostly to compensate particle number lowering due to Brownian agglomeration) and 2) counterbalancing external cloud perturbations. Traditional approach would be using electrodynamic balancing (EDB or Paul trap) taking into account the fact that particles are naturally charged by cog wheel injection. However, this technique has principal disadvantages coming from presence of opposite charges on the particles. Among other drawbacks it leads to quick reduction of the total charge-to-mass ratio of growing agglomerates, lowering of the ‘trapping strength’ followed by loosing the agglomerates - the most interesting objects of investigation. The use of the thermophoretic force (Vedernikov et al., 2007) should remove most disadvantages of the electrodynamic balancing. Mean particle velocity in a thermophoretic trap is convenient to express as

\[ v_{\text{ref}} = \langle v_\text{r} \rangle = -\frac{2 \tau_p}{1 + (\omega \tau_p)^2} \left[ v_{\text{ref}} C_z P_{\text{ref}} \omega_{\text{ref}} T_{\text{ac}}(\omega_{\text{ref}}) \right]^2 \]

where \( \tau_p \) particle relaxation time; \( \omega \) angular frequency (2-10 Hz); \( v_{\text{ref}} \) is the value of the particle thermophoretic velocity at known temperature gradient \((\Delta T)_{\text{ref}}\) and reference pressure \(P_{\text{ref}}\); \( C_z \) proportionality coefficient in the temperature profile \( T = T_0 + C_z \Delta T \) around equilibrium trap point; \( T_{\text{ac}} \) is the temperature variation amplitude on heaters at reference frequency \( \omega_{\text{ref}} \) (\( T_{\text{ac}} \) was 4.2 K for 10 Hz); \( z \) mean particle axial coordinate.

First tests in microgravity conditions of the Bremen drop tower (microgravity duration 4.7 s) were performed in a prototype chamber of the ICAPS project that imposed certain geometrical limitations on the trap (two coils, diameter 62 mm separated by 10 mm). Measured motion parameters were in agreement with the theoretical model.

![Figure 1. Typical particle trajectory.](image)

The tests allowed identifying 1) necessary modifications in the trap’s geometry and heater’s functioning to visualize squeezing effect of the dust cloud in short duration experiments and 2) potentials of laboratory use of the thermophoretic trap.

ESA PRODEX program and the Belgian Federal Science Policy Office are greatly acknowledged.