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Photophoresis on dust in disks - from monomers to aggregates

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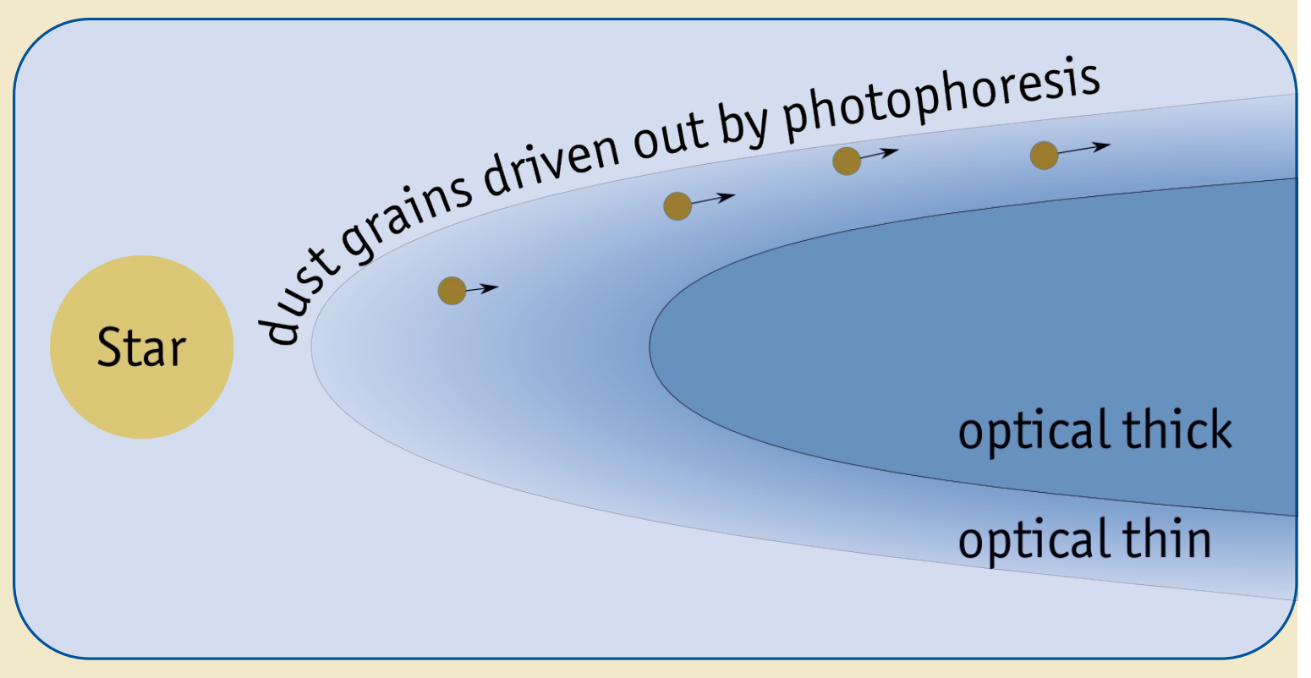
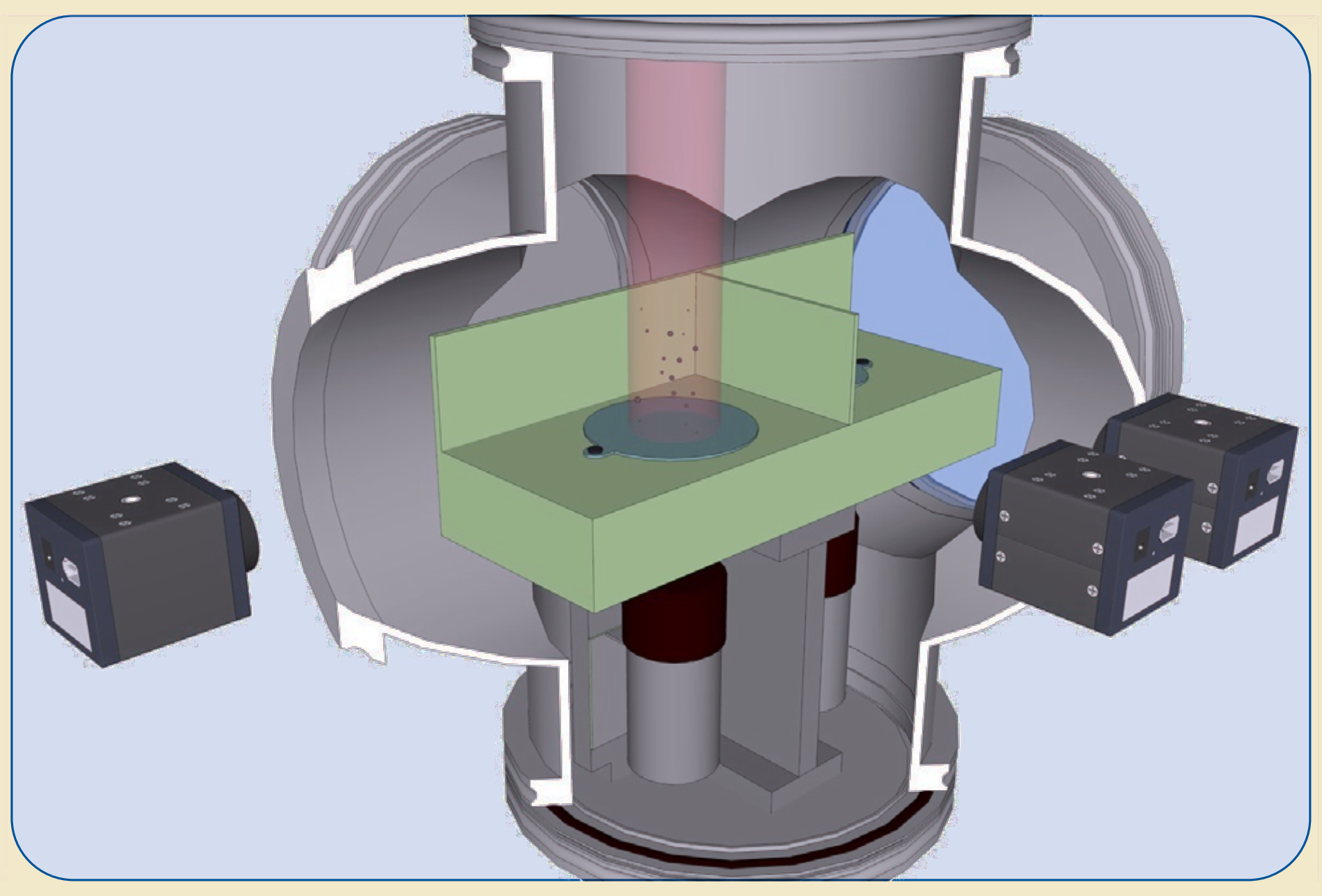
Motivation- Photophoresis in protoplanetary disks

Photophoresis acts on grains and aggregates and can drive them outward in optical thin regions of a protoplanetary disks.



Experimental Setup



Sketch of the setup: A 7 cm dust bed is illuminated by an IR laser (955 nm). The Laser Spot is widened to achieve a power density of 20 kW/m² with a beam diameter of 3.4 cm at the surface of the basaltic dust sample. Only one camera was used for this study.

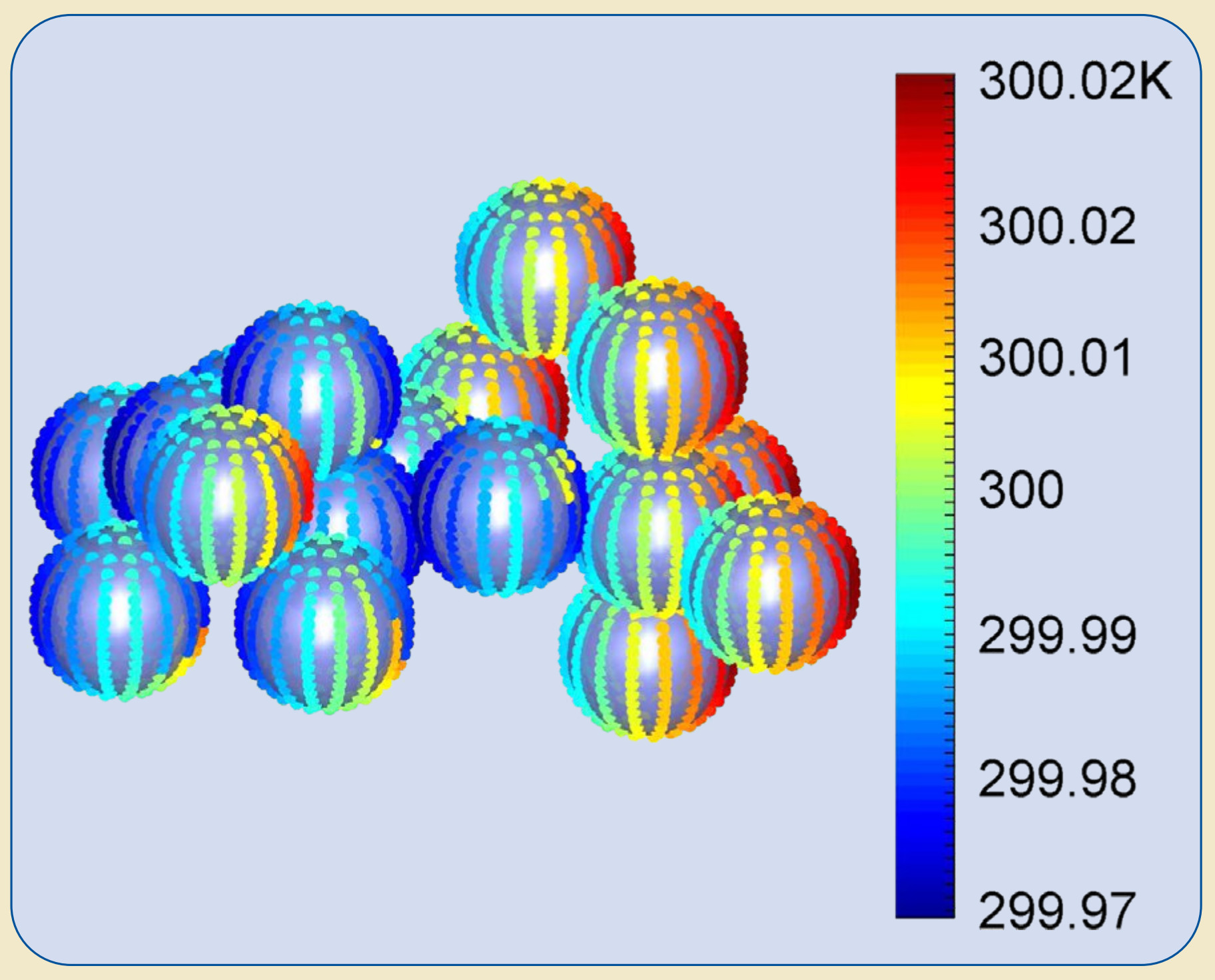
Sample image of the airborne dust during micro gravitaty. A dust bed with basaltic dust (grain size <125 µm) and a gas pressure of 4 mbar was used. During launch and the last second the dust bed was covered with a lid, 500 ms after the lift off the lid is opened and the dust bed is illuminated by an IR laser. Due to the illumination particles are ejected from the dust bed. The collection of data for this experiment begins after the lid is closed. The particles were tracked manually.

Summary

Photophoresis is a force acting on particles in low pressure environments, which can dominate the movement of aerosols. We conducted drop tower experiments with micrometer-sized basalt grains and aggregates to quantify the photophoretic forces. Most particles move along the direction of illumination, while a small number shows significant deviations. The results are consistent with numerical simulations and analytical estimates. A new result is that polydisperse small aggregates keep the bulk thermal conductivity.

Numerical Model

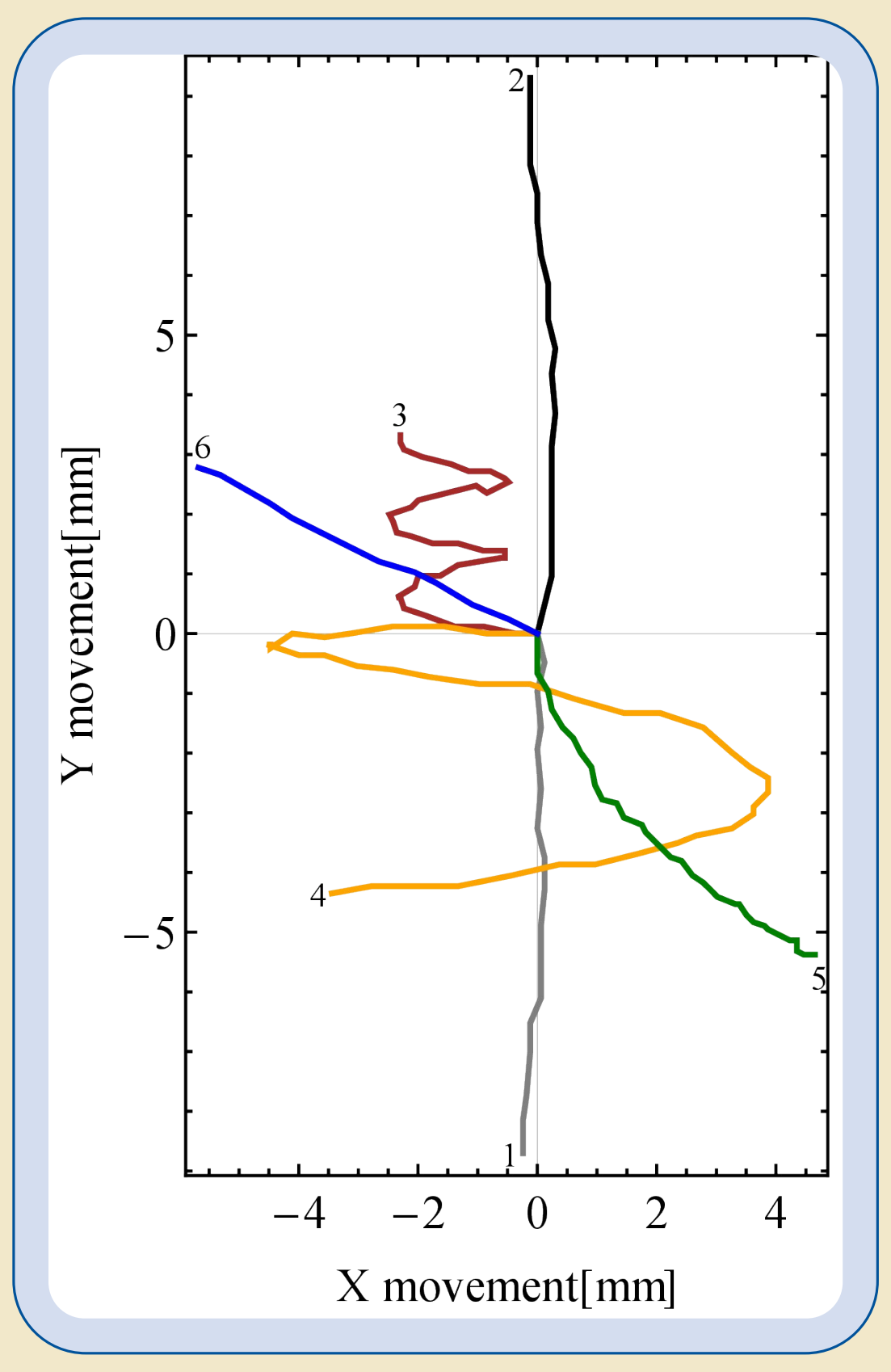
Temperature distribution of a simulated aggregate. For each surfcace patch the photon flux - with shadowing by other monomers - from a fixed light source is calculated, assuming a temperature gradient this yields the temperature distribution.



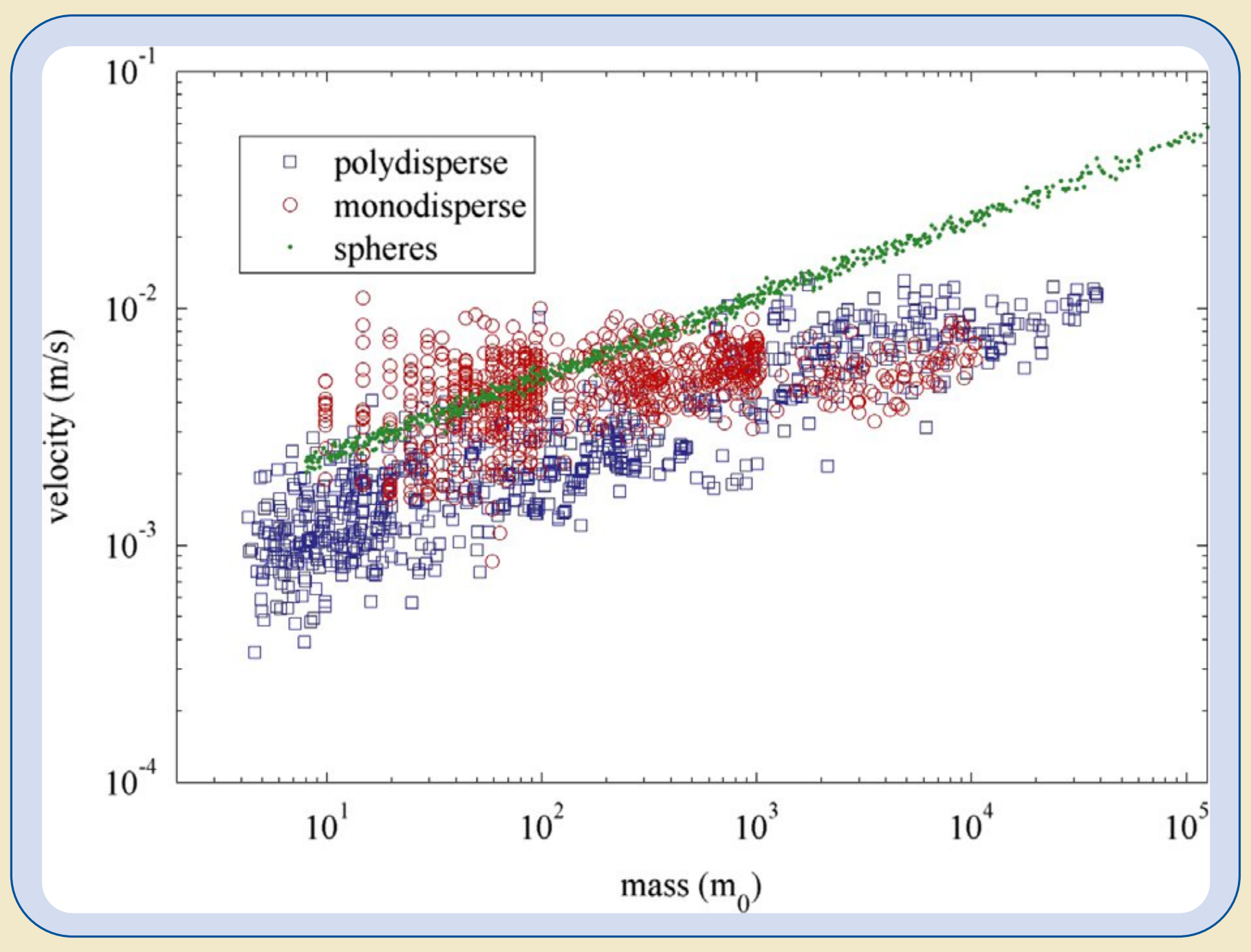
The forces are calculated with ballistic molecules imping the aggregate. After a collision the molecules are reemitted with local surface temperature ($\alpha = 1$), multiple collisions are calculated until 99% of the molecules have escaped the aggregate. The remaining molecules are ejected along the average line of sight for each path. Details of this method are described in [Matthews et al 2012]. Only the momentum transfer of the initial incoming and the final escape are taken into account, as the other collisions cancel themselves out.

Experimental Results

Selected particle trajectories corrected for the residual drift of the particle cloud. They are representing the different types of motion observed: (1 - grey) positive photophoresis, (2 - black) negative photophoresis, (3,4 - brown, orange) strong helical movement and positive photophoresis, (5,6 - green, blue) sideward movement.



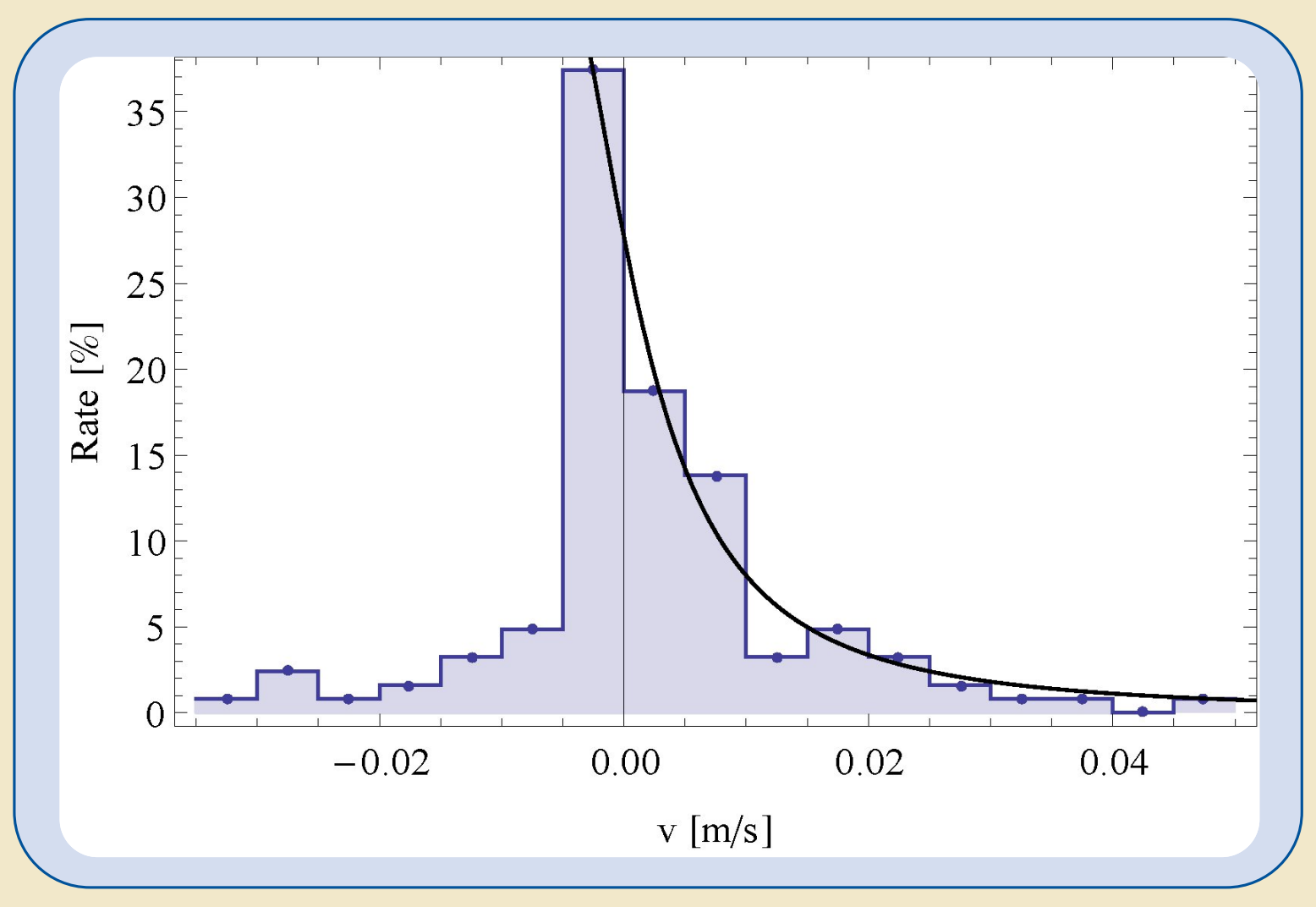
Numerical Results

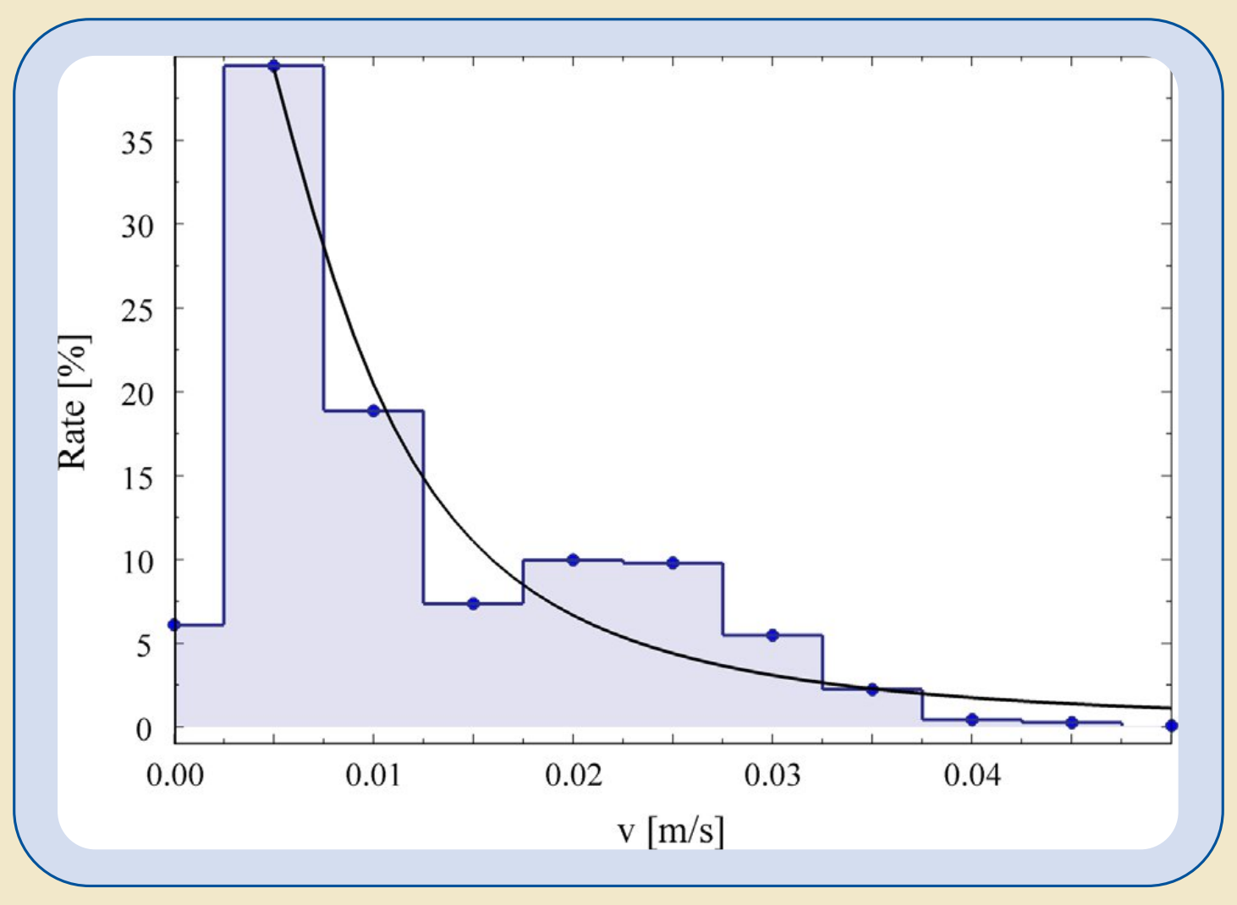


Drift velocity versus mass, normalized to the mass and velocity of a r = 1 µm sphere ($m_0 = 1.3 \cdot 10^{-14}$ kg, $v_0 = 1.1$ mm s^{-1}). (Monodisperse r = 1.7 µm , Polydisperse r = 0.5 µm to 10 µm with <r> = 1.7 µm). Aggregates have from 2 to 2000 monomers, with the size distribution from [Kelling et al 2011].

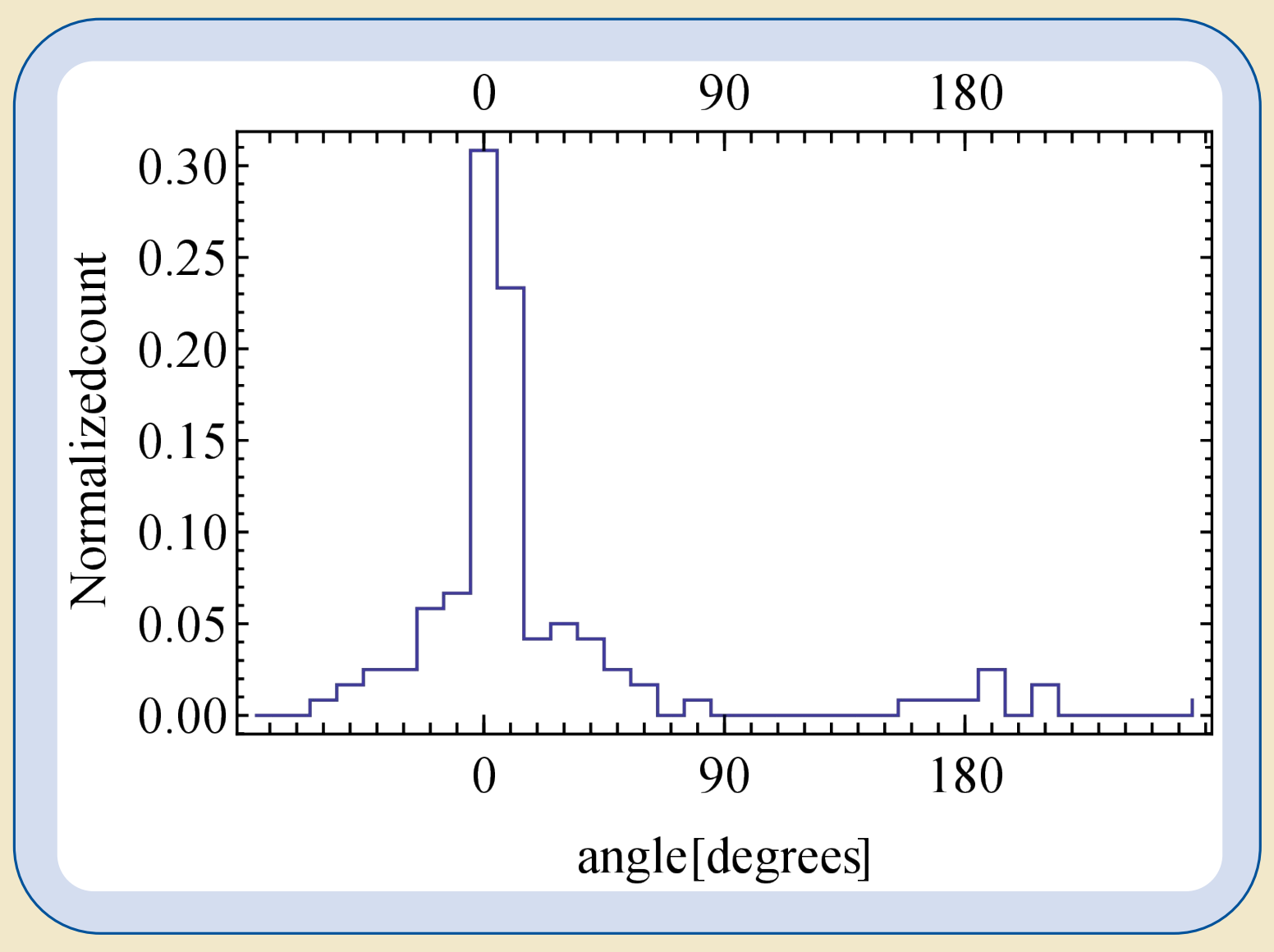
Comparison

Distribution of observed velocities in light direction. A fit was done characterizeing the movement and for extracting the size distribution (see text below).



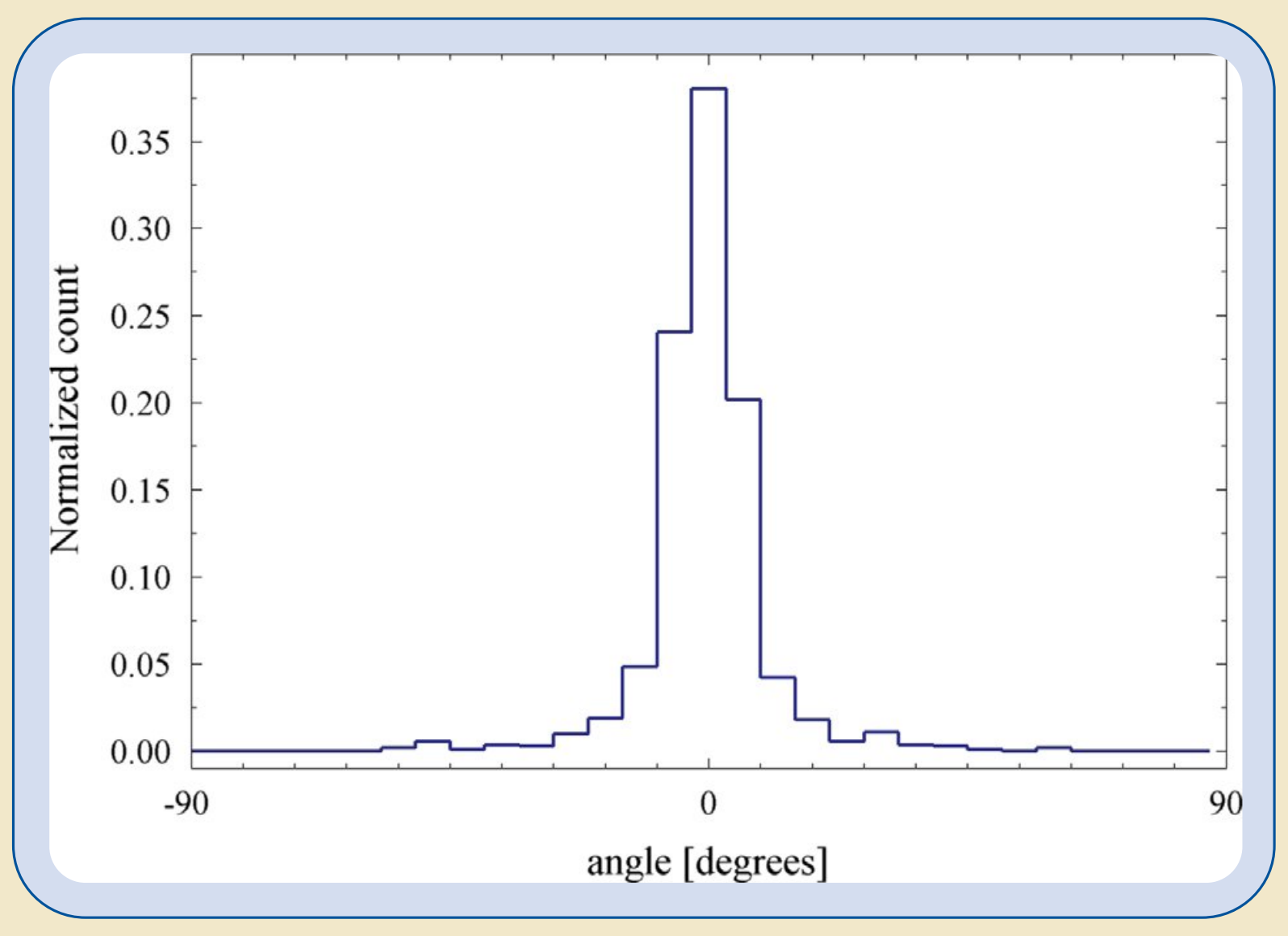


Calculated distribution of velocities for a mix of spheres between 1 µm and 10 µm and polydisperse aggregates matching the experimental results (the fit from the experimental data is shown here). A factor of 3 was used to scale the calculated results (accounting for e.g. the artificial temperature gradient chosen).



Observed angular distribution. First and last point of every track were taken into account and the direction was calculated, subtracting the residual drift of the dust cloud.

Calculated angular distribution, for the mix of single spheres and polydisperse aggregates. Negative photophoresis did not occur in the simulations, but for the majority of the particles simulation and experiment are in good agreement.

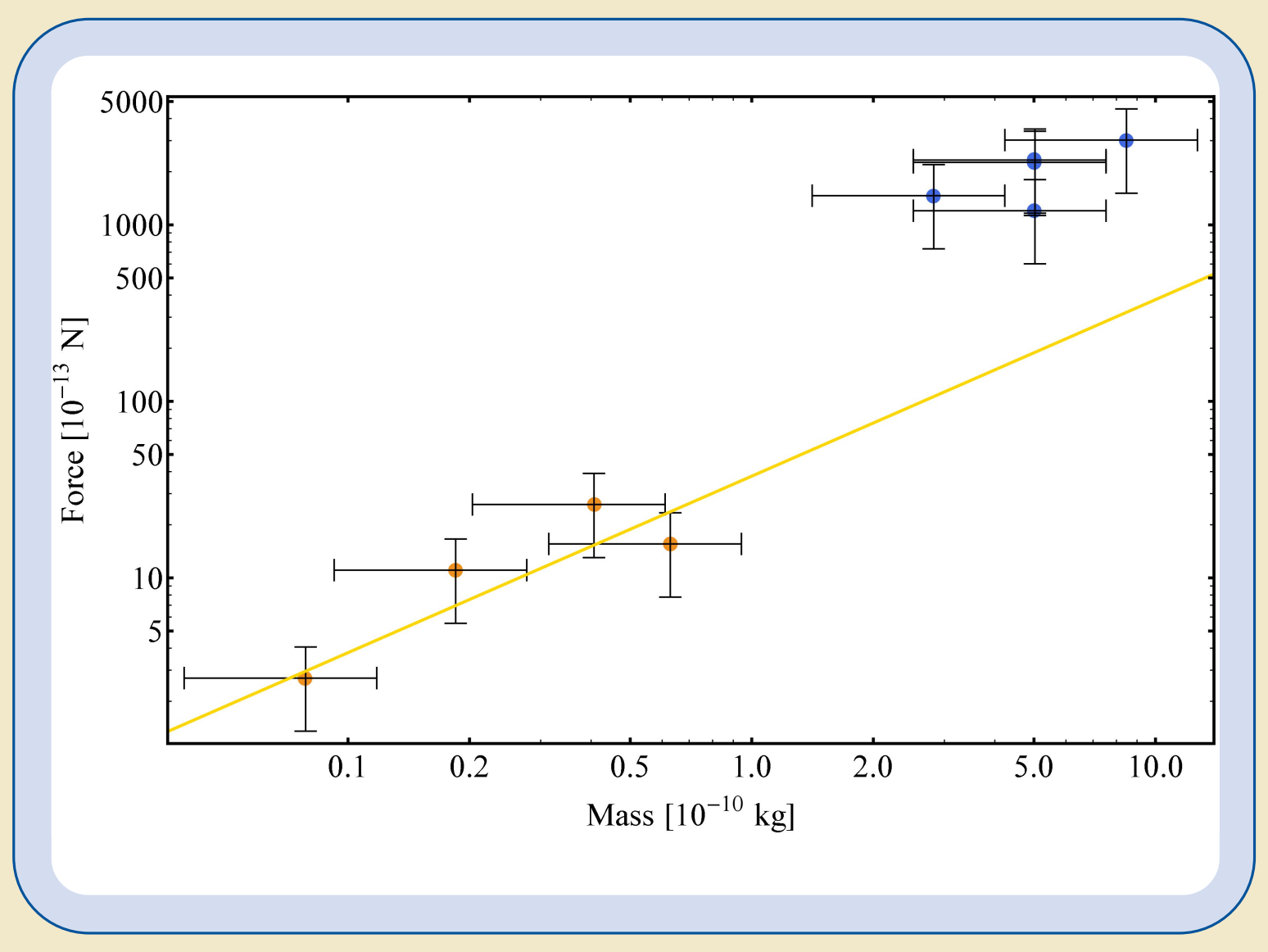


For small particles the drift velocity scales linearly with the particle size. Therefore the particle sizes from [Kelling et al. 2011] were adapted (as a fit: $p_r = a/(b+r[m]^2)$ with $a = 1.37(\pm0.07) \cdot 10^{-9}$ and $b = 2.7(\pm0.2) \cdot 10^{-11}$). With an offset velocity and an conversion factor between size and velocity one can obtain a fit for the velocity distribution. This fit yields: $p_v = a/(b+(v-v_0)^2/c^2)$ with $c = 1.37(\pm0.07) \cdot 10^{-9}$ and $v_0 = 6.2(\pm0.6)$ mm s^{-1}. The factor c is the size dependence of the terminal velocity, which theoretically can be written as $v/r \approx 33I/v_g\lambda_p$ [m²/s²K] resulting in a thermal conductivity of $\lambda_p \approx 1$ W/mK, which is close to the bulk value.

Outlook

Measured photophoretical forces on aggregates (blue) and monomers (orange) consisting of glassy carbon spheres with a diameter of ca. 100 µm. A fit for monomers is shown in yellow. Aggregates have a higher force by a factor of about 10.

[J.B. Kimery, L.S. Matthews, G. Wurm, C. de Beule, M. Küpper, T. Hyde, in prep.]



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References

Matthews,L.S.,Land,V.,Hyde,T.W. 2012, ApJ, 744,397
Kelling, T. and Wurm, G. 2011, ApJ, 730, 120
Kelling, T., Wurm, G.,Kocifaj, M., Klačka, J., Reiss,D. 2011, Icarus, 212, 935
Küpper, M., de Beule, C. Wurm, G., Matthews, L.S., Kimery, J.B., Hyde, T.W. , 2014, JAeroSci, 76, 126