Photophoresis on large sub-km size bodies in protoplanetary disks

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Open-Minded

Photophoresis is a strong non-gravitational force in optical thin environments of a protoplanetary disks

The influence on small sub-mm particles has been studied in detail. But even for large bodies photophoresis can induce forces significant for the spatial evolution in the disk! A meter sized rocky body at 2 Au distance from a sun-like star experiences a photophoretical force which may become comparable to the residual gravitation. In microgravity experiments we found that this force can be enhanced by porosity.

Physical background

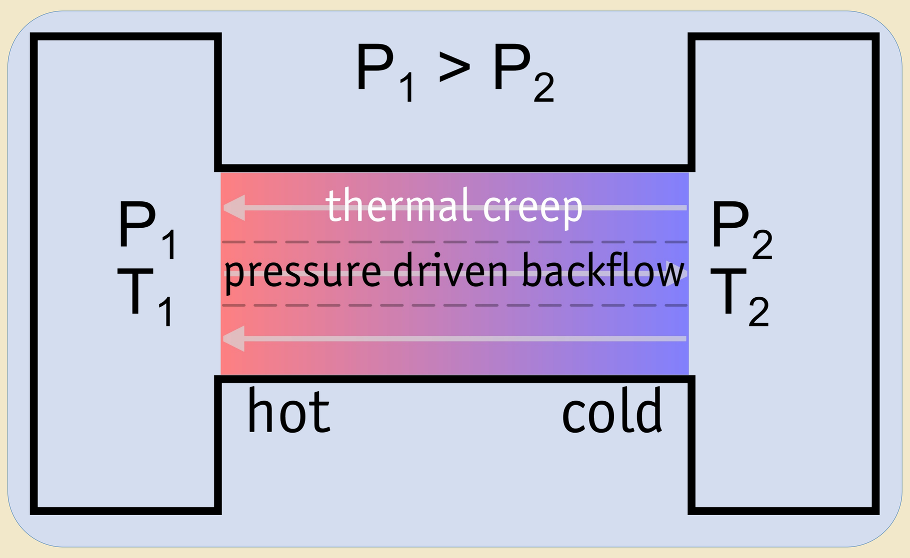

Figure 1: Sketch of the Knudsen effect. Thermal creep lets gas flow along the wall to the hotter side. The region of thermal creep is around one mean free path wide. If the capillary is larger there will be a back-flow nullifying the creep. But if the capillary diameter becomes small a pressure difference will be induced by thermal creep.

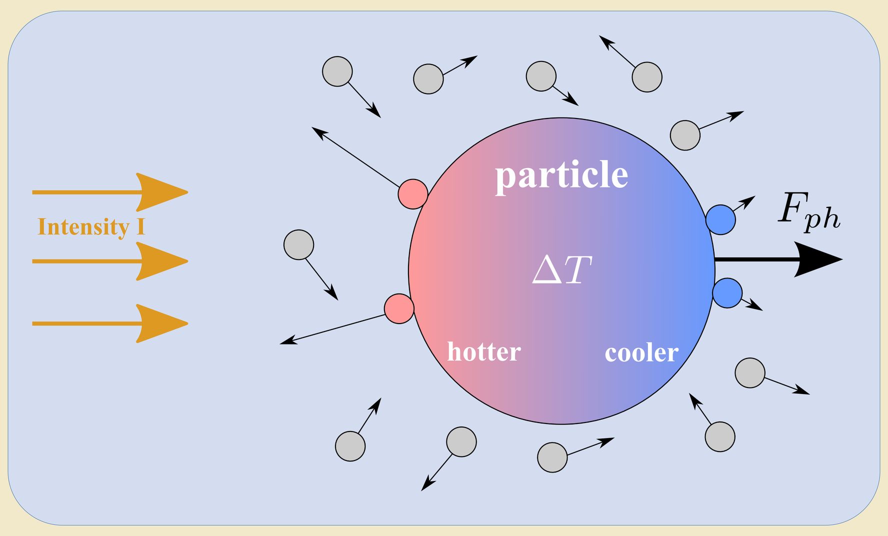

Figure 2: Illustration of the photo-phoretical force. Light induces a temperature difference. Gas molecules accommodating the cool side of the particle leave it with a smaller momentum than at the warm side, therefore the particle experiences a force. This works best when the particle is approx. one mean free path big. At lower pressures the is less gas to interact and at higher pressure collisions between the gas diminishes the effect.

The characteristic length for non-spherical bodies

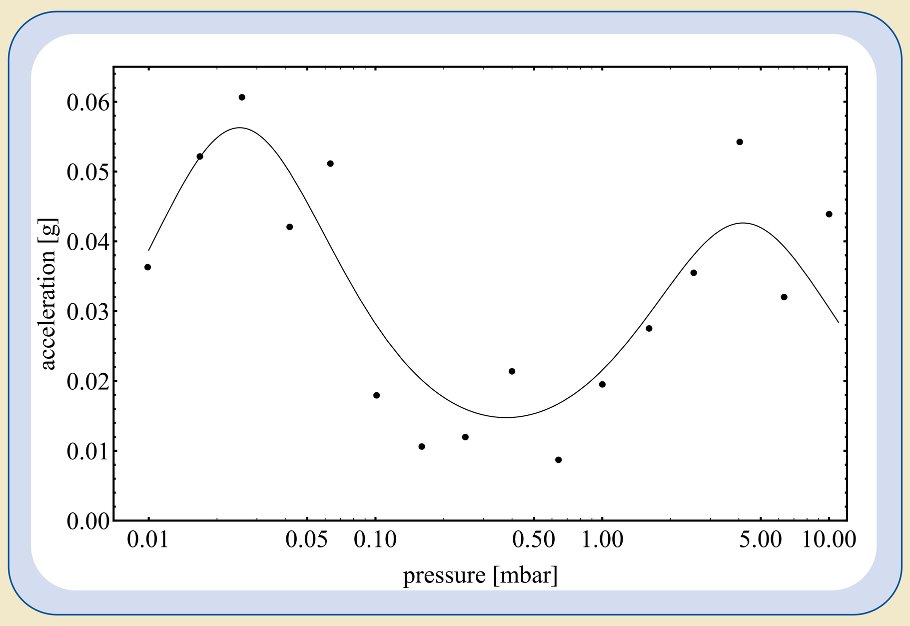

Figure 3: Pressure dependence of the phoretic acceleration on a porous sintered glass plate obtained in a parabolic flight to avoid convection. [Küpp13]

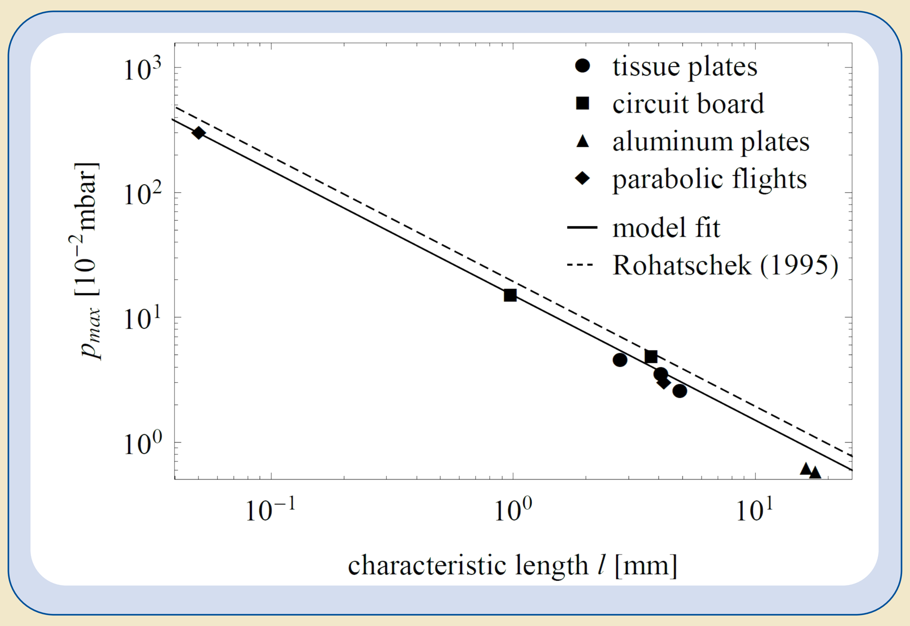

Figure 4: Fit to the force maxima for the characteristic length of the sample and the pores. Fitted Function: $l = r^{0.35}\ d^{0.65}$. [Dürm13]

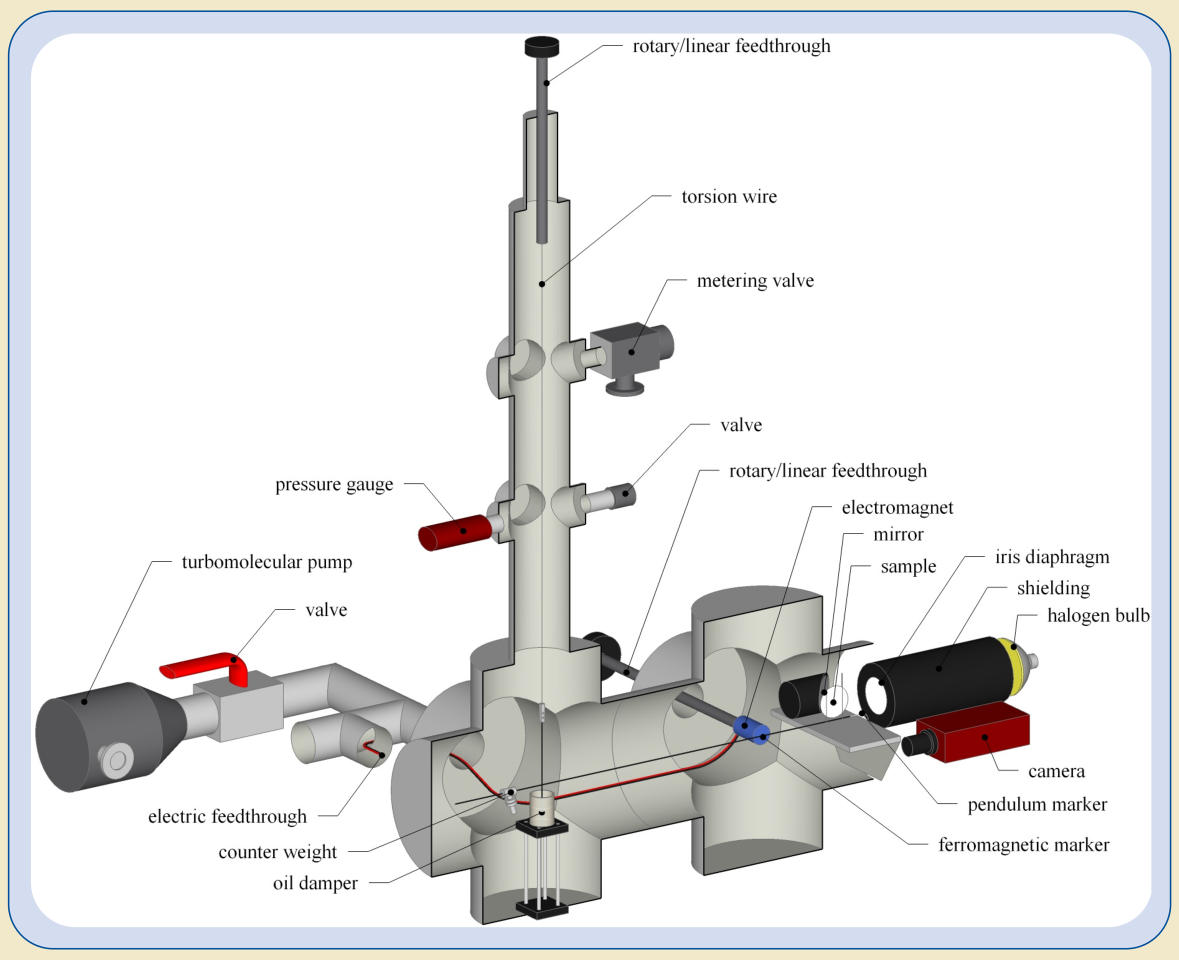

Figure 5: Setup of the torsion pendulum experiment. With this experiment the pressure dependence of the forces on the sample and the pores was measured. [Dürm13]

Revising the drift in a protoplanetary disk

An analysis following the drift velocity calculation proposed by Weidenschilling [Weid77] was conducted including photophoresis [Roha95]. For the calculation a density of 1500 kg/m³ (filling factor 0.5 for silicates) and a thermal conductivity of 0.1 W/m K and an optical thin (minimum mass solar) nebular were assumed. In a second step the force due to the pores was investigated.

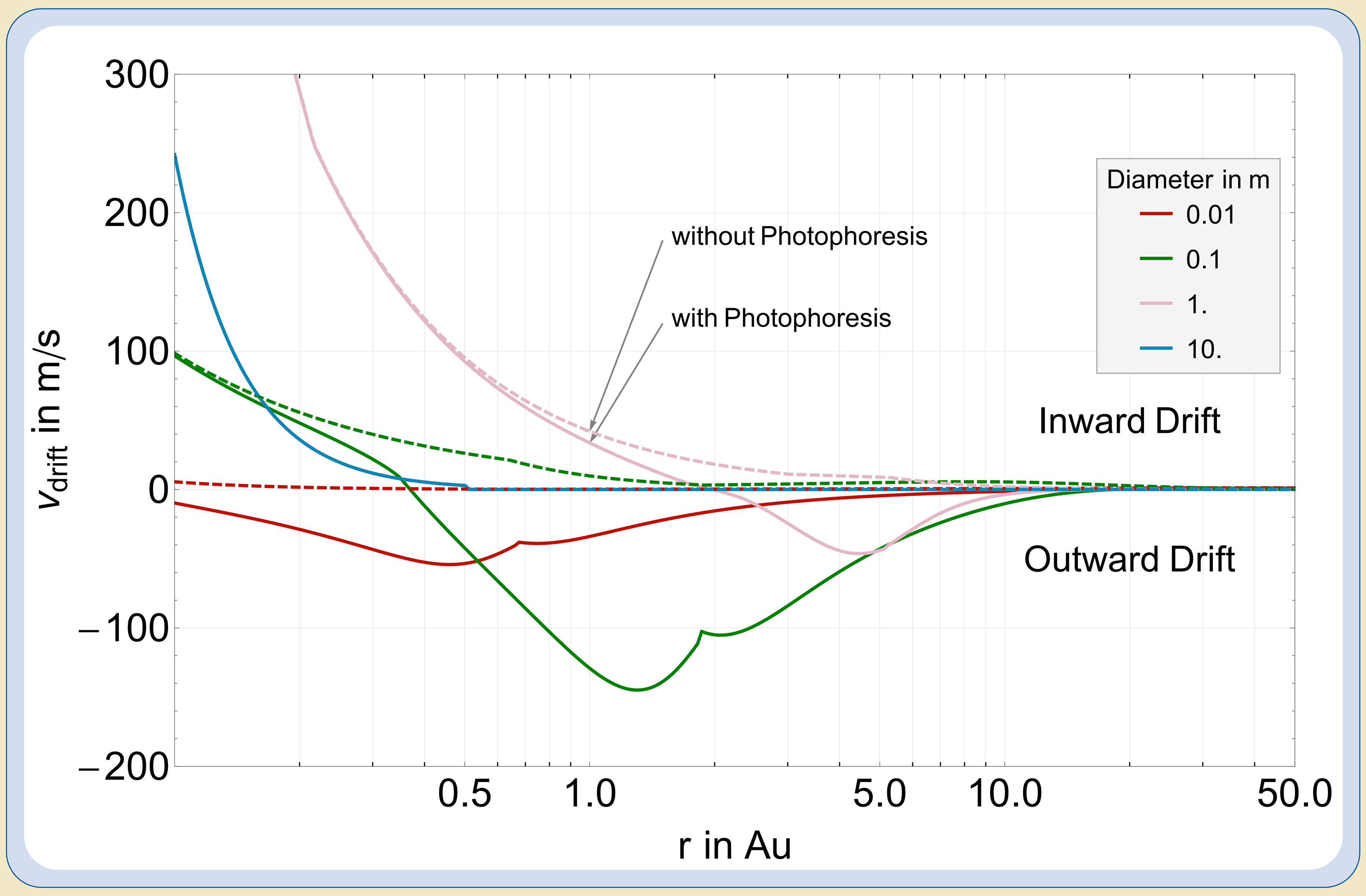

Figure 8: Comparison of the drift velocities for the MMSN nebular model [Haya81] without (dotted) and with photophoresis (solid line) acting on the particles. Photophoresis reduces the drift velocity as it is an additional outward force and can become stronger than residual gravity even for meter sized bodies.

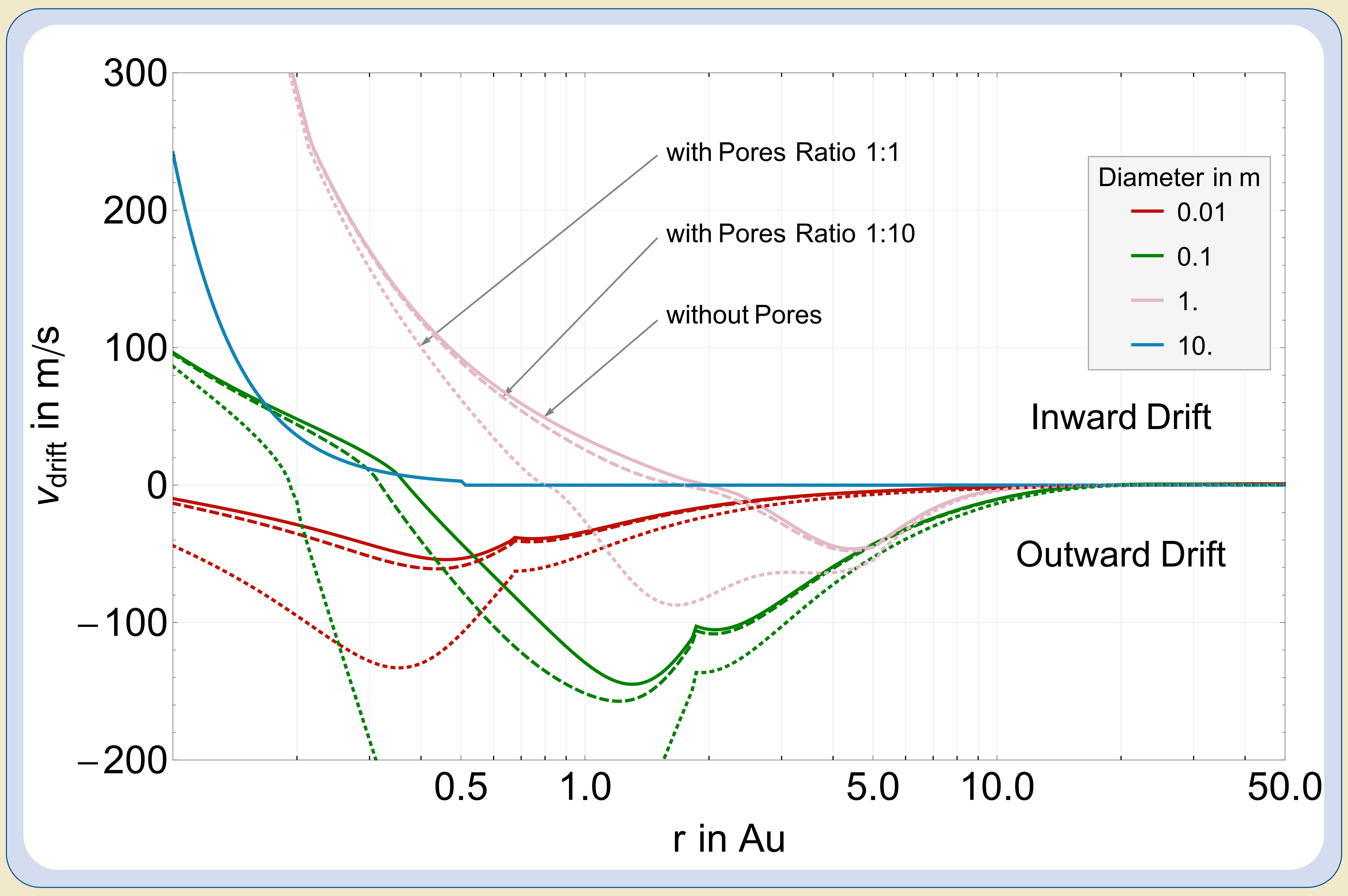

Figure 7: Comparison of the drift velocities with forces induced by mm-pores with different efficiency. The characteristic length was determined with the function obtained by the experiments (see Figure 4), taking the radius as the length of the pore. The ratio is the cumulated force of the pores compared to the force on the body itself.

Inside-Out planet formation?

The inclusion of the photophoretical force into the drift model can change the behaviour of the solids significantly and can further be enhanced by the porosity of the bodies. It leads to an outward drift when the optical thin region is large enough. This may chance the properties of the nebular itself - therefore consistent modelling of the nebular is needed. The Photophoresis can also cause fractionation in this process as the drift velocities assume the thermal conductivity of typical dusty bodies, which differ from the properties of metallic grains or rocks.

This might even lead to an inside-out planet formation mechanism. Which is already considered possible under different aspects by Chatterjee & Tan [Chat13].

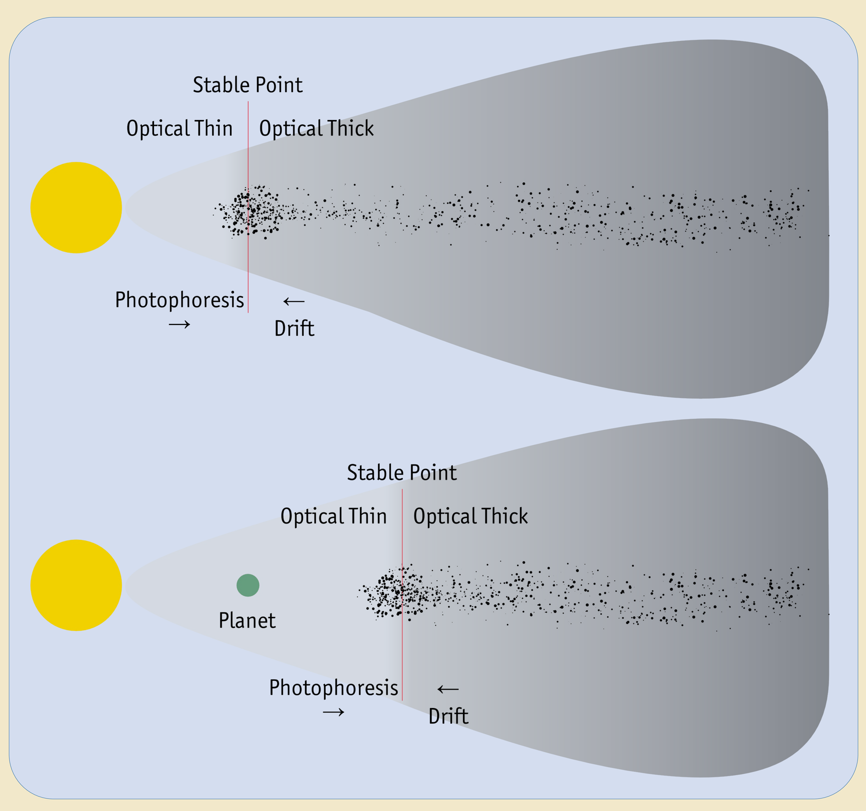

Figure 8: Sketch of Inside-Out planet formation. Photophoresis pushes bodies outward in optical thin regions, a pile up occurs as material drifts inward from the outer optical thick region. The enhanced local density triggers planet formation. Then the inner part is cleared and the gap may move further out.

Acknowledgements: We thank ESA Education - "Fly your thesis" for the possibility to conduct this experiment on a parabolic flight. This work was supported by DFG.

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References

Dürmann, C. Wurm, G., Küpper, M.,2013,A&A,subm.
Weidenschilling, S. J. 1977, MNRAS, 180, 57
Rohatschek, H., 1995, JAS, 26, 717
Küpper, M., Dürmann, C., de Beule, C., Wurm, G. 2013, MST, subm.
Hayashi, K., 1981, Progress of Theoretical Physics Supplement, 70, 35
Chatterjee, S. & Tan, J. C., 2013, APJL, submitted