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# Wake formation behind elongated insulating dust grains in drifting plasmas: numerical simulations

W.J. Miloch[1,2], S.V. Vladimirov[2], H.L. Pécseli[3], J. Trulsen[1]

[1] *Institute of Theoretical Astrophysics, University of Oslo, N-0315 Oslo, Norway*

[2] *School of Physics, The University of Sydney, Sydney, NSW 2006, Australia*

[3] *Department of Physics, University of Oslo, N-0316 Oslo, Norway*

We present results from numerical studies of the wake formation behind perfectly insulating dust grains of elongated shapes in drifting plasmas. In the presence of an ion flow, the dust grain acquires an electric dipole moment [1]. The resulting complex charge distribution on the dust surface affects the trajectories of the nearby plasma particles. This can lead to complex potential and plasma density variations in the vicinity of the grain [2], giving rise to ion focusing in particular [3, 4, 5].

We study grains of different lengths and different inclination angles $\alpha$ with respect to the supersonic ion flow. We find these two parameters (i.e., the rod length and the inclination angle) to be important for the charge distribution on the dust surface and for the wake formation behind the dust. For the case with two interacting grains, we find that the inclination angle influences the forces acting on dust grain. Simulations are carried out in two spatial dimensions by a particle-in-cell code treating ions and electrons as individual particles, and as described in more detail in [1, 5].

The widths of the grains are comparable with the electron Debye length $\lambda_{De}$, while the rod lengths exceed $\lambda_{De}$.

## Numerical results

We study dust grains with shapes given by Fig. 1. For grains placed parallel to the flow we observe the development of positive surface charge regions on the dust sides tangential to the flow. These regions have periodically distributed positive potential maxima on the rod as shown in Fig. 2. The distance between the maxima increases with the ion flow velocity. The maxima disappear for higher ion velocities on shorter rods.

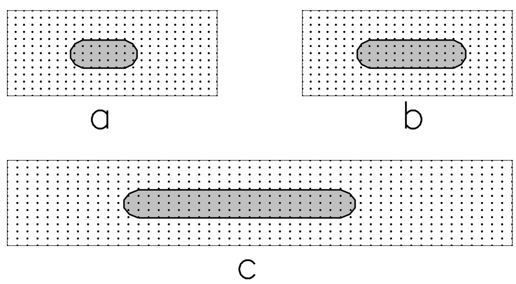


Figure 1: Sketch of dust shapes considered in the present study. The length of rods is: a) $a \approx 1.5\ \lambda_{De}$, b) $a \approx 2.5\ \lambda_{De}$, and c) $a \approx 4.5\ \lambda_{De}$. In all cases the rod width is $b = 0.75\ \lambda_{De}$.

The symmetry in the surface charge distribution is broken for tilted grains. On the shadow side of the rod, the positive potential maxima are shifted towards the rear of the rod, while on the side facing the flow they become less pronounced and move towards the front of the rod, see Fig. 2. With increasing inclination angle, the side facing the flow acquires more positive and more evenly distributed charge, while the maxima on the shadow side are displaced further towards the rear of the rod. The dust becomes charged negatively on the shadow side and positively on the side facing the flow, when the inclination angle exceeds a critical value.

The ion trajectories are distorted in the vicinity of the dust by strong local electric fields. The ions are deflected away from the front side of the rod and attracted by negatively charged regions further downstream. In the case of circular grains these ions would contribute to an ion focusing region behind the dust [3, 4, 5], but for rodlike grains the ions can be focused on the rod surface.

Tilting of the rod gives rise to asymmetric perturbations in the density and potential distributions. In particular, an asymmetry is clearly visible for ions streaming out from the ion focusing region, see Fig. 3, where a fraction of the ions emerge as a partially collimated "jet" in the region around $(x,y) = (17,28)\lambda_{De}$. The ion beam is particularly conspicuous in the vector plots showing the locally averaged ion velocity vector in Fig. 3. We interpret this part of the ion population as a fraction of the incoming ions being focussed (similar to the case of electrostatic lenses) by the asymmetric electrostatic field around the elongated, tilted dust grain.

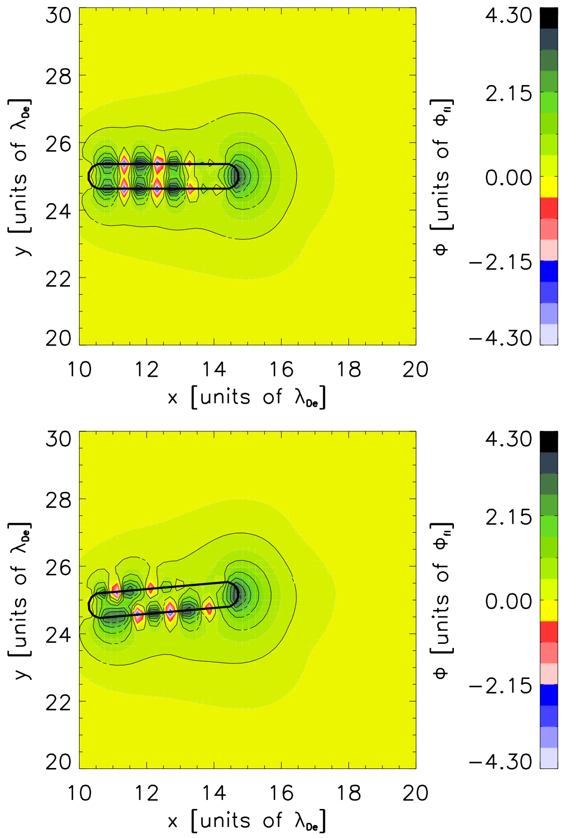


Figure 2: Potential variation for an insulating dust with the shape given by Fig. 1c) and the inclination angle $\alpha = 0^\circ$ (top) and $\alpha = 5^\circ$ (bottom) in a plasma with ion drift velocity $v_d = 2.0\ C_s$. Potential is normalized with the floating potential $\Phi_{fl} < 0$ consistent with our previous results [1]. The ion drift is in the positive $x$-direction.

For two elongated particles we find that their interaction potential strongly depends on their orientations (see Fig. 4) and that the problem is highly nonlinear.

For rods placed parallel to the flow and each other, a single ion wake is formed when the distance between rods is comparable or lower than the Debye length $\lambda_{De}$.

**Discussion**

The positions of the potential maxima on the dust surface are a function of $\alpha$. A slightly titled rod will have a broken symmetry in the charge distribution. Thus, the charge distribution on rods with $\alpha = 0^\circ$ is very sensitive to changes in $\alpha$. However, for high $\alpha$ the changes in the charge distributions are much less pronounced, and one can argue that for $\alpha = 90^\circ$ the distribution will be insensitive to small $\alpha$ variations.

Charged dust rods can exhibit rotational oscillations when organized in chains [6]. In the presence of an ion flow, the changes in the surface charge distribution may alter such oscillations, by having the interactions as a function of the inclination angles for two neighboring rods. When the ion wake is also included in the analysis, the problem becomes highly nonlinear. Here the ion jets with collimated velocities can have important implications for long range interactions of elongated dust grains.

A rod placed in the wake of another rod will disturb the ion dynamics, and the wake can not be represented by the linear combination of two wakes behind single rods. In all cases, the interaction potential and the resulting motion of the dust strongly depends on their orientation, see again Fig . 4. This can lead to non-trivial oscillations of structures of such rods.

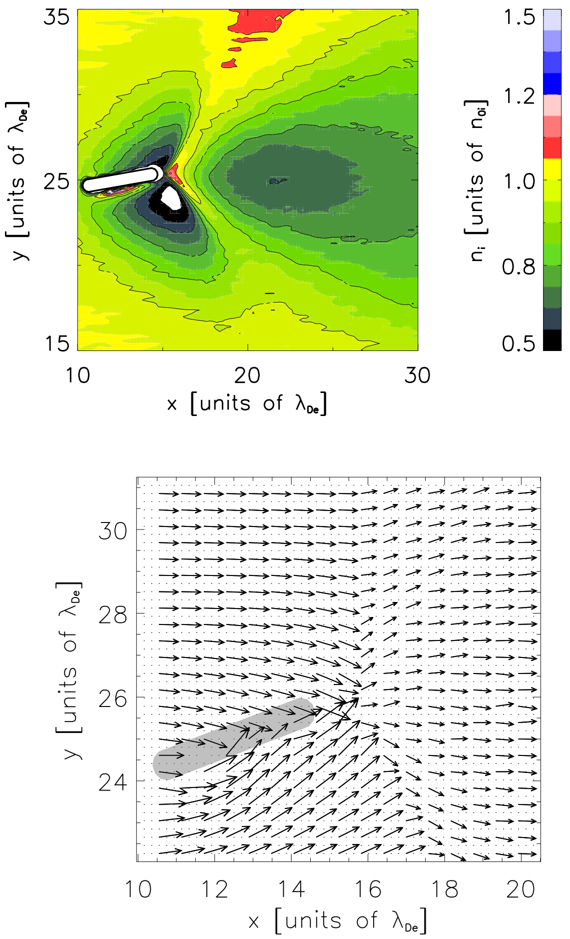


Figure 3: Top: Averaged ion density for a plasma with ion drift velocity $v_d = 2.0\ C_s$ around a long rod with inclination angle $\alpha = 10^\circ$. The white regions in the density plot represent density ratios $n_i/n_{i0} < 0.5$. Bottom: Averaged ion velocities a plasma with ion drift velocity $v_d = 2.0\ C_s$ around the long rod with the inclination angle $\alpha = 20^\circ$. The velocities are averaged over a time interval of 0.7 ion plasma periods and over grid cells by weighting the ion velocities to the nearest grid points. Since the dust surface is not placed directly on grid points, the average velocity for ions that are close to the surface appear to be plotted within the dust. The dust area is marked grey.

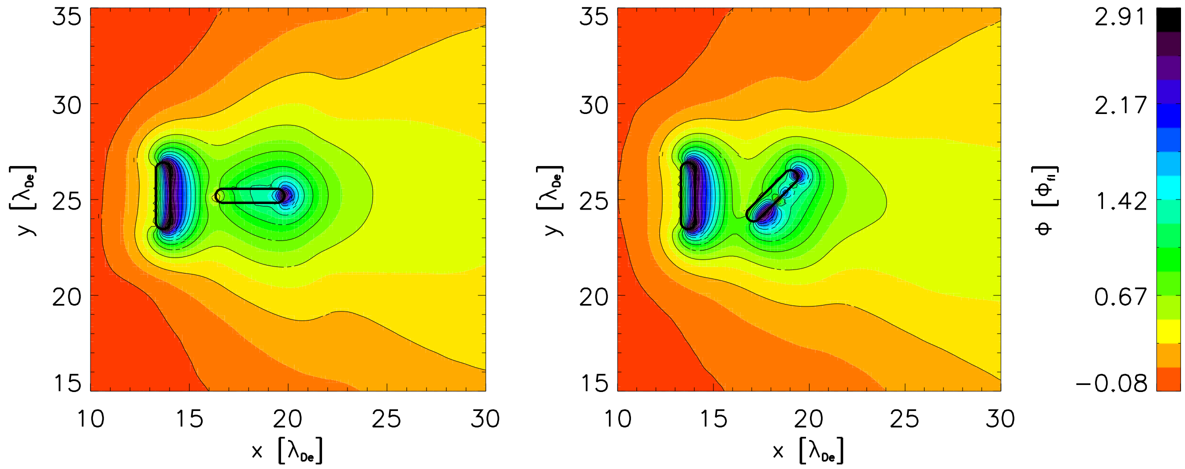


Figure 4: Potential variation for a plasma with ion drift velocity $v_d = 2.0\, C_s$ around two insulating rods with shapes given by Fig. 1b). Inclination angles are $\alpha = 90^\circ$ for the rod facing the flow, and $\alpha = 0^\circ$ and $\alpha = 45^\circ$ for the rod in the wake. Potentials are normalized as in Fig. 2, but the color scale is different. The ion drift is in the positive $x$-direction.

## References


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