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Numerical simulations of dusty surface/agglomerates charged by plasma and photoemission currents

Wojciech Miloch

DAP, 12 January 2017

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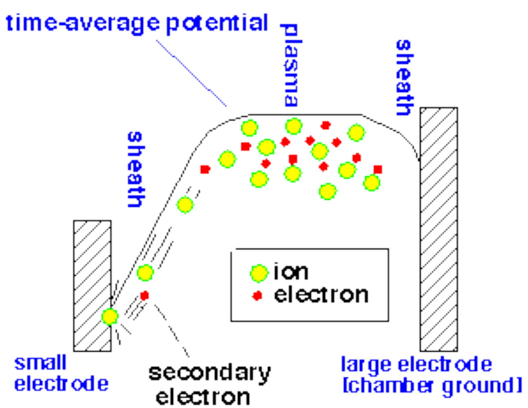
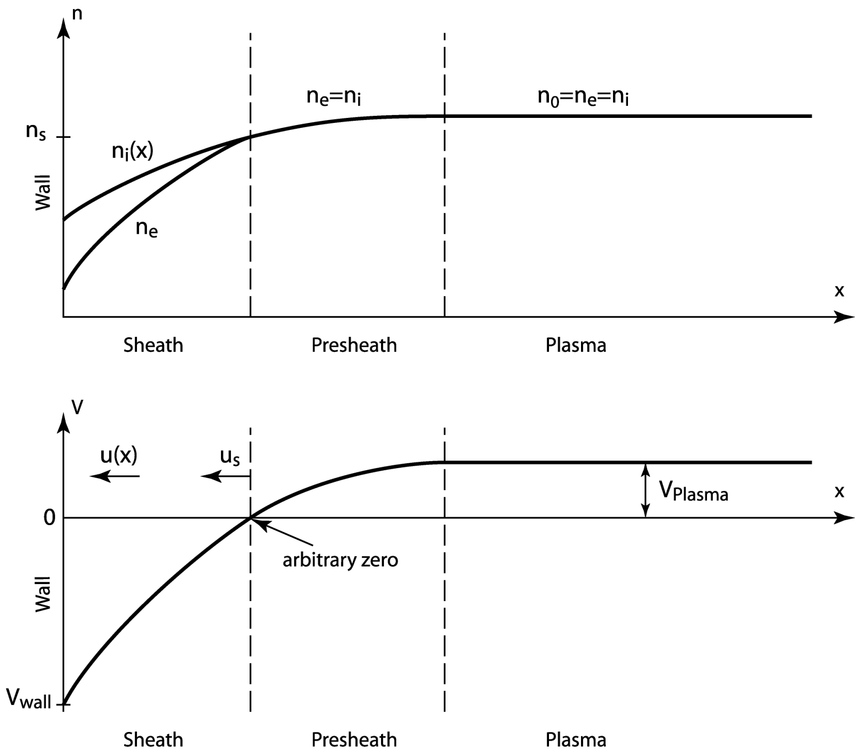
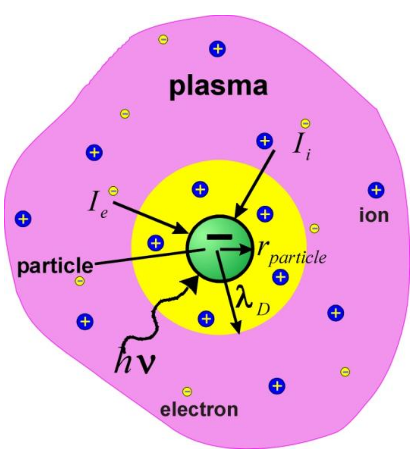
Plasma – object interaction



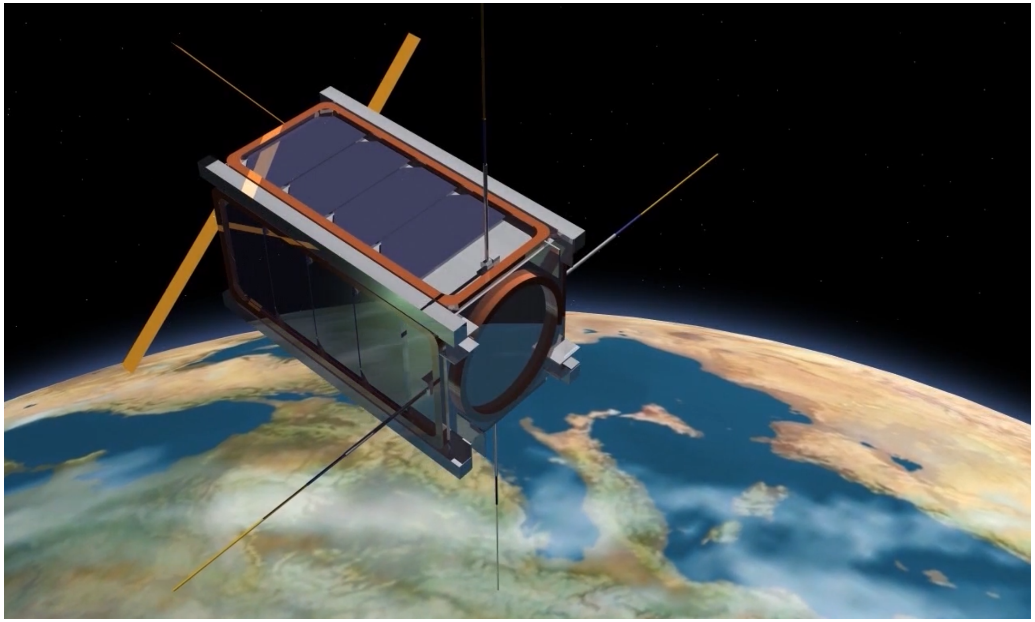


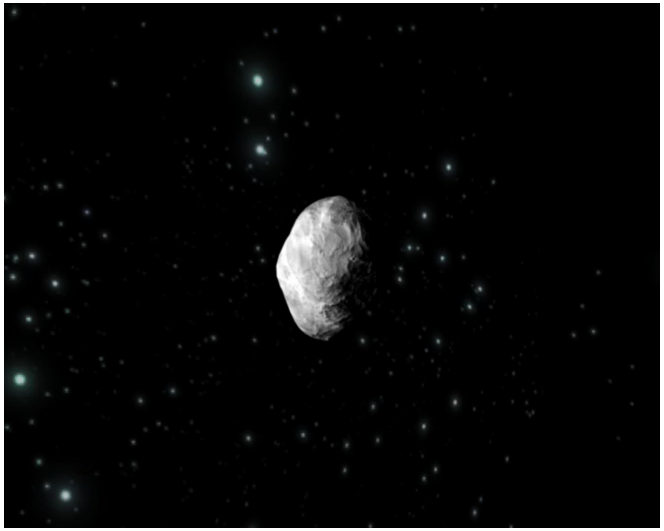


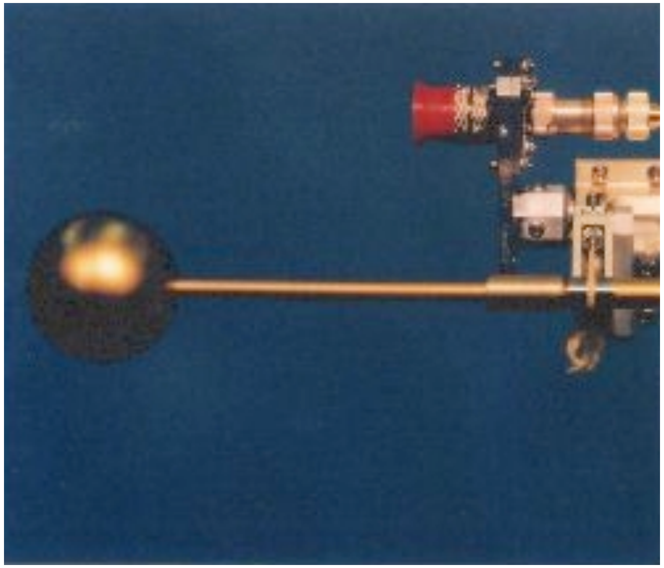
Sheath formation:
- change of velocity distributions
- quasineutrality broken

Object in plasma – is charged (floating potential)

(man-made or natural)

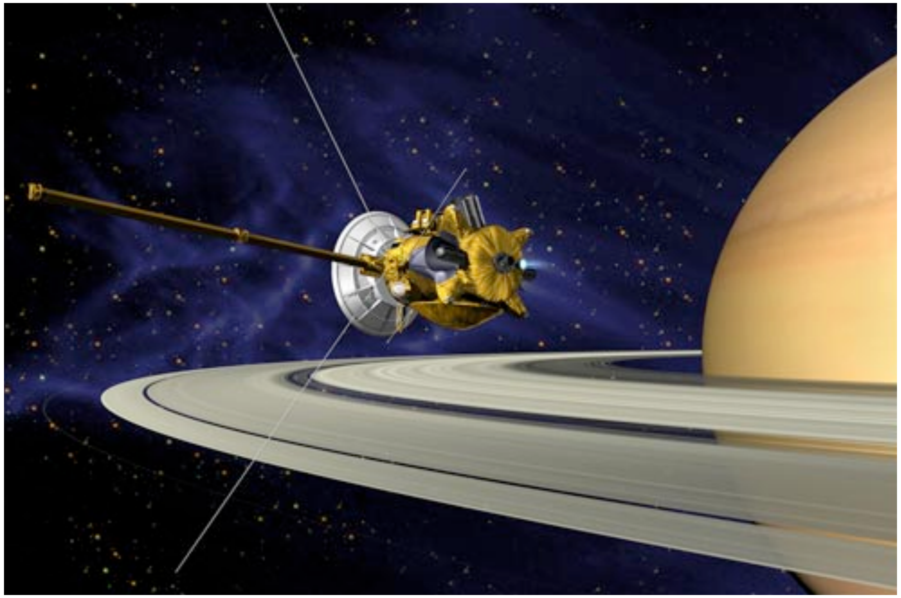


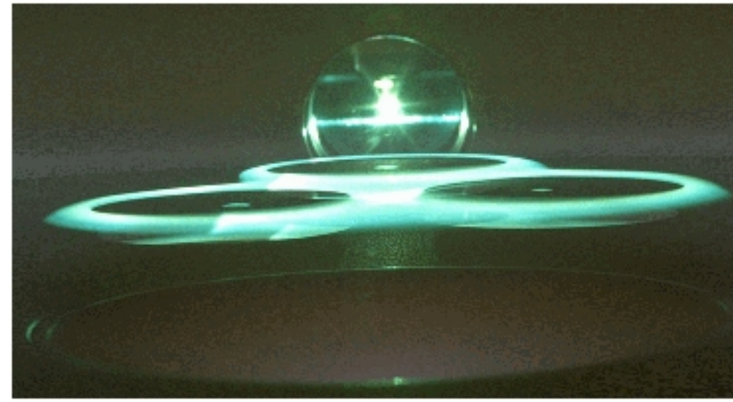


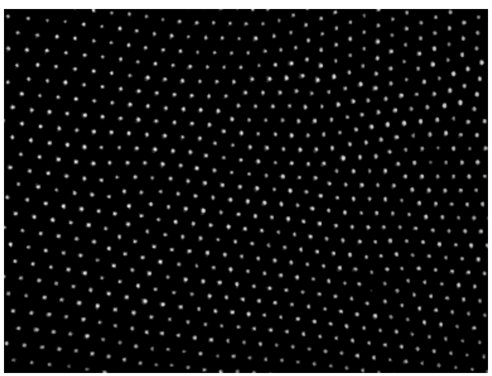


(Selwyn, et. al. 1989)

Complex plasma





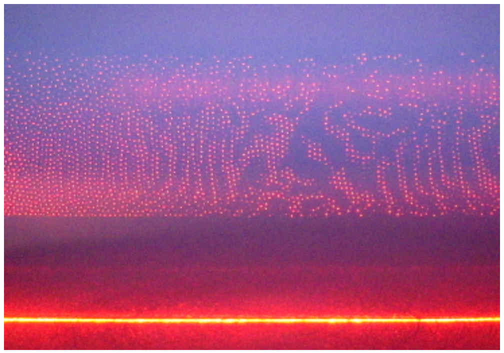


Charge – a fundamental parameter in complex plasmas

$$\Phi(r) = \frac{Q}{4\pi\epsilon_0 r}\exp\left(-\frac{r}{\lambda_D}\right)$$

$$Q = C\Phi_d, \text{where } C = 4\pi\epsilon_0 a(1 + a/\lambda_D)$$

Wakefields and interactions between dust grains



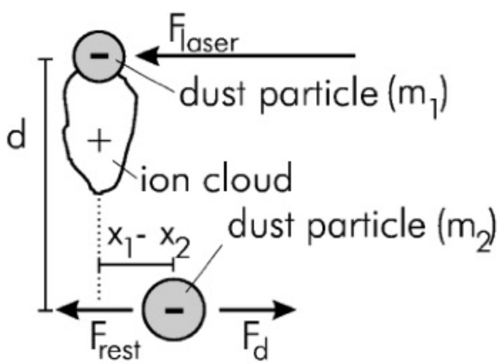
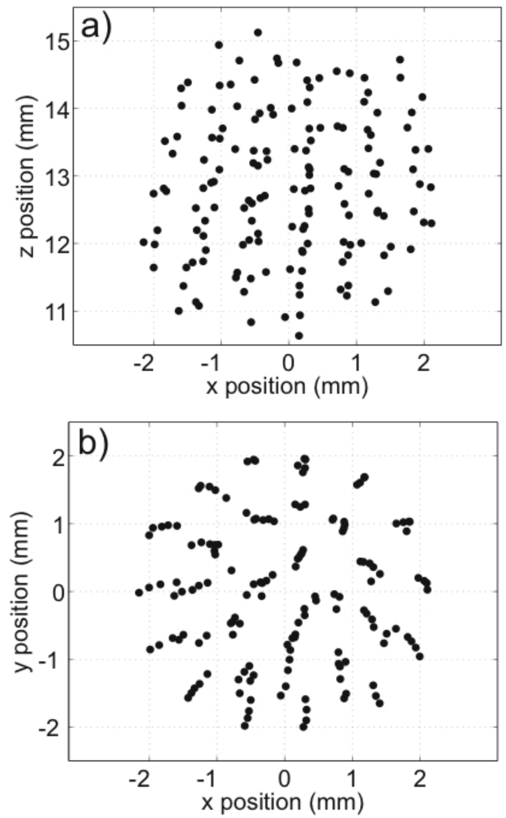
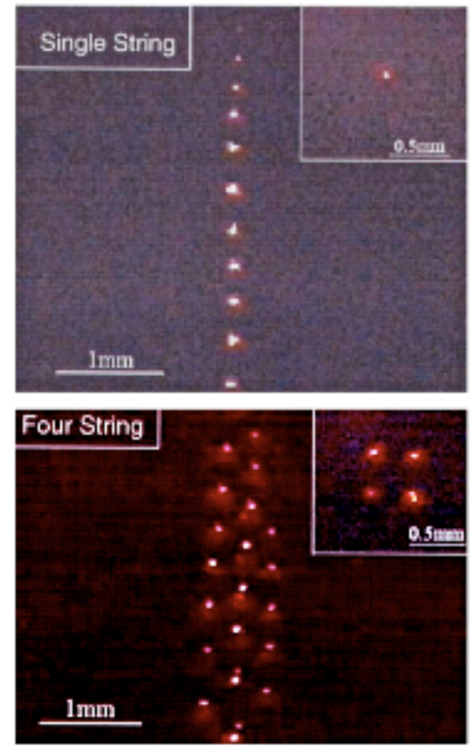


FIG. 6. Interparticle forces in the dust molecule.

A. Melzer, et. al.,
Phys. Rev. Lett., 83, 3194 (1999)



M. Kroll, et. al.,
Phys. Plasmas 17, 013702 (2010)



O. Ishihara,
J. Phys. D, 40, R121 (2007)

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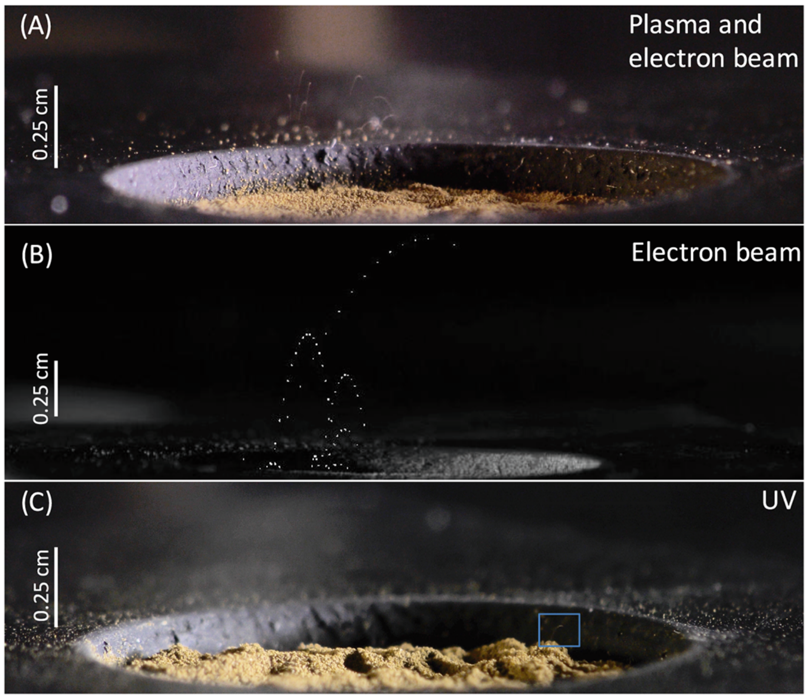
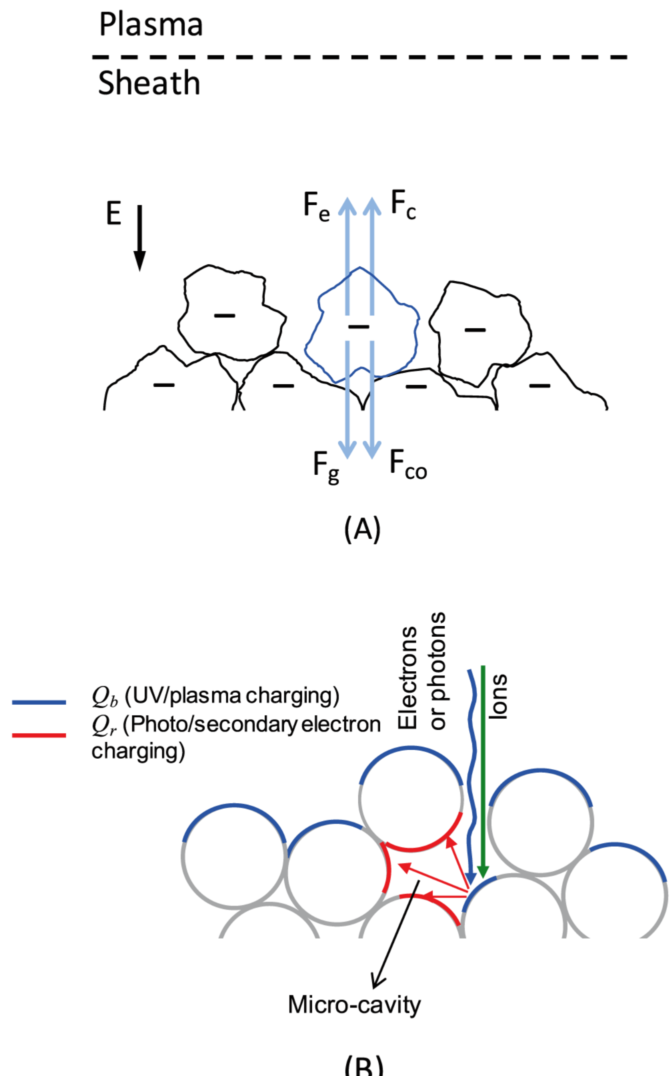
Charging in complex geometries





Dust might lift off due to strong electric fields…

Wang et. al., GRL 43, 6104, 2016

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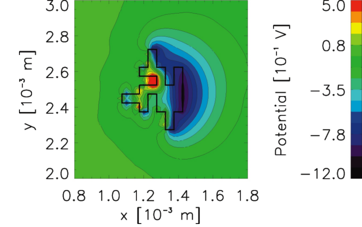


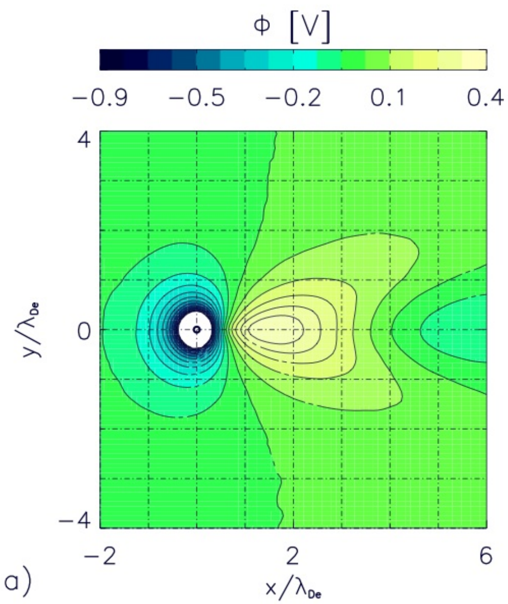
DiP3D code

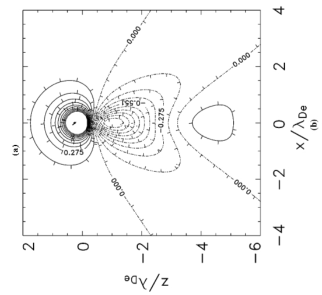
- 3D electrostatic code in Cartesian coordinates;
- Collisionless/collisional plasma;
- Flowing ions and/or electrons, ion beams can be included;
- Fixed potentials on external boundaries (Dirichlet boundary condition), plasma particles can leave the simulation box and are injected at the boundaries according to Maxwellian distributions / periodic boundaries possible;
- Objects placed inside the simulation box, perfectly conducting or perfectly insulating, can be self-consistently charged, (internal boundary conditions), MD force calculations closest to the surface.
- Photons (varied flux and angle of incidence) and photoelectric effect can be included;
- External static B field, external E field in periodic system
- May run parallel (MPI) or on a single processor.

Mach-like cone and focusing

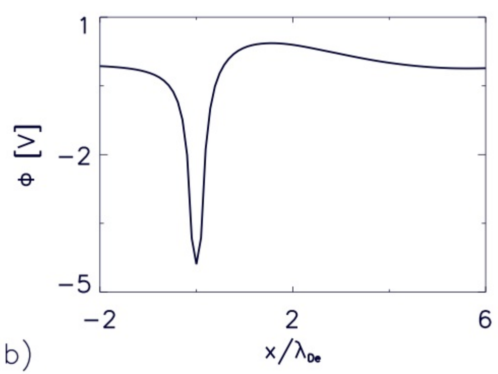
$$J_i = n_i e v_d \left[\left(1 + \frac{1}{2\xi} - \frac{2e\Phi}{kT_i \xi^2} \right) \mathrm{erf}(\xi) + \frac{1}{\sqrt{\pi}\xi} \exp\left(-\xi^2\right) \right],$$

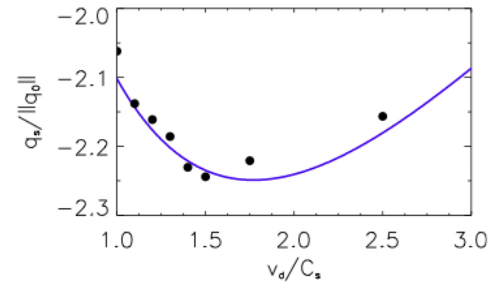
$$J_e = n_e e \sqrt{\frac{kT_e}{2\pi m_e}} \exp\left[-\frac{e\Phi}{kT_e} \right],$$

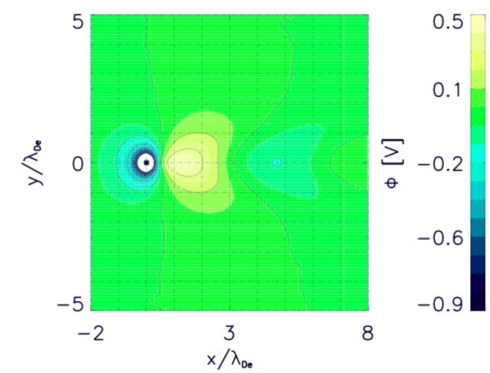


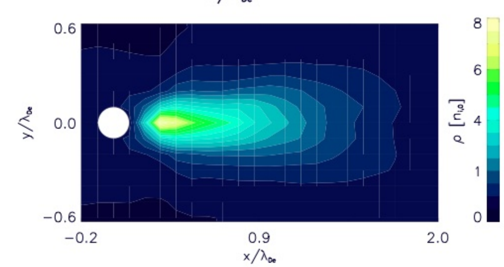


M. Lampe, et. al.
IEEE Trans. Plasma Sci.
33, 57 (2005)









$$n = 10^{13}\mathrm{m}^{-3}; T_e/T_i = 100$$

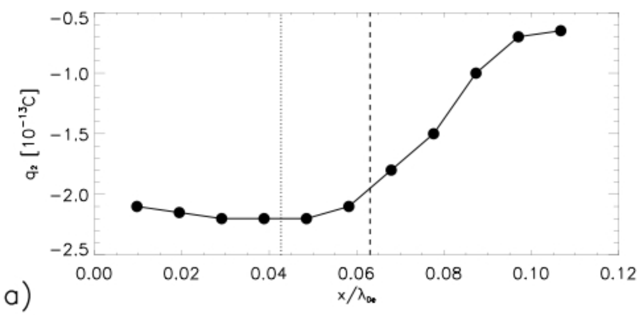
$$T_e = 3\mathrm{eV}; v_d = 1.2C_s;$$

$$\text{radius} \approx 0.1\lambda_{De}$$

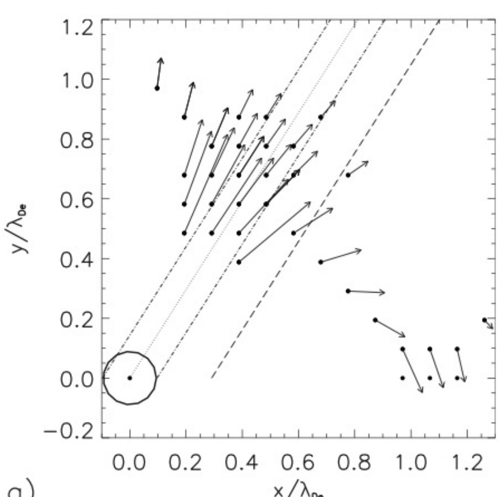
$v_d = 1C_s$

W.J. Miloch, et. al.,
Phys. Plasmas 17, 103703 (2010)

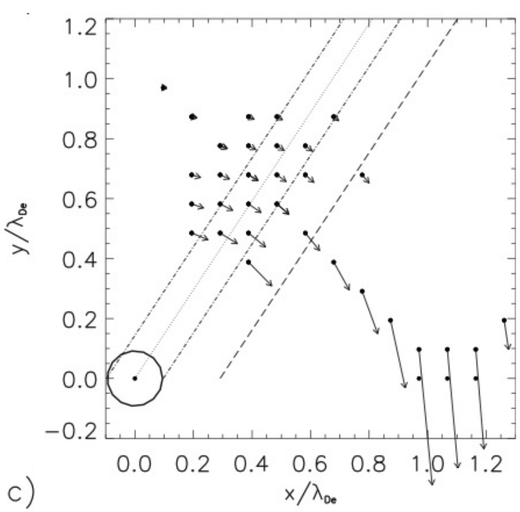
Vertical pairing…



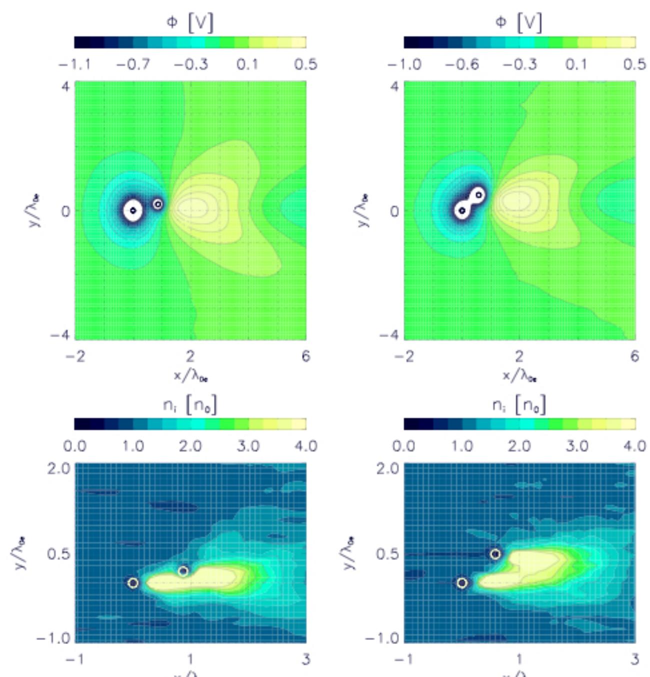
a)



a)



c)

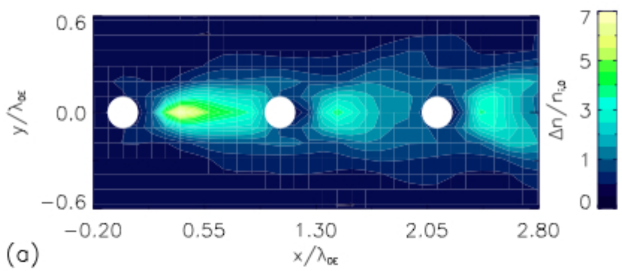


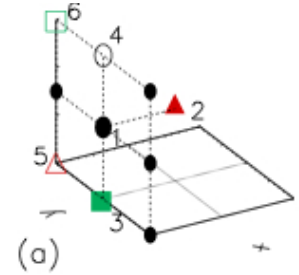
$$f_2 = \frac{q_2}{4\pi\epsilon_0}\left(\frac{q_1\vec{r}_{1,2}}{r_{1,2}^3} + \int_0^d \frac{\tilde{\rho}(x)\vec{r}_{x,2}}{r_{x,2}^3}dx\right).$$

W. J. Miloch et al. *Phys. Plasmas* 17, 103703 (2010)

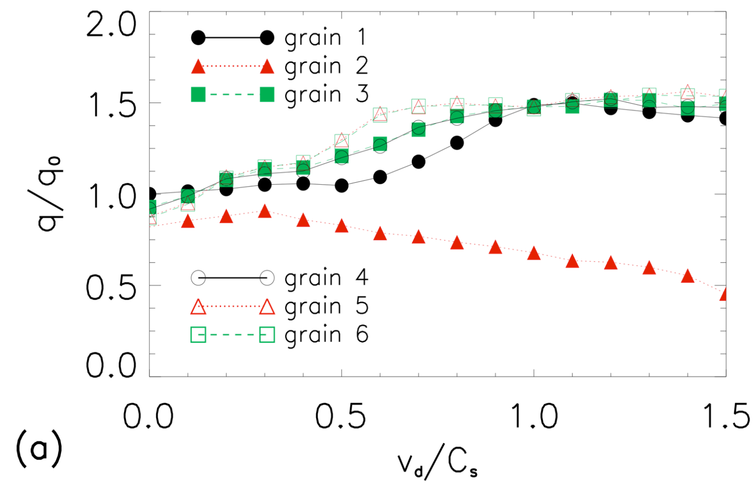
Many grains

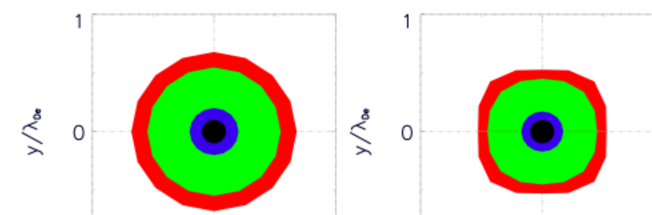
3 grains

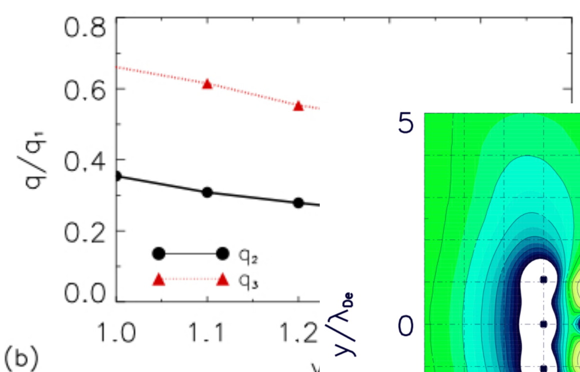


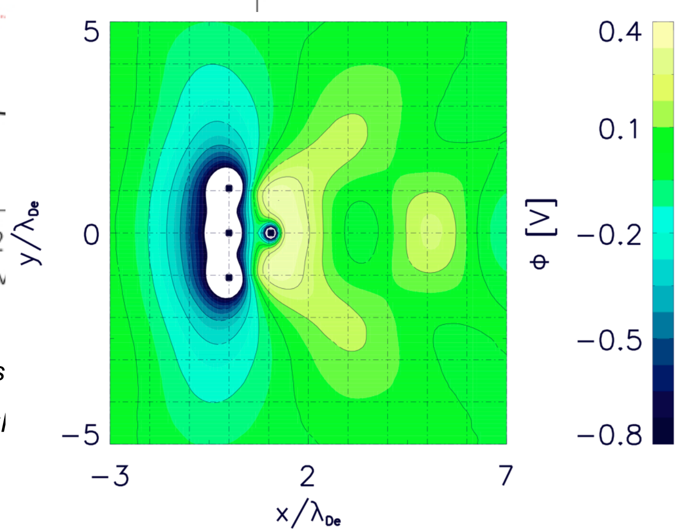


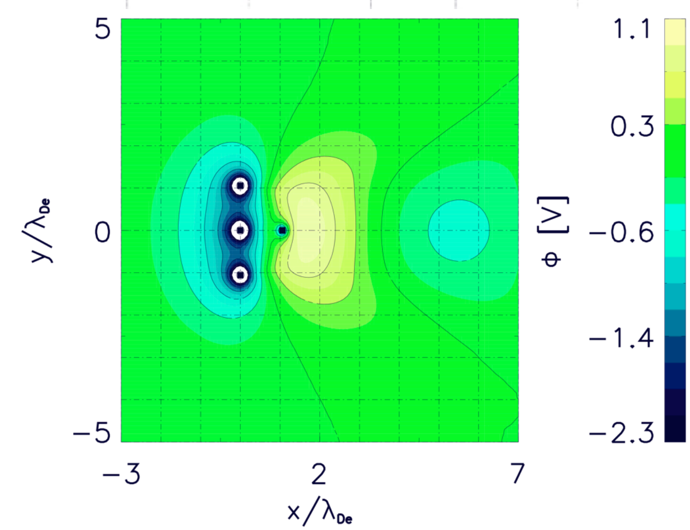
9 + 1 grains











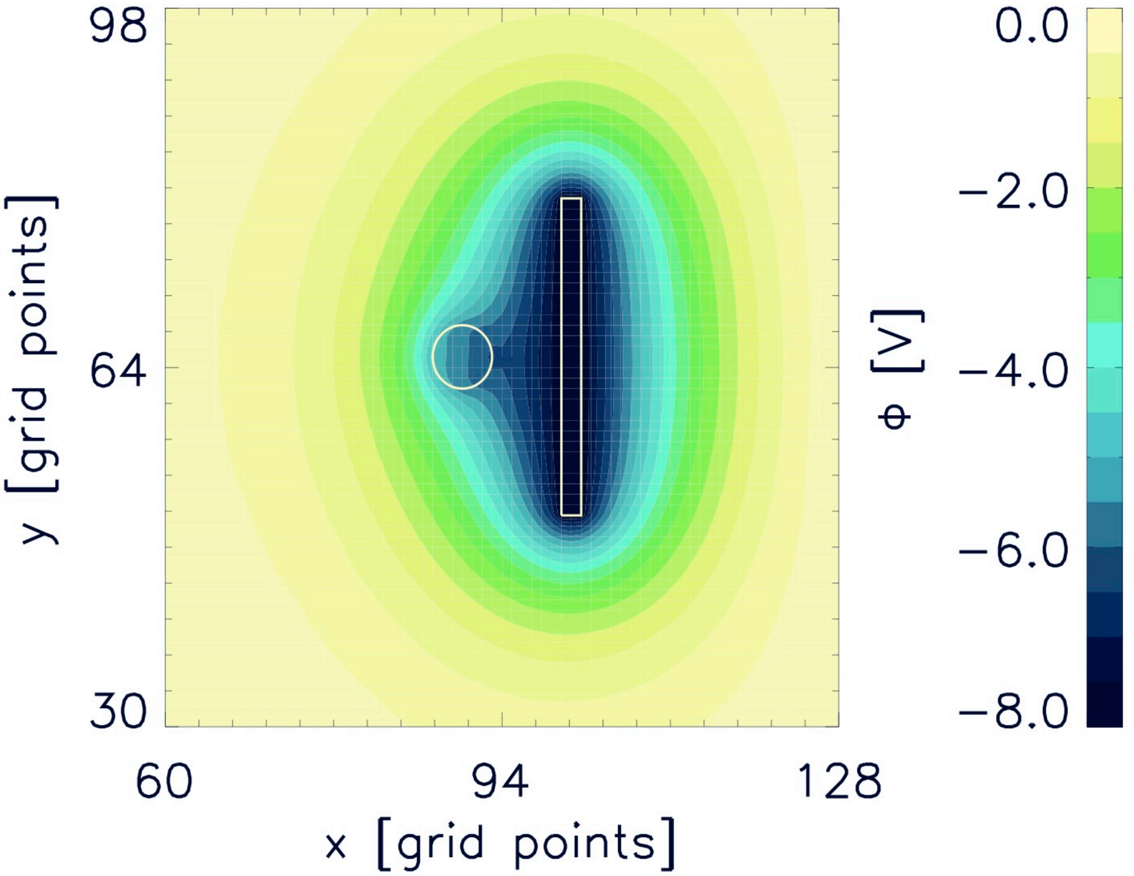
W. J. Miloch, D. Block, *Phys*

D. Block, W. J. Miloch, *PPCl*

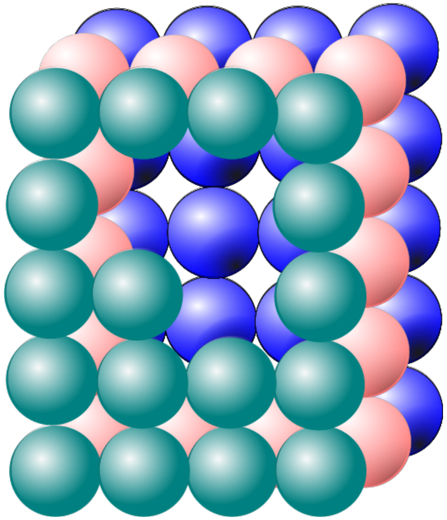
$v_d = 0.7 C_s$

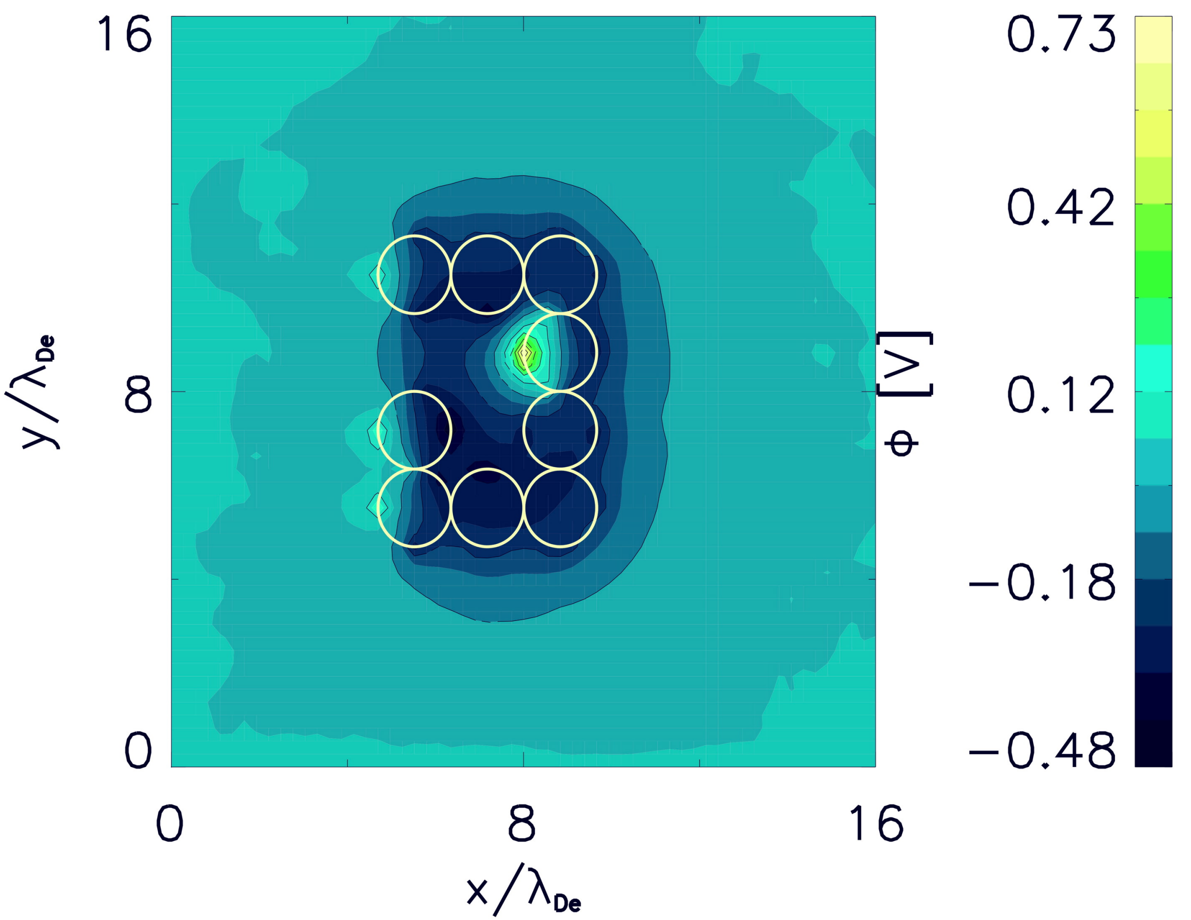
$v_d = 1.1 C_s$

Stationary plasma: a grain near a biased plate



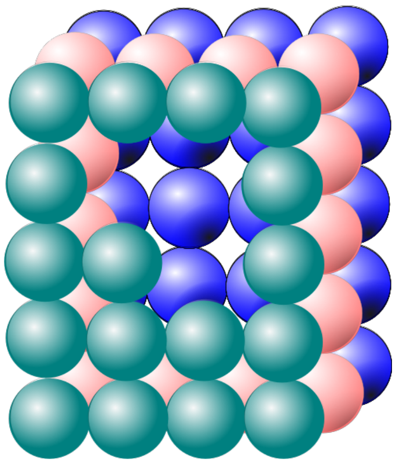
Cavity – an example of the surface

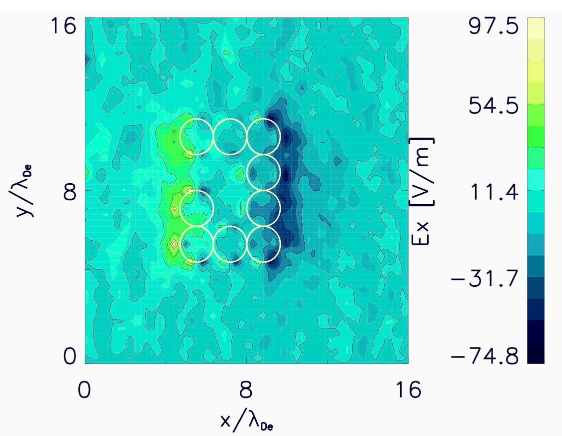


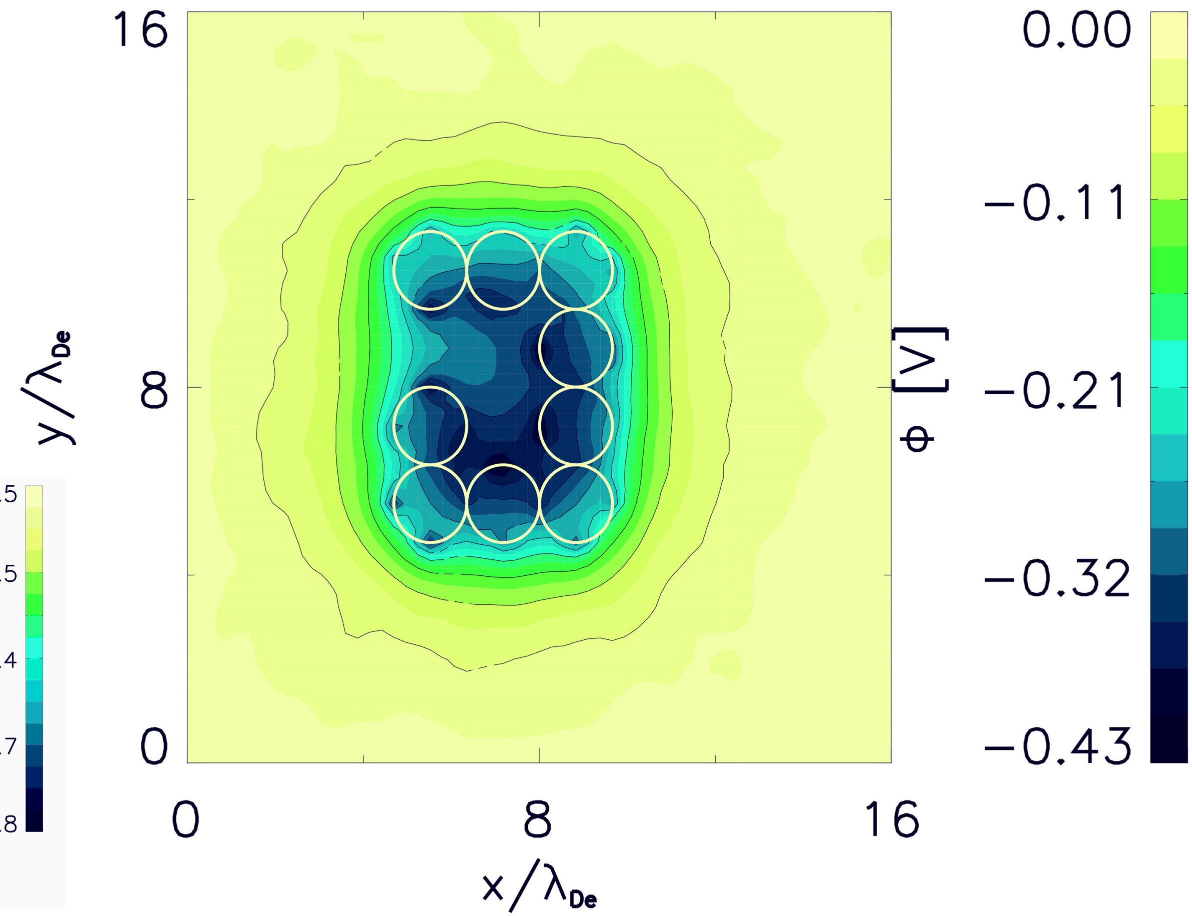


Photons: 10^18 m^{-2} s^{-1}
Photoelectron energy: 1.0 eV
Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11} \text{m}^{-3}$

Cavity – an example of the surface





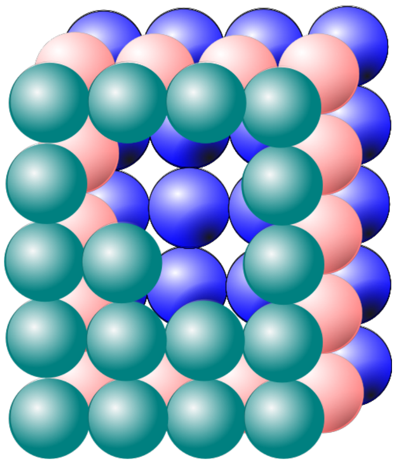


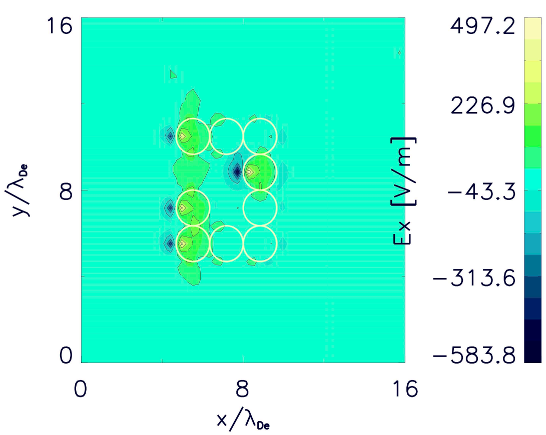
Photons: 10^19 $m^{-2}\,s^{-1}$

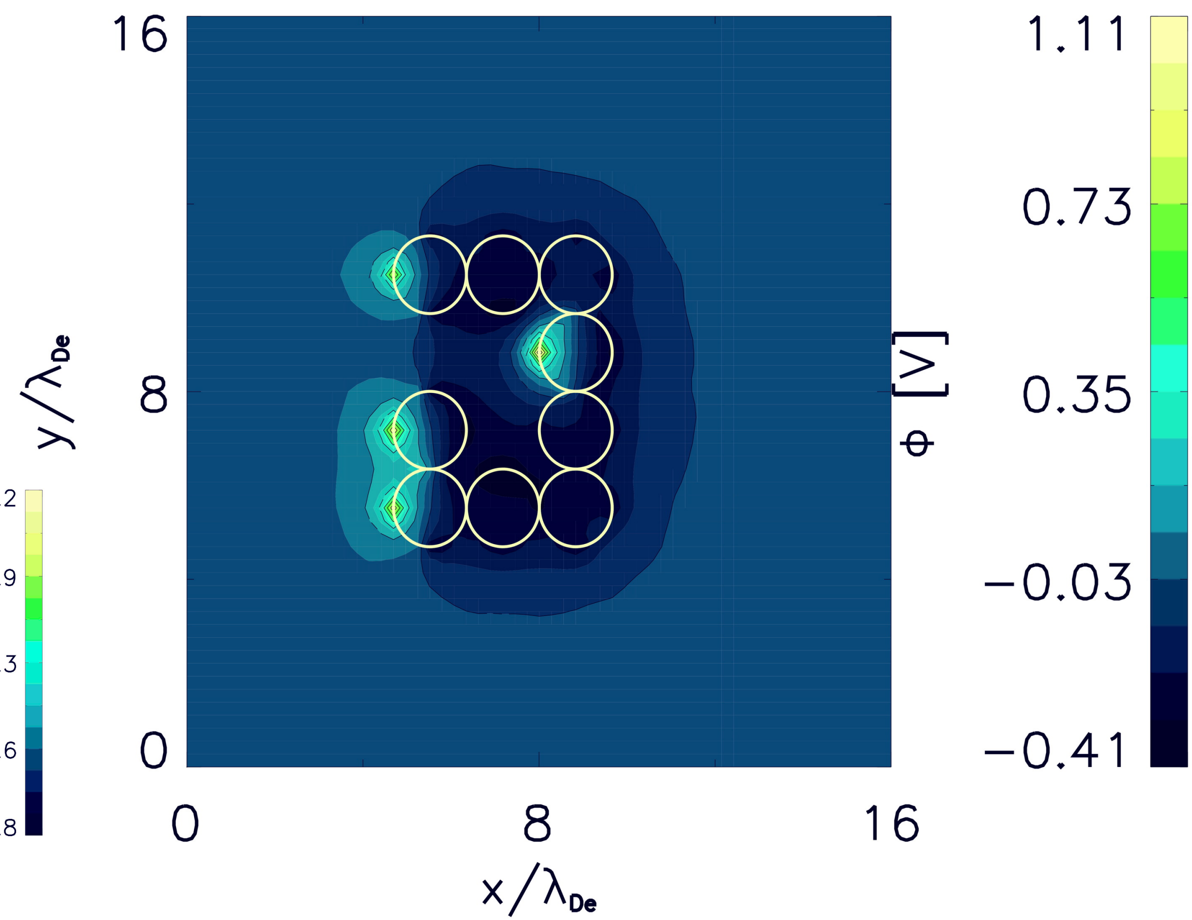
Photoelectron energy: 0.25 eV

Stationary plasma: $T_e/T_i = 3, T_e = 0.25\ \mathrm{eV}, n = 9.7 \cdot 10^{11}\mathrm{m}^{-3}$

Cavity – an example of the surface

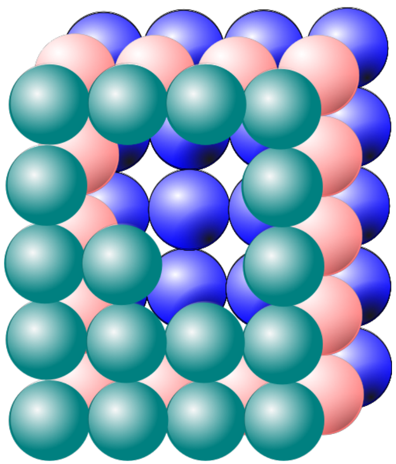


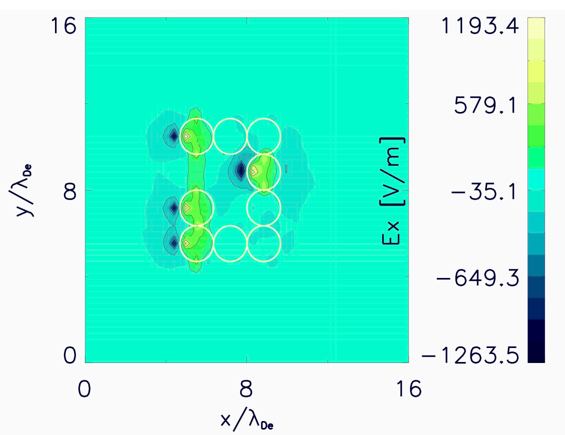


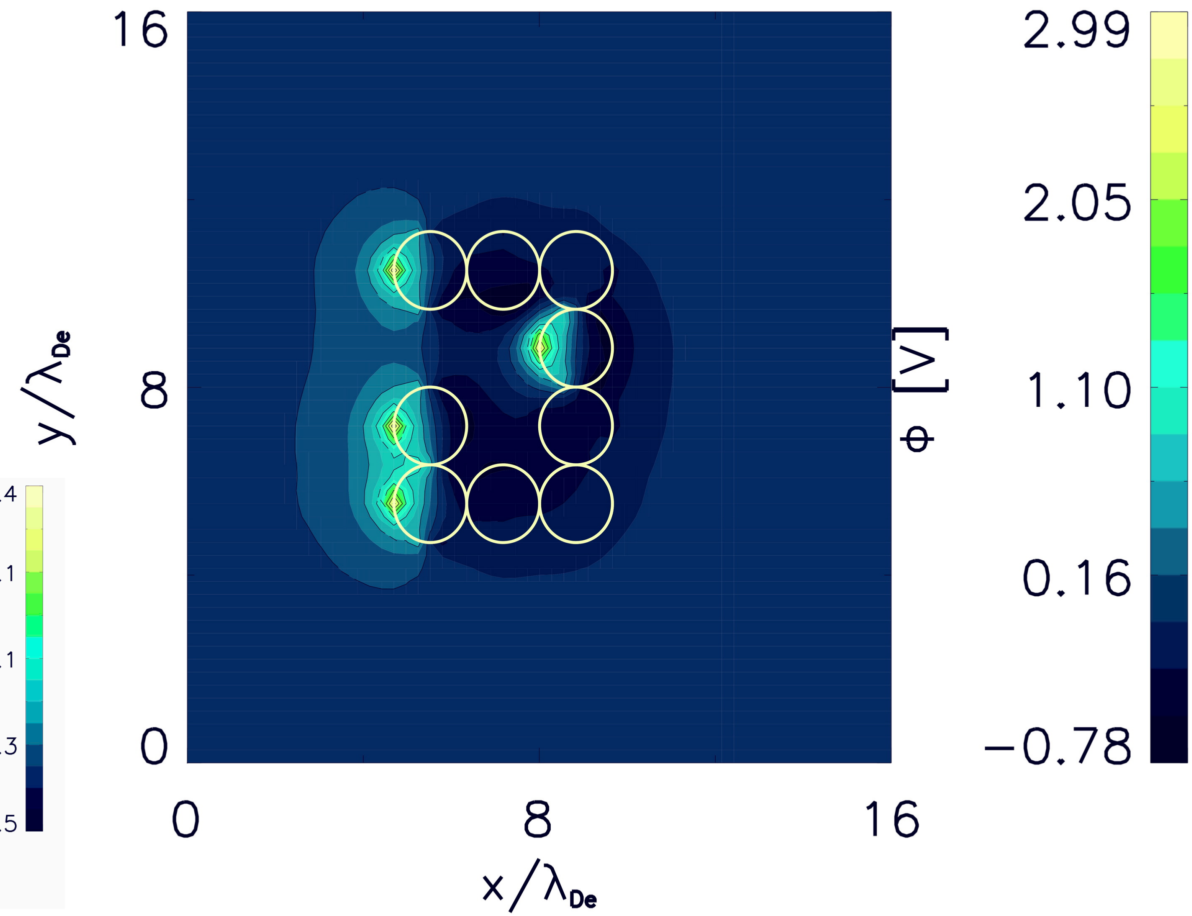


Photons: 10^19 m^{-2} s^{-1}
Photoelectron energy: 0.5 eV
Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11} \text{m}^{-3}$

Cavity – an example of the surface







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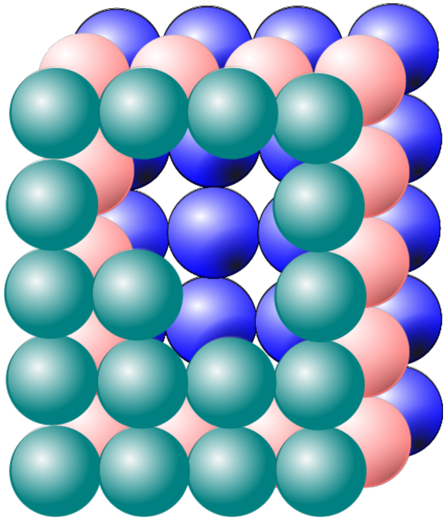
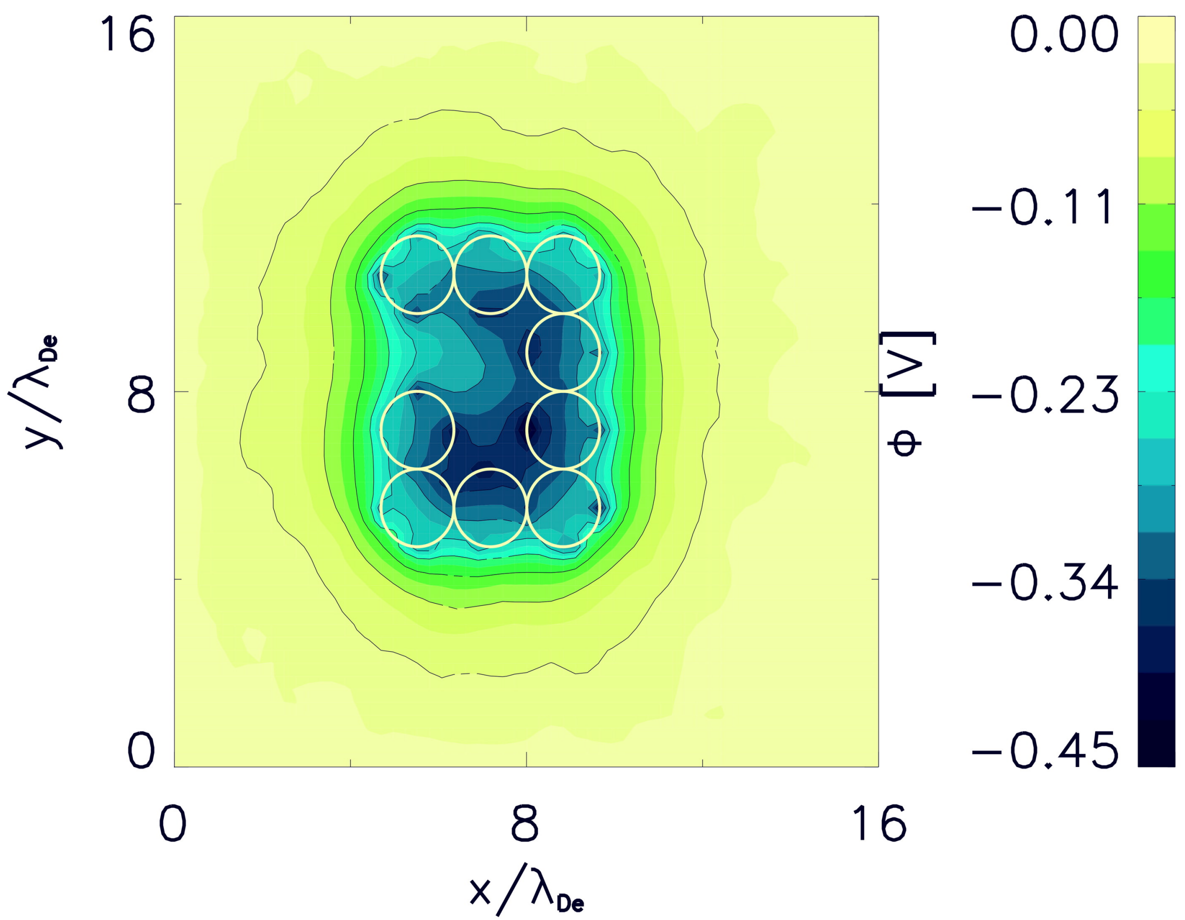
Photoelectron energy: 1.0 eV

Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11} \text{m}^{-3}$

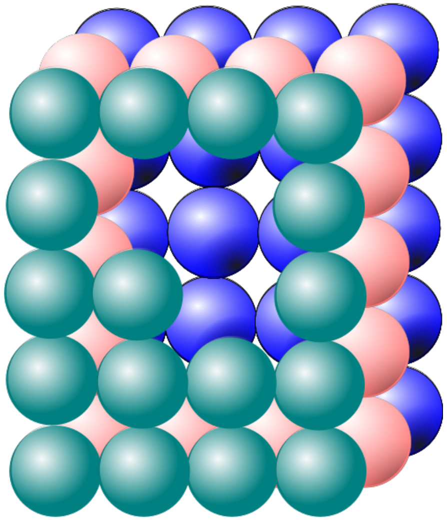
Cavity – an example of the surface

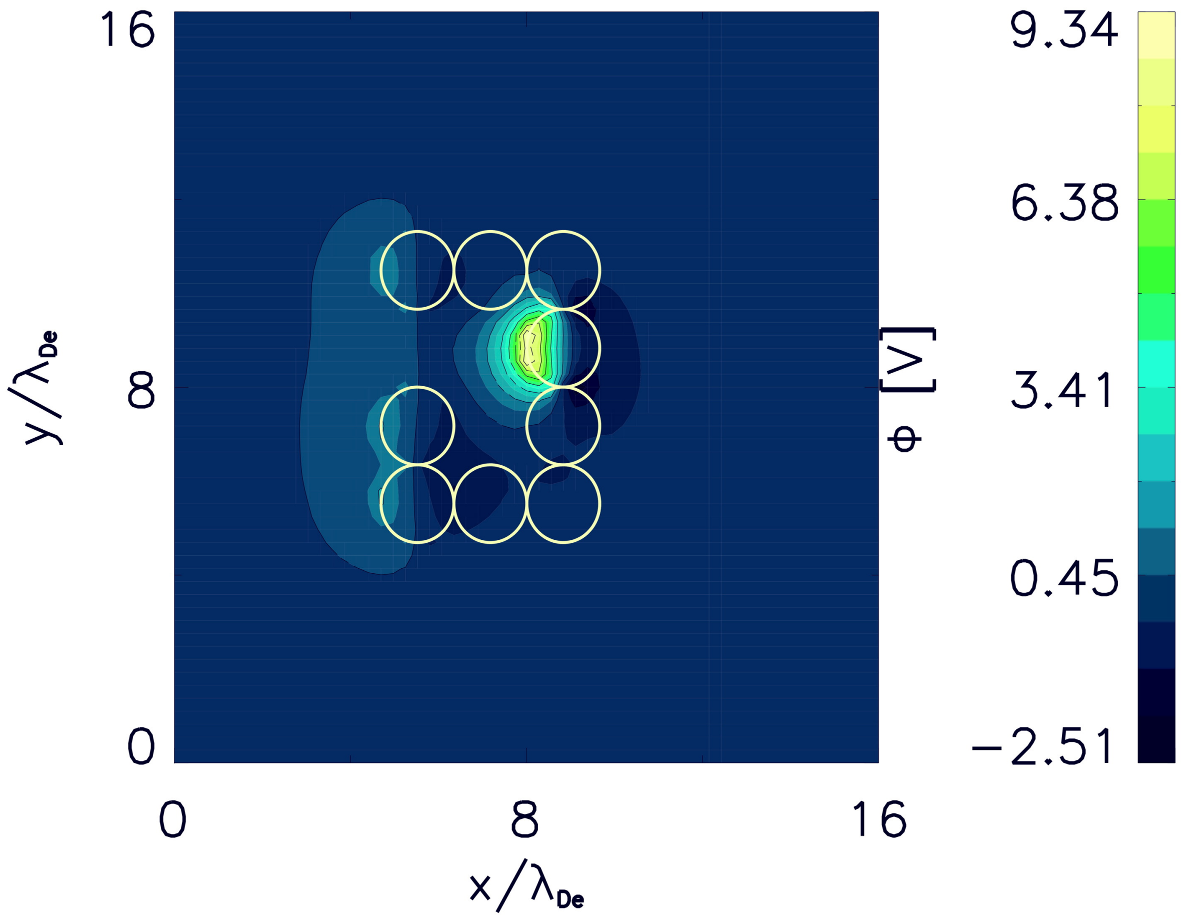




Photons: 10^20 m^{-2} s^{-1}
Photoelectron energy: 0.25 eV
Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11} \text{m}^{-3}$

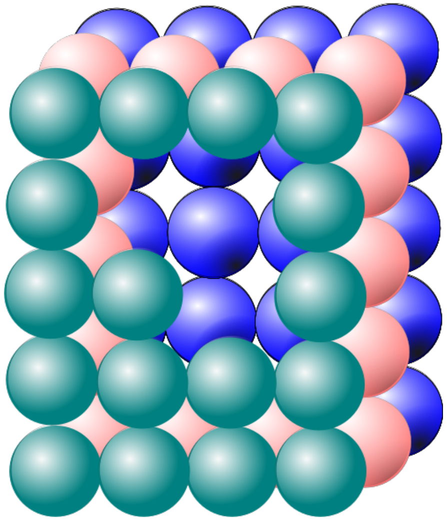
Cavity – an example of the surface

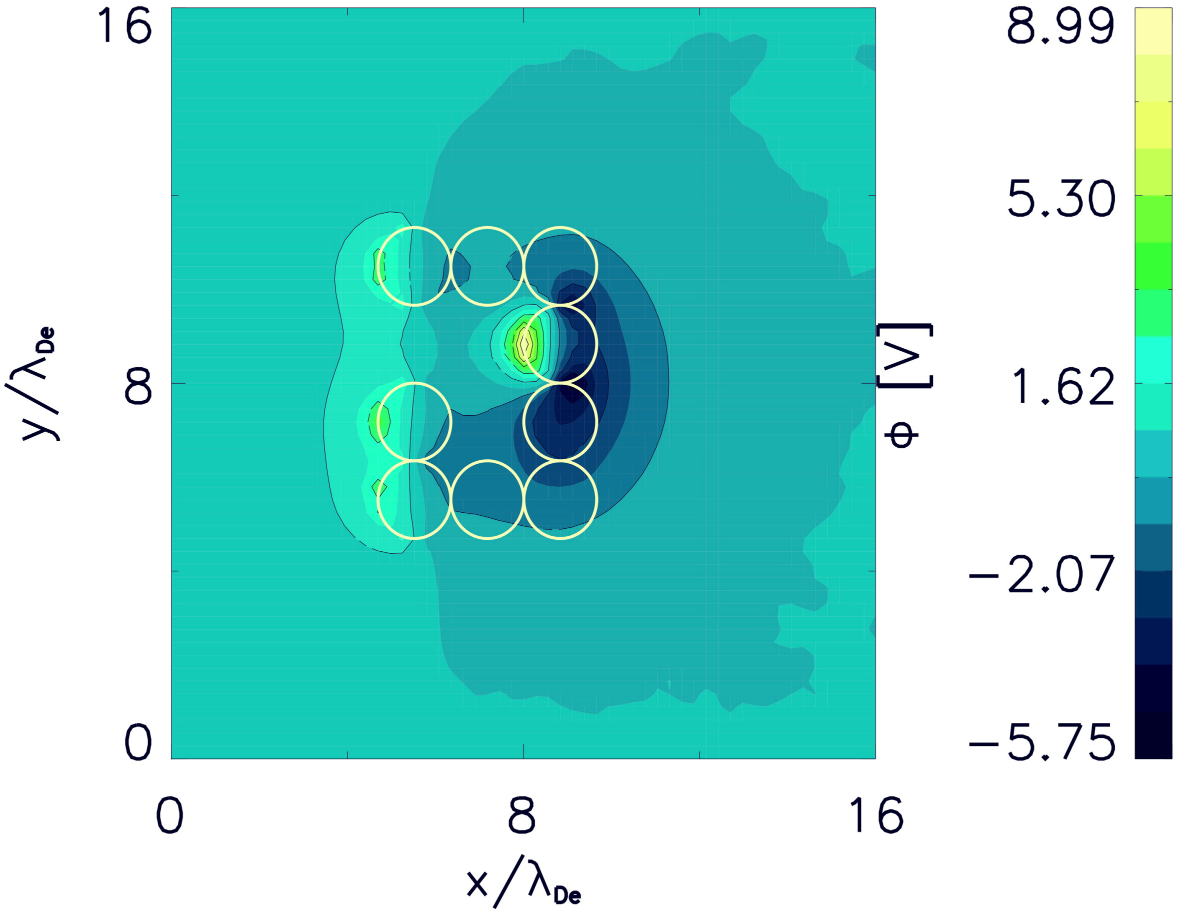




Photons: 10^20 $m^{-2}\ s^{-1}$
Photoelectron energy: 0.5 eV
Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11} \text{m}^{-3}$

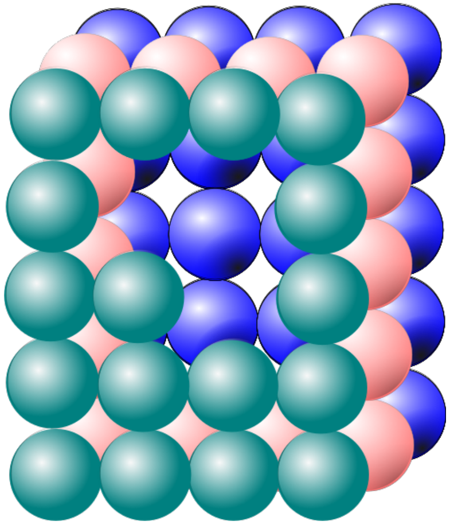
Cavity – an example of the surface

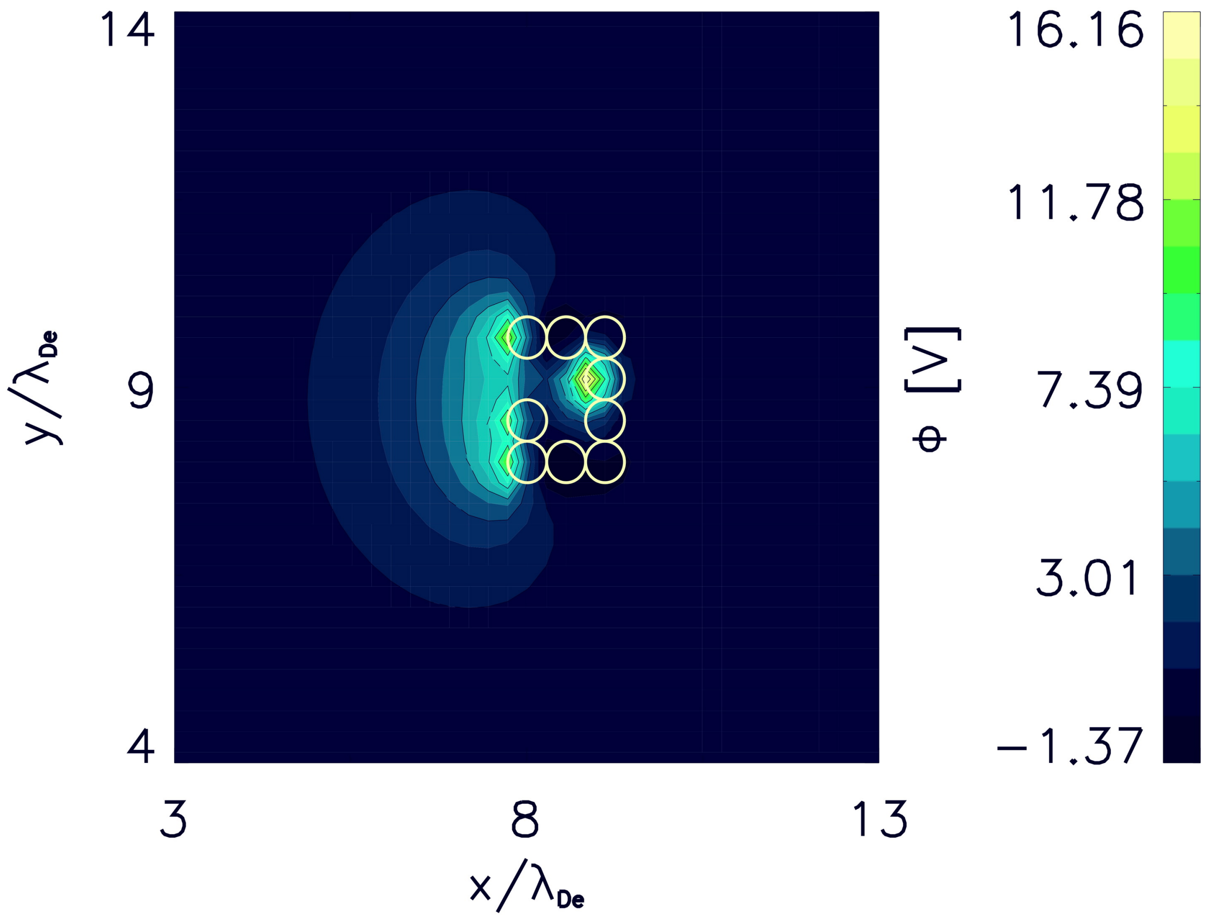




Photons: 10^20 m^{-2} s^{-1}
Photoelectron energy: 1.0 eV
Stationary plasma: $T_e/T_i = 3, T_e = 0.25\ \mathrm{eV}, n = 9.7 \cdot 10^{11} \mathrm{m}^{-3}$

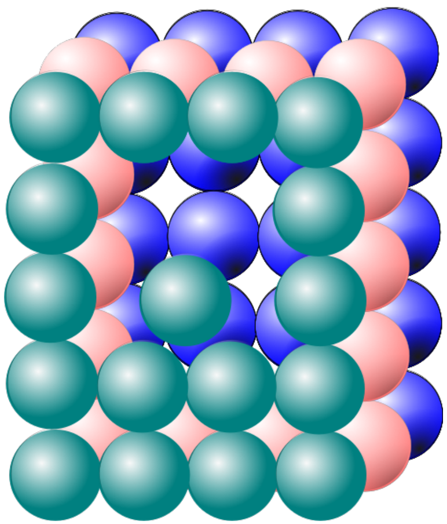
Cavity – an example of the surface

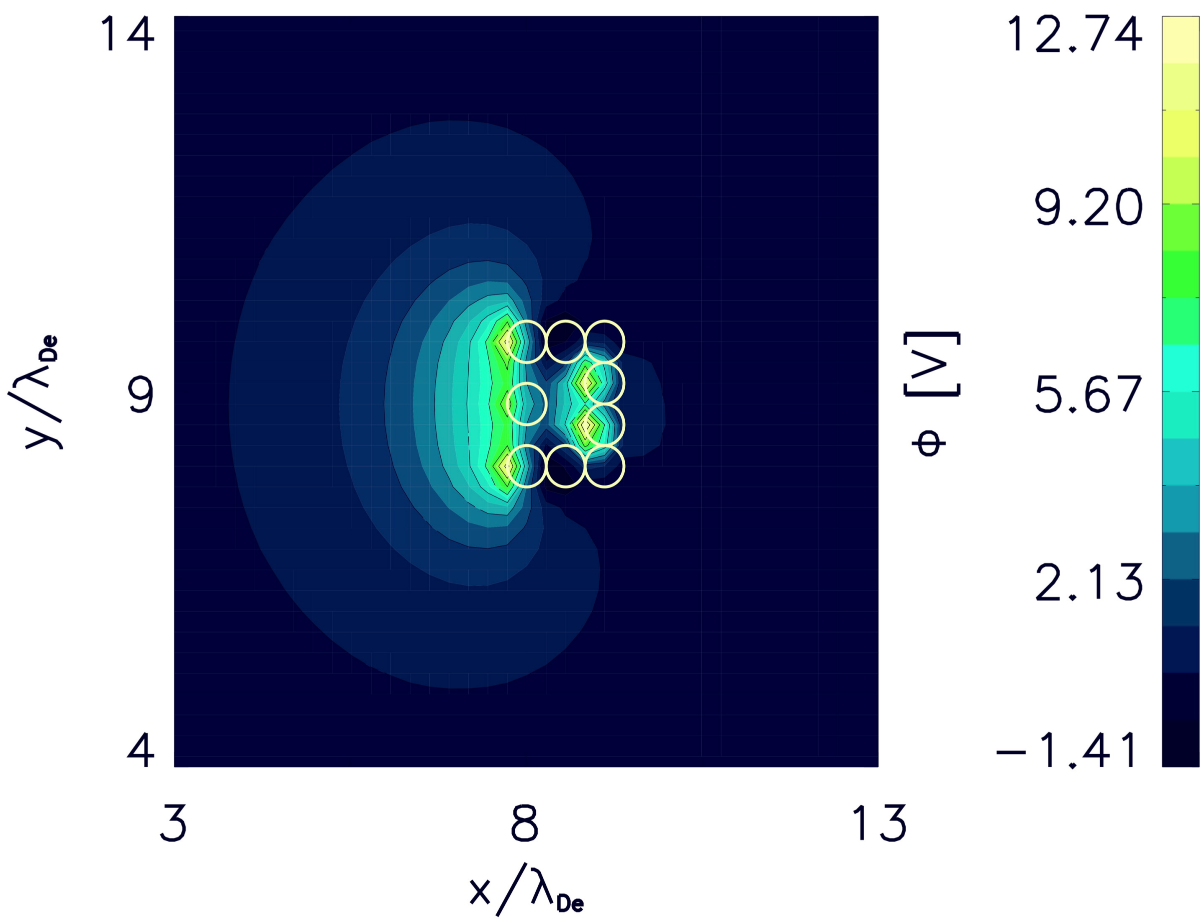




Photons: 10^19 $m^{-2}\,s^{-1}$
Photoelectron energy: 0.25 eV
Stationary plasma: $T_e/T_i = 3, T_e = 0.25\ \mathrm{eV}, n = 9.7 \cdot 10^{11}\mathrm{m}^{-3}$

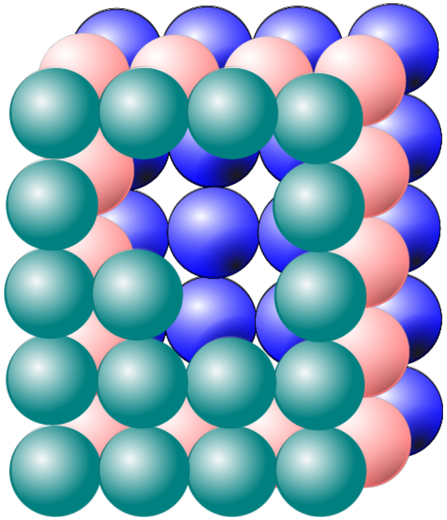
Cavity – an example of the surface

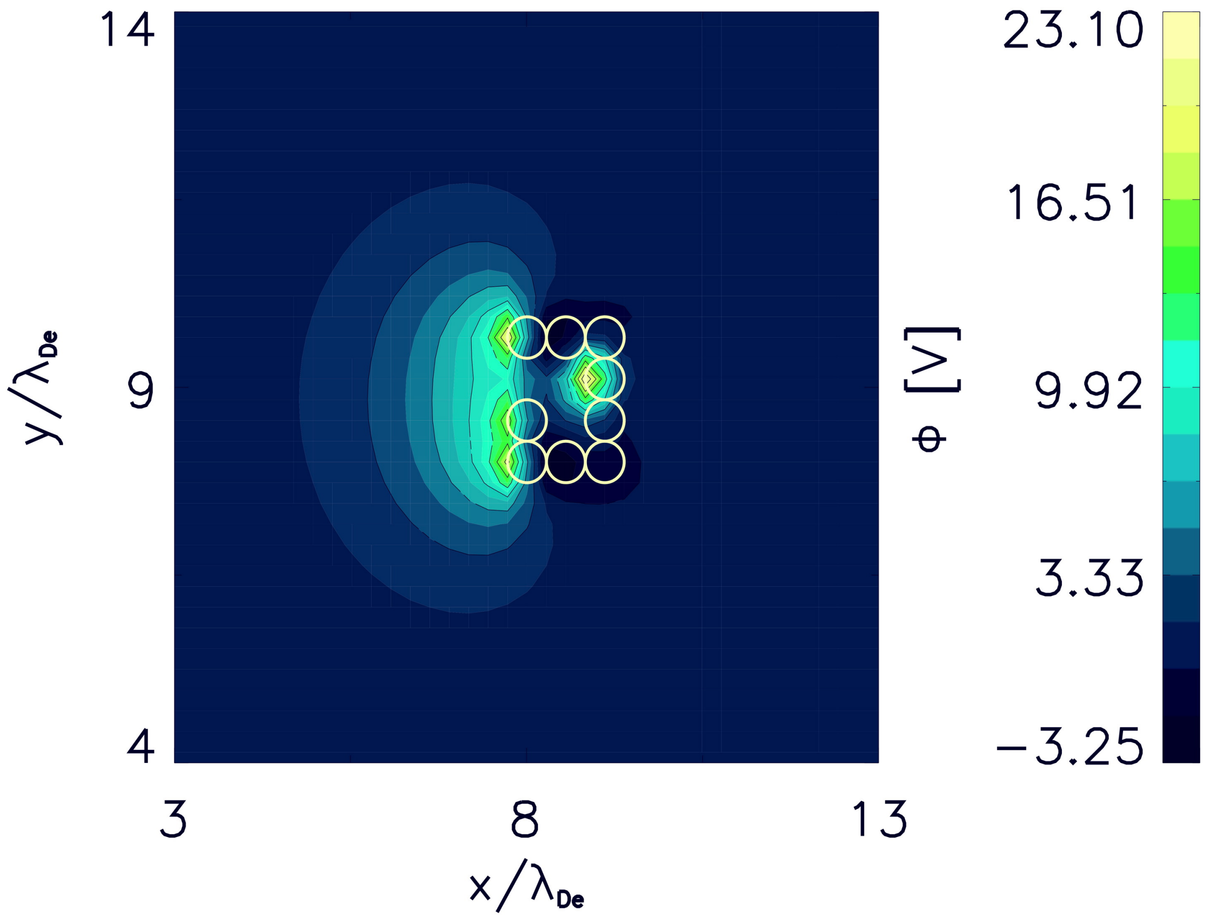




Photons: 10^19 $m^{-2} s^{-1}$
Photoelectron energy: 0.25 eV
Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11} \text{m}^{-3}$

Cavity – an example of the surface



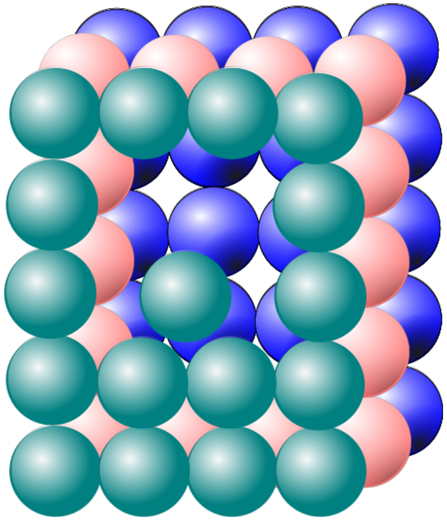


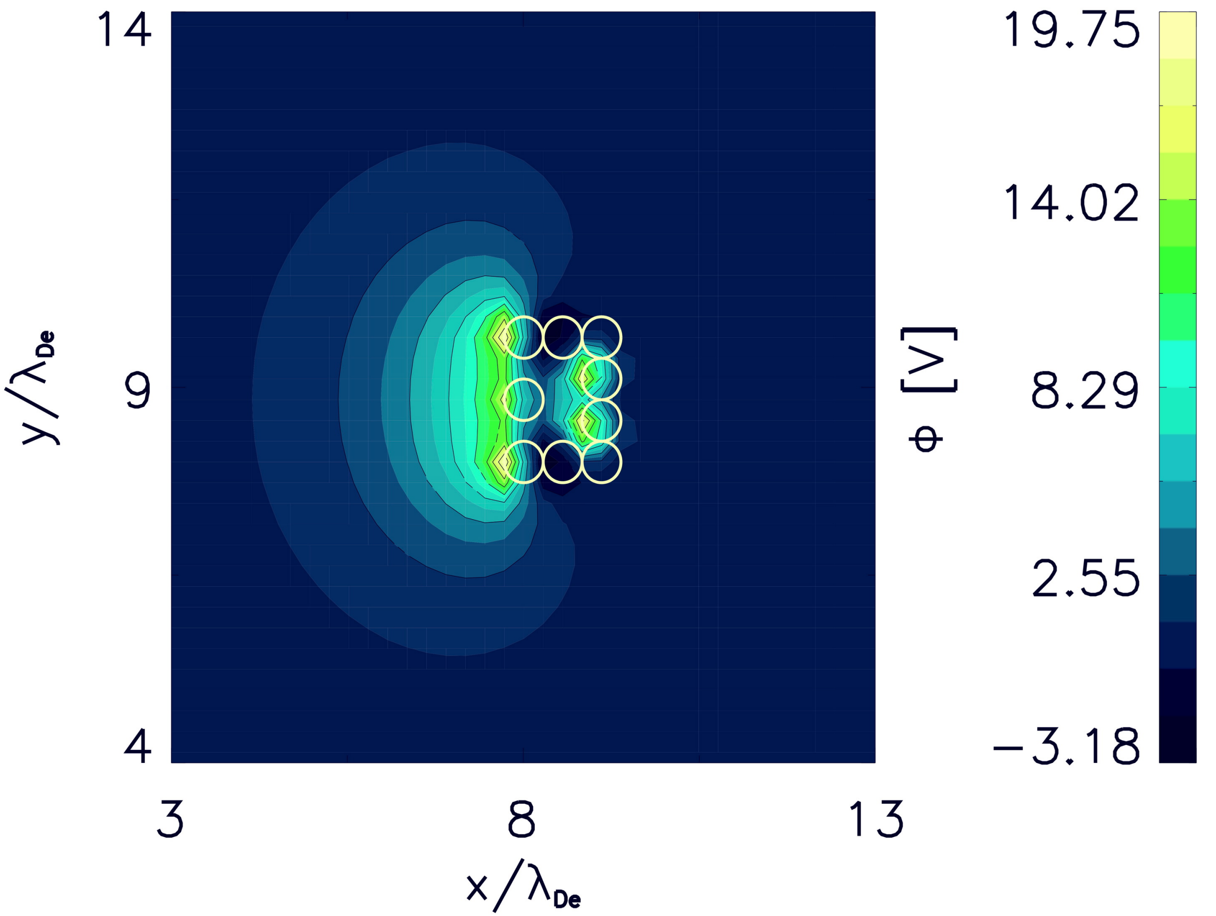
Photons: 10^19 m^{-2} s^{-1}

Photoelectron energy: 0.5 eV

Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11}\text{m}^{-3}$

Cavity – an example of the surface



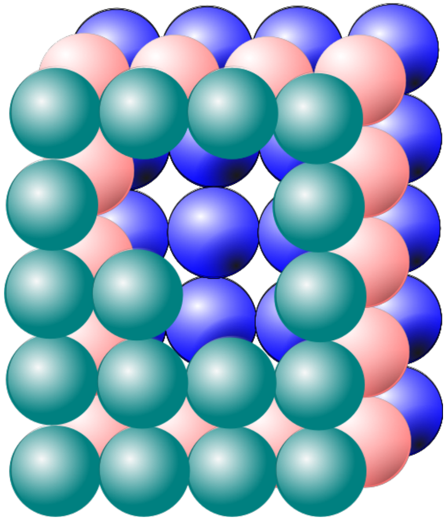


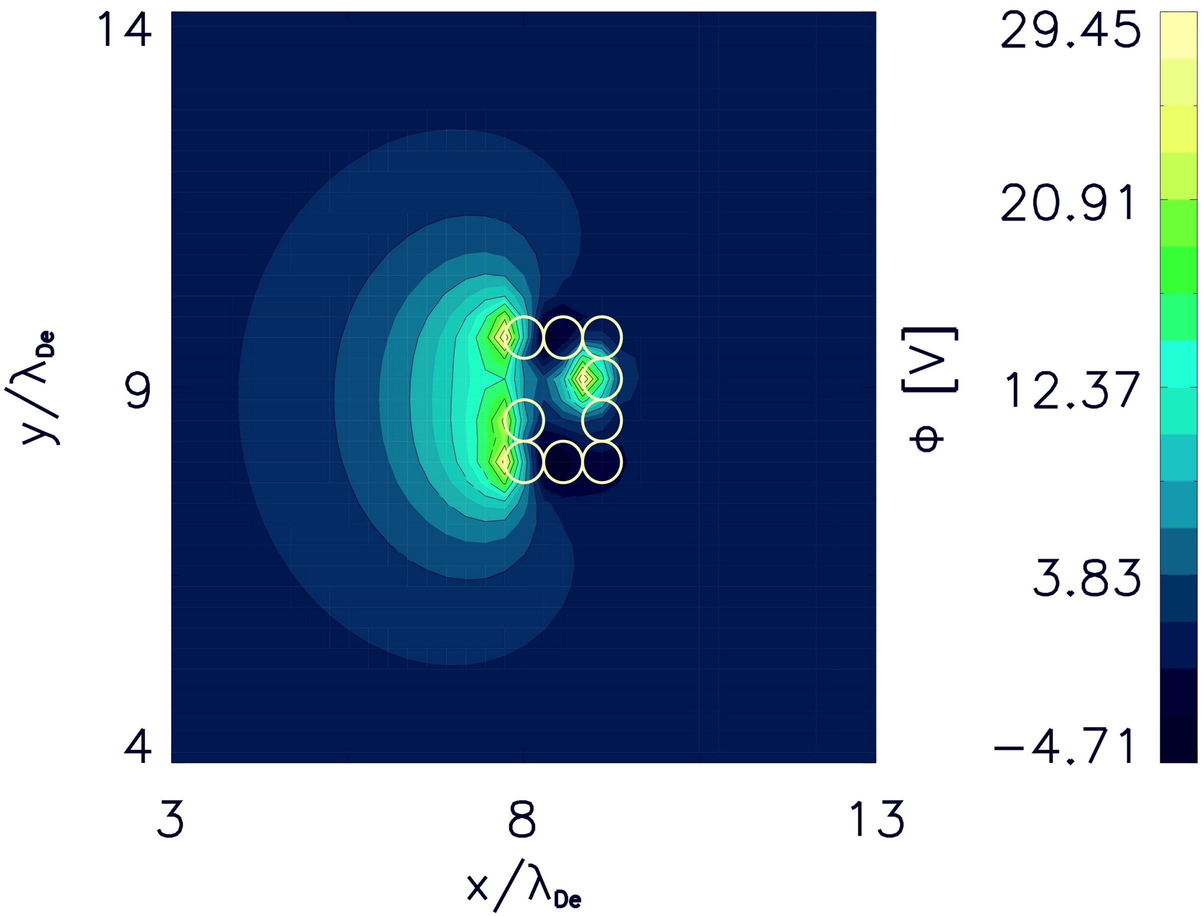
Photons: 10^19 m^{-2} s^{-1}

Photoelectron energy: 0.5 eV

Stationary plasma: $T_e/T_i = 3, T_e = 0.25 \text{ eV}, n = 9.7 \cdot 10^{11} \text{m}^{-3}$

Cavity – an example of the surface





Photons: 10^19 m^{-2} s^{-1}

Photoelectron energy: 1.0 eV

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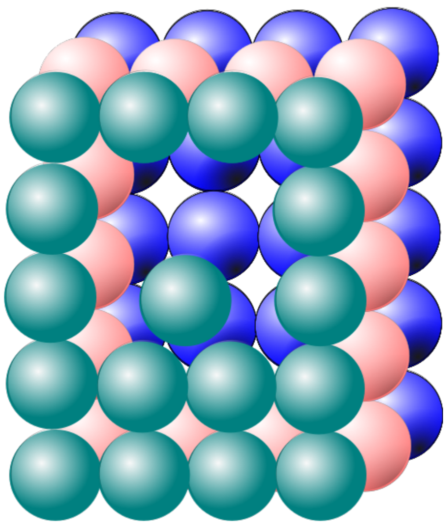

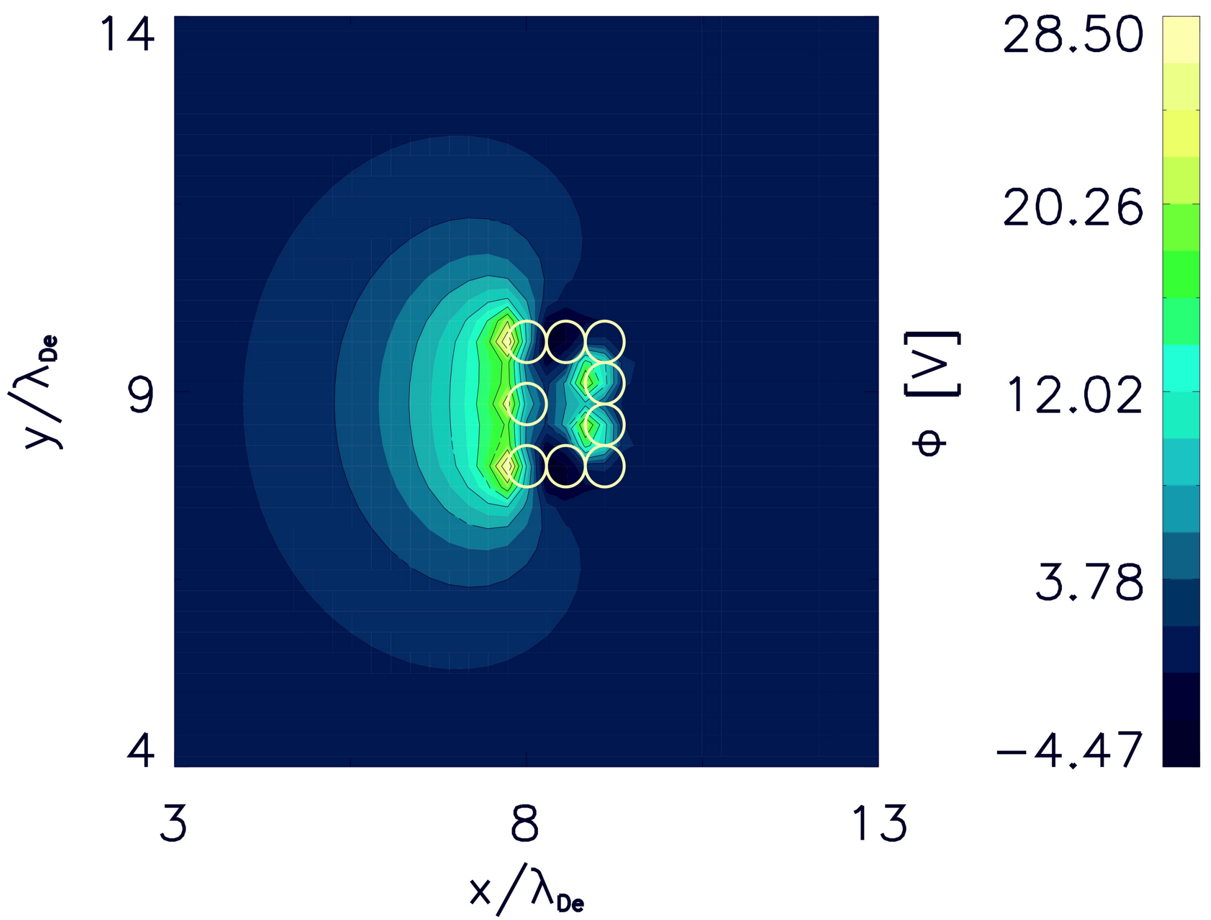

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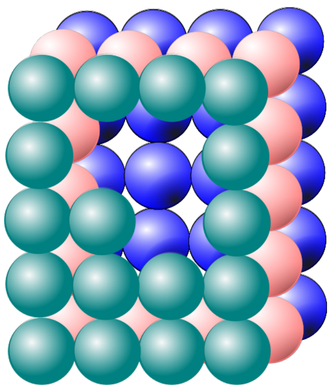

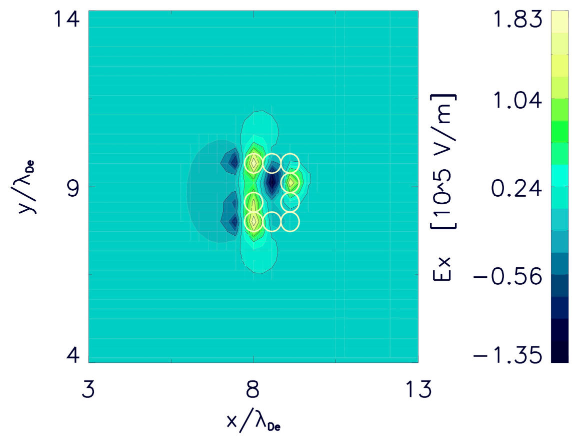

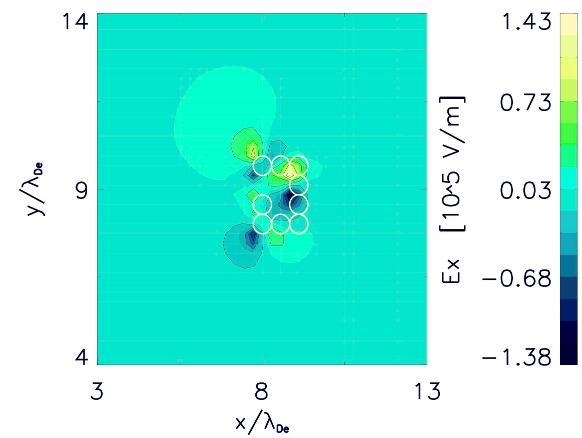

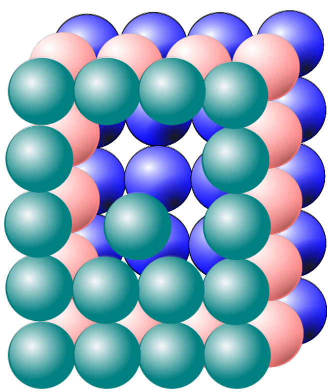

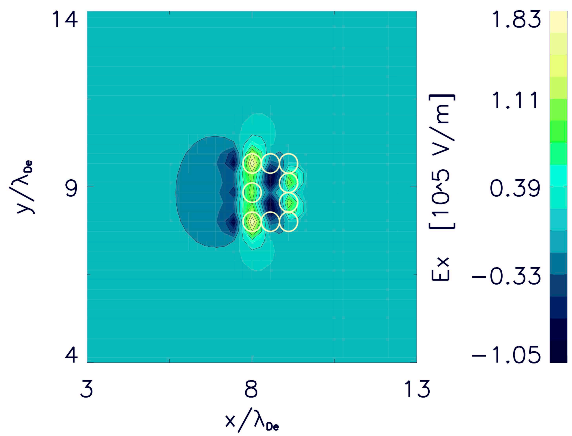

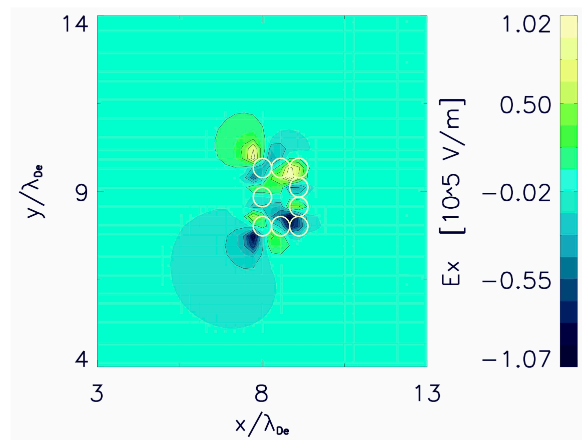

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Short summary

- With PIC codes we can simulate dust-plasma interactions by following plasma particle orbits in self-consistent fields.

- Two processes in wake formation:
  1) absorption,
  2) bending plasma trajectories / electrostatic lensing.
- Single wake can form for small relative distances between dust grains.
- Wakefield effects can align dust grains in the direction of the flow.

- Photoemission in complex geometries might be sufficient to create very strong electric fields and influence dynamics of grains over surfaces in space.

Further steps:

- ➢ Use realistic parameters to compare with experiments relevant for space conditions.
- ➢ Calculate electrostatic forces acting on the grains.
- ➢ Simulate various geometries.

4DSpace Strategic Research Initiative

Interdisciplinary science centre where 4D (3D+time) multi-scale studies of ionospheric and space plasma structures, waves, and turbulence are carried out with **integrated** experimental, theoretical and numerical modelling approach.