Electric charge and dipole of dust aggregates in the presence of ion flow

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Outline

- Dusty plasma?
- Dust electric potential
- Charging of the dust: OML theory + ion flow
- Numerical model
- Results
- Conclusions

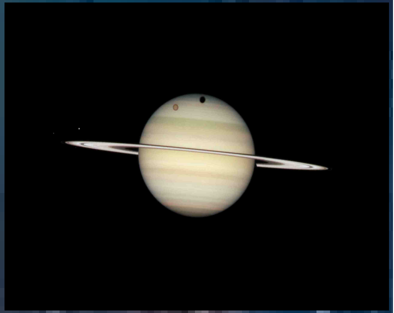
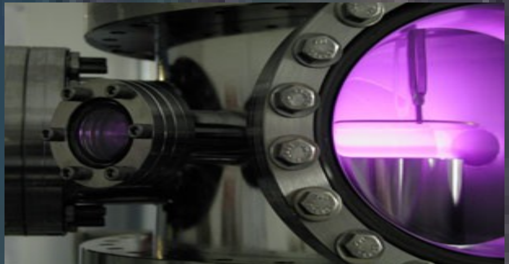
Dusty Plasma

- ~ 99% of the visible matter in the universe is Plasma. The rest is Dust

- Dusty Plasmas can be found in:

  Galaxies
  Interstellar clouds
  Stellar winds
  Protoplanetary disks
  .
  .
  .
  Industry
  Laboratory



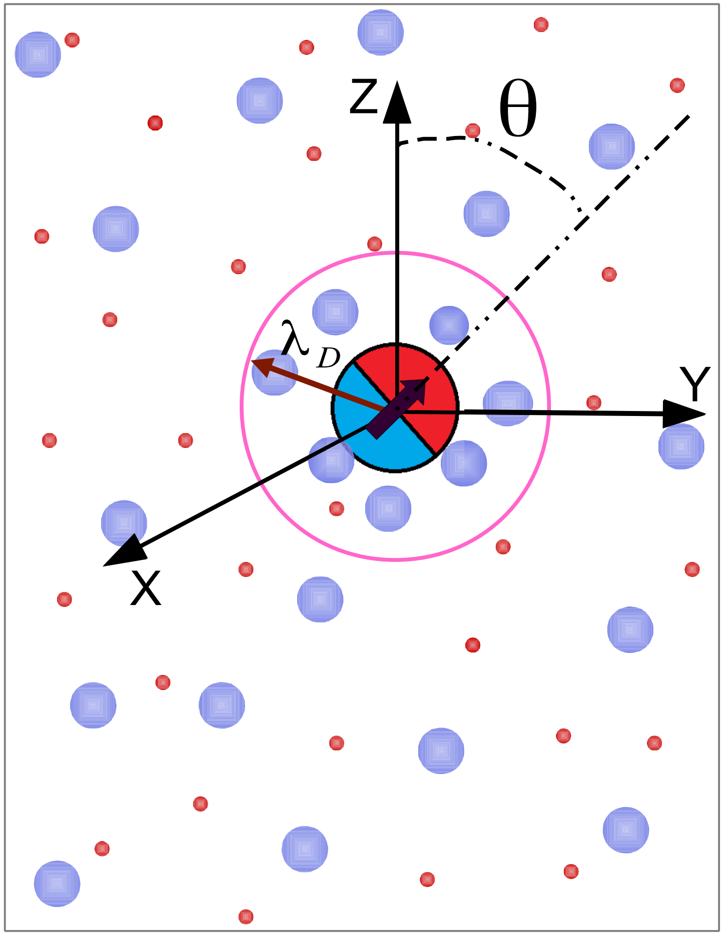

Dust electric potential

CASPER

Screened potential of a spherical charged particle:

$$\varphi_q = \frac{q_0}{4\pi\varepsilon_0 r}\frac{\exp\left(-k\left(r-a\right)\right)}{\left(1+ka\right)}$$

$$\varphi_p = \frac{p_0\cos\theta}{4\pi\varepsilon_0 r^2}\exp\left(-k\left(r-a\right)\right)\frac{3\left(1+kr\right)}{k^2a^2+3\text{ka}+3}$$



q_0 : Charge

p_0 : dipole moment

k : $1/\lambda_D$

a : radius of the dust

θ : Polar angle

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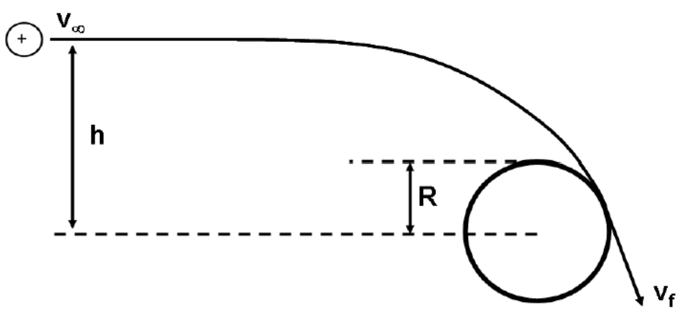
Charging of the dust

- **Collection of plasma particles**

$$J_j = q_j \int_{v_{min,j}}^{\infty} \pi v_{jn} \left(1 - \frac{2 q_j V_s}{m_j v_j^2}\right) f_j d^3 v_j$$

$$f_j(v_j) = n_j \left(\frac{m_j}{2\pi k_B T_j}\right)^{3/2} \exp\left(\frac{-m_j v_j^2}{2 k_B T_j}\right)$$

Orbital motion limited theory (OML)



- **In the presence of ion flow**

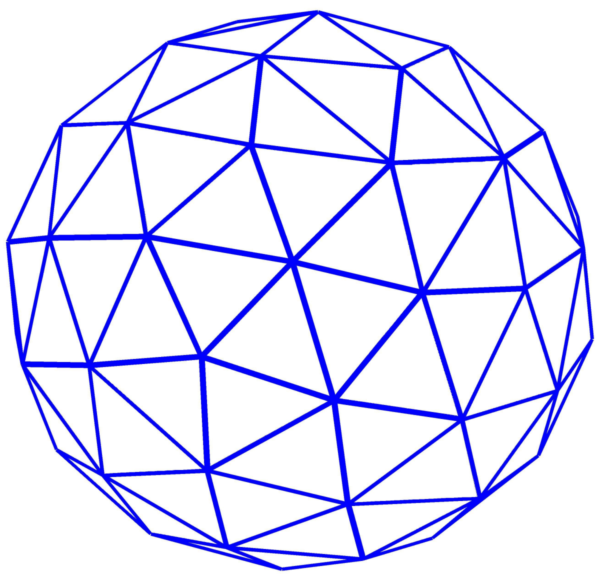
$$f_i(v_i) = n_i \left(\frac{m_i}{2\pi k_B T_i}\right)^{3/2} \exp\left(\frac{-m_i (v_i - v_{0i})^2}{2 k_B T_i}\right)$$

- **Sum currents to the dust to derive equilibrium charge**

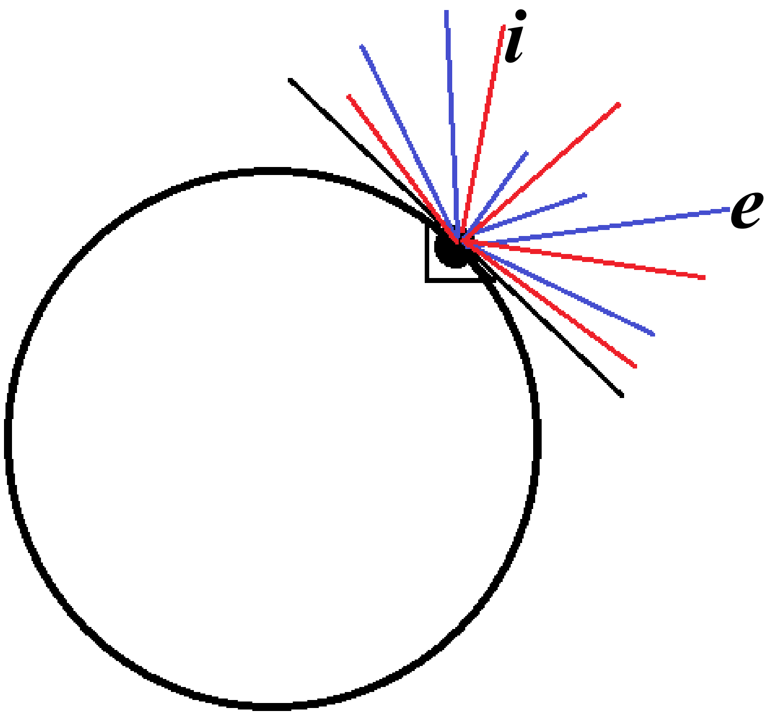
$$\frac{dQ}{dt} = \Sigma_j J_j(V_s)$$

Numerical model

- **Finds equilibrium charge,** $\frac{dQ}{dt} = \Sigma_j J_j(V_s) = 0$



Each sphere is divided to a uniform distribution of equal patches.

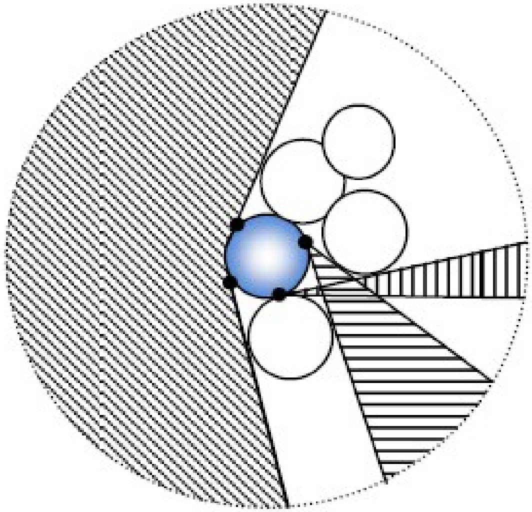


On each patch, electrons and ions collide with the surface of the dust and stick at the point of contact.

Matthews & Hyde, *NJP*,**11**, 063030, 2009

Numerical model

- **Finds equilibrium charge,** $$\frac{dQ}{dt} = \Sigma_j J_j(V_s) = 0$$



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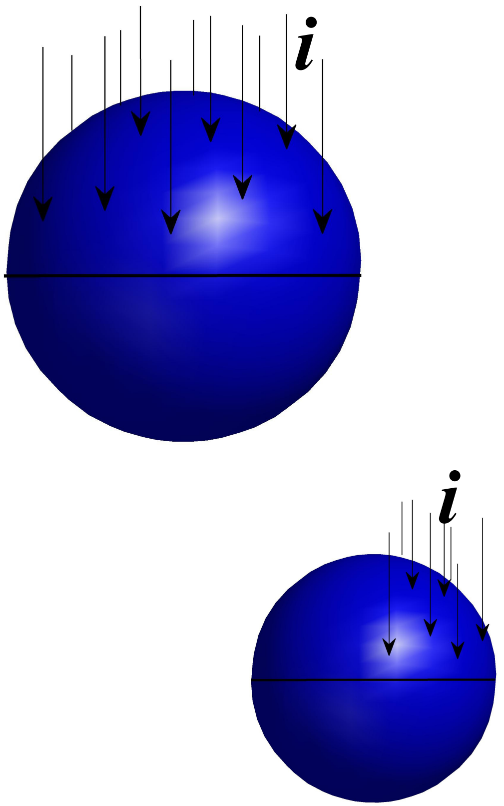


Line of sight approximation OML_LOS:
All the directions which are blocked by other monomers in an aggregate are eliminated from calculation

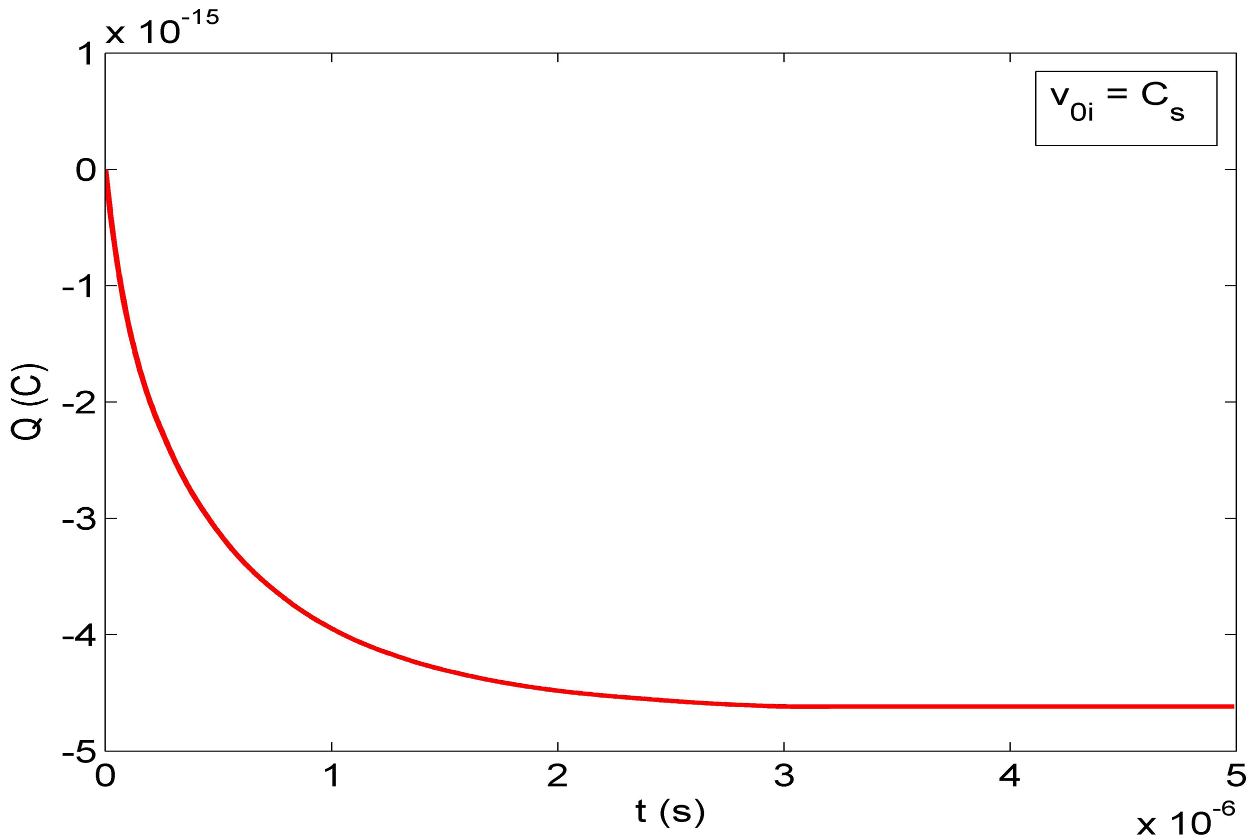
Ion flow

Matthews & Hyde, *NJP,* **11**, 063030, 2009

Single particle

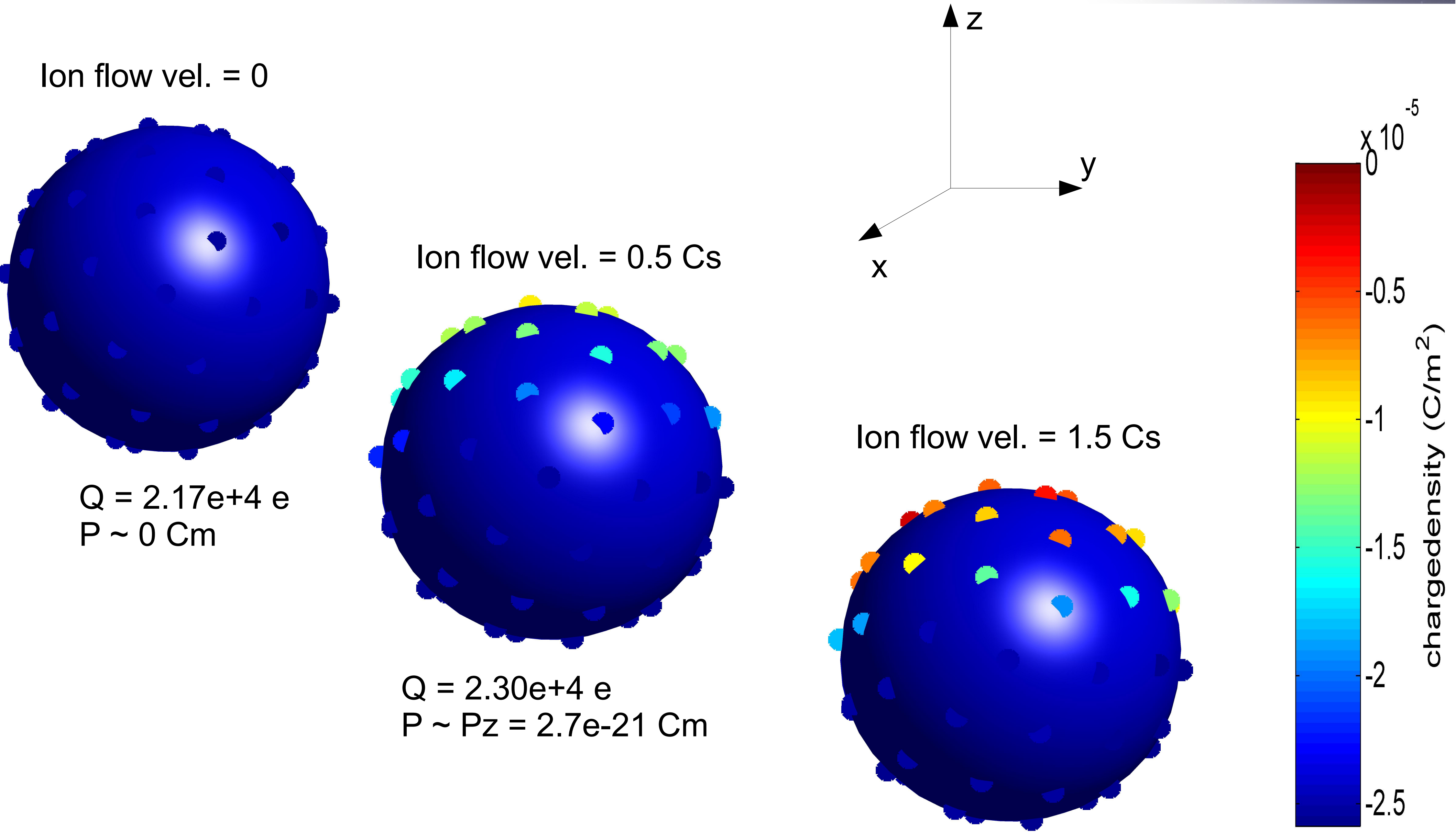
Charging of the dust

equilibrium charge: dQ/dt = 0



$$C_s = \sqrt{\frac{k_B T_e}{m_i}}$$ **: ion sound speed**

Single particle

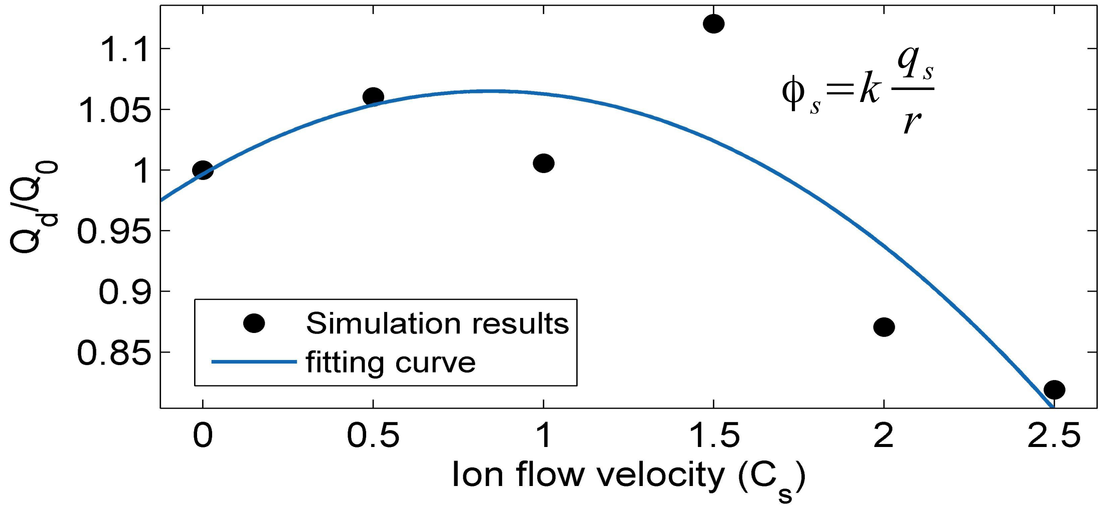


Q = 2.44e+4 e
P ~ Pz = 5.90e-21 Cm

$$C_s = \sqrt{\frac{k_B T_e}{m_i}}$$ **: ion sound speed**

Single particle

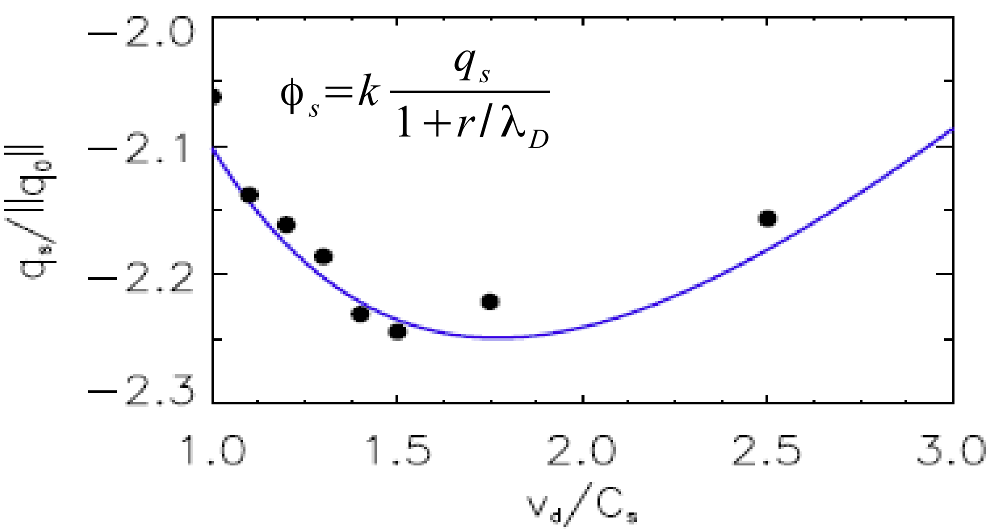
equilibrium charge at different flow velocity



$$\frac{T_e}{T_i} = 155$$

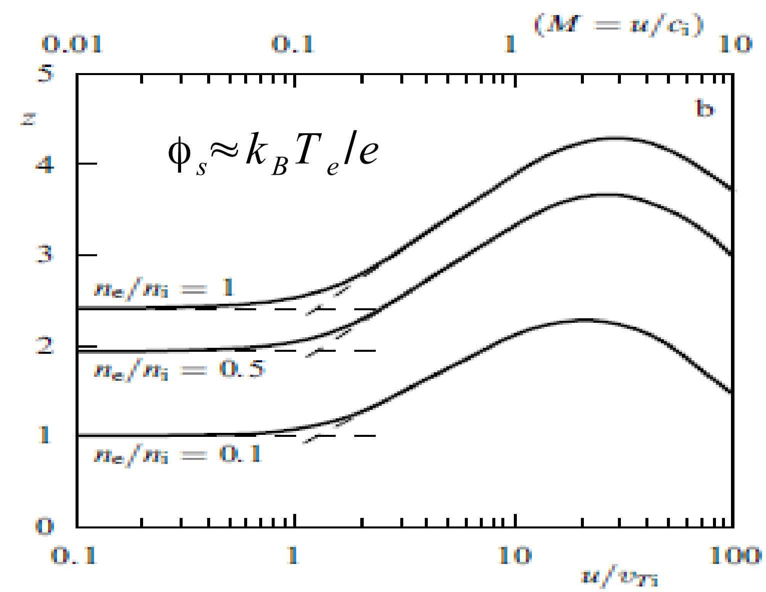
charge at different flow velocity; previous calculation :

Simulation --> OML + capacitance model



Phys. Plasmas **19**, 123703 (2012);

Numerical calculation --> OML

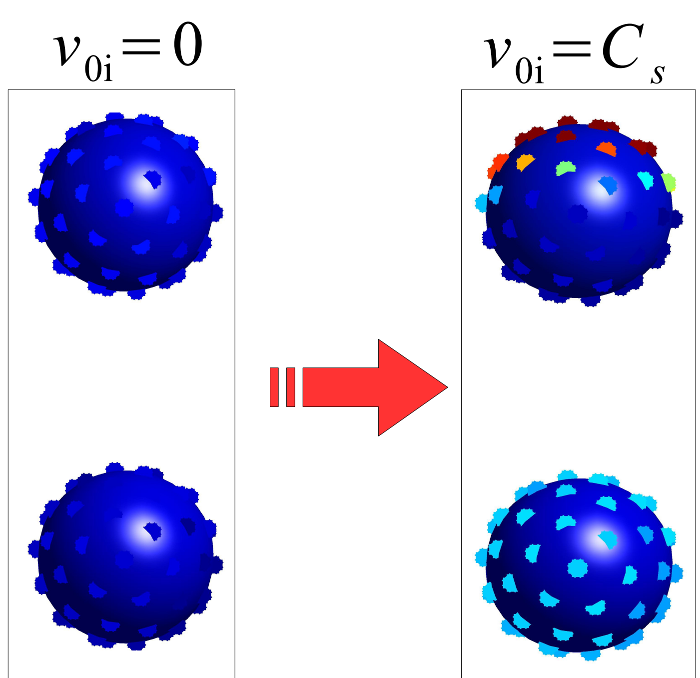


$$\frac{T_e}{T_i} = 100$$

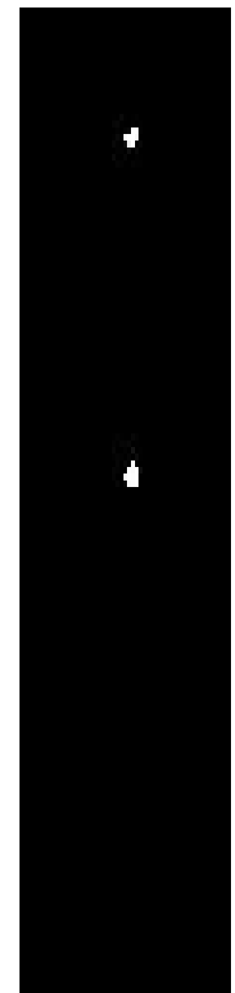
Physics-Uspekhi 47, (5) 447-492 (2004);

Two particles: comparison with Experiment (II)

Ion flow vel. (C_s)	Q_{Top} (e)	Q_{Lower} (e) ~
0	2.05e+4	2.05e+4
0.5	2.18e+4	2.05e+4
1	2.10e+4	2.05e+4
1.5	2.31e+4	2.05e+4



Two particle chain formed in the sheath of RF discharge plasma

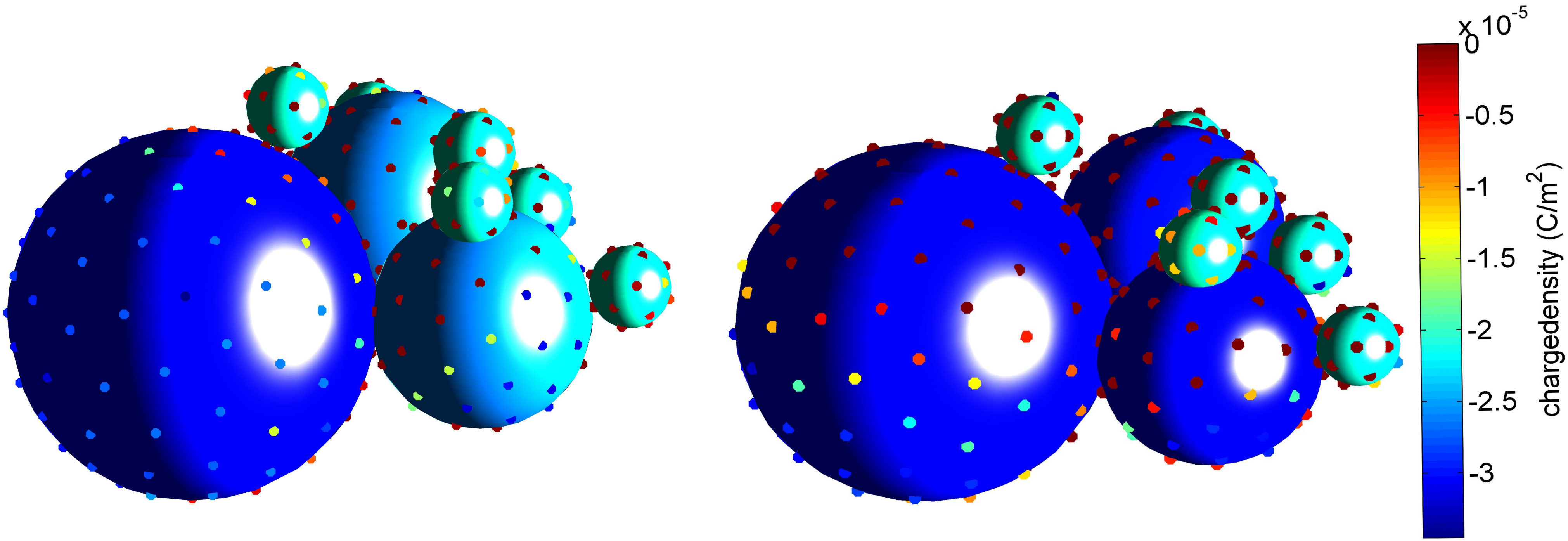


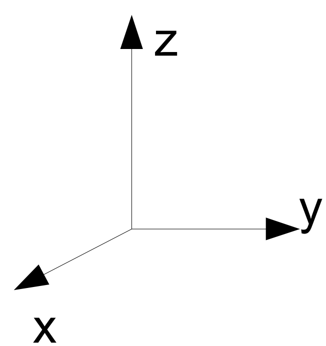
Dust aggregate

- **Dust aggregate with irregular shape consisting of spherical monomers**

Ion flow vel. = 0 Cs

Ion flow vel. = 1 Cs

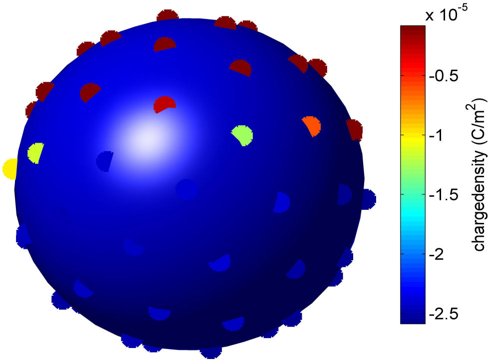




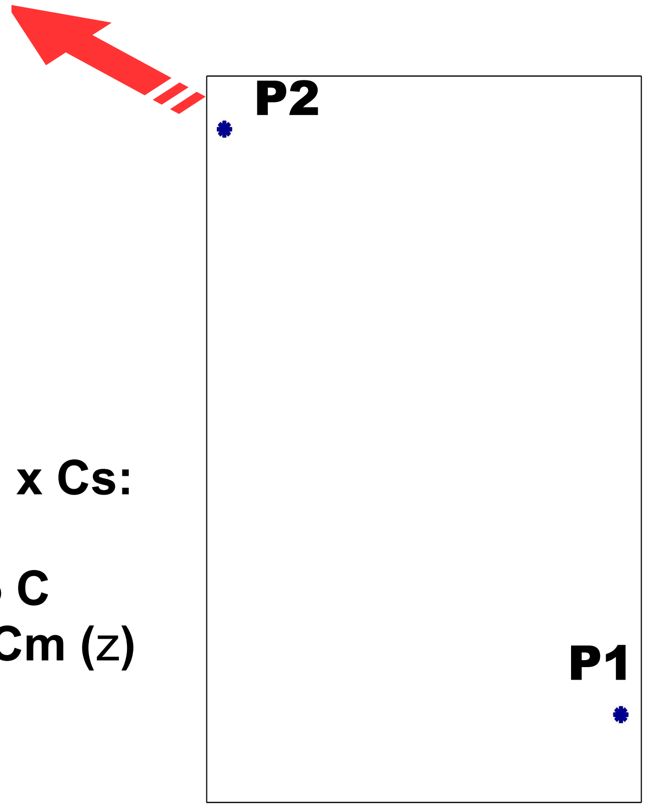
Q = 4.62e+5 e
Px = -1.01e-20 Cm
Py = -2.59e-20 Cm
Pz = +4.96e-21 Cm

Q = 4.96e+5 e
Px = -2.80e-20 Cm
Py = -2.36e-20 Cm
Pz = +2.38e-20 Cm

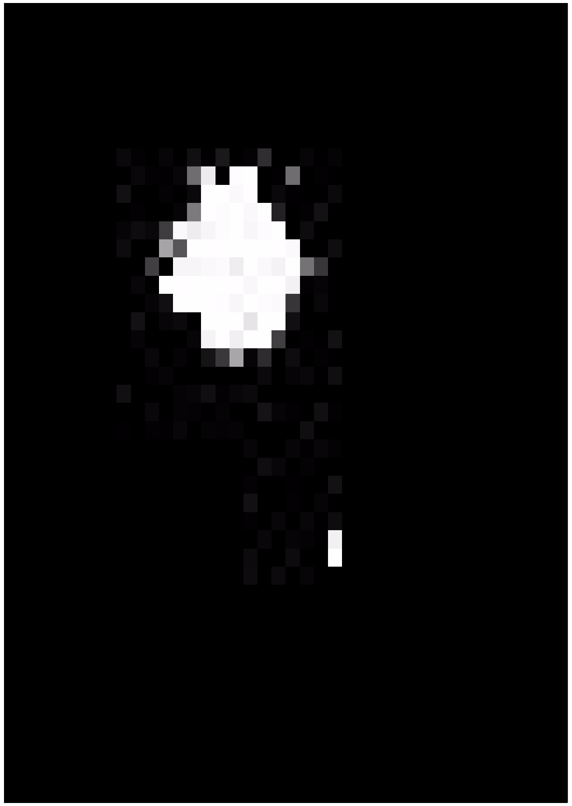
Two particles: comparison with Experiment (I)



Two particle arrangement matched with experimental data



Data collected in a RF discharge plasma



Ion flow speed = 1 x Cs:

Q1 ~ Q2 = -3.5e-15 C
P1 ~ P2 = 5.8e-21 Cm (z)

Dipole_charge interaction

- **Total forces acting on the lower particle (P1)
 in the coordinate system placed on top particle (P2):**

$$[F_{tot,1} = Q_1(E_{Q_2} + E_{p_2})]_x$$

**Where drag forces are ignored and
electric field (E) is derived from screened electric potential.**

- **From field equation in the horizontal direction:**

λ_D ~ 0.05 mm ~10R

Q1 = -4.0e-15 C

P = Pz = 6.1e-21 Cm

**In agreement
with the numerical model**

λ_D = 2.5 mm ~ 550R

Q1 = -2.1e-15 C

P = Pz = 6.6e-20 Cm

Conclusion:

A numerical model is presented which:

- Shows that the electric dipoles are formed on the surface of the non-conducting dust as a result of ion flow.
- Calculates the electric charge and dipole of a particle distribution and dust aggregates in a flowing plasma.
- For particle chain, in a range of ion flow velocities, the lower particle charge is less than top particle charge which is in agreement with the previous numerical and experimental calculations.
- It is shown that dipole charge interaction could be a candidate for explaining the attractive force between charged particles in a flowing plasma.

Thanks for your attention

Questions??..