Dust as a Diagnostic Tool to Measure Potential Distribution in Plasma

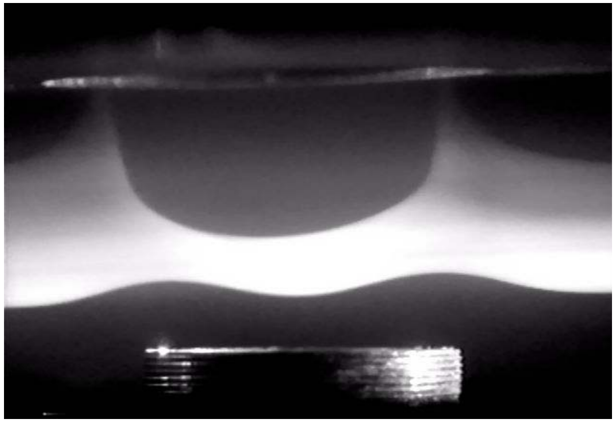
A. Samarian, W. Tsang, J. Khachan, B. James
Complex Plasma Laboratory
School of Physics, University of Sydney, NSW 2006, Australia

Complex Plasma Laboratory

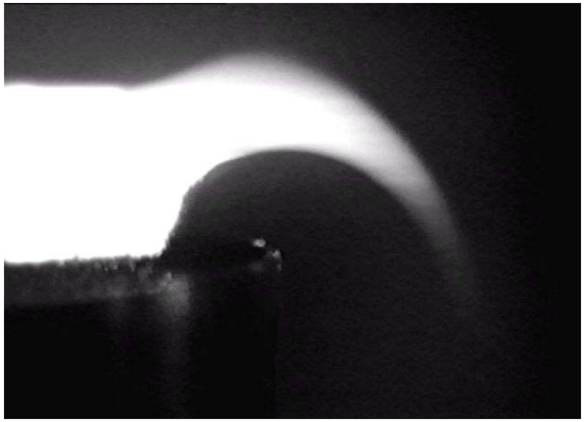
The University of Sydney
AUSTRALIA

Outline

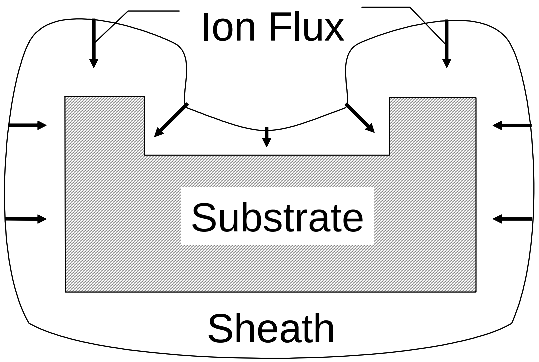
- To use micro-sized particles as diagnostic tools for the analysis of the sheath in a RF Capacitively Coupled Argon Plasma
- To evaluate the structure of the sheath
- To use sub-micrometer sized particles to visualize the sheath of irregularly shaped electrode



The upper (grounded) electrode is a disk with a central hole, a confinement ring on the lower RF powered electrode is visible.

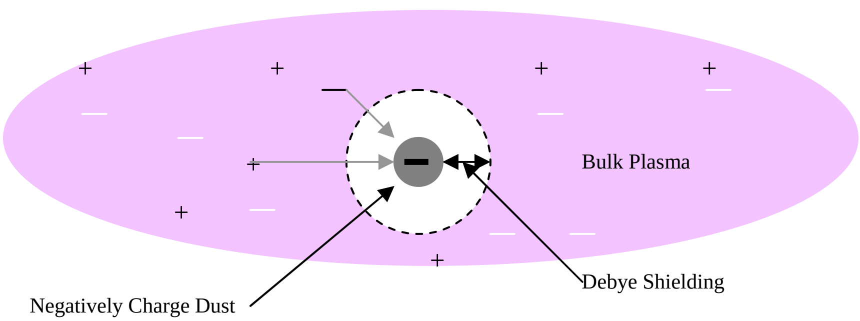


Detail of the sheath at the edge of a simple disc RF powered electrode



Schematic representation of the sheath distribution during the Plasma Immersion Ion Implantation of an irregular substrate.

Complex plasma

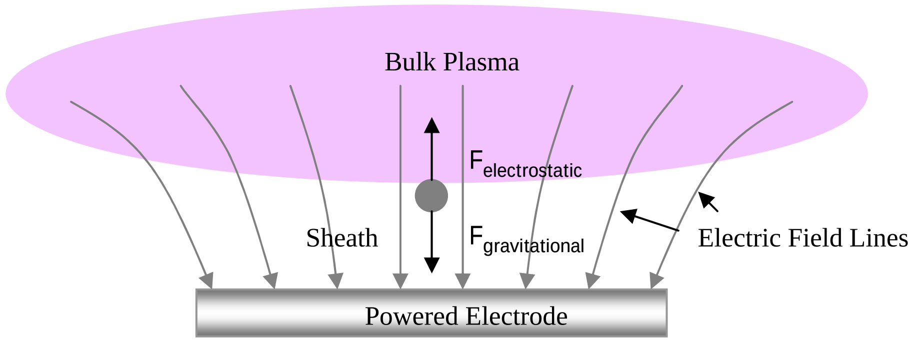


- For a dust to levitate, the following equation must be satisfied:

$$F_{gravitational} + F_{ion\ drag} = F_{electric} + F_{themophorectic}$$

$$Q_d = f\left(\frac{n_e}{n_i}, T_e, v_i\right)$$

The charge on the dust can be written as function of the electron density of the plasma (n_e), ion density (n_i), electron temperature (Te) and the ion velocity (v_i)



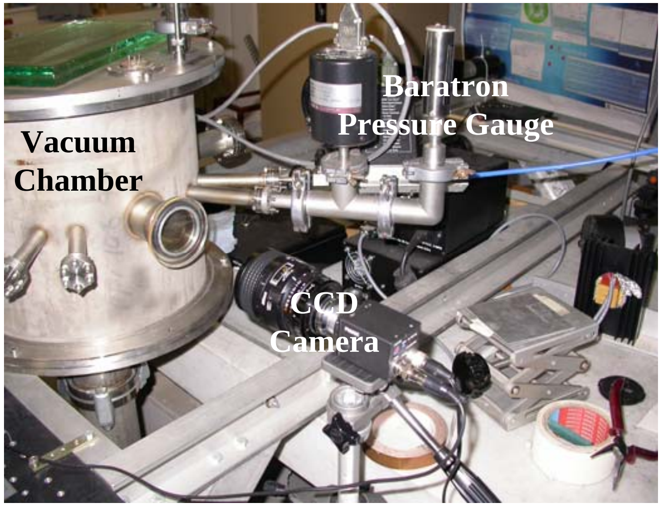
- In our operating range, the following needs to be satisfied

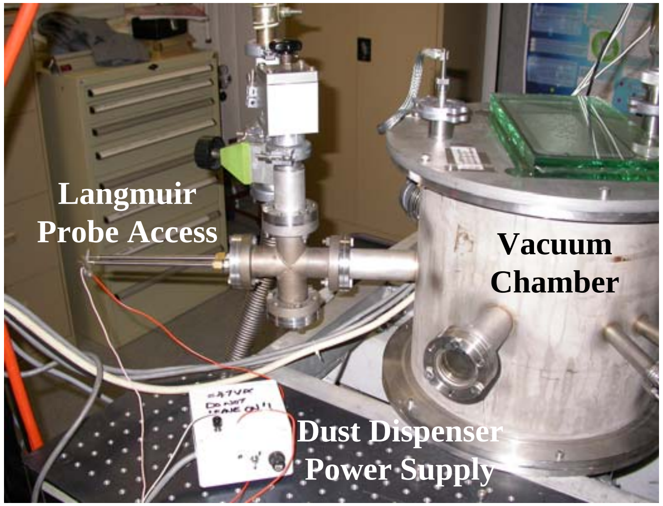
$$F_{el} = F_g$$

$$QE = mg$$

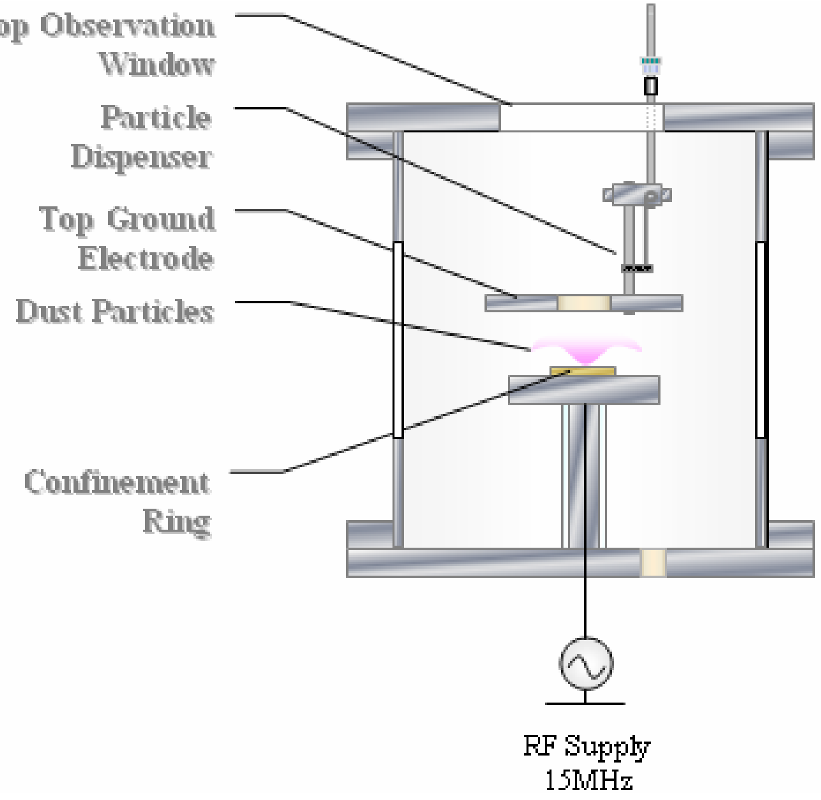
as other forces are insignificant and can be neglected

Experimental Apparatus





- The experiments were conducted in a 30 cm height by 40cm inner diameter cylindrical stainless steel vacuum chamber



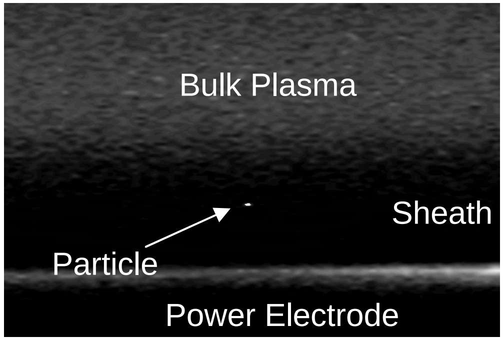
Diagnostic Procedure

- Particles illuminated by laser
- Operating Range of the Experiment:

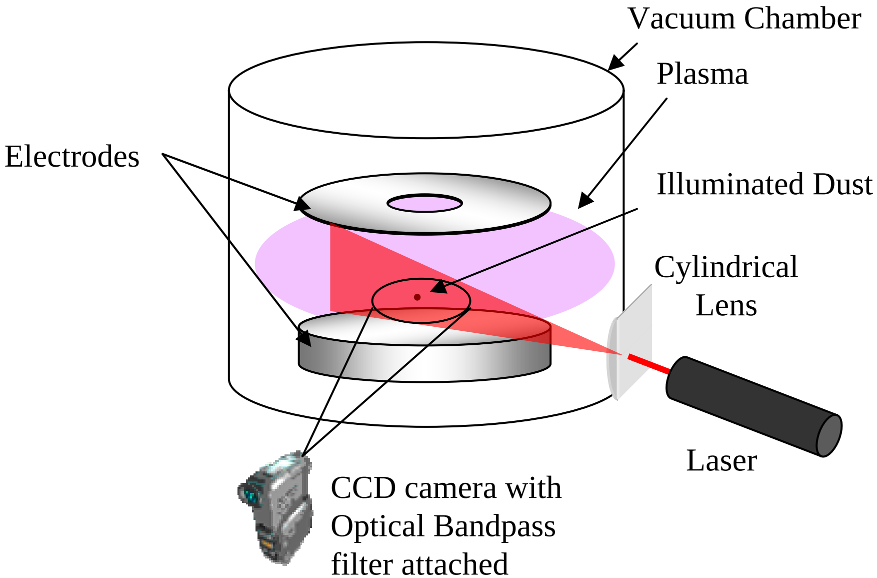
  20mTorr – 100mTorr

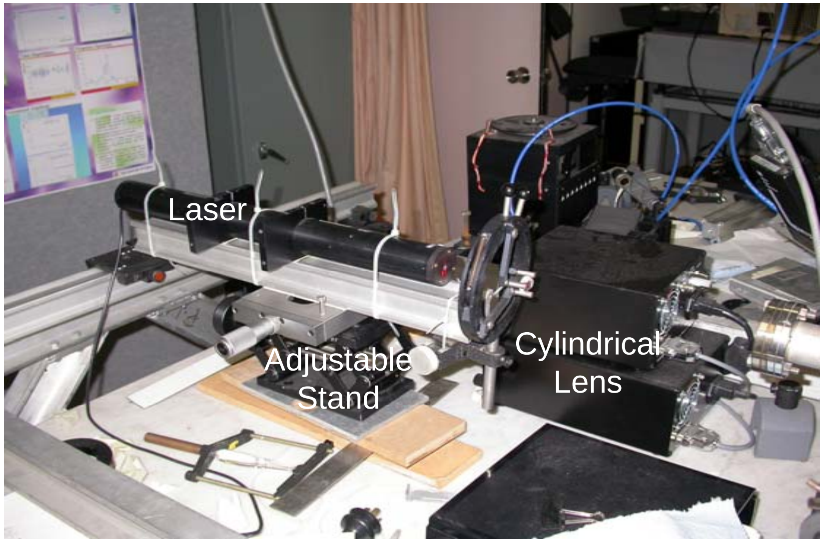
  10 – 30W

Reference frame used in the determination of dust height



Sample frame obtained from the experiment

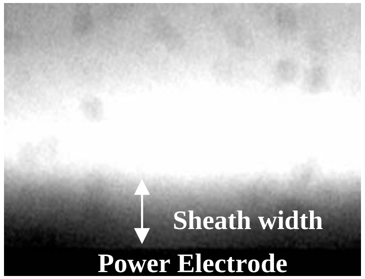


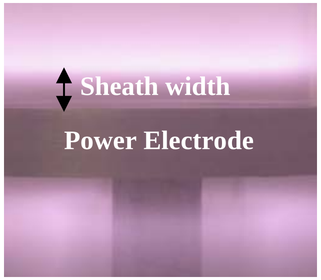


Sheath Width Determination

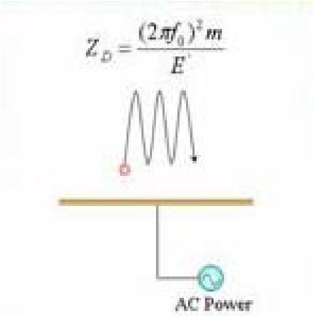
- Because the levitation of submicron particles require very small electric fields, these will in effect levitate at the sheath's edge. This was used to determine the width of the sheath

Conventional method of Sheath Width Determination



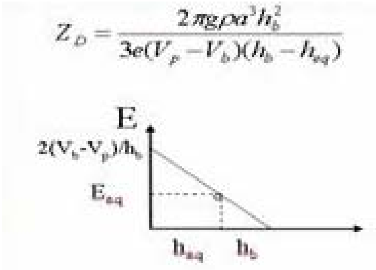


As seen, the measurement is purely subjective



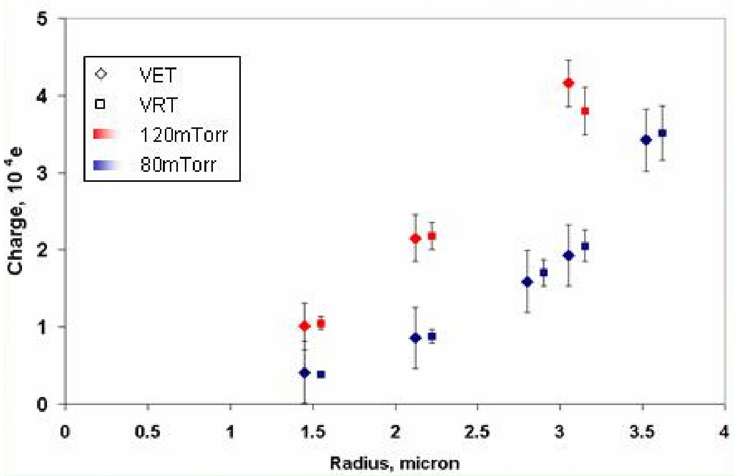
Measurement of dust charge using the Vertical Resonance Technique (VRT)

Resonance frequency of particle measured against applied potential



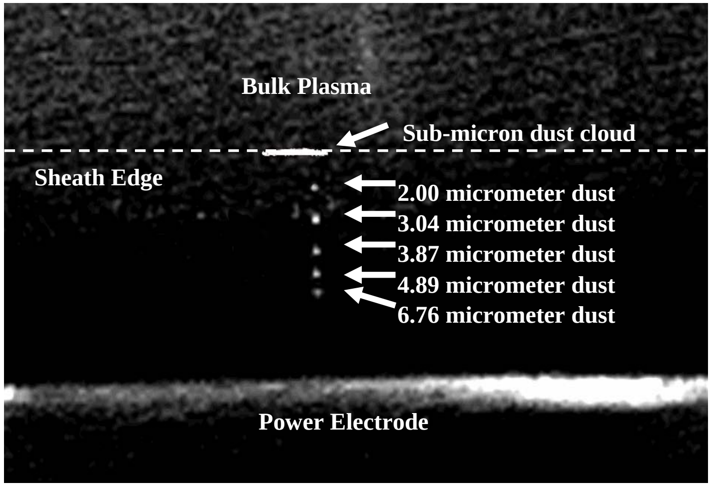
Measurement of dust charge using the Vertical Equilibrium Technique (VET)

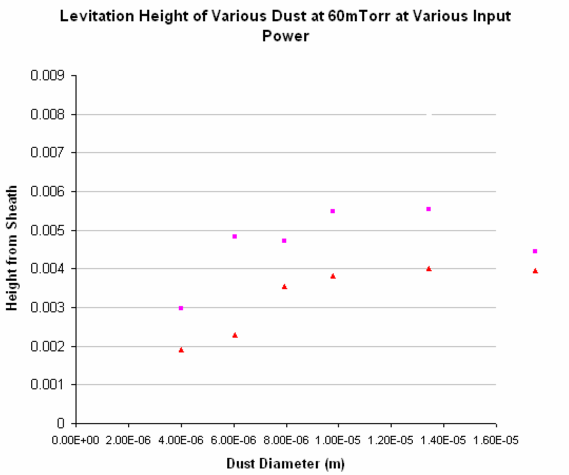
Levitation height of particle measured against plasma potential

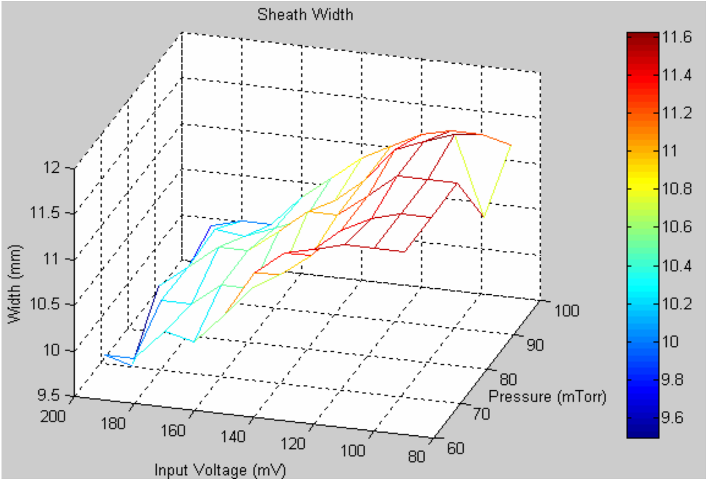


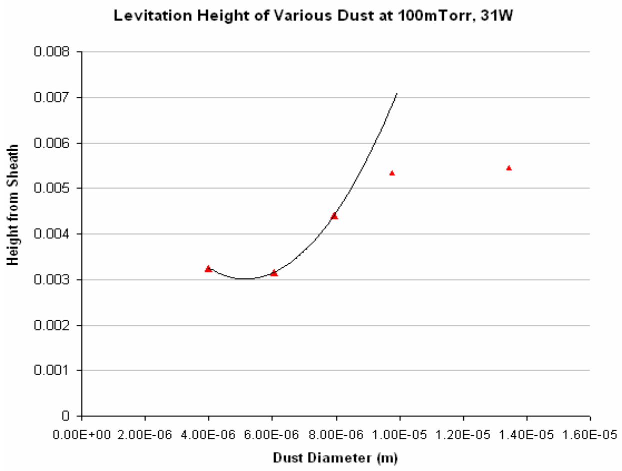
Measured charge on particles using both techniques

Results









$$QE = mg$$

$$Q \propto R$$

$$R\varphi_s E = \frac{4}{3}\pi R^3 \rho g$$

$$\varphi \propto h^2$$

$$E \propto h$$

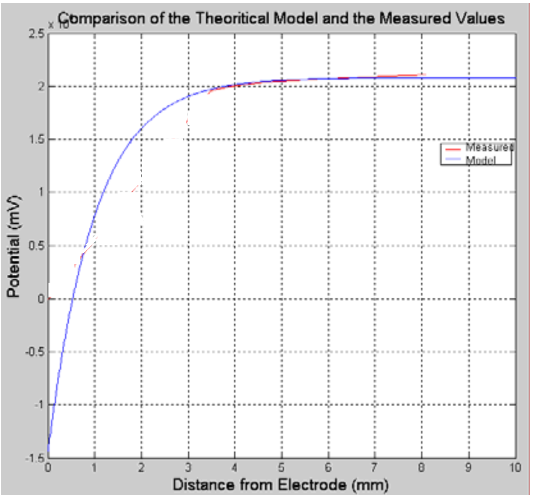
$$h \propto R^2$$

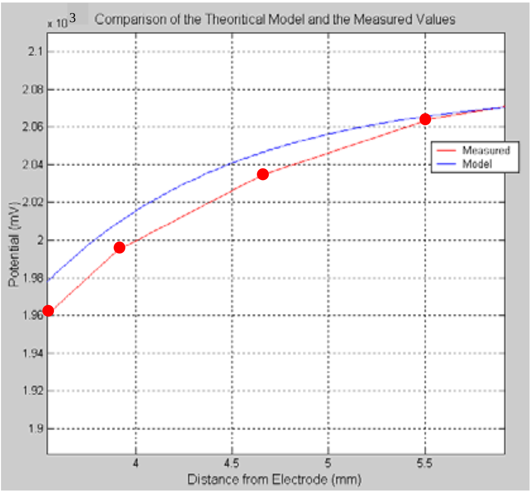
Comparison with existing models

- Poisson's Equation describes the Potential of the Sheath as a function of distance from the Sheath-Presheath Interface

$$\xi_0 \frac{d^2\phi}{dx^2} = e(n_e - n_i) = en_0\left[\exp\left(\frac{e\phi}{kT_e}\right) - \left(1-\frac{2e\phi}{Mv_0^2}\right)^{-\frac{1}{2}}\right]$$

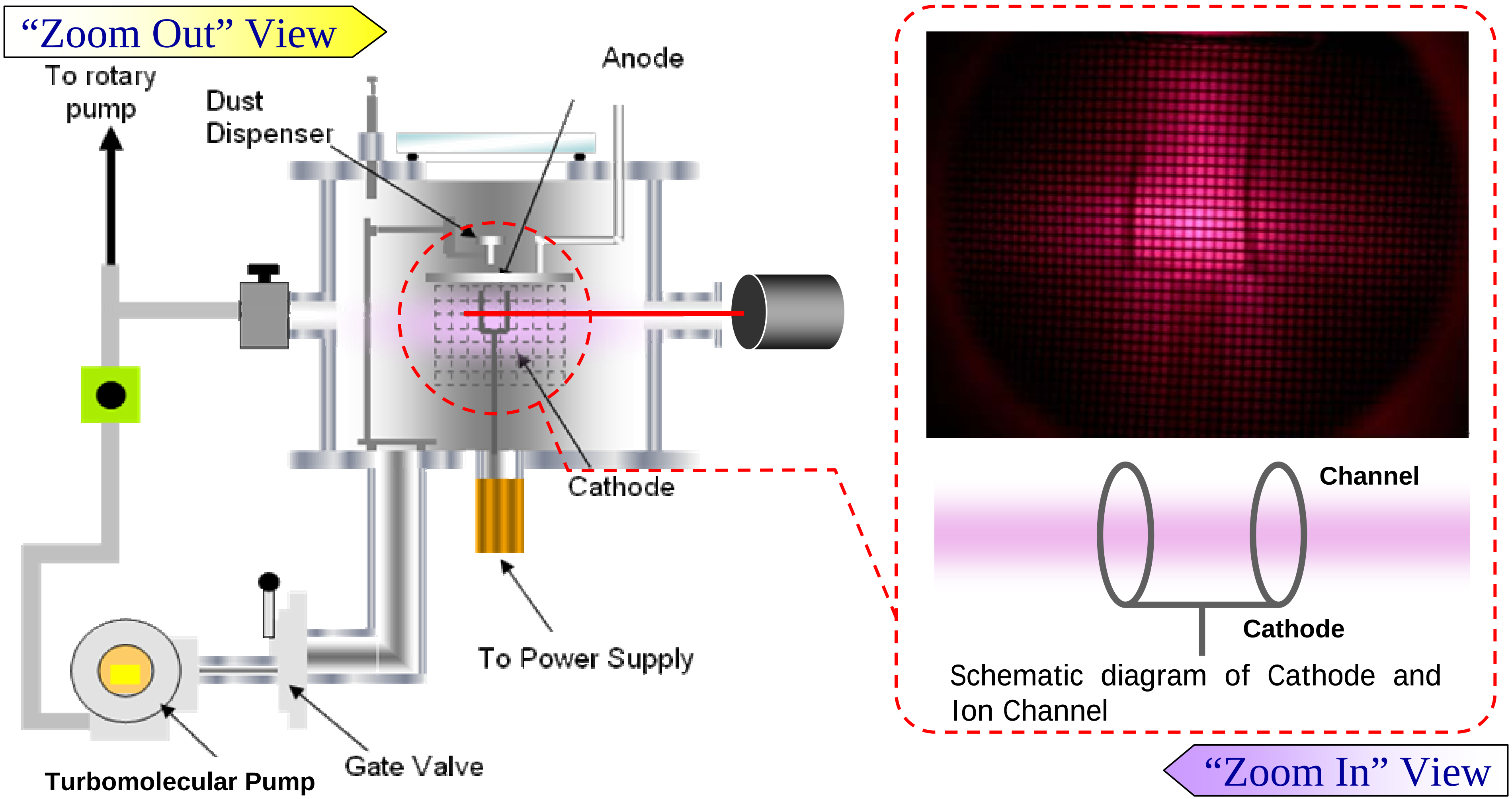
ϕ is the potential
x is the distance from Sheath-Presheath interface
n_e is the electron density
n_i is the ion density
e is the charge of an electron
k is the Boltmann's constant
T_e is the electron temperature
M is the mass of the ion
v_0 is the initial velocity of ions at the interface





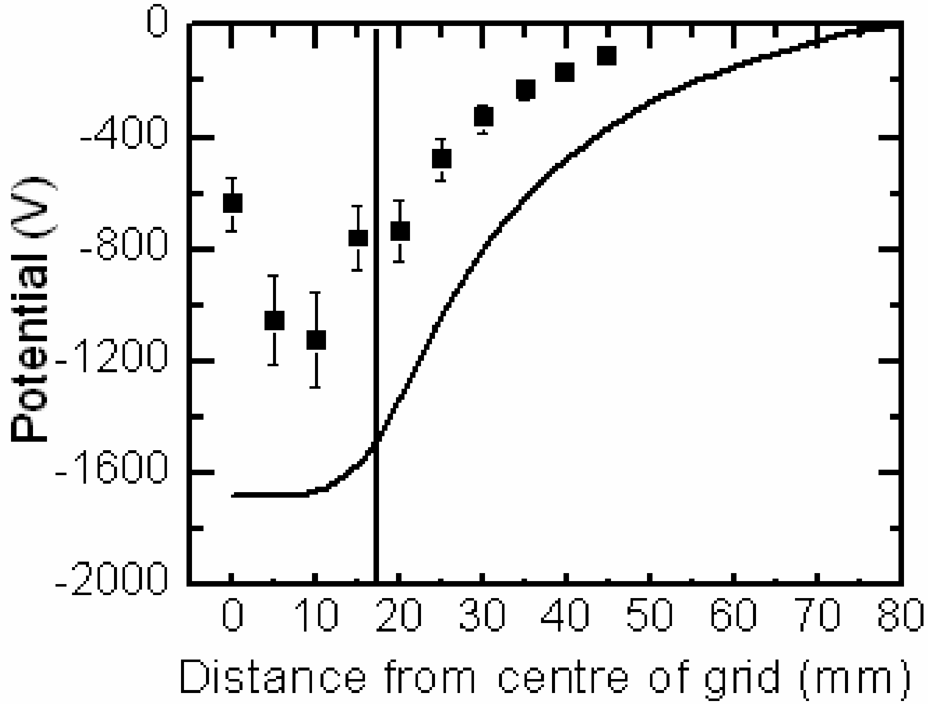
- Measured potential is consistent with theoretical model. But as we enter deeper into the sheath, discrepancies begin to appear suggesting the breakdown of the theoretical model

Inertial Electrostatic Confinement Device



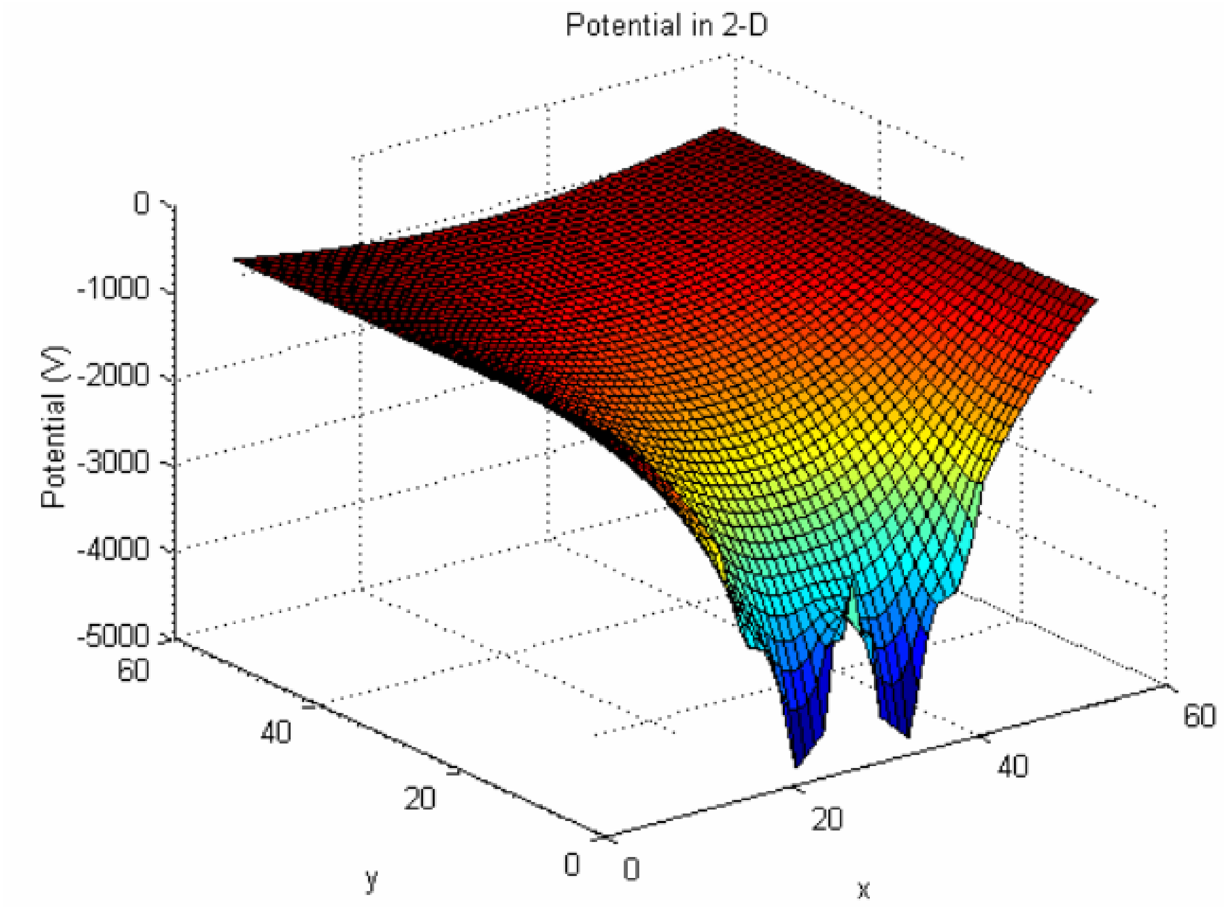
Inertial Electrostatic Confinement Device

- Plasma potential measured using a Langmuir probe



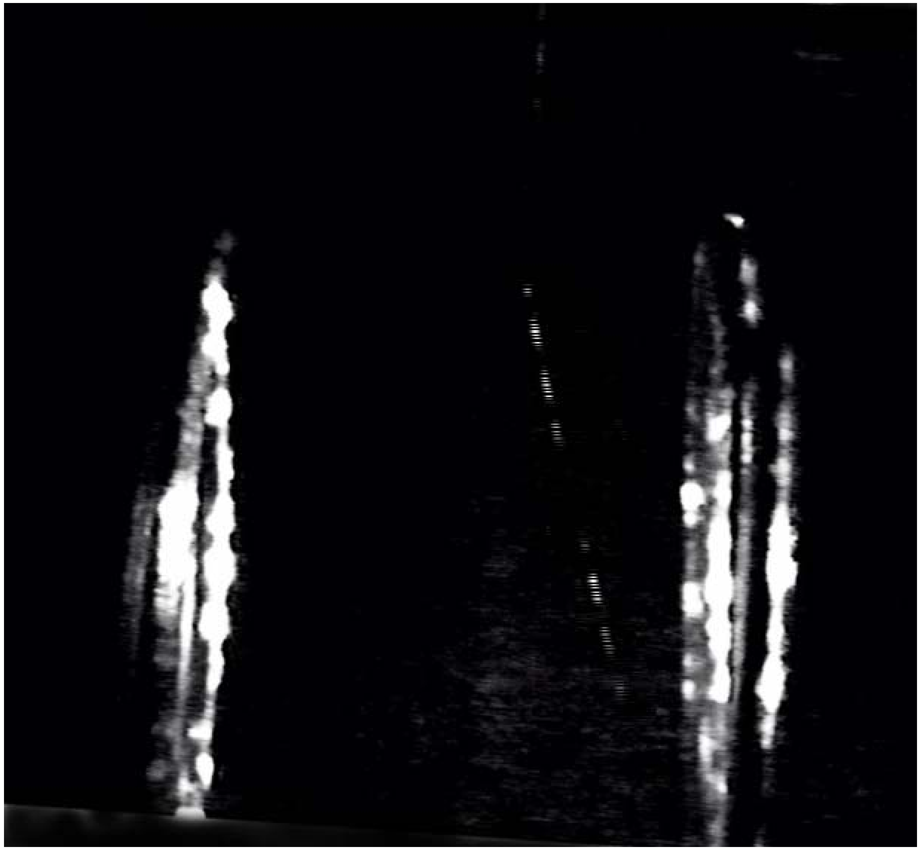
The solid line indicates the theoretical vacuum potential. The squares represent the measured potentials from the centre of the rings out. The vertical line is the location of the rings.

Voltage versus Position



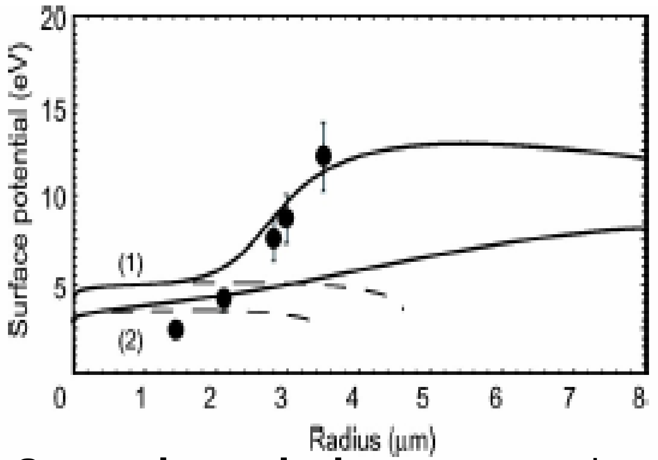
The x and y axis are in the form of matrix indices, which are have a separation of 1mm.

Dust Deflection



dust particle being deflected towards the rings are visible on the left hand side

Suprathermal electron effect



Surface potential of levitating particles versus its size for two different electron temperatures: (1) 1.5eV; (2) 1eV. The solid lines represent the dependence in the presence of supra-thermal electrons. The dashed lines are in the absence of the supra-thermal electrons, they end at the maximum possible size for particle levitation. The data points are for Melamine formaldehyde particles.

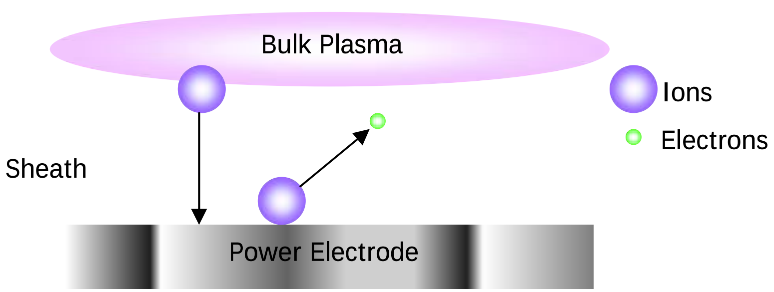
In our experiment, we managed to levitate 7 micron particles. This confirms the need to account for these electrons in sheath modeling.

$$I_e = \sqrt{8\pi} R_d^{\,2} n_e v_{Te} \exp\left(e\varphi_s / T_e\right) + \sqrt{8\pi} R_d^{\,2} n_e^h v^h_{Te} \exp\left(e\varphi_s / T_e^h\right)$$

$$I_e = \sqrt{8\pi} R_d^{\,2} n_e v_{Te} \exp\left(e\varphi_s / T^*_e\right)$$

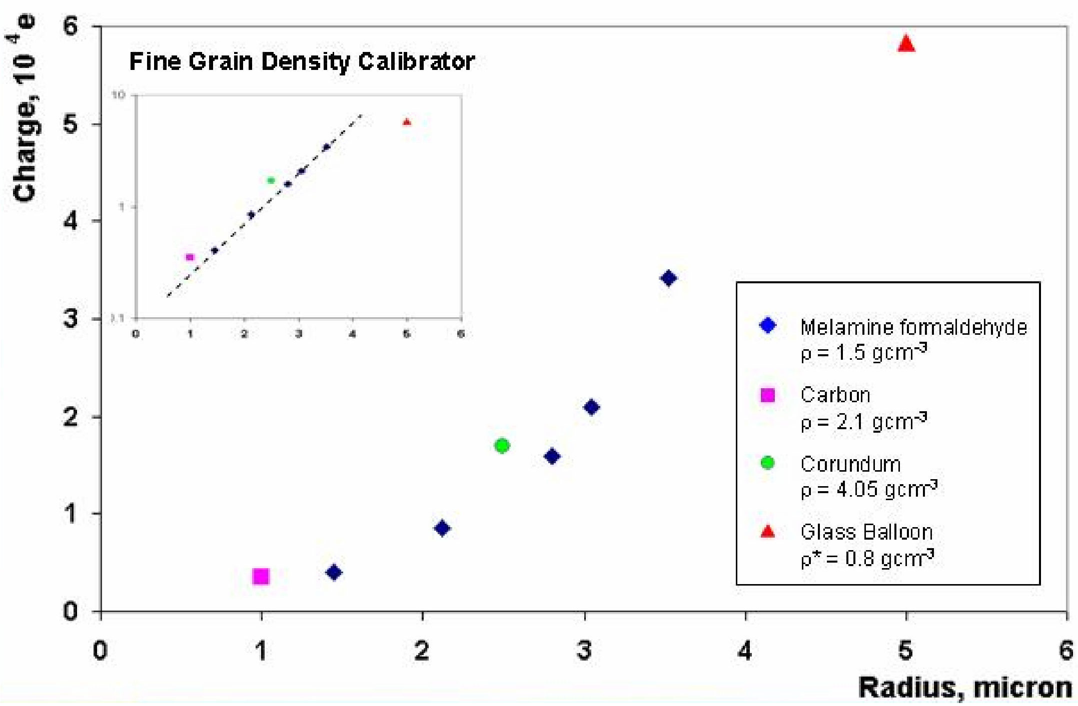
$$T_e^* = T_e \ln\left(1 + \gamma \exp\left(\frac{e\varphi_s (T_e^h - T_e)}{T_e^h T_e}\right)\right) \qquad \gamma = \frac{n_e^h}{n_e}$$

Supra-thermal electrons are the result of secondary emissions. These emissions are triggered by the ion bombardment of the electrode. These bombardments are caused by ions accelerated from sheath to electrode. Upon collision, they provide sufficient energy to knock electrons off the electrode.



The nonlinear dependence of the charge of particles levitated in the sheath indicates an increase of electron temperatures towards the electrode. This increase in temperature is most likely to be caused by the existence of the supra-thermal electrons. The increasing value of *g* towards the electrode leads to the increase of the effective electron temperature (which affects the particle charge) towards the electrode

Particle Charge as Density Calibrator



- Different dependencies of particle charge on its size can be obtained for different variations of effective electron temperature. The linear dependence can only be expected for uniform plasma.
- This suggests the possible development of such a system for measuring densities of micron or sub-micron objects and for discriminating powdered particles of any size.

Conclusions

- Micrometer sized particles can be used as a reliable diagnostic tool for sheath analysis
- The parabolic sheath approximation is valid for our operating range
- Particle charge approximation using the plasma floating potential if the particle is levitated close to the bulk plasma
- In order to determine the sheath structure accurately, the existence of supra-thermal electrons must be accounted for.
- The development of a plasma monitor tool using the particle levitation height as the prime measurement is viable
- The sheath can be used to differentiate powders of various sizes and densities