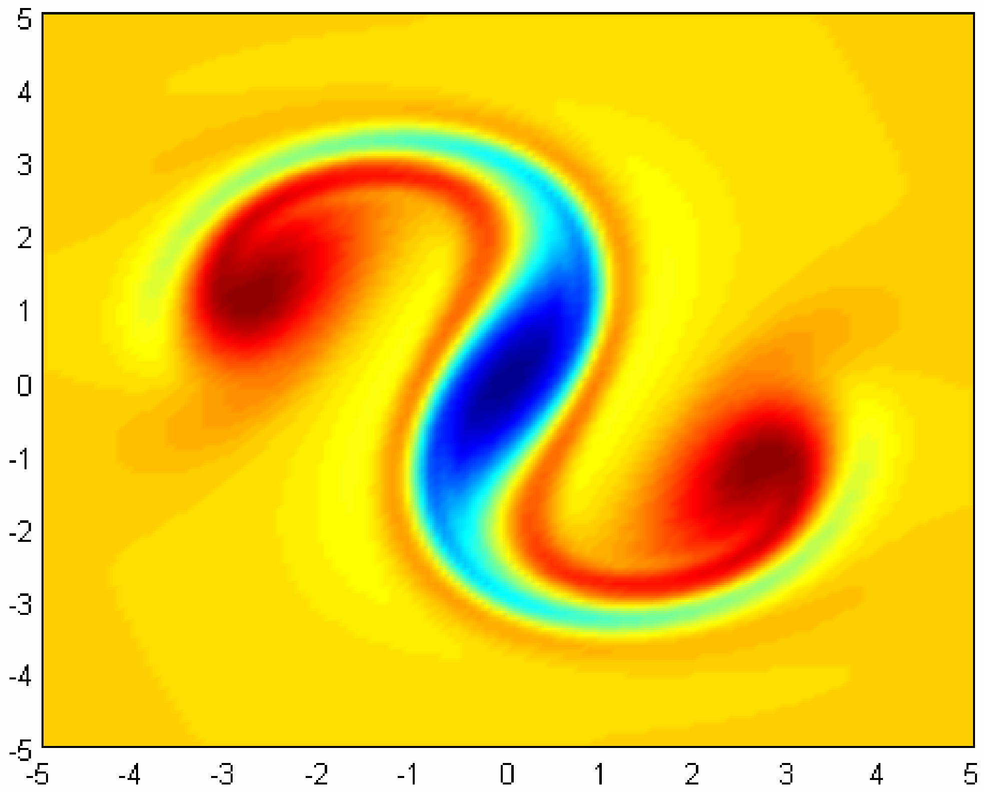
The University of Sydney
AUSTRALIA

Vortex Structures in Complex Plasmas



A.A Samarian

School of Physics, University of Sydney

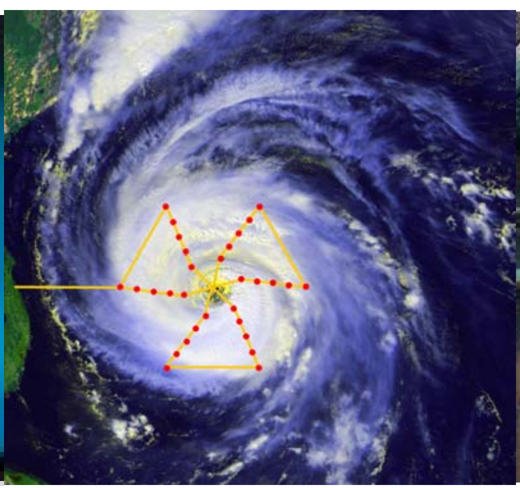
Outlines

- Introduction
- The experimental set-up
- Experimental observation of vortices
- Velocity distribution
- Description and implementation of model
- Simulated and experimental results
- Conclusion

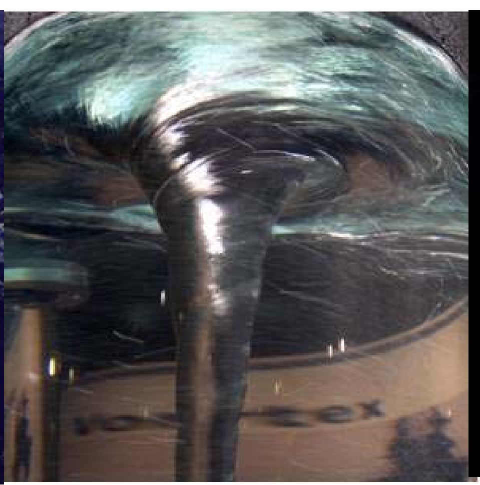
Introduction

- Dust vortices provide an opportunity to study large scale vortex structures on a kinetic level

Tornado



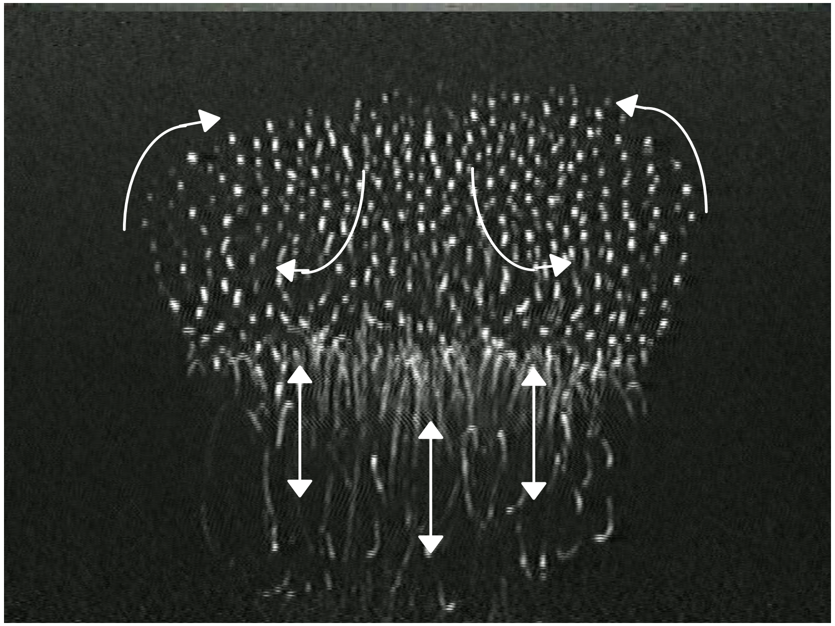
Cyclone



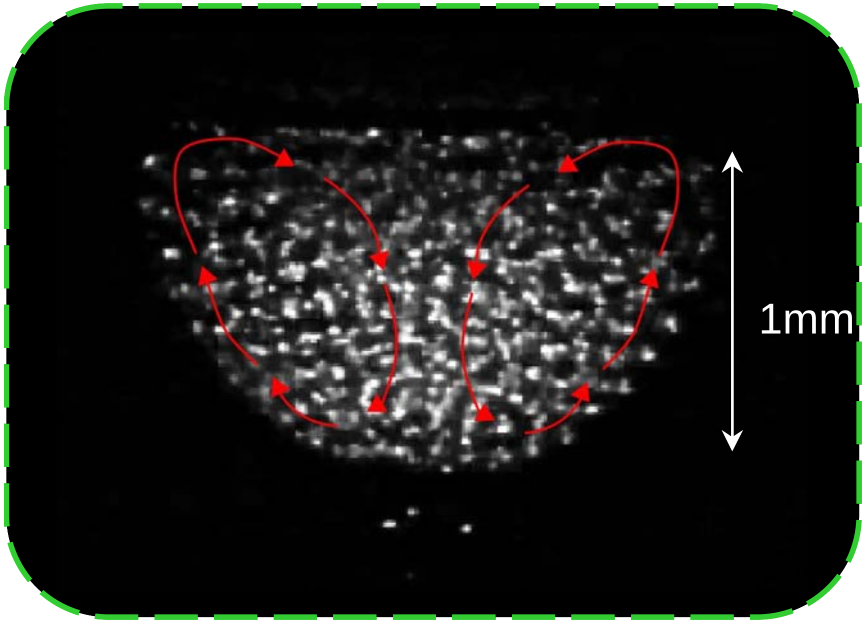
Water Vortex

Galaxy

Experimental Observation of Vortices



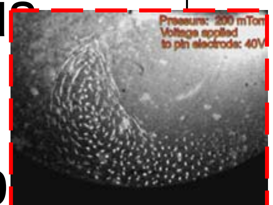
DC Discharge

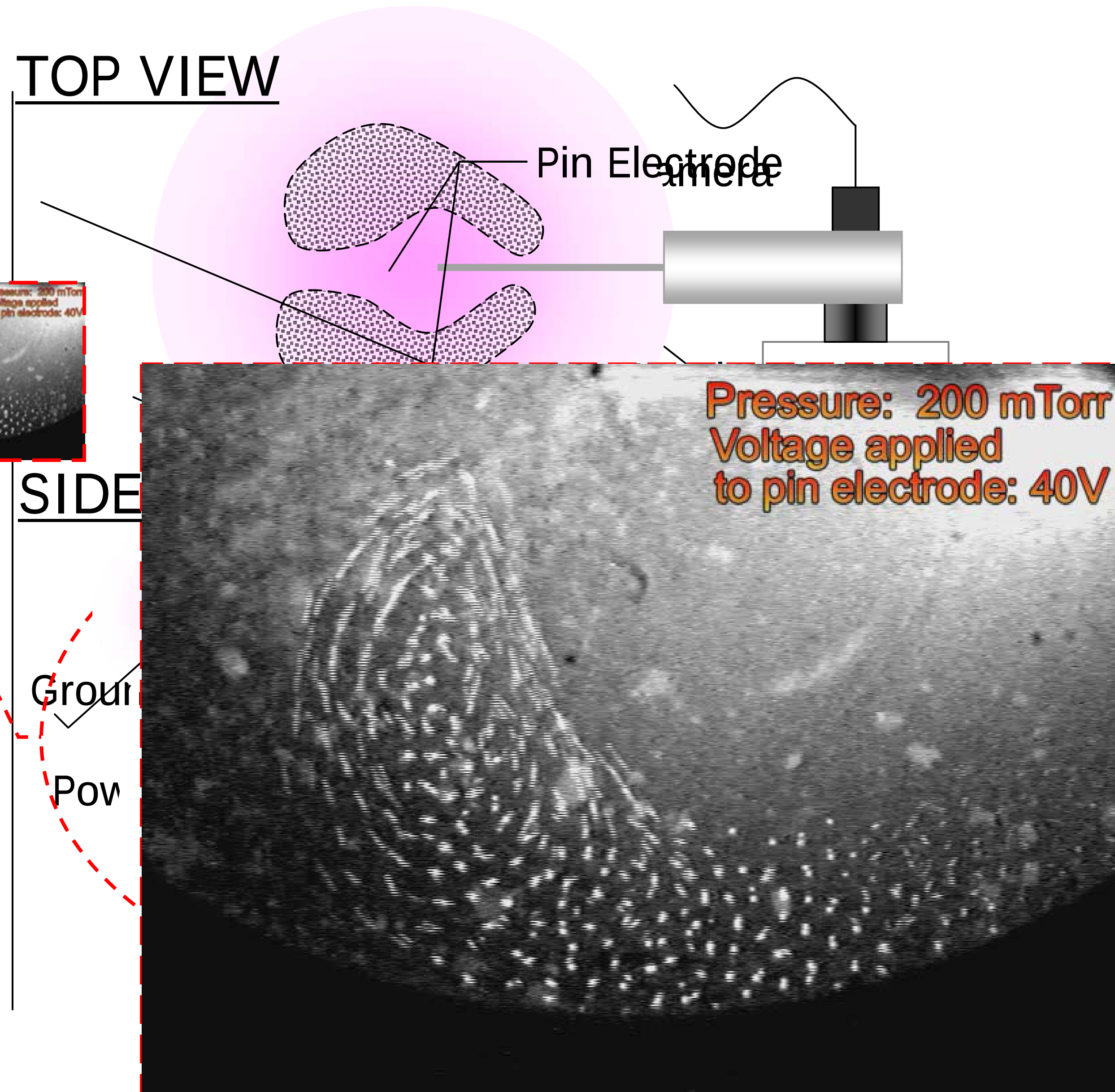


IC RF Discharge

Experimental Observation of Vortices

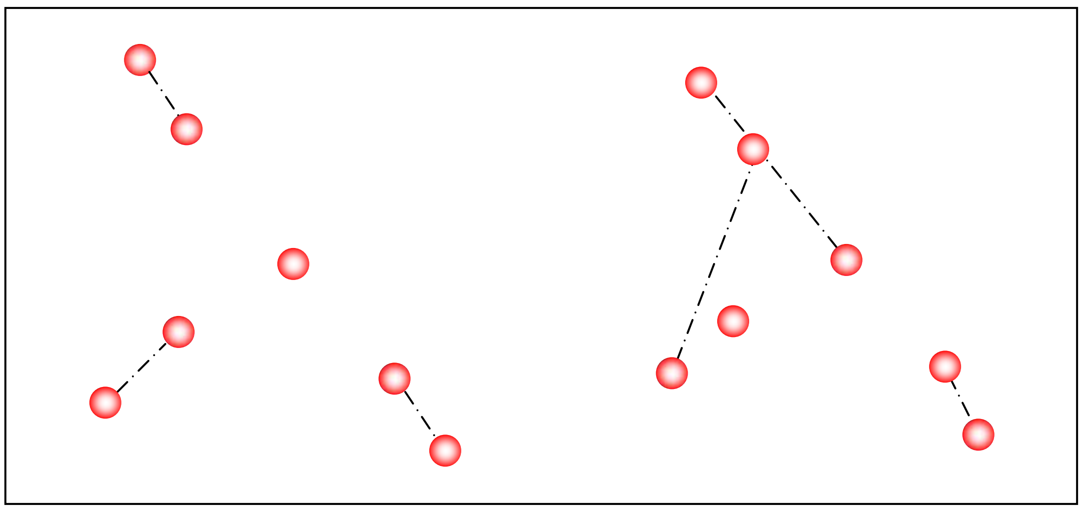
- Vortex Excitation
  - Non-homogenous plasma
  - Additional p electrode
  - Vortex pair observed in horizontal plane
  - Rotation toward probe tip



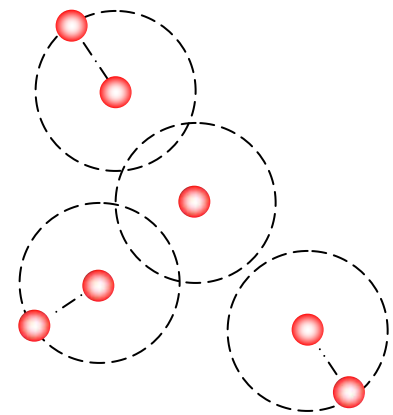


Analysis of Data

- Applied Tracking program



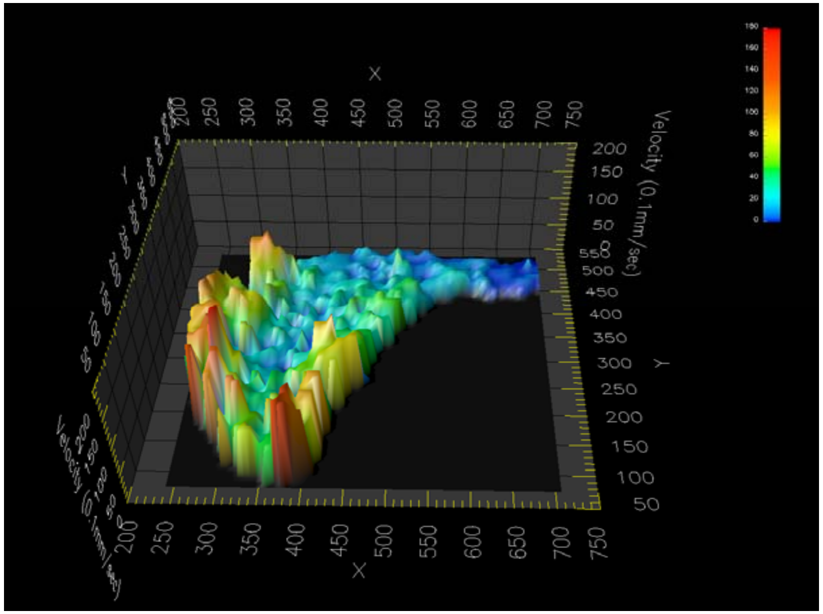
Problems with the “Closest Dust” algorithm

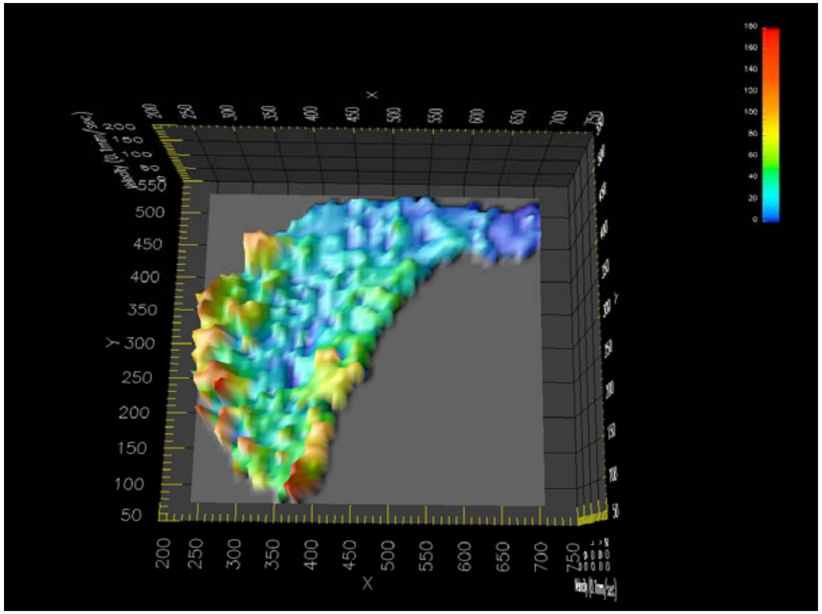


Method used

- Frame n
- Frame n + 1

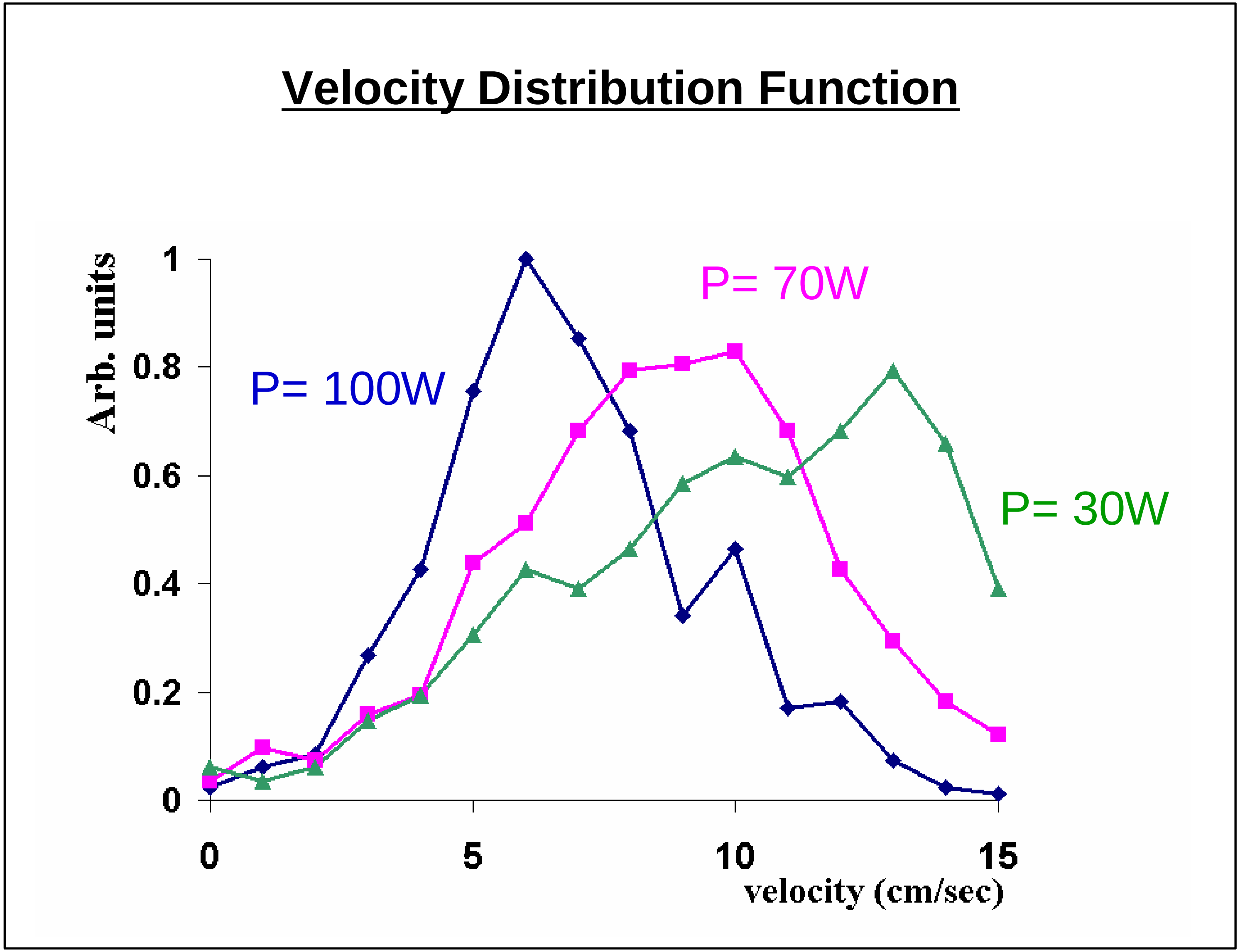
Visualisation of Velocity Map





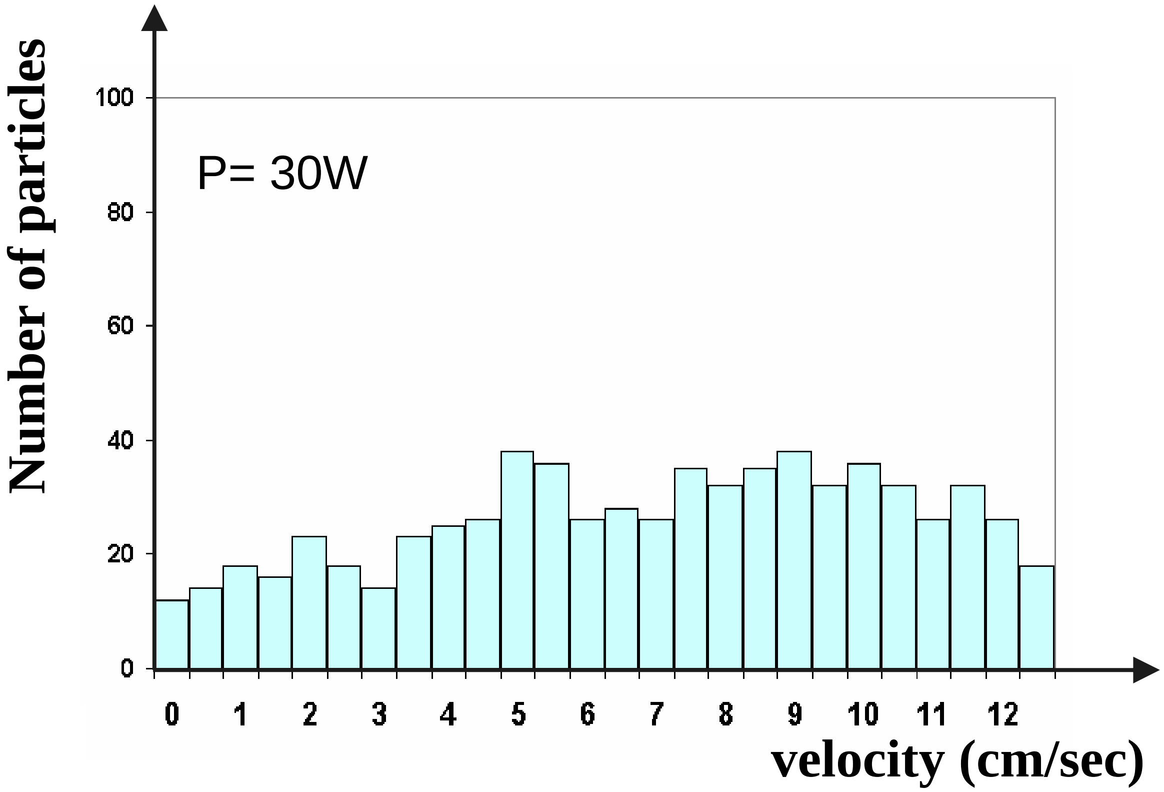
Real time rendered version

Velocity distribution

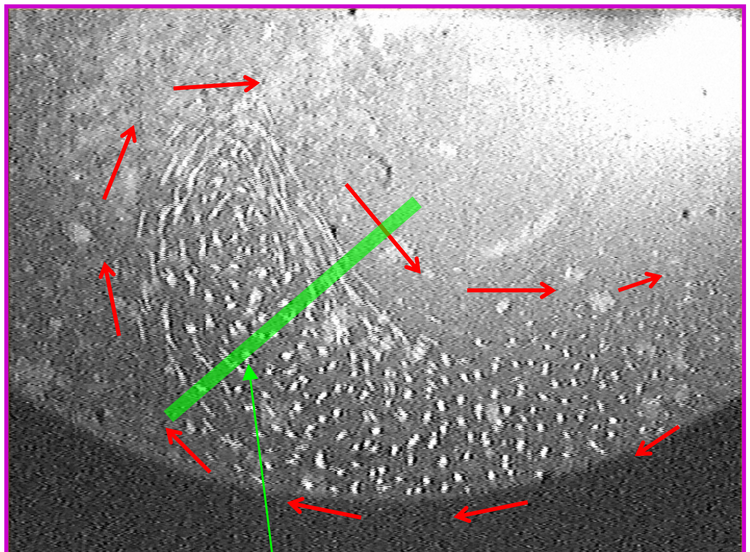


Velocity Distribution

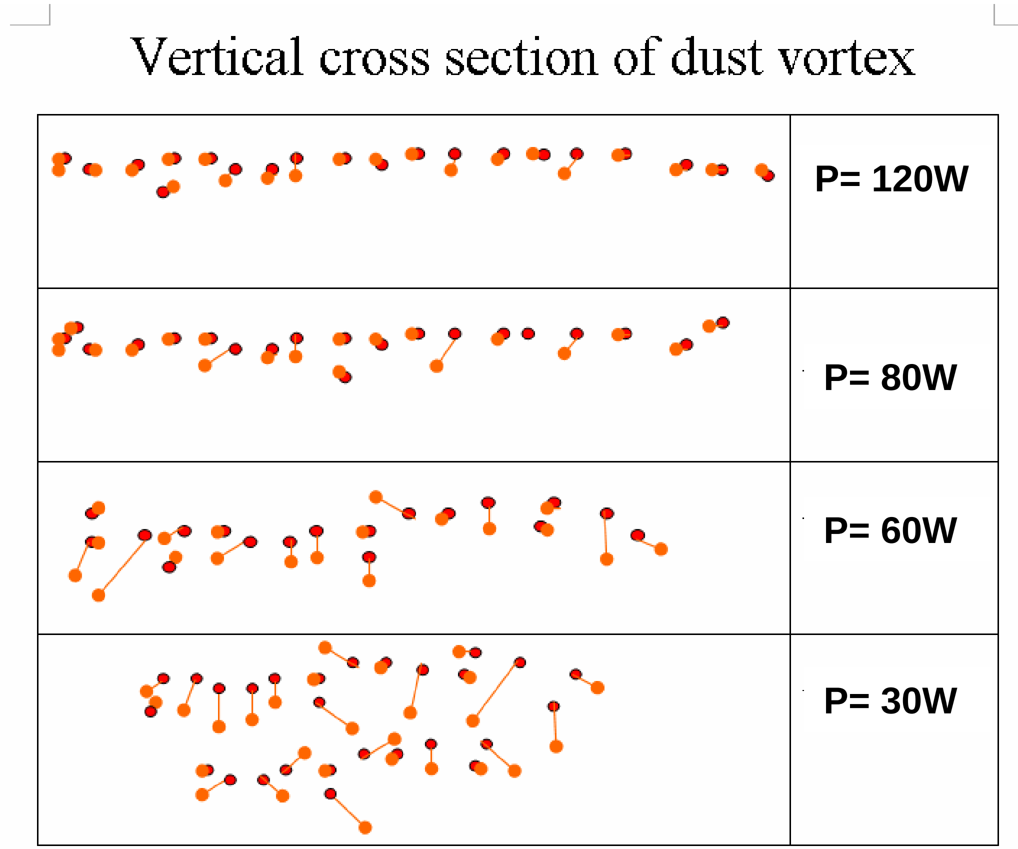
The Effect of Power on Velocity Distribution in Horizontal Plane



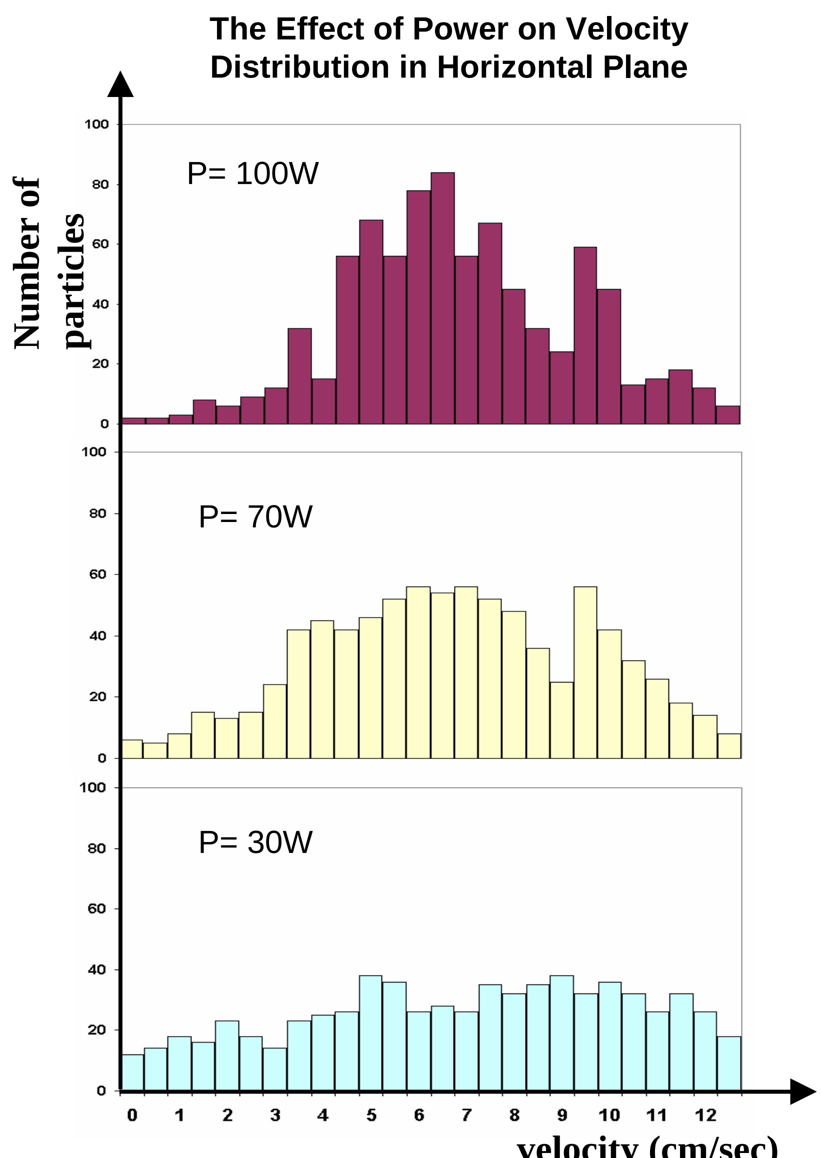
Vertical Cross Section

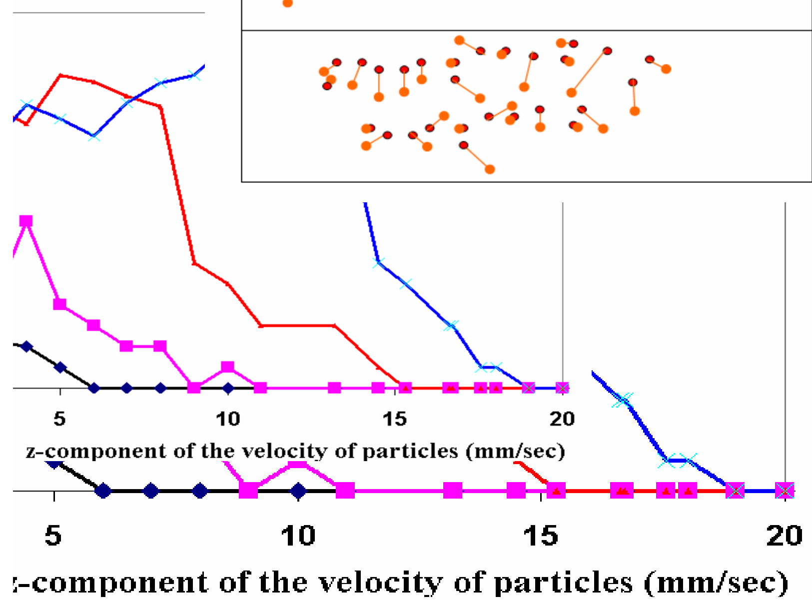


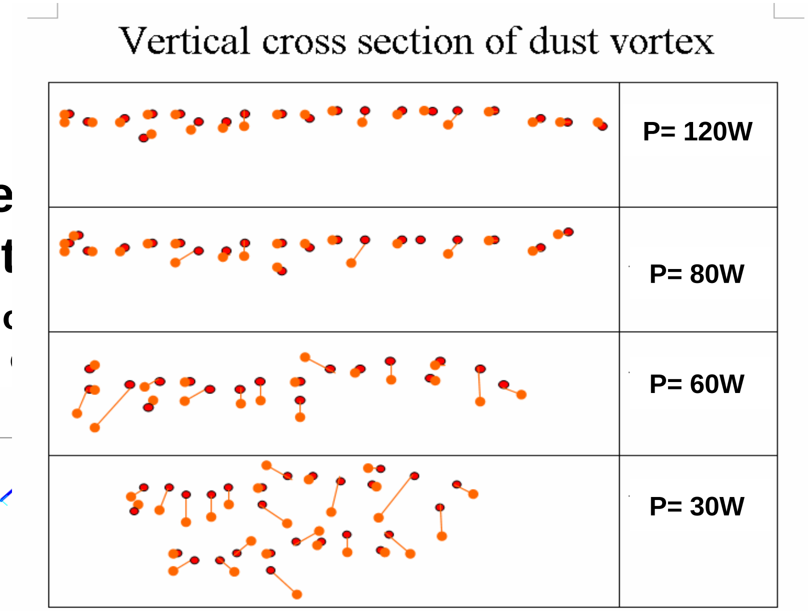
Vertical Cross Section



Vertical Component of Particle Velocity







Model Description

- Based on standard 2-D MHD equations:
  - Momentum equation:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \bullet \nabla)\mathbf{u} = \frac{-\nabla p}{nm} + \frac{q_{dust}}{m}(\mathbf{E} + \mathbf{u} \times \mathbf{B}) - \upsilon_f \mathbf{u}$$

- Introducing Vorticity: $\omega = \nabla \times \mathbf{u}$
  - Taking the curl of the momentum equation
  - Neglecting B fields and assuming incompressibility

Governing Equations

- Vorticity-Streamfunction form:

$$\nabla^2 \psi = -\omega$$

$$\mathbf{u} = \nabla \times (0,0,\psi)$$

$$\frac{\partial \omega}{\partial t} + (\mathbf{u} \bullet \nabla)\omega = \nabla \times \frac{q_{dust}}{m}\mathbf{E} - \upsilon_f \omega$$

- Form a closed set assuming q and E are known.

Vortex Generation

- Source term in vorticity equation:

$$\nabla \times \frac{q}{m}\mathbf{E} = \frac{1}{m}\left(E_y \frac{\partial q}{\partial x} - E_x \frac{\partial q}{\partial y} - q\nabla \times \nabla \phi \right)$$

$$= \frac{1}{m}\left(E_y \frac{\partial q}{\partial x} - E_x \frac{\partial q}{\partial y} \right)$$

- Charge gradient required for vortex excitation!

Plasma Model

- E field obtained from Poisson's equation:

$$\varepsilon_0 \nabla \bullet \mathbf{E} = \left(e\left(n_i - n_e\right) + q_{dust} n_{dust} + q_{probe}\right)$$

- Due to bulk electro-neutrality, approx:

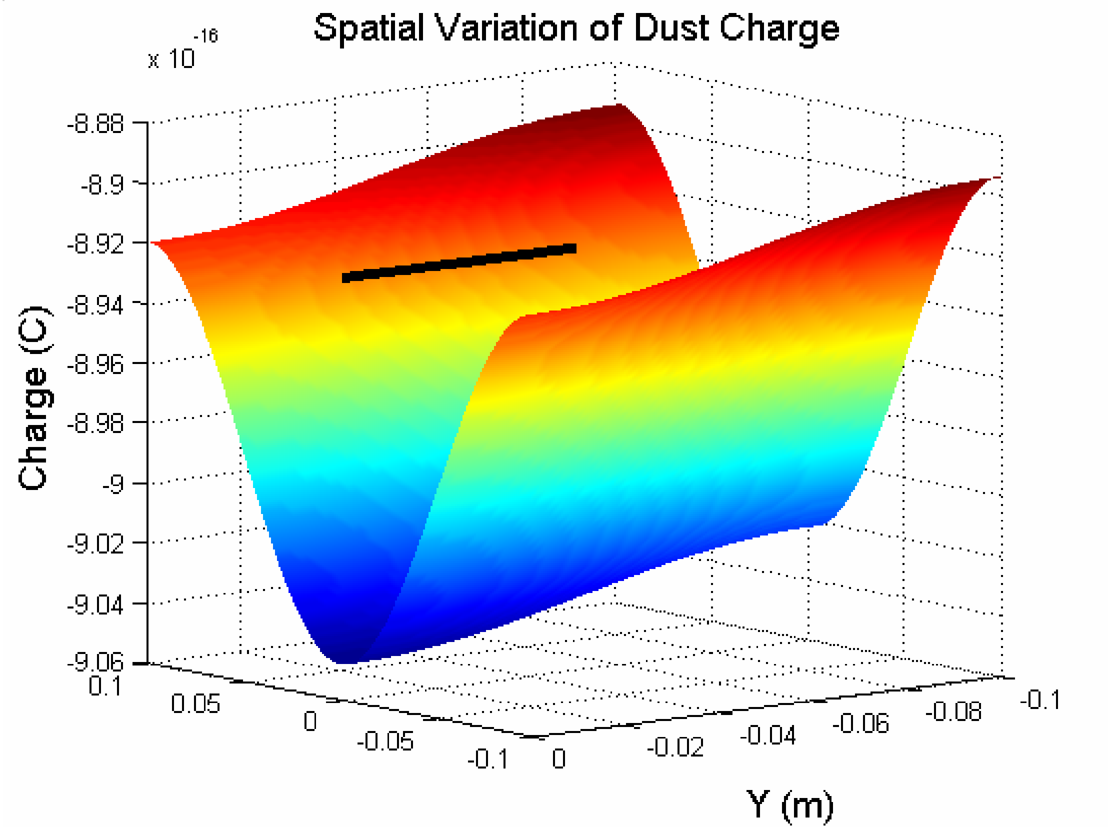
$$\varepsilon_0 \nabla \bullet \mathbf{E} = q_{probe}*$$

- Charge value chosen to approximate experimental potential

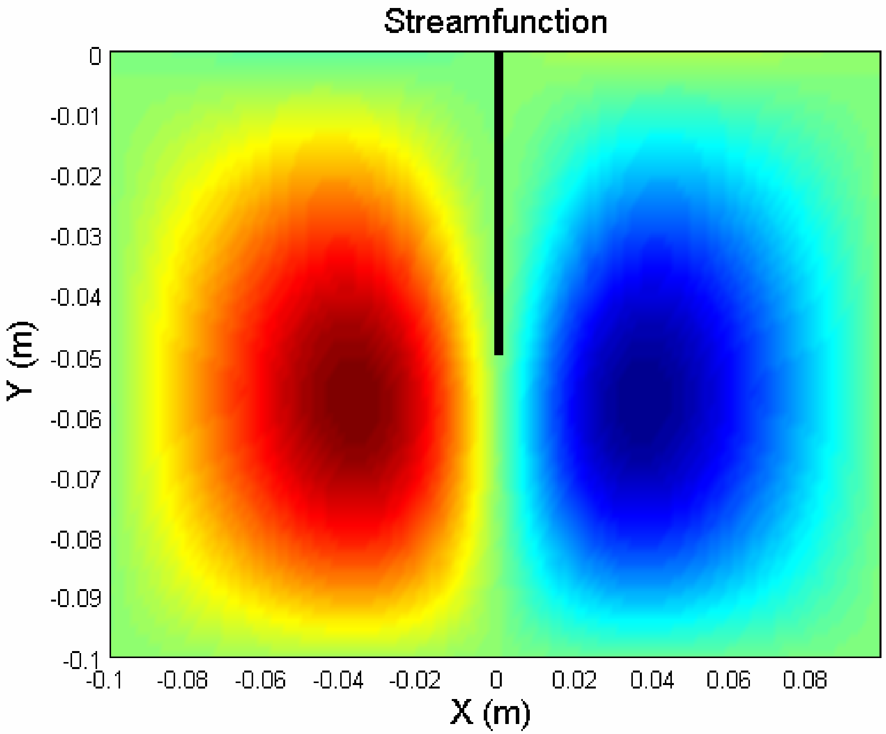
Dust Charge

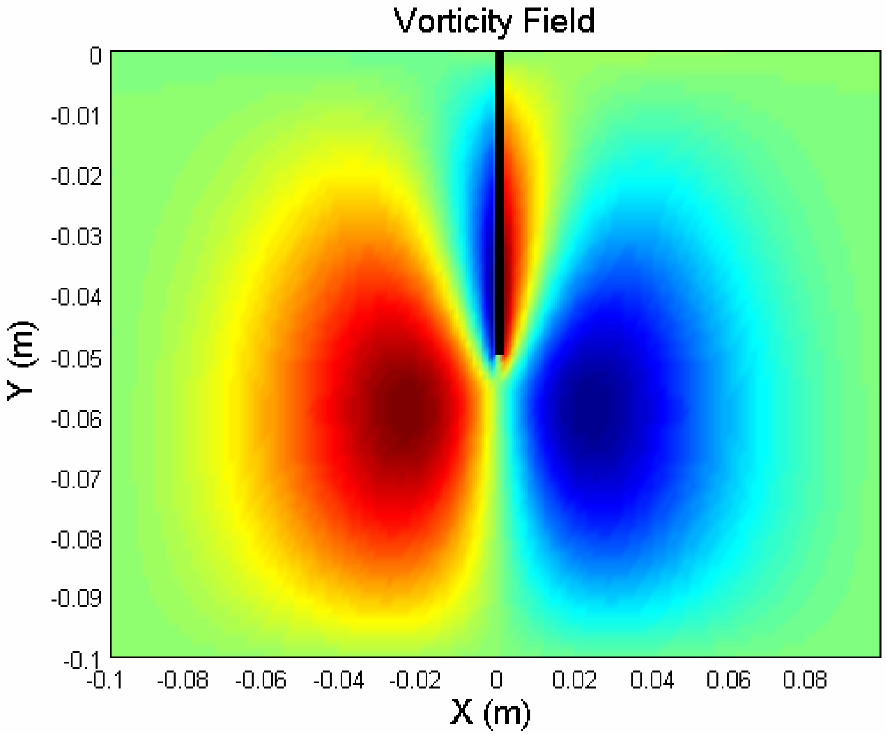
$$q_{dust}(T_e, v_i, n_i, n_e) = -e\left(\langle Z \rangle + \Delta Z(x, y)\right)$$

- Charge function:



Simulated Vortices





vf = 100 (s^{-1}), **dQ** ~ 2%<Q>, **V** = 20V

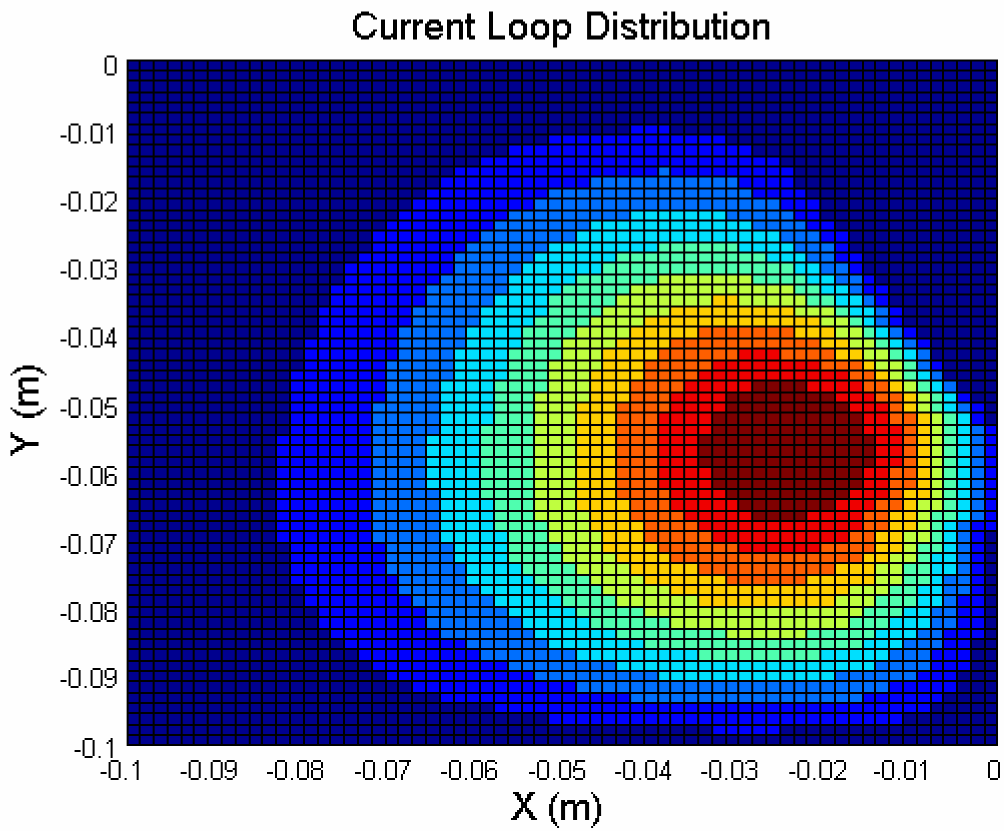
* Blue is clockwise rotation

Results

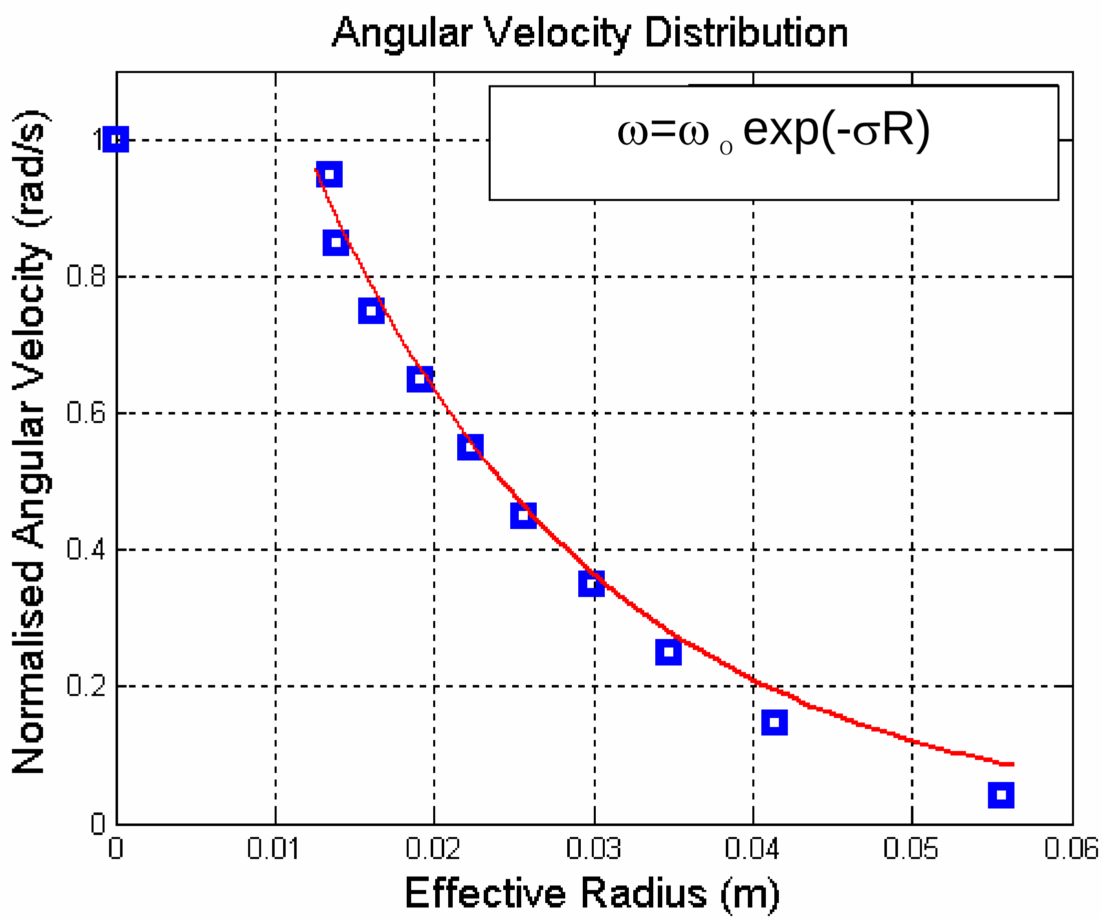
- Angular velocity distribution obtained from a current loop analysis

$$\Omega = \frac{1}{2}\nabla \times \mathbf{u}$$

$$= \frac{\omega}{2}$$

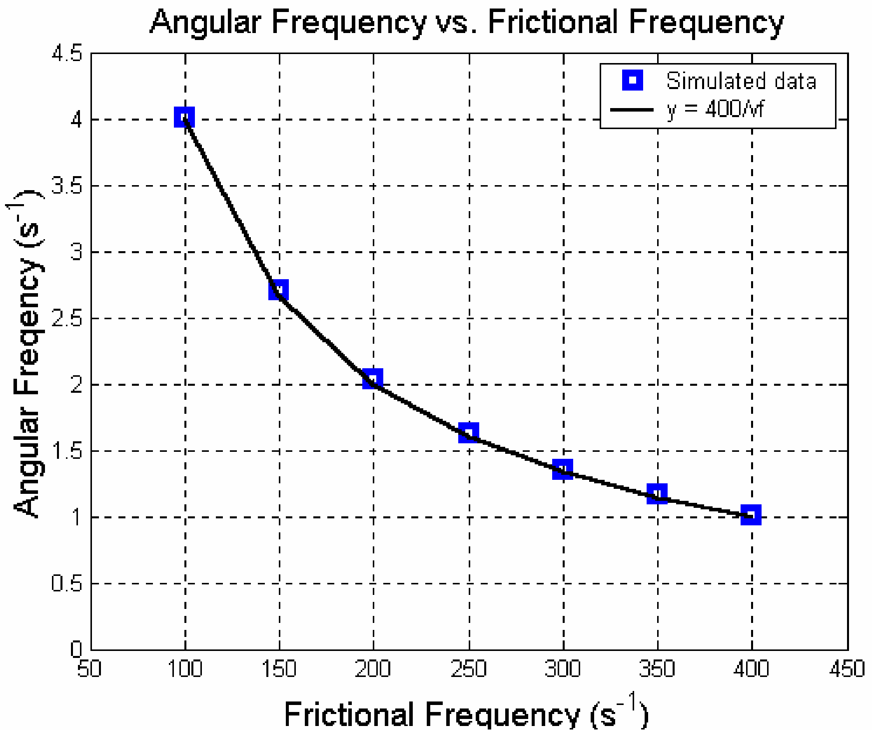


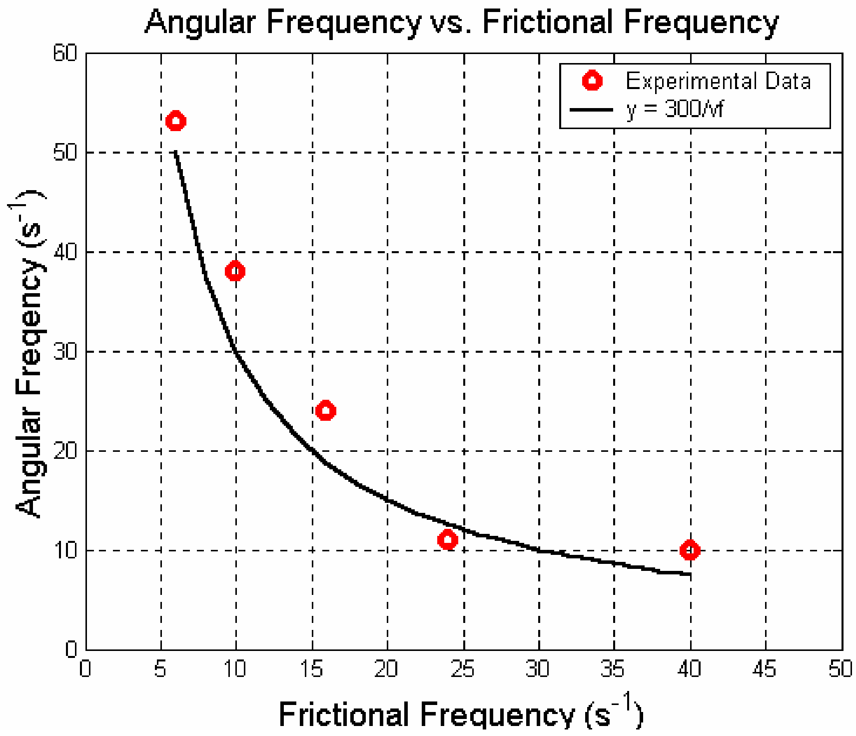
Results



Angular Velocity Distribution
ω=ω o exp(-σR)
Normalised Angular Velocity (rad/s)
Effective Radius (m)
0
0.2
0.4
0.6
0.8
1
0
0.01
0.02
0.03
0.04
0.05
0.06

Results





dQ ~ 2%<Q>, **V** = 20V

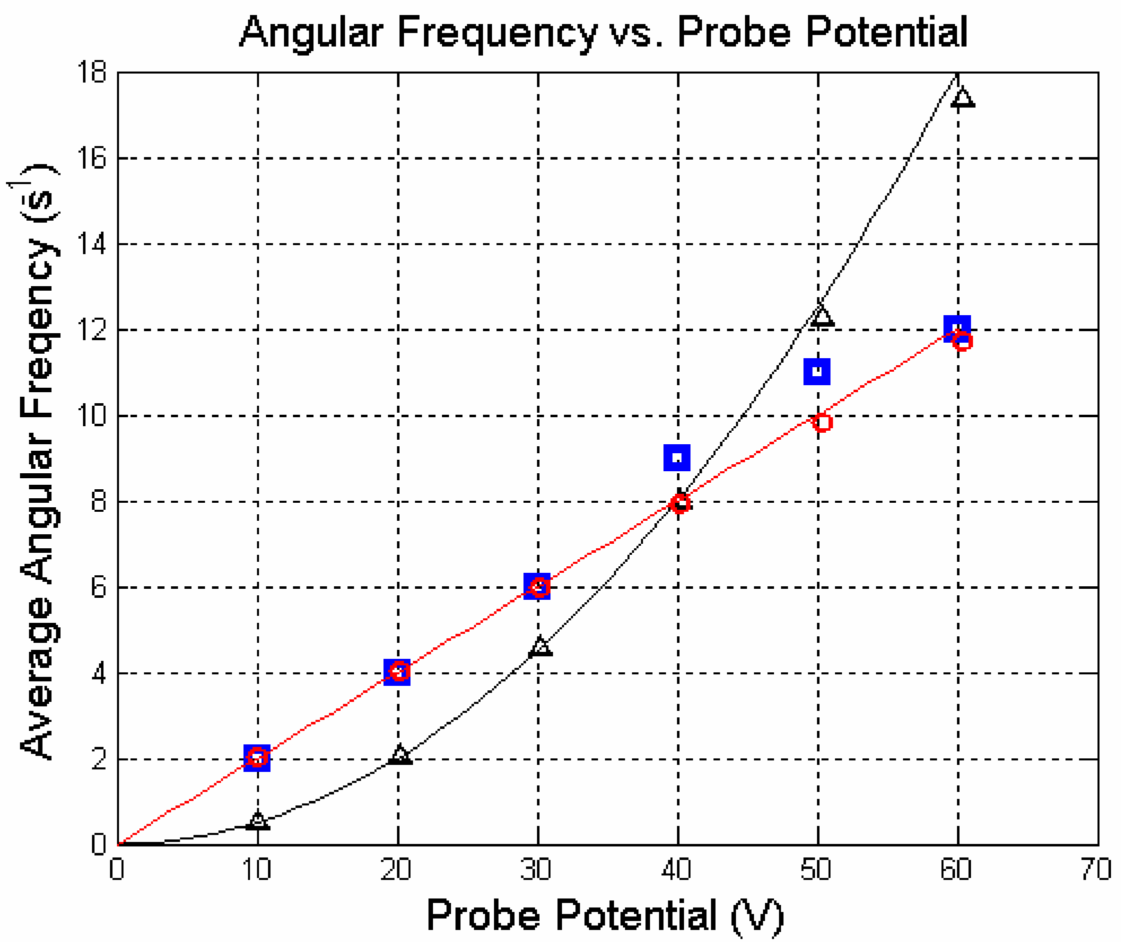
Samarian, A.A, Vaulina, O., Tsang, W., James, B.W (2002). *Formation of Vertical and Horizontal Dust Vortexes in an RF-Discharge Plasma.* Physica Scripta T98

Results

- $dQ = A*V_{probe}$
  $0<dQ<4\%<Q>$

- Constant dQ
  $dQ \sim 2\%<Q>$

vf = 100 (s^{-1})



Conclusions

- The proposed model is capable of modeling vortex structures in complex plasmas
- Vortex generation requires gradient of dust charge
- Vortex characteristics independent of charge magnitude, determined by charge gradient
- Experimental support for the simulated vortices given for:
  - General angular velocity distribution
  - Variation of angular frequency with frictional frequency
  - The dependence of angular frequency on pin electrode potential assuming the dust charge gradient was held constant