Dust as In-Situ Probes for Plasma Magnetic Field Interactions in a Dusty Plasma

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Motivation

- Lunar Swirls
  - Albedo patterns on the lunar surface.
  - No correlation to surface features.
  - Correlation to strong crustal magnetic fields.
  - Origin? Interaction of dust, plasma and magnetic fields?
- Magnetic Field Plasma Interaction
  - Fusion, Space Propulsion, Magnetospheres, etc.
- Development of a method to map electric forces in a plasma.

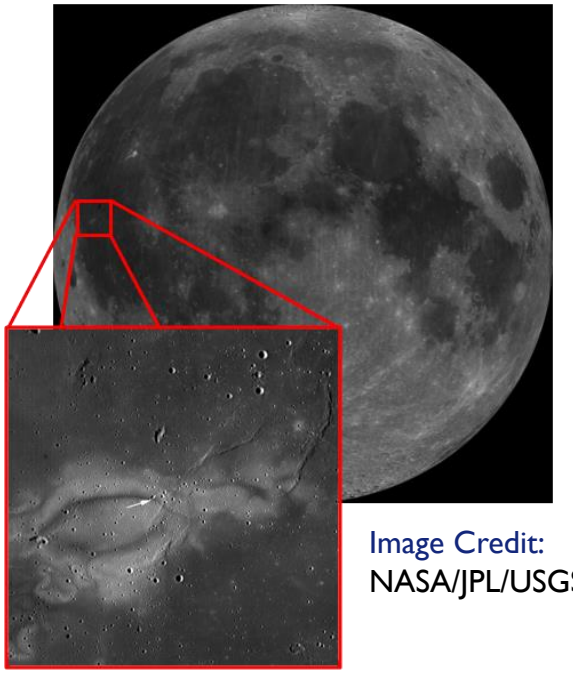
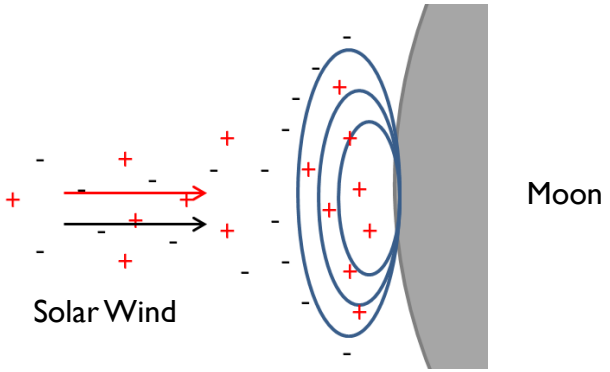
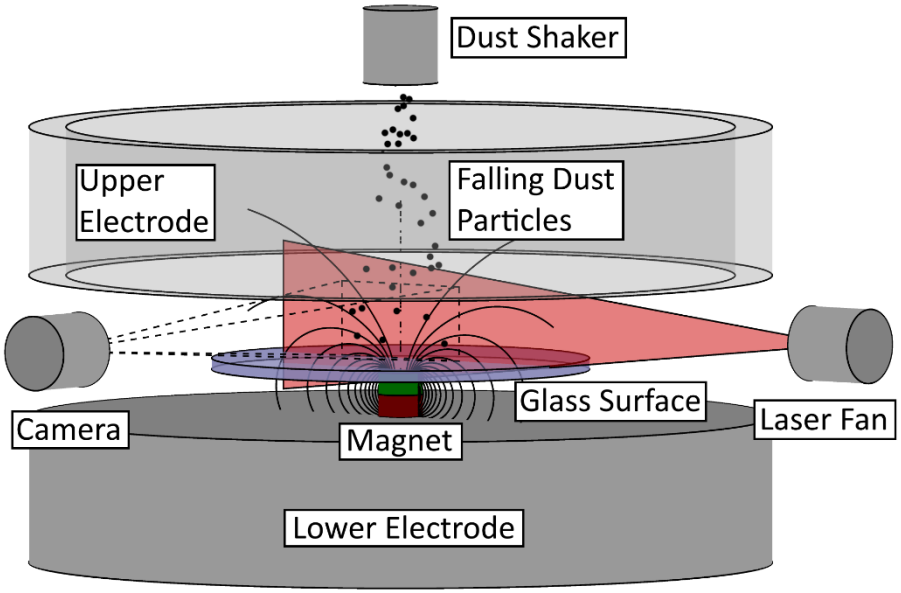


Image Credit:
NASA/JPL/USGS



Experimental Setup

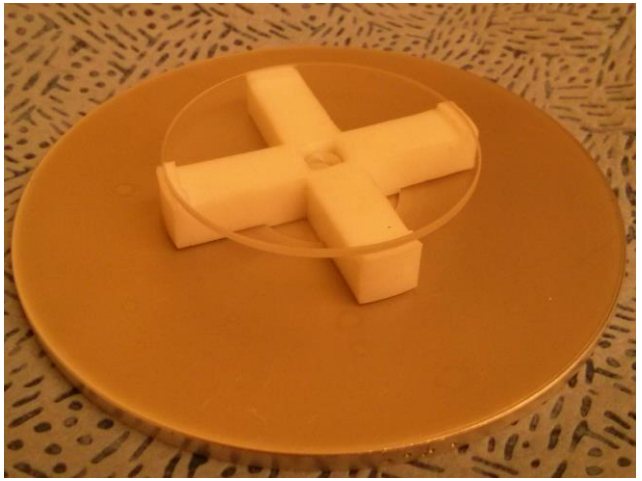
- Experiments in GEC RF reference cell.
- Investigation of plasma magnetic field interaction close to a non-conductive surface.
- Magnet platform (different magnet configurations possible) placed on lower electrode.

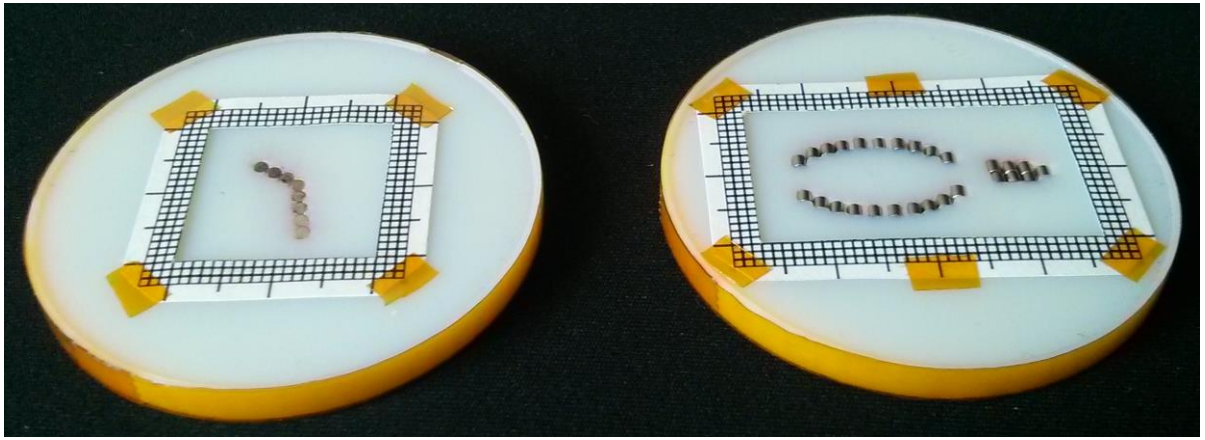


Parameter	Value
Pressure	5.3 Pa (40 mTorr)
Power	11 W
Bulk plasma density	$2 \cdot 10^{15}\ \mathrm{m}^{-3}$
Bulk electron temperature	5 eV
Magnetic flux density	< 0.3 T
Dust particles	12 micron MF

Experimental Setup

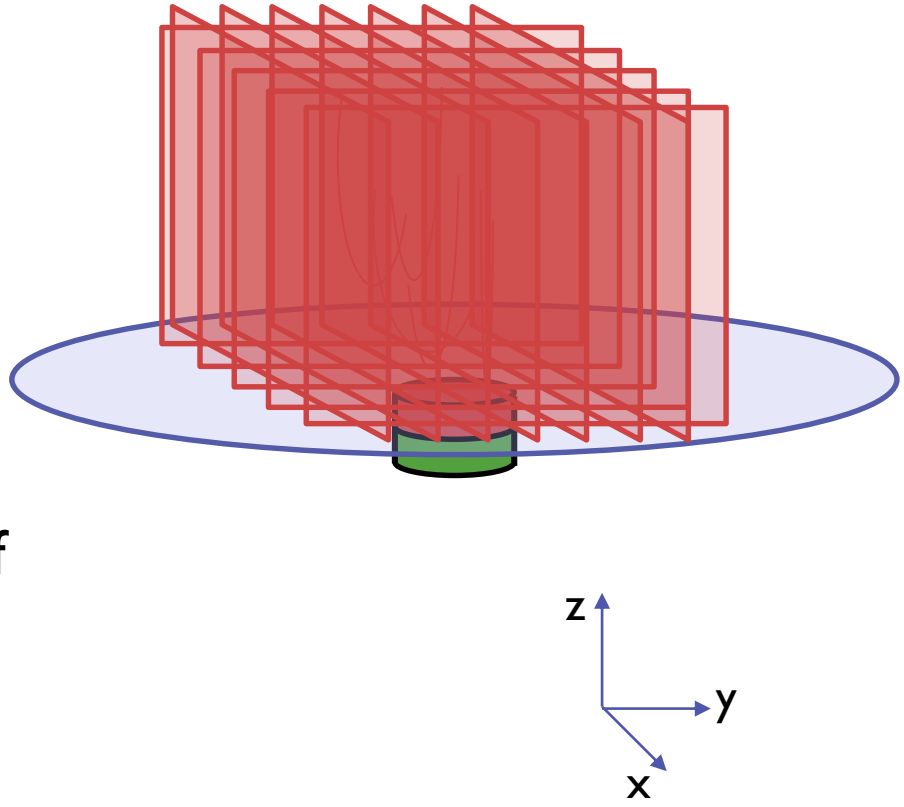
- Single neodymium dipole magnets of 6.35mm diameter in horizontal and vertical orientation.
- 3D-printed holders (ABS) for swirl magnetic field geometry with multiple neodymium dipole magnets with 1.6mm diameter.



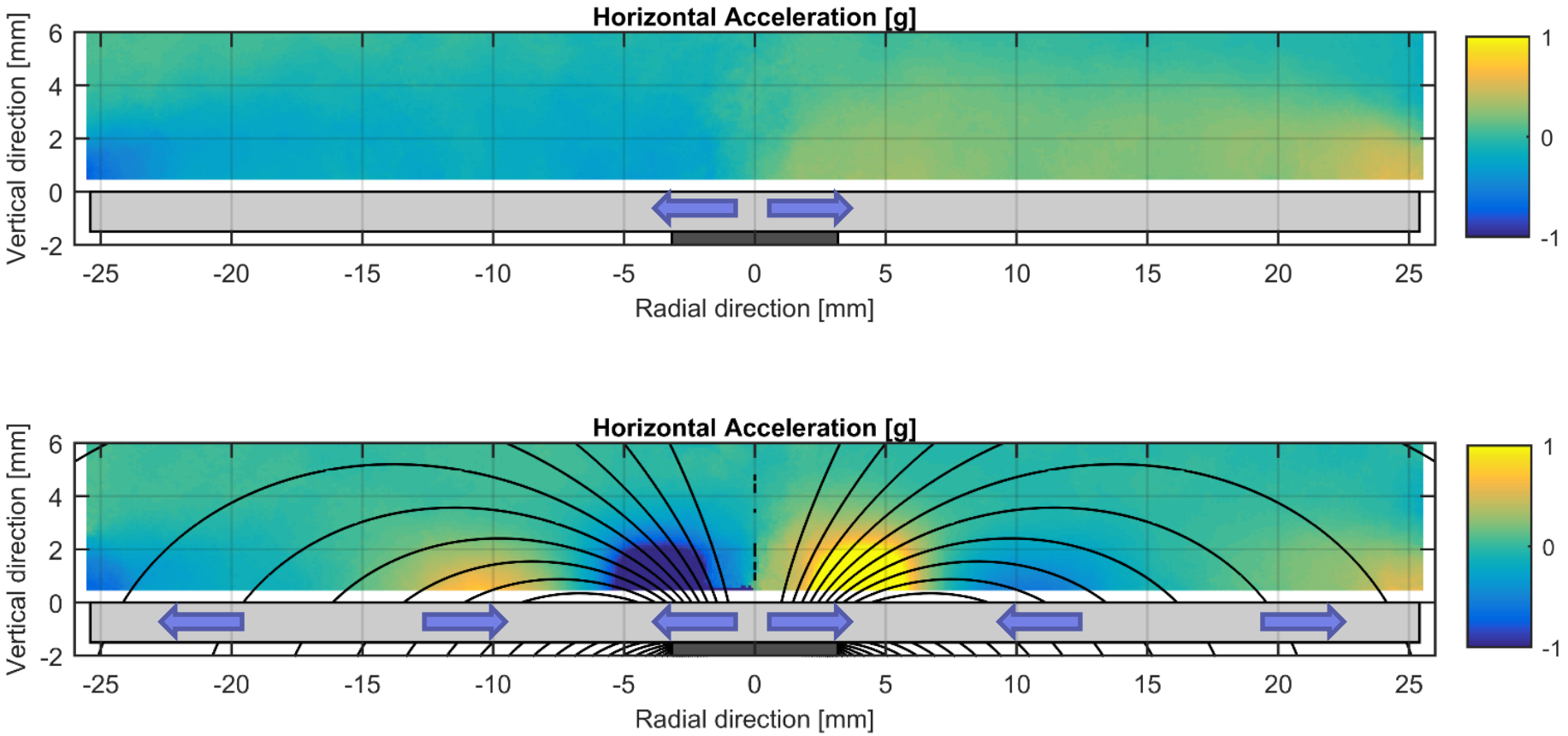


Analysis Method

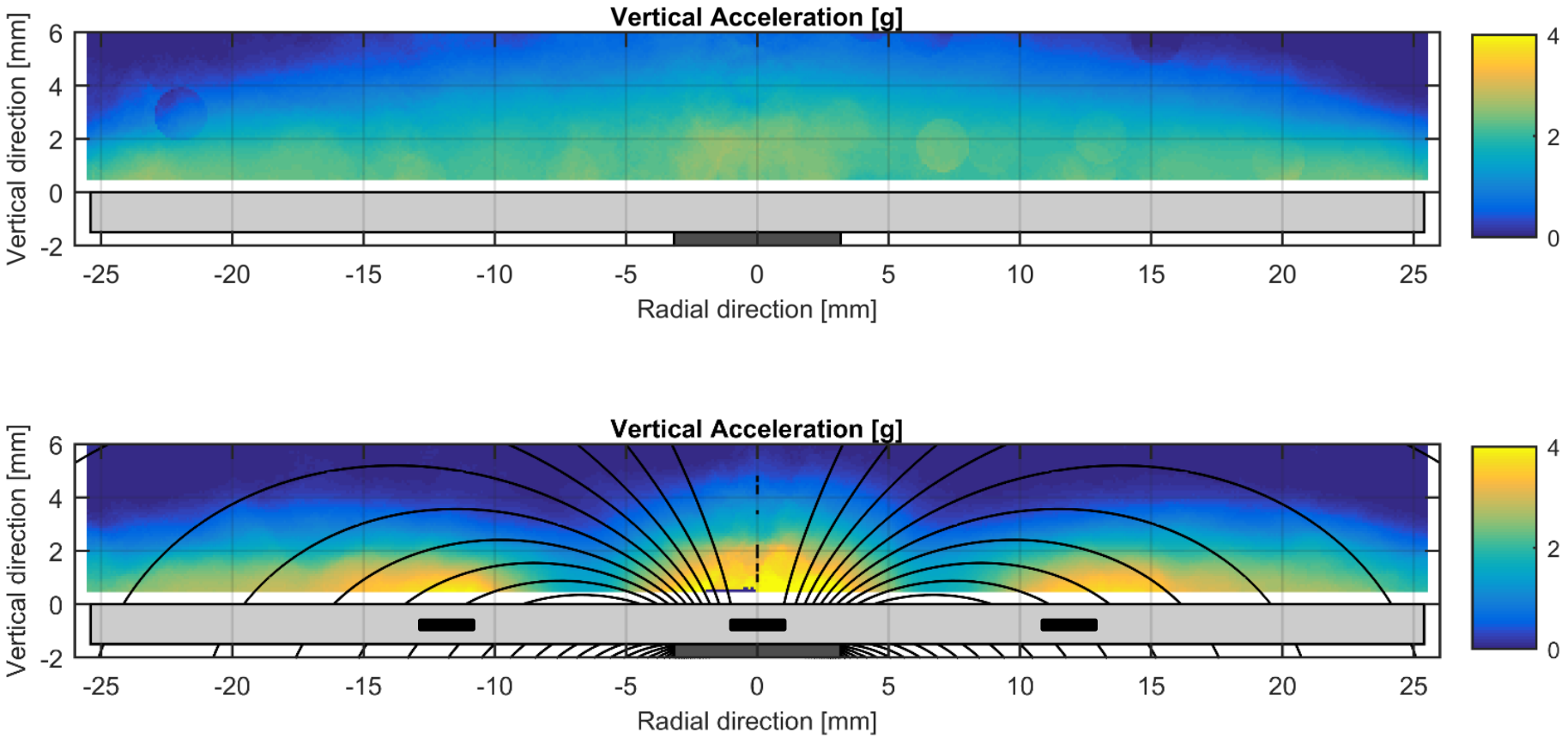
- By tracking dust particles in the laser fan with a high speed camera 2D-maps of dust accelerations can be generated.
- Moving the laser plane and taking data from two perspectives allowing creation of a 3D data set of the forces onto the dust particles.



Horizontal Accelerations (Single Dipole)

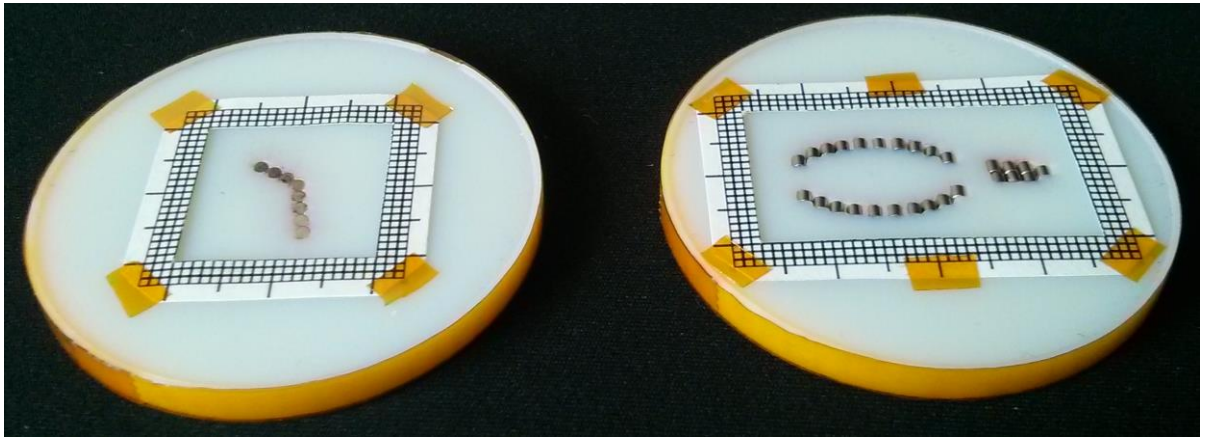


Vertical Accelerations (Single Dipole)

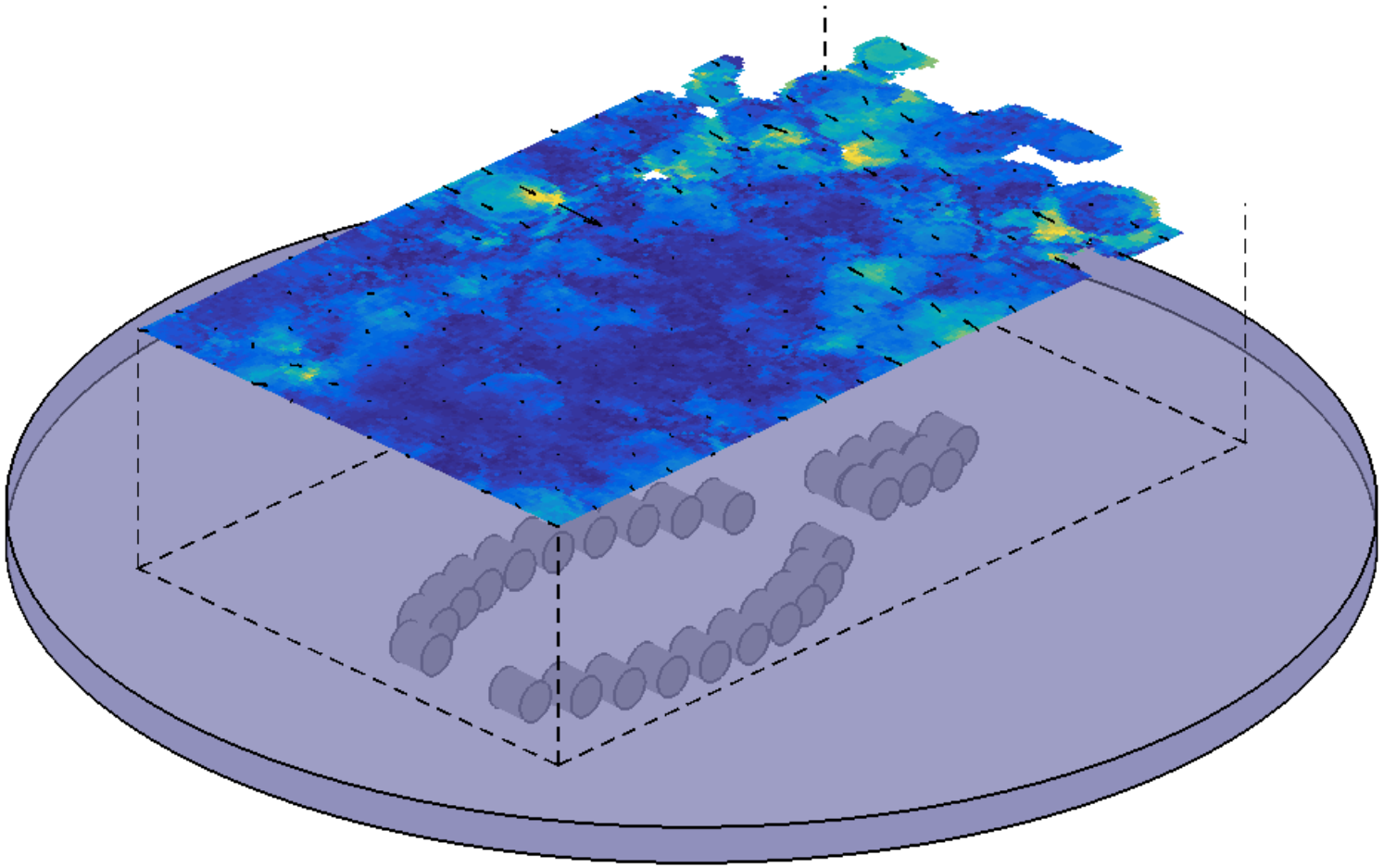


Small Scale Models of Lunar Swirls

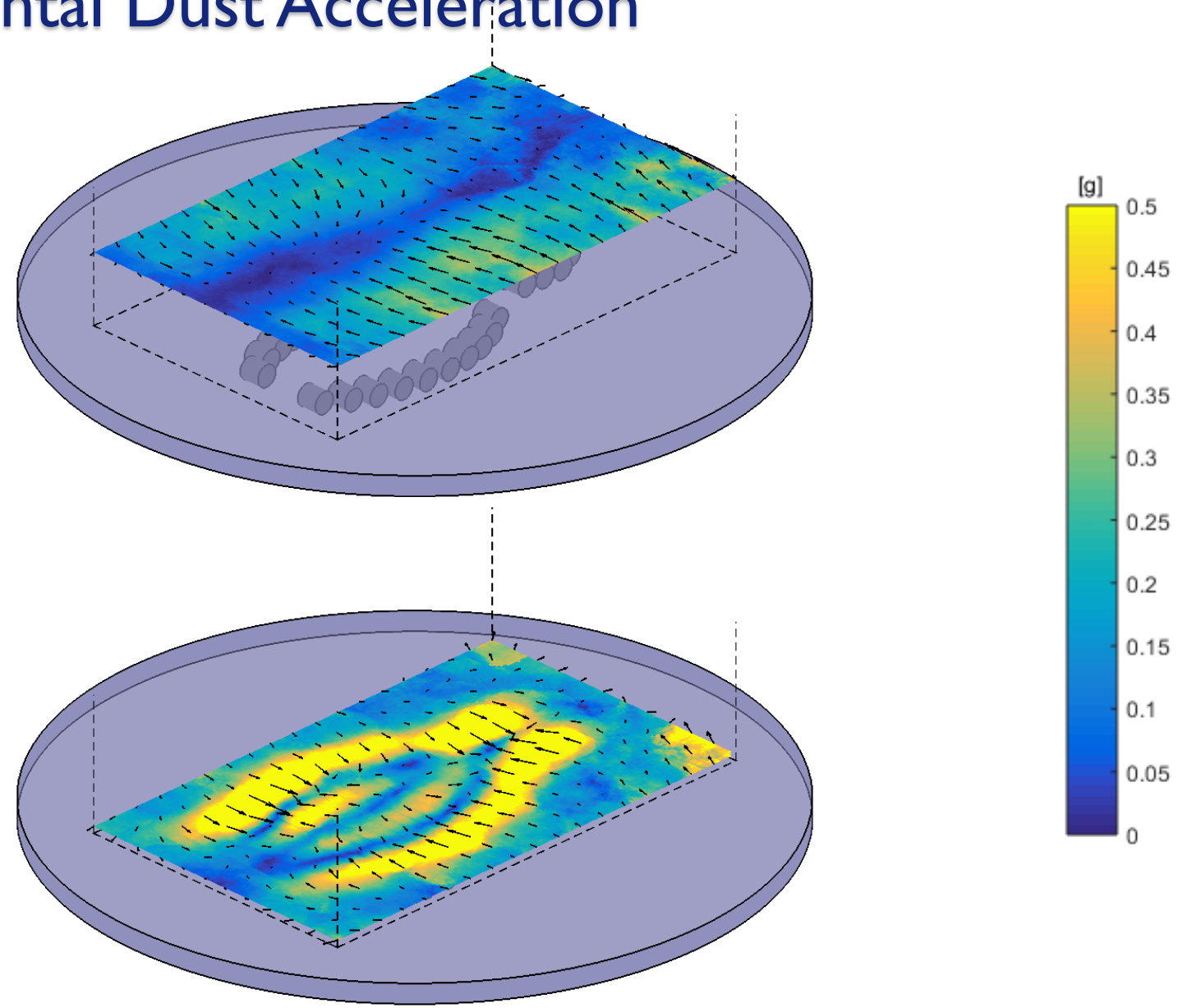
- Based on Lunar Prospector data the magnetic fields at Airy and Reiner-Gamma formation have been described by multiple dipole sources [Hemingway and Garrick-Bethell, JGR, 2012].
- Small scale versions (1:3,000,000 and 1:2,000,000) of these models have been built using dipole magnets and a 3D printer.



Reiner-Gamma Formation
Horizontal Dust Acceleration

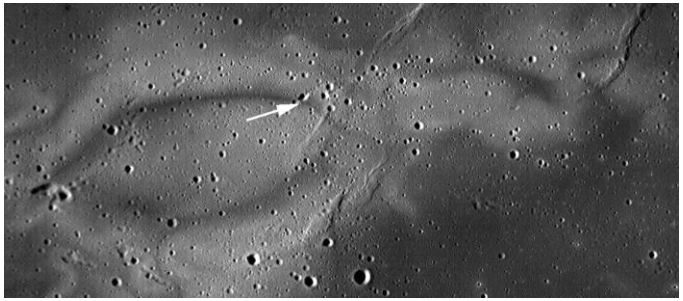


Reiner-Gamma Formation
Horizontal Dust Acceleration



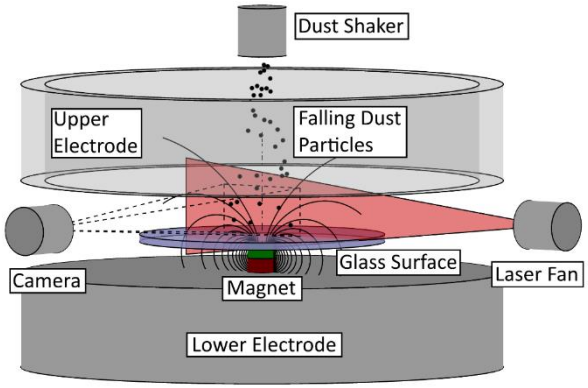
Analogy to Dust Transport on the Moon

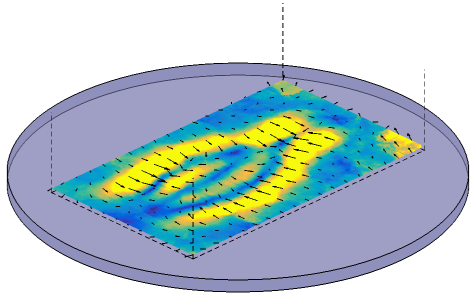
- Experiment:
  - Force and dust patterns resemble Lunar swirl.
  - Dust transported into regions of bright albedo.
- In lunar environment:
  - Dust charged positively by photemission, transport in opposite direction. *Contradicts dust transport theory of bright dust.*
  - Dark dust might be transported or immature surface uncovered.



Conclusions

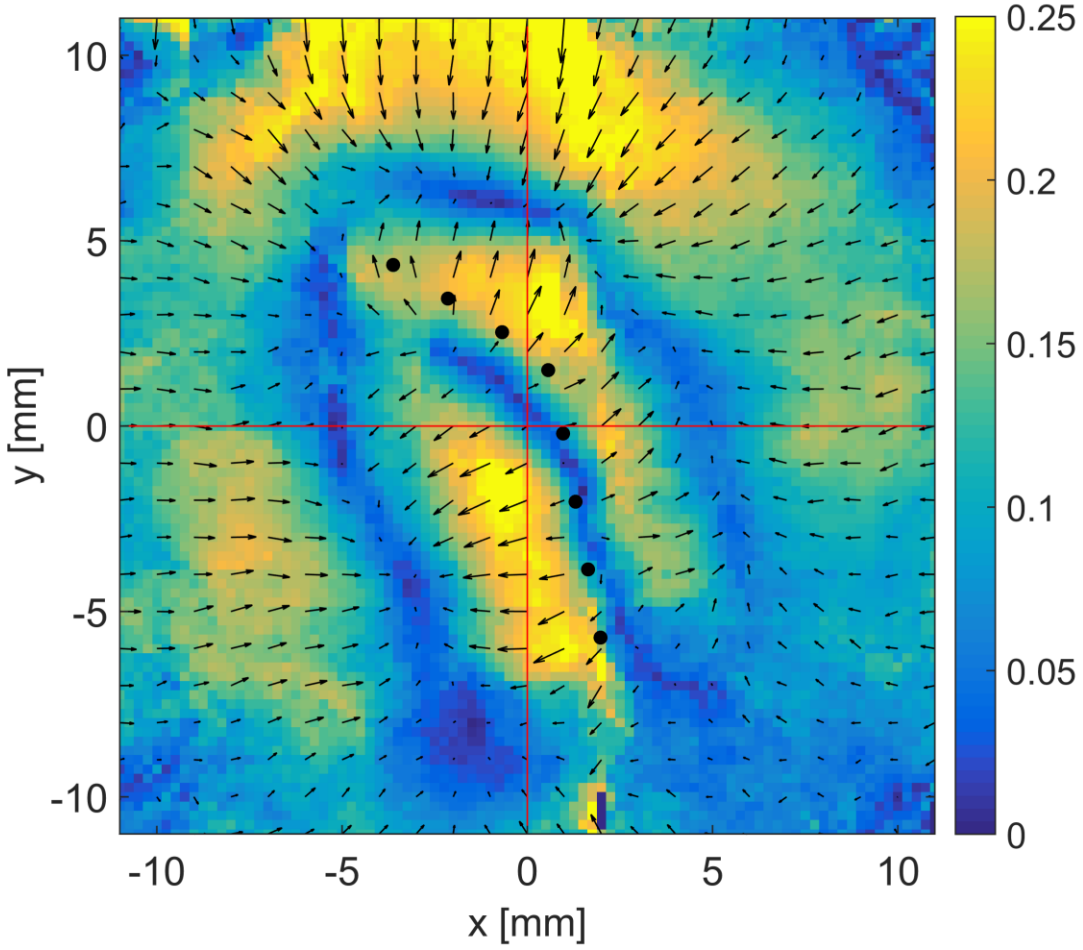
- A method has been described to use dust particles as probes to measure electric forces in a magnetically perturbed plasma.
- Models of Lunar magnetic anomalies have been built and tested with the method.
- 3D force maps have been generated and dust deposition pattern observed, resembling Lunar swirls.

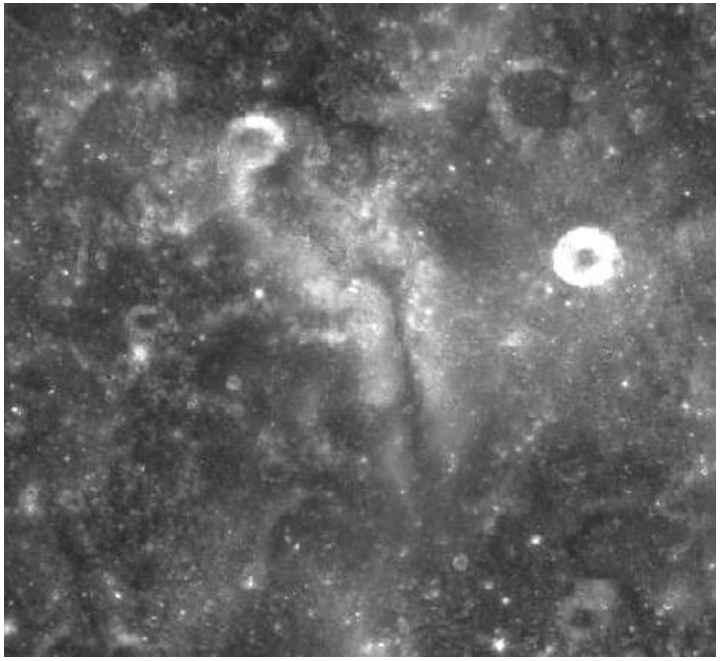




Thank you for your attention!

Airy formation results



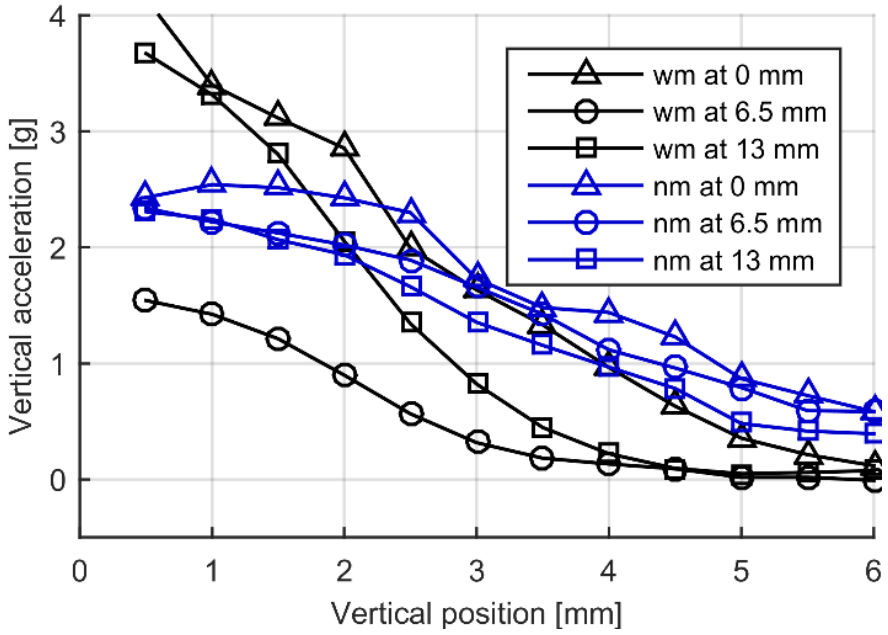


Experiment Parameters

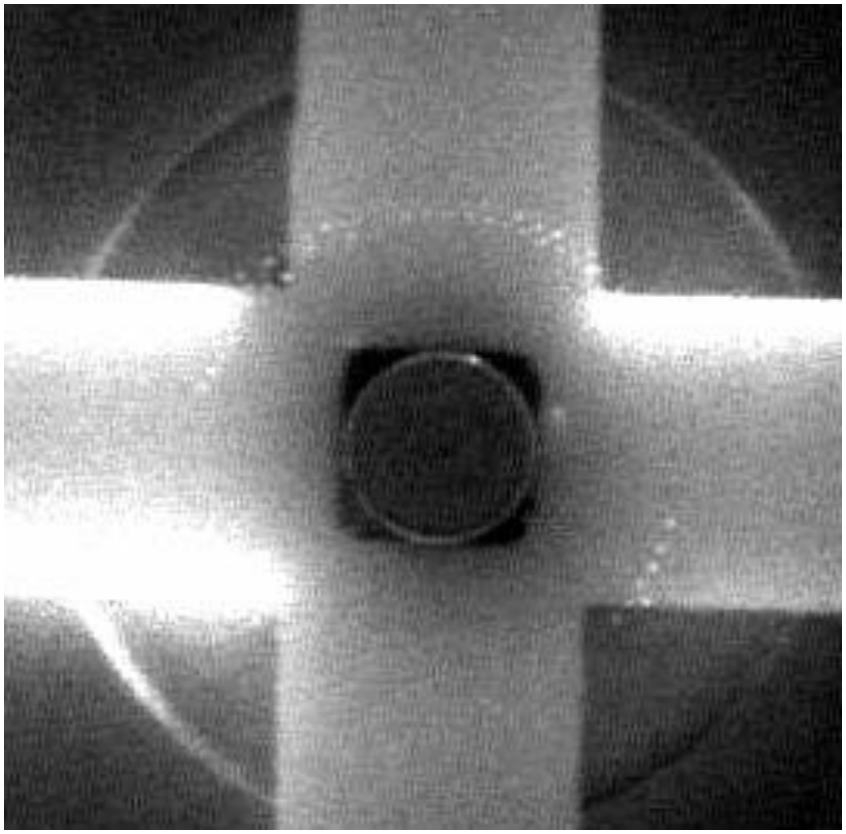
Parameter	Value
Bulk plasma density	$2 \cdot 10^{15}\ \mathrm{m}^{-3}$
Bulk electron temperature	5 eV
Pressure	5.3 Pa (40 mTorr)
Electron mean free path	7.3 mm
Ion mean free path	0.5 mm
Magnetic Flux Density	< 0.3 T
Electron Larmor radius	0.018 – 4.4 mm
Ion Larmor radius	6 – 1500 mm
Ion speed in sheath	4000 m/s

Vertical Acceleration Profiles

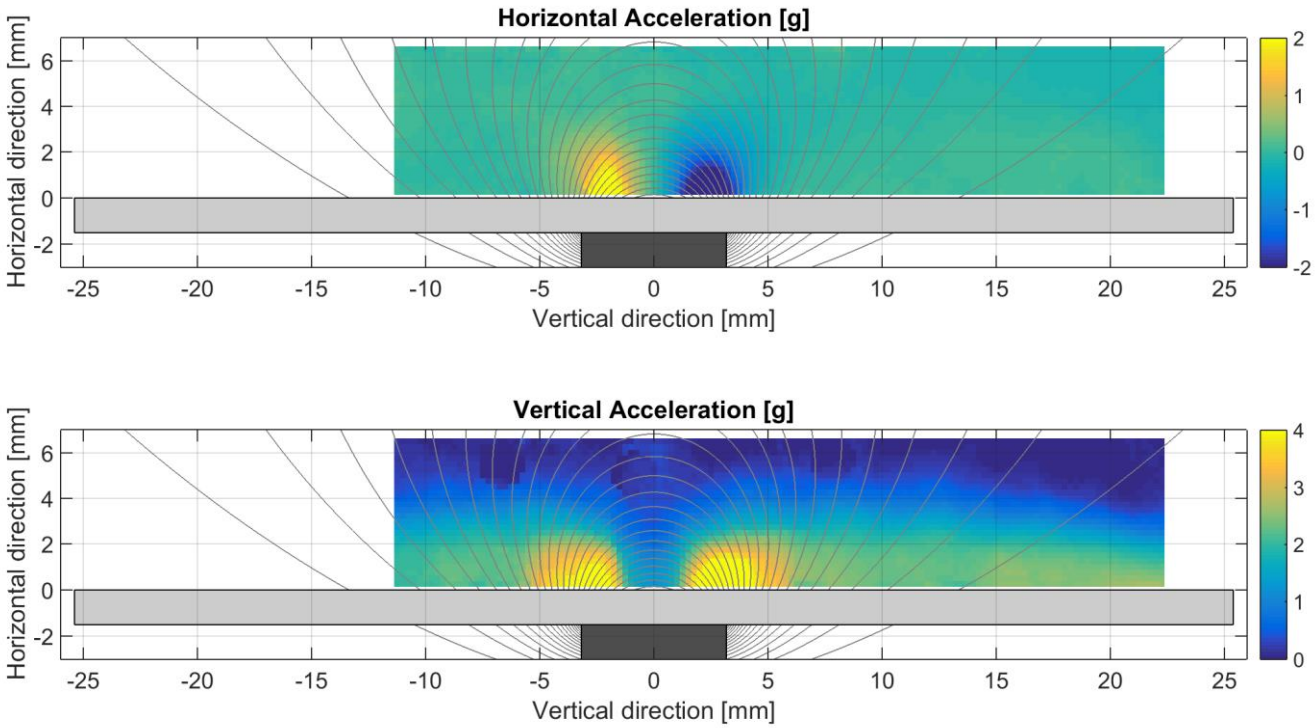
- The sheath profiles are significantly altered by the magnetic field.
- With magnetic field the Debye length in the sheath seems to be significantly reduced and the maximum deceleration depends strongly on radial position.



Levitating Particle Ring



Horizontal Magnet I



Horizontal Magnet II