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Plasma Kristal – 4: Anomalous diffusion in microgravity complex plasma cloud

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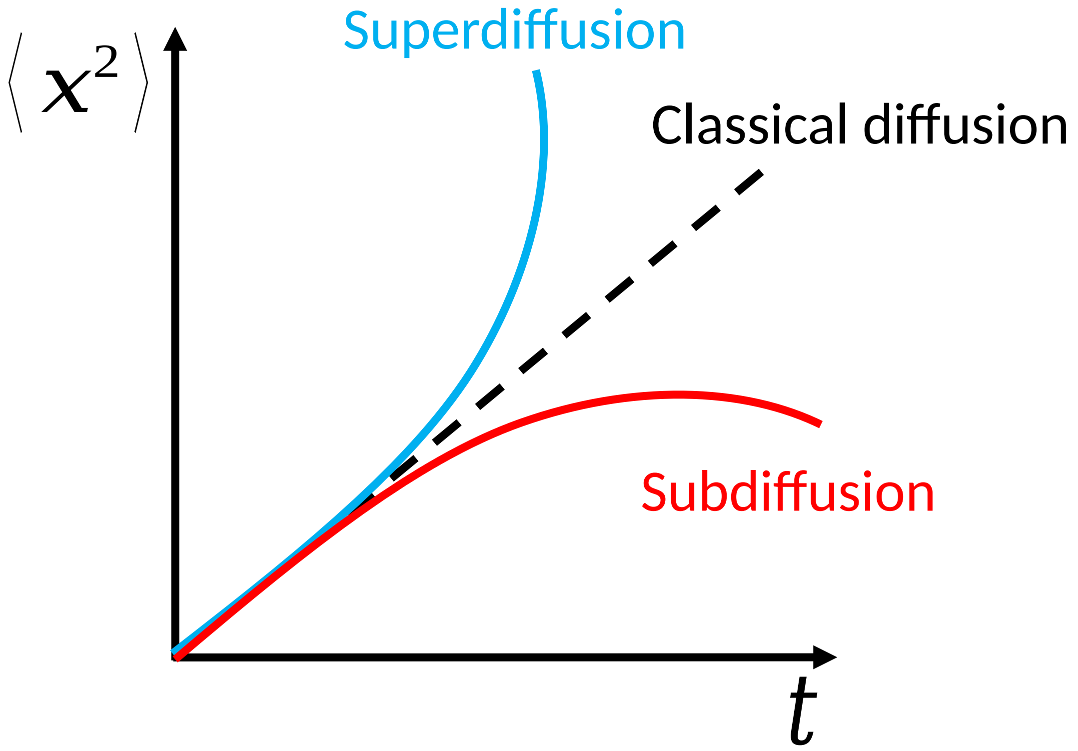
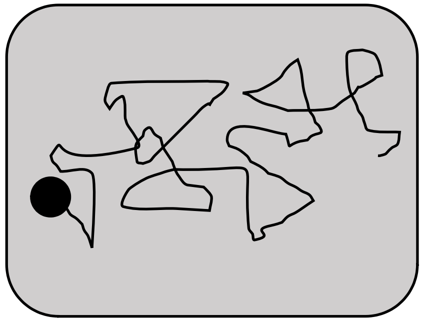
Anomalous Diffusion in dusty plasma

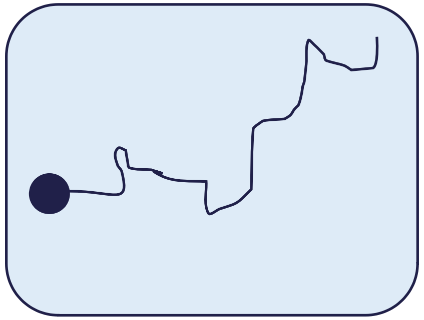
- **Diffusion:** random motion due to a gradient (concentration, pressure, temperature, etc.)
- **Observation:** mean square displacement (MSD) as a function of time



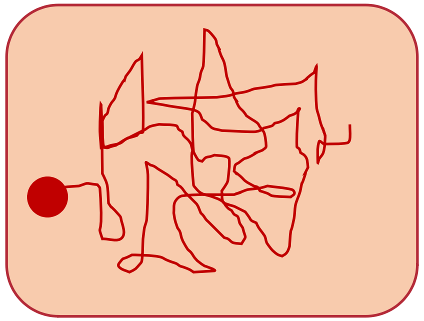
Classical diffusion	Superdiffusion	Subdiffusion
local	nonlocal	nonlocal



Random walk



Positive correlations

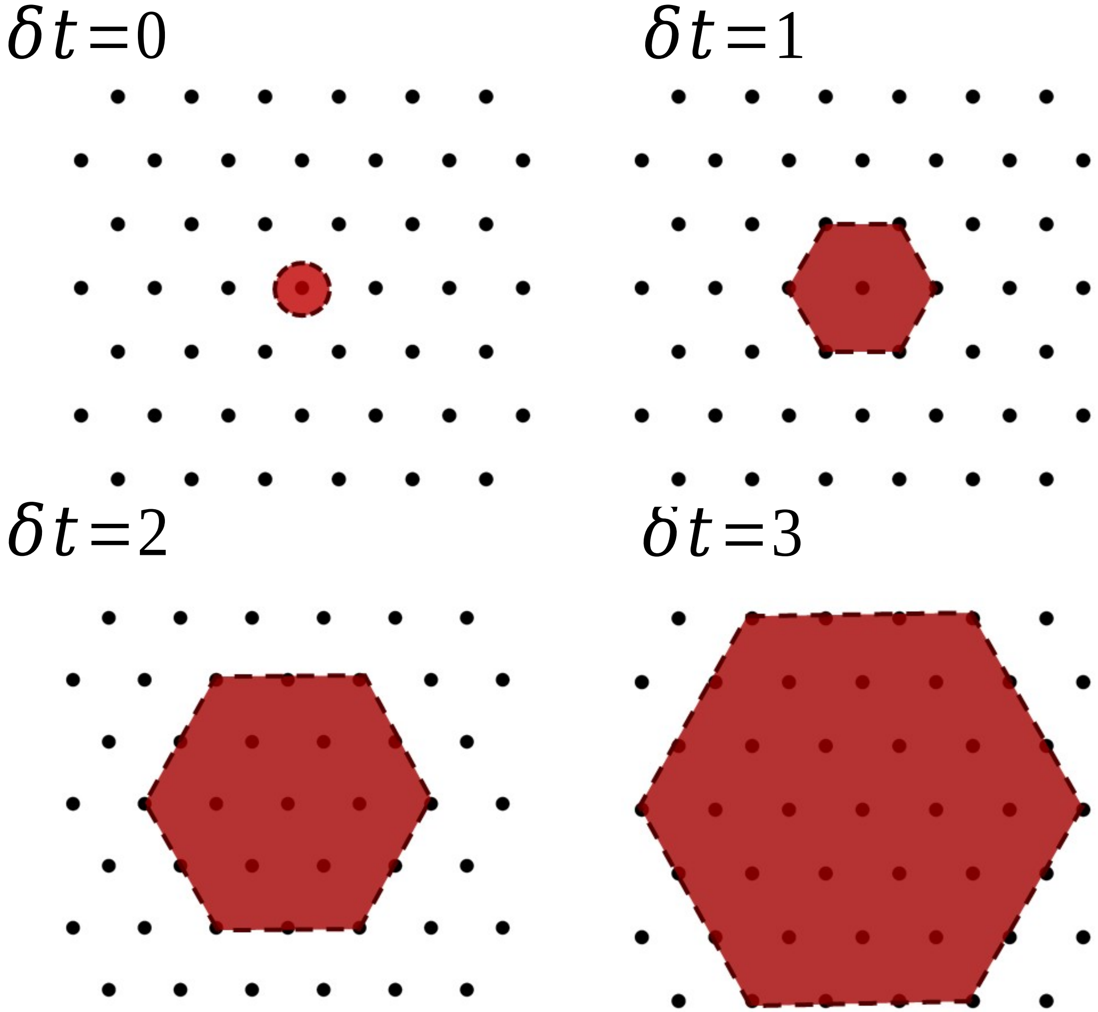


Negative correlations

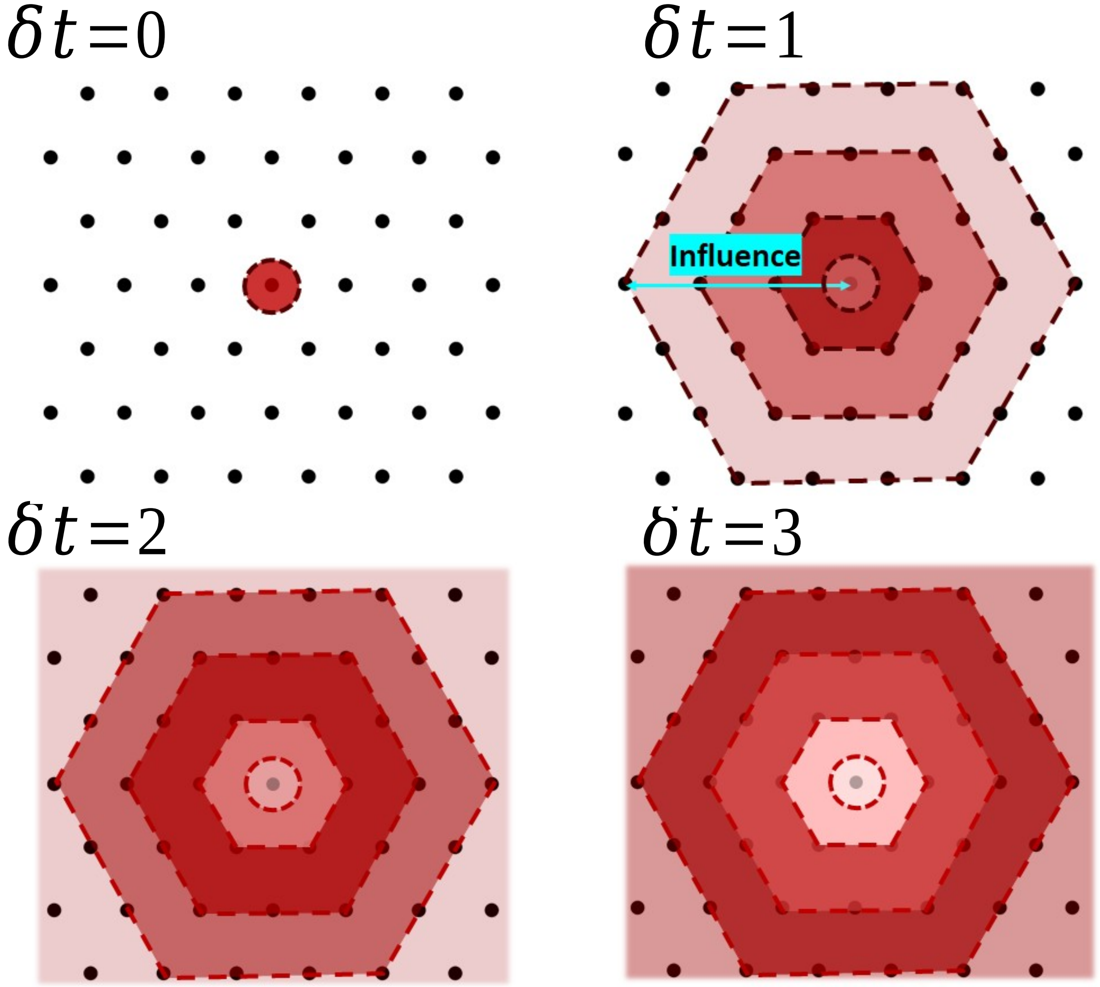
QUESTION: In a fluid with nonlocal effects, can we predict the global dynamical state through analysis of the local diffusion regime?

Fractional Laplacian model of diffusion

Nearest-neighbor hopping



Interaction at a distance



Classic Laplacian: _local operator_ of the form

- *Classic diffusion:* , weak correlations

Fractional Laplacian: , _nonlocal operator_

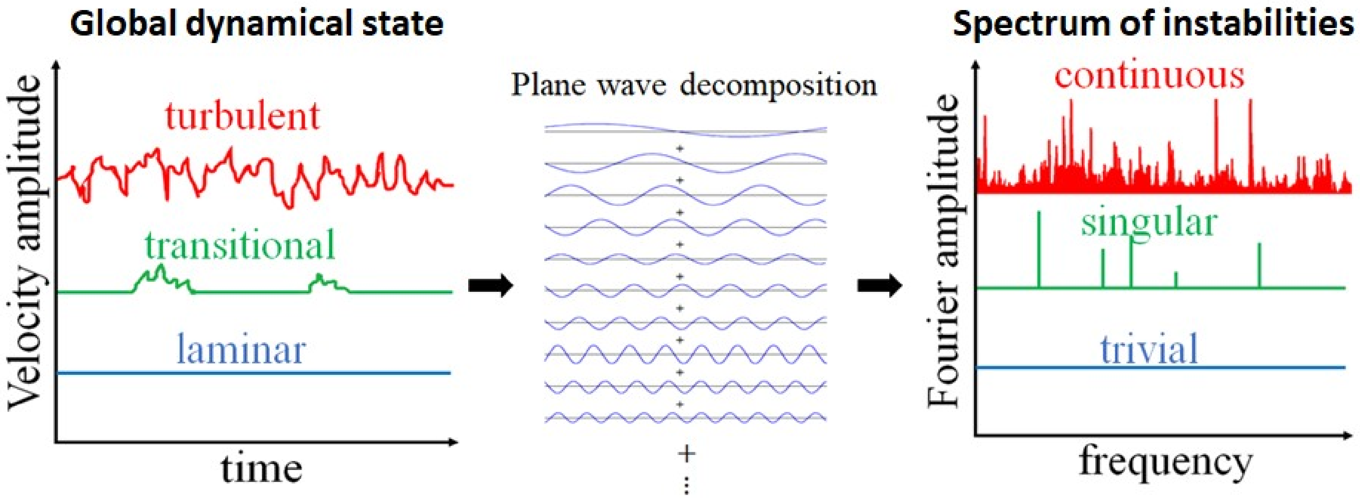
- *Superdiffusion:* , positive correlations
- *Subdiffusion:* , negative correlations

Spectral Approach to the Global Dynamics

- Consider the general Hamiltonian

Nonlocal interaction   Disorder

- Let the system be in the initial state at
  The **time evolution of the dynamics** is given by



- Compute the mathematical distance b/w any allowed energy state and **the sequence**

$$D_n = \sqrt{1 - \sum_{i=0}^{n} proj_{\{..\}} \mathbf{v}'}$$

Probability that at , the system ***is not*** in the state

Probability that at , the system is in the state

$$\Downarrow$$

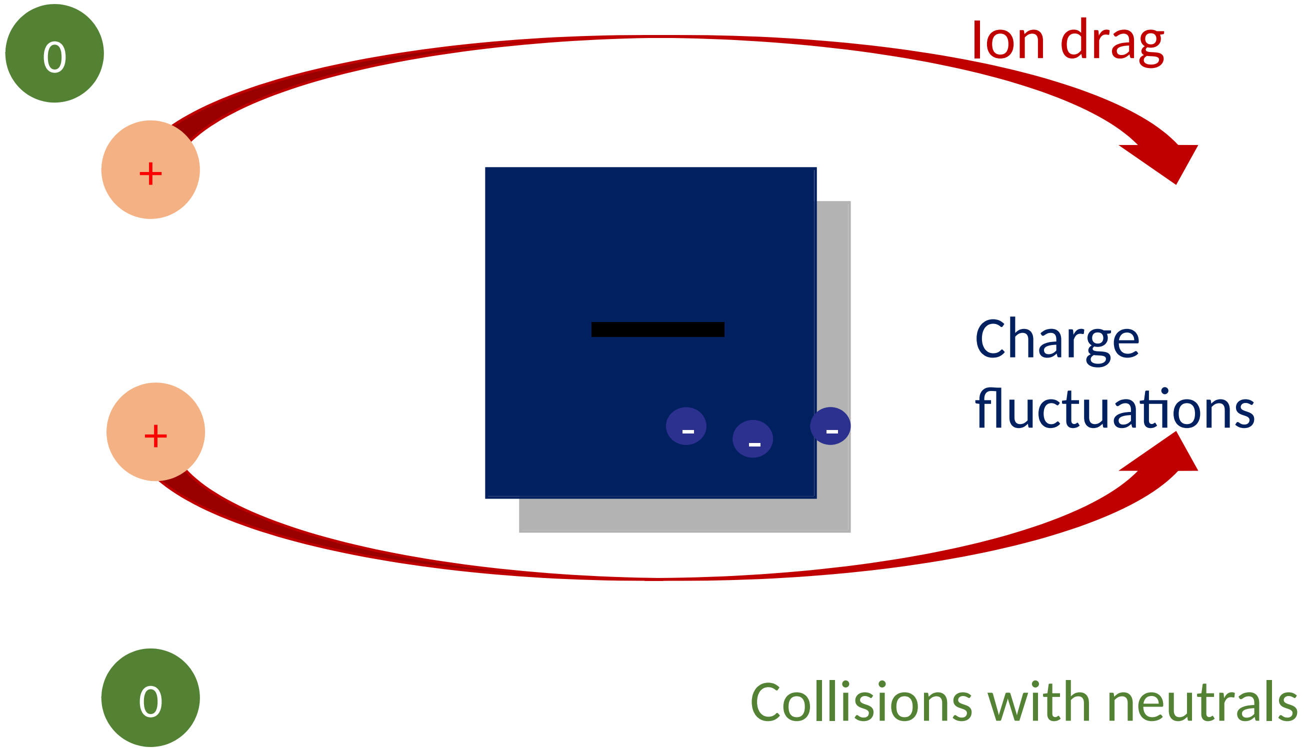
Global Dynamics:

If continuous spectrum

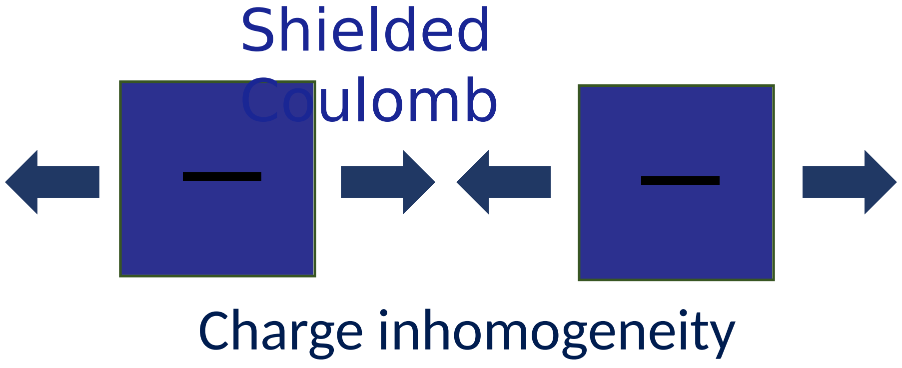
If singular spectrum

Application to dusty plasma

Dust-Plasma interactions



Dust-Dust interaction



Analysis code inputs

Fraction Diffusion regime

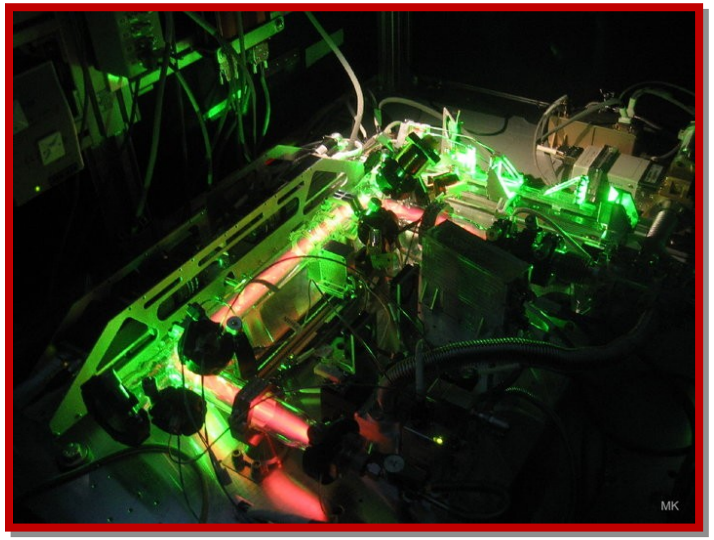
Influence Range of the nonlocal effects

Disorder Irregularities in the potential

PK-4 Dusty plasma experiments on the ISS

International Space Station
Image credit: ESA website

ELENA SEROVA holding the PK-4 experimental rack
Image credit: DLR Website



Ground model of PK-4 lab
Image credit: DLR Website

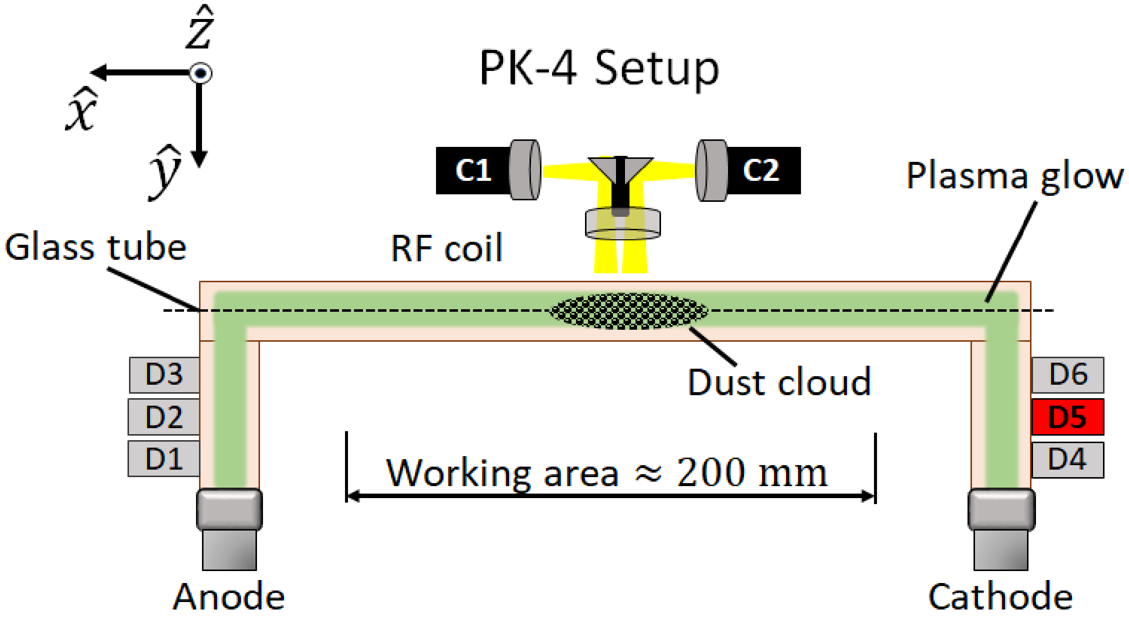
Campaign 2, June 16, 2015

Dispenser 5 (shaker): MF,

Pure DC discharge: neon

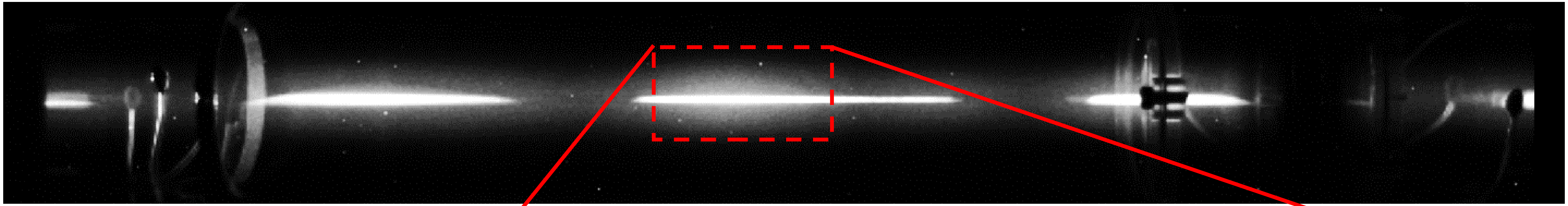
Pressure: 50 Pa

Trapping: DutyCycle: 0.72, 100Hz

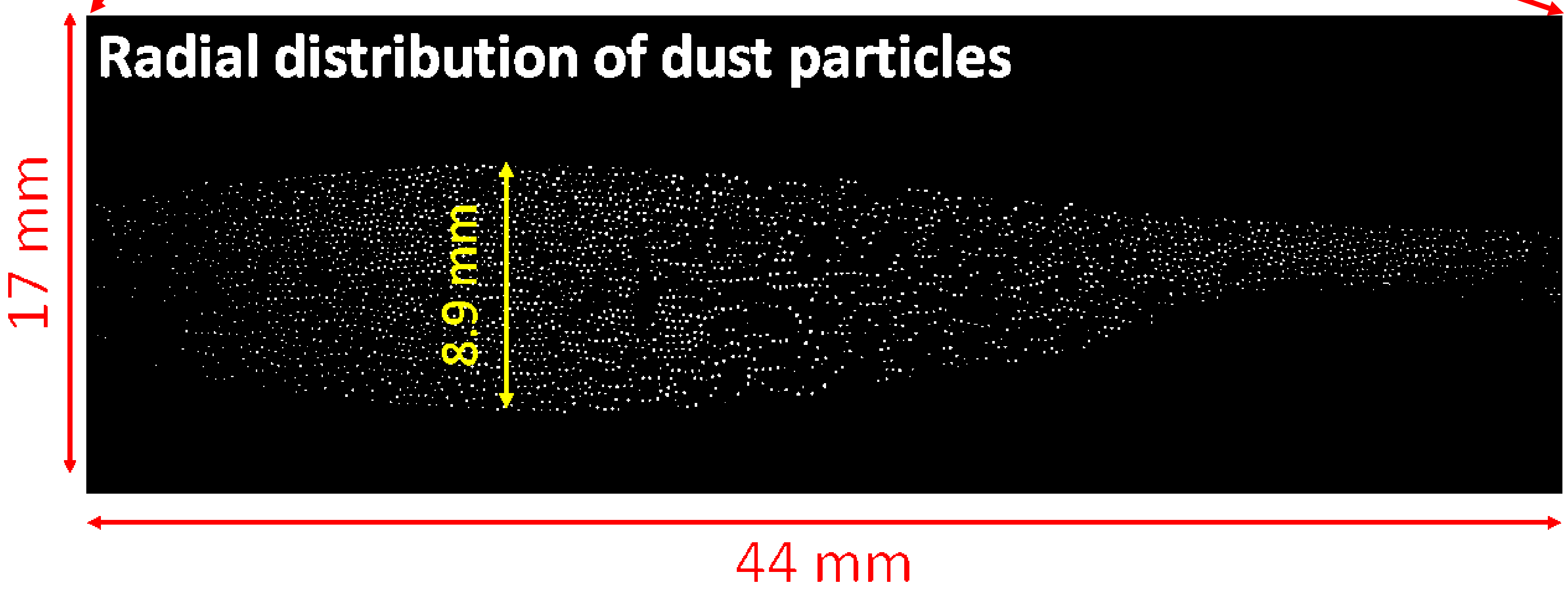


Large dust cloud in DC discharge – Imaging System

- Particle Glow Observation camera, field of view (FoV)

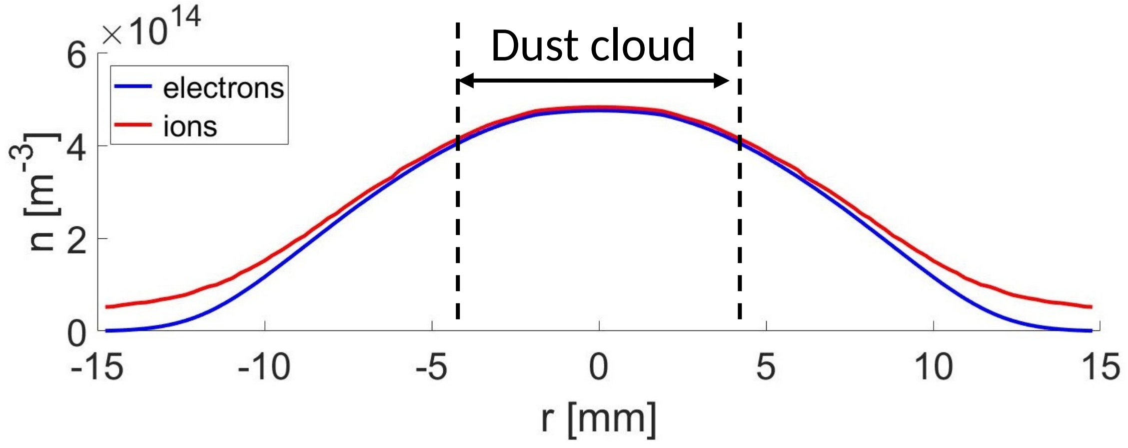


- Stitched Particle Observation cameras FoV

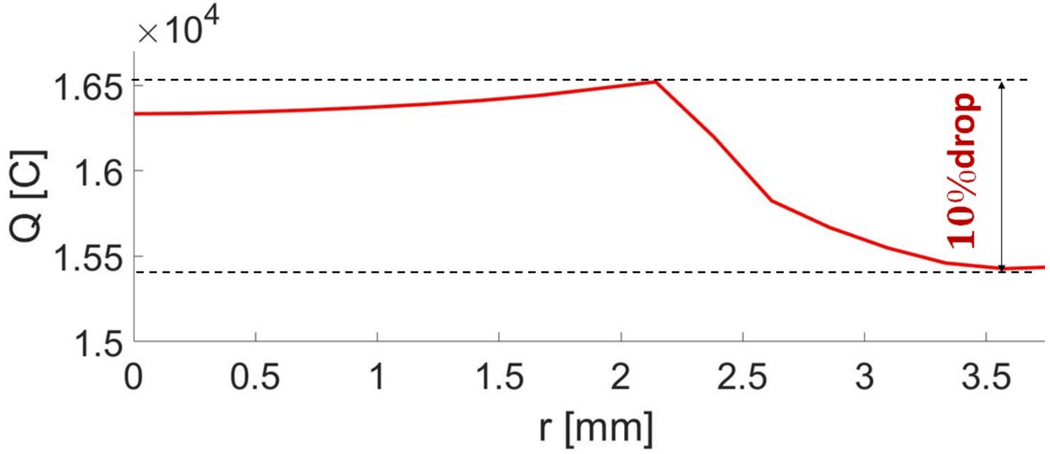


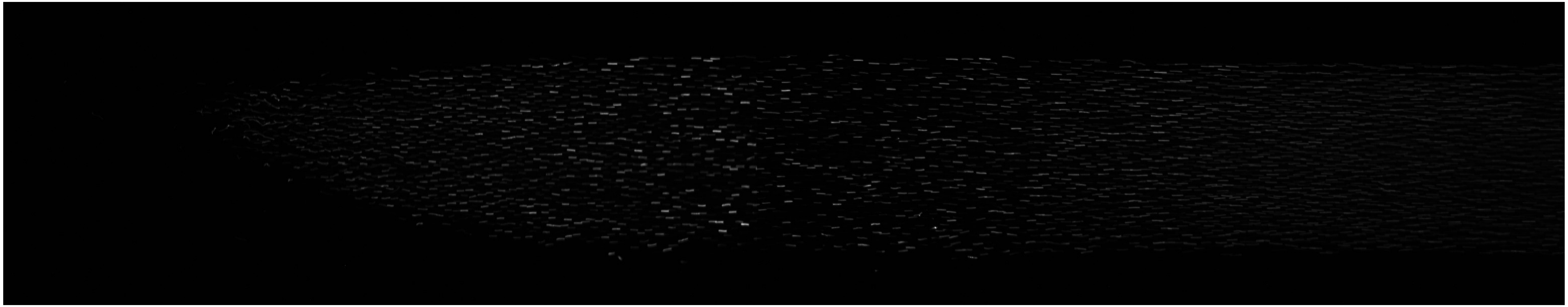
Onset of global instability

Radial distribution of and



Radial distribution of dust charge



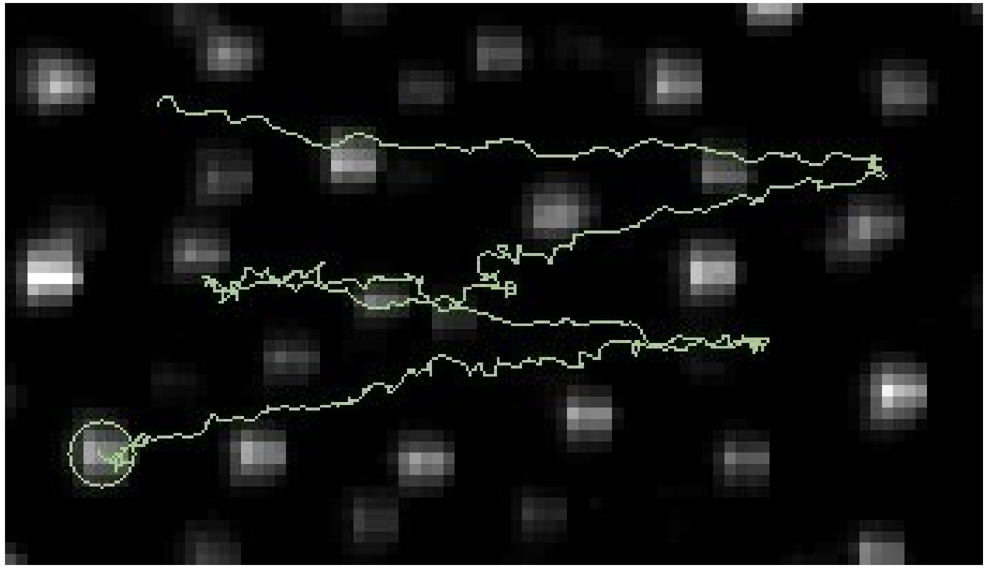


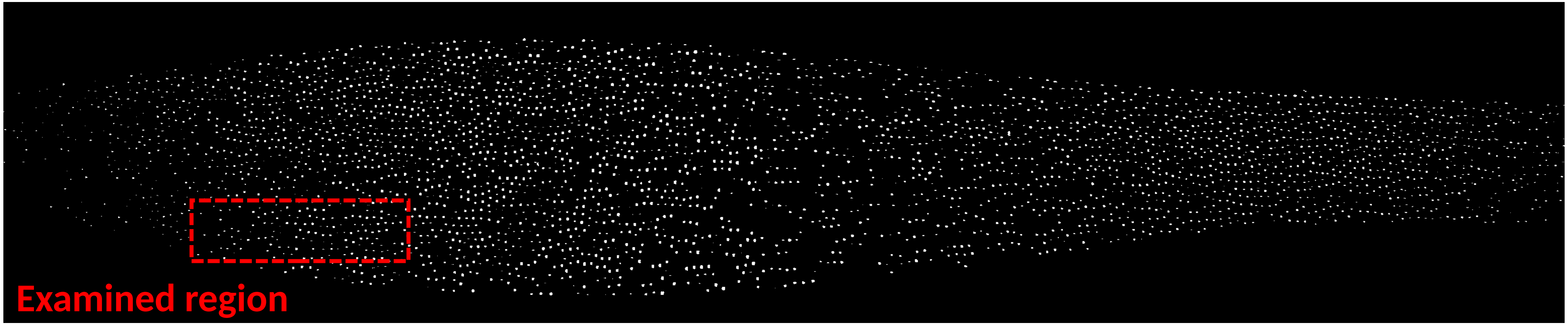
Due to , once the polarity switching is applied, layers of dust grains close to the central axis move slightly faster than the layers close to the exterior leading to the onset of global vortex instability.

Superdiffusion and global vorticity

- 153 particles over 500 frames in a region with minimum directed flow
- Mean MSD slope for grains in the region is the particles are in the superdiffusive regime.
- These results suggest a connection between superdiffusion and global vorticity

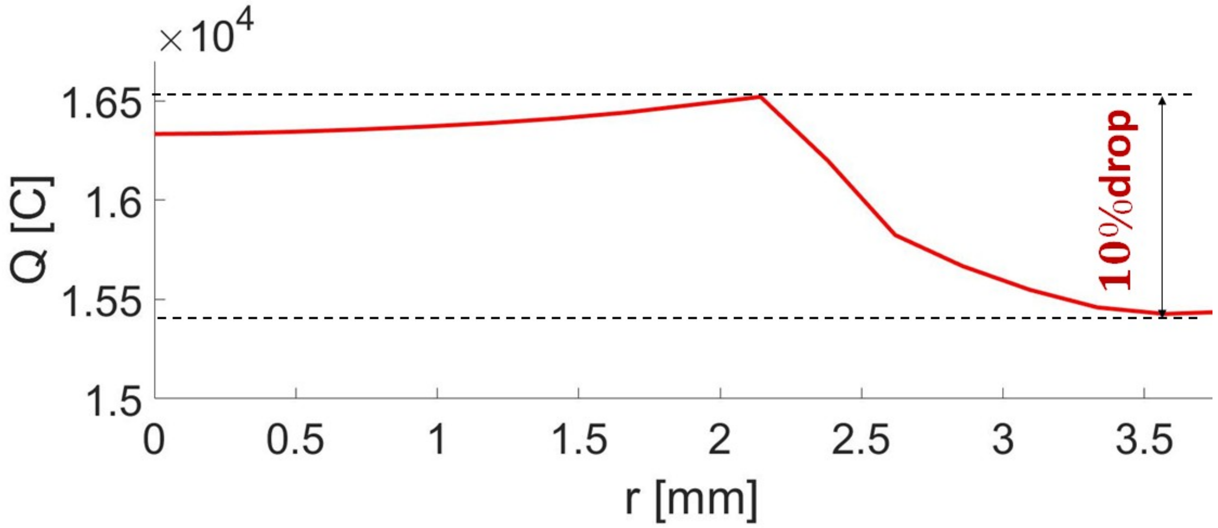
Typical trajectory



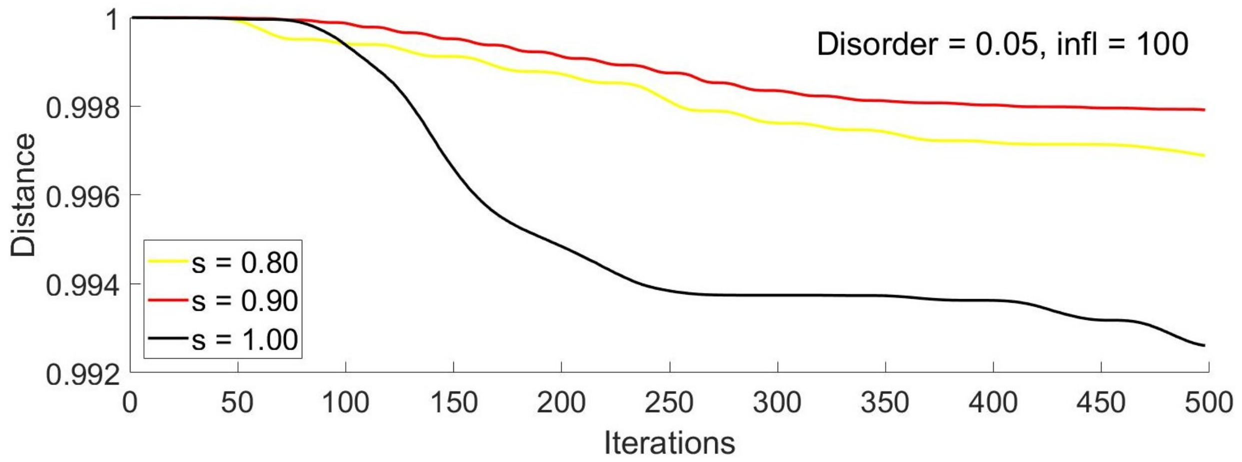


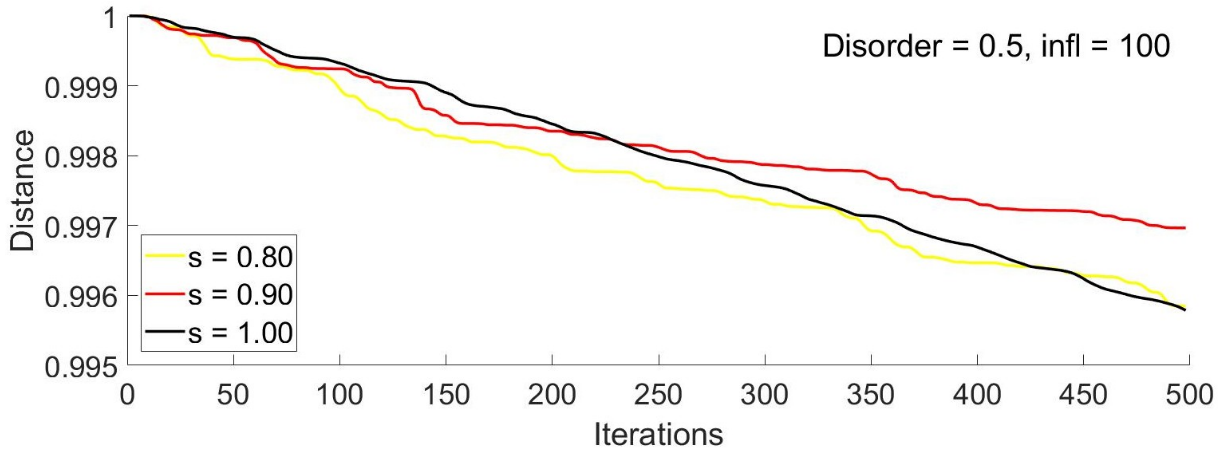
Analysis code approach – vary disorder concentration

- **Increased concentration of disorder leads to disturbances in the global vortex flow.**



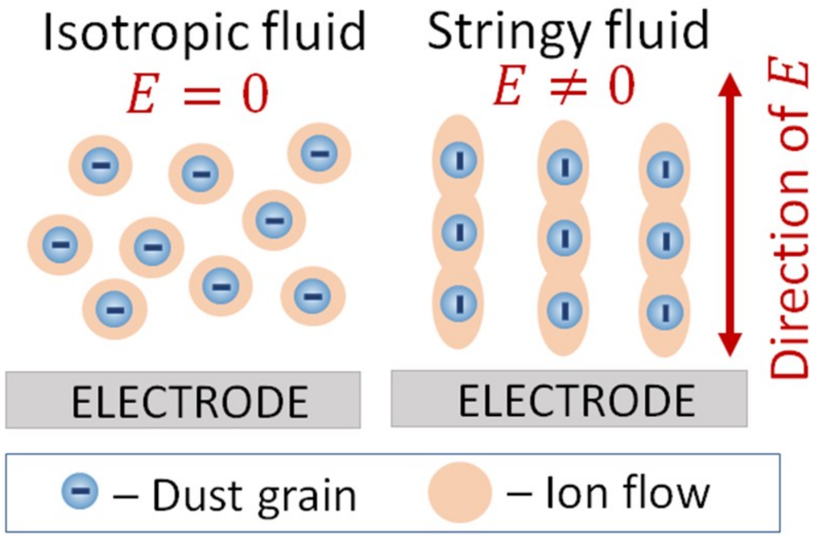
- **In the PK-4 dust cloud, the charge gradient in the radial direction leads to suppression of superdiffusion in this direction.**

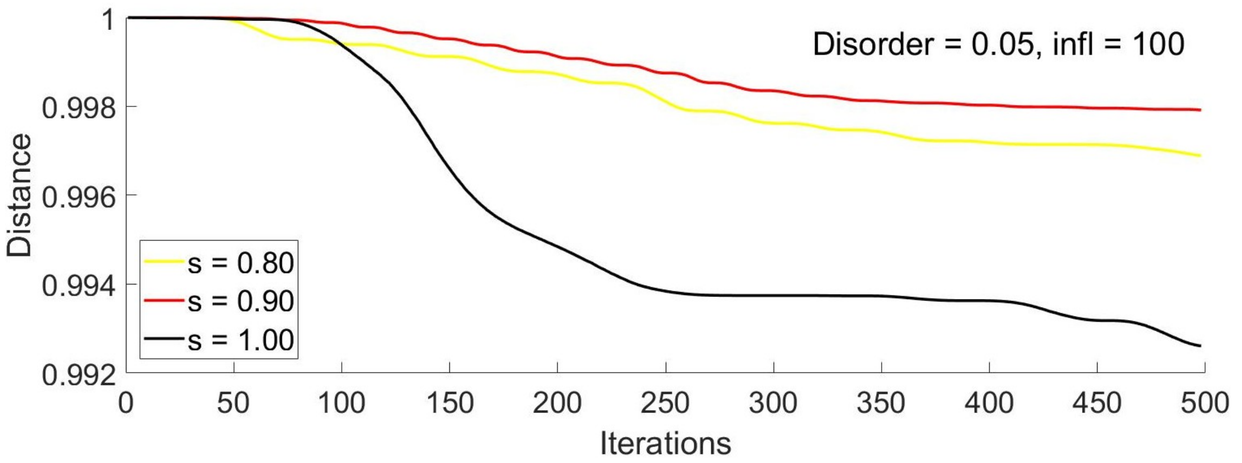


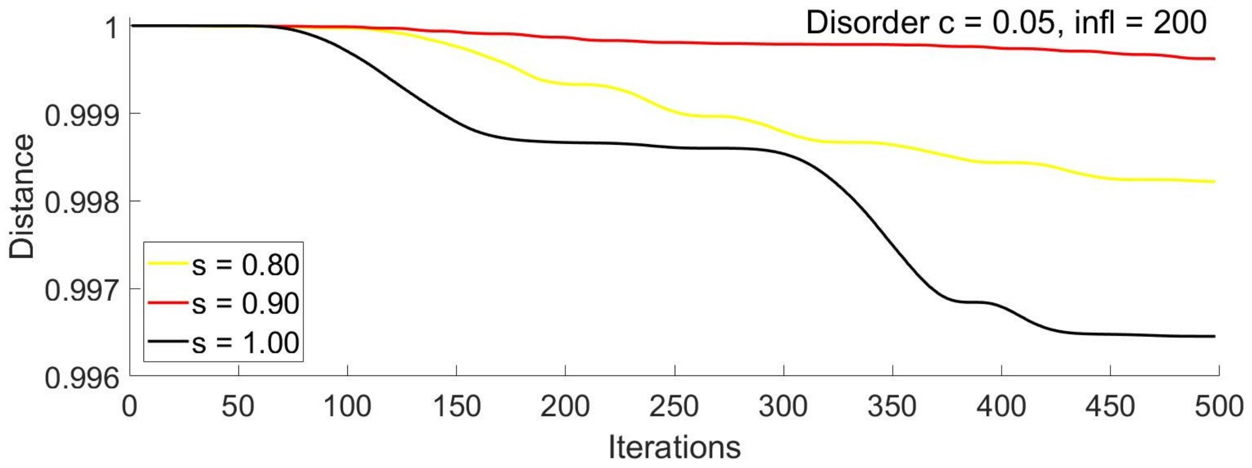


Analysis code approach – vary range of nonlocal effects

- **Increased influence when enhances the superdiffusion effect and the global vortex flow.**







- **In the PK-4 dust cloud, the range of nonlocal effects is determined by the parameters of the DC discharge and the resulting ion flow.**

Conclusions

- Dusty plasma experiments in microgravity show that superdiffusion of the dust is an indicator for a global vortex flow.
- We combine techniques from **spectral theory** and **fractional calculus** to model the dynamics of a system with nonlocal interactions;
- The analysis code demonstrates that:
  - Fractional Laplacian with can be used to model superdiffusion
  - Increasing the disorder concentration suppresses superdiffusion and the vortex flow
  - Increasing the range of nonlocal effects enhances the global vortex flow

THANK YOU!

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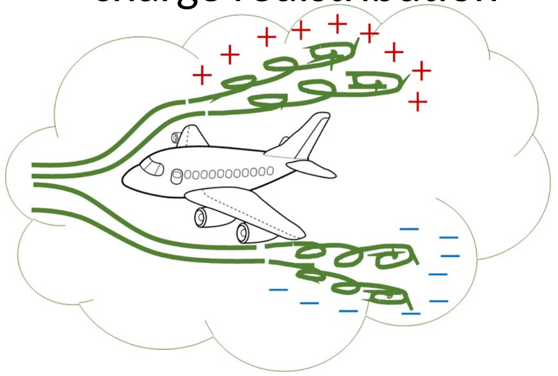
Motivation for this research

Charge-induced instabilities

Instability-guided charge redistribution



In the presence of charge in a fluid, the nonlocal interactions can cause instabilities. Instabilities, in turn, cause charge redistribution.

Anomalous diffusion on the small scales is an indicator of the global dynamics on the large scales.

Spectral approach: Combine spectral theory and fractional calculus to model anomalous diffusion.

Kinetic approach: Study microgravity experiments with dusty plasma liquids on the ISS.

Agreement b/w the two methods will provide a powerful modeling tool for the study of the global dynamical state.