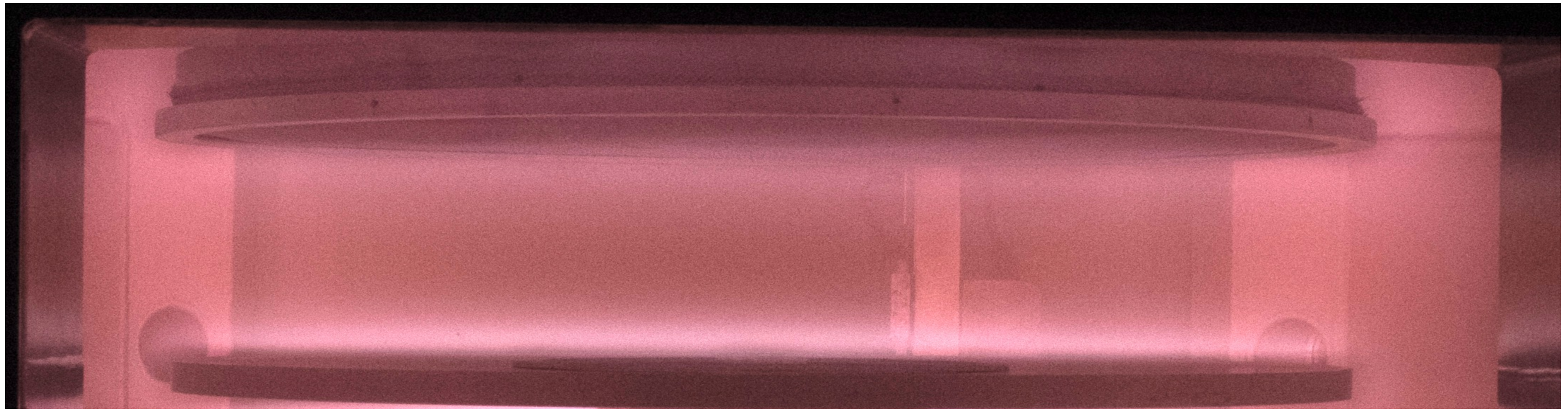


Microfluidic flow in single-layer dusty plasmas

P. Hartmann

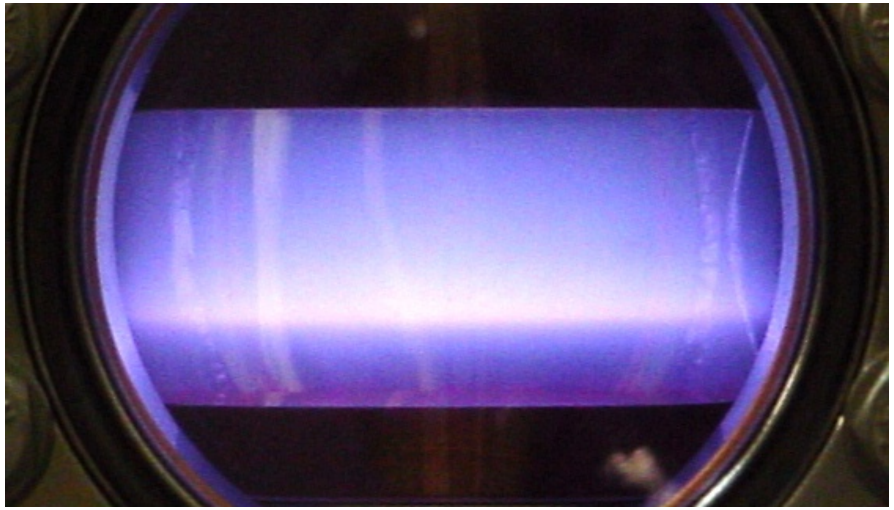
CASPER at Baylor University,
Waco, TX, USA

Wigner Research Centre for
Physics, Budapest, Hungary

Wigner 121
Scientific Symposium

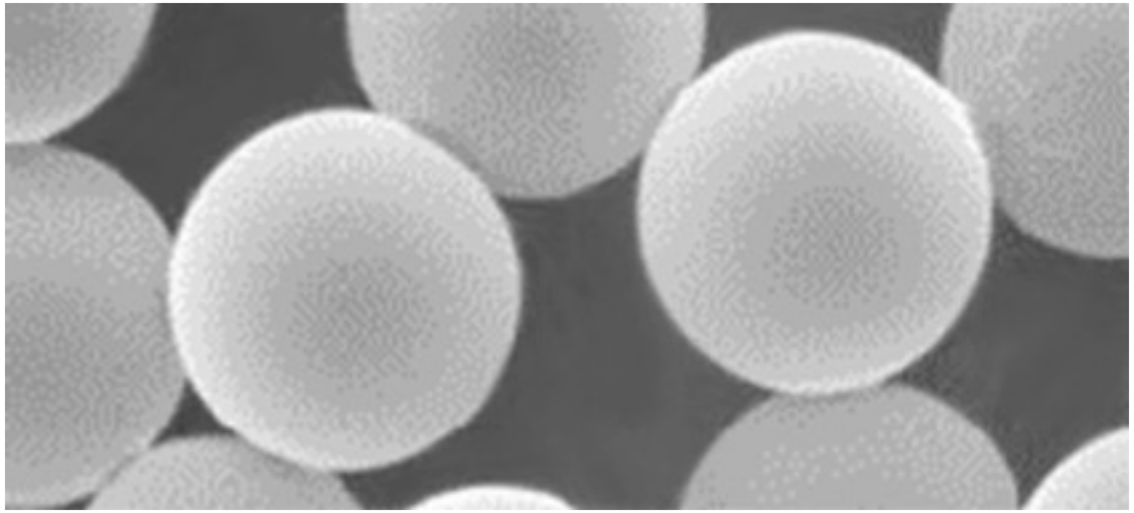
Motivation: dusty plasma experiments – open territories

Gas discharge

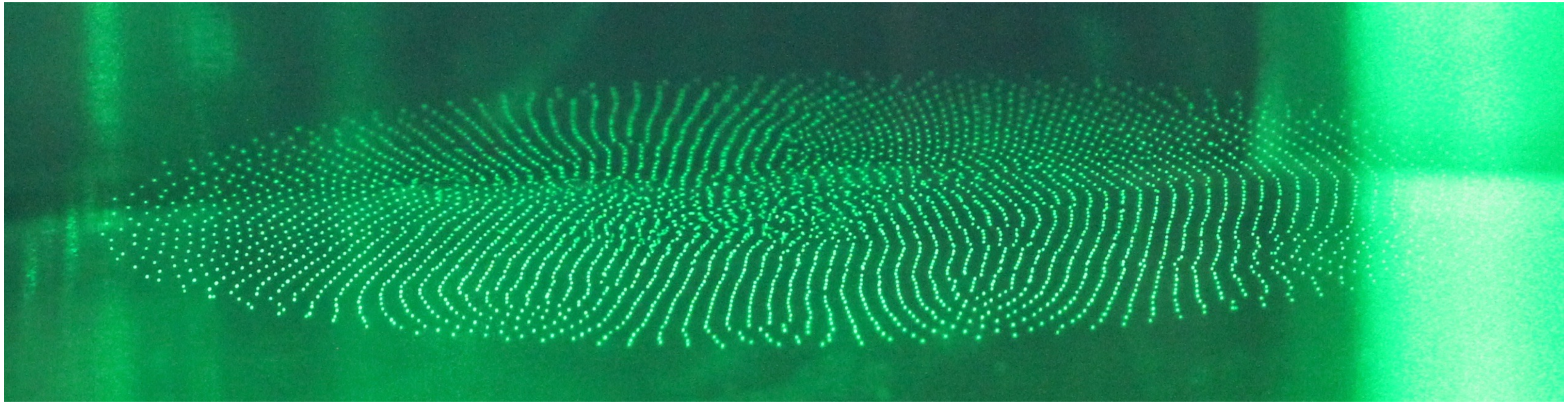


+

Dust (small solid particles)

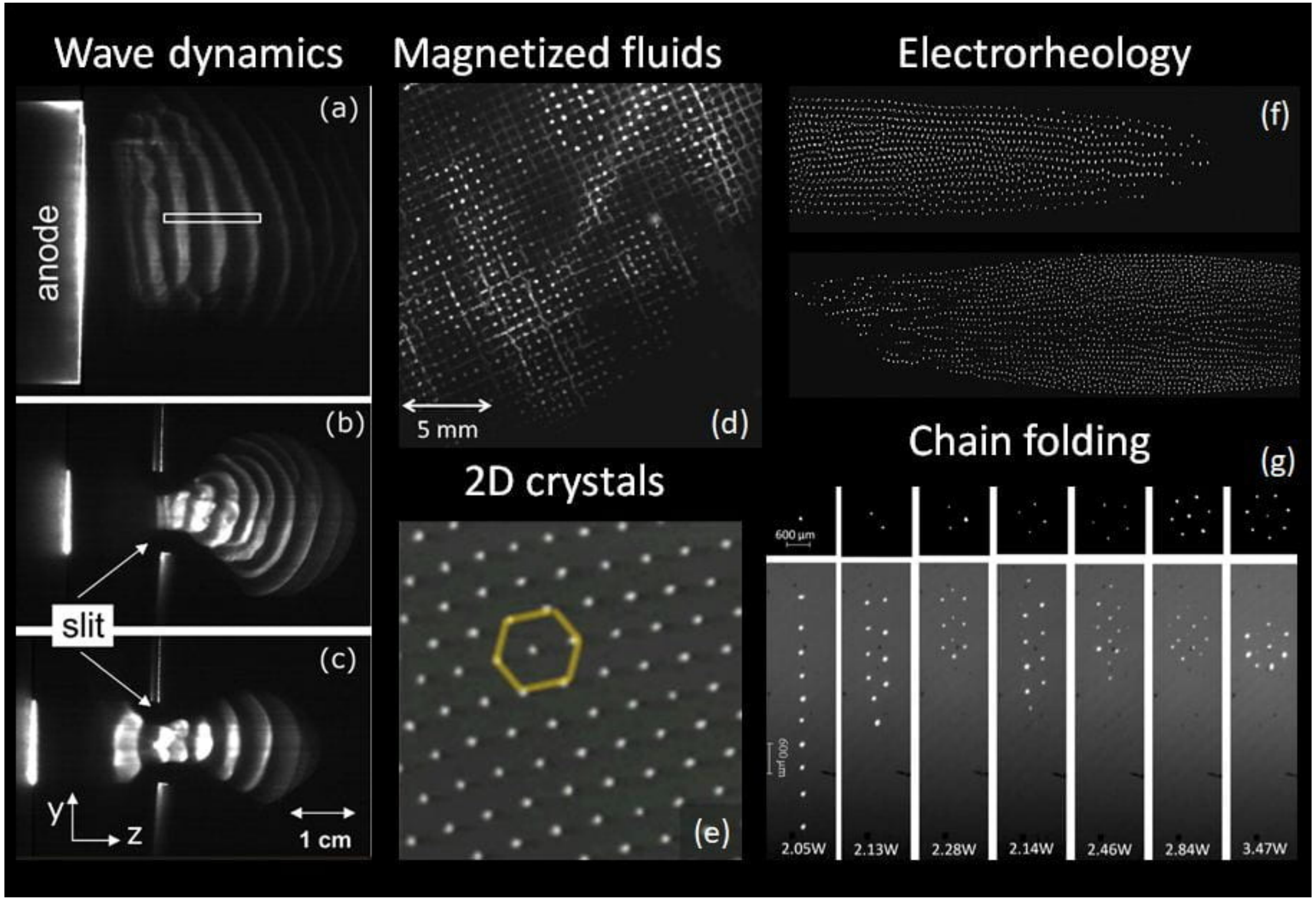


Dusty plasma



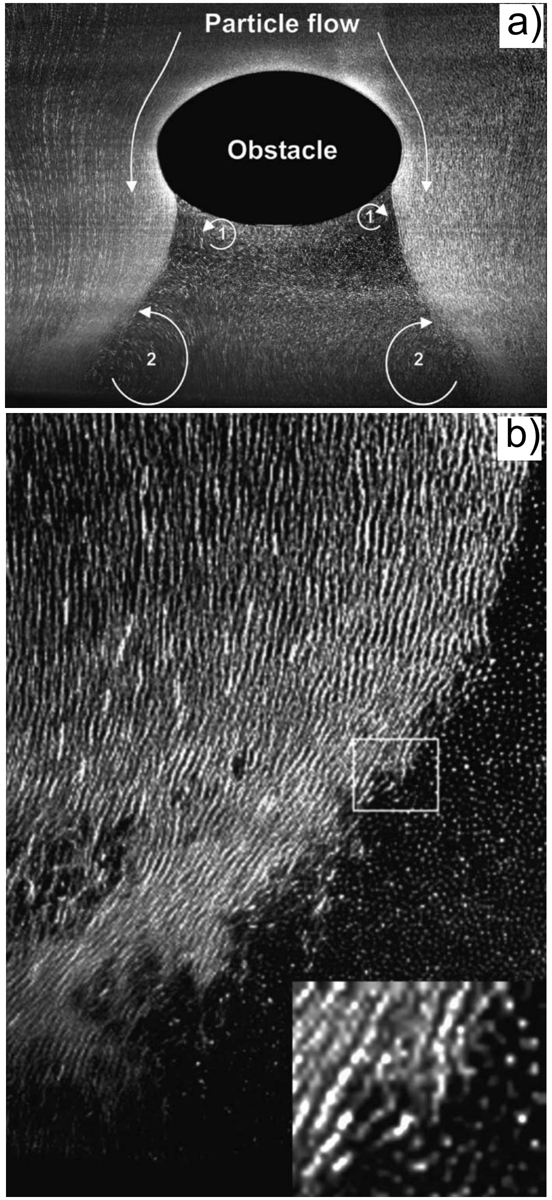
Motivation: dusty plasma experiments – open territories

Since the early years of research on strongly coupled dusty plasmas, hydrodynamics (among other branches) has always appeared to be one of the topics that might be impacted by dusty plasma research, allowing rapid progress in the understanding of various phenomena.

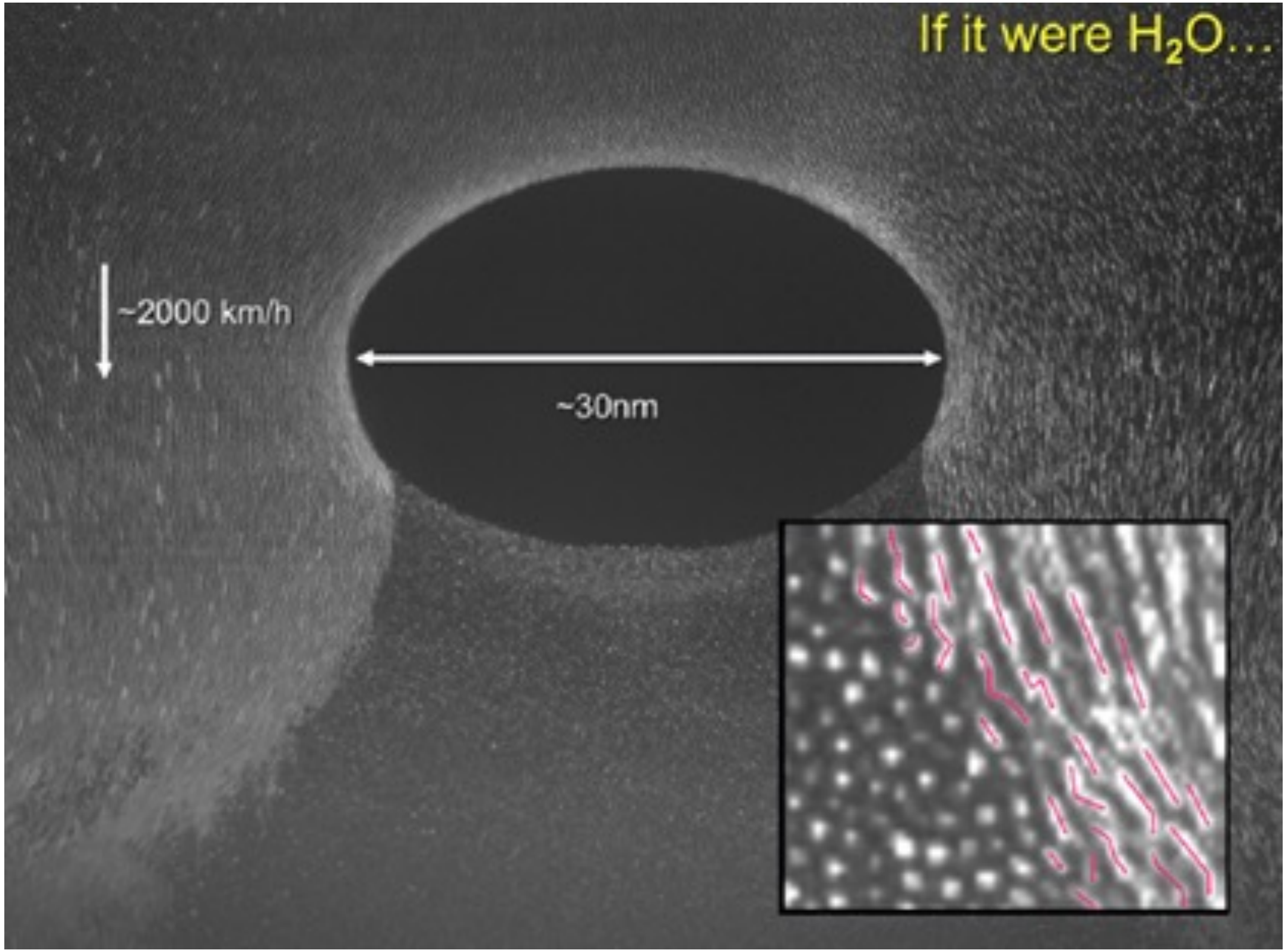


Dusty plasma analogues: (a) nonlinear waves and (b), (c) shocks (Merlino et al., 2012), (d) dust grid pattern in external magnetic field (Thomas et al., 2015), (e) 2D honeycomb monolayer (Max Planck Institute), f) electrorheological dusty plasma (PK-4 lab), (g) folding of filamentary structures (Hyde et al., 2013). [https://sites.baylor.edu/eva_kostadinova/2019/05/]

Motivation: dusty plasma experiments – particle transport

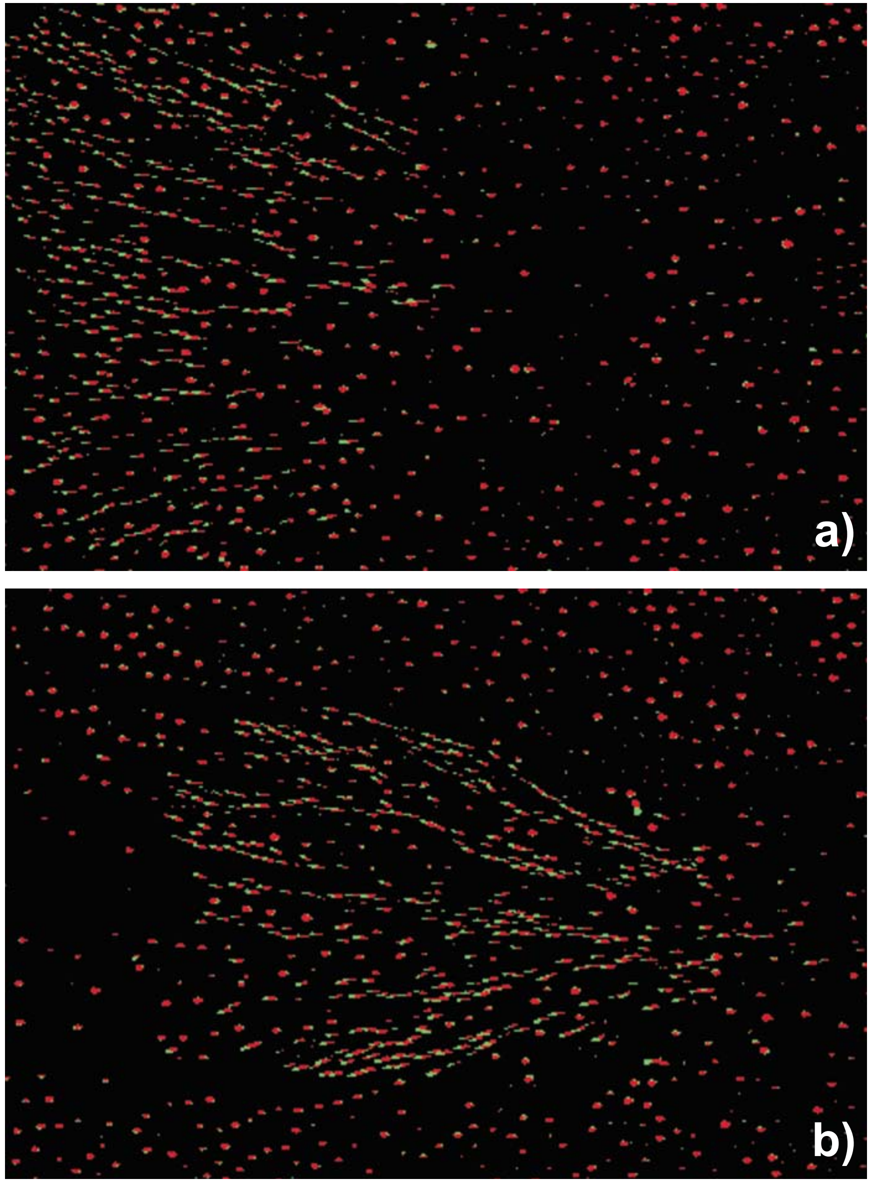


Boundary layer



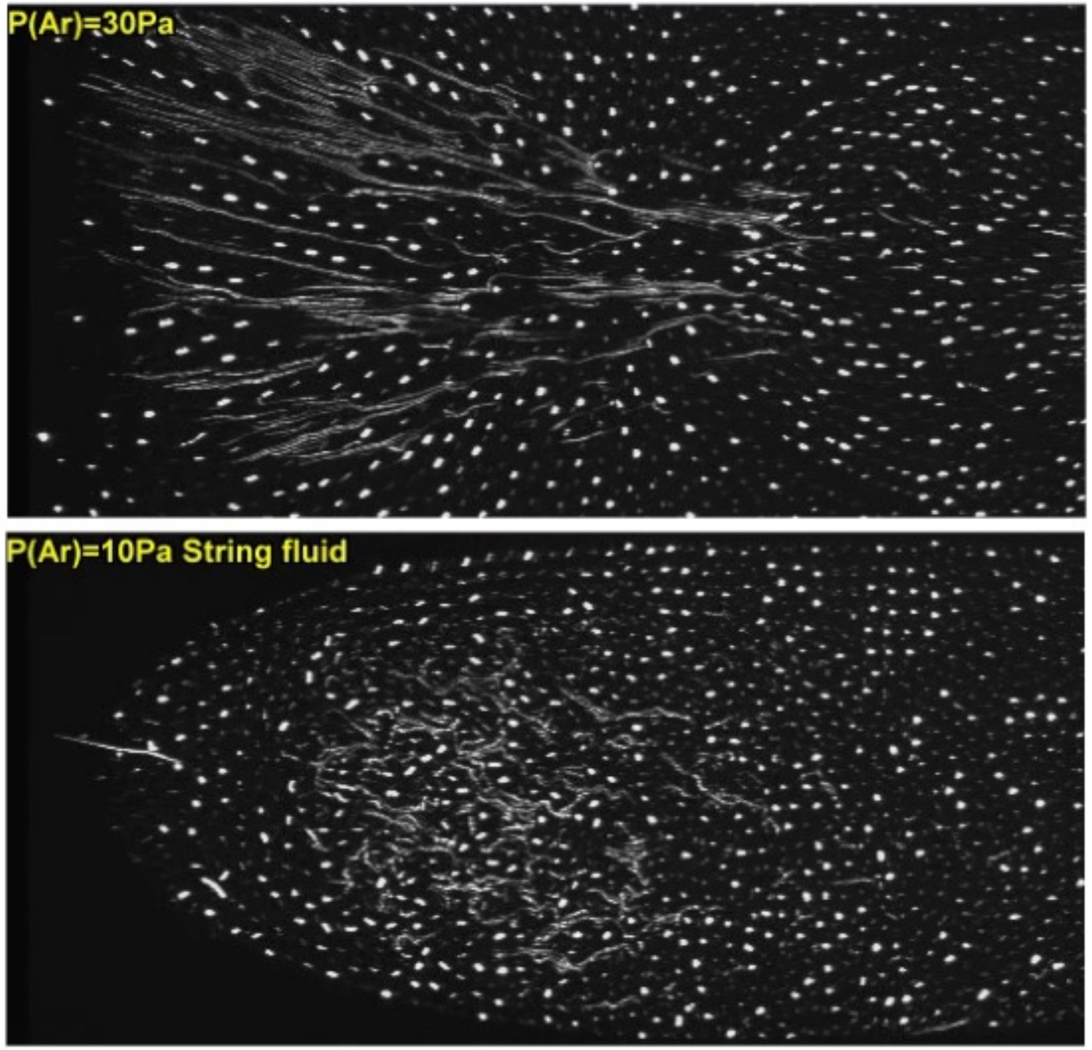
G. E. Morfill et al., *Phys. Rev. Lett.* **92** (2004) 175004.

Motivation: dusty plasma experiments – particle transport



G. E. Morfill & A. V. Ivlev, *Rev. Mod. Phys*. **81** (2009) 1353.

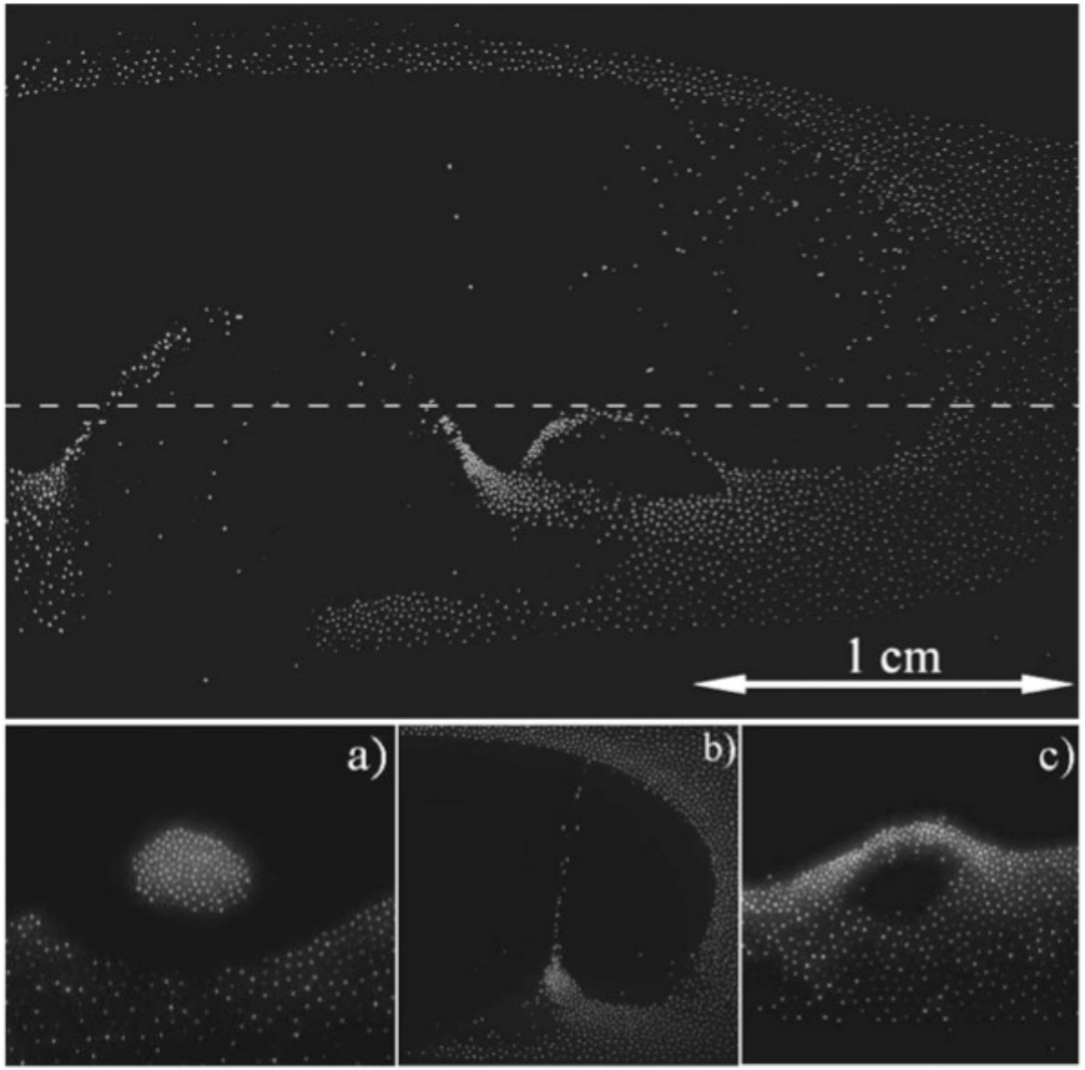
Inter-penetration

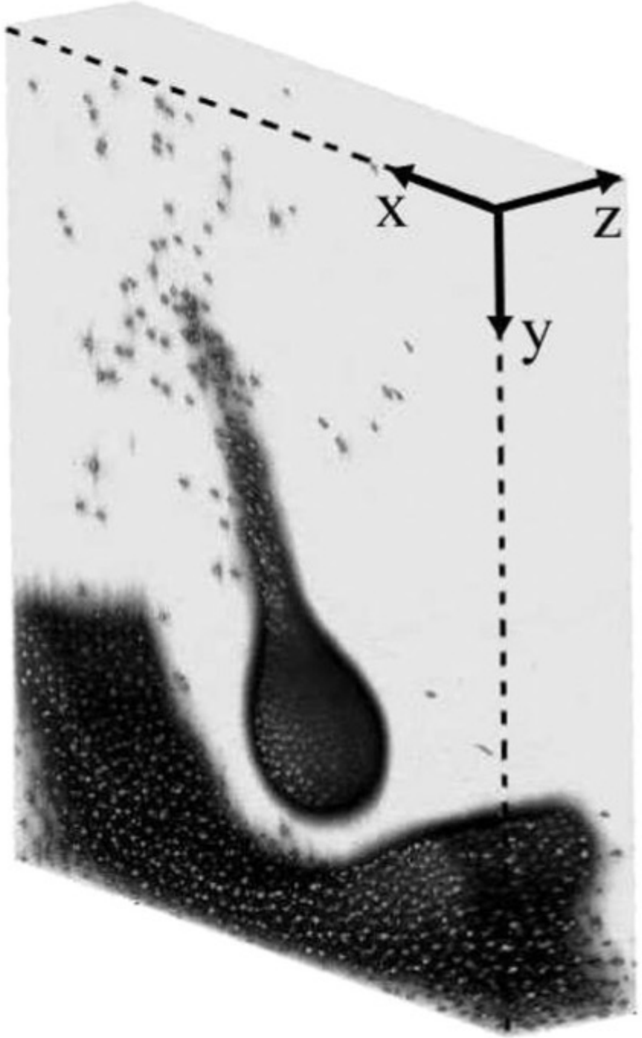


V. I. Molotkov et.al., *Int. J. Microgravity Sci. Appl*. **35**(3) (2015) 320302.

Motivation: dusty plasma experiments – particle transport

Complete madness

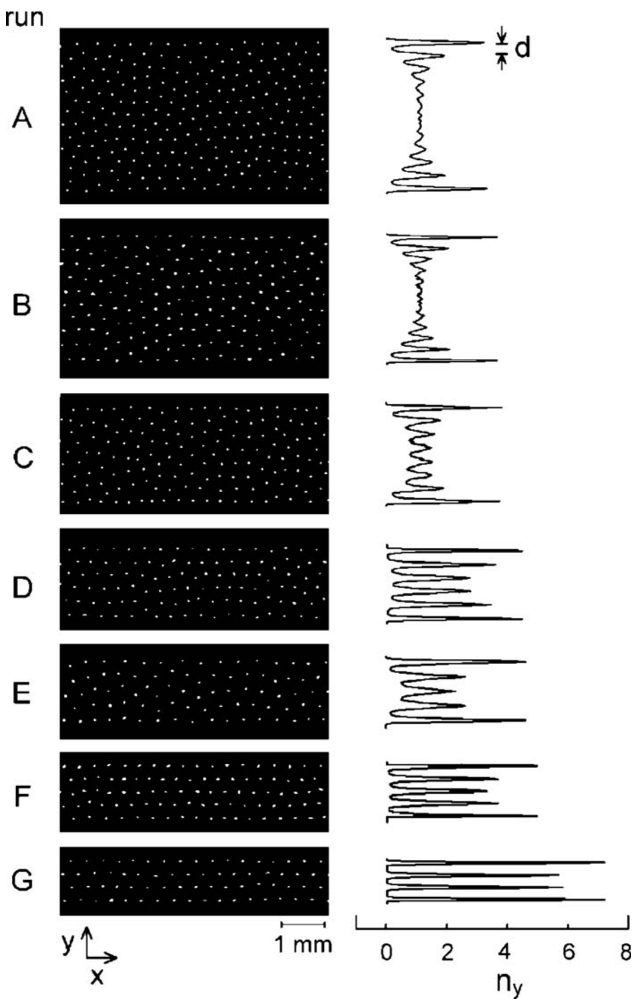


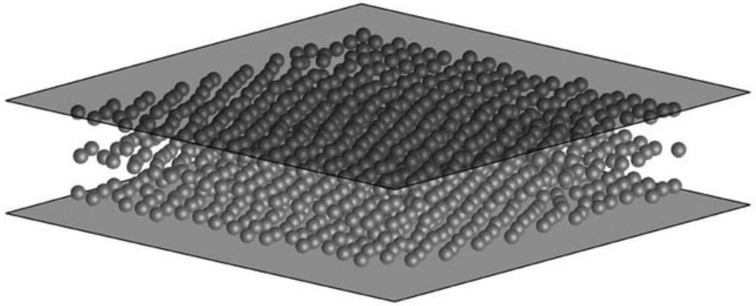


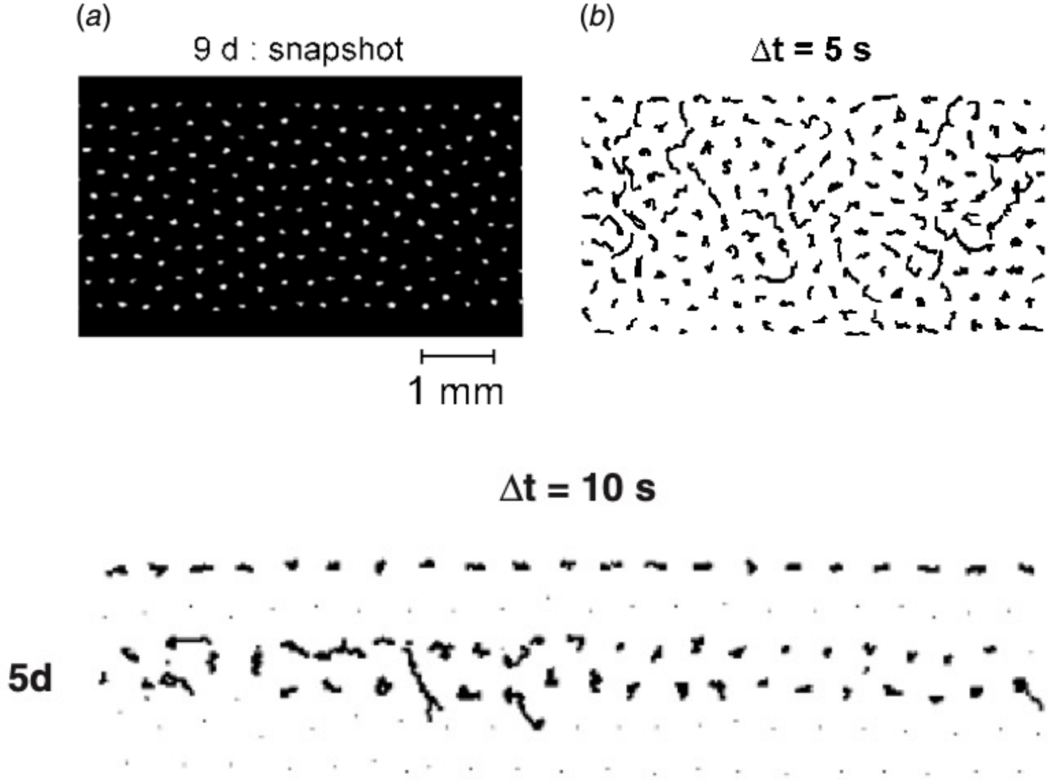
M. Schwabe, M. Rubin-Zuzic, S. Zhdanov, A. V. Ivlev, H. M. Thomas, and G. E. Morfill, Phys. Rev. Lett. **102** (2009) 255005.

Motivation: dusty plasma experiments – particle confinement

Narrow channel







G. E. Morfill & A. V. Ivlev, *Rev. Mod. Phys*. **81** (2009) 1353.

Wei-Yen Woon *et al* 2003 *J. Phys. A: Math. Gen.* **36** 6103

More recent experiments: PK-4 @ ISS

PHYSICAL REVIEW RESEARCH **2**, 033404 (2020)

Shear flow in a three-dimensional complex plasma in microgravity conditions

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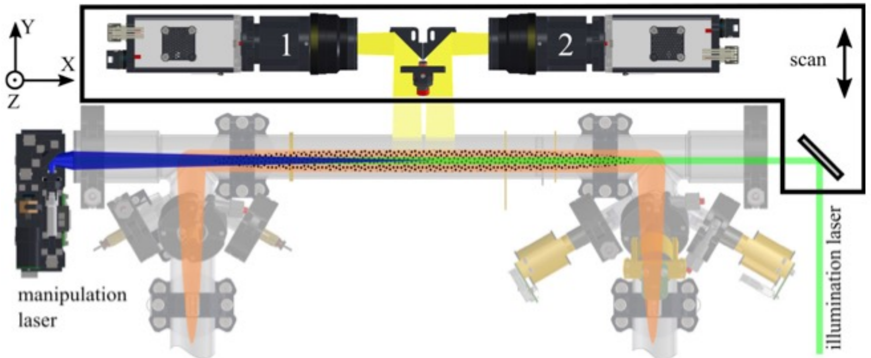
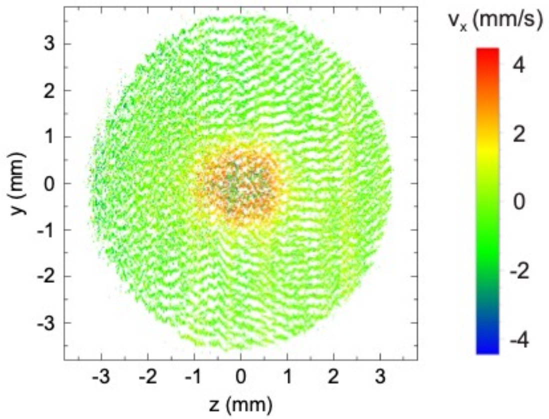
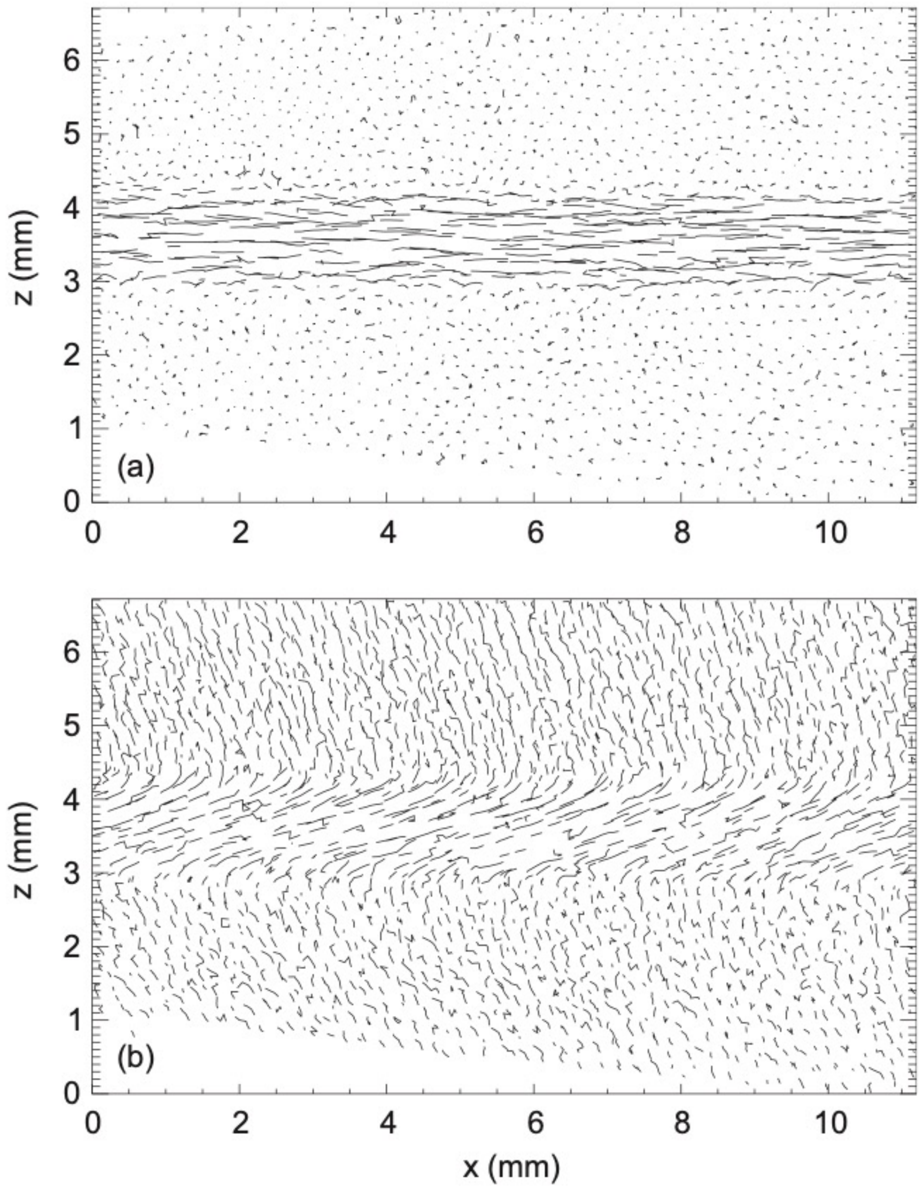
[2]*Institute for High Temperatures, Russian Academy of Sciences, Izhorskaya 13/19, 125412 Moscow, Moscow Region, Russia*
[3]*Moscow Institute of Physics and Technology, Institutsky Lane 9, 141700 Dolgoprudny, Moscow Region, Russia*
[4]*I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, 35392 Gießen, Germany*
[5]*Gagarin Research and Test Cosmonaut Training Center, 141160 Star City, Moscow Region, Russia*







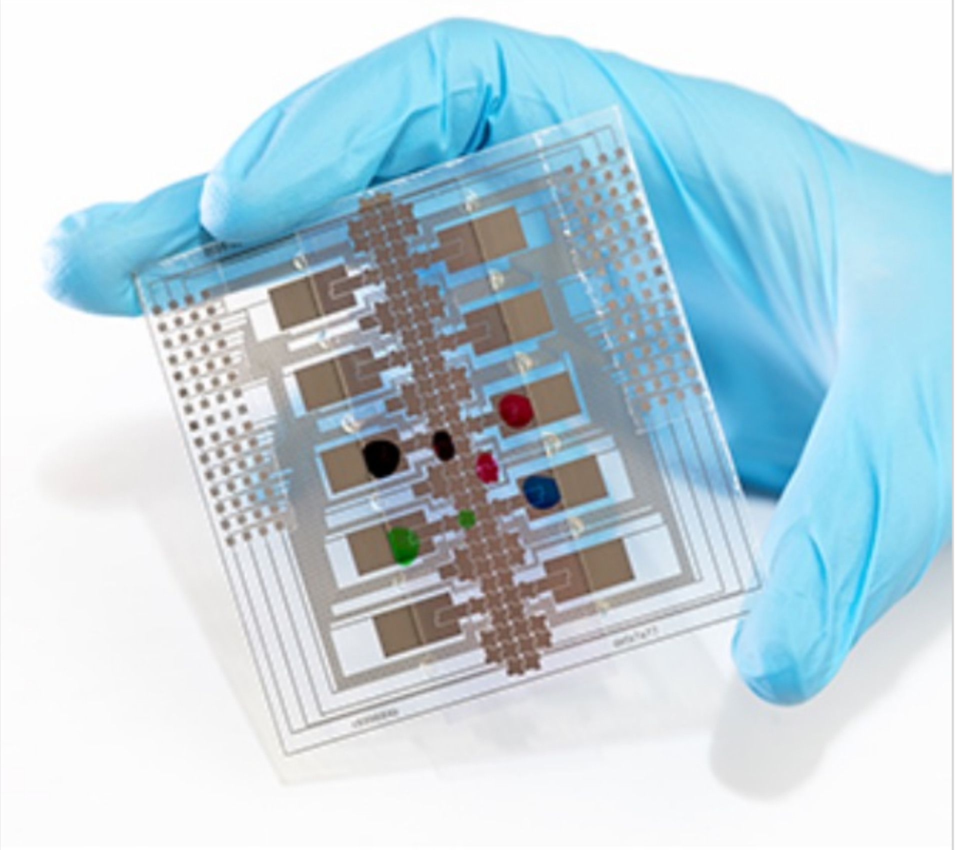
Microfluid research

However, the interdisciplinary breakthrough in this research branch is still waiting to come: the main difficulties are in the interpretation of the measured data, as it is problematic to distill the manifold of forces acting simultaneously on the dust particles.

[E.g., Lorentz force, gravity, radiation pressure, drag forces, thermophoretic force, …]

In recent years **microfluidics** became a hot topic; the flow in narrow channels is of interest for high-tech applications in the fields of biology, chemistry, physics and environmental science. The flow in straight channels are usually assumed to be laminar and the dynamics is over-damped. So far the behavior of tracer particles (regular or irregular in shape) were used to analyze flow properties. Dusty plasmas provide new possibilities to understand microfluidic flows.

Microfluid research

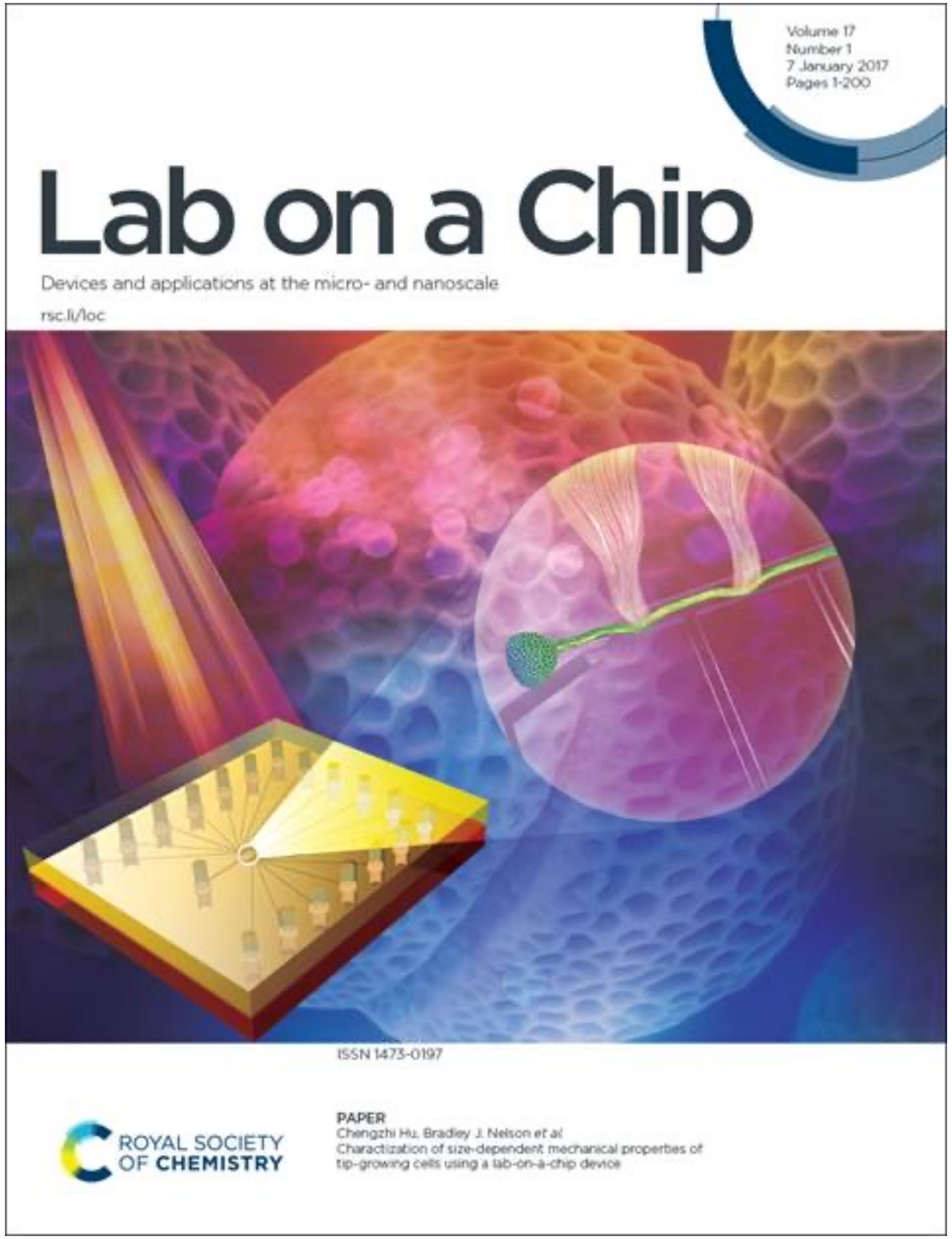


Lab-on-a-chip delivers critical immunity data for vulnerable populations

By **Marit Mitchell**

APRIL 25, 2018

Microfluid research



Novel micro- and nano-technologies and fundamental principles

- Micro- and nano-fabrication (including 3D printing, thin films)
- **Micro- and nano-fluidics (in continuous and segmented multiphase flow, droplet microfluidics, new liquids)**
- Micro- and nano-systems (sensor, actuator, reaction)
- Micro- and nano-separation technologies (molecular and cellular sorting)
- Micro- and nano-total analysis system (µTAS, nTAS)
- Digital microfluidics
- Sample preparation
- Imaging and detection

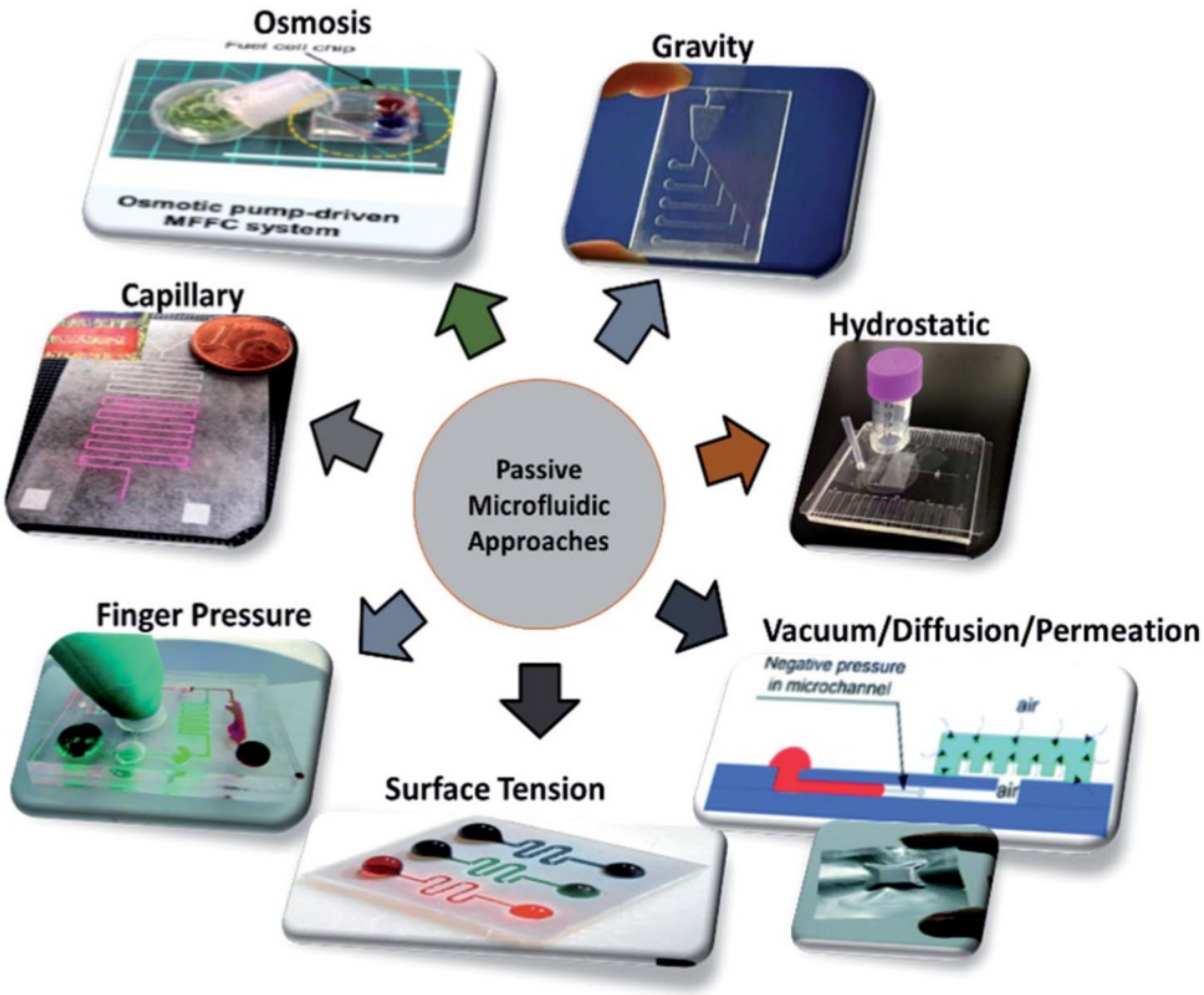
Significant biological, chemical, medical, environmental and energy applications

- Nucleic acid biotechnology and analysis (DNA and RNA sequencing, genotyping, gene manipulation)
- Protein analysis (proteomics and metabolomics for targeted and global analysis)
- Medical diagnostics (for example point of care and molecular)
- Medical devices and treatments (including implantable and wireless)
- Drug development (screening and delivery)
- Cells, tissues, organs on chip and integrated tissue engineering
- 3D cell culture
- Single cell analysis
- Cell and organism motility and interactions
- Systems and synthetic biology and medicine
- Energy, biofuels, fuel extraction
- Environmental and food monitoring for health and security

Microfluid research

Lab-on-chip (LOC)

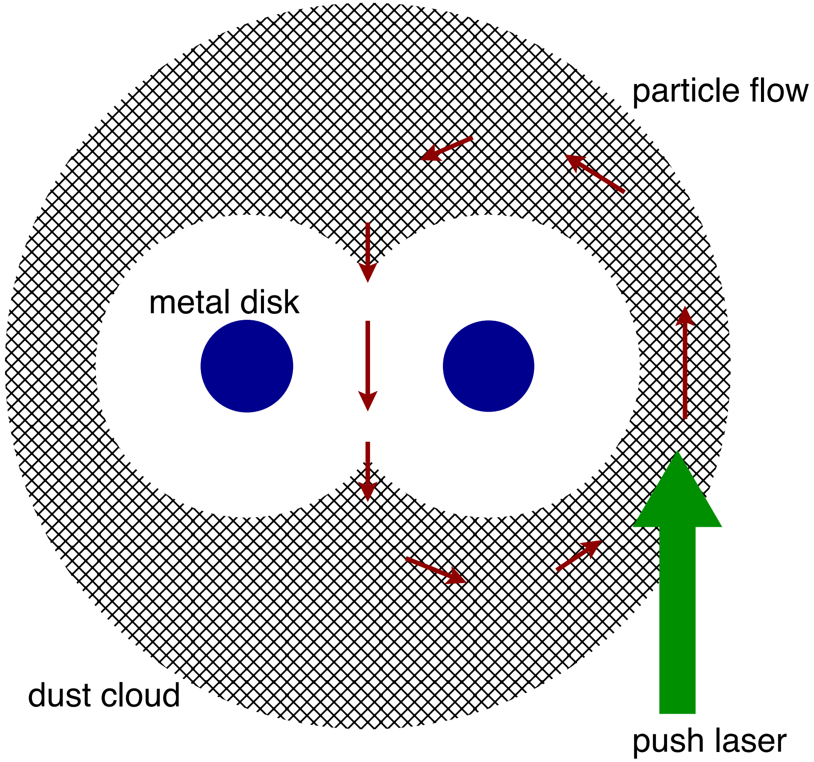
Transport of fluids can be
active (e.g., by peristaltic pumping)
or
passive (enabling simple design)

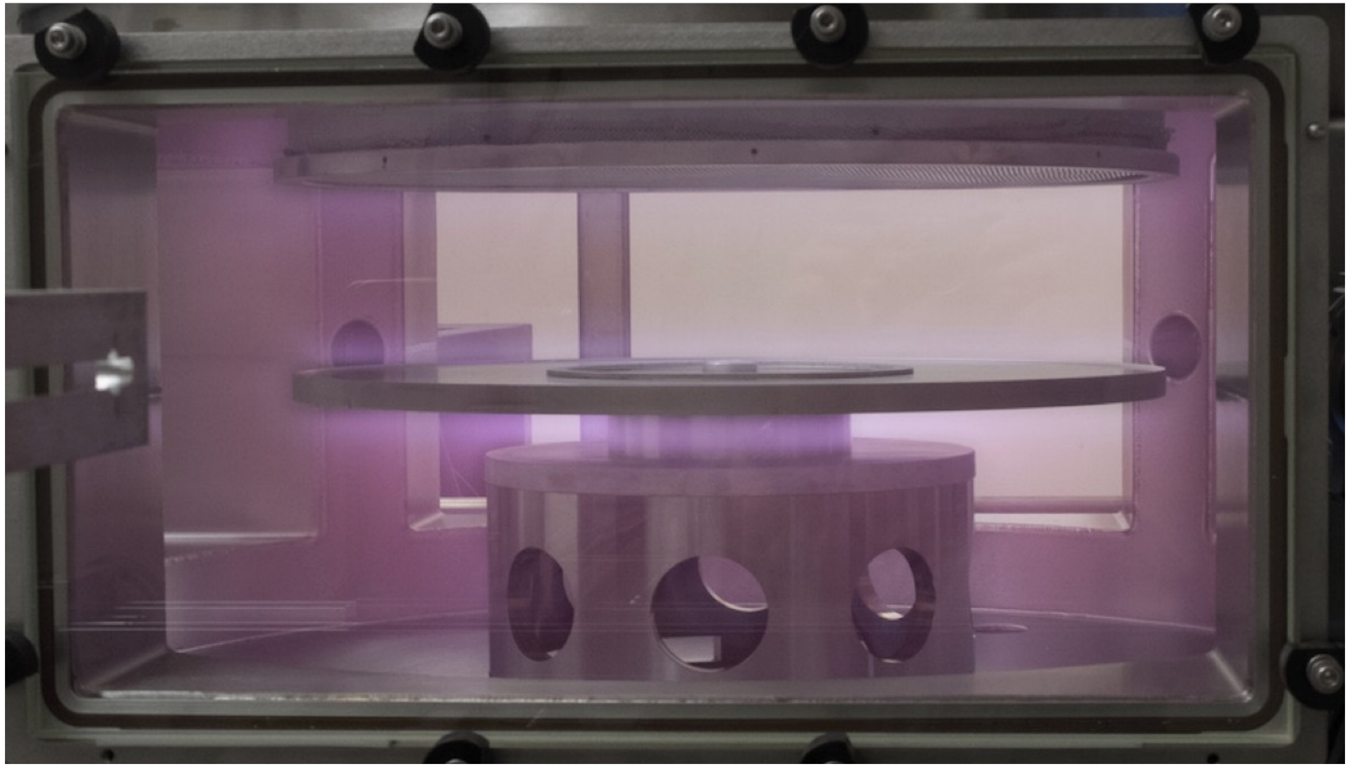


Narayanamurthy at.al., RSC Adv., 2020, 10, 11652, DOI: 10.1039/d0ra00263a

The experiment: large area CCP

This experiment was carried out in the new “large area discharge cell” of the CASPER laboratory at Baylor University.
The experiment uses a 16-inch flat horizontal electrode powered with 13.56 MHz RF electrical signal. The vacuum chamber and the upper horizontal mesh with adjustable height serve as grounded electrode for the argon gas discharge.



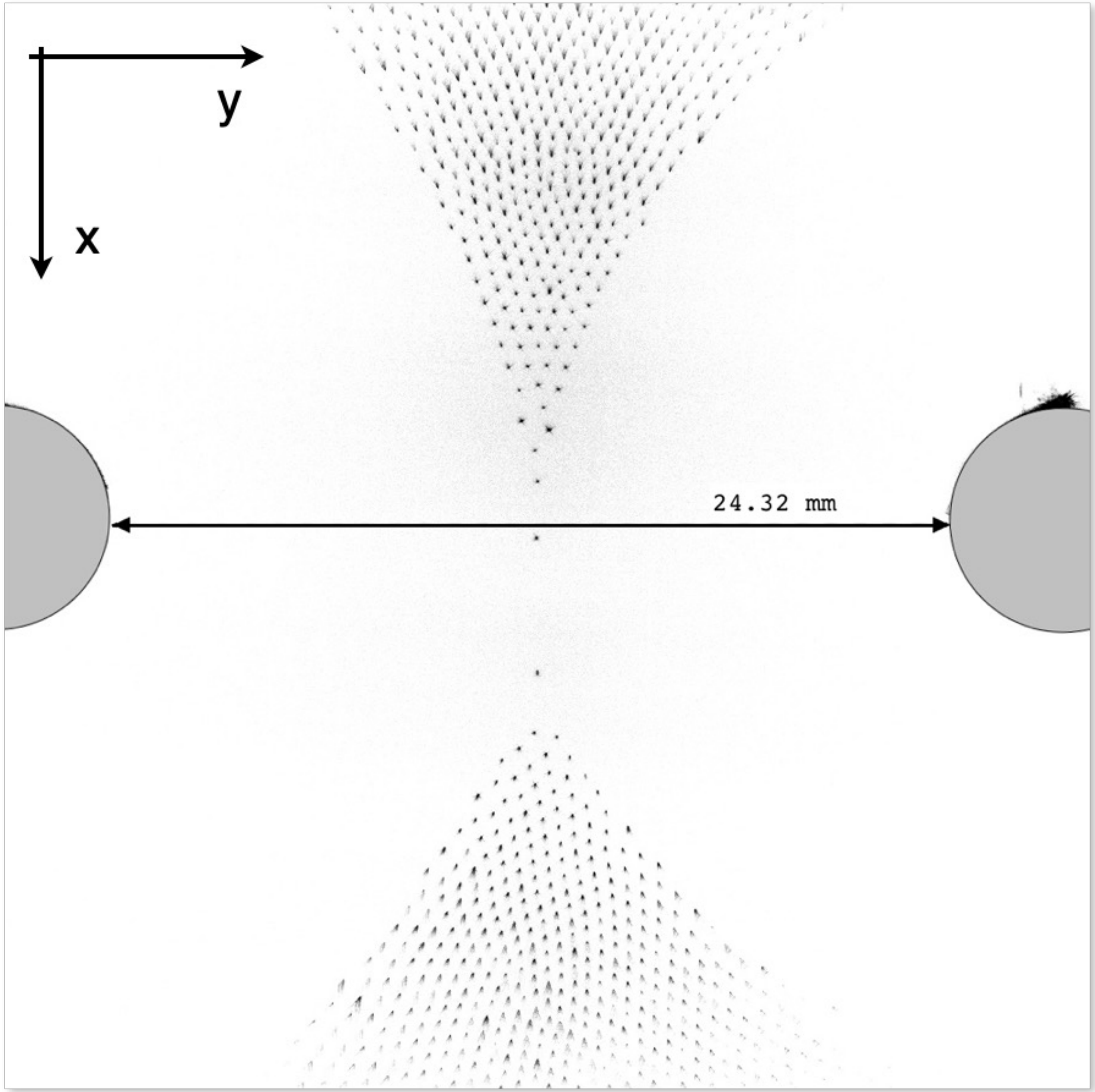


A single layer dusty plasma in the strongly coupled liquid phase was formed. To induce particle flow through a narrow channel, two metal disks were placed symmetrically on the powered electrode and indirect laser manipulation was applied to prevent the introduction of another unknown force onto the particles transiting through the channel.

The experiment: formation of the microchannel

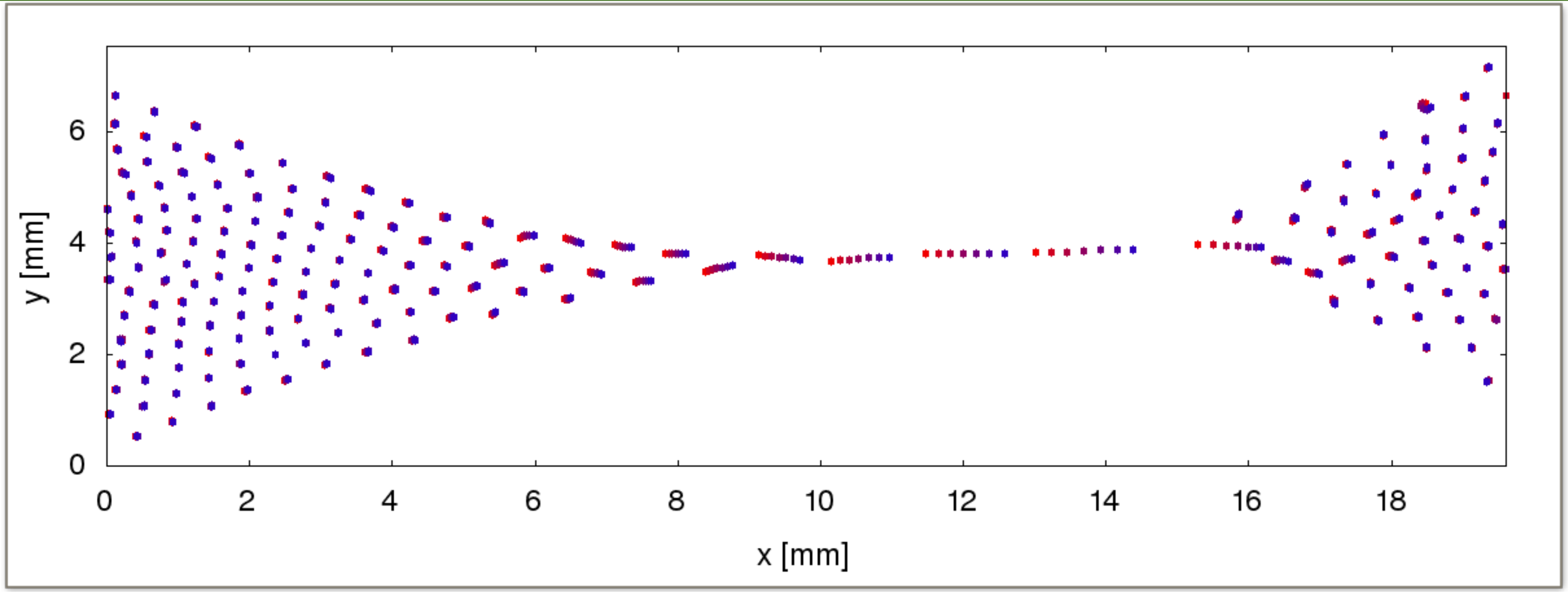
Depending on the discharge conditions, the flow pattern can be adjusted from single lane to multilane (up to 4) channel width.

The pushing laser is focused off-centered into the particle plane and is set to 5.5 W @ 532 nm.

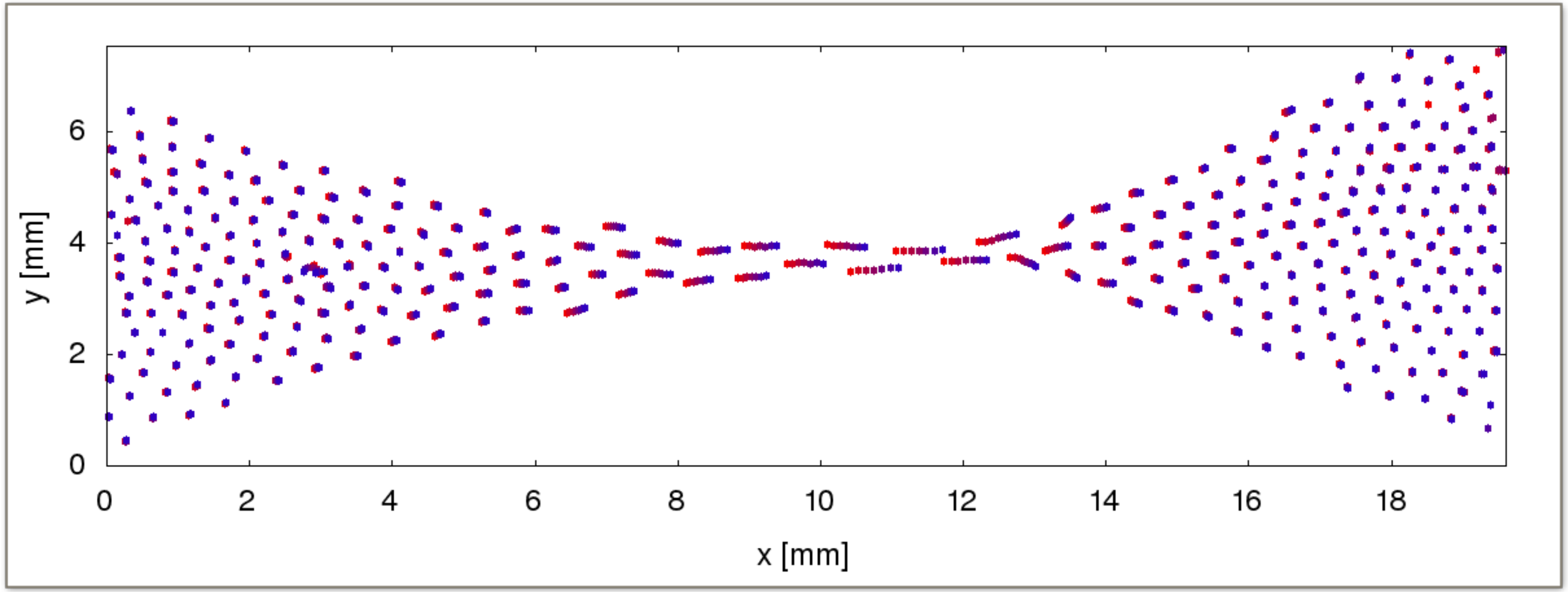


Superposition of 7 subsequent frames

Single lane channel:
Argon pressure: 8.0 Pa
RF power: 65 W
frame rate: 60 fps

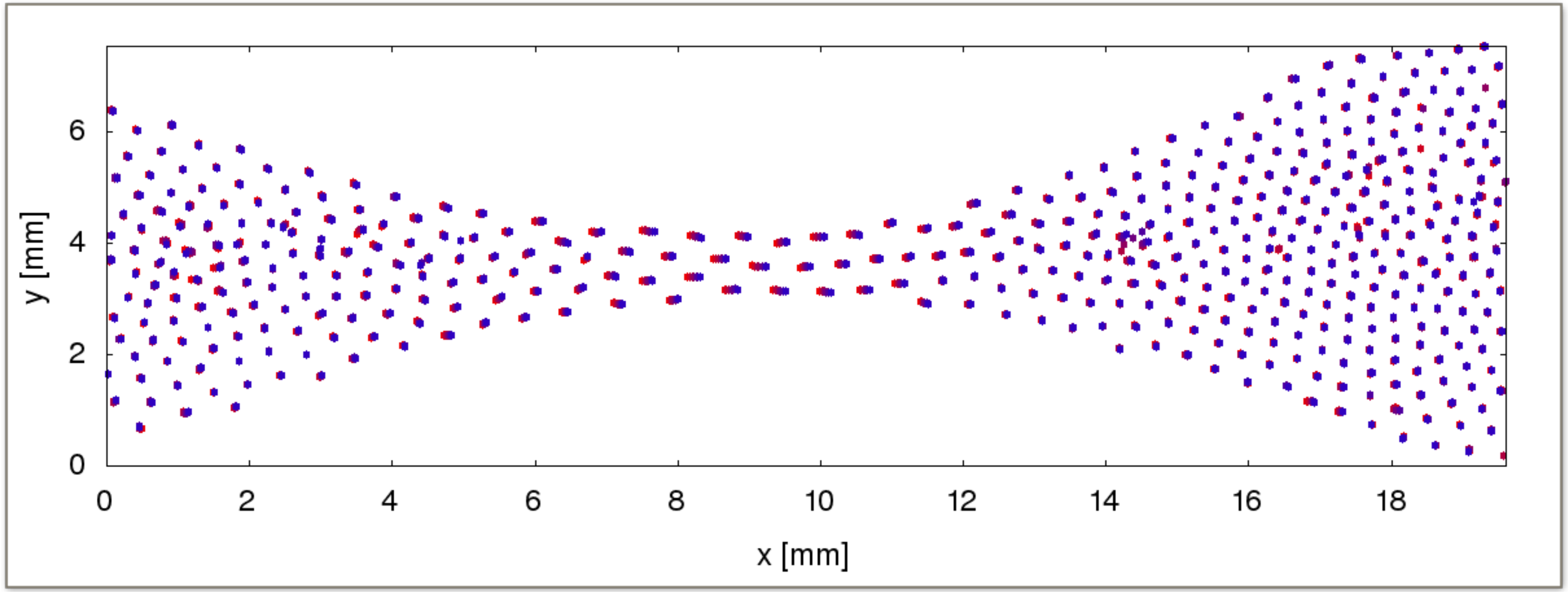


Double lane channel:
Argon pressure: 9.3 Pa
RF power: 65 W
frame rate: 60 fps

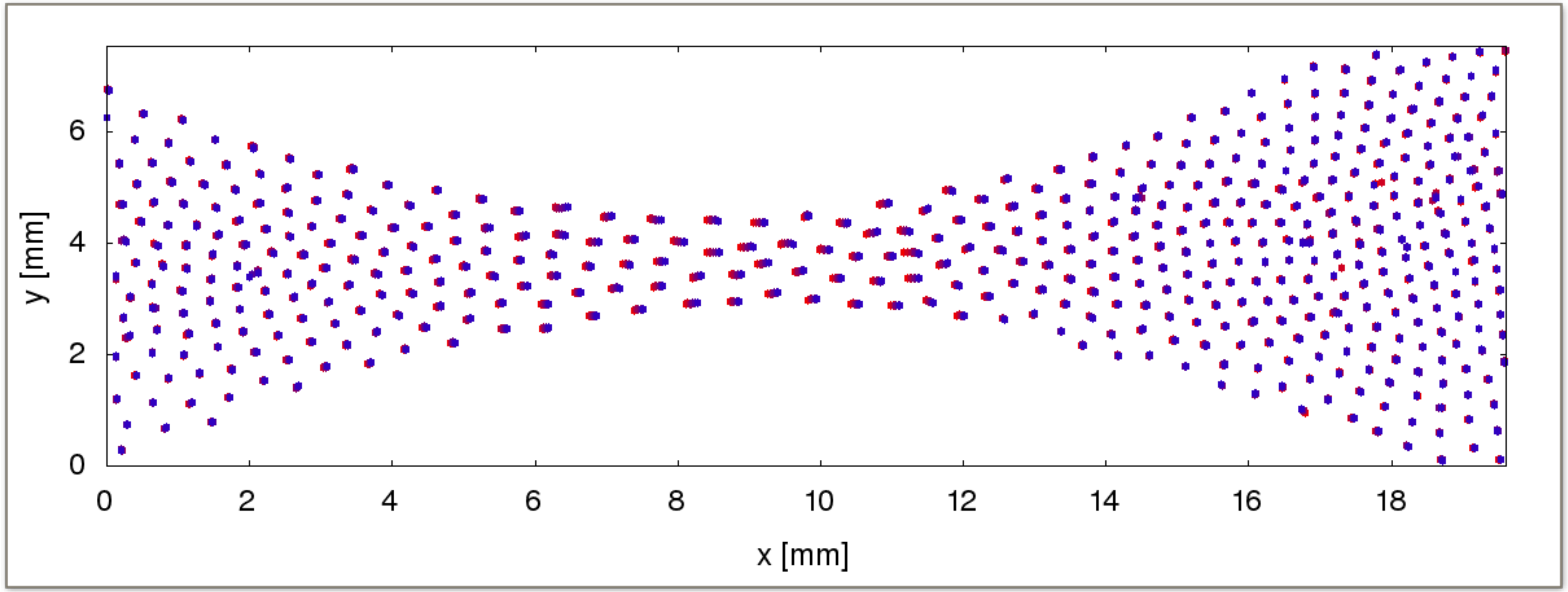


Superposition of 7 subsequent frames

Triple lane channel:
Argon pressure: 10.2 Pa
RF power: 65 W
frame rate: 60 fps

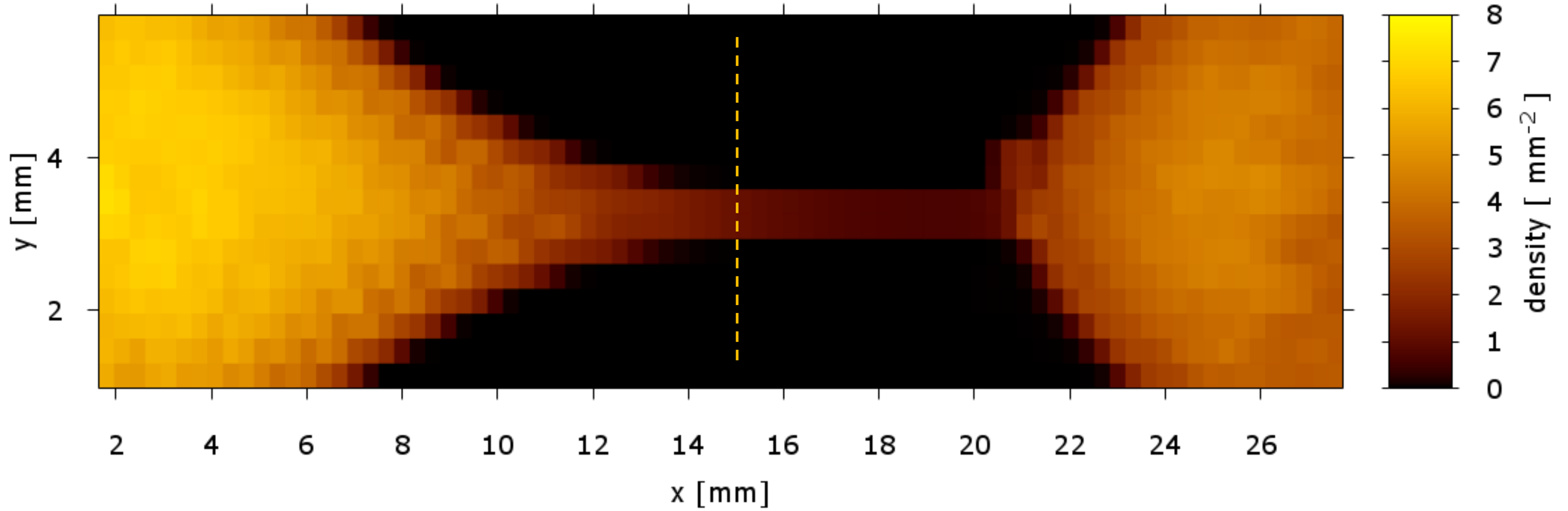


Quadruple lane channel:
Argon pressure: 10.7 Pa
RF power: 65 W
frame rate: 60 fps



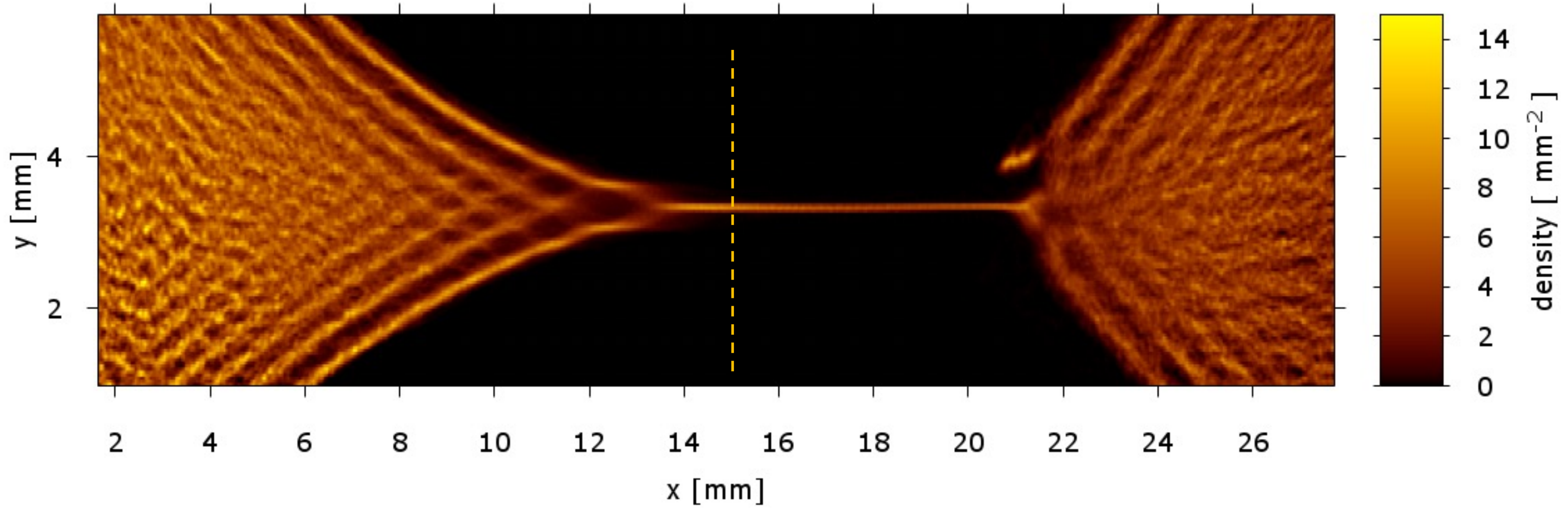
Time-averaged distributions: particle density

For every case, 8,000 video frames @ 60 fps with a resolution of 512 x 2048 pixels were recorded. The spatial resolution was 62.8 pixel/mm. Coarse and high-resolution distributions of particle densities, velocities and accelerations were determined.



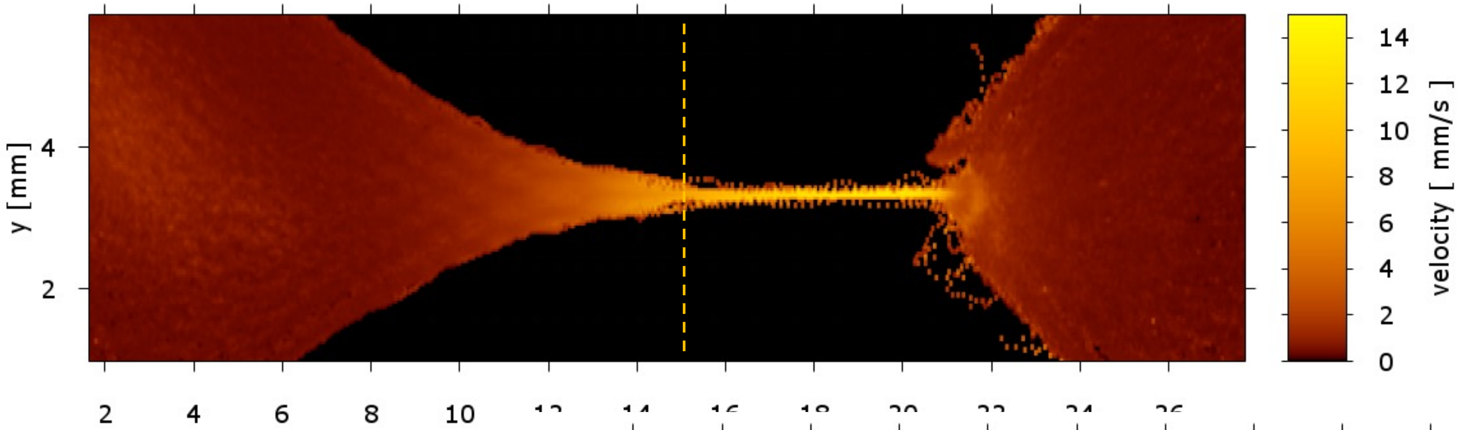
[90x23]

The driving force is the difference in density (pressure) between the two sides.

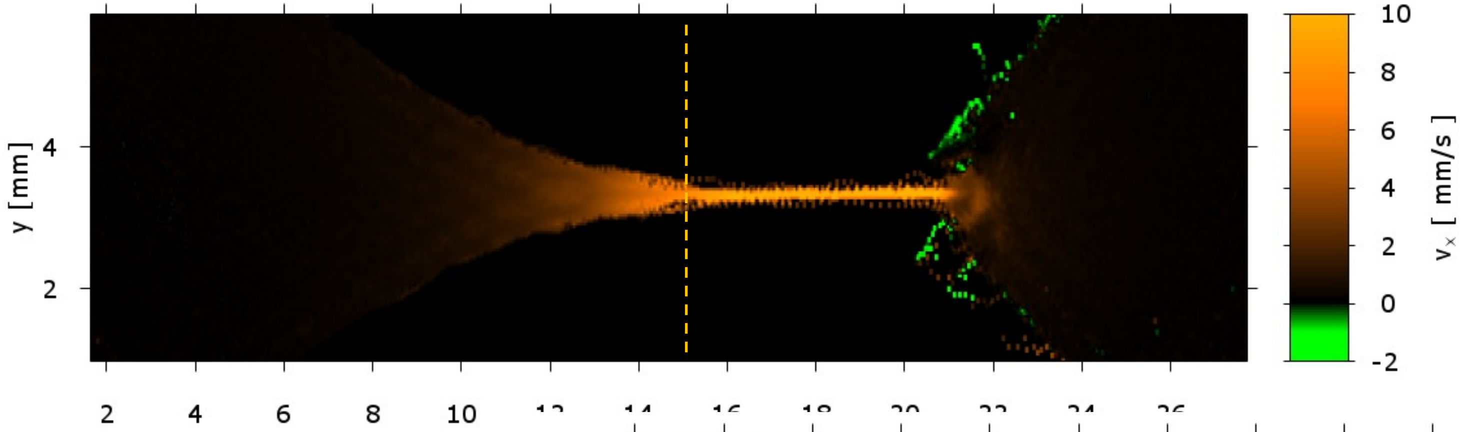


[720x180]

Time-averaged distributions: velocity (1 lane)

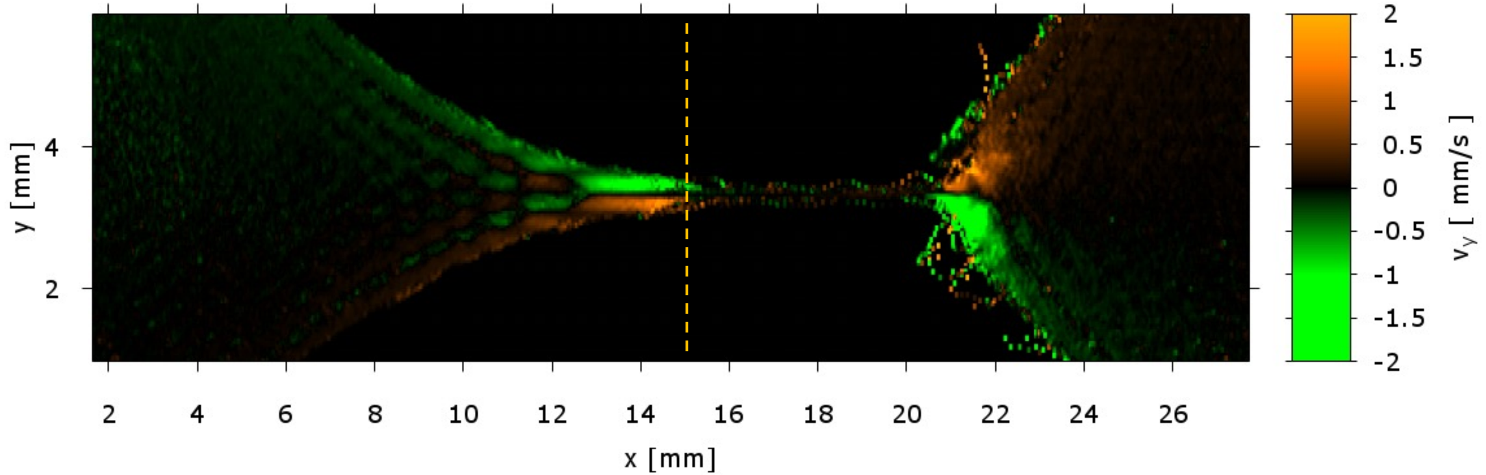


velocity amplitude: peaks in the channel, directed motion

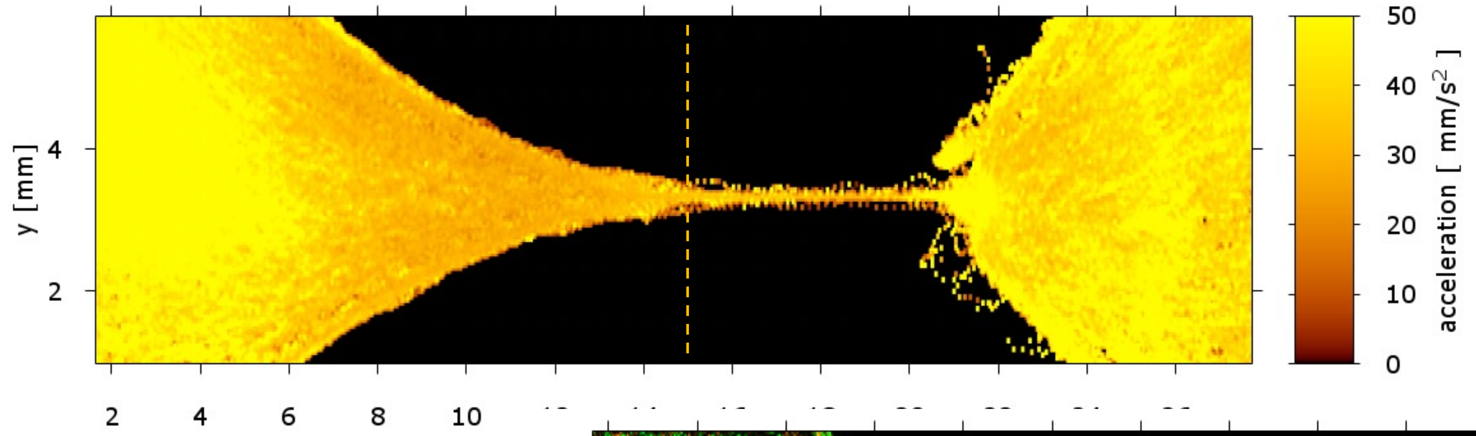


x-velocity: zero in the bulk, increasing with approaching the channel, drops rapidly after impact

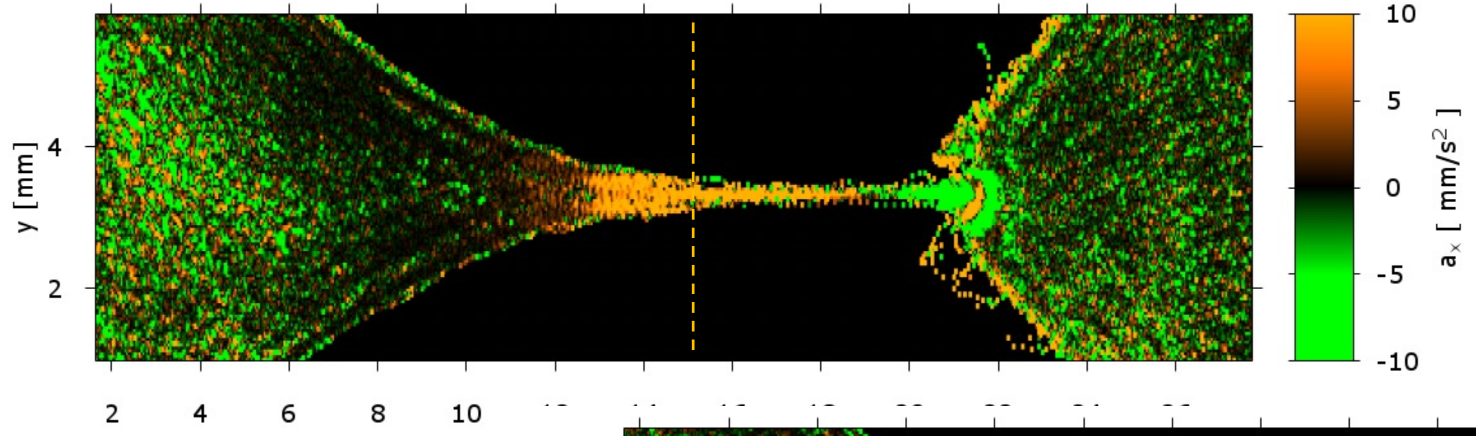
y-velocity: alternating in the source, oscillating in the channel, bipolar after impact (disordered target)



Time-averaged distributions: acceleration (1 lane)

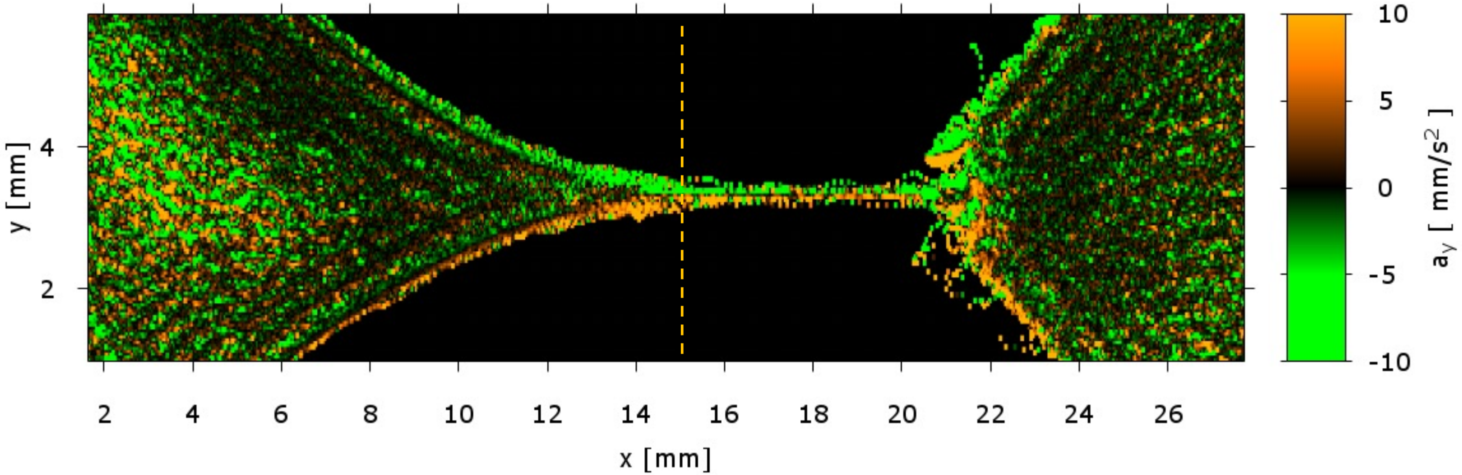


acceleration amplitude: peaks in the bulk, thermal motion

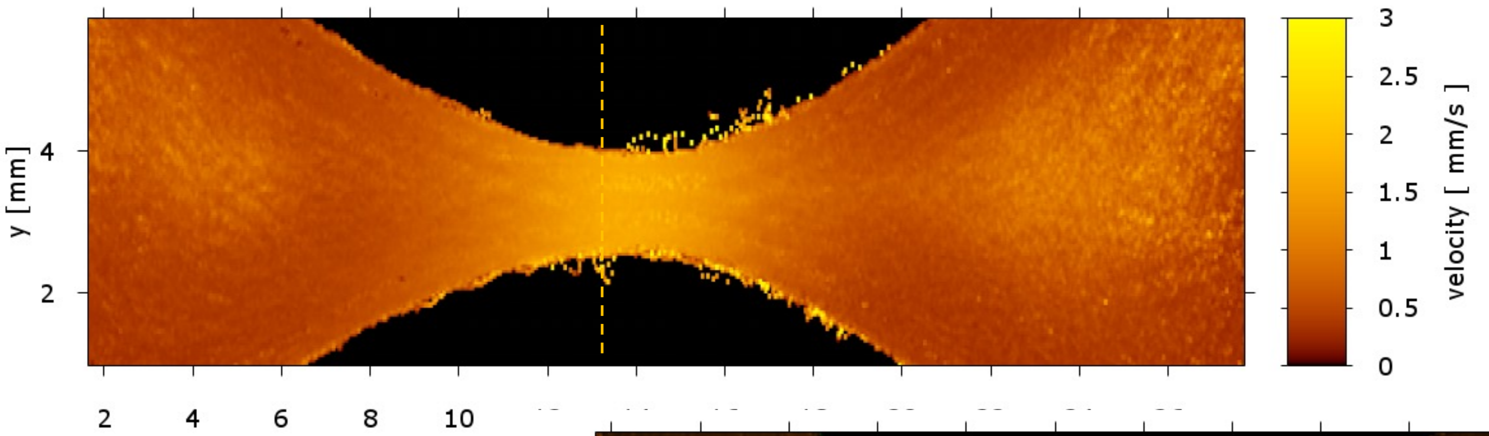


x-acceleration: positive deep in channel, reverses only at impact point

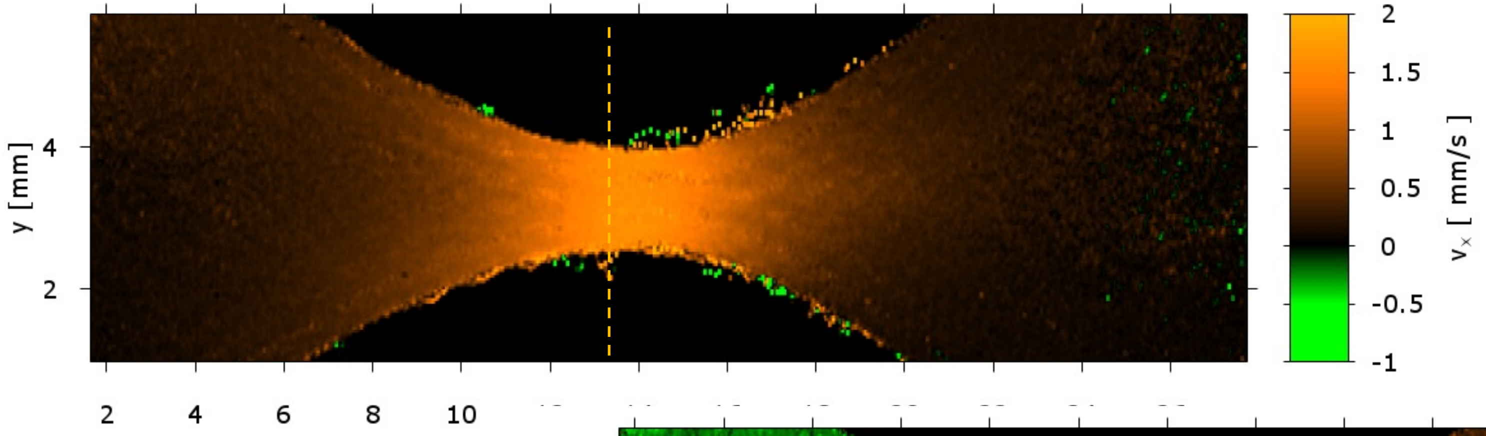
y-acceleration: oscillations around particle lanes



Time-averaged distributions: velocity (3 lanes)

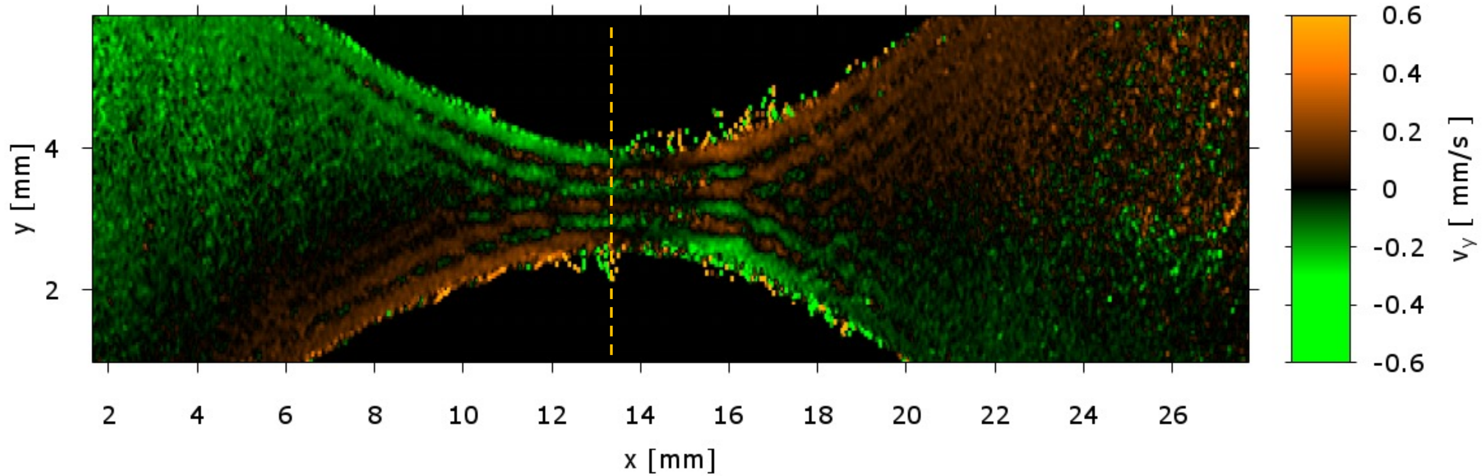


velocity amplitude: peaks in the channel, directed motion

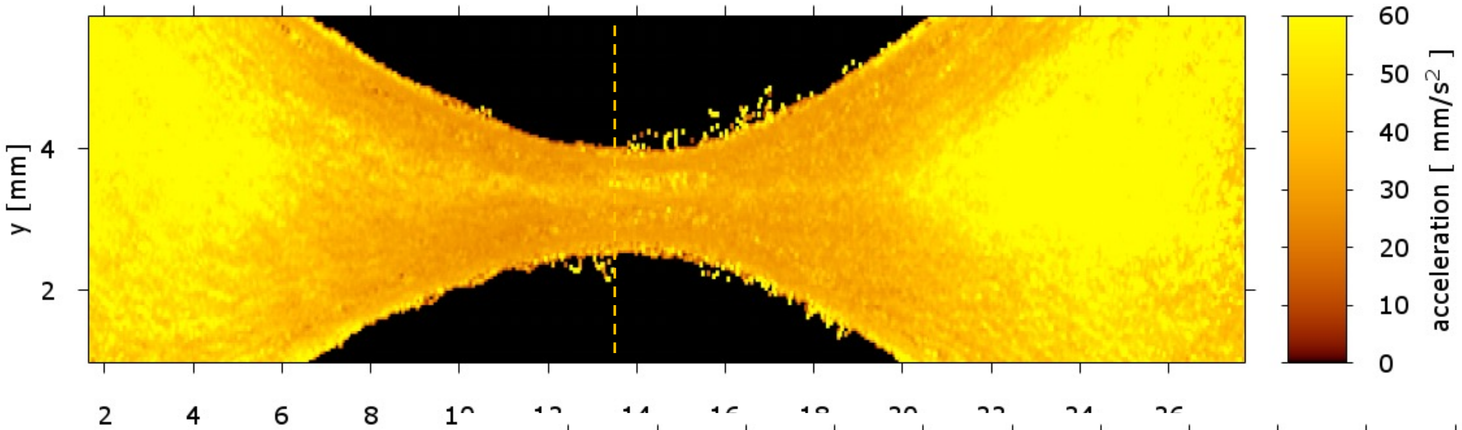


x-velocity: zero in the bulk, increasing with approaching the channel, drops rapidly after impact

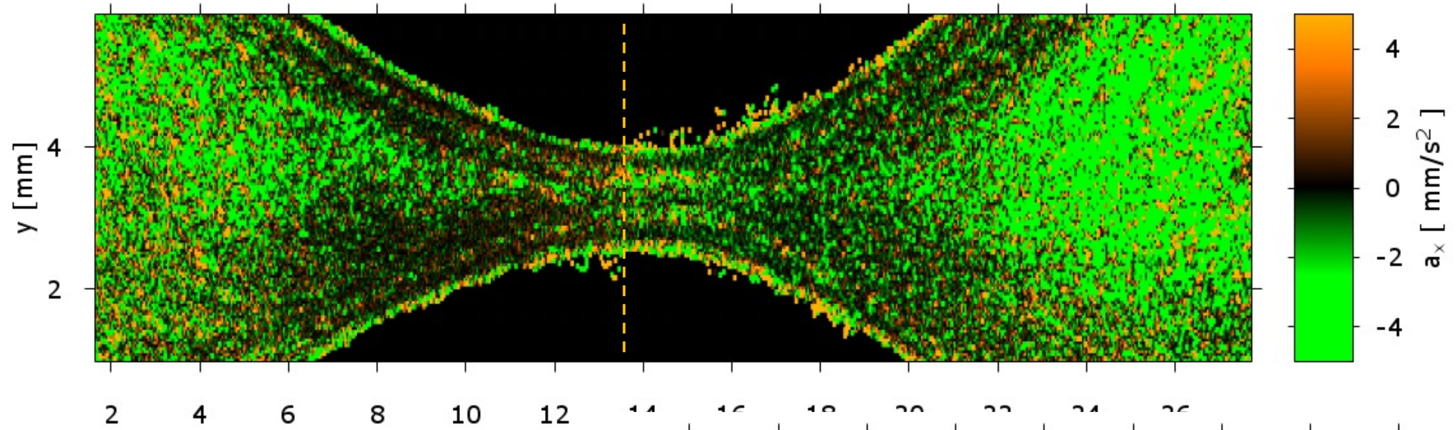
y-velocity: alternating in the source and the target



Time-averaged distributions: velocity (3 lanes)

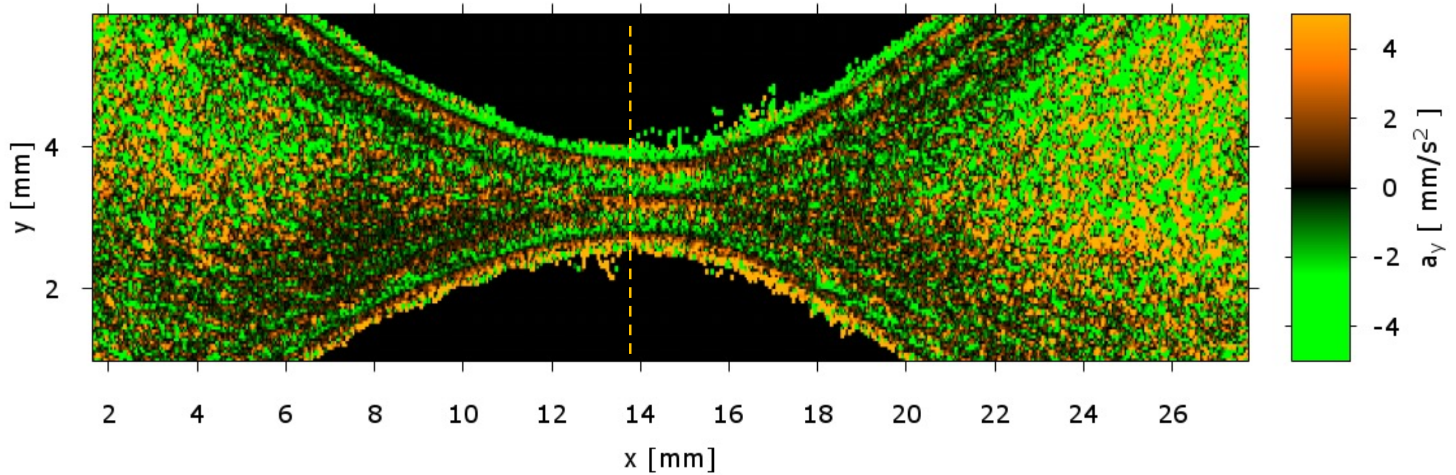


acceleration amplitude: peaks in the bulk, thermal motion



x-acceleration: low modulation amplitude

y-acceleration: oscillations around particle lanes



Summary

Using the “classical” plasma crystal experimental arrangement (low power, plane-parallel RF discharge in some inert gas + monodisperse solid particles), and forming a stable single layer ensemble the system can be well approximated by a one-component plasma model.

Introducing indirect laser manipulation, the force balance remains simple (electrostatic + friction) and the microscopic insights can be useful to derive universal conclusions.

This work was supported by the Hungarian grant NKFIH-K134462 and NASA Grant number 1571701 and NSF Grant number 1740203 and the US Department of Energy, Office of Science, Office of Fusion Energy Sciences under award number DE-SC-0021334.

Wigner 121
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