PlasmaLab/EKOPlasma – The next laboratory for complex plasma research on the International Space Station

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14th Workshop on the Physics of Dusty Plasmas, 29. May 2015, Auburn

Team:

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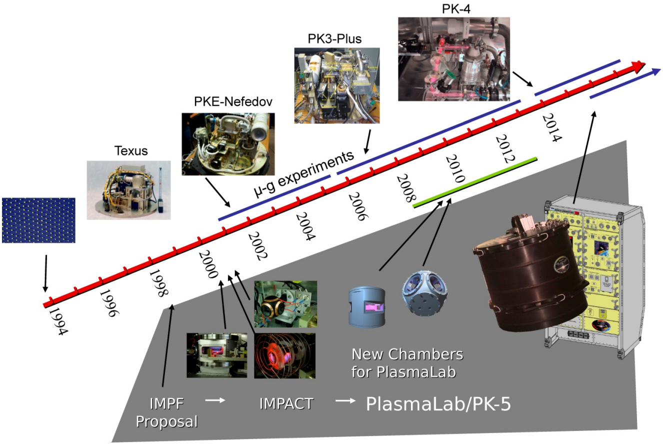
Complex Plasma experiments on the ISS



IMPF: International Microgravity Plasma Facility

IMPACT: International Multi-user Plasma, Atmospheric and Cosmic dust twin laboratory

⇒ PlasmaLab orginates from IMPACT

PlasmaLab/EKOPlasma

- continuation of the succesful Russian (RAS-Joint Institute for High Temperatures) / German (DLR-Research Group Complex Plasma, former MPE) cooperation
- next generation lab for the Russian Module after PK-4 on Columbus: EKOPlasma (<u>E</u>xperiment <u>KO</u>mplex <u>P</u>lasma)

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Technological Goals

- expanding the accessible parameter range by orders of magnitudes
- independent control of plasma parameters
- utilization of new technologies, eg. 3D particle diagnostics, high speed recording, ...

$\Rightarrow$ provide experimental platform for a wide range of scientific topics in the field of complex plasmas:

- phase transitions, phase separation, onset of turbulence, waves, ...

The Zyflex Chamber - Design

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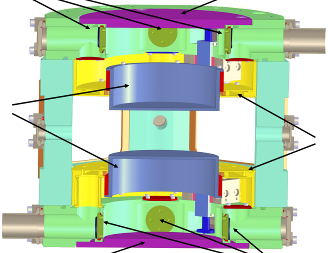
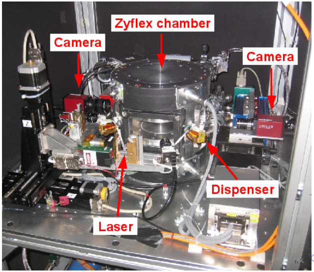
German Aerospace Center



Material:	Aluminium
Height:	250 mm
Diameter:	270 mm
Weight:	$\approx$ 20 kg
Electrode $\varnothing$:	114 mm
Guard rings width:	37.75 mm
Electrode separation:	25 . . . 75 mm
Guard ring separation:	25 . . . 75 mm

- adaptive inner geometry:
- plasma generation:
  4-channel rf generator @ 13.56 MHz
- different electrode types are available
- particle detection:
  red diode lasers, several cameras



The Zyflex Chamber - Advantages

- larger plasma volume
  ⇒ more homogeneous plasma
  ⇒ lower neutral gas pressures (weaker damping)
  ⇒ large 3D systems
- more control over parameters
  ⇒ adaptive plasma volume
  ⇒ amplitude, phase of rf-channels
  ⇒ neutral gas flow
  ⇒ electron temperature control with special electrodes
- particle dispensers are outside the main plasma volume in the chamber walls
- better diagnostics possible due to technical advances (eg. USB3 cameras, 3D diagnostics, compact lasers)

Electrode Configurations

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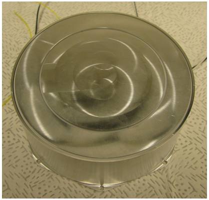
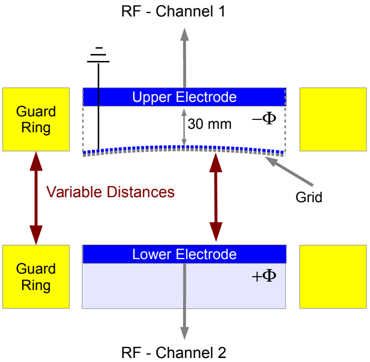
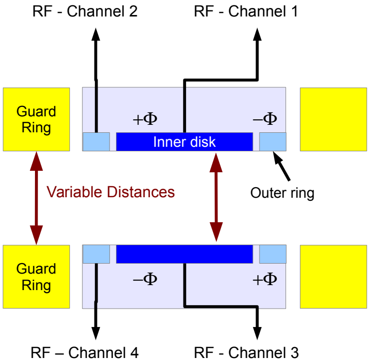
Simple electrode

Grid electrode

Segmented electrode

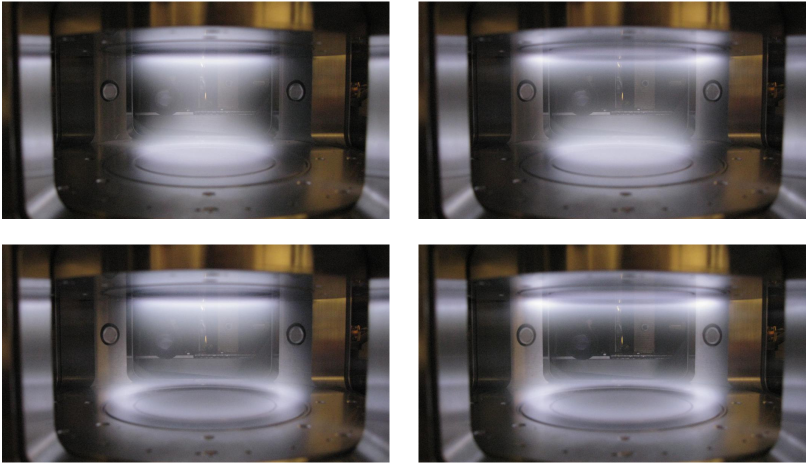






Independent Plasma Control

Segmented Electrodes



Different plasma configurations by independent control of 4 rf-channels

PIC Simulations

Influence of phase shift between rf signals: Segmented electrode

PIC Simulations

Influence of phase shift between rf signals: Segmented electrode

Top electrode

0	0	0

180	180	180

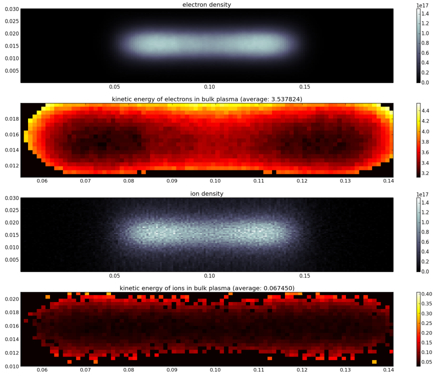
Bottom electrode

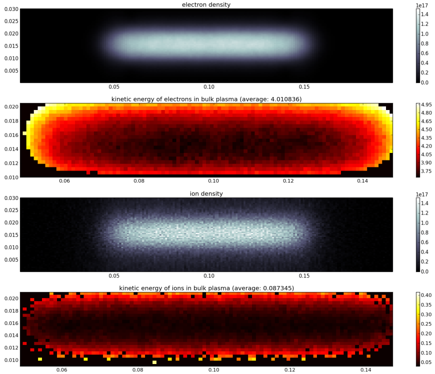
Top electrode

270	0	270

90	180	90

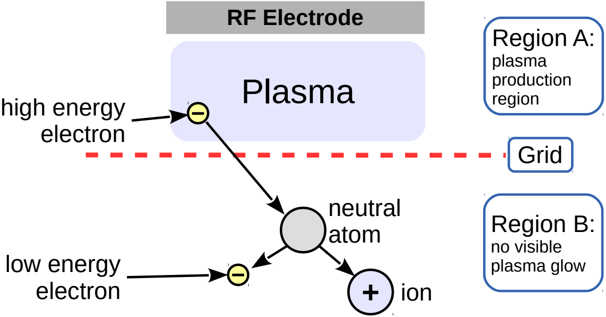
Bottom electrode





Electron Temperature Control

Grid Electrodes



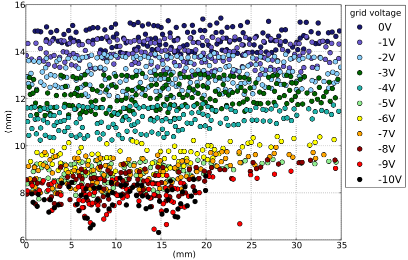
- high energy electrons pass the biased grid
- ionisation behind the grid creates low energy electron population

⇒ control of electron temperature through grid voltage
⇒ control of particle charge in that region

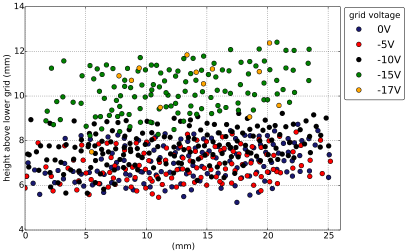
Electron Temperature Control

Grid Electrodes - First Results

Particle Positions - Experiment 1



Particle Positions - Experiment 2

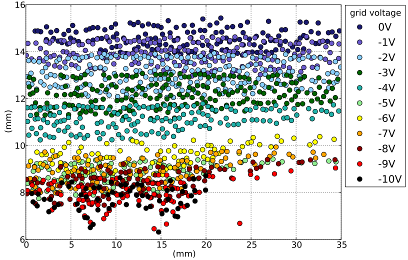


$\Rightarrow$ particle levitation height is influenced by grid voltage

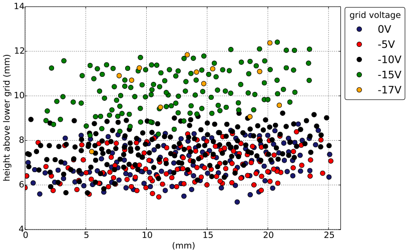
Electron Temperature Control

Grid Electrodes - First Results

Particle Positions - Experiment 1



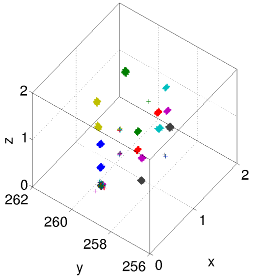
Particle Positions - Experiment 2



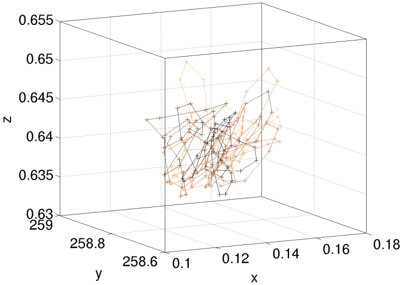
$\Rightarrow$ particle levitation height is influenced by grid voltage

more particles needed $\Rightarrow$ experiments in μg

3D Particle Diagnostics



3D particle coordinates of a small cluster in the Zyflex Chamber, taken with a stereoscopic camera setup

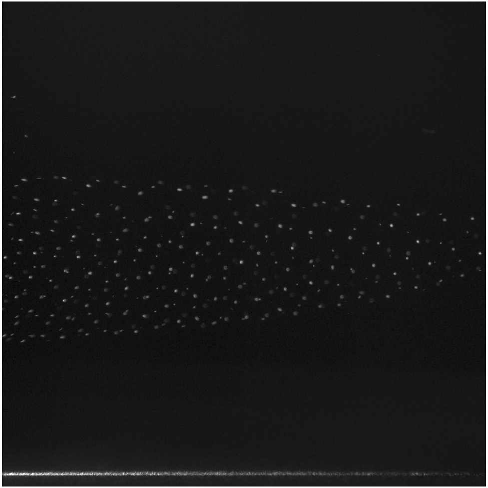


3D particle trajectory of a single particle (time is color coded)

⇒ Outlook: Improved 3D diagnostics with lightfield cameras (?) for realtime 3D observation of dynamical processes on the ISS

Recent Lab Experiment

Turbulence



- Argon, 10 Pa
- $U_{pp} = 57$ V (top electrode)
- 4.38 μm MeF particles
- distance electrodes/guard rings: 75 mm

Recent Lab Experiment

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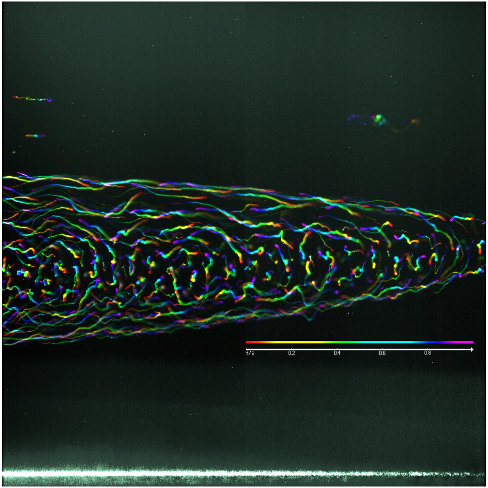
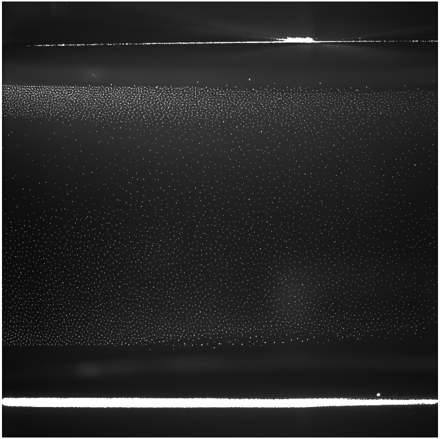


- Argon, 10 Pa
- $U_{pp} = 57$ V (top electrode)
- 4.38 μm MeF particles
- distance electrodes/guard rings: 75 mm

Experiments in μ-Gravity

Simple electrodes - guard rings on level with electrodes, 9.19 μm particles

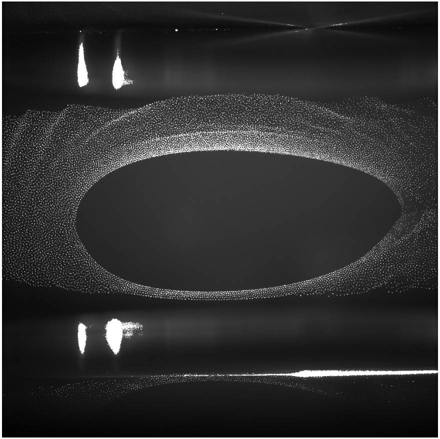
5.9 Pa, 29.2 V_{pp}



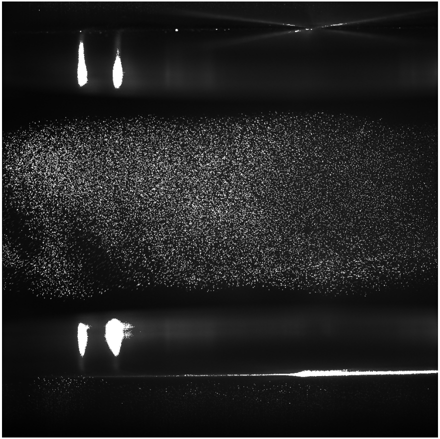
39.5 Pa, 29.2 V_{pp}

Experiments in μ-Gravity

Simple electrodes - guard ring distance decreased, 9.19 μm particles



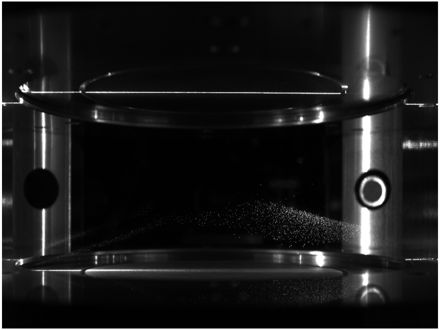
5.3 Pa, 29.2 V_{pp}



0.85 Pa, 29.2 V_{pp}

Experiments in μ-Gravity

Chamber cleaning in microgravity



Particles: 1.95 μm SiO_2 and 4.38 μm MeF

guard ring distance $<$ electrode distance

Experiments in μ-Gravity

Chamber cleaning in microgravity

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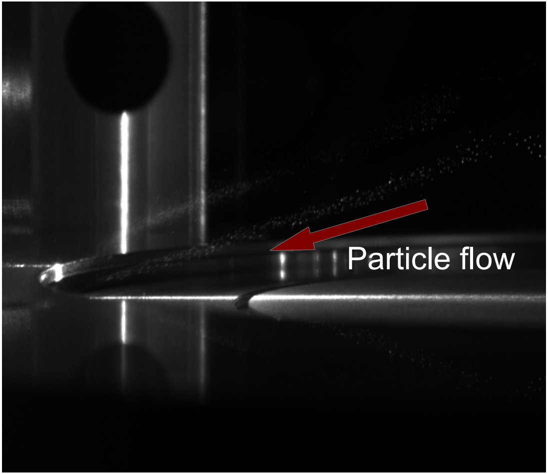

$\Rightarrow$ particles can be removed from the chamber during 0g when plasma is switched off

Summary

- three parabolic flight campaigns and numerous experiments in the lab show promising results
- several electrode types have been tested
- 2D PIC simulations are performed to characterize the plasma conditions for the different rf settings
- first tests with 3D diagnostics were performed
- new technologies for particle diagnostics are available and will be implemented: 3D lightfield cameras, fast USB 3.0 cameras for 2D high speed recording

Outlook

- 2 parabolic flight campaigns for further testing (2015/1026)
- joint scientific protocol with JIHT, feasibility study (2014-2015)
- pre-development at DLR, manufacturing of bread-board model (2014-2016)
- preliminary design review (2017)
- start of design and qualification from 2017 on
- launch to ISS: 2019 (?)

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Thank you!