CENTRE FOR INTERDISCIPLINARY PLASMA SCIENCE

PK-4 -- A Complex Plasma Experiment For The New Millennium

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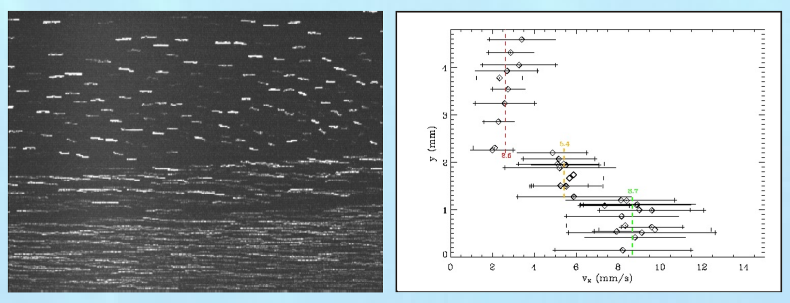
ABSTRACT: Flows, shear flows, laminar and turbulent flows on the microscopic scales are one of the fundamental issues in fluid dynamics. Due to their special properties, complex plasmas provide an excellent opportunity to study these flows, even on the scale of individual particles. To this end, experiments were conducted in the 'Plasmakristall 4' (PK-4) experimental device that uses the positive column of a high voltage dc discharge to produce complex (dusty) plasmas. The linear geometry of PK-4 provides the opportunity to study all these kinds of flow phenomena as well as waves and collisions. First observations in the prototype setup are presented.

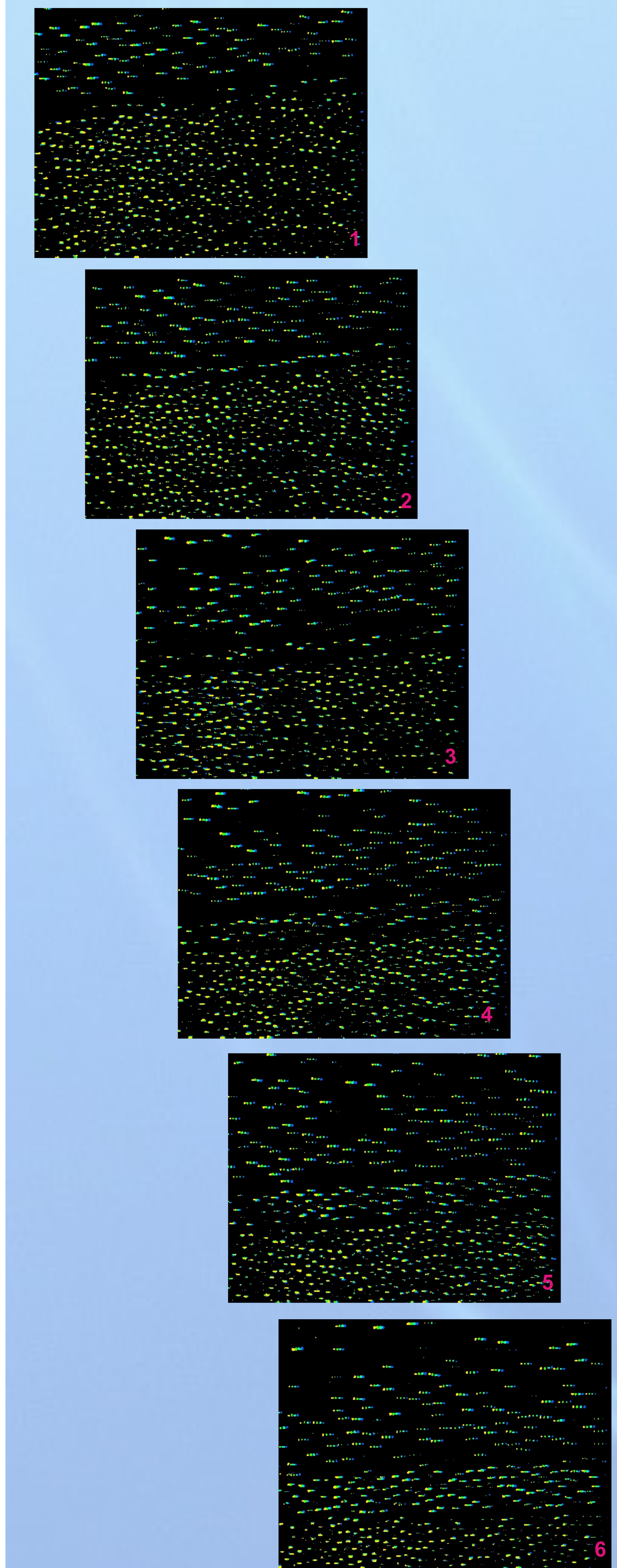
Shear flow

In this experiment, a gas flow generated a velocity gradient of the particles along the tube radius, leading to a shear flow along the tube. First, a cloud of particles was injected into the discharge tube and trapped in a rf(i) discharge in the lower end of the tube. Then, a second cloud was injected and the collision of these two clouds was observed. The second cloud penetrates the first one and lane formation (see next paragraph) of the streaming particles is observed. A few seconds later, the streaming cloud breaks apart under the influence of the shear flow.



Left: Particles streaming with different velocities at different radii (10 images added up). The center of the tube is located at the lower edge of the picture, the particles are streaming down (to the right in this camera view). Center: The velocity distribution lead to a shear-off of several layers.

Shear flow evolution



Figures 1-6: Superposition of five single frames with different colors to show the motion of the particles. Evolution of the shear flow: 1. Two separated layers; 2. An intermediate monolayer forms; 3. Zig-zag monolayer; 4. Double layer; 5. Multilayer; 6. End of movie.

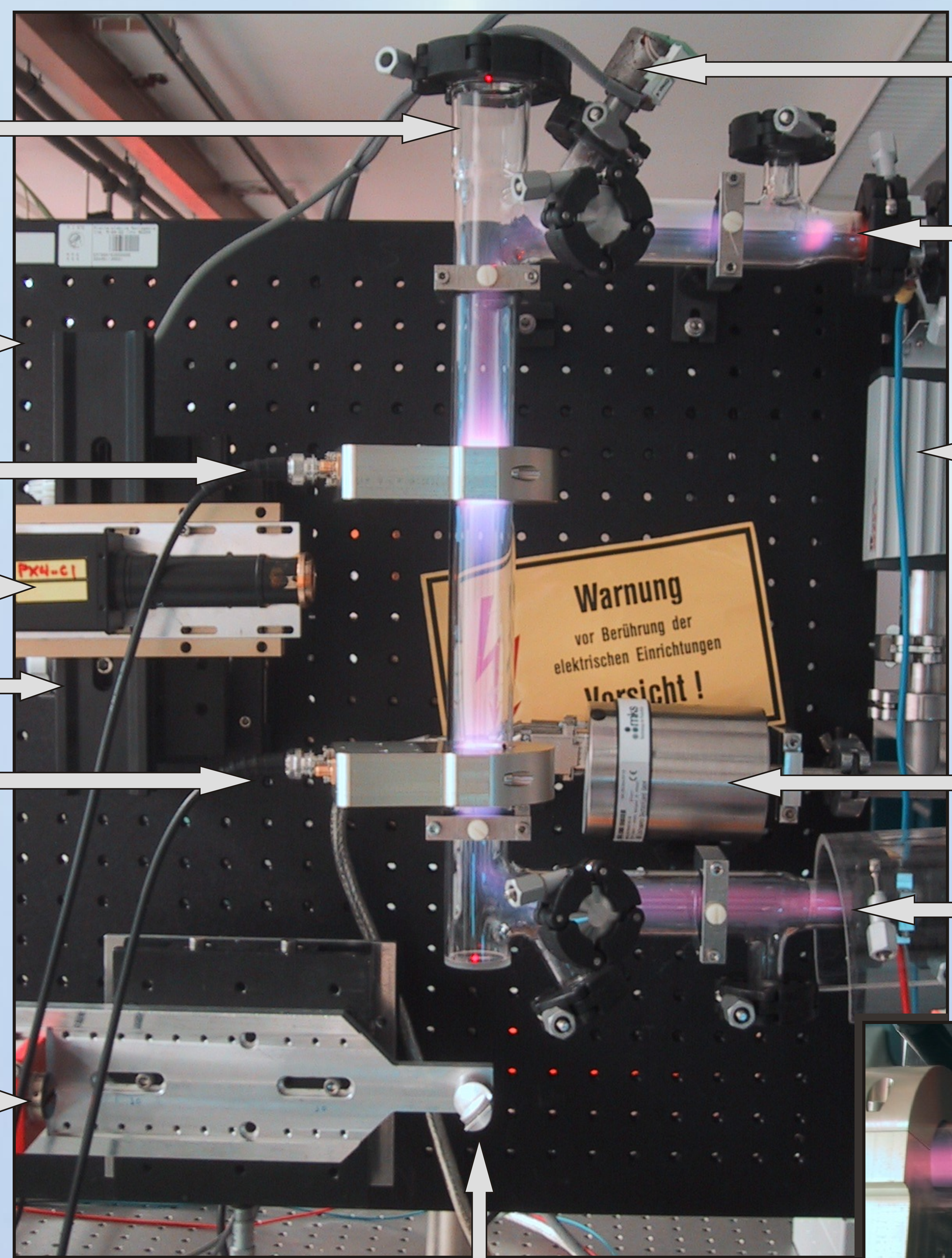
PK-4 – A DC* plasma for the ISS

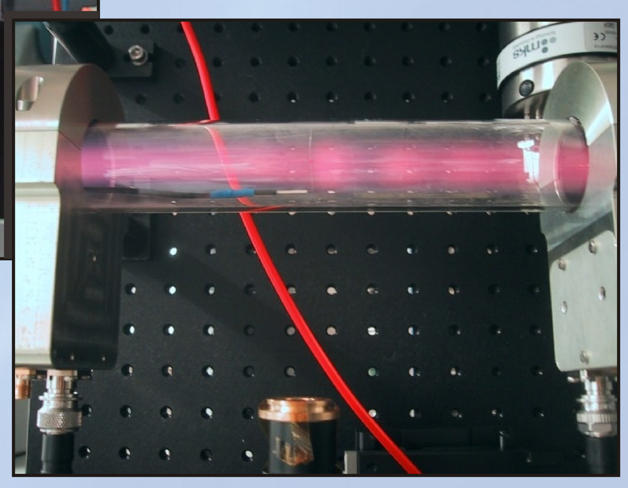
The PK-4 project is intended to fly a dc discharge tube (*modified with rf inductive coils for confinement and manipulation) on the ISS in order to conduct complex plasma experiments under microgravity conditions. The more linear design of PK-4 (compared to the rf chambers previously flown, see http://www.mpe.mpg.de/pke) allows greater optical access for diagnostics as well as laser manipulation. Examples of planned experiments are "flow, shear flow, transition to turbulence" and "compression-freezing".

In the first stage of the project (Aug 2002 – Feb 2004), a laboratory and parabolic flight "pre-development" phase will be conducted. The outcome of this phase will be a laboratory/parabolic flight test model apparatus suitable for use in defining requirements and specifications of the flight model. Also first scientific results shall be achieved.

The project will be conducted in close collaboration with our colleagues from the Institute of High Energy Densities (IHED) of the Russian Academy of Science.

The prototype setup at MPE

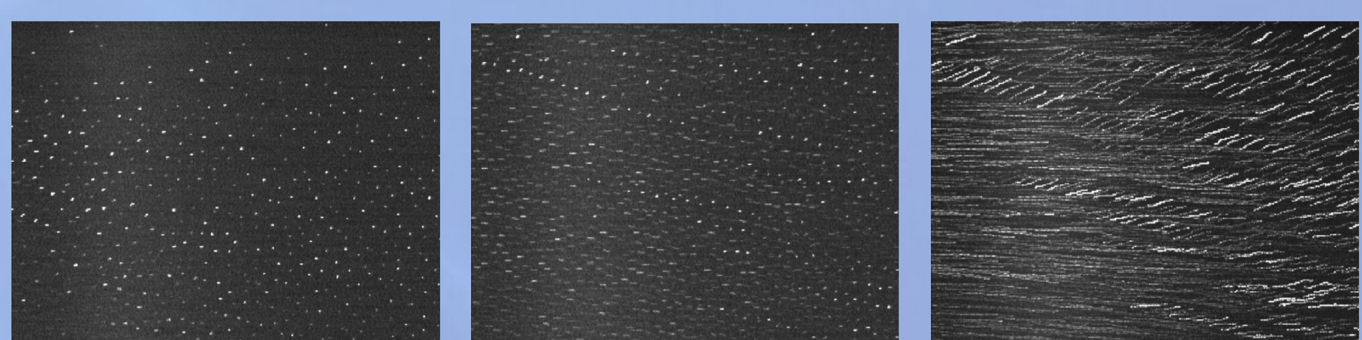




Main tube in horizontal position

Specifications:	Range	Typ.	Unit
Main Tube Length		30	cm
Inner Diameter	2 – 3	3	cm
Overall Length (=Electrode distance)		60	cm
Pressure	10 – 260	50	Pa
Gas Flow	0 – 10	0.3	sccm
Gas	Ne, Ar	Ne	
DC Voltage	0 – 6.5	1.4	kV
DC Current	0 – 5	1.0	mA
RF Power (@ 81 MHz)	0.1 – 5	0.5	W

Features:	
Main Tube Access Port	1
Supply Ports	8
Optical Window	1
Illumination Laser	1
Manipulation Laser	Planned
Dust Dispensers (max.)	4
Support Structure Axes	Tilt, Rotate
CCD Camera (640x480, max. 150 fps)	1



Lane formation process observed during the collision of two clouds of particles. Left: The stationary cloud before the collision (trapped in a rf discharge; down is to the right). Center: The second cloud impacts (from left to right), the stationary particles (bright spots) form lanes to resist the moving particles (grey streaks). Right: Addition of 10 single images to show the motion. Parameters are: 1400 V, 1 mA, 160 Pa (Ne), 0.5 sccm, 1.2 μm particles.

Collision and lane formation

As described in the previous paragraph, a cloud of stationary particles is observed when a second cloud impacts it. The stationary particles are not just swept away, instead they try to resist the 'invaders' by forming lanes. This effect is also known from the behavior of people walking along a pedestrian zone. To go one after the other is the most energy-saving way when penetrating a crowd. The dynamics of the formation of these lanes ('non-equilibrium phase transition') can now be studied with PK-4 on the kinetic level. This, along with computer simulations, will lead to a better understanding of this phenomenon.

Summary and outlook

The very first experiments with the PK-4 prototype show a huge variety of new effects and possibilities that were not achievable with the former rf plasma chambers like PKE Nefedov on the ISS. As the prototype is now being upgraded with additional hardware, like a manipulation laser, and the environment is turned into microgravity (parabolic flight campaign in October 2003) more effects will be seen and more chances for new physics will arise. A promising start for a new experiment in space.

So PK-4 and the new millennium have something in common: THIS IS JUST THE BEGINNING!

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