PlasmaLab — Next Generation Plasma Chambers For The ISS*

D. P. Mohr[1], C. A. Knapek[1], U. Konopka[2], L. Wörner[1], C.-R. Du[1], R. Heidemann[1], G. Wildgruber[1], M. Rubin-Zuzic[1], G. E. Morfill[1], H. M. Thomas[1]

[1] *Max Planck Institute for extraterrestrial Physics, Garching, Germany.*

[2] *Physics Dept., Auburn University, Auburn, USA.*

The next generation of plasma chambers for the research on complex plasmas in microgravity conditions on board of the International Space Station (ISS), developed within the scope of PlasmaLab project, is presented, including the first scientific results from experiments on ground and in microgravity conditions during parabolic flight campaigns.

A complex plasma is a plasma with the additional component of micrometer-sized particles. The particles acquire a high charge due to the streaming of ions and electrons to their surface, and they interact via a screened Coulomb potential. [1] [2] [3]

Typically, noble gas rf or dc discharges are used with pressures of $1-100$ Pa, electron temperature of $2-3$ eV, and plasma densities of $10^{14}-10^{16}$ m^{-3}. The particle motion in the dilute gas is nearly undamped, and the particles are visible by simple video cameras, making complex plasmas a perfect model system to study particle interactions (e.g. phase transitions, self-organization, waves, transport phenomena) on the kinetic level. Since gravity has a strong influence on the particles, experiments under microgravity conditions are essential. The chambers developed in PlasmaLab will be follow-up of several successful international projects studying complex plasmas in microgravity: PKE-Nefedov, the first basic science experiment on the ISS in 2001, was followed by PK-3 Plus in 2005 [4]. Both were cylindrical plasma chambers using rf signals for plasma generation. The next project PK-4 will be launched in 2014 with a dc/rf discharge in a glass tube.

Within the PlasmaLab project two new chambers are developed: the “Zyflex” and the “Dodecahedron” chamber. The “Zyflex” chamber is a cylindrical plasma chamber with 2 parallel electrodes for plasma generation (see Fig. 1(a)). The electrodes with a diameter of 12 cm are surrounded by grounded guard rings, and the chamber features a flexible interior design space. The distance between the electrodes, and also between the guard rings, can be varied independently from 2.5 – 7.5 cm, even during a running experiment. The electrode setup is modular and allows for an easy exchange of electrodes. The changeable geometry of the plasma volume, combined with the use of specific electrodes, offers an extension of the accessible plasma

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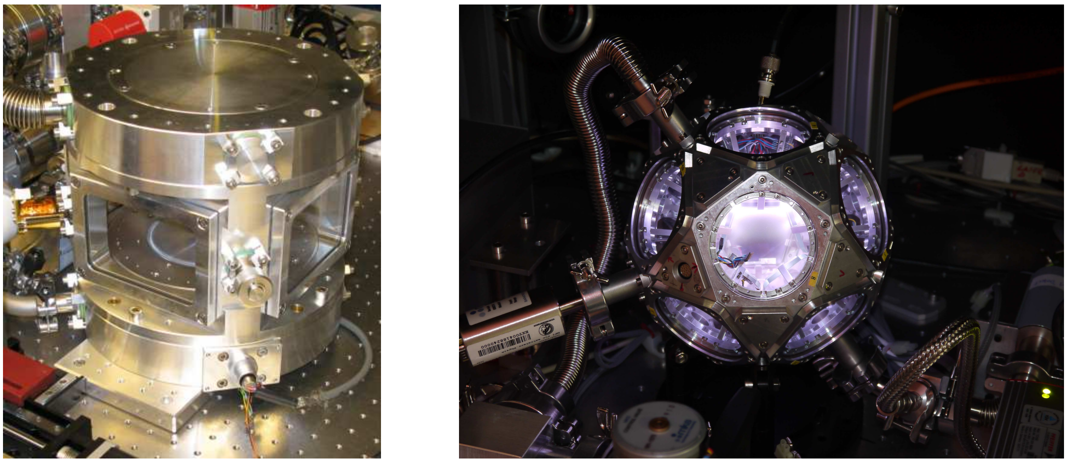
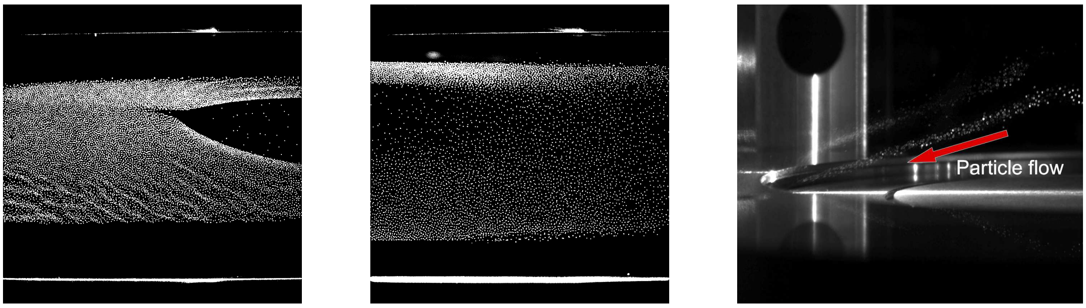


(a) “Zyflex” Chamber (b) “Dodecahedron” Chamber

Figure 1: Plasma chambers for the research on complex plasmas in microgravity



(a) 5.9 Pa, 29.2 V_{pp} (b) 39.5 Pa, 29.2 V_{pp} (c) Particles can be removed from the chamber in 0 g

Figure 2: Experiments in μ-Gravity with the “Zyflex” chamber

parameter range by magnitudes (e.g. to low pressure < 1 Pa), and therefore opens up new possibilities for the complex plasma research. A multi-channel rf generator with a driving frequency of 13.56 MHz has been developed. It provides up to 4 signals whose amplitude and phase can be controlled independently. With this, up to 4 electrodes/electrode parts can be driven.

Several electrodes have been built and tested in parabolic flights. Fig. 2 shows particle distributions during the 0 g phase in a parabolic flight for melamine-formaldehyde particles with a diameter of 9.19 μm which were injected into an Argon rf discharge. Simple electrodes were used with a symmetric discharge, and experiments were performed at different neutral gas pressures.

The possibility to remove particles from the chamber in 0 g was also tested (Fig. 2(c)). By moving an electrode below the level of the guard ring, a gap was opened leading towards the pumping system. After switching off the plasma during microgravity, particles were sucked through the gap. This procedure gives the opportunity to clean the chamber from residual parti-

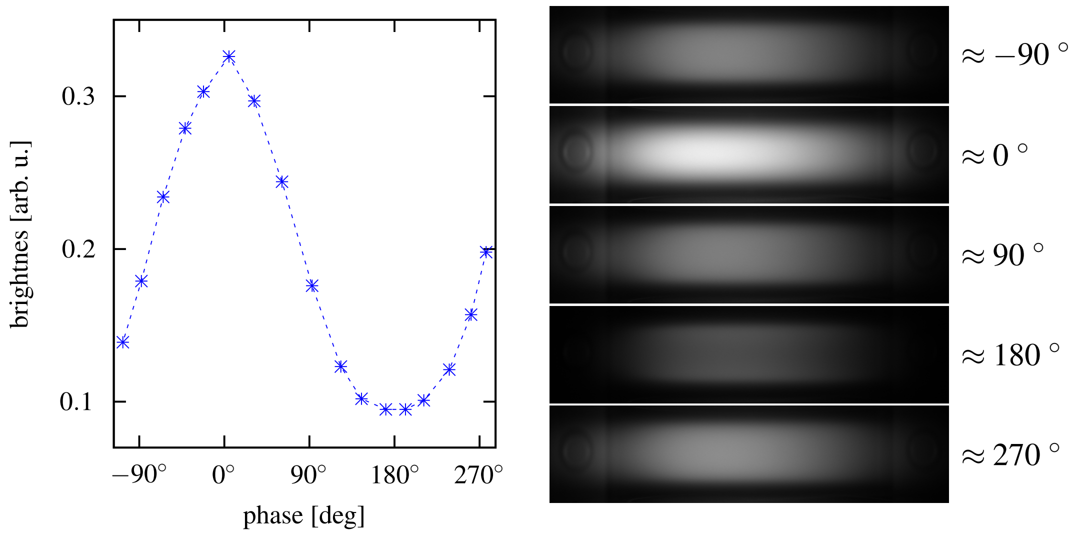


Figure 3: Plasma brightness, measured for different phases between the rf signals to the upper and lower electrodes

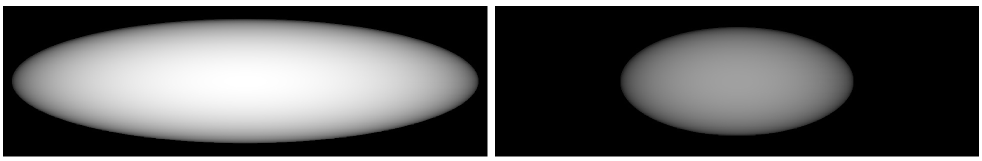


Figure 4: Plasma brightness, simulation for an ellipsoid

cles on the ISS.

A segmented electrode consisting of two electrically isolated parts and additional Peltier elements for temperature manipulation of the neutral gas is currently tested. Here, each electrode part can be connected to its own rf channel. Possible plasma configurations with these electrodes range from a central plasma to toroidal shapes.

The effect of the manipulation of the phase between rf signals connected to different electrodes can be observed in the plasma brightness (Fig. 3). While a phase of 180 deg (push-pull mode) gives a uniform plasma, modes close to 0 deg (push-push mode) cause a spatially wider plasma. Assuming an axially symmetric plasma emitting light at every point in the same way, the measured brightness can be explained from the geometry of the plasma. For example an ellipsoid E with the semi-principal axes a, $b = a$ and c emitting light at every point results in an observed brightness H of:

$$H(x,z) = \text{const.} \cdot 2\sqrt{a^2\left(1 - \frac{x^2}{a^2} - \frac{z^2}{c^2}\right)}$$

A simulation of this brightness for two ellipsoids with different semi-principal axes is visualized in Fig. 4.

The “Dodecahedron” chamber, consisting of 12 ITO-coated glass electrodes, is the advancement of spherical plasma chambers, with the advantage of optical access through even windows (see Fig. 1(b)). Assembled inside the chamber the pentagonal electrodes form a dodecahedron. Each electrode is driven by an independently controllable channel of a custom built 12-channel rf generator.

This particular chamber design is chosen in order to enable the generation of isotropic plasma conditions with the possibility of manipulation of the particle interaction potential by controlling the ion flow with dc-offsets on the electrodes. The chamber was tested successfully in a parabolic flight campaign. A plasma was ignited and particles were injected. To obtain an isotropic plasma, the rf signals were cycled ($1-2000$ Hz) in quick succession through pairs or sets of electrodes.

The experiences from parabolic flights now give us the opportunity to improve the technical setup for the space station. Both chambers provide new and unique possibilities for the research on complex plasmas in microgravity.

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