COMPLEX PLASMA LABORATORY PK-3 PLUS ON THE INTERNATIONAL SPACE STATION AND FIRST EXPERIMENTS

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The research of complex plasmas under microgravity conditions provide new insights and allows to observe phenomena, which are suppressed under gravity conditions on Earth even where gravity is compensated by other forces, e.g. thermophoretic force. The consecutive "Plasma Crystal" facilities PKE-Nefedov and PK-3 Plus on the International Space Station ISS allow this research since the beginning of the colonisation of the ISS in 2001. PKE-Nefedov [1] was operational from 2001 to 2005 and yielded in many interesting results, e.g. the discovery of a gelation transition in the agglomeration of charged particles [2], the decharging of a complex plasma [3], the investigation of the coalescence of two complex plasma drops [4], linear dispersion relation [5], etc.

PK-3 Plus is the second-generation laboratory for the investigation of complex plasmas under microgravity conditions on the International Space Station (ISS). It has a more advanced hardware, software and diagnostics than its precursor PKE-Nefedov [1].

The PK-3 Plus laboratory [6] consists of a symmetrically driven rf-plasma chamber, which can produce a plasma in argon or neon with or without gas flow. Additionally, microparticles of sizes and materials: 1.55±0.04 µm Silica, 2.55±0.04 µm , 3.42±0.06 µm , 6.81±0.1 µm , 9.19±0.09 µm and 14.9±0.26 µm Melamine-Formaldehyde can be introduced into the plasma between the two electrodes. A detailed description of the set-up can be found in [6].

The first experiments with PK-3 Plus show the perfect functioning of the apparatus and provided much better insights into the properties of complex plasmas. In particular, the "void" in the centre of the complex plasma cloud can now be easily closed, thus providing a much better homogeneity of the complex plasma which is essential for many studies. Moreover, the use of the function generator at frequencies above the dust plasma frequency provides many possibilities for new experiments. In this paper we will introduce some of the new interesting experimental results.

First of all it is the discovery of electrorheological (ER) plasmas which can be formed with the "PK-3 Plus" laboratory on the ISS [7]. ER fluids are fluids containing colloids which react on external electrical fields changing the viscosity by orders of magnitude. A similar physical process can be investigated in complex plasmas on the most fundamental - the kinetic - level by the use of low frequency fields. Sinusoidal out-of-phase signals were applied to the rf electrodes at frequency 100 Hz, with the peak-to-peak voltage between 26.6 V and 65.6 V varied in steps of 2.2 V. In each experiment an ac field was first ramped up, and then ramped down. At weak fields charged particles form a strongly coupled isotropic fluid phase with typical short-range order. As the field is increased above a certain threshold, particles start to rearrange themselves and become more and more ordered, until eventually well defined particle strings are formed (see Fig. 1). The transition between isotropic and string fluid states is fully reversible – decreasing the field brings the particles back into their initial isotropic state. The trend to form strings increases with particle size, which is in line with theoretical estimates.

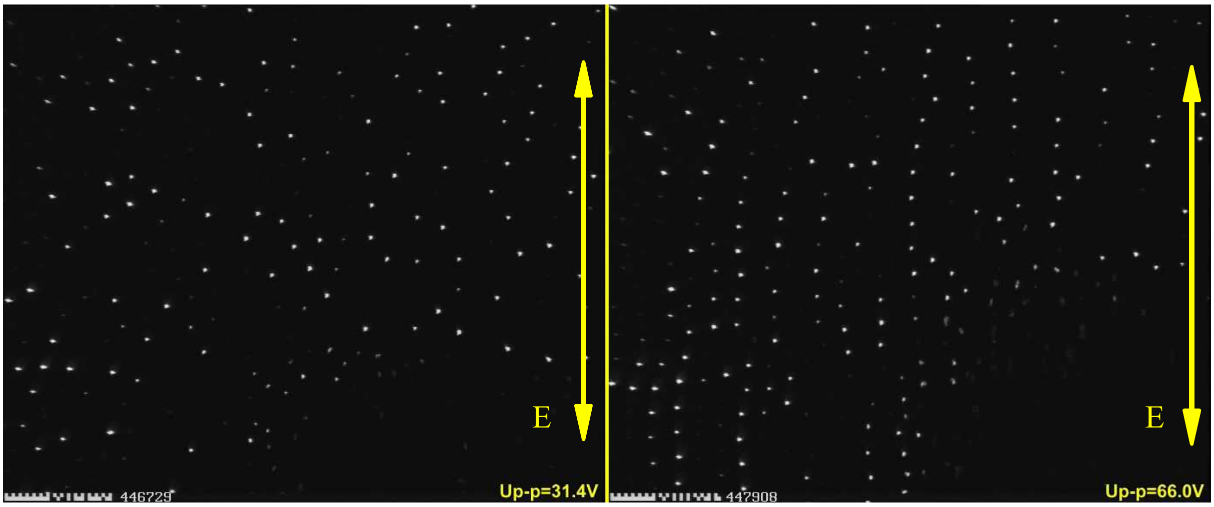

Fig. 1. Formation of developed strings in ER plasmas. Original high resolution images show isotropic fluid at 31.4 V, string fluid at 66.0 V.

The other interesting phenomenon is interpenetration of two clouds of different grain sizes. In these experiments the structure consisting of 14.9 or 9.19 or 6.81 µm was built initially. Then 3.42 µm grains were injected from the left side. The peculiarity of the installation design is the position of the 3.42 µm grains injector: particles are injected in the plane illuminated by the laser sheet. The 3.42 µm grains penetrate through the stable structure of bigger particles towards the chamber centre. Lane formation is observed in the outer region while the speed of the penetrating grains is high. Closer to the middle of the structure the grains speed reduces and they form a droplet. Fig. 2 shows an example of the interpenetration. The process of lane formation is of interest for several fields, e.g. for studying colloidal systems [8]. We made also experiments when big particle cloud was in string fluid state under the influence of the low frequency electric field. It should be noted that lane formation was not observed under these conditions. We suppose that the reason of such behaviour is the much stronger interaction between big particles similar to [8].

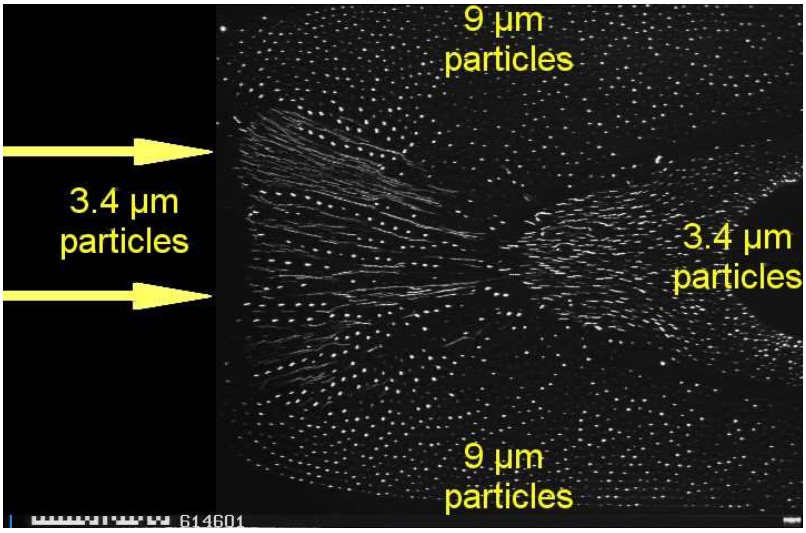

Fig. 2. Interpenetration of 3.4 µm particles through a 9.2 µm particles structure. The lane formation region is clearly seen. The picture shows a superposition of 4 consecutive original video images.

Additionally we performed a crystallization-melting experiment. In this experiment we organized the 1.55 µm particles structure at 30 Pa. During a pressure decrease to 10 Pa the structure crystallizes. After the the crystallization we start to increase pressure up to ~20 Pa. During the pressure increase the structure melts (see Fig. 3).

Fig. 3. Melting of a plasma crystal. High resolution images show the crystal structure at P=16.3 Pa (left) and liquid structure at P=23.6 Pa (right).

This behaviour we observed is opposite to the one found in [9].

The pair distribution functions $g(r)$ for different stages of the experiment presented in Fig. 4. It is seen that for lowest pressure the ratio $g(r_{min})/g(r_{max})$ is 0.18. On the other hand after the pressure increase this ratio reaches 0.26 that indicates transition to liquid state [10].

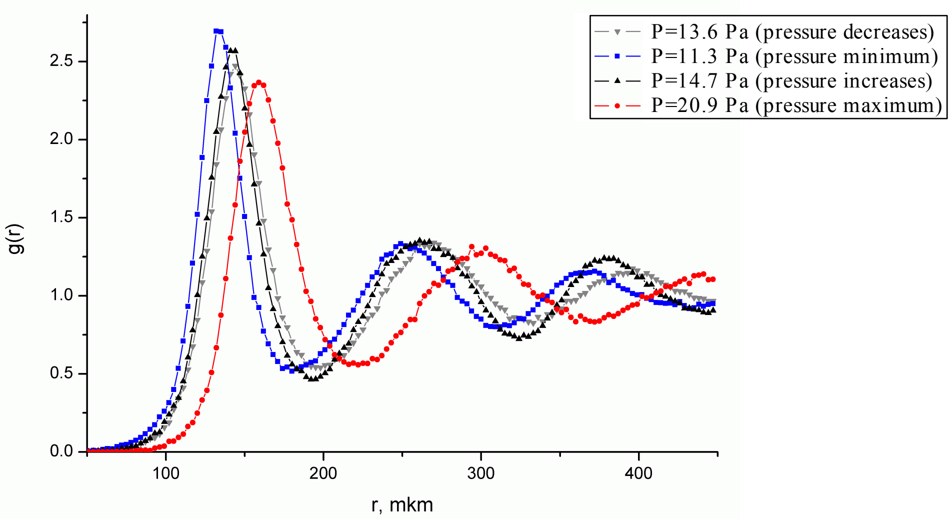

Fig. 4. Pair distribution functions $g(r)$ at different pressures.

This work was supported by DLR/BMWi Grant No. 50WP0203, and by RFBR Grant No. 08–02–00444.

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