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# SELF-EXCITED DUST DENSITY WAVES IN THE BOUNDARY REGION OF A COMPLEX PLASMA UNDER MICROGRAVITY

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Dust density waves (DDW) were observed in many dusty plasma experiments (e.g. [1,2,3]). These waves appear spontaneously at low gas pressures in the presence of electric fields which induce strong directed ion flows. One prominent example of a DDW is the dust acoustic wave (DAW) [4], which shows an acoustic dispersion $\omega = kC_{DAW}$ at long wavelength. Recently, in experiments performed under weightlessness, we observed a new type of DDWs which propagates under a certain angle obliquely to the direction of the ion flow. This observation cannot be explained by the theory of DAWs. We presented a model which explains the observed behavior of these so-called obliquely propagating dust density waves (OPDDW) [5]. In this contribution we focus on a more detailed spatiotemporal analysis of experimental data from a recent parabolic flight campaign.

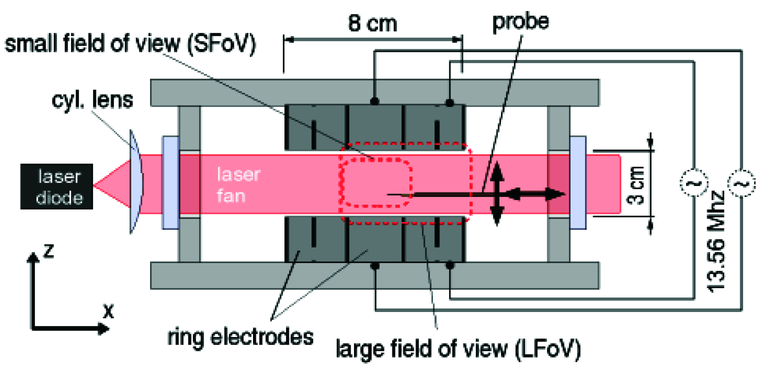


Figure 1: Vertical section through the IMPK-K discharge chamber. From [1].

The experiments were performed in the IMPF-K device (see Fig. 1) [6], which is a symmetric parallel plate rf discharge. The chamber has two opposing pairs of electrodes with a gap of 3 cm in between. Each pair consists of a central disc electrode of 3 cm diameter and a surrounding ring electrode with an outer diameter of 8 cm. To shape the plasma inside the chamber the rf amplitude on the outer ring electrodes and the central disks can be adjusted independently. For this experiment the rf peak-to-peak voltages were $U_{rf,d} = 73\ V_{pp}$ at the

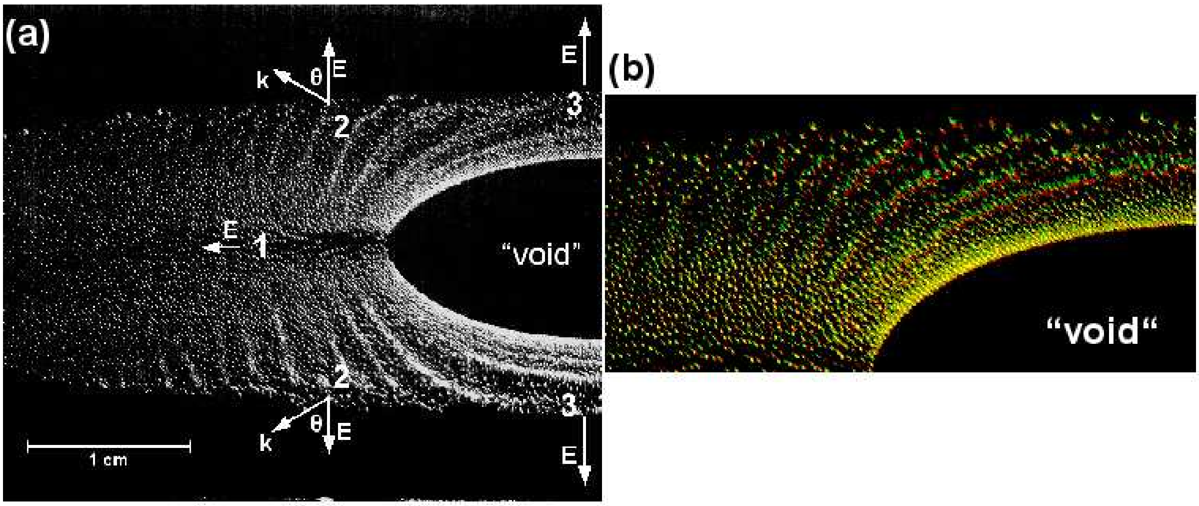


Fig. 2: (a) Vertical section through the dust cloud. Self-excited dust density waves emerge at the void edge and propagate into the dust cloud. (b) Closeup of the upper left quadrant of the dust cloud. The image is a superposition of two successive video frames (frame 1: red, frame 2: green).

disk and $U_{rf,r}$ = 63 $V_{pp}$ at the ring. The discharge is operated in push-pull mode and the self-bias was suppressed. Argon was used as neutral gas background at a pressure of 18 Pa. A Langmuir probe can be moved into the plasma to measure the plasma parameters, which yields a plasma density $n_{e,i} = 2 \times 10^{14}$ $m^{-3}$ and an electron temperature $T_e$ = 3.5 eV in the center of the discharge. Monodisperse spherical melamine-formaldehyde particles with a diameter of d=6.8 μm were injected into the plasma. The number density of the dust inside the discharge was derived from the image data and is estimated to $n_d = 4 \times 10^{10}$ $m^{-3}$. The charge of the particles was assumed as $q_d$=-8300e, which is consistent with recent charging models [7] considering a collisional plasma. The dust inside the chamber is illuminated by a thin vertical laser sheet, which intersects the confined dust cloud at its center. The dust is observed at right angle by a high-speed CMOS camera (1280x1024 pixel @ 100 fps).
Figure 2(a) shows a vertical section through the dust cloud under microgravity conditions. The right edge of the image shows the center of the discharge, the upper and lower edges correspond to the surface of the electrodes. The dust is distributed around a central dust-free region ("void"). Inside the void a radially outwards directed ion flow induces an ion-drag force on the dust particles, which exceeds the confining electric force. At the chosen discharge parameters, self-excited dust density waves emerge spontaneously, which is visible as a significant spatially periodic intensity modulation in Fig. 2(a). The waves are launched at the void edge as a consequence of the outward directed ion flow and propagate into the dust cloud. In the outer region of the dust cloud in the midplane [see arrow 1 in Fig. 2(a)] as well

as above and below the void [see arrows 3 in Fig. 2(a)] the waves propagate parallel to the ion flow. Its direction is given by the electric field, which points perpendicular towards the electrodes and radially outwards in the midplane of the discharge. Besides our observations, wave propagation in the direction of the ion flow was observed in other experiments [1,2,3] and is expected from theory [2,3]. In contrast to these earlier investigations, we also found a different type of waves [see arrows 2 in Fig. 2(a)]. Here, the waves propagate at a certain angle θ with respect to the electric field, which points perpendicular towards the electrodes. A model which explains the existence these obliquely propagating dust density wave (OPDDW) was presented elsewhere [5]. According to that model the wave shows a preference for oblique propagation to the electric field when the ion velocitiy is close to the Bohm velocity, whereas it merges to an ordinary DDW in regions with slower ions. This prediction of the model is is in good agreement with the observation. In the midplane of the discharge moderate electric fields induce a radially outwards pointing slow subsonic ion-flow (arrow 1), which results in a parallel wave propagation. Close to the sheath, between the dust cloud and the electrodes (arrows 2), strong electric fields accelerate the ions to Bohm velocity and the wave propagates obliquely. In addition, the rotational symmetry of the system requires that the wave propagates perpendicular towards the electrodes, i.e. parallel to the ion flow directly above and below the void, even in the presence of high ion velocities.

Figure 2(b) shows a close-up of the upper left quadrant of the vertical section. The image is a super-position of two successive video frames (frame 1: red, frame 2: green). Particle motion is indicated by distinct red and green dots, stationary particles appear yellow. Remarkably, the boundary of the dust cloud towards the sheath is strongly affected by the wave and shows an interesting complex motion of the individual particles. Although it is, in principle, possible to derive a velocity map of the particles from this data, the limited resolution requires further experiments to allow a detailed analysis of this feature. For a more detailed analysis of the wave field in the bulk of the dust cloud, the temporal evolution of each pixel in the wave region was analyzed for 512 successive video frames. Figure 3(a) shows the power spectrum of the temporal intensity evolution of a sample pixel located at (x,y)=(250, 150) pixel inside the wave field. It shows a single peak at a frequency f=9.8 Hz, which indicates a monochromatic wave propagating through the dusty plasma. The observed frequency is similar to earlier observations [5]. Although, the earlier experiments were performed with much smaller particles (d=3.4 μm) and slightly different discharge conditions. A reconstruction of the wave field is presented in Fig. 3(b). It shows the real part of the Fourier decomposition at a frequency of 9.8 Hz.

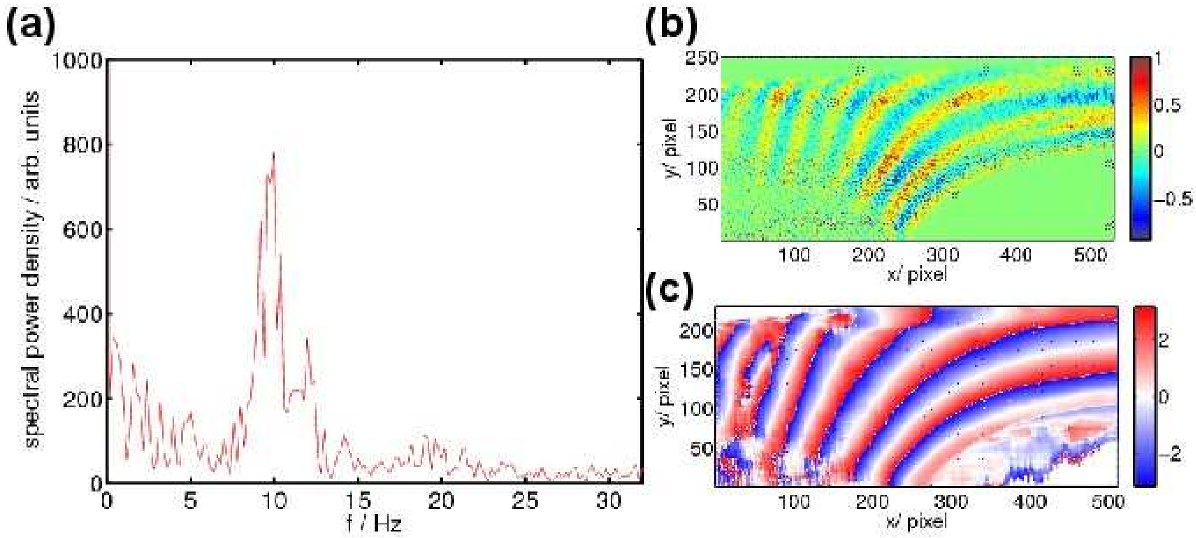


Figure 3: (a) Power spectrum of the temporal intensity evolution of a pixel located at (x,y)=(250,150) pixel. (b) Map of the real part of the Fourier decomposition at f=9.8 Hz. (c) Phase map of the 9.8 Hz spectral component.

This allows to image only the wave of the desired frequency without being distorted by other (random) oscillations and distortions due to inhomogeneities of the illumination or the dust density. From the real and imaginary part of the Fourier decomposition the phase of the wave field was derived. A spatial map of the phase is shown in Fig. 3(c). This map allows to clearly identify the wave fronts at the sharp boundary between red and blue which indicates the transition from positive to negative phase angles. The methods presented here are a powerful set of tools to systematically explore the observed wave phenomena over a wider rage of plasma parameter on future flight campaigns. In addition, our observations suggest further experiments which will focus on the motion of individual particles close to the sheaths, where interesting dynamical effects are expected. This work was supported by DLR under contract 50WM0339 and in parts by DFG under contract SFB-TR24 A2.

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