Self-excited waves in complex plasmas under microgravity conditions

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Self-excitation of density waves is ubiquitous in complex plasmas. Present experiments were performed in microgravity conditions using the Plasmakristall-4 (PK-4) facility on the International Space Station. This setup is very well suited for the investigations of the self-excited waves, since it allows an independent variation of the average electric field experienced by the microparticles by means of high-frequency (hundreds Hz) discharge polarity switching. The electric field and the ion streaming instability associated with it are supposed to constitute the mechanism of the self-excitation. In our experiments, we investigated the influence of the discharge polarity reversal on the self-excited wave pattern. Also, the dependence of the pattern on gas pressure, discharge current, microparticle size and polarity switching duty cycle was studied. We also report on the self-excitation of a new anomalously slow wave mode, which is most likely strongly affected by the attractive wake interactions.

1. Introduction

Dust density waves constitute a significant research topic in dusty plasma physics [1]. The reason for that is that self-excitation of these waves is observed in all types of discharges - dc, inductively and capacitively coupled rf, under laboratory and microgravity conditions, with micrometer- and nanometer-sized dust particles.

Ion-streaming instability associated with sheath or bulk electric field is usually identified as a self-excitation mechanism of the dust density waves. Although, so far, there seem to be no experimental observations that contradict this hypothesis, on the other hand, there were no experiments conducted that would directly target the dependence of the self-excited wave patterns on the fundamental parameter which controls the self-excitation mechanism, namely, on the electric field.

Plasmakristall-4 (PK-4) facility on board the International Space Station [2] is the best-suited setup for studying self-excited density waves in complex plasmas. Its versatile power supply controlling the dc discharge allows variation of the average electric field experienced by the microparticles, while keeping other parameters practically constant.

2. Experimental setup

In the PK-4 facility [2], the plasma is created in a cylindrical (3 cm inner diameter and 20 cm working area length) glass chamber by means of a dc discharge. Two types of monodisperse plastic microspheres with diameters 3.38 μm and 6.86 μm, respectively, were used in the experiments. The microparticles suspended in the plasma were illuminated by a sheet of green laser and observed by the two particle observation (PO) videocameras with the resolution of about 14 μm/pix. Experiments were conducted in the flight model of PK-4 under microgravity conditions on board the International Space Station.

3. Results and discussion

3.1. Polarity-reversal experiment

In this experiment [3] (performed in Campaign 4, in February 2017), the 3.38 μm diameter microparticles were injected and trapped in the rf plasma. The suspension was then allowed to drift first in a dc discharge with negative polarity for some seconds and after that, the discharge polarity was reversed.

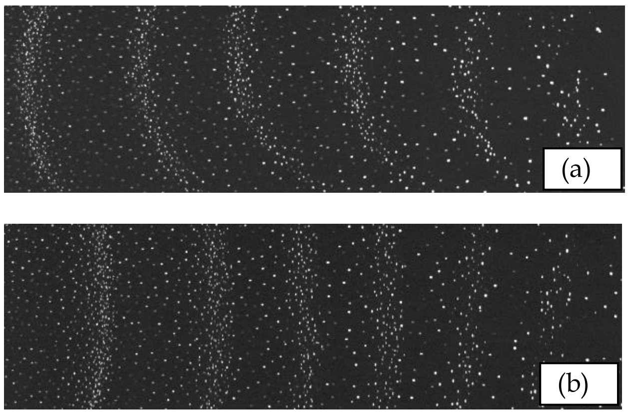

Fig. 1. Images of the self-excited dust density waves at (a) negative and (b) positive polarity. Microparticles are 6.86 μm diameter microspheres, neon pressure is 0.2 mbar, discharge current 0.5 mA.

At both discharge polarities, the dust density waves (DDW) were excited. It has been shown that the observed wave patterns are compatible with the ion-streaming mechanism of self-excitation. Non-uniformities in the spatiotemporal distribution of the phase velocity were attributed to the axial variation of electric field in a dc discharge containing a microparticle suspension [4].

3.2. Systematic investigations of the self-excitation in a dc discharge.

In PK-4 Campaign 5 (November 2018), the polarity reversal experiment was extended to a comprehensive investigation of the DDW self-excitation. The experiment procedure similar to the one of the polarity-reversal experiment was used. First, a suspension of microparticles was trapped in a rf discharge and then it was subjected to a polarity-switched dc discharge (with the polarity switching frequency of 500 Hz) with different duty cycles and currents. The suspension was bounced back and forth in such a way that it always remained in the field of view of the PO cameras (Fig. 1). The experiment was repeated for different microparticle sizes and different gas pressures. The results are discussed in terms of the ion streaming mechanism of self-excitation.

3.3. Self-excitation of the “slow” DDW mode.

It was noticed already from the PK-4 commissioning, that there is an unusually slow wave mode excited in a suspension of microparticles trapped in an apparently symmetric polarity-switched discharge. The phase velocity of the wave was significantly lower than the estimated dust acoustic velocity. Estimated residual forces would correspond to the uncompensated electric field about 10% of that of the pure dc discharge, i.e. ~0.2 V/cm.

The low phase velocity of the waves can be explained by the presence of wake-mediated attraction between the microparticles. This possibility was confirmed by molecular dynamics simulation of the microparticles interacting via the electrostatic potential with an attractive term. The excitation mechanism for this mode is being investigated.

4. Conclusions

PK-4 is an excellent platform for the systematic studies of the DDW self-excitation in a dc discharge. Under microgravity, the electric field can be freely varied, whereas in ground experiments it is limited by the microparticle levitation conditions. Also in PK-4 a new anomalously “slow” wave mode was observed. Its low phase velocity can be explained by the strong wake-mediated interactions between the microparticles.

5. Acknowledgements

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