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Experimental Study of Dust-Dynamics in Magnetized Complex Plasmas

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Waves in dusty plasmas have been the subject of much theoretical work during the last decade. Experiments in this field, however, are still rare. The reason for this imbalance lies in the experimental challenges involved. The first is gravity, which leads to sedimentation of the particles to a thin layer at the bottom of the plasma. For high frequency modes, such as the transverse electromagnetic wave [1], it is sufficient to let the dust particles rain through the plasma. For the low-frequency modes, the situation is quite different. Here, free falling particles cannot be used, because the dust particle velocity becomes comparable to the phase velocity of the wave. Therefore, a confinement is required that is much longer than a wave period [2]. Dust confinement in radio-frequency plasmas is severely impeded by the formation of dust-free regions in the center of the plasma as seen in laboratory [3] or microgravity experiments [4]. In this contribution we show, how these obstacles can be overcome using a set-up similar to Thompson's experiment [2], where the confinement is accomplished by electric forces a few times higher than the gravitation force. The trapped particles form a cylindrical cloud of usually ~ 2 cm length up to one centimeter in diameter. The dispersion realation of an externally driven low frequency dust mode is measured and compared with theory.

The experiments are performed in the device Matilda II, which consists of a 1 m long vacuum vessel with 27 cm inner diameter and has an axial magnetic field of up to 50 mT. A thermionic discharge provides the plasma. The cathode filament is a loop (Ø 8 mm) of tungsten wire (Ø 0.1 mm) which is heated by a grounded power supply. The anode is a copper disk of 3 cm diameter biased at a positve voltage up to 150 V. Cathode and anode have a distance of 40 cm. The discharge is operated in a regime where a fire rod with up to 20 cm length establishes near the anode. The plasma potential inside the fire rod is typically about 100 V. Plasma density and electron temperature are $n_e = 1 \times 10^{15}\,\mathrm{m}^{-3}$ and $T_e = 5\,e\mathrm{V}$. The plasma potentials are measured with an emissive probe, whereas the plasma densities and electron temperatures are taken from Langmuir probe measurements. The probe tips can be positioned along the central axis and in radial direction by sliding and rotating of the probe rod. The dust motion was observed by a CCD camera with a resolution of 640 x 480 pixels at a maximum of 32 frames per second (fps) or, at lower resolutions, with up to

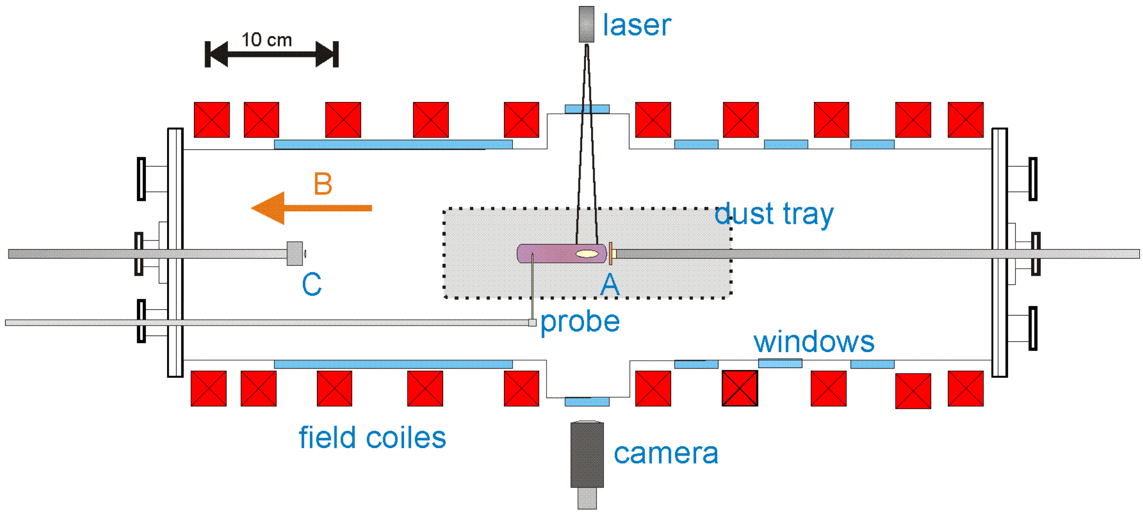

Fig. 1. Top view of the experimental setup.

120 fps. A laser diode illuminated the entire cloud through the opposing window, permitting the camera to record the forward-scattered light, i.e. to observe particles of micrometer size. In our experiment we use kaolin powder (density 2600 kg/m^3) with grain sizes from a tenth to little more than one micron. The dust was spread onto a grounded tray (see Fig. 1) about 4 cm below the discharge. At the conditions where dust can be trapped, the trap fills itself with dust by attracting the negative particles from the tray into the highly positive plasma. The particles are trapped in the anode side of the fire rod.

Fig. 2 shows three photos of trapped particles. All images show dust clouds with a particle density $n_d = 5$ mm^{-3}. The first image (0 Hz) is recorded without any modulation of the anode potential. In the other panels (18 Hz and 24 Hz) the anode potential is modulated by a sine voltage of 10 V amplitude. By means of this modulation, visible dust density waves are excited. In both cases, the distance between two wave crests can be directly obtained from the image. The wavelengths are $\lambda = 4.5$ mm (18 Hz) and $\lambda = 3$ mm (24 Hz). Hence, the dispersion relation can be directly measured. Fig. 3 shows the resulting dispersion relation obtained by variation of modulation frequency (12 - 28 Hz) and neutral gas pressure (1.6 - 2.4 Pa). For each, the corresponding phase velocity $v_{ph} = \omega / k$ is found in the range from 6 to 12 cm/s, which is a typical result for dust-acoustic waves (DAW) [5,6]. The DAW in its simplest form is described by [7]:

$$1 + \frac{1}{k^2 \lambda_D^2} - \frac{\omega_{pd}^2}{\omega^2} = 0 \qquad (1)$$

ω is the (modulation) frequency, k the wave number of the excited wave, λ_D the linearized Debye length and ω_{pd} the dust plasma frequency. For $\omega_{pd} = 180$ s^{-1} and $v_{ph} = 11$ cm s^{-1} a

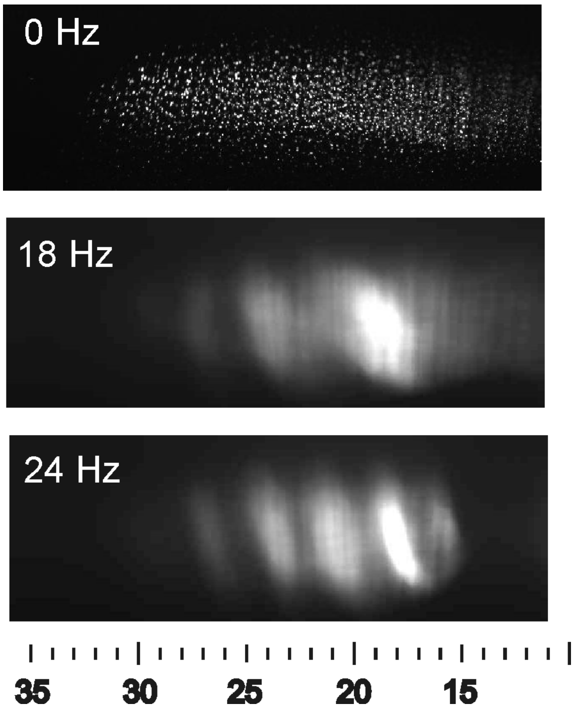

Fig. 2: Three images of a trapped dust cloud. The scale indicates the distance from the anode plate in mm. The labels denote the excitation frequency. The lower two images have been smoothed and intensified in order to visualize the local dust density.

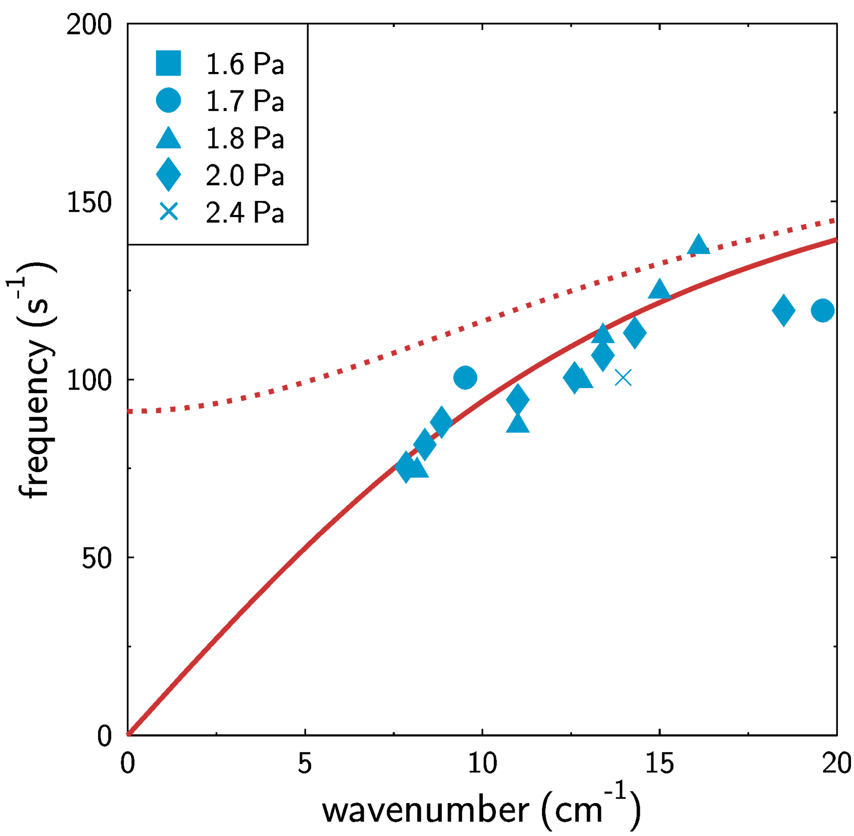

Fig. 3: Dispersion relation. The experimental results are obtained by variation of neutral gas pressure and modulation frequency. The solid line is a fit of Eq. 1 to the data with ω_{pd} = 180 s^{-1} and v_{ph} = 11 cm s^{-1}. The dashed line is a fit according to [8] for the same parameter.

good agreement of experimental data with eq. 1 is found (see Fig. 3). With $\omega_{pd} = \sqrt{q_d^2 n_d / (\epsilon_0 m_d)}$, this result can be used to calculate the charge q_d for a dust particle with radius $r = 0.5$ µm. It yields $q_d = 1{,}600e$ which is smaller than the value from the capacitance model ($q_d = 3{,}800e$).

Due to the cylindrical shape of the dust cloud, one might expect that the radial boundary acts like a wave guide. Shukla and Rosenberg presented a linear dispersion relation for such a wave guide mode [8]. The solution for a wave guide with 5 mm diameter and the same values of ω_{pd} and v_{ph} is plotted in Fig. 3 as dashed line. Obviously, this theory predicts a cut off well above all our measurements. Therefore, it seems that the radial boundaries have not to be taken into account for our system.

In conclusion, it has been demonstrated that the strong electrostatic forces around the anode are able to compensate gravitation and confine particles even for a magnetic field of 50 mT, which is considerably higher than in previous experiments. It was shown that modulation of the anode potential excites dust acoustic waves, which are in agreement with the dispersion relation of dust acoustic waves in unmagnetized plasmas. Effects of the radial boundaries of the cylindrical dust cloud seem to play no role. However, further experiments with monodisperse dust particles are needed to refine these findings and to allow for a quantitative and critical comparision of experiment and theory.

[1] T. Trottenberg, B. Brede, D. Block, A. Piel, Phys. Plasmas **10**, 4627 (2003)
[2] C. Thompson, A. Barkan, N. D'Angelo, R.L. Merlino, Phys. Plasmas 4, 2331 (1997)
[3] D. Samsonov, A.V. Ivlev, G.E. Morfill, J. Goree, Phys. Rev. E **63**, 025401 (2001)
[4] G.E. Morfill, H.M. Thomas, U. Konopka, H. Rothermel, M. Zuzic, A. Ivlev, J. Goree, Phys. Rev. Lett. **83**, 1598 (1999)
[5] J.H. Chu, Ji-Bin Du, I. Lin, J. Phys. D **27**, 296 (1994)
[6]A. Barkan, R.L. Merlino, N. D'Angelo, Phys. Plasmas **2**, 3563 (1995)
[7] N.N. Rao, P.K. Shukla, M.Y. Yu, Planet. Space Sci. **38**, 543 (1990)
[8] P.K. Shukla, M. Rosenberg, Phys. Plasmas **6**, 1038 (1999)