Nonlinear Vertical Oscillations of a Particle in a Sheath of a rf Discharge

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Abstract

Dusty (complex) plasmas are composed of weakly ionized gas and charged microparticles that represent the plasma state of soft matter. A growing field for physics research, measuring the spatial distribution of the electric field in the plasma sheath has been the goal of much research. A method based on the experimental investigation of vertical oscillations of a single particle in the sheath of a low-pressure radio-frequency discharge is proposed. The theory of anharmonic oscillations gives estimates for the first two anharmonic terms in an expansion of the sheath potential around the particle equilibrium.

Method

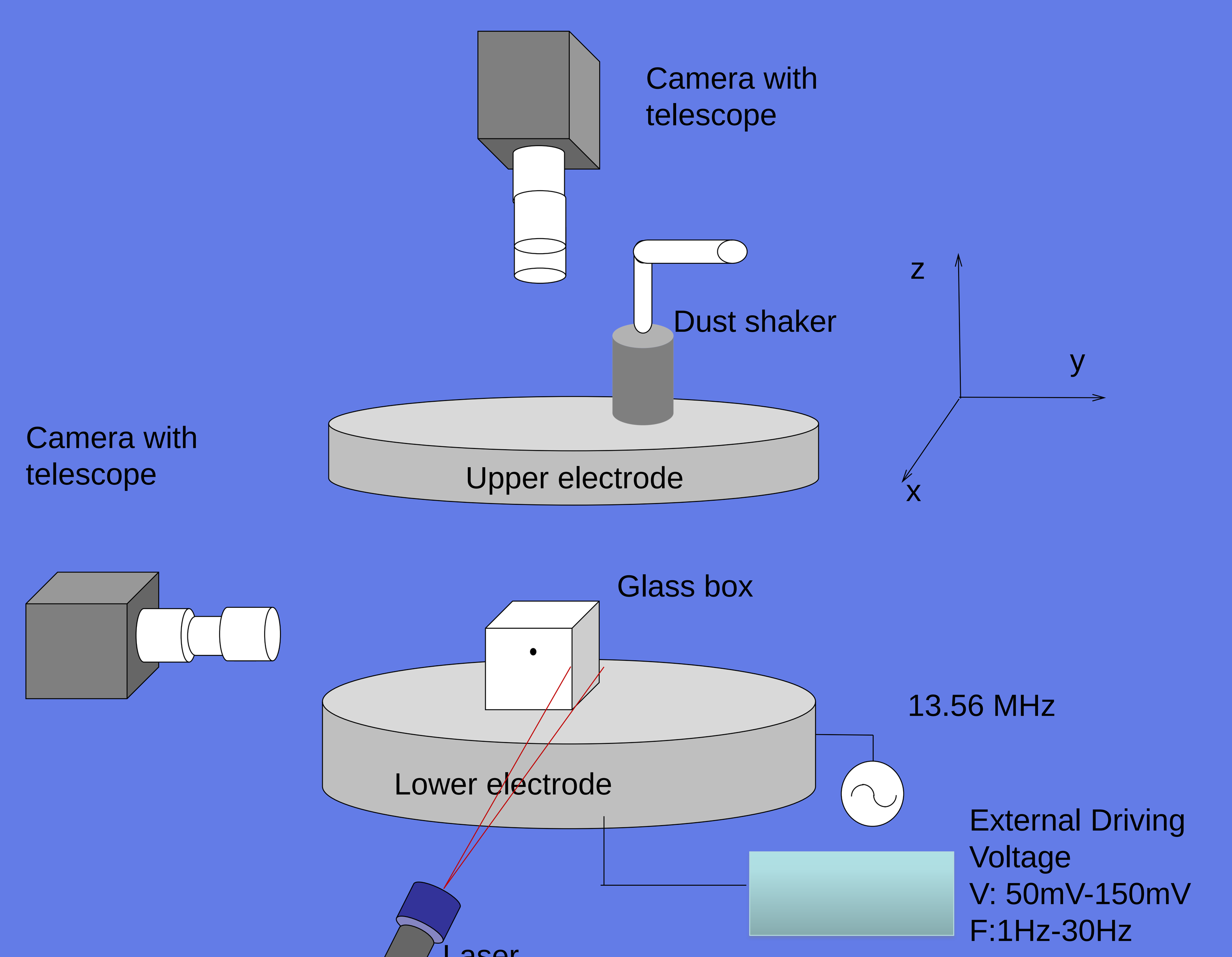

Figure 1. The experiments were performed in a Gaseous Electronic Conference rf reference cell. An open-ended glass box having dimensions of 12 mm x 10.5 mm and thickness of 2 mm was placed on the lower electrode, which is coupled to a rf generator inducing an external DC bias.

Theory

Without excitation, a particle is levitated in the minimum of the potential well (z = 0) where:

$$Mg = QE_0 \qquad (1)$$

The electrostatic energy of the particle,

$$U = Q\phi \qquad (2)$$

can be expanded around z = 0 in the series

$$U(z) = U_0'z + \frac{1}{2}U_0''z^2 + \frac{1}{6}U_0'''z^3 + \frac{1}{24}U_0^{(4)}z^4 + O(z^5) \qquad (3)$$

Using the equilibrium condition

$$Mg = QE_0 \equiv -U_0' \qquad (4)$$

And the definition of resonance frequency,

$$M\omega_0^2 = -QE_0' \equiv U_0'' \qquad (5)$$

We rewrite the potential as

$$U(z) \cong M\left(-gz + \frac{1}{2}\omega_0^2 z^2 + \frac{1}{3}\alpha z^3 + \frac{1}{4}\beta z^4\right) \qquad (6)$$

Where alpha and beta are the anharmonic coefficients. Using perturbation theory, and solving for the Forced Damped Linear Oscillator, we solved for these coefficients and estimated the potential in a rather wide

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References

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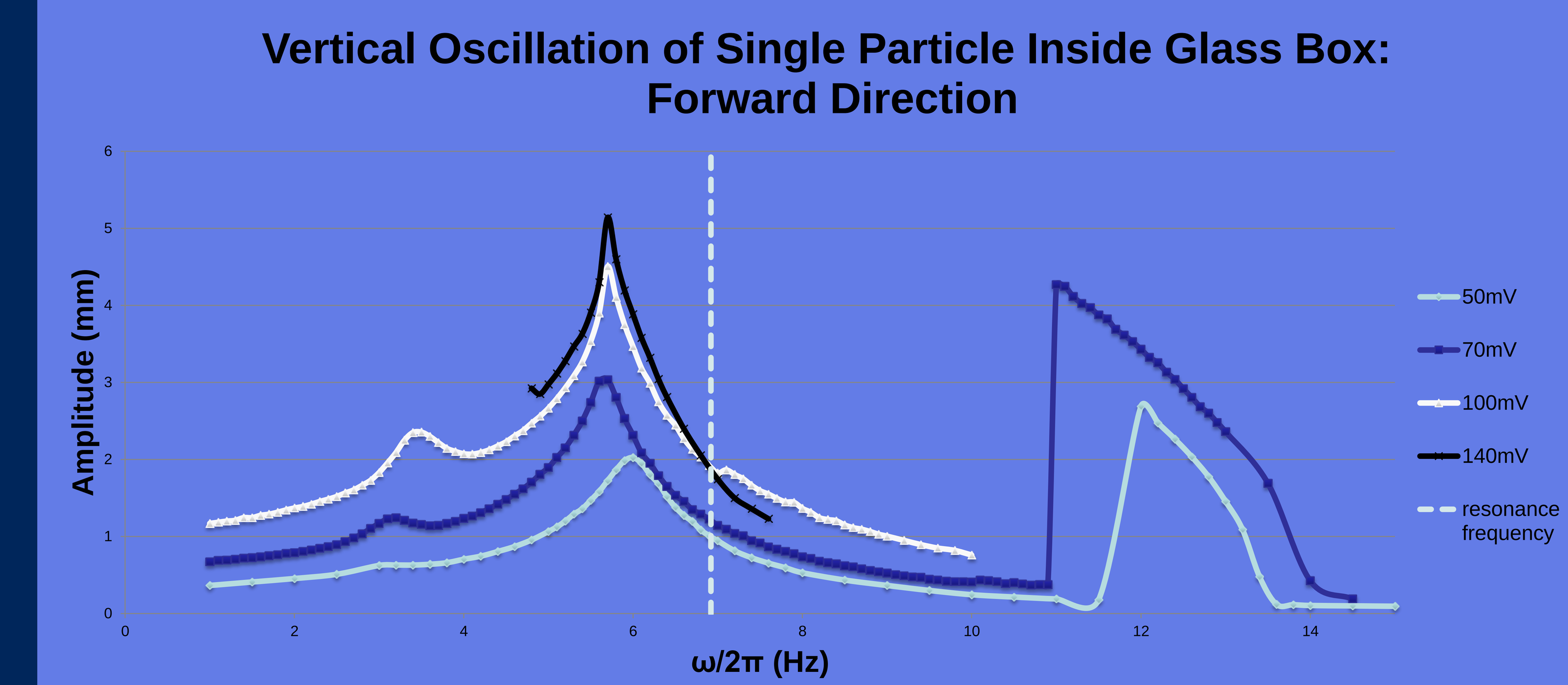
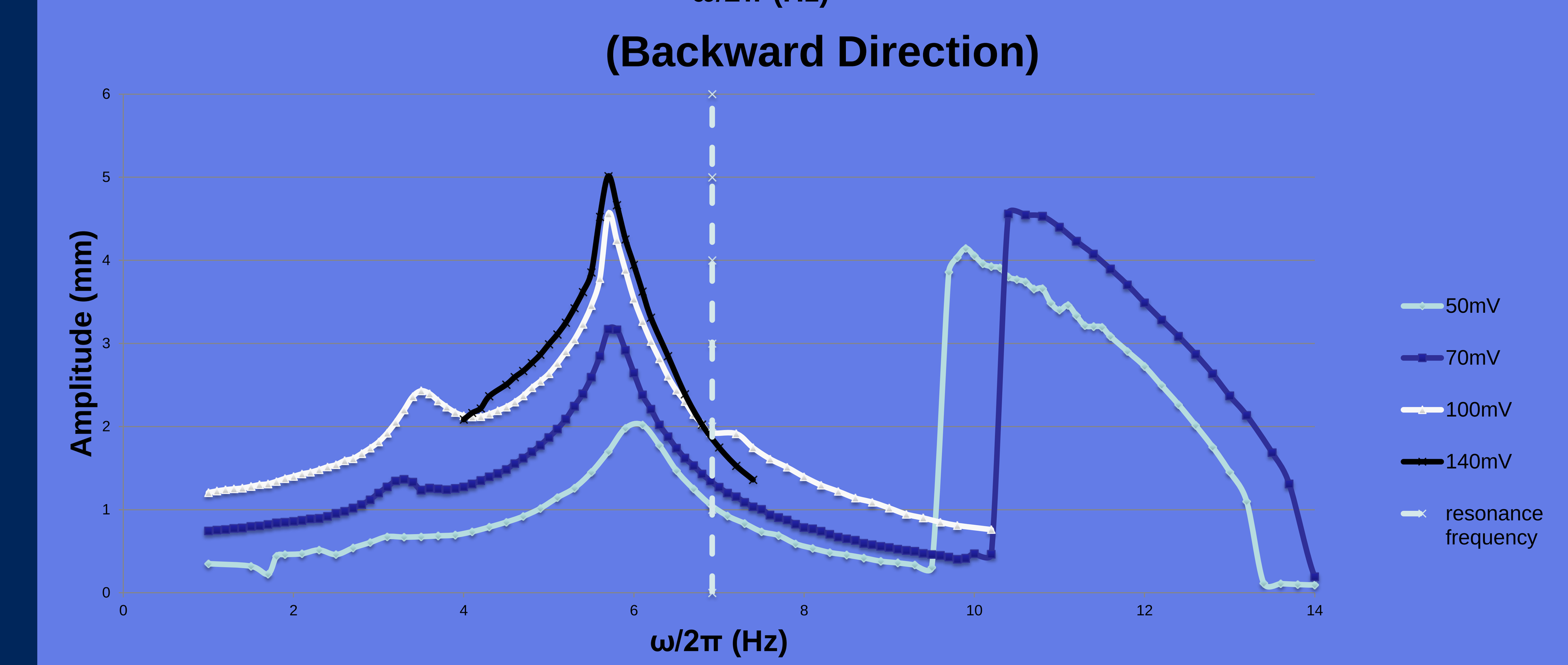
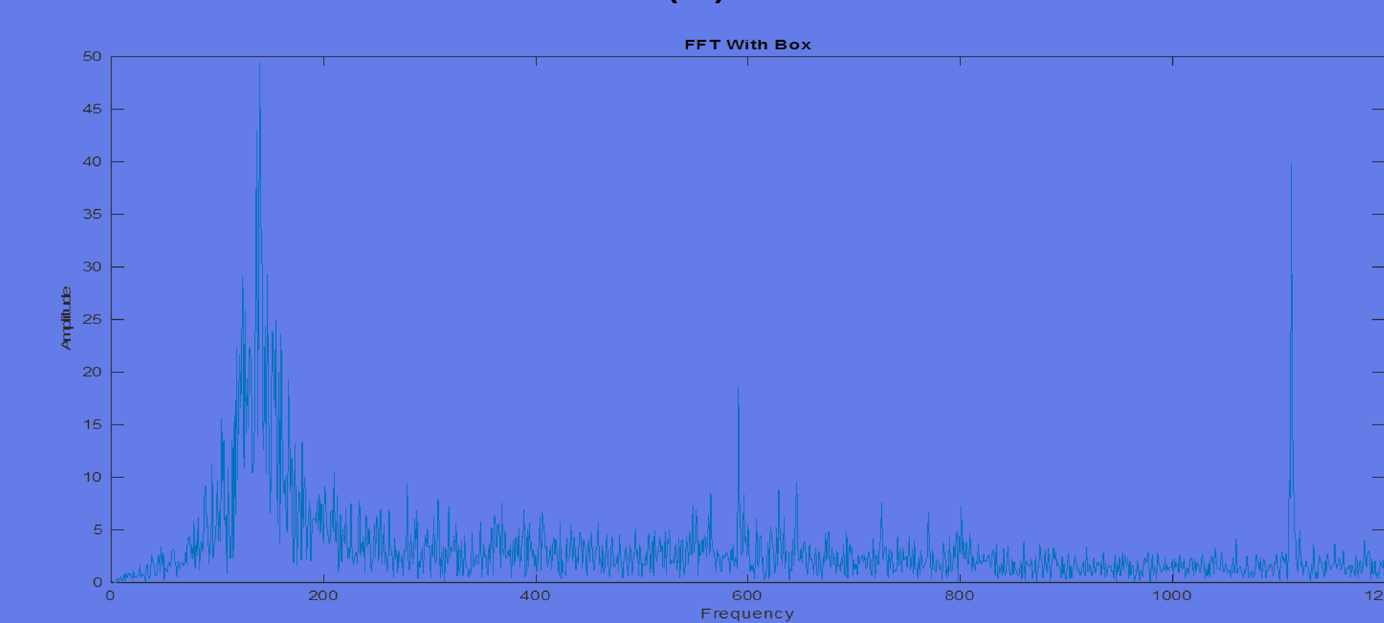
Results

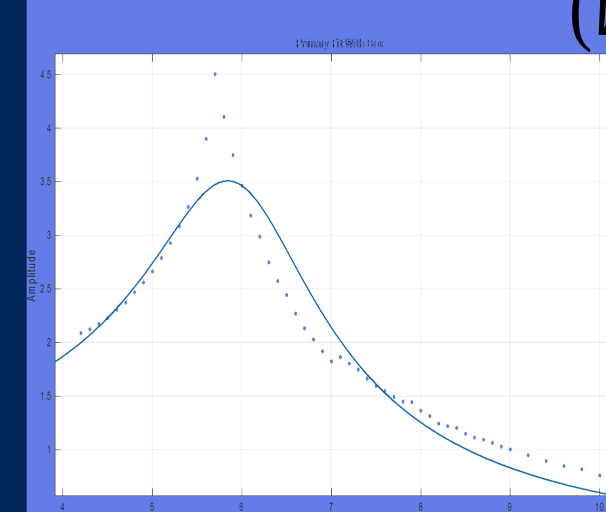




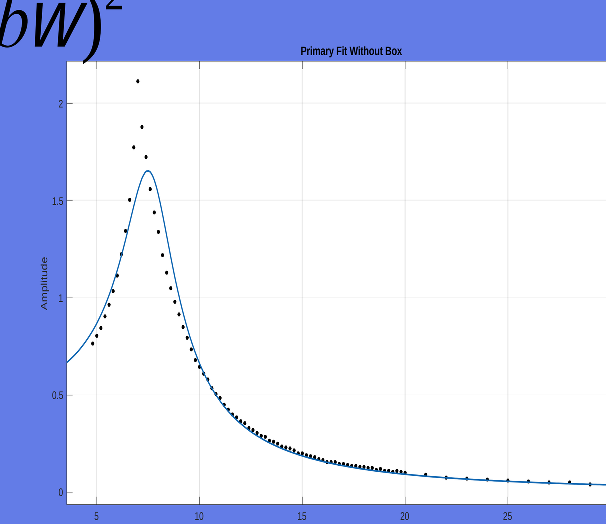


Forced Damped Linear Oscillator Fit

$$y = \frac{\omega \times \beta \times A}{(\omega - \omega_0)^2 + (\beta\omega)^2} \qquad (7)$$



$\omega_0 = 5.785 \quad \beta = 0.42$



$\omega_0 = 7.32 \quad \beta = 0.28$