Particle pairs as diagnostic tool in complex plasmas

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1. Complex (dusty) plasmas

Complex, or dusty plasmas are suspensions of charged micron-size solid particles in a plasma, often in the (pre)sheath area above the lower electrode in a gas discharge. The particles interact with each other via a screened Coulomb potential; together with confining fields naturally present in plasmas, this may lead to the emergence of ordered structures. The simplest form of such ordering is a particle pair. In fact, pairing of particles is a ubiquitous phenomenon in complex plasmas. It was observed in various settings from isolated pairs and larger strings to pairs in 2D crystals and particle bilayers. An important role in the formation of particle pairs belongs to the plasma wakes that appear behind charged particles in the flow of ions [1]. Plasma wakes lead to elongated screening clouds around particles, build-up of positive space charge downstream of the ion flow and the emergence of attractive component in the interparticle interaction.

2. Particle pairs as diagnostic tool

Since micron-size particles immersed in a plasma act as tiny electrostatic probes, various researchers offered to use them for plasma diagnostic purpose [2]. In the present contribution, we use particle pairs to locally probe plasma parameters in their levitation region. For this purpose, a specially designed "pair state" of complex plasma was prepared where particles formed multiple pairs that were vertically oriented, had a well-defined size, and levitated at the same height but were weakly coupled with each other and did not form any regular structure, see Fig. 1 [3].

2.1. Evaluating screening length

Our measurements showed that the vertical size of particle pairs Δz closely follows the electron Debye screening length λ_{De} in the bulk plasma; in a wide range of experimental parameters $\Delta z \approx 0.7\lambda_{De}$ [3]. The Debye screening length was calculated from the electron density and temperature measured with a Langmuir probe in the bulk plasma ≈5 mm above the sheath edge. This finding can be used for a quick estimate of the Debye screening length in experiments with complex plasmas.

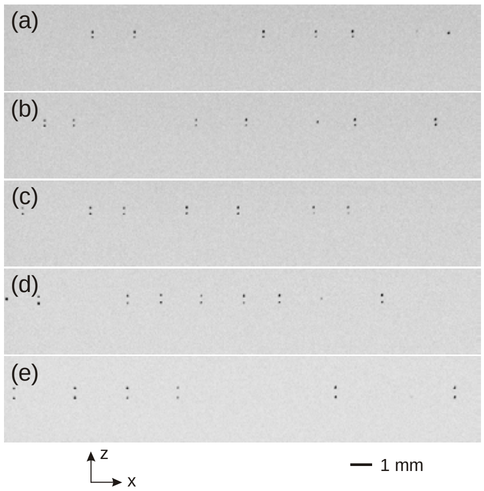

Fig. 1: *"Pair state" of complex plasma (side view). As the rf voltage was reduced from 352 V in (a) to 122 V in (e), the pairs shifted downward and extended vertically.*

2.2. Evaluating particle charge

The theoretical model of particle pairing proposed in [3] attributes the vertical confinement of the lower particle to the non-uniform field of plasma sheath, while the lateral confinement is due to the horizontal wake field. In this model, the following relation holds (in cgs units): $(\Delta z)^3/L_E \approx 2Q^2/(mg)$, where $L_E=g/\omega_0^2$ is the sheath field inhomogeneity length, ω_0 is the resonance frequency of dust particle vertical oscillations, Q and m are particle charge and mass, respectively, and g is gravitational acceleration. The particle charge can therefore be expressed as $Q \approx [(\Delta z)^3 mg/(2L_E)]^{1/2}$. This formula can be used to estimate the particle charge in a complex plasma without the need to measure plasma parameters such as plasma density and electron temperature.

References

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