Dynamical properties of harmonically confined charged particles in plasma

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Abstract

In the first approach, experimental dusty plasma structures are often described as systems of parabolically confined particles, interacting by the screened Coulomb potential. On the effect of the confinement, the systems acquire inhomogeneity of their structural and dynamical properties. There is a simplified analytical model describing radial profile of frequencies of thermal oscillations, based on an expansion in a series of potential energy of particle near it's equilibrium position. In this work the analytical model is evolved. Besides it, in the work MD simulations are provided to obtain velocity autocorrelation function and amplitudes of thermal oscillations of every particle in the system. The Fourier transform of VACF can be interpreted as vibrational density of states (VDOS) g(ω), which is used to perform averaging of frequency. We calculate two different values of frequency:

$$\langle \omega^{-2} \rangle = \frac{\int \frac{g(\omega)}{\omega^2} d\omega}{\int g(\omega) d\omega}$$

and

$$\langle \omega^{2} \rangle = \frac{\int g(\omega)\omega^2 d\omega}{\int g(\omega) d\omega}$$

This is necessary for explanation of the difference between amplitudes of thermal oscillations in finite systems in the trap and infinite bulk. To perform an explanation we divide the finite system into thin rings to obtain "rings with constant density of particles".

Results

- MD shows that there is a spatial nonuniformity of amplitudes and frequencies of thermal oscillations in a finite system of harmonically confined charged particles. This is confirmed by the difference in particles' oscillation spectra in different regions of a finite system.
- It is also shown that the value of $\langle \omega^2 \rangle^{1/2}$ in bulk is approximately equal to the one in a ring subsystem of a finite system (of respective density).
- It is demonstrated that the value of $\langle \omega^{-2} \rangle^{-1/2}$ in bulk is greater than the one in the central region of a finite system (center and bulk have equal density).
- It is shown that amplitudes and frequencies of particles' thermal oscillations in considered conditions are related via low-temperature approximation $\langle u^2 \rangle = \frac{kT}{m} \left\langle \frac{1}{\omega^2} \right\rangle$.

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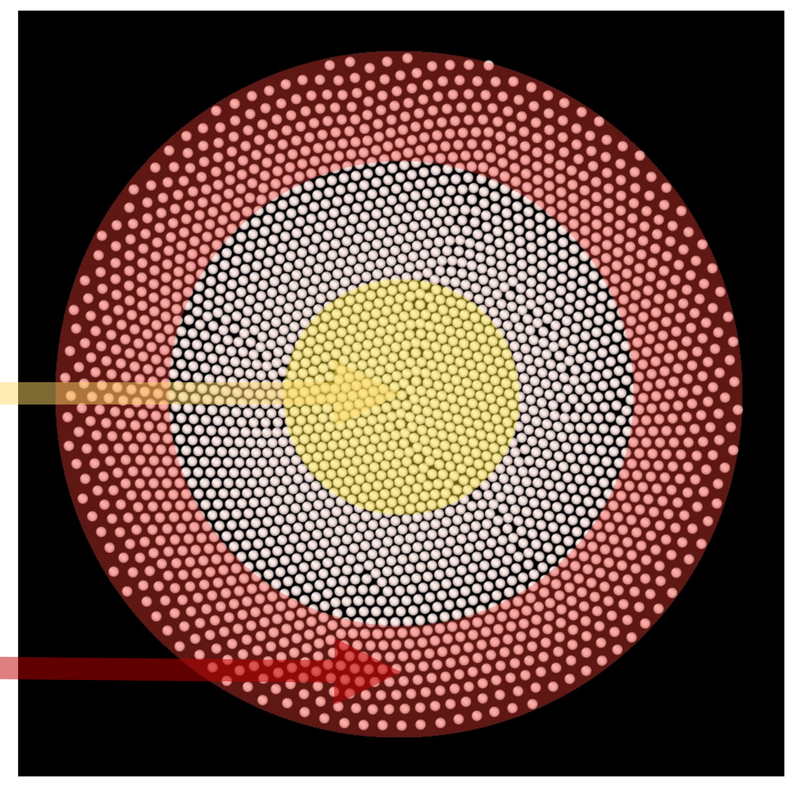
System configuration

Potential energy for interaction and confinement:

$$U_i = \sum_{j \neq i} \frac{Q^2}{r_{ij}} e^{-\kappa r_{ij}} + \frac{1}{2}\alpha Q d_i$$

Center

Periphery

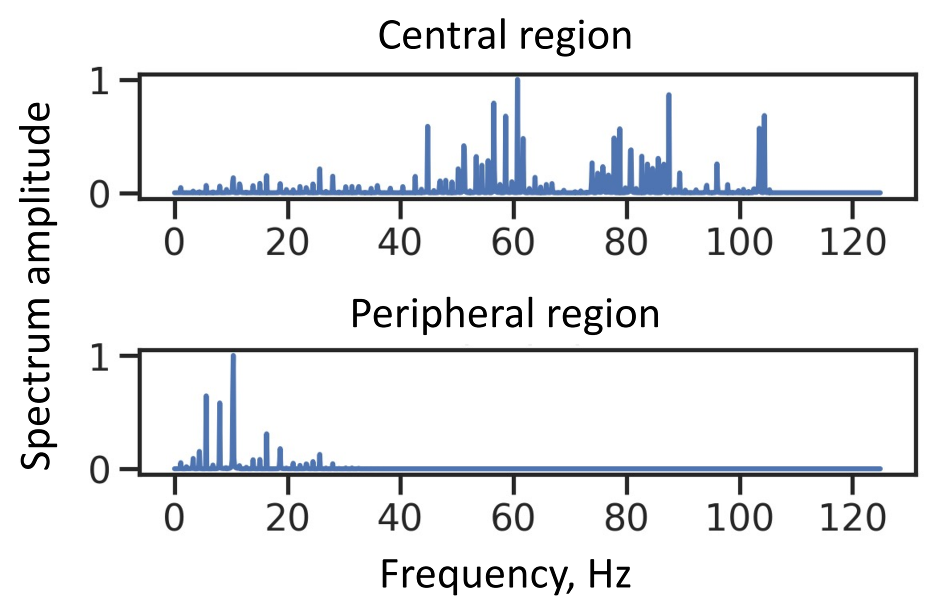


Spectra inhomogeneity

Central spectrum is *wider* than peripheral one.

0–110 Hz vs. 0–30Hz

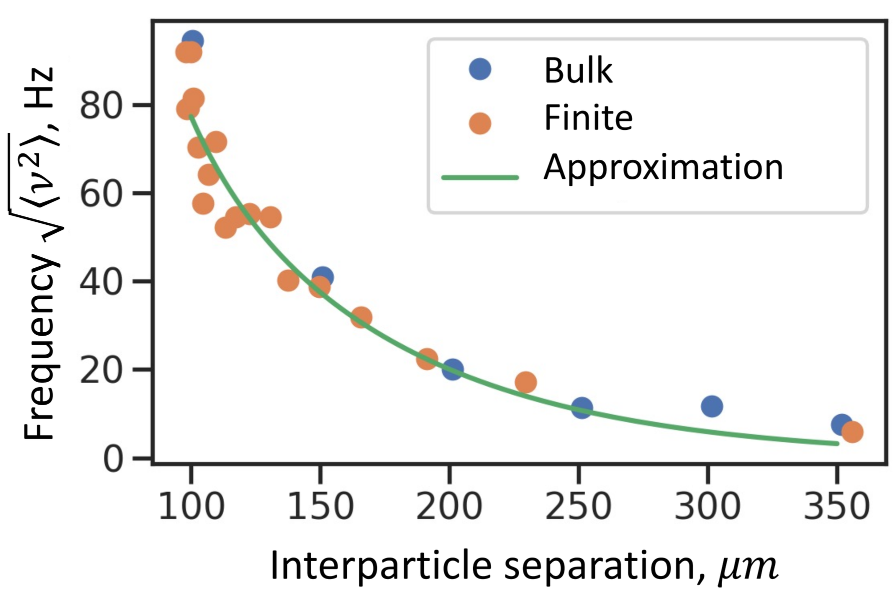
It affects on averaged frequencies.



Frequencies and amplitudes

Frequency $\sqrt{\langle \omega^2 \rangle}$ in bulk *is equal* to the one in a finite ring of respective density.

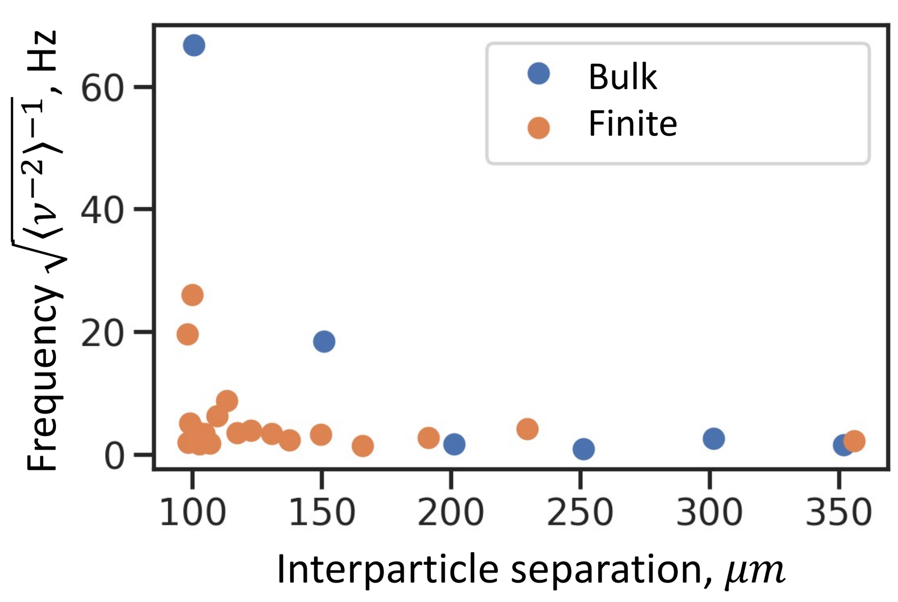
Approximation is based on an expansion in a series of potential energy of particle near it's equilibrium position.



Frequency $\sqrt{\langle \omega^{-2} \rangle^{-1}}$ in bulk *is greater* than the one in a finite ring of respective density.

There is a low-temperature approximation $\langle E_{kin} \rangle = \langle E_{pot} \rangle$. Hence, there is a relationship between amplitude $\sqrt{\langle u^2 \rangle}$ and frequency $\sqrt{\langle \omega^{-2} \rangle^{-1}}$:

$$\langle u^2 \rangle = \frac{kT}{m} \left\langle \frac{1}{\omega^2} \right\rangle.$$



As the theory implies, MD shows that amplitude of thermal oscillations $\sqrt{\langle u^2 \rangle}$ in bulk is lower than the one in a finite ring of respective density.