# Cage correlation functions of three-dimensional Yukawa systems in external magnetic field

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We investigate the effect of an external magnetic field on the cage correlation functions of the particles in a three-dimensional strongly coupled Yukawa system, via numerical simulations. The results show that with increasing strength of the magnetic field the caging time increases, i.e. the particles remain caged for a longer time. The investigation of the cage correlation functions is carried out in a wide range of the system parameters (coupling strength $\Gamma$, screening parameter $\kappa$, and reduced magnetic field strength $\beta$ ).

## 1. Introduction

The interest in the physics of complex plasmas has been continuously increasing during last few years. Motivated by their applications and by the need of understanding their fundamental physical effects, the properties of dusty plasmas are actively investigated on the basis of theoretical and experimental methods.

In many settings complex plasmas are affected by external electric and magnetic fields. The influence of magnetic fields on strongly coupled dusty plasmas became an important topic in the last few years [1,2]. The results of theoretical and simulation studies have shown the formation of magnetoplasmons and their higher harmonics in strongly coupled Coulomb and Yukawa systems [1]. The effect of magnetic field on the velocity autocorrelation and the caging of particles in two dimensional Yukawa liquids have been studied in Ref. [3].

## 2. Simulation method

We investigate the cage correlation functions of three–dimensional Yukawa systems in external magnetic fields by the molecular dynamic simulation method. The particles in such systems interact via screened Coulomb (Debye-Hückel, or Yukawa) potential:

$$\phi(r) = \frac{Q}{4\pi\varepsilon_0}\frac{\exp(-r/\lambda_D)}{r}, \qquad (1)$$

where $Q$ is the charge of the particles and $\lambda_D$ is the screening (Debye) length. The ratio of the nearest - neighbour potential energy to the thermal energy is expressed by the coupling parameter

$$\Gamma = \frac{Q^2}{4\pi\varepsilon_0 a k_B T}, \qquad (2)$$

where $T$ is the temperature, $\kappa = a/\lambda_D$ is the screening parameter, $a = (3/4\pi n)^{1/3}$ is the Wigner-Seitz radius, and $n$ is the number density of the particles.

The strength of the magnetic field is expressed in terms of

$$\beta = \frac{\omega_c}{\omega_p}, \qquad (3)$$

where $\omega_c = QB/m$ is the cyclotron frequency and $\omega_p = \sqrt{nQ^2/\varepsilon m}$ is the plasma frequency.

The changes of the surroundings of the particles at $t=0$ and $t>0$ are measured by the list correlation function:

$$C_l(t) = \frac{\langle l_i(t)\cdot l_i(0)\rangle}{\langle l_i(0)^2\rangle}, \qquad (4)$$

where $l_i$ is the "neighbor list" of particle $i$, which consists of 0-s and 1-s, the latter represent the particles situated within the first correlation shell around particle $i$. $\langle\cdot\rangle$ denotes averaging over particles and initial times. The number of particles that have left the original cage of particle $i$ at time $t$ can be determined as

$$n_i^{out}(t) = \left|l_i(0)^2\right| - l_i(0)\cdot l_i(t), \qquad (5)$$

where the first term gives the number of particles around particle $i$ at $t=0$, while the second term gives the number of "original" particles that remained in the surrounding after time $t$ elapsed. The cage correlation function $C_{cage}^c(t)$ can be calculated by averaging over particles and initial times, of the function $\left\langle \Theta(c-n_i^{out}) \right\rangle$:

$$C_{cage}^{c}(t) = \left\langle \Theta(c-n_i^{out}) \right\rangle, \qquad (6)$$

where $\Theta$ is the Heaviside function. For our conditions the average number of neighbors (situated within the first correlation shell of the particles) is 14. We define the cages to be decorrelated when half of these neighbors leave the cage with 90% probability, i.e. $C_{\text{cage}}^{7}$ ($t_{\text{cage}}$)=0.1.

## 3. Results and conclusion

We have investigated the influence of an external magnetic field on the cage correlation functions in a wide range of the system parameters.

The results (Fig. 1) show that with an increase of the magnetic field parameter the caging time increases, i.e. the particles remain in the cage for a longer time. This follows from the decrease of the Larmor radius of the particles at growing magnetic fields.

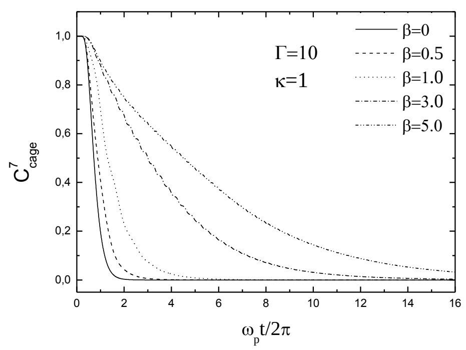


Figure 1 – Cage correlation functions of 3D Yukawa systems characterized by $\Gamma = 10, \kappa = 1$, at different normalized magnetic field strengths $\beta = \omega_c / \omega_p$.

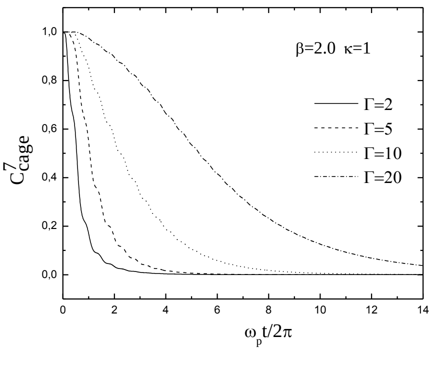


Figure 2 – Cage correlation functions at $\beta = 2, \kappa = 1$, for different values of the coupling parameter.

Figures 1 and 2 show that in the magnetized system (starting from β approximately equal to 1), periodic oscillations on the cage correlation functions show up at small values of the coupling parameter. These oscillations - caused by particles, which exit and subsequently return to the cages - disappear at approximately Γ = 50 for $\kappa = 1$, due to the fact that particles get increasingly more localized at higher coupling. The dependences of the $t_{cage}$ on the coupling parameter and on the magnetic field strength are shown in Figs. 3 and 4, respectively. The magnetic field significantly increases the caging time.

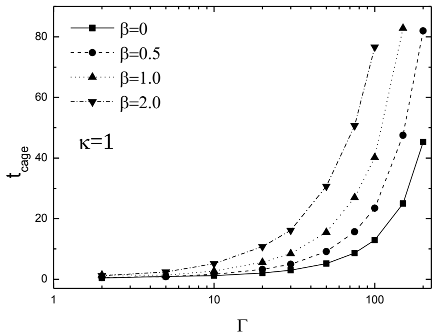


Figure 3 –Dependence of the $t_{cage}$ on the coupling parameter at different normalized magnetic field strengths.

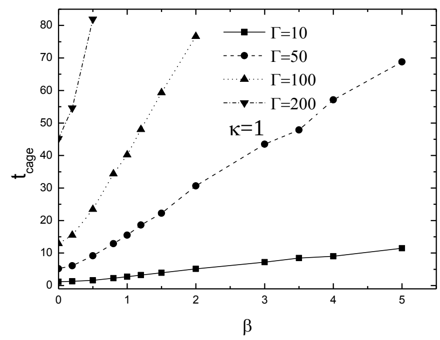


Figure 4 – Dependence of the $t_{cage}$ on the magnetic field strengths at different values of the coupling parameter.

[1] P. Hartmann, Z. Donkó, T. Ott, H. Kählert and M. Bonitz, *Phys. Rev. Lett.* **111** (2013) 155002; M. Bonitz, Z. Donkó, T. Ott, H. Kählert, and P. Hartmann, *Phys. Rev. Lett.* **105** (2010) 055002.

[2] T. Ott and M. Bonitz, *Phys. Rev. Lett.* **107** (2011) 35003.

[3] K.N. Dzhumagulova, R.U. Masheeva, T.S. Ramazanov and Z. Donkó, *Phys. Rev. Lett.* **89** (2014) 033104.

[4] Q. Spreiter and M. Walter, *Journal of Computational Physics* **152** (1999) 102–119.

[5] Z. Donkó, G. J. Kalman, and K. I. Golden, *Phys. Rev. Lett.* **88** (2002) 225001.