IETP, al-Farabi Kazakh National University, Almaty,Kazakhstan

New model of dusty plasma particles interaction

F. B. Baimbetov, A.E. Davletov,
Z.A. Kudyshev, E.S.Mukhametkarimov

September 2009, PNP 13, Chernogolovka

Outlook

- Dimensionless parameters of dusty plasma
- Renormalization of plasma particles interaction
- Micropotentials
- Results
  - Macropotentials
  - Macropotential of dust-dust interaction
  - Radial distribution function
- Conclusion

Dimensionless parameters of dusty plasmas

Coupling parameter of dust grains: $\Gamma_d = \dfrac{Z_d e^2}{a_d k_B T_d}$

$a_d = (3/4\pi n_d)^{1/3}$ - average intergrain distance

$Z_d = Q/e$; Q - dust grain charge

Dimensionless screening parameter defined as follows: $\kappa = \dfrac{a_d}{\lambda_d}$

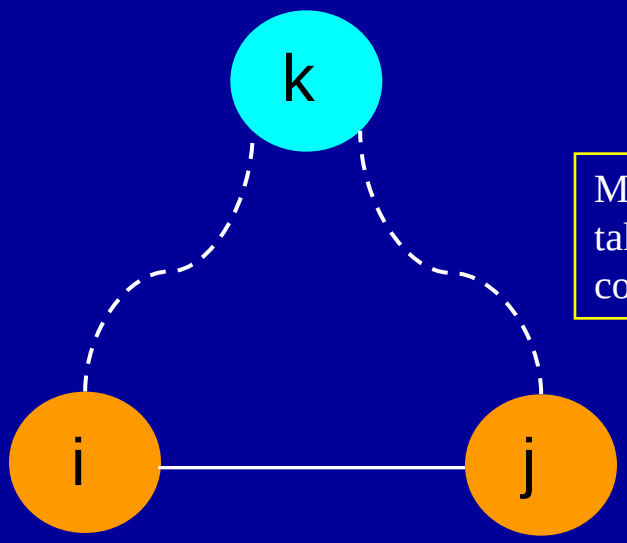
where $\dfrac{1}{\lambda_d^2} = \dfrac{1}{\lambda_e^2} + \dfrac{1}{\lambda_i^2}$ - plasma Debye radius

$\lambda_\alpha = \sqrt{k_B T_\alpha / 4\pi n_\alpha e^2}$ $, \alpha = i, e$ - electron (ion) Debye radius

Coupling parameter of plasma: $\Gamma = \dfrac{e^2}{a k_B T_e}$

where $a = (3/4\pi n)^{1/3}$ -average distance between plasma particles

Renormalization of plasma particles interaction



$$F_{ij}^{mac} = F_{ij}^{mic} + \sum_k \int F_{ik}^{mic} P(\mathbf{r}_{ik}, \mathbf{r}_{jk}) d\mathbf{r}_k$$

Macroscopic force, which takes into account the collective events

Microscopic force of interaction between plasma particles

Probability density

$$\mathbf{F}_{ij}^{mic} = -\nabla_i \varphi_{ij}$$

$$\mathbf{F}_{ij}^{mac} = -\nabla_i \Phi_{ij}$$

$$P(\mathbf{r}_{ik}, \mathbf{r}_{jk}) = \frac{1}{V} \exp\left(-\frac{\Phi_{ik} + \Phi_{jk}}{k_B T} \right)$$

Generalized Boltzmann -Poisson equation

$$\Delta_i \Phi_{ij}(\mathbf{r}_i^a, \mathbf{r}_j^b) = \Delta_i \varphi_{ij}(\mathbf{r}_i^a, \mathbf{r}_j^b) - \sum_c \frac{n_c}{k_B T} \int \Delta_i \varphi_{ik}(\mathbf{r}_i^a, \mathbf{r}_k^c) \Phi_{jk}(\mathbf{r}_j^b, \mathbf{r}_k^c) d\mathbf{r}_k^c$$

**Baimbetov F.B., Arkhipov Yu.V., Davletov A.E. Thermodynamics of partially ionized hydrogen plasmas: Pseudopotential approach in chemical models. Phys. Plasma 2005, v.5, p. 315-321*

Solution to the generalized Boltzmann-Poisson equation

For the three component plasma of interest the solution to the Boltzmann – Poisson equation takes the form

$$\tilde{\Phi}_{ab}(k) = \frac{1}{\Delta}(\tilde{\varphi}_{ab}(k) + \sum_{c=e,i,d} A_c[\tilde{\varphi}_{cc}(k)\tilde{\varphi}_{ab}(k) - \tilde{\varphi}_{ac}(k)\tilde{\varphi}_{bc}(k)] + \tag{1}$$

$$\delta_{ab}\sum_{c,f=e,i,d} A_c A_f \left[\frac{\begin{array}{l}\tilde{\varphi}_{ac}(k)\tilde{\varphi}_{af}(k)\tilde{\varphi}_{cf}(k) + \\ \tilde{\varphi}_{aa}(k)\tilde{\varphi}_{cc}(k)\tilde{\varphi}_{ff}(k) - \tilde{\varphi}_{aa}(k)\tilde{\varphi}_{cf}(k)^2 - \tilde{\varphi}_{cc}(k)\tilde{\varphi}_{af}(k)^2 - \tilde{\varphi}_{ff}(k)\tilde{\varphi}_{ac}(k)^2\end{array}}{2}\right])$$

with

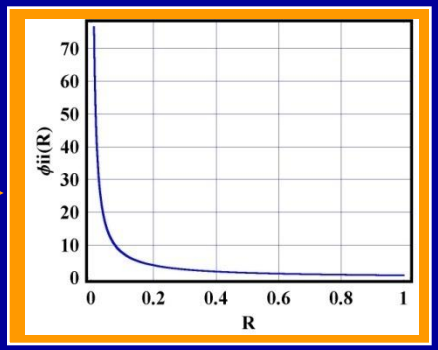
$$\Delta = 1 + \sum_{a=e,i,d} A_a\tilde{\varphi}_{aa}(k) + \sum_{a,b} A_a A_b[\tilde{\varphi}_{aa}(k)\tilde{\varphi}_{bb}(k) - \tilde{\varphi}_{ab}(k)^2] + A_a A_b A_c \times$$

$$[\frac{\tilde{\varphi}_{ab}(k)\tilde{\varphi}_{bc}(k)\tilde{\varphi}_{ac}(k)}{3} + \frac{\tilde{\varphi}_{aa}(k)\tilde{\varphi}_{bb}(k)\tilde{\varphi}_{cc}(k) - \tilde{\varphi}_{aa}(k)\tilde{\varphi}_{bc}(k)^2 - \tilde{\varphi}_{bb}(k)\tilde{\varphi}_{ac}(k)^2 - \tilde{\varphi}_{cc}(k)\tilde{\varphi}_{ab}(k)^2}{6}]$$

Micropotentials

The buffer plasma is considered fully ionized and electrons and ions interact via the Coulomb potential:

$$\varphi_{ee}(r) = \varphi_{ii}(r) = -\varphi_{ei}(r) = \frac{e^2}{r}$$



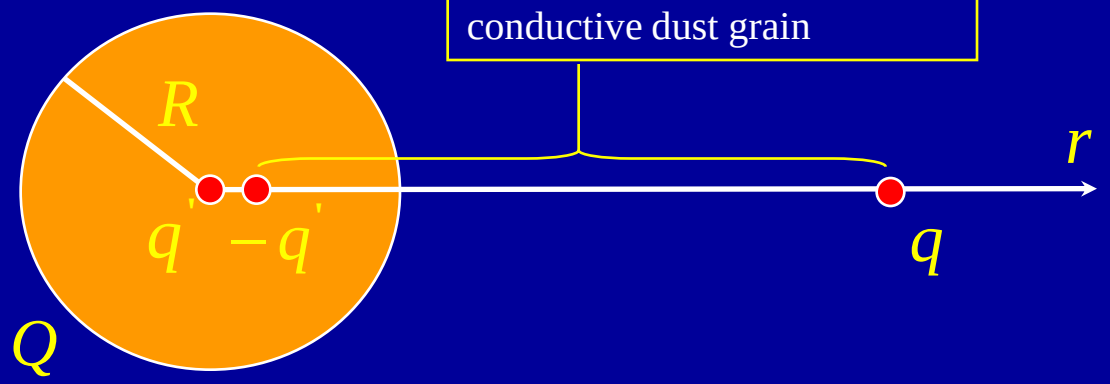
Micropotentials

The micropotentials of interaction between charged particles and the dust grain are obtained from *electrostatic images*

Interaction between charged particle and its images in conductive dust grain

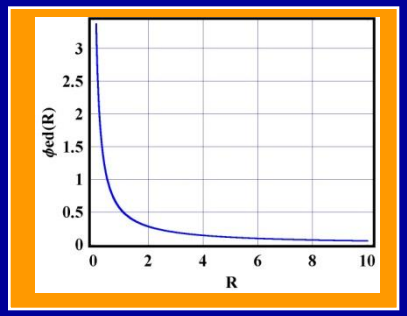
+

Coulomb interaction between dust grain and the charged particle



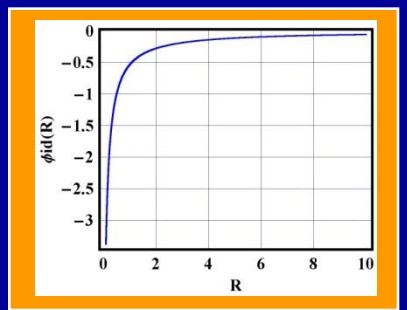
Micropotential of grain – electron interaction:

$$\varphi_{de}(r) = \frac{Z_d e^2}{r} - \frac{e^2 R^3}{2r^2(r^2 - R^2)}$$



Micropotential of grain – ion interaction:

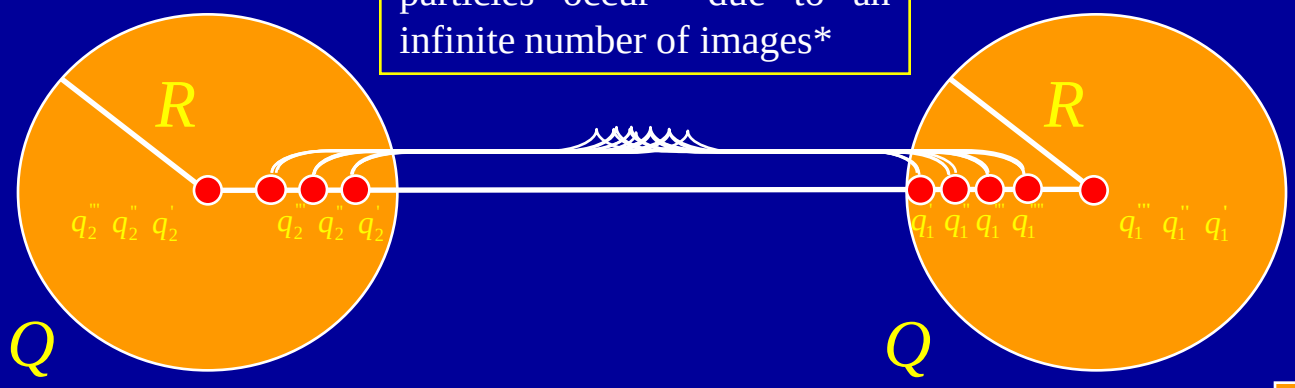
$$\varphi_{di}(r) = -\frac{Z_d e^2}{r} - \frac{e^2 R^3}{2r^2(r^2 - R^2)}$$



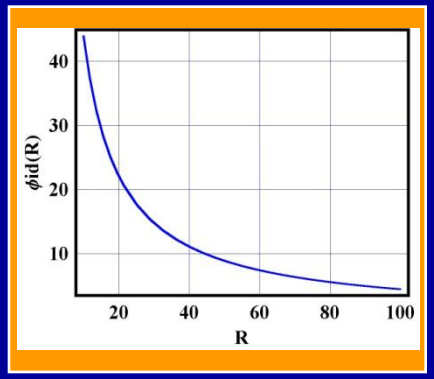
Micropotentials

The micropotential of interaction between dust grains

Interaction between dust particles occur due to an infinite number of images*



$$\varphi_{dd}(r) = \frac{Z_d^2 e^2}{R}\left[\frac{1}{Sinh[\beta]\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{Sinh[n\beta]}} - 1\right]$$



where $Cosh[\beta] = \frac{r}{2R}$

**V.A. Saranin, UFN vol. 169, No. 4 (1999).*

Results

Macropotential of electron-electron interaction:

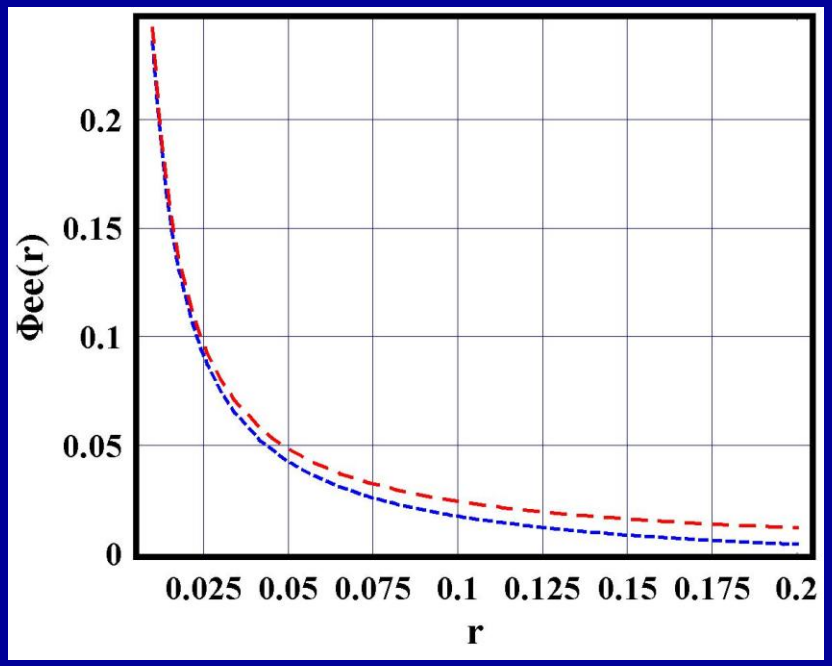


Fig.1. Dependence of electron-electron macropotential on dimensionless distance. Blue curve: macropotential ($\Gamma = 0.1; Z_d = 100; \alpha = 0.95; \kappa = 1; T_e / T_d = 6$). Red curve: micropotential with the same plasma parameters.

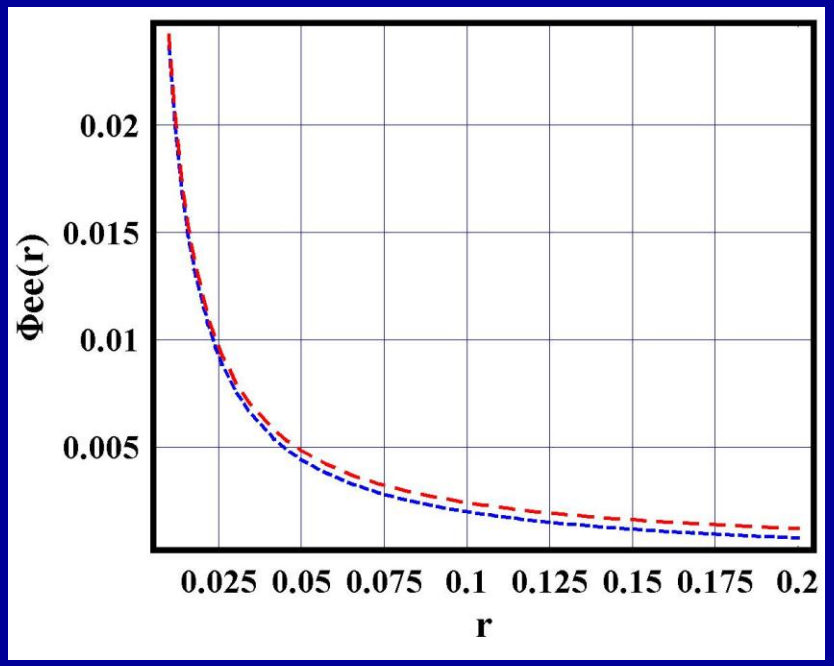


Fig.2. Dependence of electron-electron macropotential on dimensionless distance. Blue curve: macropotential ($\Gamma = 0.1; Z_d = 100; \alpha = 0.95; \kappa = 10; T_e / T_d = 6$). Red curve: micropotential with the same plasma parameters.

Results

Macropotential of electron-proton interaction:

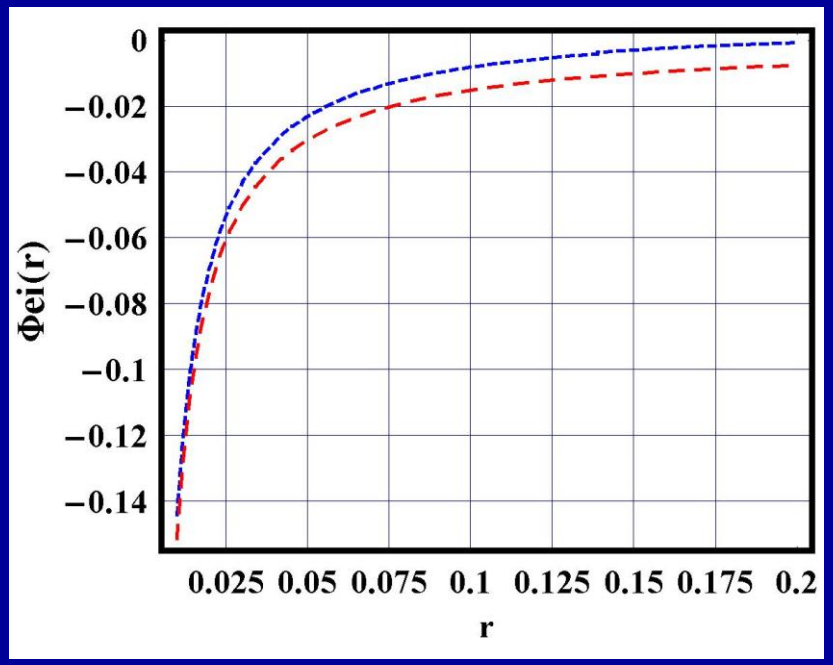


Fig.3. Dependence of electron-proton macropotential on dimensionless distance. Blue curve: macropotential ($\Gamma = 0.1; Z_d = 100; \alpha = 0.95; \kappa = 1; T_e / T_d = 6$). Red curve: micropotential with the same plasma parameters.

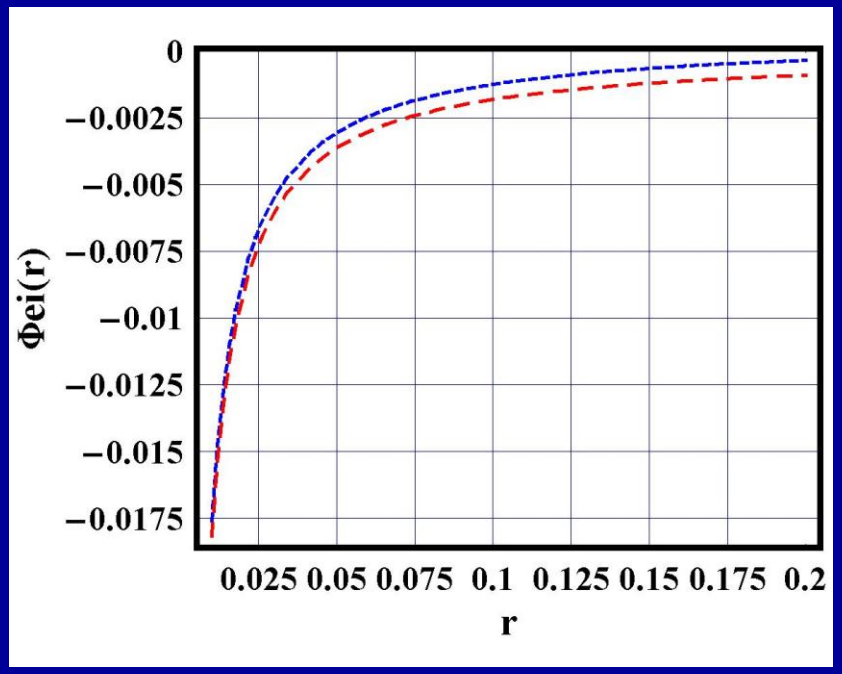


Fig.4. Dependence of electron-proton macropotential on dimensionless distance. Blue curve: macropotential ($\Gamma = 0.1; Z_d = 100; \alpha = 0.95; \kappa = 10; T_e / T_d = 6$). Red curve: micropotential with the same plasma parameters.

Results

Macropotential of proton-proton interaction:

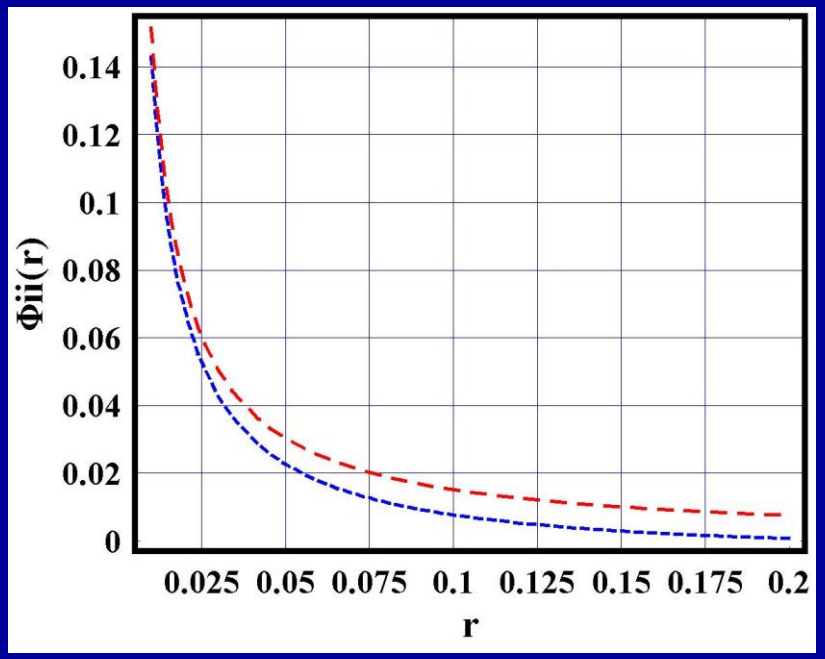


Fig.5. Dependence of proton-proton macropotential on dimensionless distance. Blue curve: macropotential ($\Gamma = 0.1; Z_d = 100; \alpha = 0.95; \kappa = 1; T_e / T_d = 6$). Red curve: micropotential with the same plasma parameters.

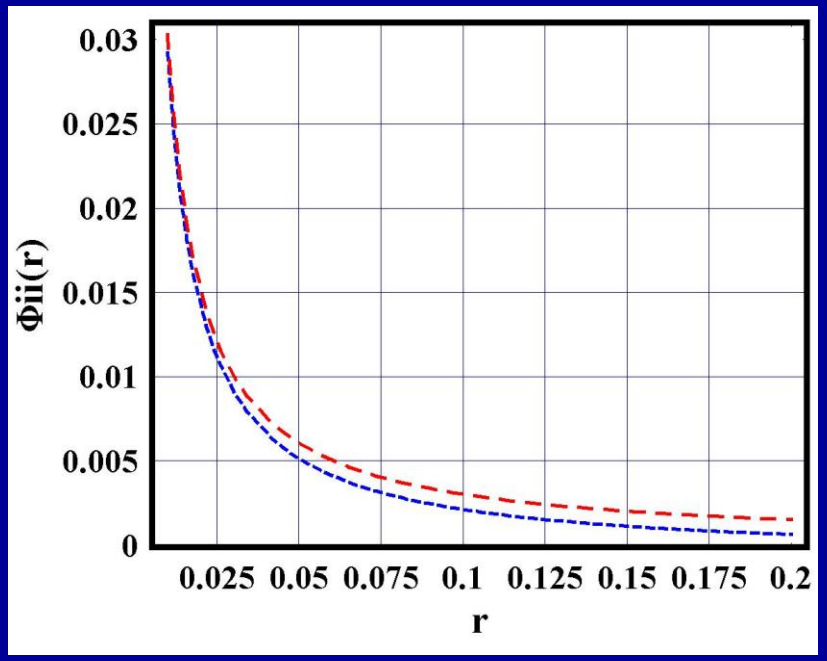


Fig.6. Dependence of proton-proton macropotential on dimensionless distance. Blue curve: macropotential ($\Gamma = 0.1; Z_d = 100; \alpha = 0.95; \kappa = 10; T_e / T_d = 6$). Red curve: micropotential with the same plasma parameters.

Results

Macropotential of grain-electron interaction:

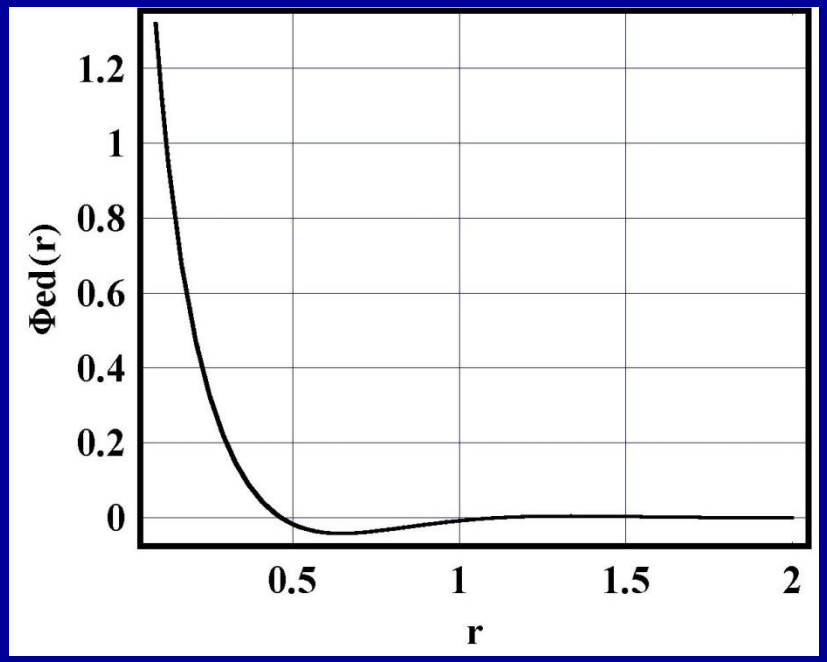


Fig.7. Dependence of grain-electron macropotential on dimensionless distance. $\Gamma_d = 180; Z_d = 100; \alpha = 0.95; \kappa = 0.8;)$

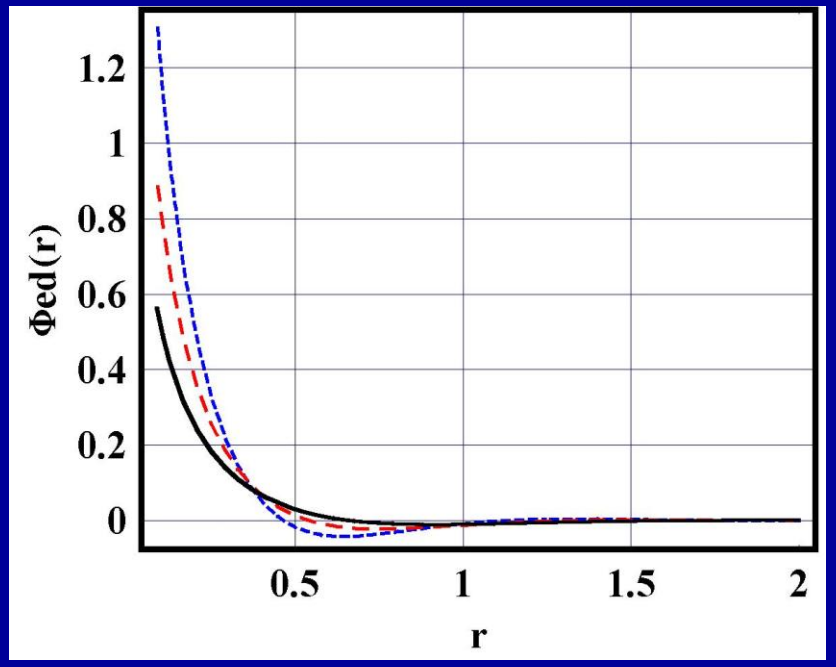


Fig.8. Dependence of grain-electron macropotential on dimensionless distance. Blue dashed curve: macropotential ($\Gamma_d = 180; Z_d = 100; \alpha = 0.95; \kappa = 0.8;$). Red dashed curve: $\Gamma_d = 120; Z_d = 100; \alpha = 0.95; \kappa = 1.2;$ Black solid curve: $\Gamma_d = 72; Z_d = 100; \alpha = 0.95; \kappa = 2;$

Results

Macropotential of dusty-proton interaction:

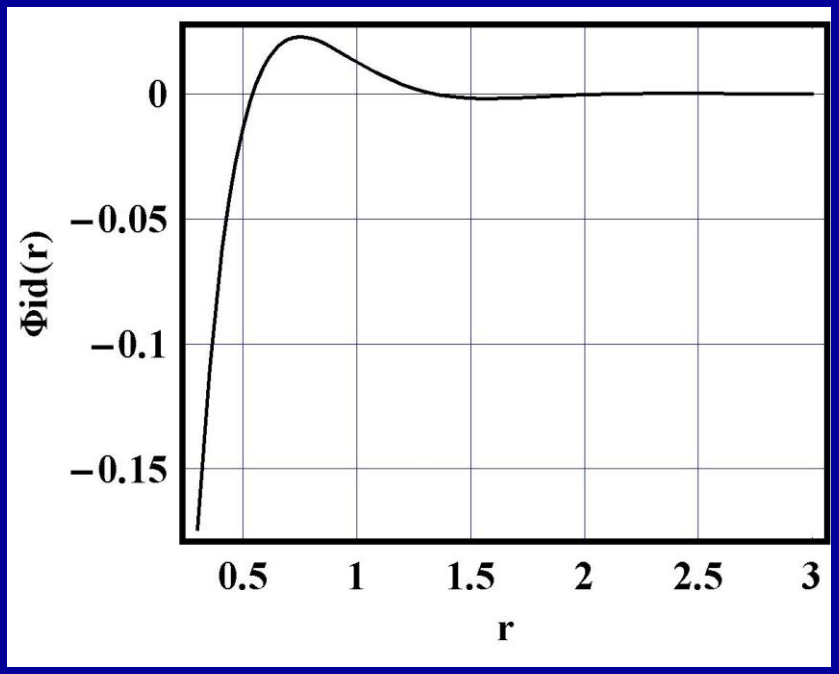


Fig.9. Dependence of dusty-proton macropotential on dimensionless distance. $(\Gamma_d = 120; Z_d = 100; \alpha = 0.95; \kappa = 1.2;)$

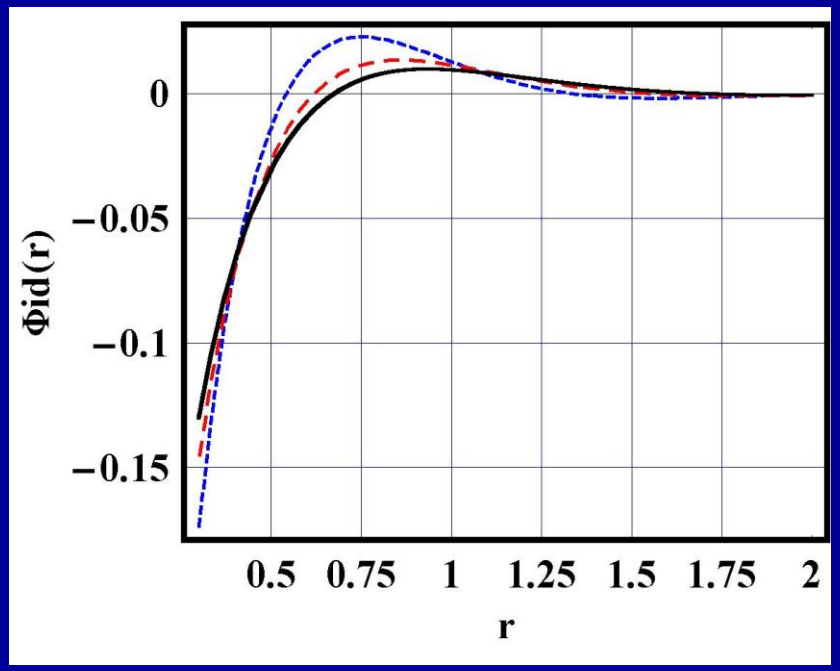


Fig.10. Dependence of dusty-proton macropotential on dimensionless distance. Blue dashed curve: macropotential $\Gamma_d = 180;$ $(Z_d = 100; \alpha = 0.95; \kappa = 0.8;)$. Red dashed curve: $\Gamma_d = 120; Z_d = 100; \alpha = 0.95; \kappa = 1.2;$ Black solid curve: $\Gamma_d = 72; Z_d = 100; \alpha = 0.95;$ $\kappa = 2;$

Results

Macropotential of grain-grain interaction:

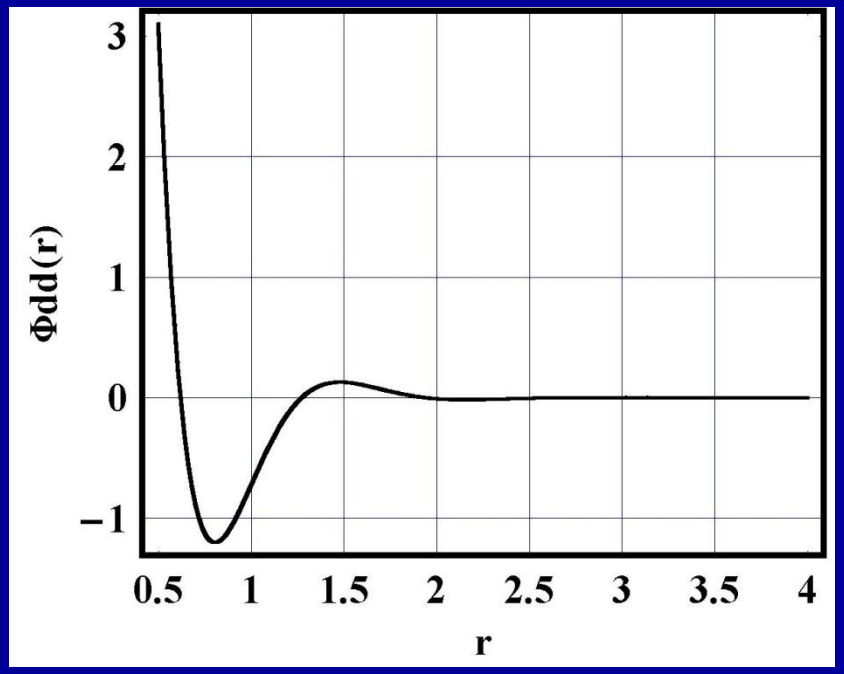


Fig.11. Dependence of grain-grain macropotential on dimensionless distance. $\Gamma_d = 180; Z_d = 100; \alpha = 0.95; \kappa = 0.8;$

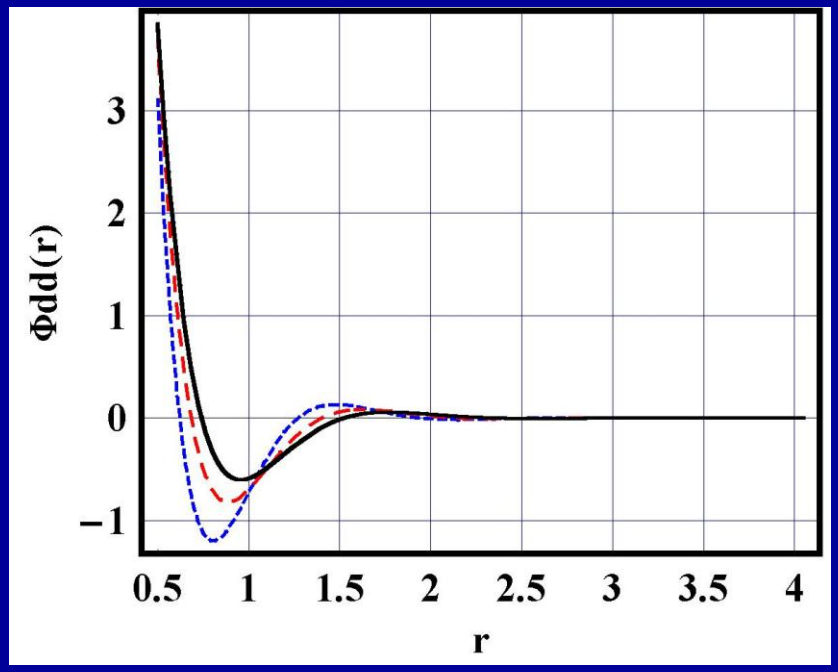


Fig.12. Dependence of grain-grain macropotential on dimensionless distance. Blue dashed curve: macropotential($\Gamma_d = 180;$ $Z_d = 100; \alpha = 0.95; \kappa = 0.8;$) Red dashed curve: $\Gamma_d = 145; Z_d = 100; \alpha = 0.95; \kappa = 1;$ Black solid curve $\Gamma_d = 120; Z_d = 100; \alpha = 0.95;$ $\kappa = 1.2;$

Results

Macropotential of grain-grain interaction:

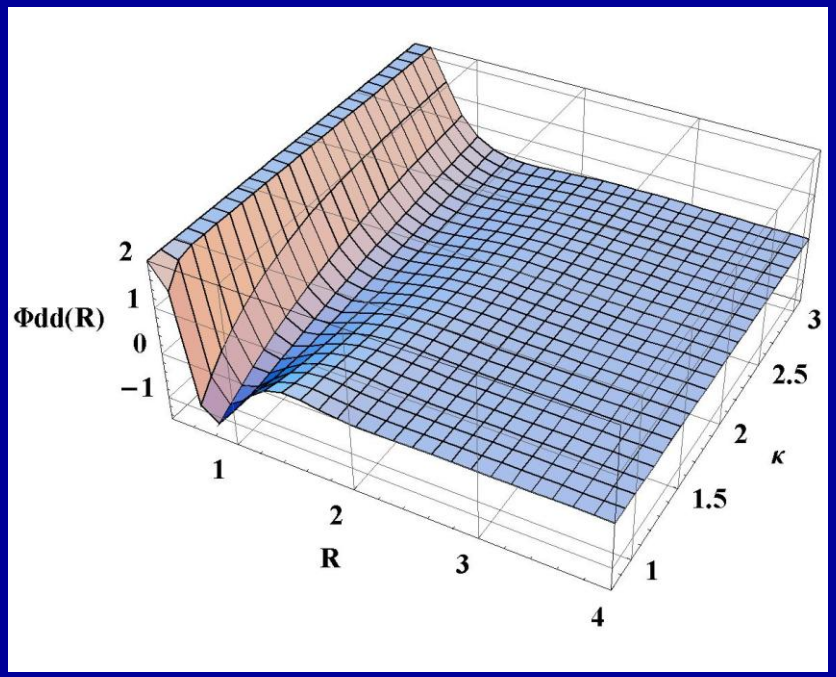


Fig.13. Dependence of grain-grain macropotential on dimensionless distance and dimensionless screening parameter.

$\Gamma = 0.01; Z_d = 100; \alpha = 0.95$

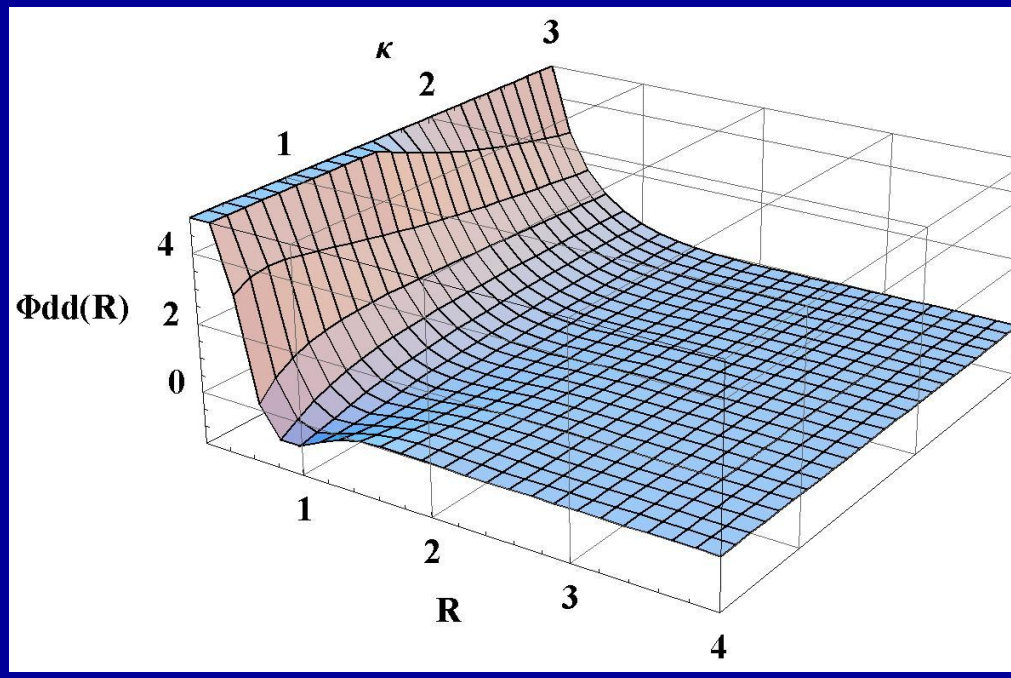


Fig.14. Dependence of grain-grain macropotential on dimensionless distance and dimensionless screening parameter.

$\Gamma = 0.05; Z_d = 100; \alpha = 0.95$

Conclusion

- The simple renormalization of plasma particle interactions adequately takes into account the collective events

- The polarization phenomena together with the screening effects can cause the onset of attraction forces between grains in dusty plasmas

Thank you for your attention!