The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA

1953-27

International Workshop on the Frontiers of Modern Plasma Physics

14 - 25 July 2008

3D Complex plasmas: Experiments versus Simulations.

B.A. Klumov
Max-Planck Institute for Extraterrestrial Physics
Garching bei Munchen
Germany

Max-Planck-Institut für extraterrestrische Physik

3D Complex plasmas: Experiments versus Simulations

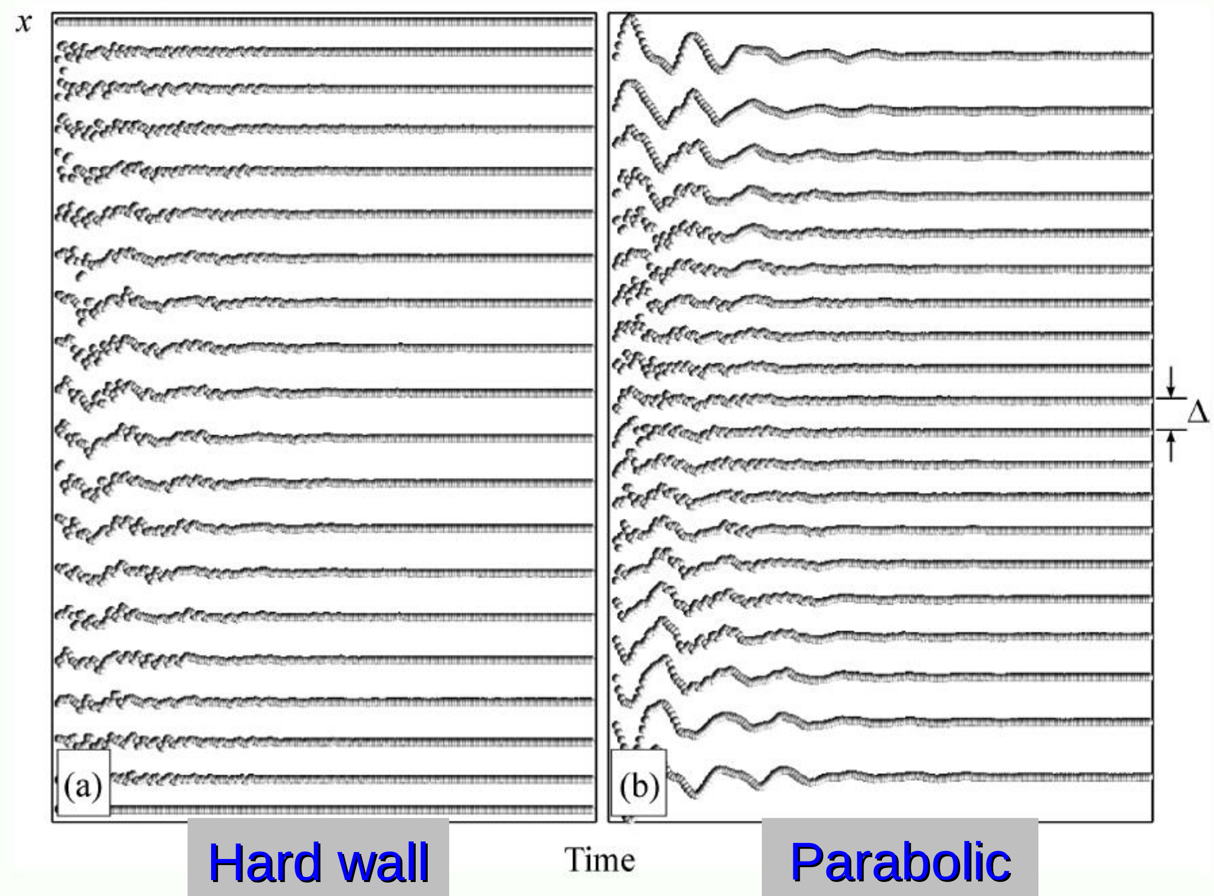
B. Klumov and PK3+ Team

International Workshop on the Frontiers of Modern Plasma Physics

14 - 25 July 2008, ICTP, Trieste

1D Yukawa system @ different confinements

$$m\ddot{\mathbf{r}}_i = -Z_{\mathrm{d}}\nabla\Phi_{\mathrm{c}} - Z_{\mathrm{d}}\sum\nabla\phi - m\gamma\dot{\mathbf{r}}_i + \mathbf{L}_i$$

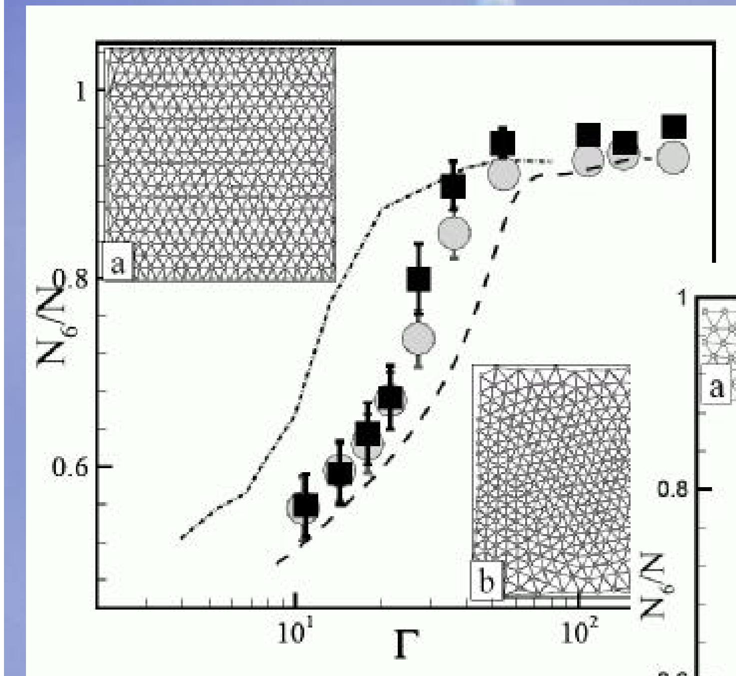


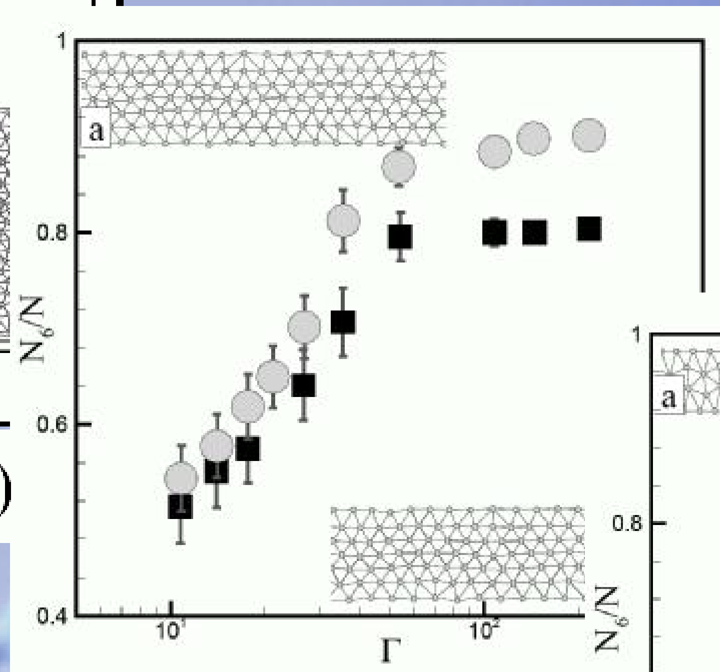
NB: Different dependencies of inter particle distance Δ versus x at steady-state stage

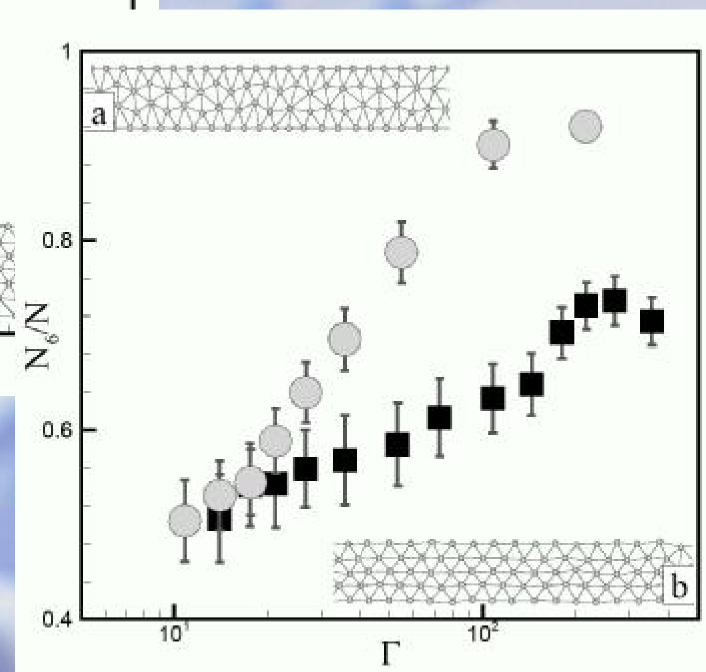
Complex plasmas in narrow channels: MD simulations of 2D Yukawa system (Klumov, JETPL, 2007)

$$\varphi(r) = (Ze/r)\exp(-r/\lambda_D)$$

decrease the “wall” separation







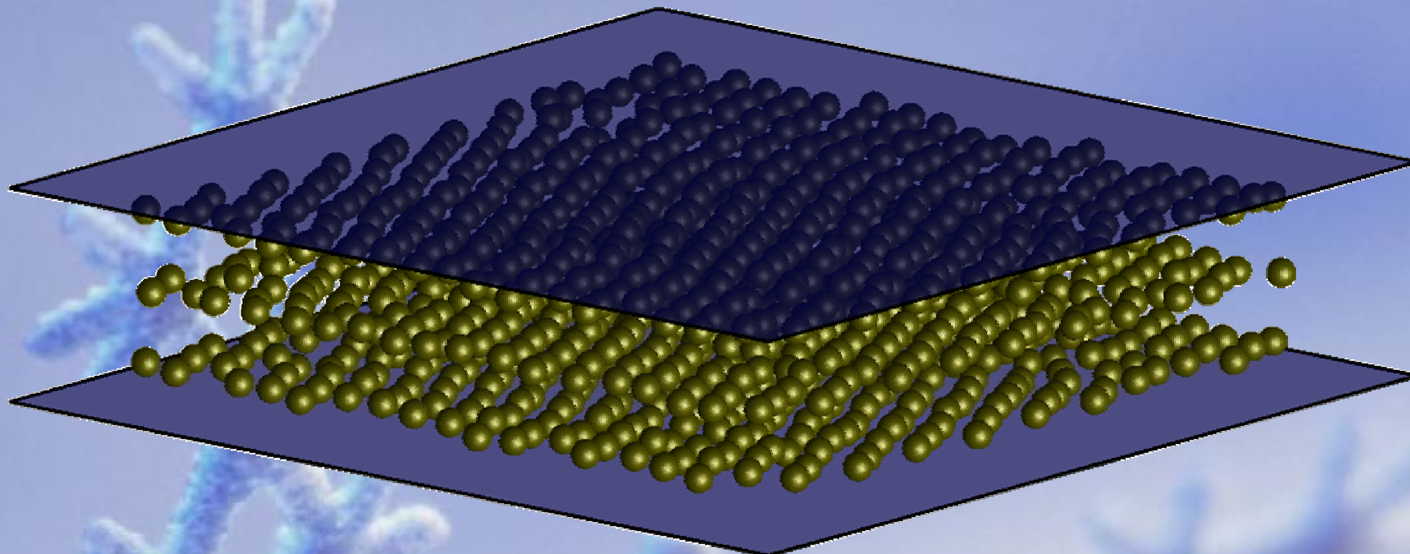
$$\Gamma \equiv (Z_d^2/\Delta T_d)\exp(-\kappa)$$

$$\kappa = \Delta/\lambda_D$$

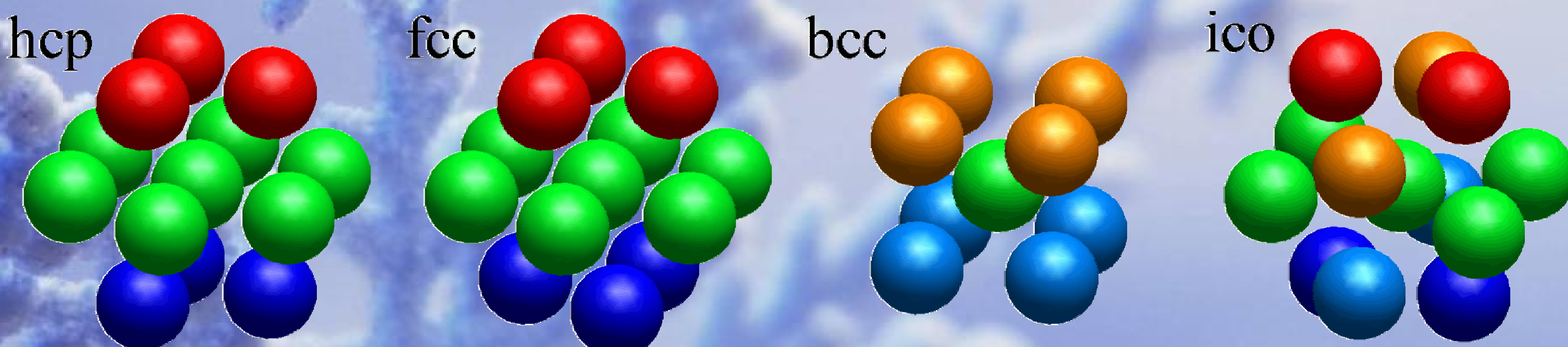
■ Hard wall

● Parabolic

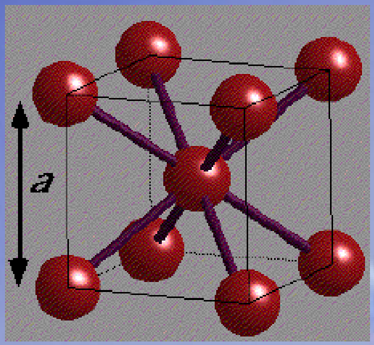
Complex plasmas in narrow channels: MD simulations of Yukawa system (Klumov, JETPL, 2008)

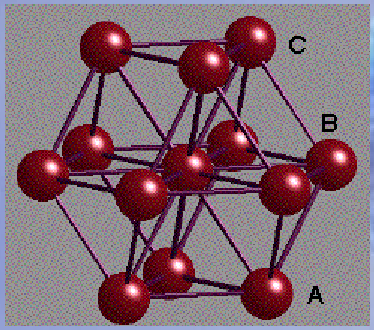


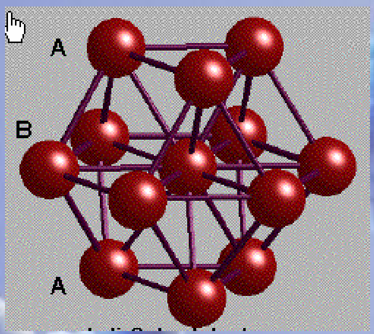
Periodic boundary conditions (x, y) + confinement (z)

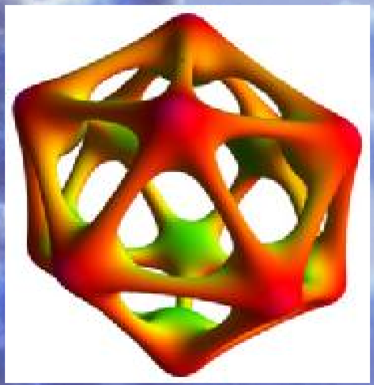


Local order of 3D system of particles

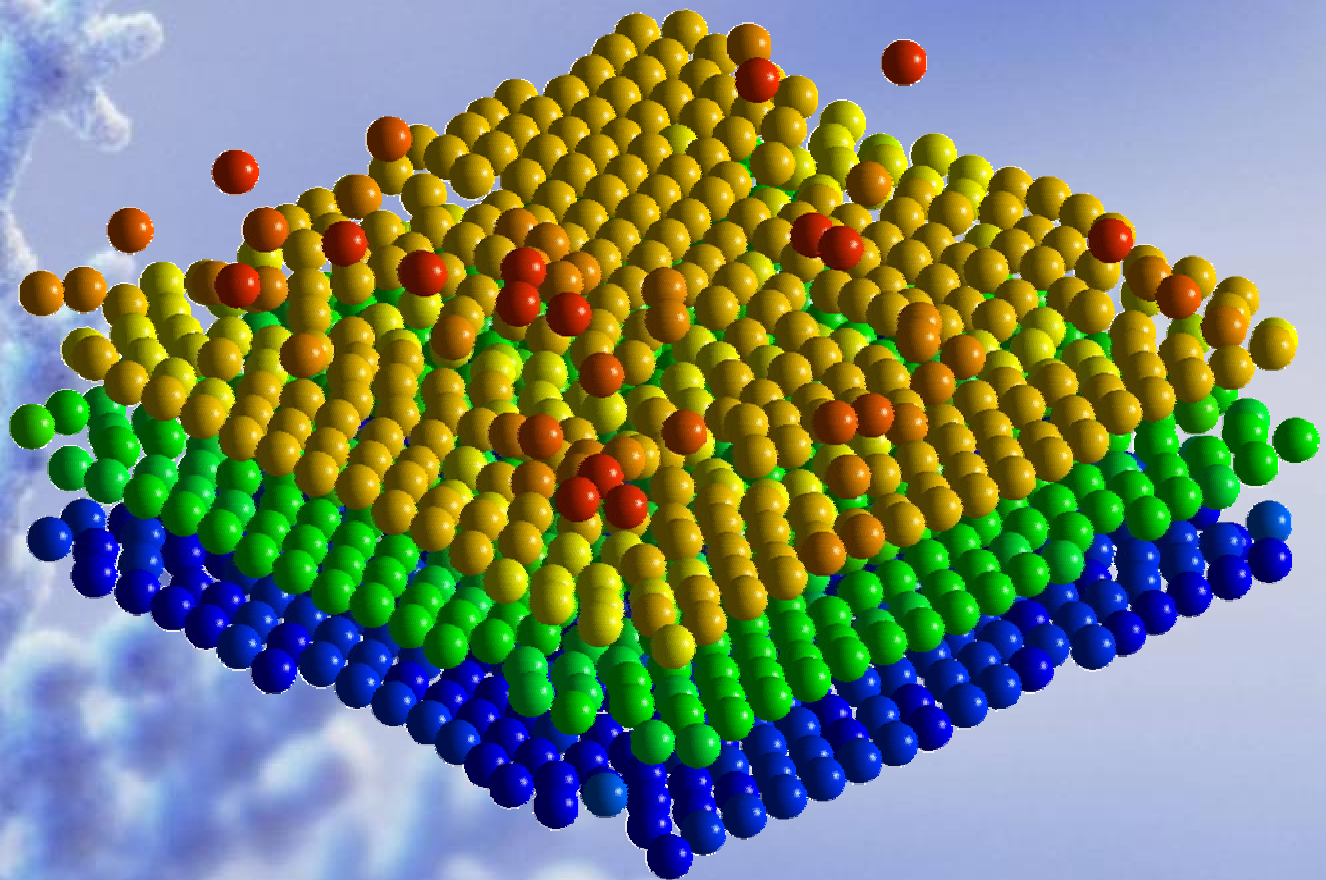




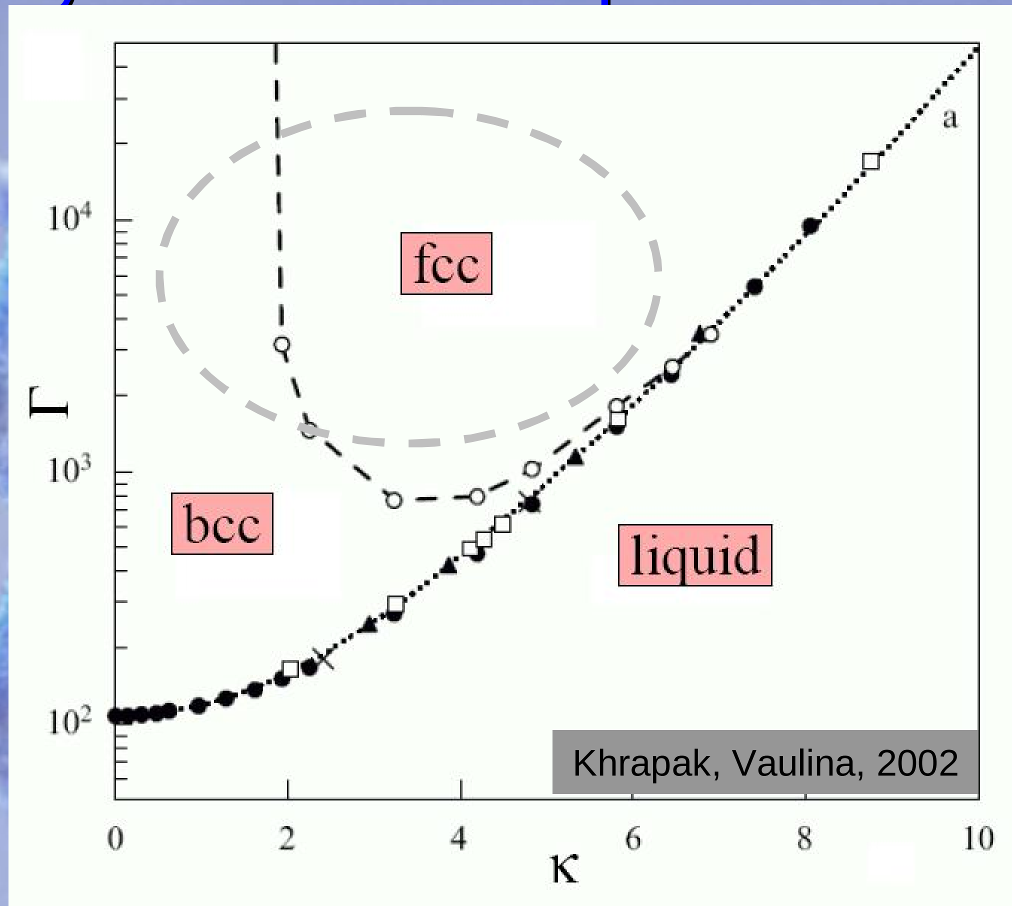


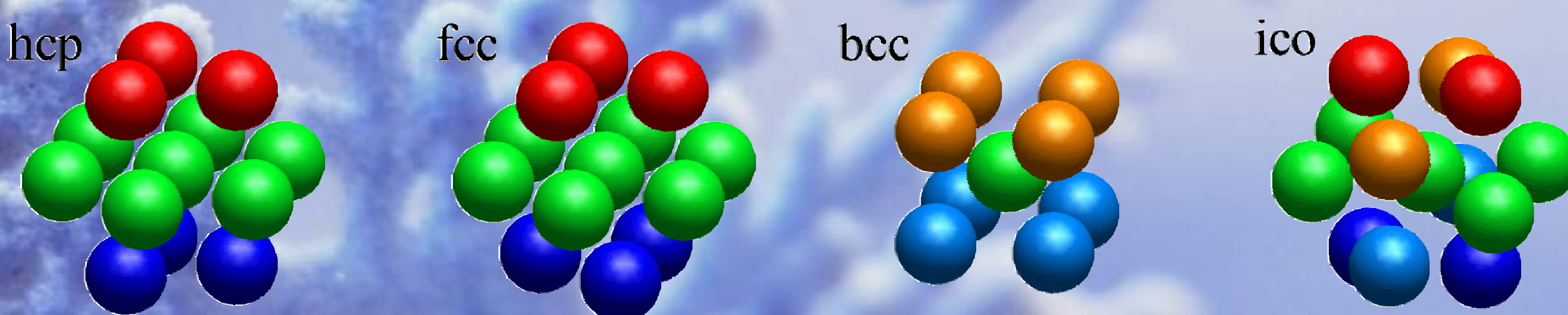


Three adjacent layers can be used to identify CCP lattice types



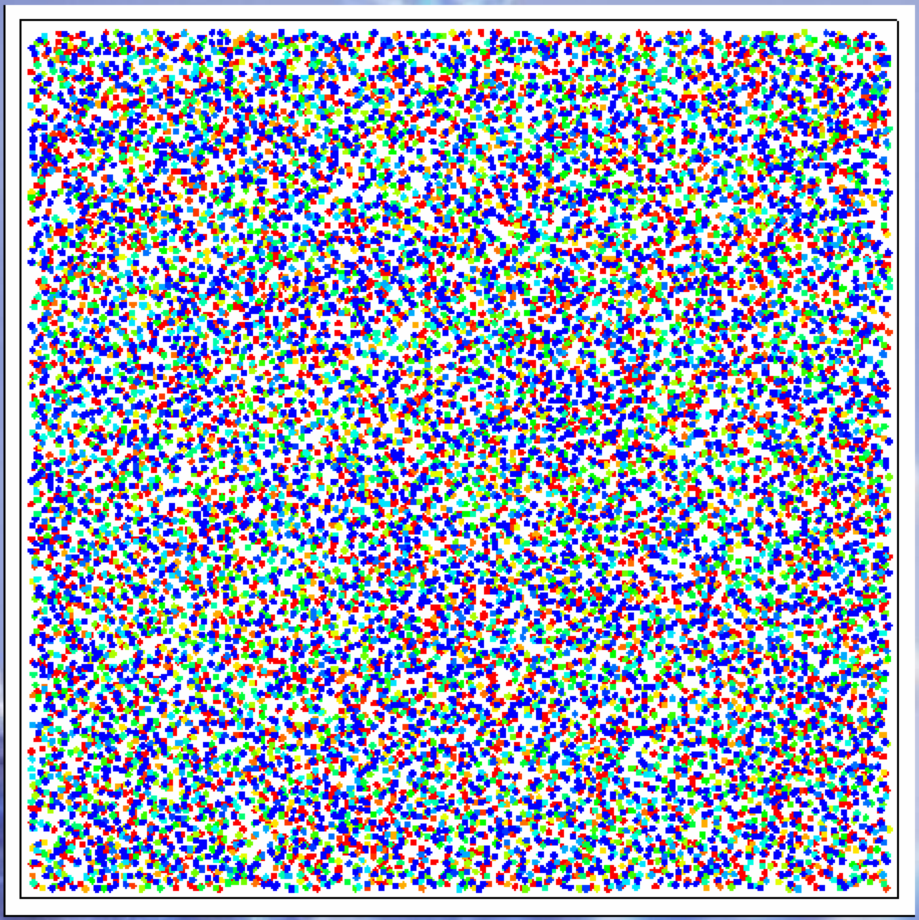
Yukawa system + PBC: equilibrium lattice types



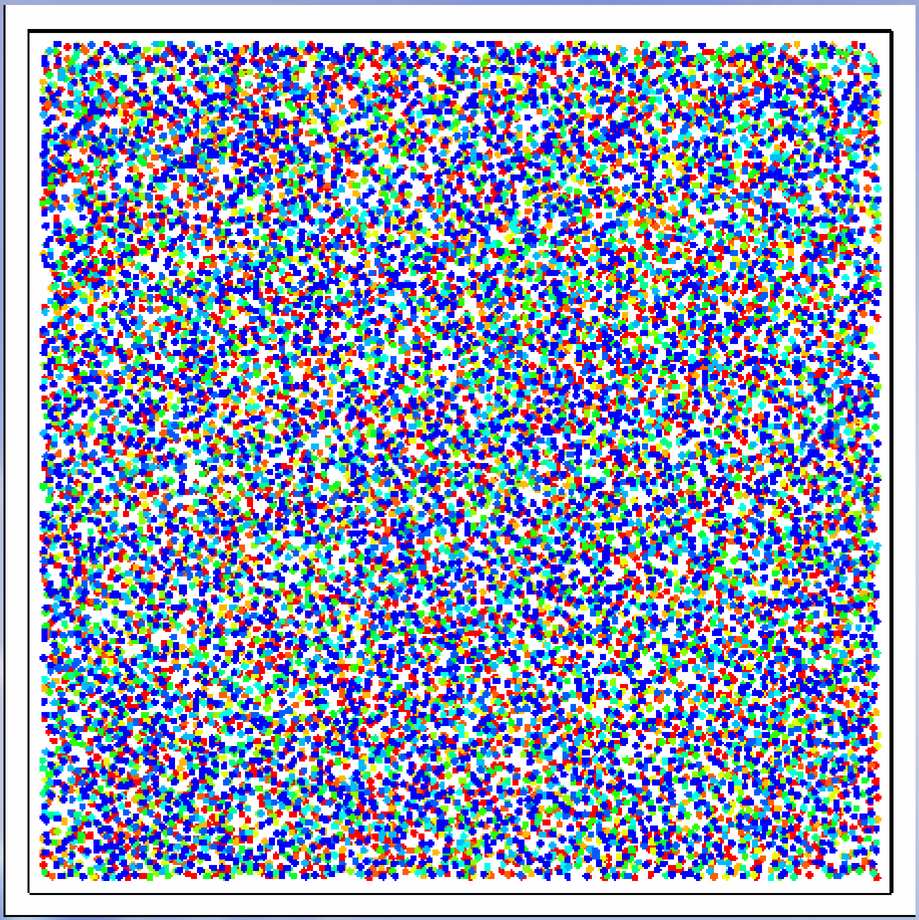


3D Yukawa system in narrow channel: MD simulations

Top view: the layers are color-coded by the depth



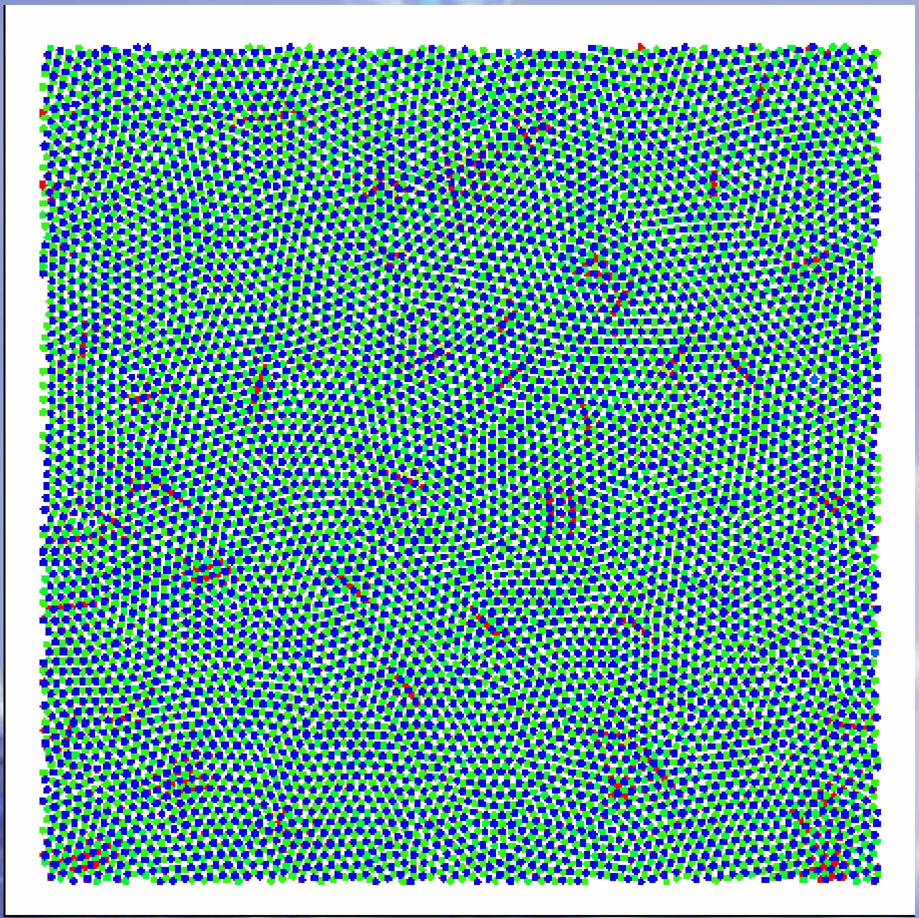
Parabolic confinement

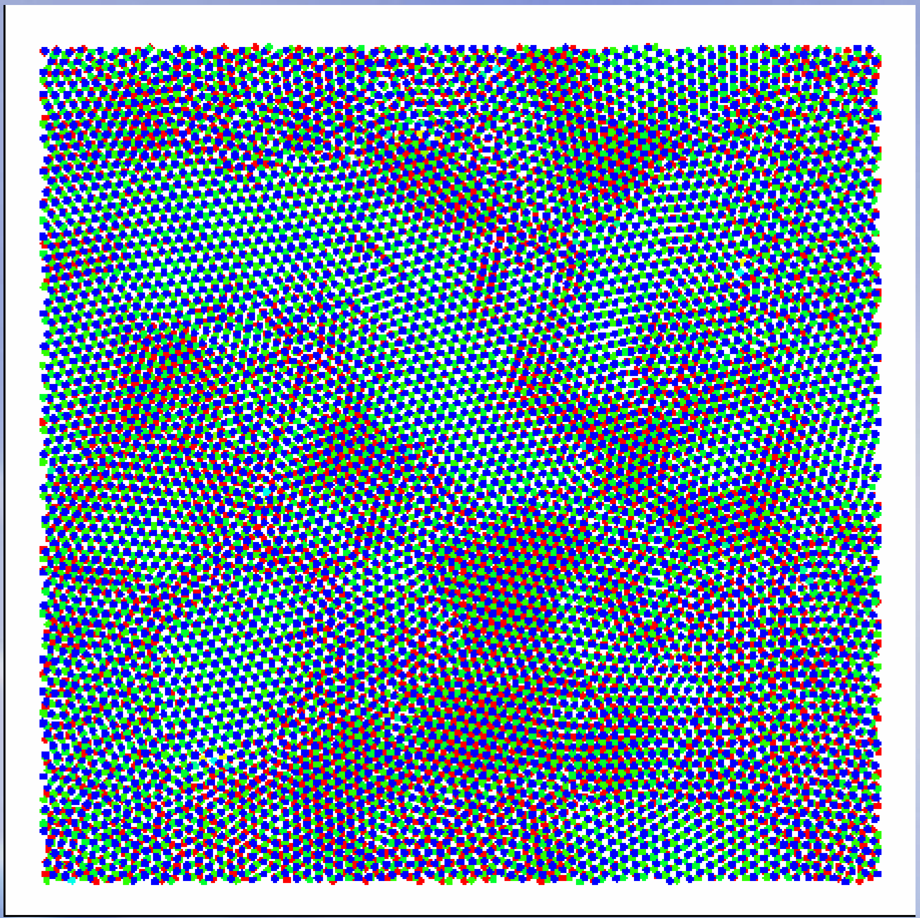


Hard wall

3D Yukawa system in narrow channel: MD simulations

Top view: the layers are color-coded by the depth



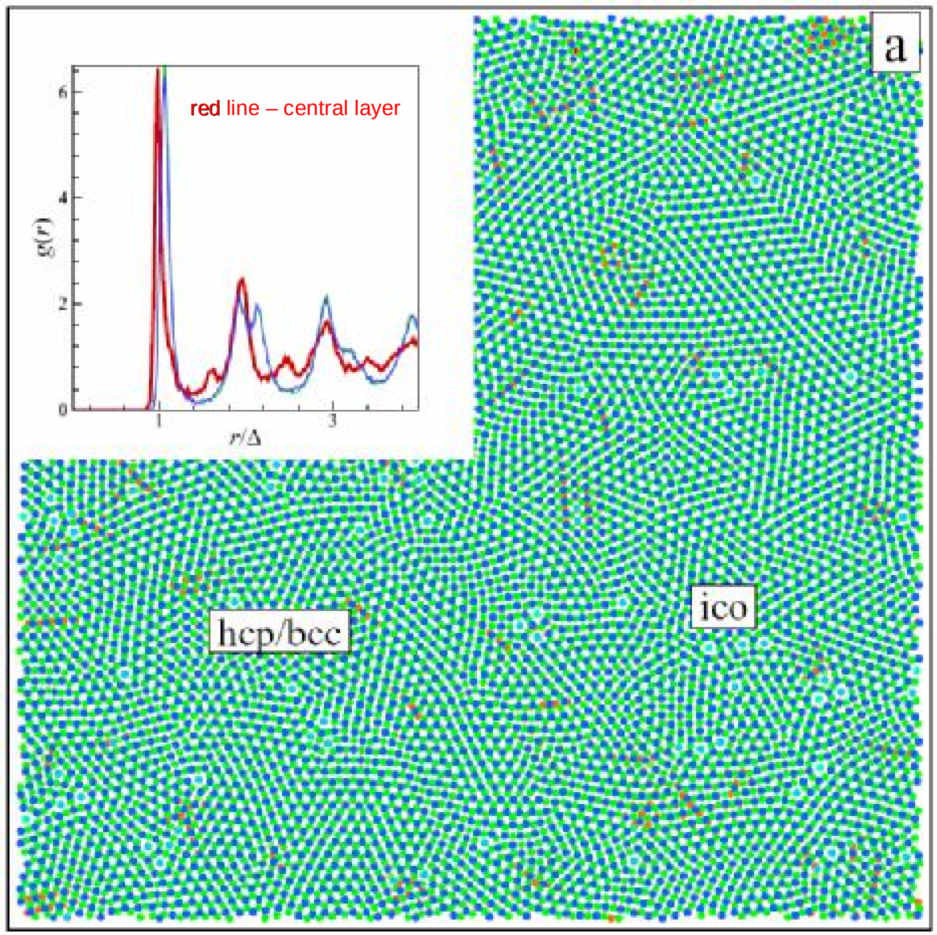


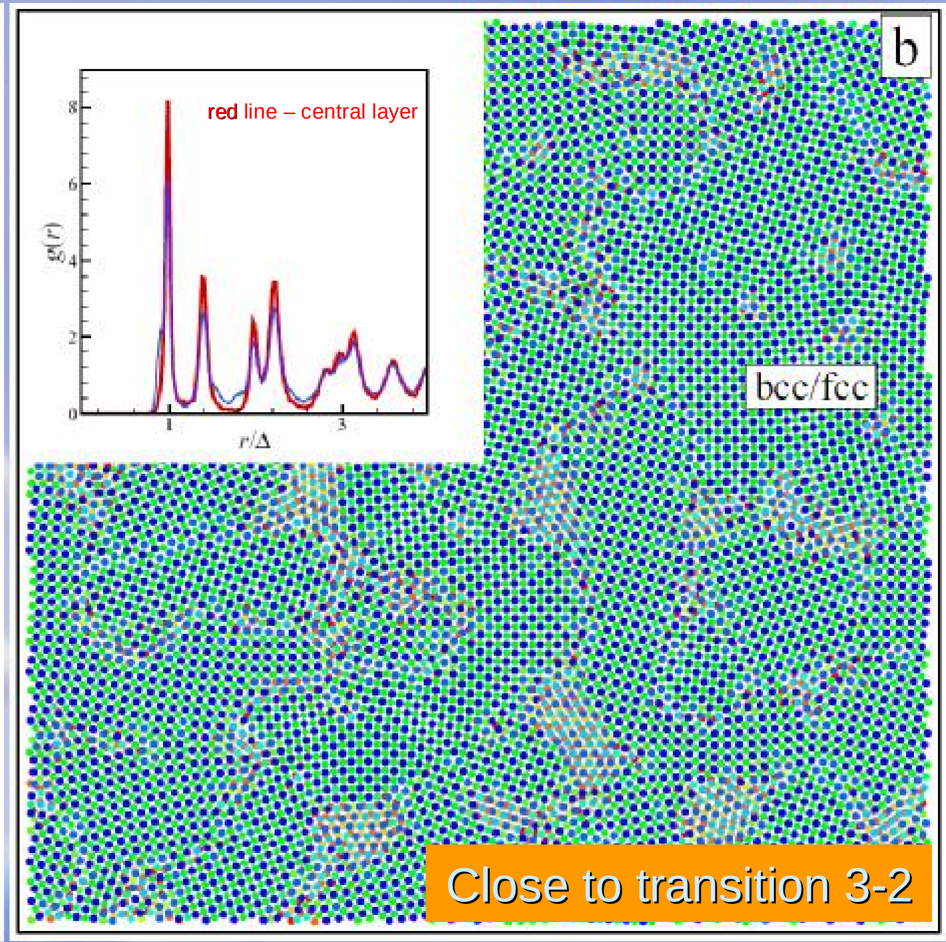
Parabolic confinement

Hard wall

1. Complex plasmas in narrow channels. MD simulations of 3-layers Yukawa system: the parabolic confinement case study

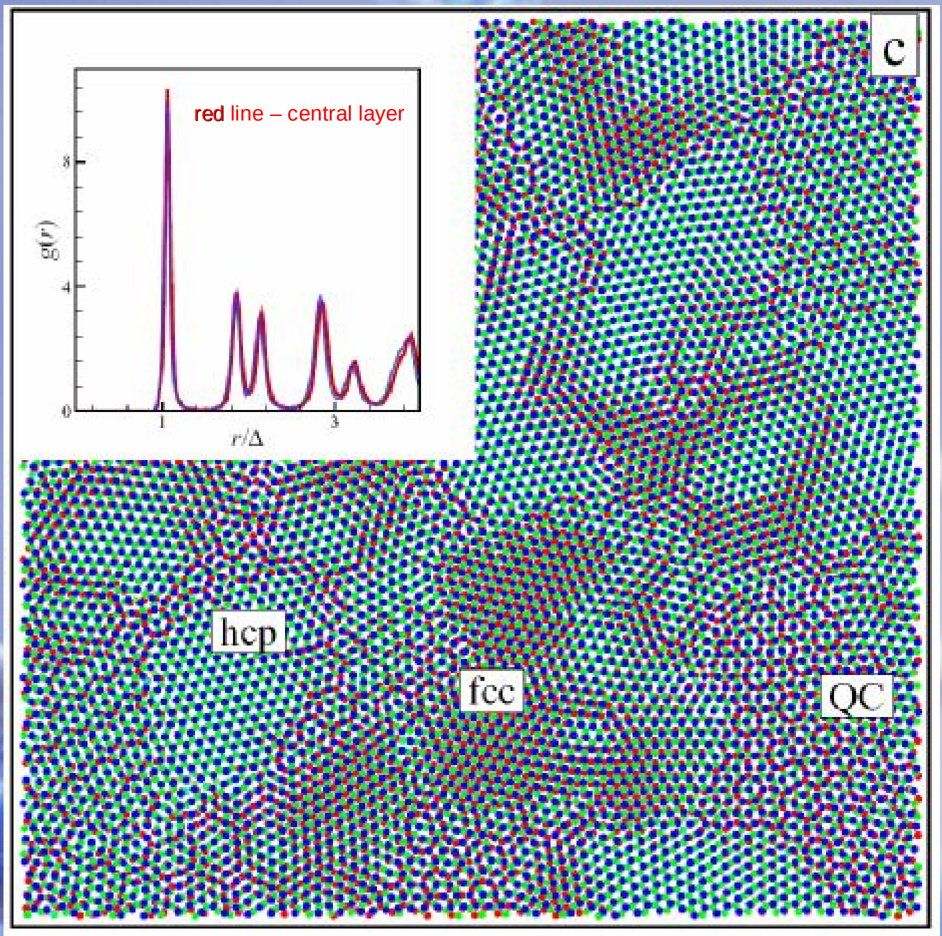
Top view : the layers are color-coded by *z*-coordinate

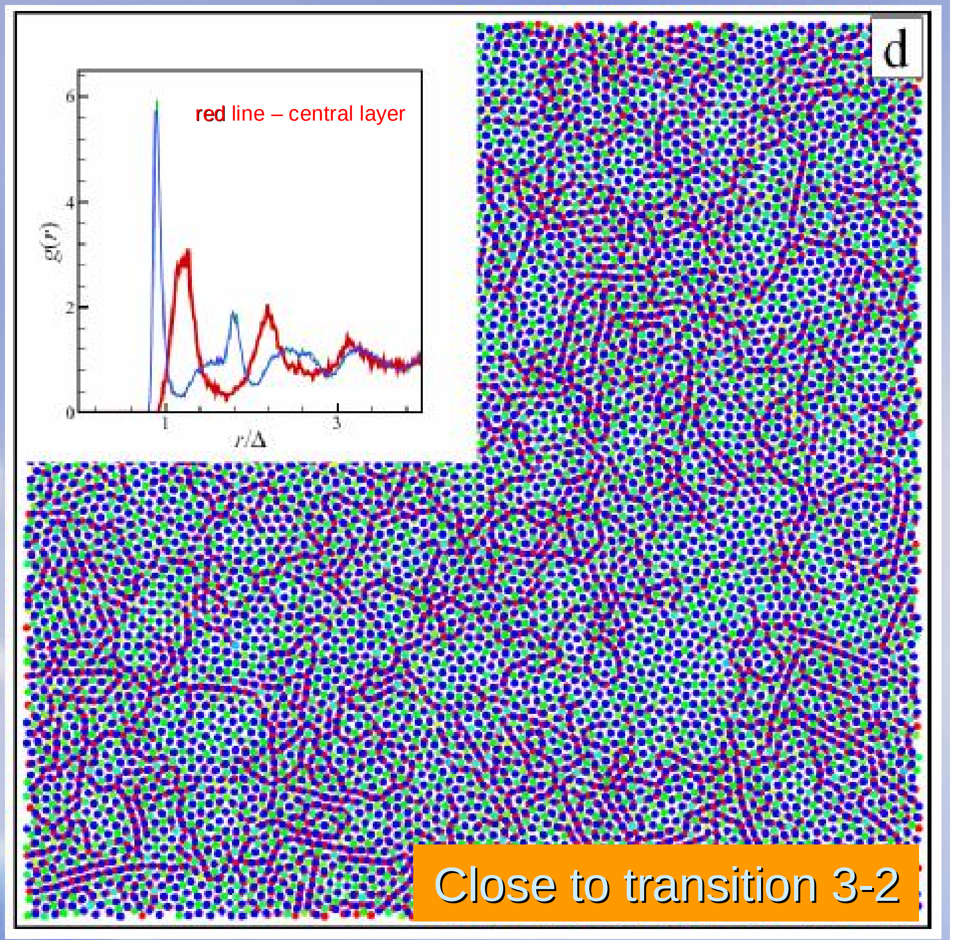




1. Complex plasmas in narrow channels. MD simulations of 3-layers Yukawa system: the hard wall confinement case study

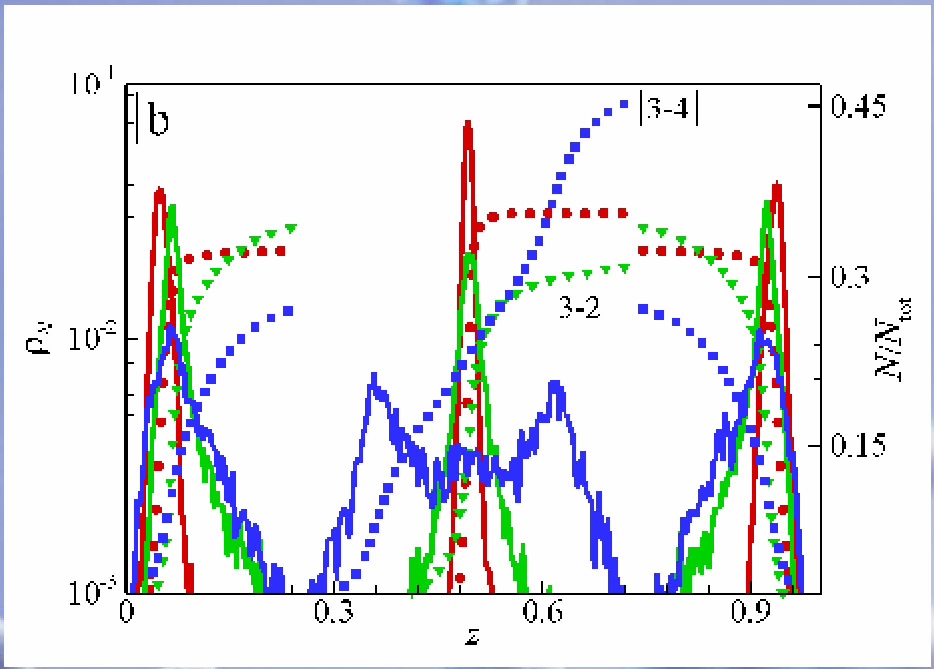
Top view : the layers are color-coded by *z*-coordinate



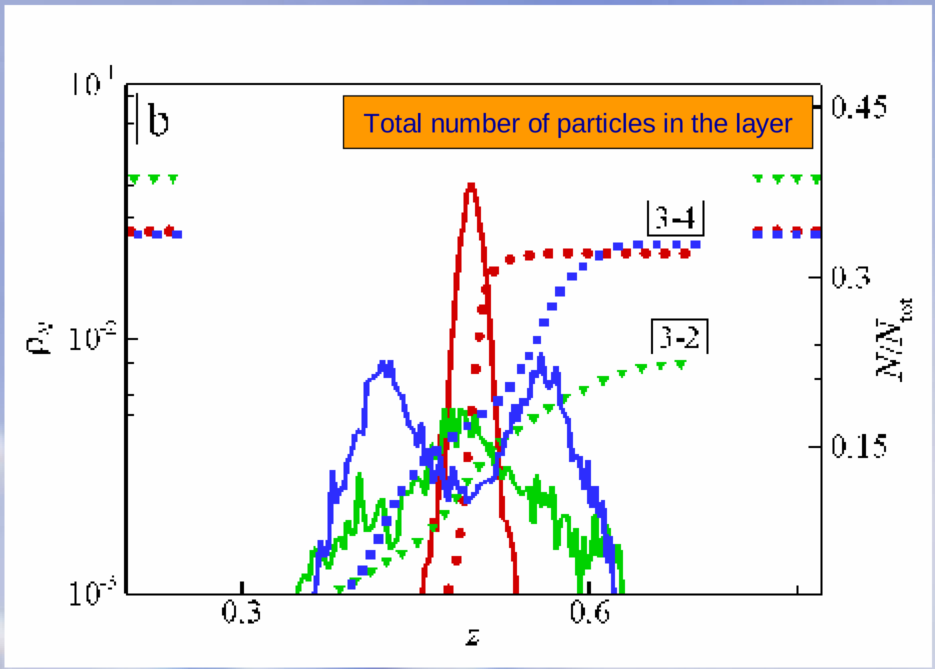


1. Complex plasmas in narrow channels. MD simulations of 3-layers Yukawa system

Particle distributions at different "wall separations"



Parabolic confinement

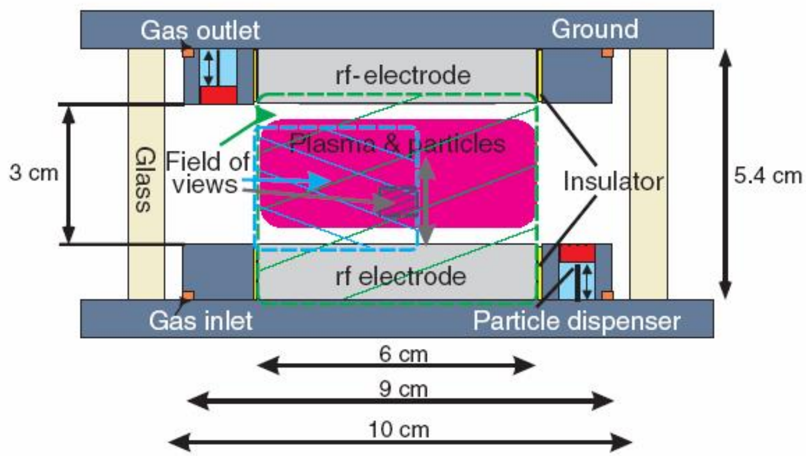


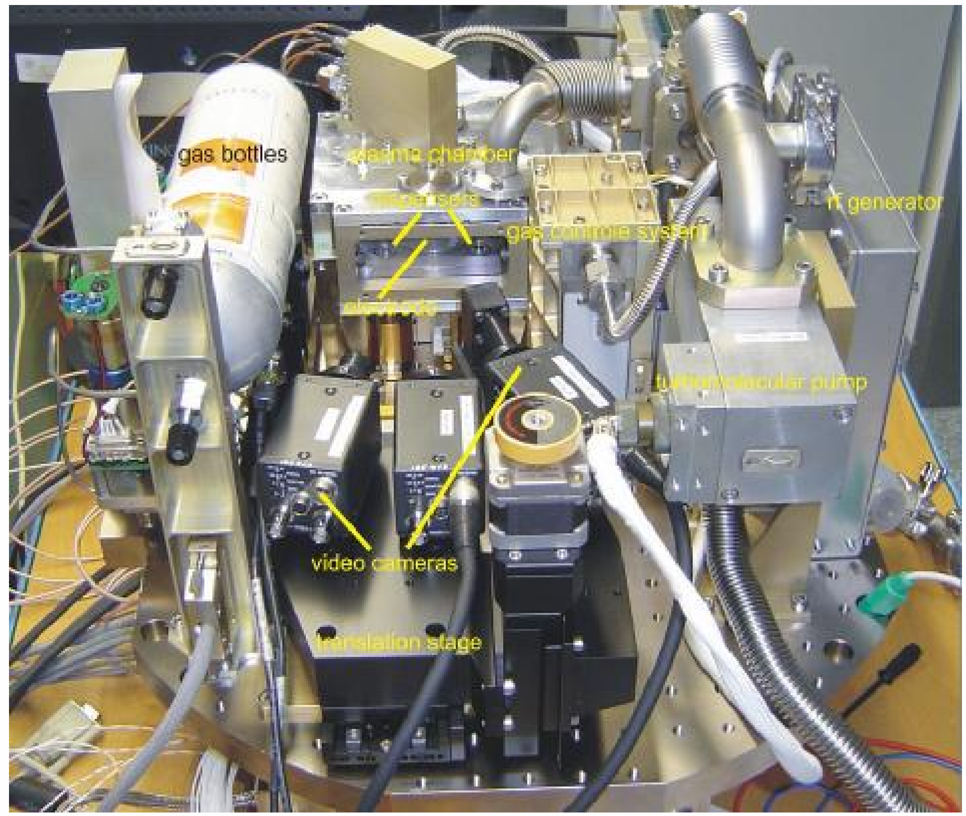
Hard wall confinement

Bifurcations of 3-layer Yukawa systems @ compression/expansion: 3-2 and 3-4 transitions

N.B. Confinement impacts strongly on the particle distribution and on the local order as well

Complex plasma laboratory PK-3 Plus onboard the International Space Station (Thomas et al., NJP, 2008)

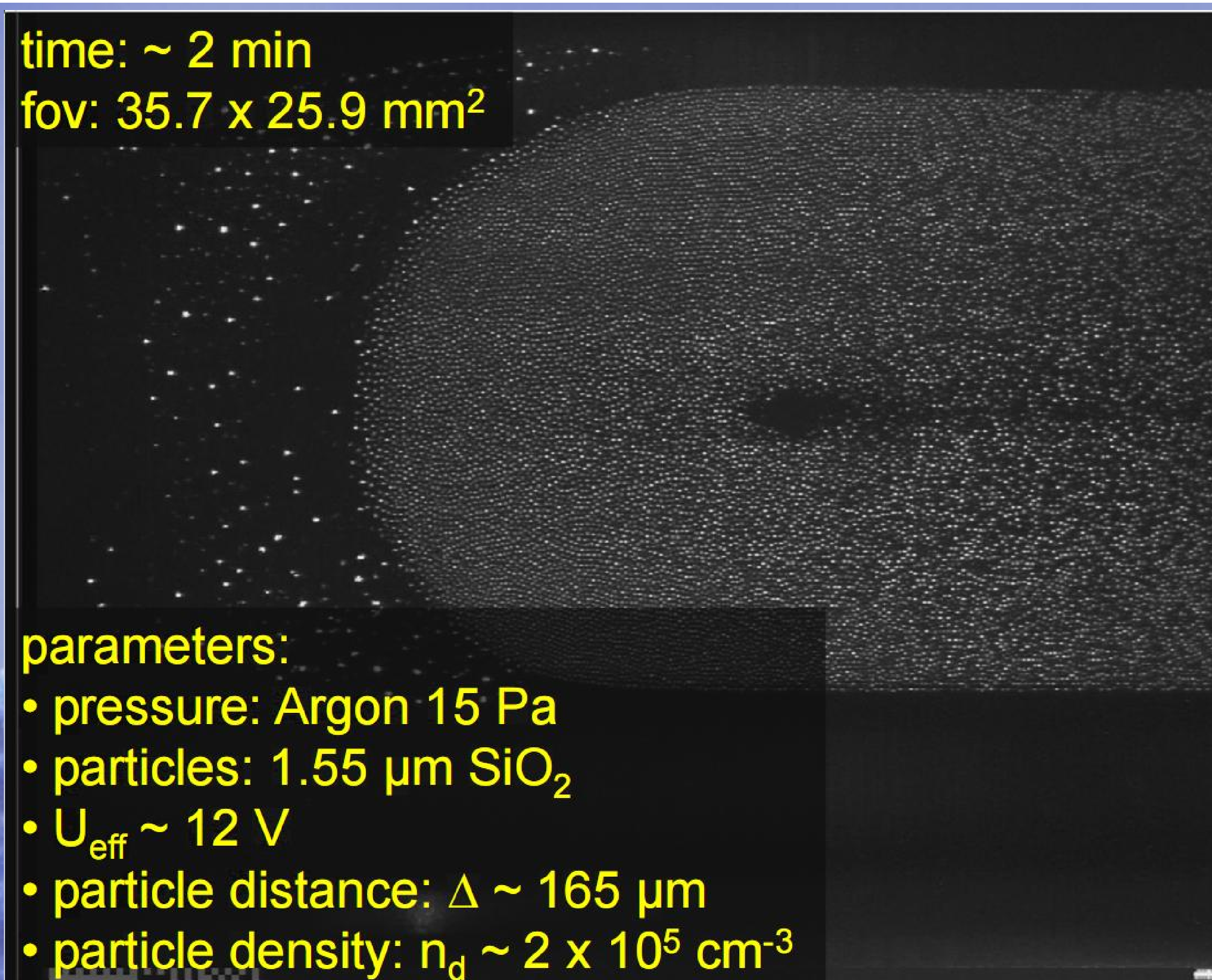




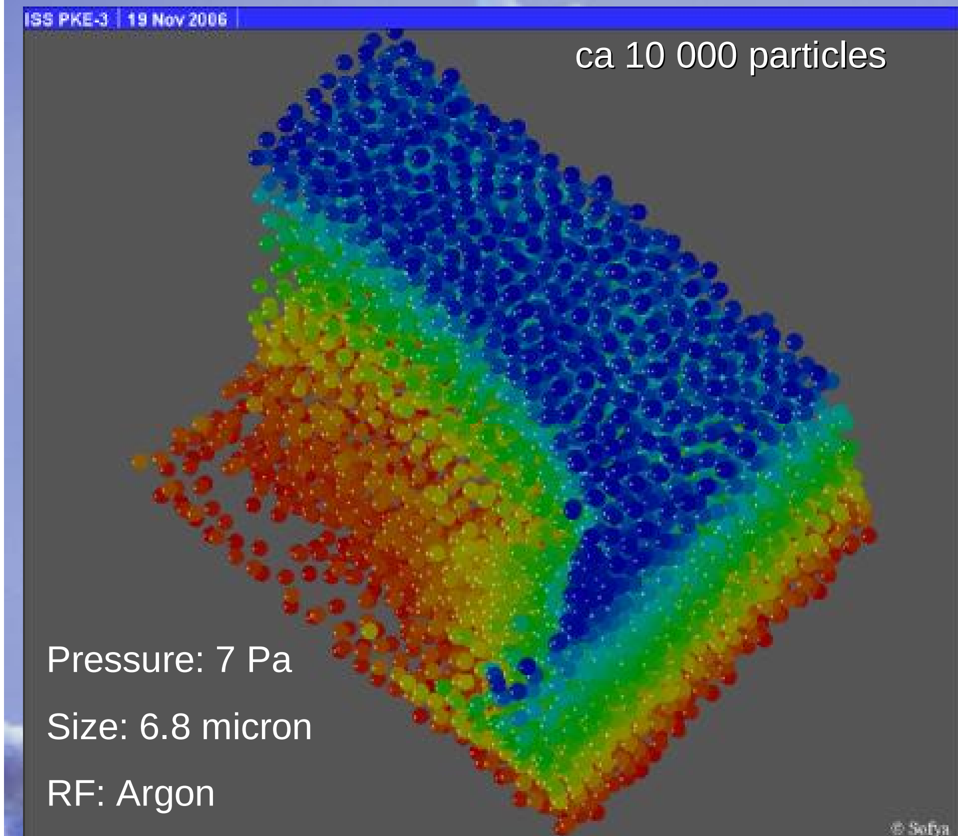
RF, argon, neon, particles: 1.55, 2.55, 3.42, 6.81, 9.19 and 14.92 μm

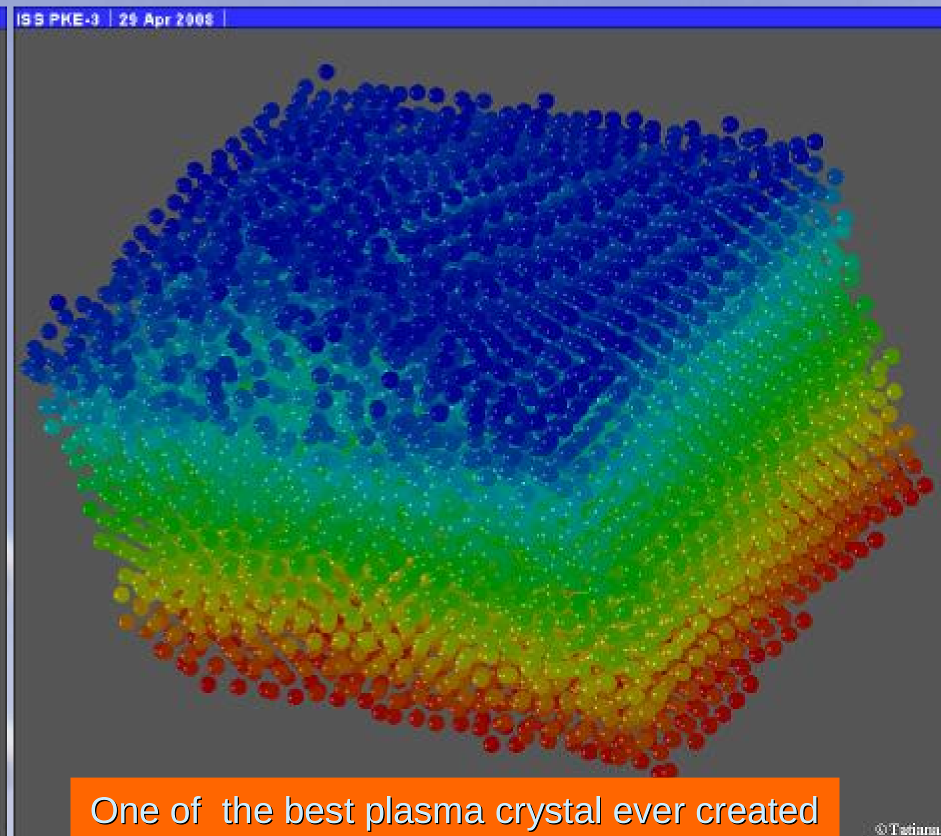
Pressure: 8 - 15 Pa

Complex plasmas @ microgravity conditions (PKE-3+, 2006-2008)



Complex plasmas @ microgravity conditions (PKE-3+, 2006-2008)

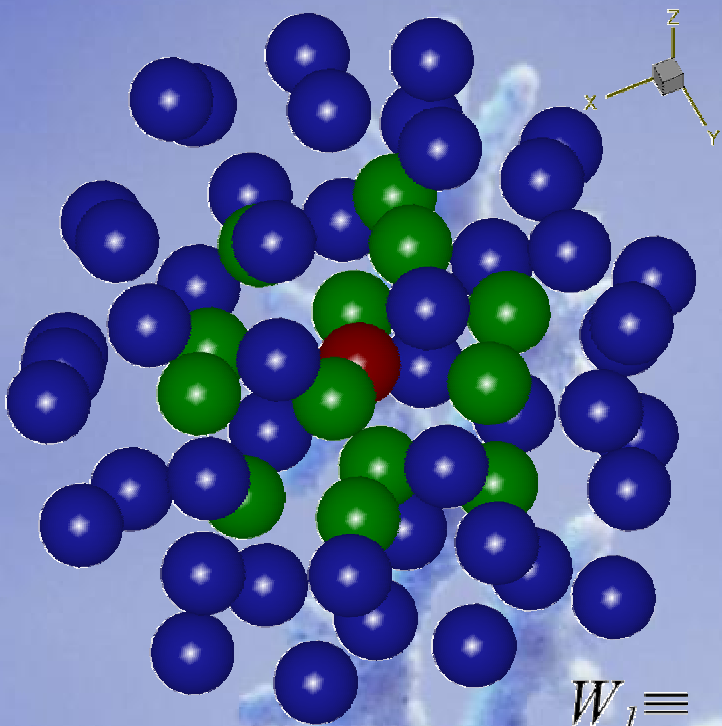




The experiments were performed onboard International Space Station.

Increasing low frequency voltage was applied to RF electrodes changing the complex plasma from glassy to crystalline state

Local order analysis: basic concepts (Steinhardt, 1983)



$$\overline{q}_{lm}(i) \equiv \frac{1}{N_b(i)} \sum_{j=1}^{N_b(i)} Y_{lm}(\hat{\mathbf{r}}_{ij})$$

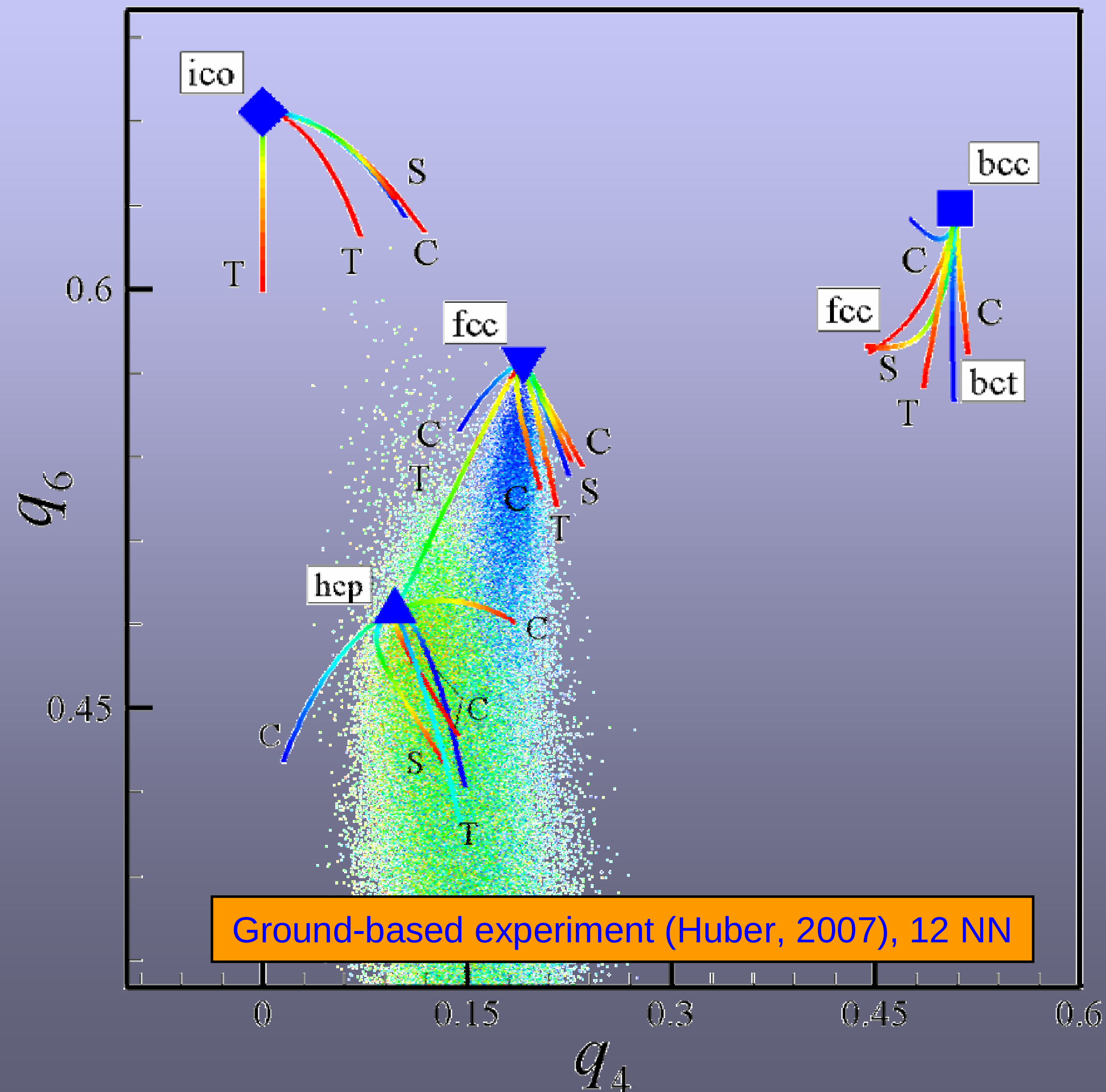
$$Q_l \equiv \sqrt{\frac{4\pi}{2l+1} \sum_{m=-l}^{l} \left|\overline{Q}_{lm}\right|^2}$$

$$W_l \equiv \sum_{\substack{m_1, m_2, m_3 \\ m_1+m_2+m_3=0}} \begin{pmatrix} l & l & l \\ m_1 & m_2 & m_3 \end{pmatrix} \overline{Q}_{lm_1} \overline{Q}_{lm_2} \overline{Q}_{lm_3}$$

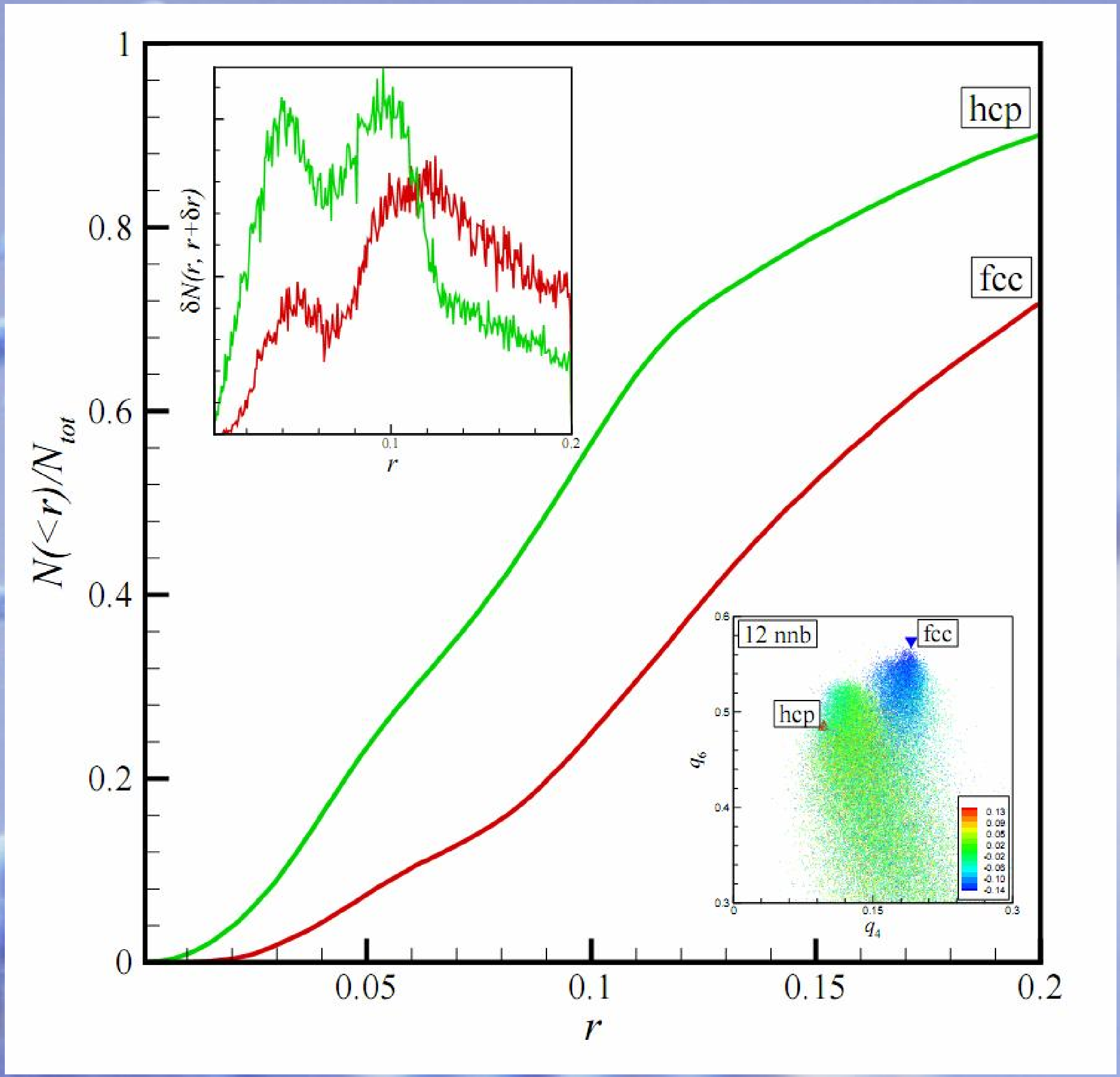
	Q_4	Q_6	$\widehat{W}_4$	$\widehat{W}_6$
fcc	0.191	0.575	−0.159	−0.013
hcp	0.097	0.485	0.134	−0.012
bcc	0.036	0.511	0.159	0.013
sc	0.764	0.354	0.159	0.013
Icosahedral	0	0.663	0	−0.170
(liquid)	0	0	0	0

Rotational invariants of various lattice types @ different distortions:

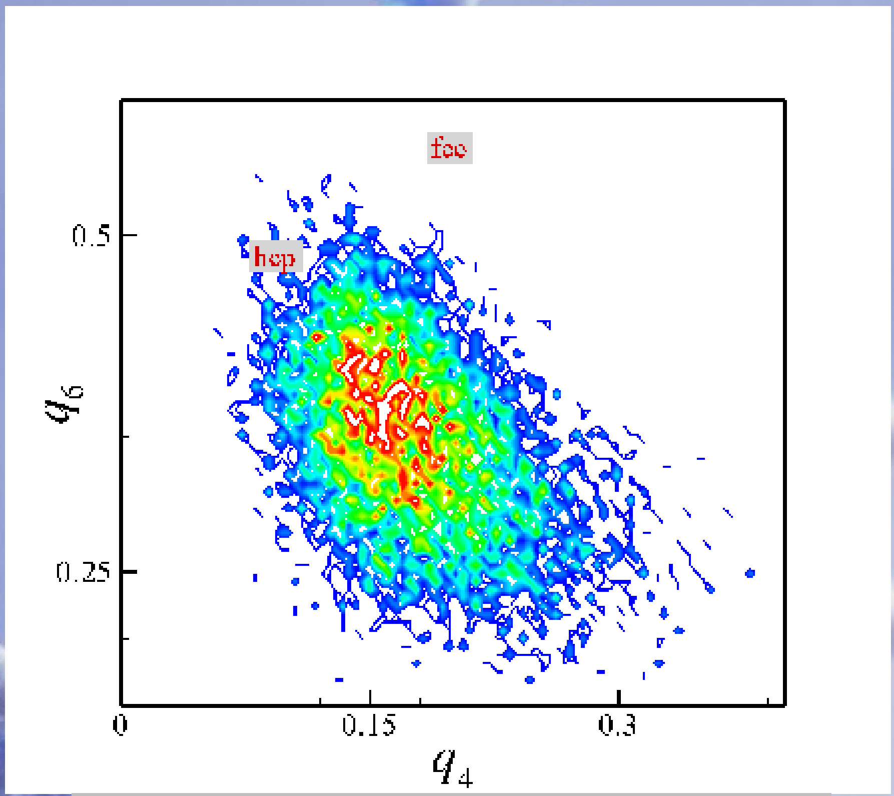
Torsion (T), Shear (S), Compression (C)



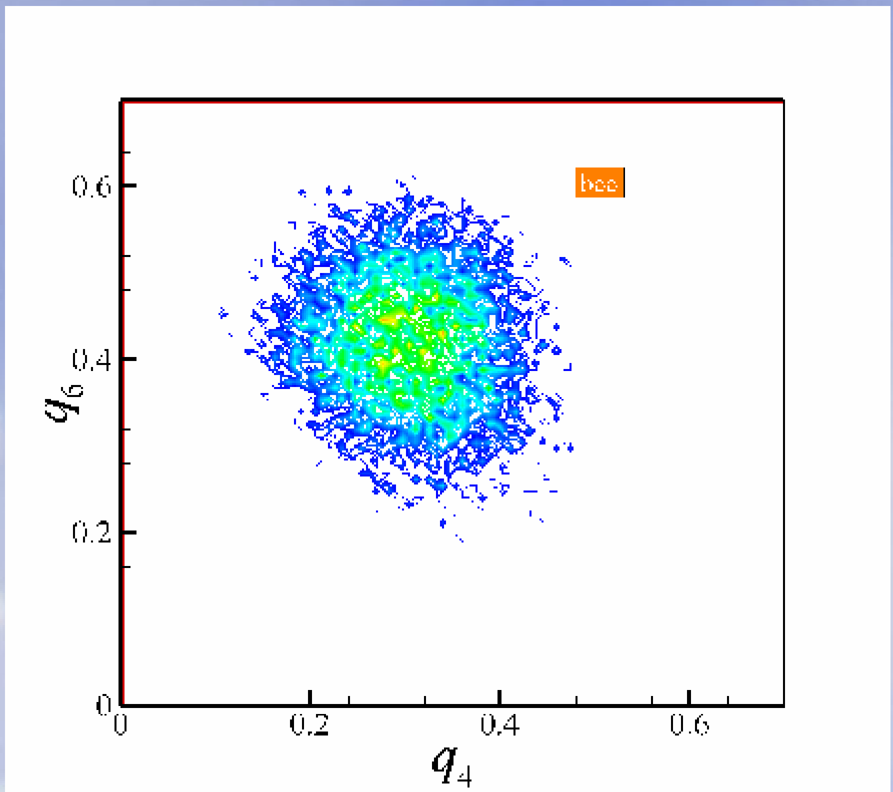
How to quantify number of crystalline-like particles



Local order analysis of 3D ISS data



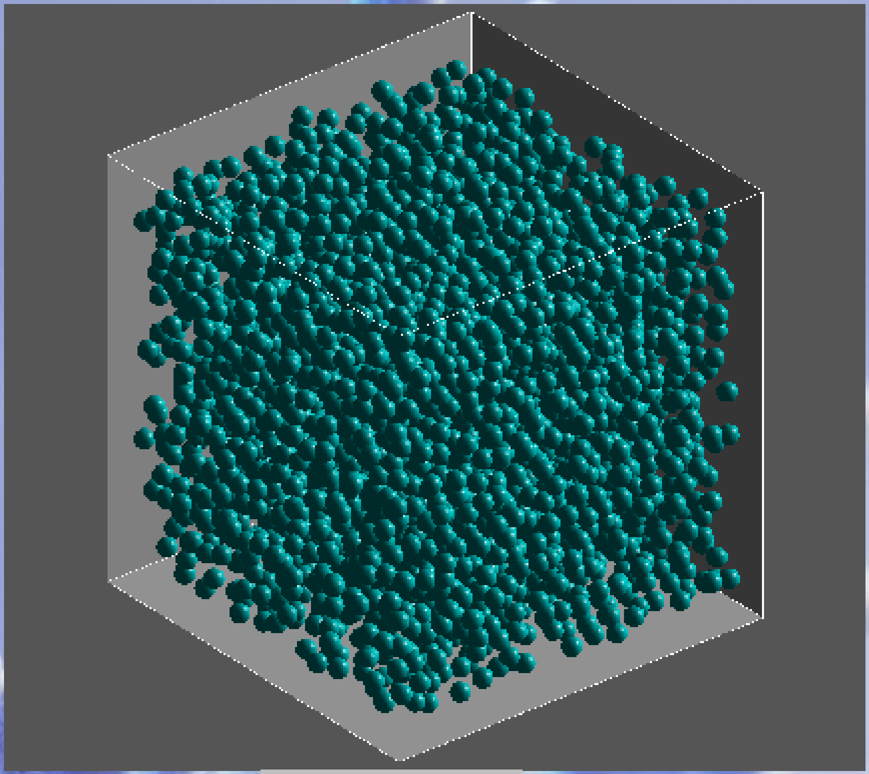
By using 12 nearest neighbors



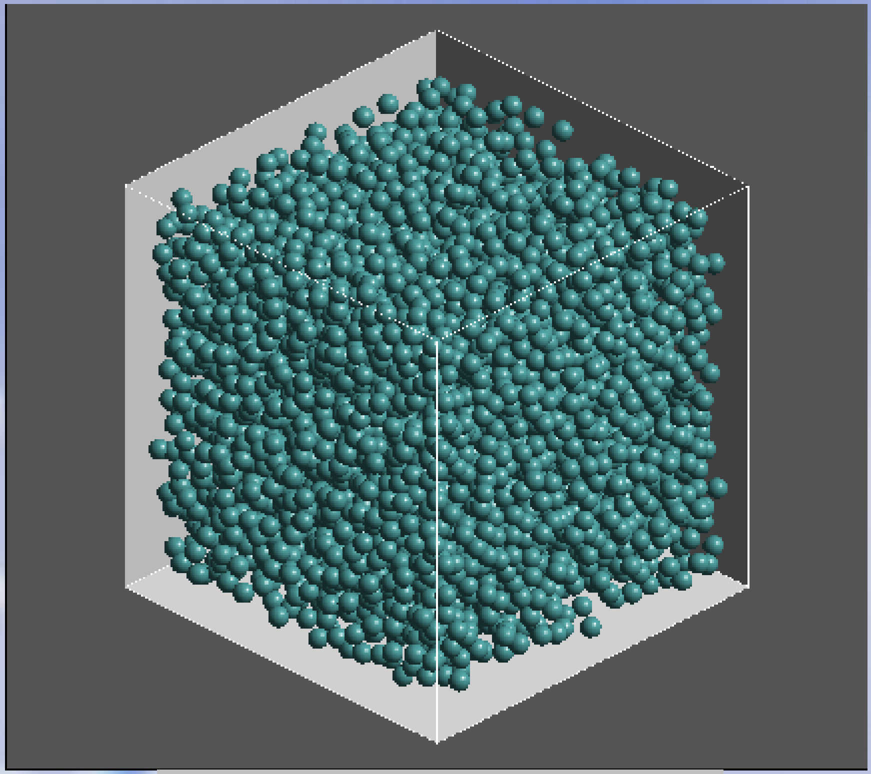
By using 8 nearest neighbors

MD simulations of Yukawa system crystallization

$$m\ddot{\mathbf{r}}_i = -Z_\mathrm{d}\nabla\Phi_\mathrm{c} - Z_\mathrm{d}\sum\nabla\phi - m\gamma\dot{\mathbf{r}}_i + \mathbf{L}_i$$

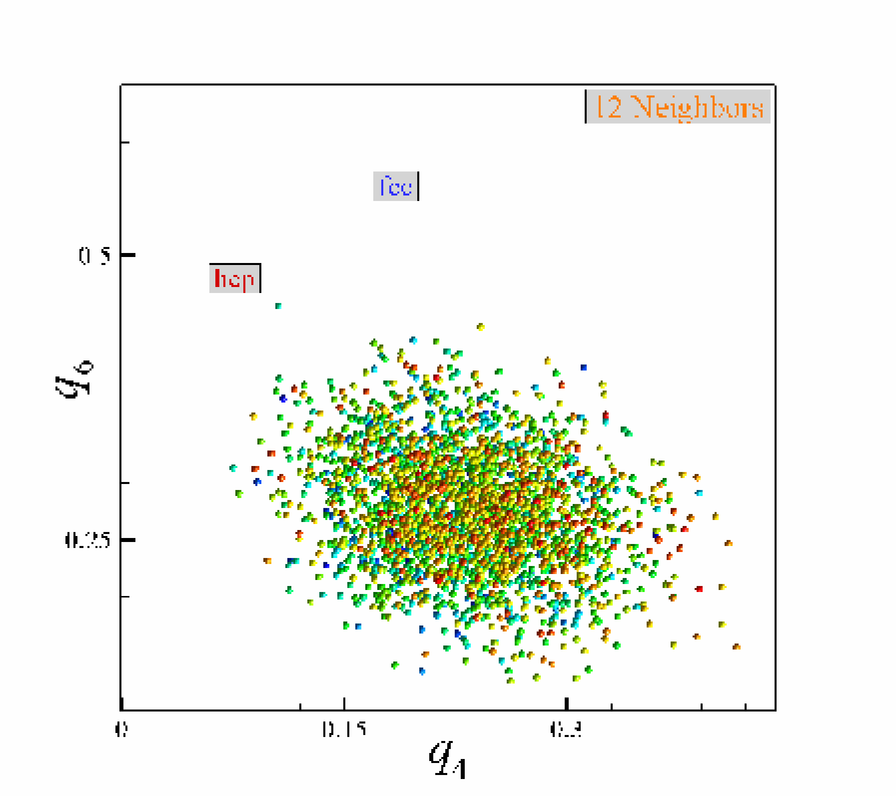


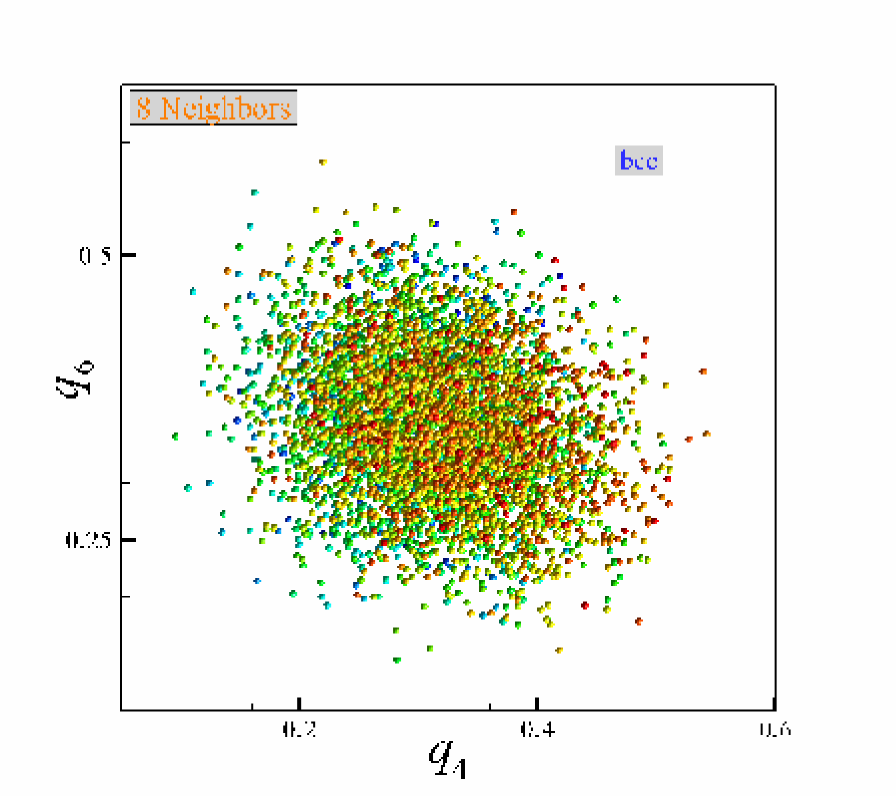
Hard wall



Parabolic confinement

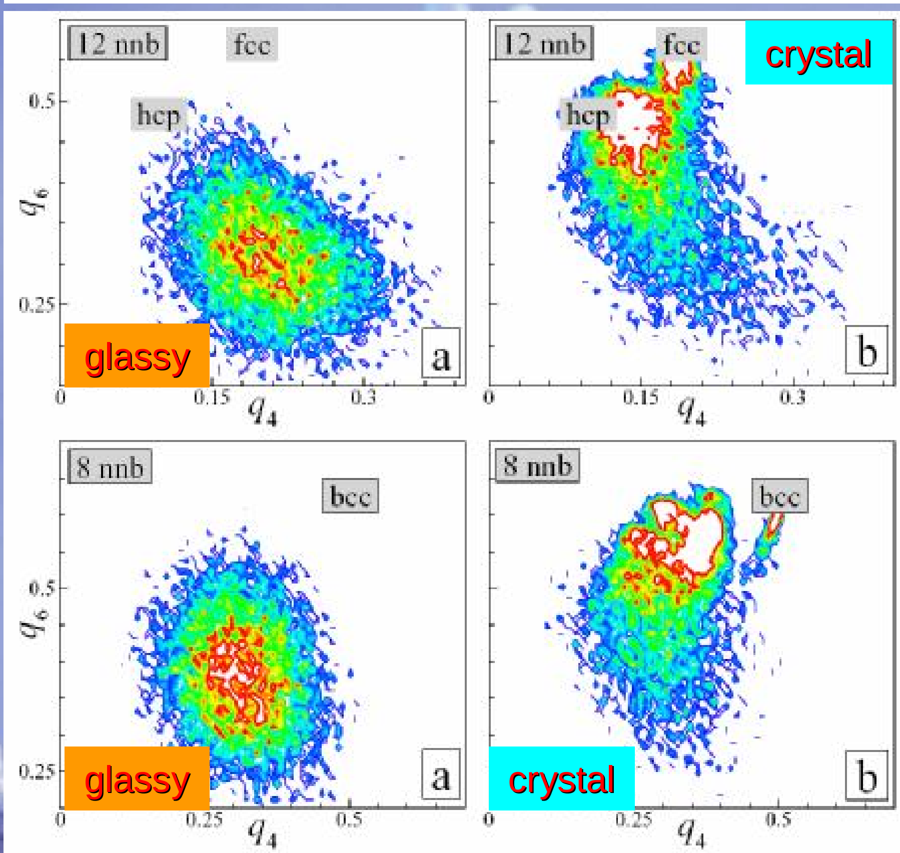
Crystallization of Yukawa system: q4-q6 plane



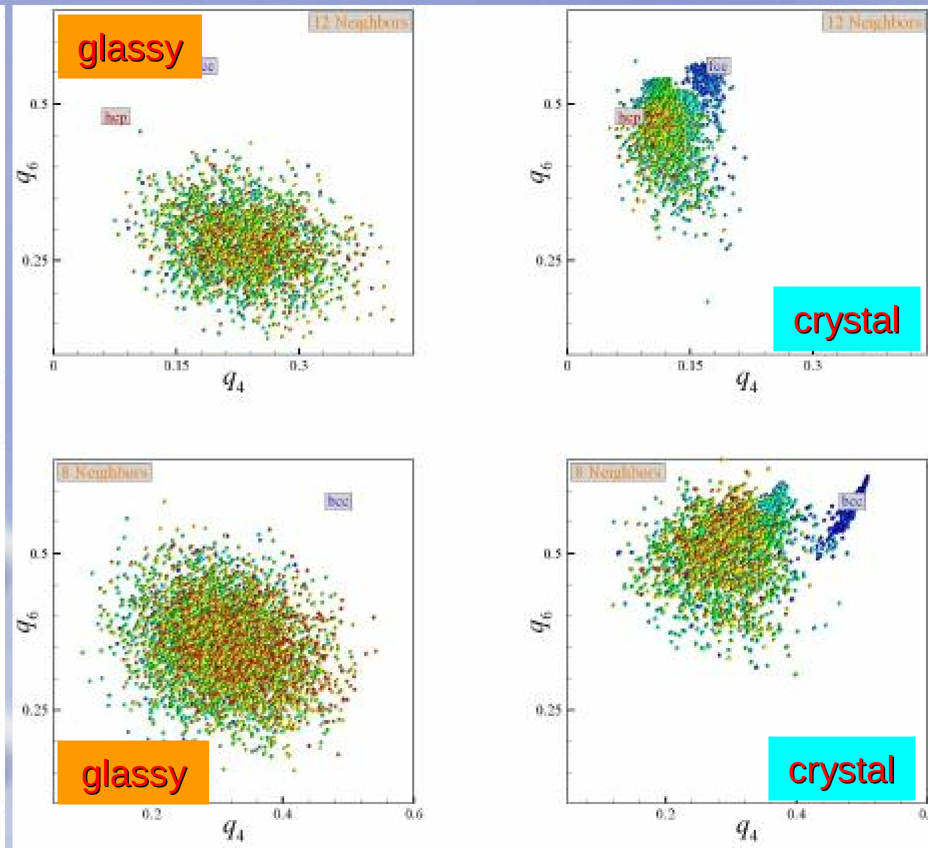


Hard wall confinement

2. Complex plasmas @ microgravity: local order analysis of electrorheological plasmas experiments (PK3+, 2007)



PKE-3 Plus (2007)

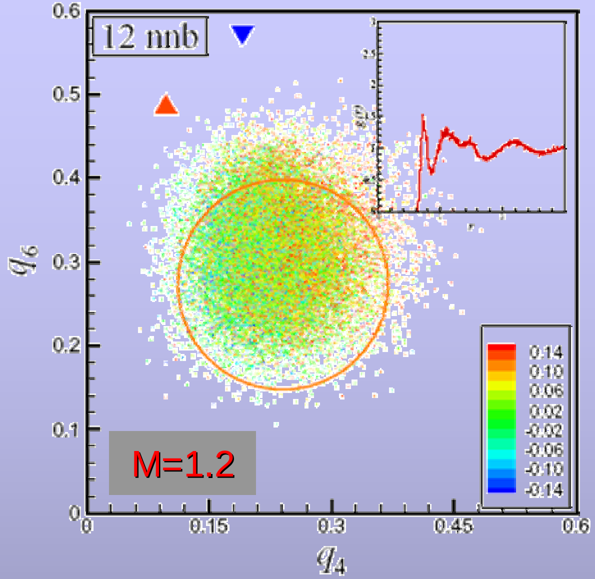


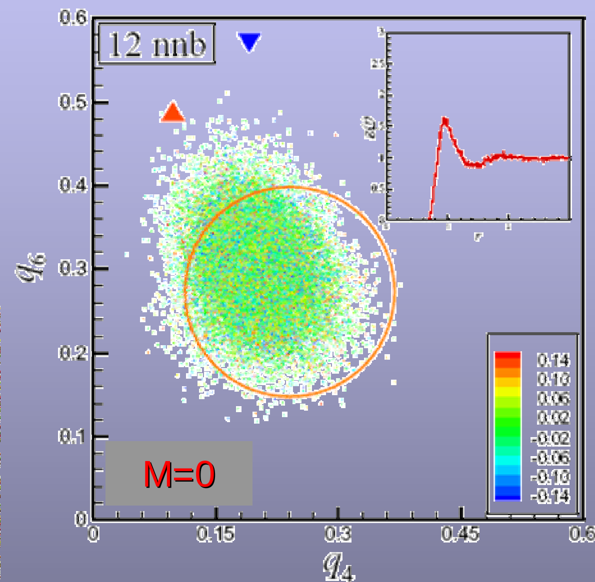
MD simulations (hard wall)

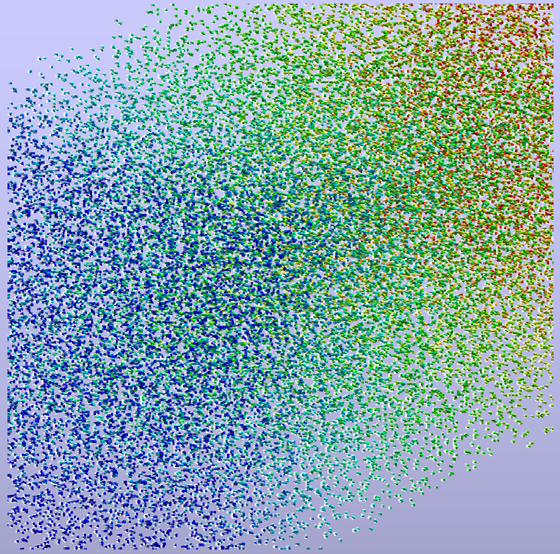
N.B. Observed local order is reproduced remarkably well by a simple Yukawa system !

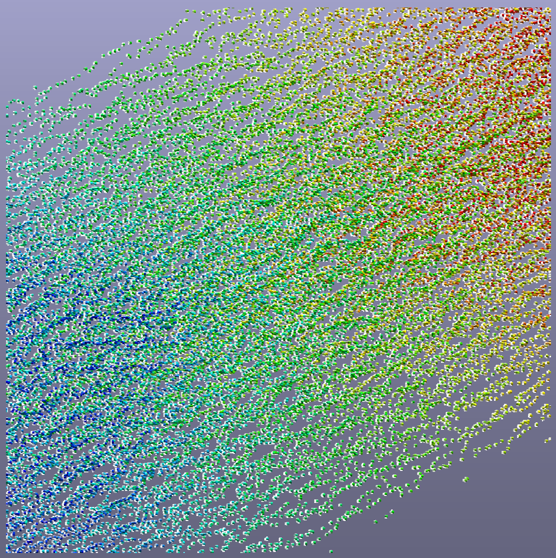
Dust particles with supersonic ion flow (Yukawa + wake potential)

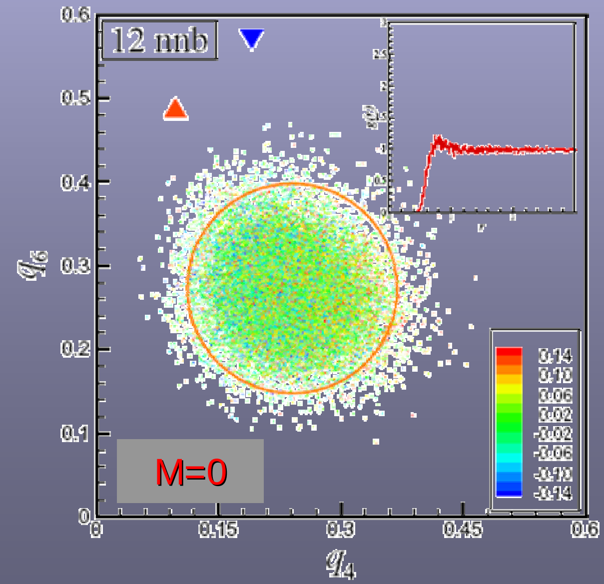
(G. Joyce, 2008)



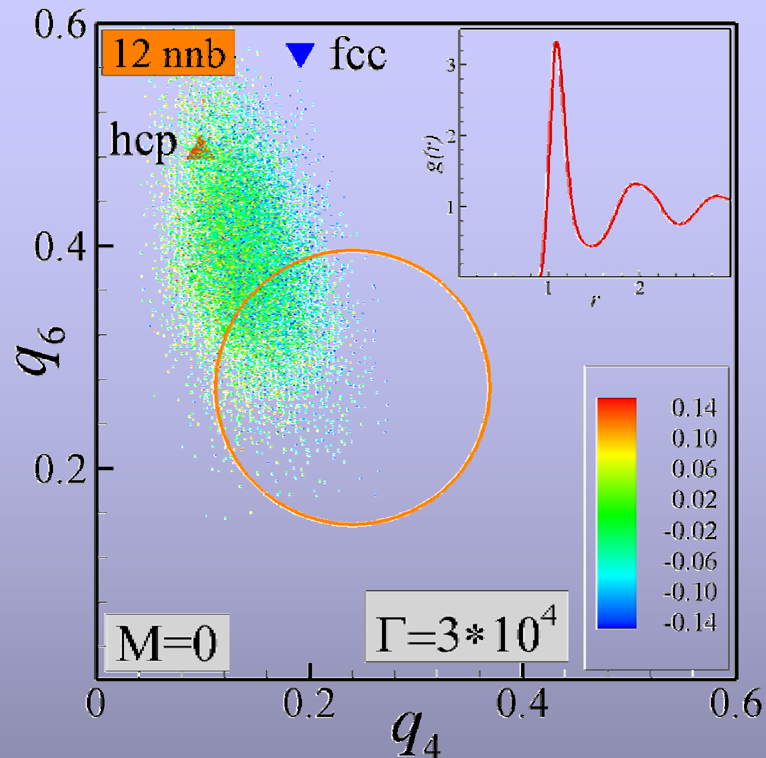


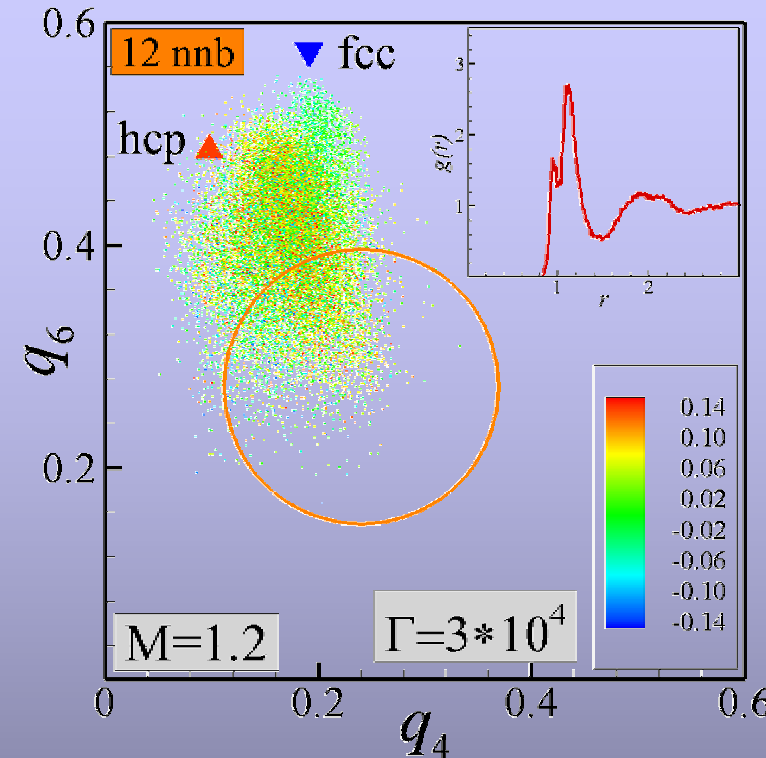


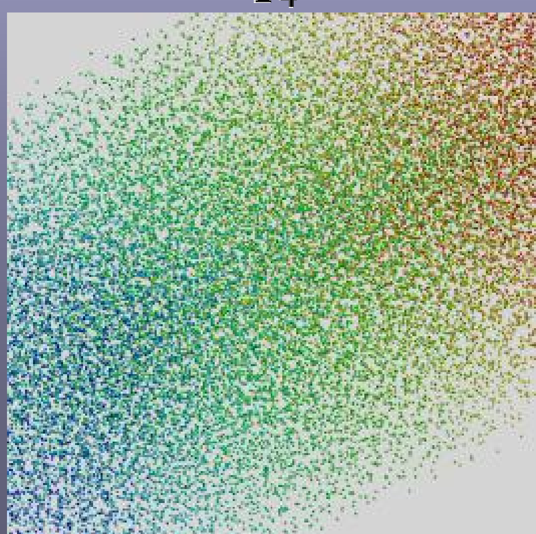


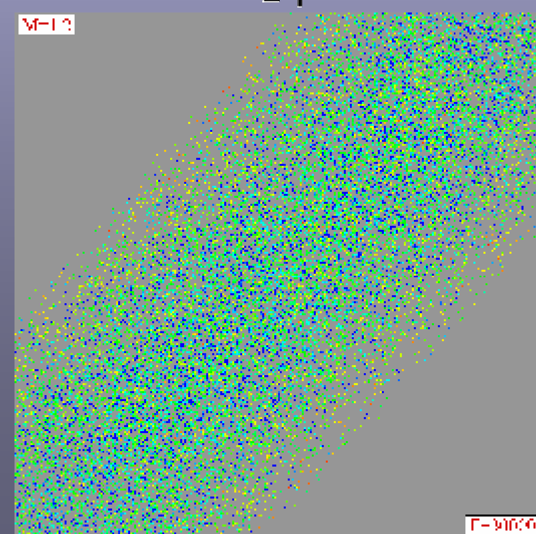


Dust particles with supersonic ion flow (Yukawa + wake potential)







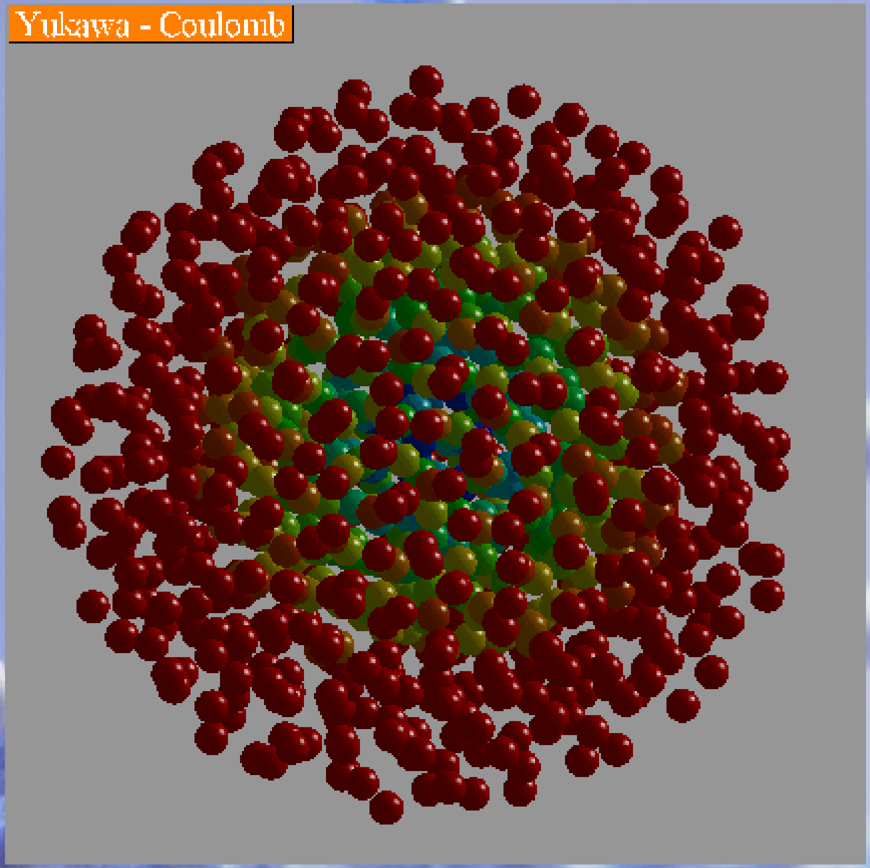


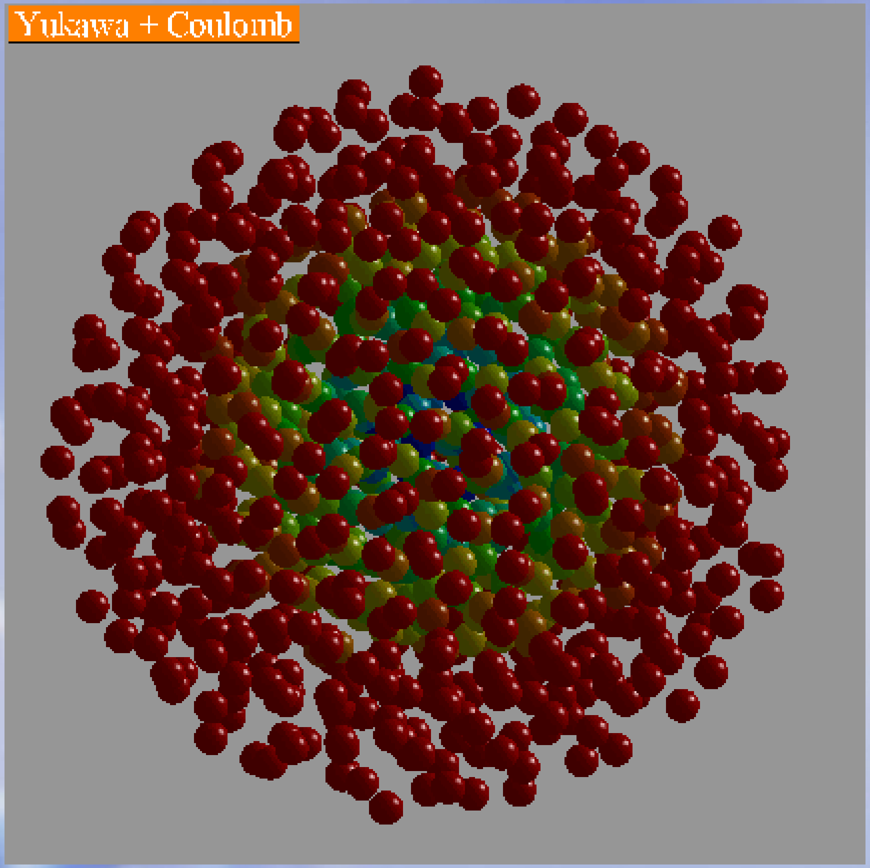
Interparticle potentials: typical lattice types

Yukawa (DH)	$\phi(r) = (Q/r)\exp(-r/\lambda)$	hcp/fcc/bcc
LJ	$v_{\mathrm{LJ}}(r_{ij}) = 4\varepsilon\left[\left(\frac{\sigma}{r_{ij}}\right)^{12} - \left(\frac{\sigma}{r_{ij}}\right)^{6}\right]$	hcp/fcc/bcc/ico
Lennard-Jones-Gauss	$V(r) = \varepsilon\left\{\left(\frac{\sigma}{r}\right)^{12} - 2\left(\frac{\sigma}{r}\right)^{6} + \varepsilon_0 \exp\left[-\frac{(r-r_0)^2}{2\sigma_0^2}\right]\right\}$	QC
Dzugutov	$V(r) = A(r^{-m} - B)\exp\left(\frac{c}{r-a}\right)\Theta(a-r) + B\exp\left(\frac{d}{r-b}\right)\Theta(b-r)$	QC

Anisotropic: Yukawa + wake, etc: hcp/fcc/bct/bco….?

Collisional ions in complex plasmas: impact on inter particle potential (Khrapak et al, PRL, 2008)






THANK YOU