Max-Planck-Institut für extraterrestrische Physik

Complex plasmas in 3D: narrow channels, local order and beyond

B. A. Klumov, P.Huber, G. Morfill

Workshop on the Non-ideal Plasma Physics

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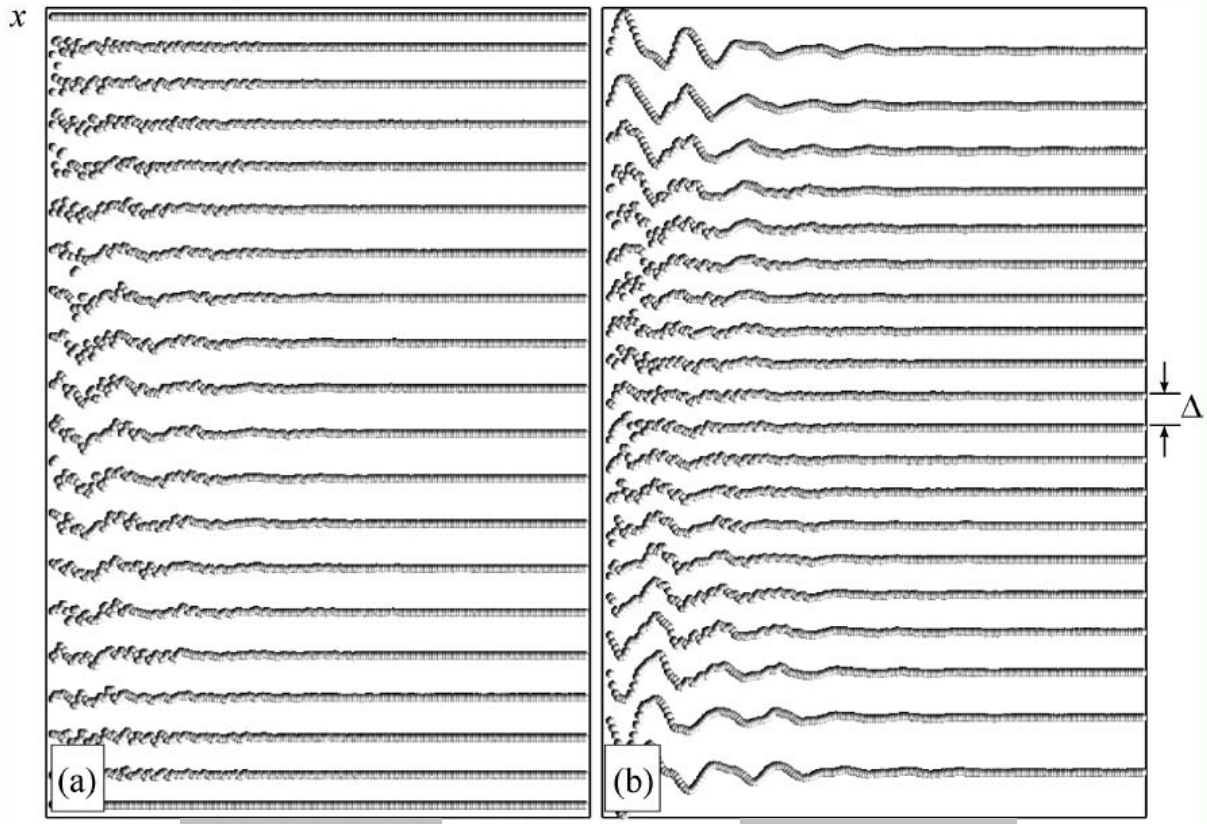
1D Yukawa system @ different confinements

$$m\ddot{\mathbf{r}}_i = -Z_d \nabla \Phi_c - Z_d \sum \nabla \phi - m\gamma \dot{\mathbf{r}}_i + \mathbf{L}_i$$



Hard wall

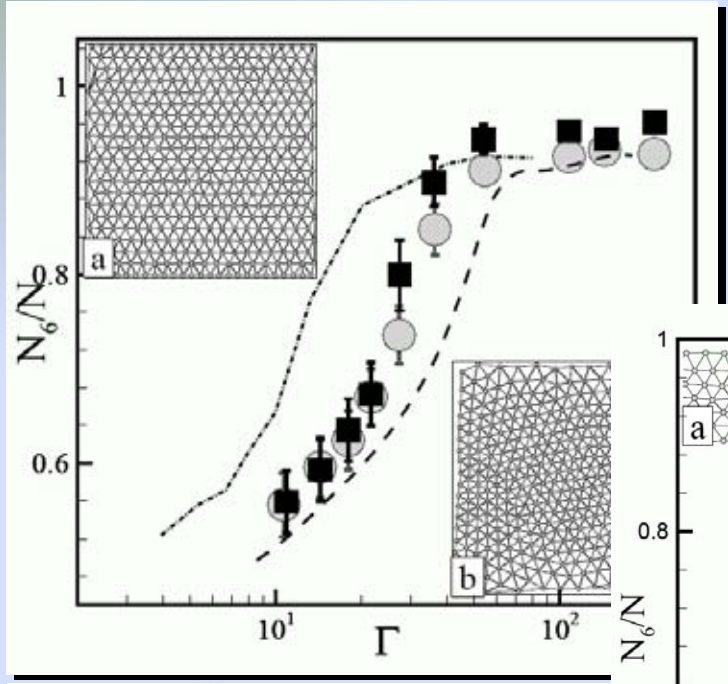
Parabolic

Different dependencies of inter particle distance versus *x* at steady-state

Local order of 2D Yukawa system for a few aspect ratios (Klumov and Morfill, JETPL, 2007)

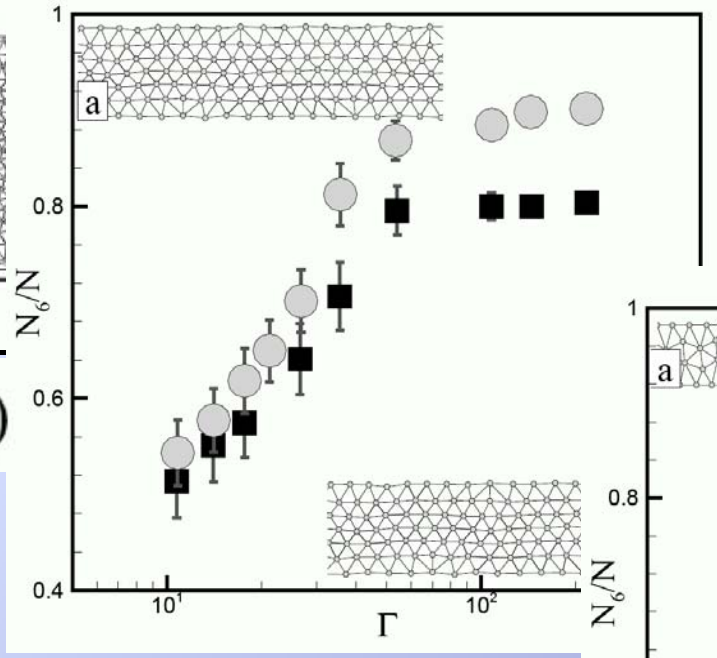
$$\varphi(r) = (Ze/r)\exp(-r/\lambda_D)$$

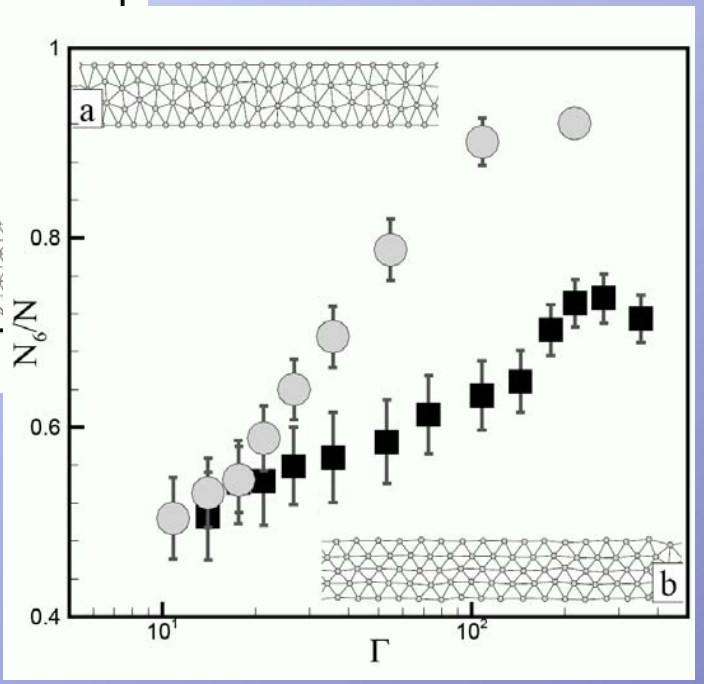
decrease the "wall" separation



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

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

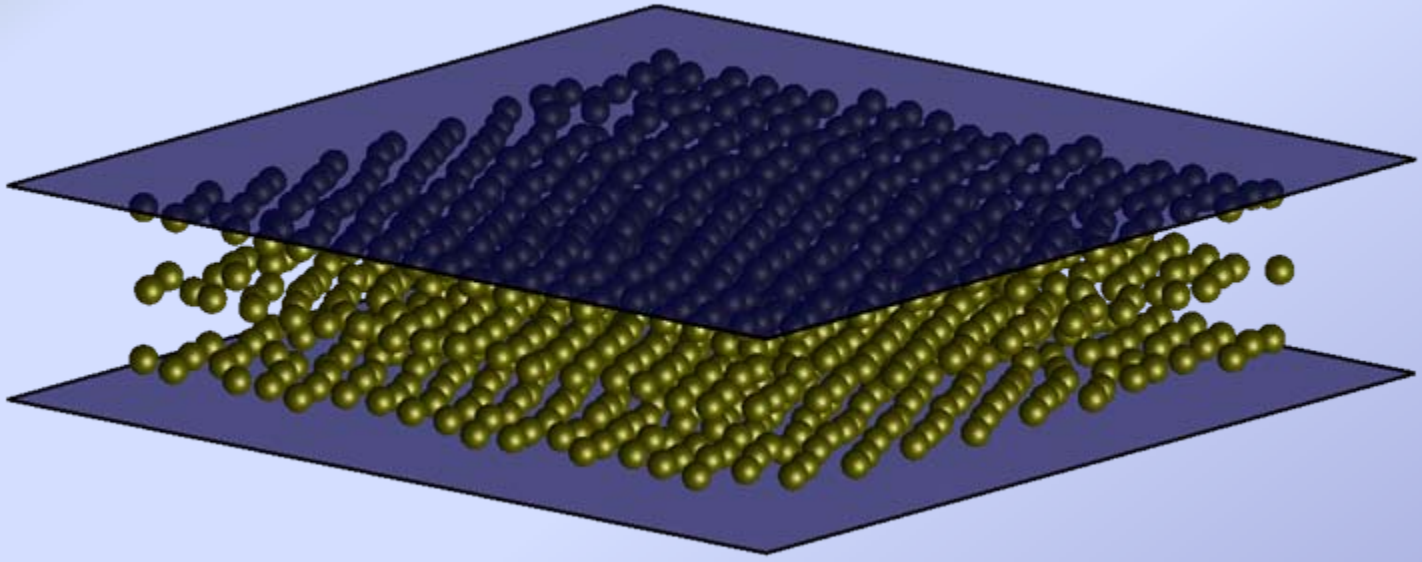




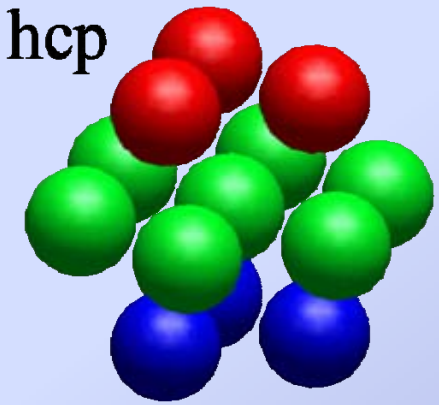
Hard wall

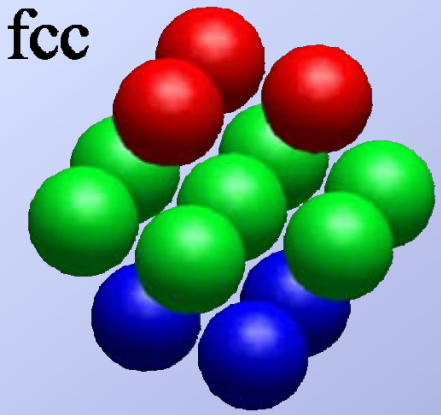
Parabolic

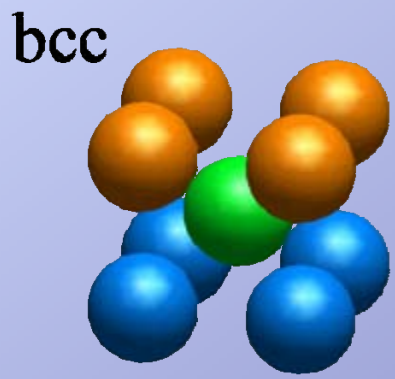
Local order of 3D Yukawa system in narrow channel (Klumov, Morfill, JETPL, 2007)

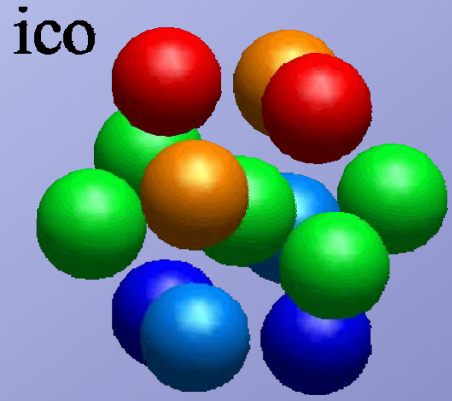


Periodic boundary conditions (x, y) + confinement (z)

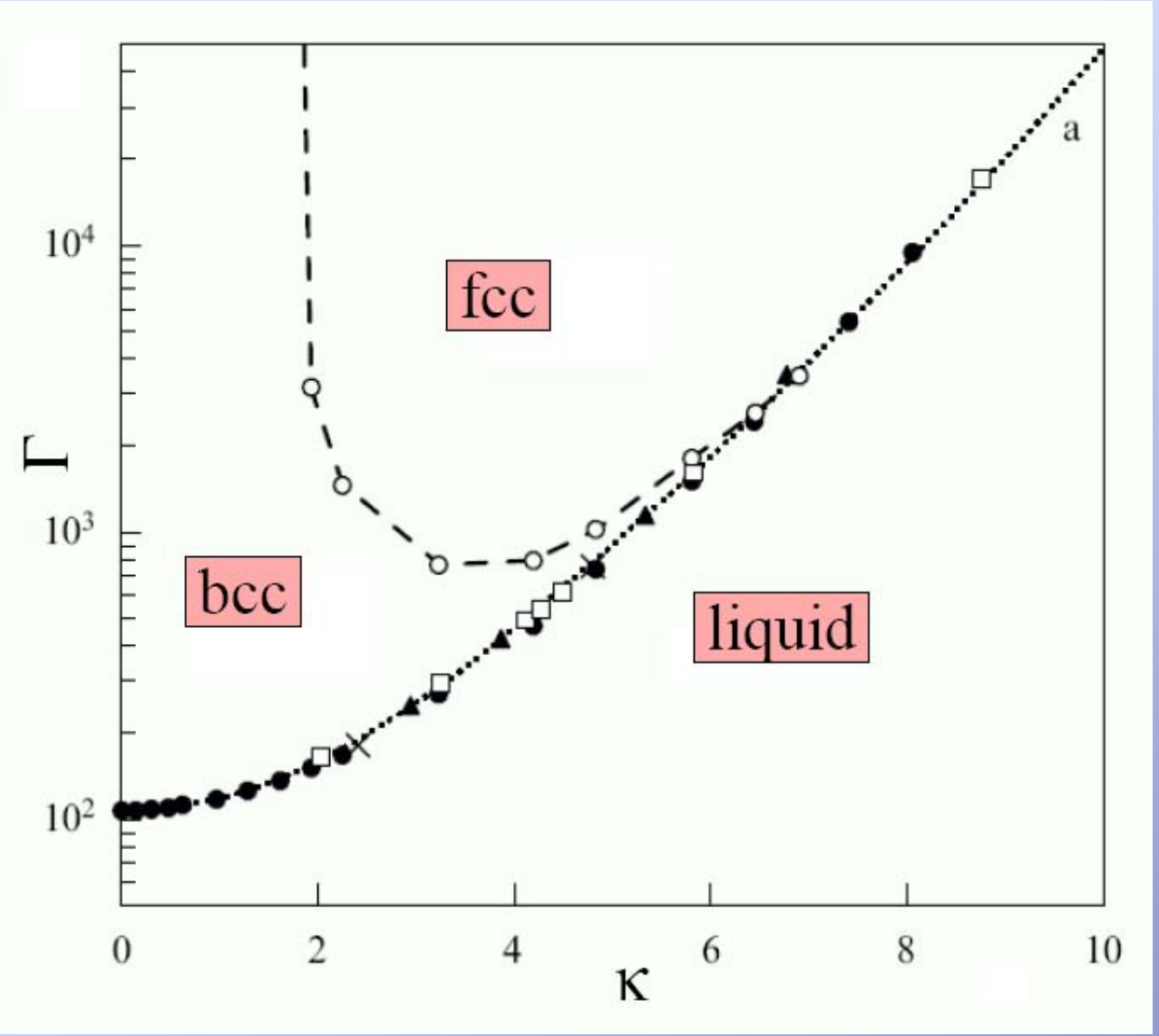


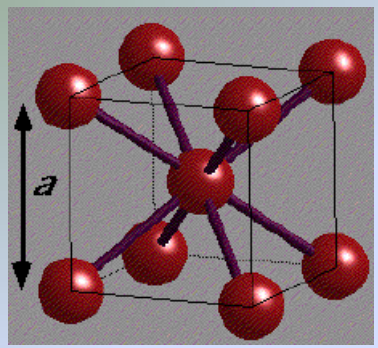


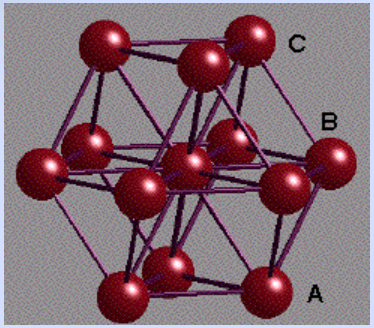


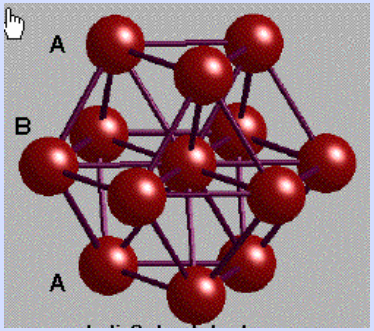


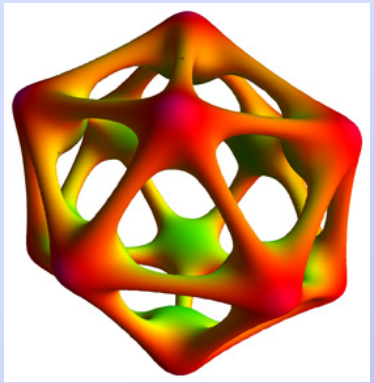
Yukawa system + PBC: equilibrium lattice types





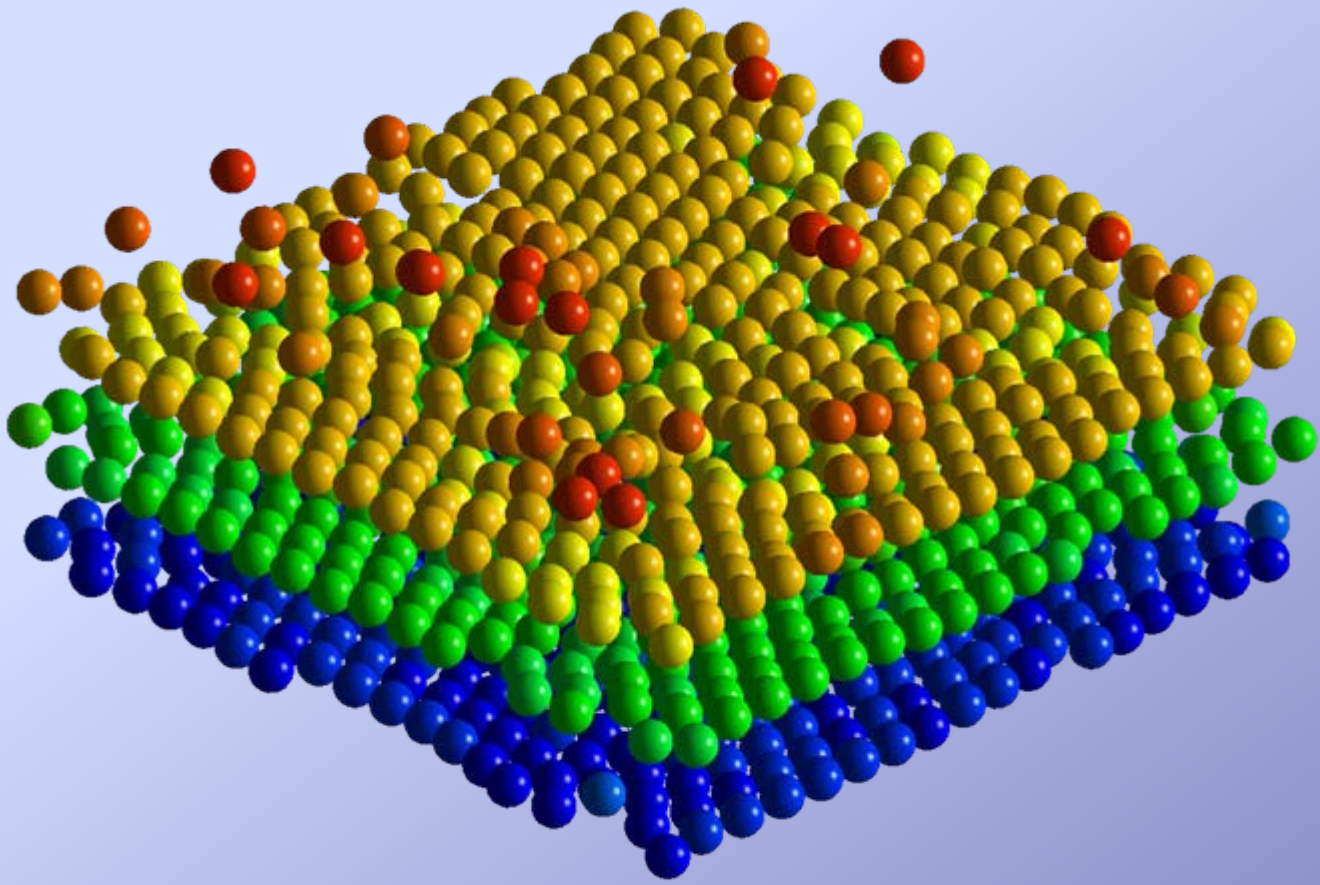






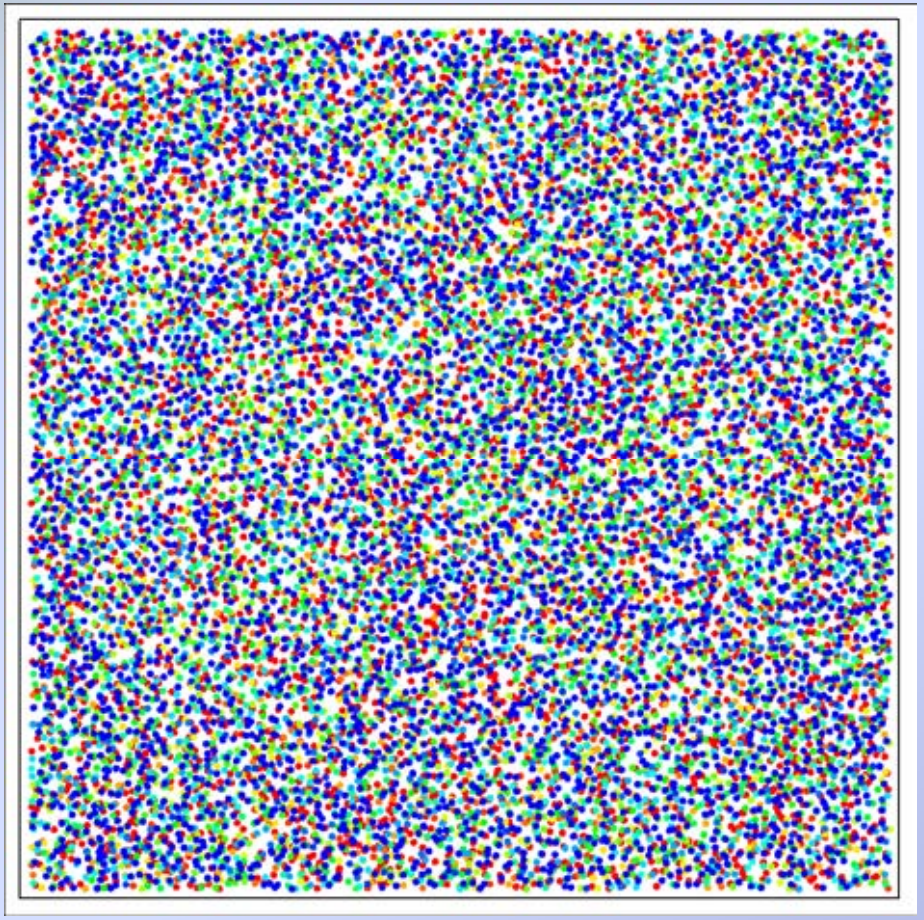
Local order of 3D system of particles

Three adjacent layers can be used to identify CCP lattice types

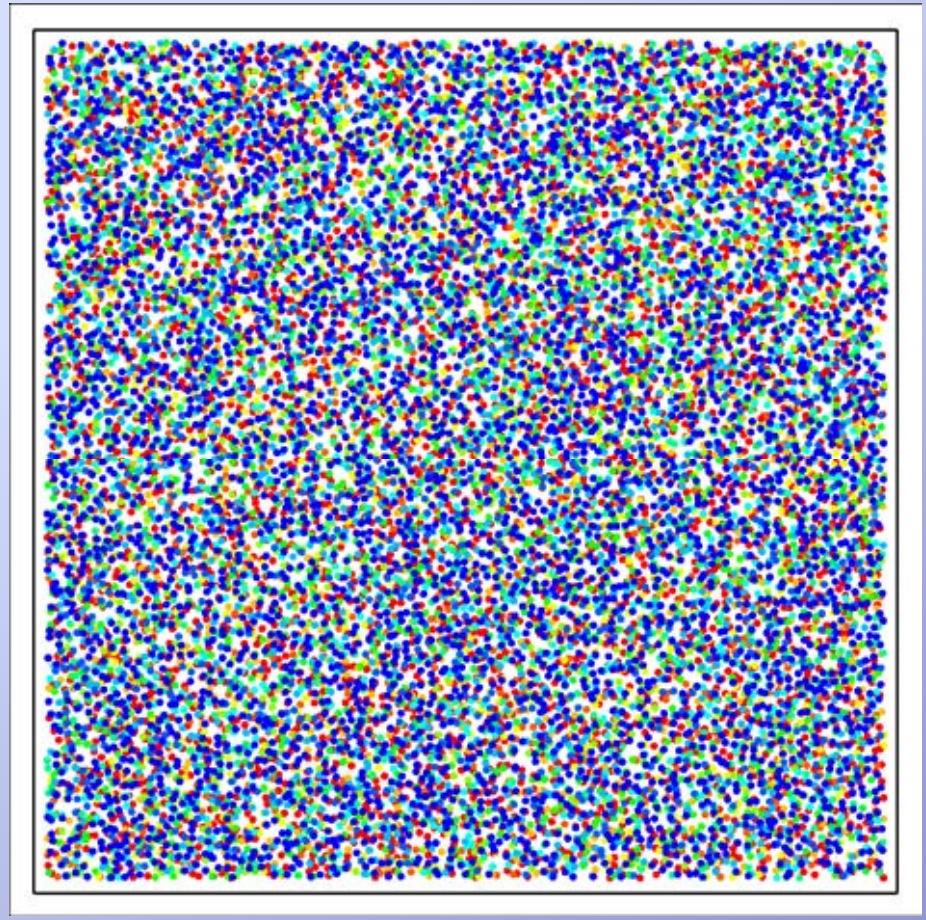


3D Yukawa system in narrow channel: MD simulations

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



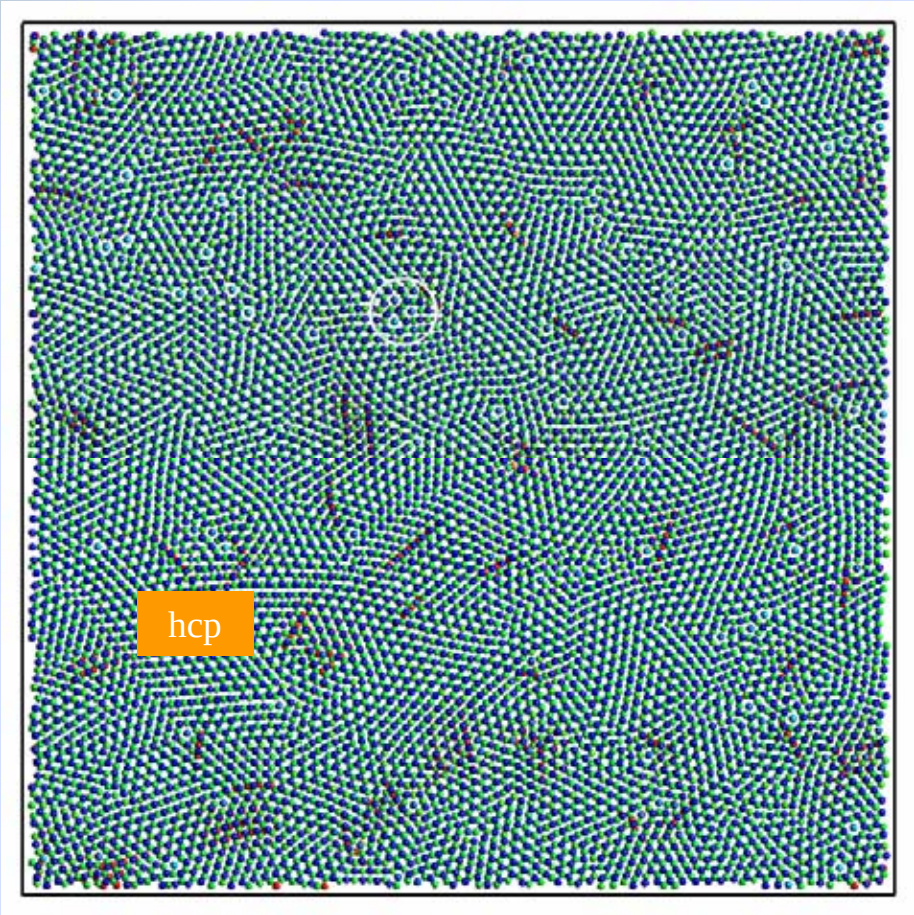
Parabolic confinement



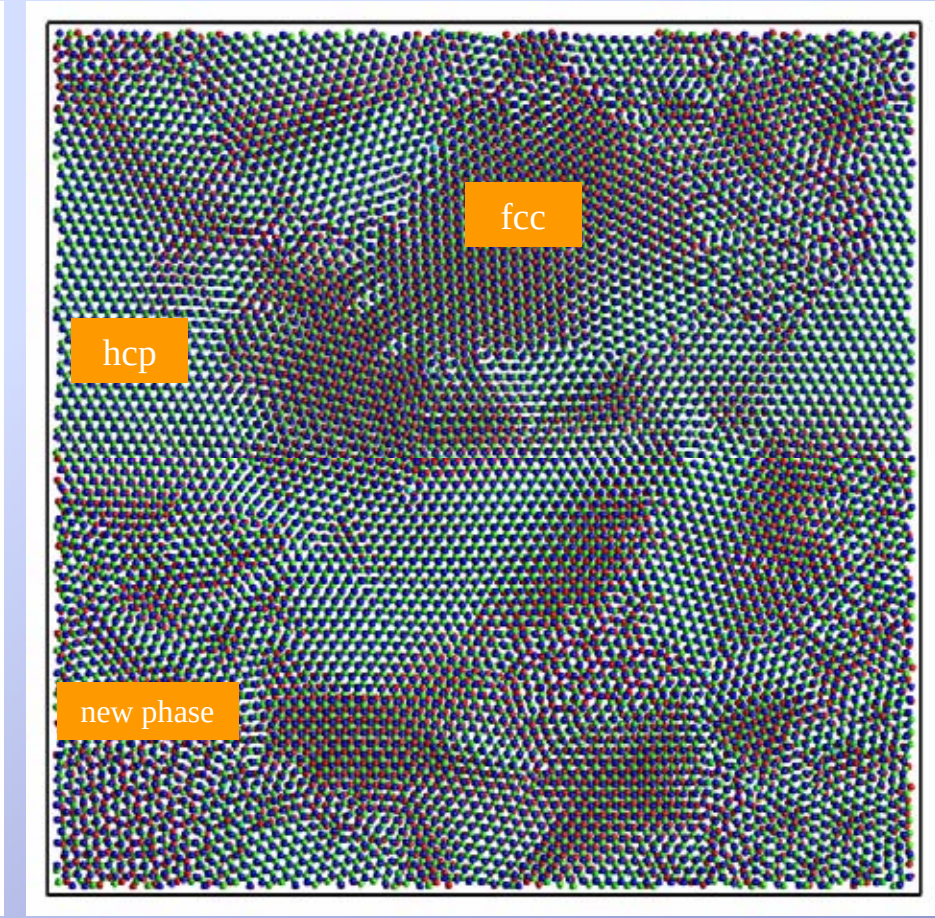
Hard wall

3D Yukawa system in narrow channel: MD simulations

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

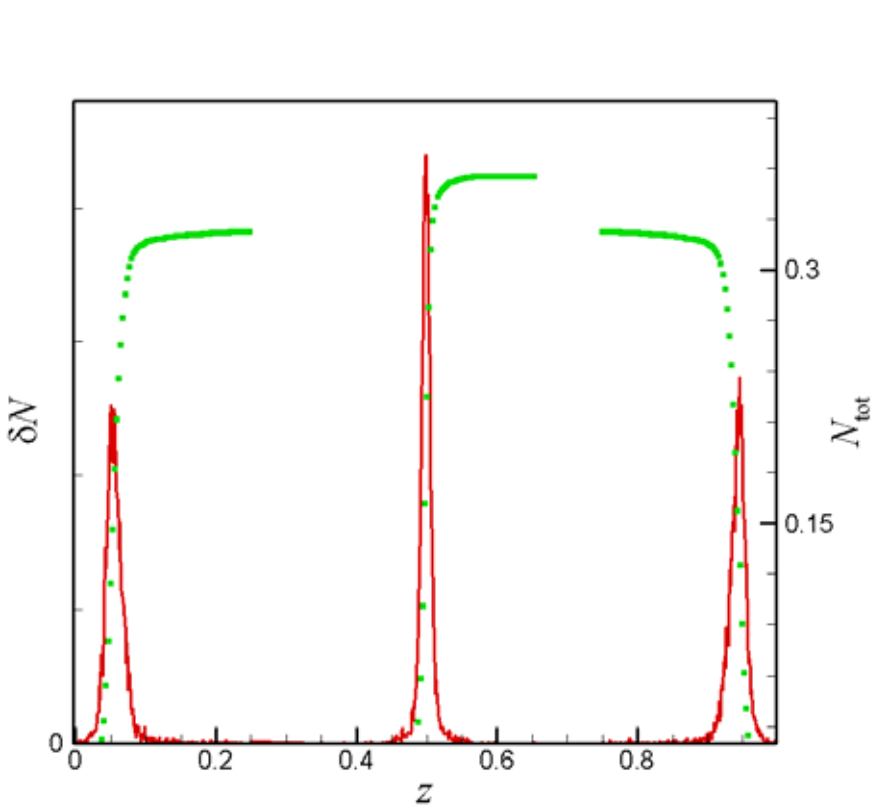


Parabolic confinement

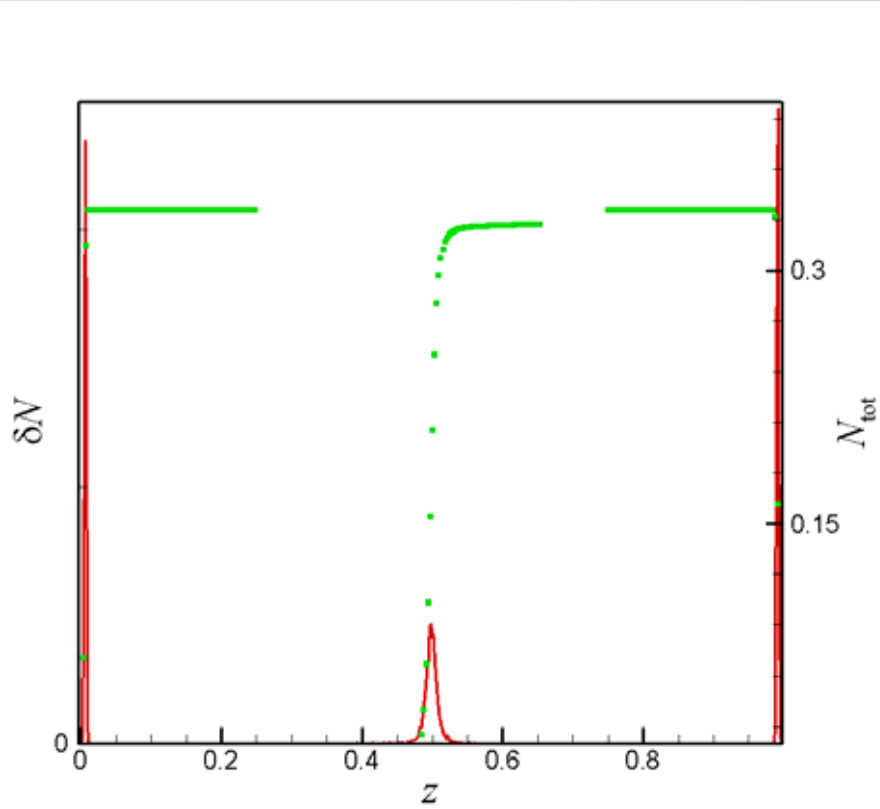


Hard wall

3D Yukawa system in the narrow channel: MD simulations

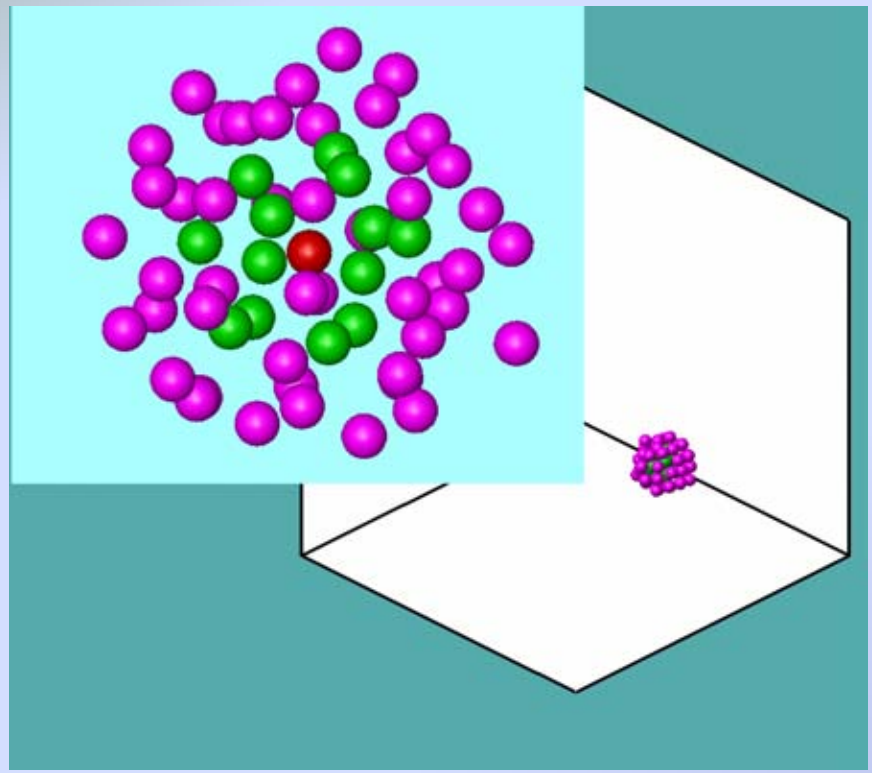


Parabolic confinement



Hard wall

How to define the local order by using particle positions?



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

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

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

Step 1: to find N-nearest neighbors

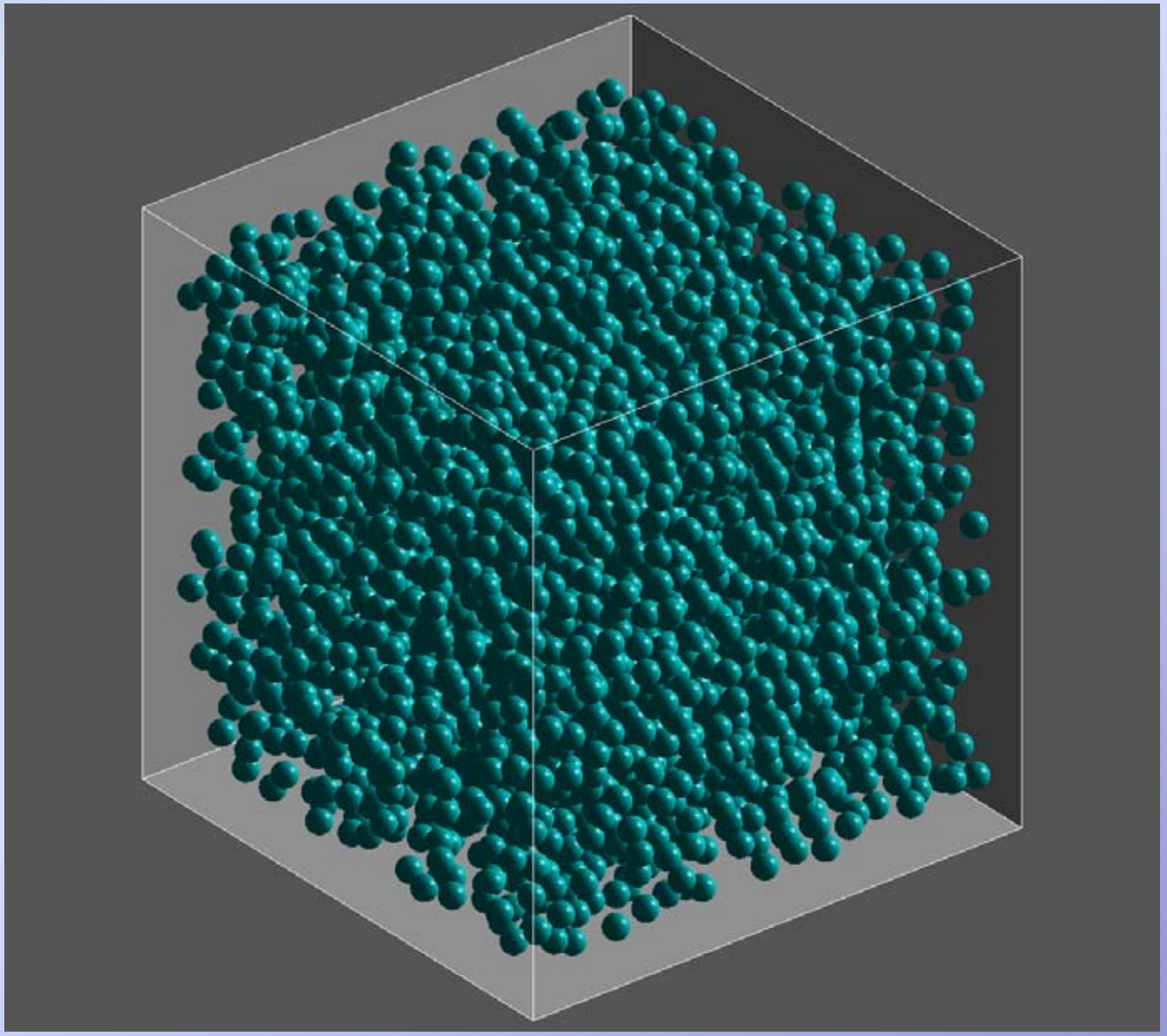
Step 2: to calculate the local bond-order parameters

Step 3: to calculate local rotational invariants

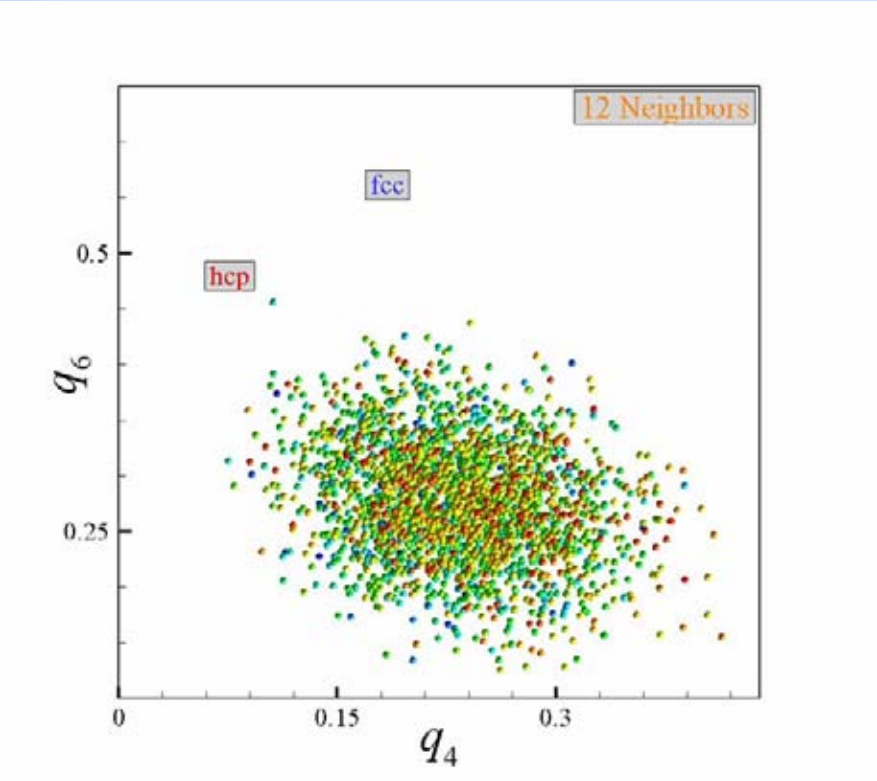
Step 4: to identify the local structure

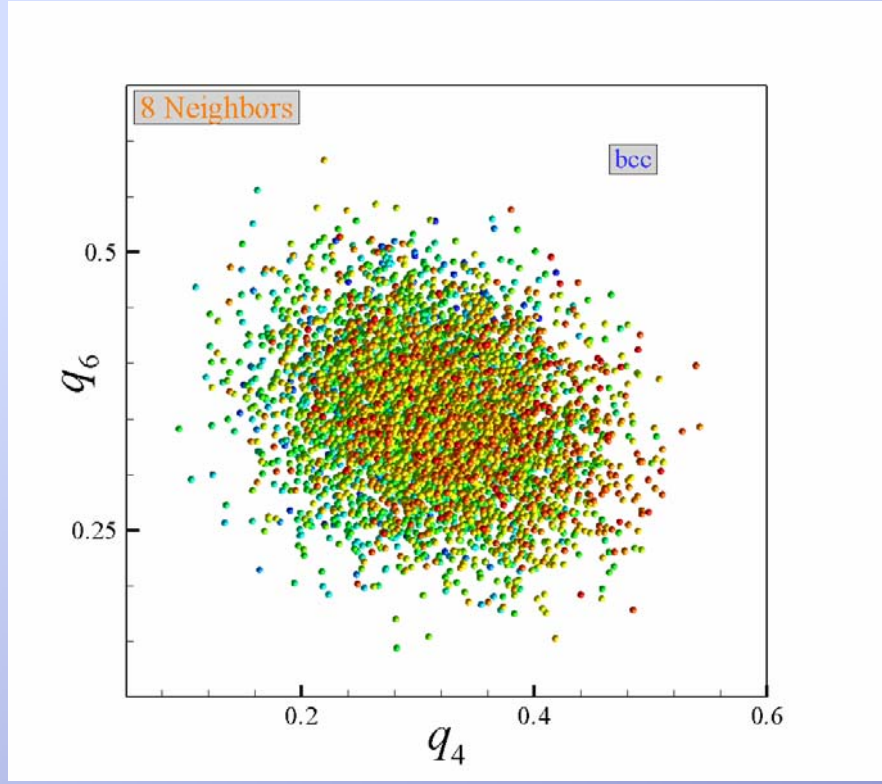
	Q_4	Q_6	$\hat{W}_4$	$\hat{W}_6$
fcc	0.191	0.575	−0.159	−0.013
hcp	0.097	0.485	0.134	−0.012
bcc	0.036	0.511	0.159	0.013
sc	0.764	0.354	0.159	0.013
Icosahedral	0	0.663	0	−0.170
(liquid)	0	0	0	0

Crystallization in 3D: MD simulations (PBC, hard wall)

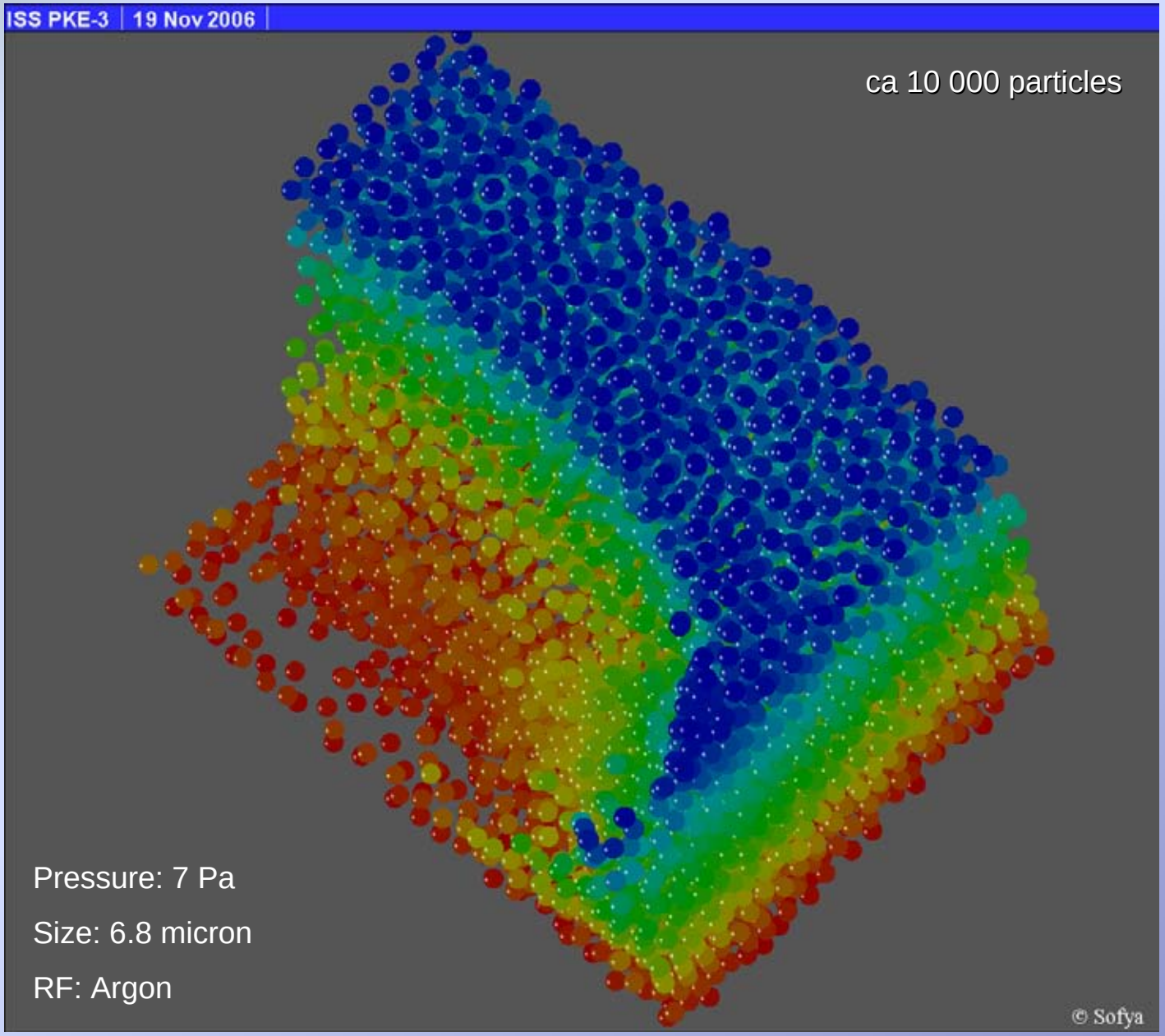


Local order analysis of 3D MD simulations

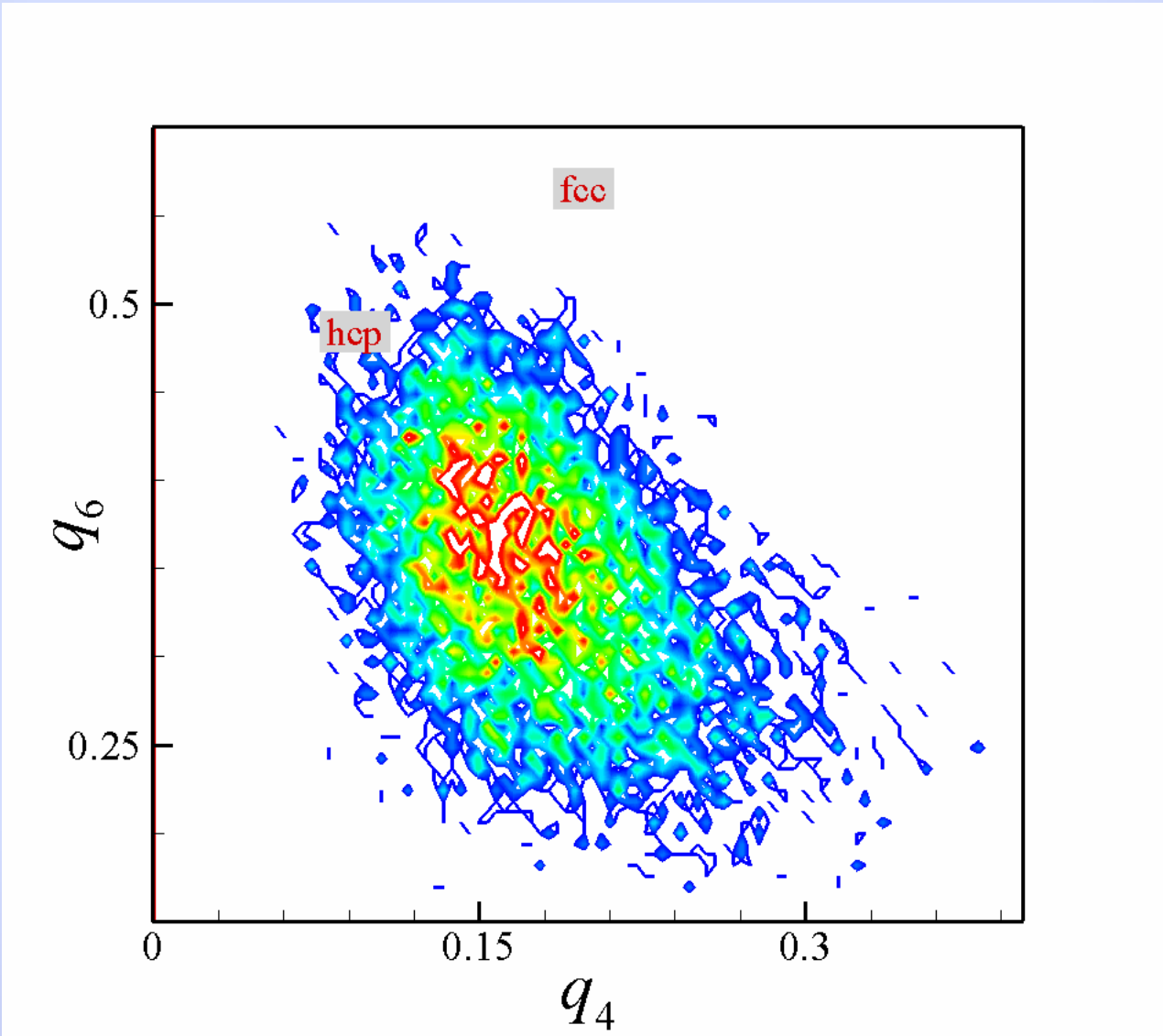




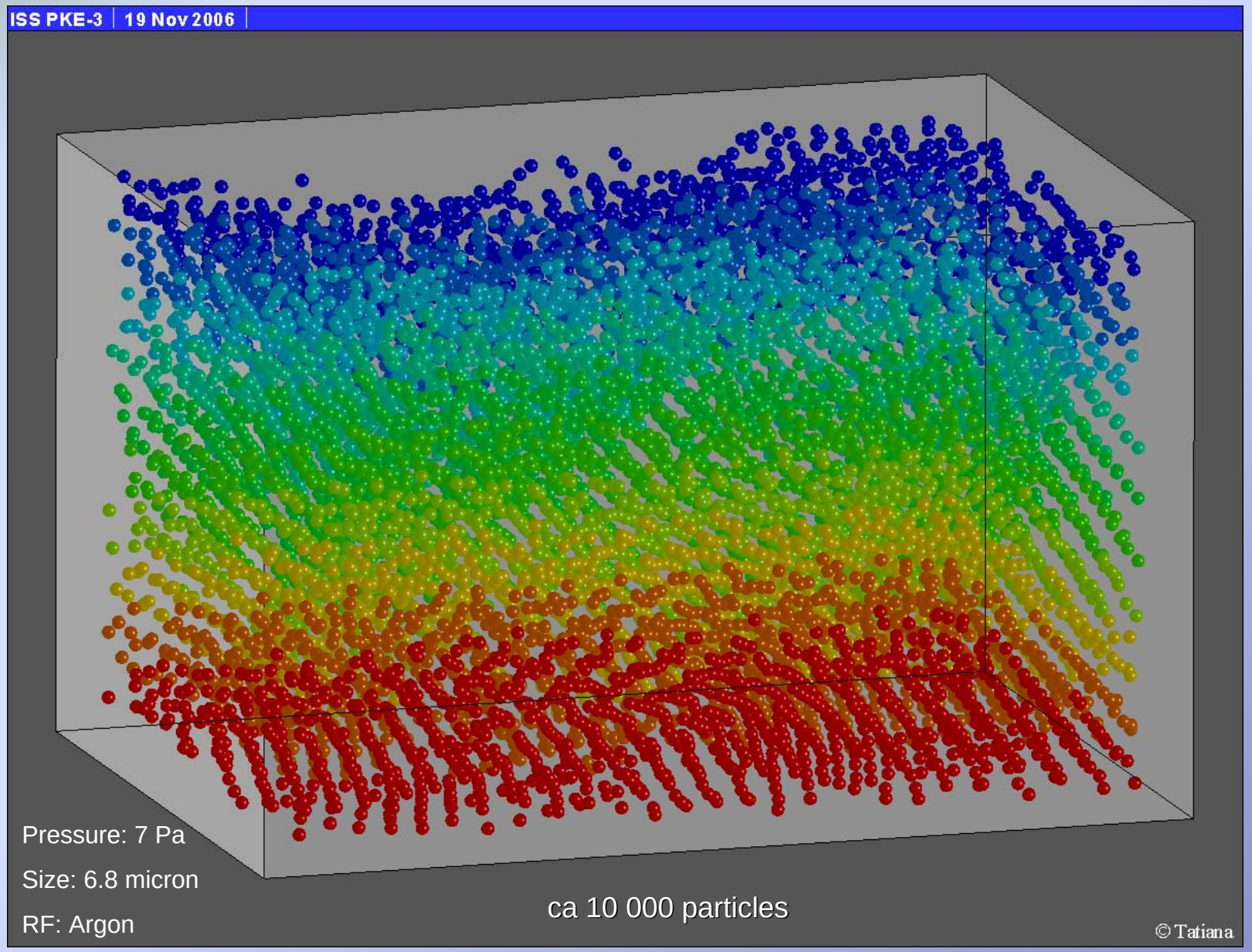
Plasma crystal @ microgravity: PKE-3 data (November 2006)



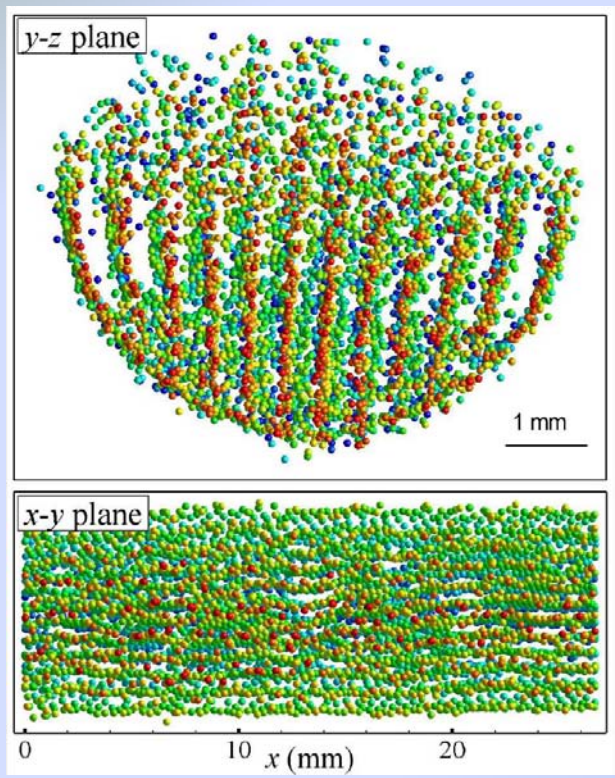
Local order analysis of 3D ISS data

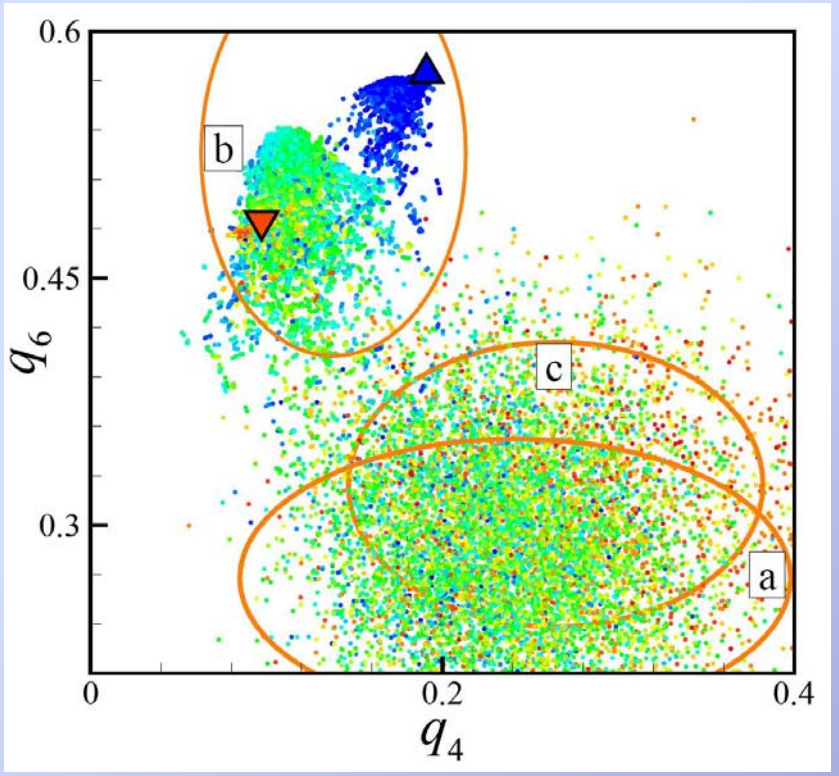


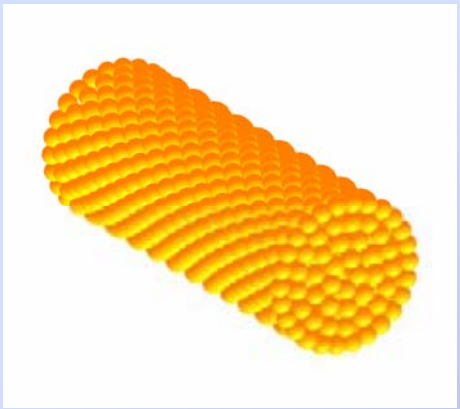
Complex plasma @ microgravity: the best crystal ever obtained

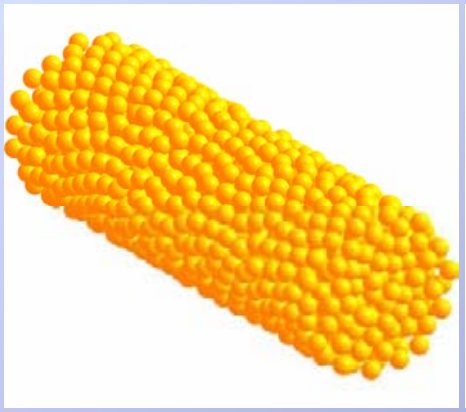


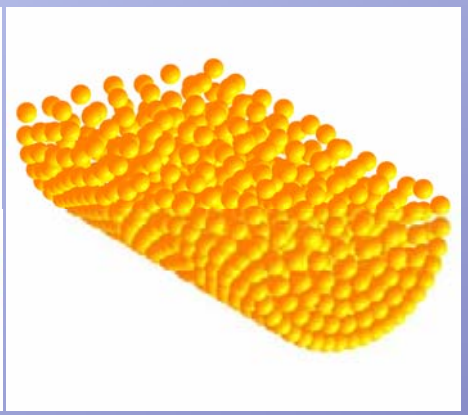
Complex plasmas at cylindrical confinement: MD & experiment (S. Mitic, 2007)



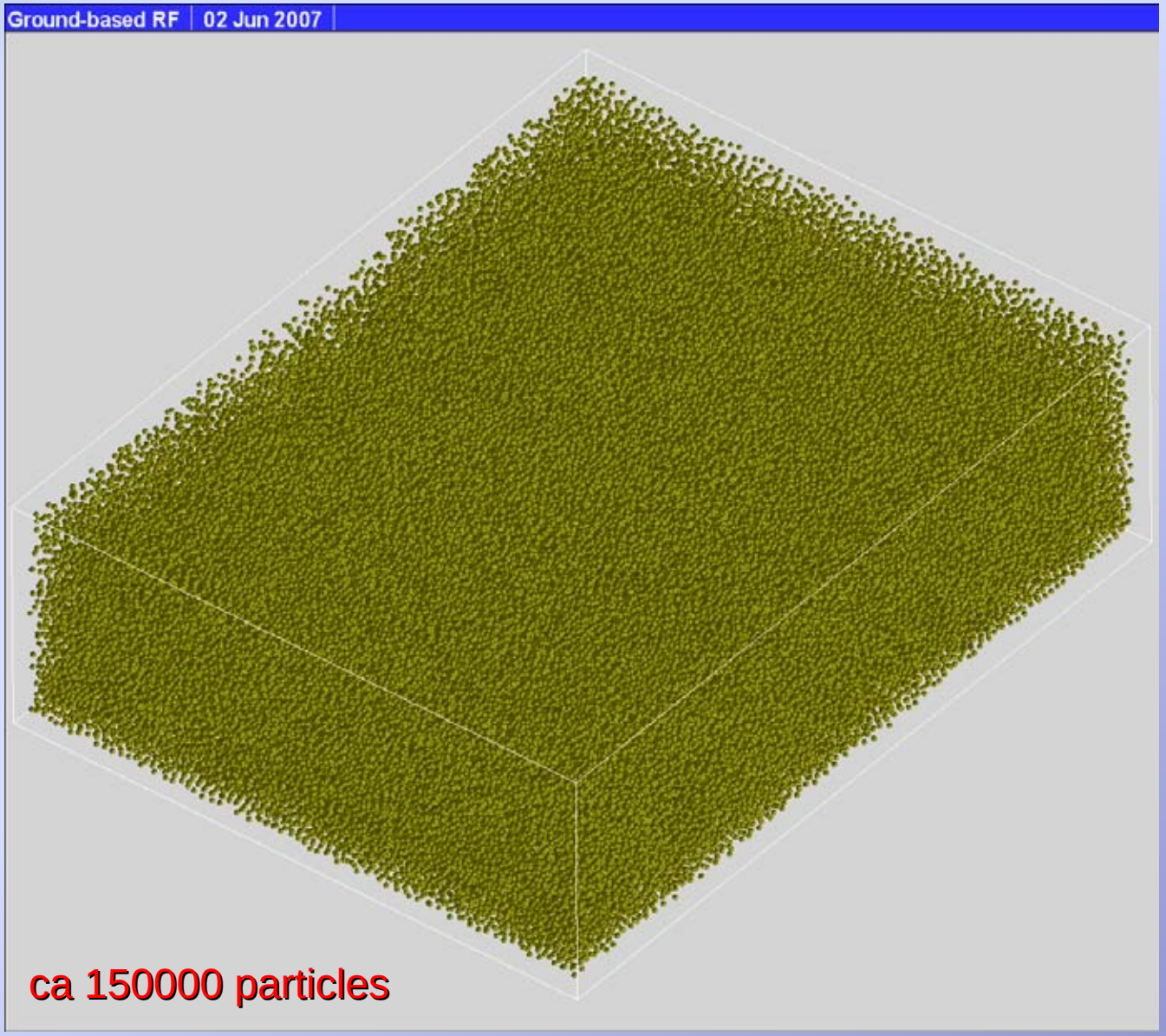




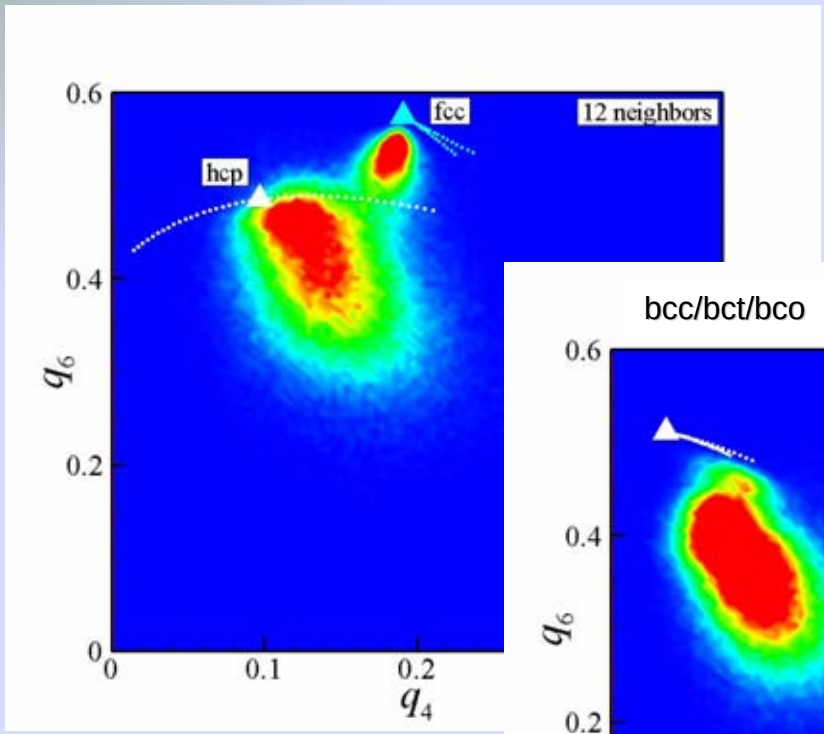




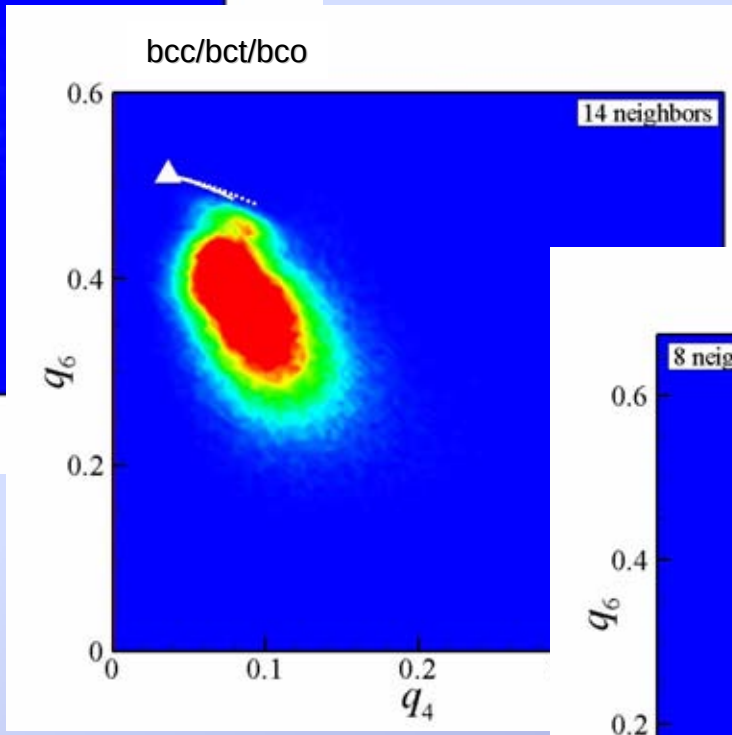
Complex plasmas in 3D: ground-based experiment (P.Huber, 2007)

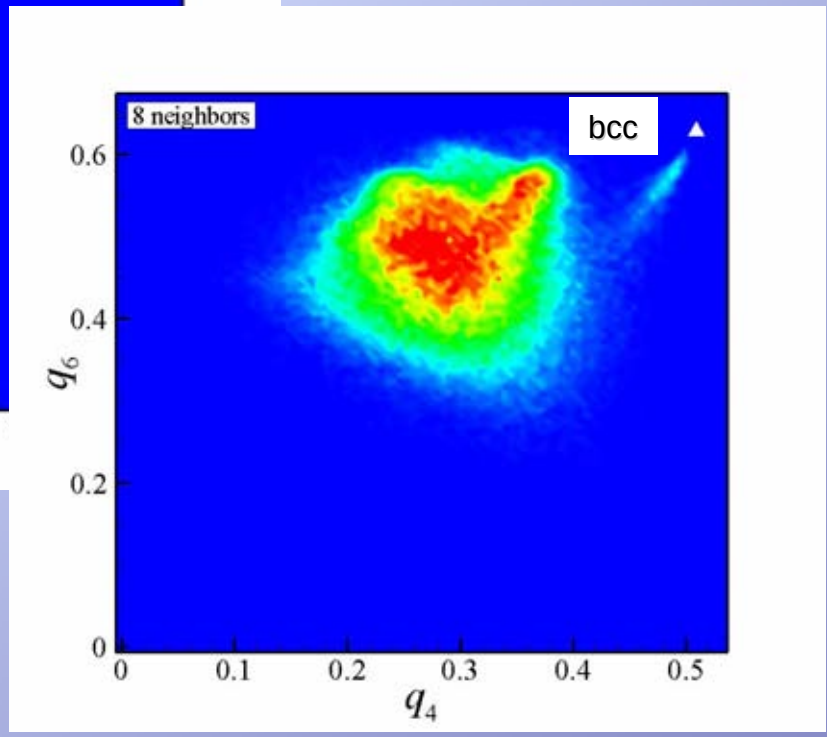


Local order analysis of recent ground-based experiments (cntnd)



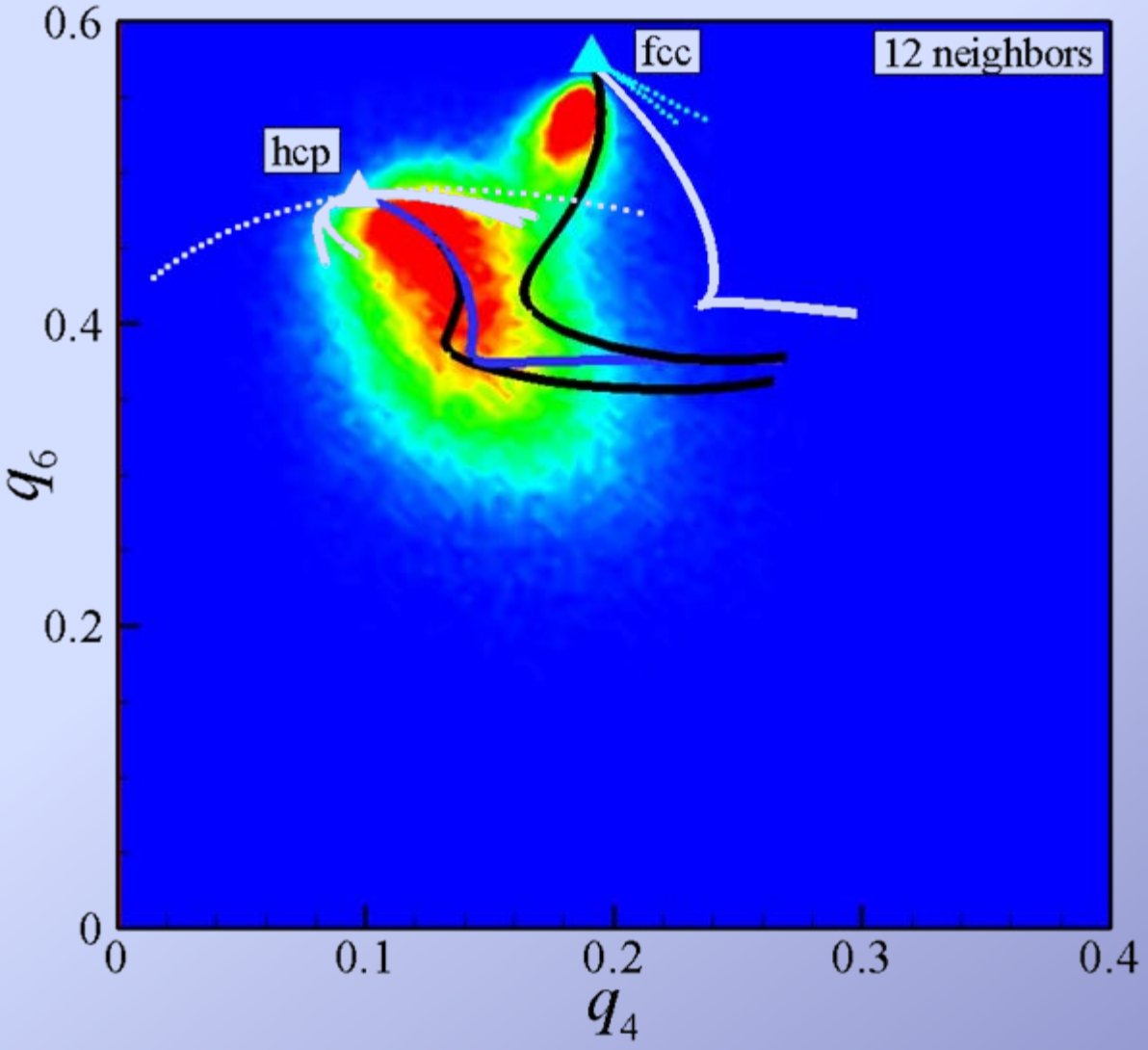
bcc/bct/bco



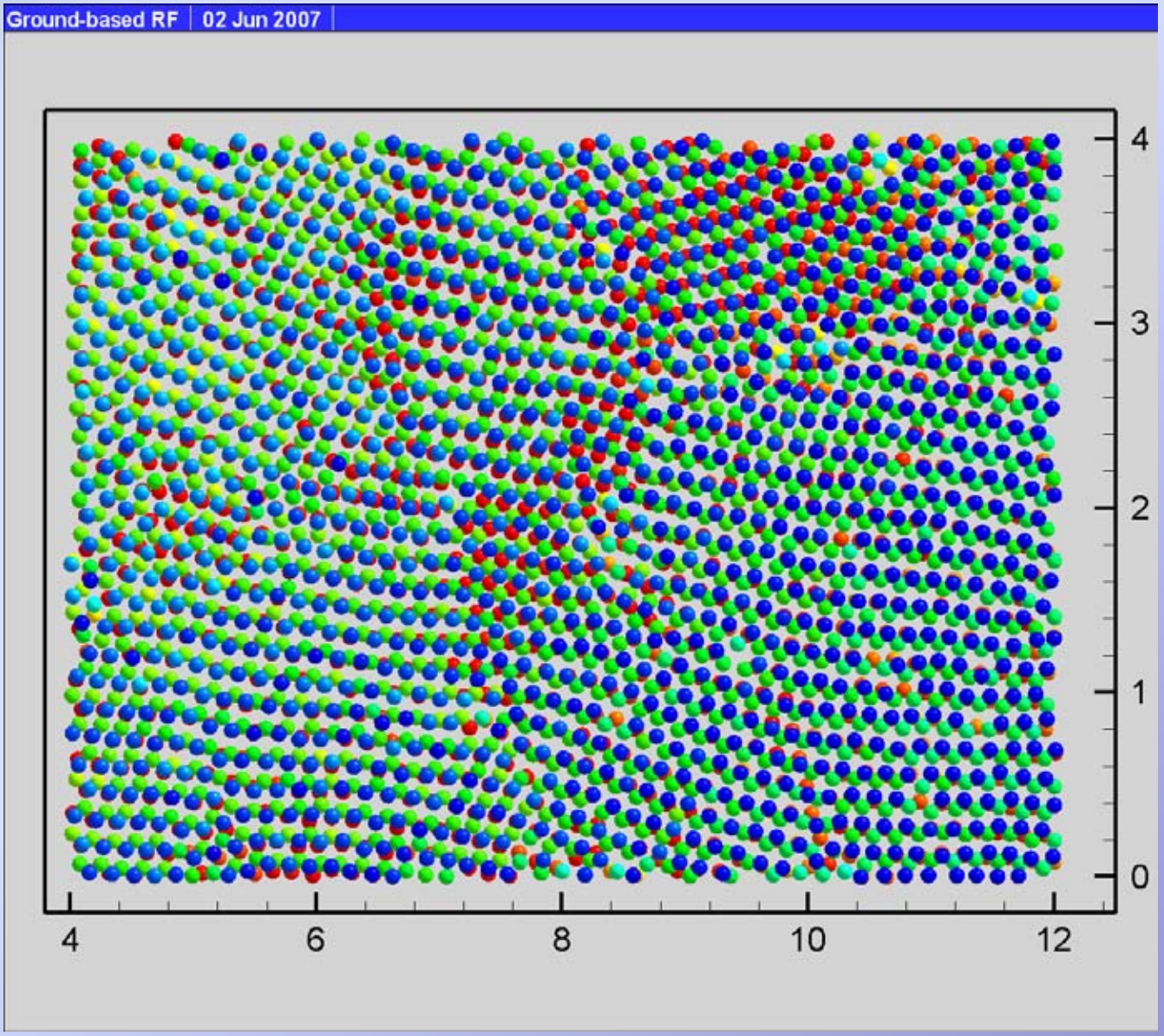


Local order analysis of recent ground-based experiments

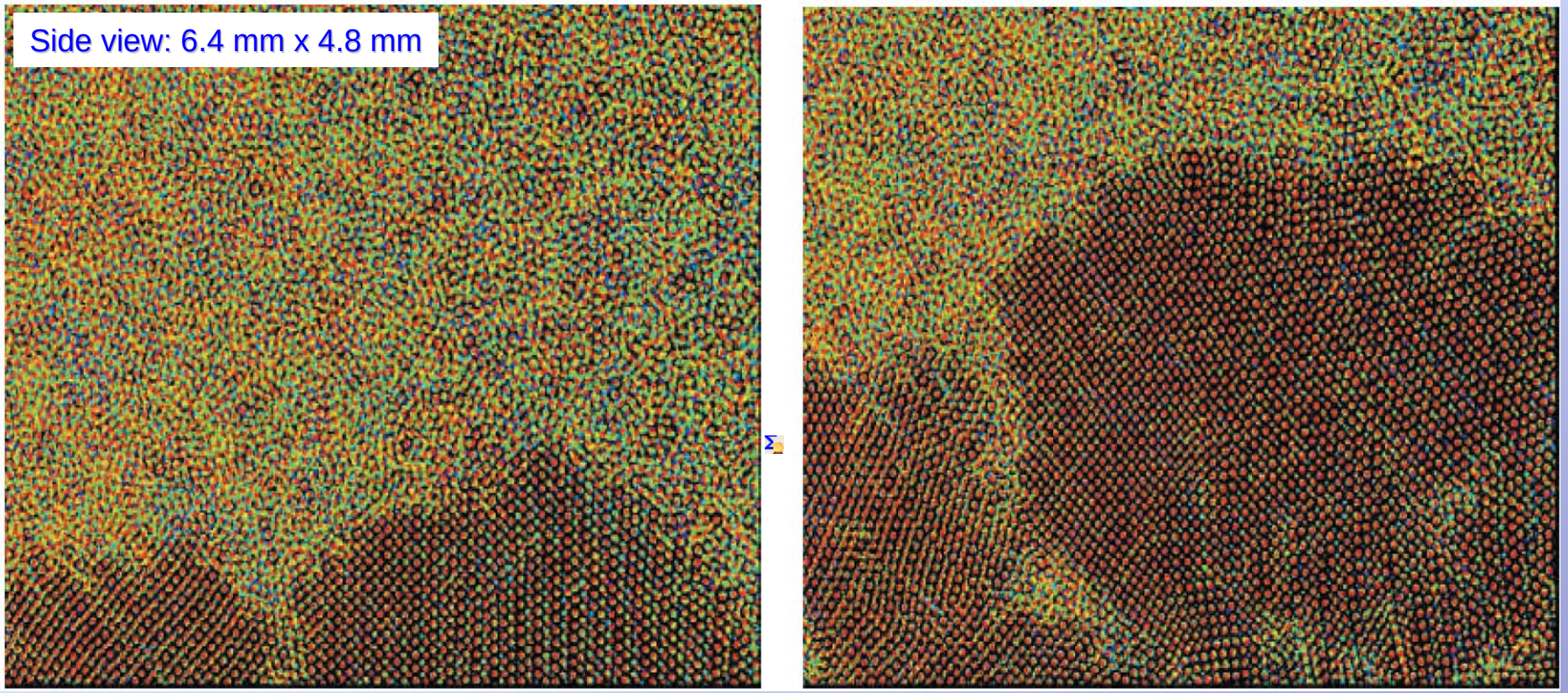
Rotational invariants of hcp & fcc @ different shear levels



Complex plasmas in 3D: ground-based experiment (ca 150000 ptcl)



First observations of crystallization fronts in complex plasmas (M. Rubin-Zuzic, et al, *Nature*, 2006)



Development of the front at two different times (16 s apart)

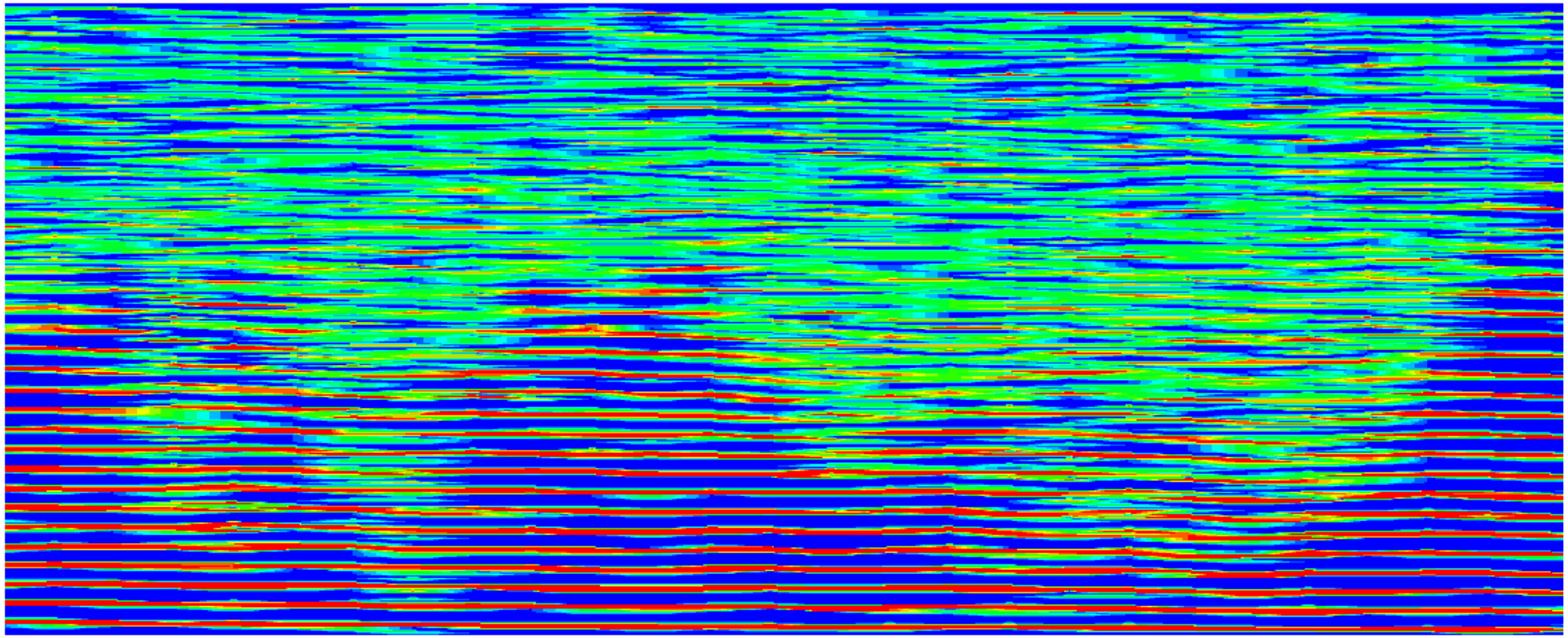
Pressure: 0.23 mbar

Size: 1.28 micron

RF: Argon

Local order analysis of recent ground-based experiment (cntnd) (P. Huber, 2007)

Particle density (x, y) vs z for the final frame



ca 150 000 particles


THANK YOU