Deutsches Zentrum für Luft- und Raumfahrt,
Forschungsgruppe Komplexe Plasmen

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Synchronisation of particle motion in compressed two-dimensional plasma crystals

Ingo Laut, Christoph Räth, Sergey Zhdanov,
Vladimir Nosenko, Lénaïc Couëdel und Hubertus Thomas

Knowledge for Tomorrow

Synchronization of particle motion in compressed two-dimensional plasma crystals

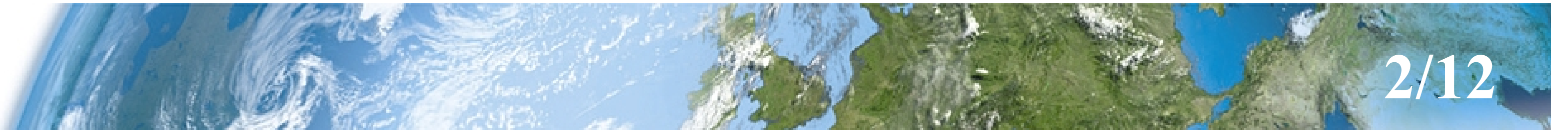
Introduction

- Theory of the mode-coupling instability (MCI)
- Experimental observation
- Molecular-dynamics simulations

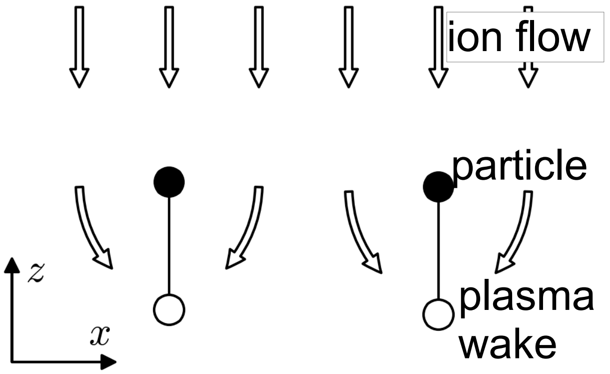
Results

- Asymmetric triggering of MCI
- Synchronized motion

Conclusion

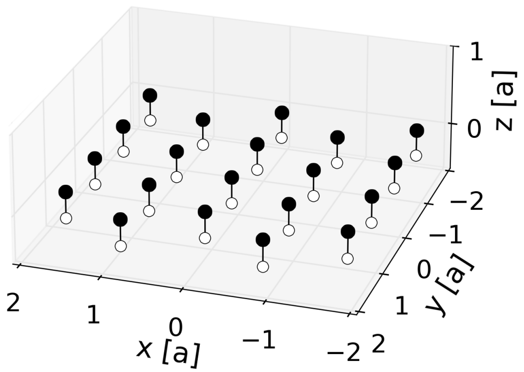


Theory: Model of a 2D crystal



Yukawa-interactions: particle-particle (repulsive) and *wake*-particle (attractive)

$$\mathbf{F}_{ji} = \frac{Q^2}{r_{ji}^2} \exp\left(-\frac{r_{ji}}{\lambda}\right)\left(1+\frac{r_{ji}}{\lambda}\right)\frac{\mathbf{r}_{ji}}{r_{ji}}$$
$$- \frac{q|Q|}{r_{w_{ji}}^2} \exp\left(-\frac{r_{w_{ji}}}{\lambda}\right)\left(1+\frac{r_{w_{ji}}}{\lambda}\right)\frac{\mathbf{r}_{w_{ji}}}{r_{w_{ji}}}$$

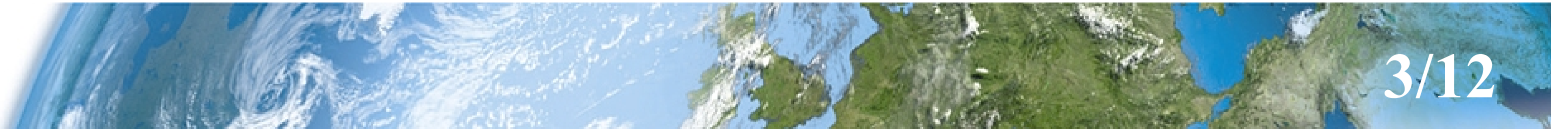


friction $\mathbf{F}_{\mathrm{fr}} = -m\nu\dot{\mathbf{r}}_i$

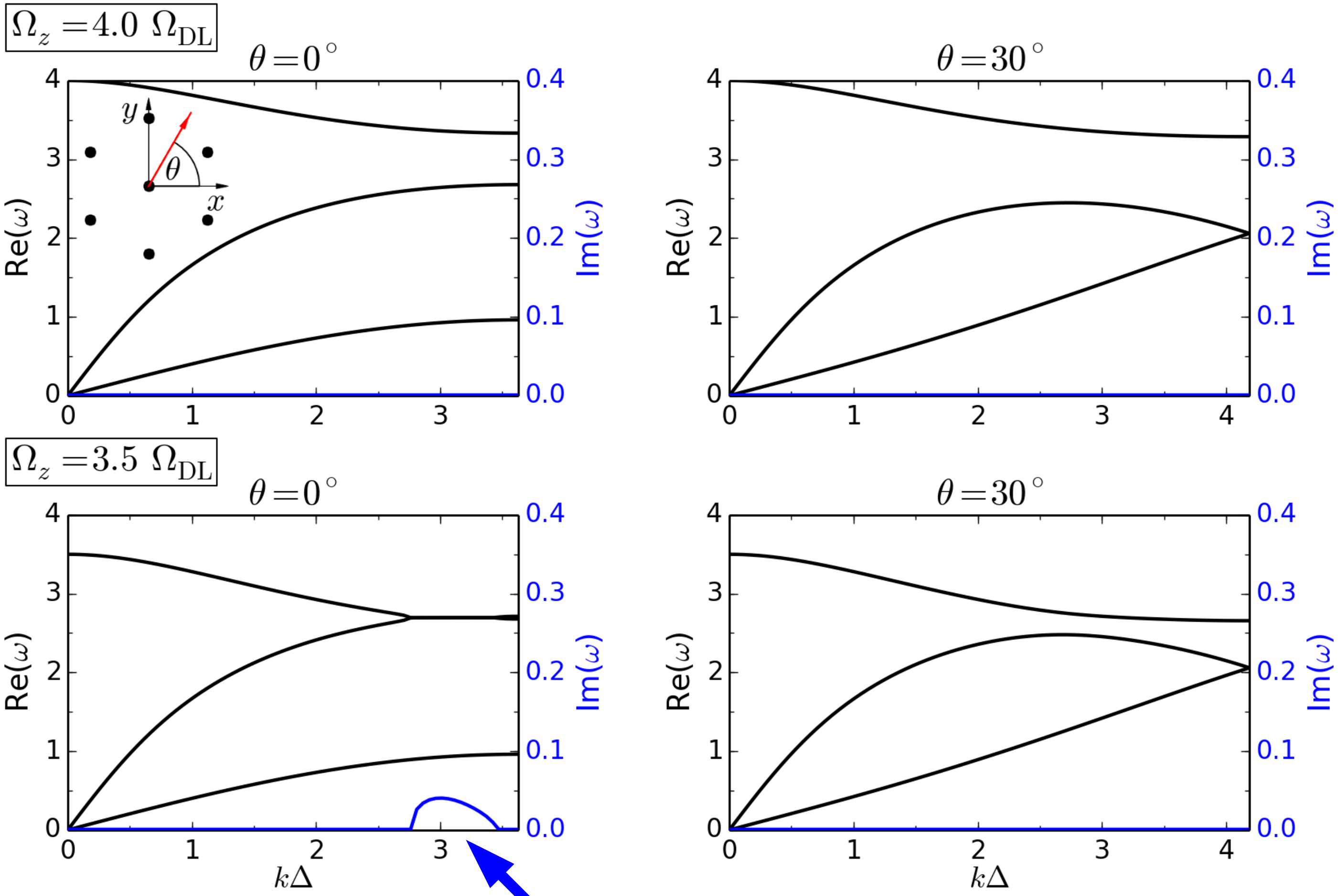
external potential $\mathbf{C}_i = -m\begin{pmatrix} 0 \\ 0 \\ \Omega_z^2 z_i \end{pmatrix}$

equations of motion for particle *i*:

$$m\ddot{\mathbf{r}}_i = \sum_{j\neq i}\mathbf{F}_{ji} + \mathbf{F}_{\mathrm{fr}} + \mathbf{C}_i$$

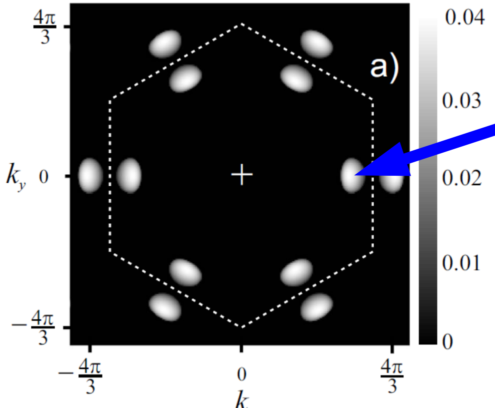


Theory: Dispersion relations



There are three different wave modes in the crystal.

The instable hybrid mode forms when the vertical potential is weak enough.

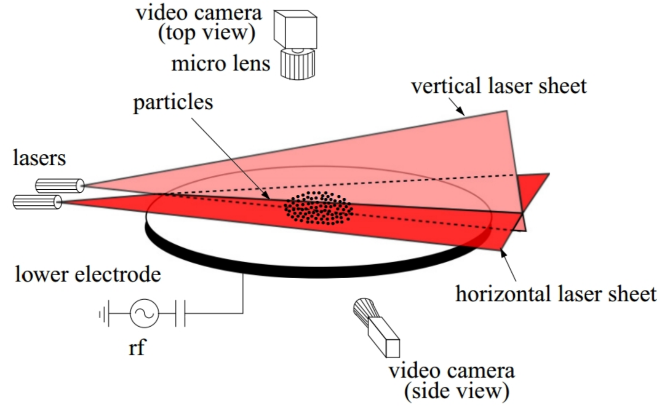


mode coupling instability (MCI)

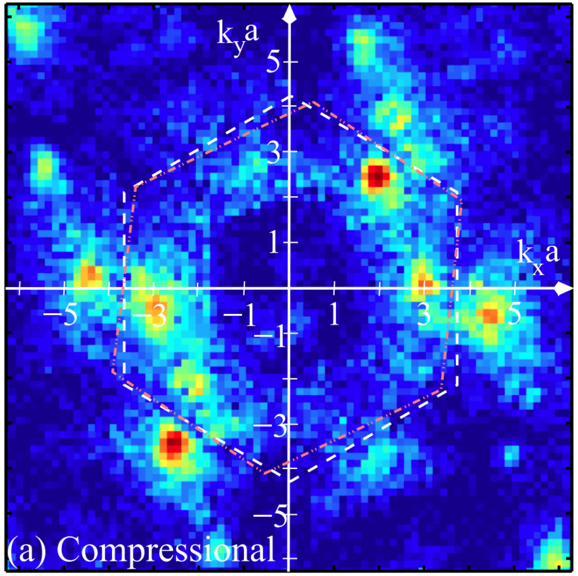
Zhdanov, Ivlev and Morfill
Phys. Plasmas **16** 083706 (2009)

Experimental observation

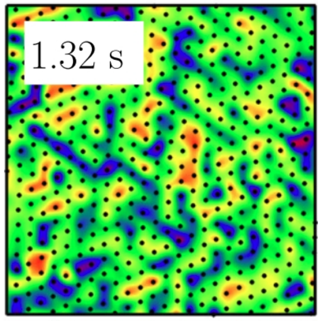
Setup GEC chamber



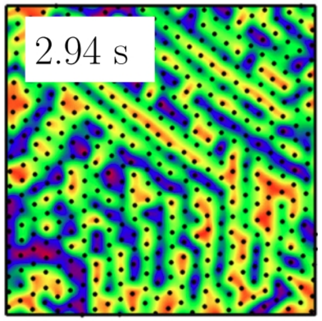
Spectrum



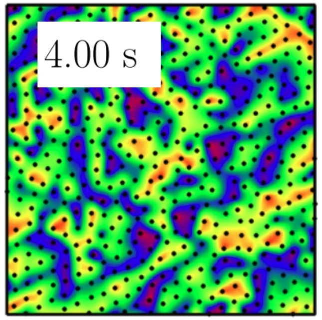
Instantaneous phases of particle oscillations



Crystalline structure; weak, non-synchroneous particle movement.



Alternating lines of synchronized particles.



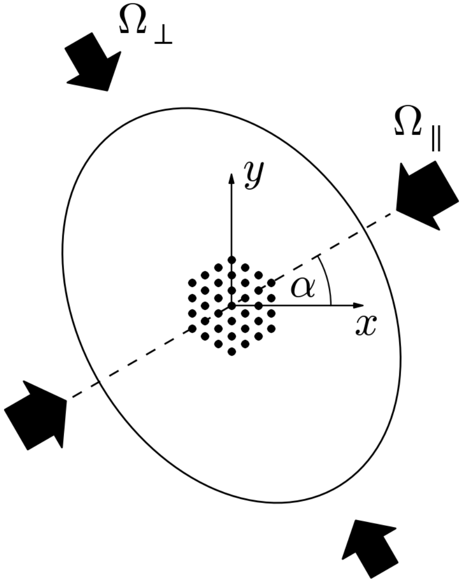
Unordered particle motion in molten crystal.

Couëdel, Zhdanov, Nosenko, Ivlev, Thomas and Morfill
Phys. Rev. E **89** 053108 (2014)

Molecular-dynamics simulations

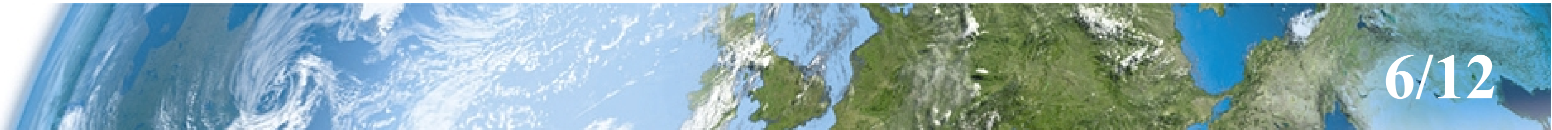
- Equation of motion

$$m\ddot{\mathbf{r}}_i = \mathbf{F}_{\mathrm{fr}} + \sum_{j\neq i}\mathbf{F}_{ji} + \mathbf{C}_i + \mathbf{L}_i$$



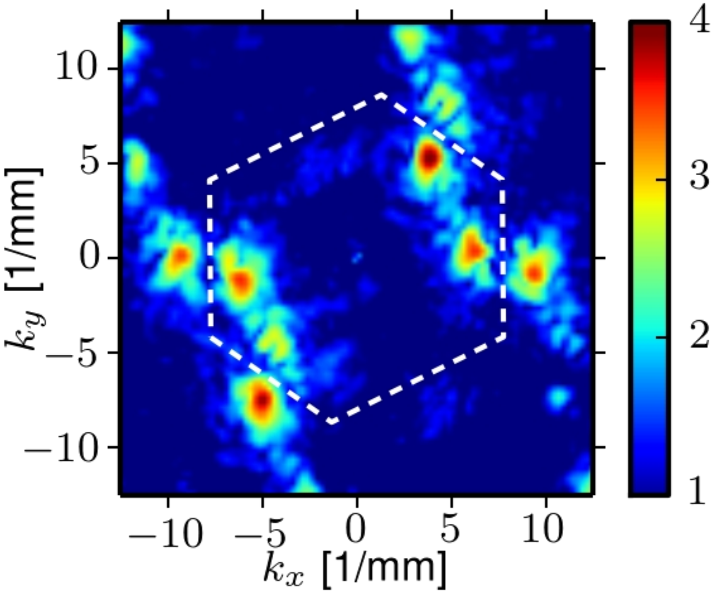
$\mathbf{F}_{\mathrm{fr}}$	friction
$\mathbf{F}_{ji}$	Yukawa-interaction
$\mathbf{C}_i$	anisotropic confinement allows control of strength and direction of compression of the crystal.
$\mathbf{L}_i$	Langevin heat bath

- The simulation reproduces the anisotropic pair correlation function of the experiment for $\alpha = 30^\circ$

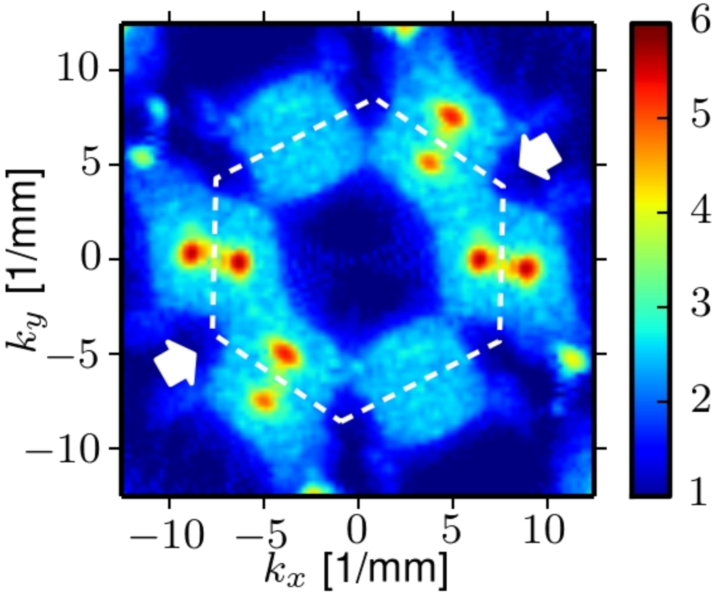


Asymmetric triggering of MCI

Experiment



Simulation



The anisotropic confinement controlls the asymmetric triggering of MCI.

Laut, Räth, Zhdanov, Nosenko, Couëdel and Thomas
EPL **110** 65001 (2015)

Order parameter for synchronized motion

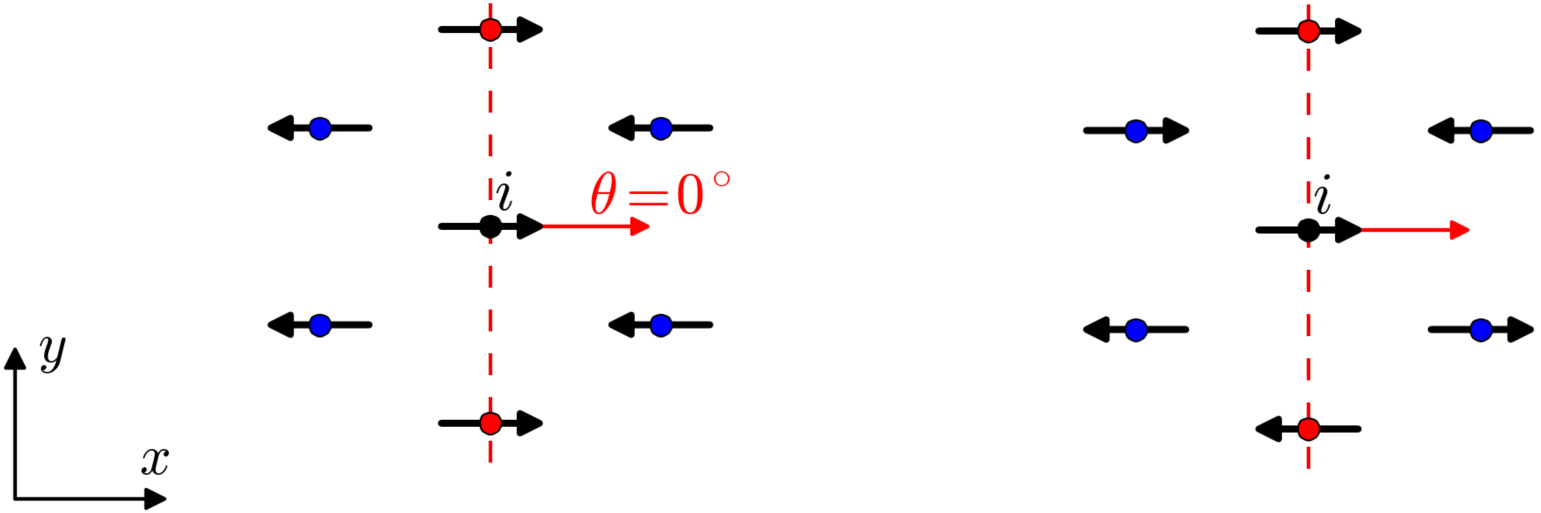
$$R_{i,\theta}(t) = \frac{1}{\mathrm{nn}}\left(\sum_{j=1}^{\mathrm{nn}}\left[k_j \cos(\phi_{j,\theta} - \phi_{i,\theta})\right]\right)$$

$$re^{i\psi} = \frac{1}{N}\sum_{j=1}^{N} e^{i\theta_j}$$

Kuramoto (1984)

$k_j = +1$ if j und i are on the same line

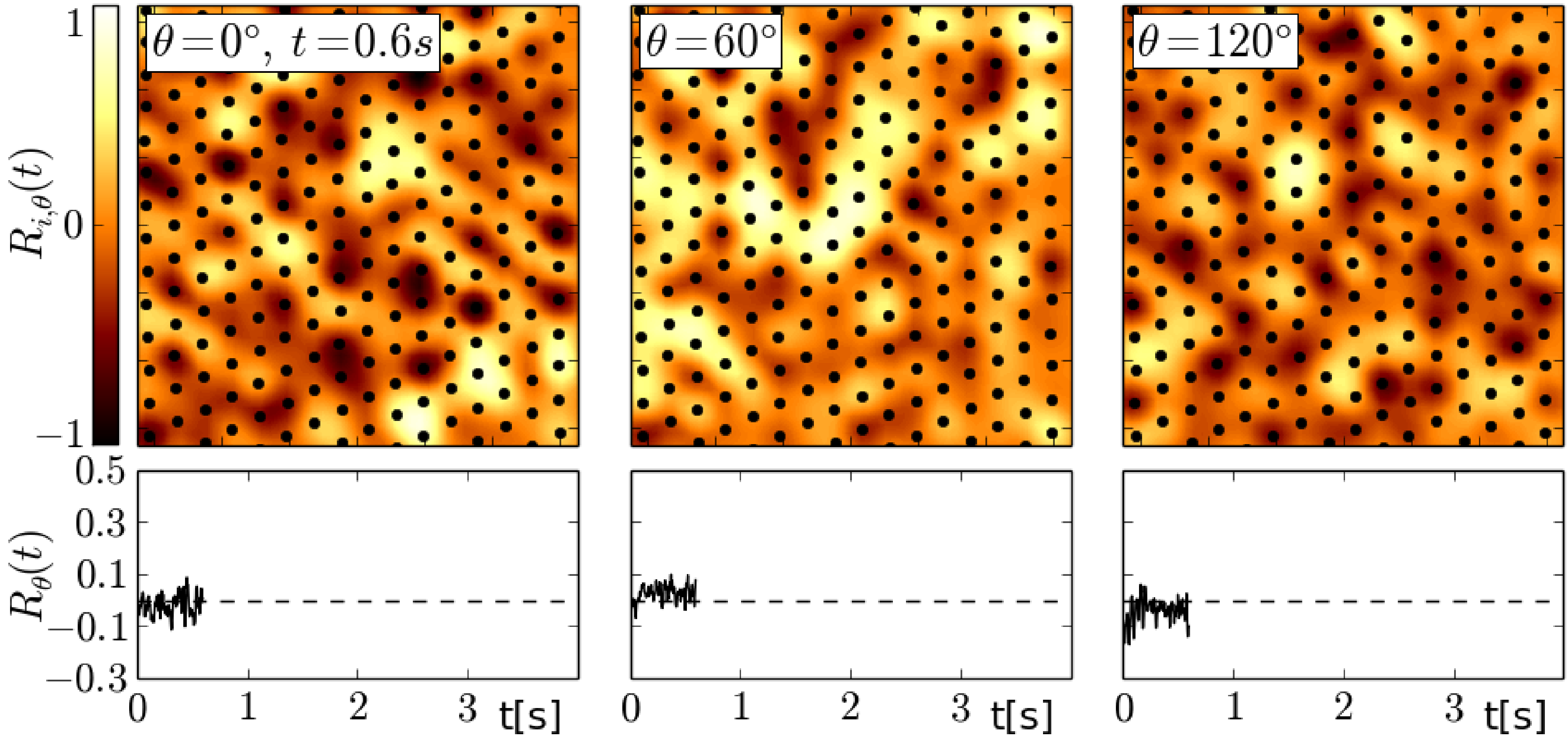
$k_j = -1$ otherwise



$R_{i,\theta=0}(t) = 1$ $R_{i,\theta=0}(t) = 0$

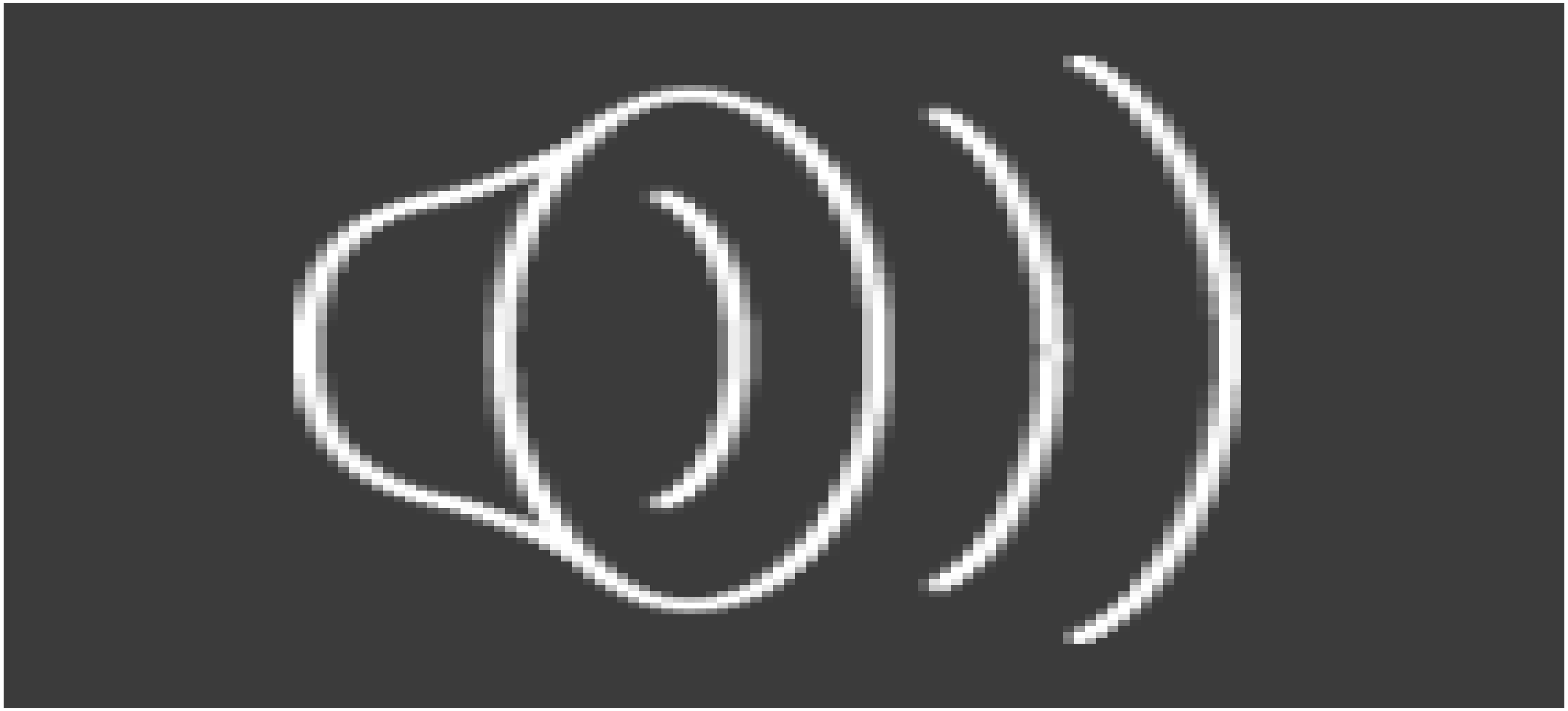
Order parameter for synchronized motion

Experiment



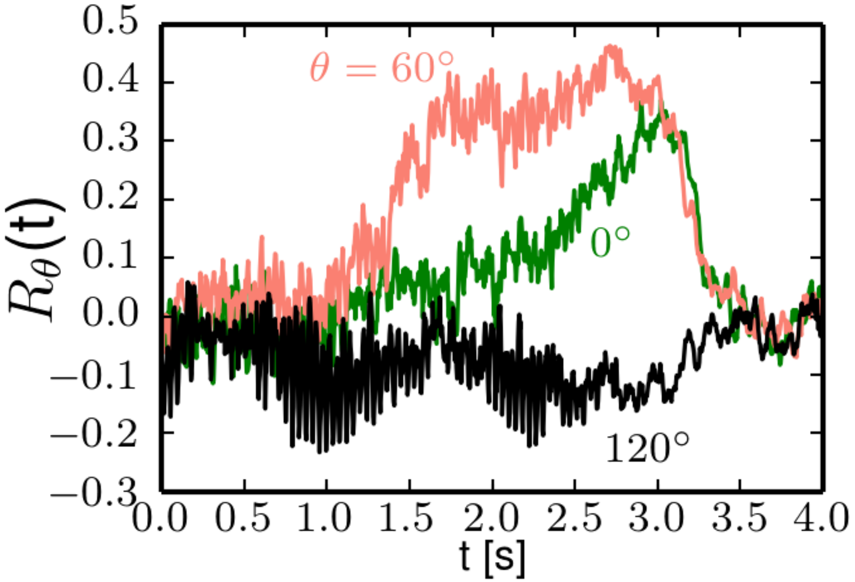
Order parameter for synchronized motion

Experiment

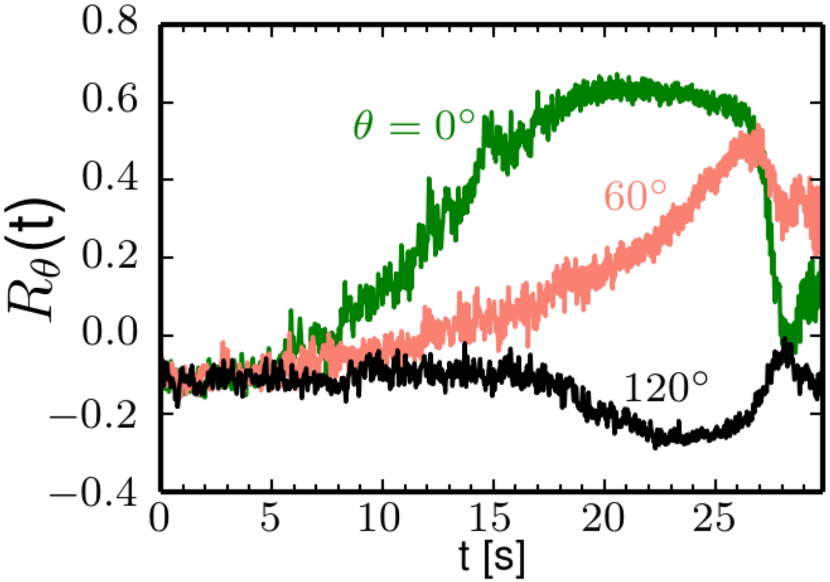


Order parameter for synchronized motion

Experiment



Simulation



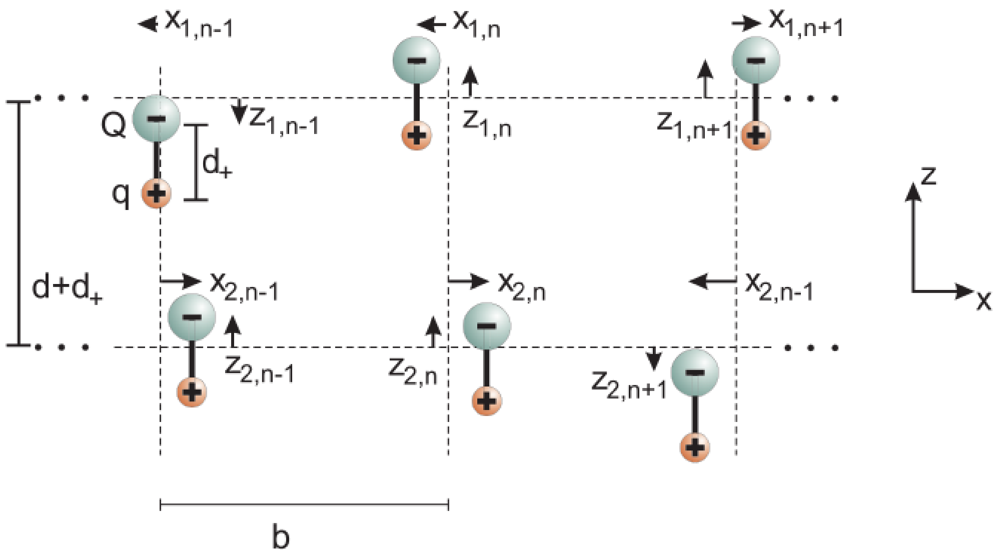
Conclusion

- Anisotropic particle confinement controls the asymmetric triggering of the mode-coupling instability: good agreement of experiment, simulation and theory

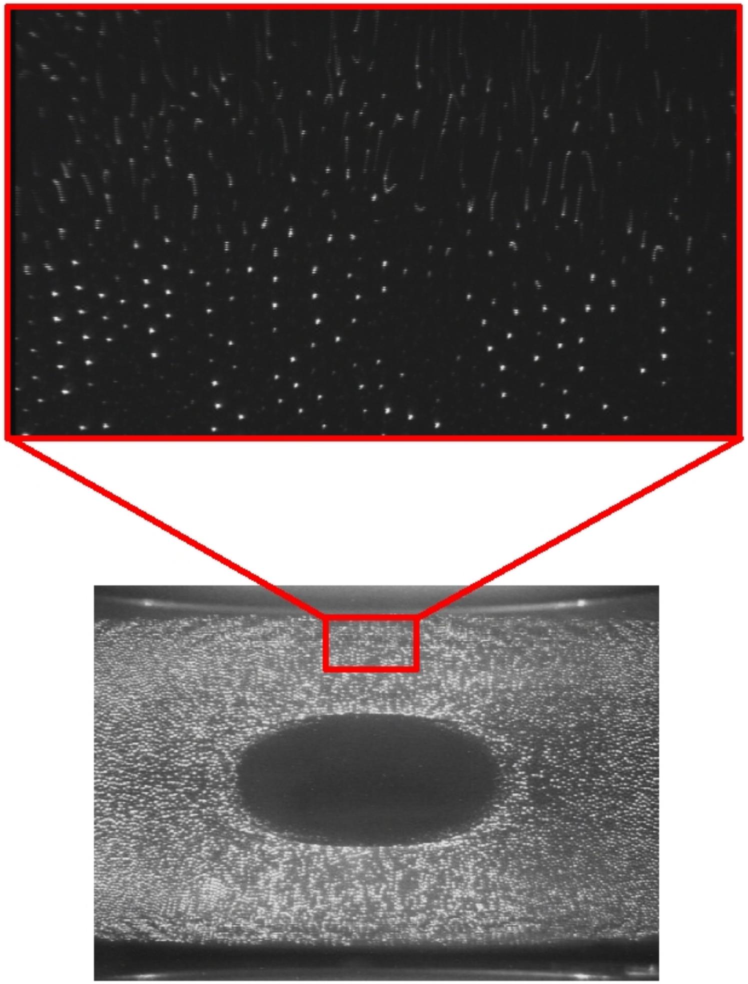
- Our order parameter derived from the Kuramoto model is sensible to direction dependent synchronization

- Next steps: harmonics generation during MCI, experiments in large 3D Crystals

Outlook: MCI in 3D

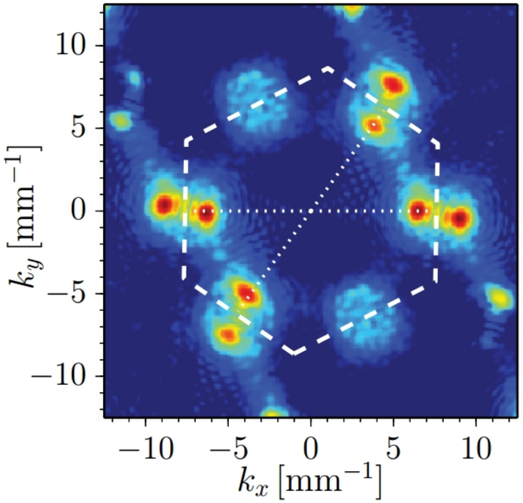


Melzer, Phys. Rev. E **90** 053103 (2015)

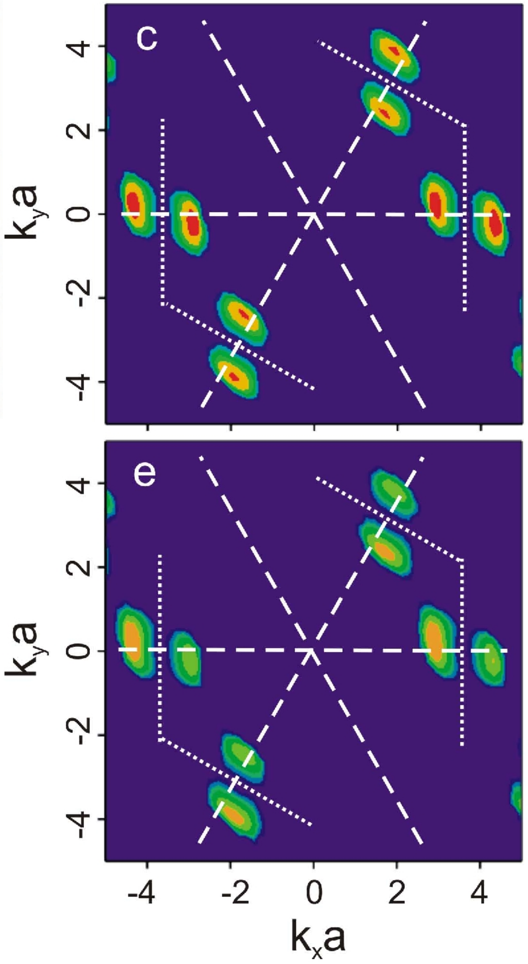


Gebrochene Links-Rechts Symmetrie

Simulation

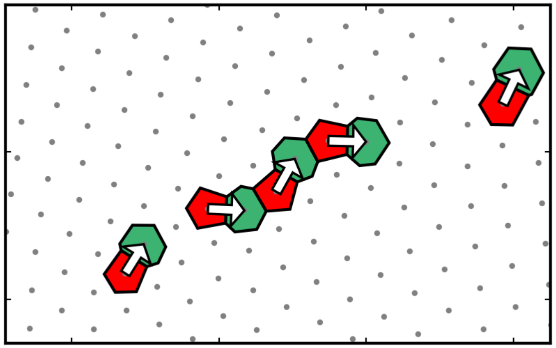


Theorie



Links-Rechts Asymmetrie im theoretischen Modell durch effektiven Phononenfluss. Mögliche Ursachen:

- Streuung an Defekten

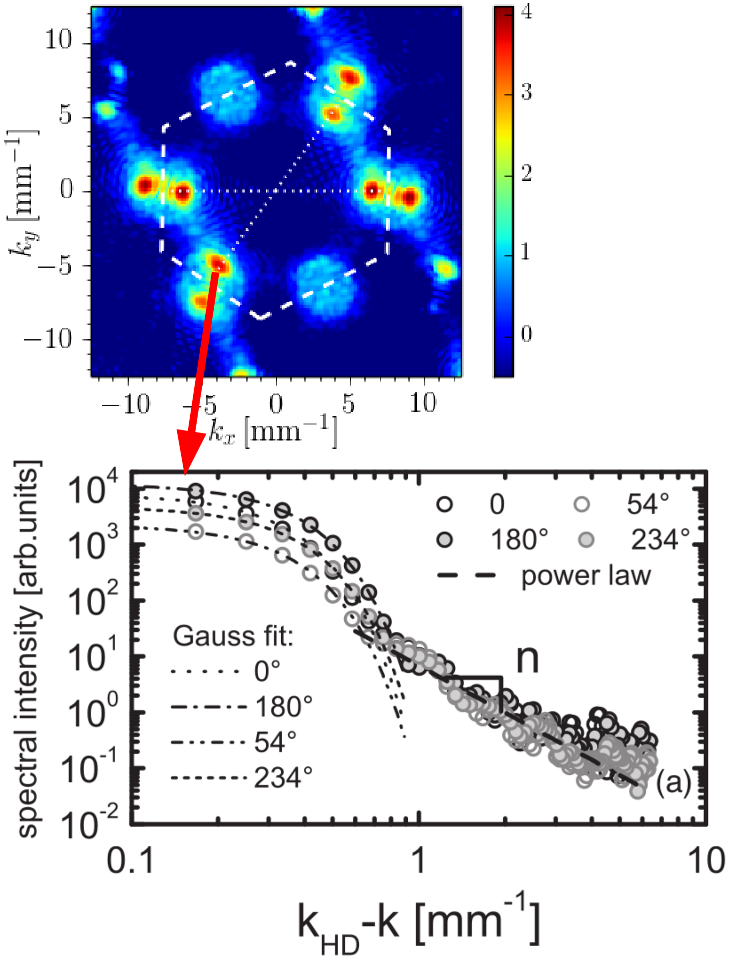


- Umklapp-Prozesse

Laut, Zhdanov, Räth, Thomas and Morfill
Phys. Rev. E **93** 013204 (2016)

Turbulente Halos

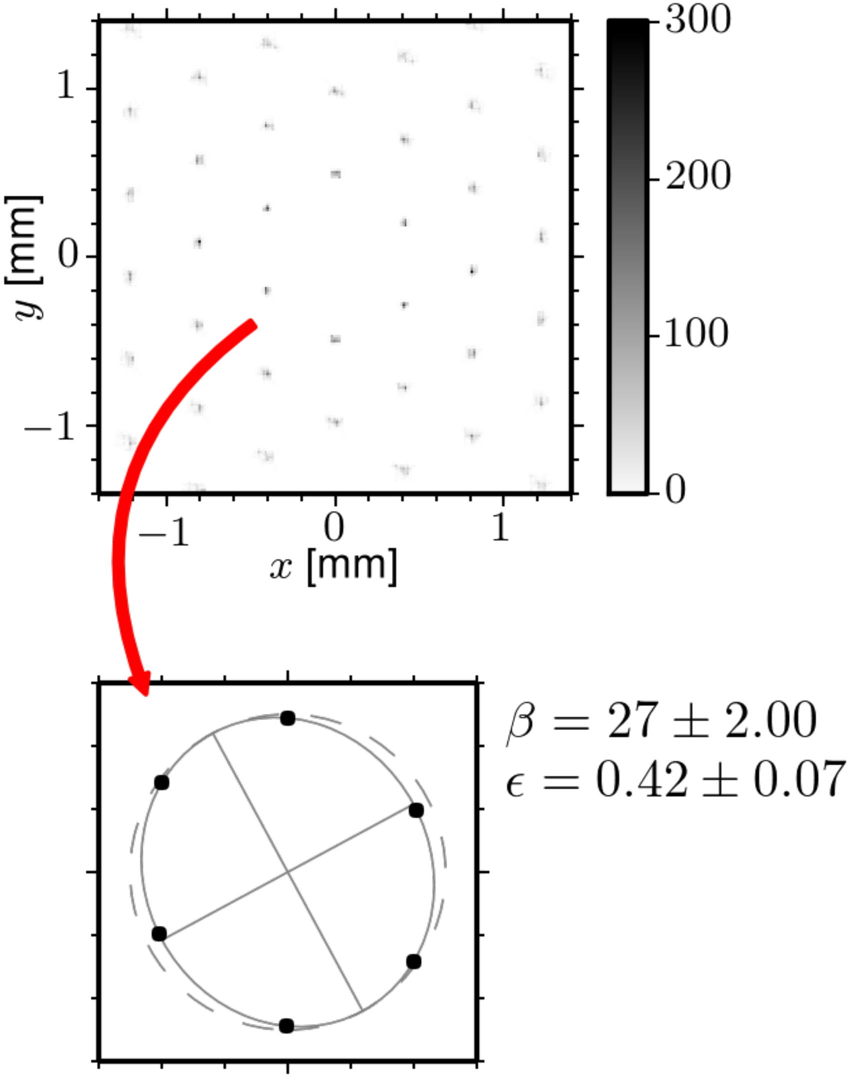
Neben dem exponentiellen Kern folgt die 1D Intensitätsverteilung einem Potenzgesetz mit n=3.



Laut, Zhdanov, Räth, Thomas and Morfill
Phys. Rev. E **93** 013204 (2016)

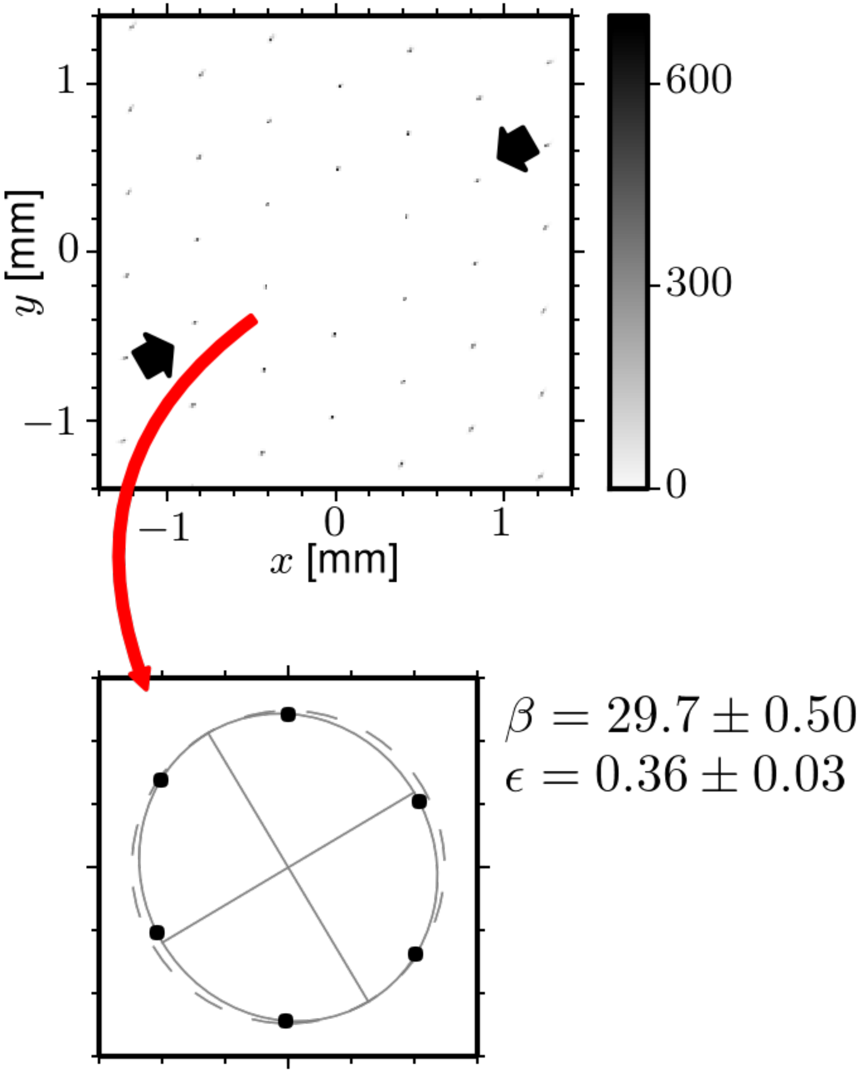
Paarkorrelationsfunktion $\alpha = 30^\circ$

Experiment



$\beta = 27 \pm 2.00$
$\epsilon = 0.42 \pm 0.07$

Simulation



$\beta = 29.7 \pm 0.50$
$\epsilon = 0.36 \pm 0.03$