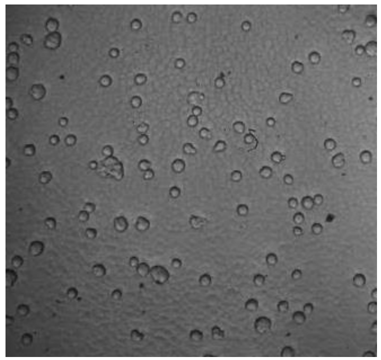
ETH zürich

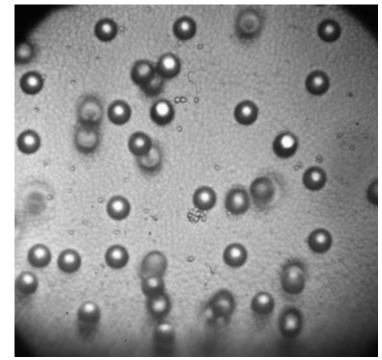
Simulation of Pearl-Chain Formation in Acoustics

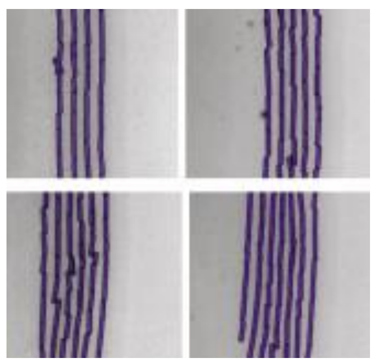
Baasch Thierry, Ivo Leibacher and Jürg Dual
Institute for Mechanical Systems, ETHZ

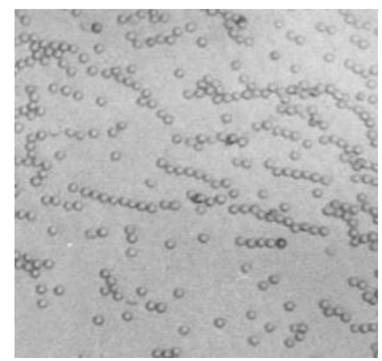
COMSOL CONFERENCE 2016 MUNICH

Motivation









Provide physical insights with Simulation and Experiments

References: 1) Nyborg, Wesley L. "Theoretical criterion for acoustic aggregation." *Ultrasound in medicine & biology* 15.2 (1989): 93-99.
2) Collino, Rachel R., et al. "Acoustic field controlled patterning and assembly of anisotropic particles." *Extreme Mechanics Letters* 5 (2015): 37-46.

ETH zürich

Physical Modelling

Mechanical contact forces

- Smoothed potentials (stiff/non-linear springs etc.)
- Non-smooth potentials

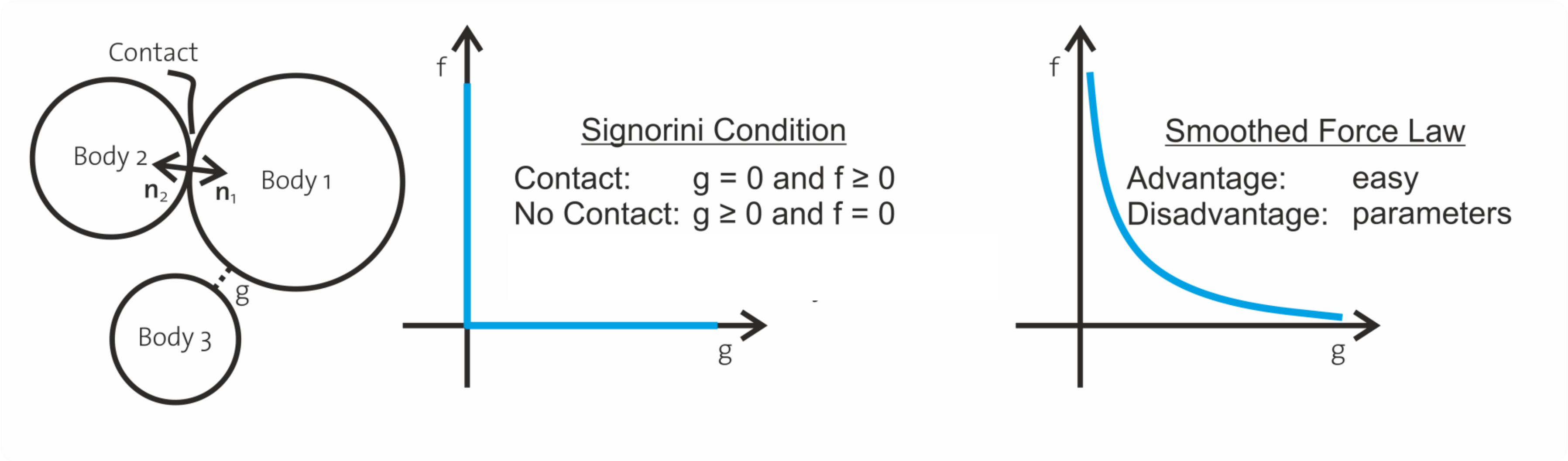
Primary & secondary acoustic radiation forces

- Semi analytically
- COMSOL

First order Stokes drag

- No hydrodynamic interactions are considered

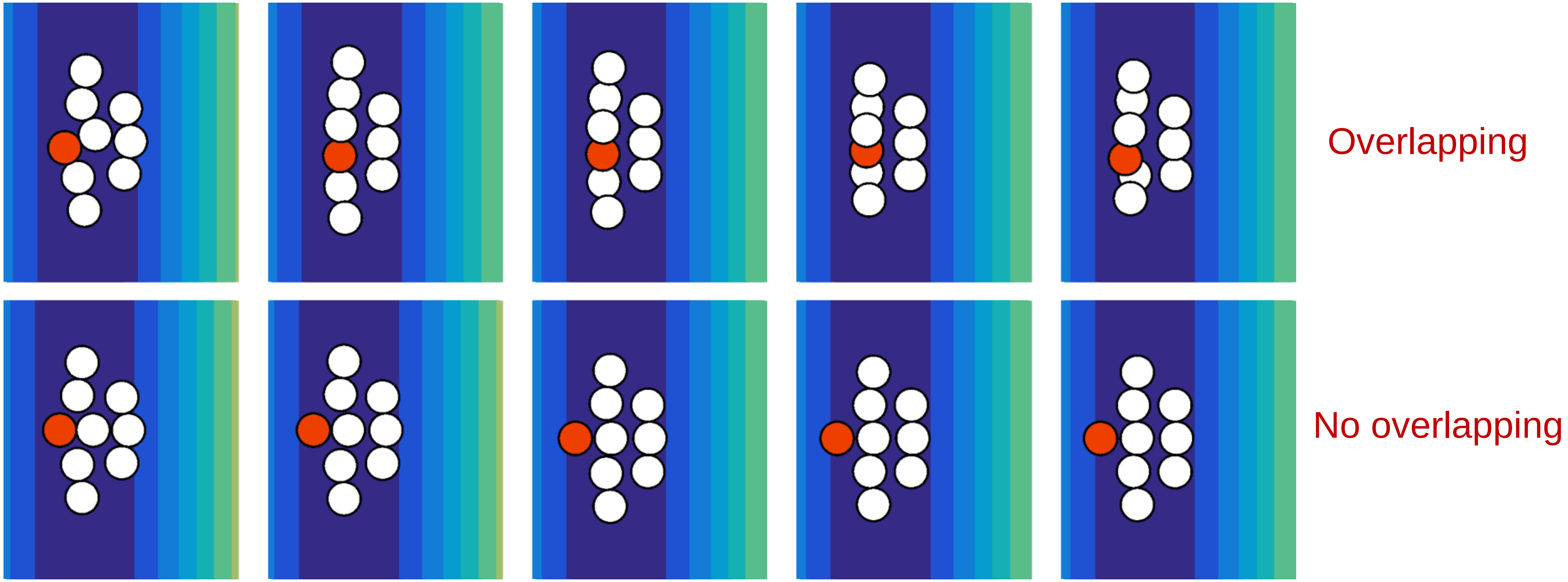
Contact Forces, in the Context of Non-smooth Dynamics



1) Moreau, Jean J. "Unilateral contact and dry friction in finite freedom dynamics." Nonsmooth mechanics and Applications. Springer Vienna, 1988. 1-82

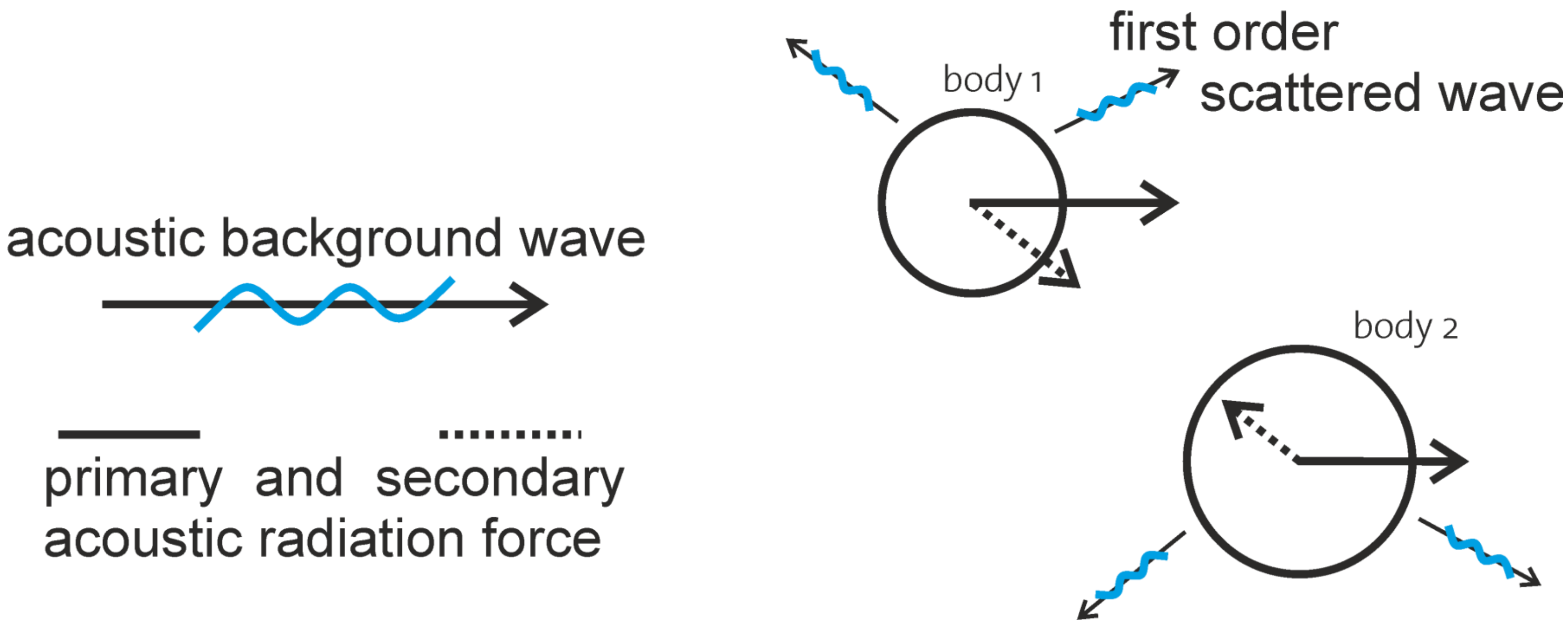
Correction to Numerical Drift

- Standard algorithm is velocity based: Steady drift can occur
- Solved By Drift Correction algorithm!



References: 1) Nützi, Gabriel Elias. *Non-Smooth Granular Rigid Body Dynamics with Applications to Chute Flows*. Diss. ETH Zurich, 2016.

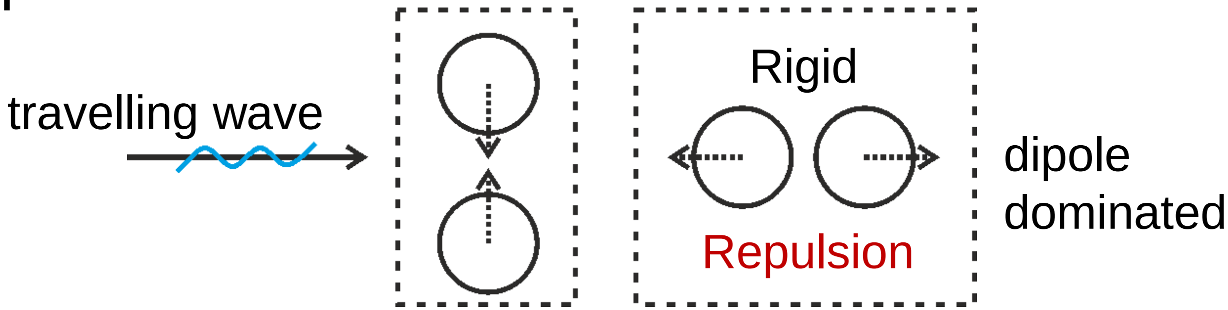
Acoustic Radiation Forces (ARF)



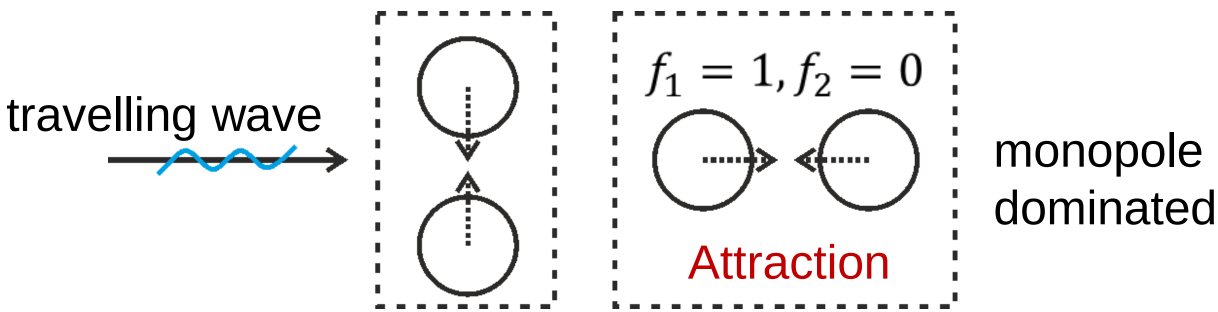
References: 1) Silva, Glauber T., and Henrik Bruus. "Acoustic interaction forces between small particles in an ideal fluid." Physical Review E 90.6 (2014): 063007.
.

Direction of Secondary ARF

- Example 1



- Example 2 (classical Bjerknes, kr≪1)



References: 1) Silva, Glauber T., and Henrik Bruus. "Acoustic interaction forces between small particles in an ideal fluid." Physical Review E 90.6 (2014): 063007.
.

Some considerations in 1D Standing Wave

- Primary acoustic radiation force

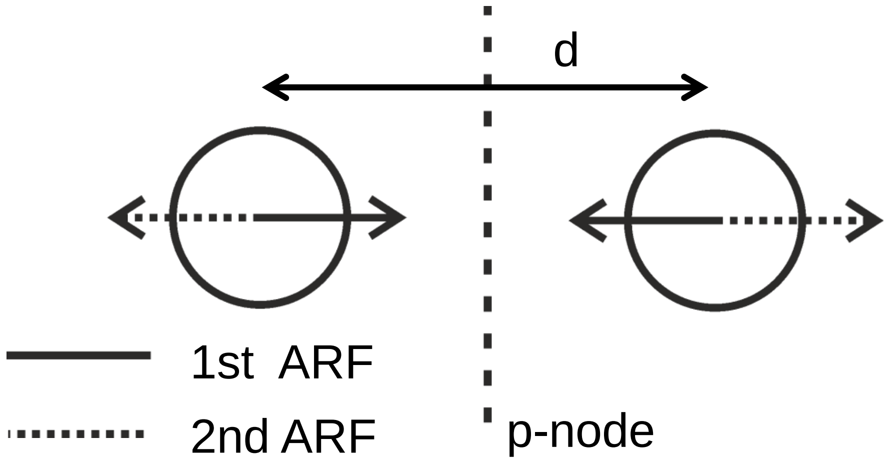
$$F_{rad} = 4\pi\Phi(f_1, f_2)ka^3E_{ac}\sin(2k_y y)$$

- Secondary ARF close to p-node

$$F_{int} \approx \frac{8\pi}{3d^4}a^6E_{ac}(1-\bar{\rho})^2\cos^2(k_y y)(1-3\cos(\phi)),\ \text{for small d}$$

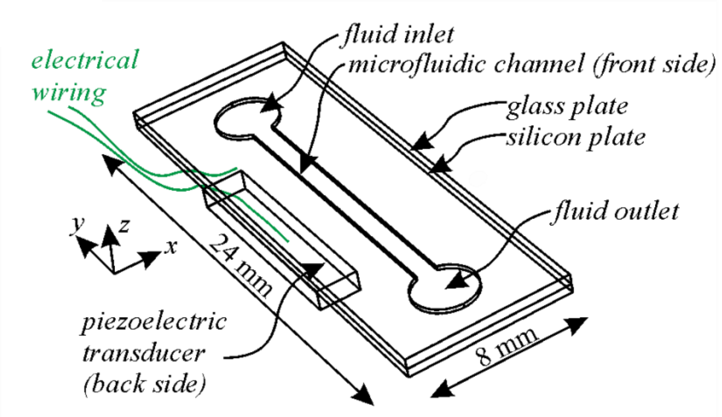
Equilibrium

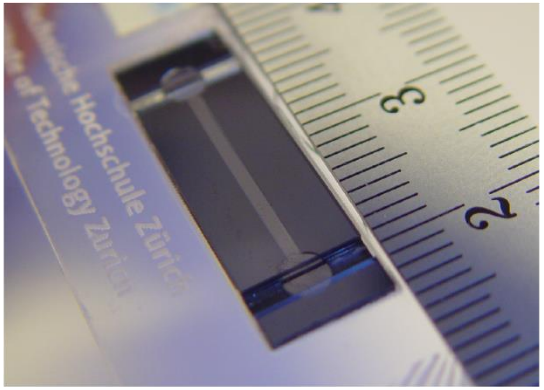
$$\frac{F_{rad}}{F_{int}} = 1 \Rightarrow \bar{d} \propto \left(\frac{1}{a^2k^2}\cdot\frac{\Phi(f_1, f_2)}{(1-\bar{\rho})^2}\right), \bar{d} = \frac{d}{a}$$



Experimental Setup

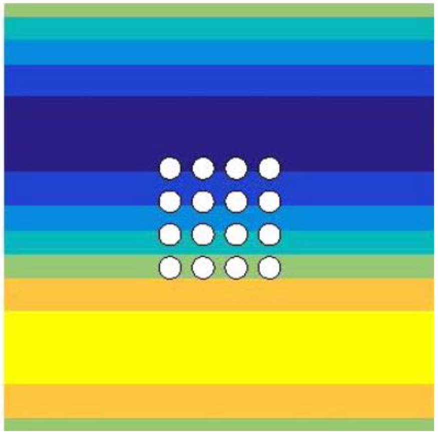
- Bulk acoustic wave device
- Piezo transducer excites resonances
- Channel is etched into silicon wafer
- Glass slide bonded on top

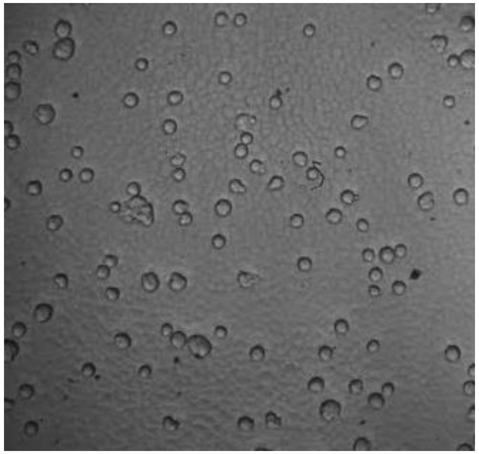




Simulations

Experiments





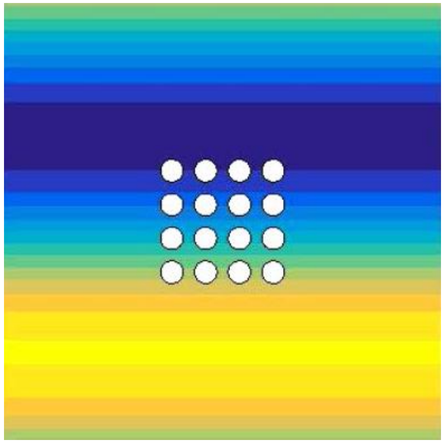
Glass part. (10 μm)

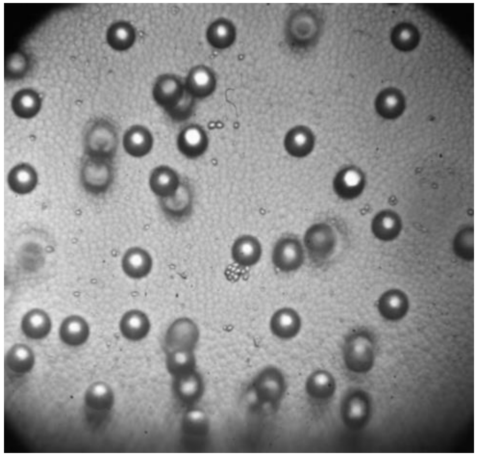
$\rho_p > \rho_w$

Line-formation!

immersed in water

frequency = 1.5 MHz





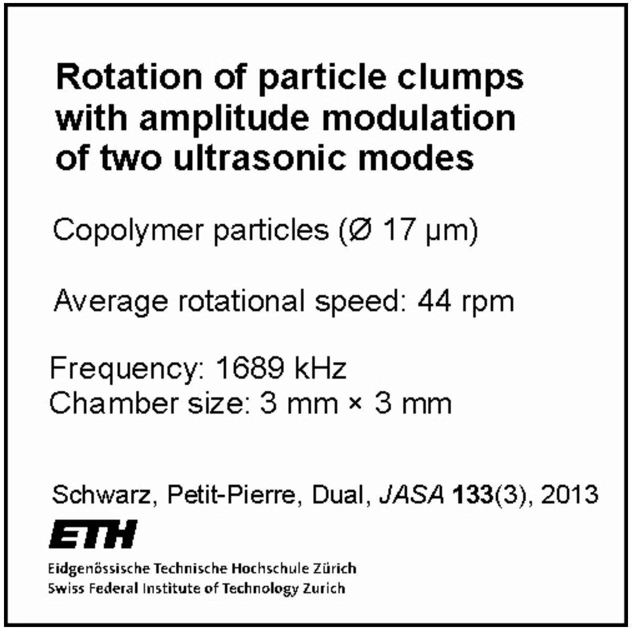
Polystyrene part. (25 μm)

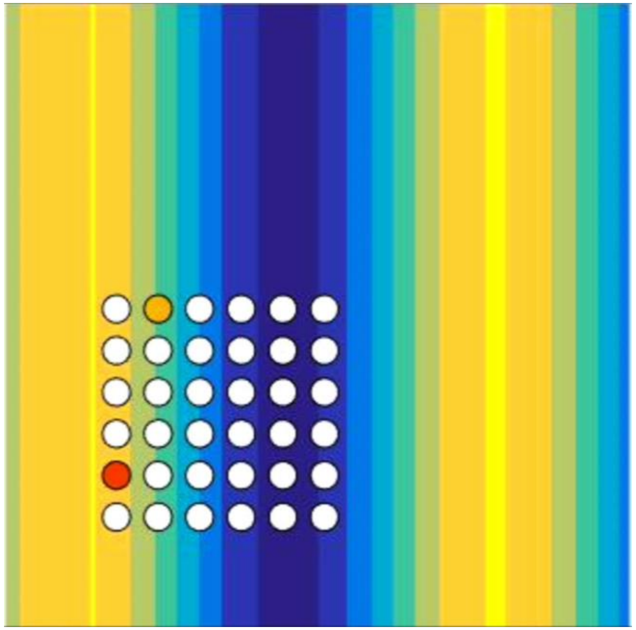
$\rho_p \approx \rho_w$

No line-formation

Rotation of Particle Clumps

- Amplitude modulation of 2 orthogonal waves
- Simulated with copolymer particles (f_1=0.768, f_1=0.034)
- Particle diameter 100μm
- Inspired by the work of Thomas Schwarz





1) Schwarz, Thomas. *Rotation of particles by ultrasonic manipulation*. Diss. Diss., Eidgenössische Technische Hochschule ETH Zürich, Nr. 21572, 2013, 2013.

Comsol

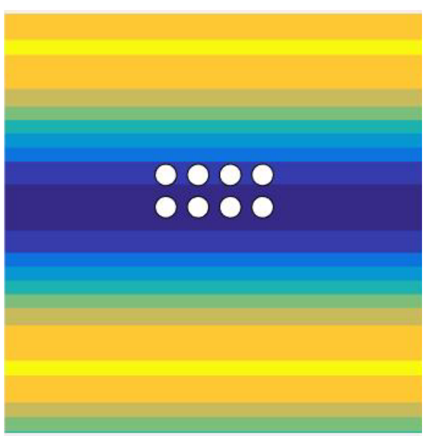
- Simulating complete scattering
- No assumptions regarding: wavelength, scattering coefficients, rescattering events etc.
- Simulations may take more time

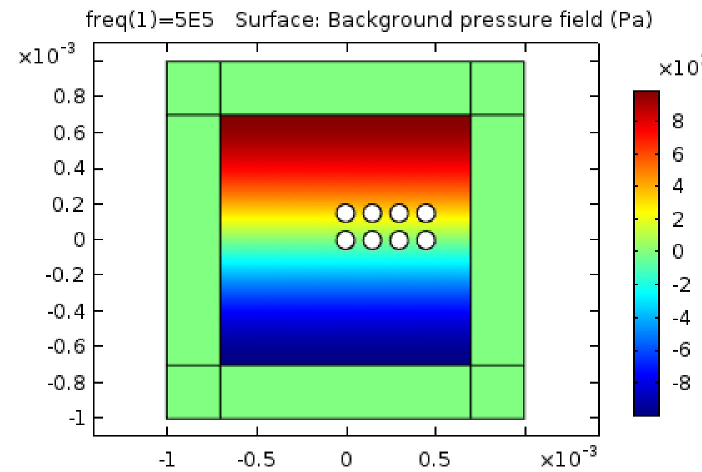
Outlook: Using Comsol (2-D Proof of Principle)

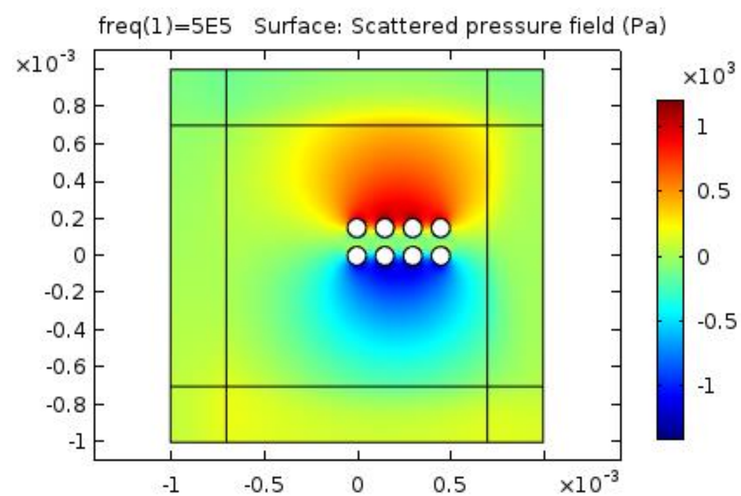
MATLAB
Contact forces

LiveLink

COMSOL
Acoustic forces







Outlook

- Include hydrodynamic effects
- Simulate more particles
- Simulate more complex geometries
- Include acoustic streaming