Acoustic tweezers:

Theory and Applications

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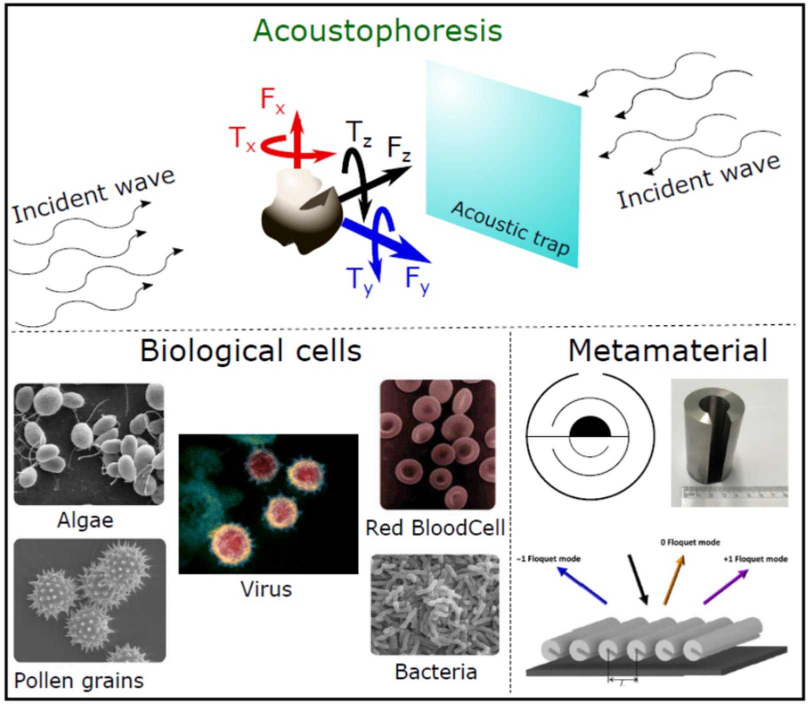
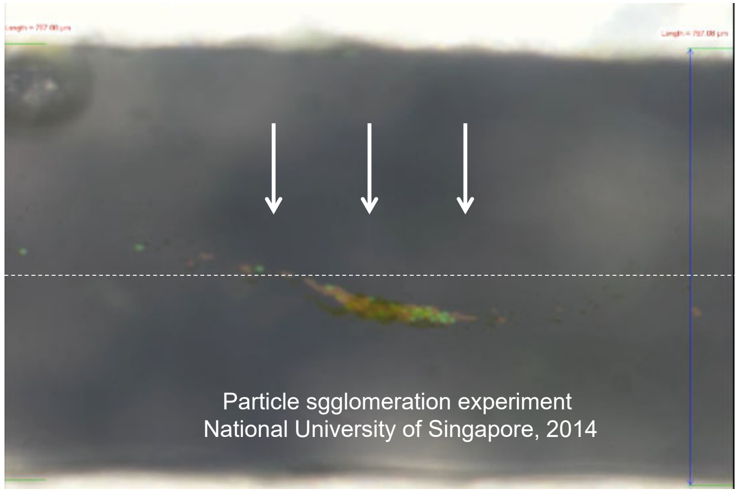
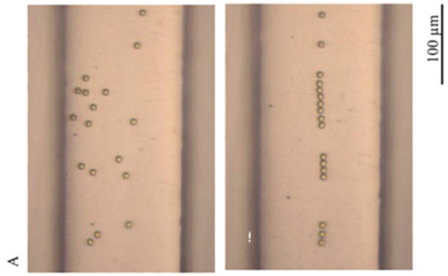
Acousto-phoresis

Manipulation of particles with sound waves







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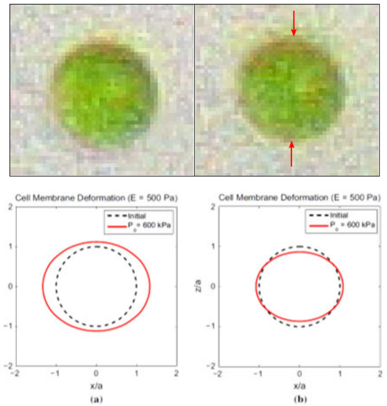
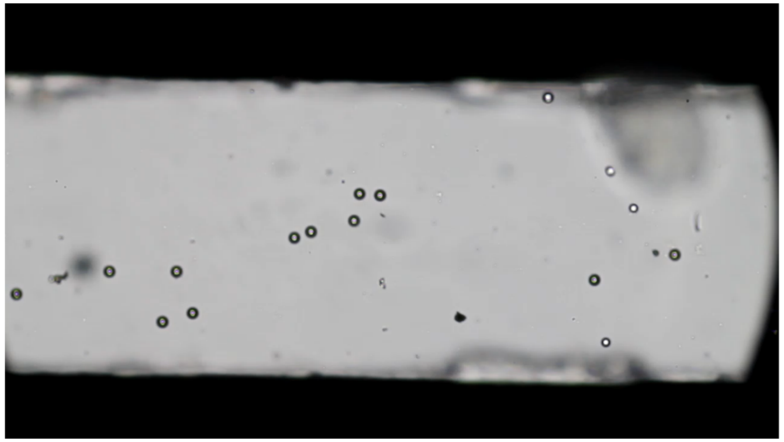
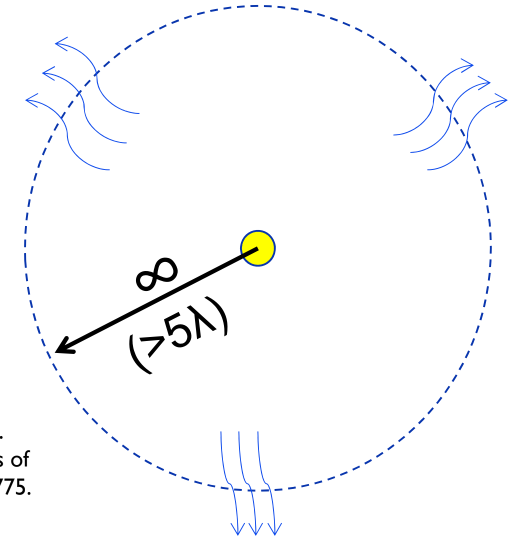




Wijaya, F. B., Mohapatra A. R., **Sepehrirahnama S.**, Lim K.-M. "Coupled acoustic-shell model for experimental study of cell stiffness under acoustophoresis", Microfluid Nanofluid (2016) 20:69

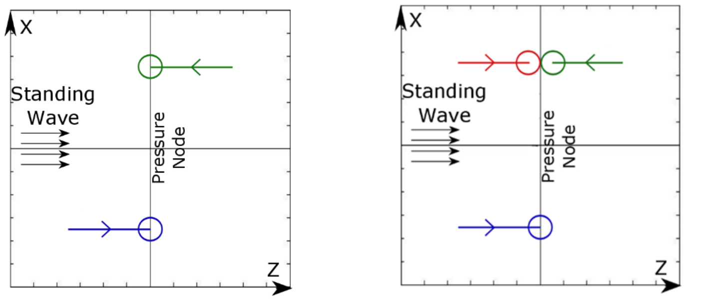
Acoustic Radiation Force



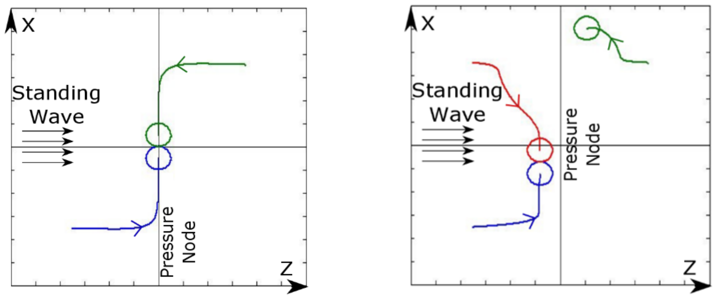
$$\mathbf{F} = -\left\langle \frac{\alpha_{pp}}{2\rho_f}\boldsymbol{\nabla}\left[p_i^2\right]\right\rangle_{r=0} + \left\langle j\omega\boldsymbol{\alpha}_{vv}\mathbf{v}_i\cdot\boldsymbol{\nabla}\mathbf{v}_i\right\rangle_{r=0} + \left\langle \frac{1}{\rho_f}\boldsymbol{\alpha}_{pv}\cdot\left[p_i\boldsymbol{\nabla}\mathbf{v}_i - \mathbf{v}_i\boldsymbol{\nabla}p_i\right]\right\rangle_{r=0}$$

Sepehrirahnama, S., Oberst, S., Chiang, Y. K., & Powell, D. (2021). Acoustic radiation force and radiation torque beyond particles: Effects of non-spherical shape and Willis coupling. arXiv preprint arXiv:2107.01775.

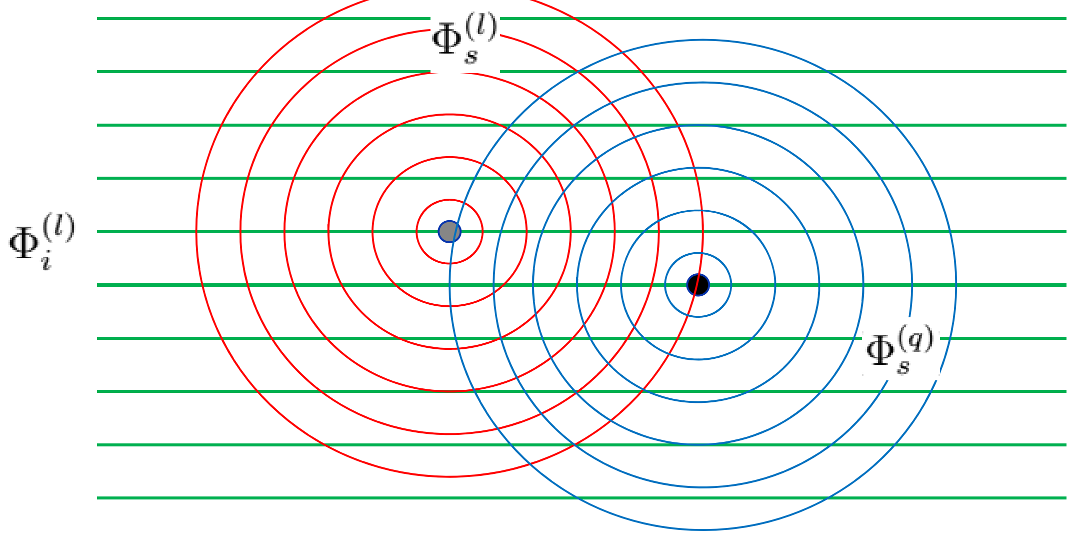
Sepehrirahnama, S., Lim, K. M., & Chau, F. S. (2015). Numerical study of interparticle radiation force acting on rigid spheres in a standing wave. The Journal of the Acoustical Society of America, 137(5), 2614-2622.



(a) without interaction forces (c) without interaction forces

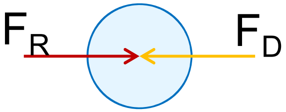


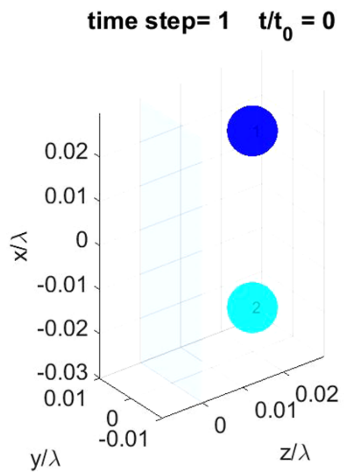
(b) with interaction forces (d) with interaction forces

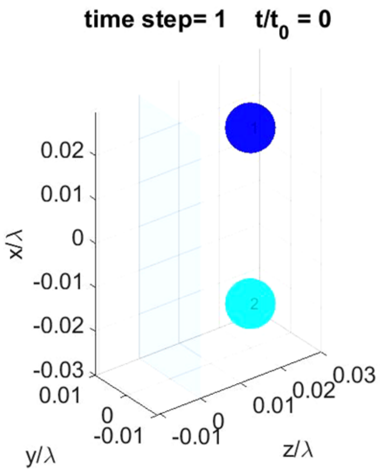


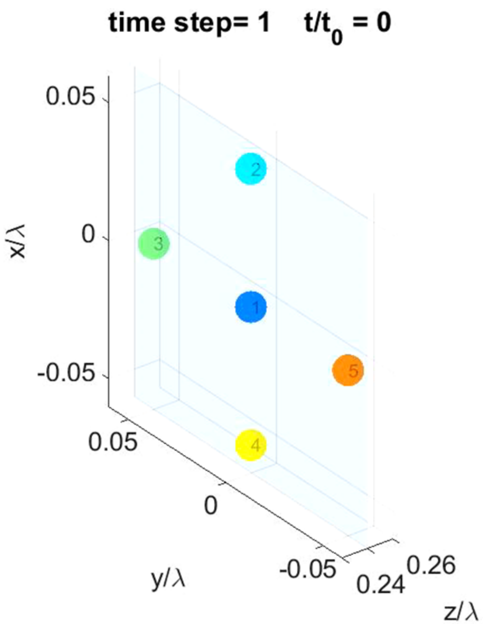
Acoustic agglomeration

1. Acoustic inter-particle force
2. Dynamic equilibrium

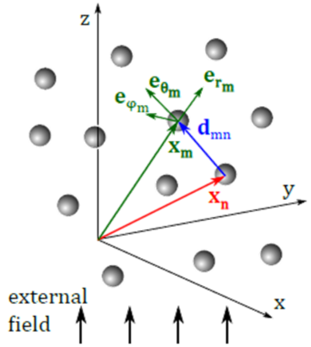


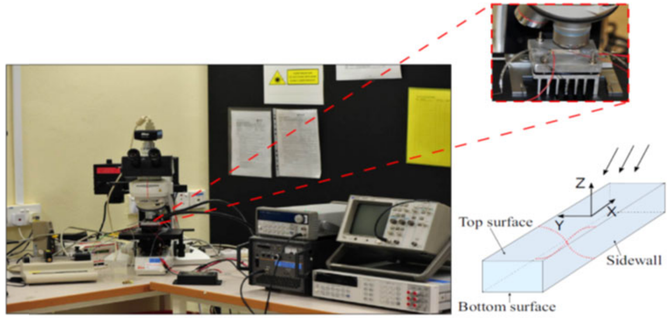


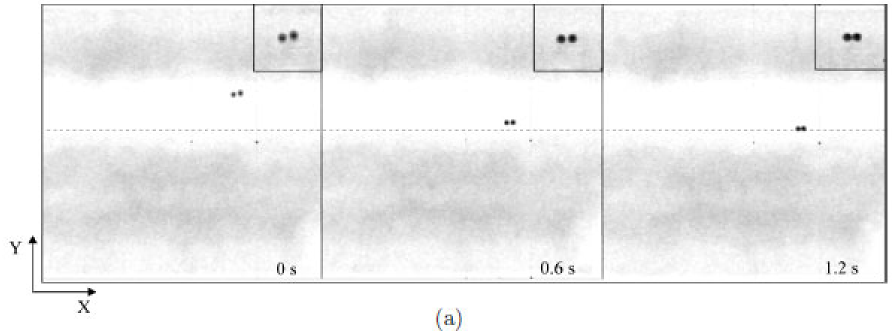


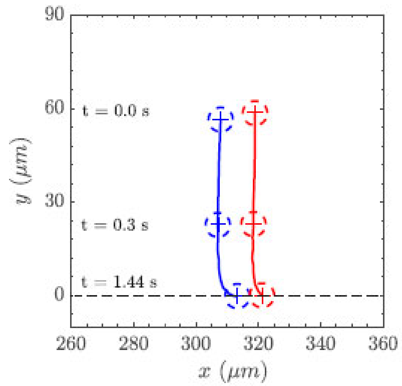


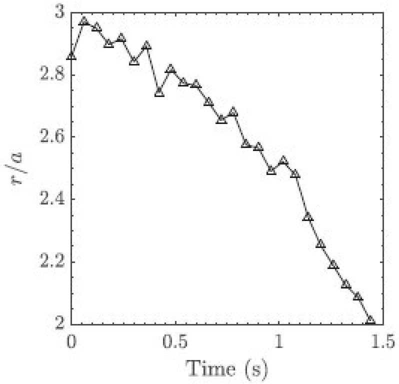
Sepehrirahnama, S., Lim, K. M. (2020). Acoustophoretic agglomeration patterns of particulate phase in a host fluid. Microfluidics and Nanofluidics, 24(12), 1-14.











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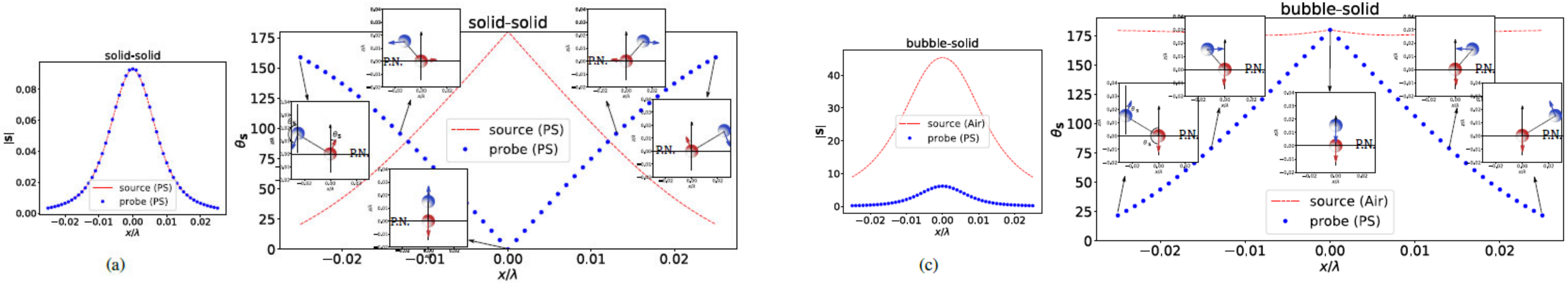
Acoustic Agglomeration

Primary radiation force

$$\mathbf{F}_n^0 = -\nabla G_n^0 \qquad G_n^0 = \Omega_n \left\langle \frac{\kappa_f}{2}\alpha_n p_0^2 - \frac{3}{4}\rho_f \beta_n v_0^2 \right\rangle,$$

Inter-particle radiation force

$$\mathbf{F}_n^m = -\nabla G_n^m \qquad G_n^m = \Omega_n \left\langle \kappa_f \alpha_n \left(p_m p_0 + \frac{1}{2} p_m^2 + \frac{1}{2} \sum_{\substack{l=1 \\ l \neq m,n}}^{N} p_m p_l \right) - \frac{3}{2}\rho_f \beta_n \left(\mathbf{v}_m \cdot \mathbf{v}_0 + \frac{1}{2} v_m^2 + \frac{1}{2} \sum_{\substack{l=1 \\ l \neq m,n}}^{N} \mathbf{v}_m \cdot \mathbf{v}_l \right) \right\rangle$$



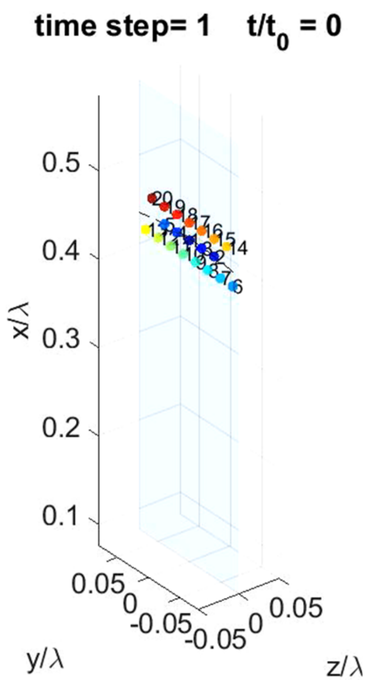
(a) (b) (c) (d)

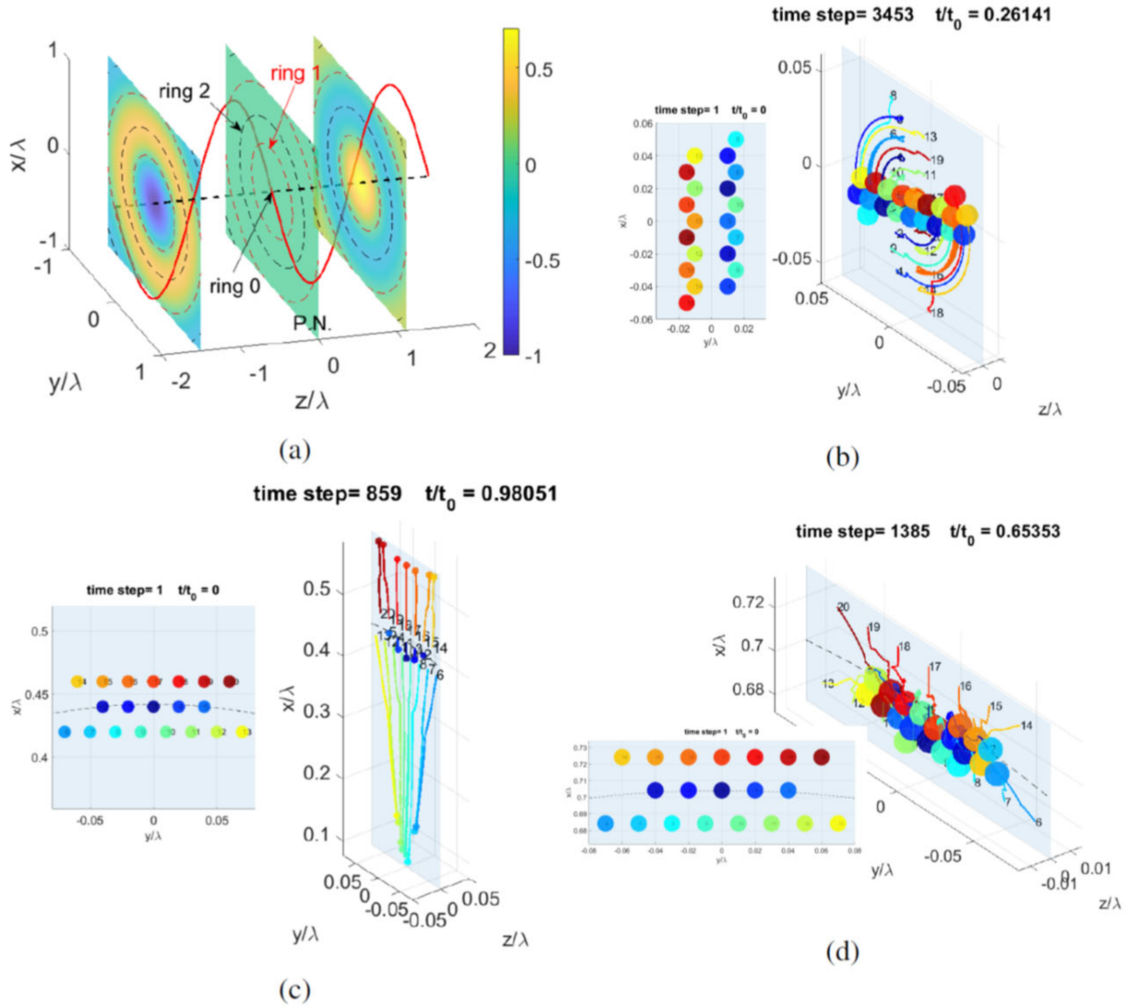
Sepehrirhnama, S., Lim, K. M. (2020). Generalized potential theory for close-range acoustic interactions in the Rayleigh limit. Physical Review E, 102(4), 043307.

Acoustic agglomeration

1. Cluster formation
2. Cluster dynamics

$$p = AJ_0(k_R R)\cos(k_z z + \pi/2)e^{-i\omega t}$$

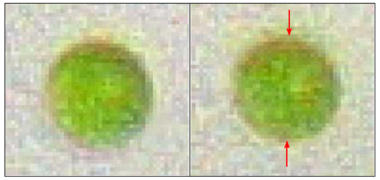


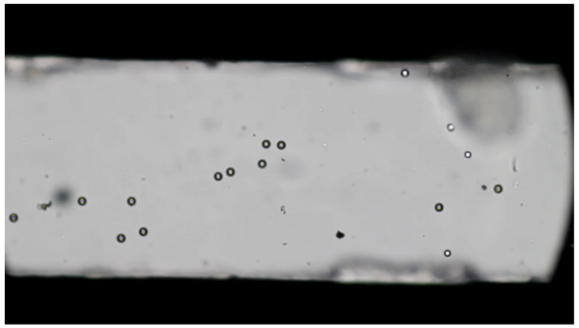


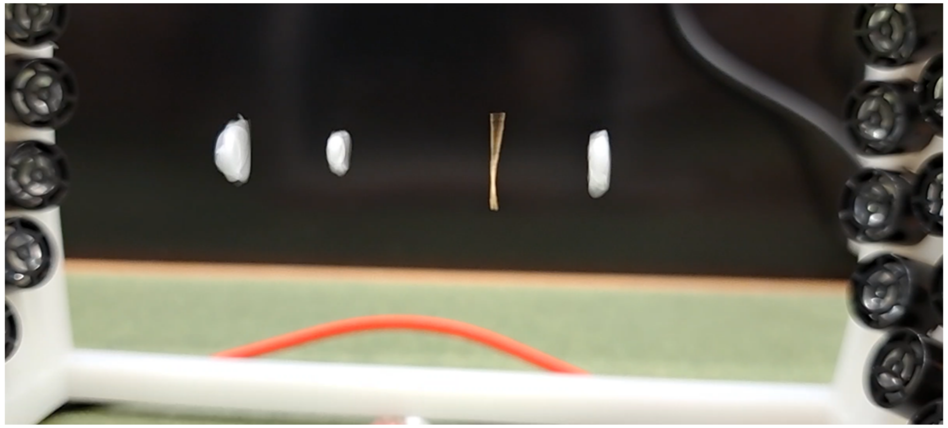
Sepehrirahnama, S., & Lim, K. M. (2020). Acoustophoretic agglomeration patterns of particulate phase in a host fluid. Microfluidics and Nanofluidics, 24(12), 1-14.

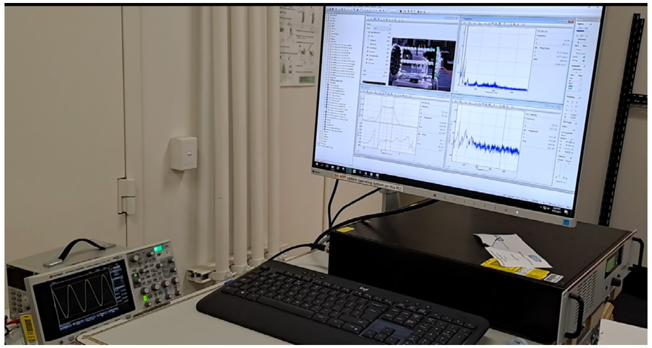
Applications

1. Single excitation
2. Dual excitation
3. Manipulation of membrane or beam-like structures
4. Microfluidics









Shape effects

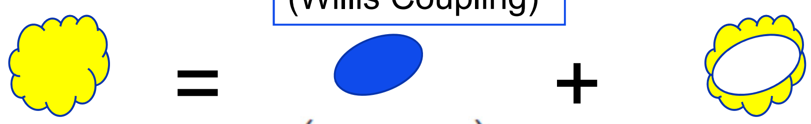
monopole
dipole

$$\begin{bmatrix} M \\ \mathbf{D} \end{bmatrix} = \frac{1}{\Omega} \begin{pmatrix} \alpha_{pp} & \boldsymbol{\alpha}_{pv}^T \\ \boldsymbol{\alpha}_{vp} & \boldsymbol{\alpha}_{vv} \end{pmatrix} \begin{bmatrix} p_i \\ \mathbf{v}_i \end{bmatrix}$$

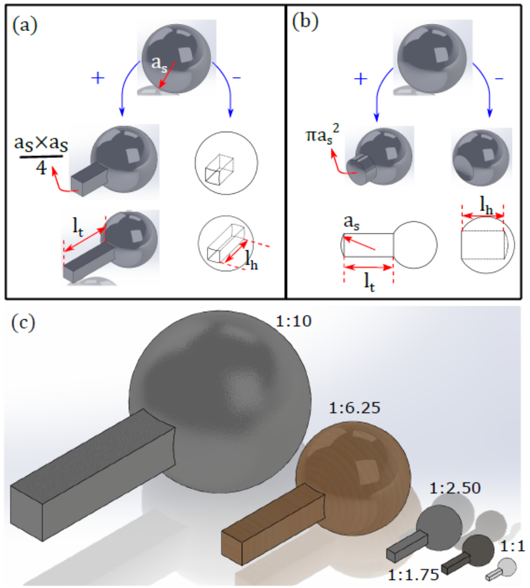
incident field

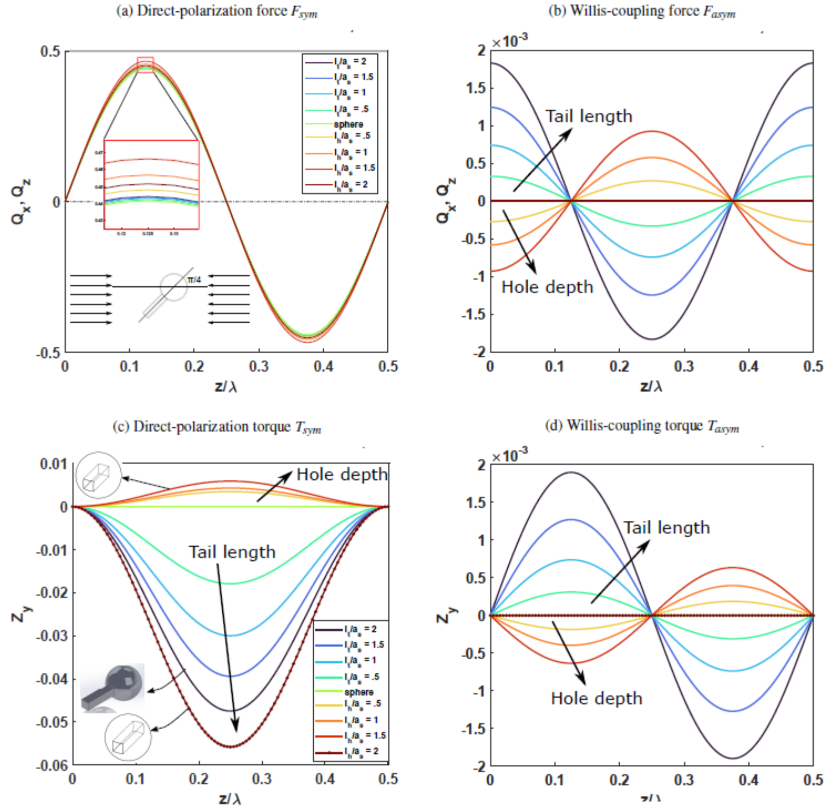
Asymmetry (Willis Coupling)

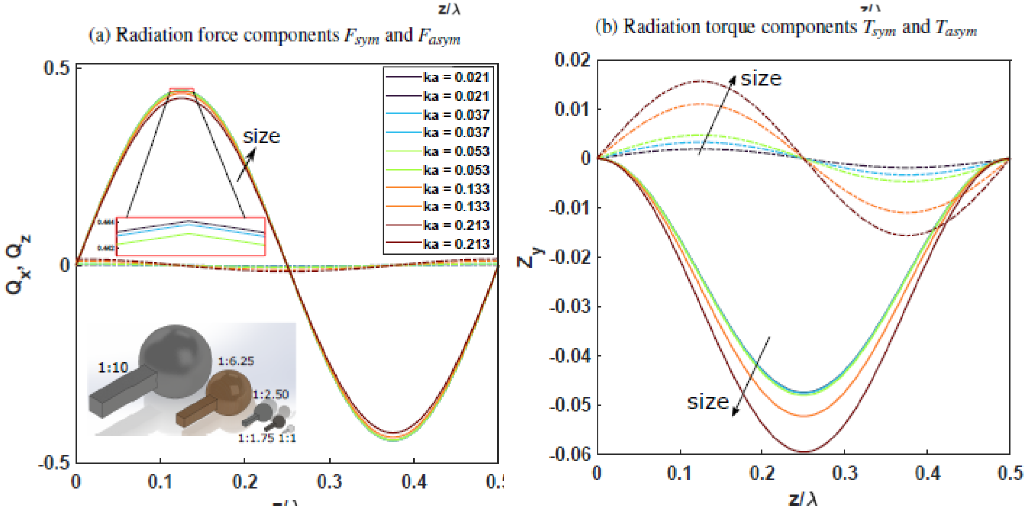
Symmetry



$$= \begin{pmatrix} \alpha_{pp} & 0 \\ 0 & \boldsymbol{\alpha}_{vv} \end{pmatrix} + \begin{pmatrix} 0 & \boldsymbol{\alpha}_{pv}^T \\ \boldsymbol{\alpha}_{vp} & 0 \end{pmatrix}$$







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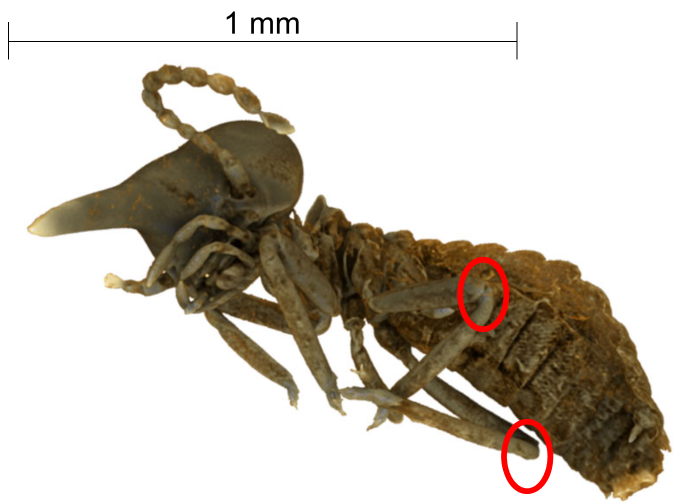
Future…

1. Opto-acoustophoresis - multiscale tweezers for biological applications
   - Collaboration with Photonics Lab @ UTS Techlab

2. Bio-acoustic and biogenic materials - study of insect sensory appendages
   - PhD project on termite legs and antenna

3. Ultrasound multi-tweezing
   - High precision manipulation of multiple objects
   - Contactless modal analysis
   - Ultrasound meta-materials



Voxel size of 800 nm

Subgenual Organ (SO)
Courtesy of Travers Sansom

Advanced manipulation platform for structures from millimetres to micrometres

Research Funding and collaborators

UTS
UNIVERSITY OF TECHNOLOGY, SYDNEY

Australian Government
Australian Research Council

DEFENCE INNOVATION NETWORK
To go far, go together

Australian Government
Department of Defence

Collaborators:

David Powell, Senior Lecturer, ADFA, UNSW, Canberra

Yan Kei Chiang, Postdoctoral Research Fellow, ADFA, UNSW, Canberra

Travers Sansom, PhD Student, UTS, Sydney

Thank you!

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