The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

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Introduction to Optofluidics

1 - 5 June 2009

Statistical microhydrodynamics: fluid phenomena at the micron scale

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Statistical microhydrodynamics: fluid phenomena at the micron scale

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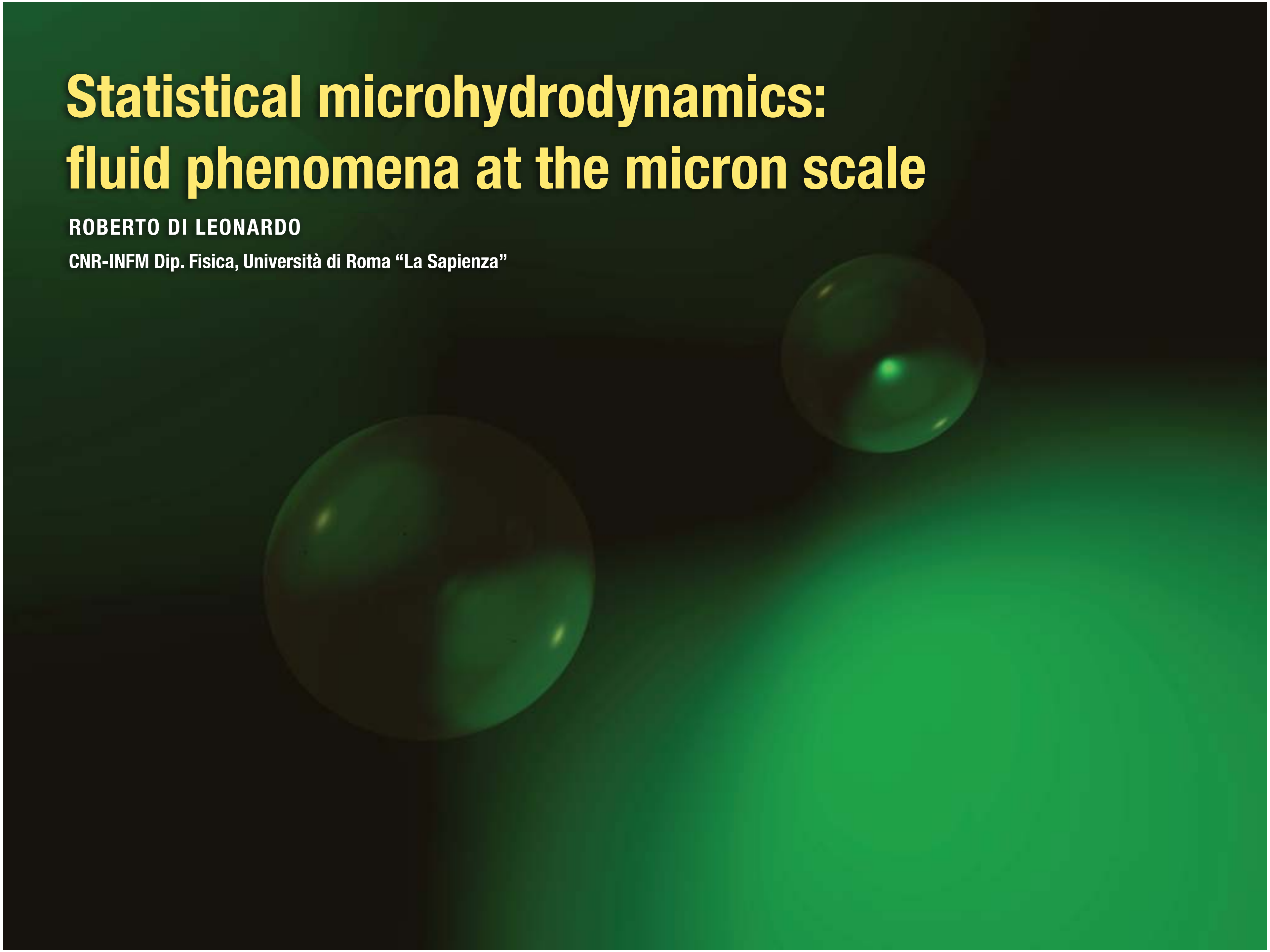


Mesoscopic world

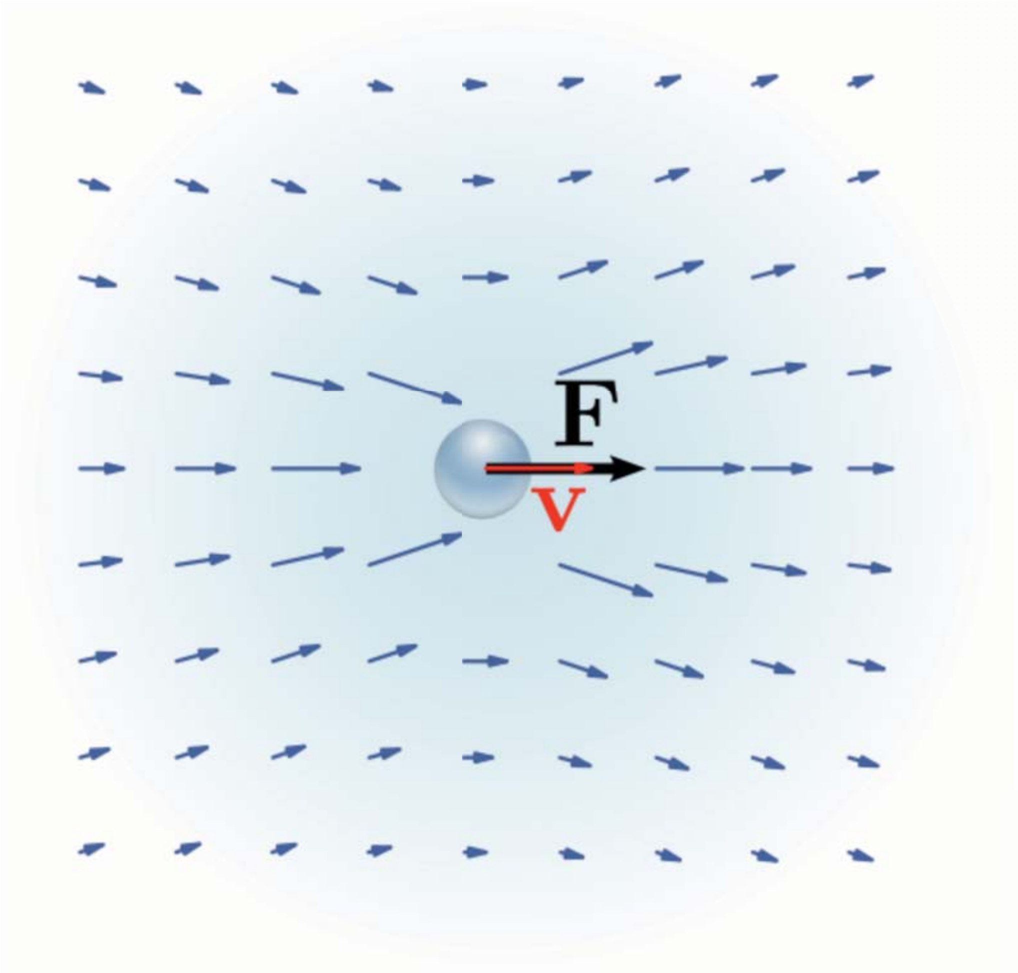
MESOSCOPIC

- inertialess dynamics
- surface forces
- noisy environment
- light pushes

INERTIALESS DYNAMICS

Hydrodynamic interactions

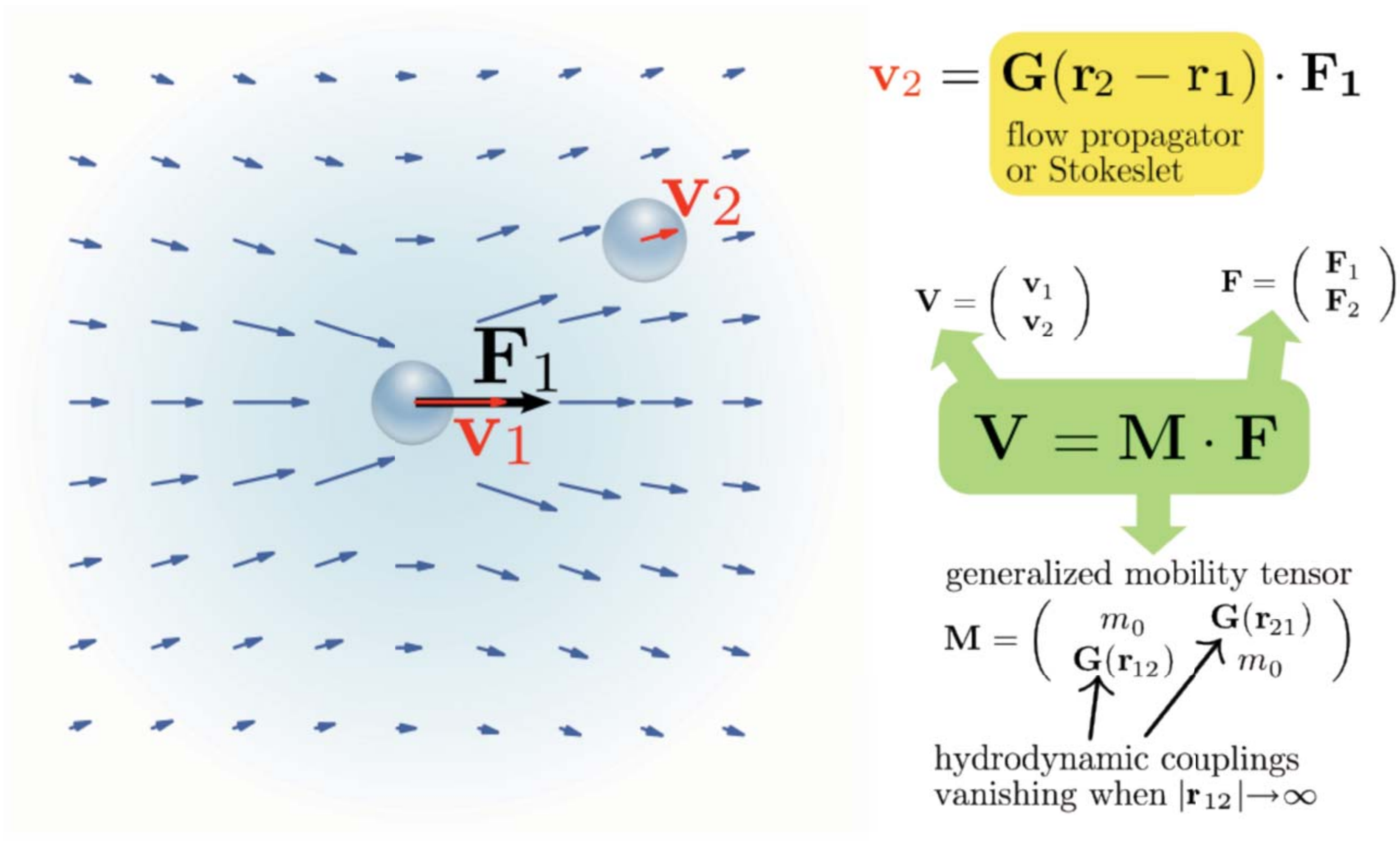
Hydrodynamics interactions



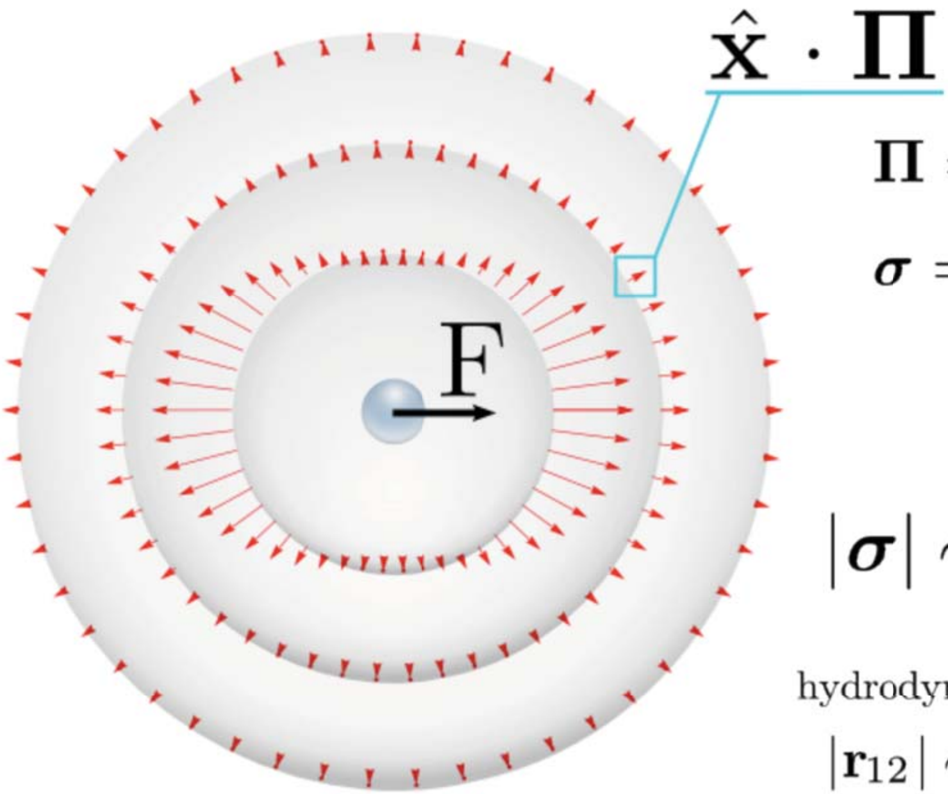
$$\mathbf{v} = m_0 \cdot \mathbf{F}$$

mobility $m_0 = \dfrac{1}{6\pi\mu a}$

Hydrodynamics interactions



Hydrodynamics interactions



$$\mathbf{\Pi} = p\mathbb{1} - \boldsymbol{\sigma}$$

$$\boldsymbol{\sigma} = \eta \left(\nabla \boldsymbol{v} + \nabla \boldsymbol{v}^T \right)$$

$$\downarrow$$

$$|\boldsymbol{\sigma}| \sim \frac{1}{r^2} \Rightarrow |\boldsymbol{v}| \sim \frac{1}{r}$$

hydrodynamic interactions are long ranged

$$|\mathbf{r}_{12}| \sim 100a \Rightarrow G/m_0 \sim 10^{-2}$$

Hydrodynamic interactions of trapped beads

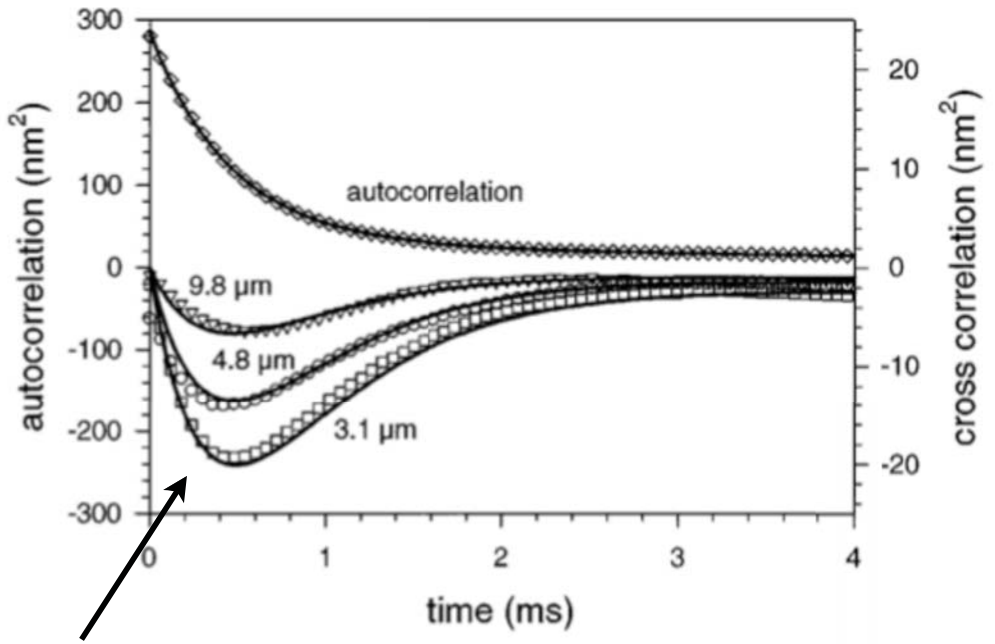
VOLUME 82, NUMBER 10 PHYSICAL REVIEW LETTERS 8 MARCH 1999

Direct Measurement of Hydrodynamic Cross Correlations between Two Particles in an External Potential

Jens-Christian Meiners and Stephen R. Quake

Department of Applied Physics, California Institute of Technology, Pasadena, California 91125

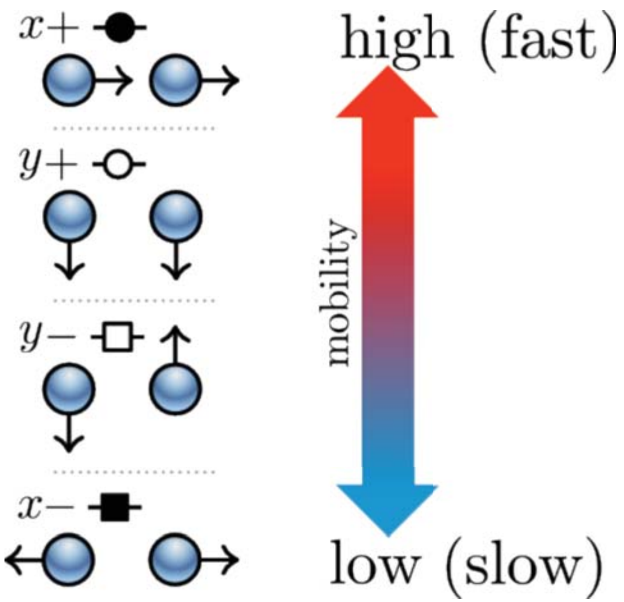
(Received 22 October 1998)



$$\langle x_1(0)x_2(t)\rangle$$

Hydrodynamic eigenmodes

EIGENMODES OF THE MOBILITY MATRIX



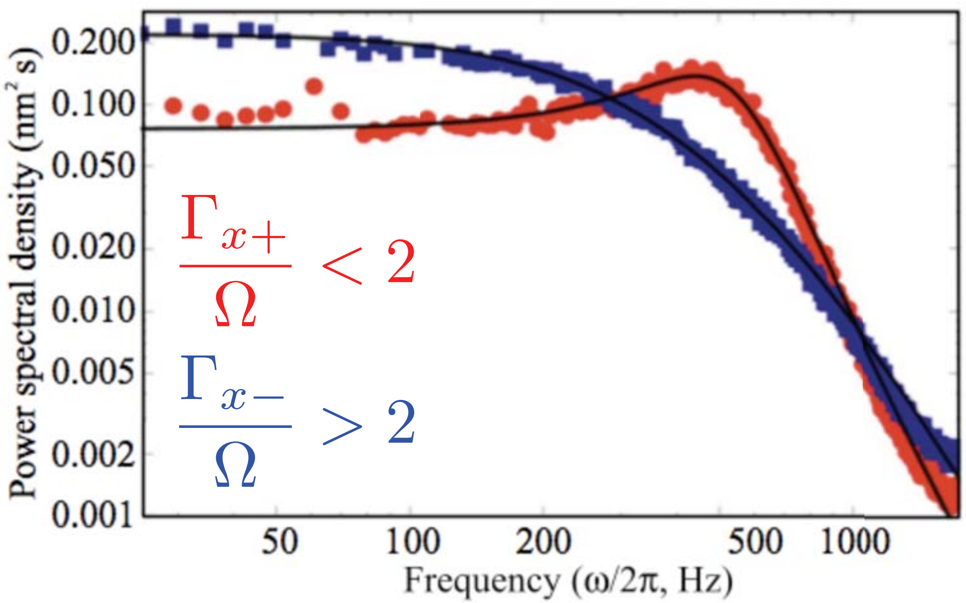
DECOUPLED LANGEVIN DYNAMICS

$$\ddot{Q}_j(t) + \Omega^2 Q_j(t) + \Gamma_j \dot{Q}(t) = \xi_j(t)$$

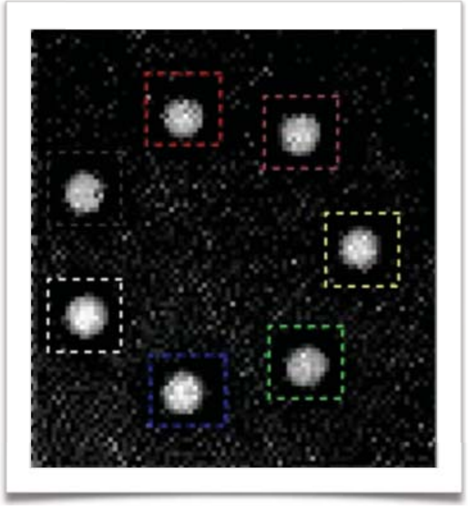
$j = x+, y+, y-, x-$

HYDRODYNAMICALLY COUPLED LIQUID DROPLETS

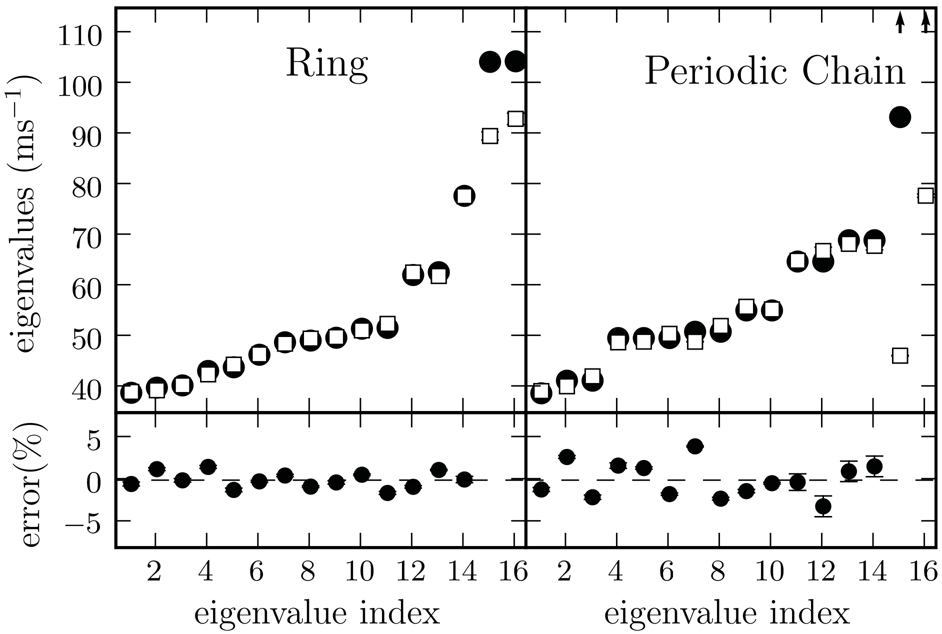
YAO et al. NJP (2009)

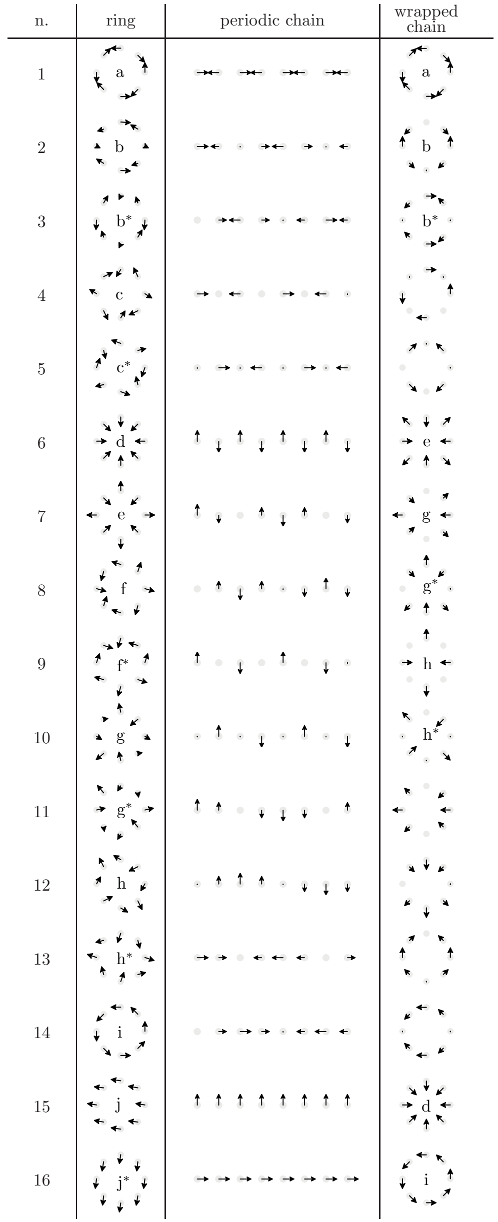


Hydrodynamic eigenmodes



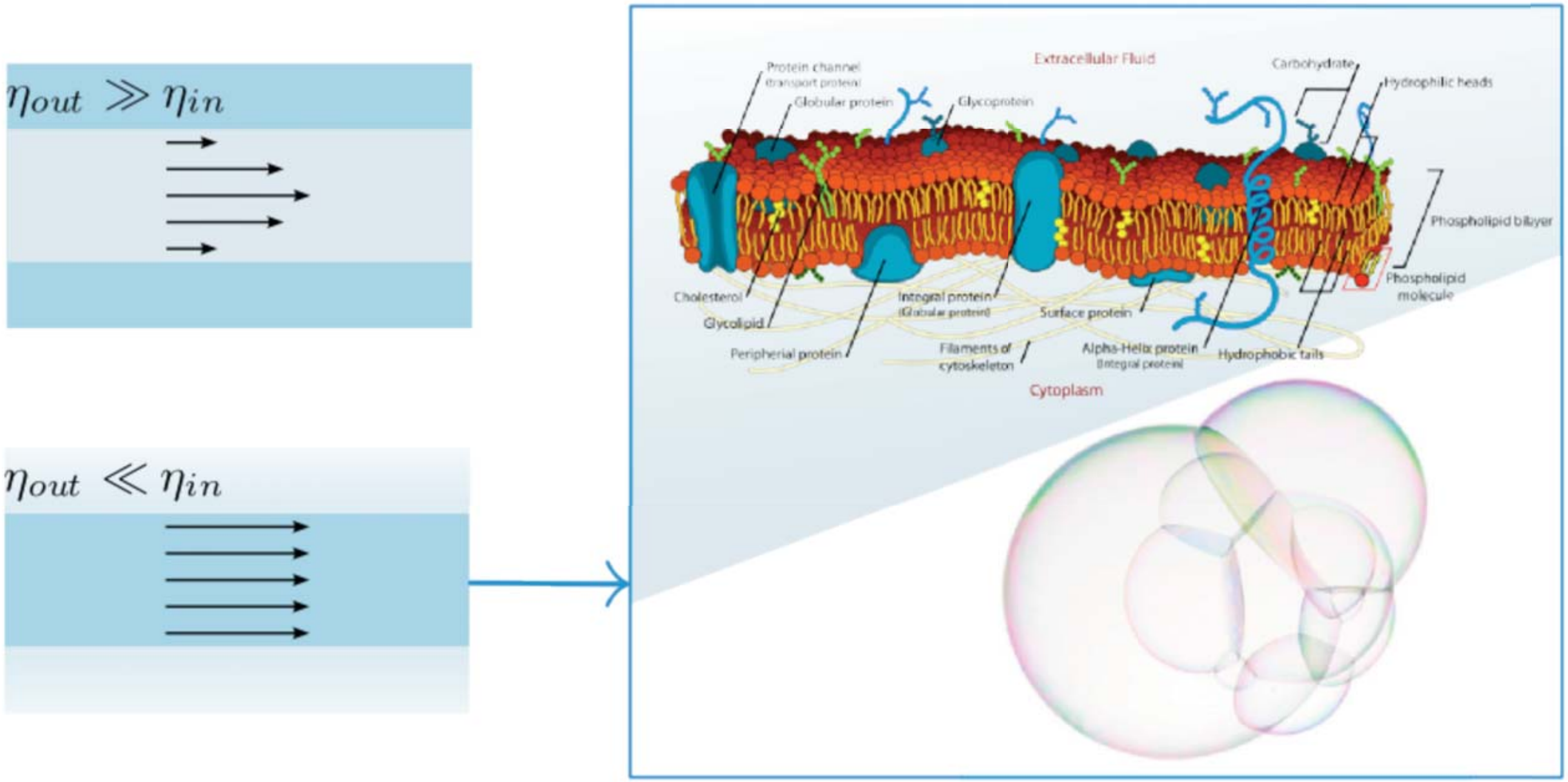
DI LEONARDO et al. PRE (2007)



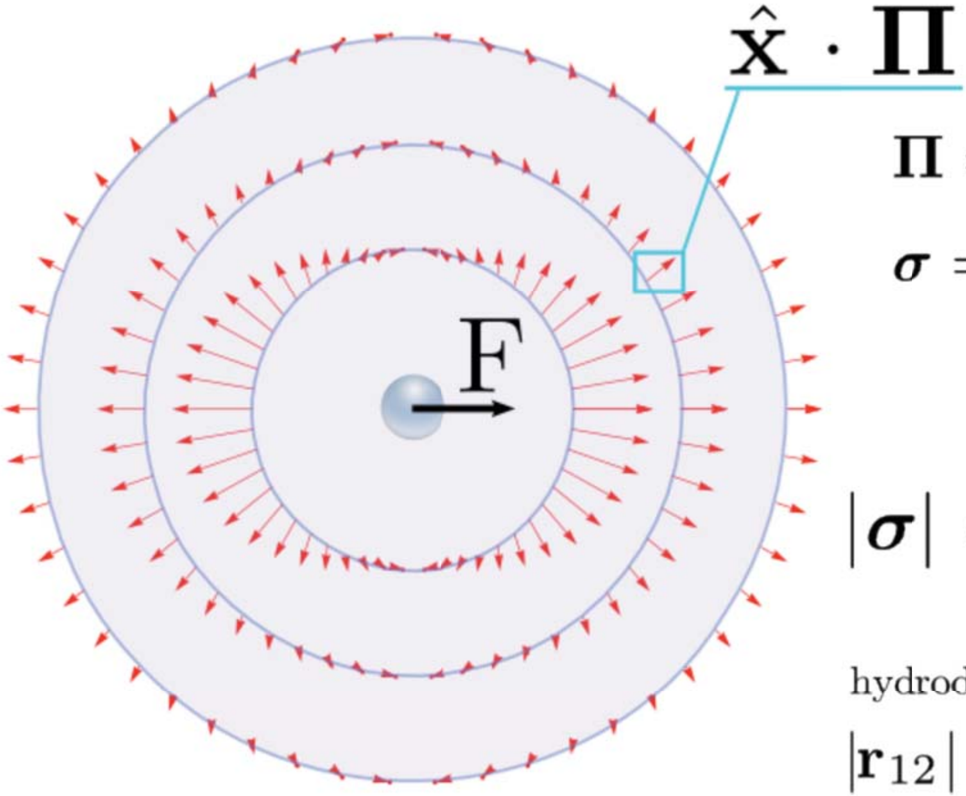


Hydrodynamics interactions in 2D

$$2\text{D} \text{ :one dimension is irrelevant} \implies \frac{\partial}{\partial z}\left[\,\cdots\,\right] = 0$$



Hydrodynamics interactions



$$\mathbf{\Pi} = p\mathbb{1} - \boldsymbol{\sigma}$$

$$\boldsymbol{\sigma} = \eta \left(\nabla \boldsymbol{v} + \nabla \boldsymbol{v}^T \right)$$

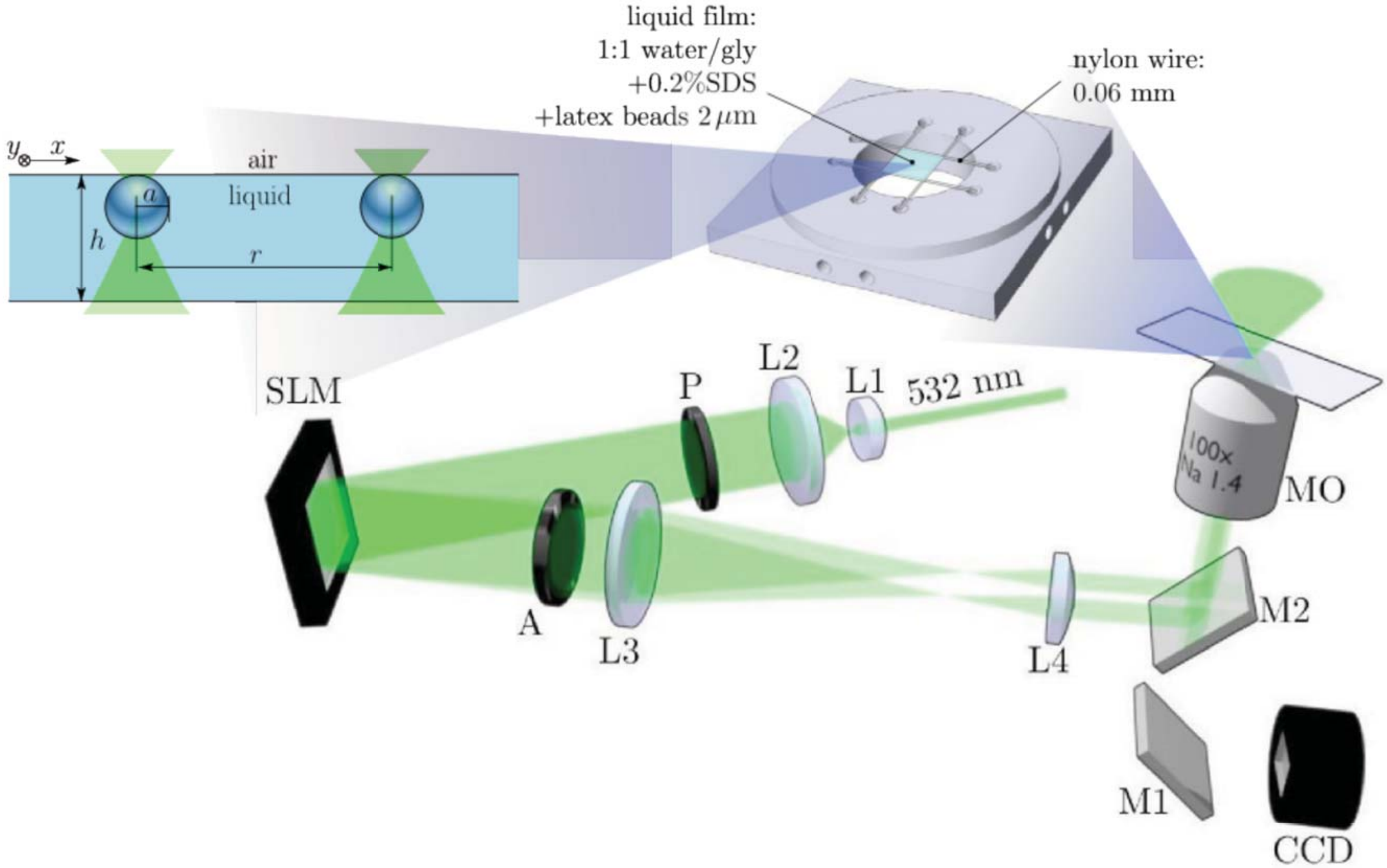
$$\downarrow$$

$$|\boldsymbol{\sigma}| \sim \frac{1}{r} \Rightarrow |\boldsymbol{v}| \sim \log(r)$$

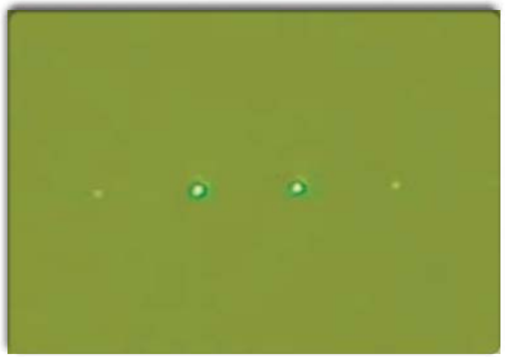
hydrodyn. inter. are <u>extremely long ranged</u>

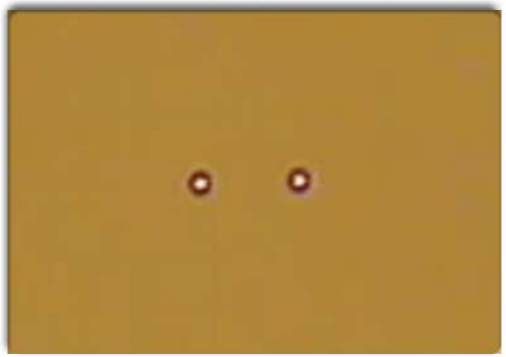
$$|\mathbf{r}_{12}| \sim 100a \Rightarrow G/m_0 \sim 1 \text{ !!!}$$

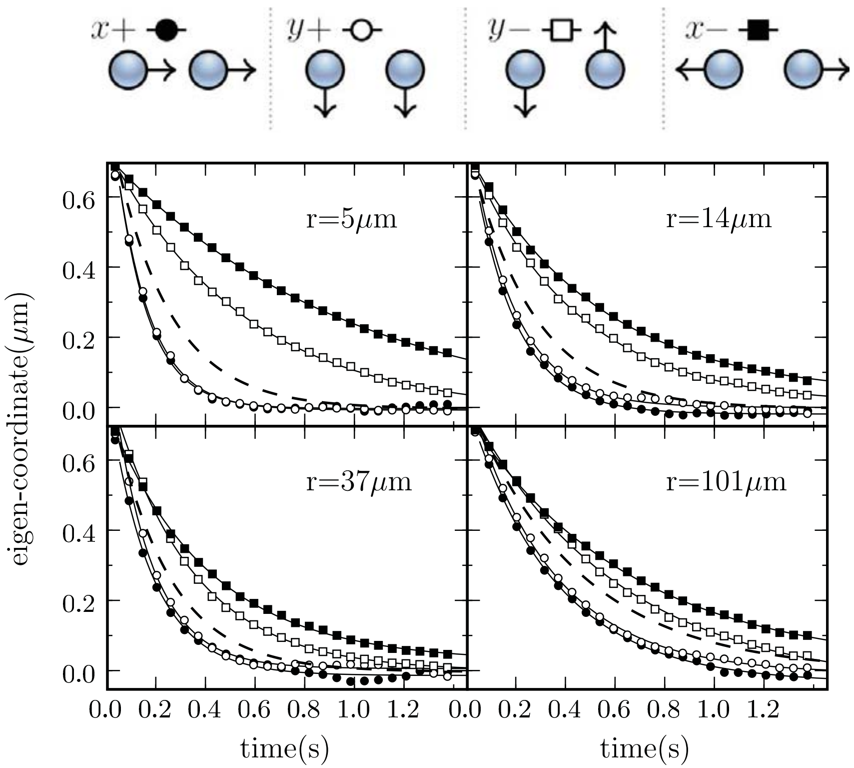
Trapping in a soap film



Hydrodynamics interactions in 2D

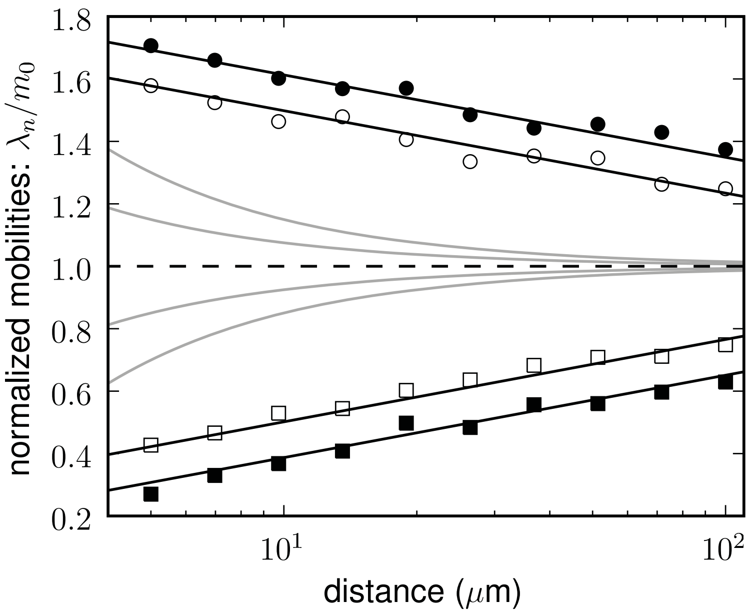






the power you need to transport an array of N particles doesn't depend on N

⇑

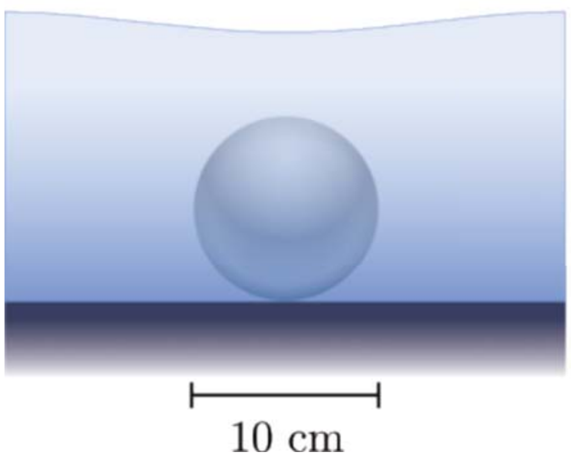


SURFACE FORCES

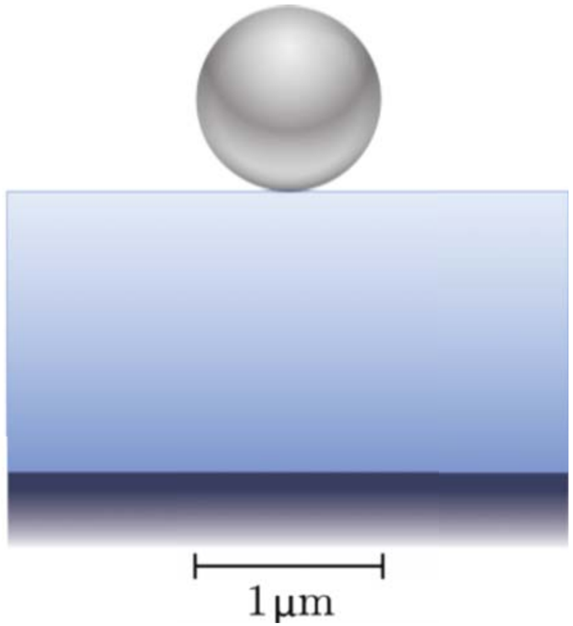
Capillary interactions

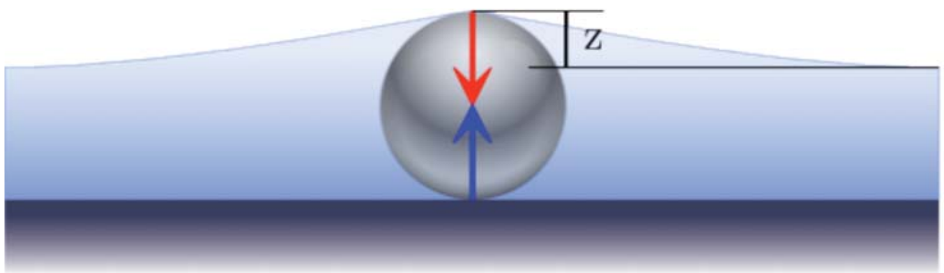
Capillary interactions

MACROSCOPIC



MESOSCOPIC

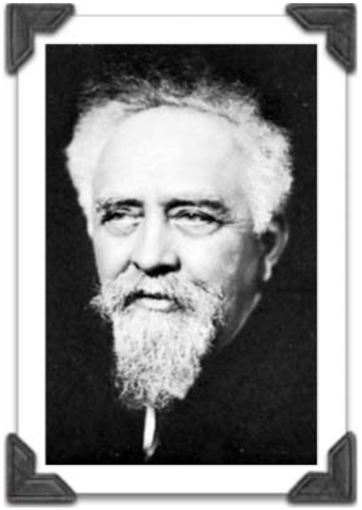




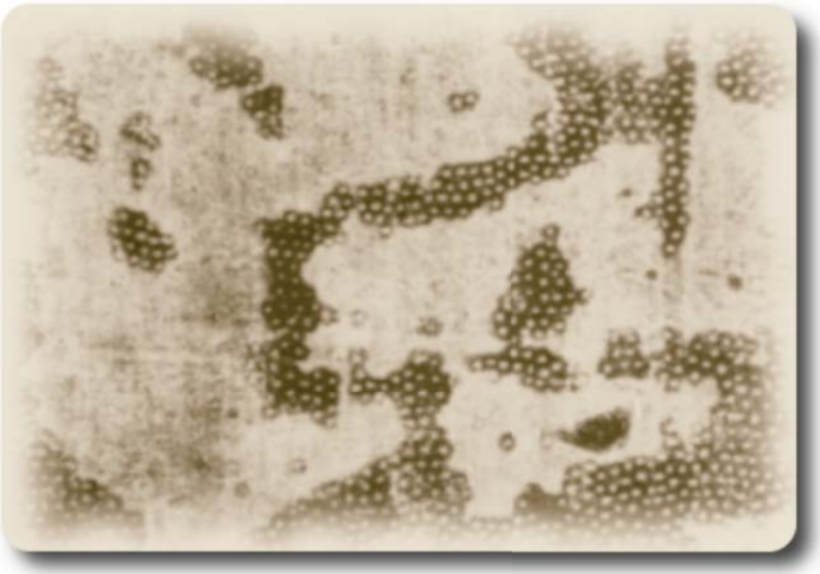
$$\rightarrow F = -kz$$

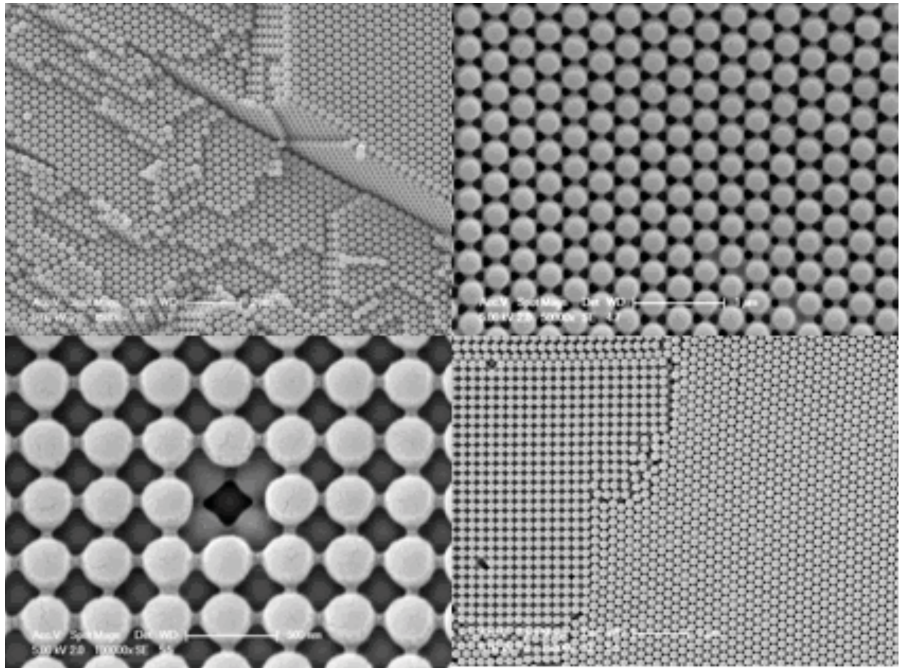
$$k \simeq 4\pi\gamma = 1 \text{ nN/nm}$$

Capillary interactions

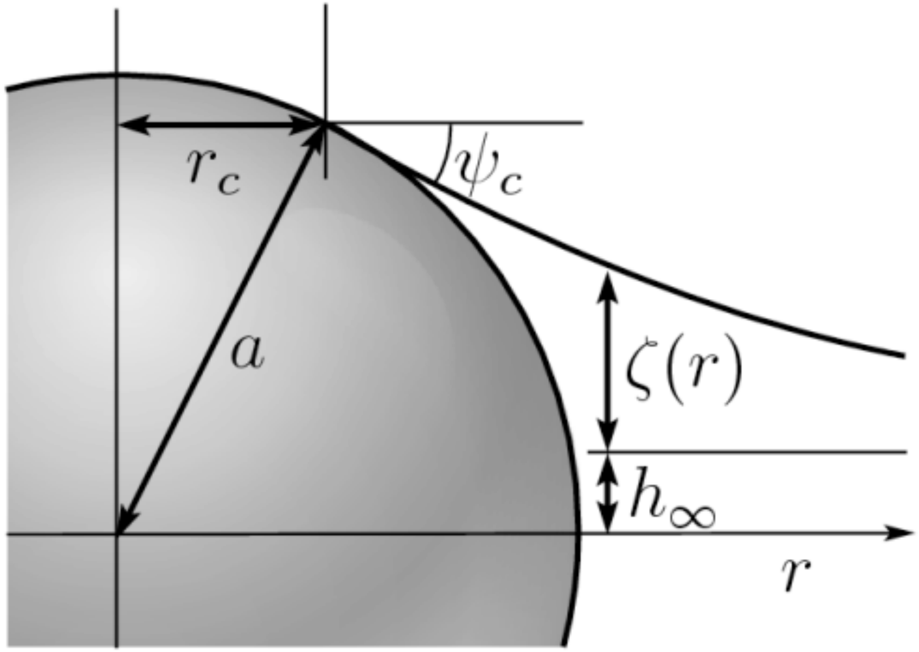


J. PERRIN J. ANN. CHIM. PHYS. (1909)





Capillary interactions



$$F(r) = 2 \;\; 2\pi r_c \;\; \psi_c \gamma \;\; \frac{\partial \zeta}{\partial r}$$

small gradient approximation:

$$\gamma \nabla^2 \zeta = \rho g \zeta$$

$$\Downarrow$$

$$\zeta(r) = -r_c \psi_c \log(qr)$$

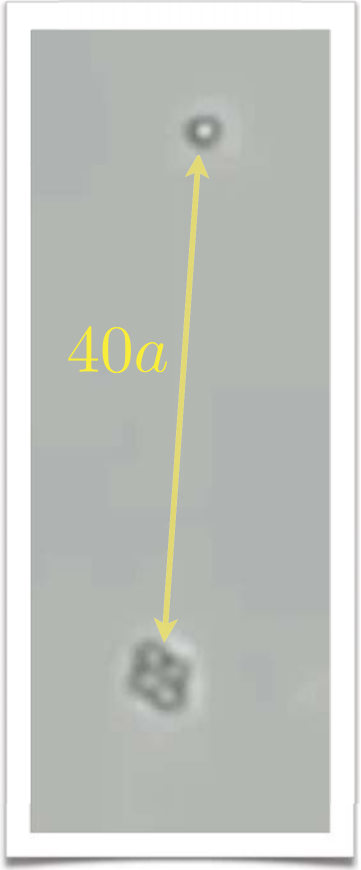
$$\Downarrow$$

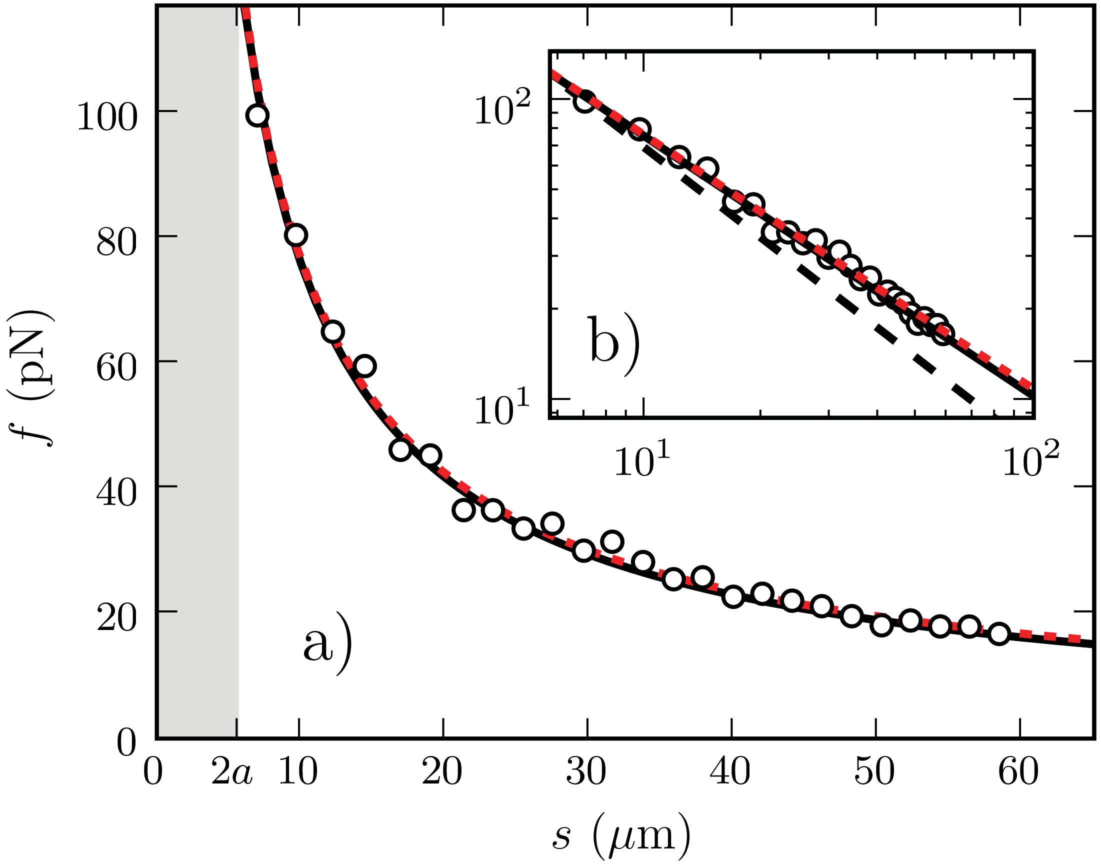
$$F(r) = 4\pi r_c^2 \psi_c^2 \gamma \frac{1}{r} \sim \frac{1}{r^\nu} \quad \nu = 0.84 \div 0.9$$

weak r dependence

VERY LONG RANDE NATURE OF CAPILLARY INTERACTIONS

R. DI LEONARDO, et al. PRL (2008)





SURFACE FORCES

Thermophoresis

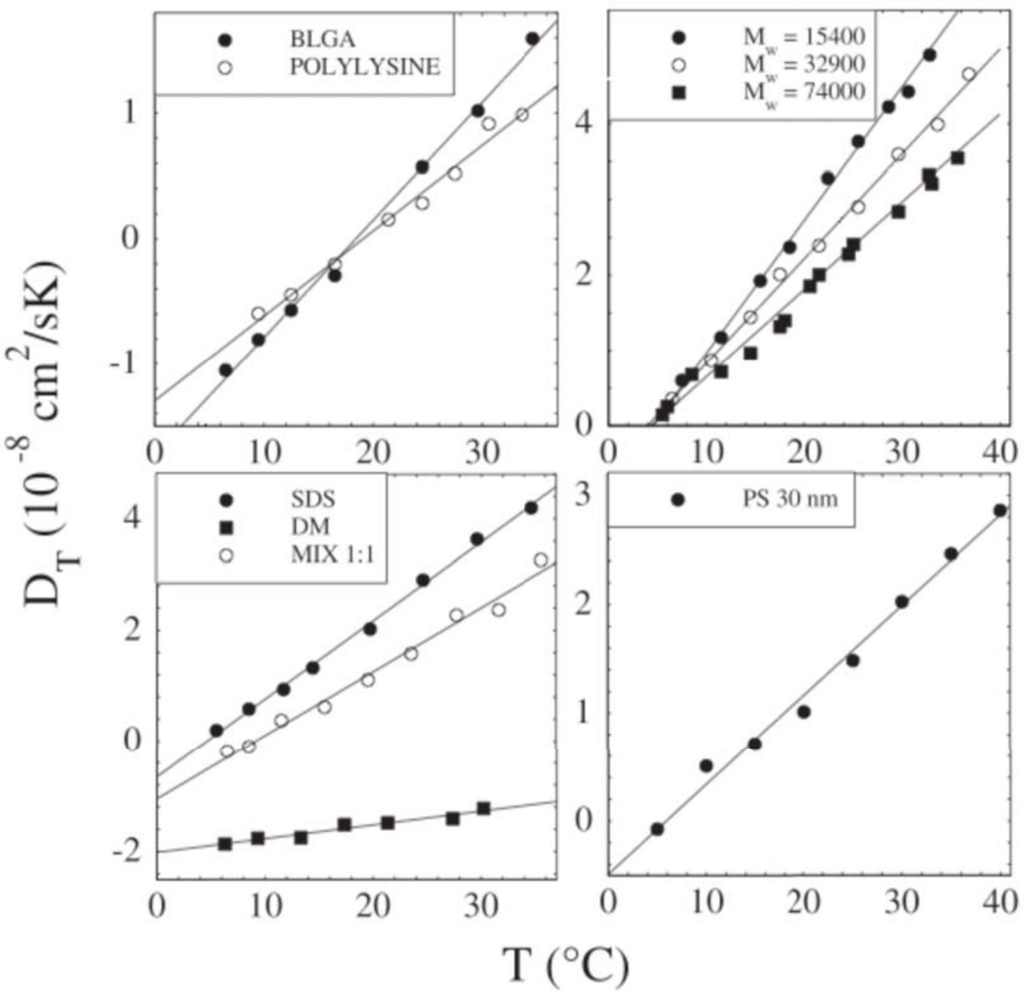
Thermophoresis

$$\longrightarrow \nabla T$$

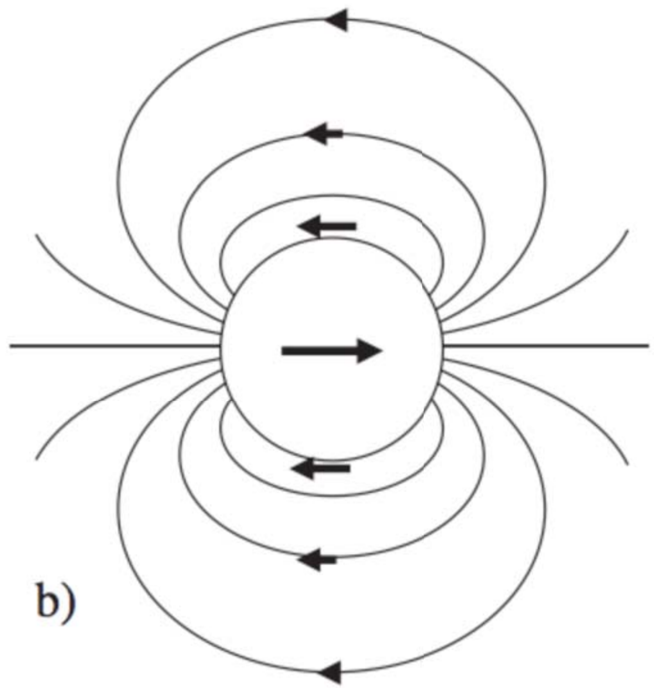
DRIFT VELOCITY $U = -D_T \nabla T$

Thermophoresis

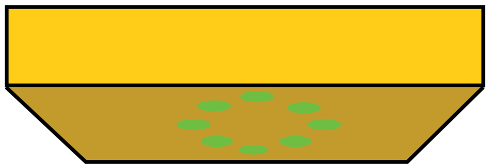
IACOPINI, et al. EPJ E (2006)



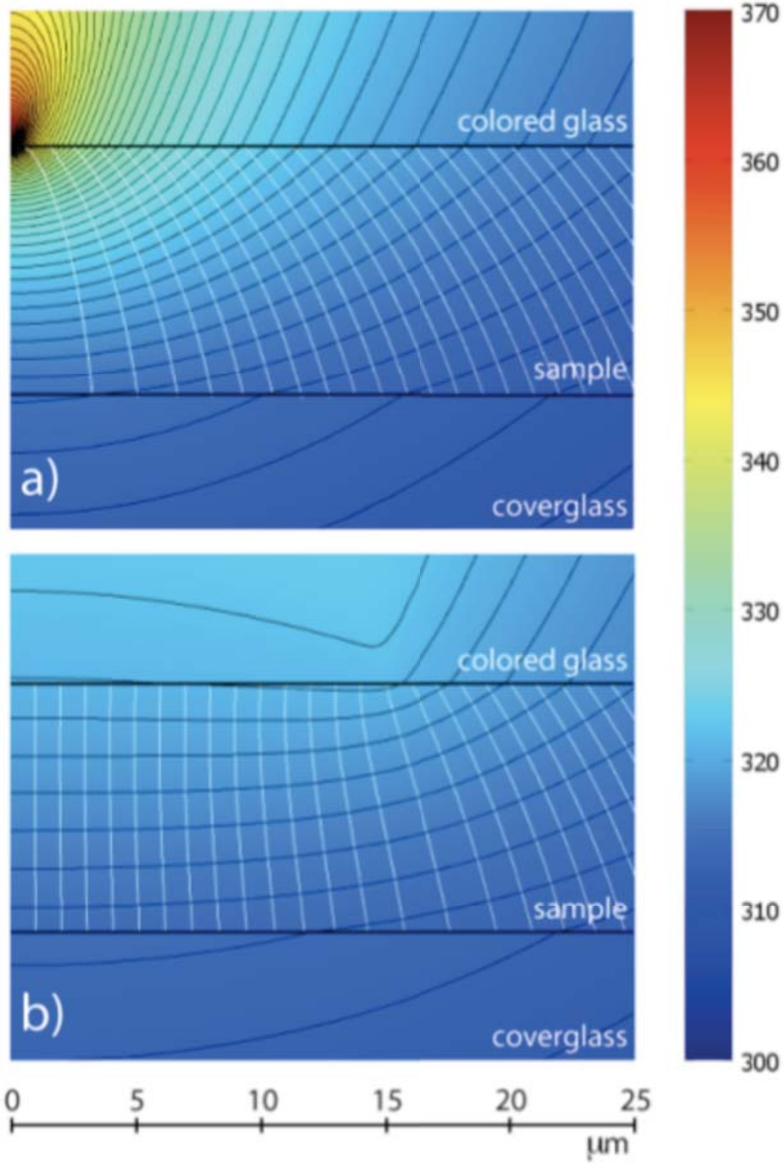
WURGER PRL (2007)



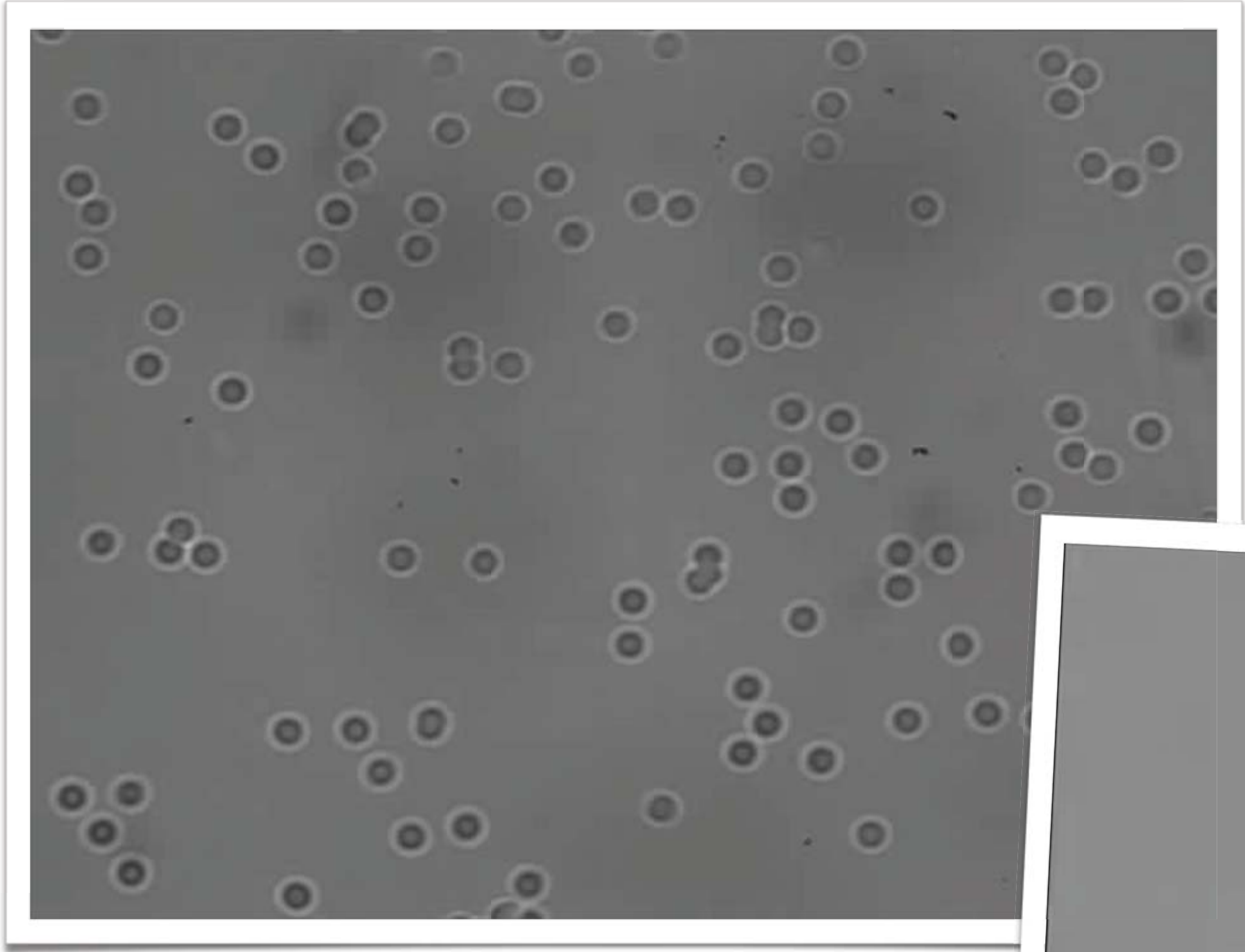
Holographically generated T gradients

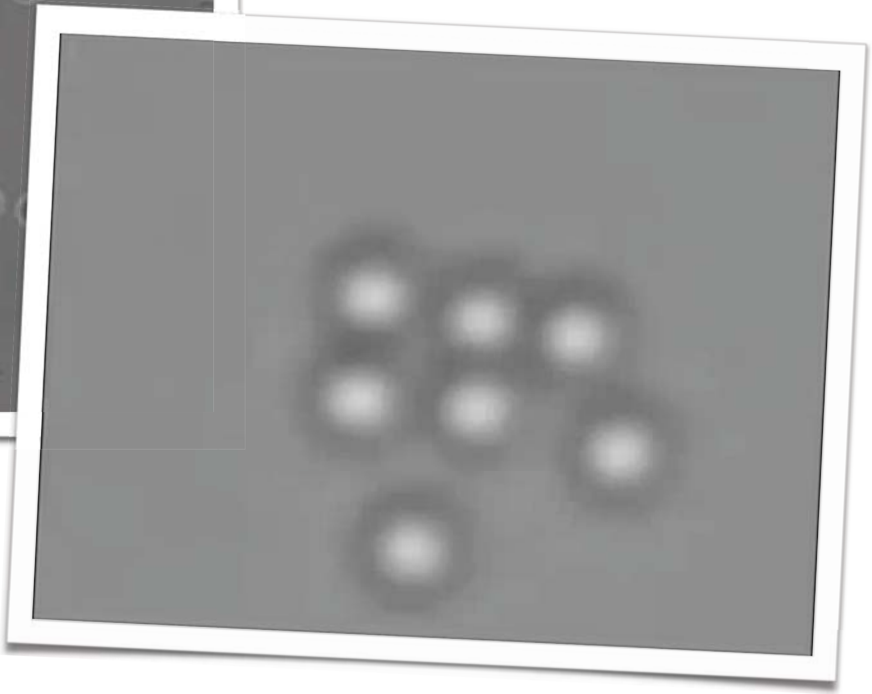


Di LEONARDO et al. LANGMUIR (2009)

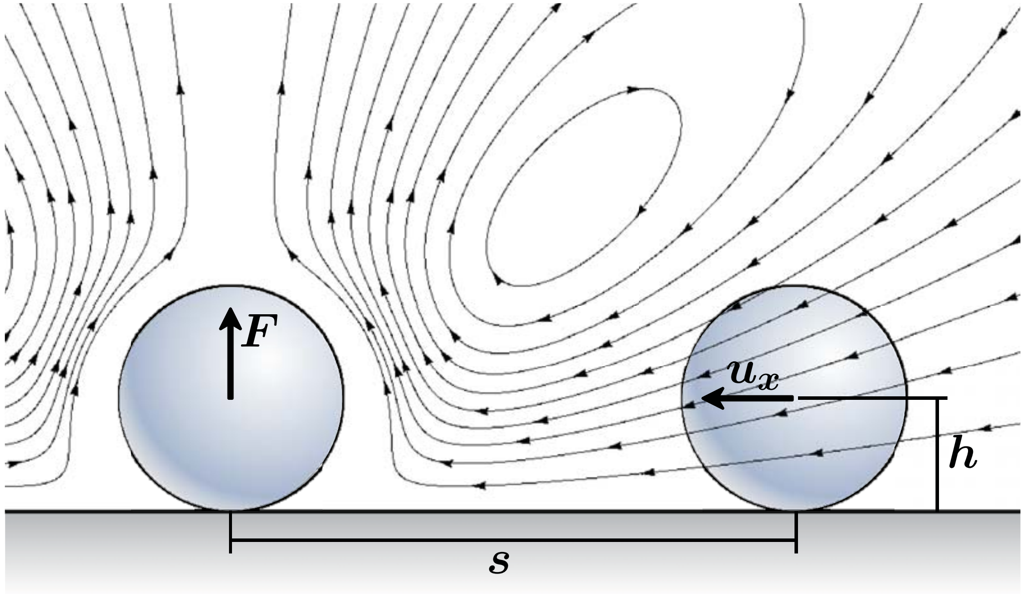


Colloidal attraction!





A novel colloidal interaction

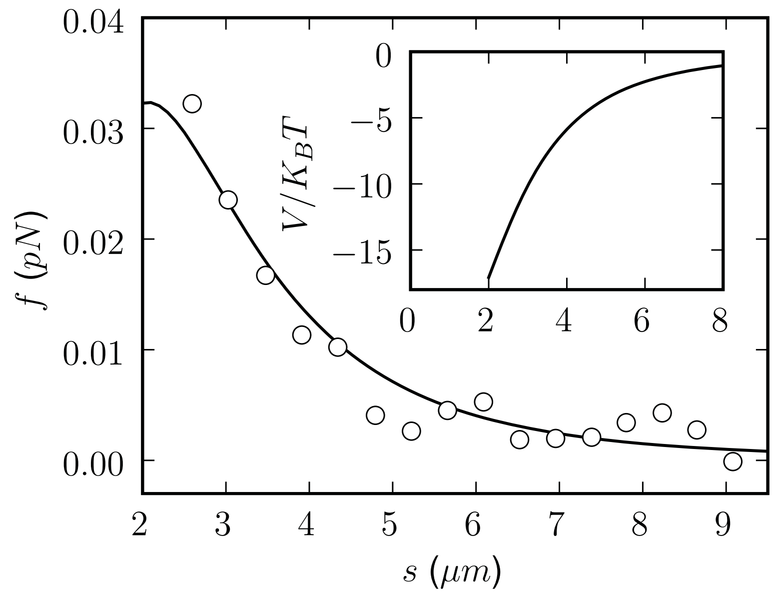


COLLOIDAL ATTRACTION INDUCED BY TEMPERATURE GRADIENTS

R. DI LEONARDO, et al. Langmuir (2009)

WEINERT & BRAUN PRL (2008)

$$\frac{F}{K_{\mathsf{B}}T/a} = -18\lambda S_{\mathsf{T}}\,\nabla T\,\frac{a^5}{s^4}$$



NOISY ENVIRONMENT

Brownian parametric oscillator

The Brownian parametric oscillator

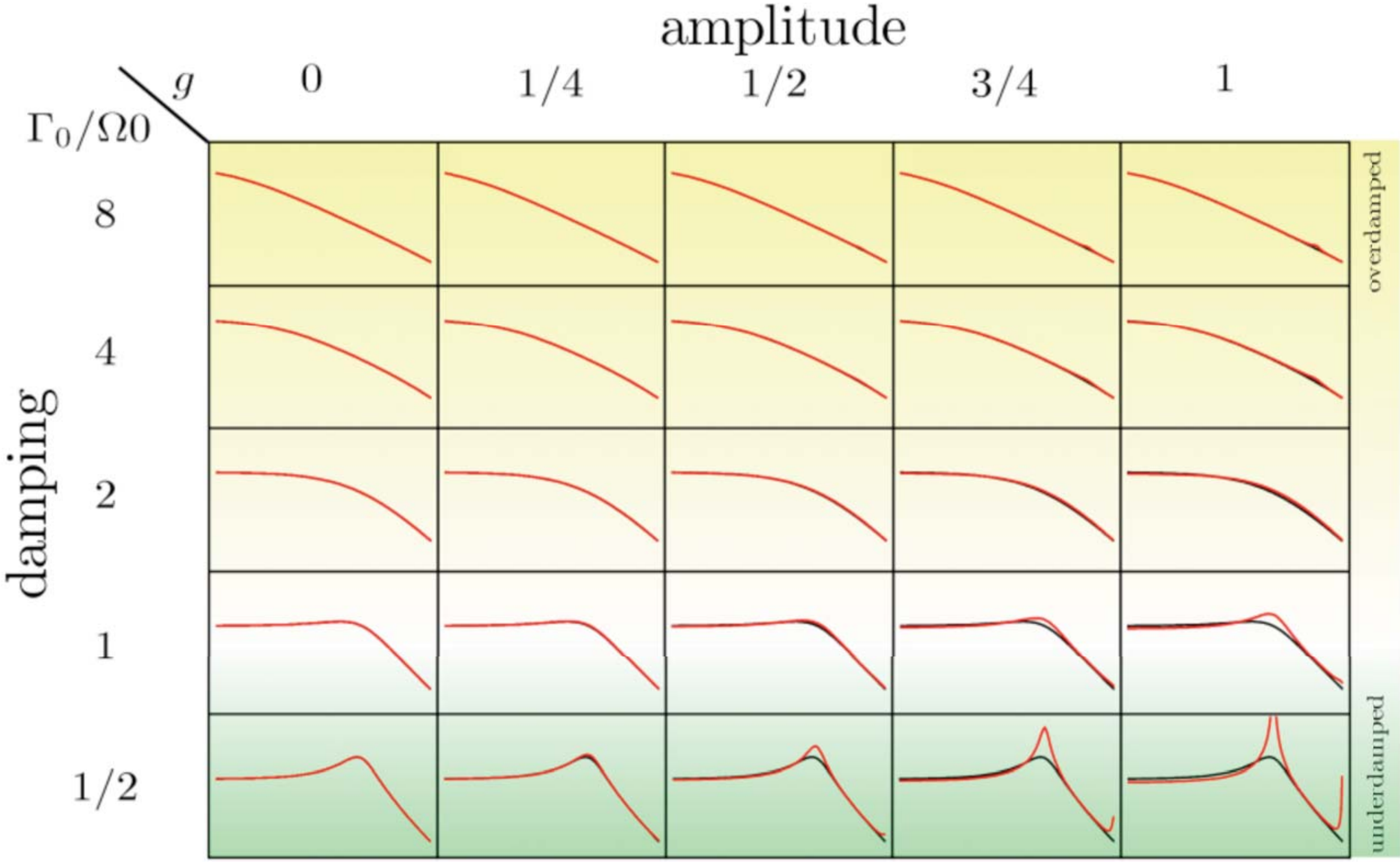
PARAMETRIC RESONANCE

$$\ddot{x}(t) + \Omega_0^2(t)x(t) + \Gamma_0\dot{x}(t) = 0$$

THE BROWNIAN PARAMETRIC OSCILLATOR

$$\ddot{x}(t) + \Omega_0^2(t)x(t) + \Gamma_0\dot{x}(t) = \xi(t)$$

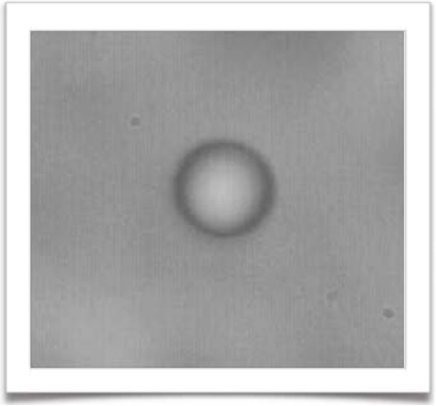
The Brownian parametric oscillator



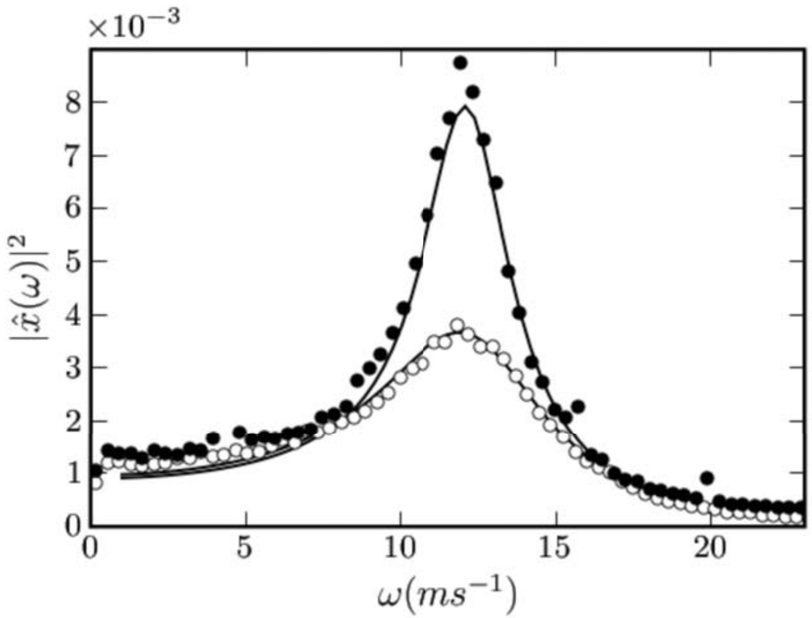
The Brownian parametric oscillator

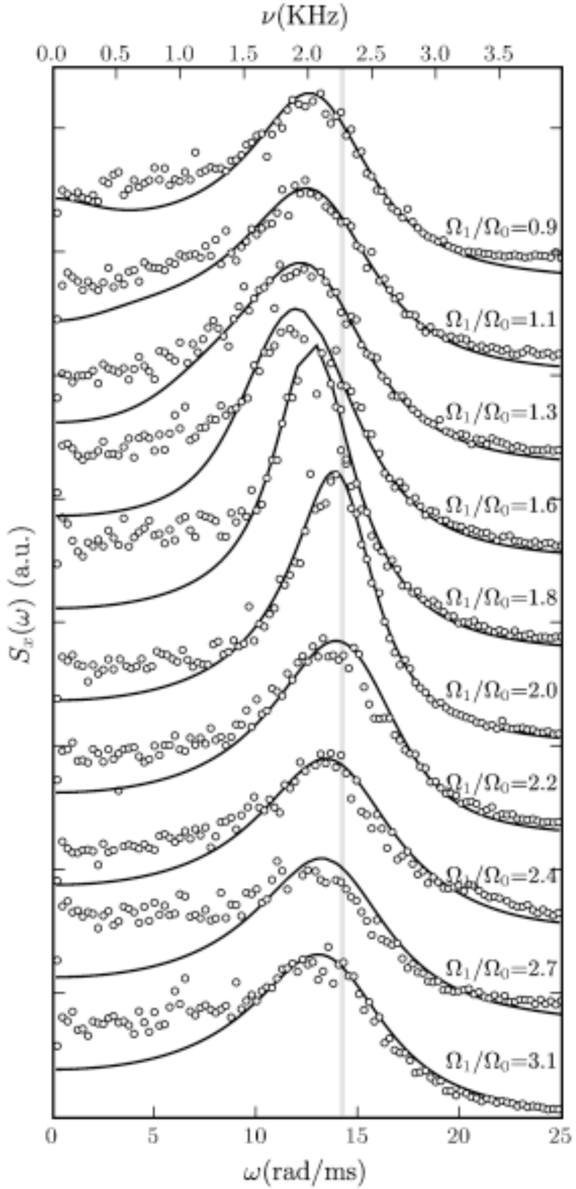
PARAMETRIC EXCITATION OF OPTICALLY TRAPPED AEROSOLS

R. DI LEONARDO, et al. PRL (2007)



WATER DROPLET (2000 fps)





Collaborations

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