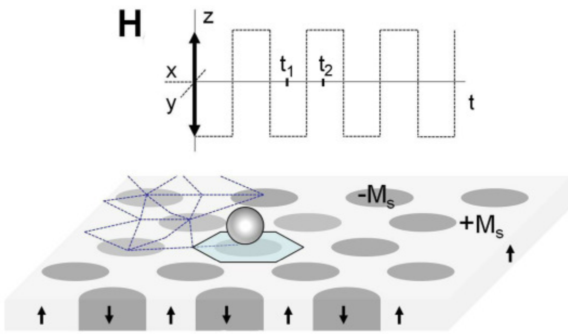
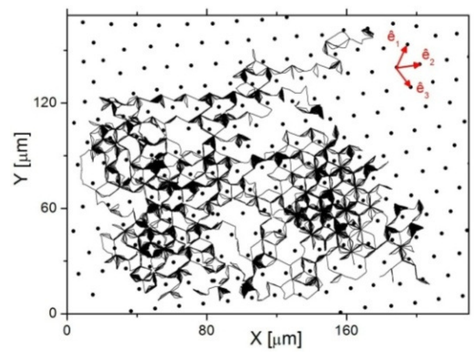
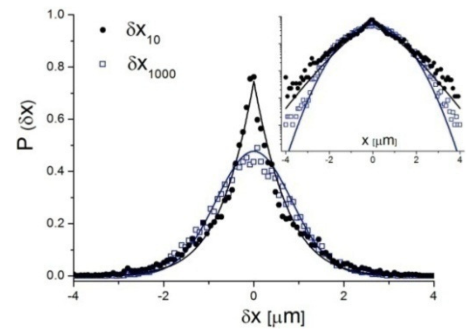
Antipersistent Random Walk in a Two State Flashing Magnetic Potential







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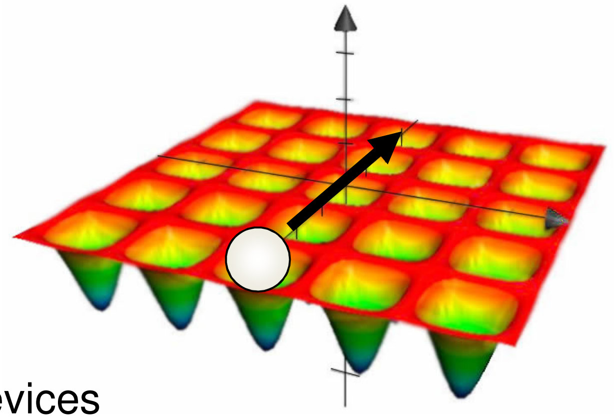
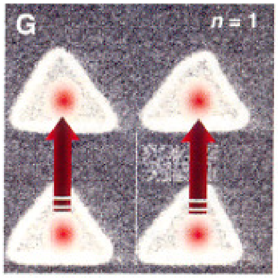
Transport and diffusion in periodic potentials



Examples

- superconducting devices
- charge density waves
- electronic devices
- atoms in optical lattices
- biological motors

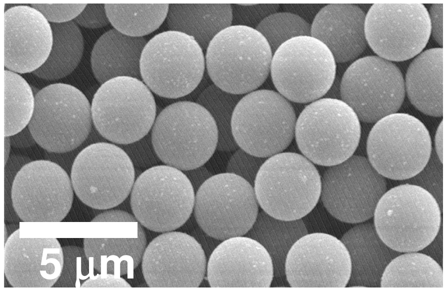
etc…



Rectifier of vortices pinned in Ni Triangles

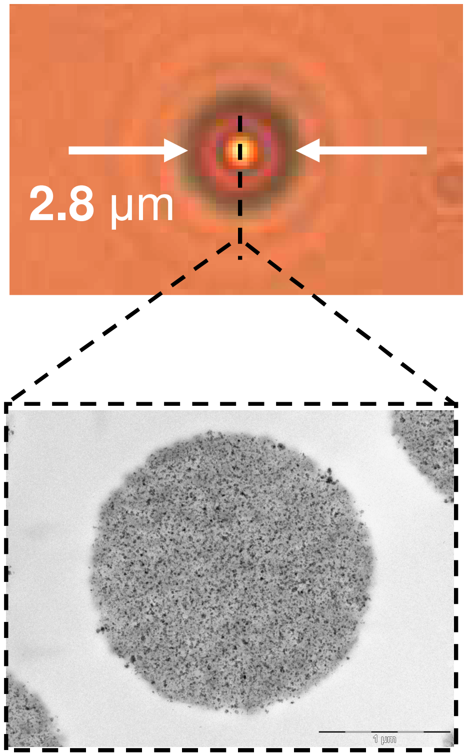
J. E. Villegas et al. *Science*, 302, 1188 (2003)

Why colloids ?



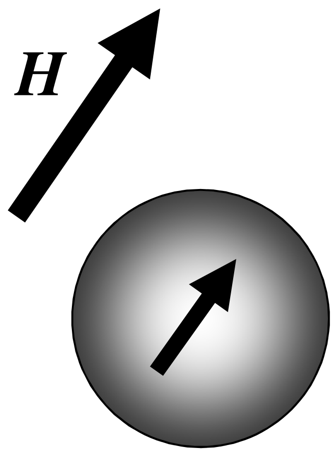
- Experimentally accessible time and length scales
- Ubiquitous technological applications
- Easily manipulated using external fields

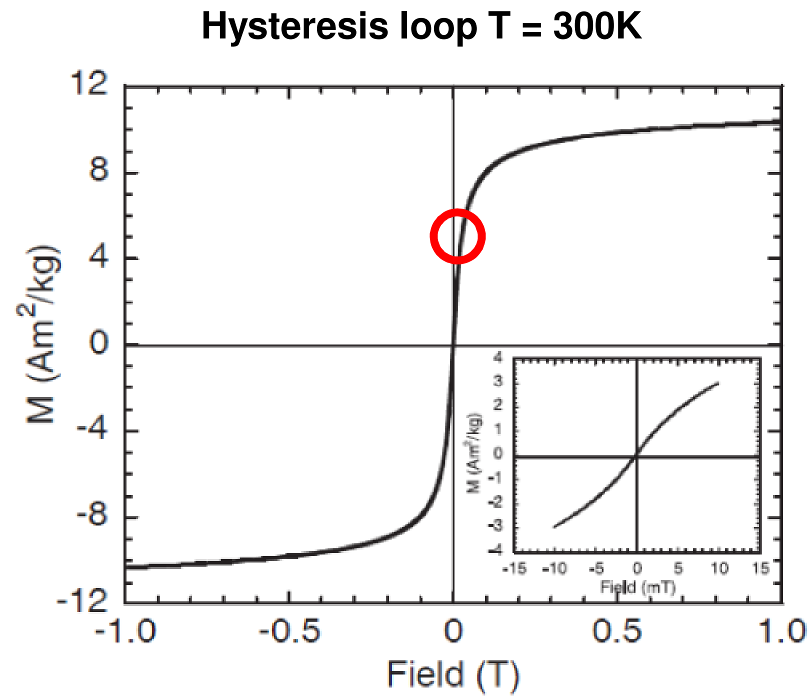
Paramagnetic colloids



T.E.M. cross section

Dynabeads M-280
Surface = COOH
22% doped with Fe_2O_3

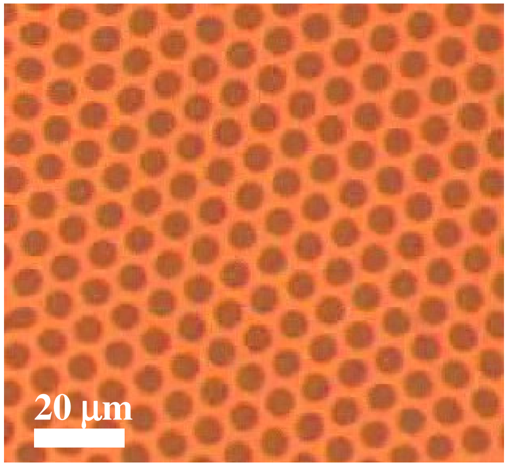




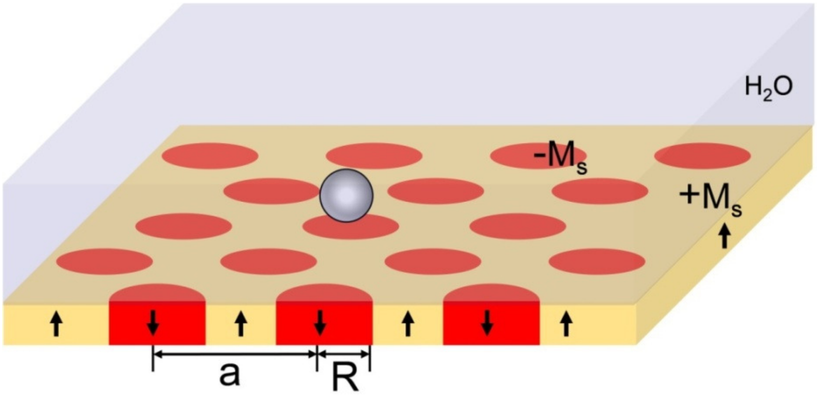
$$\boldsymbol{m} = V\chi\boldsymbol{H}$$

$$E = -\mu\,\boldsymbol{m}\cdot\boldsymbol{H} \sim H^2$$

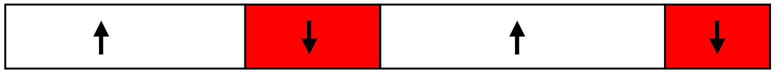
Magnetic periodic potential



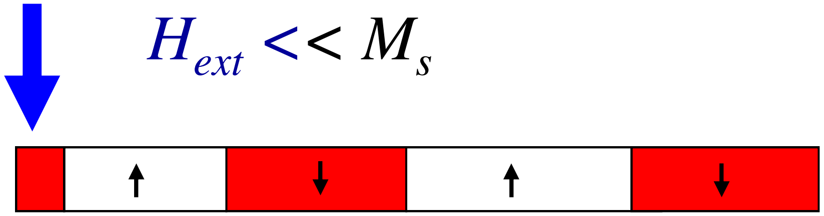
Ferrite garnet film
$Y_{2.5}Bi_{0.5}Fe_{5-q}Ga_qO_{12}$
(q = 0.5-1)
thickness ~ 4 µm
M_s = 1.7·10[4] A/m.
a = 11.6 µm
R = 4.2 µm

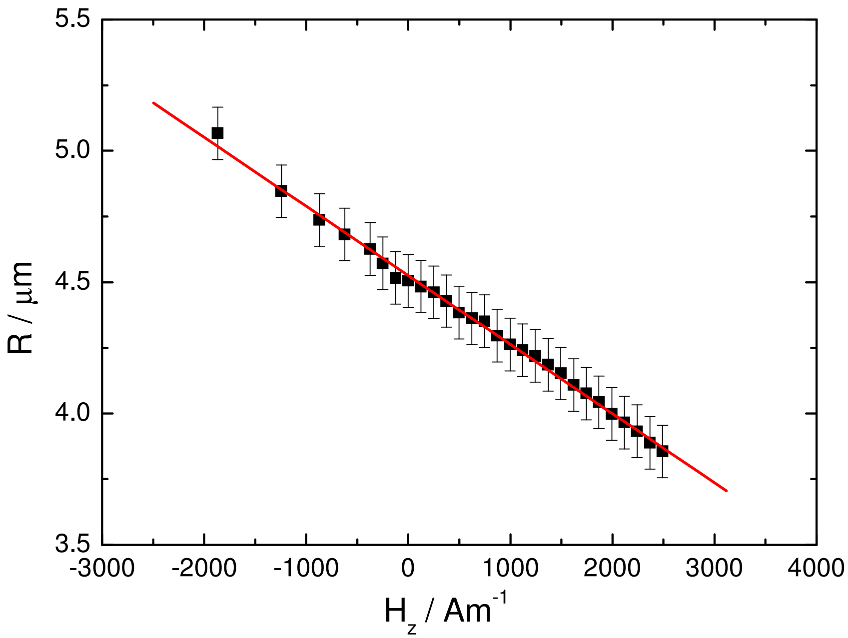


$H_z = 0$

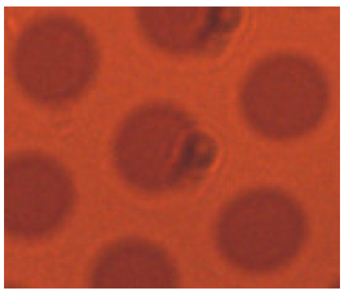


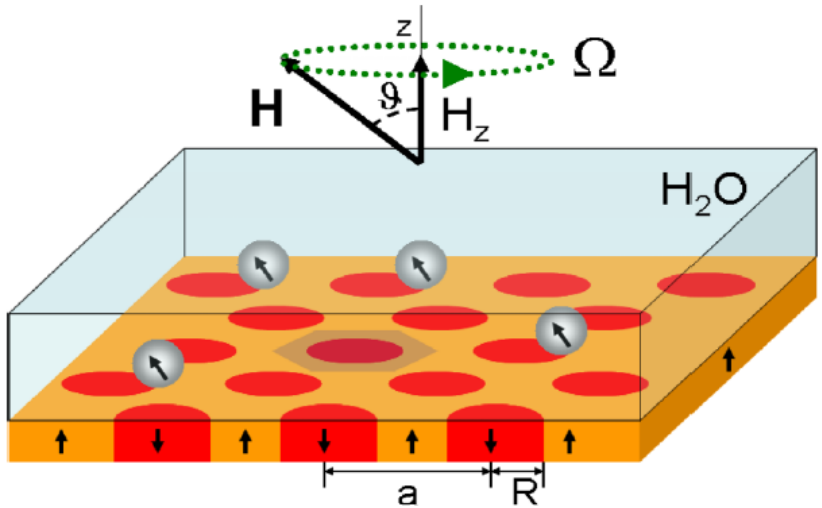
$H_{ext} << M_s$

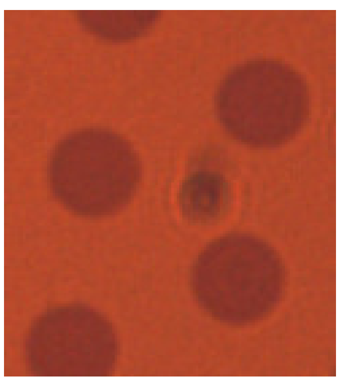


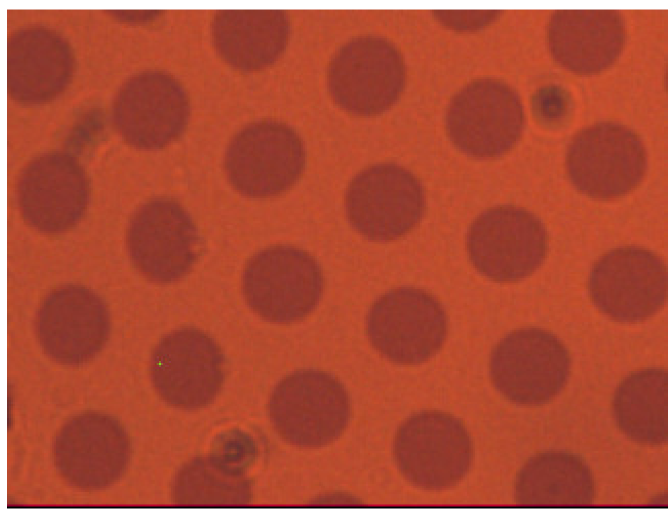


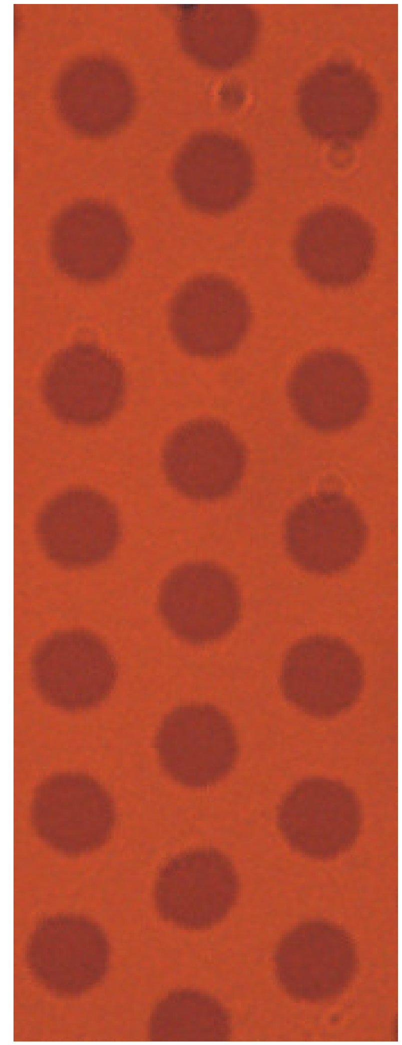
Directed transport





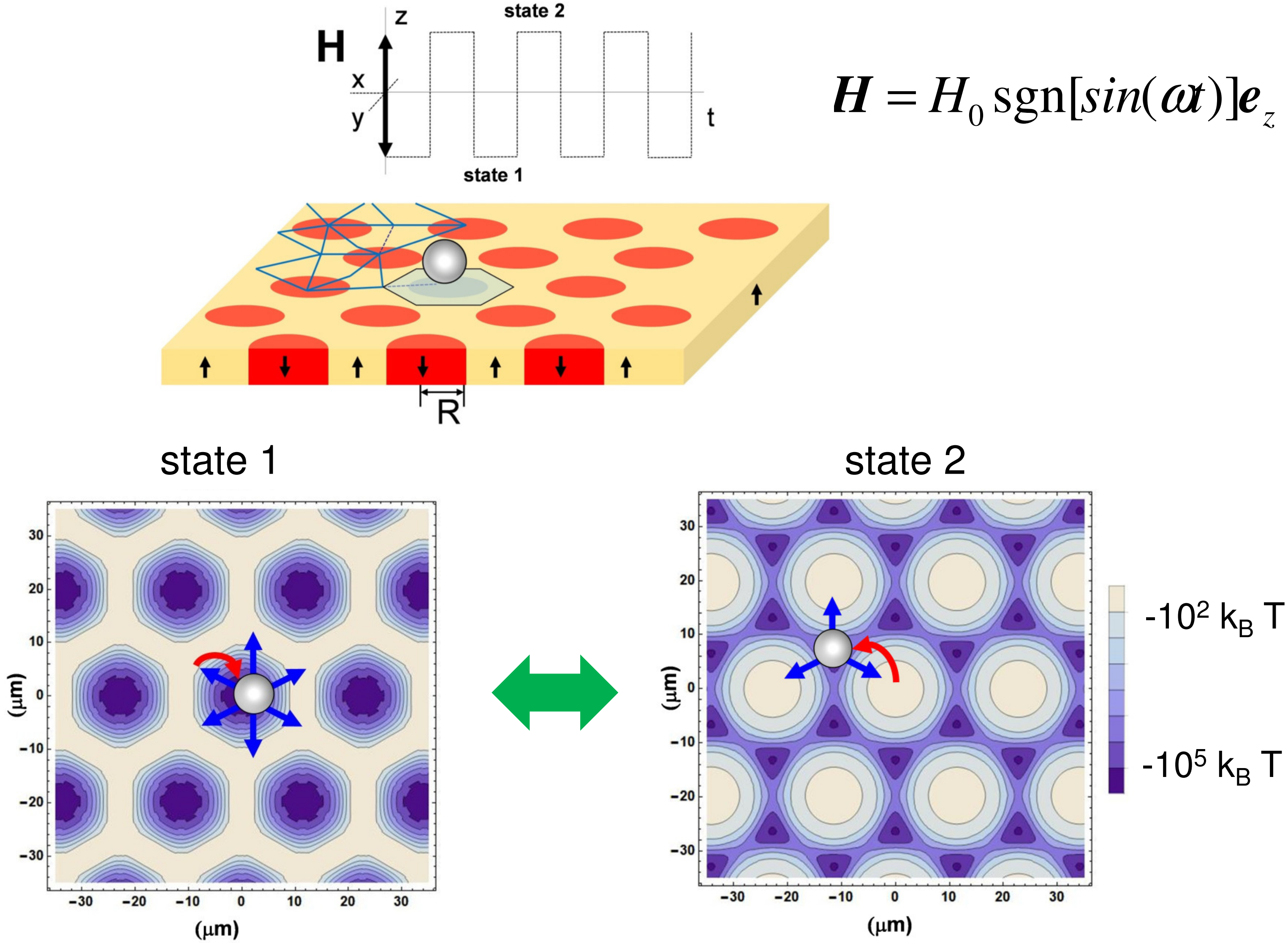






P. Tierno, T. H. Johansen, T. M. Fischer, *PRL 99*, 38303, (2007)

Two state flashing potential



$$\boldsymbol{H} = H_0\,\mathrm{sgn}[\sin(\omega t)]\boldsymbol{e}_z$$

Theoretical model

Overdamped eq. of motion

$$\eta \frac{dr}{dt} = -\nabla U(r,t) + \sqrt{2D}\xi(t)$$

negligible

Magnetic energy

$$U(r,t) = -\mu_0 \boldsymbol{m} \cdot \boldsymbol{H}_{tot}$$

$$\boldsymbol{m} = V\chi \boldsymbol{H}_{tot}$$

Magnetic moment

$$\boldsymbol{H}_{tot} = \boldsymbol{H} + \boldsymbol{H}_{stray}$$

Global field

Flashing field

$$\boldsymbol{H} = H_0 \,\mathrm{sgn}(sin(\omega t))\boldsymbol{e}_z$$

$$\boldsymbol{H}_{stray} = \boldsymbol{H}_b - \boldsymbol{H}_l$$

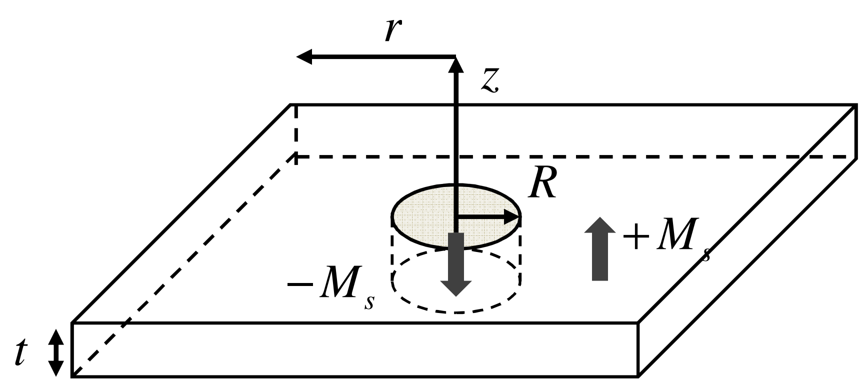
Magnetic bubbles

Film contribution

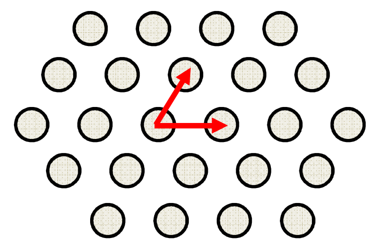
Field from 1 bubble

$$\boldsymbol{h} = -\nabla \varphi(r,z)$$

$$\varphi(r,z) = M_s R \int_0^\infty J_1(kR) J_0(kr) e^{-kz}(1-e^{-kt}) dk$$



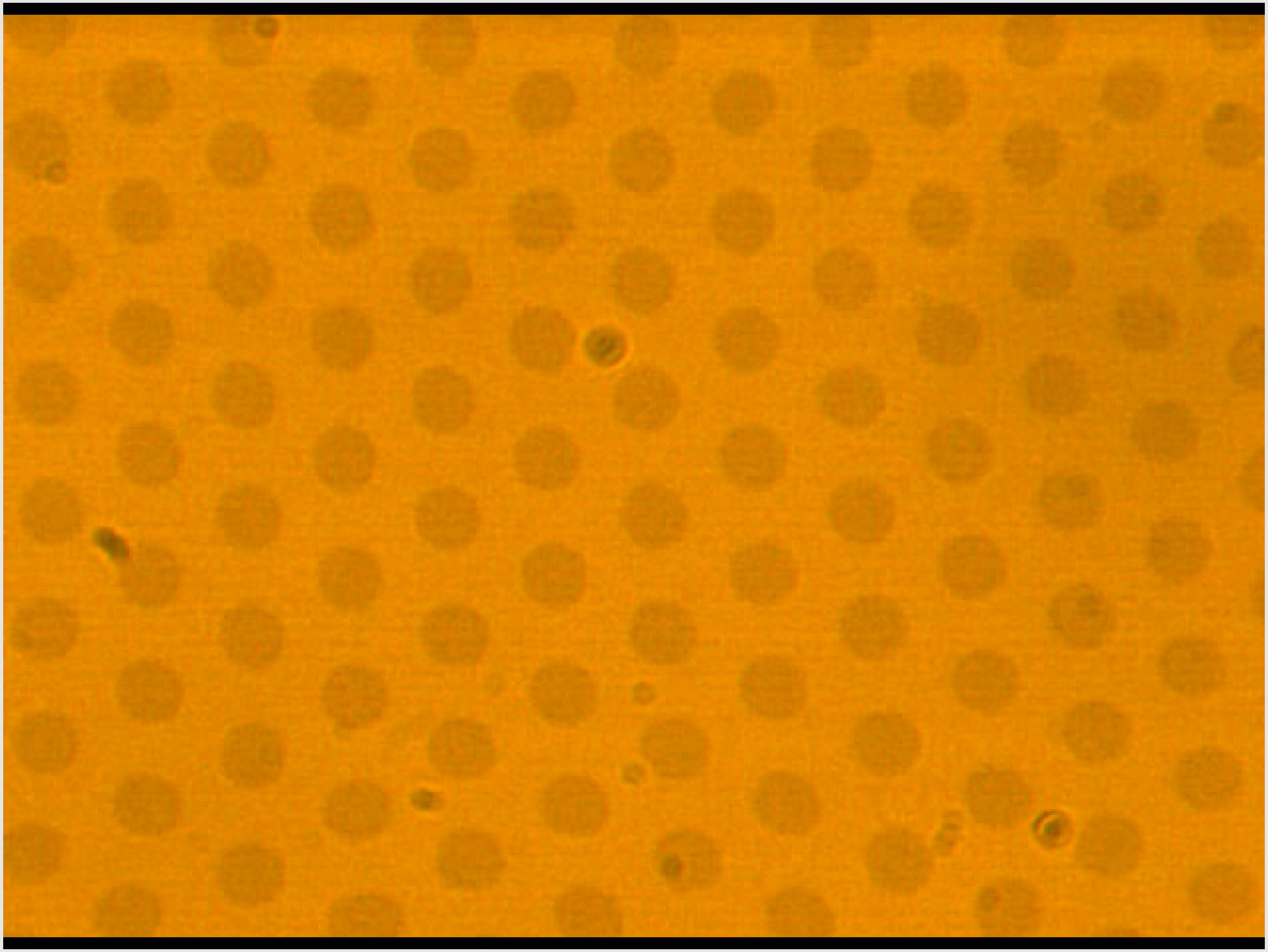
Field from N bubble



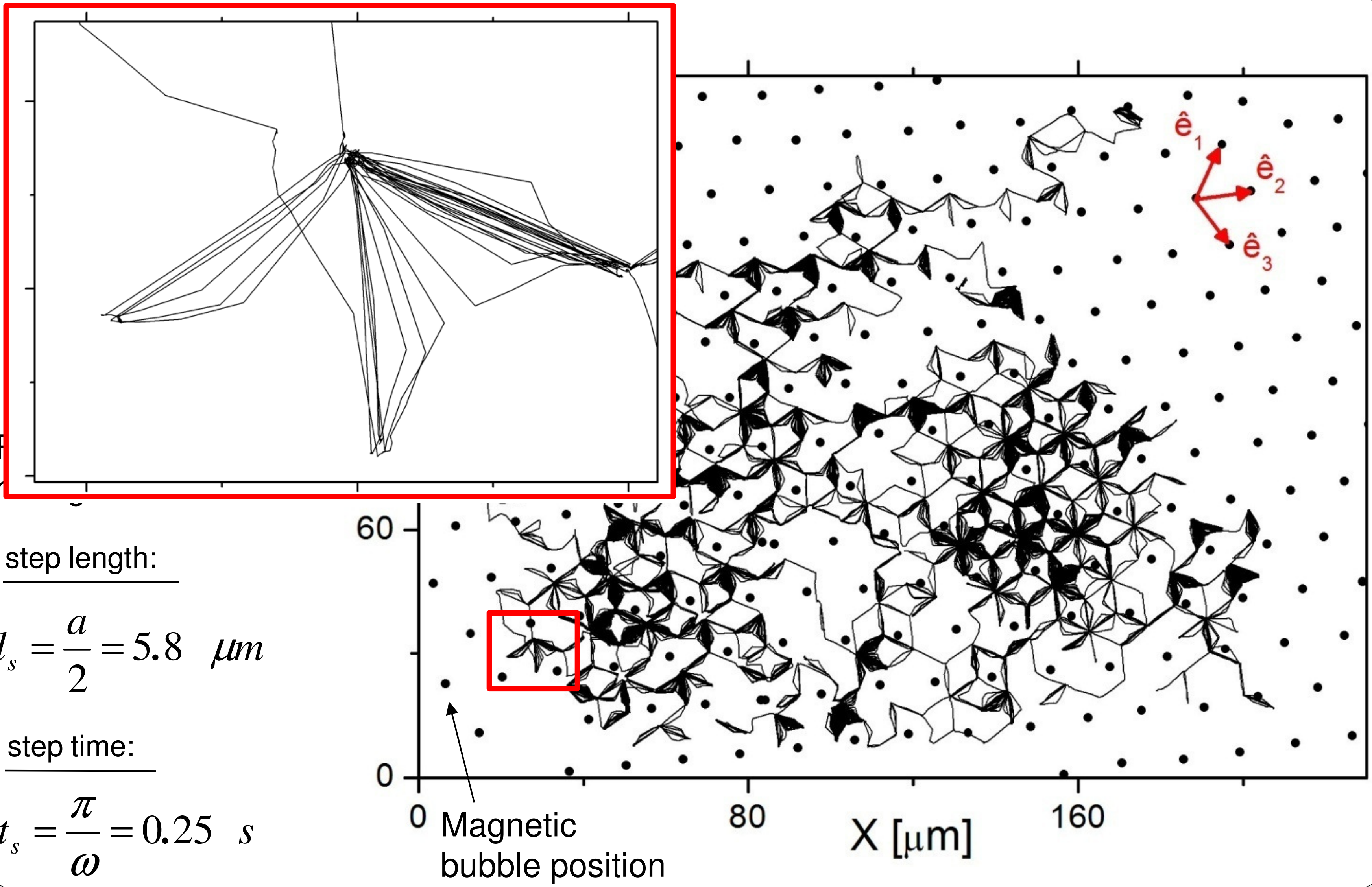
$$\boldsymbol{H}_b = \sum_{n,m} \boldsymbol{h}_{nm}$$

W. F. Druyvesteyn, et al. *Philips Res. Rep.* 27, 7 (1972)

Two state flashing potential



Two state flashing potential



step length:

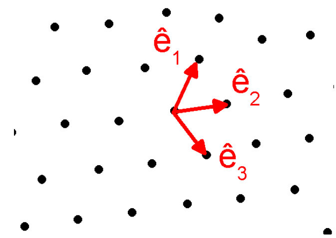
$$l_s = \frac{a}{2} = 5.8 \quad \mu m$$

step time:

$$t_s = \frac{\pi}{\omega} = 0.25 \quad s$$

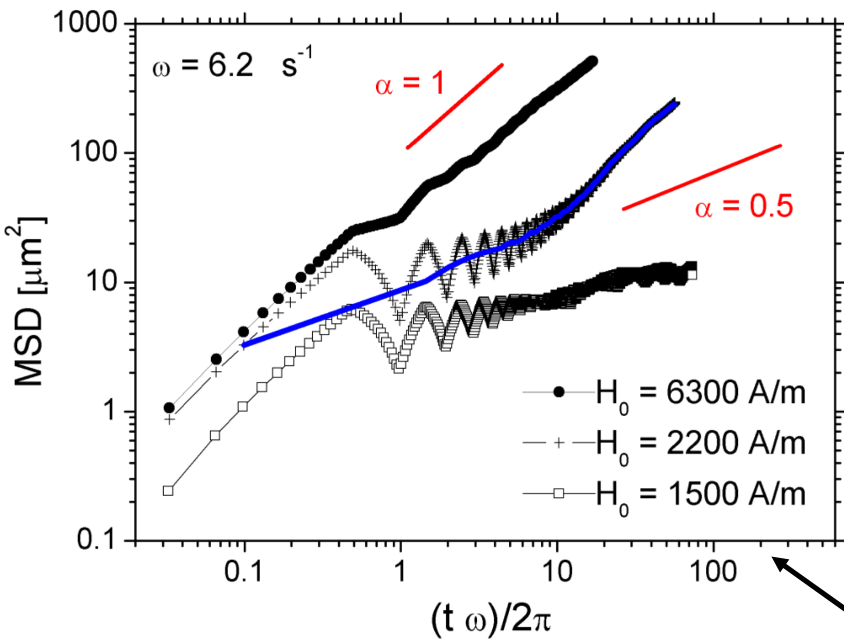
Mean square displacements

System isotropy:
$MSD_{e_1} = MSD_{e_2} = MSD_{e_3}$

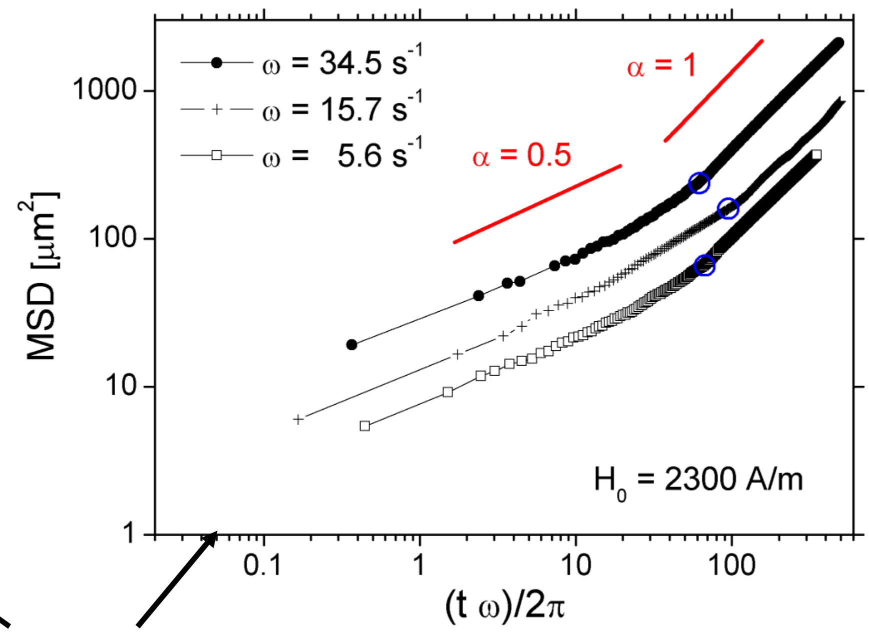


Reduces to 1D

Varying field

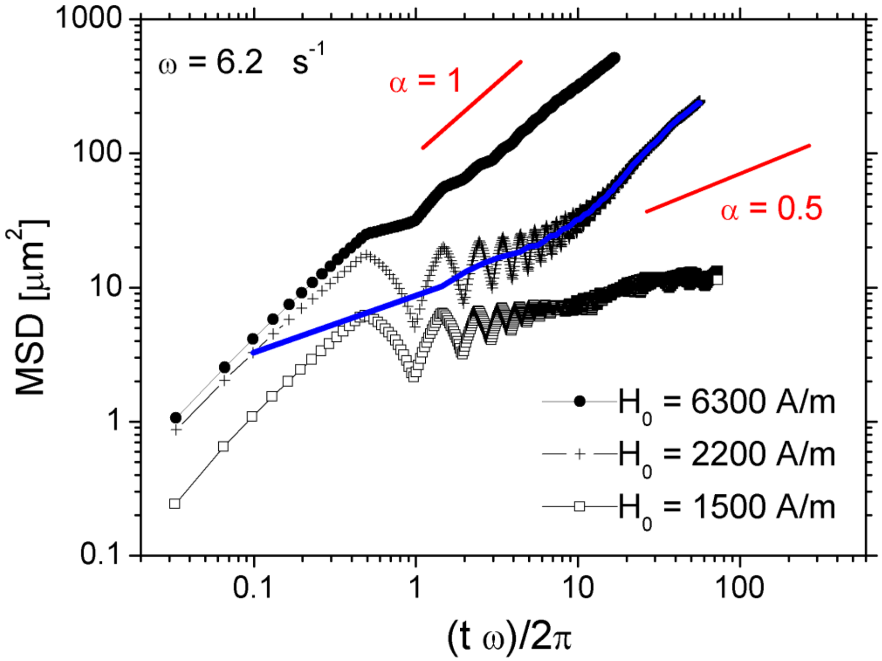


Varying frequency



In all sub-diffusive regimes $\alpha \in [0.48;0.53]$

Diffusive regime



$$D = \lim_{t \to \infty} \frac{MSD(t)}{2t} = 14.6 \ \mu m^2 s^{-1}$$

Theory (diffusion on isotropic lattice)

$$D = \frac{l^2}{4t_s} = 15.0 \ \mu m^2 s^{-1}$$

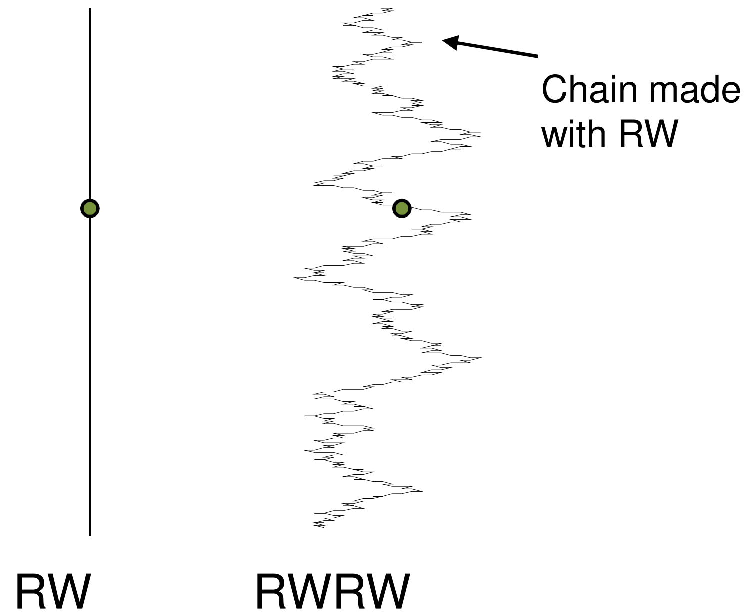
$l = a/2$ distance between traps

Self-diffusion on glass $D_{glass} = 0.17 \mu m^2 s^{-1}$ **enhanced!**

Self-diffusion on garnet $D_{garnet} \sim 10^{-4} \ \mu m^2 s^{-1}$ **giant!**

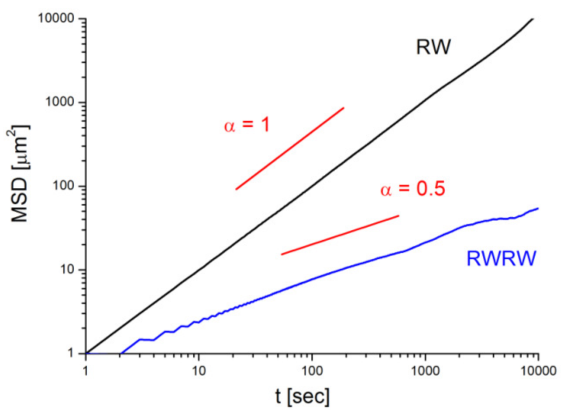
Subdiffusive regime: which one?

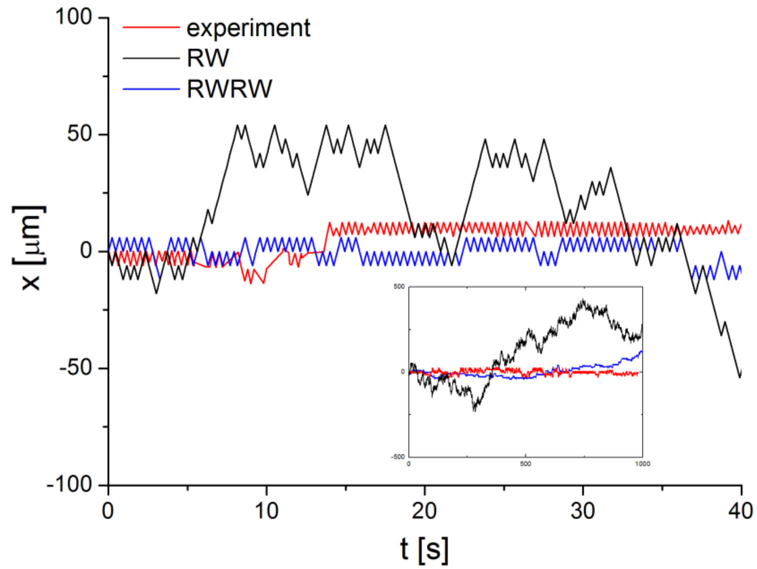
Random Walk on a Random Walk (RWRW)



- monomer reptation in polymer
- tortuosity of chemical path etc…

- **obstruction** no trapping!
- steps at fixed times (diffusion on a fractal)
  at random times (CTRW)
- Robust subdiffusion with $\alpha = 0.5$
- exactly solvable model! (PDF, MSD …)

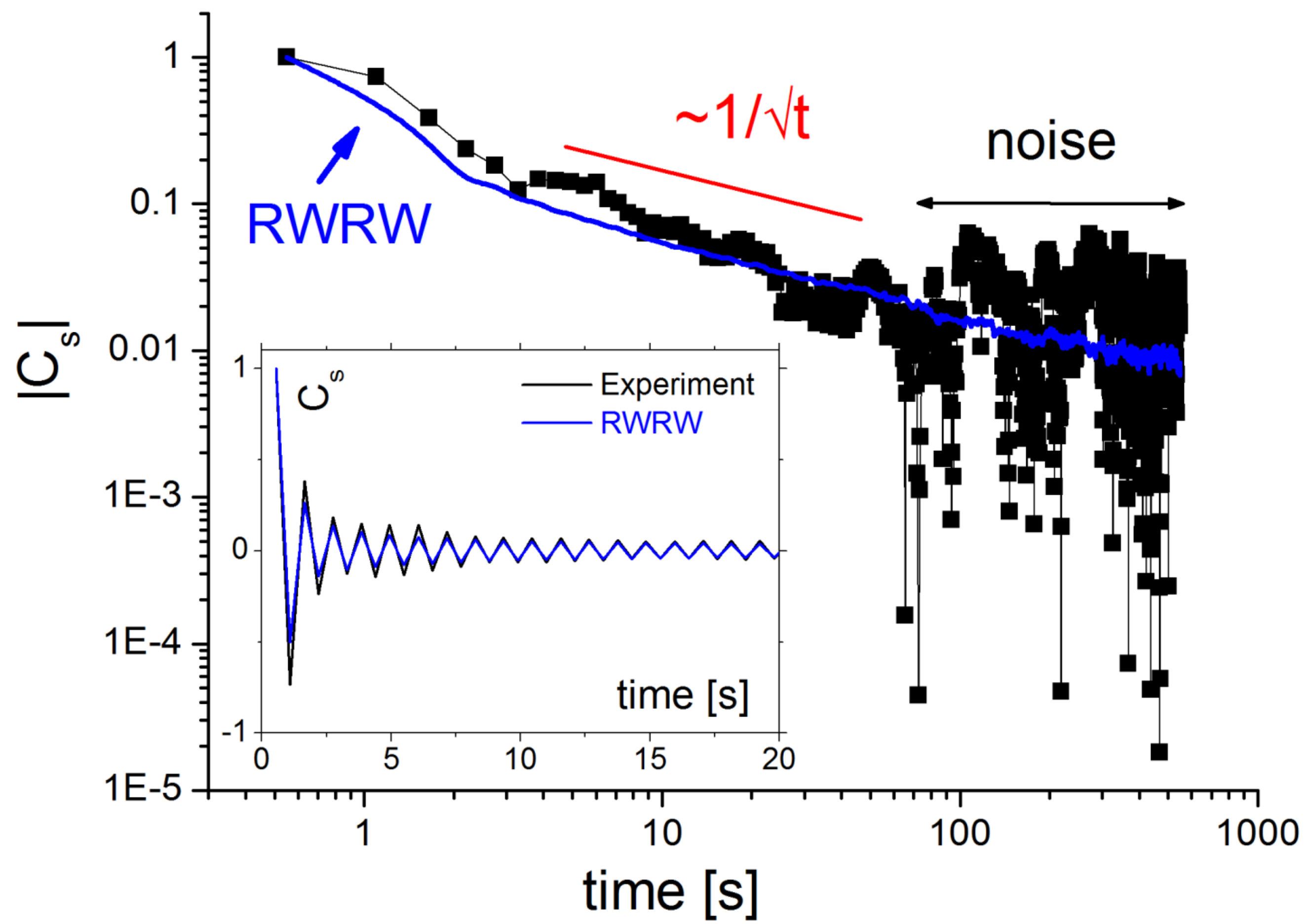




K. W. Kehr, R. Kutner, Physica 110A, 535 (1982)

Step-step correlation function

$$C_S = \langle s(0) \cdot s(t) \rangle / \langle s(0)^2 \rangle$$



Normalized PDF of relative displacements

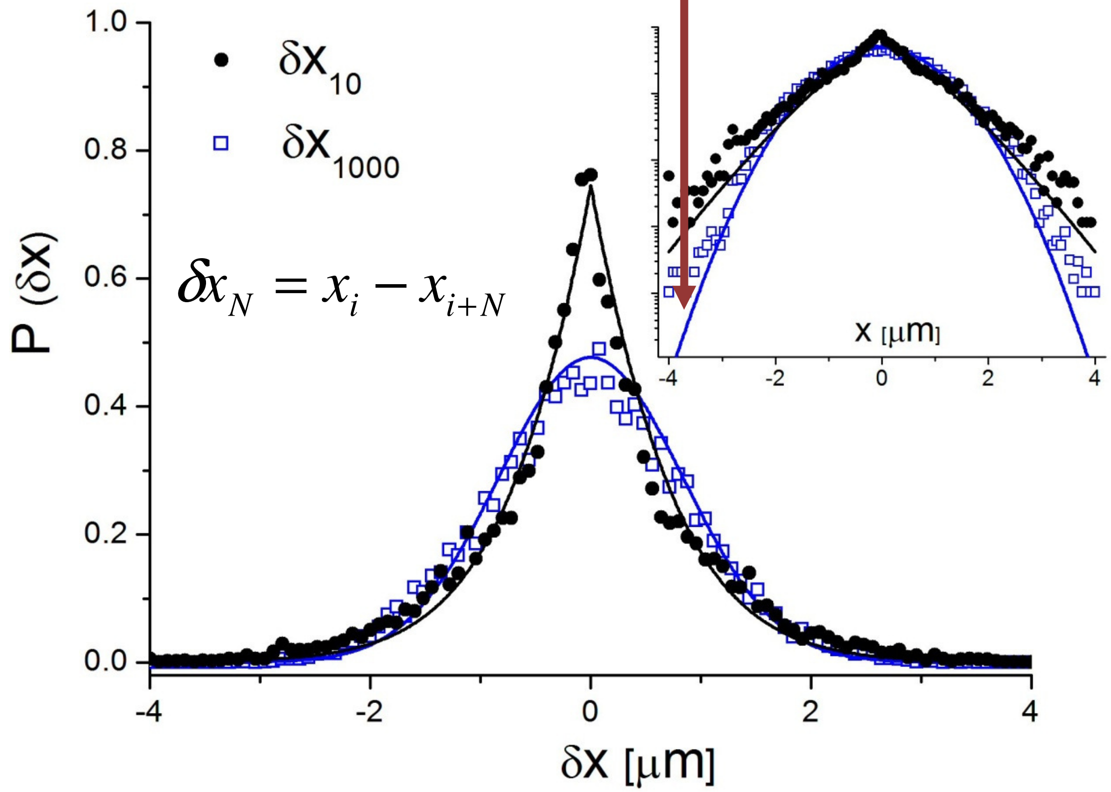
RW on RW model: non Gaussian PDF

$$p(x,b) = \frac{1}{\pi}\sqrt{\frac{1}{b}}\int_0^\infty \frac{1}{\sqrt{s}}\exp\left(-\frac{x^2}{2s} - \frac{s^2}{2b}\right)ds$$

Fitting parameter

Gaussian with the same dispersion

$$\sigma = \sqrt{\frac{b}{2\pi}}$$



subdiffusive

diffusive

P. Tierno, F. Sagués, T. H. Johansen, I. M. Sokolov, *PRL 109*, 70601, (2012)

Physical origin subdiffusion

Pinning alters circular shape

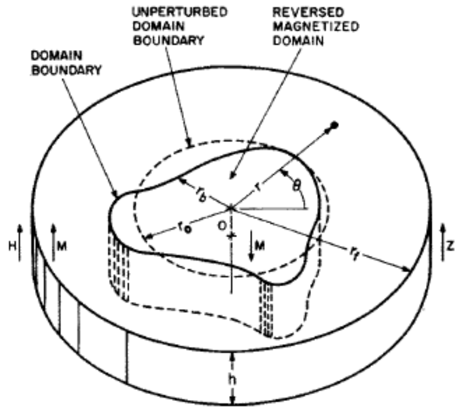
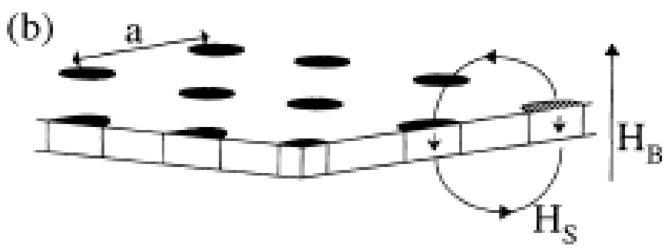


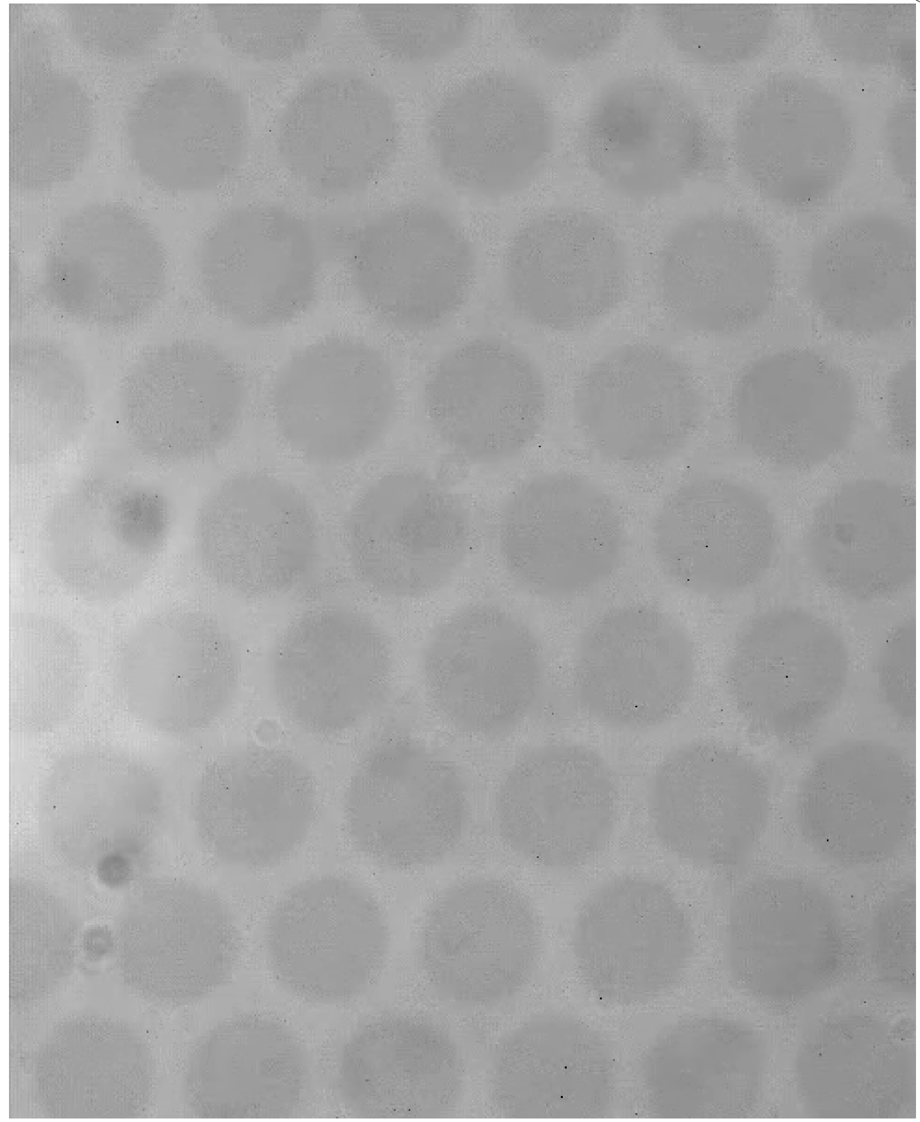
FIG. 2. Domain configuration and coordinate system.

A. A. Thiele J . Appl,. Phys. 41, 1139 (1970)

Dipolar interactions between bubbles



R. Seshadri et al. PRB 46, 5142 (1992)



To end...

Future scenarios

- Particle sorting/mixing based on different dispersive behavior
- Transport of biological cells

Acknowledgements

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IDEAS

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...and you for the attention!