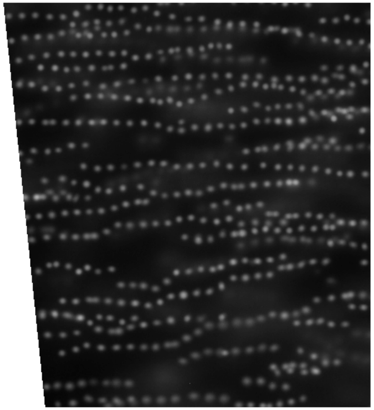
Dynamics of field-driven colloids

Edward Hayden, Tatsuo Izawa,

Anand Yethiraj

Memorial University,

St. John's, Newfoundland



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Why?

Driven colloids can be a model system...

- for dynamics in confined geometries.

- example: ion motion through narrow channels in membranes.

- for dynamics in glassy systems.

Normal diffusion

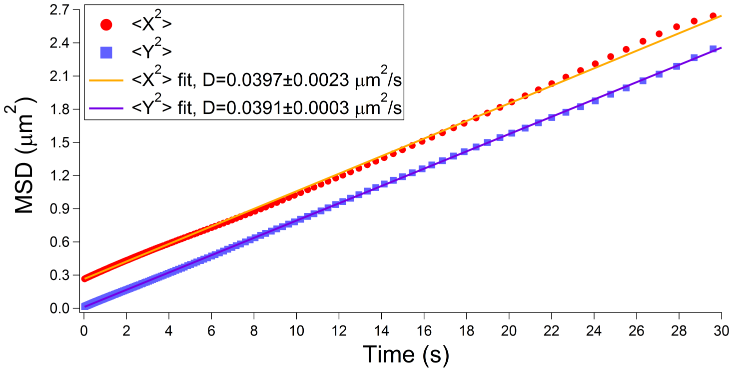
Bulk Diffusion

- A random walk at all times: $W_x(t) = \langle (x(t) - x(0))^2 \rangle \sim 2Dt$
- Stokes-Einstein relation: $D_{bulk} = k_B T/(6\pi\eta R)$

2D diffusion at distance h from a surface

- "Faxen's law": $D(h) = f(h) D_{bulk}$
- Example: R = 1μm fluorescent PMMA spheres in index-matching solvent (bromocyclohexane–cis-trans-decalin)

- $D_{bulk} = 0.1\mu\text{m}^2/\text{s}$
- $D_{surface} = 0.04\mu\text{m}^2/\text{s}$



Particle hydrodynamics

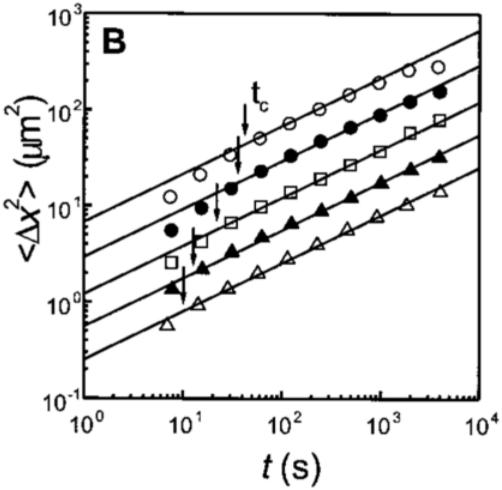
- Finite concentrations: inter-particle hydrodynamic interactions can slow things further.

Diffusion in 1D: “singe-file” diffusion

Hodgkin & Keynes, *J. Physiol.* **128**, 61 (1955).

- Mechanical model for ion transport in membranes

Wei, Bechinger, Leiderer, *Science* **287**, 625 (2000)



Nelissen, Misko, Peeters *Europhys. Lett.* **80**, 56004 (2007).

- Short time: random walk with $W_x(t) \sim t^1$
- intermediate time: single-file regime with $W_x(t) \sim t^{0.5}$
- long time: normal collective diffusion of chain, $W_x(t) \sim t^1$.

Quasi-1D diffusion and interactions

Quasi-1D diffusion

Lucena..Peeters, *Phys. Rev. E* **87**, 012307 (2013).

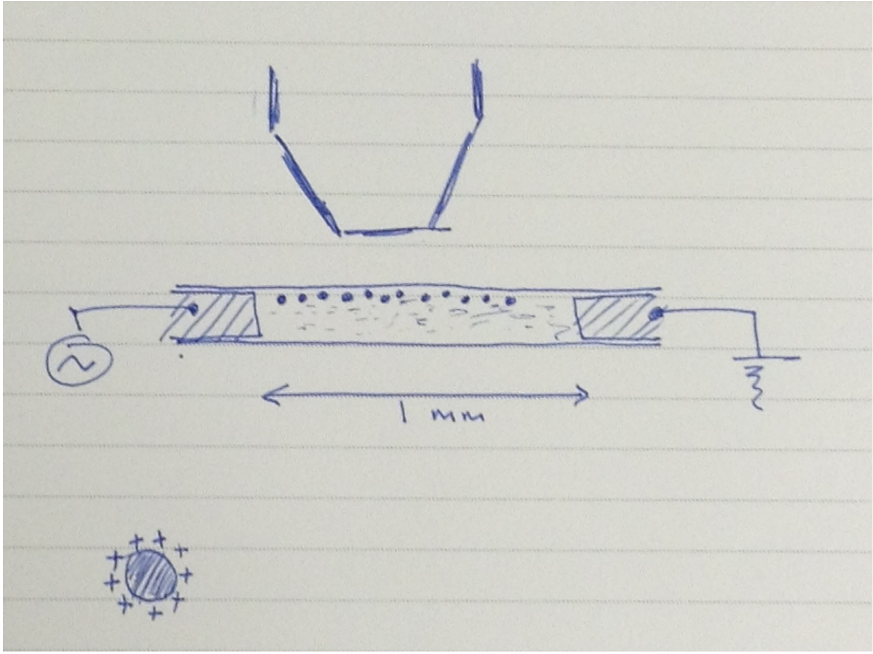
- relaxing the 1D constraint, define confinement parameter χ
- strong confinement (large χ): $W_x(t) \sim t^{0.5}$
- lower χ: $W_x(t) \sim t^{\gamma}$ with γ increasing from 0.5 to 1.0

The role of attractive inter-particle interactions

Lucena..Peeters, *Phys. Rev. E* **87**, 012307 (2013).

- $\gamma < 0.5$

Experimental setup



- Fluorescent PMMA microspheres in an index-matching solvent
- Particles sediment upwards
- Positively charged, extended double layer

Crossover: dielectric $\leftrightarrow$ ionic

10 Hz: polarization charge is the source of dipolar interaction

- Dynamics as a function of frequency.

Quasi-1D diffusion with dipolar attractions

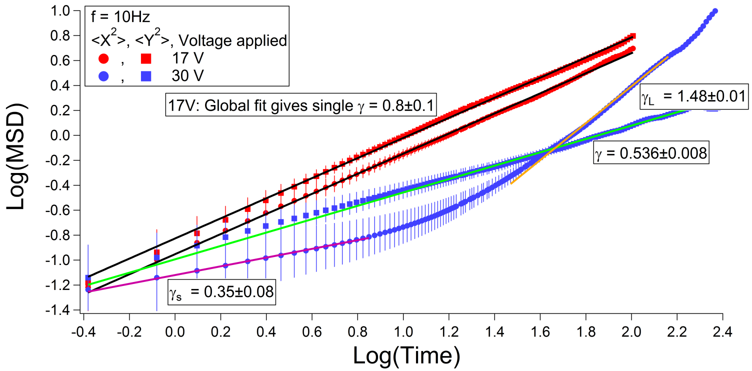
Long-time chain dynamics: 10 Hz

17 V/mm

30 V/mm

Quasi-1D diffusion with dipolar attractions

Anisotropic structures induce anomalous dynamics

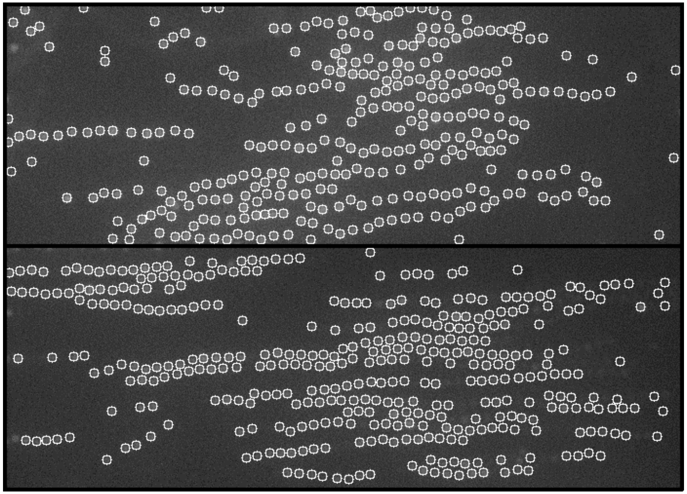


17 V/mm: chain formation results in:

- sub-diffusive motion at all times with $D_X < D_Y$.
- same power law: $\gamma_X = \gamma_Y \sim 0.8$

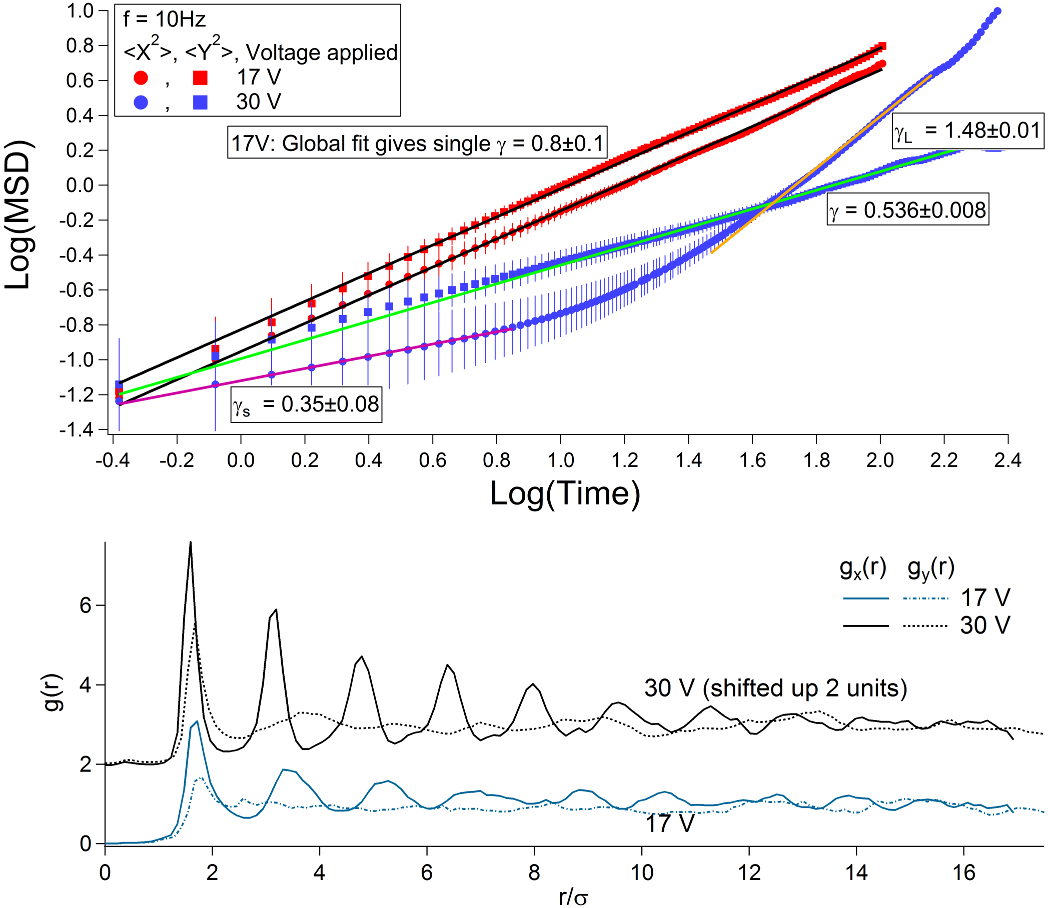
30 V/mm: stronger structuring:

- anisotropic dynamics: along the field (X)
- short times: : $\gamma_X \sim 0.35$
- long times: : $\gamma \sim 1.5$!
- perpendicular to the field (Y)
- sub-diffusive all times: : $\gamma_Y \sim 0.5$



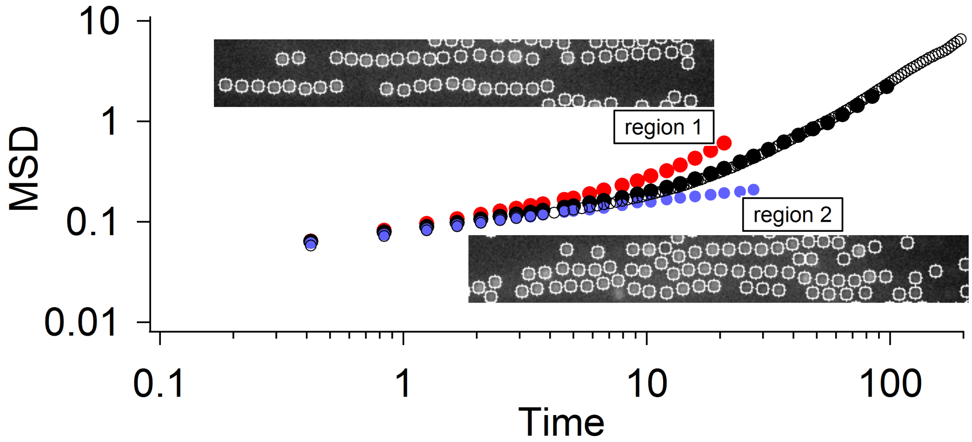
Quasi-1D diffusion with dipolar attractions

Anisotropic structures induce anomalous dynamics



Quasi-1D diffusion with dipolar attractions

Different regions



Dynamics in dipolar colloids simulations

Jordanovic, Jaeger & Klapp, Phys. Rev. Lett. 106, 038301, 2011

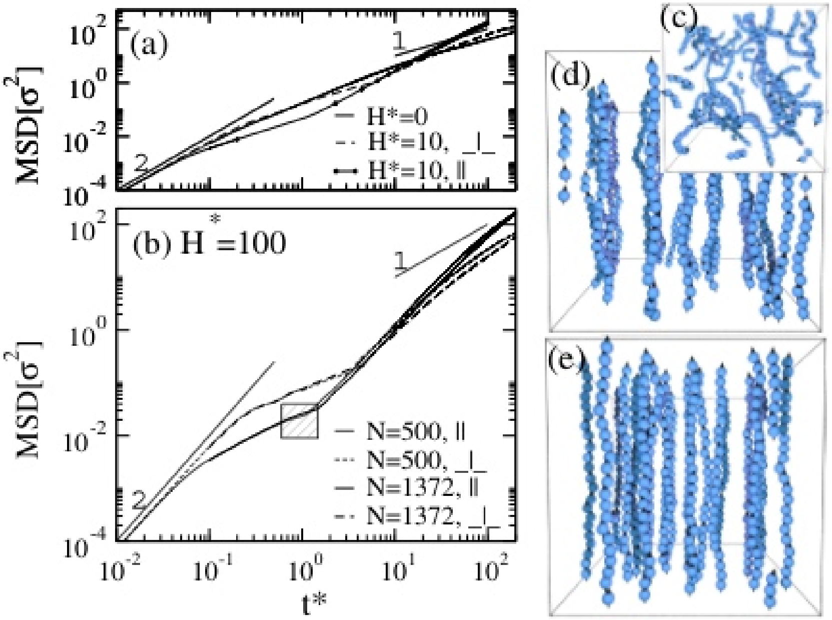


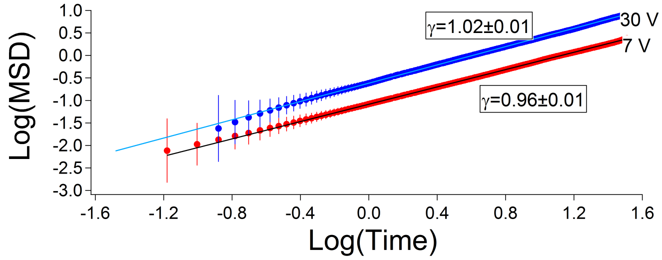
FIG. 2 (color online). (a)–(b) MSDs for $\lambda = 7$ and $H^* = 0$, 10, 100. (b) Includes data for two system sizes; the box indicates the subdiffusive regime. (c)–(e) Corresponding snapshots.

- low field: short-time ballistic $\rightarrow$ long times diffusive
- high field: Caging (sub-diffusive) and super-diffusive behaviours

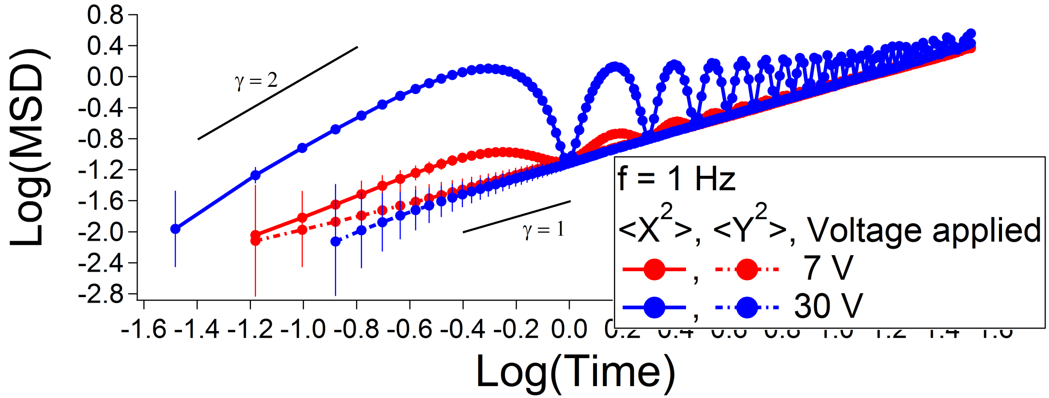
Low frequency dynamics: 1 Hz

Isotropic diffusion + time-dependent oscillations along field

- First signs of electrophoresis
- At frequencies below 1Hz, can get electrophoresis without structure formation.
- Normal diffusion perpendicular to the field



- Oscillatory motion + normal diffusion along field



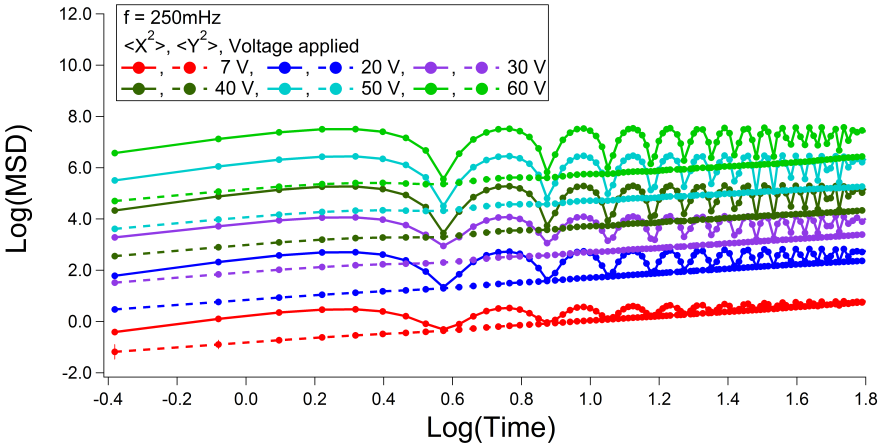
AC electrophoresis

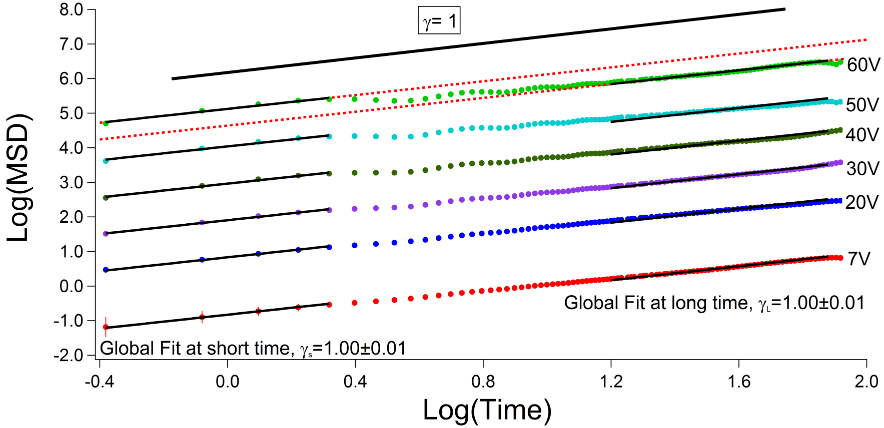
$f = 250$ **mHz**

- Dynamics as a function of amplitude.

Low frequency dynamics: 250 mHz

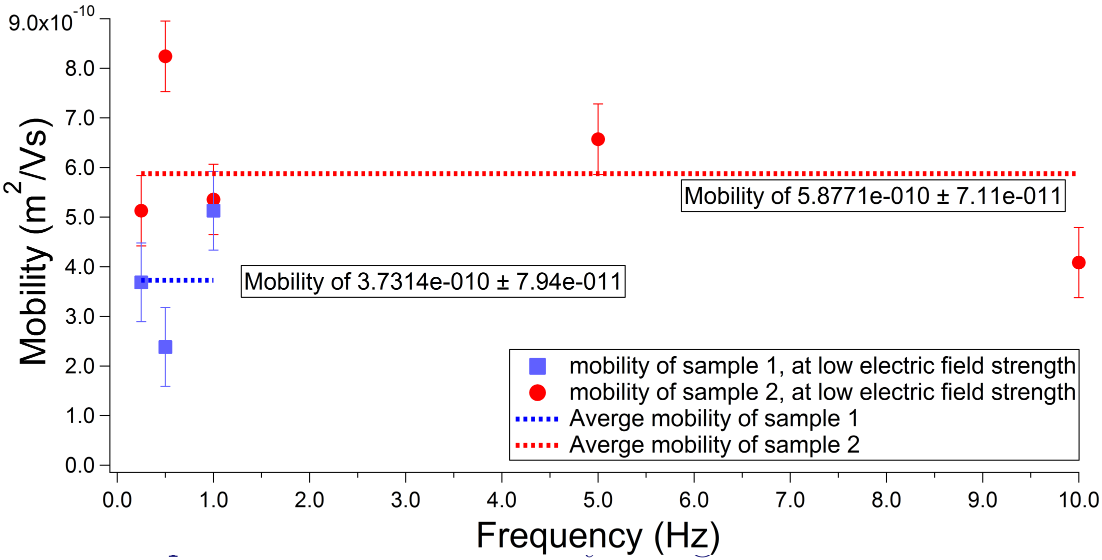
Stronger electrophoretic motion





Extracting particle ζ potentials

Electrophoretic mobilities



- EH01: $3.7 \pm 0.8 \mathrm{m}^2/(\mathrm{V.s})$
- EH02: $5.9 \pm 0.8 \mathrm{m}^2/(\mathrm{V.s})$
- ζ = 30 - 40 mV

Two results

Anomalous dynamics of dipolar chains

- In the regime where dipoles are induced by an extended, distorted double layer.
- Short-time sub-diffusive behaviour is an extension of single-file diffusion to interacting and quasi-1D situations.
- Long-time super-diffusive behaviour at high coupling strength is unexplained:

- chain-chain attractions?

- subtle effect of small oscillations?

AC electrophoresis

- Opens a window into true out-of-equilibrium driven, dissipative systems.

Thanks

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