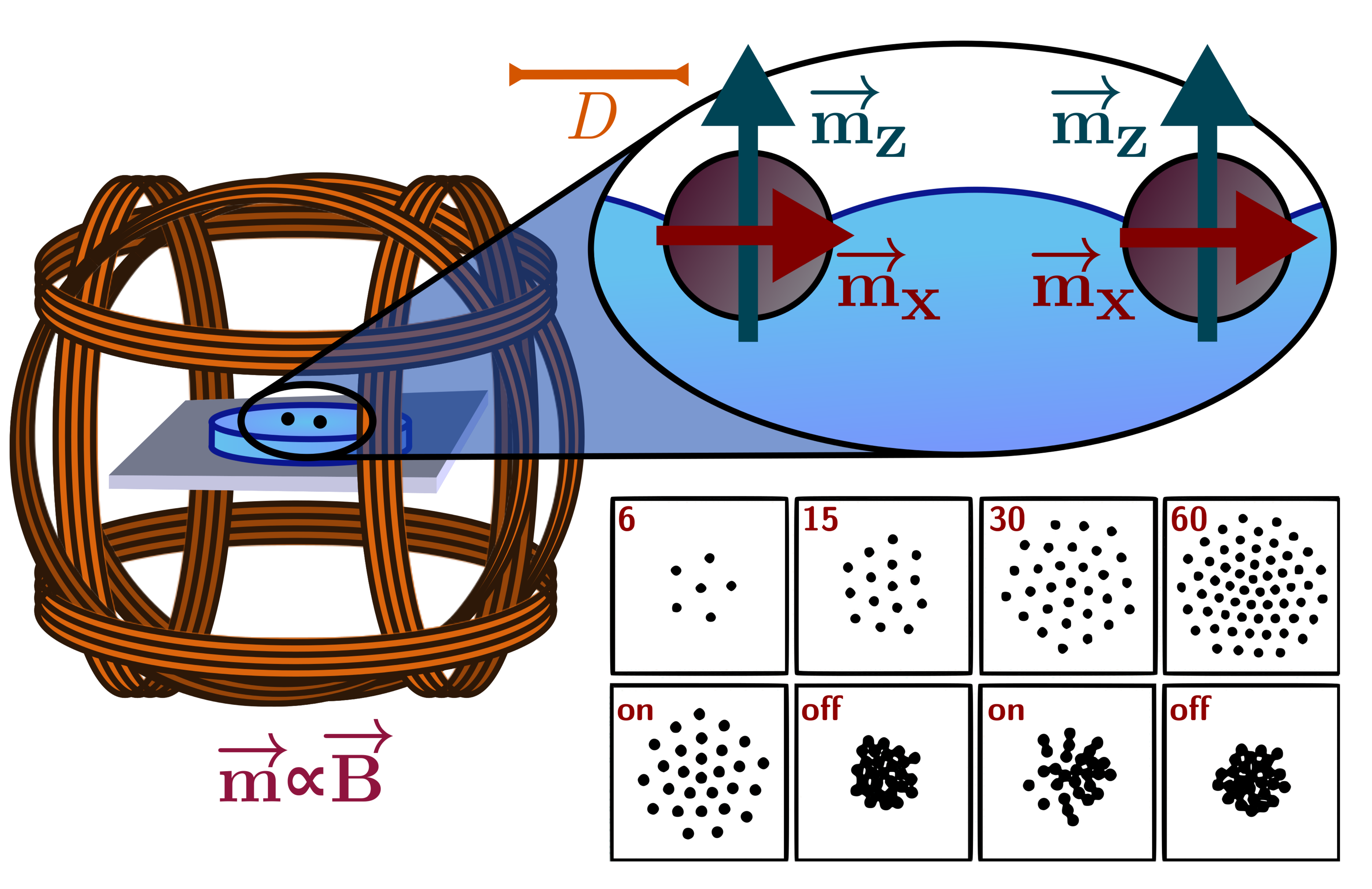
Complex magnetocapillary microswimmers

Galien Grosjean, Nicolas Vandewalle, Guillaume Lagubeau & Maxime Hubert

GRASP - Physics Department,
University of Liège, B-4000 Liège, Belgium.
http://www.grasp-lab.org

Setup

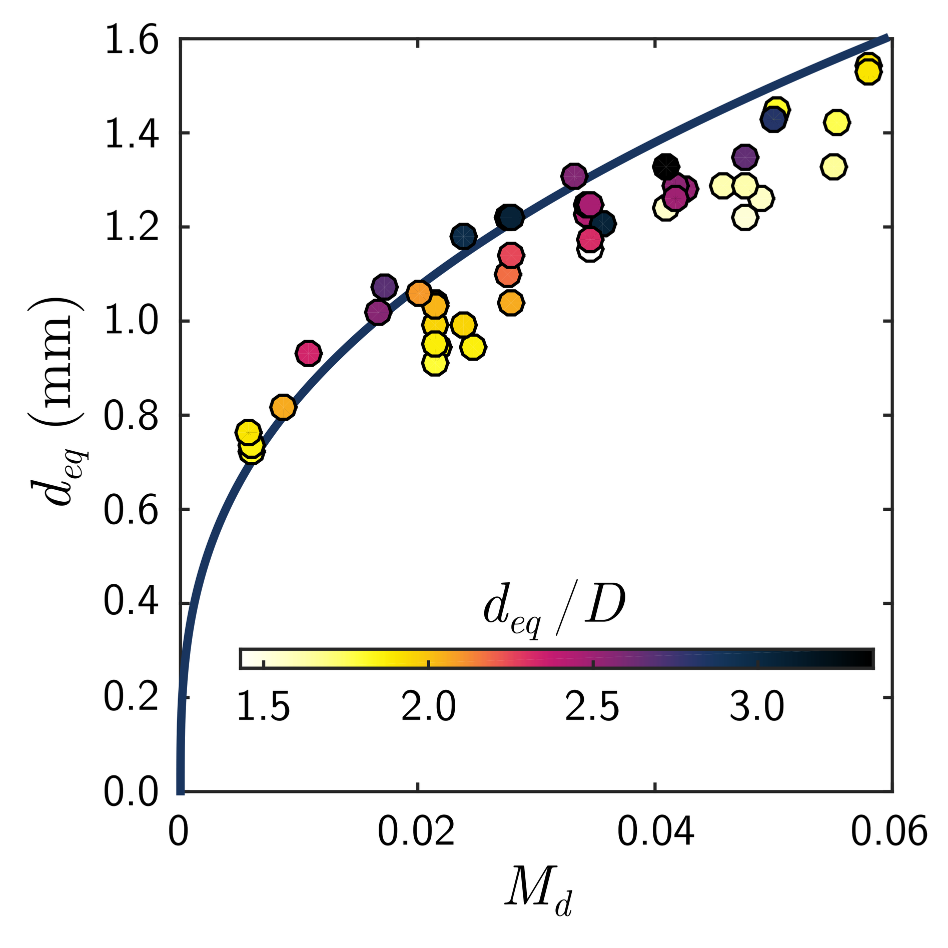


Equilibrium

Pair potential = Capillary attraction + Dipole-dipole interaction

$$U = U_c + U_m = \Gamma \left[K_0(\tilde{d}) + \frac{M_d}{\tilde{d}^3} + \frac{M_\theta}{\tilde{d}^3} \sin^2\theta \right] \quad (1)$$

with $\tilde{d} = d/l_c$ and the magnetocapillary numbers M_d and M_θ.



M_d, M_θ compare **magnetism** and **capillarity**. We have

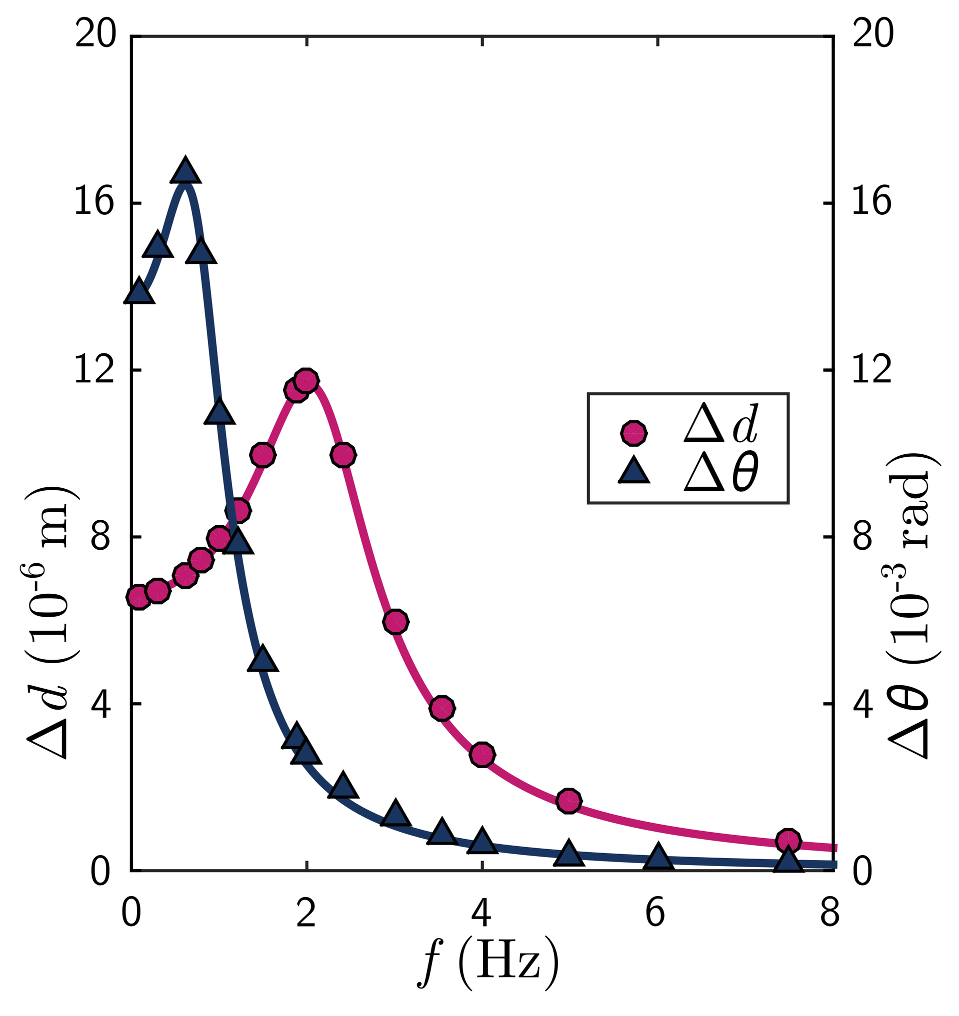
$$M_d \propto \left(m_z^2 - 2m_x^2\right)/\Gamma\,, \qquad M_\theta \propto m_x^2/\Gamma\,. \quad (2)$$

Eq. (1) gives **equilibrium**

$$\theta_{eq} = 0\,, \qquad \tilde{d}_{eq}^4 K_1(\tilde{d}_{eq}) = 3M_d\,. \quad (3)$$

Does not work if $d_{eq}/D < 2\ldots$ superposition approximation!

Perturbative analysis



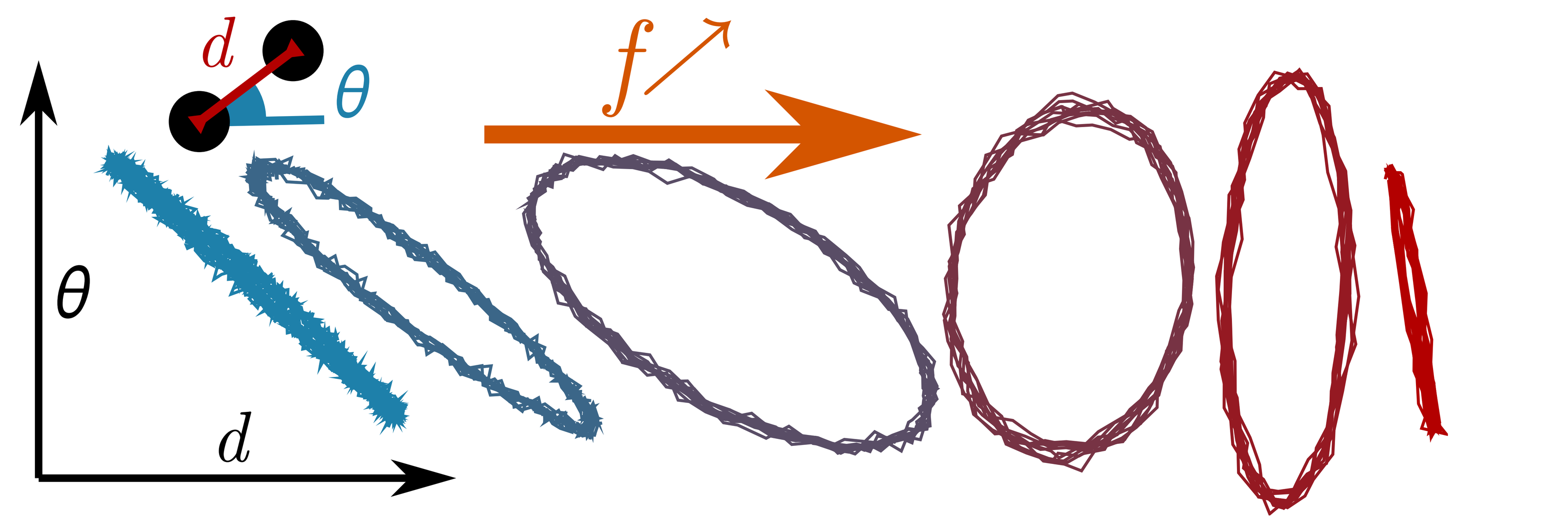
Two modes, depending on perturbation orientation with magnetic field:

- **radial** d, stronger at 0°,
- **orthoradial** θ, stronger at 90°.

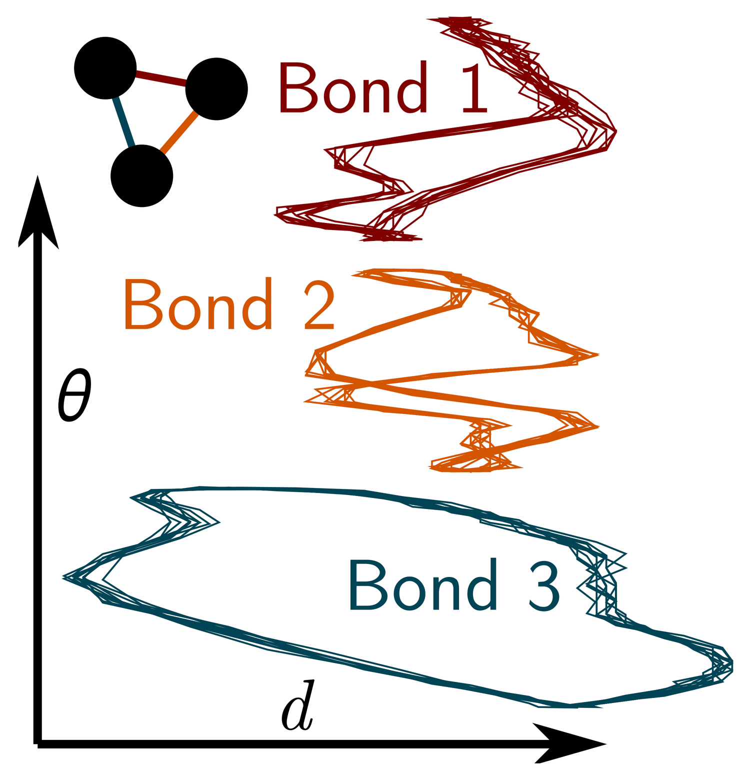
Even though Re $\ll 1$, Q factor $q = \omega_0\tau/2$ can be > 1.

Harmonic resonances at low Re!

Cycles



Modes can be out of phase → **non-reciprocal** motion. Necessary for low Re swimming!

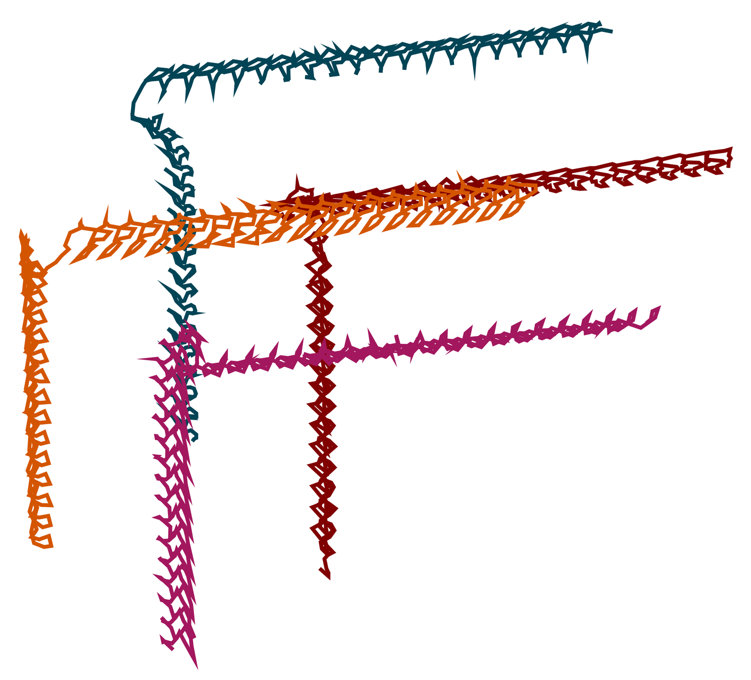


Perturbative analysis describes basic behavior.

However, **nonlinearity** and **couplings** matter for efficient swimming.

Swimming trajectories

Remote control can be achieved by changing field orientation!



Influence of **geometry**! Example: fast 90° turn with 4 beads.

How can we combine many bonds in **large assemblies**?

Conclusion and references

Magnetocapillary bonds: versatile **building blocks** [1] for **self-assemblies** [2] and **microswimmers** [3]. Rich nonlinear dynamics that ought to be studied!

[1] Lagubeau G., Grosjean G., Darras A., Lumay G., Hubert M. & Vandewalle N. *Statics and dynamics of magneto-capillary bonds* in preparation (2015).
[2] Vandewalle N., Clermont L., Terwagne D., Dorbolo S., Mersch E. & Lumay G. *Phys. Rev. E*, **85** (2012) 041402.
[3] Grosjean G., Lagubeau G., Darras A., Hubert M., Lumay G. & Vandewalle N. *Remote control of self-assembled microswimmers* arXiv:1507.00865 preprint (2015).