APS physics

MARCH MEETING 2022

APS satellite meet, ICTS

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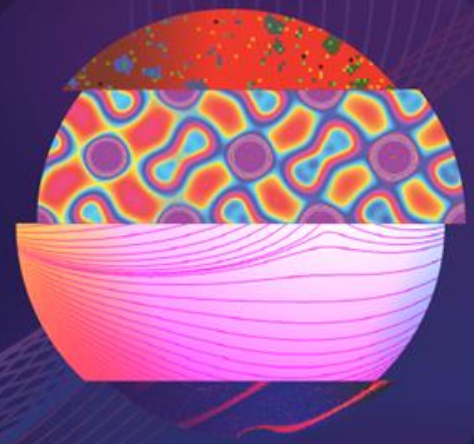
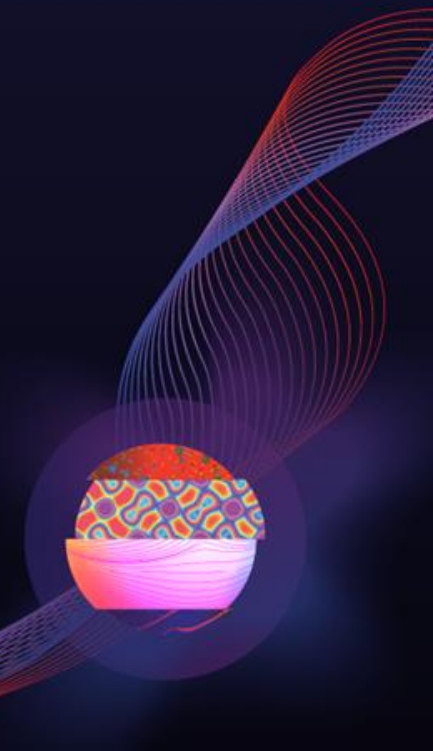


APS physics MARCH MEETING 2022

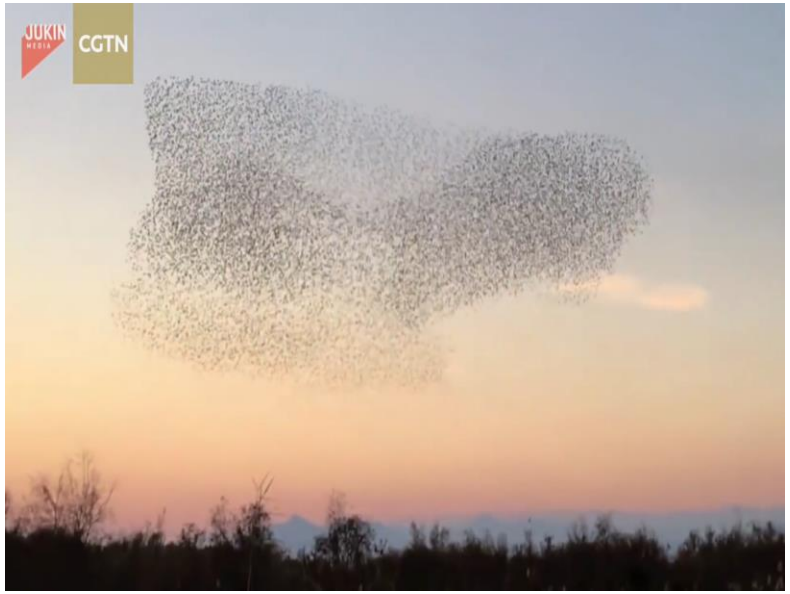
Development of all-magnetic active matter



Active matter systems are composed of energy consuming/ dissipating components which are intrinsically out of thermal equilibrium.

This phenomenon is present in processes ranging from

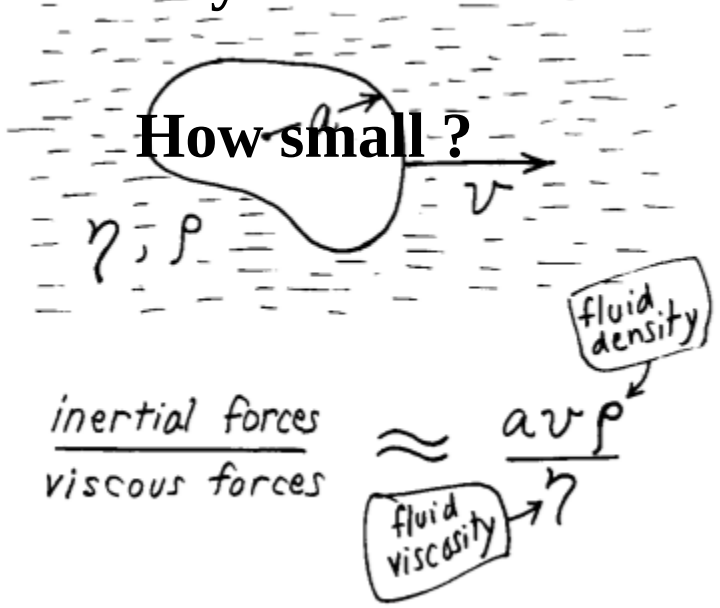
- intra-cellular transport
- bird migration
- marine life
- bacterial colonies
- even human migration !



**youtube

Life at low Reynolds number

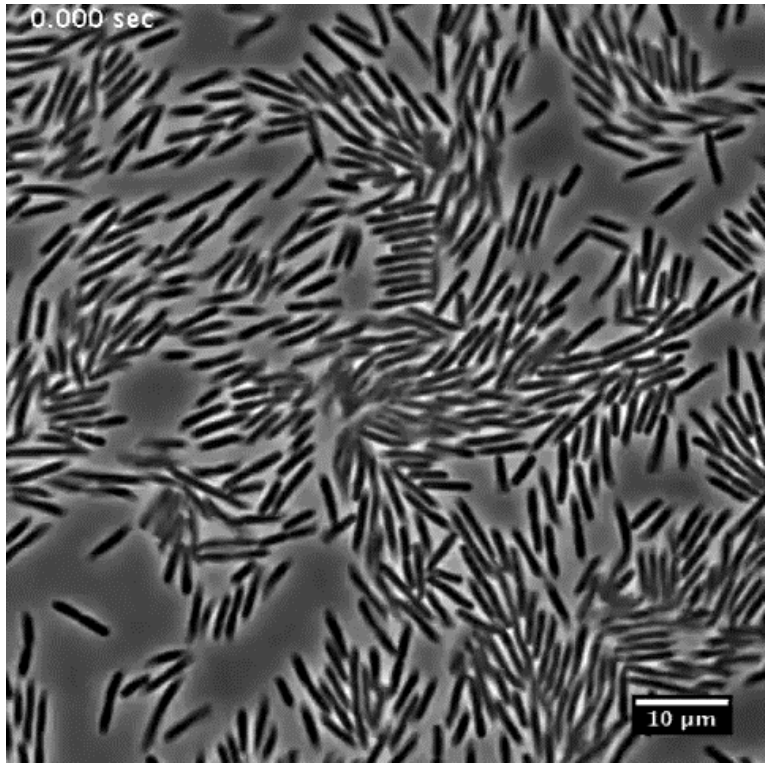
Our focus : Systems at small scales



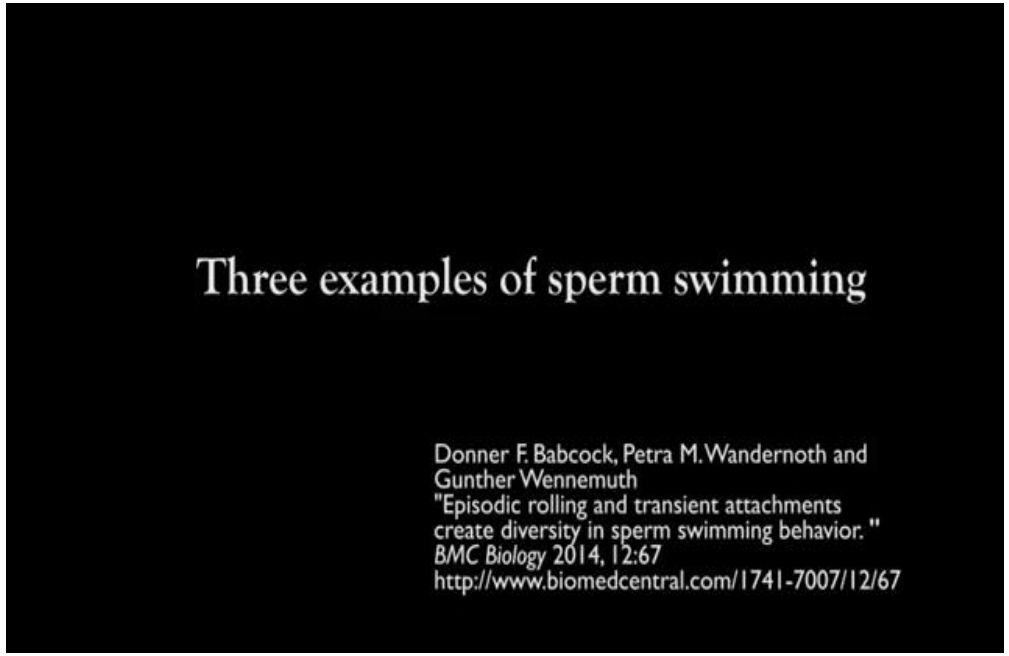
$$Re = av\rho/\eta$$

At small scales, inertial forces are negligible and viscous (friction) forces dominate.

Life at Low Reynolds number, E.M. Purcell, 1976



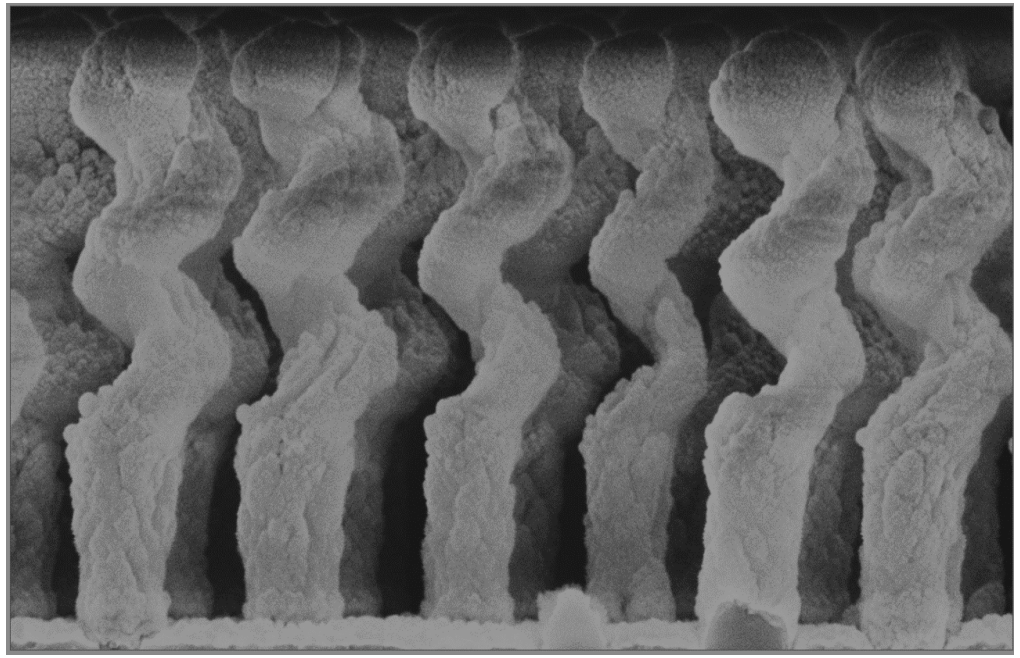
Bacterial colony



Swimming of Sperms

**Youtube

Our artificial system of magnetic swimmers



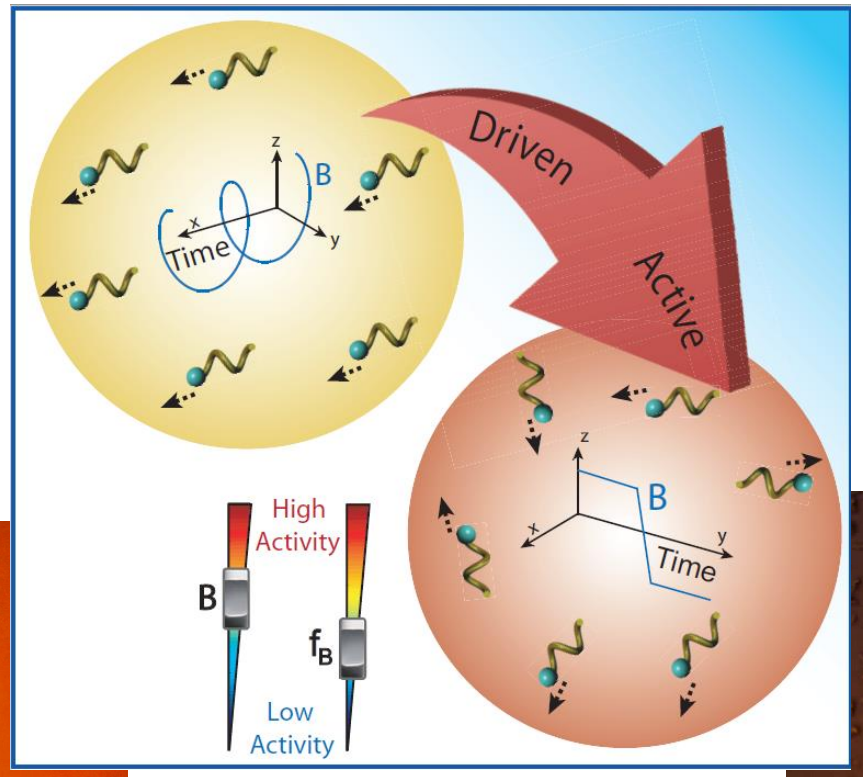
Scale of the system – 1~5 μm

Energy source – magnetic field

Helical structure – corkscrew motion

Permanent magnetic moment – due to ferromagnetic element

Under a rotating magnetic field – translational motion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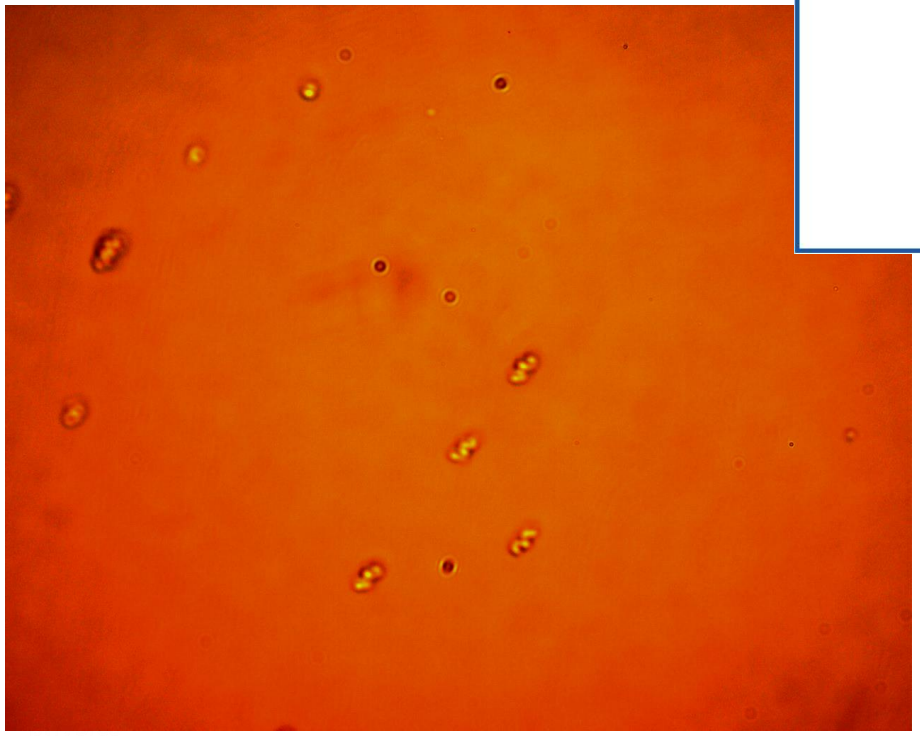
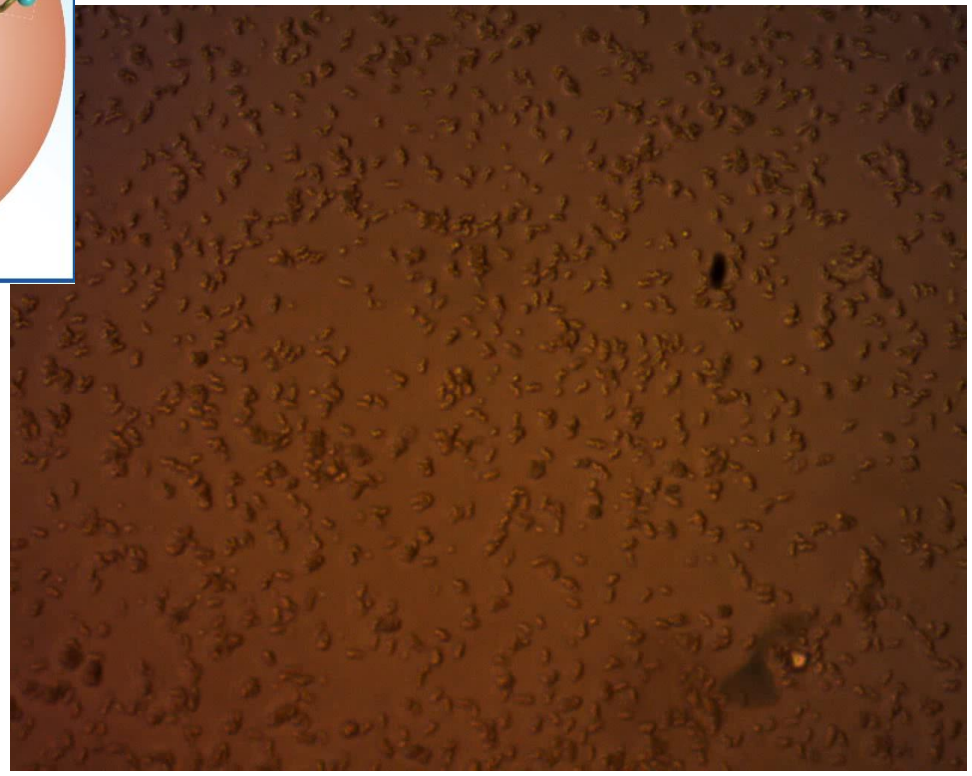




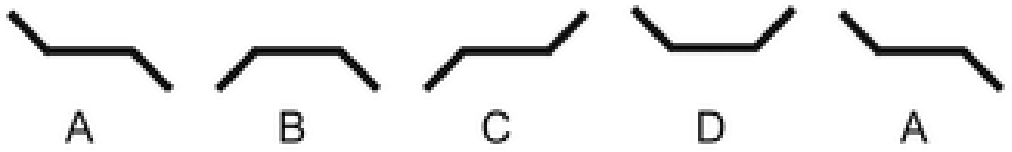
Motion at small scales is dictated by Scallop theorem

A swimmer that exhibits time-symmetric motion cannot achieve net displacement in a low Reynolds number, Newtonian fluid environment.

Navier - Stokes:

$$-\nabla p + \eta \nabla^2 \vec{v} = \rho \frac{\partial \vec{v}}{\partial t} + \rho (\vec{v} \cdot \nabla) \vec{v}$$

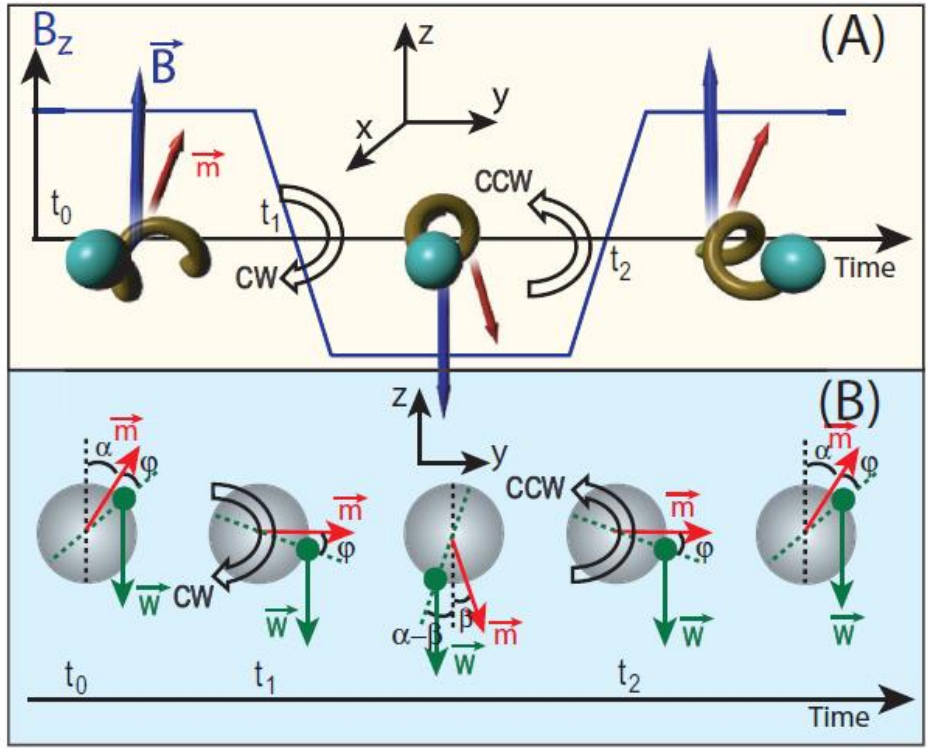
Not preferred



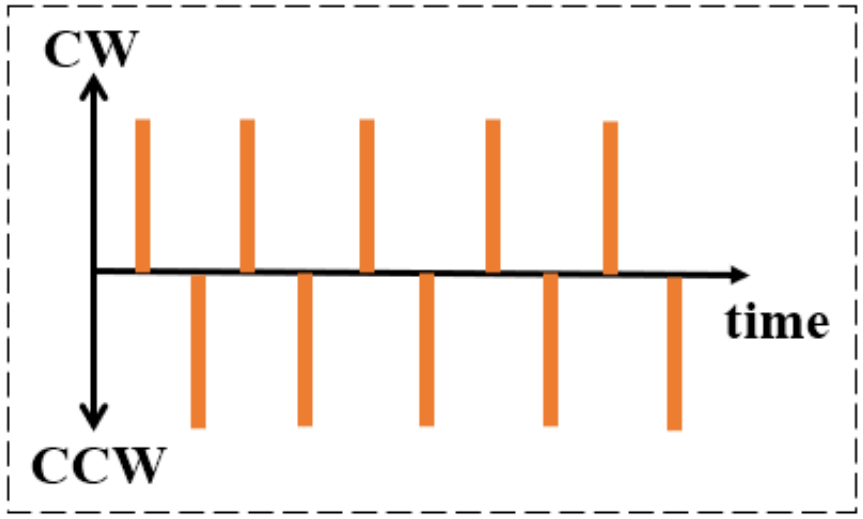
Preferred

Life at Low Reynolds number, E.M. Purcell, 1976

With time, clockwise (CW) and counterclockwise (CCW) turns continue alternately

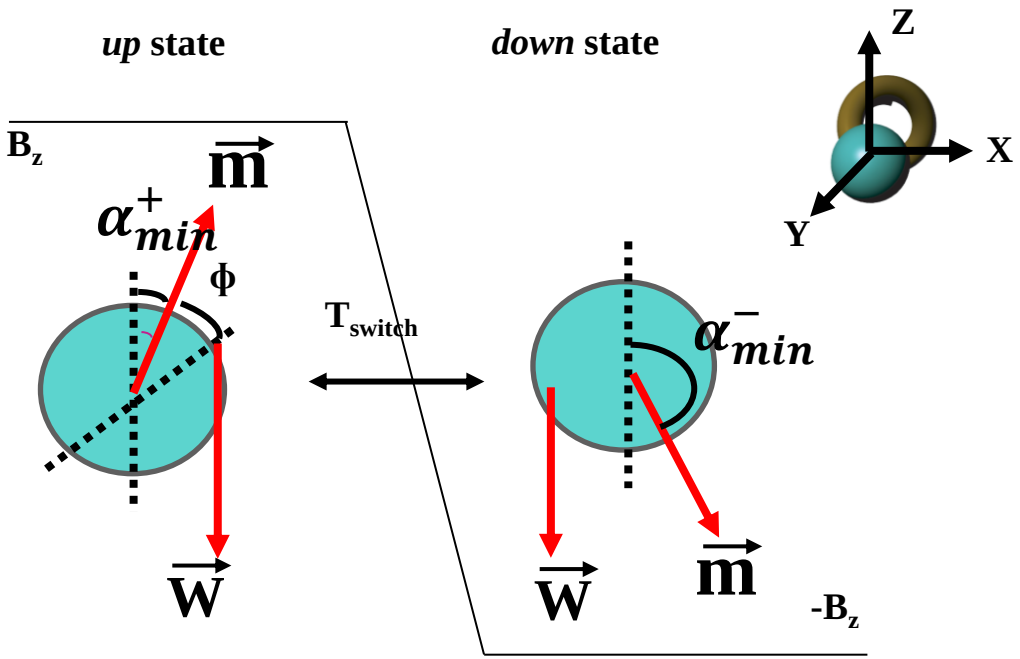


CW=CCW

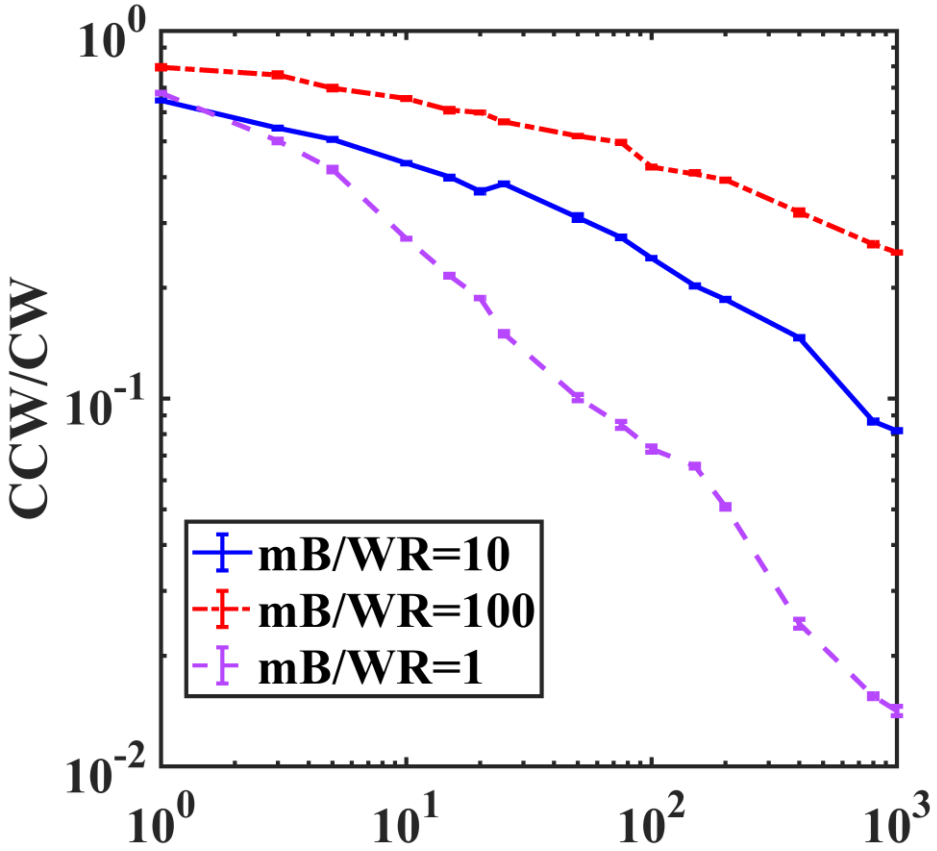


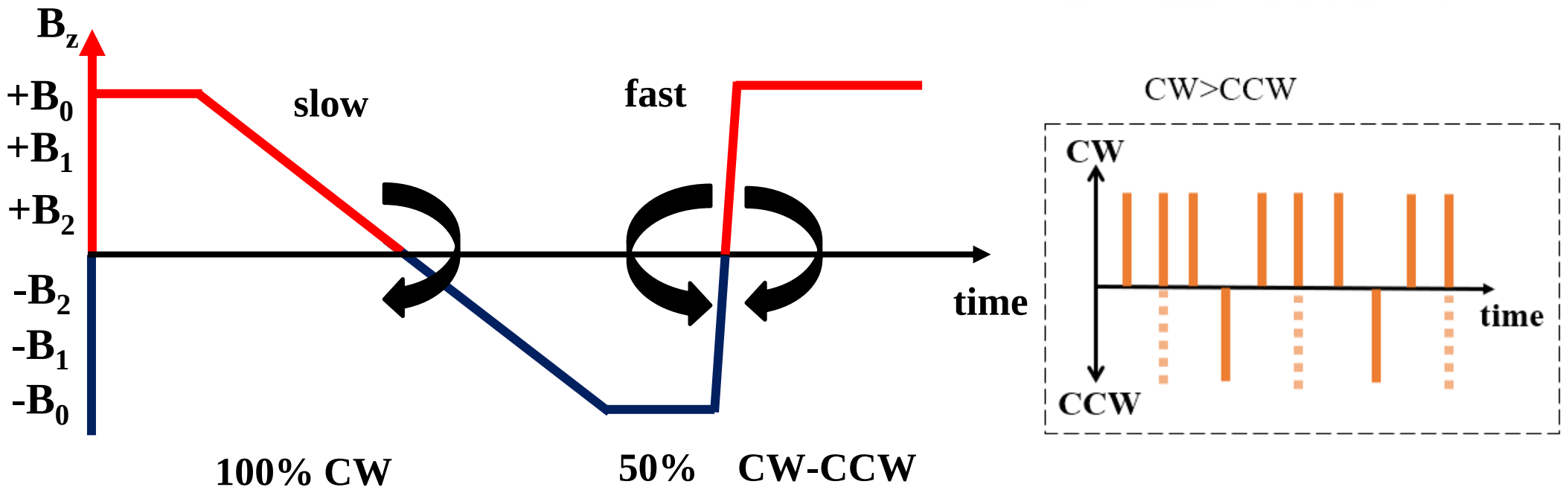
$$-mB_z(t)\sin(\alpha) + WRsin(\alpha+\varphi) = \gamma_l \frac{d\alpha}{dt}$$

$$\alpha(t+\Delta t) = \alpha(t) + \Delta t \frac{d\alpha}{dt} + \zeta_r(t)$$



Ratio of turns as a function of switching time between +B and -B

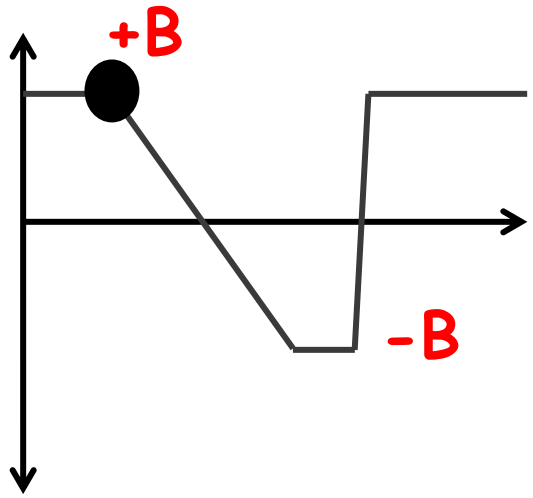




Experimentally obtained statistics

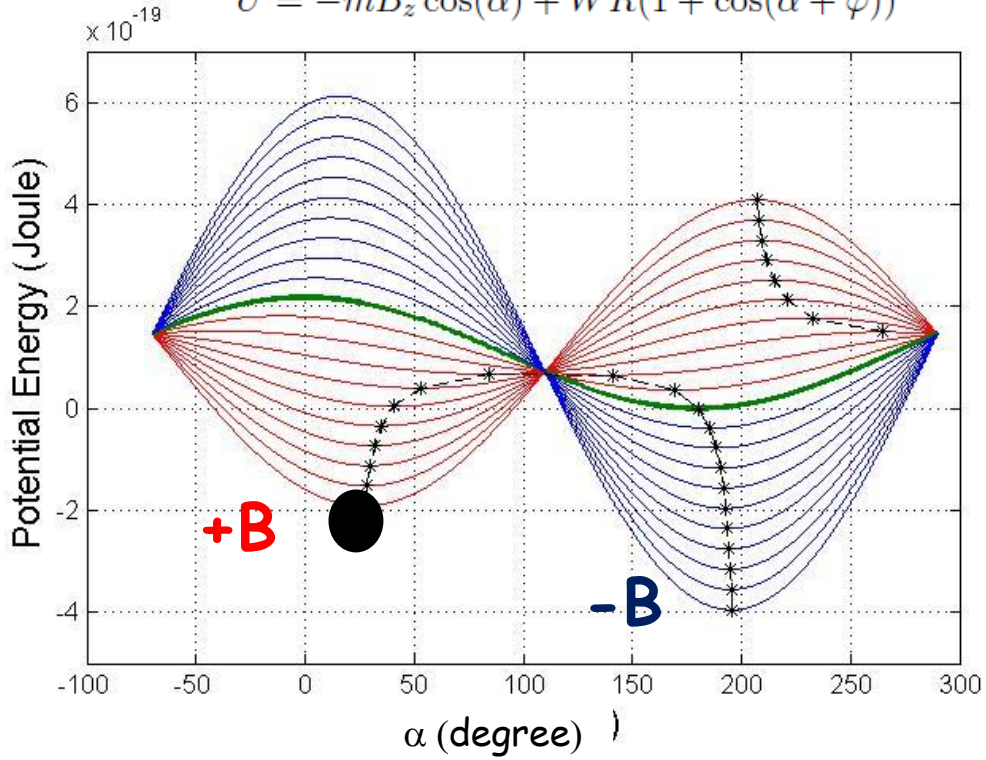
	CW	CCW
Slow Switching	94%	6%
Fast Switching	43%	57%

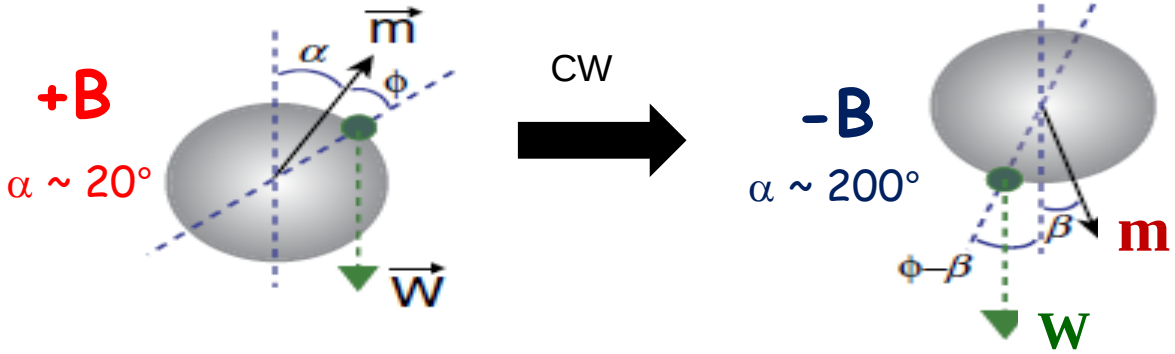
Energy, time scale, noise



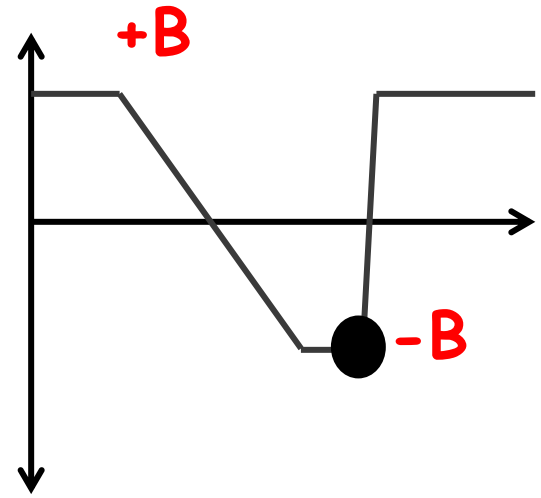
Total energy = Magnetic + Gravitational

$$U = -mB_z\cos(\alpha) + WR(1+\cos(\alpha+\varphi))$$





Energy, time scale, noise



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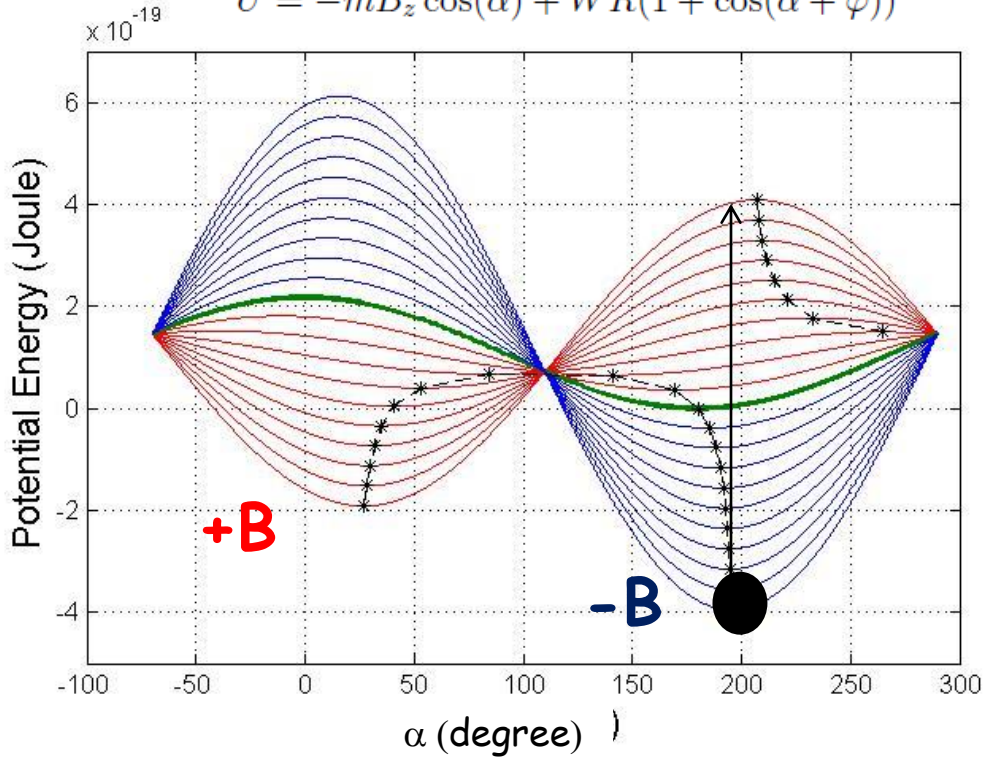
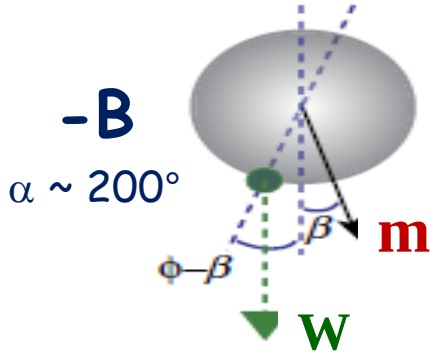
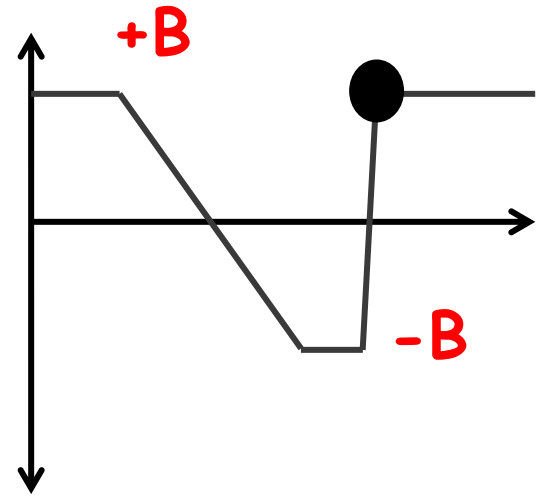


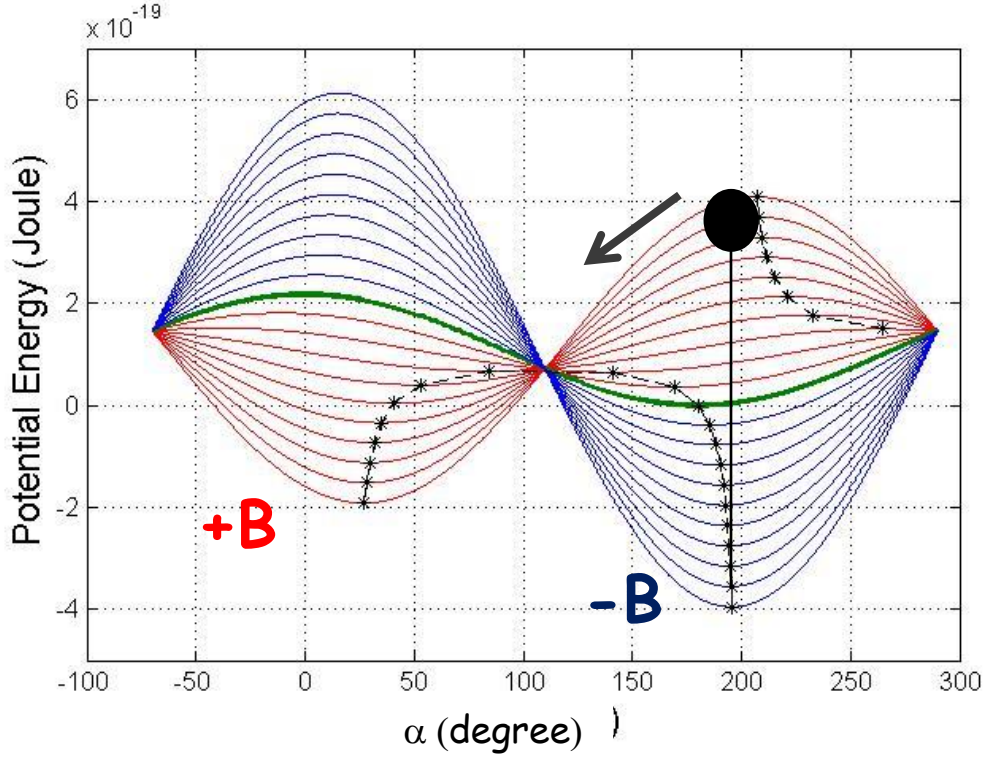


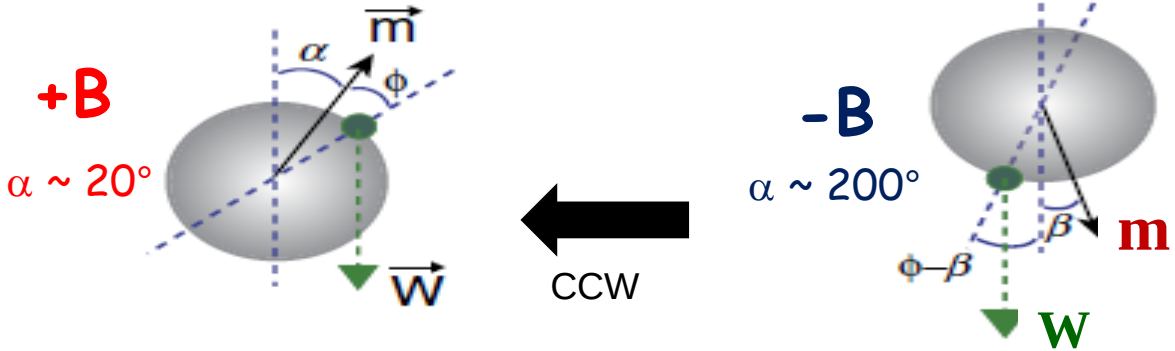
Energy, time scale, noise



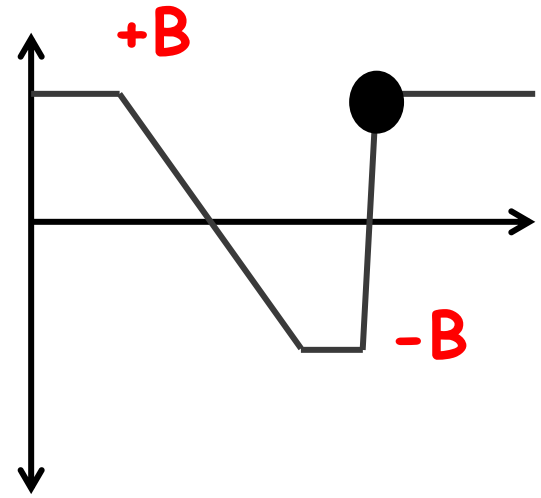
Back and forth

Total energy = Magnetic + Gravitational



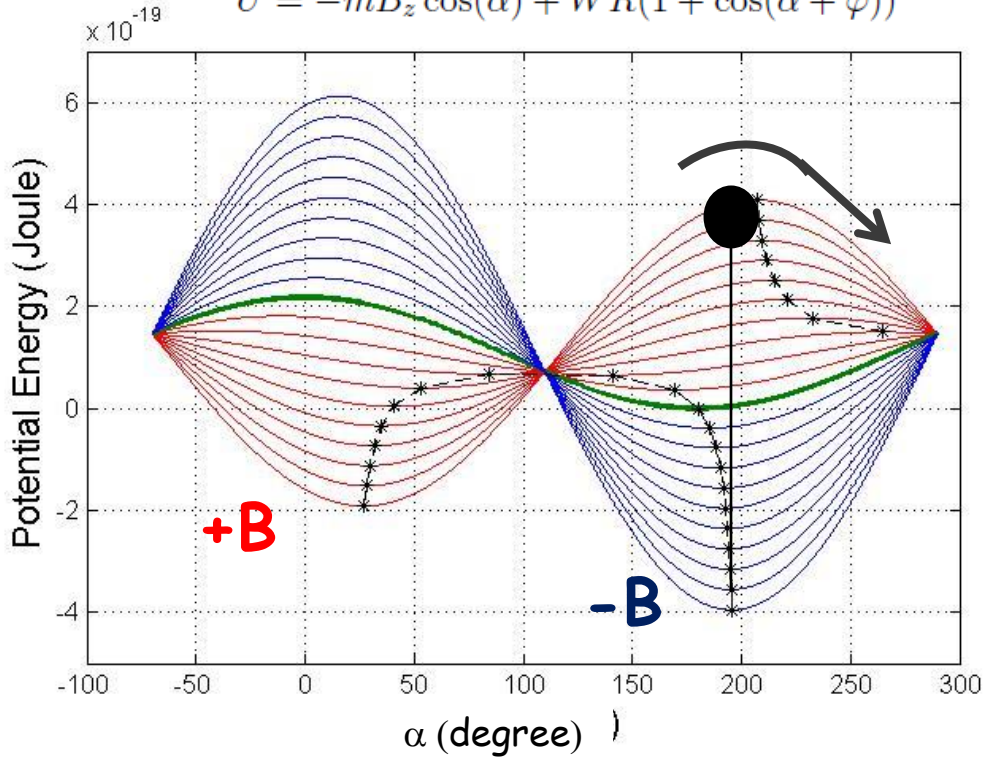


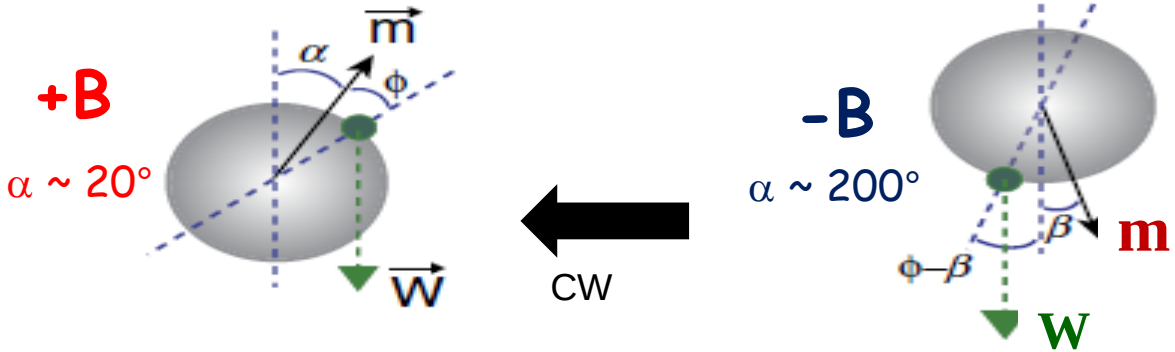
Energy, time scale, noise



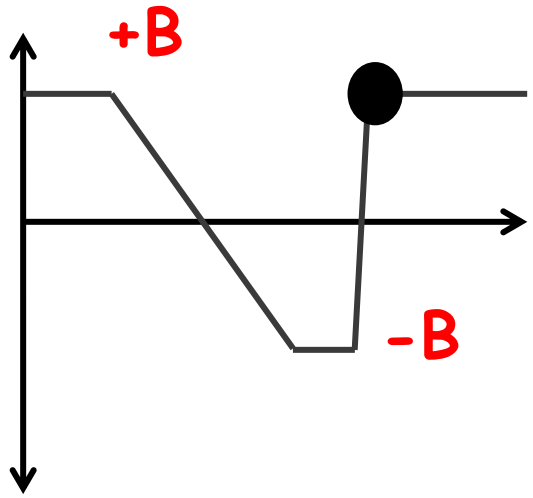
Total energy = Magnetic + Gravitational

$$U = -mB_z\cos(\alpha) + WR(1+\cos(\alpha+\varphi))$$



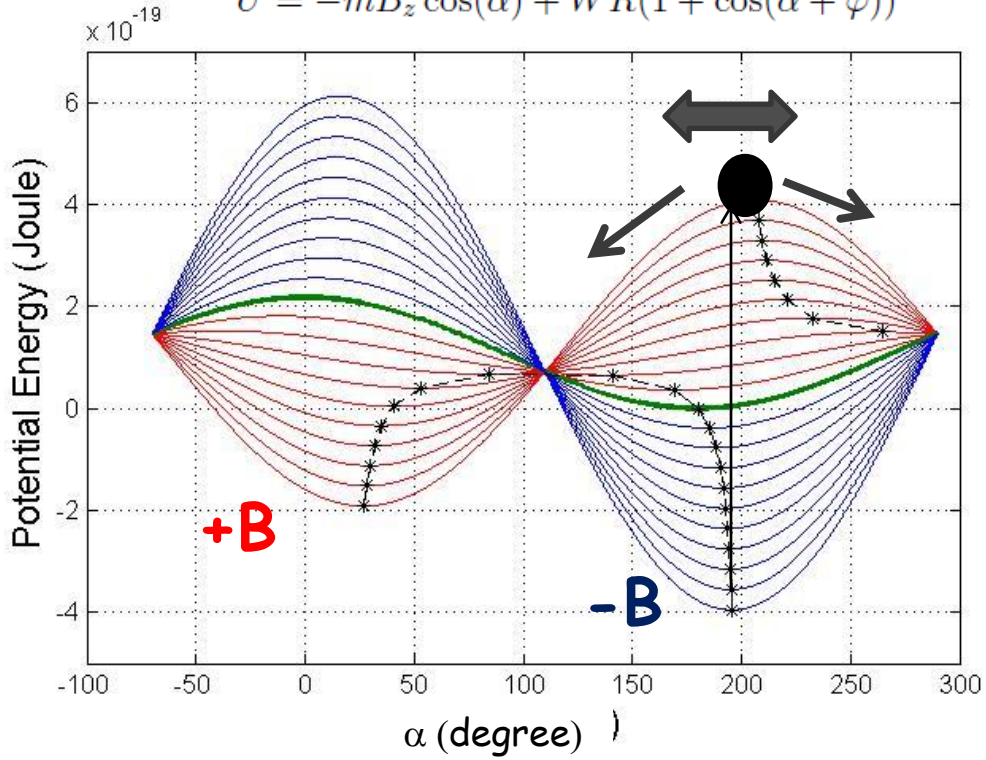


Energy, time scale, noise

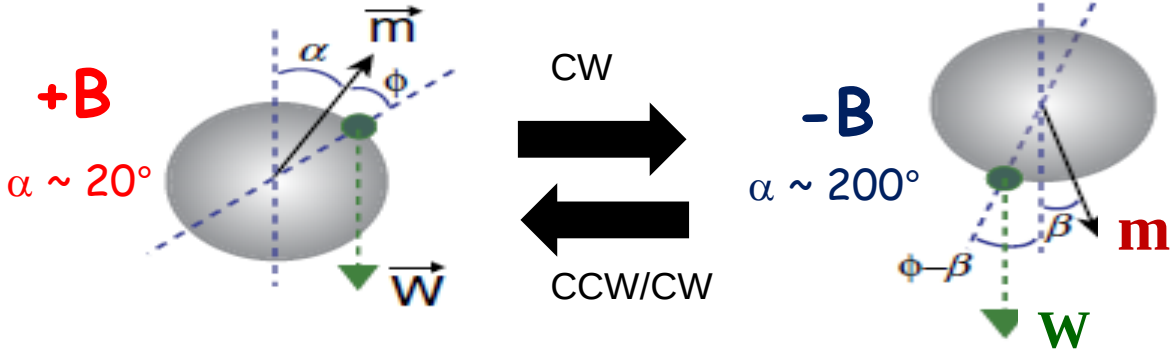


Total energy = Magnetic + Gravitational

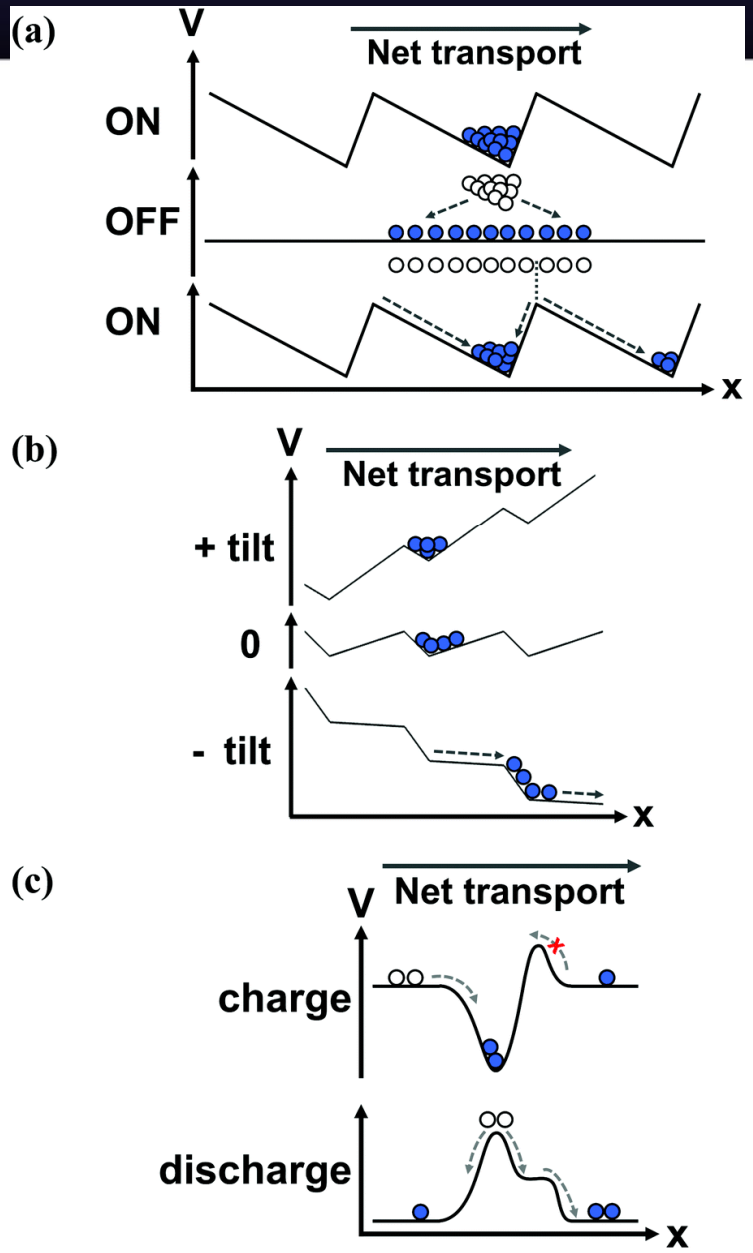
$$U = -mB_z\cos(\alpha) + WR(1+\cos(\alpha+\varphi))$$



Noise necessary in breaking CW-CCW symmetry



Brownian ratchet principle

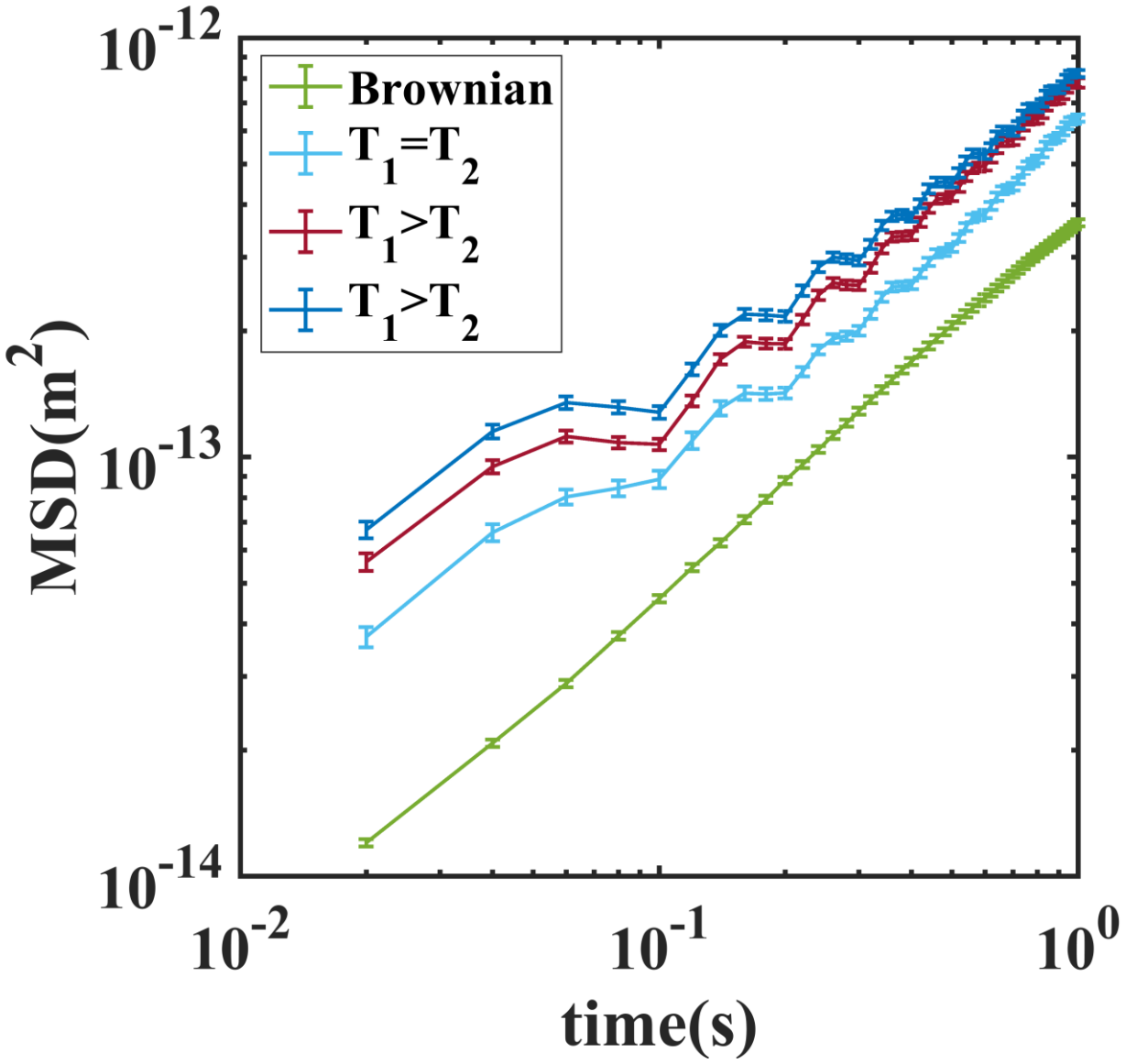


An introduction to ratchets in Chemistry and Biology, Materials Horizons

Asymmetric spatially modulating periodic potential + non-equilibrium system + thermal noise

$$U = -mB_z\cos(\alpha) + WR(1+\cos(\alpha+\varphi))$$

Enhanced diffusivity



In a nutshell,

We have designed an artificial active system which is easily tunable
to study the various phenomenological ideas like flocking, swarming and phase separation.

The system can be tuned very easily from driven to an active system;
With reciprocal to non-reciprocal swimming.

Collective motion of such swimmers show interesting features which is the work currently being pursued.

References:

[1] Mandal, P., Patil, G., Kakoty, H., & Ghosh, A. (2018). Magnetic Active Matter Based on Helical Propulsion. Accounts of chemical research, 51(11), 2689-2698.

[2] Mandal, Pranay, and Ambarish Ghosh. "Observation of enhanced diffusivity in magnetically powered reciprocal swimmers." Physical review letters 111.24 (2013): 248101

[3] Patil, G., & Ghosh, A. (2021). Anomalous Behavior of Highly Active Helical Swimmers. Frontiers in Physics, 8, 656.

[4] Patil, G., Mandal, P., & Ghosh, A., Breaking reciprocity of a magnetic helical swimmer using the principle of ratchet, *To be submitted*

Thank You