MASTER INTERNSHIP OFFER (6 months) + FUNDED PhD THESIS

Transport and extreme statistics for bacterial ecology, a controlled system: magnetotactic bacteria in porous media

Supervisors: Waisbord Nicolas & Jean-François Rupprecht, Marseille Luminy (France)

Pitch: Magnetotactic bacteria (MTB) propel themselves along Earth's magnetic field. Our hypothesis is that the magnetic field modulates dispersion within sediments and thereby promotes MTB biodiversity in heterogeneous environments. We will reframe this question of microbial colonization of sediments within the framework of extreme-value statistical physics: the key is not the average but the arrival of the first bacterium that seeds a colony. The analysis will link the statistics of these rare events to the heterogeneity of pores, flows, and bacterial properties.

Keywords: active matter, transport in porous media, magnetotactic bacteria, microfluidics, natural sediments, first-passage time, microbial ecology, niche partitioning.

Context: Magnetotactic bacteria (MTB) are microorganisms capable of orienting themselves along Earth's magnetic field lines thanks to chains of magnetic nanocrystals within their membranes. These bacteria have been studied for 60 years in soluble media, while they essentially live in a highly localized manner, confined to the first millimeters of aquatic sediments. What has limited the study of these bacteria under real conditions is that sediments are porous, opaque, and dense media that are difficult to access. We have developed several microfluidic systems that allow mimicking the physics of flows in artificial sediment under a microscope. Our recent work on MTBs in model porous media reveals rich, non-linear physics, with vortical trapping phenomena, heavy-tailed passage time distributions, and "bacterial diode" regimes where flow can be completely blocked under certain conditions – where the applied magnetic field plays the role of a control parameter for these non-linearities.

PhD project ambition: This work aims to answer a major question in the field: what is the evolutionary advantage of magnetotaxis in these disordered confined environments? Recent work suggests that at the individual scale, the magnetic field helps bacteria navigate well. In this thesis, we will test a complementary and competitive hypothesis, according to which the magnetic field also controls niche selection within sediments and thus increases MTB biodiversity in these heterogeneous environments.

Method: We propose to model the microbiological colonization of sediments as a problem of extreme statistical physics, where the magnetic field controls the finer scales of niche partitioning. Until now, approaches have focused on averaged properties of porous media. However, in the context of microbial ecology, what is critical is the question of the first bacterium, the one that will generate a new colony. It is therefore this complex transport and extreme statistics that will interest us for MTBs in sediments. This statistic will be strongly correlated with the statistics of pore and flow heterogeneities, but also with bacterial sensitivity to the magnetic field.

M2 internship research project: In this internship, we will focus on transport and seek to quantify and model bacterial flux through, first (step 1) a transparent model porous medium, then (step 2) through a real sediment. We will center our study on first passage time (FPT) statistics. We will compare the sensitivity of FPT statistics to the magnetic field through a real, opaque sediment, and a transparent micromodel where trajectories can be reconstructed to allow us to establish a realistic test model system for porous media from the transport perspective. The methodology is structured around:

(i) **designing** microfluidic devices with controlled geometries to establish reference measurements of FPT distributions as a function of magnetic field and flow conditions;

(ii) **integrating** real sediment samples from MTB-rich sites into these devices to perform direct measurements through natural porous structures;

(iii) **modelling** the detailed statistical analysis of these distributions, with particular attention to heavy tails and non-ergodic behaviors.

The comparison between transparent model geometries (where trajectories can be reconstructed) and opaque real sediments (where only FPTs are accessible) will identify which structural properties of these sediments effectively control their exploration by MTBs.

Skills to be developed: Microfluidics, microscopy, image processing and trajectory analysis, stochastic modeling (CTRW, Langevin), environmental sample handling.

Desired skills: The ideal candidate is a physicist who enjoys understanding fundamental mechanisms (here: transport in porous media) but is ready to gradually open up to broader biological and ecological questions. Taste for experimentation (from tinkering to fine manipulation). Solid background in statistical physics and stochastic processes. Capabilities in data processing and image analysis (Python, Matlab, or equivalent). Autonomy, scientific curiosity and open-mindedness: the project will evolve from fundamental transport physics toward broader microbial ecology questions.

Work environment

Supervision: Waisbord Nicolas and Jean-François Rupprecht, respectively Associate Professor AMU and CNRS Researcher and the Laboratoire de Chimie Bactérienne & Laboratoire Adhésion Inflammation, Marseille, respectively.

Equipment: Complete microfluidic platform (micro-fabrication and microscopy). **Collaborations:** Microbial ecologists for sampling and field studies.

PhD funding: PhD thesis already funded (3 years guaranteed after internship). **PhD start:** anytime in 2026. **Internship duration:** 6 months (flexible dates, ideally February-July or March-August 2026).

To apply: Informal inquiries are welcome. Please send us a CV, M1 and M2 transcripts, motivation letter (1 page max explaining your interest in this project at the physics/biology/ecology interface) and contacts of 1-2 references to: nwaisbord@imm.cnrs.fr and rupprecht.jf@gmail.com.

References

- Waisbord et al., *Nature Communications* (2021) - Fluidic bacterial diodes rectify magnetotactic cell motility in porous environments
- Petroff et al., *eLife* (2025) - Optimal navigation in pore networks
- Codutti et al., *eLife* (2025) - Physiological magnetic fields and navigation in simulated sediments