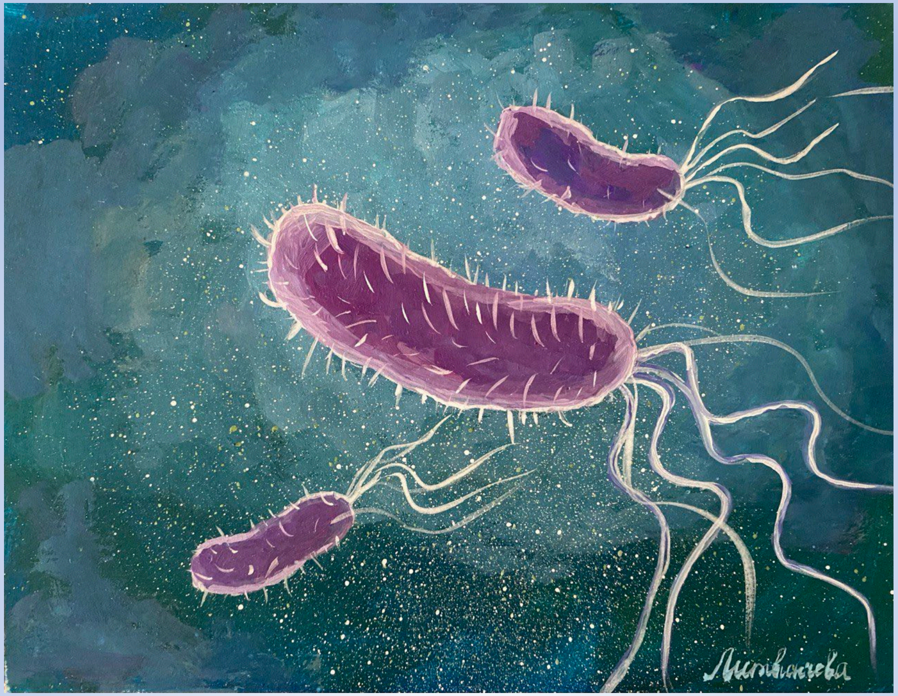
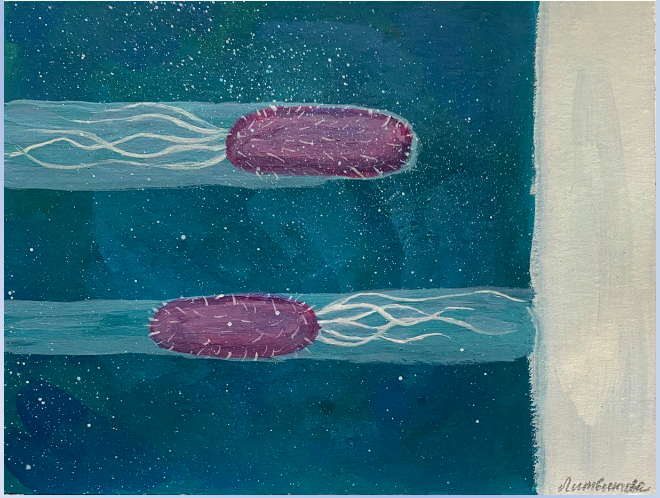


Alexander Gavrikov:
Visual research portfolio

Bacterial motion in mucus (e.g. cervical, gastric)

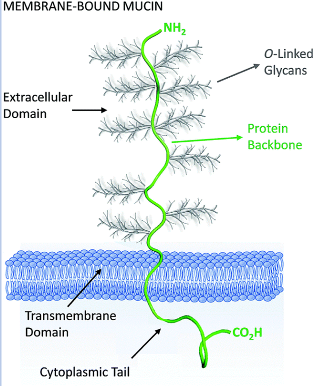
- Investigating bacterial motion in mucus contributes to better understanding and potentially mitigating infectious processes in organs lined with mucus
- Bacterial motion in mucus strikingly differs from water: bacteria ‘burrow’ tunnels and form ‘bacterial trains’



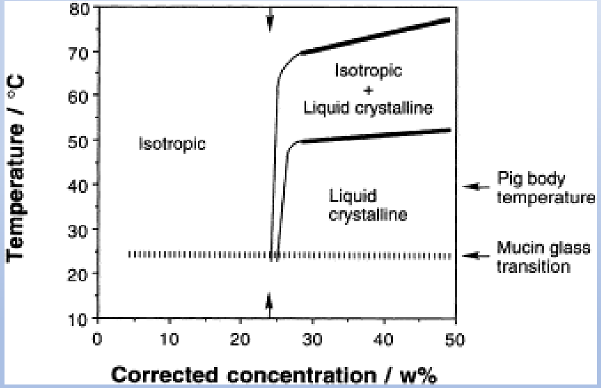
Bacteria “burrow” transient tunnels in mucus: a sketch

Mucus

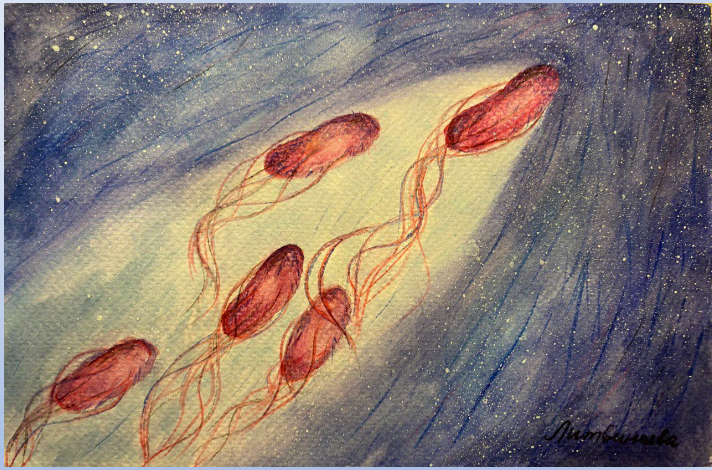
Besides memory effects, mucus shows liquid crystalline (LC) properties at high concentrations of mucin—long polymer molecules that forms a network



Mucin [Martínez-Sáez et al, Chem Soc Rev 2017]



[Davies & Viney, Thermochimica Acta 1998]

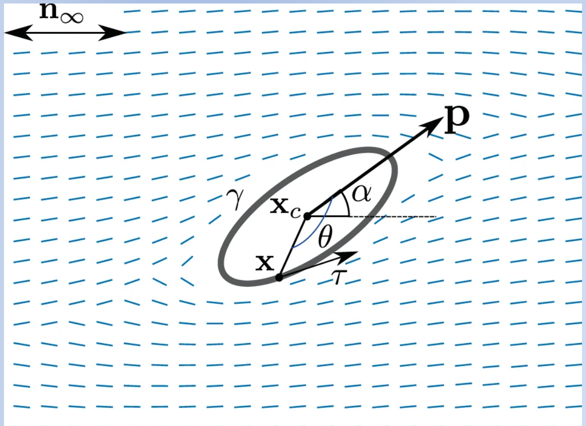


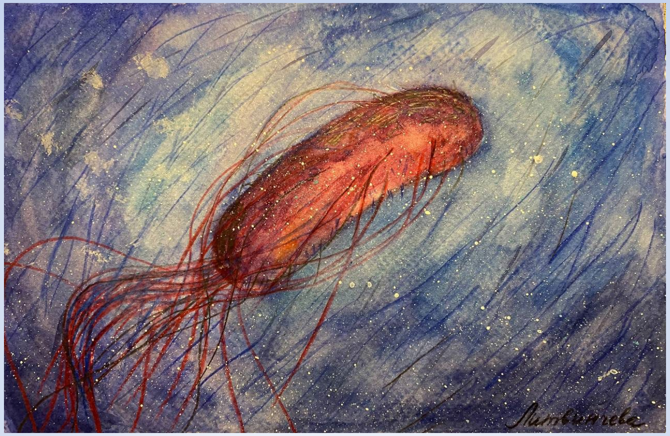
Bacteria swim as a group: a sketch

Modeling: Mucus

Mucus is modeled as viscoelastic (VE) liquid crystal via 2 nonlinear tensor partial differential equations (PDEs) + Stokes equation describing the flow of mucus (contains LC elastic and VE stresses) *[Hemingway et al, PRL 2015]*

Modeling: Bacteria

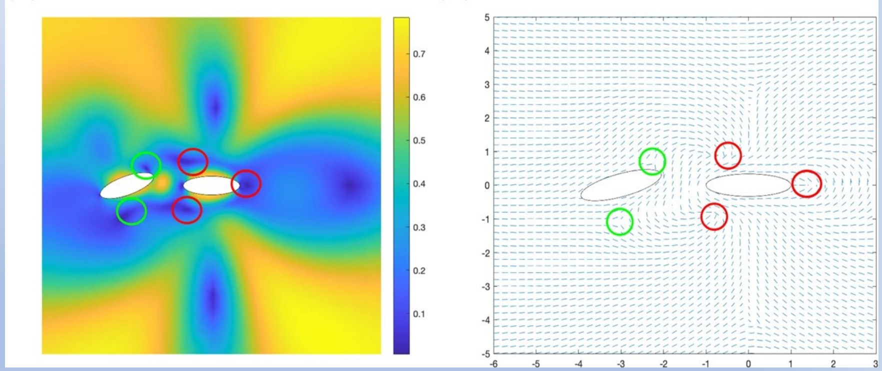




- Several bacteria—each bacteria is modeled as a rigid body
- Many bacteria—each bacteria is modelled as a point source

Bacteria (right) is modeled as a rigid body (left), see Chi, **Gavrikov**, Berlyand, Aronson. Interaction of microswimmers in viscoelastic liquid crystals. *Commun Phys* **5**, 274 (2022). https://doi.org/10.1038/s42005-022-01056-1

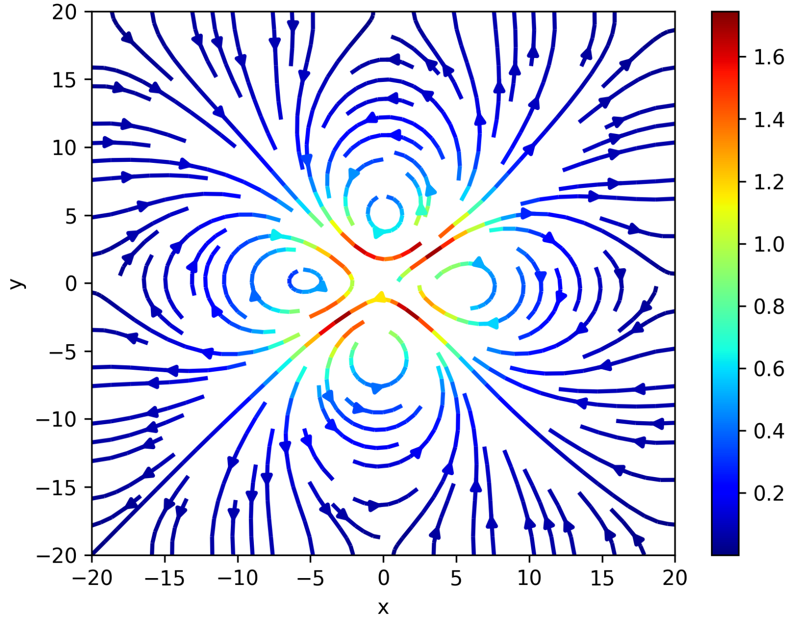
Results in this paper explain formation of bacterial trains via suppression of anisotropy and interaction of defects



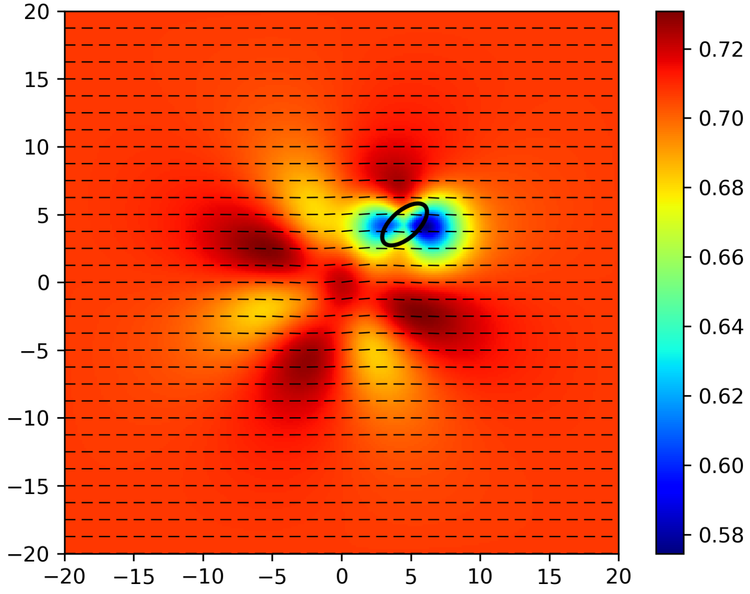
Bacterium catches another one in its trail, and they travel together head-to-tail

Current work: collective bacterial motion in mucus

Bacteria are modeled as point sources. Then the time-dependent PDEs can be solved via Fast Fourier Transform on GPUs



Viscous dipole: streamlines

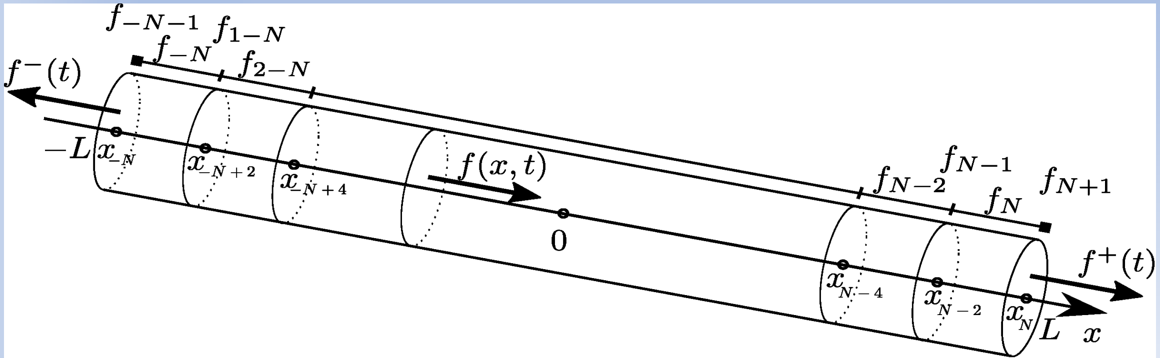


Elastic point force: nematic field and anisotropy level

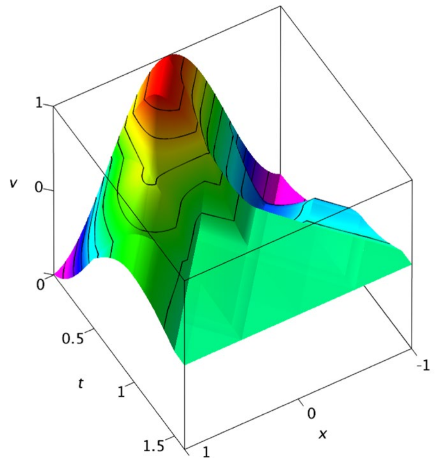
Preliminary results:

- viscoelasticity enhances collective effects
- easier to form clusters/more stable clusters
- tunnels (zone of suppressed anisotropy) are ‘open’ for a longer time

Smart structures: controlling longitudinal motion of elastic bodies via piezoactuators



N identical piezoactuators attached to a rod along its length; driving forces are applied at rod ends, see G. Kostin, **A. Gavrikov** Optimal Motions of an Elastic Structure under Finite-Dimensional Distributed Control arXiv:2304.05765 [math.OC]



Controlled motion of the rod: displacements reach zero terminal state

Main challenge:

- Control of infinite-dimensional system via finite-dimensional input

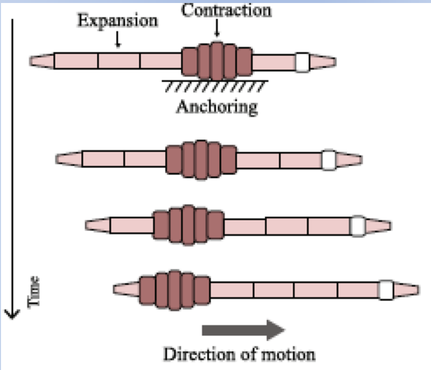
Main results:

- Variational formulation of the optimal control problem
- Analytical solution via traveling waves

Applications:

- Accurate horizontal instrument alignment
- Active vibration damping
- Frequency filtration

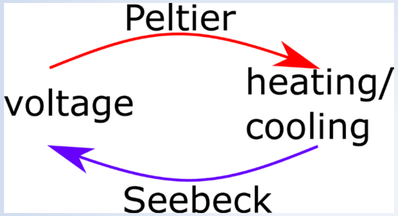
Biomechanical analogue: peristaltic locomotion



[Masuda et al, Biomimetic and Biohybrid Systems, 2018]

Controlling temperature distribution via thermoelectrical converters

Thermoelectrical converters, in particular, Peltier elements (PE) transform heat into electricity and vice versa due to Peltier and Seebeck effects



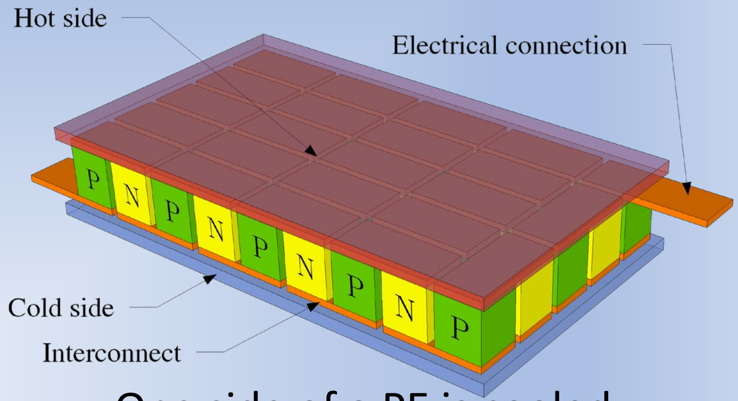
Peltier

voltage

heating/ cooling

Seebeck

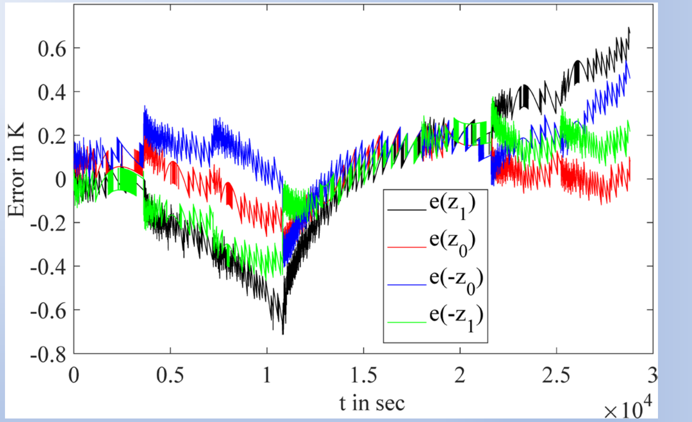
Experimental setup:
1 PE between 2 cylinders



One side of a PE is cooled, another is heated *[Wikipedia]*

Main results:

- A control-oriented nonlinear PDE model of the PE-solid body system has been proposed and experimentally verified
- Several numerical control algorithms, including constrained optimization, have been developed for a two-body system with one PE in between. This allows for obtaining a desired temperature distribution in one body, while the other serves as a heat sink



Experimental validation:
the model's mismatch is on the order of magnitude of ambient temperature variations