Microrobots for Medicine

Simone Schuerle, PhD
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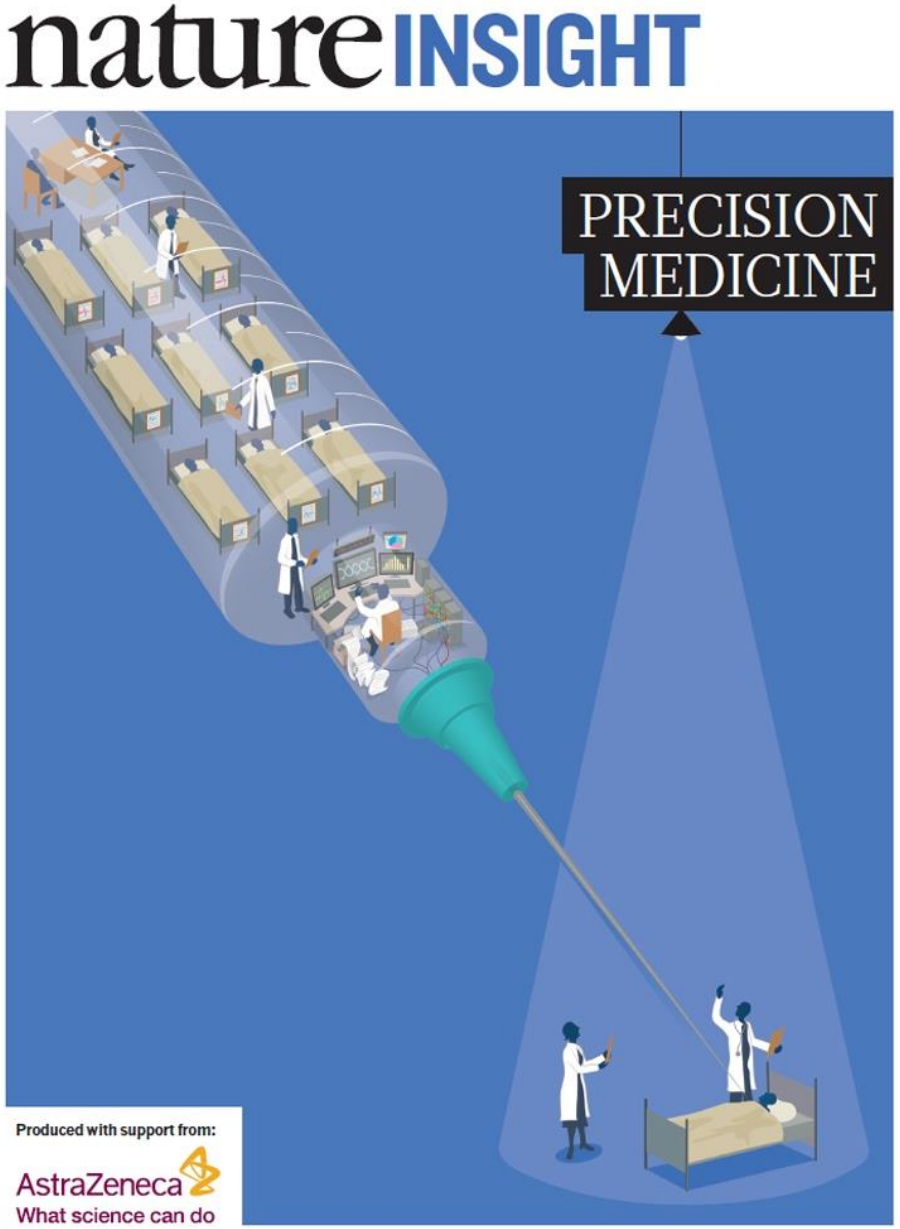
MEDICAL
MICROSYSTEMS

Interactive Sequence

- Whiat is your background?
- What comes to your mind when you hear about microorbots for medicine?

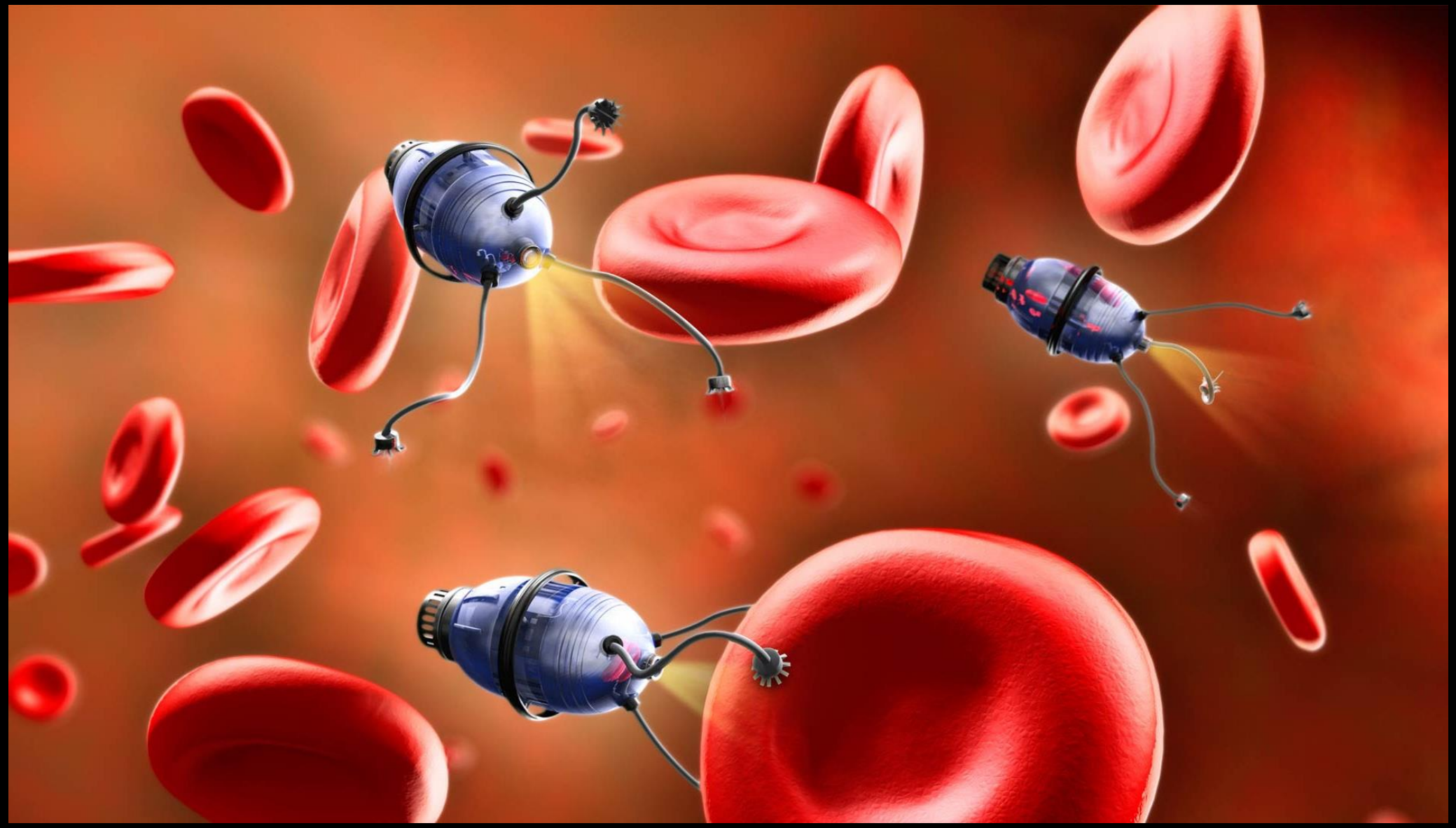
3 min

Trend towards precision medicine



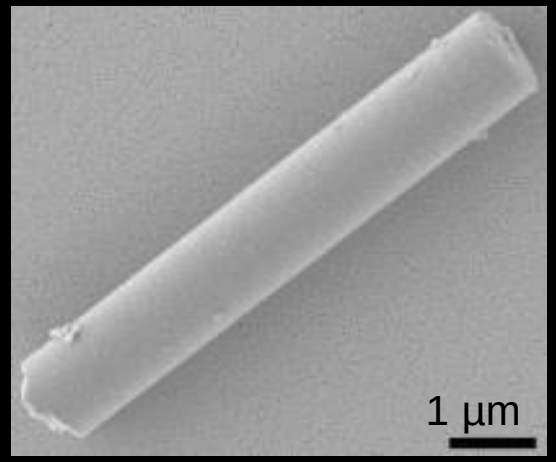
We need new tools to improve diagnosis at the point of care and treat diseases in a more targeted fashion

Microrobots for medicine…



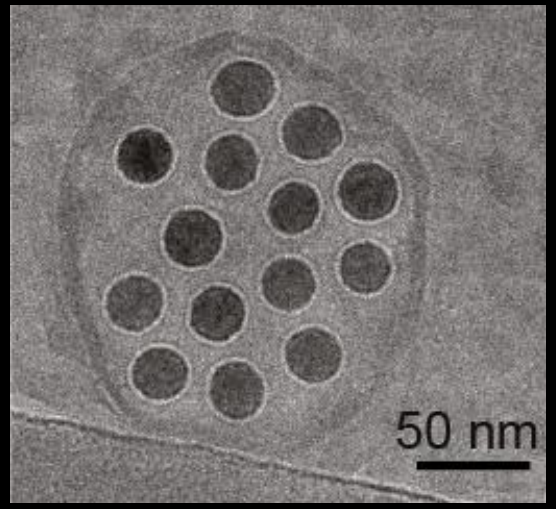
Google search result for “microrobot”

…might look more like that



Synthetic inorganic

Assgeirsson et al, Lab Chip, 2021

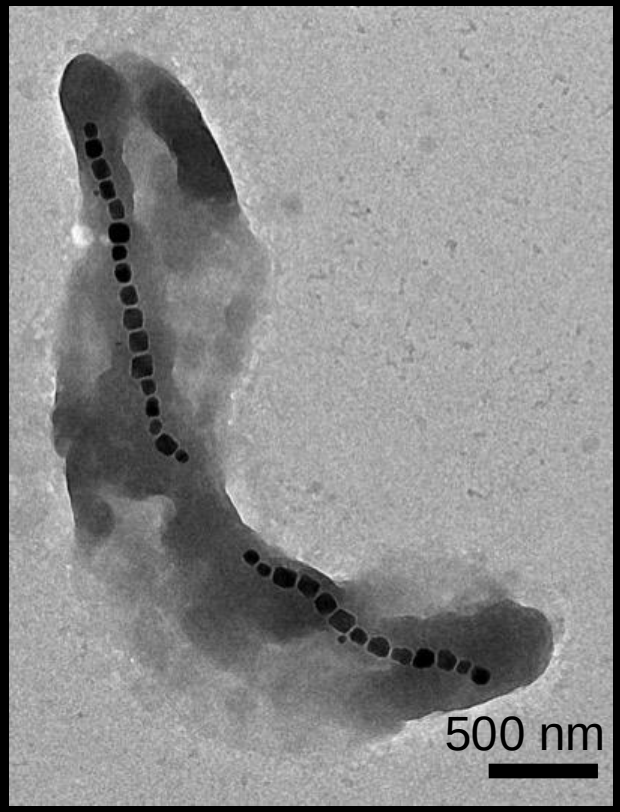


Synthetic organic & inorganic

Schuerle et al, Nanoletters, 2016

Bio-inspired

Schuerle et al, Sci Adv, 2019



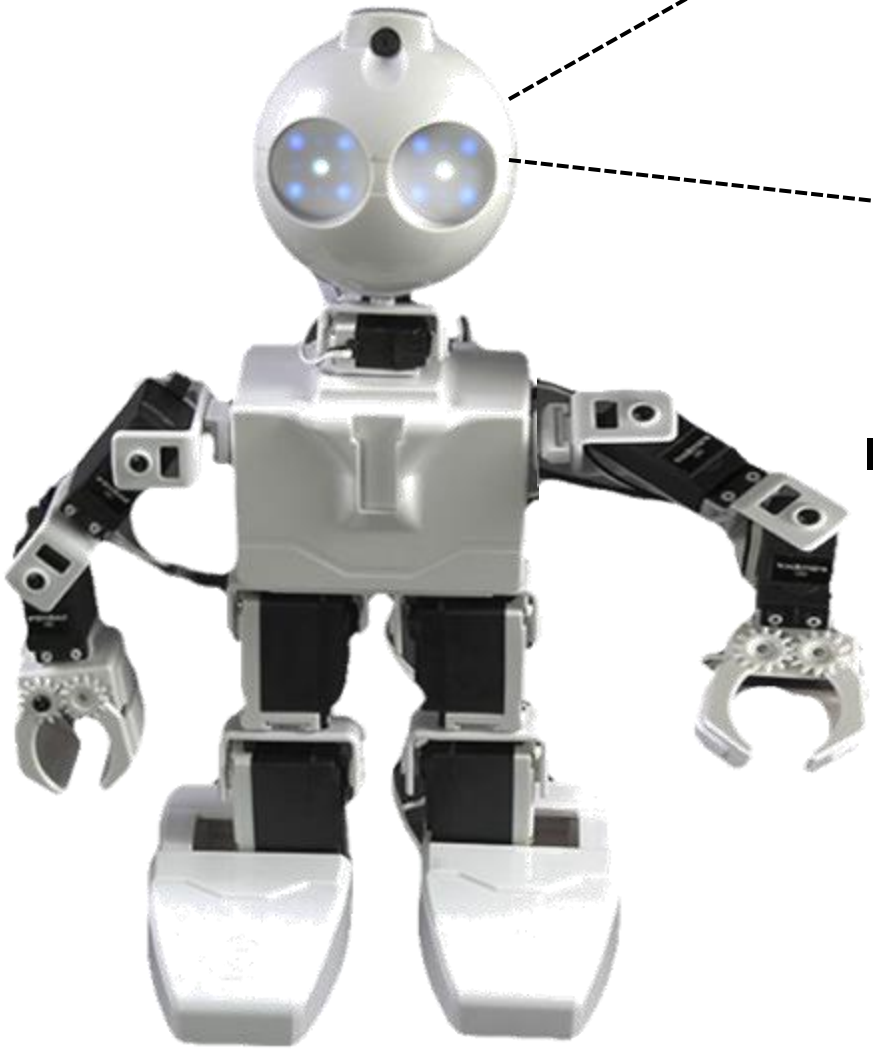
Biological/Biohybrid

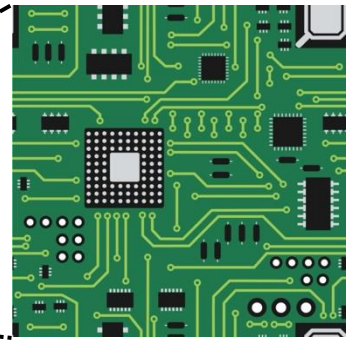
Schuerle et al, Sci Adv, 2019

Principles from robotics

Input

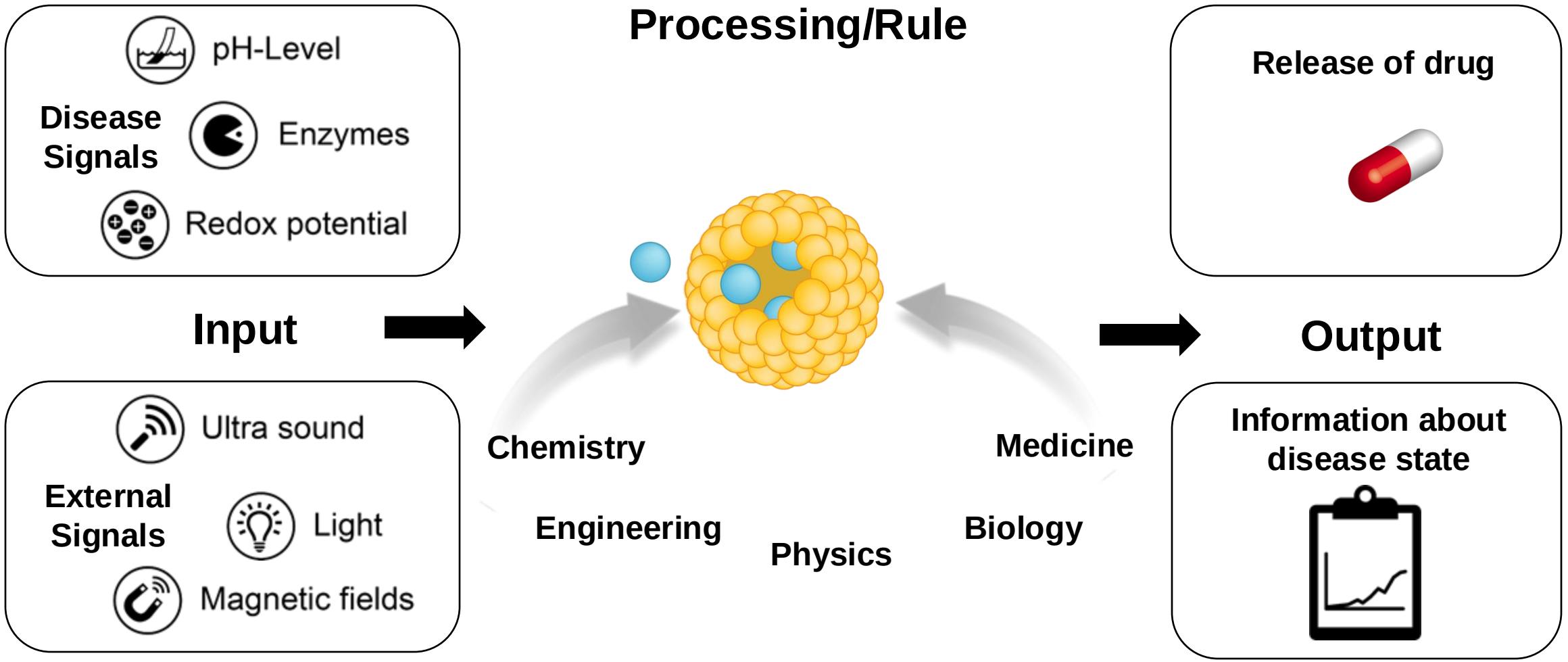
Processing/Rule

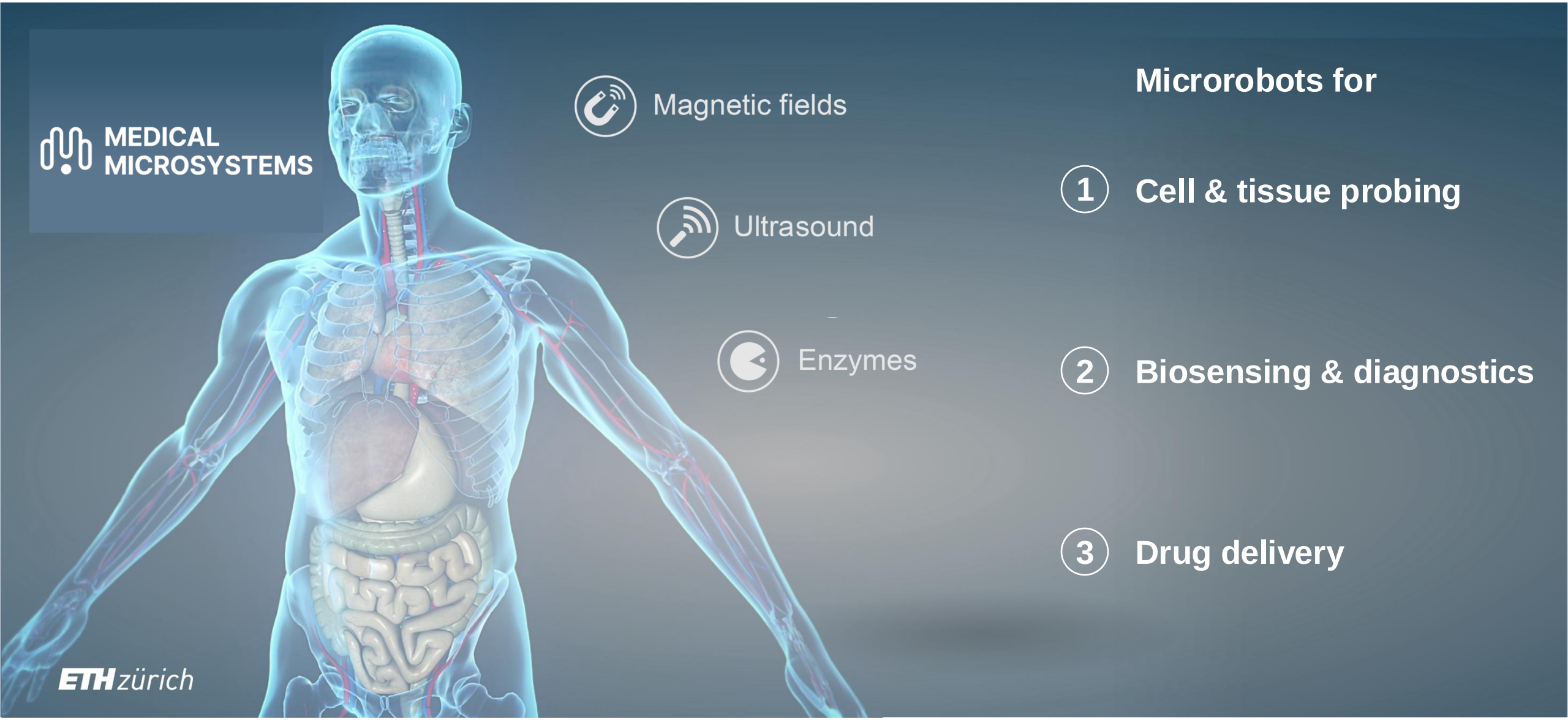


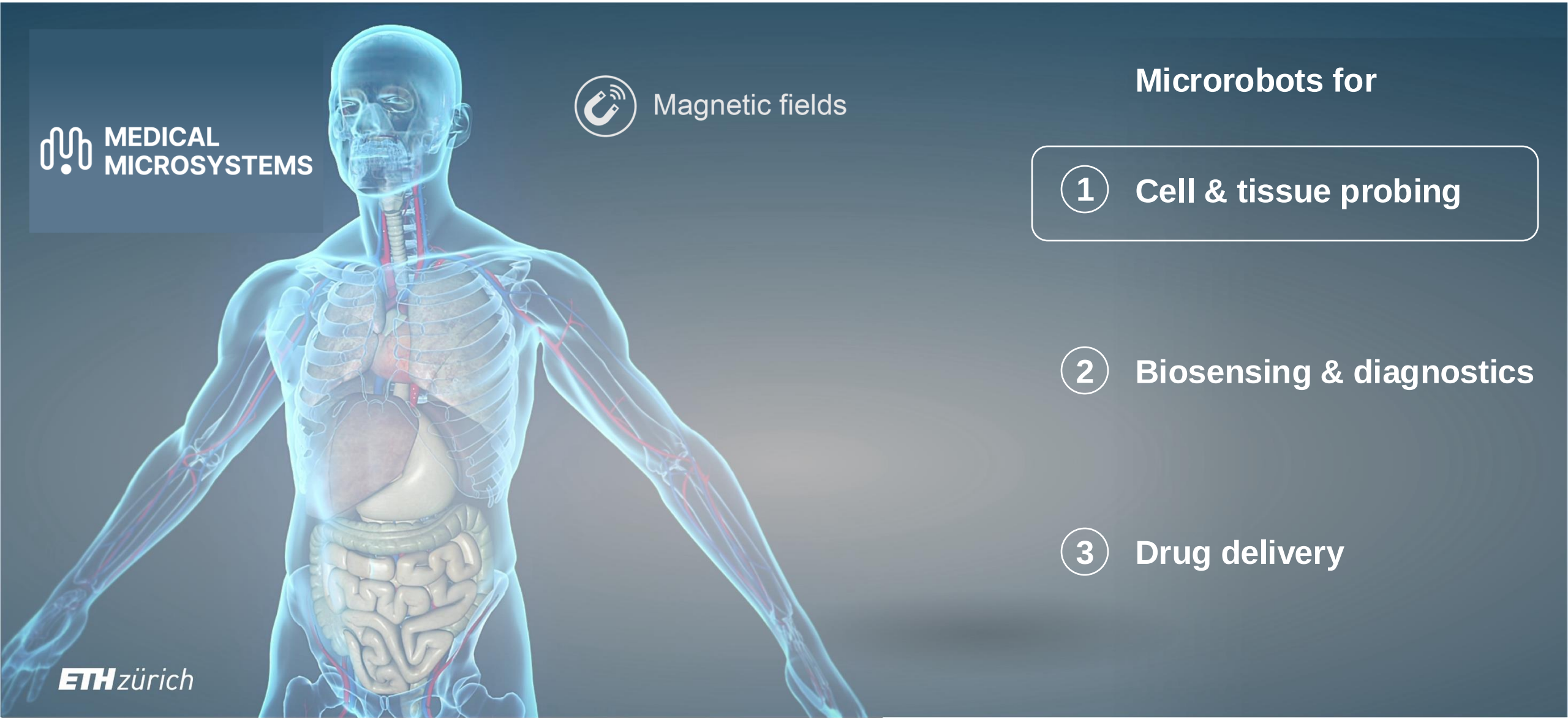


Output

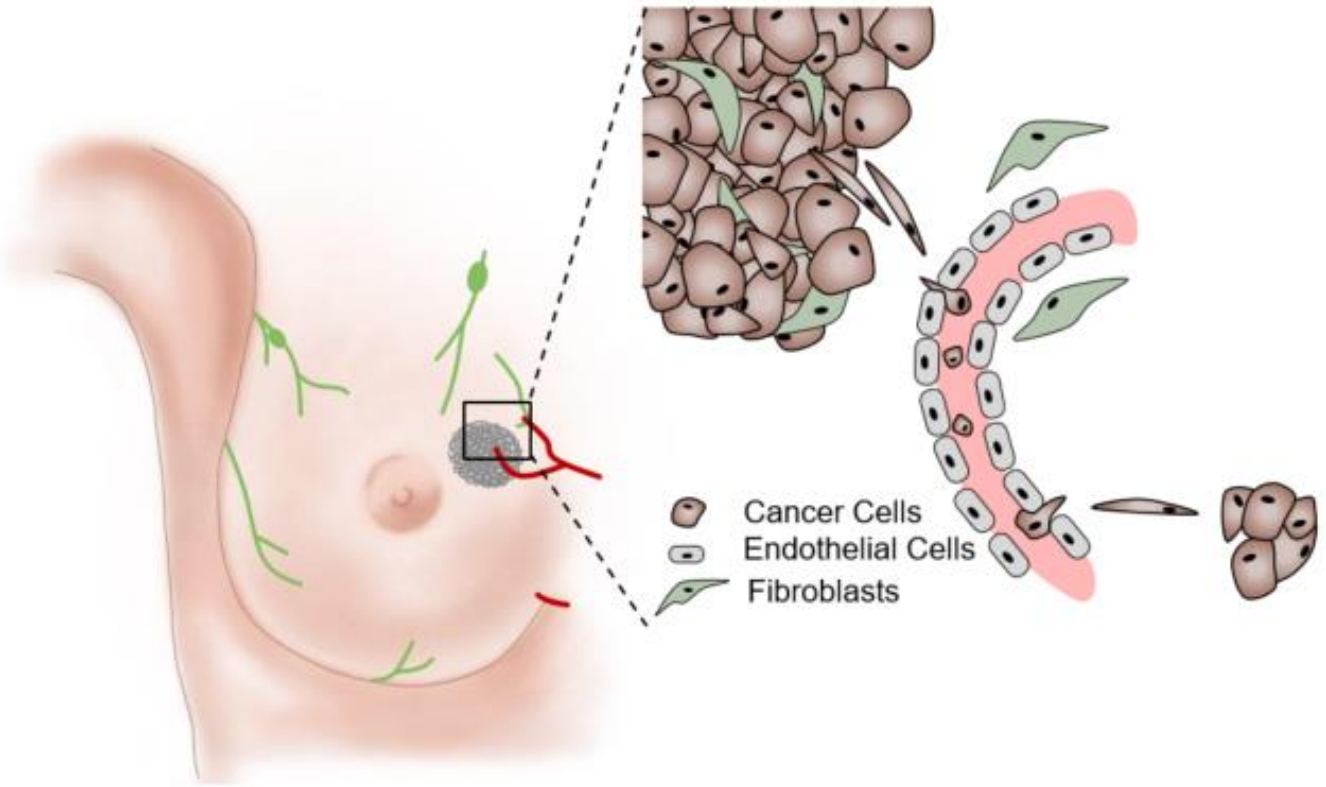
Principles from robotics

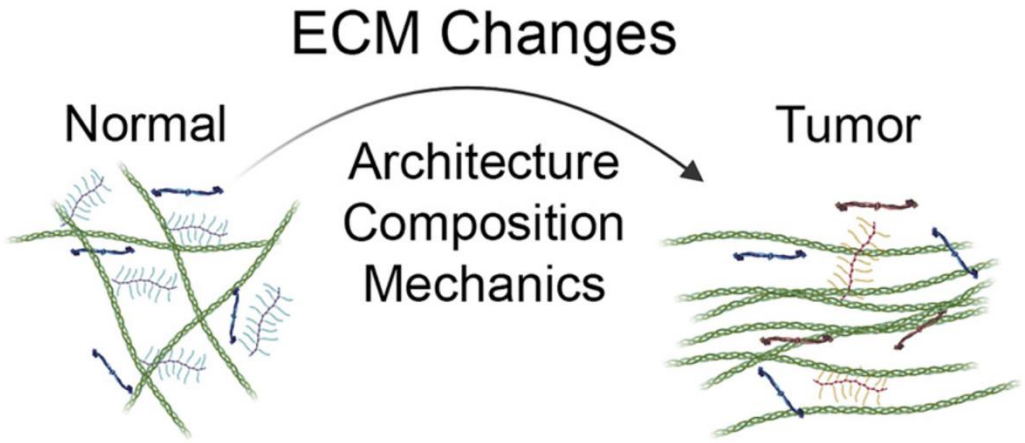



MEDICAL MICROSYSTEMS
Magnetic fields
Ultrasound
Enzymes
Microrobots for
1 Cell & tissue probing
2 Biosensing & diagnostics
3 Drug delivery
ETH zürich


MEDICAL
MICROSYSTEMS
Magnetic fields
Microrobots for
1 Cell & tissue probing
2 Biosensing & diagnostics
3 Drug delivery
ETH zürich

Tissue stiffening as a driver in cancer progression

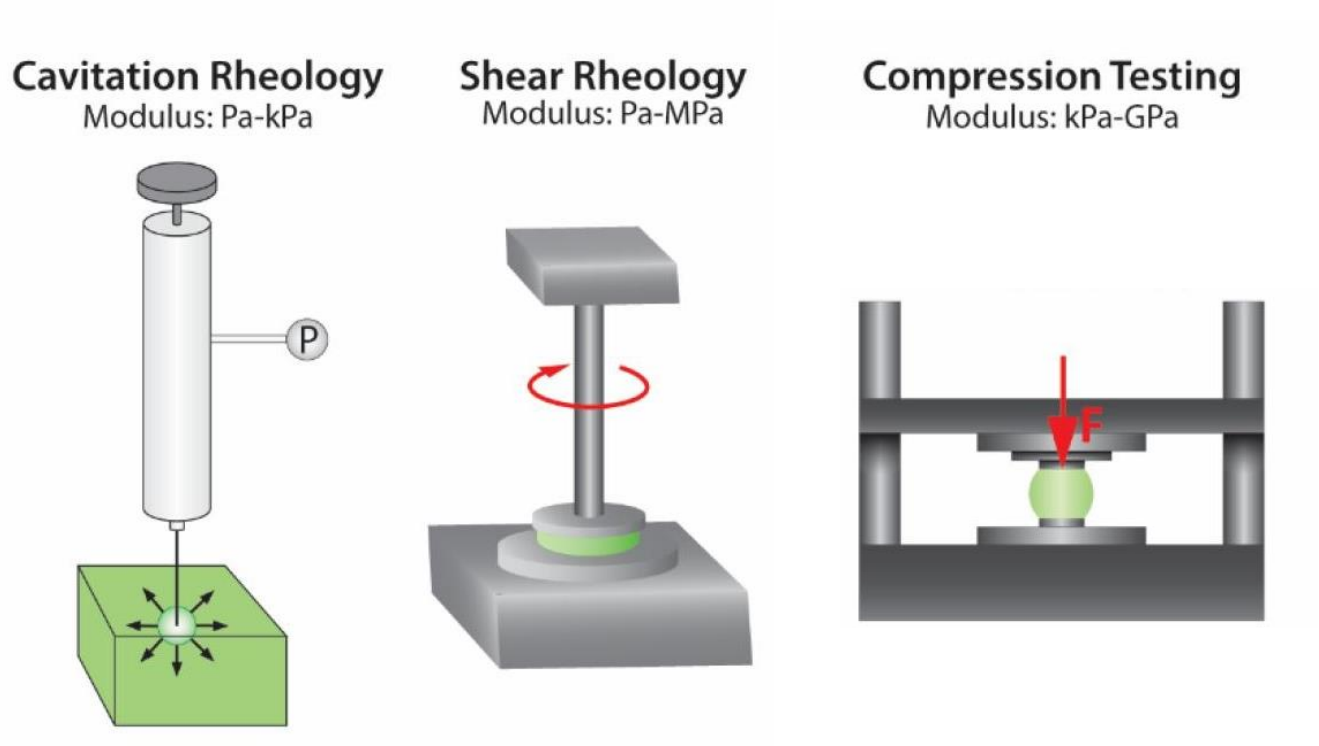


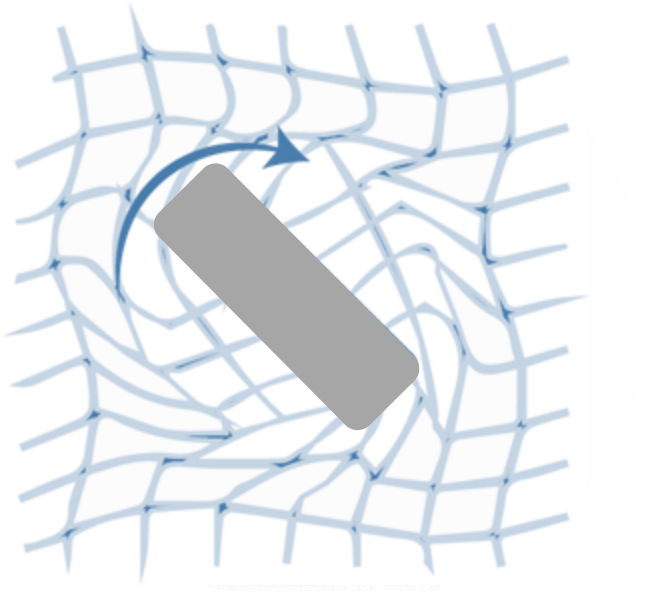


Micek et al., *iScience,* 2020

Understanding and altering tissue mechanics at the microscale to inform drug development

Probing mechanical properties at the microscale





in situ microprobe to infer local shear moduli

Narayanan et al., Front. Bioeng.., 2020

Magnetism

Interactive Sequence

- Form groups of 3-4 students
- Think about the following questions:
  - What do you know about magnetism?
  - Which classes of magnetism do you know?
  - To which category belongs human tissue?

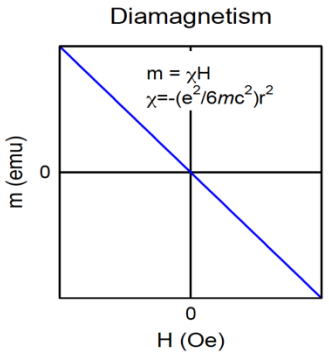
5 min

Classes of magnetism

Can utilize the susceptibility to categorize types of magneti $\chi = \frac{\vec{M}}{\vec{H}}$

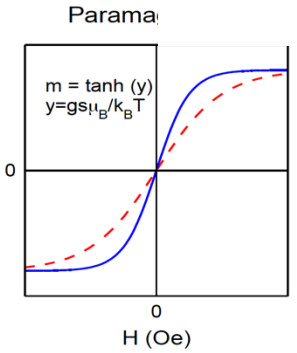
- χ is small and negative (~ -10^{-5} – 10^{-6}): DIAMAGNETIC

examples: gold, copper, silver, bismuth, silica, many molecules (and supercondu



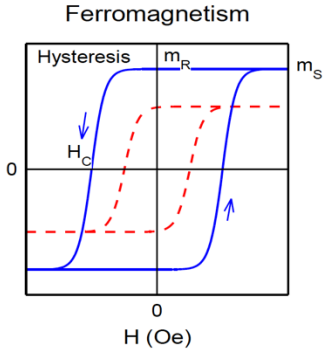
- χ is small and positive (~ 10^{-3} or 10^{-6}): PARMAGENTIC

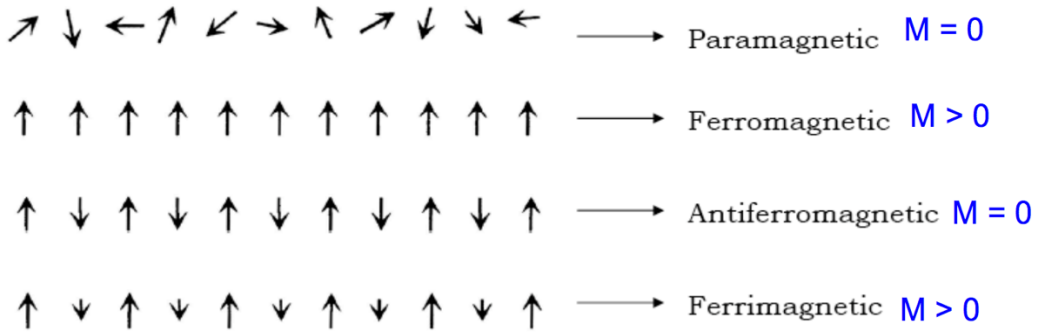
examples: aluminum, platinum, manganese



- χ is large and positive (>>1; 50 – 10,000): FERROMAGNETIC

examples: iron, cobalt, gadolinium





Levitating frog und strawberry

Levitating frog

https://www.youtube.com/watch?v=A1vyB-O5i6E

Levitating strawberry

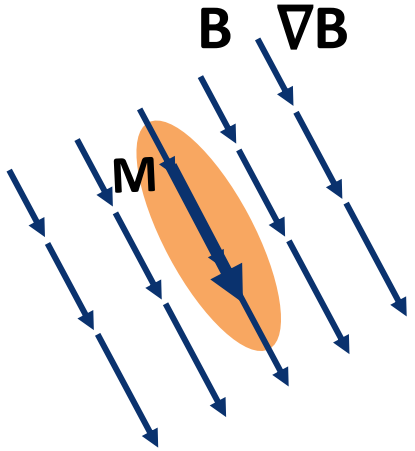
https://www.youtube.com/watch?v=uY8btfJZ9Z8

Applying magnetic forces and torques

Magnetic Torque: $\mathbf{T} = u\,\mathbf{M} \times \mathbf{B}$

Object System

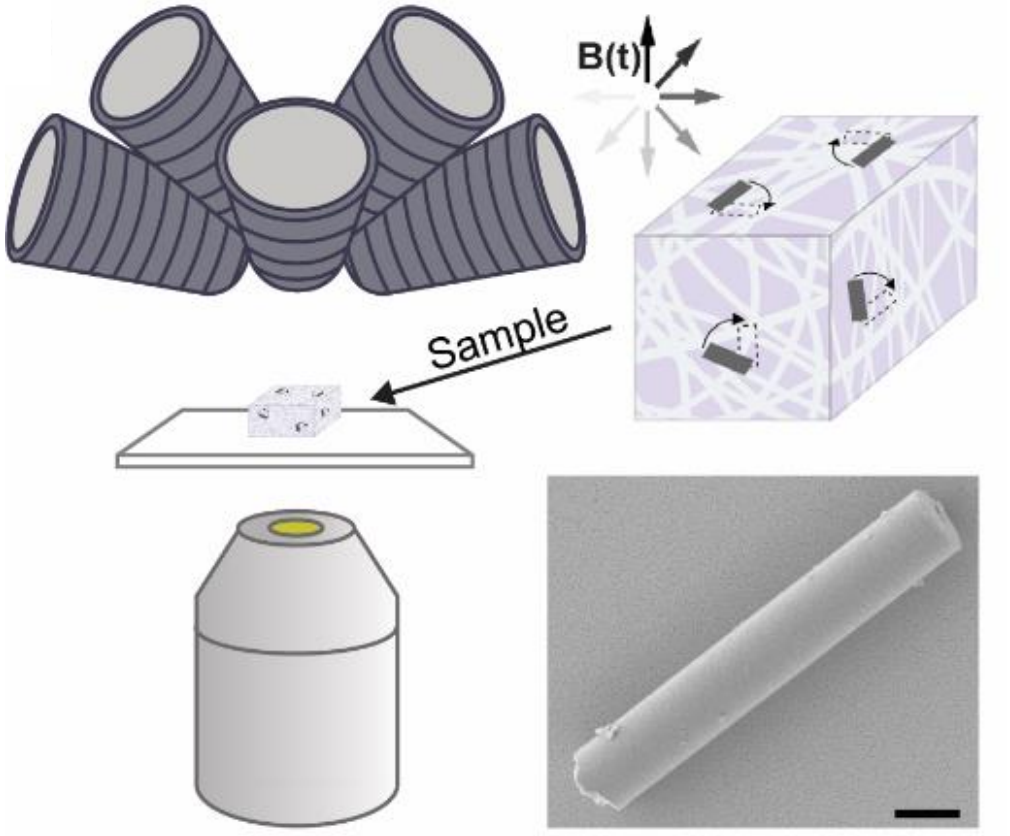
Magnetic Force: $\mathbf{F} = u\,(\mathbf{M} \times \nabla)\,\mathbf{B}$

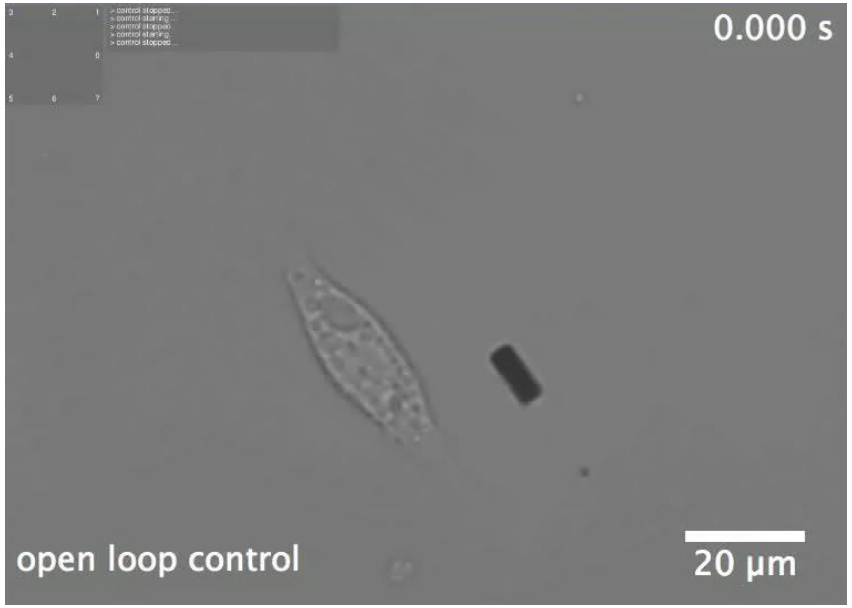


$$\downarrow \quad \nabla \times \mathbf{B} = 0$$

$$\mathbf{F} = u \begin{pmatrix} \frac{\partial \mathbf{B}}{\partial x} & \frac{\partial \mathbf{B}}{\partial y} & \frac{\partial \mathbf{B}}{\partial z} \end{pmatrix}^{T} \mathbf{M}$$

Microrobots for wireless *in situ* probing of tissues





Schuerle, Avalos, et al., Sci Rob, 2017

Kummer et al., *IEEE Transactions on Robotics,* 2010

Schuerle et al., *IEEE Transactions on Magnetism and Magnetic Materials,* 2013

Conflict of interest disclosure:
Simone Schuerle is co-founder of Magnebotix AG

Fabrication of magnetic microrobots for tissue probing

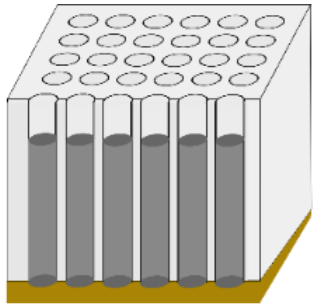
Dr. Asgeirsson

Dr. Christiansen

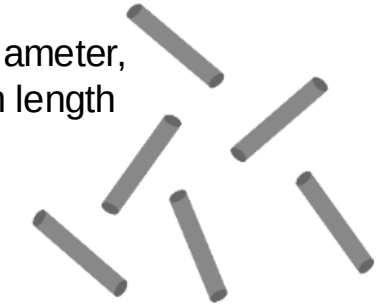
Dr. Valentin

Dr. Nima Mirkhani

Microrobot synthesis

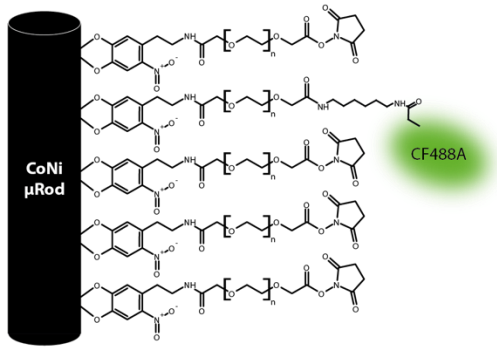


1-3 µm diameter,
10-20 µm length



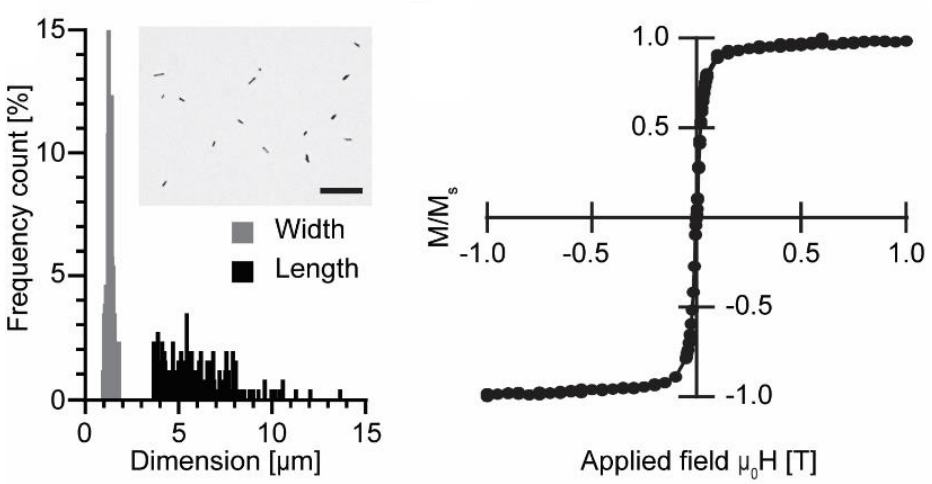
In collabortaion by Prof. Salvador Pané, D-MATL

Microrobot functionalization

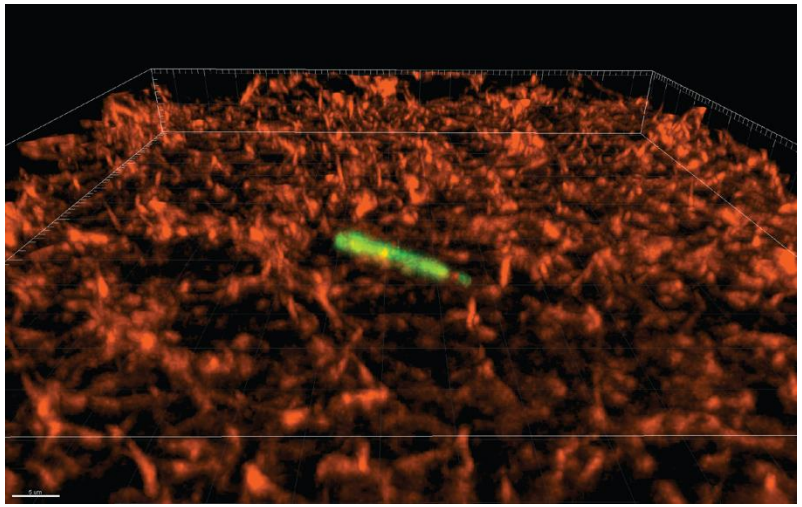


20% ND-PEG-CF488A, 80% ND-PEG-NHS

Microrobot characterization

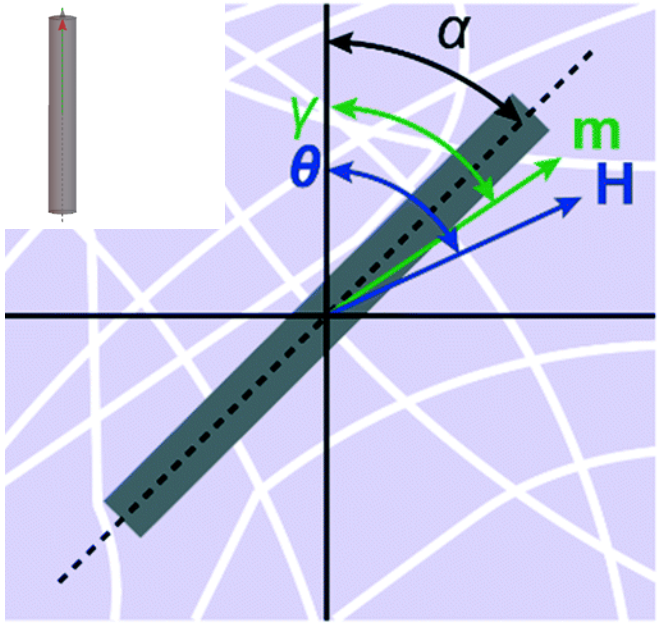


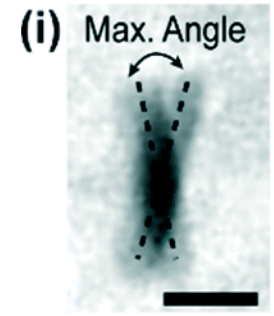
Microrobot embedding

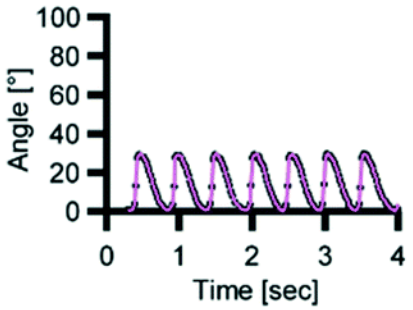


Asgeirsson et al., Lab on a Chip, 2021

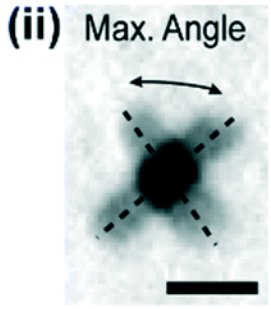
Microrobot actuation and readout: extracting local estimated shear moduli

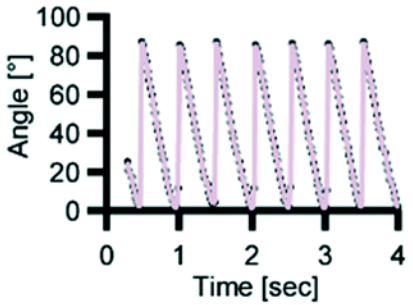






→ Stiff





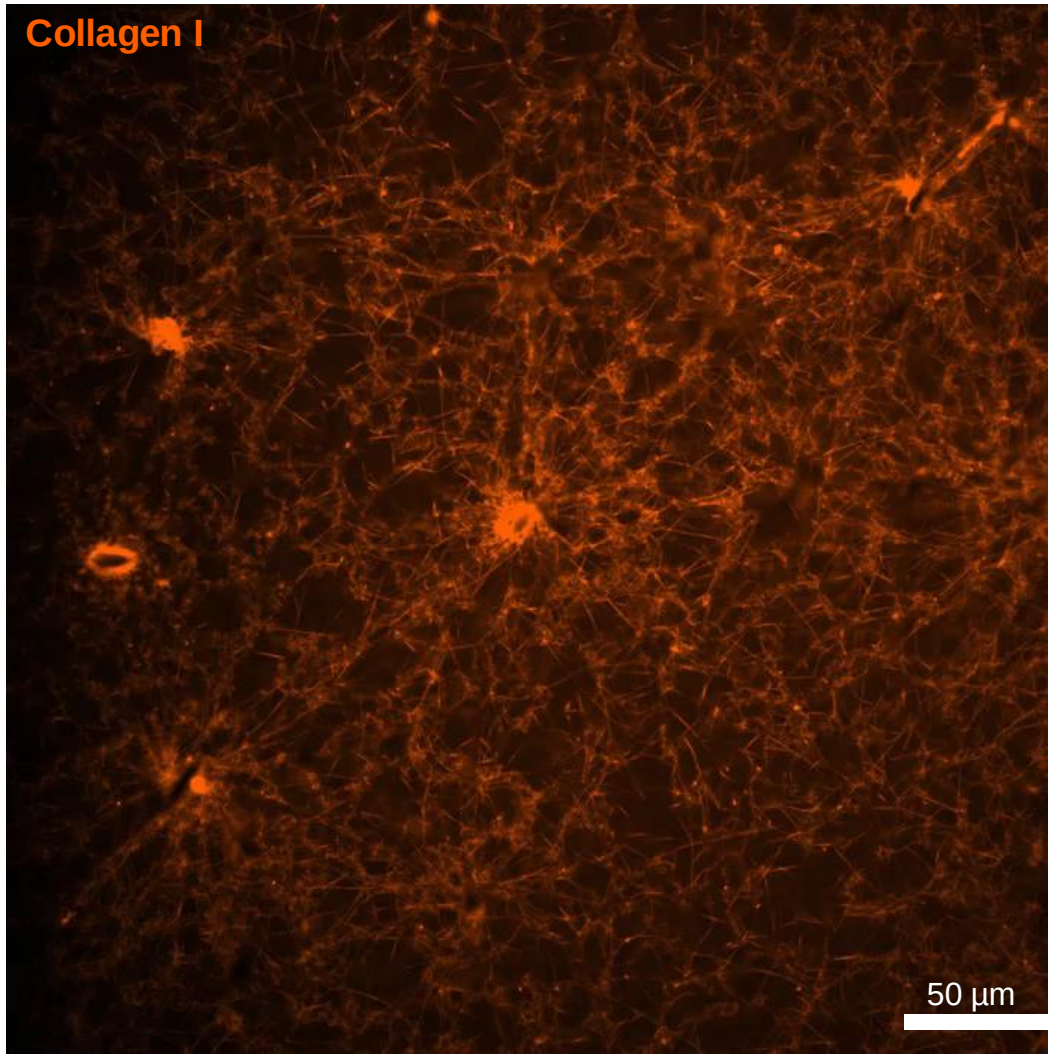
→ Less stiff

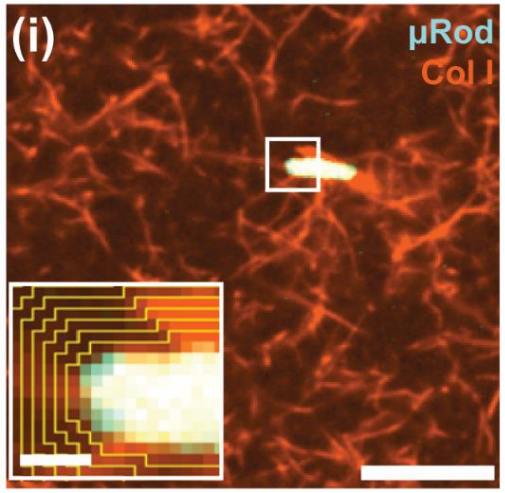
$$U(\gamma,\alpha,\theta) = U_{mech}(\alpha) + U_{field}(\gamma,\theta) + U_{ani}(\gamma,\alpha)$$

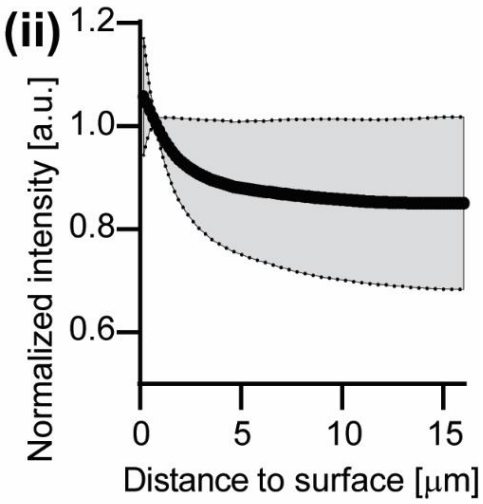
↓

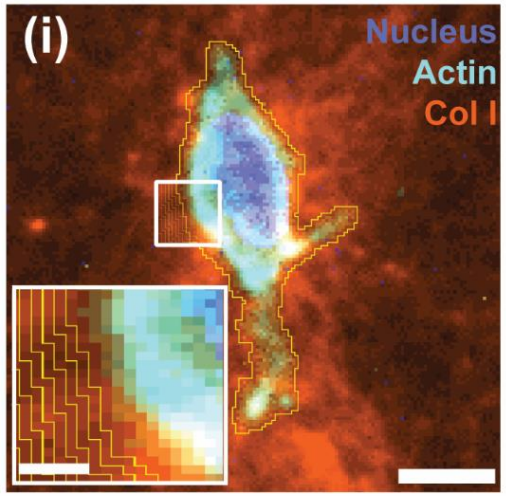
Effective shear moduli *G*

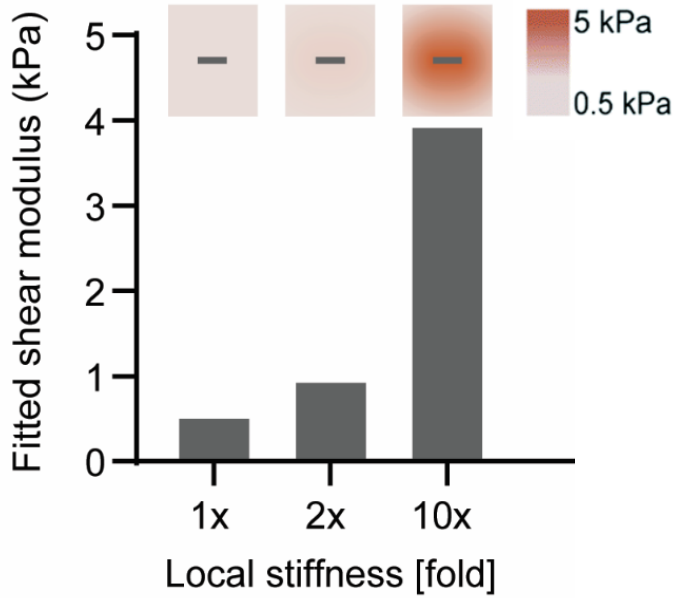
Probing the mechanical environment of a cell *in vitro*



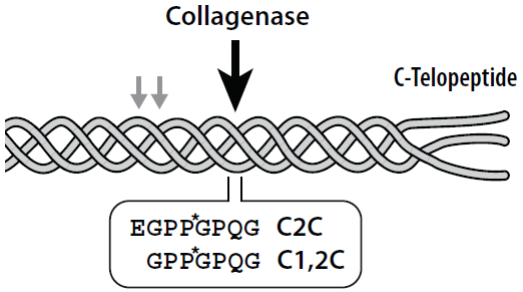


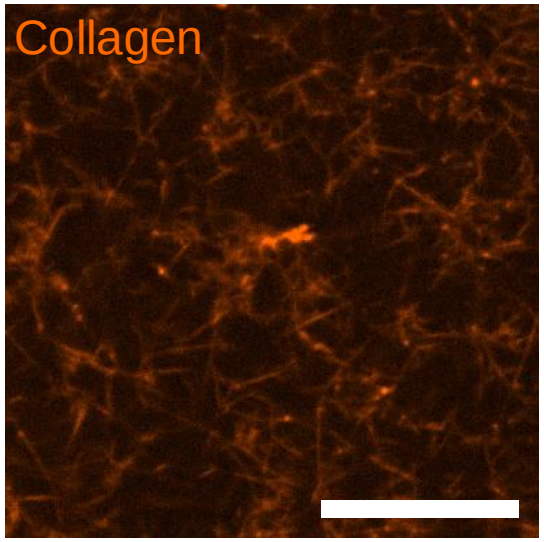




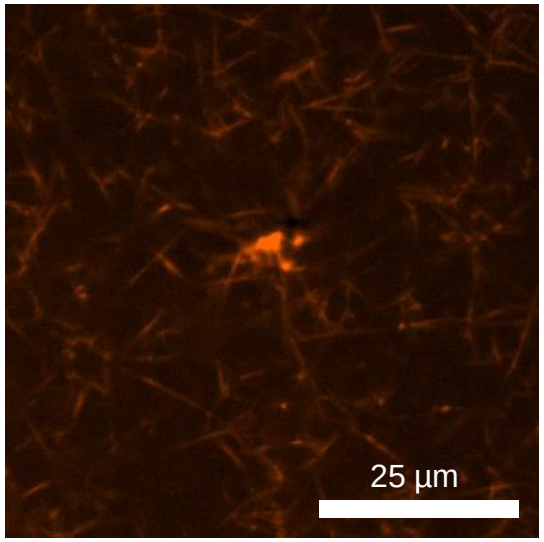


Stiffness probing with temporal resolution
µRods sense matrix softening during enzymatic degradation

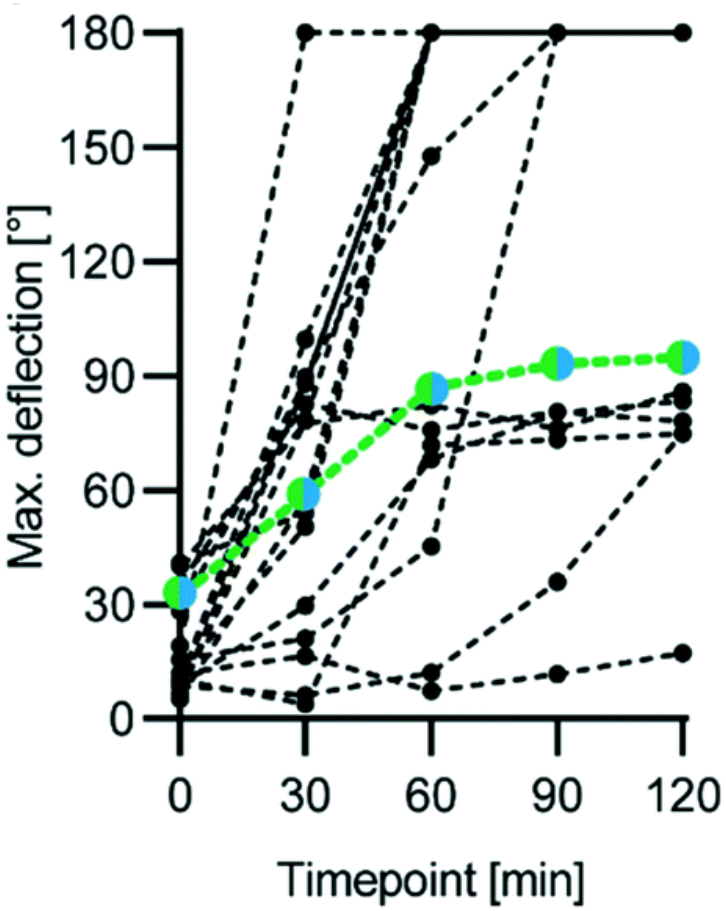




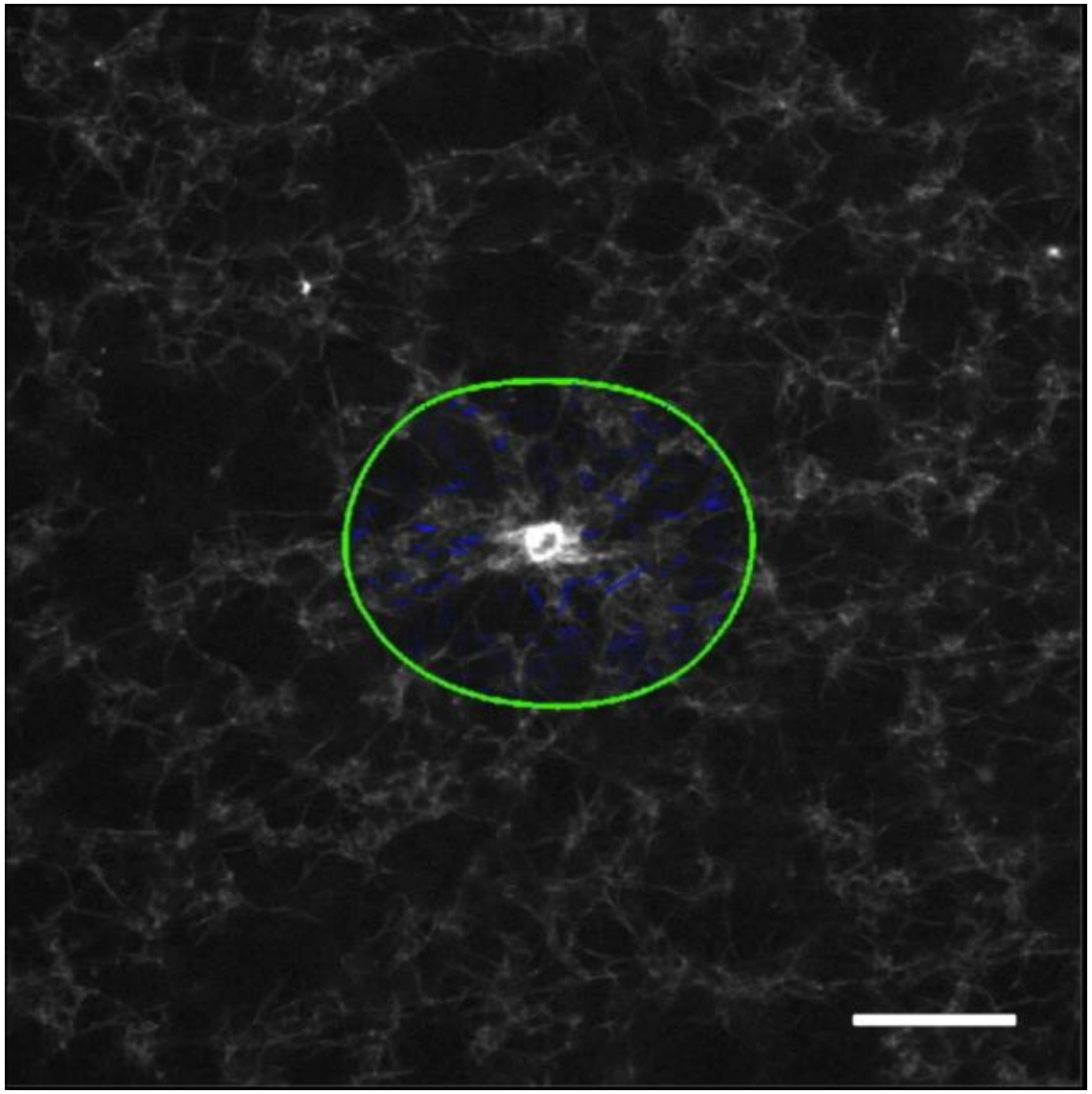
immediately after collagenase addition

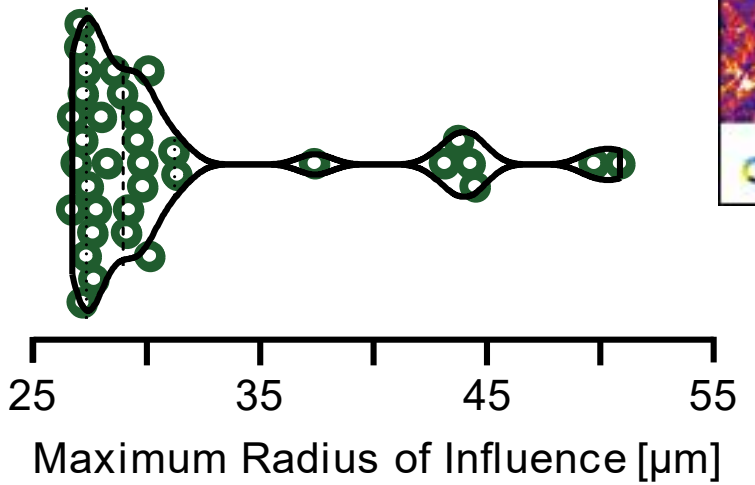


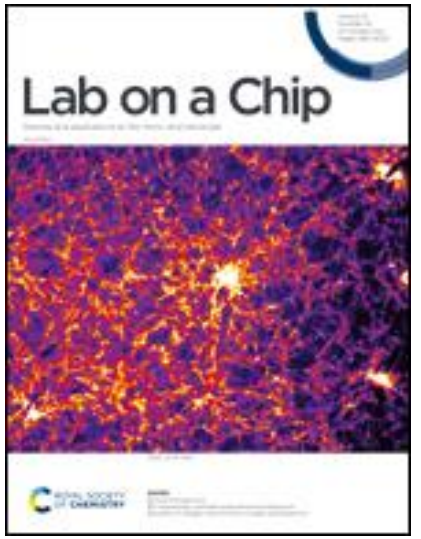
2h after incubation



Applying controlled mechanical cues



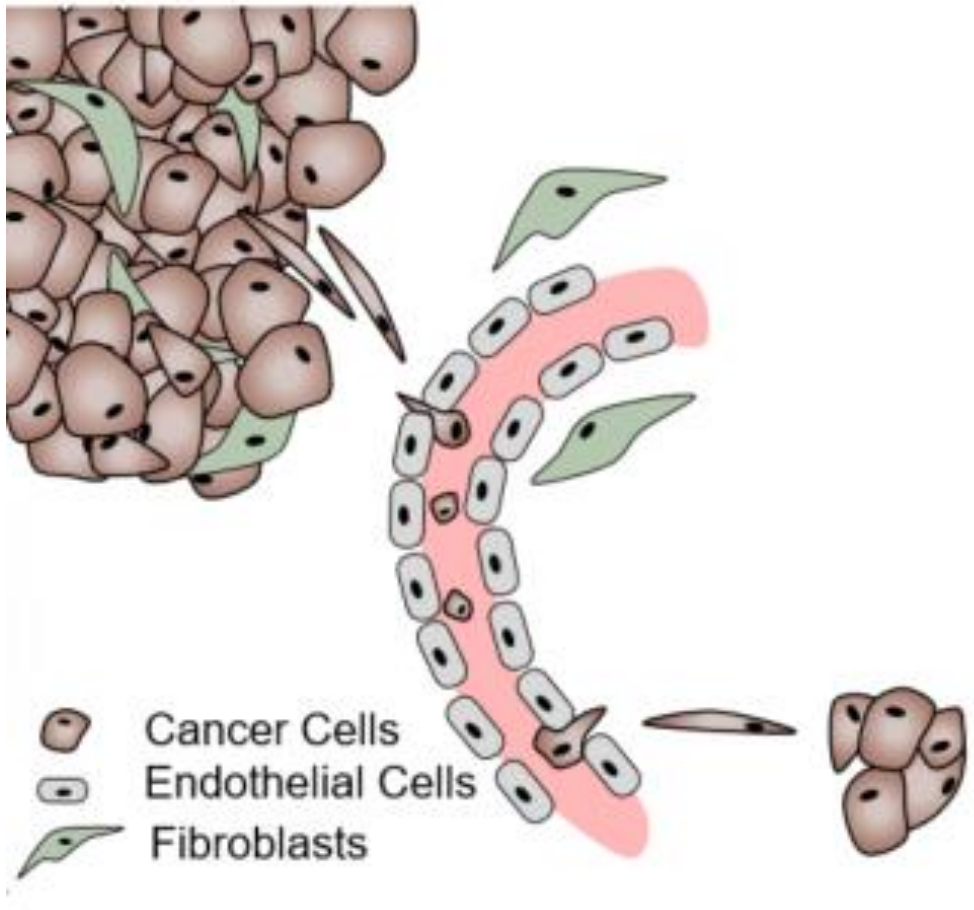




Our microrobots deflect collagen matrices over several tens of micron and can apply tens of pNm torques, similar to cell contractile moments!

Asgeirsson et al., Lab on a Chip, 2021

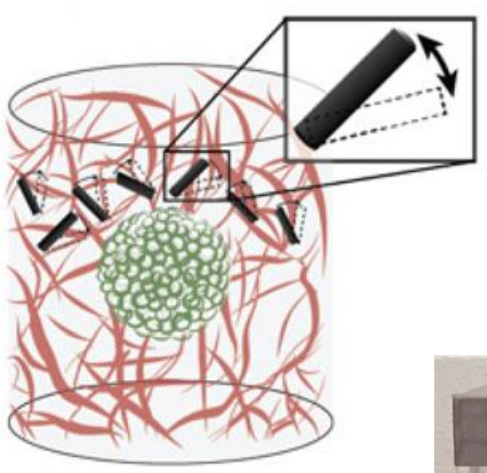
Applying controlled mechanical cues to the tumor microenvironment

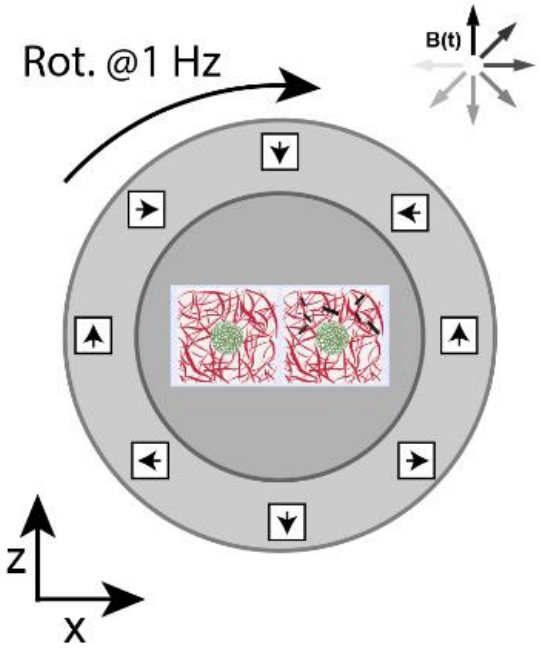


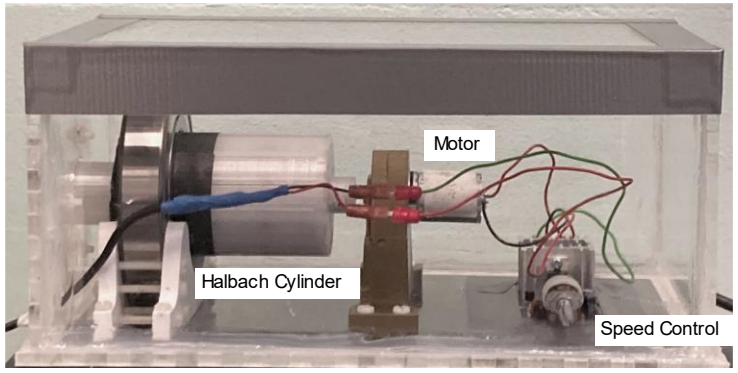
How do mechanical cues affect cancer invasion?

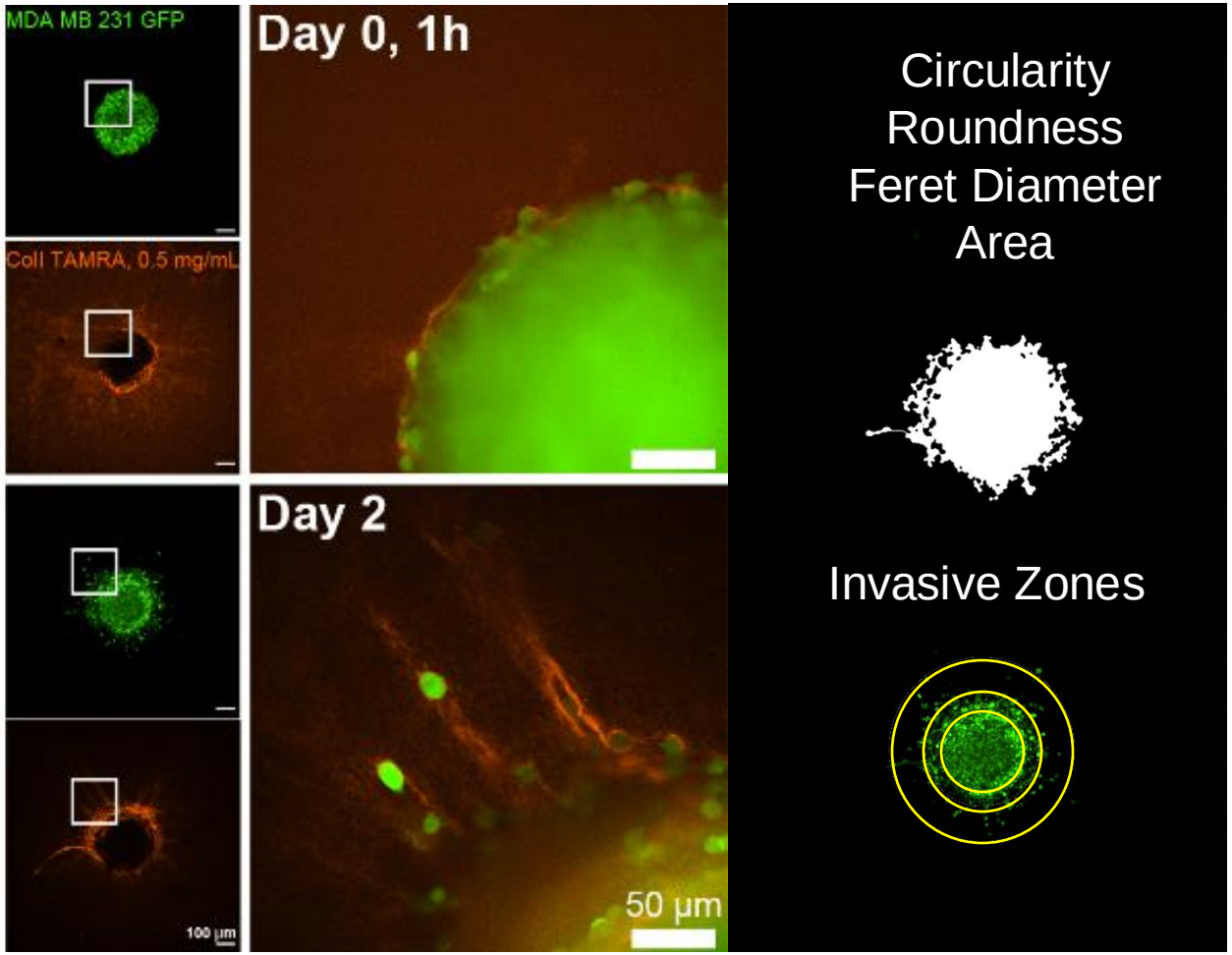
Applying controlled mechanical cues to the tumor microenvironment

How do mechanical cues affect cancer invasion?



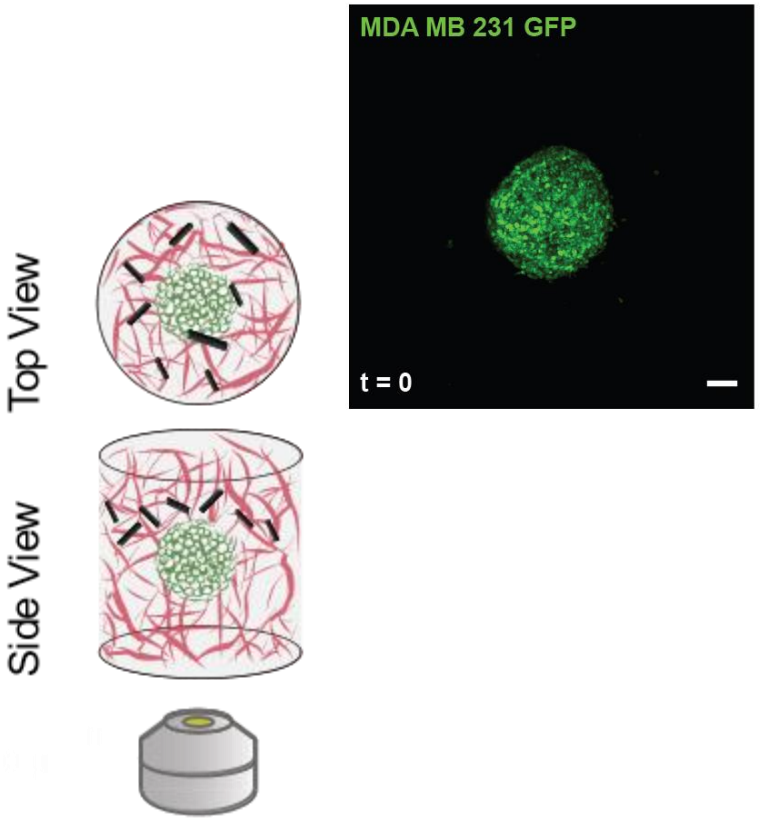


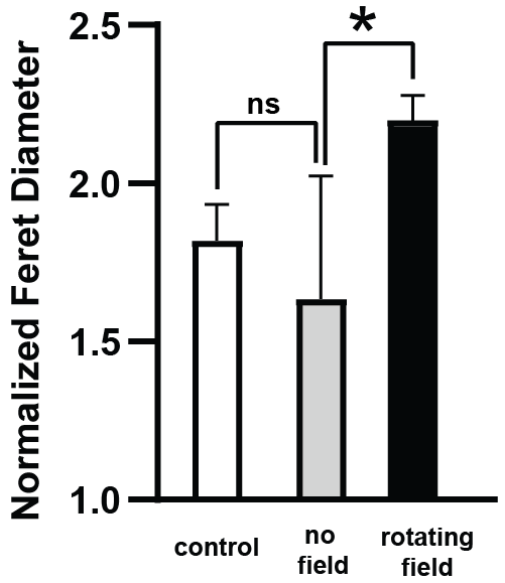




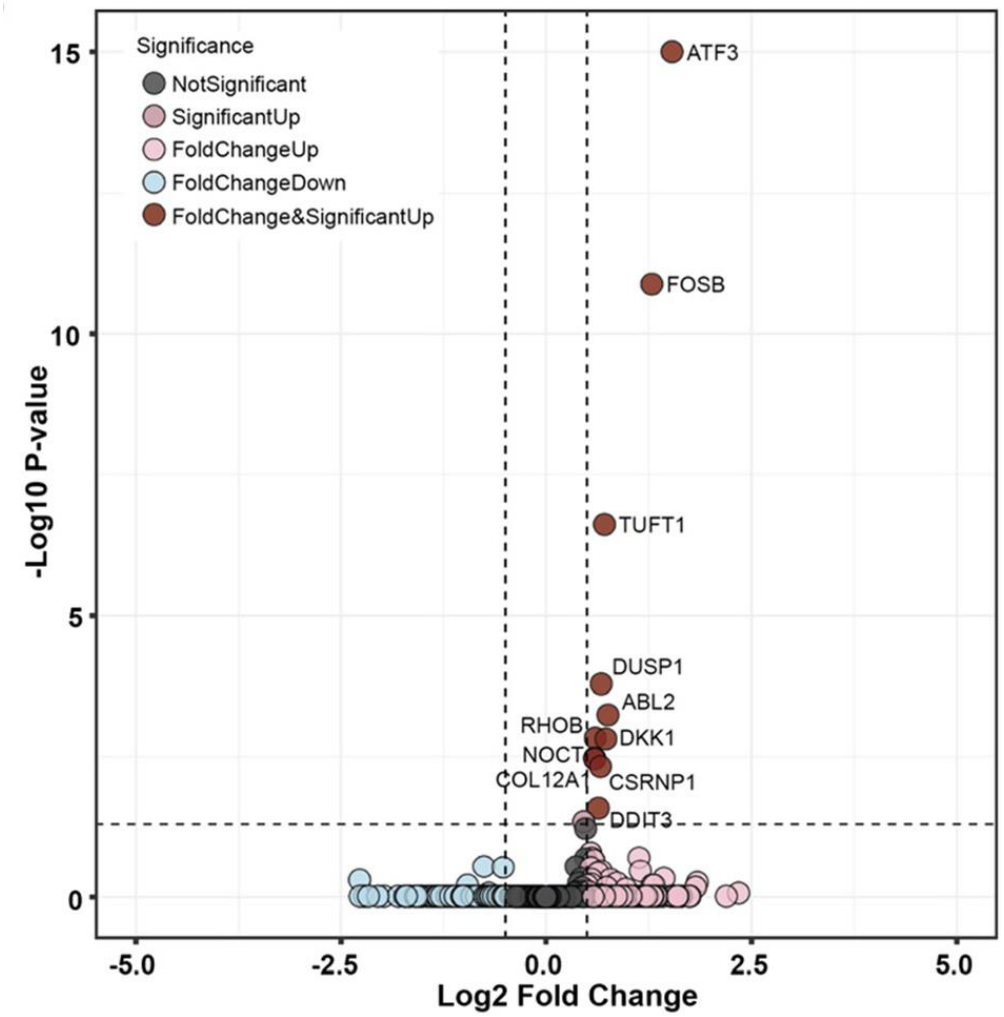
In collaboration with Ece Su Idliz and Nicola Acteo

Mechanical cues drive cancer cell invasion

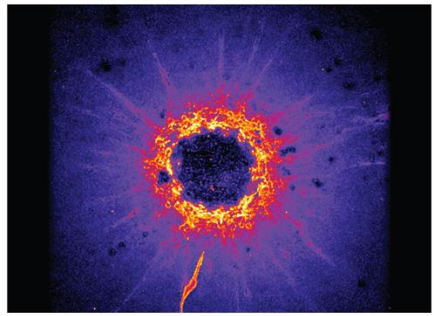


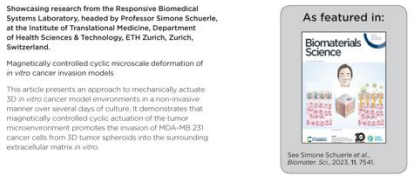


Magnetically induced mechanical deformation triggers expression of migration- and mechano-related genes

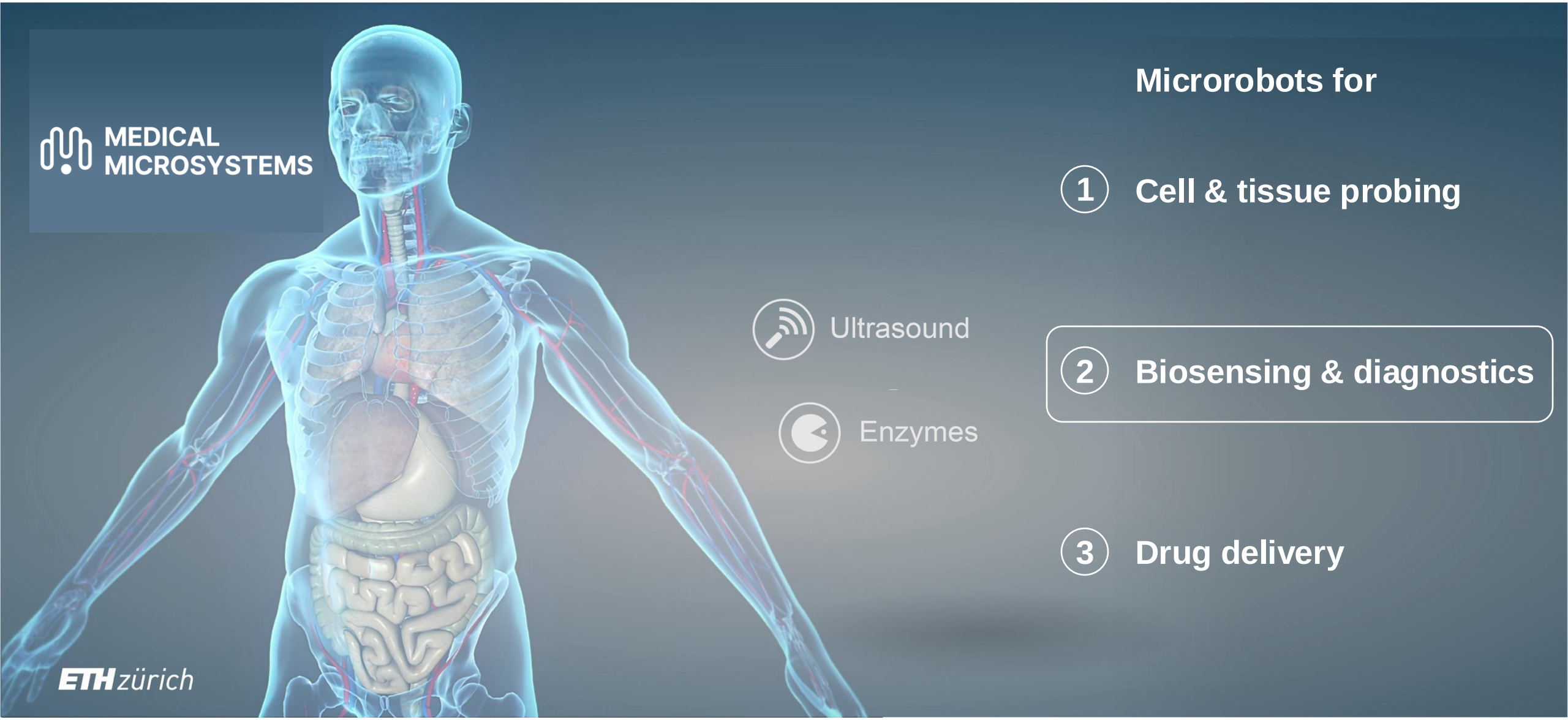


Asgeirsson et al., Biomaterials Science, 2023





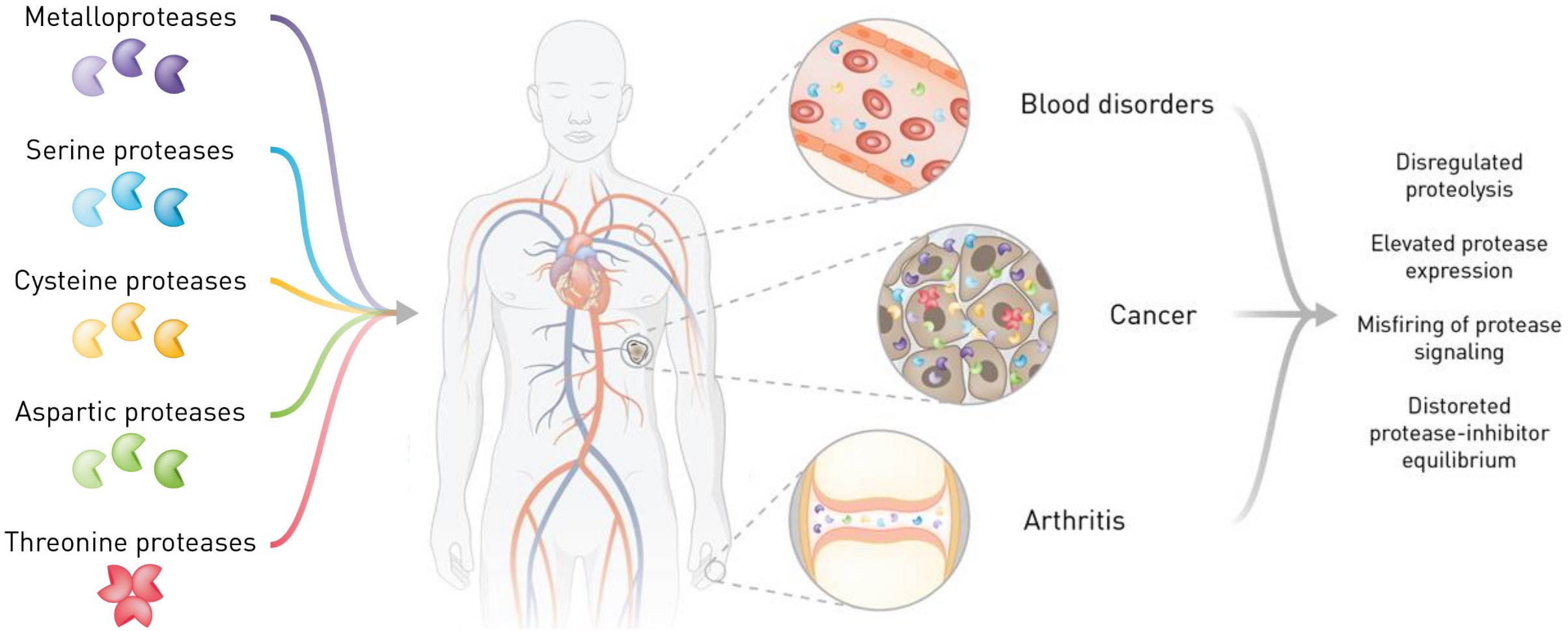
In collaboration with Ece Su Idliz and Nicola Acteo



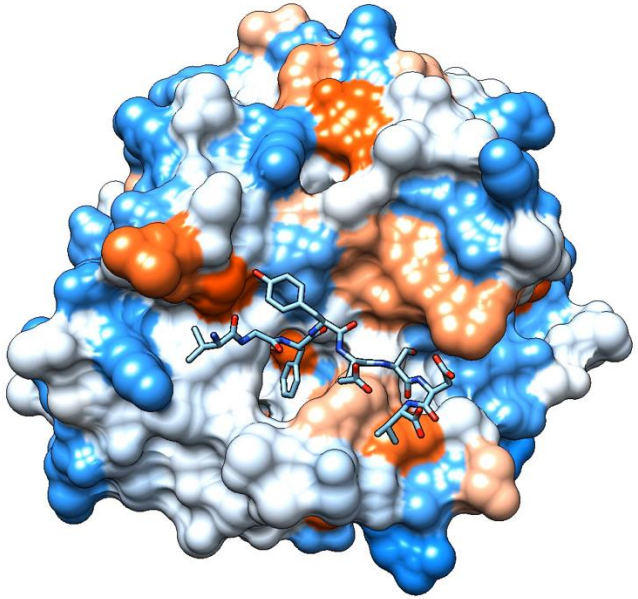
Microrobots for

1. Cell & tissue probing
2. Biosensing & diagnostics
3. Drug delivery

Proteases are an important hallmark of disease

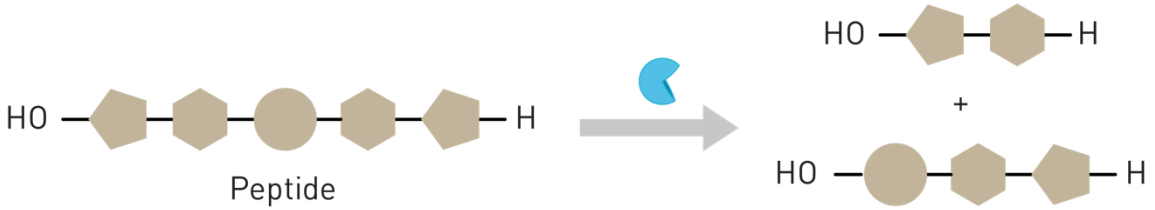


Proteases are molecular scissors

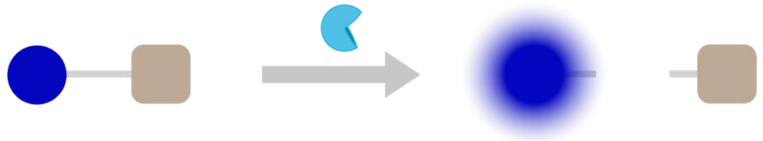


VGFYESDV octapeptide cleaved by MMP-2

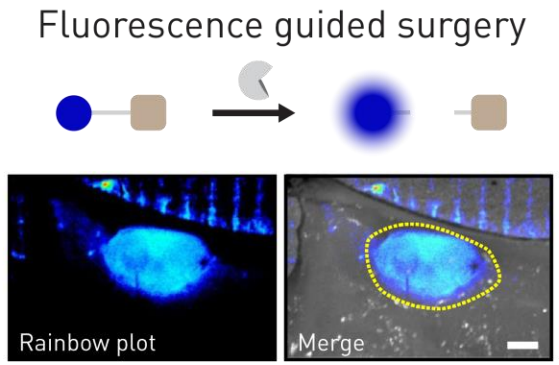
Proteases break peptide bonds via hydrolysis



Protease activity can be measured with peptide substrates and quenched fluorescent probes



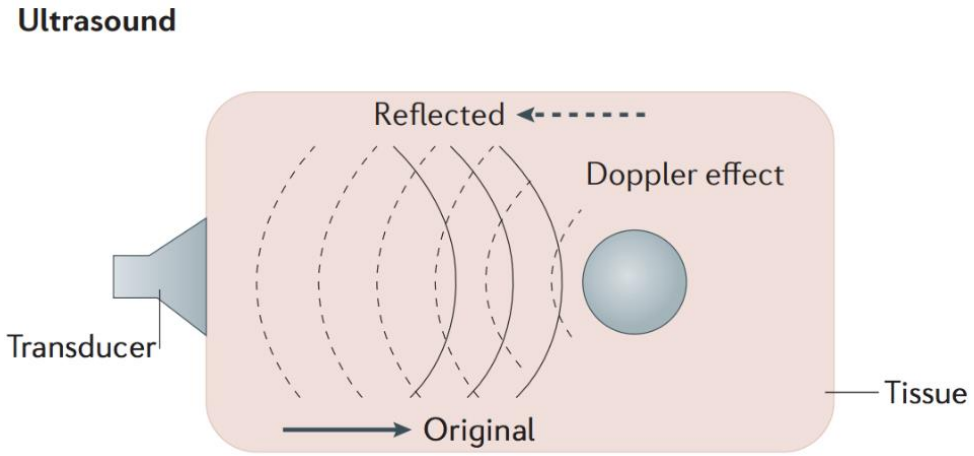
Biosensing of proteases



J.C. Widen et al., *Nat. Bio. Med. Eng.*, **2021**

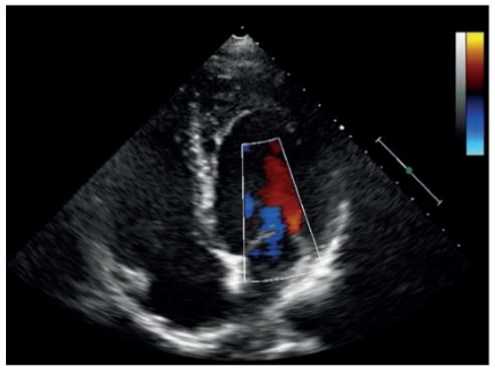
Ultrasound imaging

- 1 to 10 MHz sound waves
- Mechanical wave propagates at a speed dependent on the acoustic impedance of the medium
- Respective echo signal is used to construct an image
- Imaging depth limited in most organs to approx. 10 cm
- High resolution
- High endogenous contrast



Fetus (ultrasound)

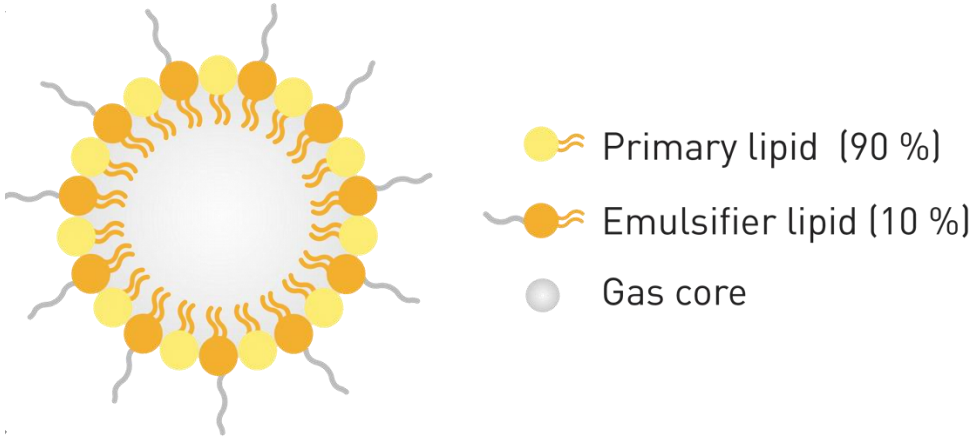
Cardiac (ultrasound Doppler)

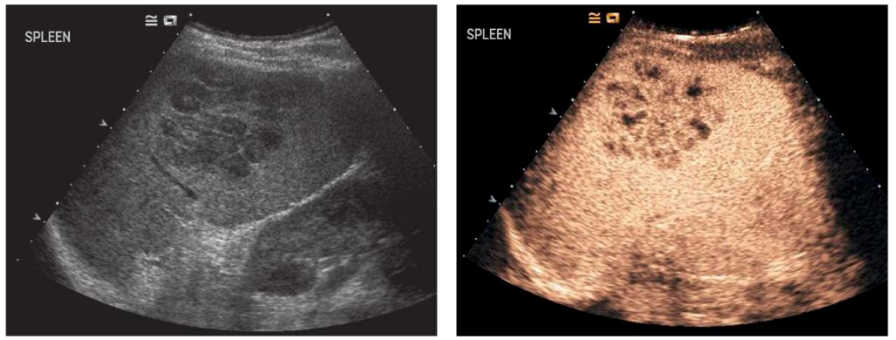


Gambhir et al., Nature Rev Material, 2017.

Microbubbles offer a platform to integrate responsiveness

Microbubble as ultrasound contrast agents

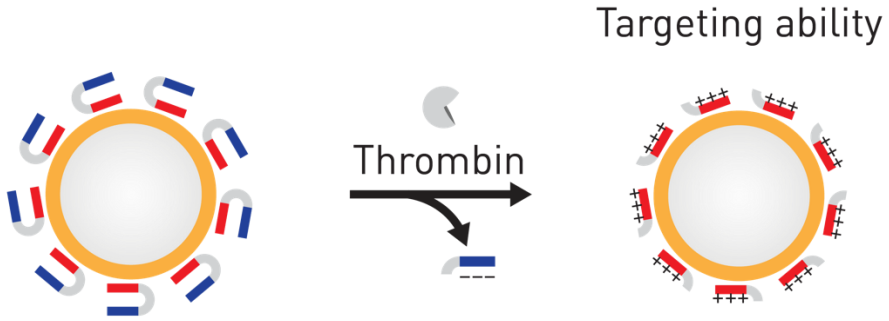




P.L. Allan et al., *Clinical Ultrasound*, **2011**

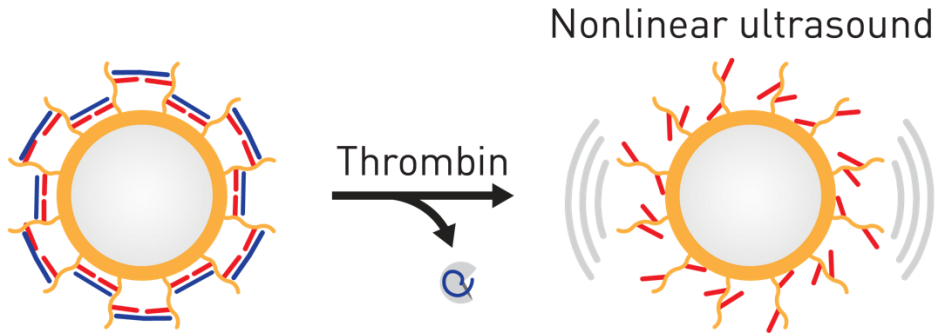
Incorporation of responsiveness through modulation of the shell

Chemical modulation of shell parameters



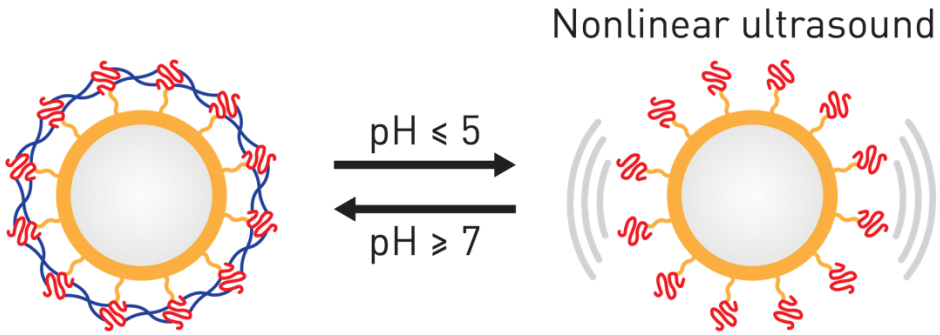
J. Lux et al., *ACS Appl. Mater. Interfaces*, **2017**

Mechanical modulation of shell through aptamer hybridization



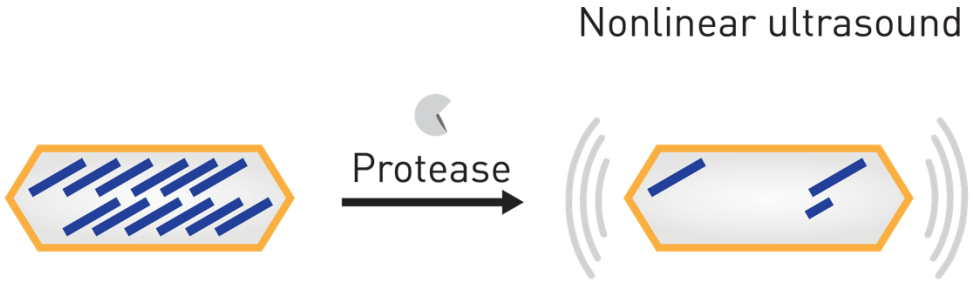
M.A. Nakatsuka et al., *Adv. Mater*, **2012**

Mechanical modulation of shell through pH-based cleavage



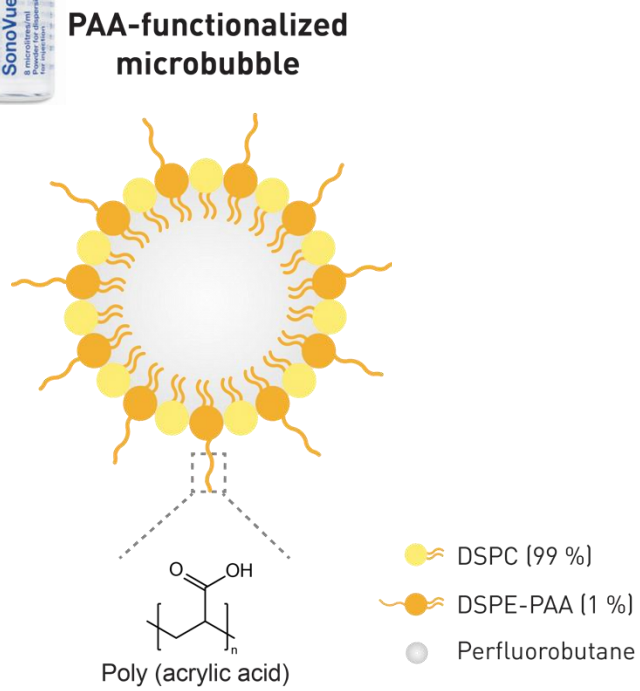
M.W.N. Burns et al., *ACS Appl. Mater. Interfaces*, **2020**

Mechanical modulation of bacterial gas vesicles through protease cleavage

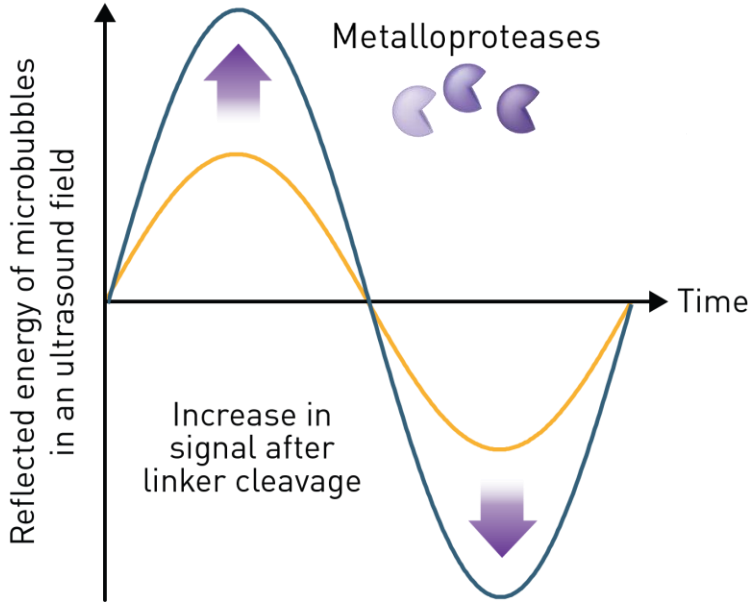


A. Lakshmanan et al., *Nat. Chem. Bio.*, **2020**

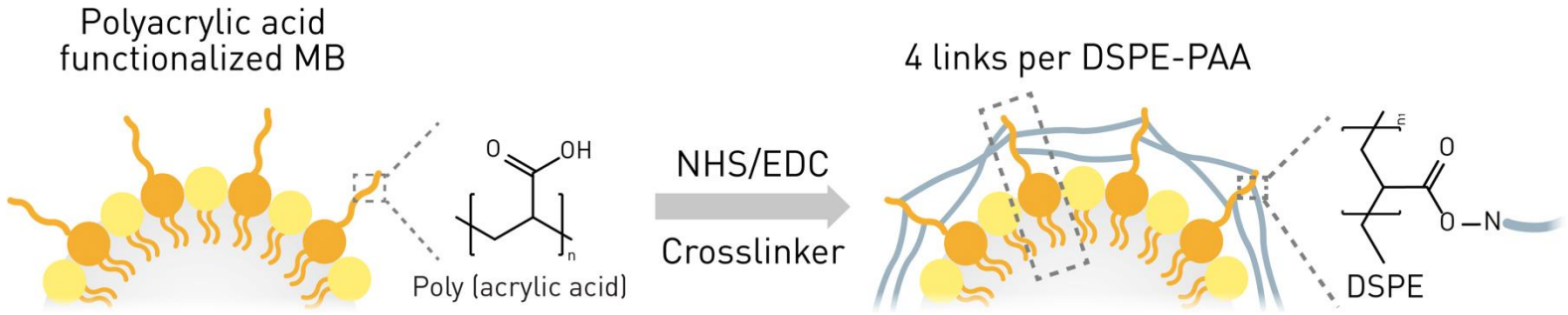
Protease responsive ultrasound contrast agents (PRUCAs)

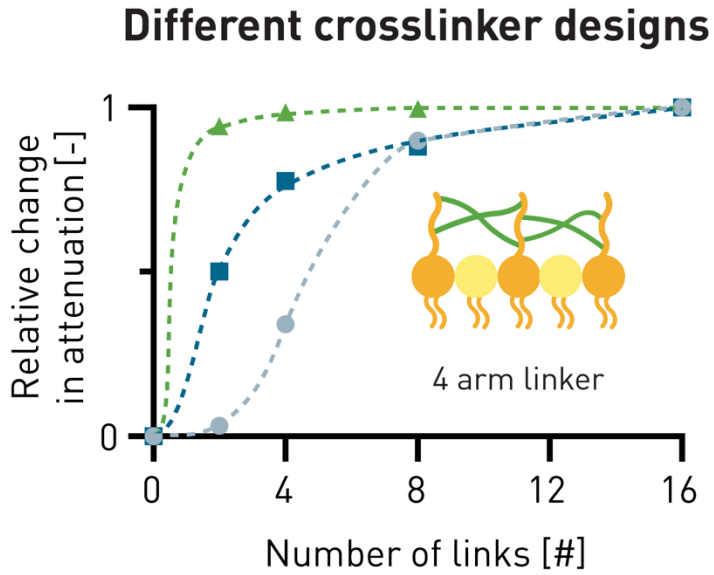


Dr. Dragana Ristanovic

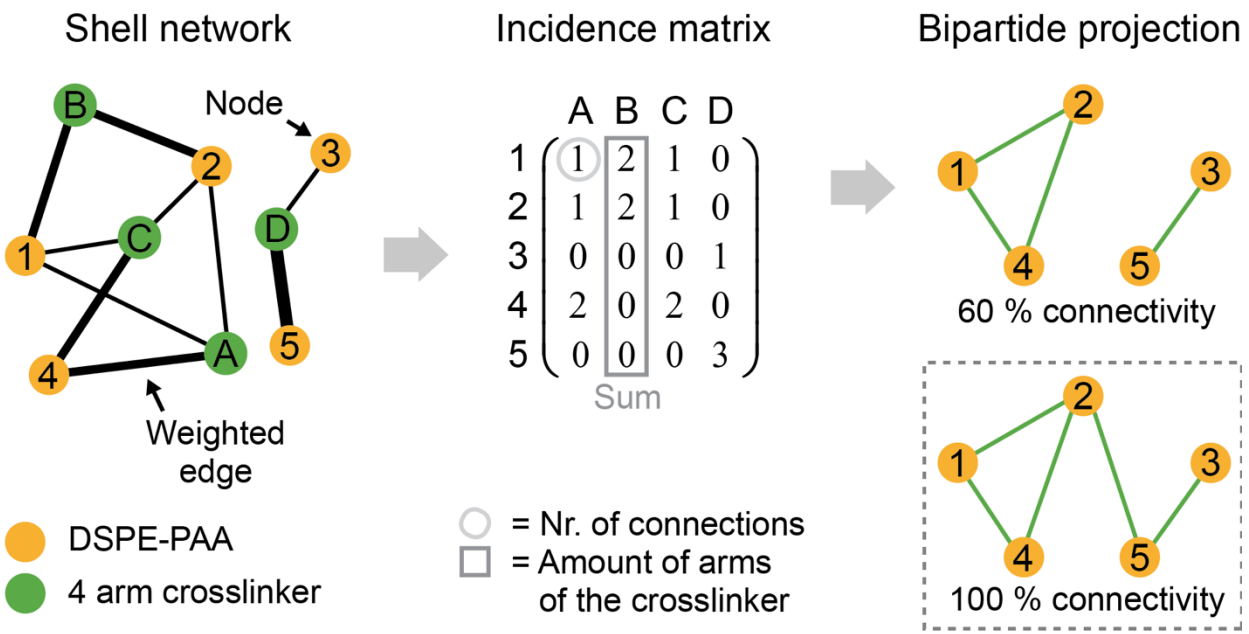


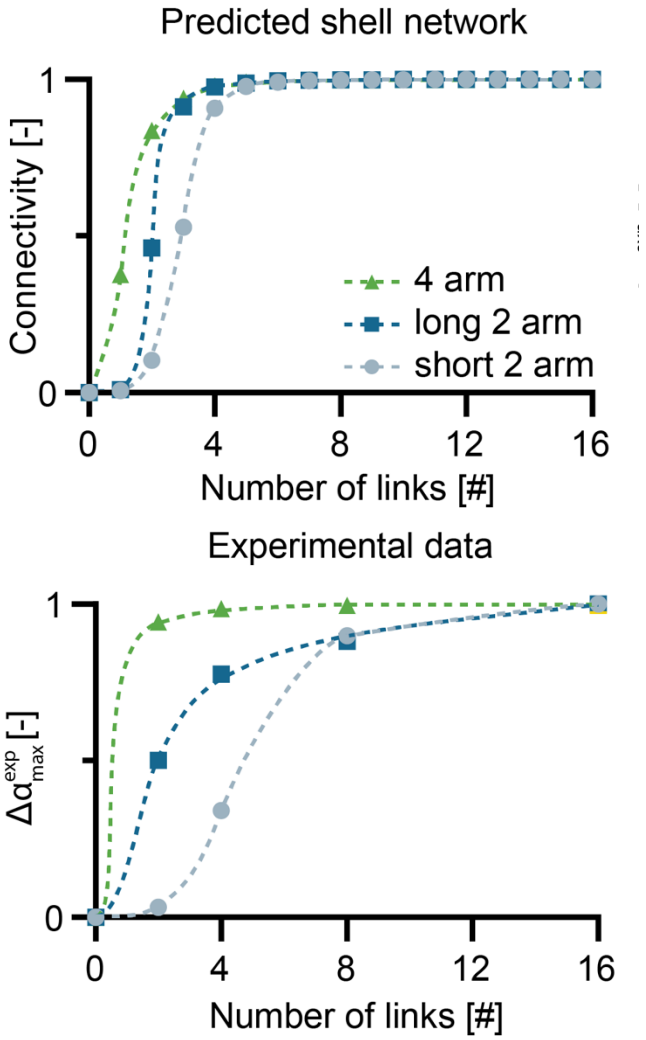
Crosslinking modulates mechanical properties of microbubbles



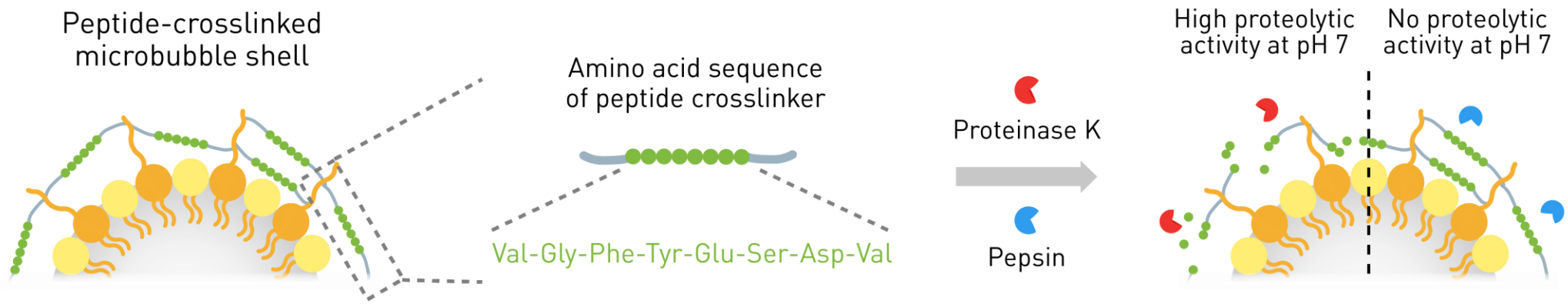


Network model predicts observed influence of crosslinker





Peptide-crosslinked microbubbles report proteolytic activity

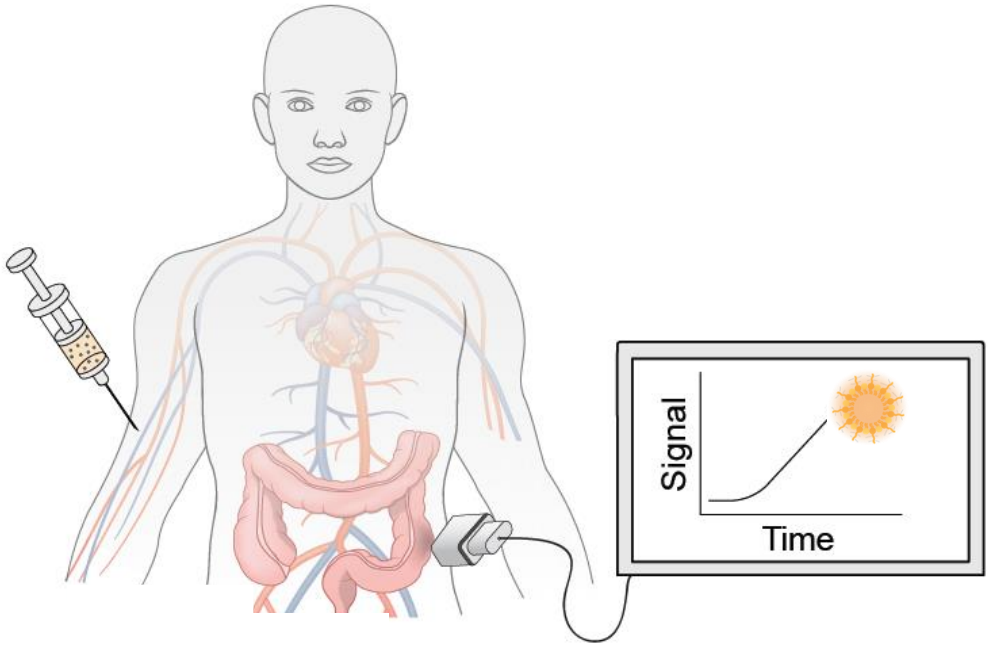


Dubey , Christiansen, Vizovisek, Gebhardt, Feike, Schuerle, Small, 2022, and EU Patent Application No.: EP19202465

Diagnostic targets

We are now working on applying this concept for

- Rheumatoid arthritis
- Inflammatory bowel disease
- Lung fibrosis
- Skin fibrosis
- Infection

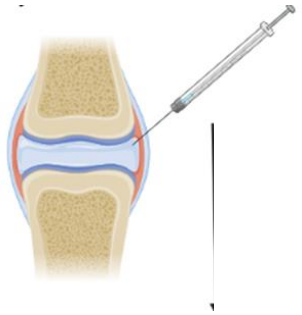


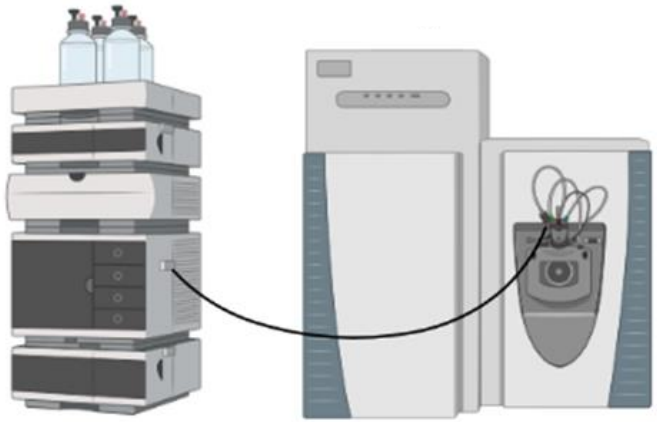
Pascal Poc

Ines Oberhuber

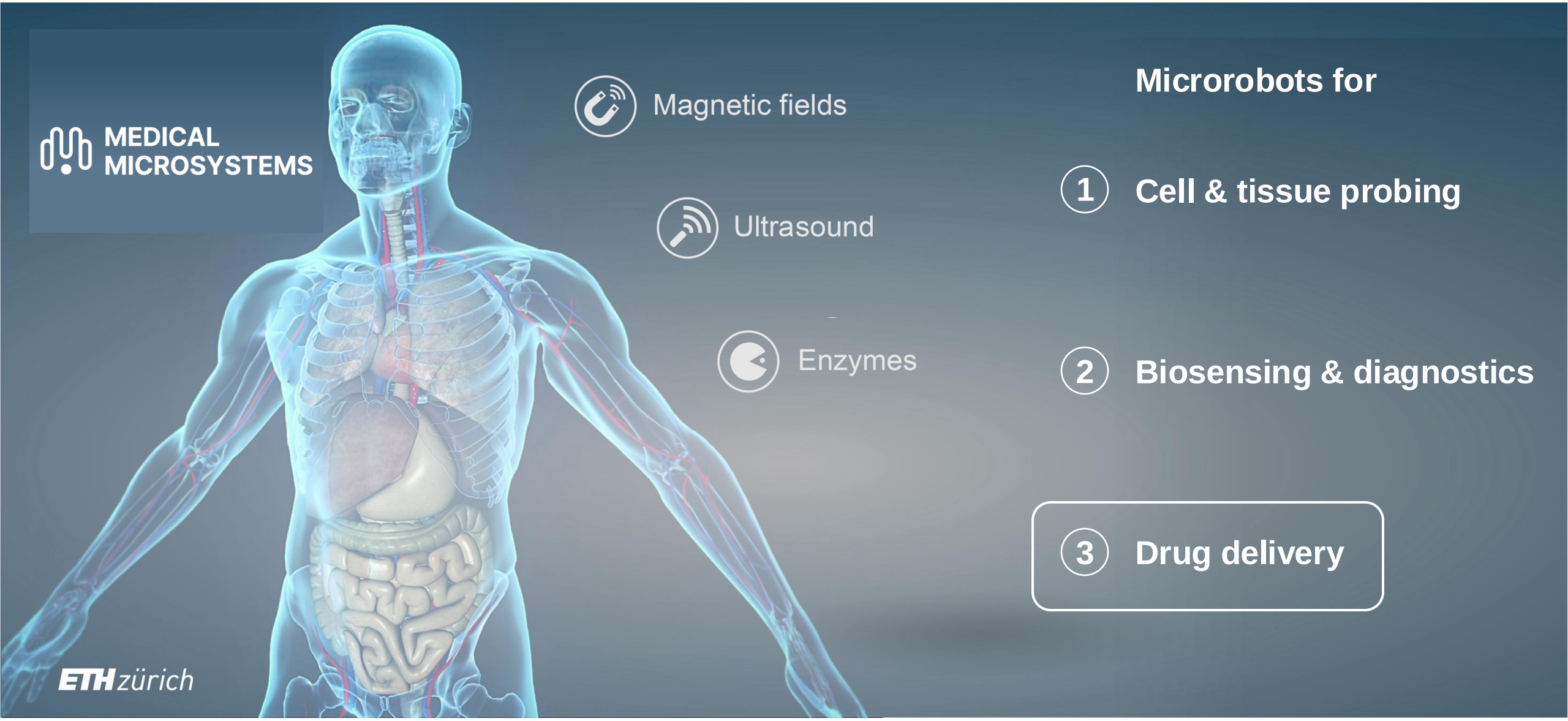
Gut biopsy samples

Synovial fluid samples

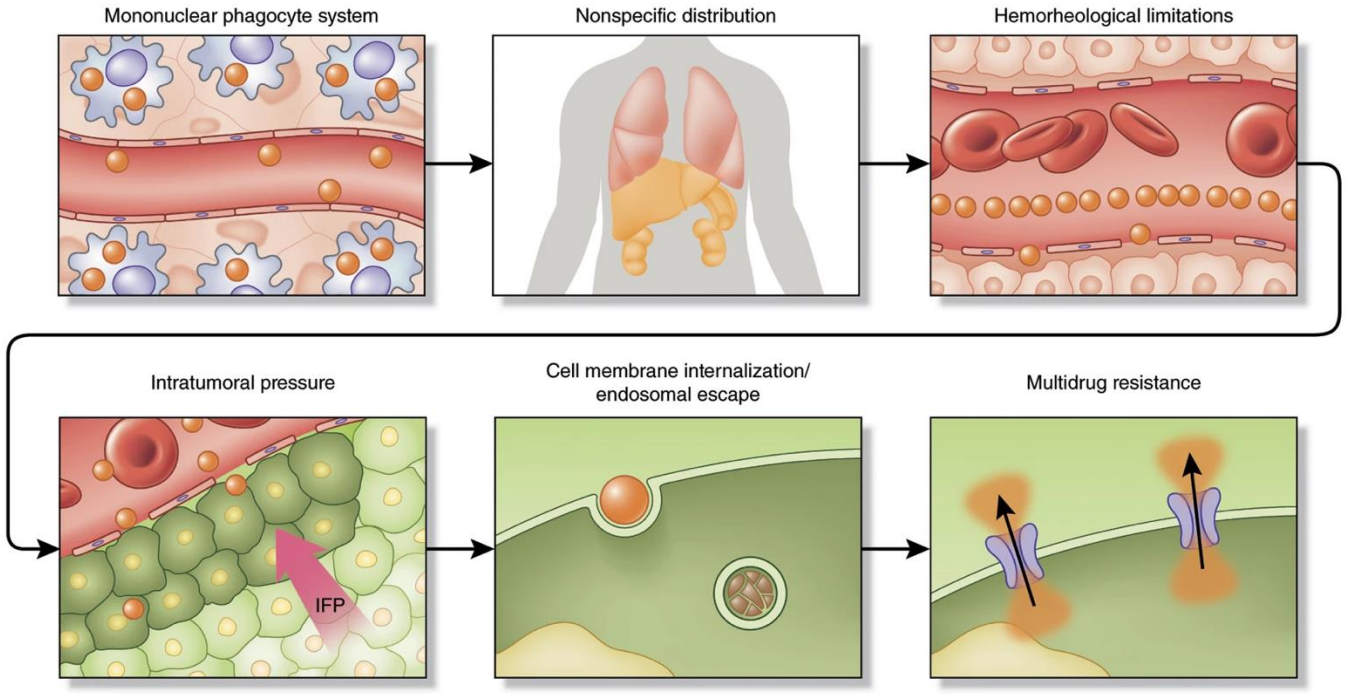


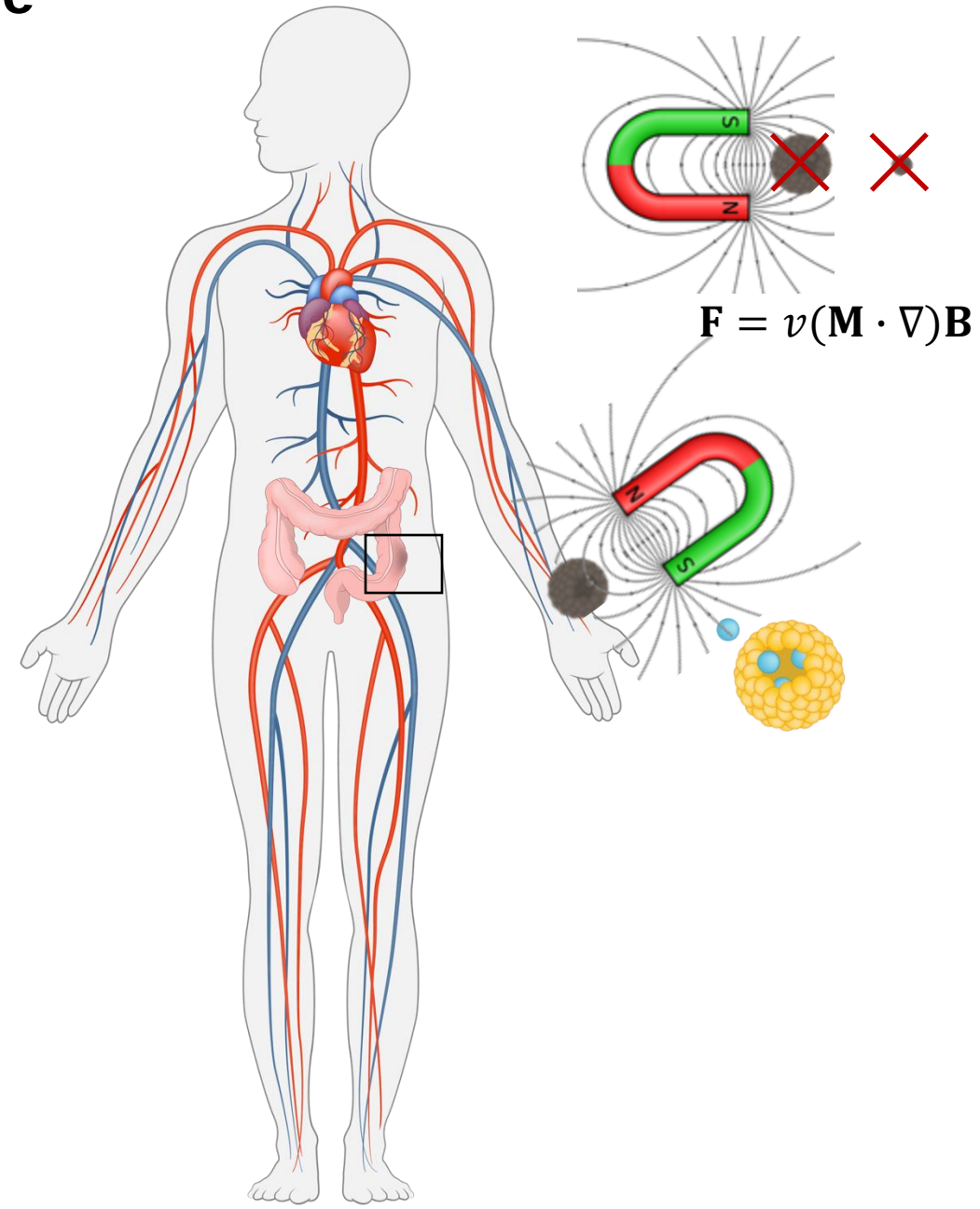


LC-MS/MS analysis of the proteome and the intrinsic peptidome


MEDICAL MICROSYSTEMS
Magnetic fields
Ultrasound
Enzymes
Microrobots for
1 Cell & tissue probing
2 Biosensing & diagnostics
3 Drug delivery
ETH zürich

The delivery problem of (cancer) nanomedicine



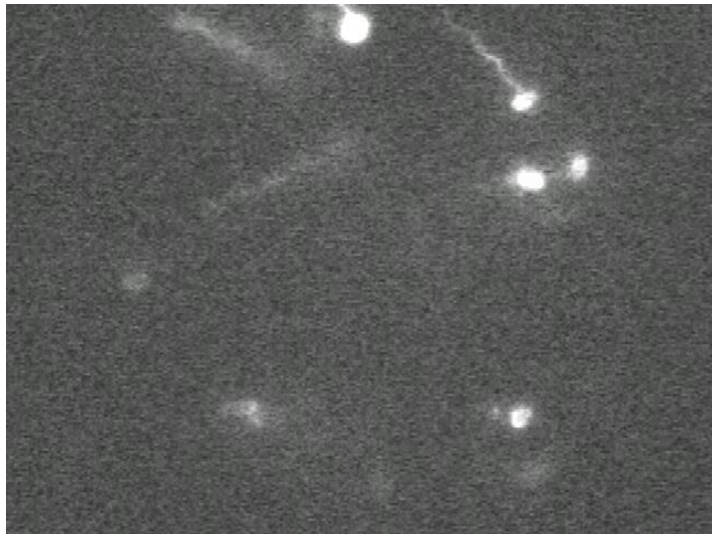


Only a dismal fraction of nanoparticle-based drugs reaches the tumor sites

Blanco, Shen, Ferrari, Nature Biotechnology, 33, 941–951 (2015)

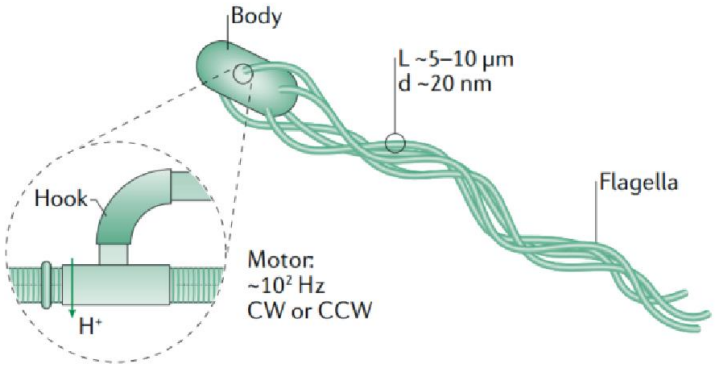
Bioinspired microrobots as delivery vehicles

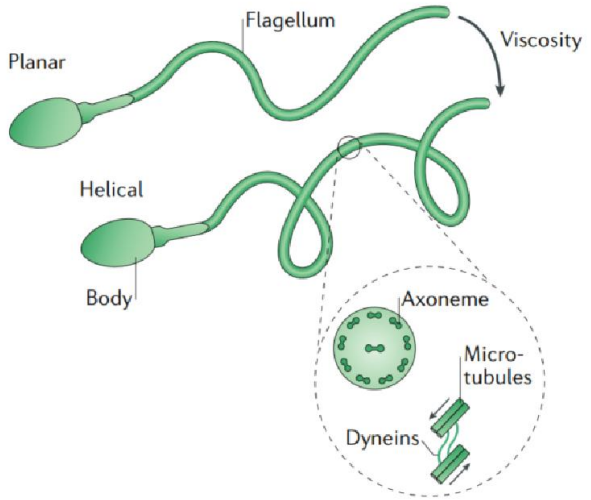
E. coli

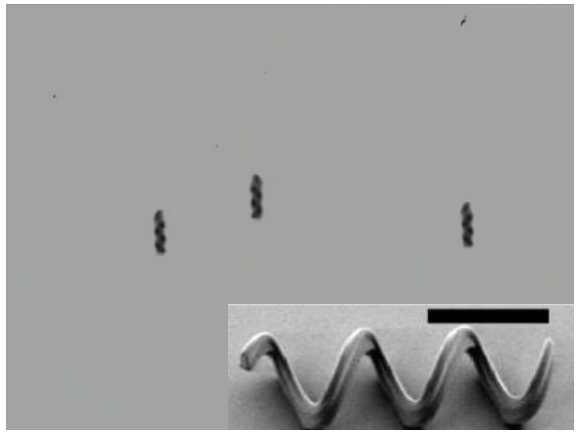


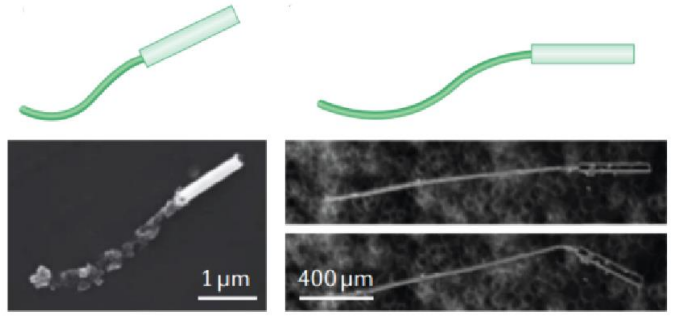
Video: Howard Berg

Non-reciprocal motion as effective means for propulsion at the Low Reynolds numbers





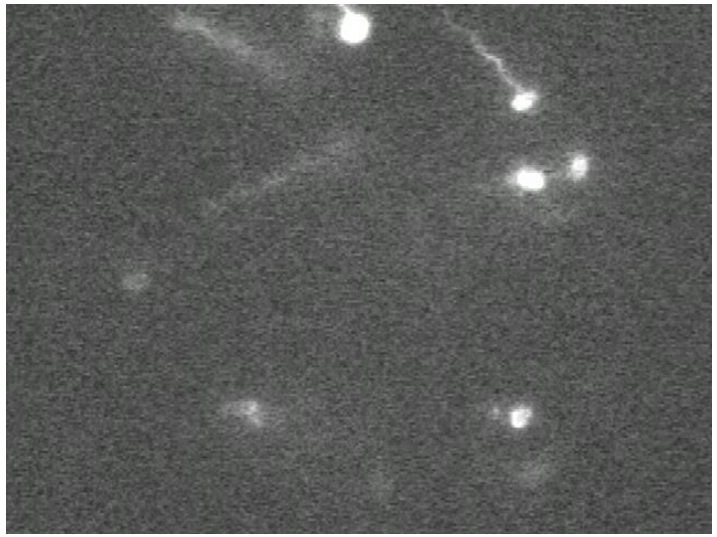




Using magnetic fields as external motor

*Palagi, S., Fischer, P. Bioinspired microrobots. Nat Rev Mater **3**, 113–124 (2018).*

Biological/biohybrid microrobots: a robotics perspective



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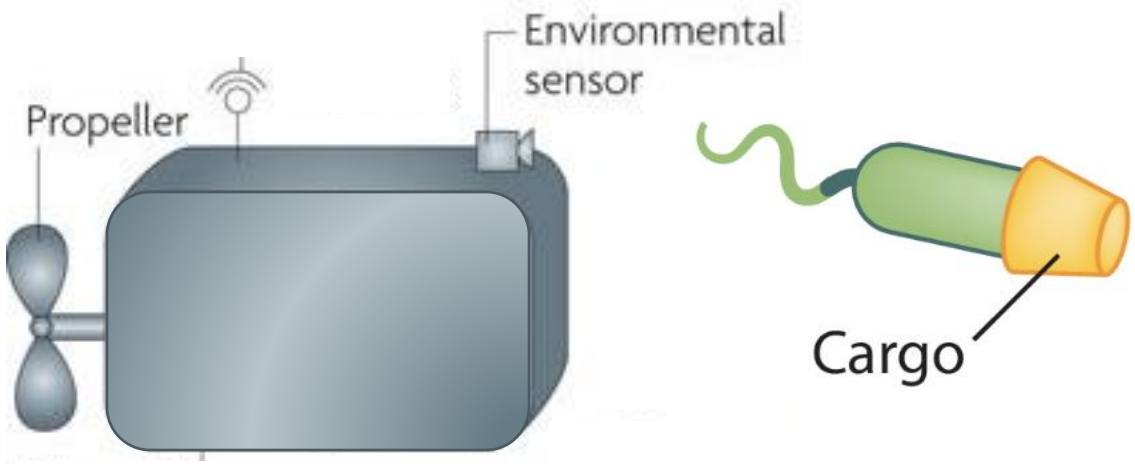
Non-reciprocal motion as effective means for propulsion at the Low Reynolds numbers



Adapted from Forbes, Nat Rev Cancer, 2010
Christiansen et al, Annu Rev Control Robot Auton Sys, 2022

Bacteria are somewhat smart "microrobots"

- On board sensing, e.g. chemotaxis
- Self propulsion

Bacteria for medical applications– a (b)old idea

German physician W. Buschin observes tumour regression after administration of *S. pyogenes*

R. Pearl finds lower incidence of cancer in patients with active TB

1868 — 1891 — 1929

American physician William Coley treats hundreds of patients over 30 years with his toxin consisting of inactivated bacteria

BIOMED VALLEY DISCOVERIES

- Oldest form of immunotherapy, experiencing a renaissance
- Anaerobic bacteria amplify in tumors
- They provoke immune response
- Native or genetically engineered for on board drug production

CNV-NT: Clostridium novyi-NT — Tumor-fighting Bacteria

Source: In-licensed from Johns Hopkins University
Stage: Phase I

But…

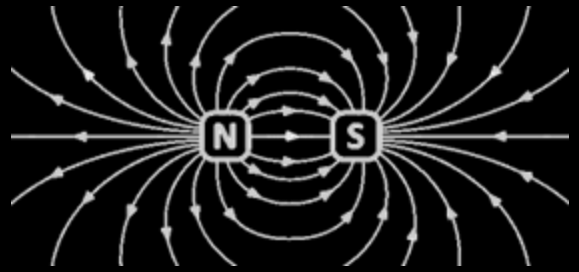
- Clinical trials limited to intratumoral injection
  - Only about 1% of intravenously administered dose reaches tumor
  - Limited tumor penetration
  - Limited tolerable dose

Need for effective control to increase safety and efficacy at acceptable dosages

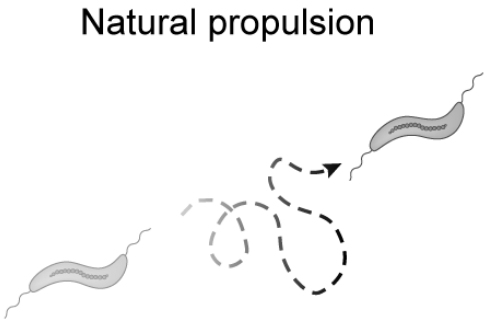
Effective powering

Feedback and Tracking

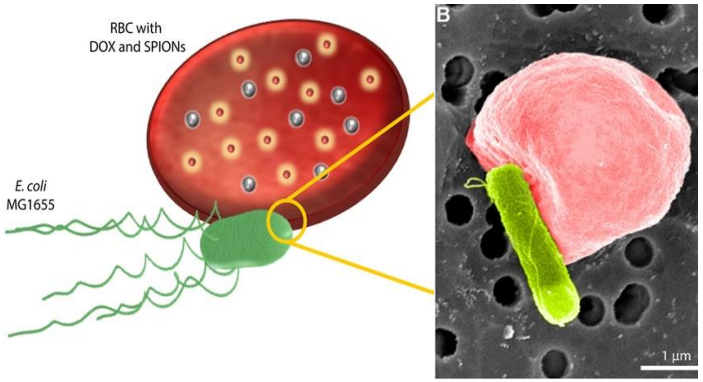
Controllability



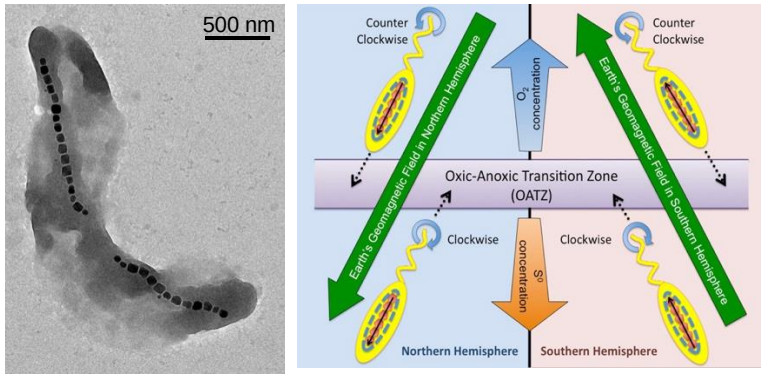
Means to magnetically control living bacteria-based microrobots



0.1 pN

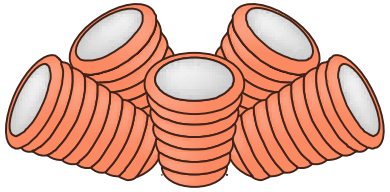


Alapan et al. *Sci Rob*, 2018

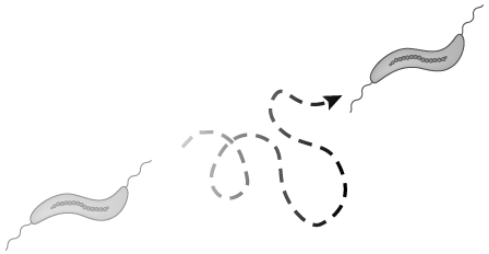


Schuerle *et al.*, *Sci. Adv.*, 2019

Means to magnetically control living bacteria-based microrobots



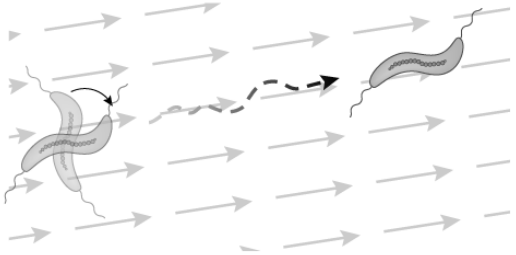
Natural propulsion



0.1 pN

Directing magnetic field

$\vec{B}$

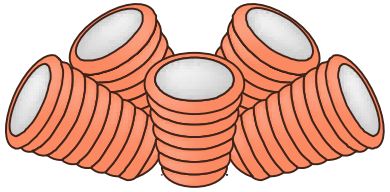


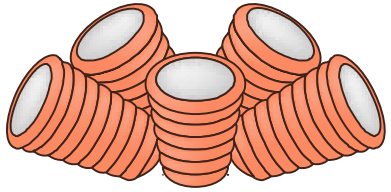
0.1 pN

Limited by molecular motor
Limited to paraturmoral injections

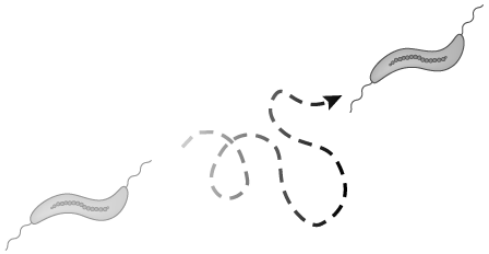
Conflict of interest disclosure: Simone Schuerle is co-founder of Magnebotix AG

Means to magnetically control living bacteria-based microrobots





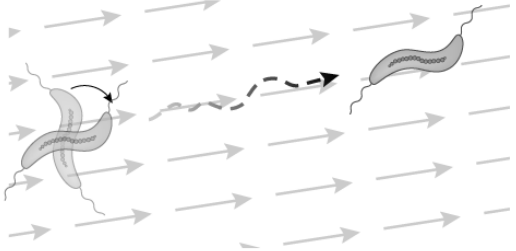
Natural propulsion



0.1 pN

Directing magnetic field

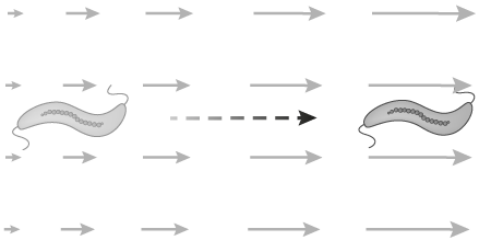
$\vec{B}$



0.1 pN

Magnetic field gradient

$\nabla\vec{B}$



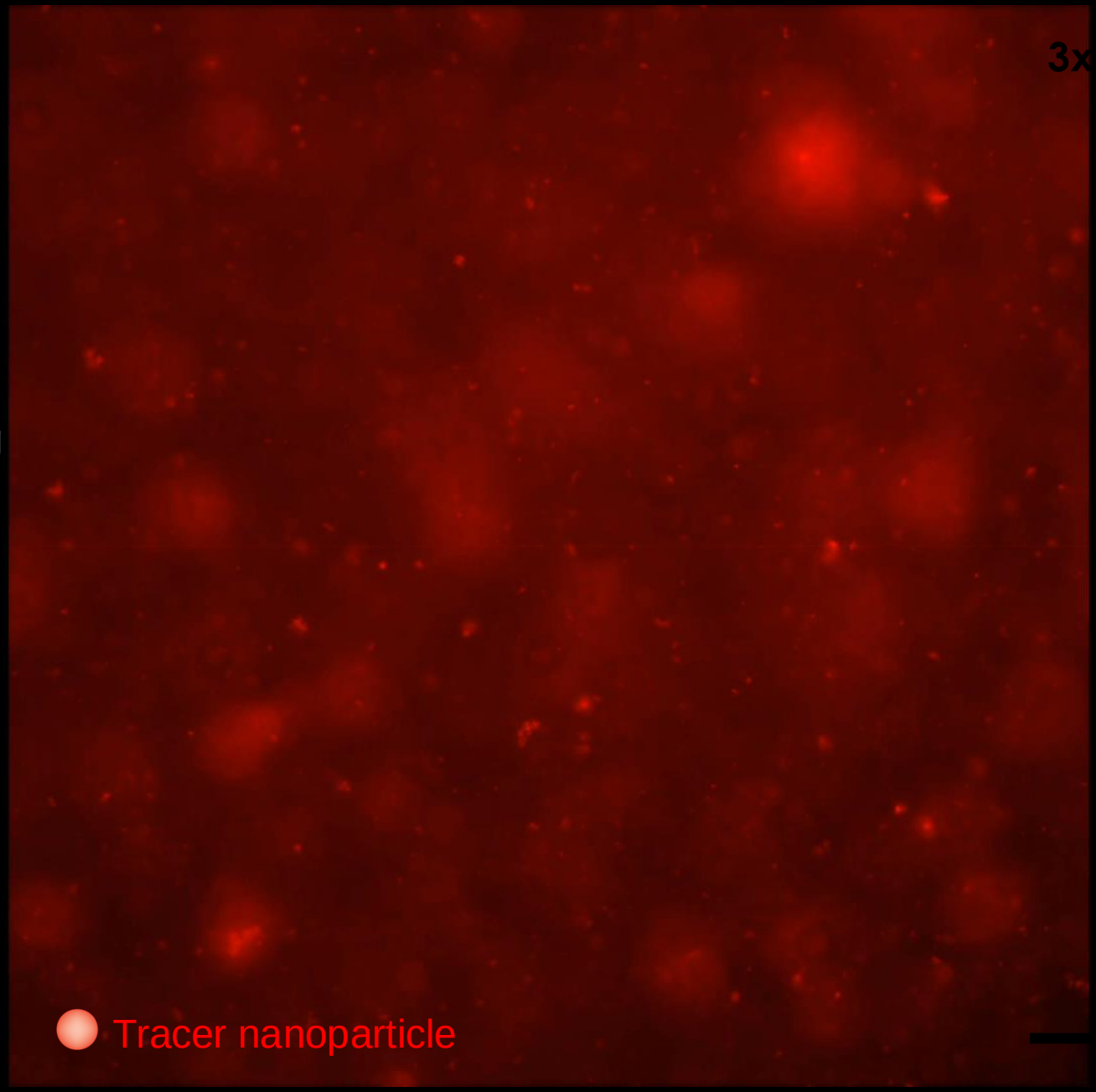
1 pN
1300 T/m

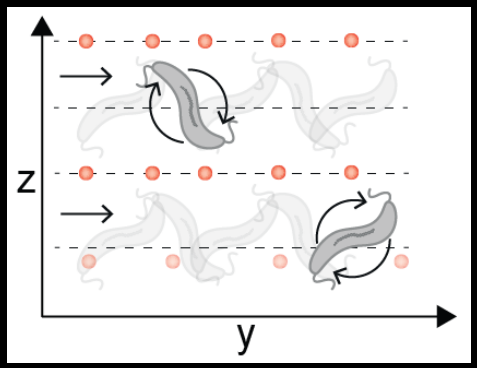
Limited by molecular motor
Limited to paraturmoral injections

Poorly scalable
Limited to superficial targets

Magnetic torque based bacterial swarm control is powerful

Effective powering and control!

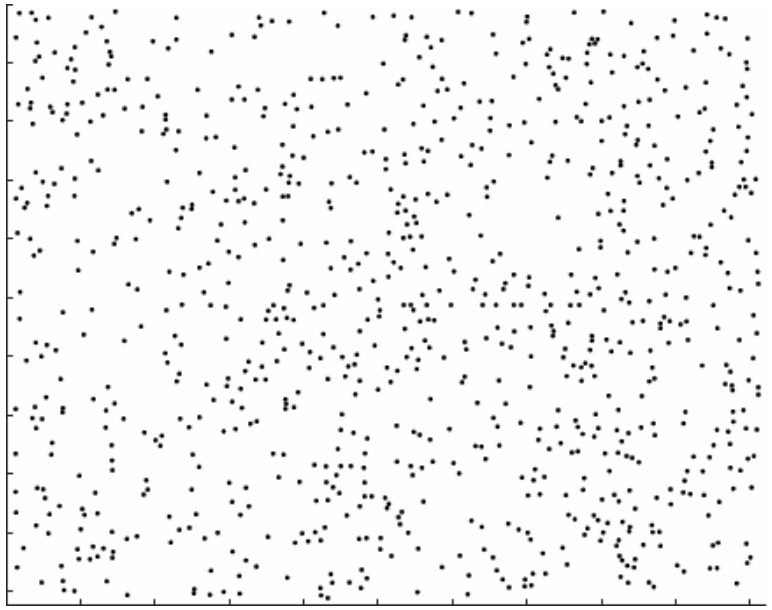


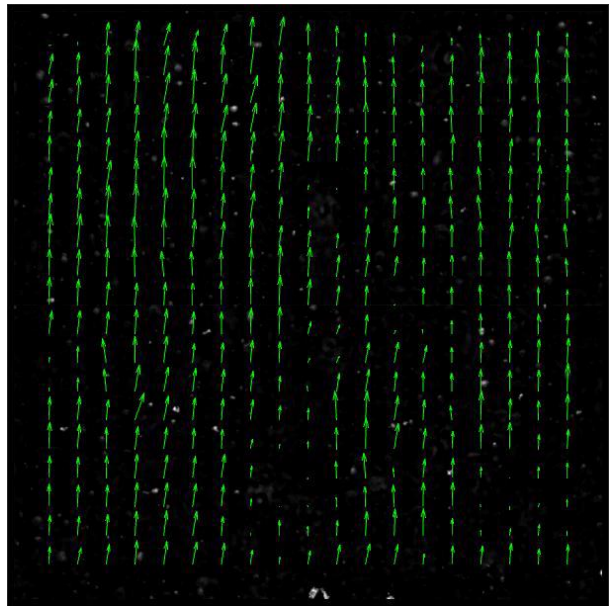


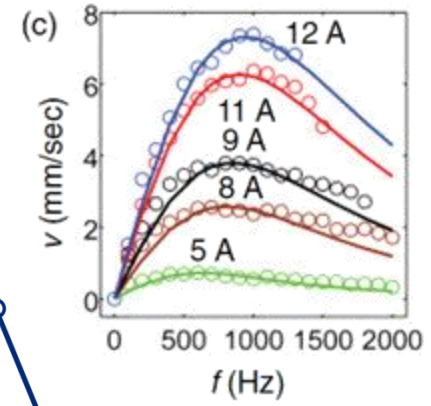
Schuerle et al., *Sci Adv 2019*

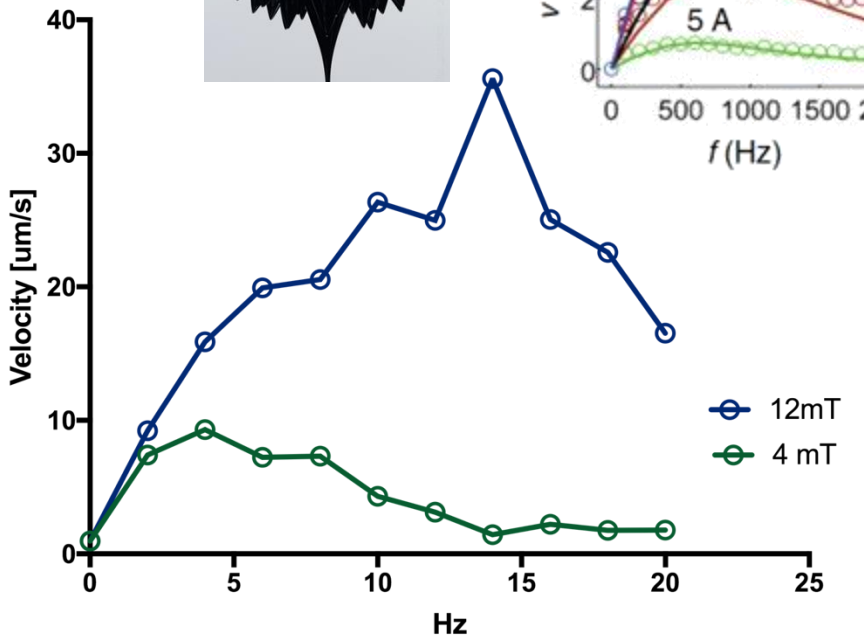
Ferrohydrodynamics with bacterial swarms as living ferrofluids

Zahn et al., Appl Phys Lett 2007.







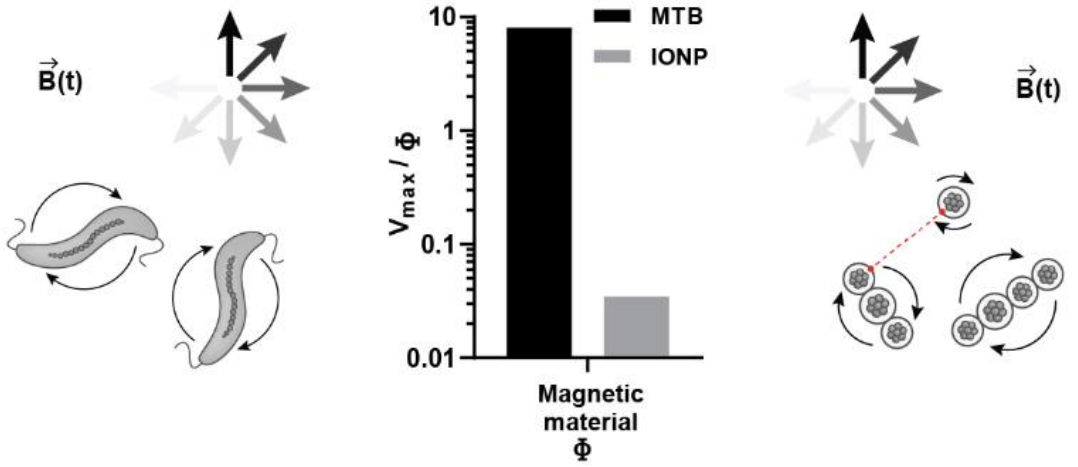


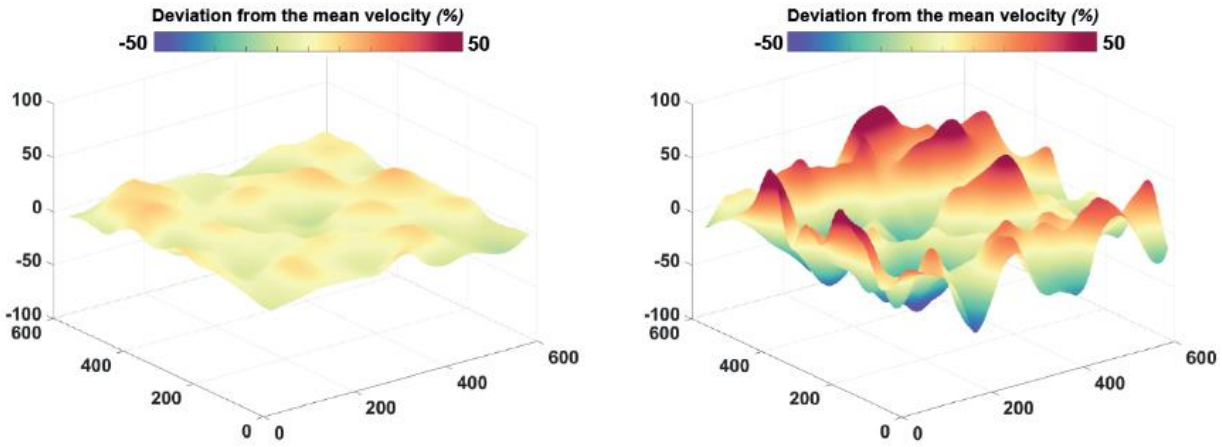
Response of bacterial swarms under rotating magnetic fields similar to synthetic ferrofluids

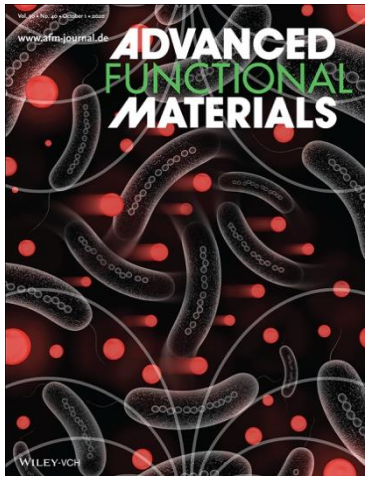
Magnetotactic bacteria generate higher flow rates

Dr. Nima Mirkhani

- Relatively large and elongated bacterial body
- Shape anisotropy and magnetic ordering of magnetosome chains



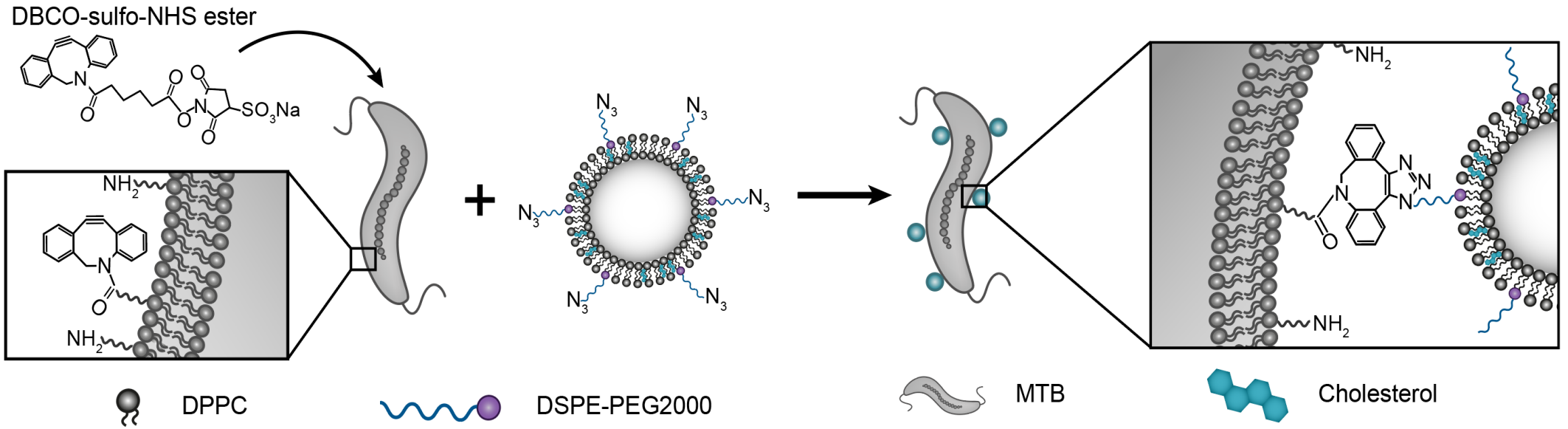


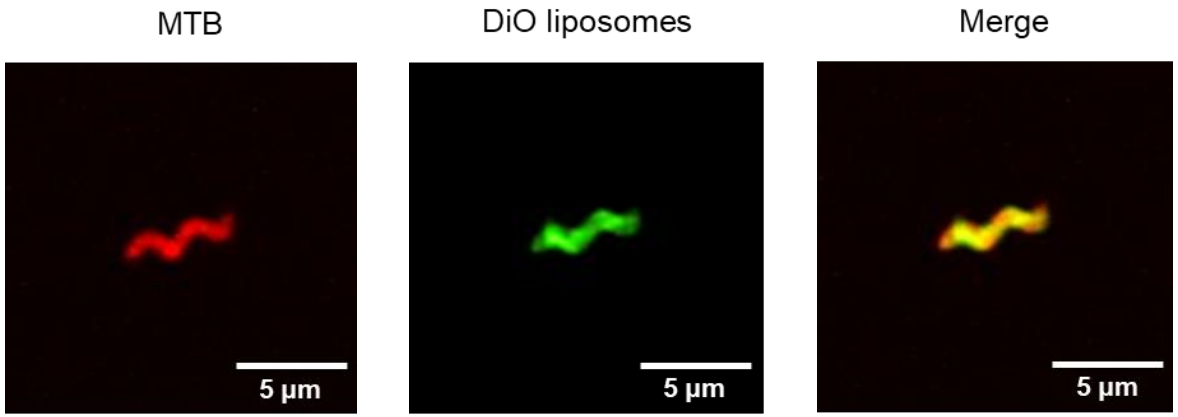


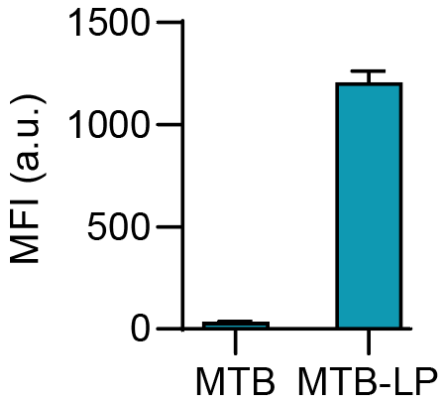
Mirkhani et al. *Adv Functional Mat, 2020*

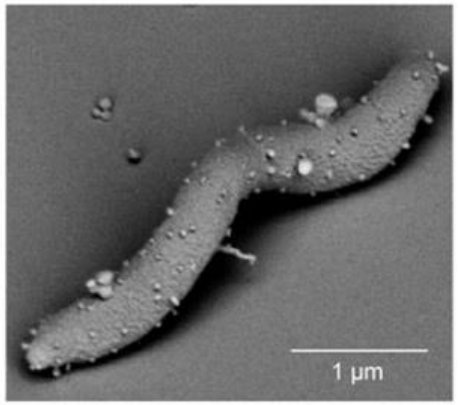
Living microrobots with liposomes as versatile drug nanocargo

Dr. Tintotenda Gwisai



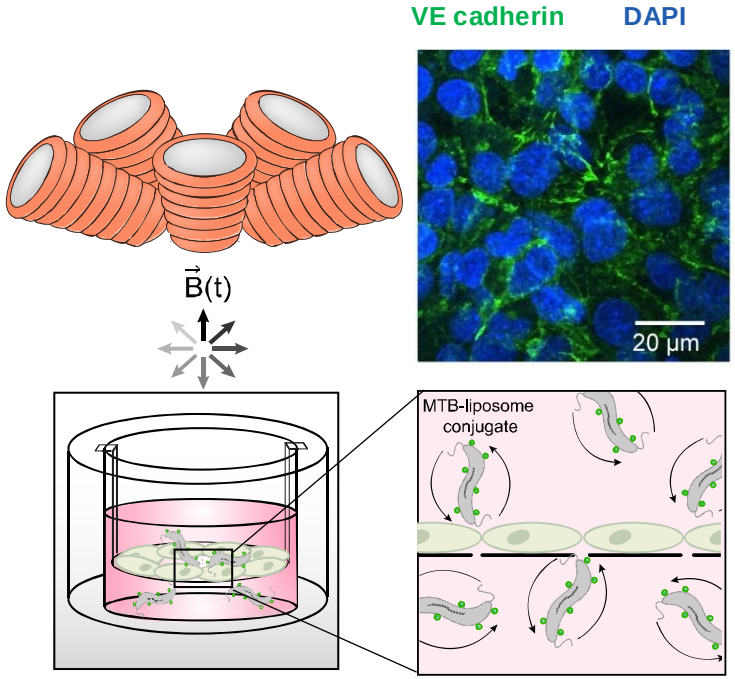


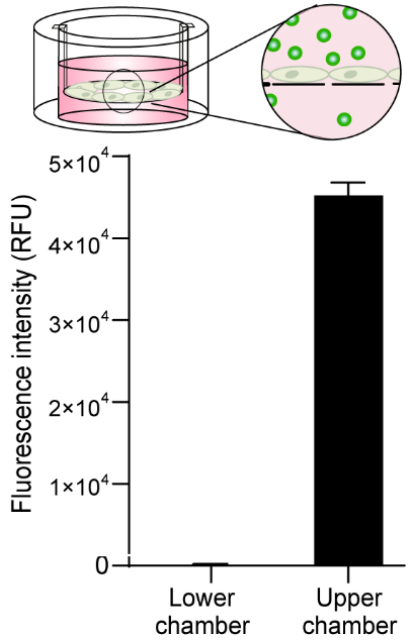


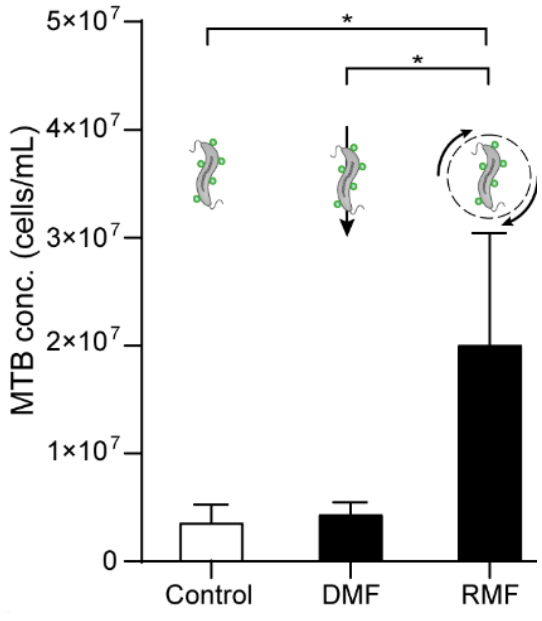


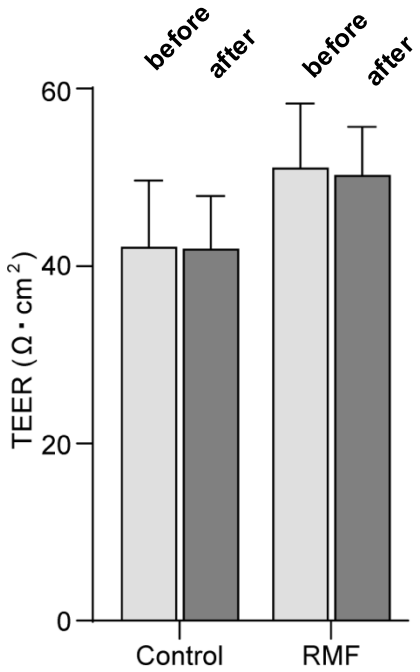
Gwisai et al, Adv Therap, 2024

Torque driven magnetic control of living microrobots increases transport across physiological barriers





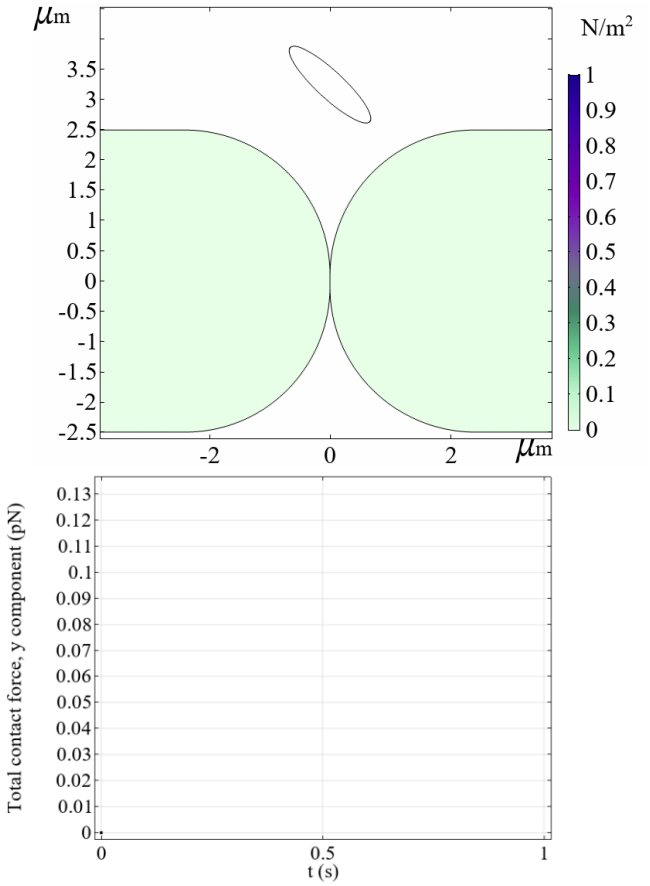




RMF = 24 Hz, 20 mT, 1 hour, n = 3, *P < 0.05

Higher applied forces are needed to break and open cell-cell junctions

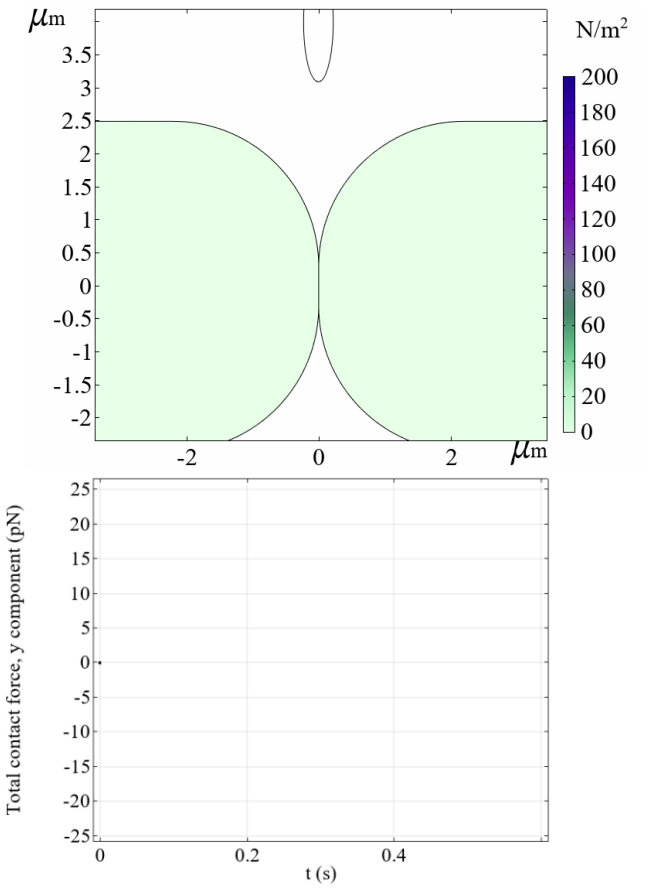
Contact force caused by the rotational actuation near a junction



~ 0.1 pN

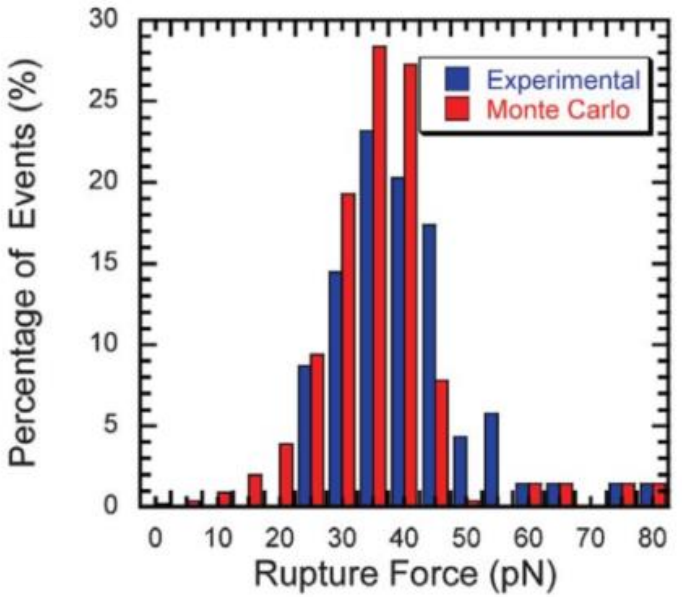
<

Elastic resistance profile of a micron-sized object passing through a junction



~ 10 pN

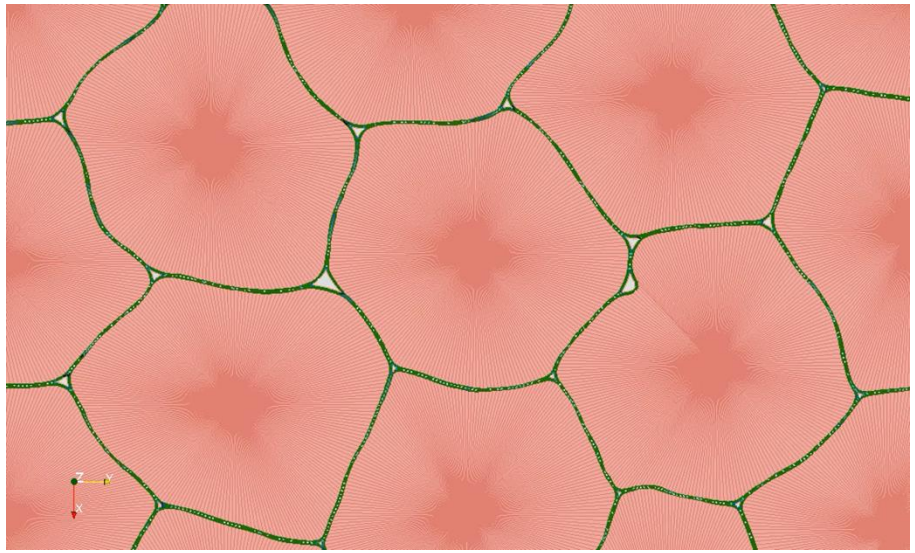
Distributions of forces required to break single VE-cadherin/VE-cadherin bonds



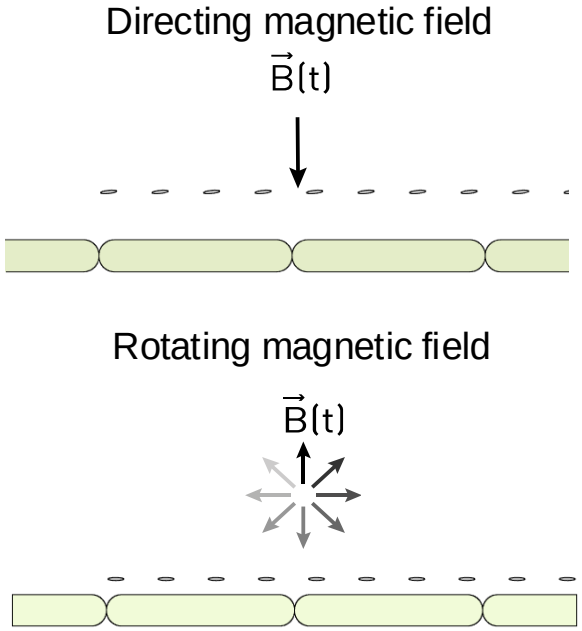
Panorchan, P., et al, *J. Mol. Biol.* (2006) 358, 665–674

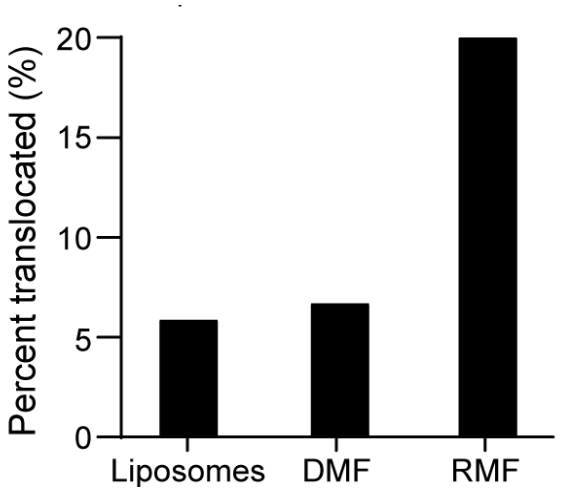
~ 10 pN

Increased surface exploration as driving mechanism of translocation



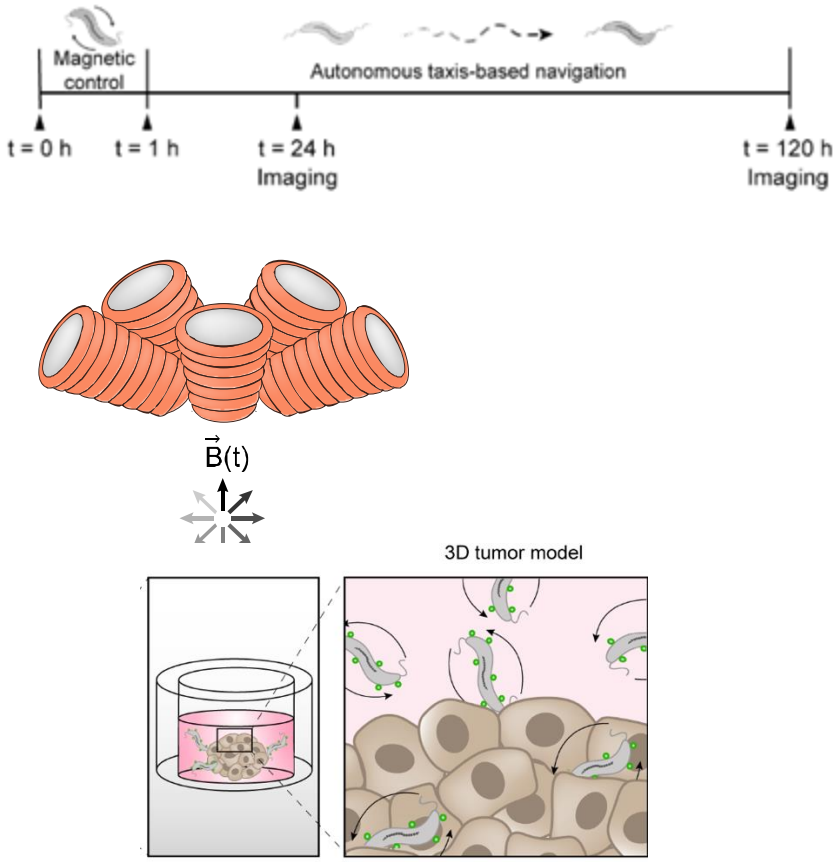
Escribano, J., *PLoS Comput Biol*, 2019,15(5)

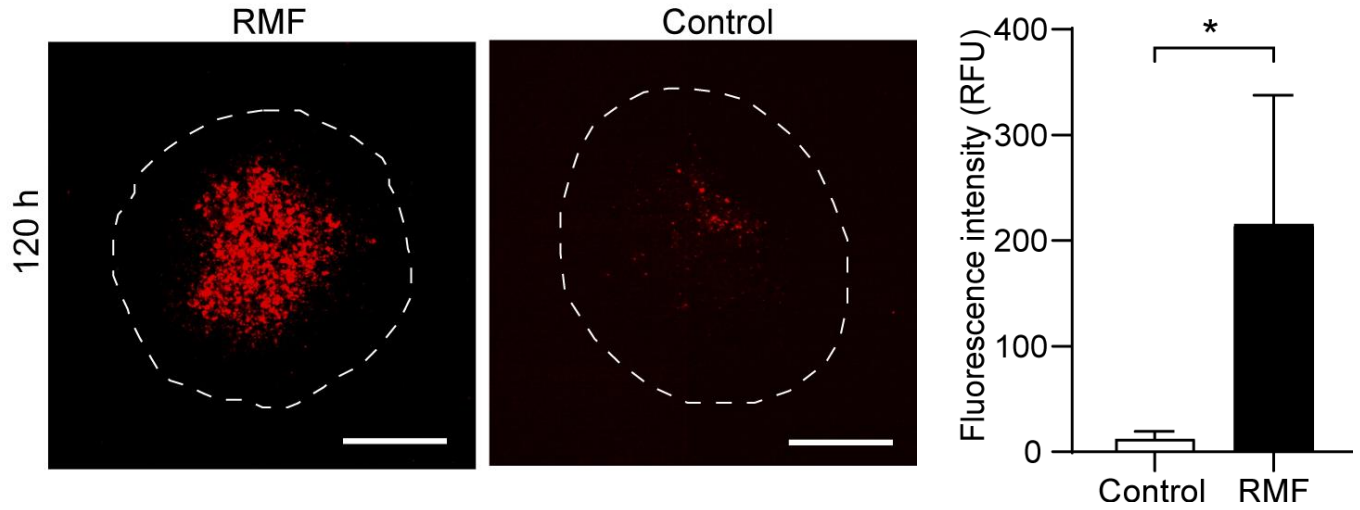




Torque driven control increases infiltration in 3D tumor models

MCF-7 (breast adenocarcinoma) spheroids model avascular solid tumors



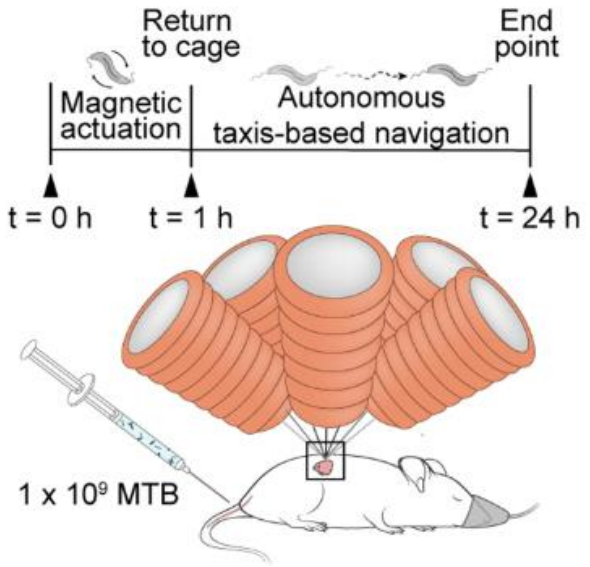


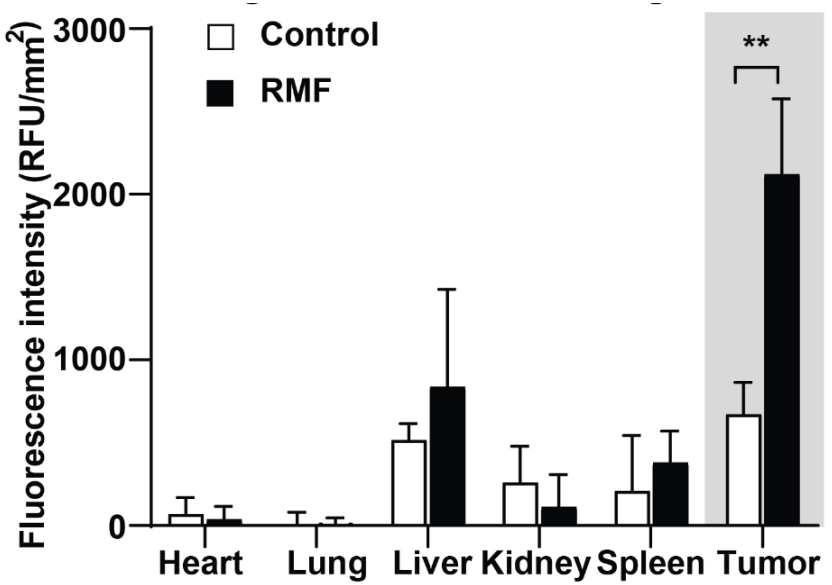
RMF = 24 Hz, 20 mT, 1 hour; $n = 3$; $^{*}P < 0.05$, $^{**}P < 0.01$; Scale bar = 200μm

Magnetic torque-driven motion with taxis-based navigation results in robust tumor colonization

Gwisai, T., et al. *Sci Rob*, 2022

Torque driven control increases tumor infiltration of living microrobots

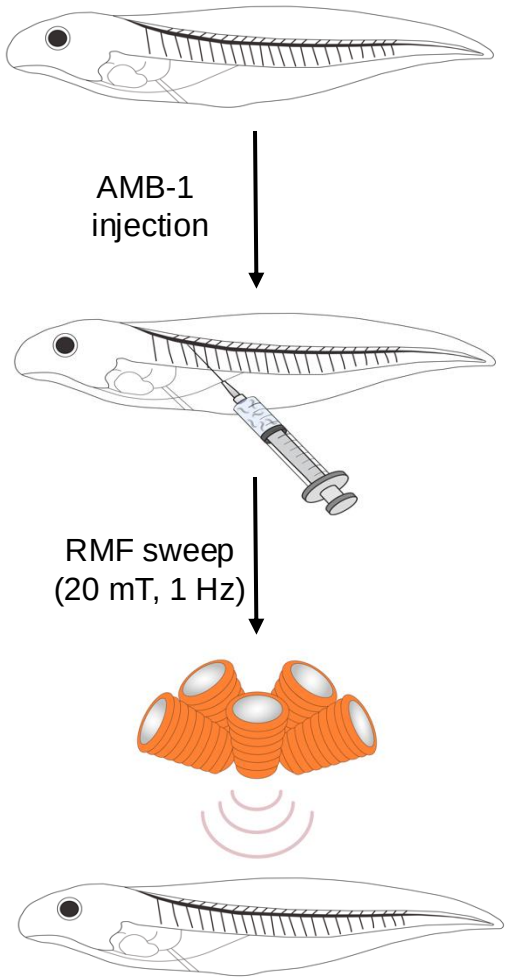


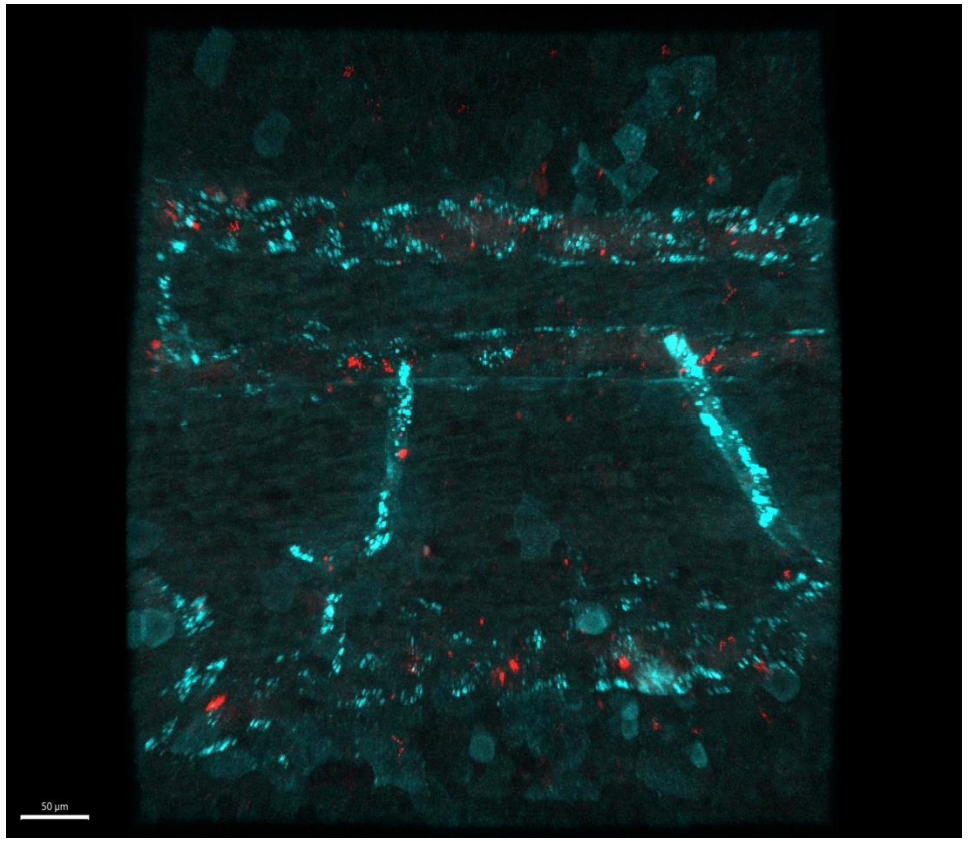


We introduced a hybrid control approach
leveraging torque-driven control and autonomous tumor taxis
by combing robotics and biology

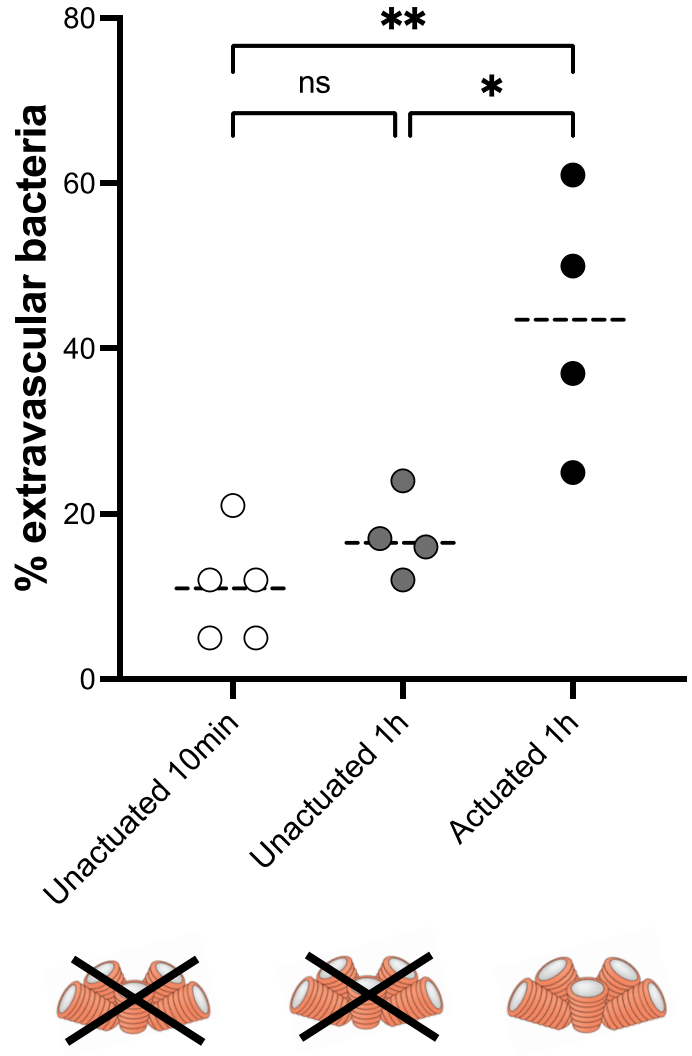
Gwisai *et al., Sci Rob, 2022*

Live imaging of microrobot extravasation in embryos of *X. laevis*





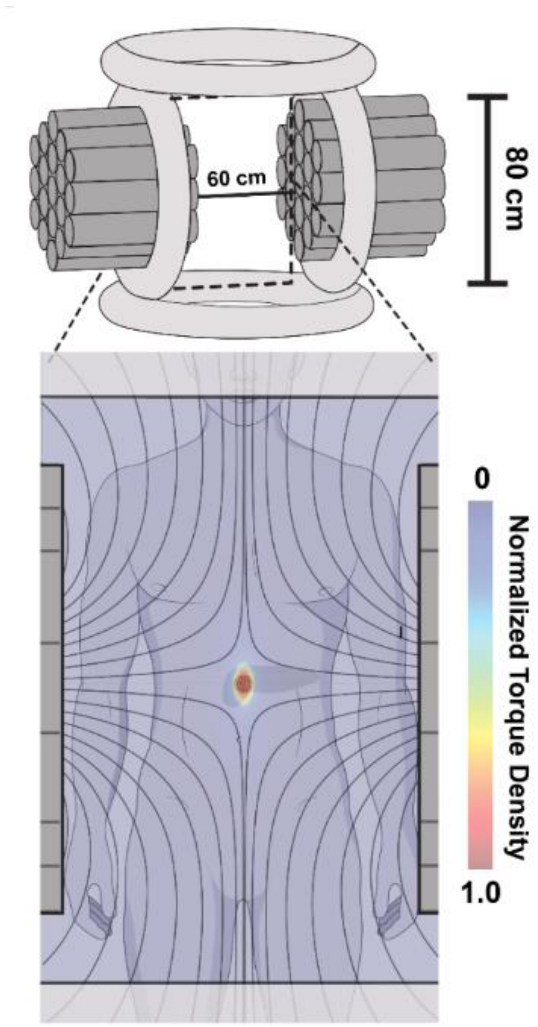
intravascular bacteria
extravascular bacteria

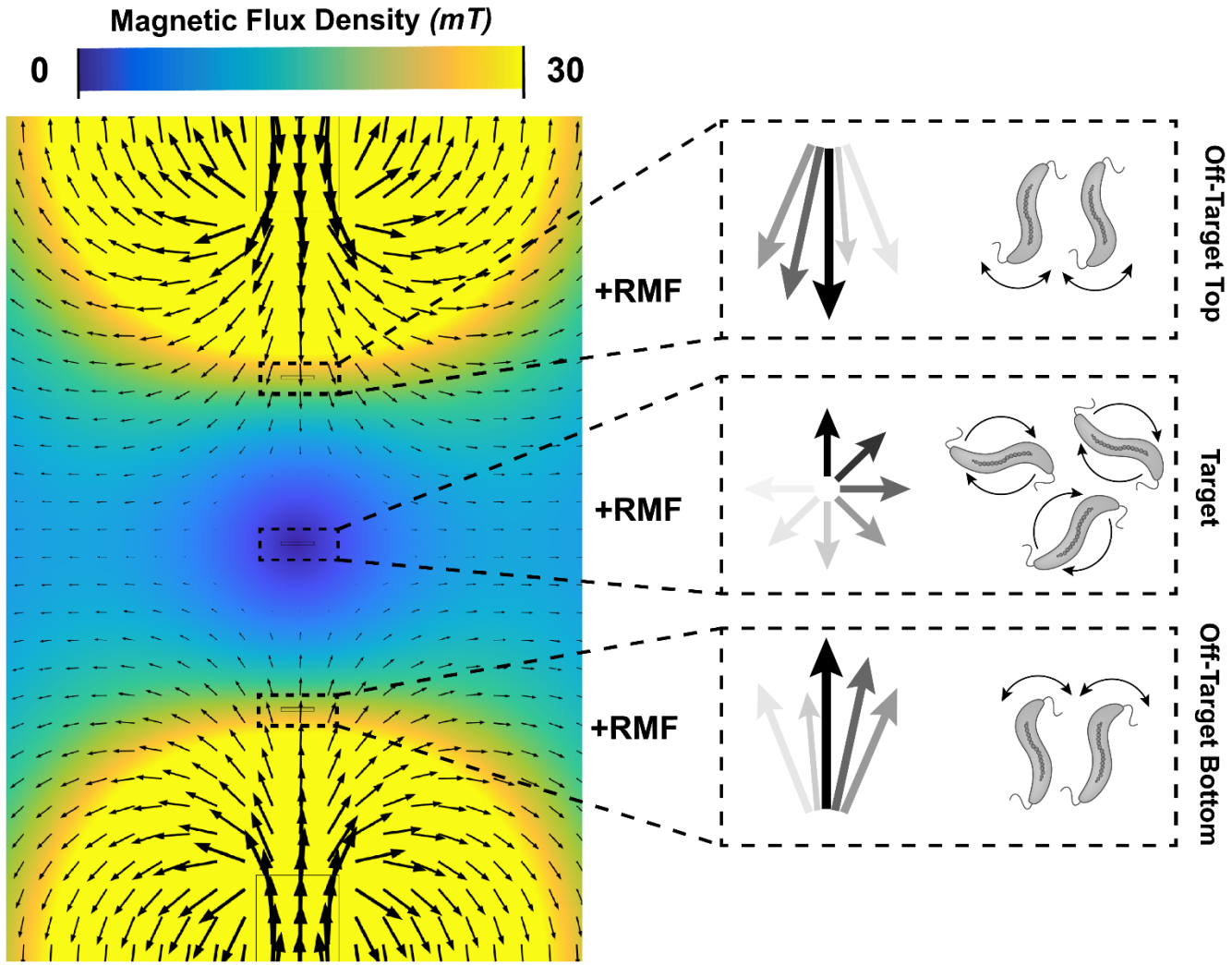


In collaboration with Taiyo Yamamoto, Lienkamp group (UZH, Institute of Anatomy)

unublished

Can we increase spatial selectivity and scale to human patients?



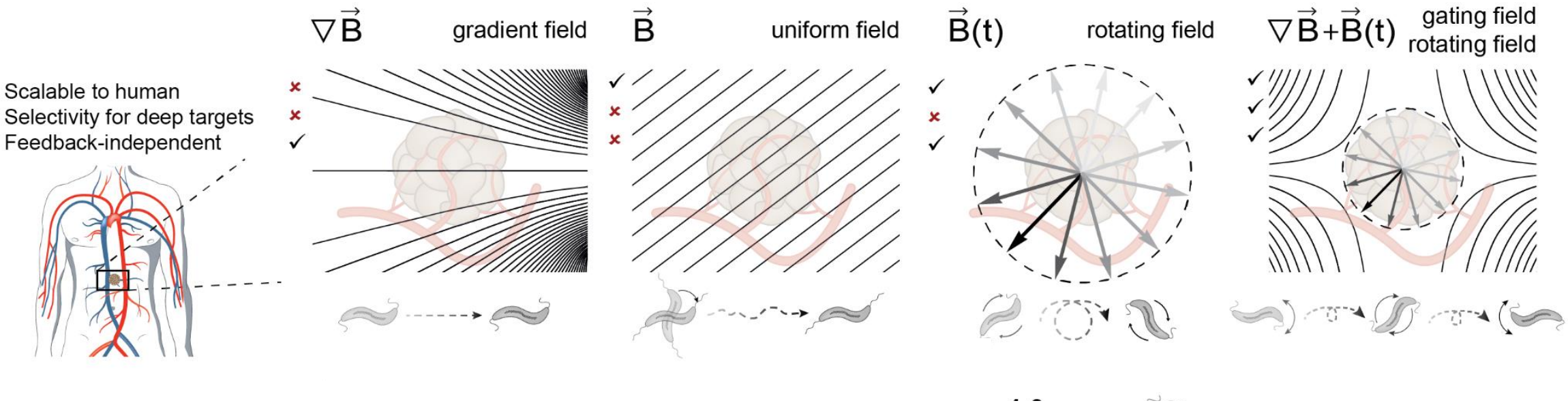


Dr. Nima Mirkhani

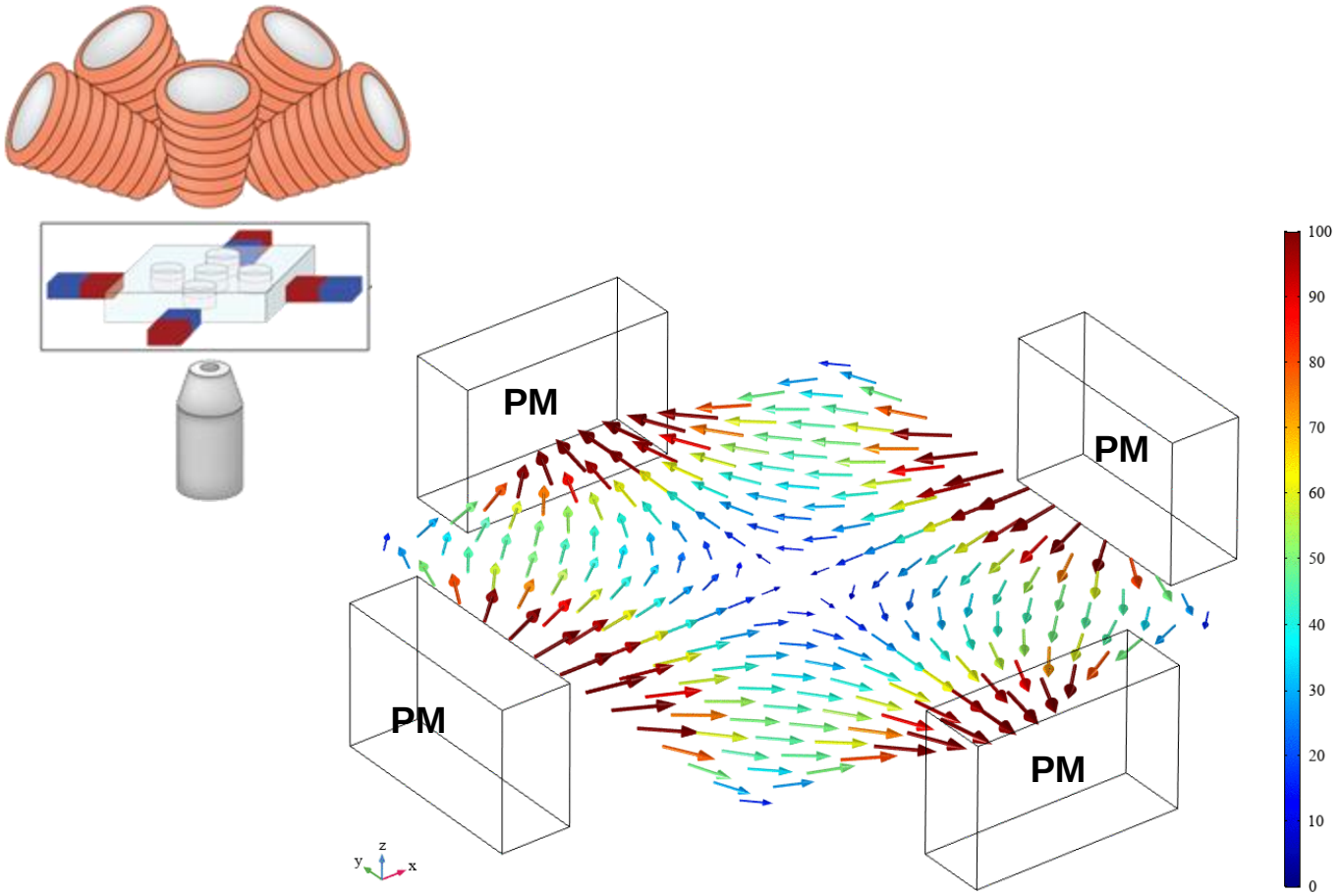
Dr. Michael Christiansen

Mirkhani, N et al. *Adv Functional Mat, 2020*

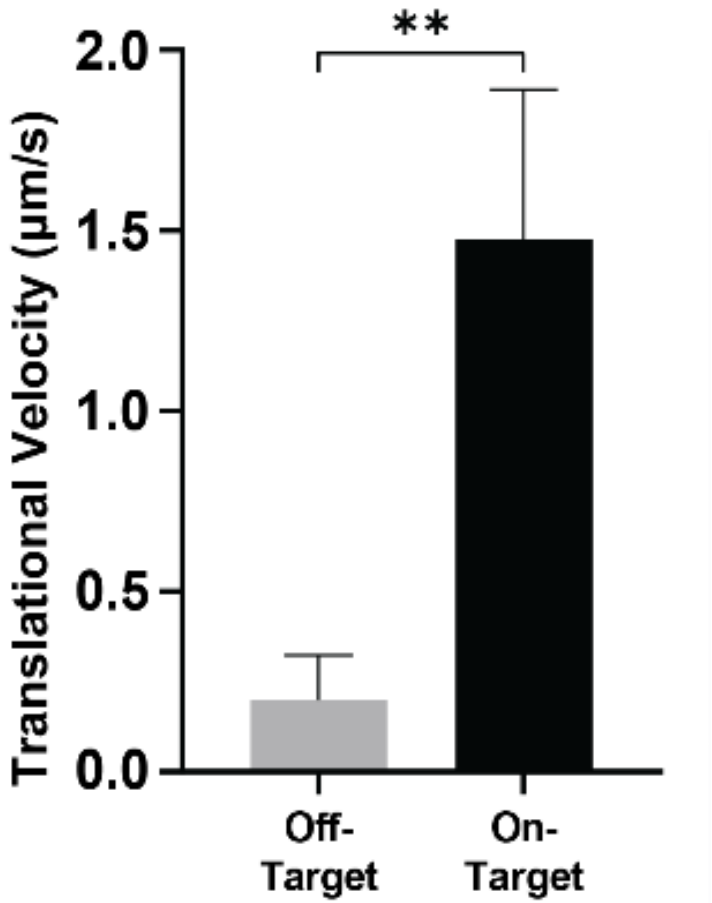
Can we increase spatial selectivity and scale to human patients?



Focussing torque to enhance safety and efficacy



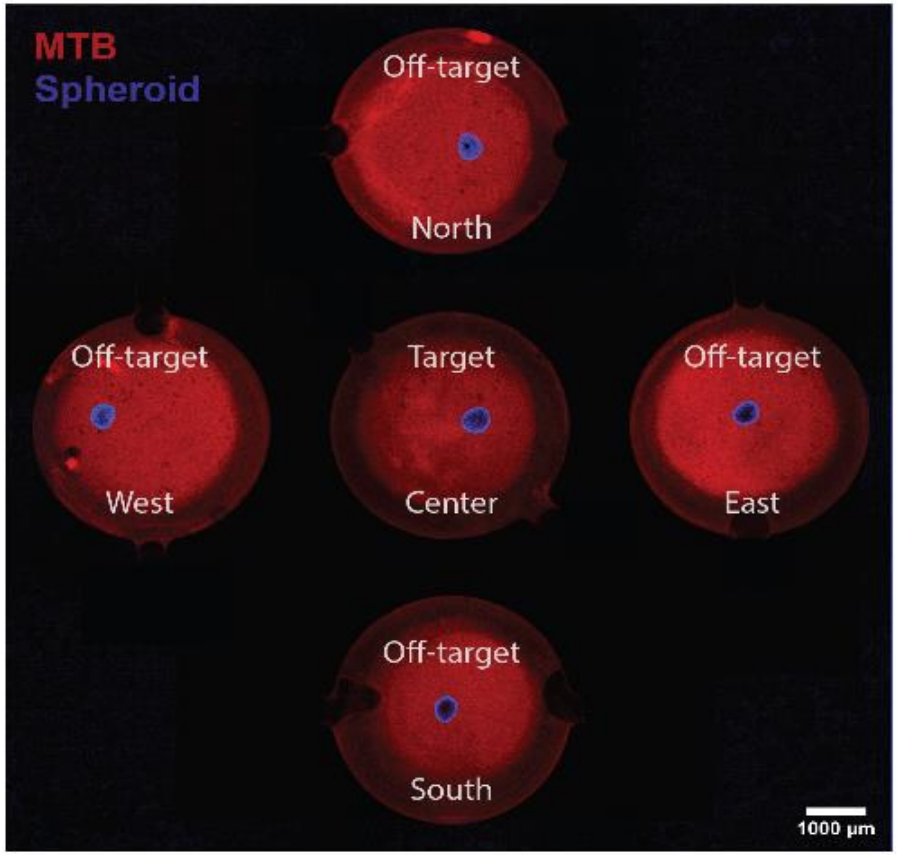
RMF + Permanent Magnet (PM)

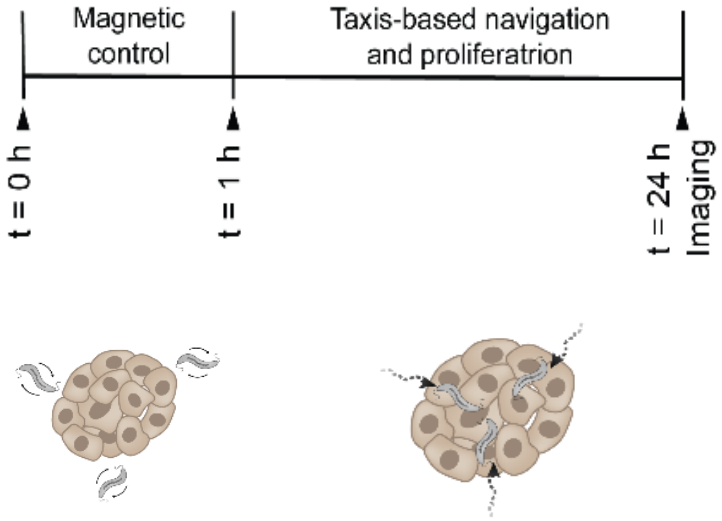


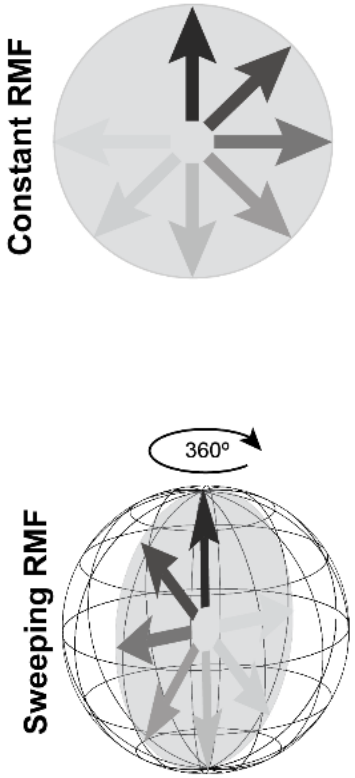
Suppresion of trorque actuation in off target regions

Mirkhani et al., *Nat Comm,* 2024

Sweeping fields to actuate open loop in 3D: no position feedback needed

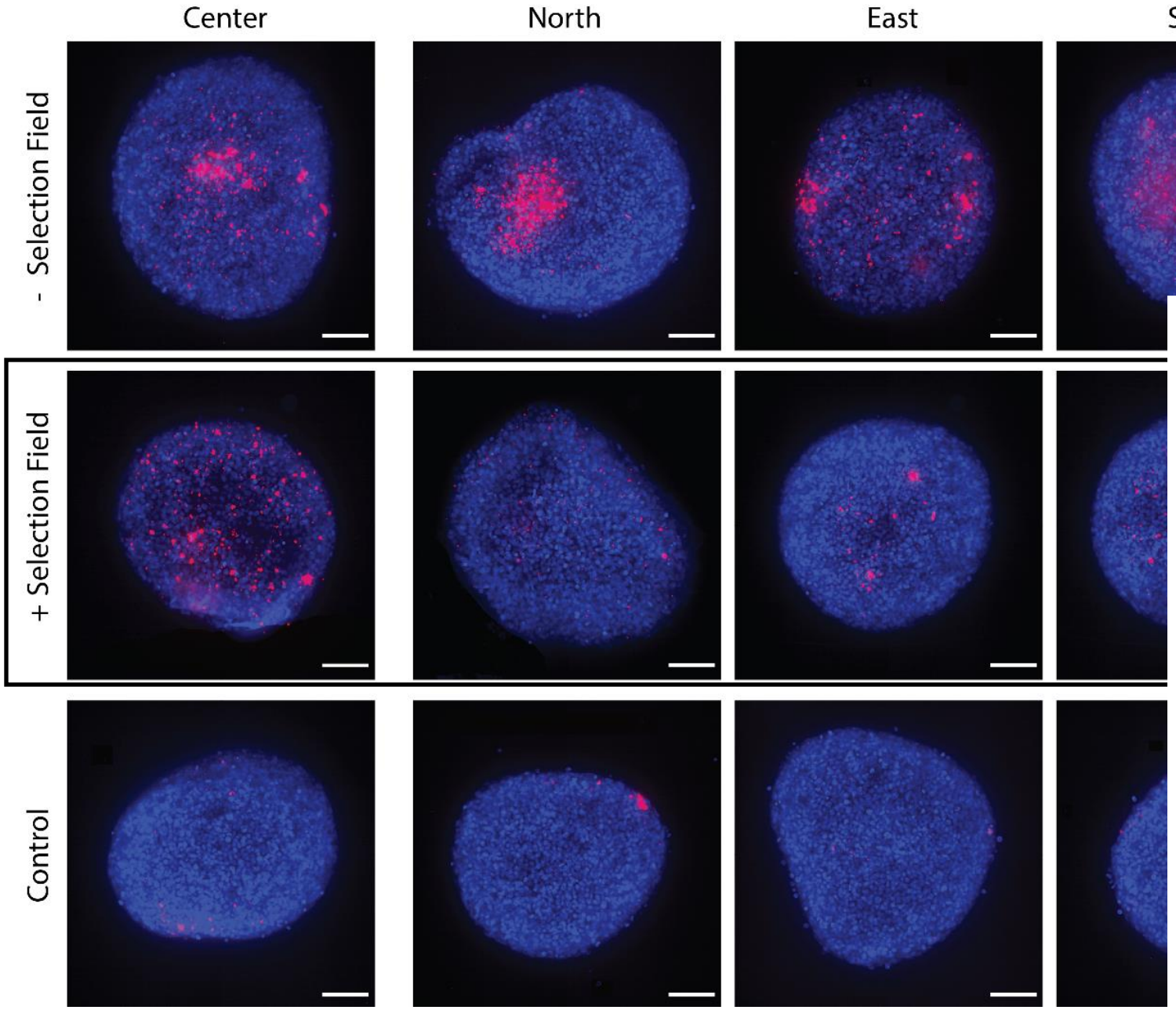


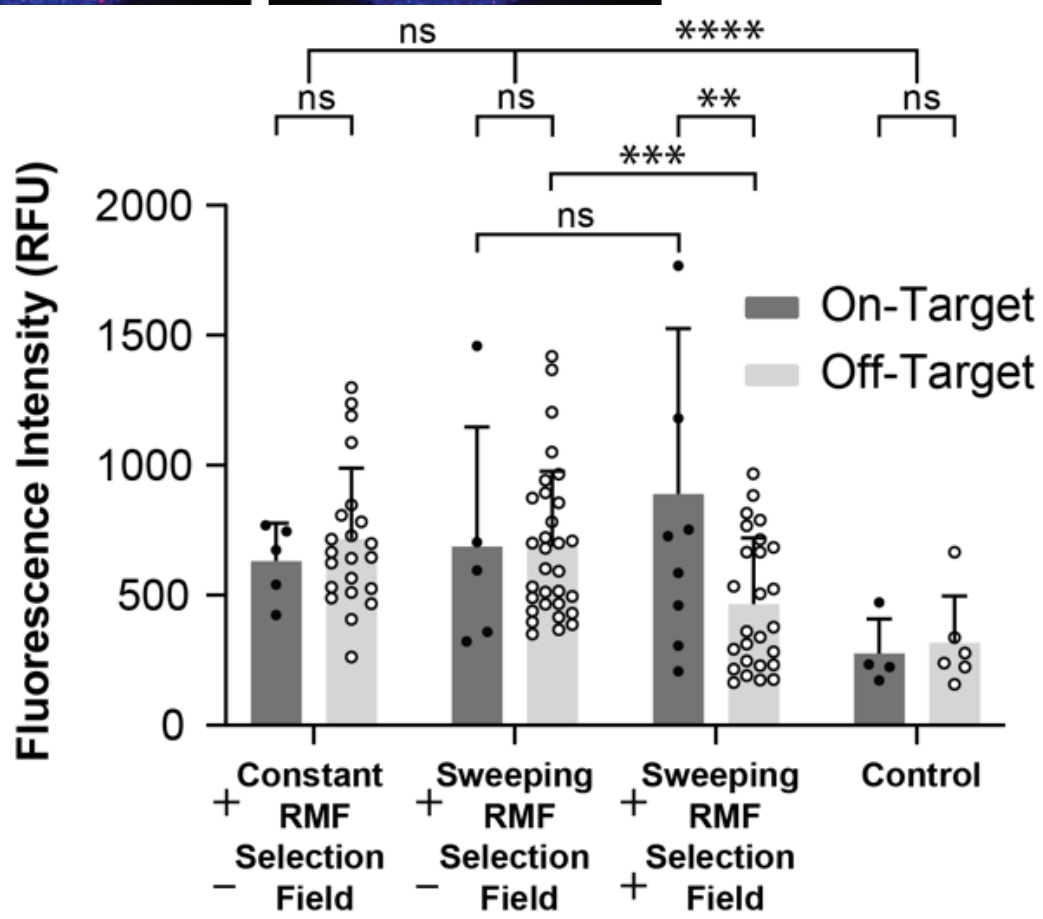




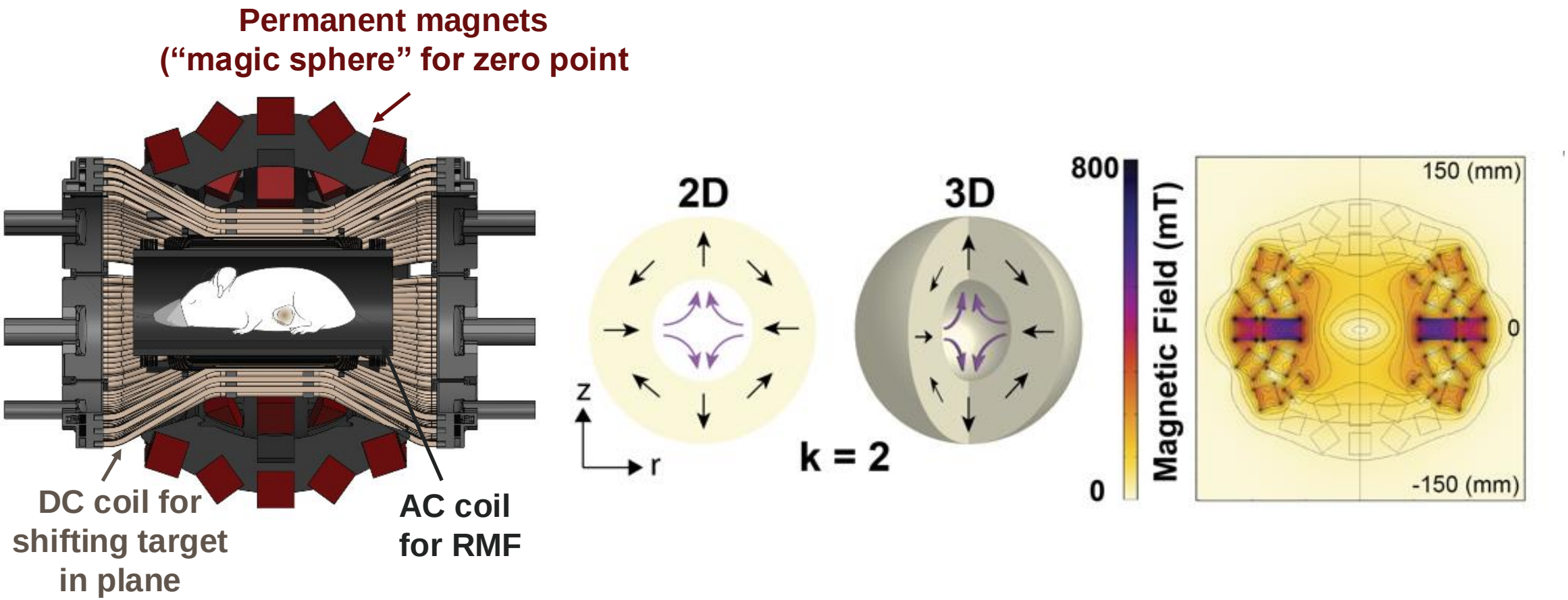
Mirkhani et al., *Nat Comm,* 2024

Torque focusing controls tumor colonization spatially





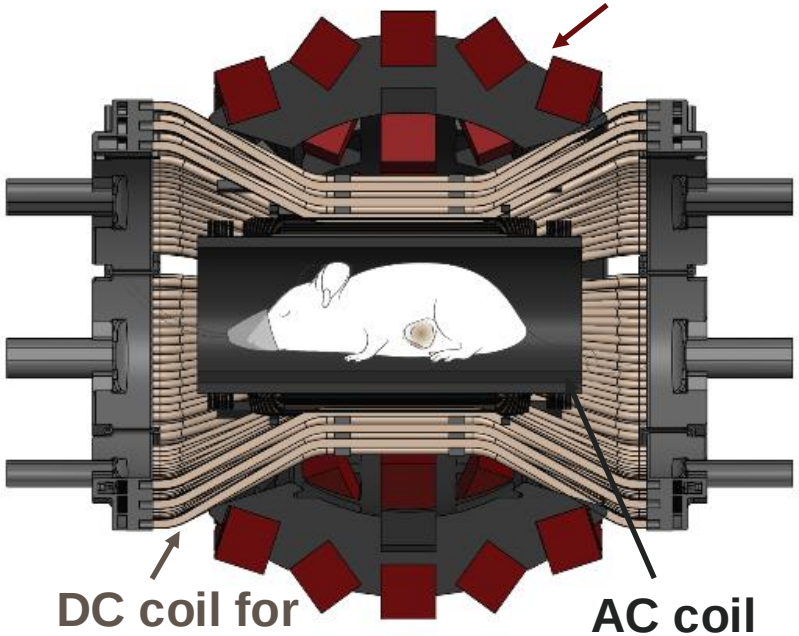
Design of an in vivo torque focusing setup



Mirkhani et al., *Nat Comm,* 2024

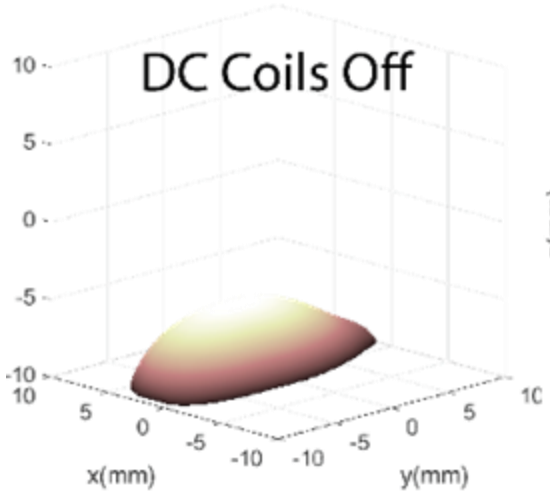
Design of an in vivo torque focusing setup

Permanent magnets
(“magic sphere” for zero point



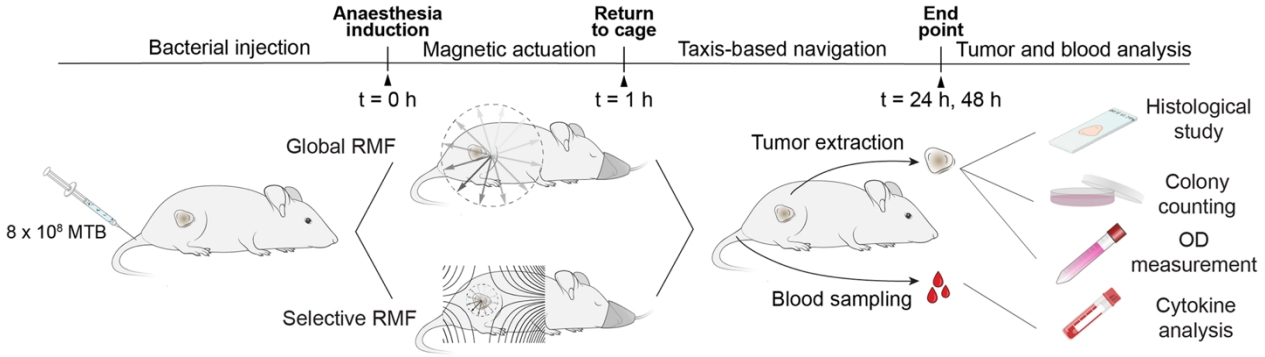
DC coil for shifting target in plane

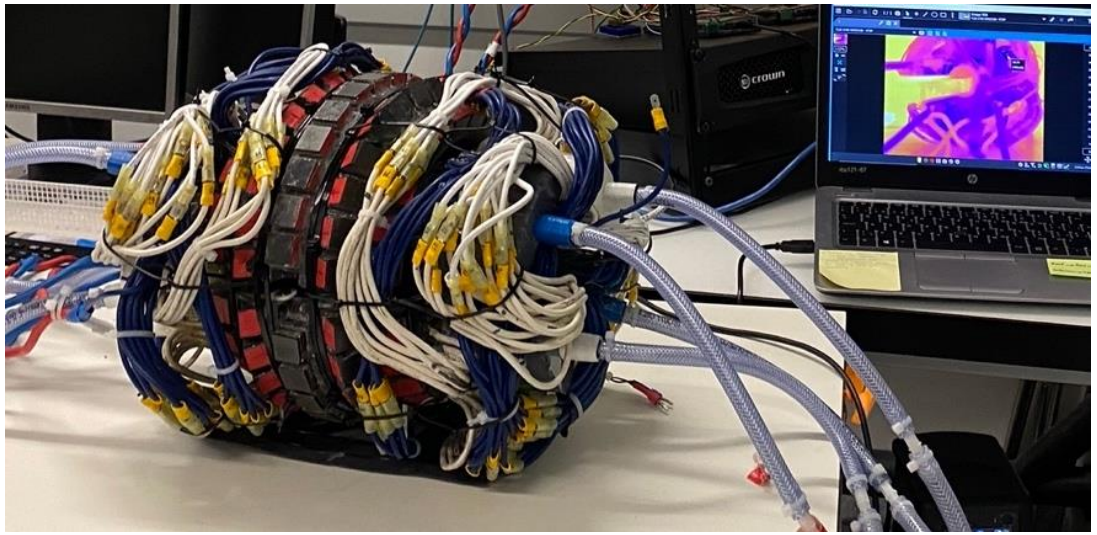
AC coil for RMF

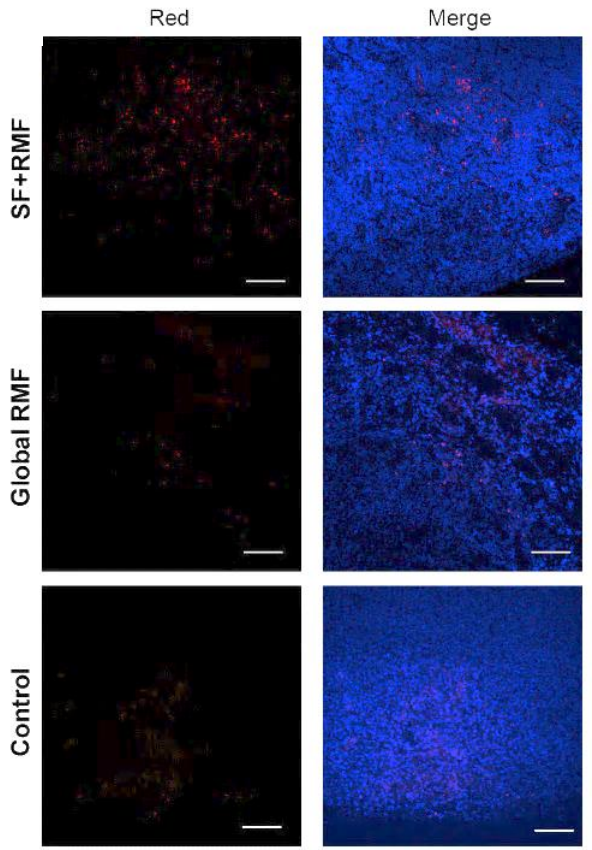


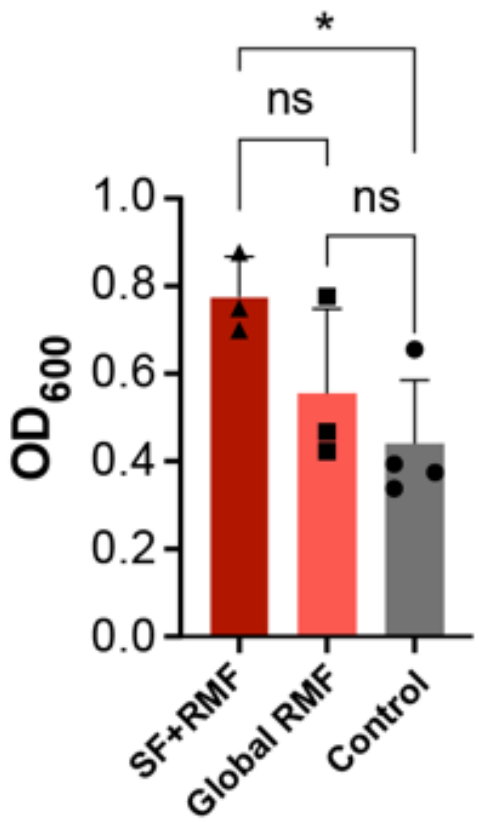
Mirkhani et al., *Nat Comm,* 2024

Proof of concept demonstrates further increase in tumor accumulation







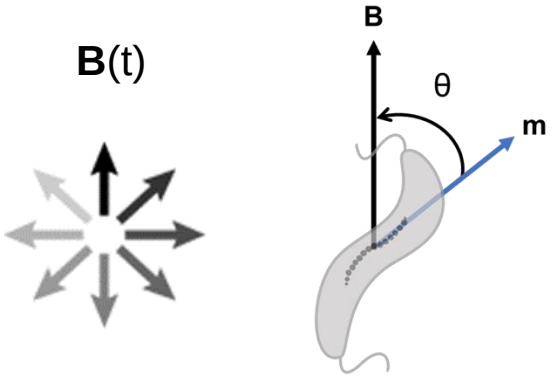


Increasing spatial selectivity down to mm resolution through suppresion of actuation in off target regions

Mirkhani et al., *Nat Comm,* 2024

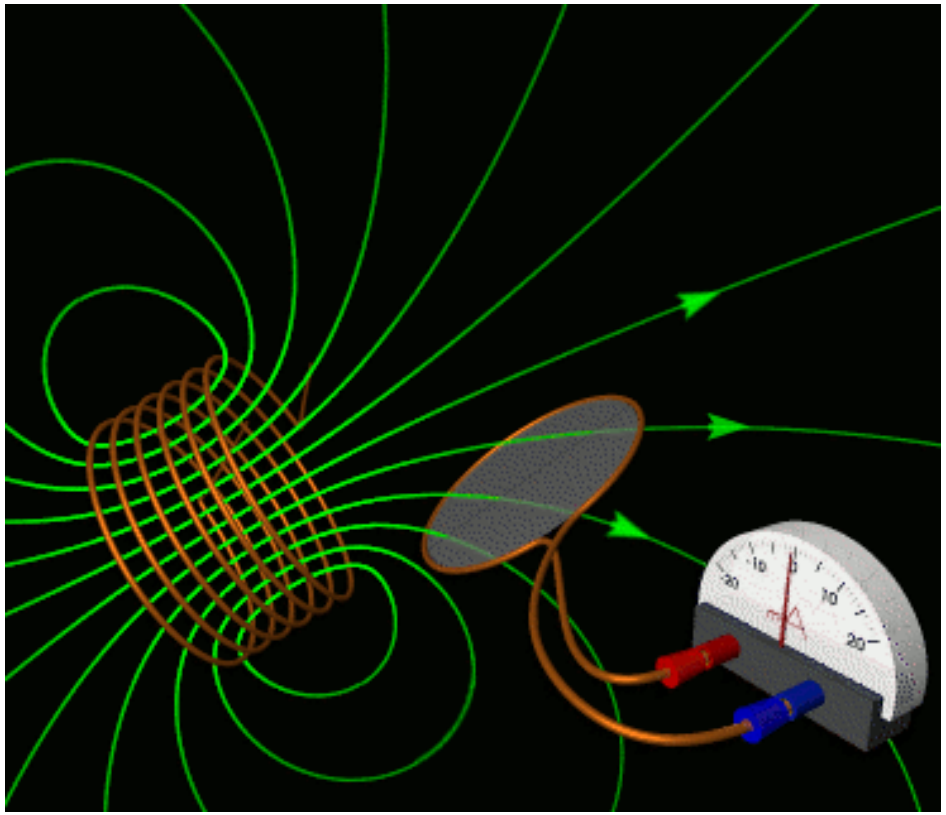
Finally: integrating feedback via inductive detection

Dr. Michael Christiansen



m - magnetic dipole moment
B - external magnetic field
θ - steady state lag angle

Making use of Faraday's law of induction



Media source: Wikimedia Commons. CC BY-SA Ponor

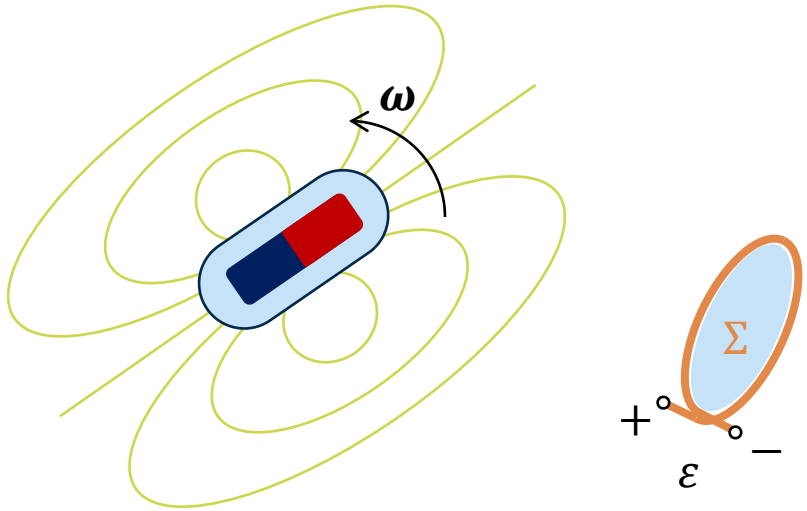
Inductive Detection Basics

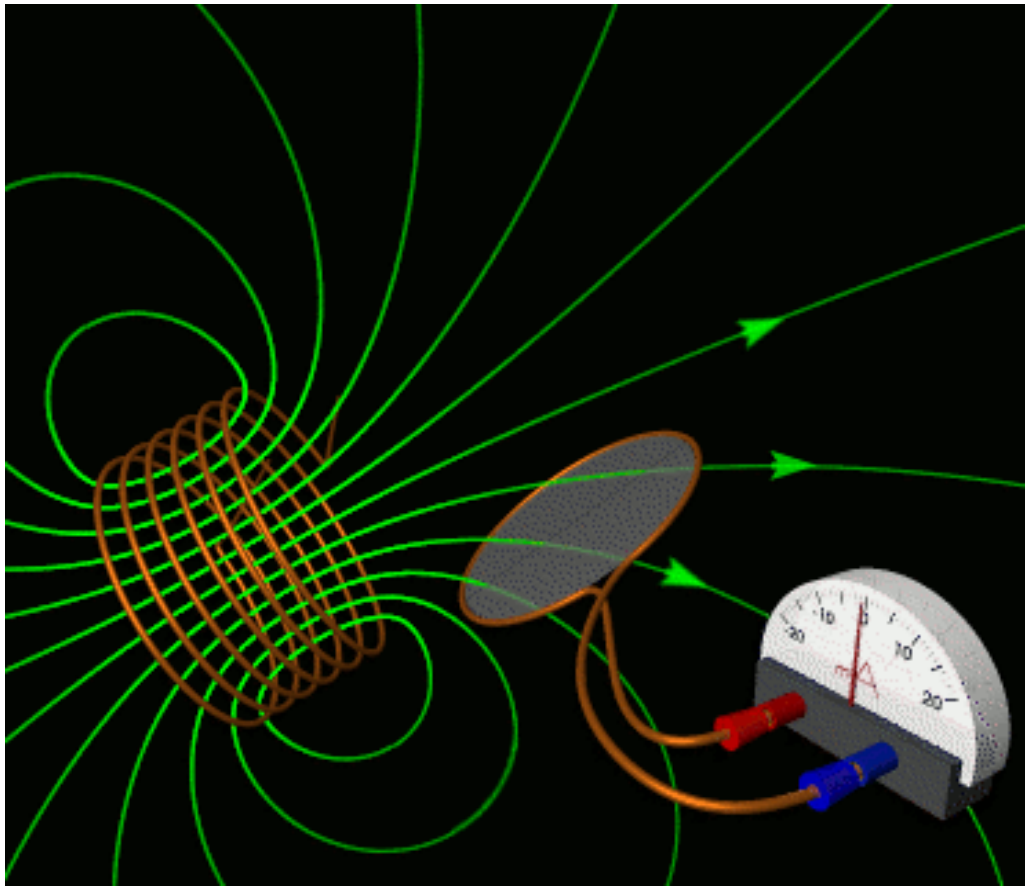
$$\varepsilon = -\frac{d\Phi_B}{dt}$$

Magnetic flux through the loop

Electromotive force
(~ Voltage)

$$\Phi_B = \int_\Sigma \boldsymbol{B} \cdot d\boldsymbol{A}$$

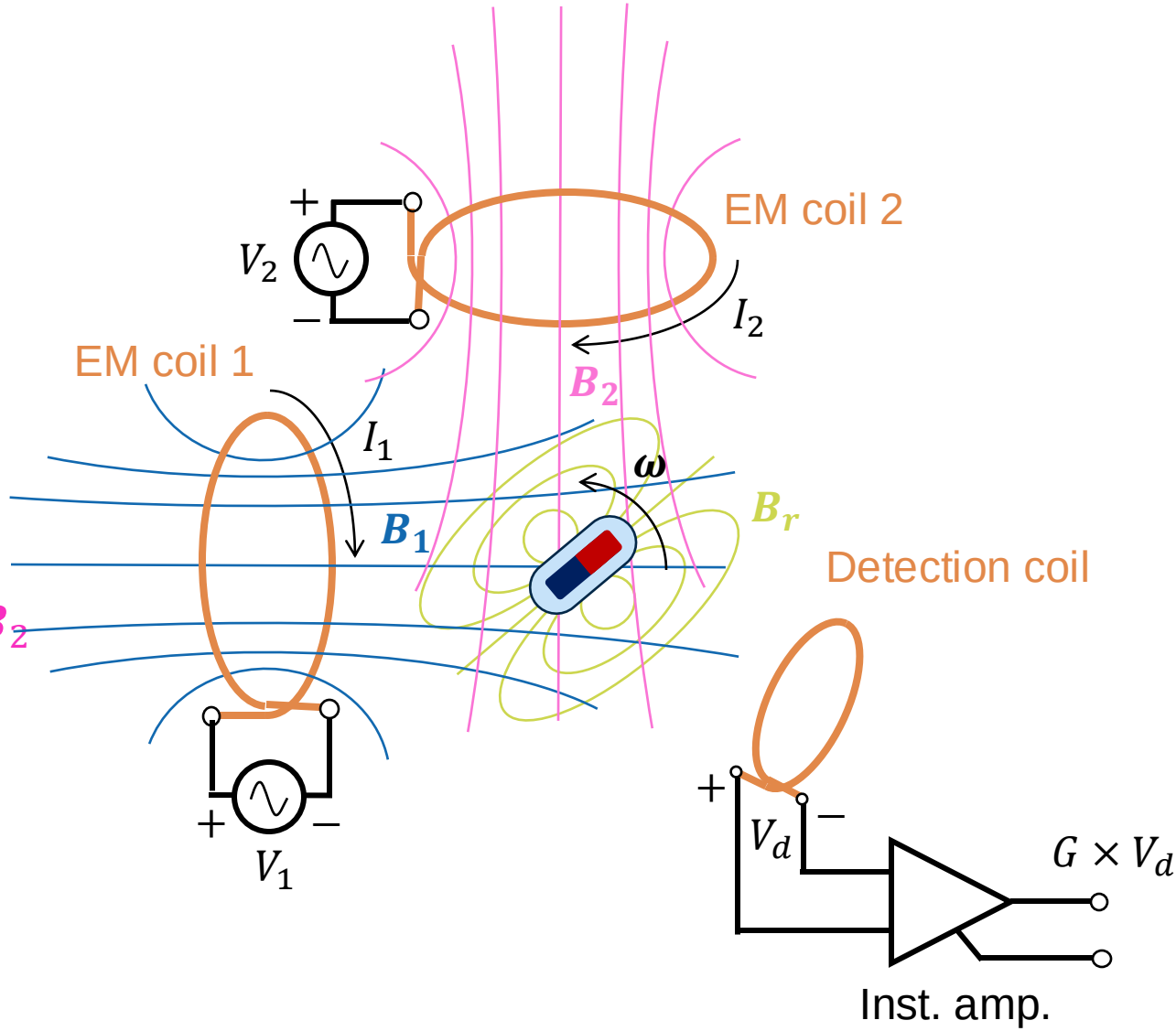




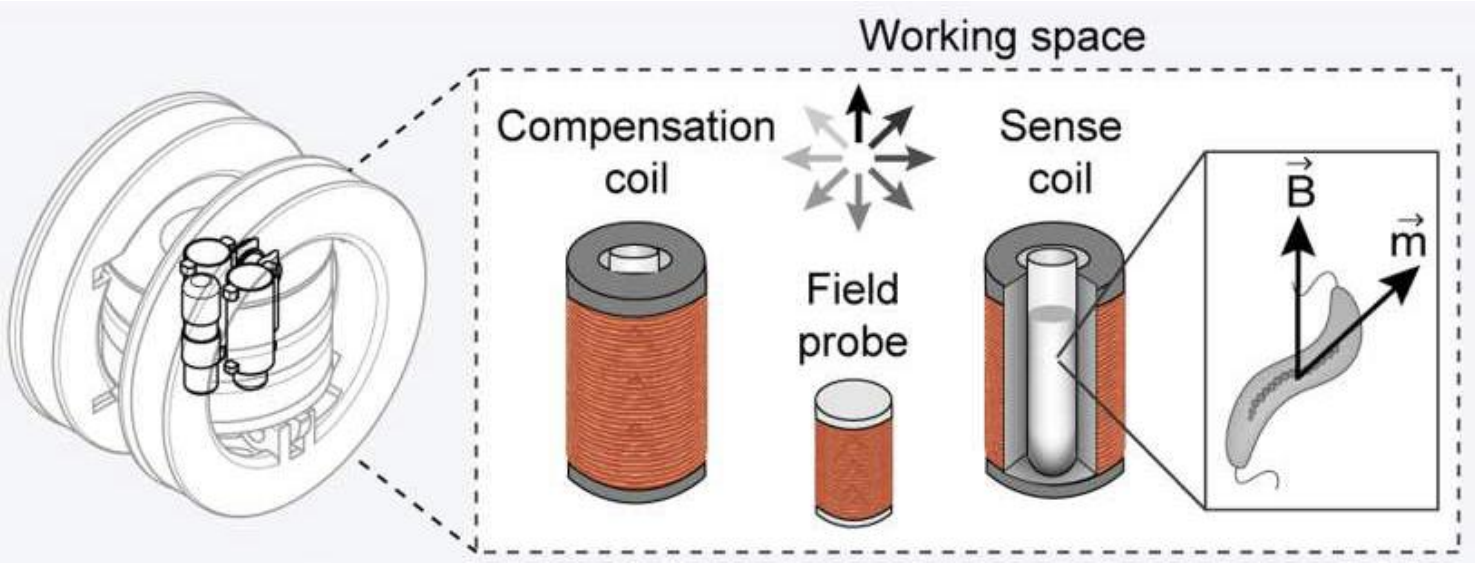
Media source: Wikimedia Commons. CC BY-SA Ponor

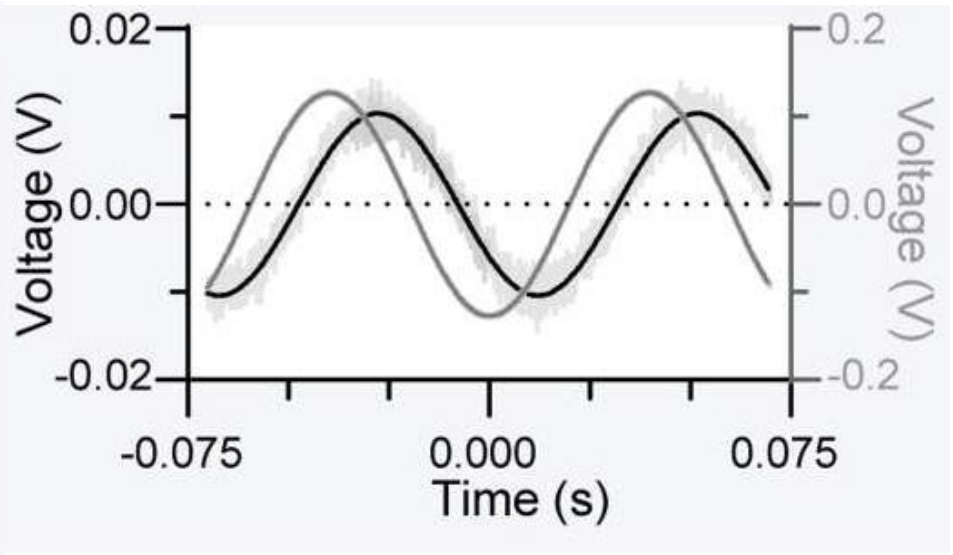
Inductive Detection Basics

- We drive the electromagnets (EM) with sinusoidal voltages
  - $V_1 = |V_1| \cos \omega t$
  - $V_2 = |V_2| \sin \omega t$
- This creates a rotating magnetic field (RMF) $\boldsymbol{B_1} + \boldsymbol{B_2}$.
- The RMF causes the magnetic robot to spin.
- The time-varying magnetic fields $\boldsymbol{B_r} + \boldsymbol{B_1} + \boldsymbol{B_2}$ create an emf (voltage) in the detection coil.



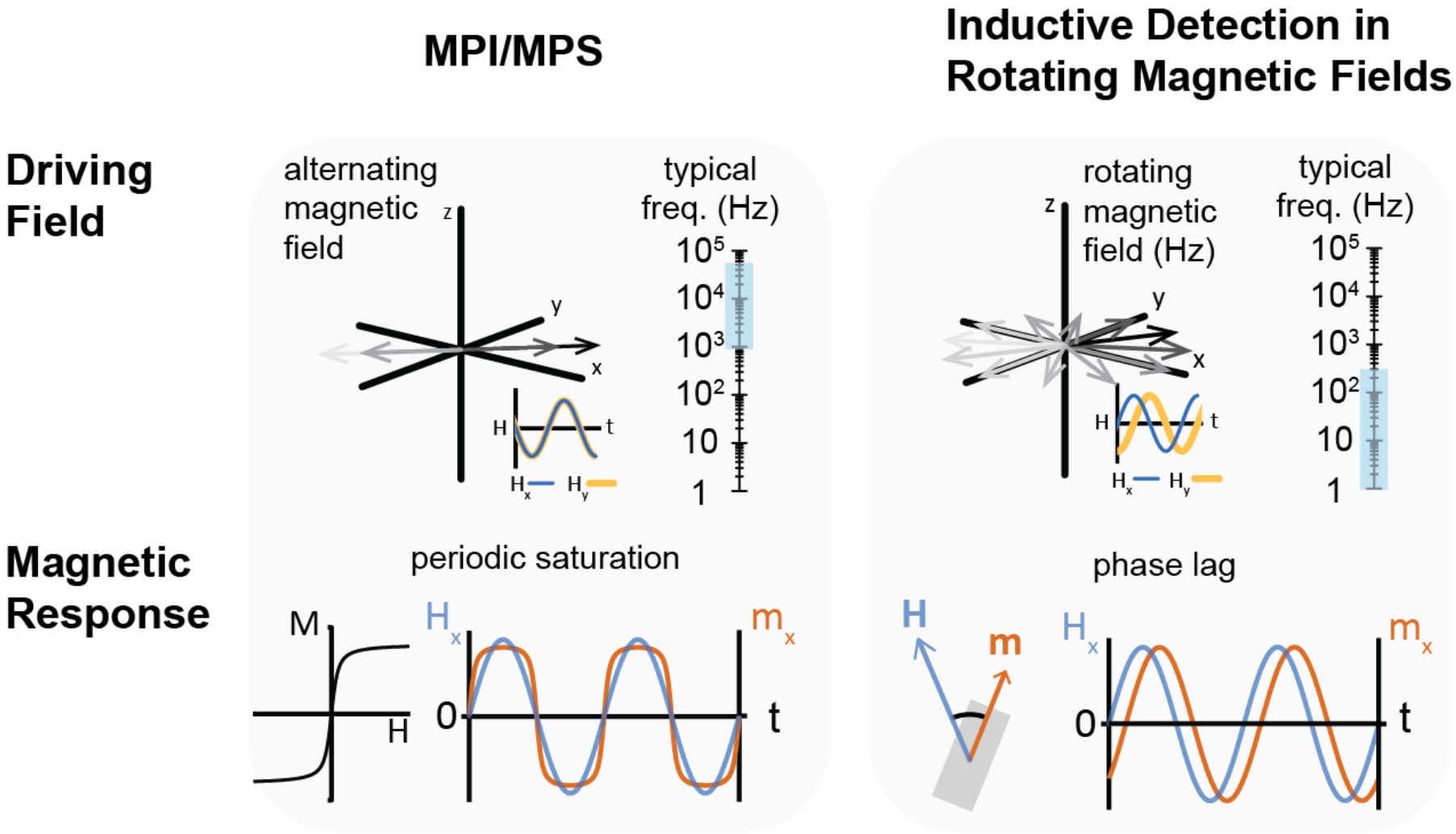
Finally: integrating feedback via inductive detection





Gwisai et al, Sci Rob, 2022

Key Differences between Inductive Detection in MPI and Rotating Fields



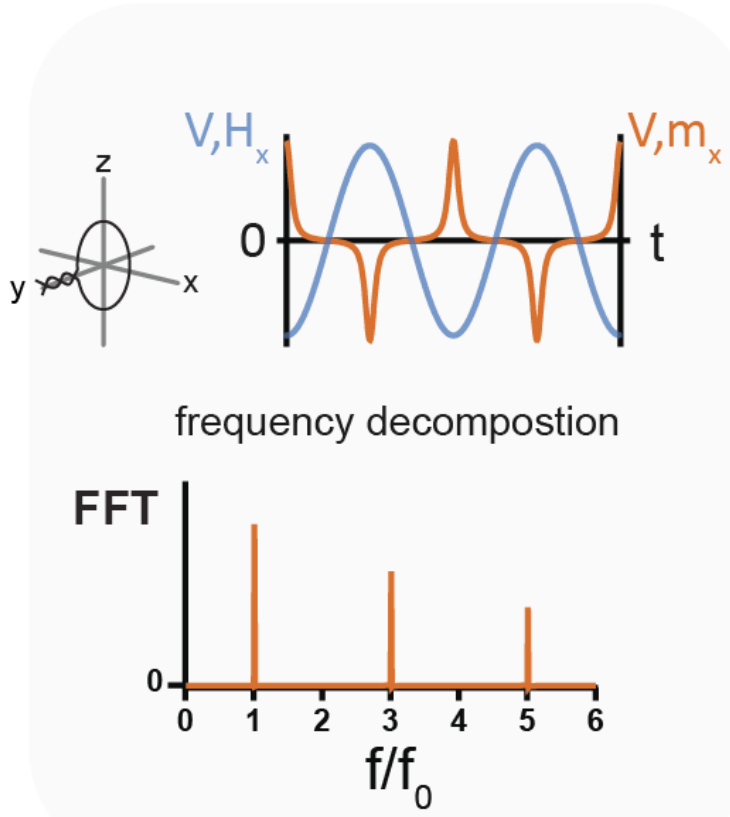
Christiansen et al., PNAS Nexxus, 2023

Key Differences between Inductive Detection in MPI and Rotating Fields

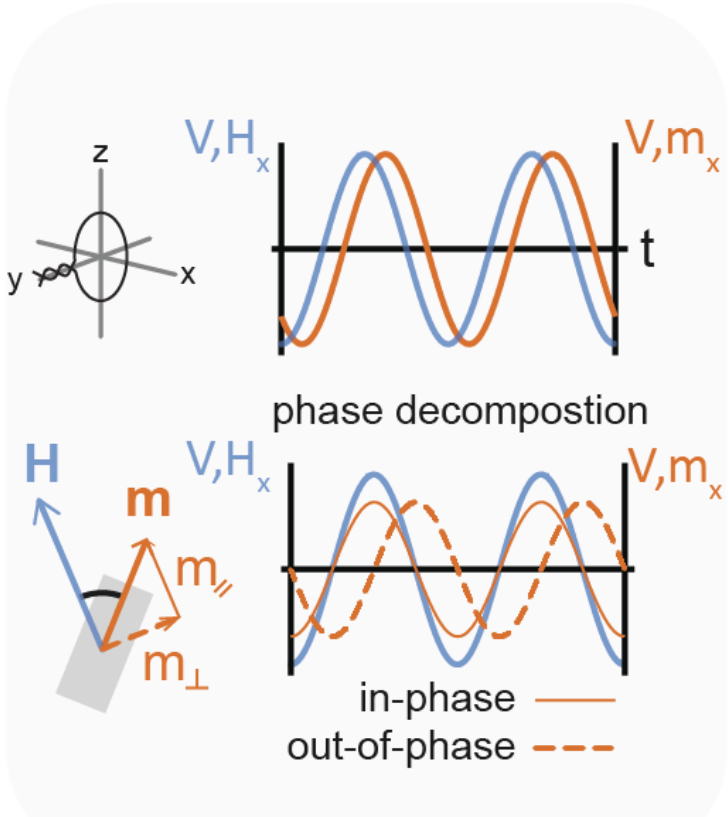
Inductive Signal

Signal Isolation

MPI/MPS

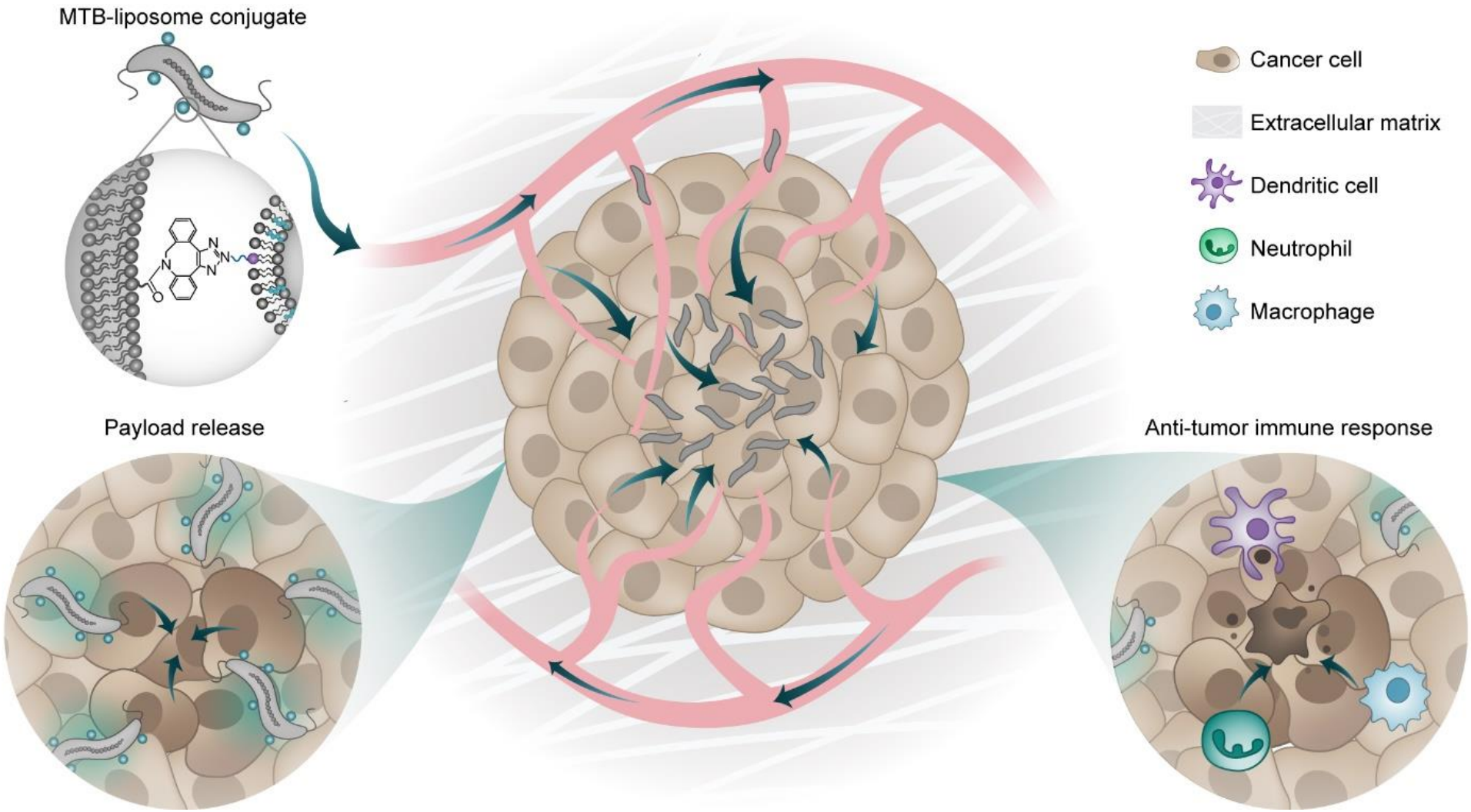


Inductive Detection in Rotating Magnetic Fields



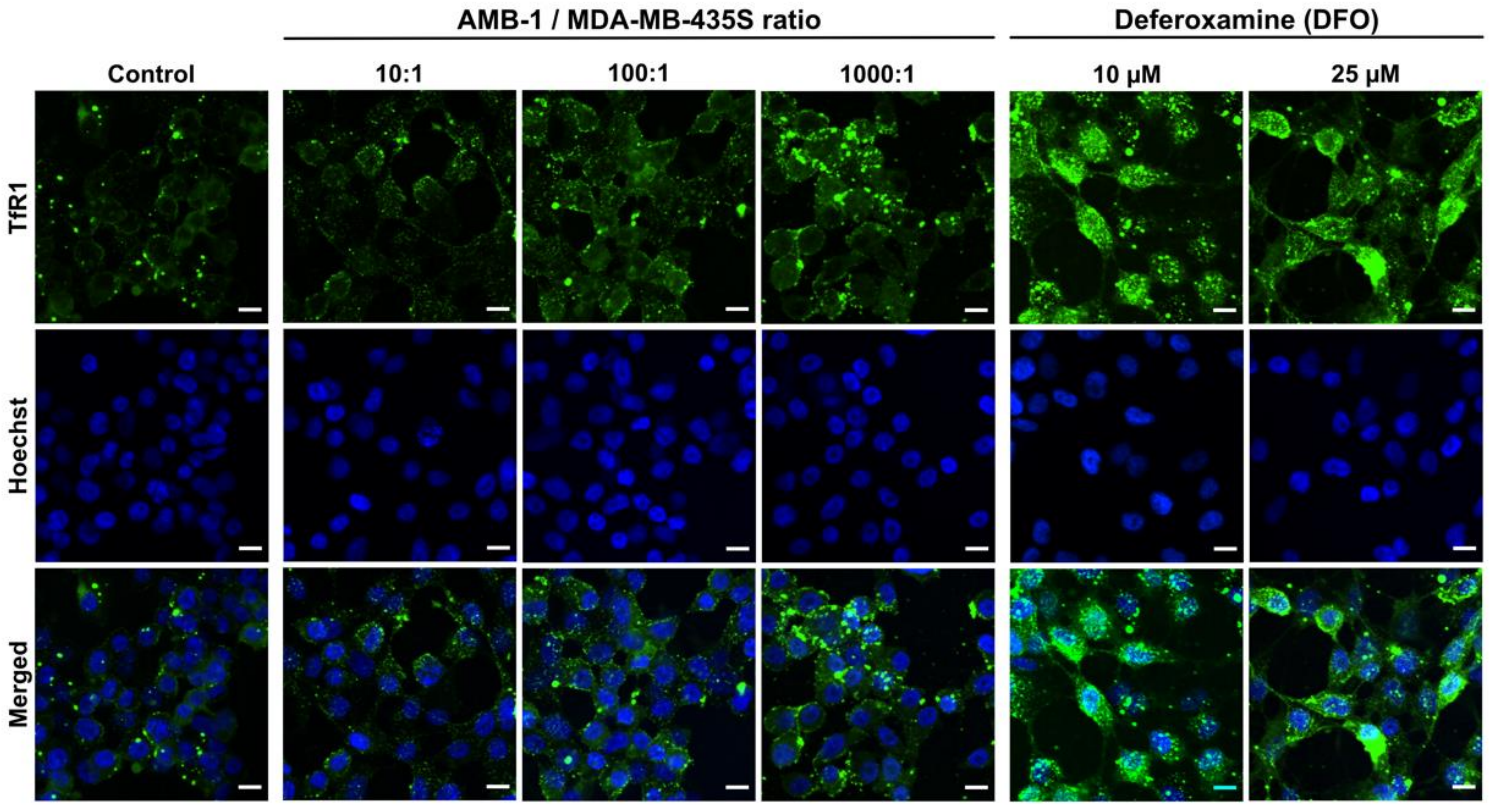
Christiansen et al., PNAS Nexxus, 2023

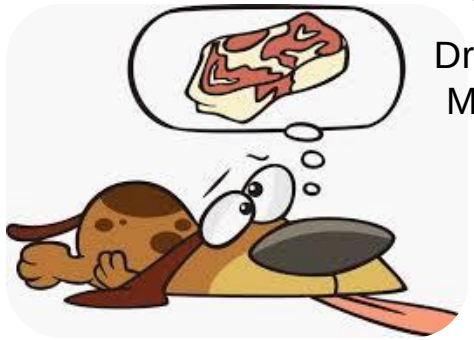
Investigating and engineering therapeutic pathways

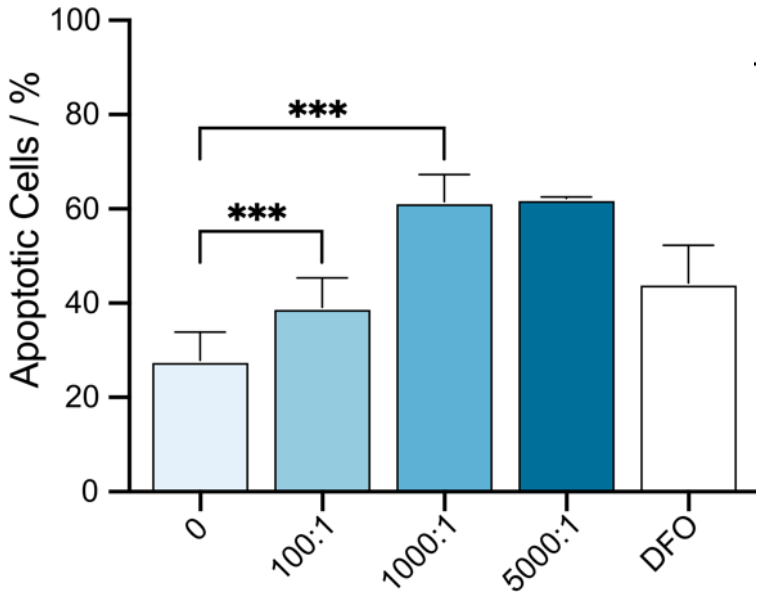


Innate capability as living iron chelator

Dr. Stefano Menghini



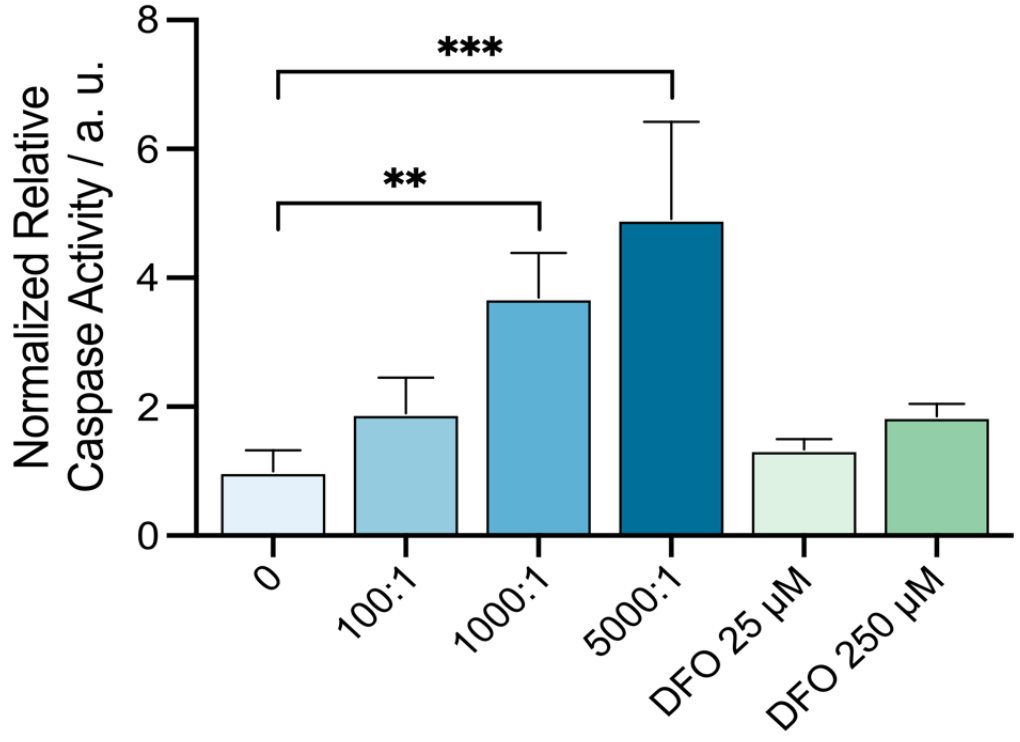


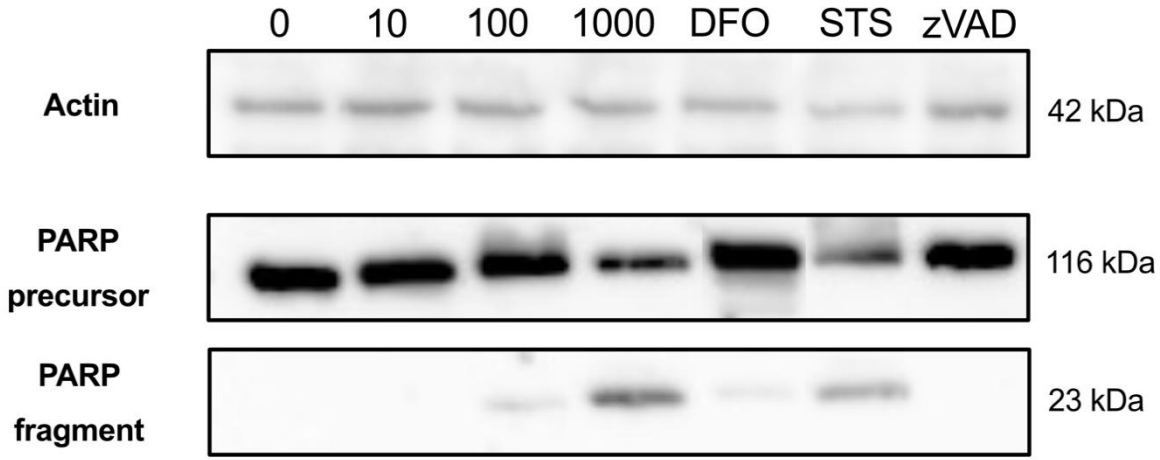


AMB-1 upregulate TfR1 expression and induce apopotosis

Menghini et al, Int J Mol Sc, 2021, and Menghini et al, Cancer Metabolism, 2023

And they trigger caspase activity and apopotic markers

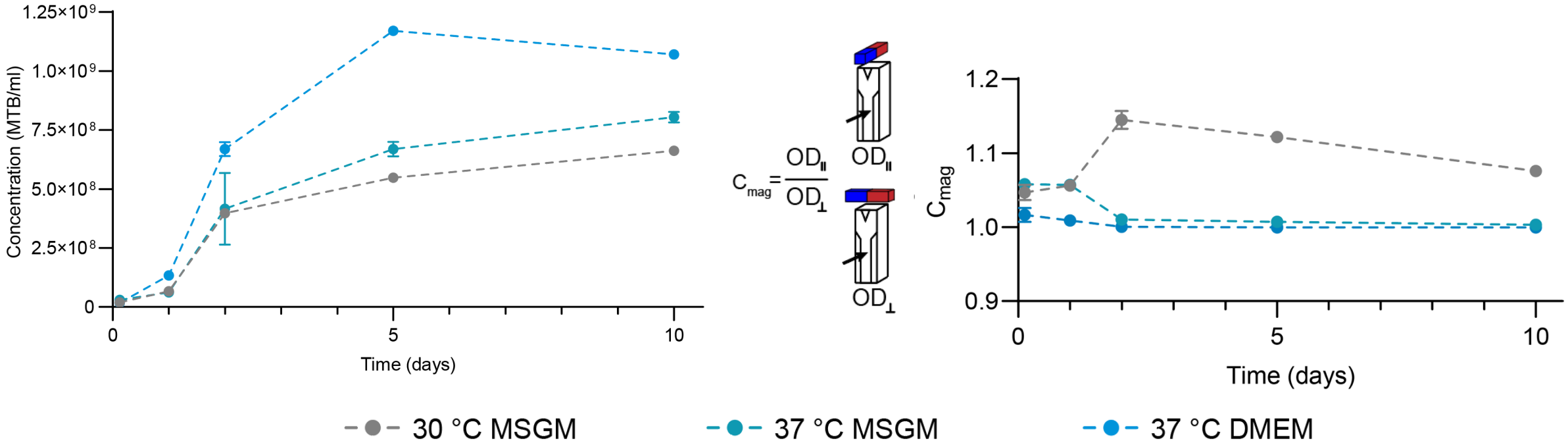




Menghini et al, Cancer Metabolism, 2023

AMB-1 proliferate under physiological conditions

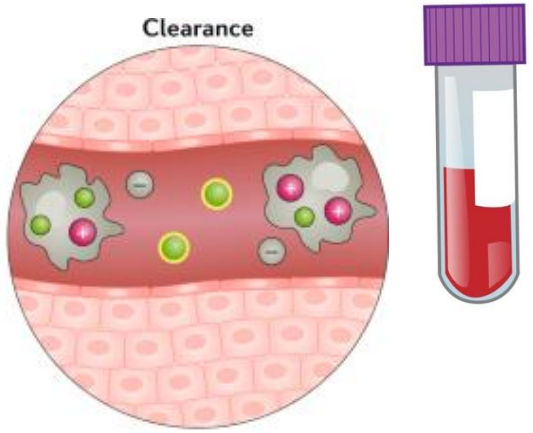
Dr. Tino Gwisai



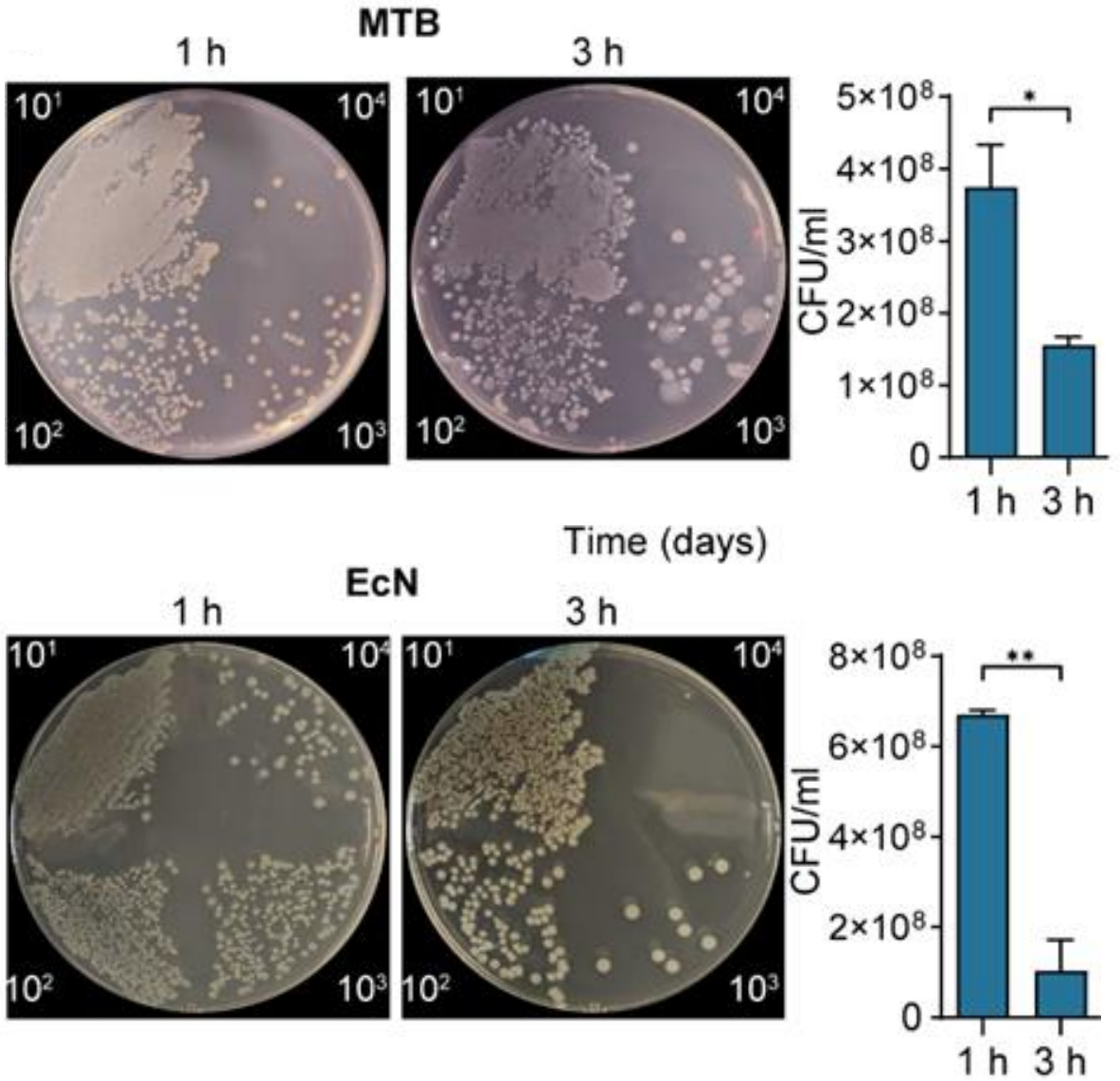
MTB proliferate at 37˚C, which has implications for tumour colonisation

Gwisai, et al *Adv Therap,* 2024

And remain viable with comparatively low clearance in human whole blood



Magnetic actuation should be applied within 1 hour when viable, magnetic MTB may still be in circulation



SCIENCE IMMUNOLOGY | RESEARCH ARTICLE

INNATE IMMUNITY

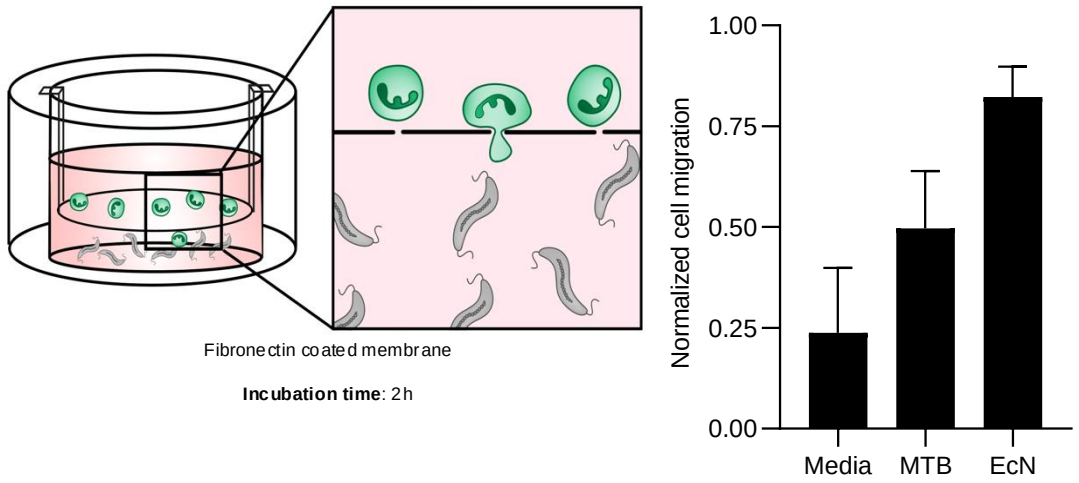
Deep-sea microbes as tools to refine the rules of innate immune pattern recognition

Anna E. Gauthier[1,2,3], Courtney E. Chandler[4], Valentina Poli[5], Francesca M. Gardner[4], Aranteiti Tekiau[6], Richard Smith[4], Kevin S. Bonham[7], Erik E. Cordes[8], Timothy M. Shank[9], Ivan Zanoni[5], David R. Goodlett[4,10], Steven J. Biller[7], Robert K. Ernst[4], Randi D. Rotjan[3]*, Jonathan C. Kagan[1]*

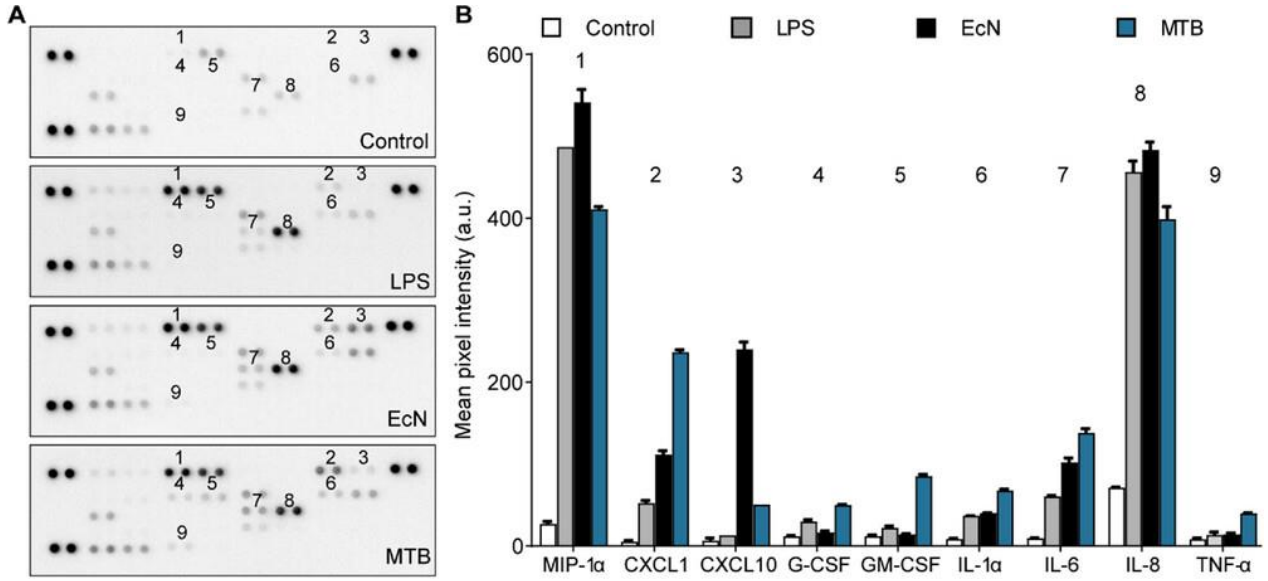
"[…]**LPS receptors were unable to detect 80% of deep-sea bacteria examined** […]"

Gwisai et al, Adv Therap, 2024

AMB-1 increases expression of proinflammatory cytokines

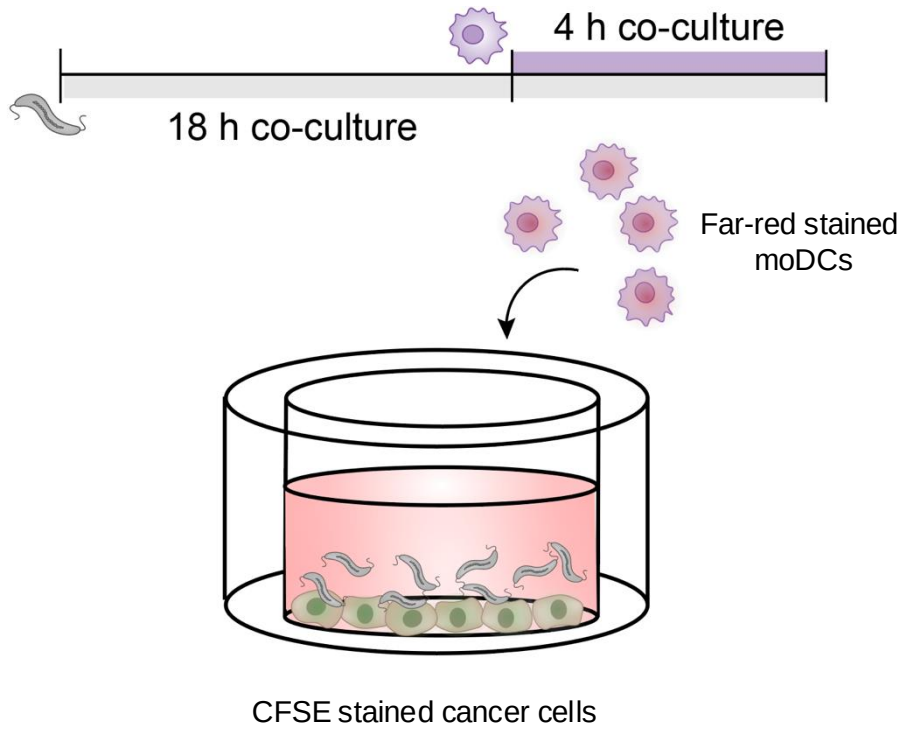


Macrophage cytokine production

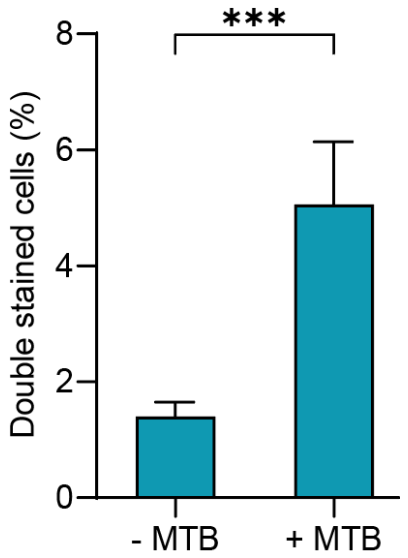


Gwisai, et al *Adv Therap,* 2024

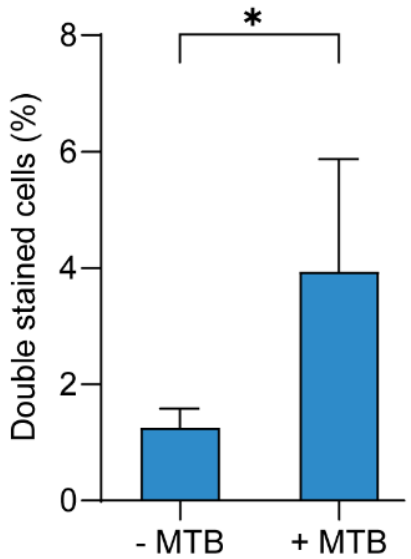
AMB-1 induce moDC maturation and increase the uptake of cancer cell material



Far red & CFSE positive cells

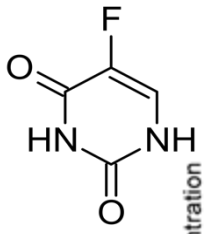


Far red & CD83 positive cells

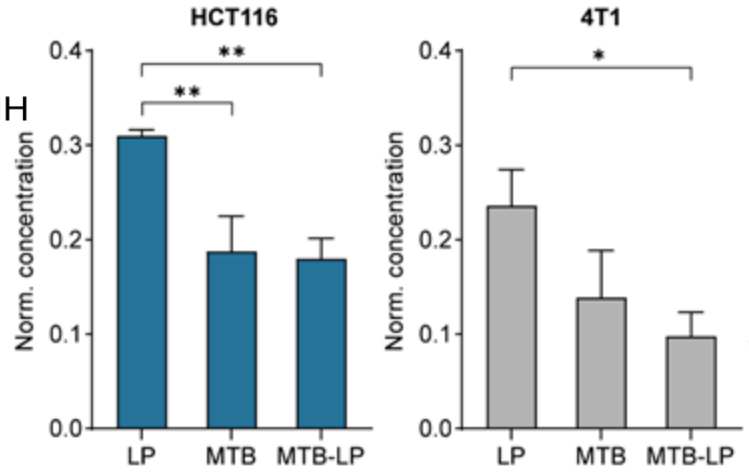


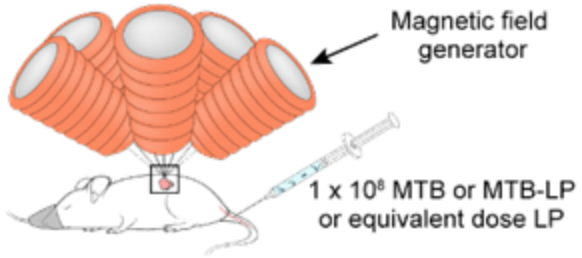
Gwisai, et al *Adv Therap,* 2024

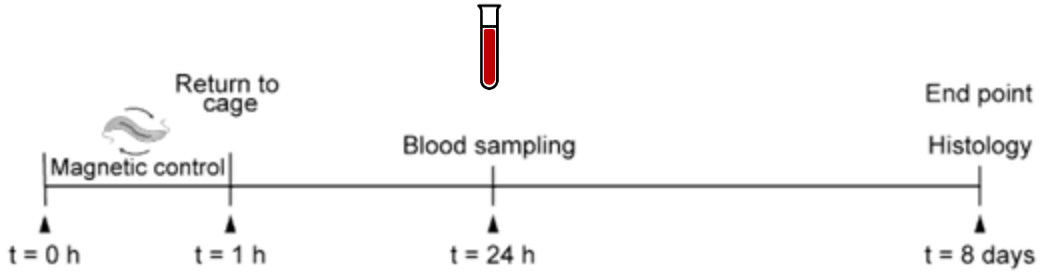
Bacterial microrobots: AMB-1 with cargo trigger desired immune response

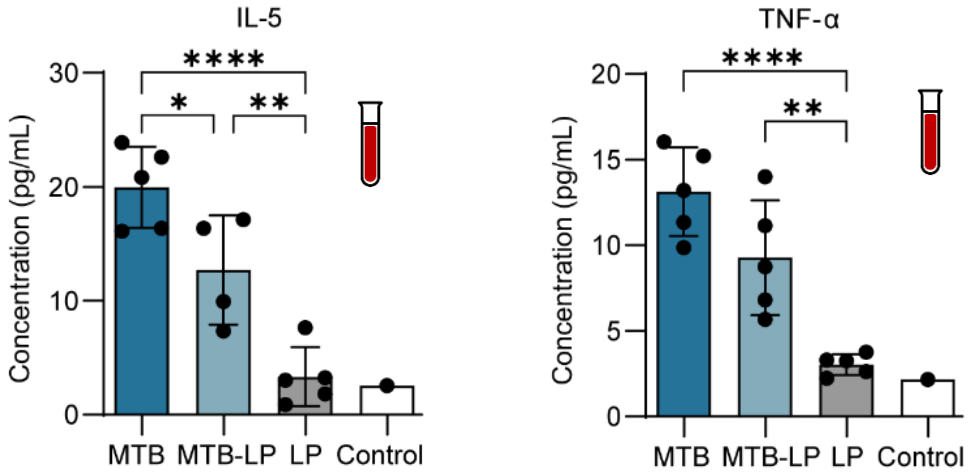


5-FU

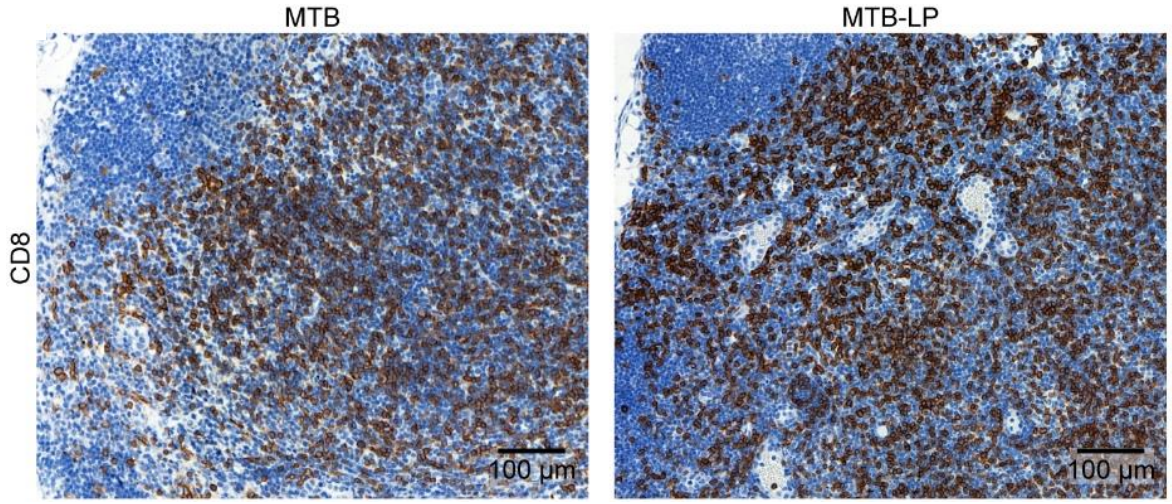








Increased serum level cytokines with positive consequences regarding differentiation and recruitement of T helper cells



CD8+ cells and CD4+ cells inflitration into tumors

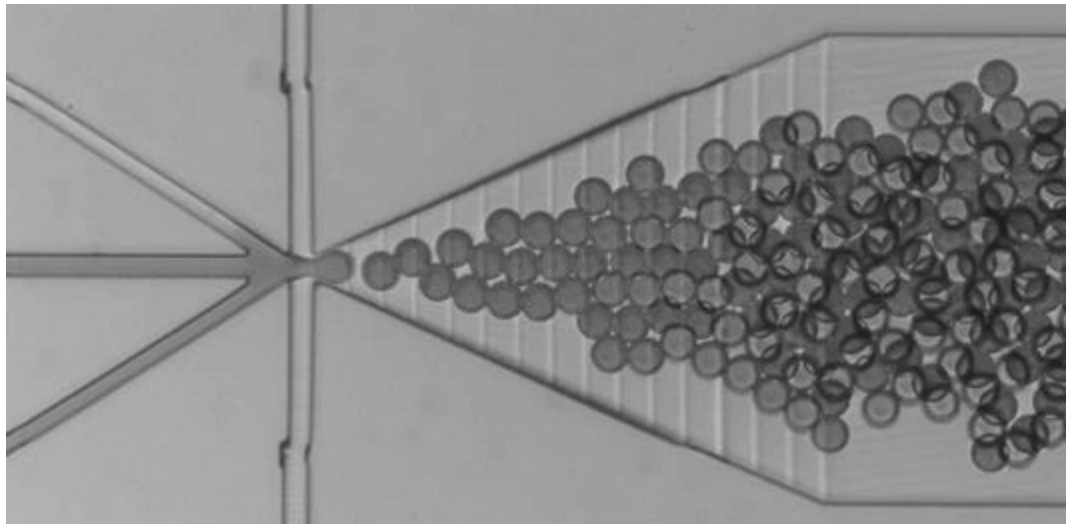
Gwisai, et al *Adv Therap,* 2024

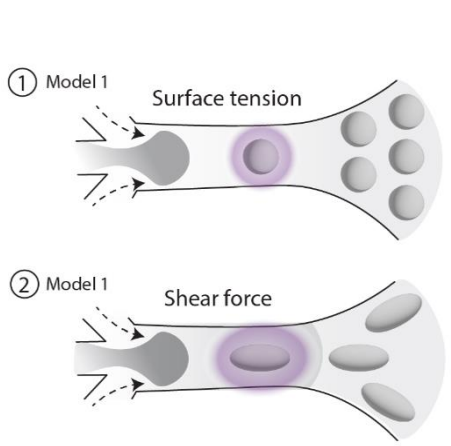
Can we make synthetic microrobots similar to the desired properties of bacteria?

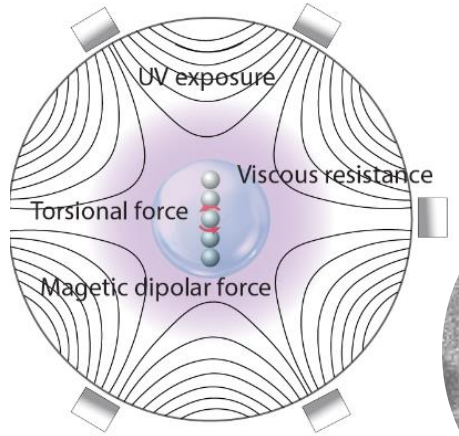
Yimo Yan

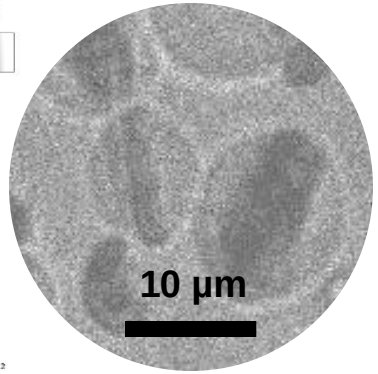
Droplet-based microfluidics for synthesis of microrobots inspired by magnetotactic bacteria

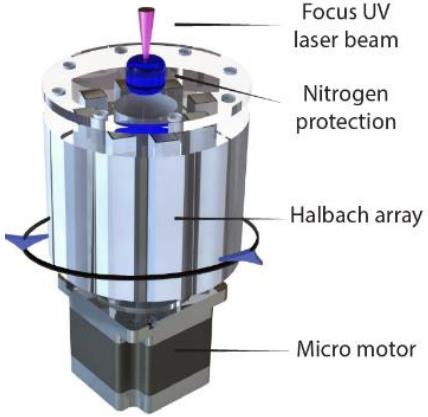
Hydrogel: Poly(ethylene glycol) diacrylate (PEGDA)
Photo imitator: Lap
Magnetic particle: Magnetite MNPs, 10nm

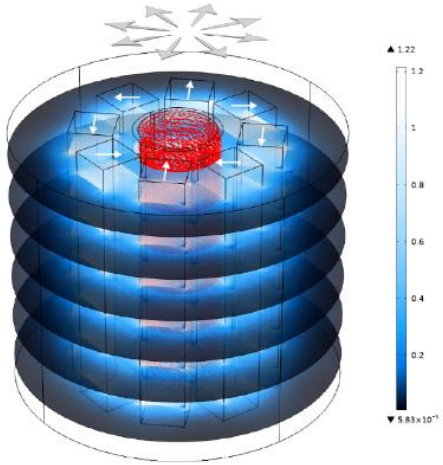








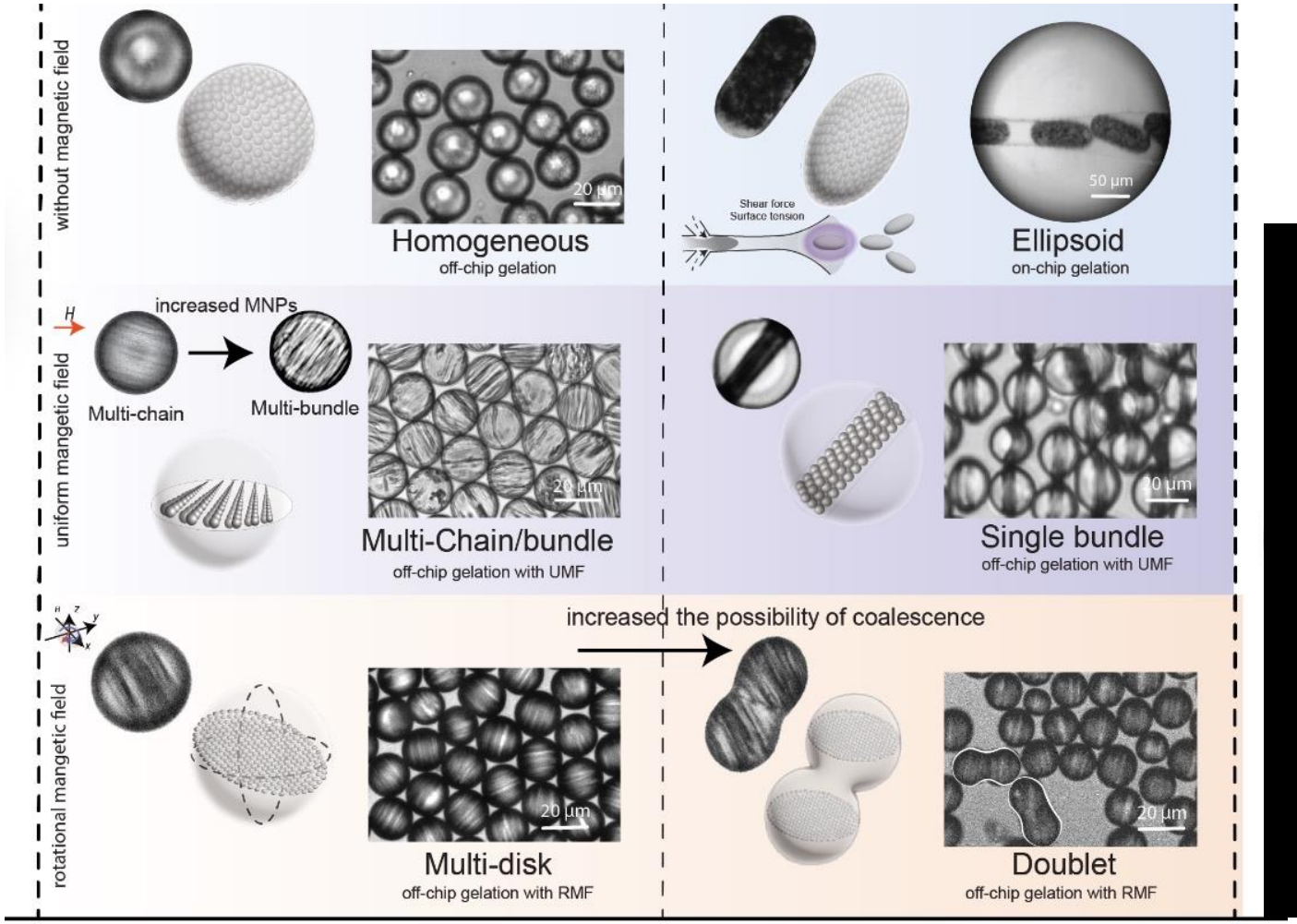




Magnetic hydrogel droplet generation → **Photopolymerization under magnetic field**

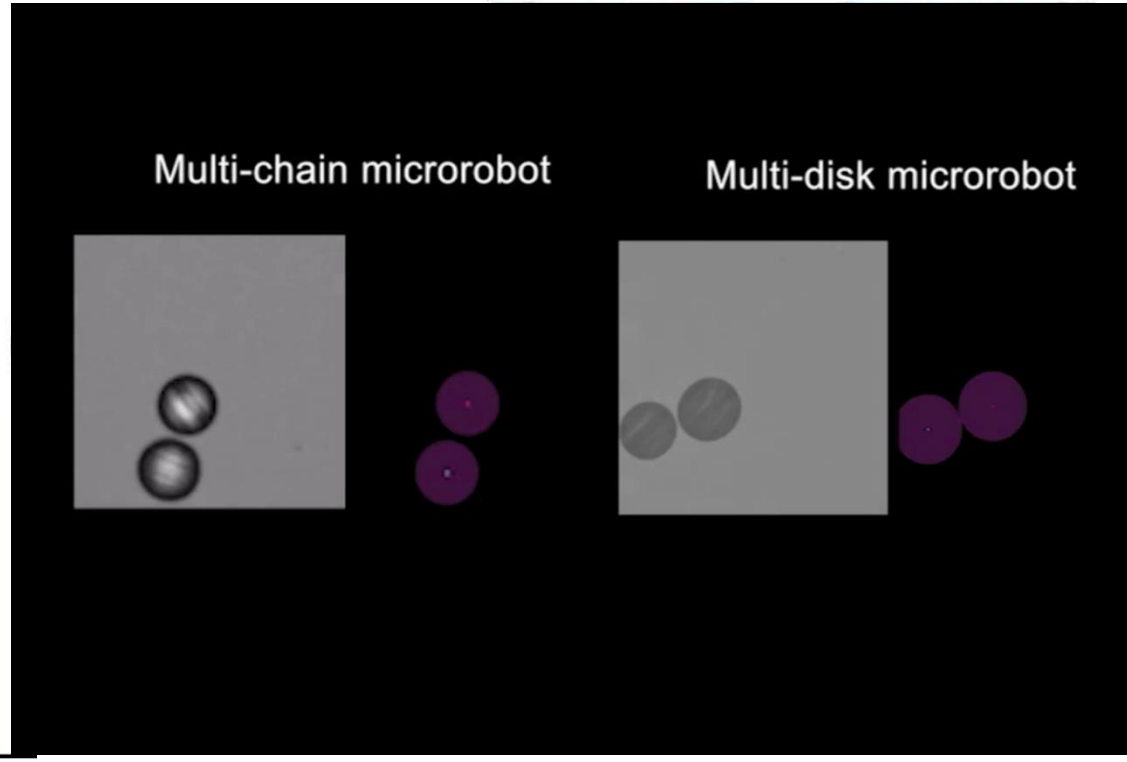
in collaboration with Prof. Andrew deMello

Encoding magnetic responsiveness



Distinct supradomains

Distinct interactions



Yan, Sing,…, de Mello*, Schuerle*., *Comm Eng,* 2024

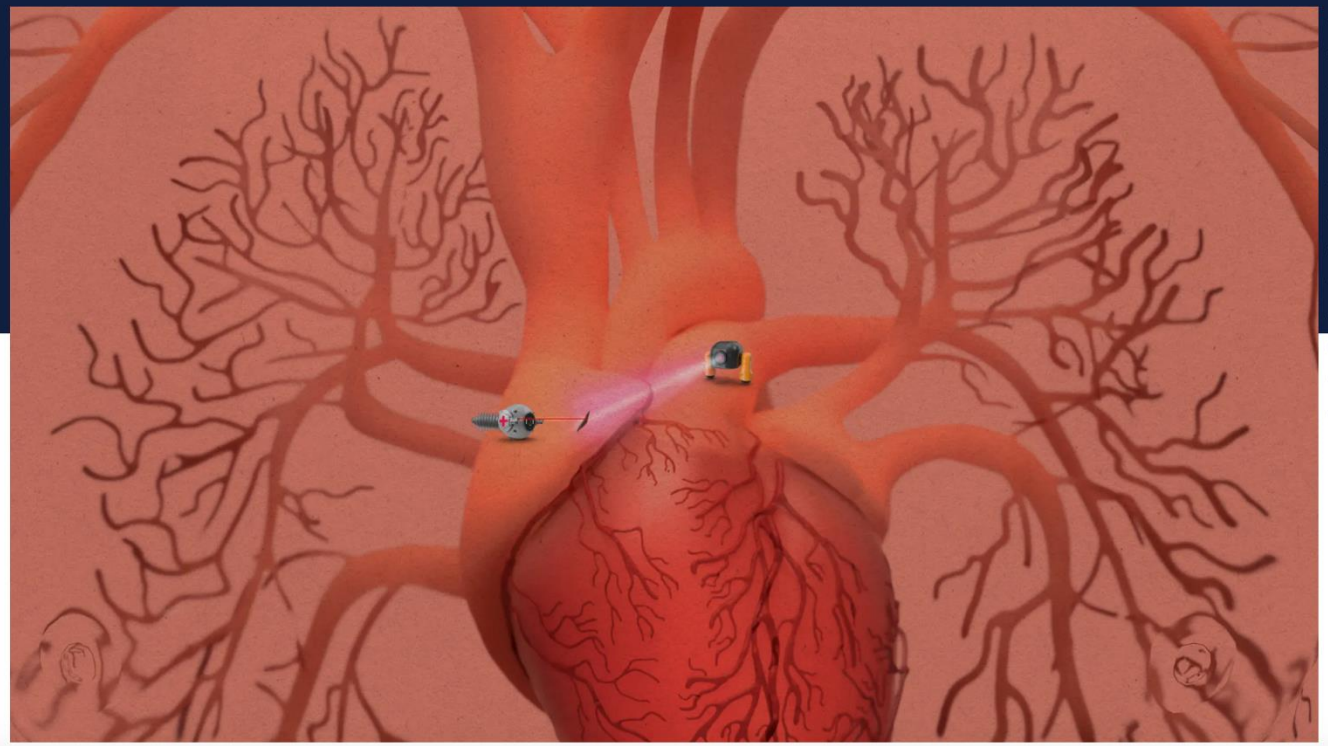
PEGDA v/v

Medical microrobots that can travel inside your body are (still) on their way

Microrobots released into the body could bust up clots, deliver cancer drugs, and even guide listless sperm to their target.

By Cassandra Willyard

December 8, 2023



Microrobots are helpful tools

- To study mechanical cues at the cellular scale
- To locally report protease for diagnostics
- To improve efficacy of drug delivery

Vast biomedical application space to explore

THANKS to my team, collaborators and funding agencies

MEDICAL MICROSYSTEMS

Team

- Dr. Claire Schirmer
- Dr. Michael Christiansen
- Dr. Cameron Forbrigger
- Dr. Johannes Bücheler
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- Pascal Poc, PhD student
- Ines Oberhuber, PhD student
- Xiang Wang, PhD student
- Fan Li, PhD student
- Elena Totter, PhD student
- Tim Grossrieder, PhD student
- Emilie Einsiedel, PhD student
- All MML semester students

Alumni

- Dr. Nima Mirkhani (Postdoc, Oxford University)
- Dr. Tinotenda Gwisai (Postdoc at Novartis)
- Dr. Stefano Menghini (CEO of biomed startup)

Collaborators

- Prof. Nicola Aceto, ETHZ
- Prof. Andrew Di Mello, ETHZ
- Prof. Volkmar Falk, Charité Berlin
- Dr. Nikola Cesavoric, ETHZ
- Prof. Tal Danino, Columbia University

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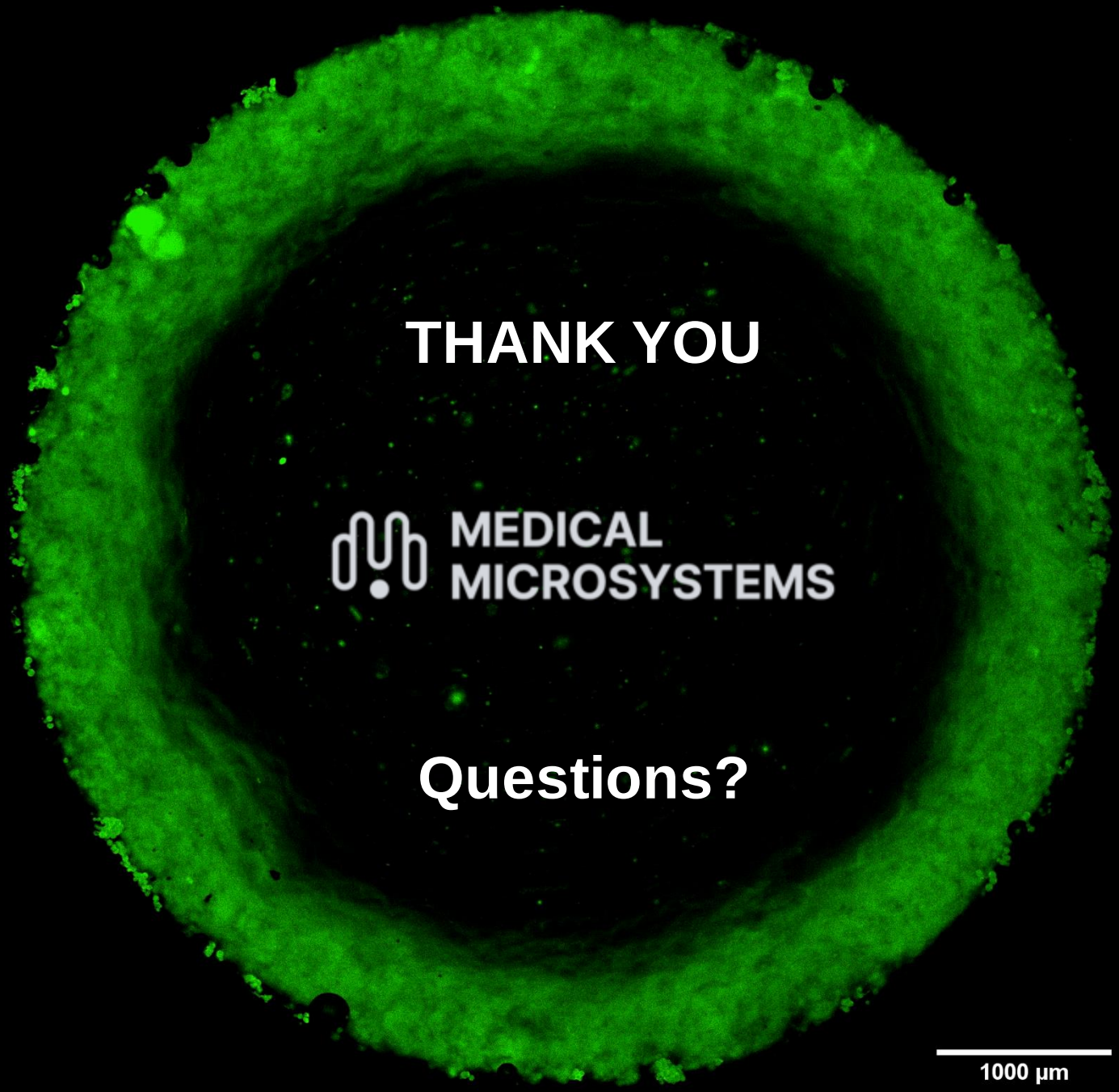
THANK YOU
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MICROSYSTEMS
Questions?
1000 µm