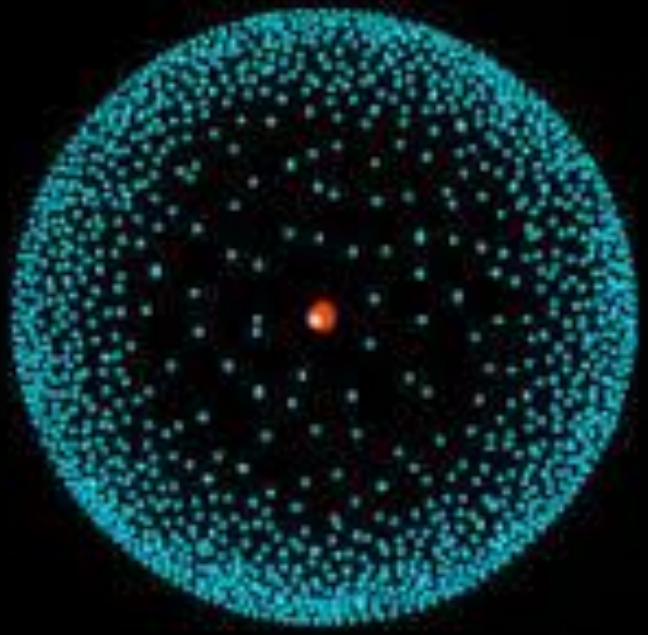
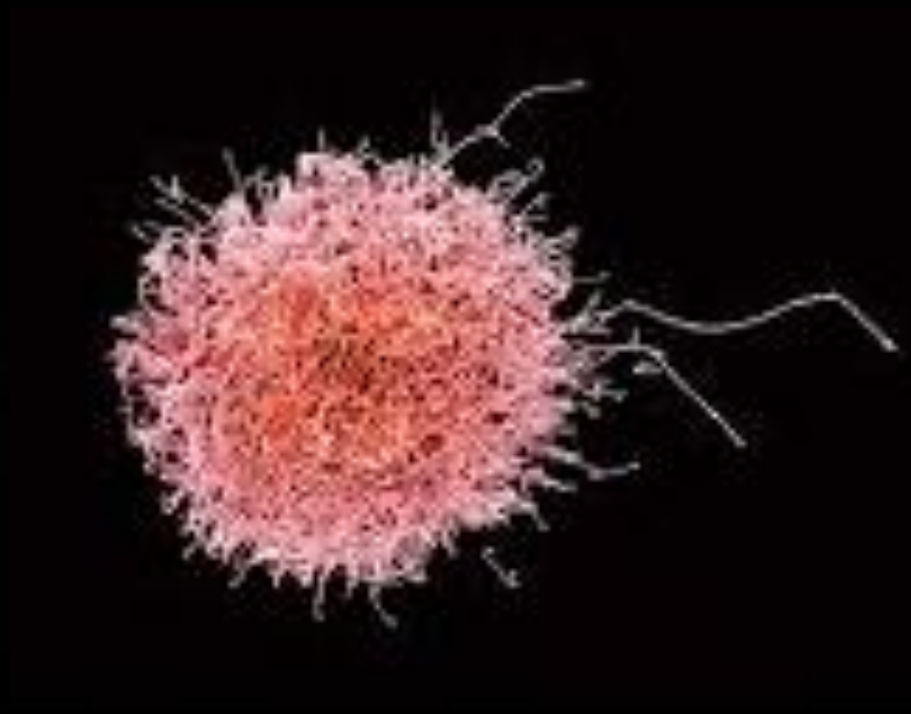
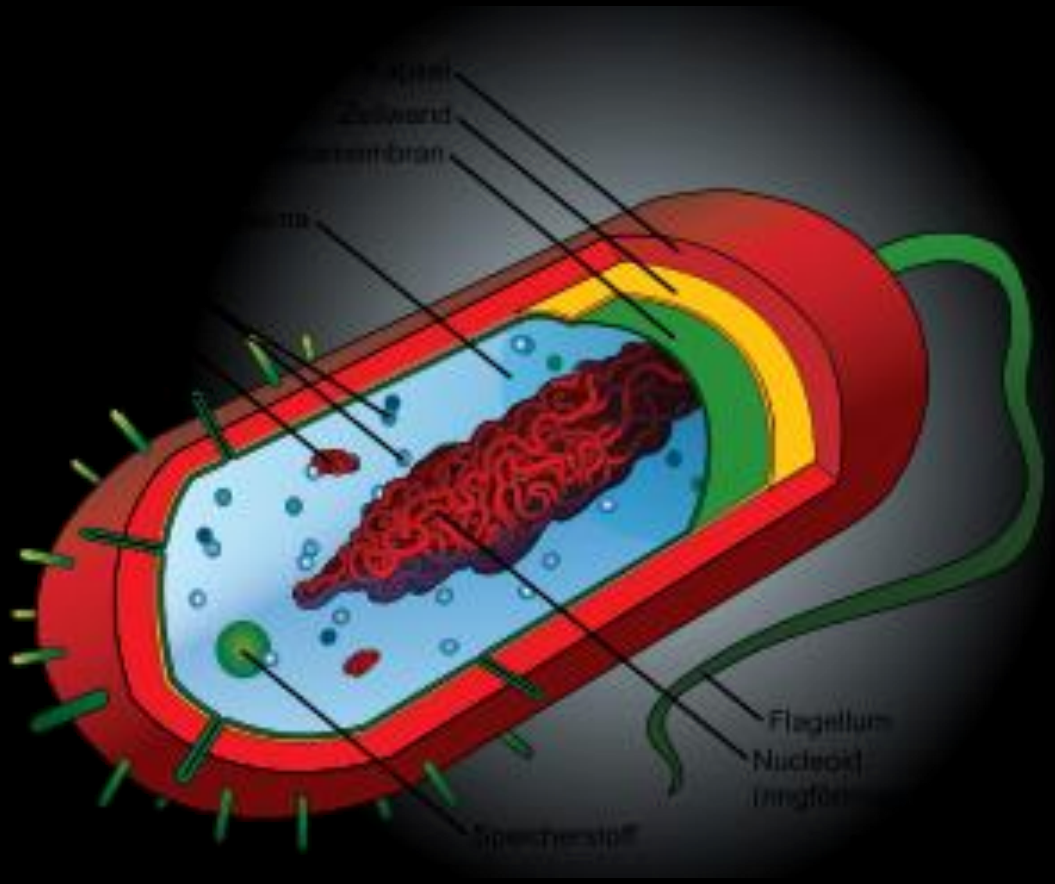
Is there a „Hydrogen Atom“ of biology?

Petra Schwille, MPIB Martinsried/Munich





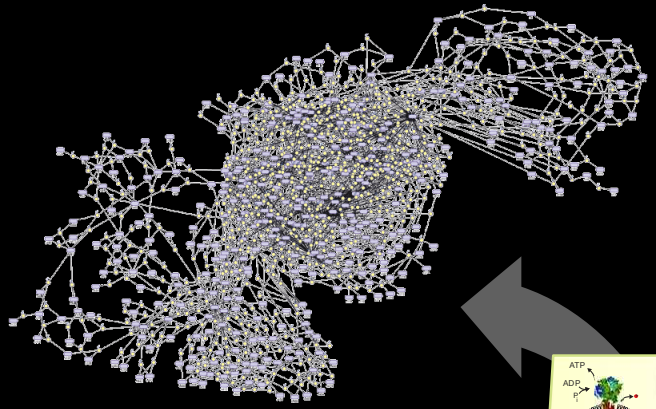
Cell theory and its conundrum



1. All living organisms are composed of cells
2. The cell is the basic unit of life
3. Cells arise from pre-existing cells

Our ambition: Build cells from minimal modules

Complexity of modern cellular networks



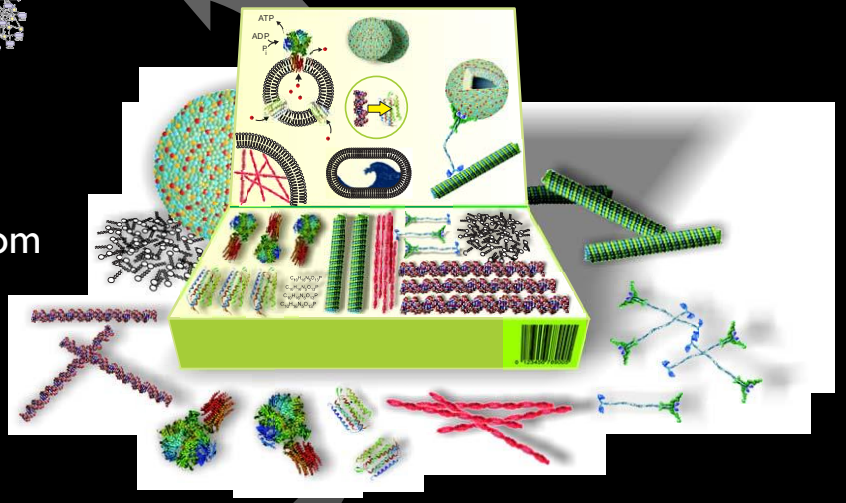
Top down

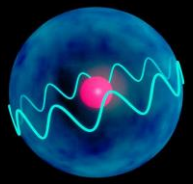
Minimal cell

Bottom up

Origin of life

assembly from functional modules





Understanding from frst principles

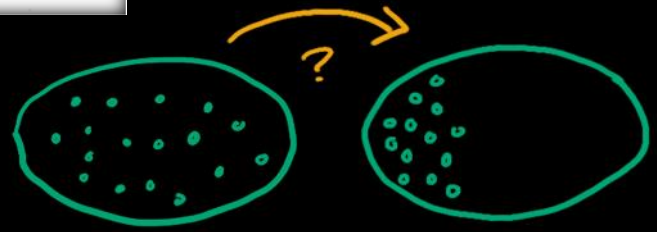
Pattern formation through energy dissipation

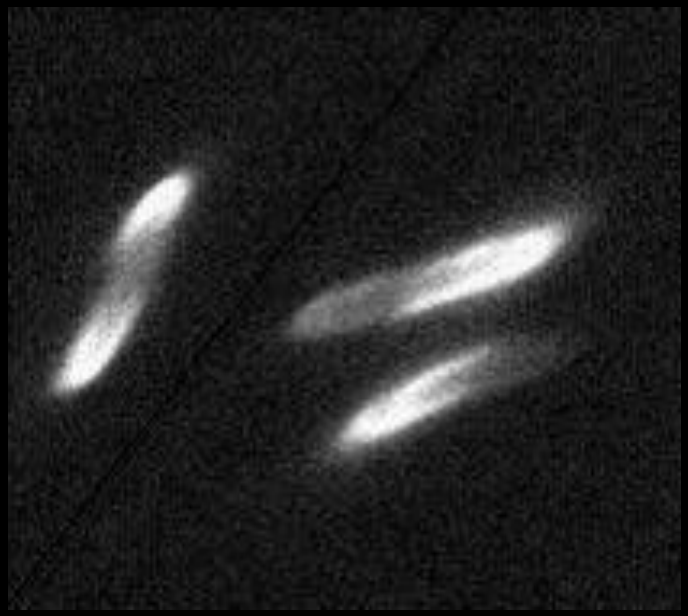
Martin Loose

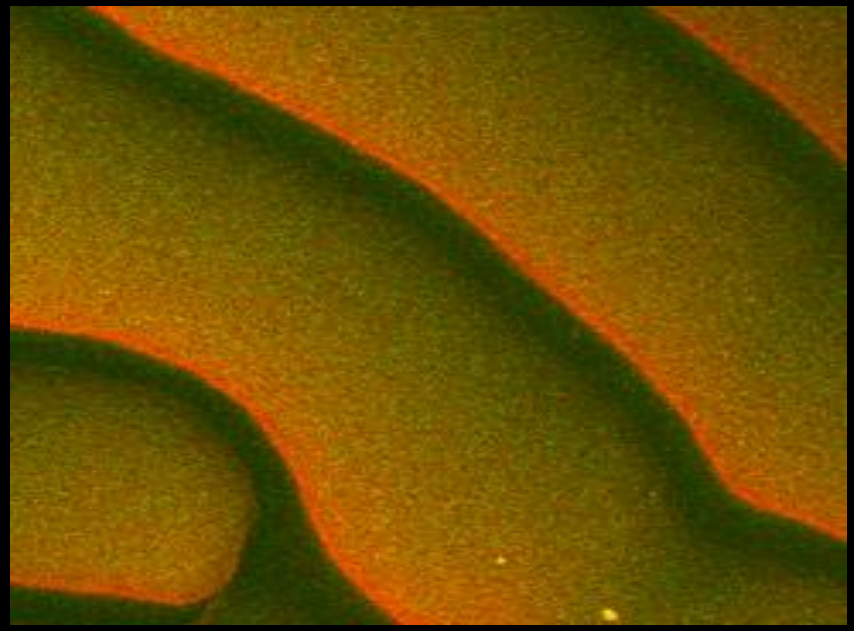
THE CHEMICAL BASIS OF MORPHOGENESIS

By A. M. TURING, F.R.S. *University of Manchester*

(*Received* 9 *November* 1951—*Revised* 15 *March* 1952)



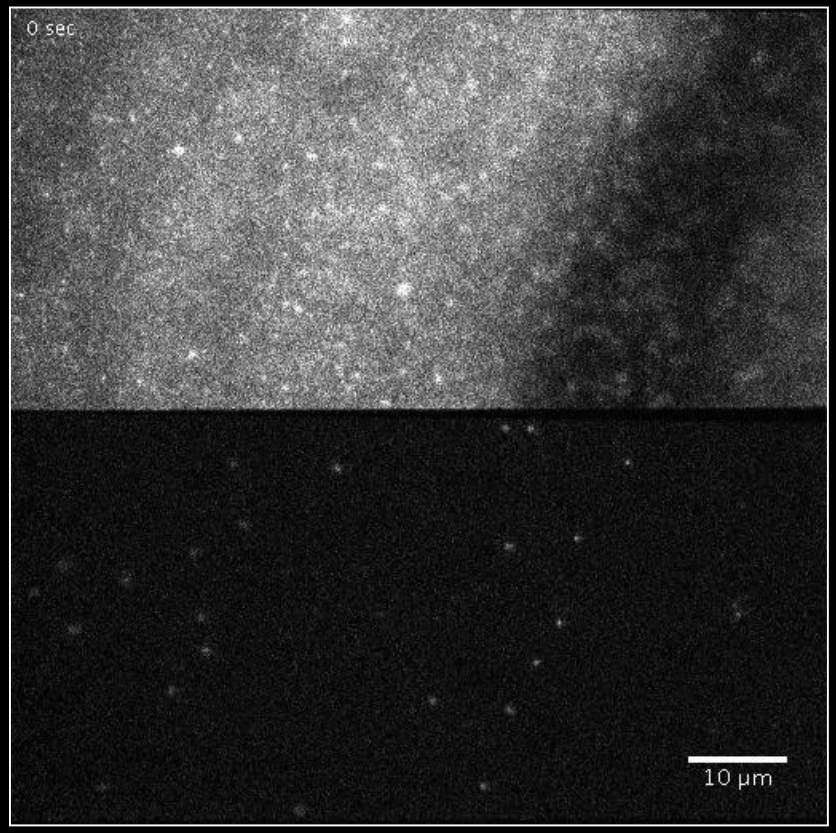


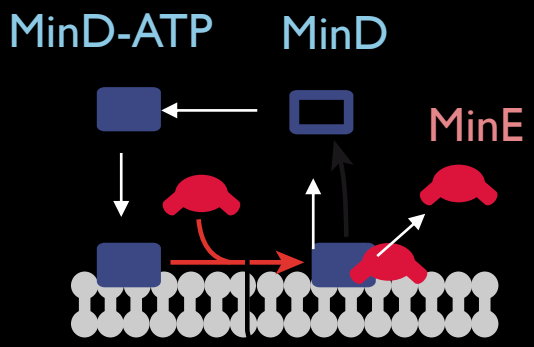


Min protein oscillations from E.coli to position the division ring

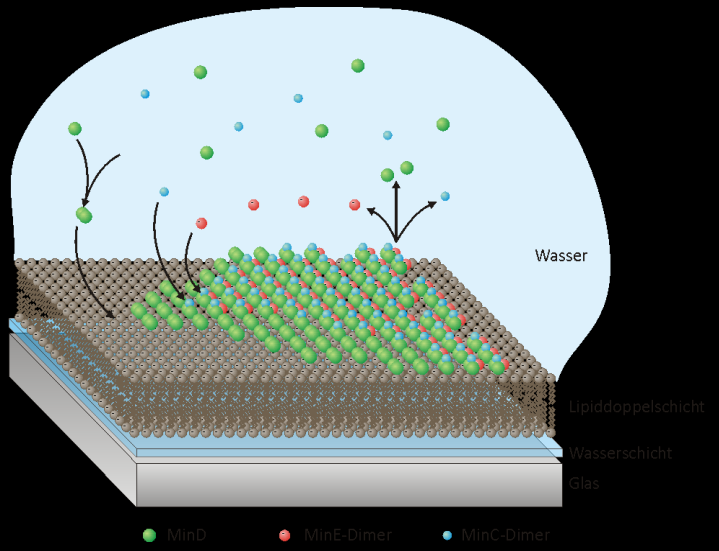
Loose et al., Science 2008

The cycle involves a membrane switch





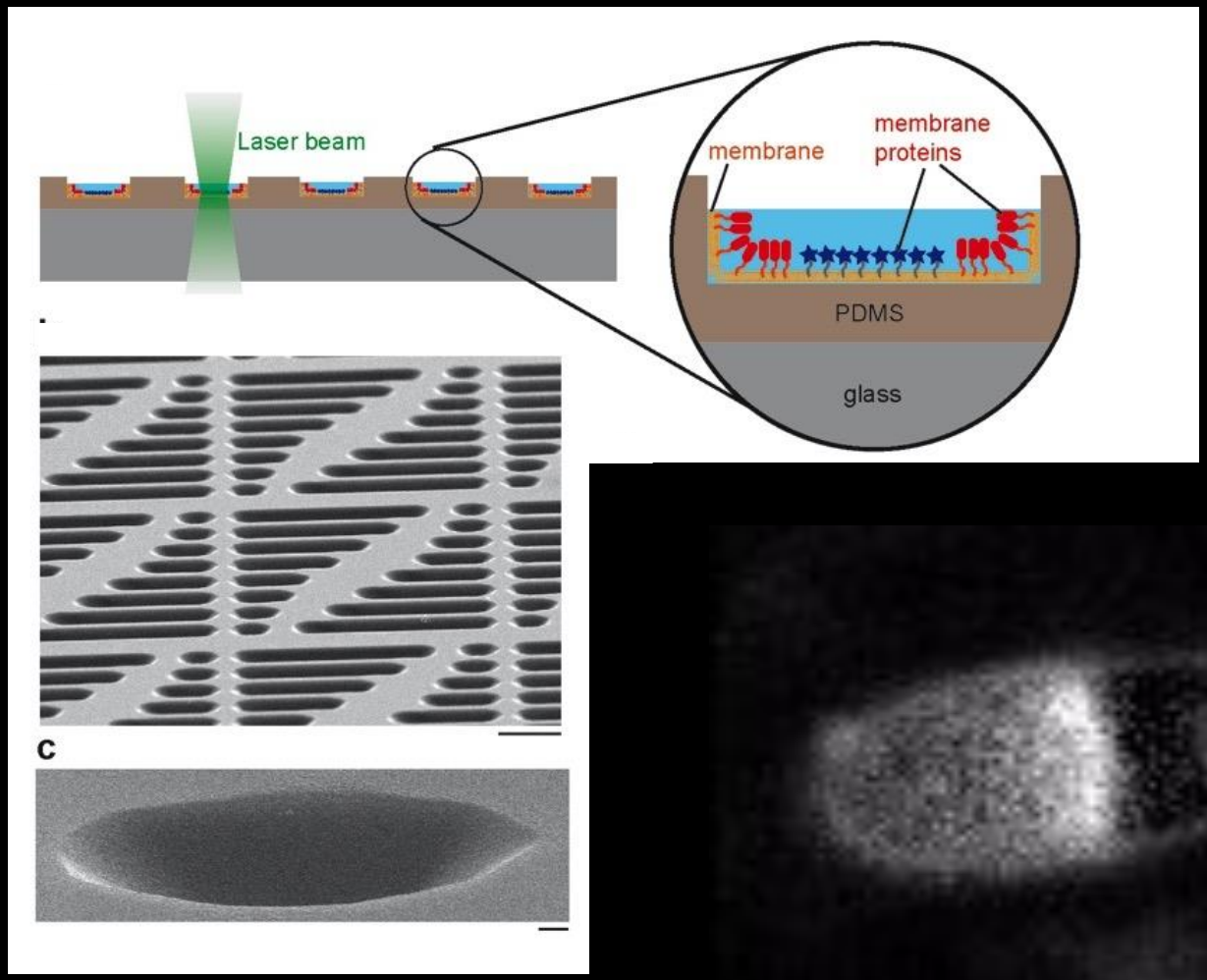
ATP-driven self-organization



Feedback of MinE-catalyzed ATP hydrolysis/detachment on reversibly membrane-targeted MinD-ATP

Reconstitution of Min oscillations in PDMS cavities

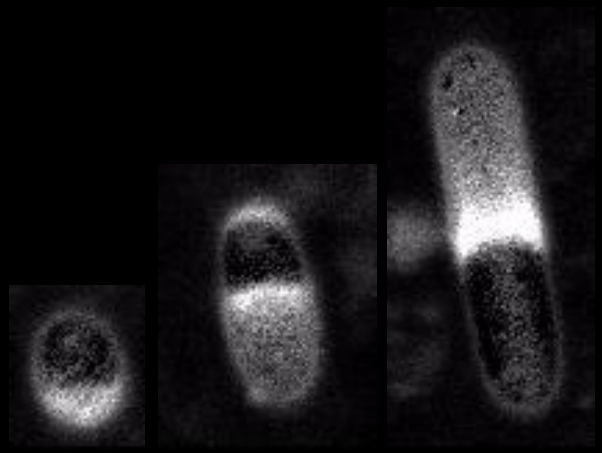
Katja Zieske



Cavity: 10 µm wide, 25 µm long, 10 µm high

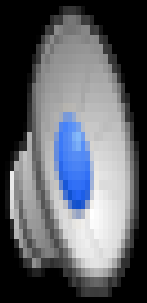
Zieske and Schwille, Angewandte Chemie Int. Ed. 2013

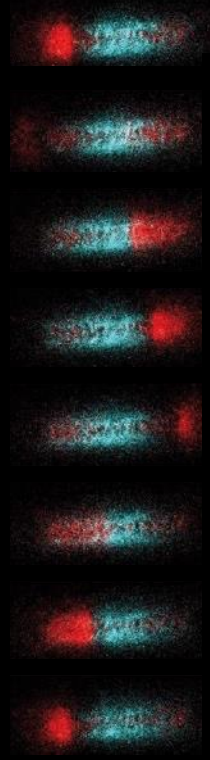
Oscillations respond to compartment length and position FtsZ

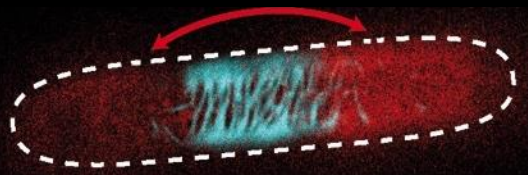


l/w=1.5 l/w=2.5 l/w=4.5

l/w=4.5







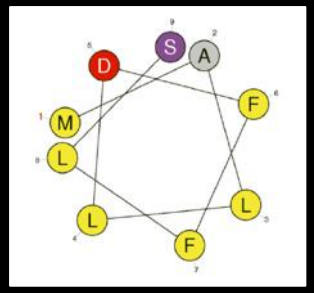
Perpendicular alignment of FtsZ filaments

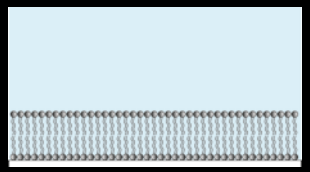
Time-averaged Min gradient

Zieske and Schwille, Angewandte 2013, eLife 2014

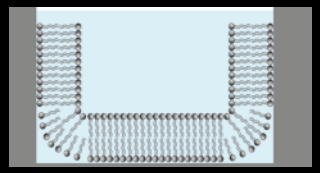
Engineering membrane affinity changes oscillation phenotype

Simon Kretschmer



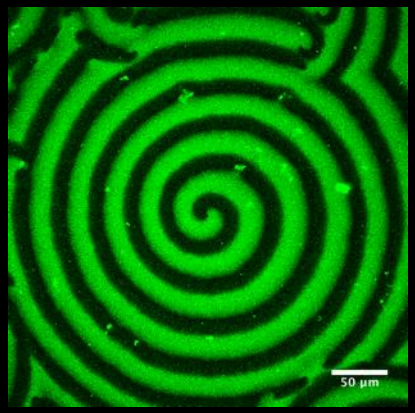


Flat Membrane

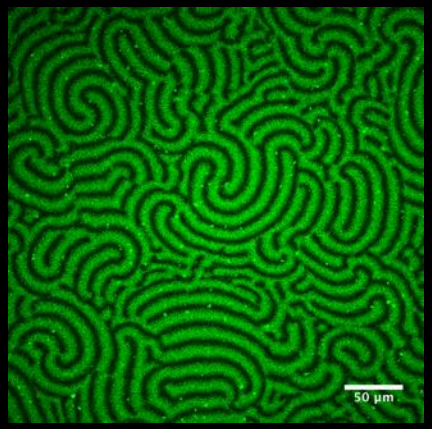


PDMS μ-compartments

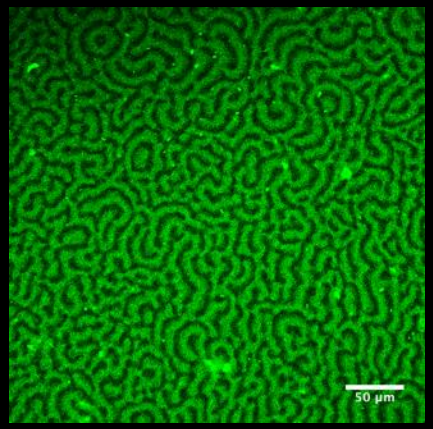
MinE WT



MinE L3E



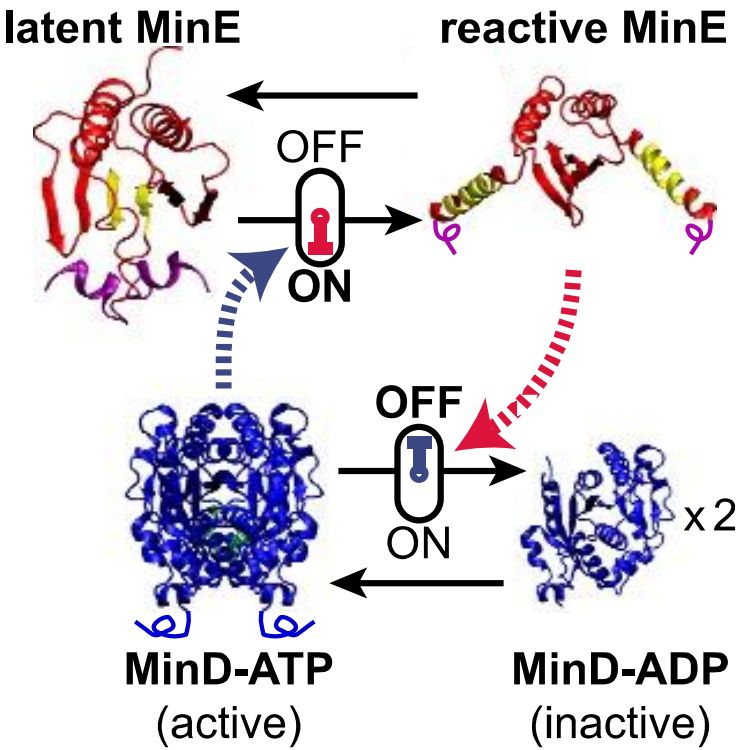
MinE$^{13\text{-}88}$ (ΔMTS)

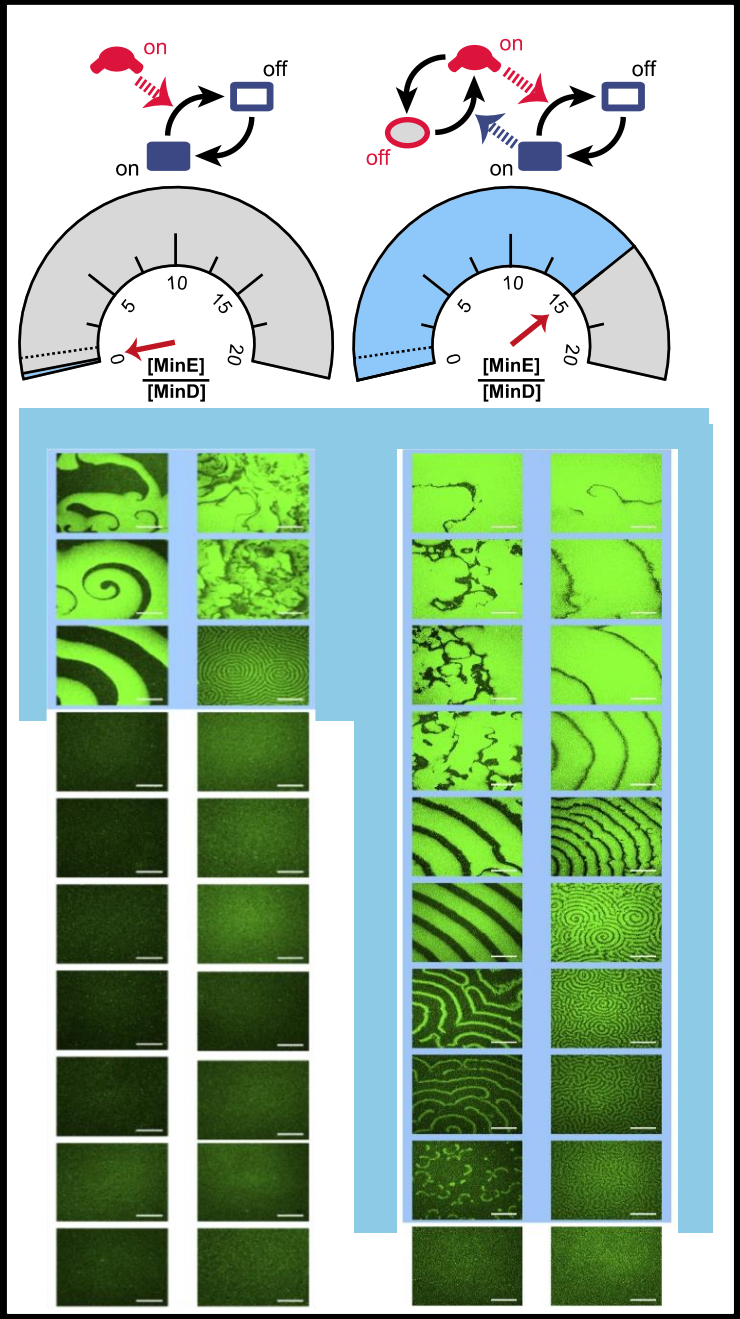


eGFP-MinD fluorescence

Kretschmer et al., *PLoS ONE 2017*

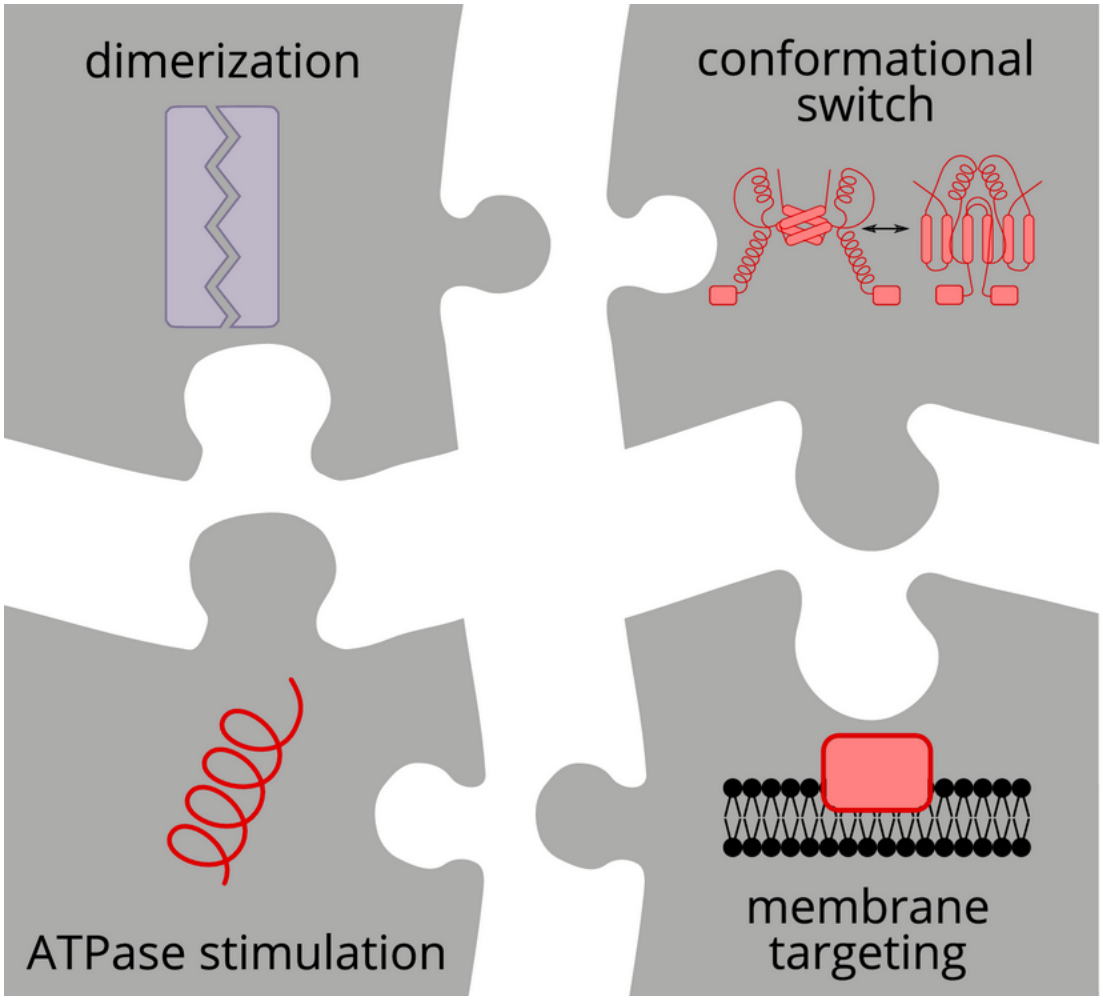
Coupled switches enhance robustness of pattern formation





Denk*, Kretschmer* et al., PNAS 2018

Designing an effector for pattern formation from scratch



pattern formation

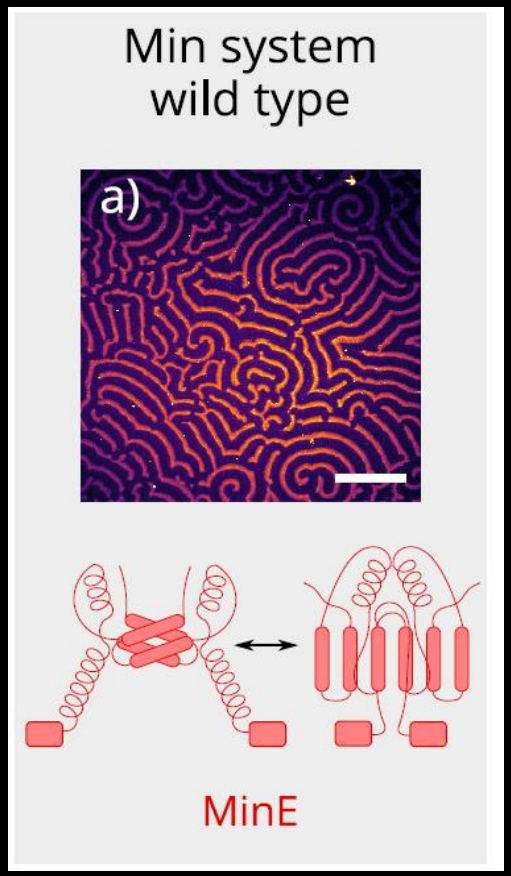
full-length MinE

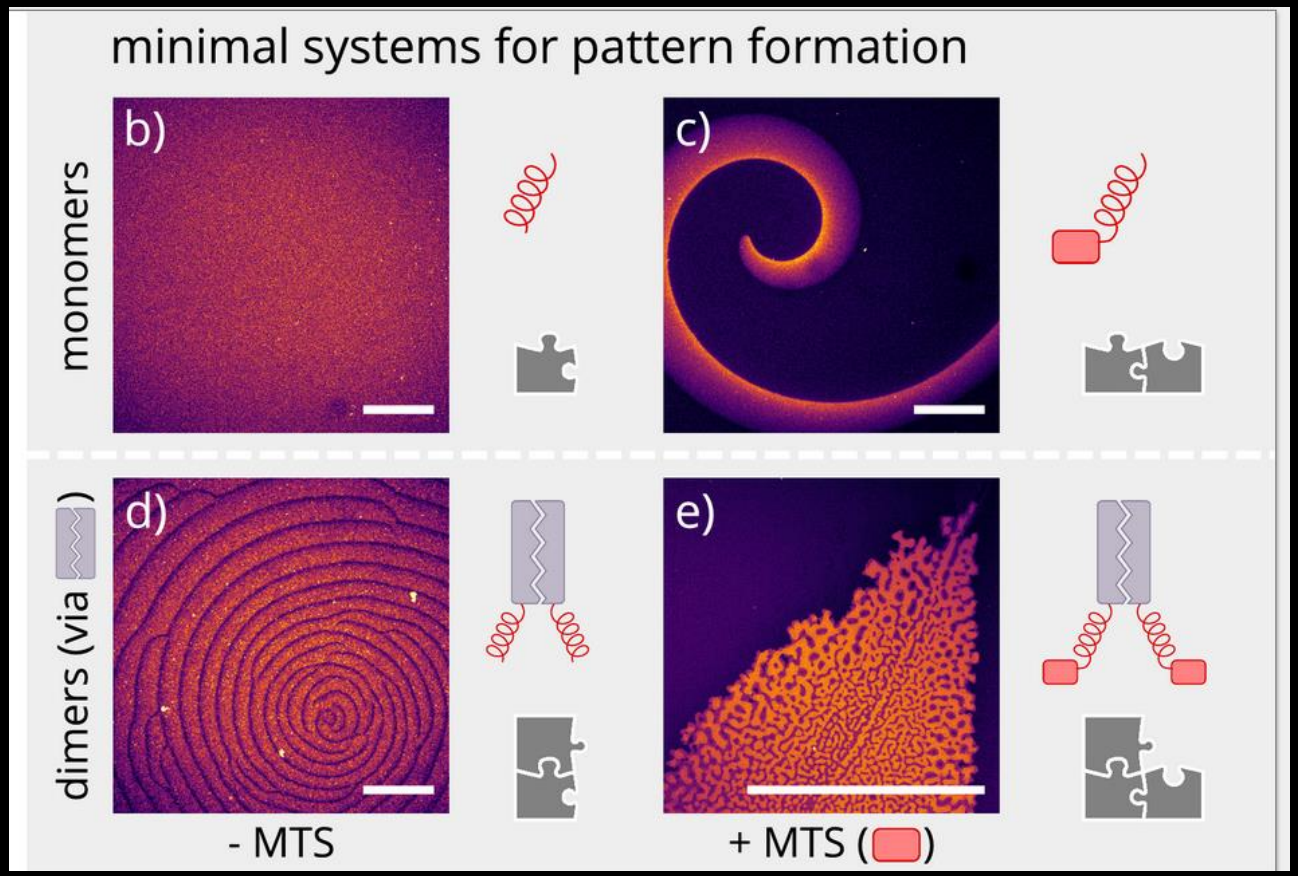
minimal MinE peptide

functional MinE peptides

How minimal can a pattern-forming system be?

Philipp Glock





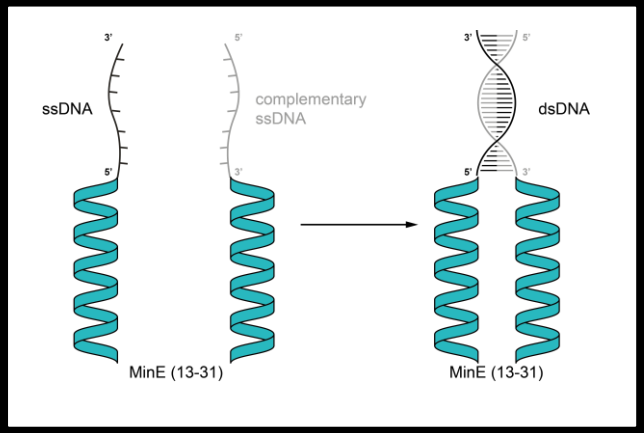
MinE reduction

Glock et al., eLife, 2019

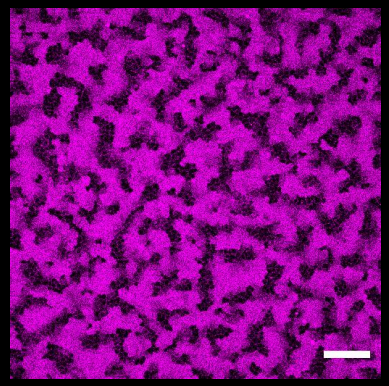
Engineering patterns based on DNA-protein chimeras

Tamara Heermann

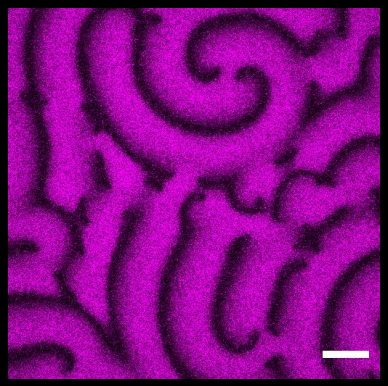
minimal MinE with 10mer DNA



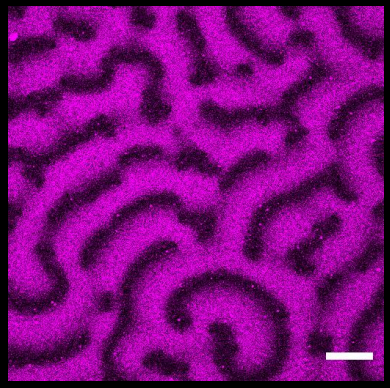
40 nM

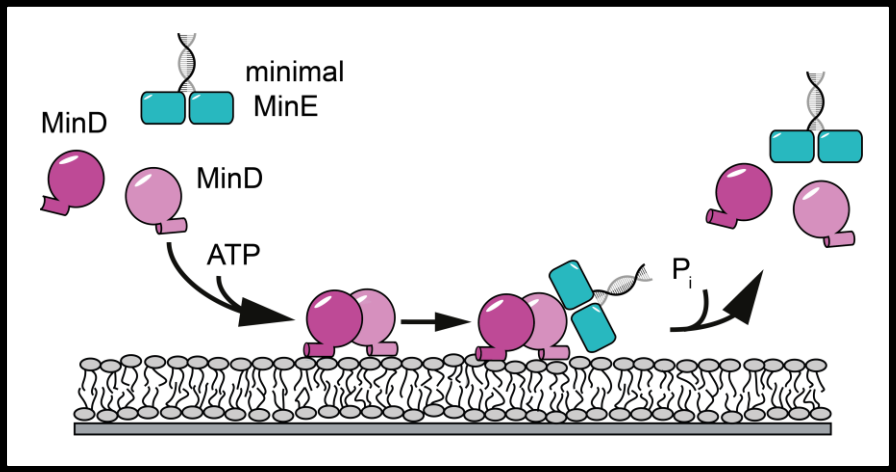


60 nM

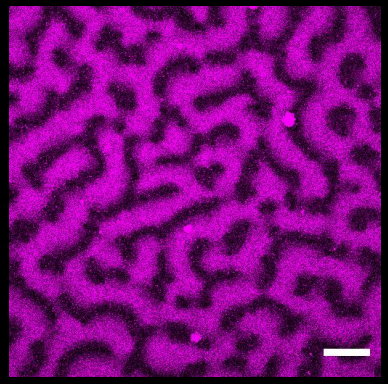


80 nM

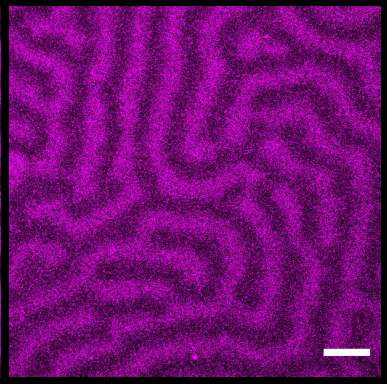




100 nM



200 nM

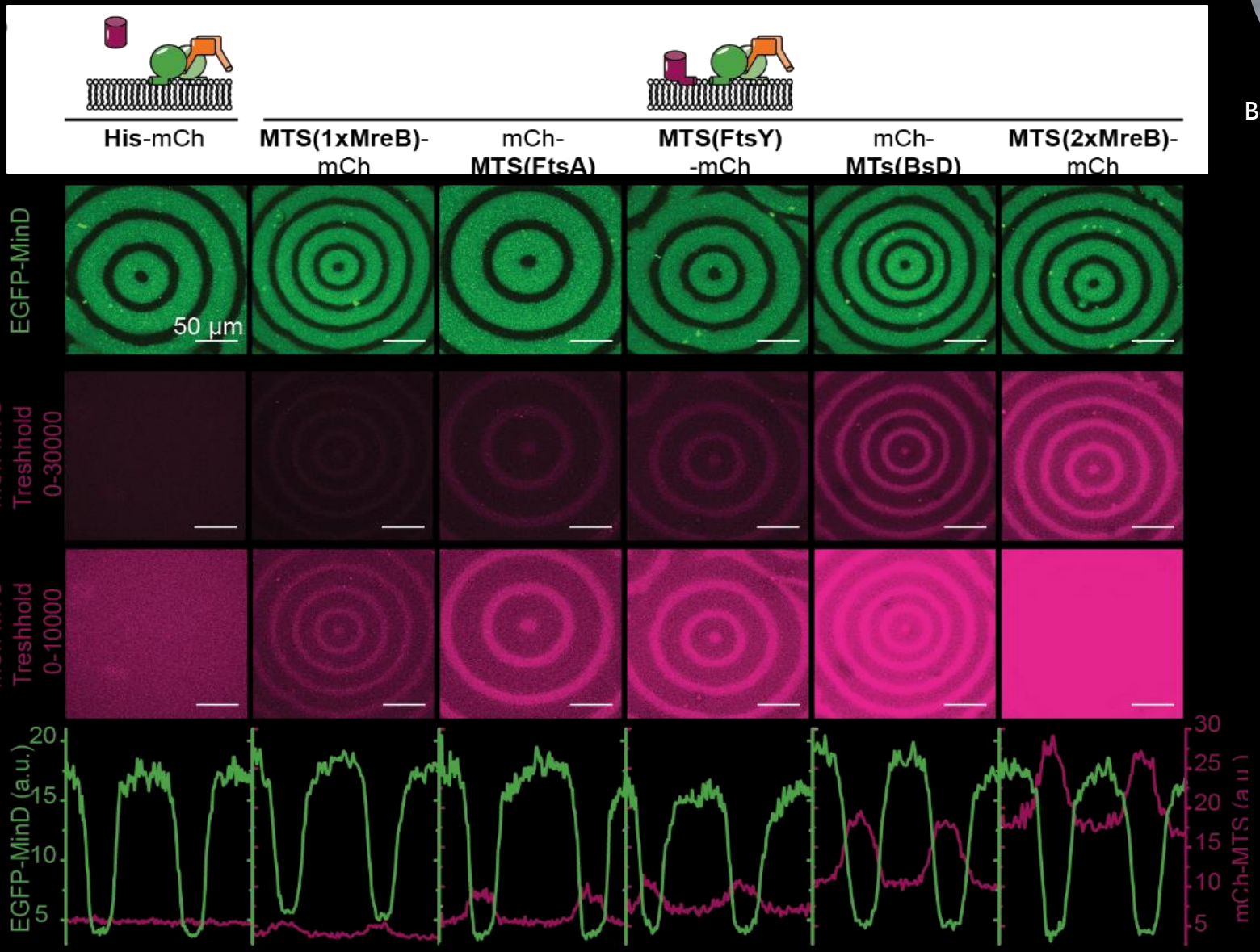


constant 1 uM MinD (30 % Atto655-KCK-MinD)

Heermann et al., *in revision*

Generic regulation of mts-attached proteins by MinDE

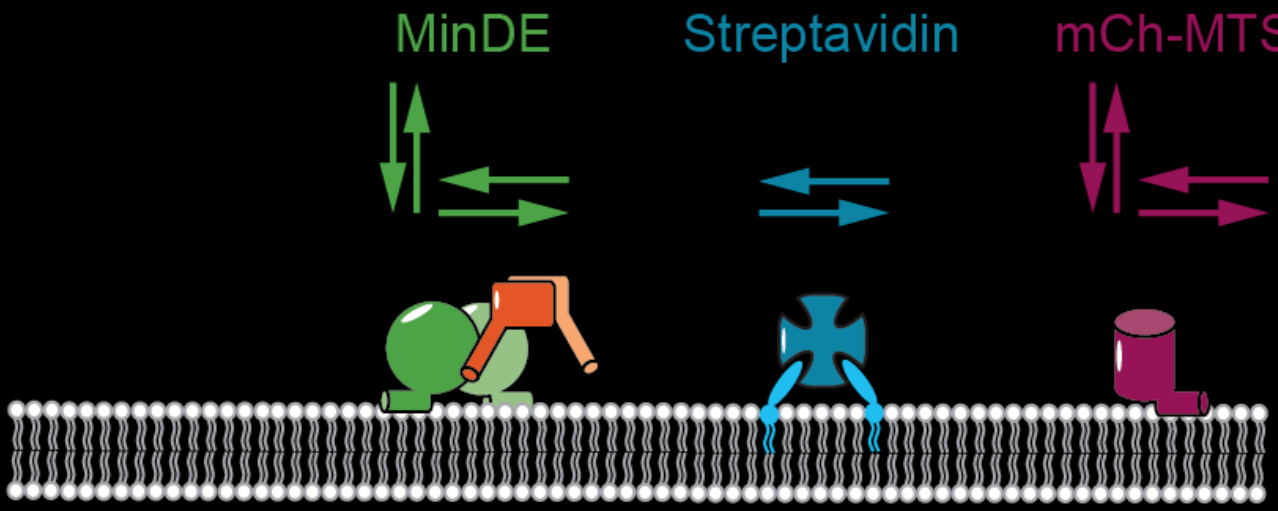
Beatrice Ramm



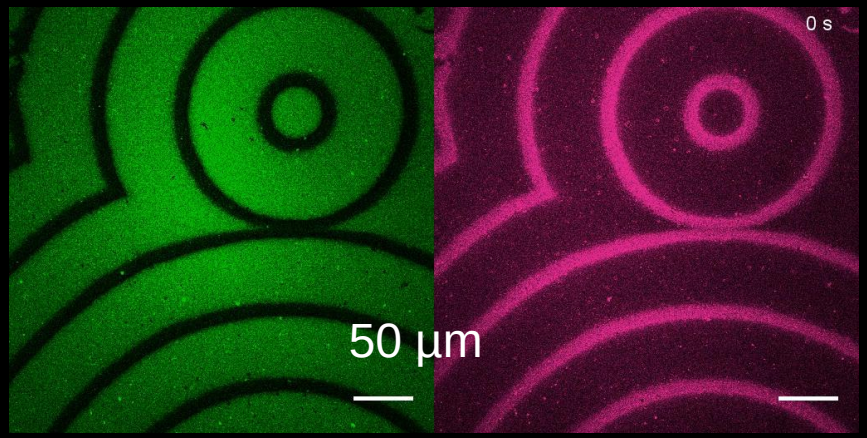
Ramm et al., Nature Comm, 2018

Functional emergence of protein patterns: I. Transport of non-related particles

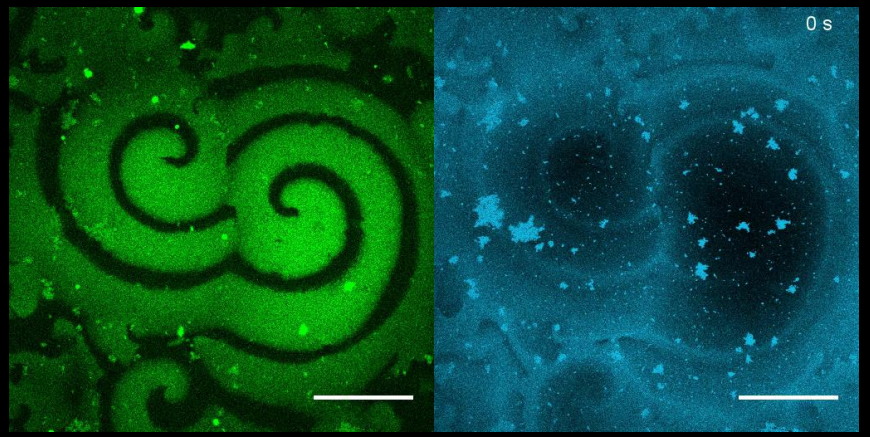
Beatrice Ramm



EGFP-MinD mCh-MTS

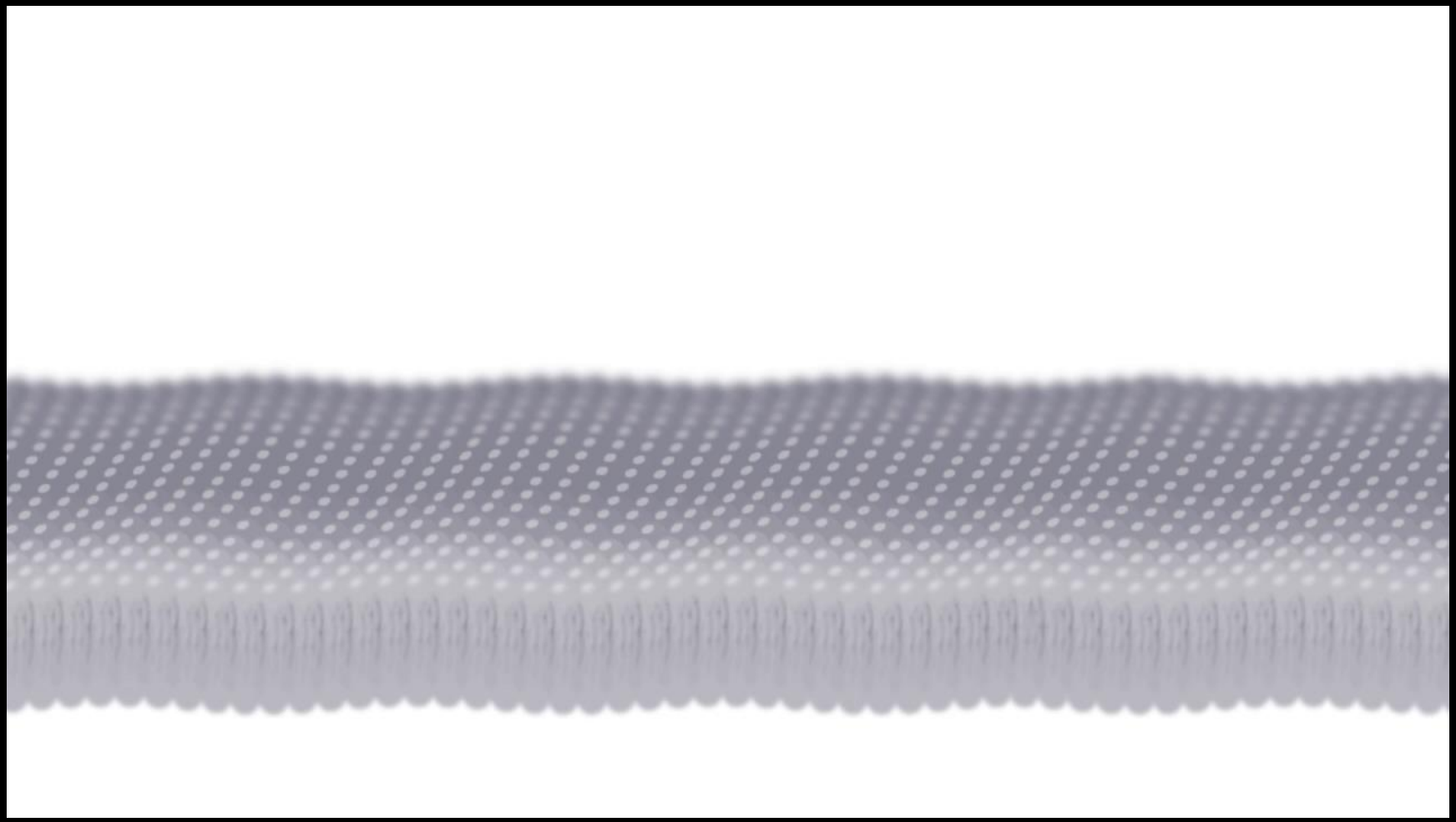


EGFP-MinD Streptavidin



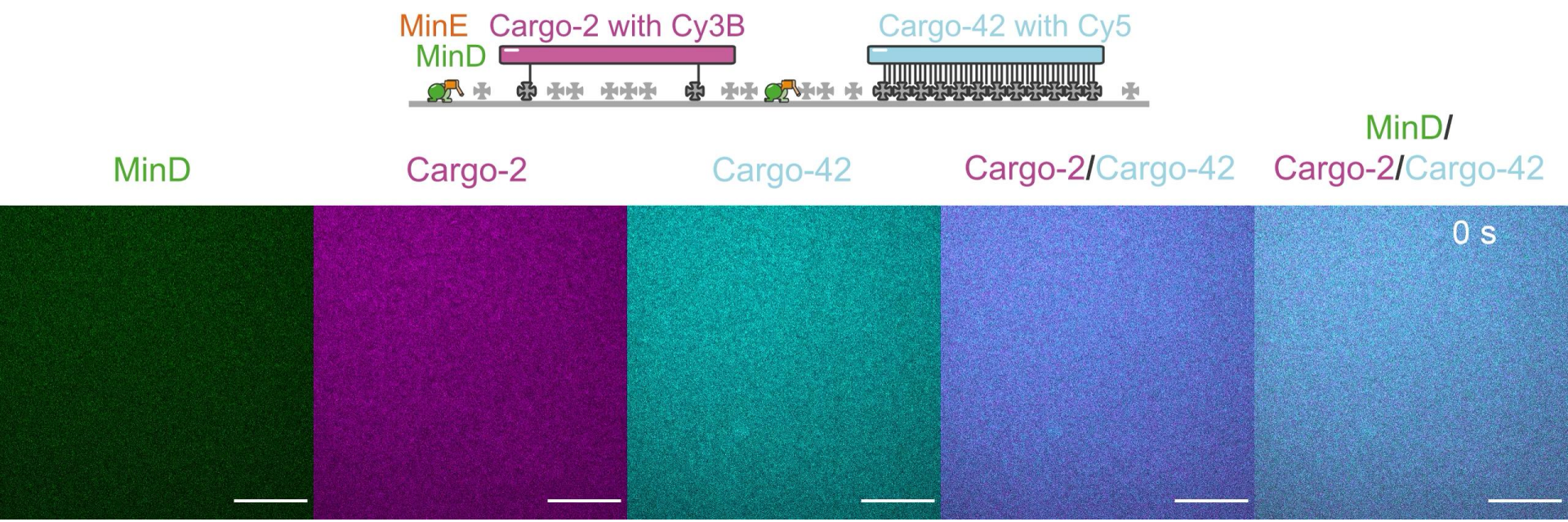
Ramm *et al.* Nat Commun (2018)

Diffusiophoresis:
A new motor-free directional transport mechanism



Ramm et al., Nature Physics in press

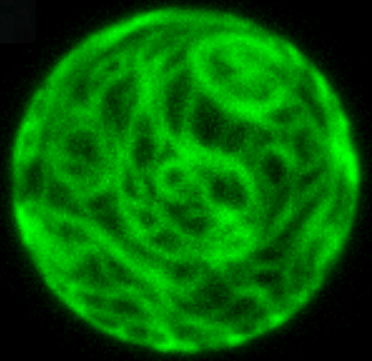
Selective transport according to membrane occupation points to a mechanical force being exerted

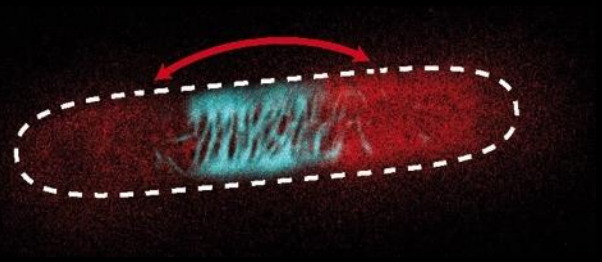


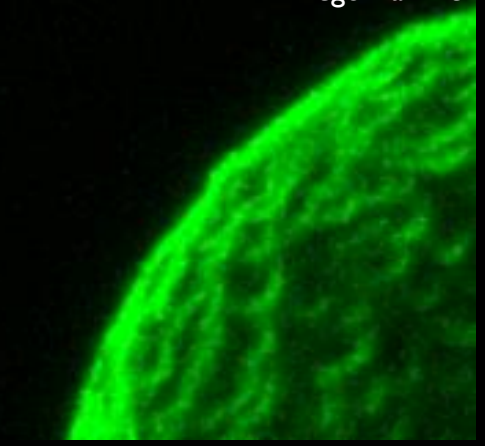
Ramm et al., Nature Physics in press

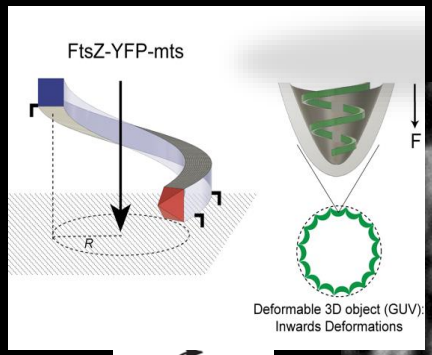
FtsZ – force induction by active filaments?

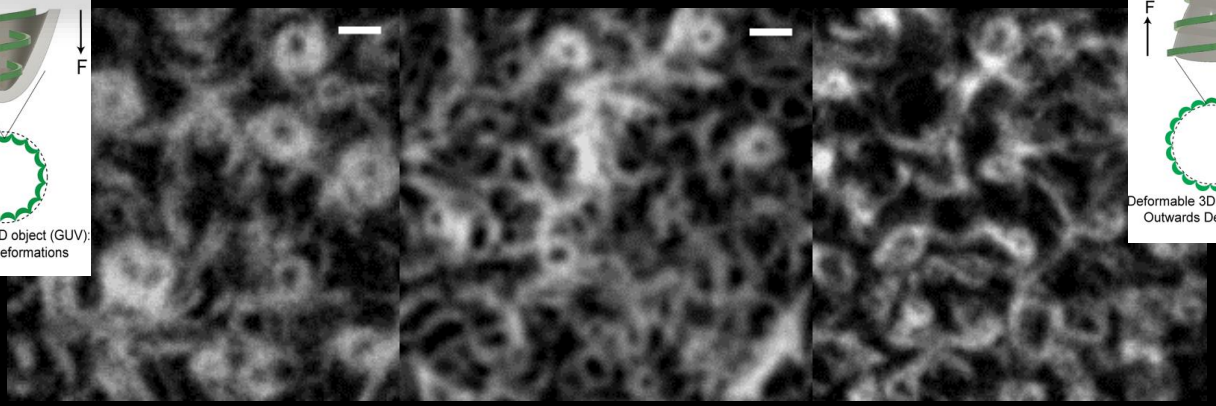
Diego Ramirez

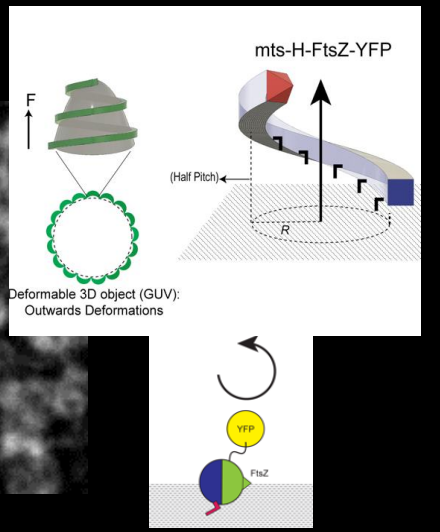












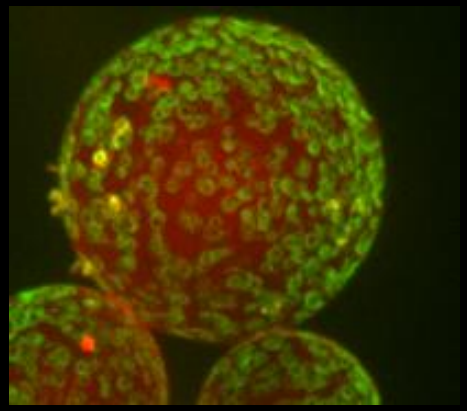
C-terminal

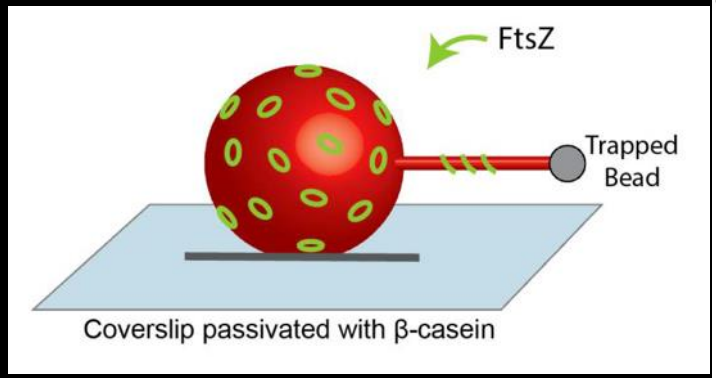
GTP inactive

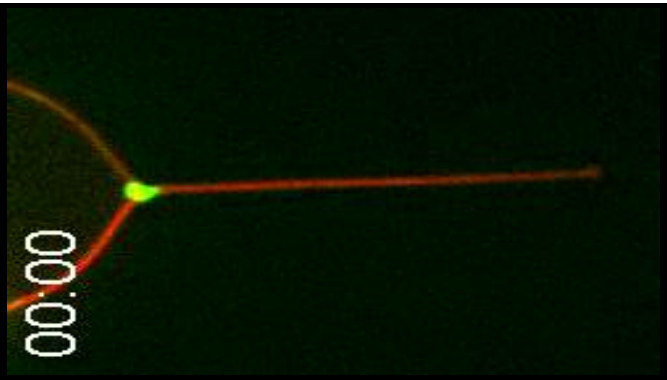
N-terminal

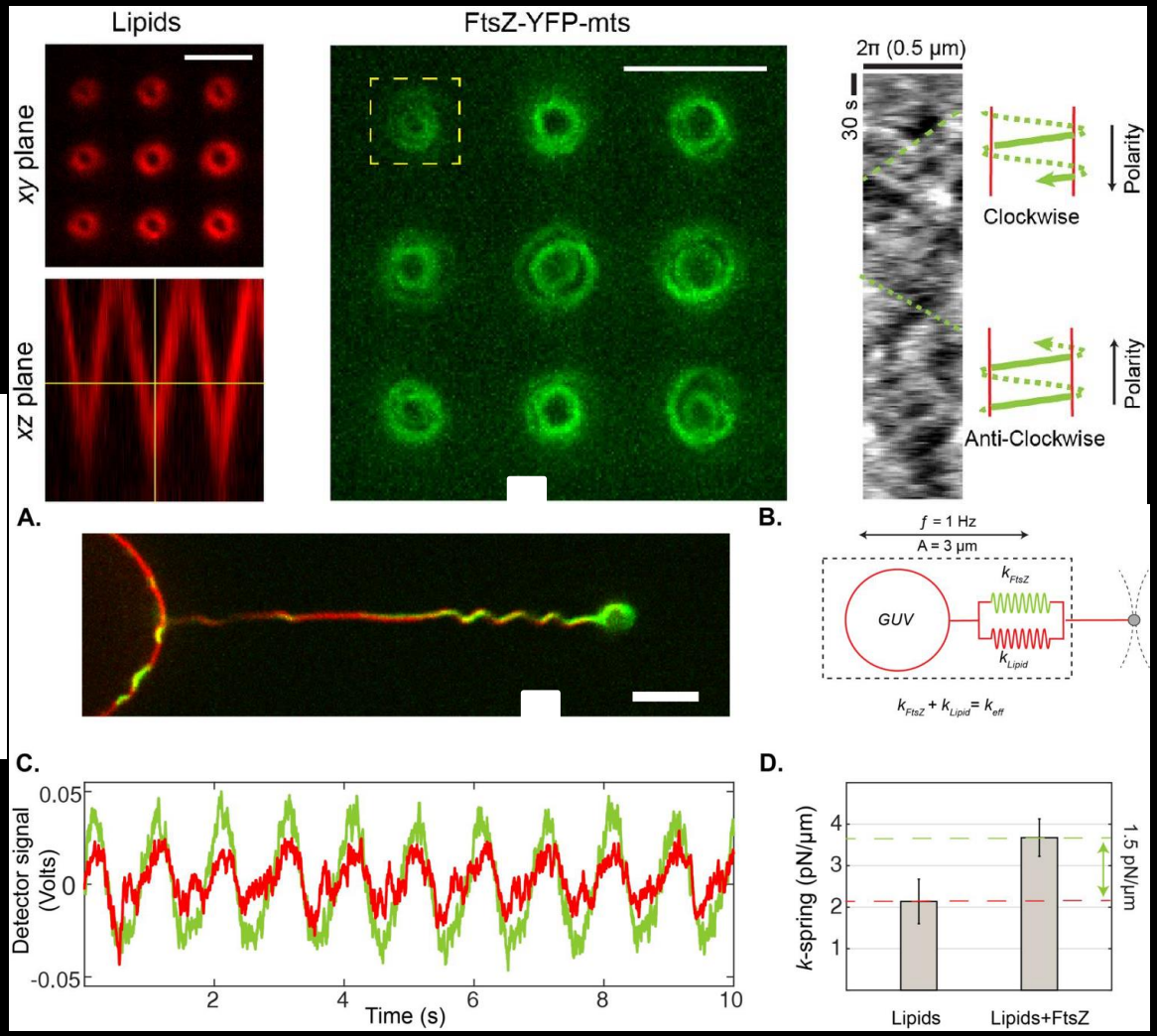
Ramirez et al., PloS Biol., 2018

Bidirectional treadmilling exerts a force





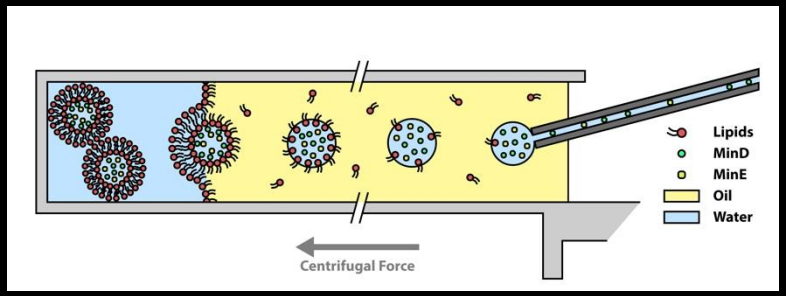


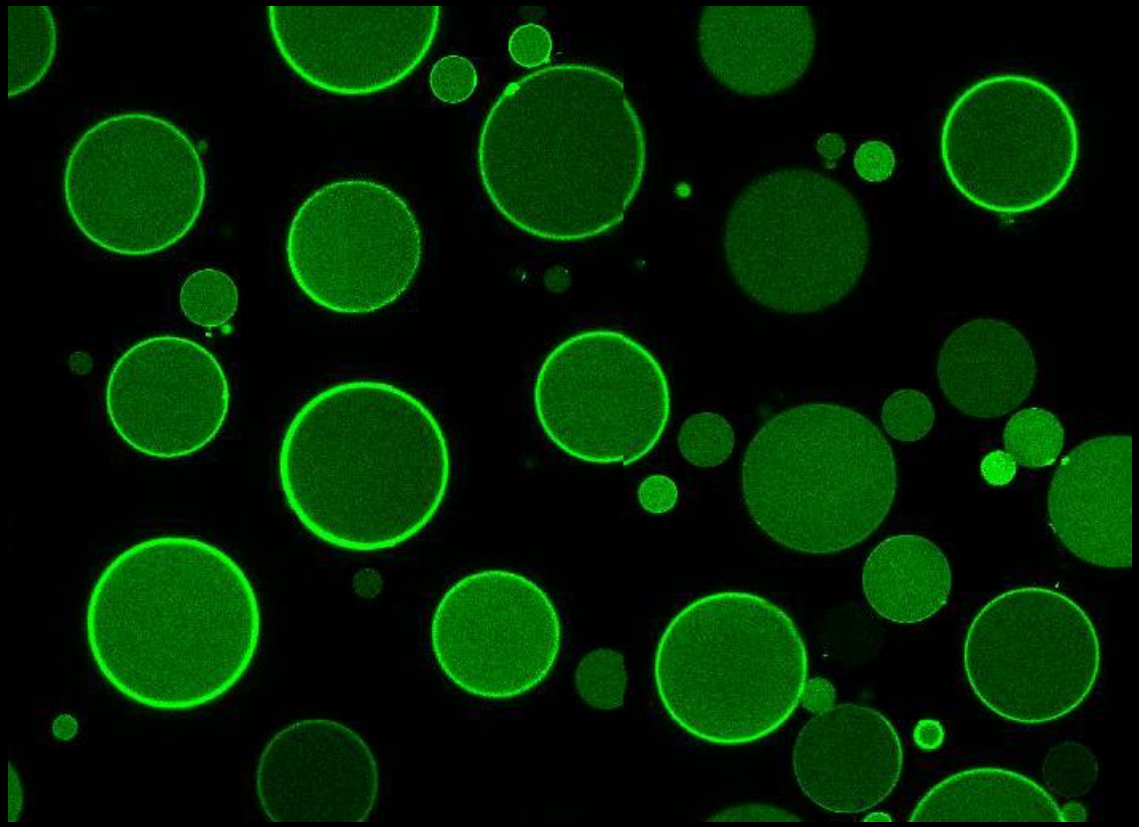


Ramirez et al., PloS Biol. 2018
Ramirez et al., in revision

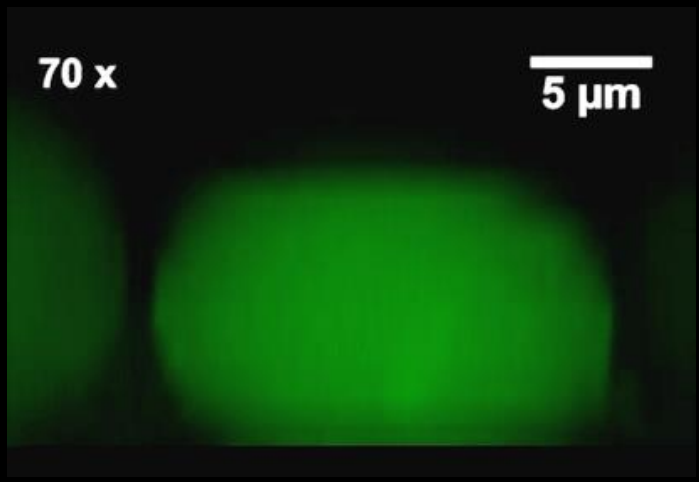
Beating Vesicles - Min Proteins in GUVs

Thomas Litschel





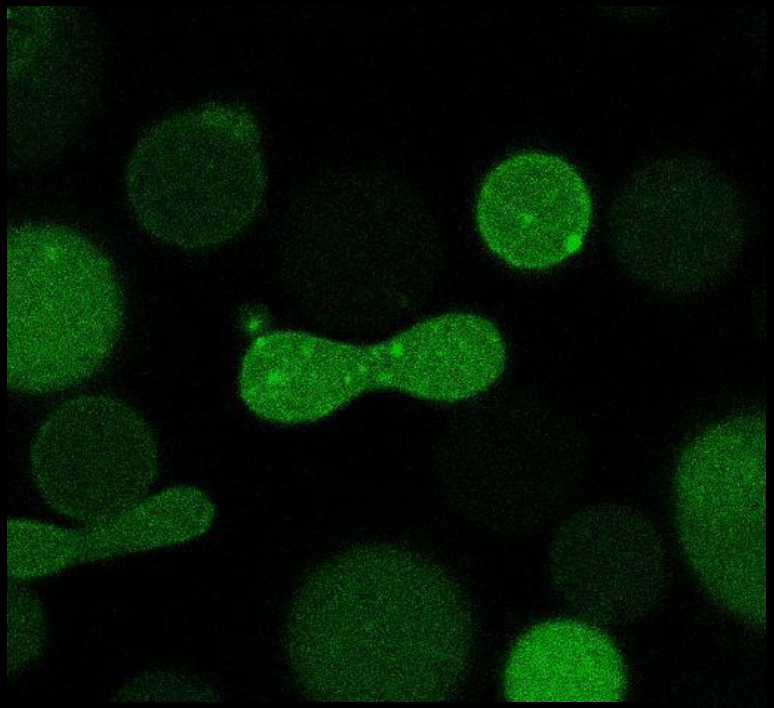
Z-Stack "Side View"

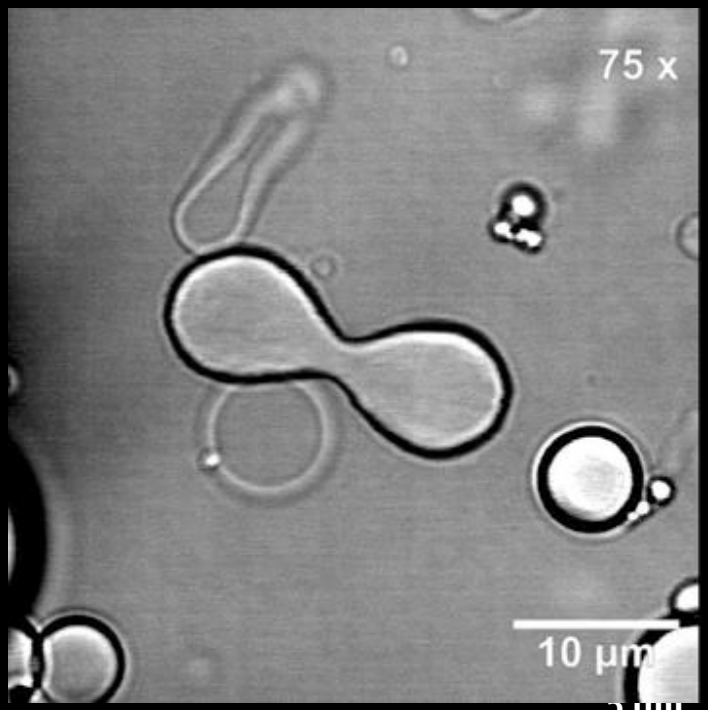


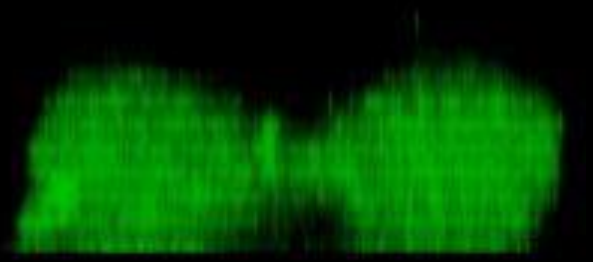
Litschel et al. Angewandte Chemie *2018*

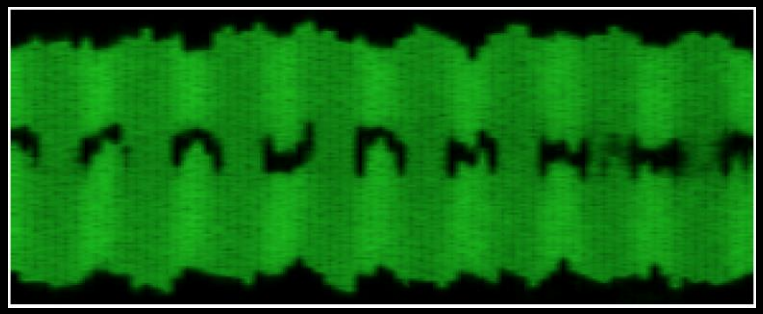
Vesicle Deformation in Concert with Min Oscillations

Thomas Litschel









Litschel et al. Angewandte Chemie *2018*

What did we learn from our work with reconstituted proteins?

- There are „*hidden functions*“ to be observed *in vitro*
- These functions may not be „*physiologically relevant*“
- But they may be *very relevant* in understanding the evolutionary development of cellular functions
- They may be *ideal modules for the bottom-up reconstitution* of minimal cells

Thank you!

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MAX PLANCK RESEARCH NETWORK
IN SYNTHETIC BIOLOGY

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