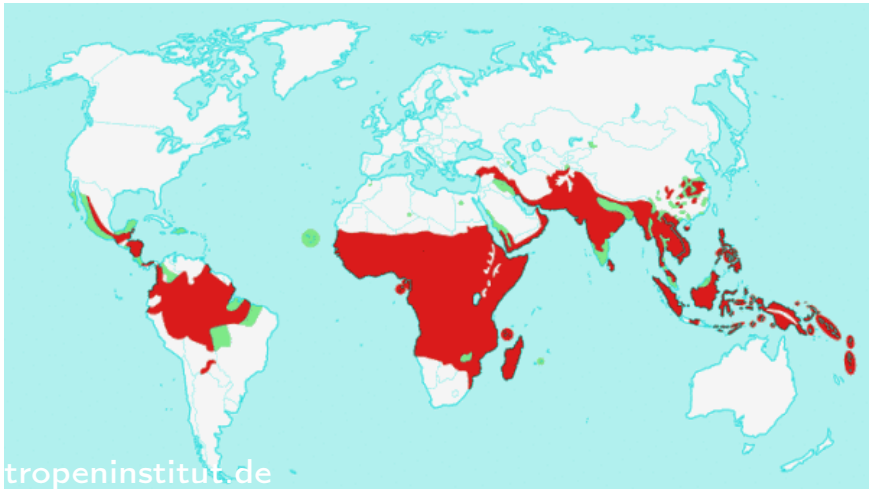
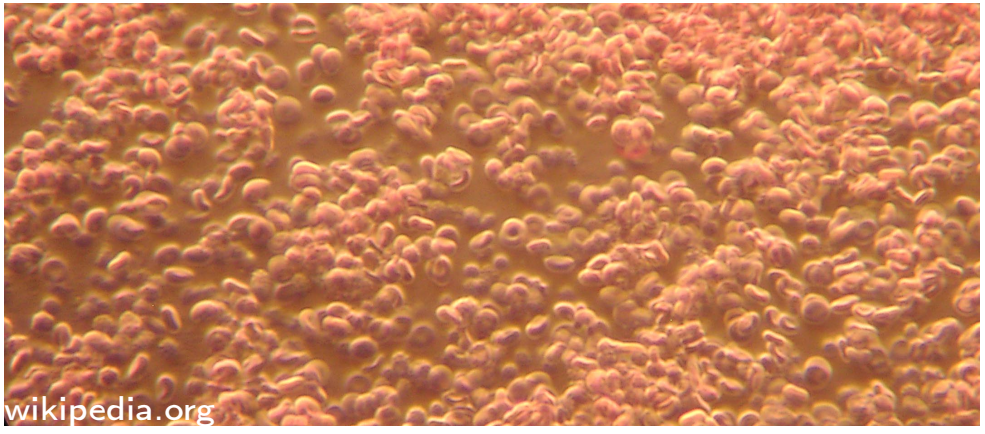
Passive separation of blood components in microfluidic devices — a simulation view

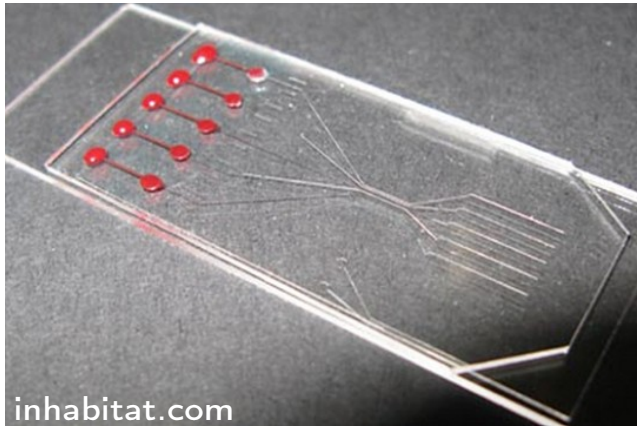
Timm Krüger, Rohan Vernekar

Flowing Matter Across the Scales
27 March 2015
Roma

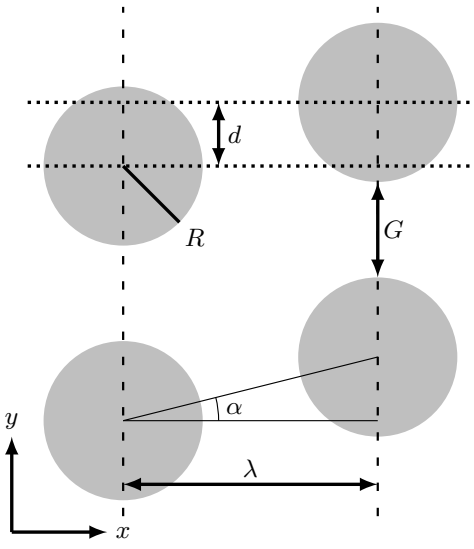
Malaria

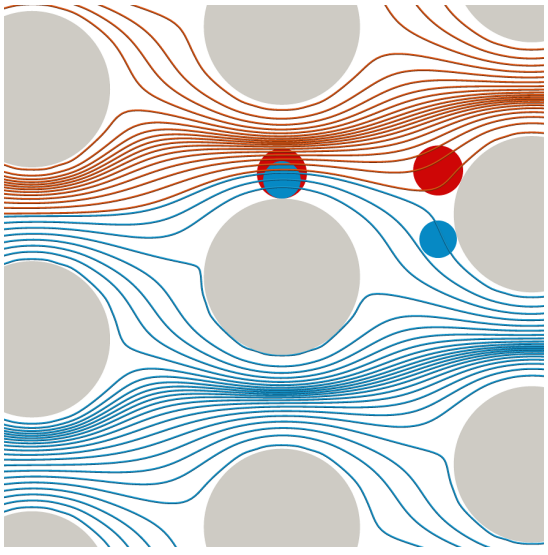


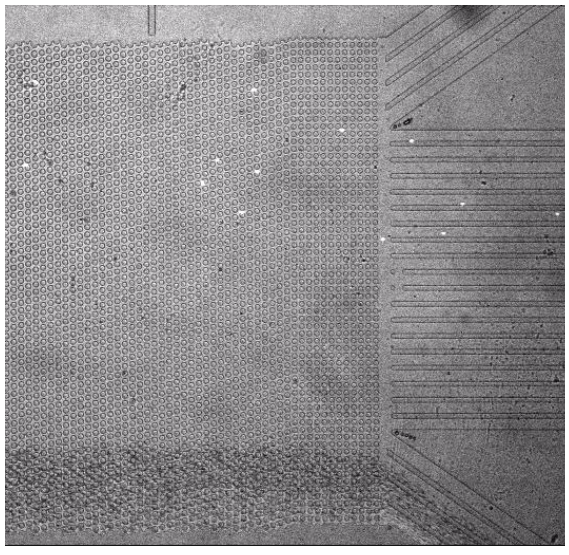




Deterministic lateral displacement







Volume exclusion

- Sensitive to particle size
- Irreversible trajectories, even at $Re = 0$

Design parameters

- Row shift d
- Gap size G
- Pillar radius R

Huang et al. (Science, 2004)

RBC membrane (1)

Strain energy density

$$w_S = \frac{\kappa_S}{12}\left(I_1^2 + 2I_1 - 2I_2\right) + \frac{\kappa_\alpha}{12} I_2^2$$

κ_S: shear modulus
κ_α: extensional modulus
I_1, I_2: strain invariants

Skalak et al. (Biophys. J., 1973)

Bending energy density

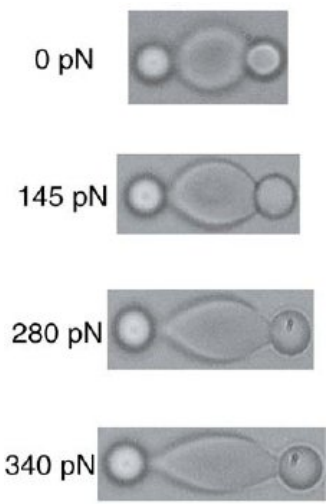
$$w_B = \frac{\kappa_B}{2}(C - C_0)^2$$

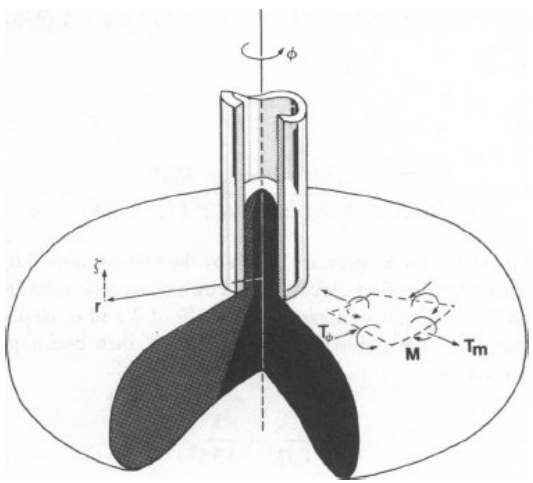
κ_B: bending modulus
C: curvature

Helfrich (Z. Naturforsch. C, 1973)

Moduli from experiments:

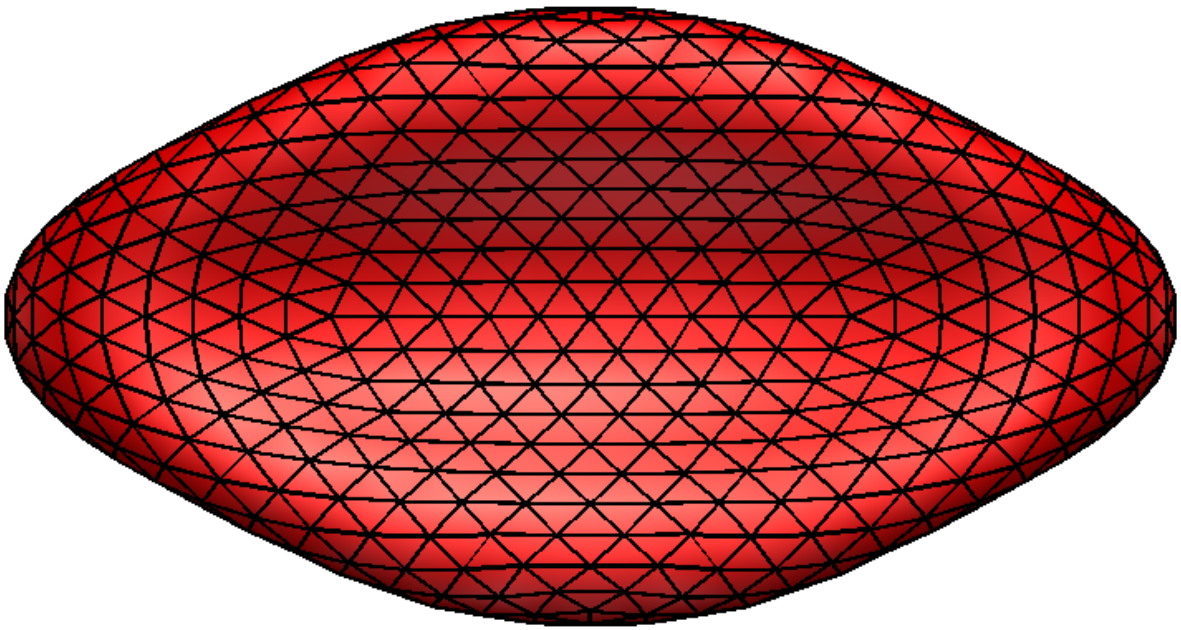
- $\kappa_S = 5\,\mu\mathrm{N/m}$
- $\kappa_\alpha = 0.5\,\mathrm{N/m}$
- $\kappa_B = 2 \cdot 10^{-19}\,\mathrm{N\,m}$



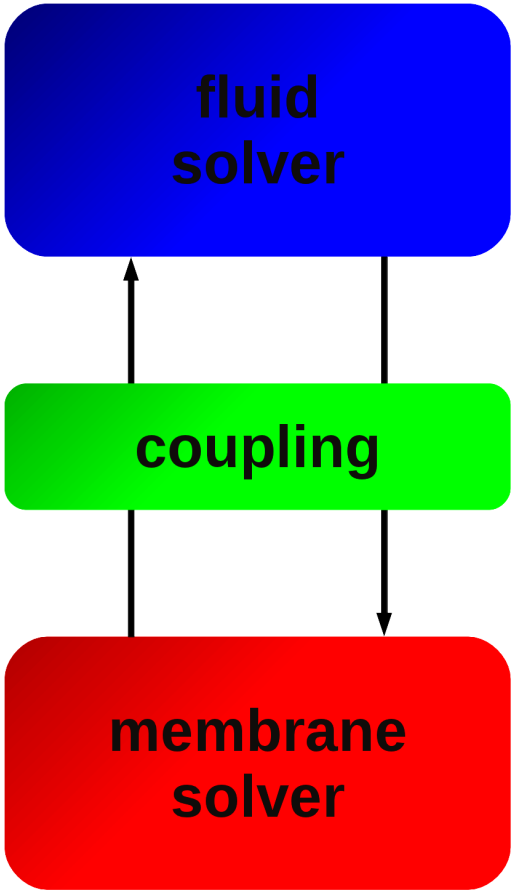


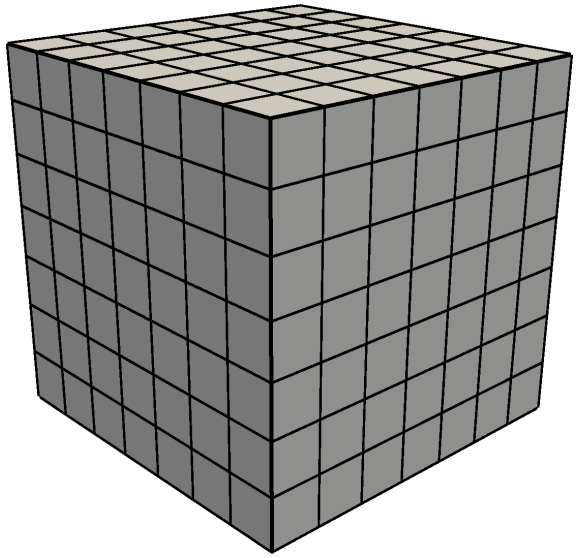
Dao et al. (J. Mech. Phys. Solids, 2003)
Evans (Biophys. J., 1983)

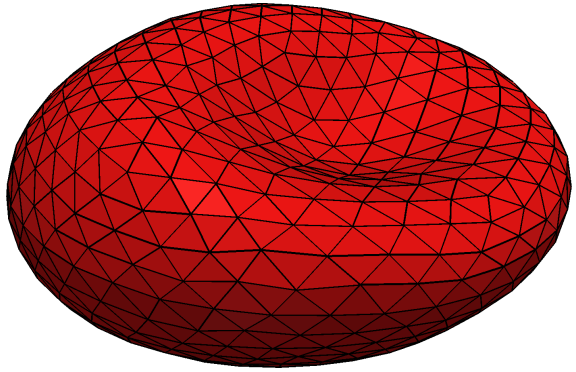
RBC membrane (2)



Method overview

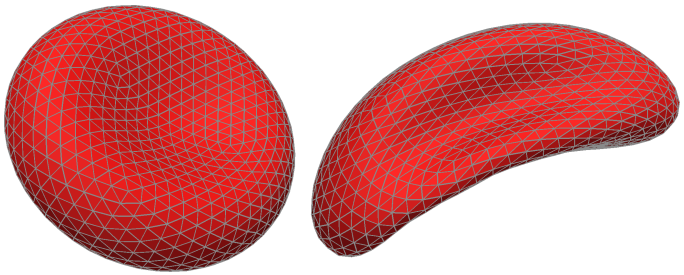






- Fluid solver: LBM (Eulerian)
- Membrane solver: FEM (Lagrangian)
- Fluid-membrane coupling: IBM

RBC trajectories

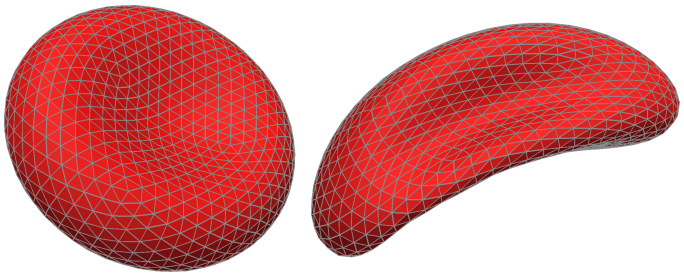


Particle deformability quantified by capillary number

$$Ca = \frac{\sigma r}{\kappa_S}$$

σ: stress on RBC surface
(due to applied pressure drop)

RBC trajectories



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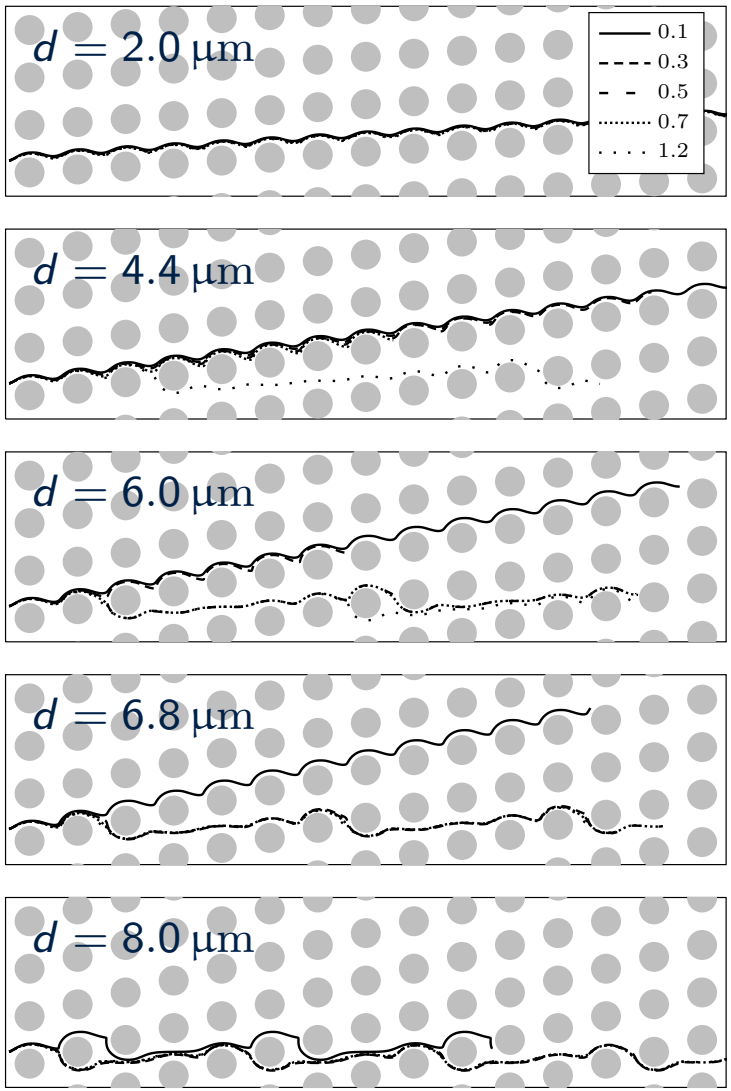
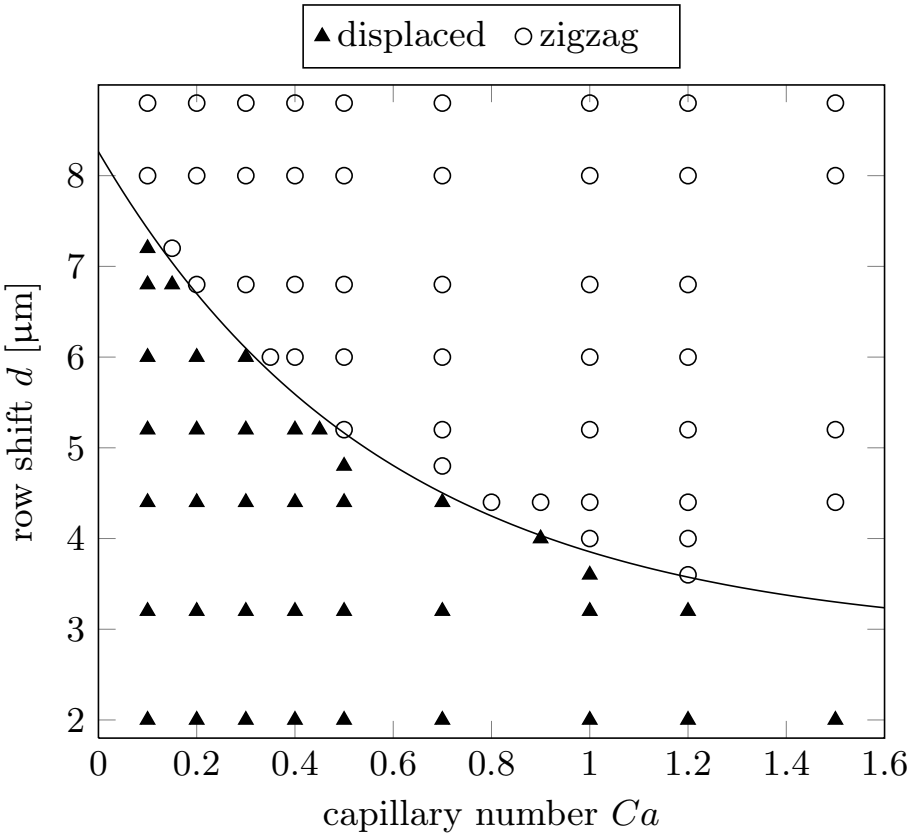
Main observation

Separation by deformability possible

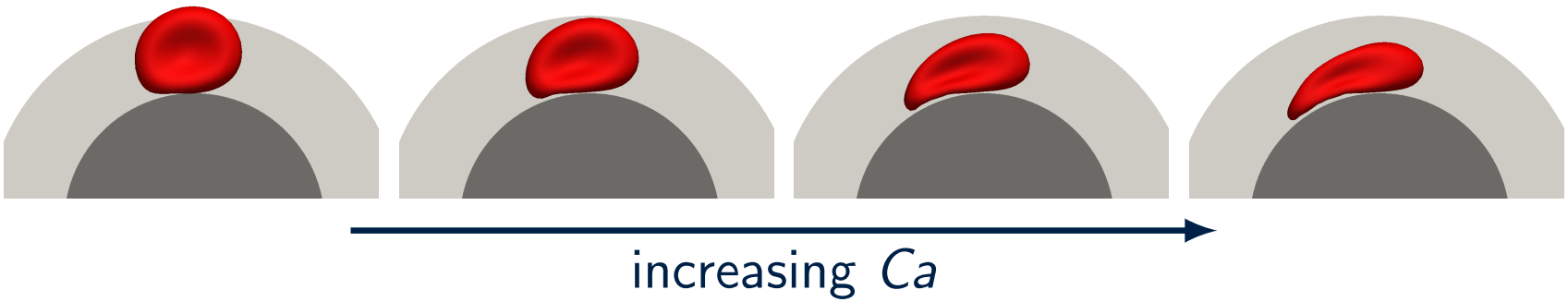


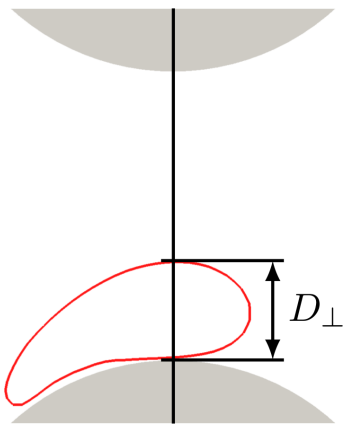
"Phase space" for RBC separation



- Critical separation line: $d_{\mathrm{cr}}(Ca) \Leftrightarrow Ca_{\mathrm{cr}}(d)$
- Can choose d to separate particle species with given Ca_1 and Ca_2

Effective RBC size





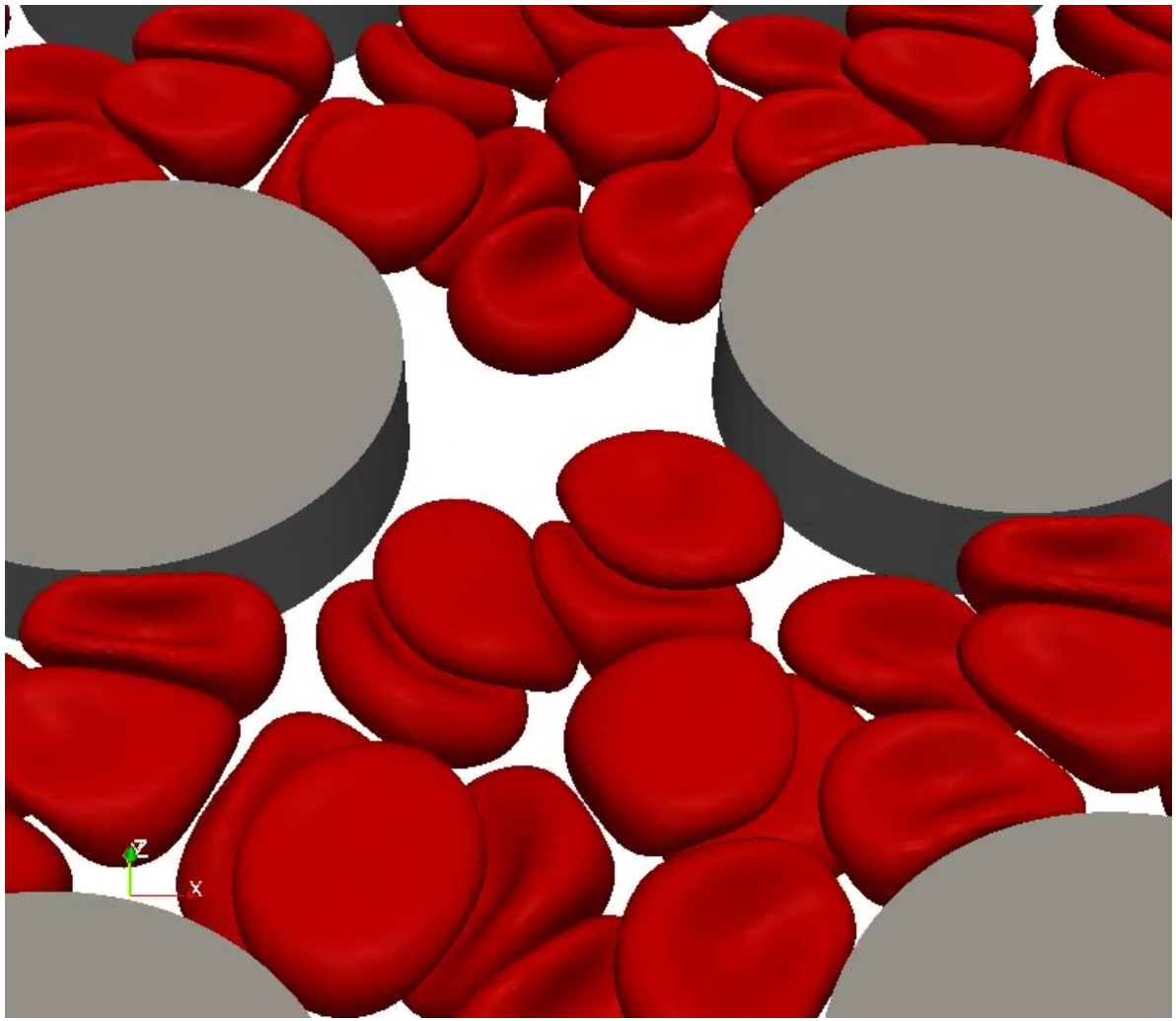
- Define effective RBC diameter $D_\perp$
- Take largest extension during passage

Key mechanism for separation

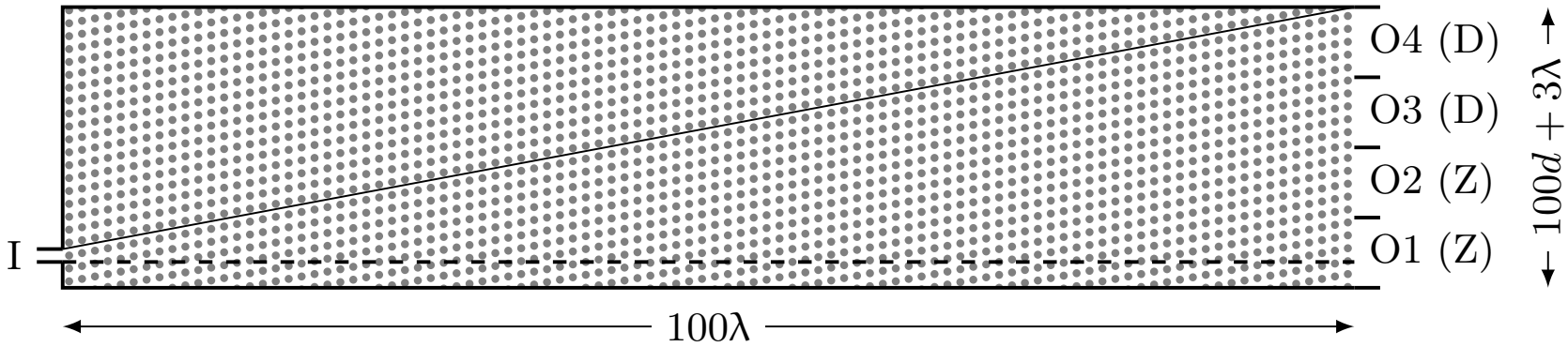
Apparent lateral RBC extension during passage

TK, Holmes, Coveney. Biomicrofluidics 8 (2014)

What happens at higher volume fractions?



Trajectories for denser suspensions (1)



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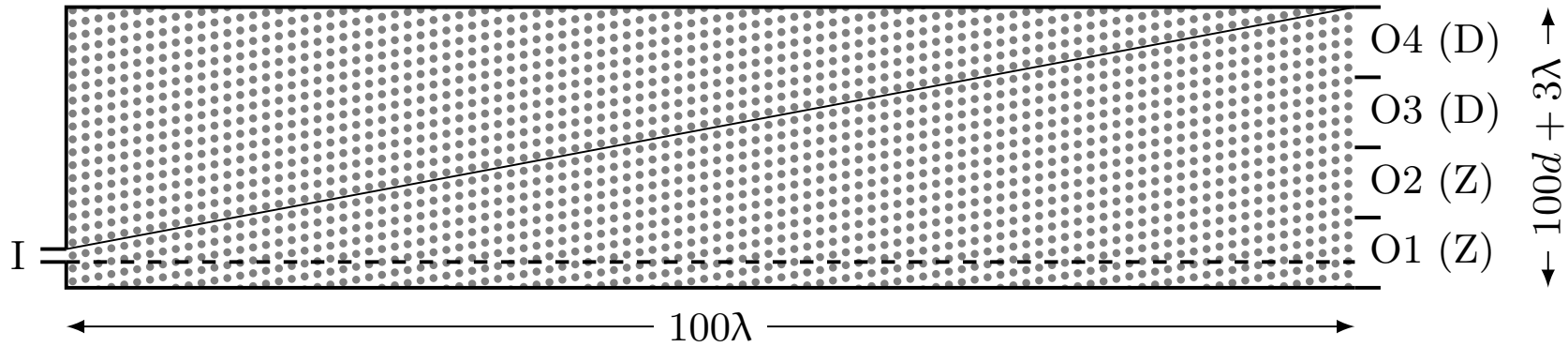
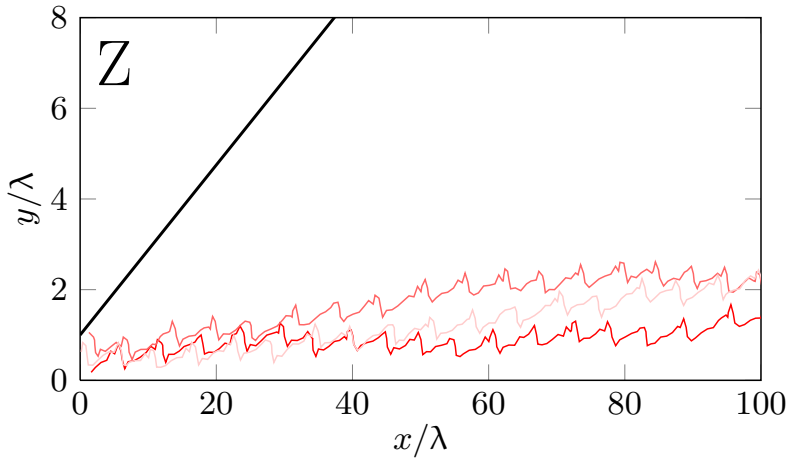
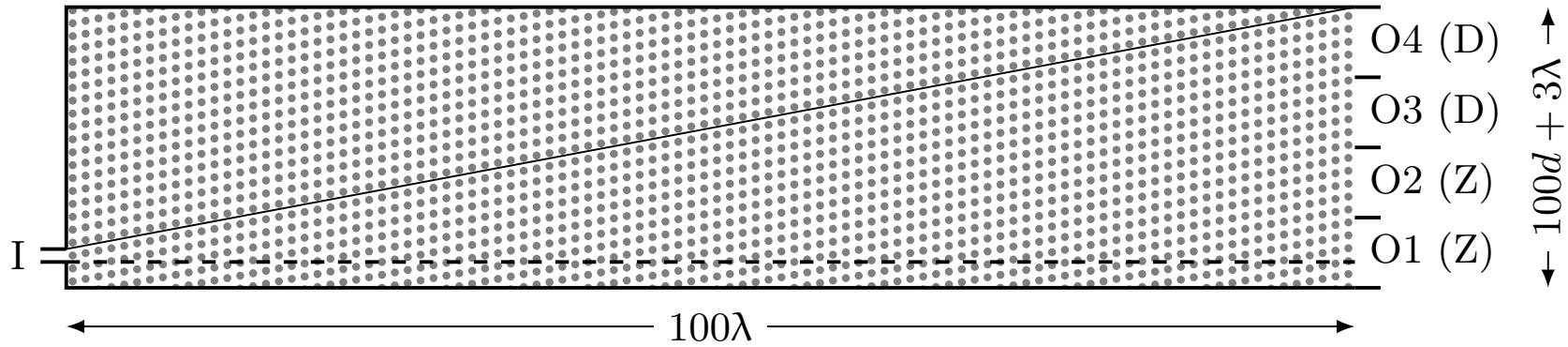


$d = 6.0\,\mu\mathrm{m},\ Ca = 1.0 \Longrightarrow$ expected zigzag (Z)



$Ht = 8\%$

Trajectories for denser suspensions (1)



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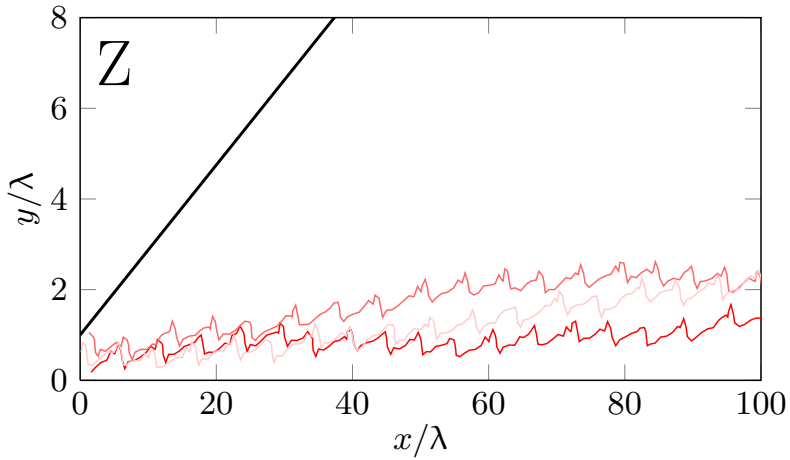
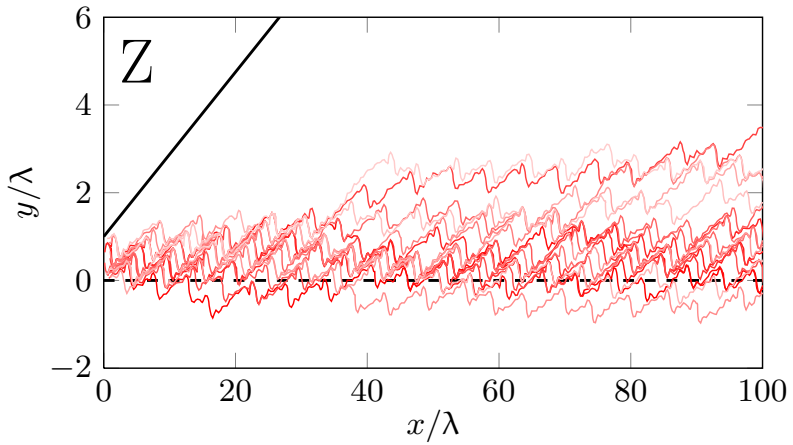
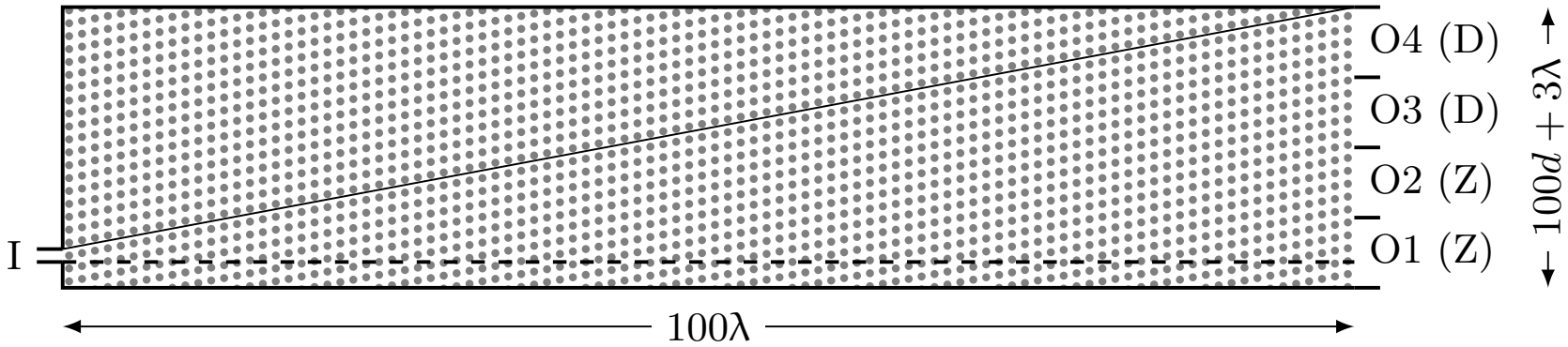


$Ht = 8\%$

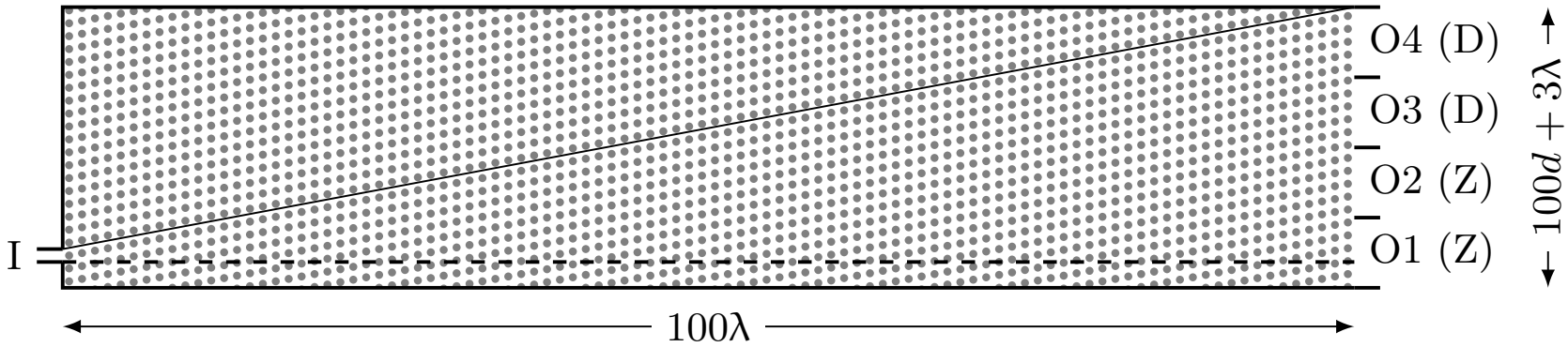


$Ht = 45\%$

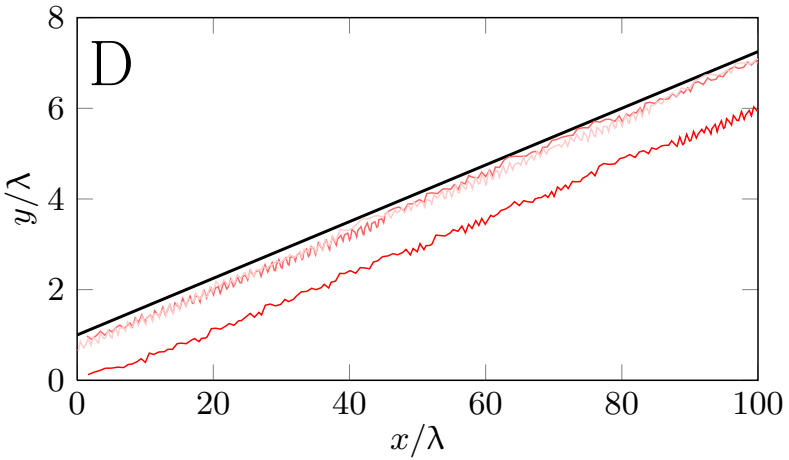
Trajectories for denser suspensions (2)



Trajectories for denser suspensions (2)

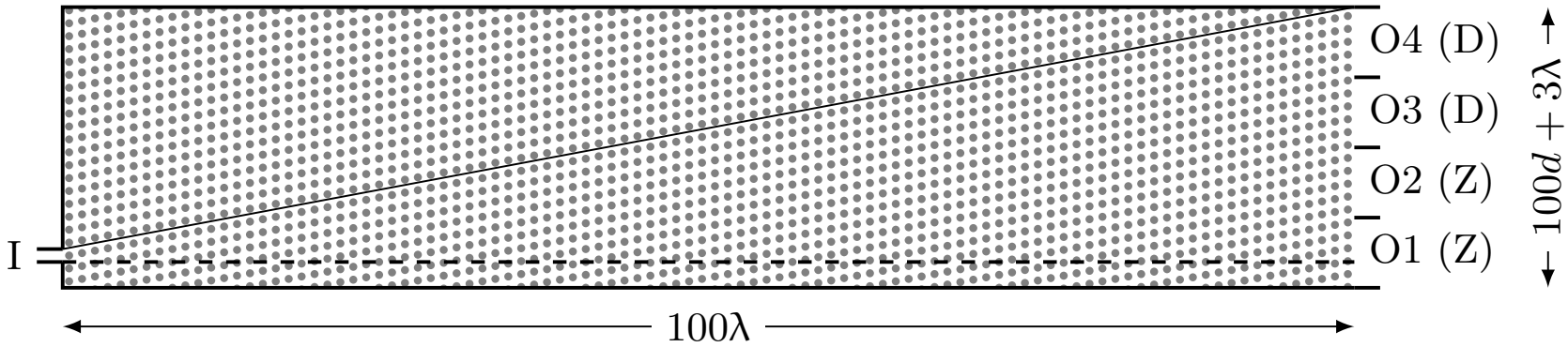


$d = 2.0\,\mu\mathrm{m},\ Ca = 1.0 \Longrightarrow$ expected displacement (D)



$Ht = 8\%$

Trajectories for denser suspensions (2)



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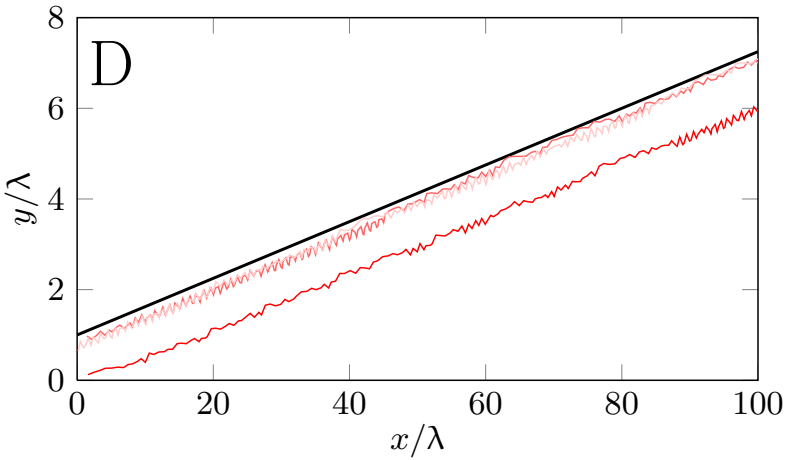

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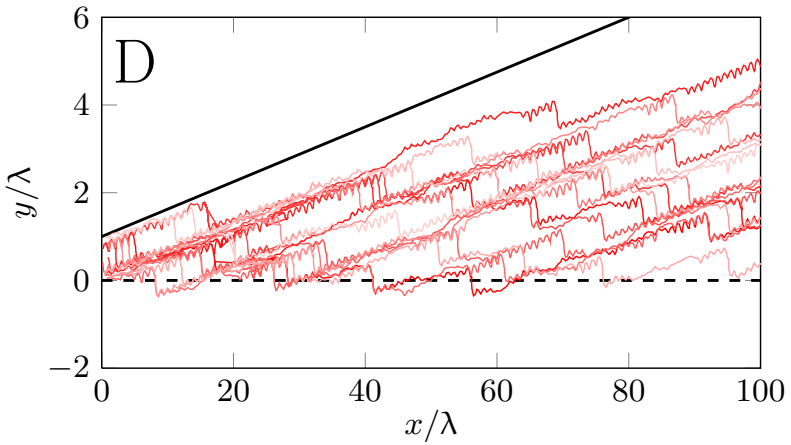
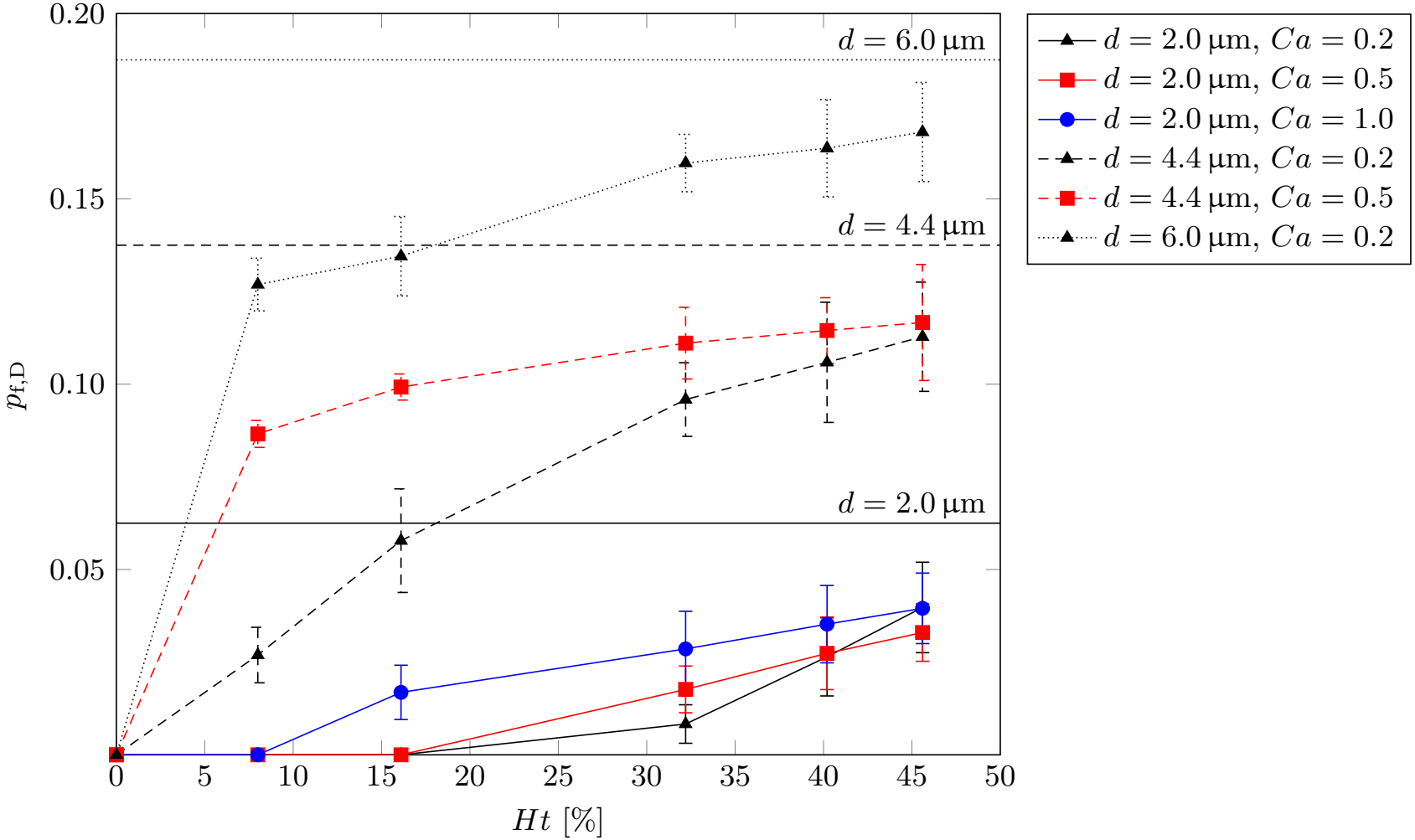


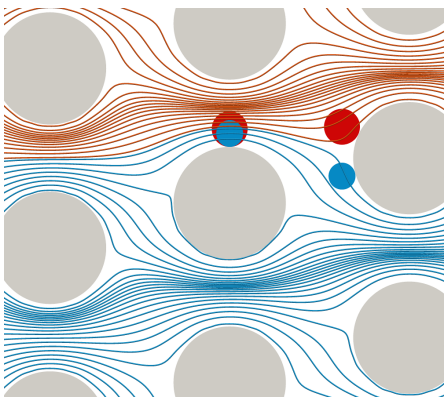
$Ht = 45\%$

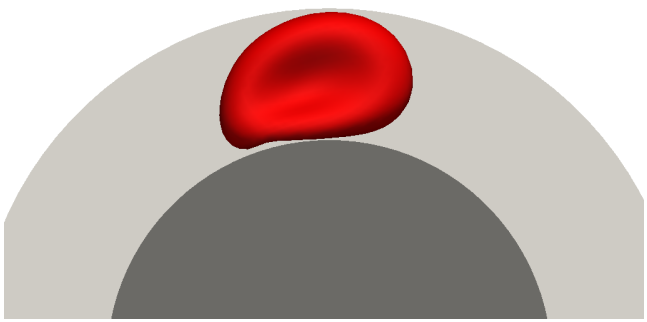
Displacement failures

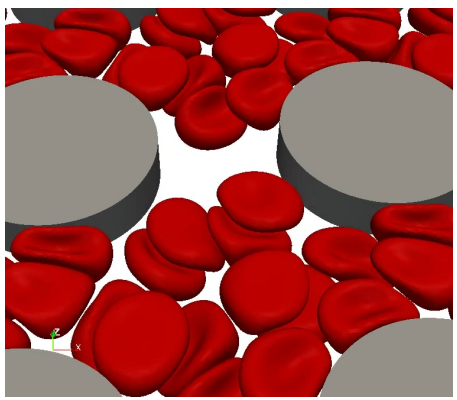


Summary

- Ultimate goal: smart geometries for passive separation
  $\Longrightarrow$ disease detection
- Here: deformability-based separation of RBCs
- Current problem: can it work at high volume fraction?
  $\Longrightarrow$ avoid dilution







Conference announcement

- **Home**
- Important dates
- Abstract submission
- Invited speakers & programme
- Fees & registration
- Travel & visa
- Accommodation
- Proceedings
- Recent DSFDs

Welcome to DSFD 2015

We are delighted to host the 24th Discrete Simulation of Fluid Dynamics (DSFD) conference in Edinburgh on **13th–17th July 2015**. The venue is The Royal Society of Edinburgh.

The local organisation is based at The University of Edinburgh and University of Strathclyde (contact local organisers at dsfd2015-info@ed.ac.uk).

Join the DSFD mailing list and follow us on Twitter to receive conference updates: @DSFD_Conference

Important notice: Edinburgh will be *extremely busy* during the conference. Please consider reserving accommodation now, even if unsure whether you will attend - most providers allow cancellation at no cost.

`http://www.dsfd2015.ed.ac.uk/home`