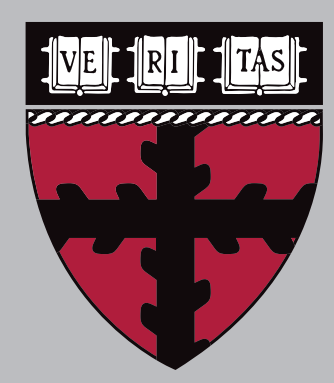




HARVARD

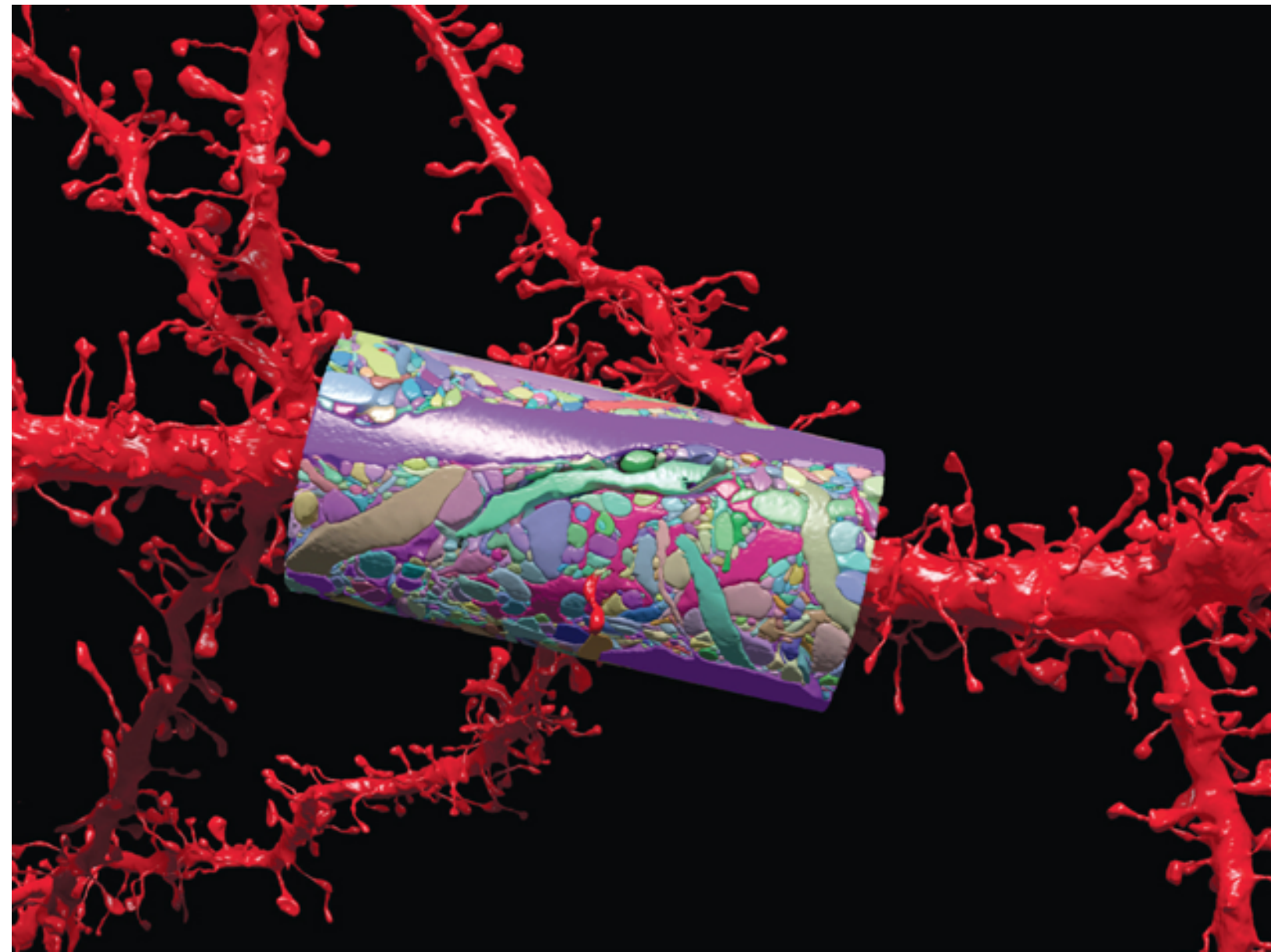
John A. Paulson
School of Engineering
and Applied Sciences

SIMULATING VESICLE TRAFFICKING IN DENDRITIC SPINES

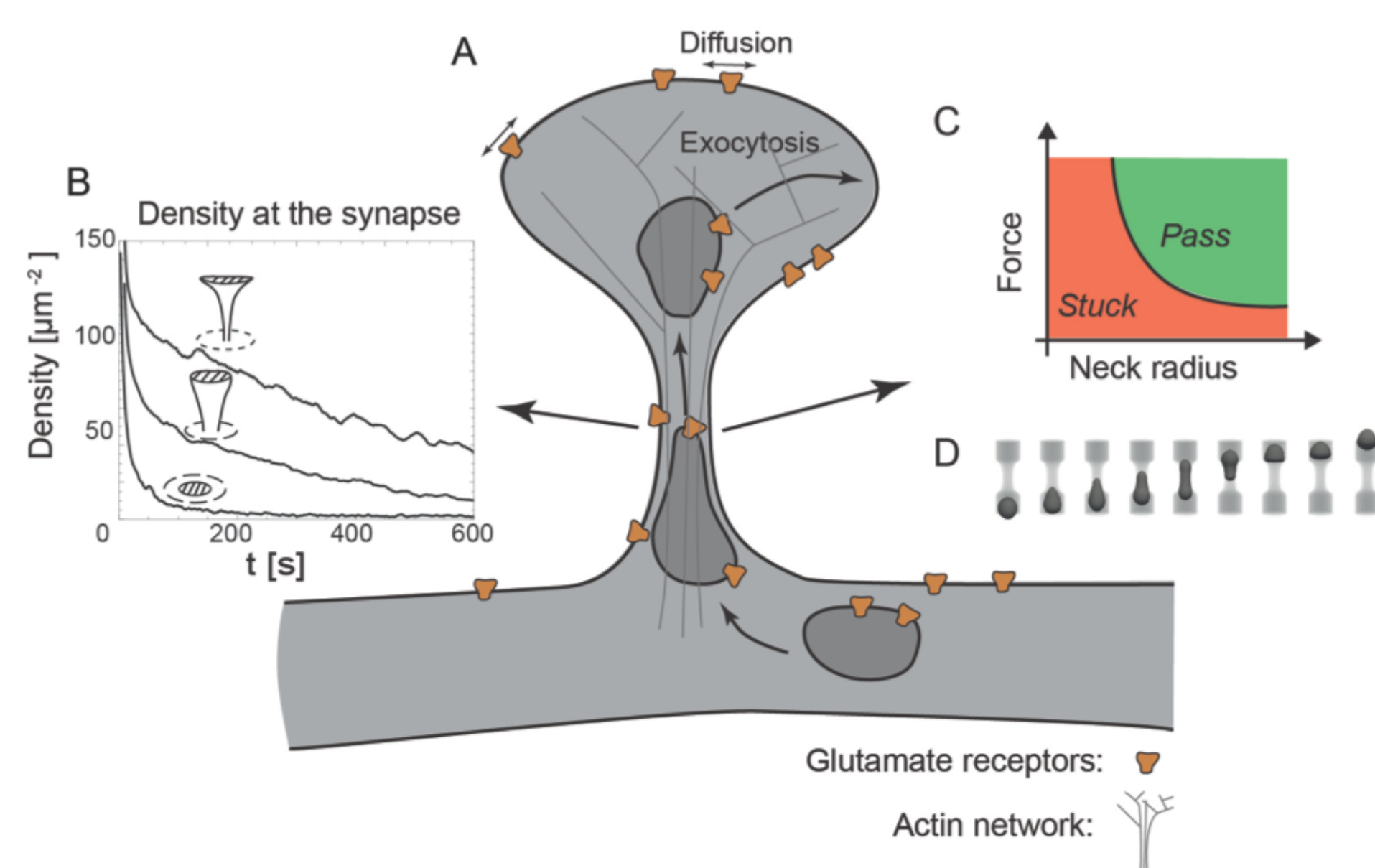
THOMAS FAI (TFAI@SEAS.HARVARD.EDU), HARVARD UNIVERSITY

MOTIVATION

Dendritic spines are mushroom-shaped structures characteristic of postsynaptic sites (image: Lichtman Lab, Harvard)

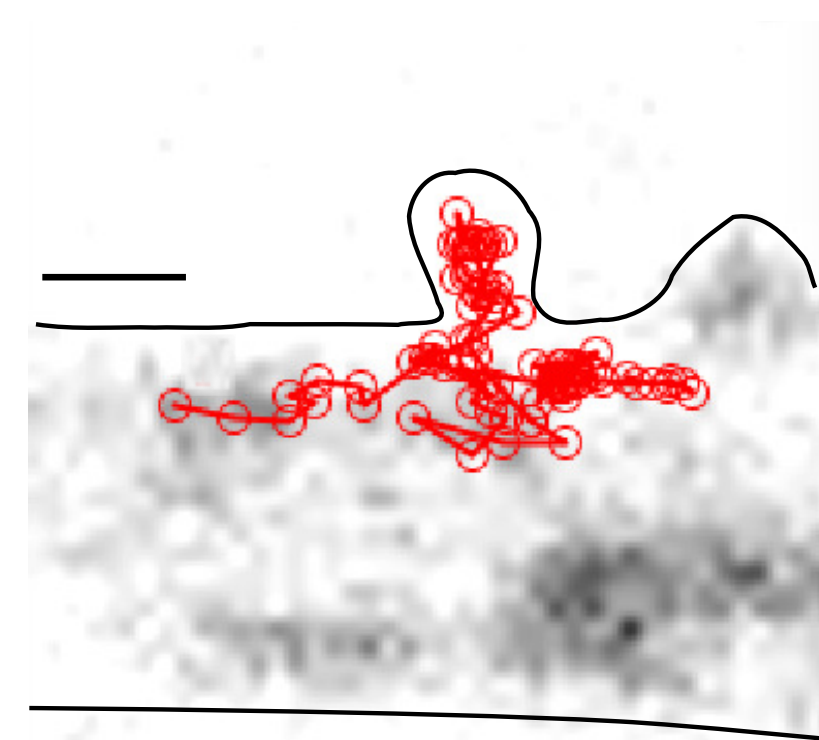


Motors force vesicles into spines (Adrian et al, *Frontiers in Neuroanatomy* 2014)

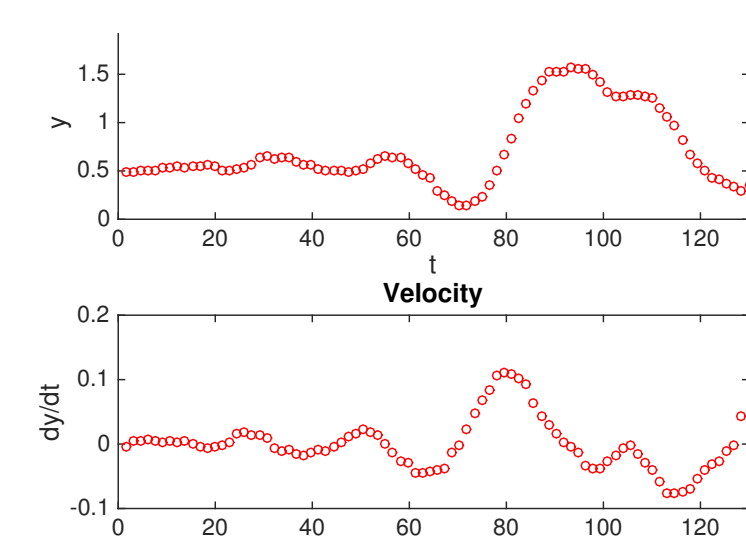


Vesicle trajectories are non-trivial

(Kapitein Lab, Utrecht)

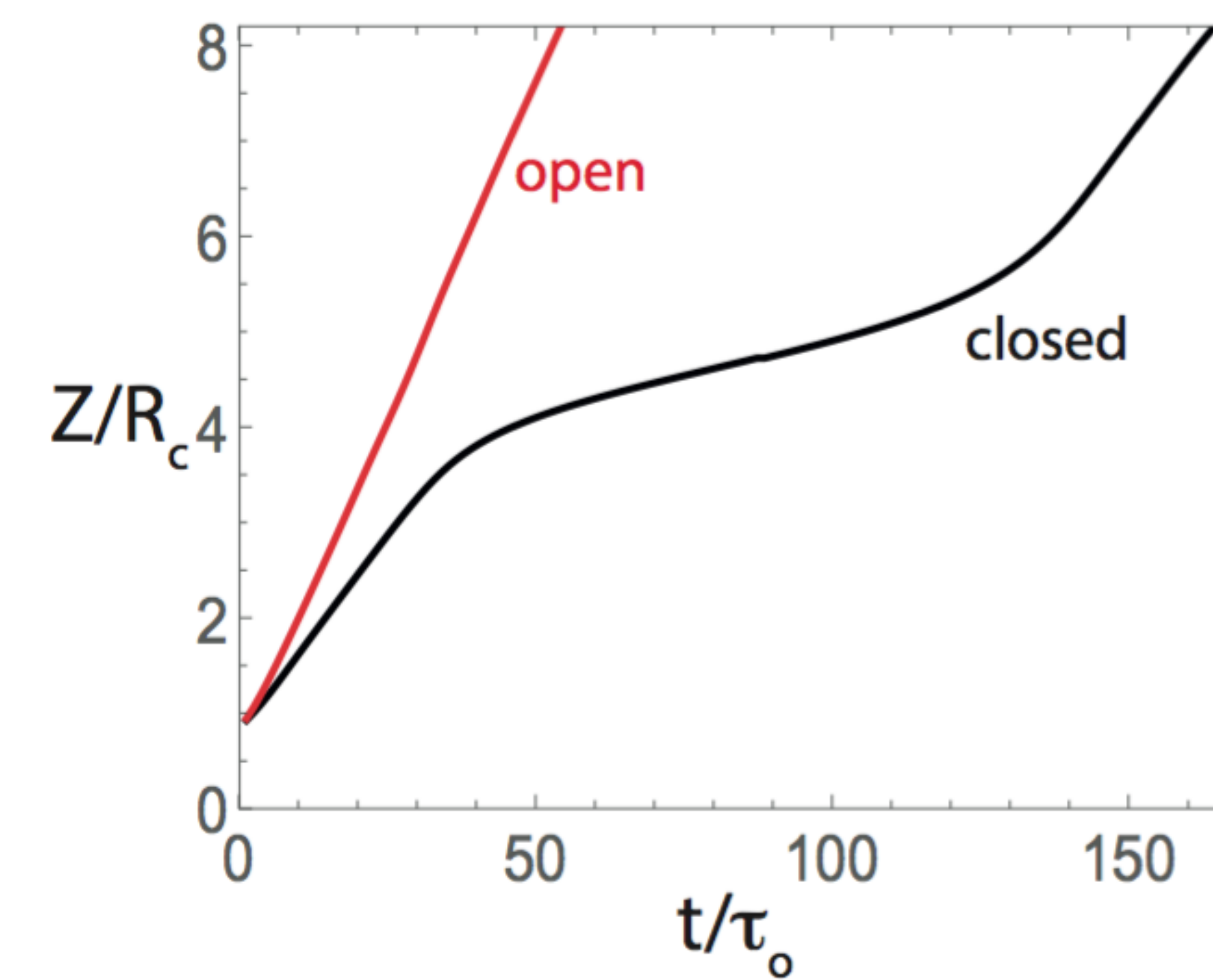
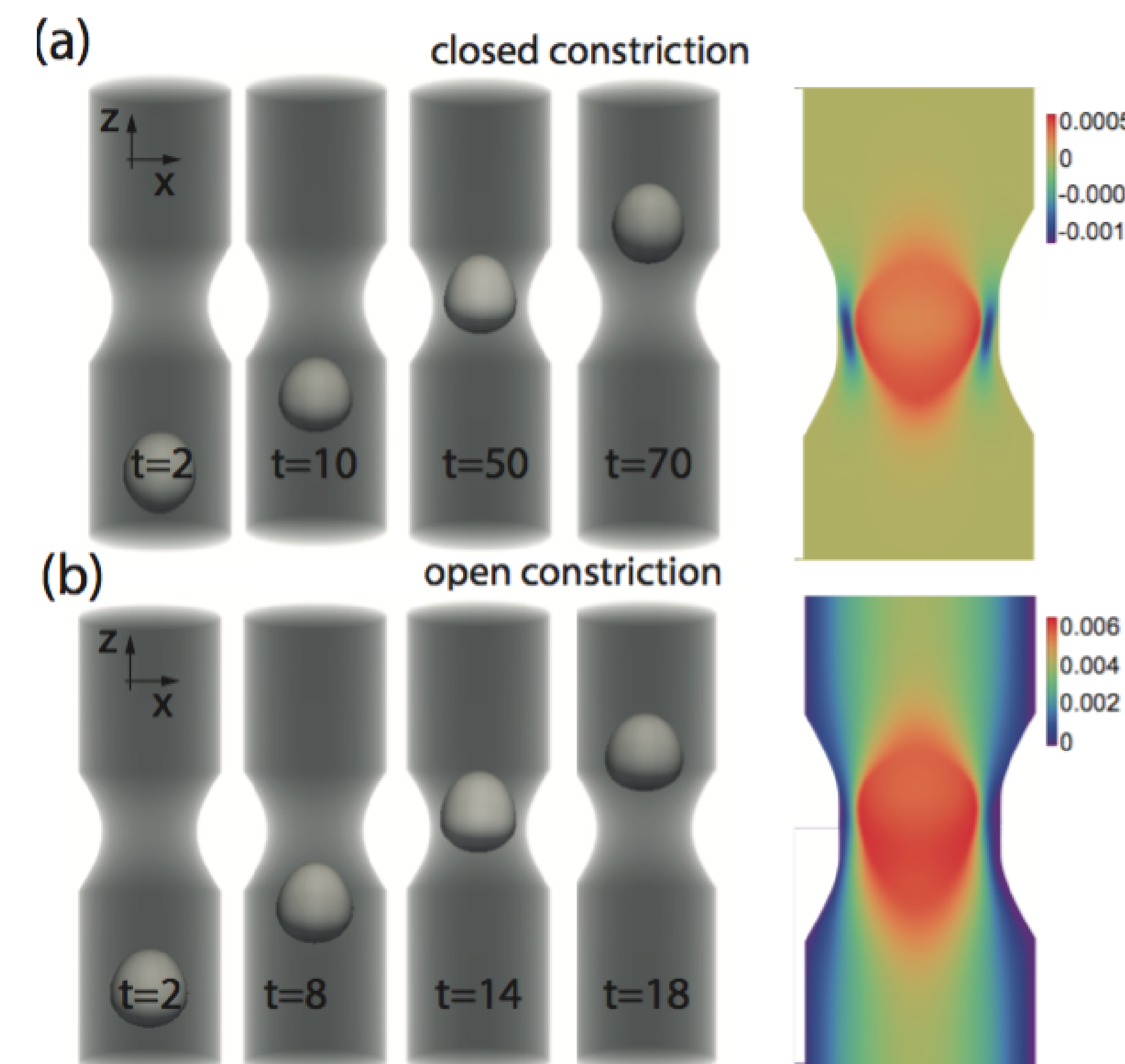


Tracking data



Trajectory

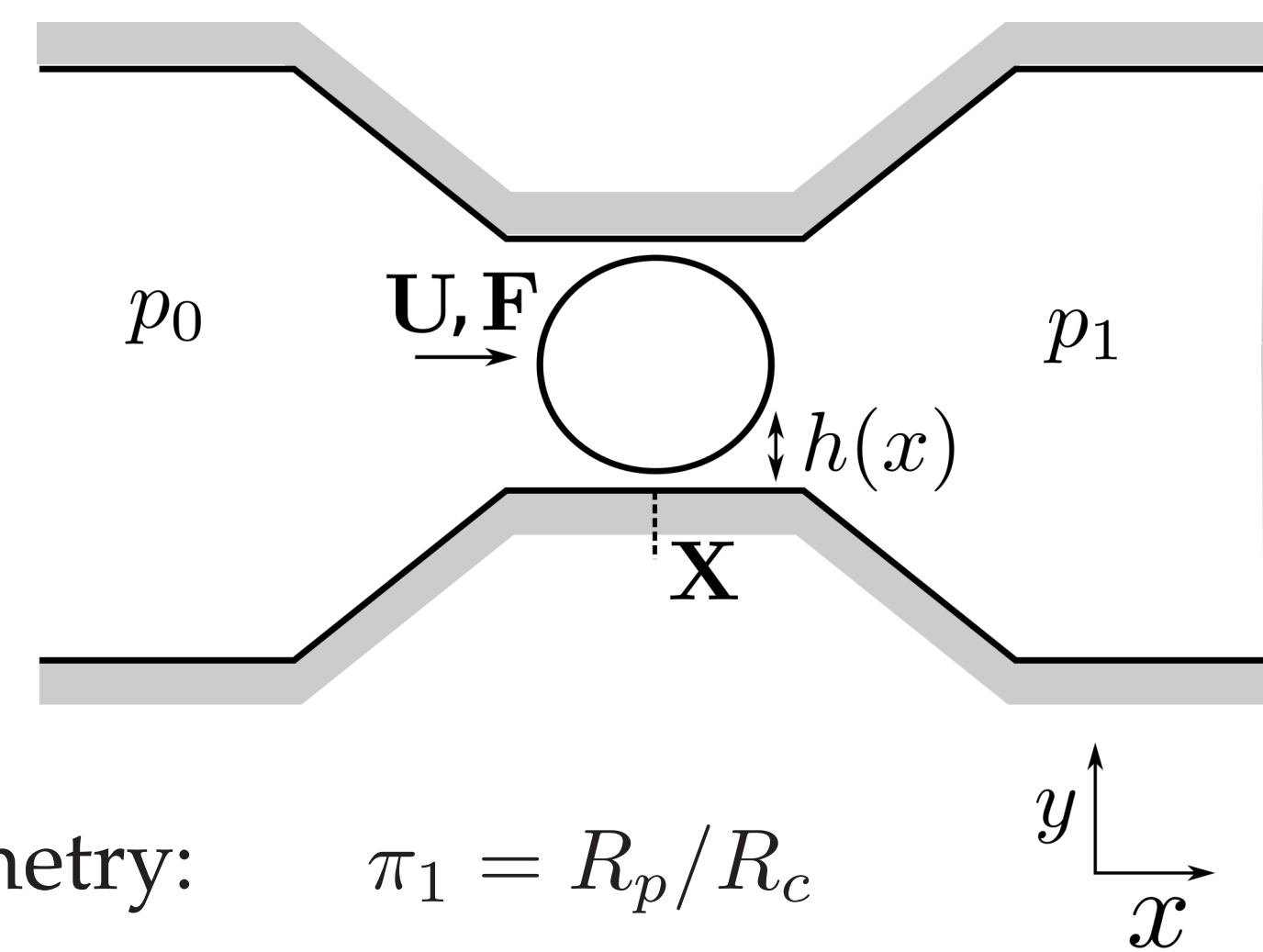
GEOMETRY MATTERS: CLOSED CAP SLOWS PASSAGE



Remy Kusters, TU Eindhoven

LUBRICATION MODEL

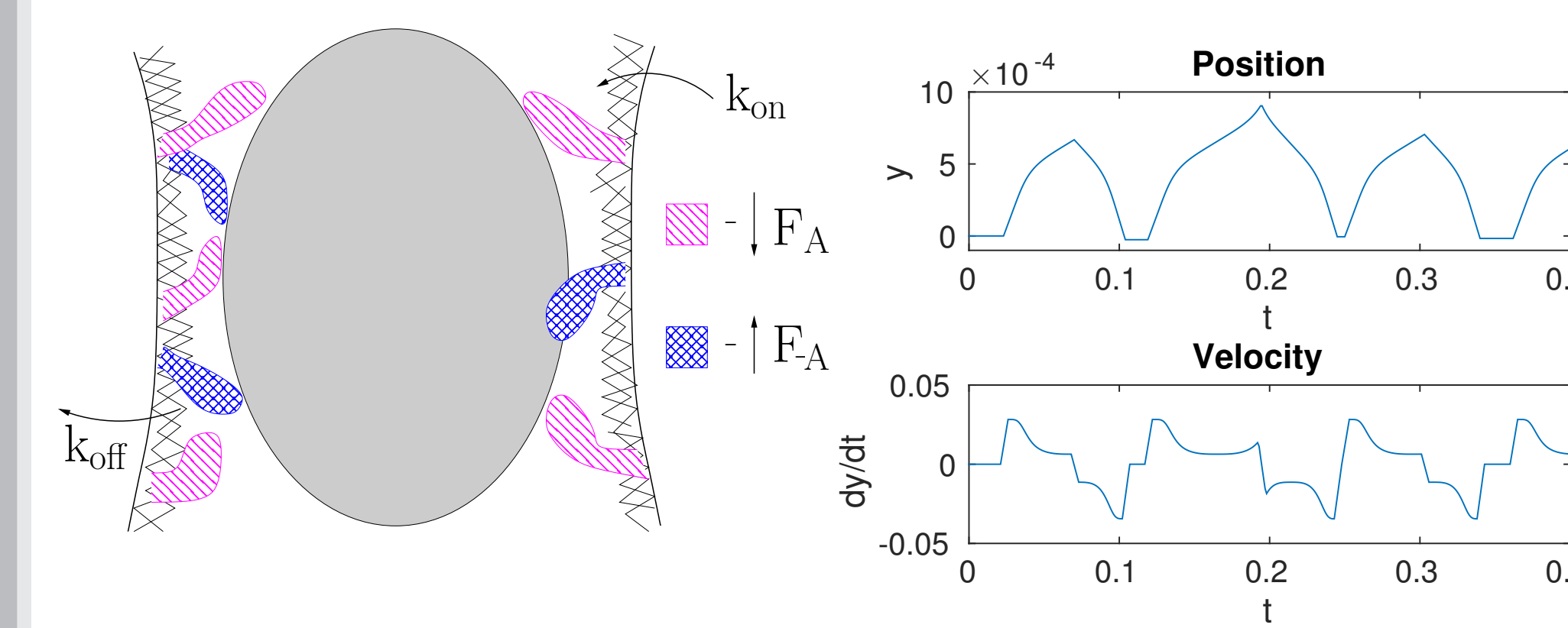
$p(x)$ - pressure
 Q - flow
 U - velocity
 $h(x)$ - height



Geometry: $\pi_1 = R_p/R_c$

Elasticity: $\pi_2 = FC/(\pi R_p^3)$

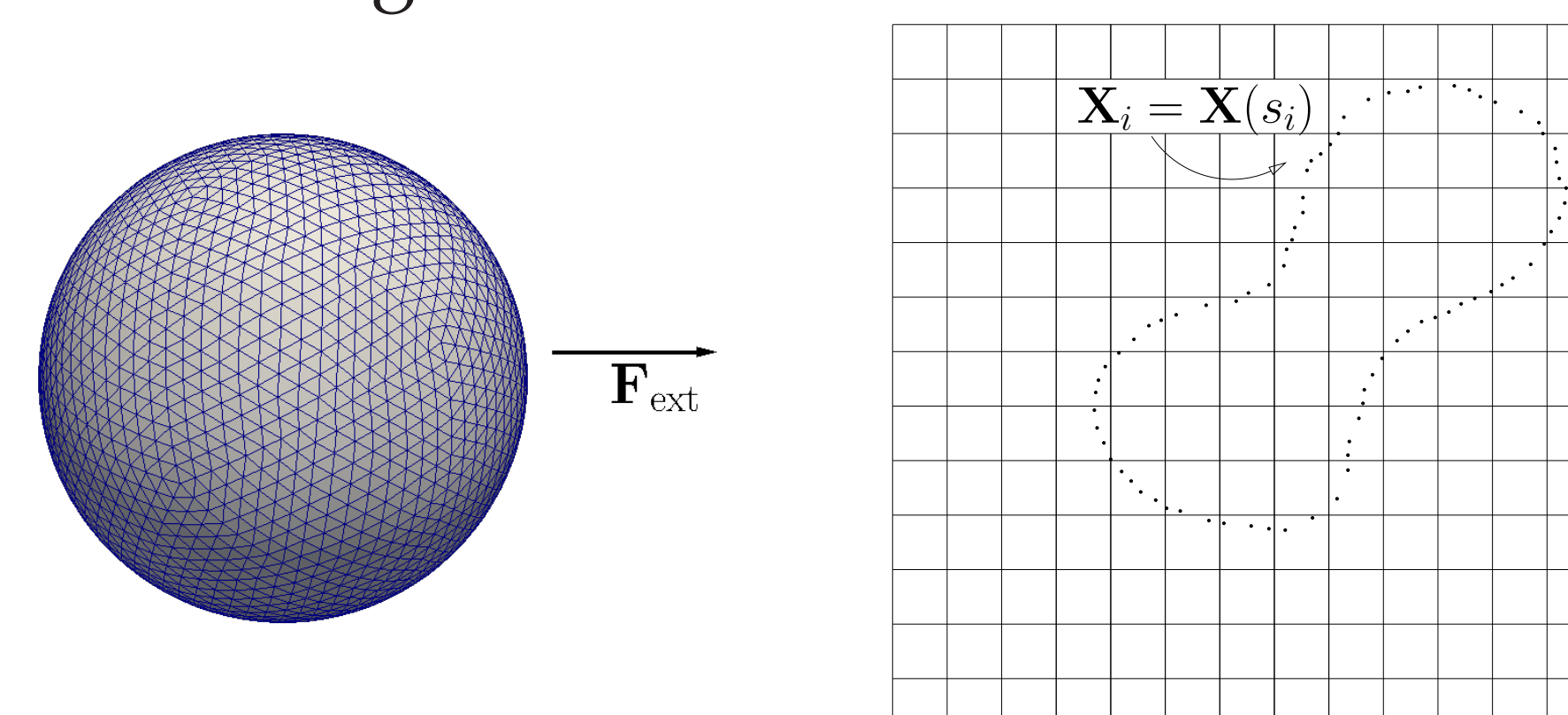
FORCING BY MOTORS



Motors introduce multistable dynamics

IMMERSED BOUNDARY METHOD

- Fluid-structure interaction
- Regularized delta function to communicate between grids.



Formulation:

$$\rho(\mathbf{x}, t) \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) + \nabla p = \mu \Delta \mathbf{u} + \mathbf{f}(\mathbf{x}, t)$$

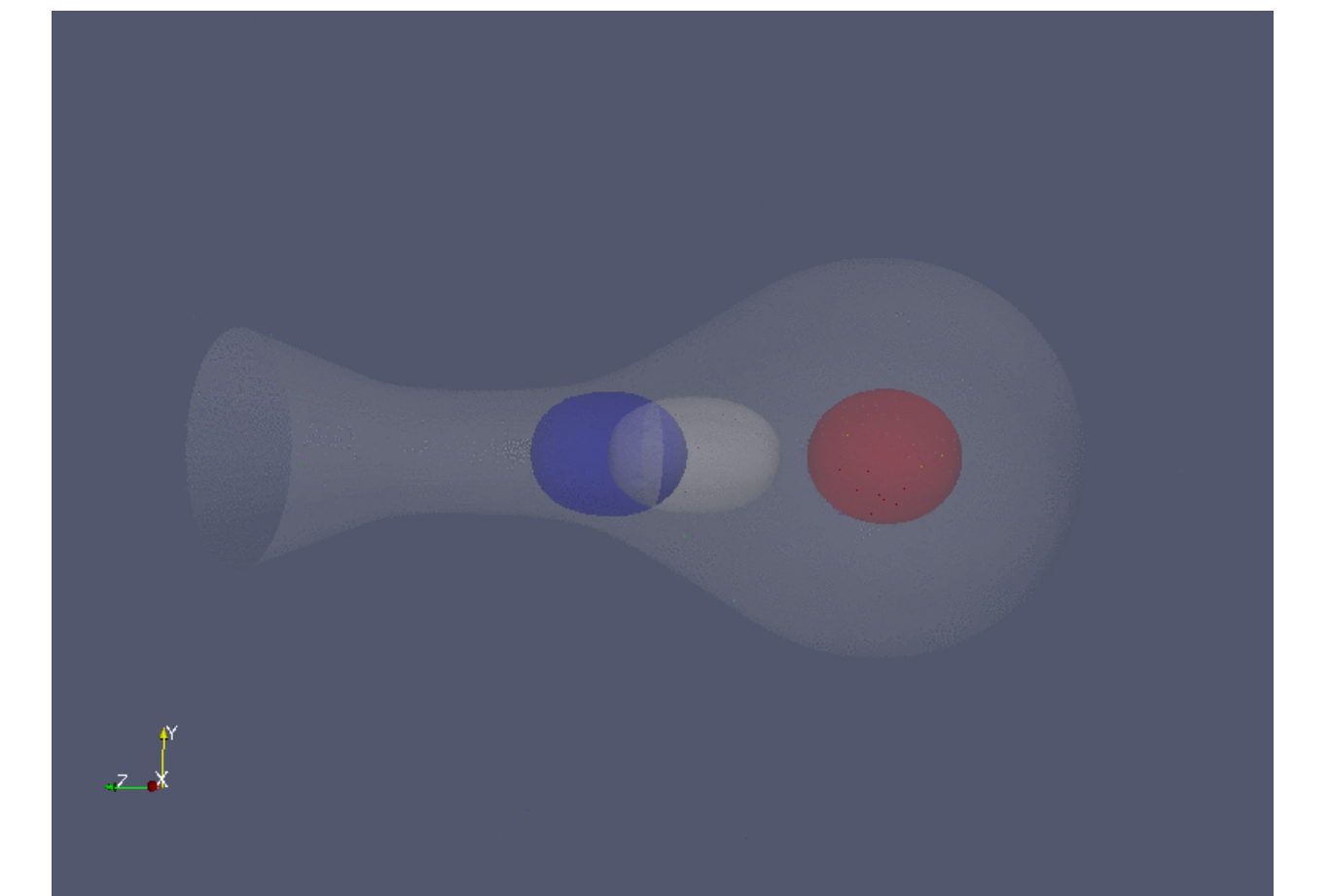
$$\nabla \cdot \mathbf{u} = 0$$

$$\mathbf{f}(\mathbf{x}, t) = \int \mathbf{F}(\mathbf{q}, t) \delta(\mathbf{x} - \mathbf{X}(\mathbf{q}, t)) d\mathbf{q}$$

$$\frac{\partial \mathbf{X}}{\partial t}(\mathbf{q}, t) = \int \mathbf{u}(\mathbf{x}, t) \delta(\mathbf{x} - \mathbf{X}(\mathbf{q}, t)) d\mathbf{x}$$

$$\mathbf{F}(\mathbf{q}, t) = \mathcal{F}[\mathbf{X}(\cdot, t)](\mathbf{q})$$

NUMERICAL DIFFICULTIES



Hard to resolve boundary layers: not converged

LUBRICATED IB METHOD

Mean velocity:

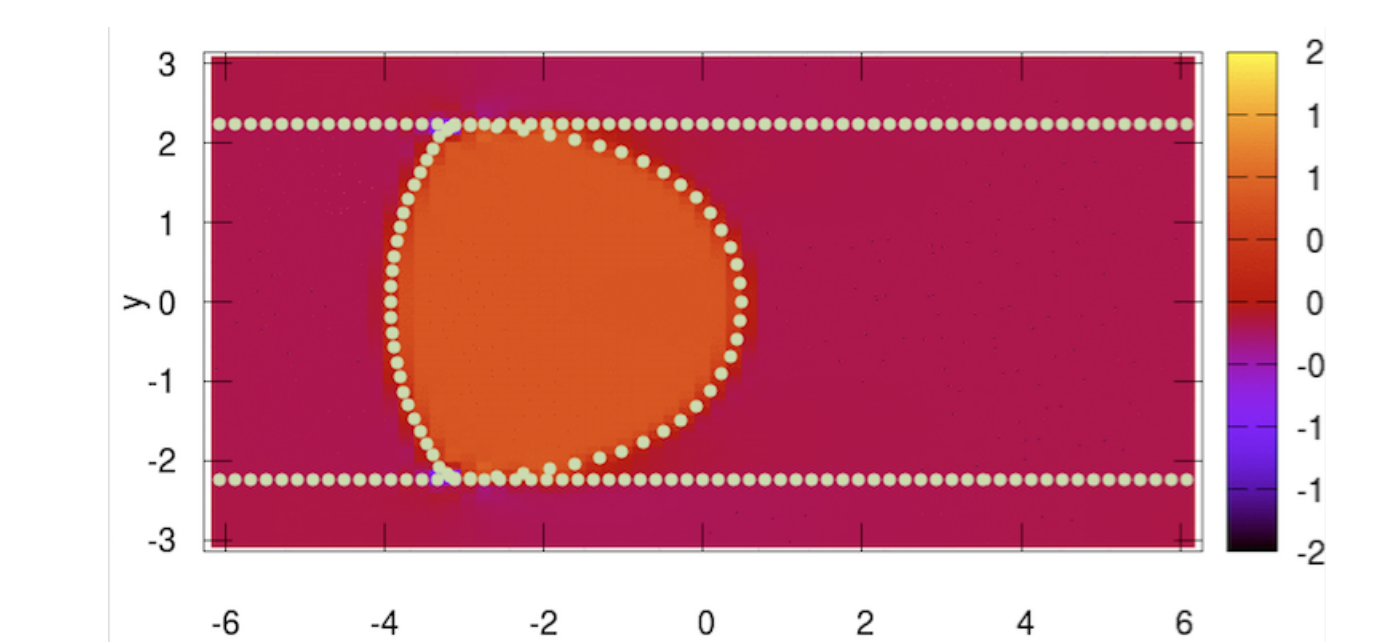
$$U_h + U_0 = U_h^{IB} + U_0^{IB}$$

Relative velocity:

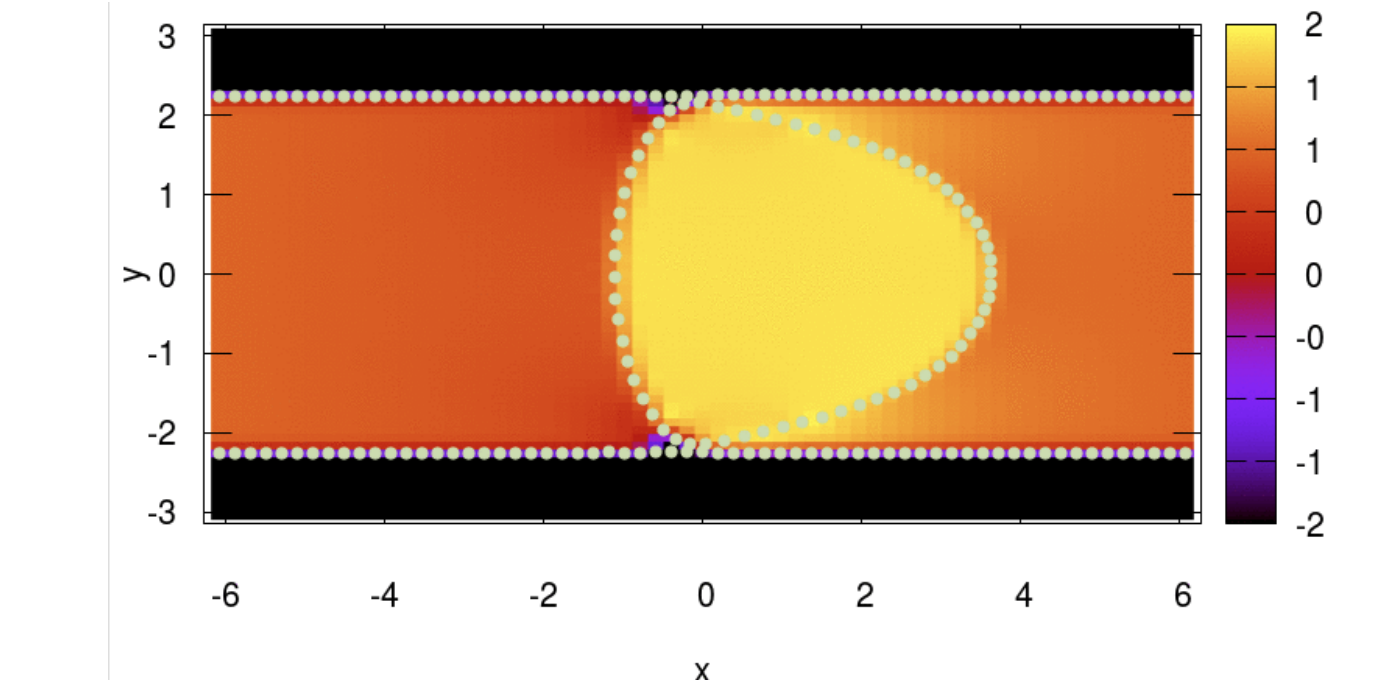
$$U_h - U_0 = \frac{h}{2} \left(\frac{F_h - F_0}{\mu} + \frac{\partial u}{\partial y} \Big|_{0^-} + \frac{\partial u}{\partial y} \Big|_{h^+} \right)$$

RESULTS IN CHANNEL FLOW

Standard method



Lubricated method



REFERENCES

- [1] Fai, Kusters, Harting, Rycroft, and Mahadevan, , Active elastohydrodynamics of vesicles in narrow, blind constrictions, Submitted.
- [2] Fai and Rycroft, Lubricated immersed boundary method in two dimensions, arXiv:1701.08865