Flowing Matter 2016 Porto

Amoeboid Swimming in Confined Geometry

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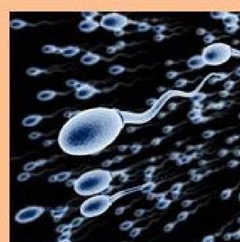
Swimming in Stokes flow

Various microswimmers in nature

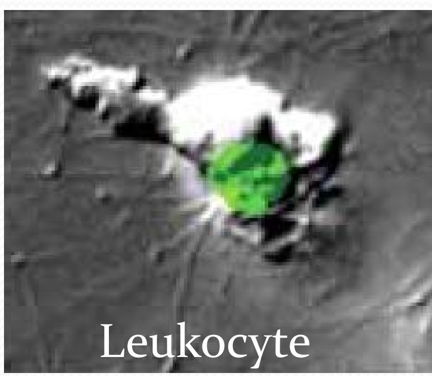

E. Coli


sperm

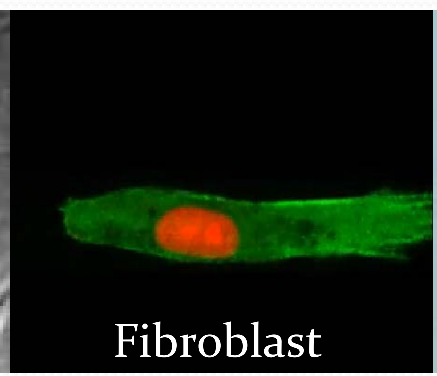

algae


paramecium

New swimming strategy - amoeboid motion

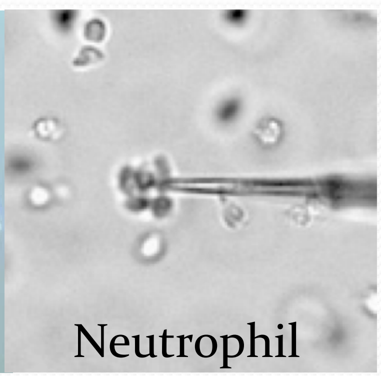


T. Lämmermann *et al.*, Nature (2008)



R.J. Petrie *et al.*, Science (2014)

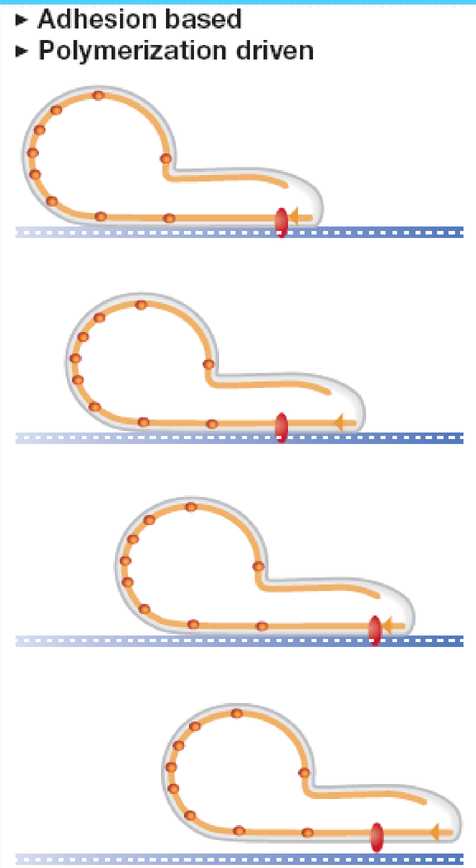
M. Arroyo *et al.*, PNAS (2013)

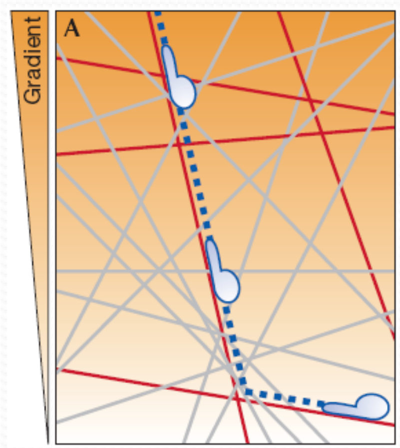


N. P. Barry *et al.*, PNAS (2010)

Two important ways of migration

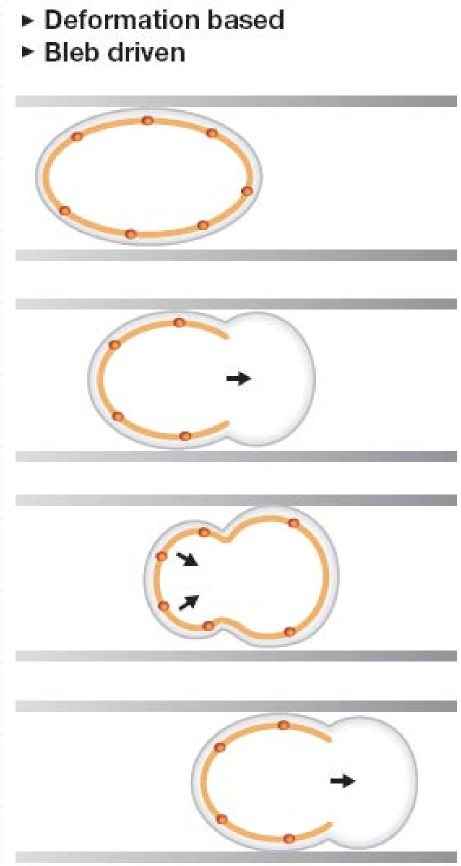
A) adhesion based migration

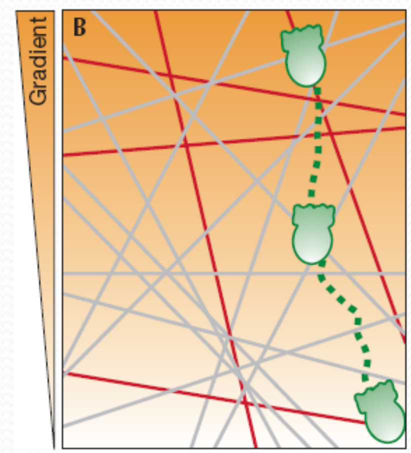




Mesenchymal cells

B) deformation based migration





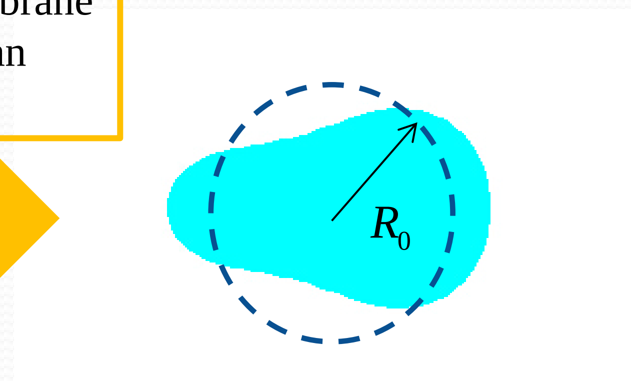
Leukocytes

J. Renkawitz *et al.*, EMBO report (2010), G. Charras *et al.*, Nat .Rev. Mol. Cell Biol. (2008)

2D amoeboid swimmer

A 2D inextensible membrane is employed to model an amoeboid swimmer.

Abstract Model



$$f_{\mathrm{A}}(\mathbf{r}_i,t)=\sum_{k=2}^{3}\hat{f}_k(t)\mathrm{e}^{iks}\ ,\ \mathbf{f}_{\mathrm{A}}(\mathbf{r}_i,t)=f_{\mathrm{A}}(\mathbf{r}_i,t)\mathbf{n}(\mathbf{r}_i,t)$$

$k=1$ only contributes a unidirectional translation in space $\left(\text{an ignorable change of } \mathrm{O}\left((\Delta \mathrm{r})^2\right) \text{ in other directions}\right)$, while $k=0$ contributes a discontinuous jump on the membrane.

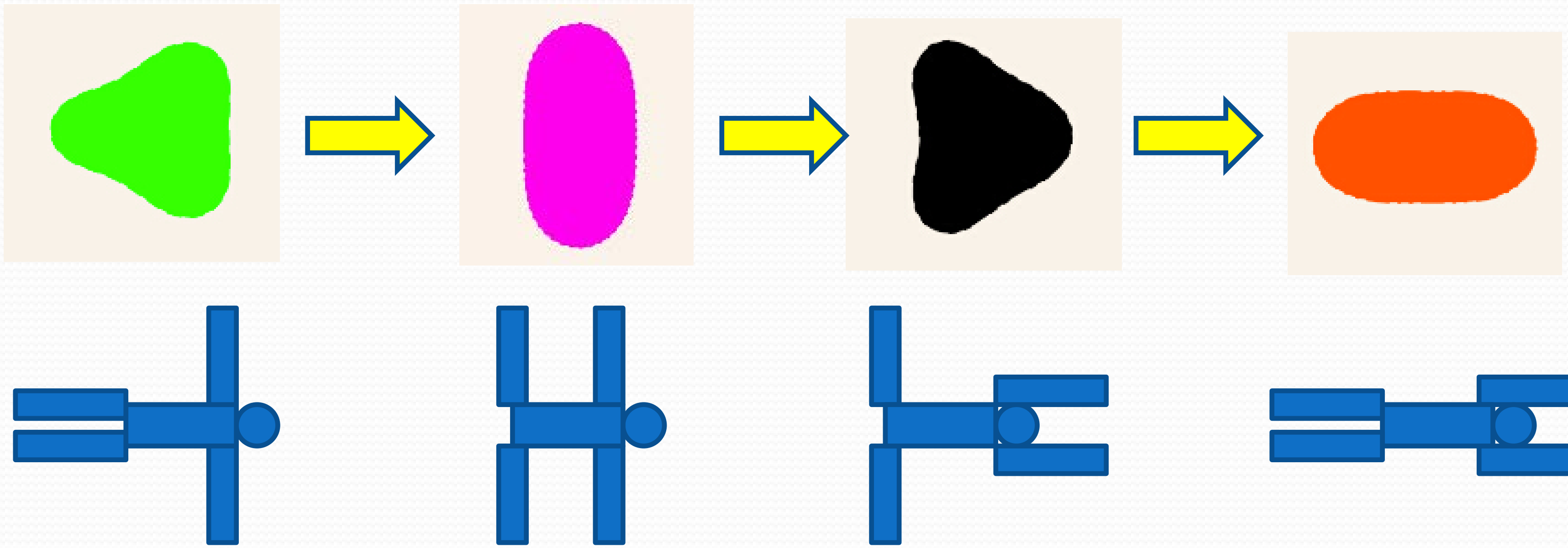
$$\mathbf{f}(\mathbf{r}_i)=\mathbf{f}_{\mathrm{A}}(\mathbf{r}_i)+\mathbf{f}_{\mathrm{T}}(\mathbf{r}_i)+\mathbf{f}_0+\tilde{f}_0\mathbf{t},$$
$$=\mathbf{f}_{\mathrm{A}}(\mathbf{r}_i)-\zeta c\mathbf{n}+\frac{\partial\zeta}{\partial s}\mathbf{t}+\mathbf{f}_0+\tilde{f}_0\mathbf{t},$$

$$\mathbf{F}_{\mathrm{total}}=\oint\mathbf{f}(\mathbf{r}_i)\,ds=0,$$

$$\mathbf{T}_{\mathrm{total}}=\oint\left[\mathbf{r}_i\times\mathbf{f}(\mathbf{r}_i)\right]ds=0.$$

Amoeboid swimming strategy

A non-reciprocal deformation cycle for amoeboid swimming



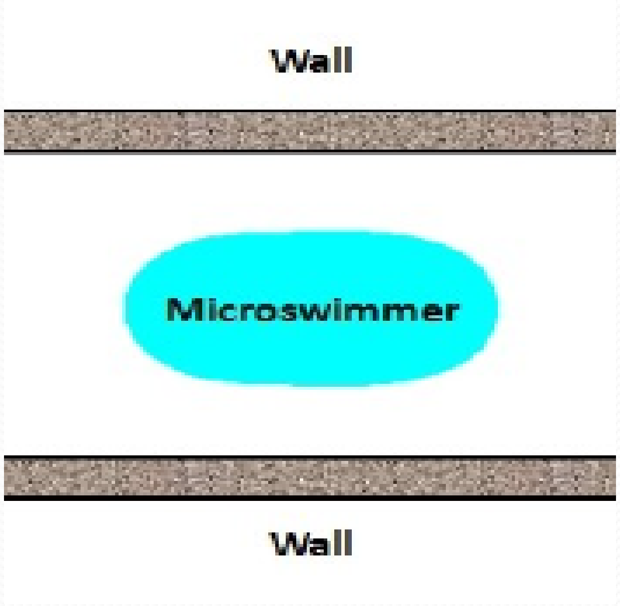
Boundary integral method

An appropriate boundary integral method with a double wall Green's function kernel is applied to describe a simple rigid confined geometry

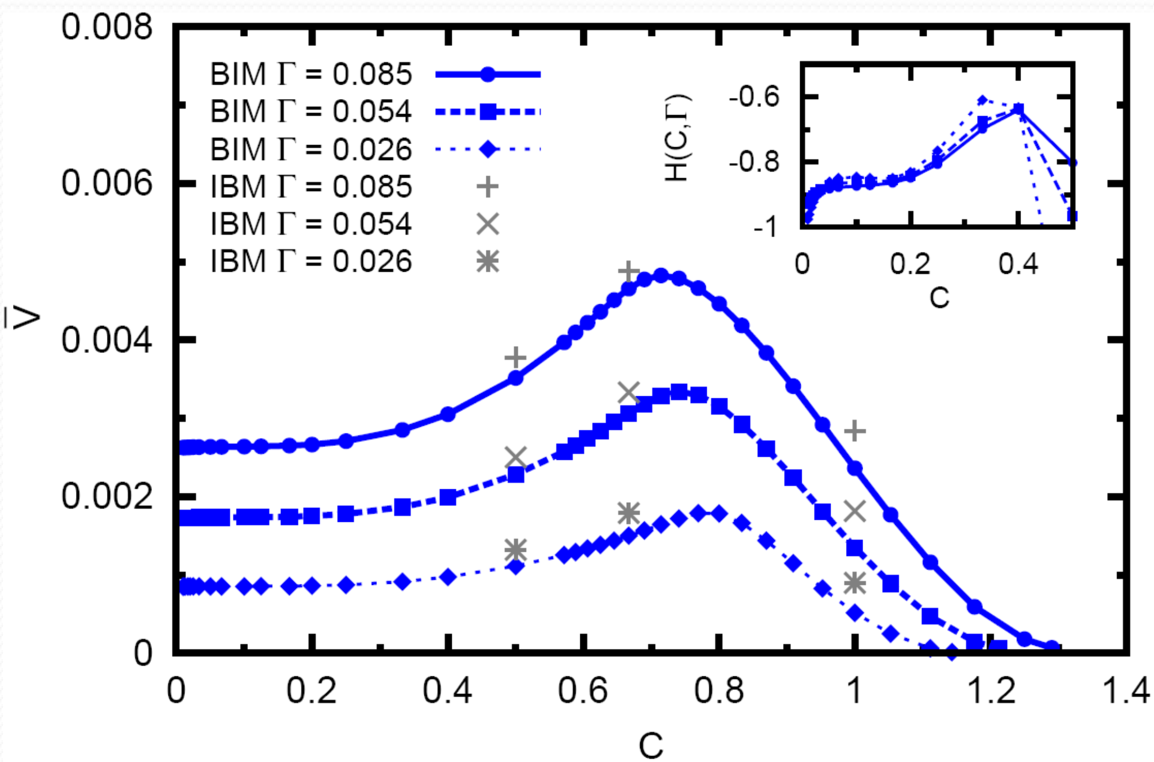
$$\mathbf{v}(\mathbf{r}_0) = \frac{1}{2\pi\eta_0(1+\lambda)} \int_{\text{mem}} ds\, \mathbf{f}(\mathbf{r}) \cdot G^{2\text{W}}(\mathbf{r},\mathbf{r}_0)$$

$$+\frac{1-\lambda}{2\pi(1+\lambda)} \int_{\text{mem}} ds\, \mathbf{v}(\mathbf{r}) \cdot T^{2\text{W}}(\mathbf{r},\mathbf{r}_0) \cdot \mathbf{n}(\mathbf{r}),$$

where $G^{2\text{W}}(\mathbf{r},\mathbf{r}_0) = G^{\text{F}}(\mathbf{r},\mathbf{r}_0) + G^{\text{H}}(\mathbf{r},\mathbf{r}_0)$, $T^{2\text{W}}(\mathbf{r},\mathbf{r}_0) = T^{\text{F}}(\mathbf{r},\mathbf{r}_0) + T^{\text{H}}(\mathbf{r},\mathbf{r}_0)$. G^{H} and T^{H} meet the non-slip boundary conditions on two walls.



Confined velocities and a scaling function for weak confined regime



H. Wu *et al.*, arXiv:1502.03975

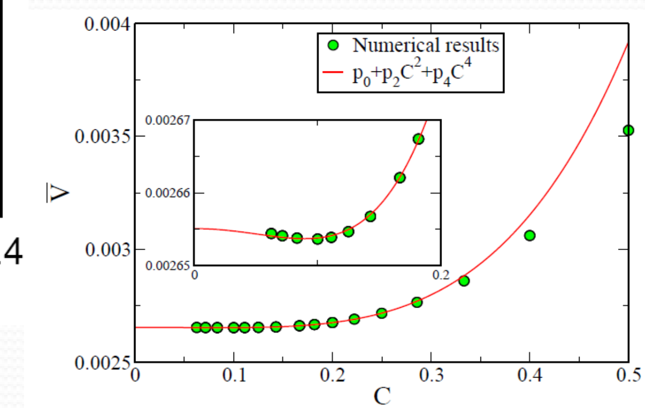
Strength of confinement: $C=\frac{2R_0}{W}$,

W is the distance between two walls.

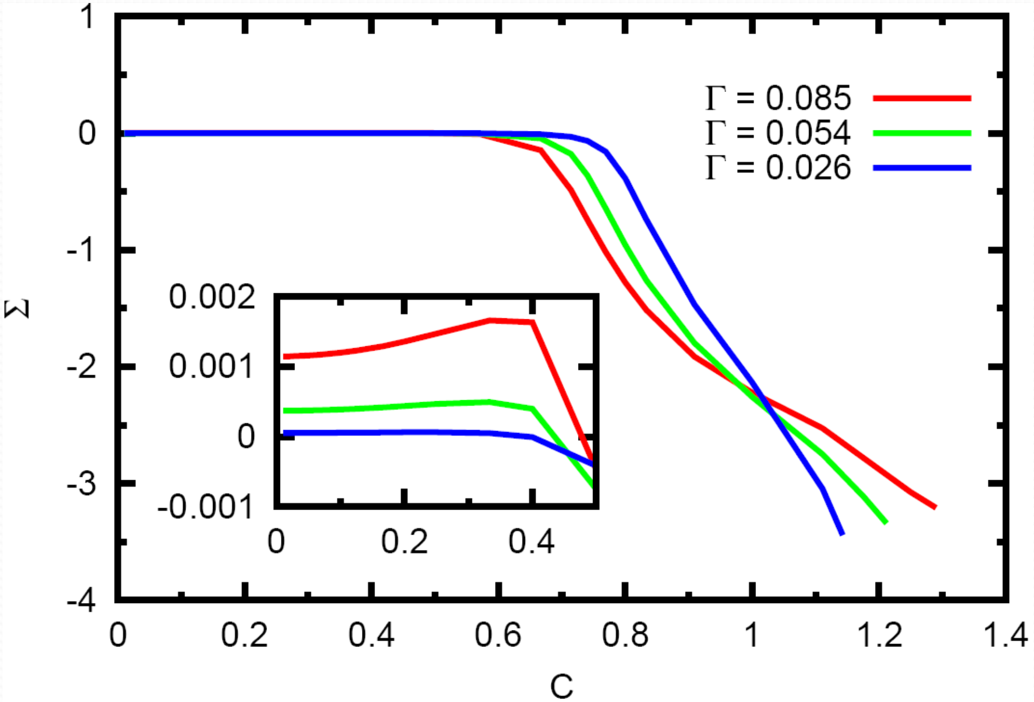
$$H(C,\Gamma)=\left[\frac{\bar{V}(C,\Gamma)}{(\alpha_0+\alpha_4 C^4)\Gamma}-1\right]\frac{1}{\Gamma},$$

$$\bar{V}(C,\Gamma)=VT_c/R_0,$$

Γ is normalized excess length.



Wall-induced pusher-puller transition



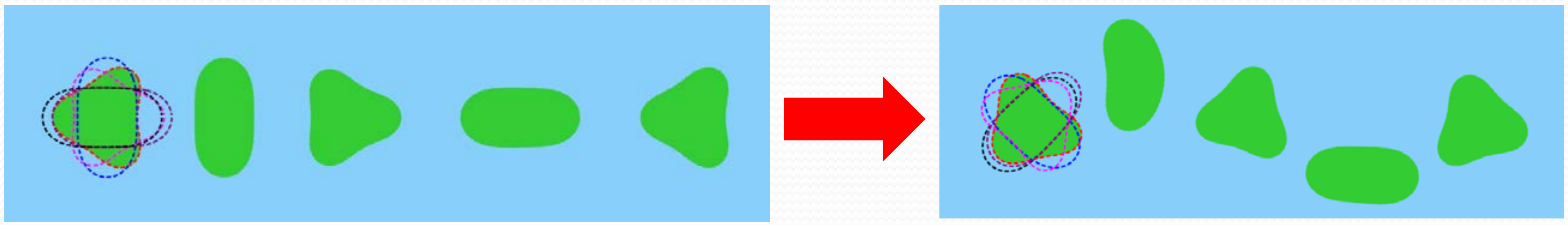
Stresslet $\Sigma = \sigma_{xx} - \sigma_{yy}$ for axisymetric case

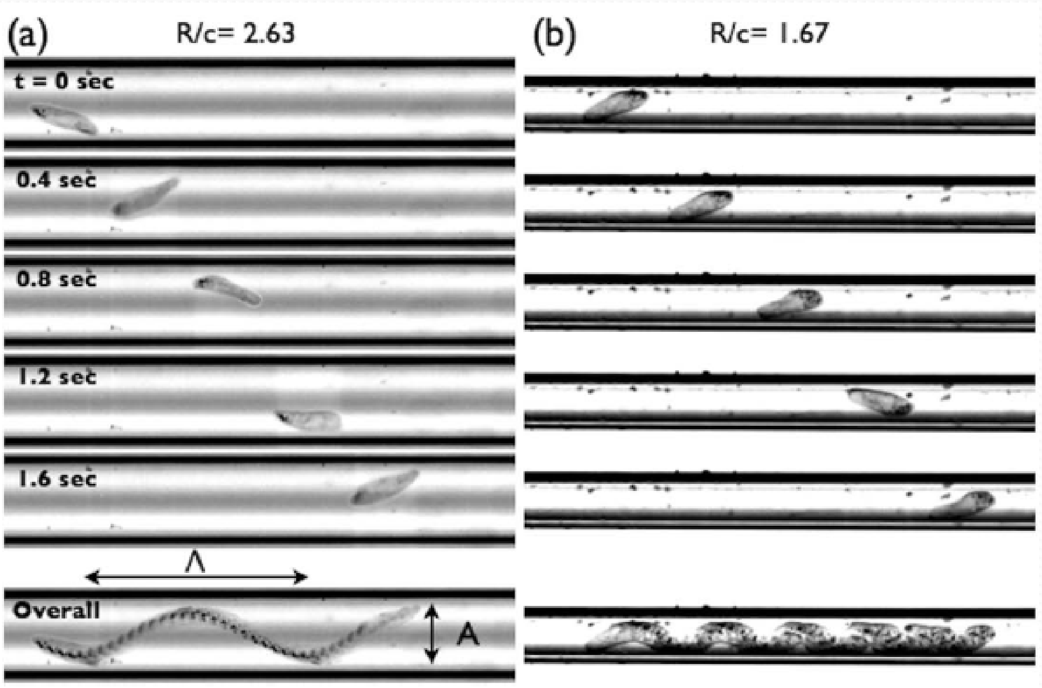
$$\begin{cases} \Sigma > 0, & \text{pusher at weak confinement,} \\ \Sigma = 0, & \text{at a critical transition point,} \\ \Sigma < 0, & \text{puller at strong confinement.} \end{cases}$$

where x represents the orientaion of amoeboid motion, while y is orthogonal.

H. Wu *et al.*, Phys. Rev. E **92**, 050701(R) (2015)

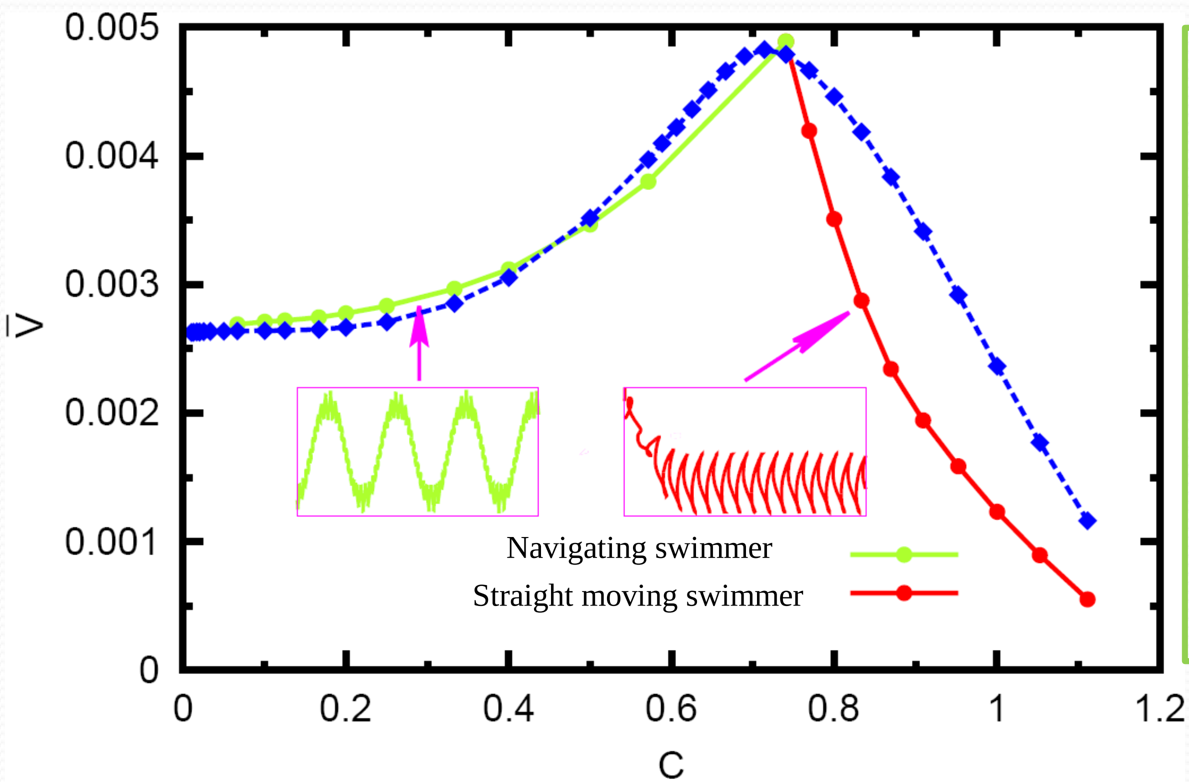
Instability of amoeboid swimming – navigating motion





S. Jana *et al.*, Phys. Fluids (2010)

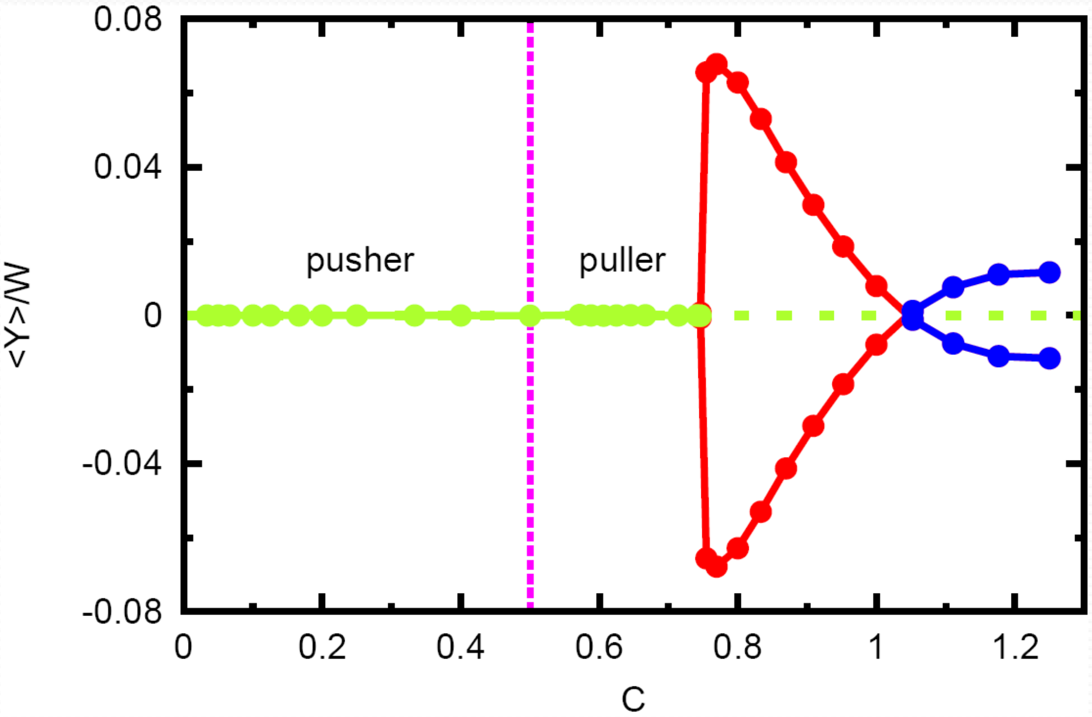
Navigating and straight motions with oscillations of amoeboid cycle



Instability of amoeboid axial swimming depends on the competition between the stresslet and the source doublet. Navigating swimmer turns into quasi-straight moving swimmer via a critical transition point of the strength of confinement.

H. Wu *et al.*, Phys. Rev. E **92**, 050701(R) (2015)

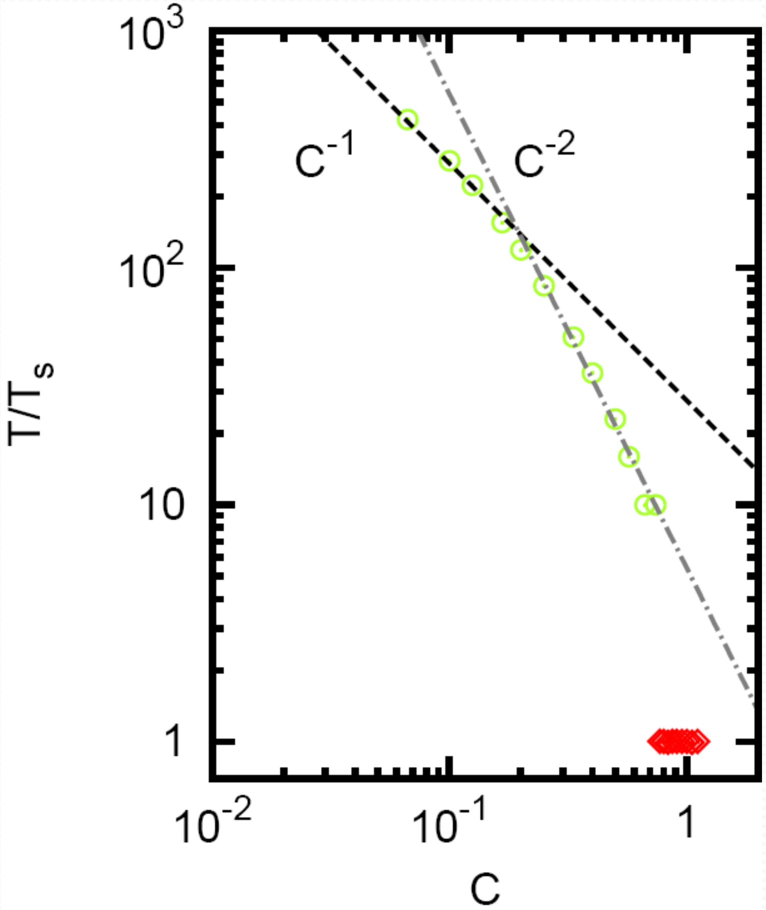
Bifurcation of navigation behavior



Spontaneous symmetry-breaking bifurcation occurs between navigating motion and quasi-straight motion. Two symmetric solutions exit and one prevails over the other one depending on initial conditions.

H. Wu *et al.*, Phys. Rev. E **92**, 050701(R) (2015)

Power laws of confined navigation



$$\begin{cases} T \propto C^{-1}, \text{ at weak confined regime,} \\ T \propto C^{-2}, \text{ at intermediate confined regime,} \\ T = T_S, \text{ at strong confined regime.} \end{cases}$$

H. Wu *et al.*, Phys. Rev. E **92**, 050701(R) (2015)

Conclusions

This work presents a real sense of the coupling between shape change and wall effect.

- Wall-induced pusher-puller transition.
- Instability of confined amoeboid swimming.
- Spontaneous symmetry-breaking bifurcation.
- Different power laws governing confined regimes.

Thanks for your attention!