1) Moving Sausages
2) The First Universal Law of Cell Migration

$$\tau = Ae^{\beta v}$$

Matthieu Piel, matthieu.piel@curie.fr
Systems Biology
of Cell Polarity and Cell Division,
UMR 144, Institut Curie/CNRS

The first universal law of cell migration?

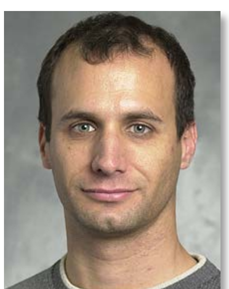
An unexpected outcome of the First World Cell Race:
Cytoskeletal flows impose a universal coupling
between cell speed and cell persistence

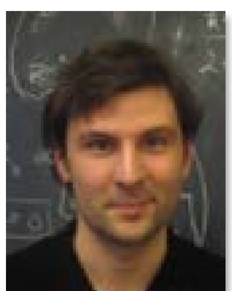
$$\tau = A e^{\beta v}$$

Persistence time → τ

Instantaneous speed → v

Theory



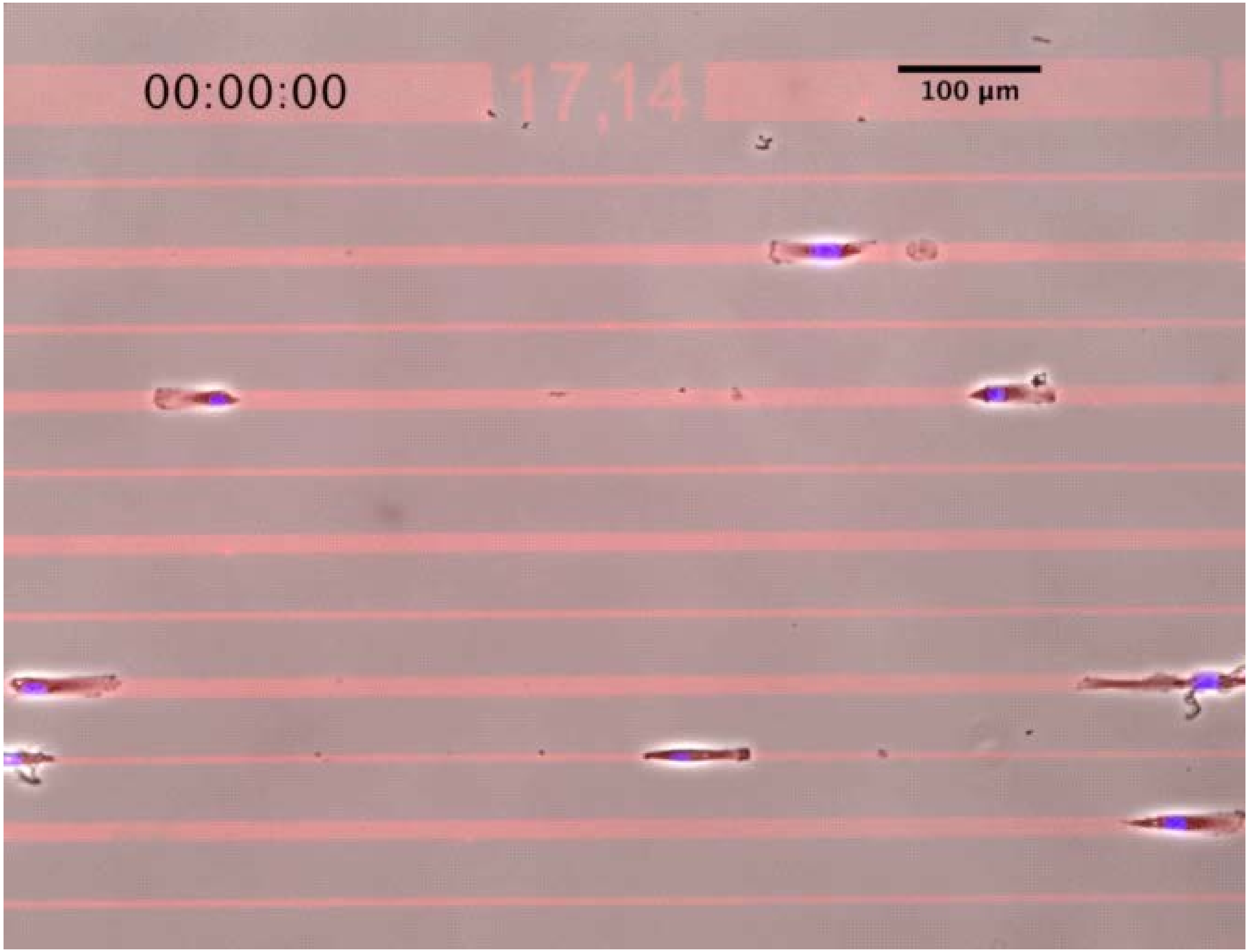


Exp. Vienna


Exp. Paris


Raphael Voituriez Verena Rupprecht Paolo Maiuri
Nir Gov J.F.Ruprecht Stefan Wieser F. Lautenschlaeger

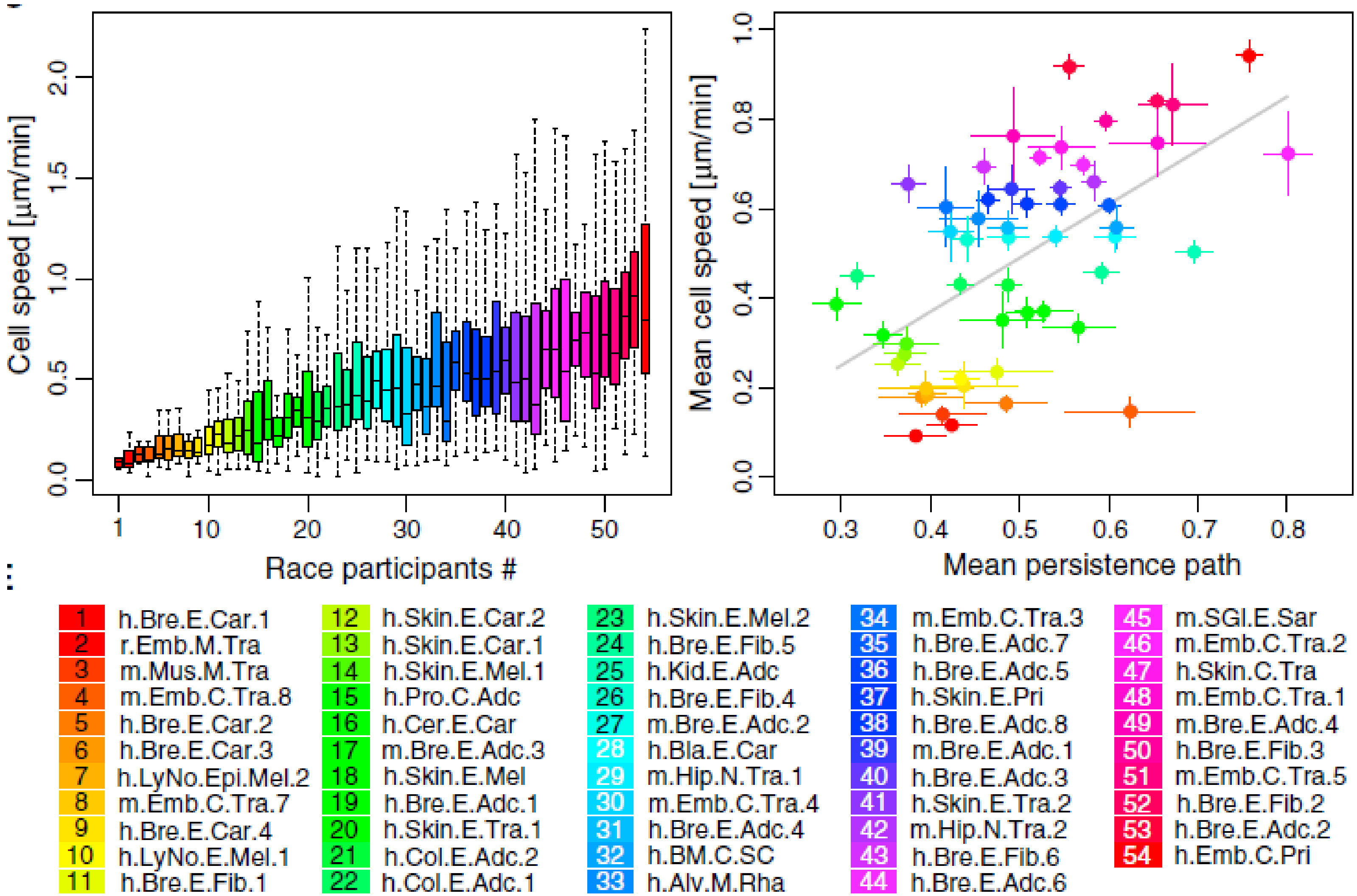
Micropatterns for migrating cells: the First World Cell Race (2011)



Movie: T. Vignault

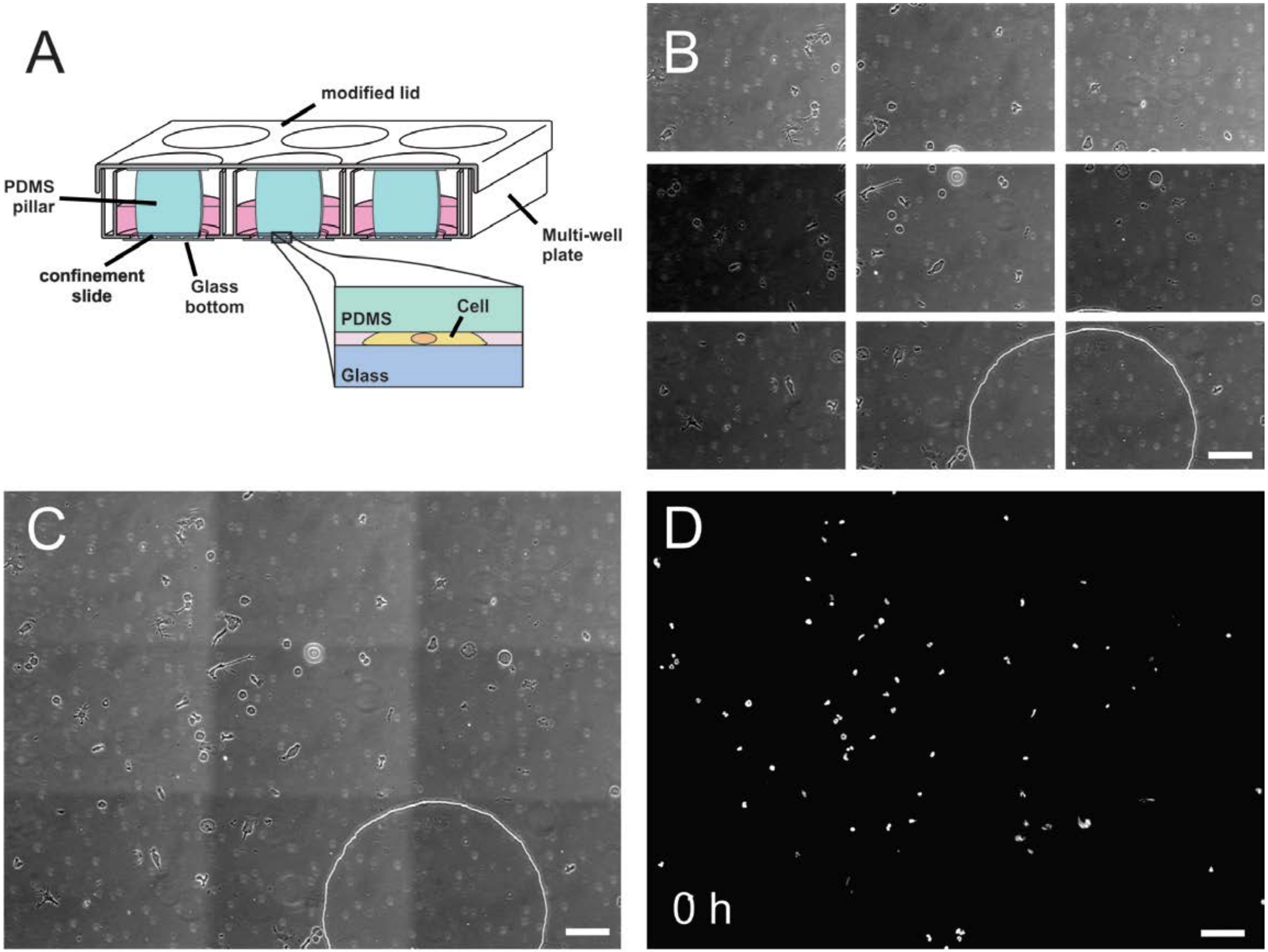
(see also Pouthas et al., JCS 2008 and Doyles et al., JCB 2009)

Faster cells are also more persistent, revealing a coupling between the motor and the steering wheel

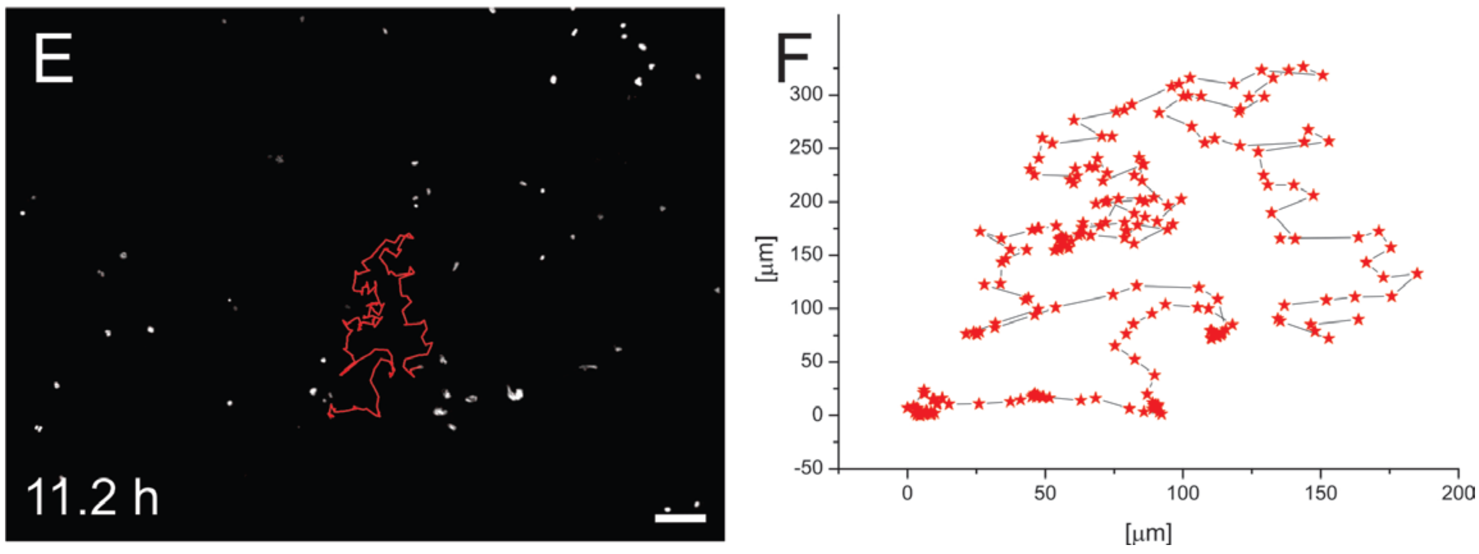


Maiuri et al., Cur Biol 2012

Recording long cell tracks: not so simple



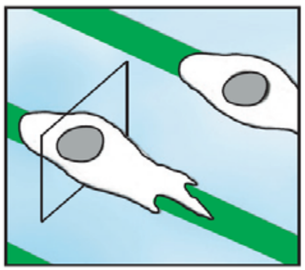
Recording long cell tracks: not so simple



Important points:

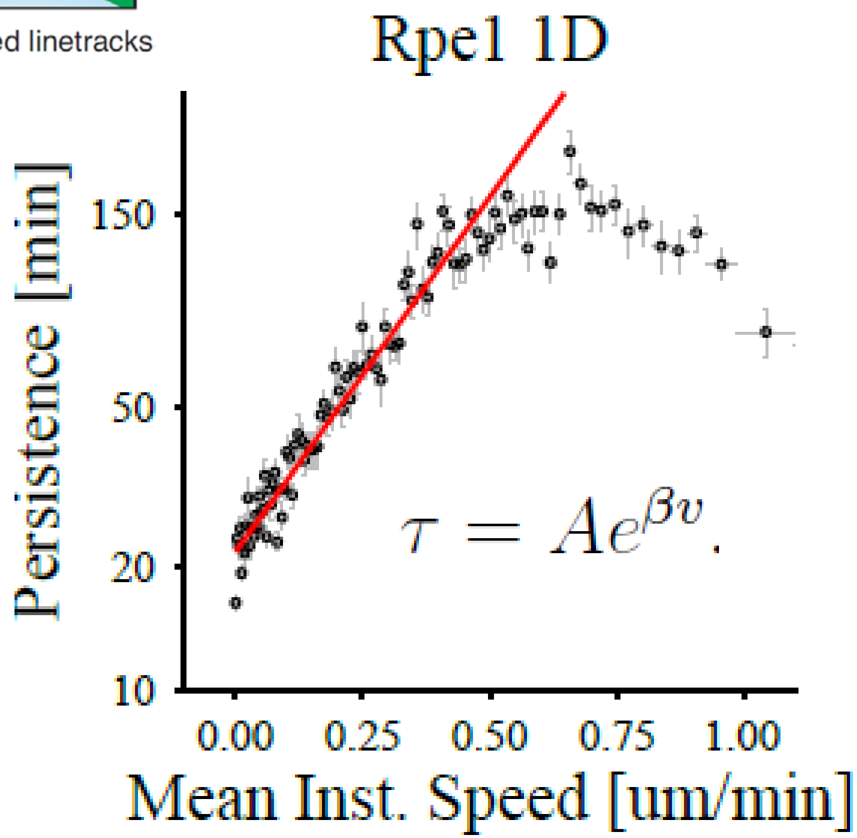
1) No convective flows: requires a roof
2) Long tracks: stitching
3) A focus keeping system

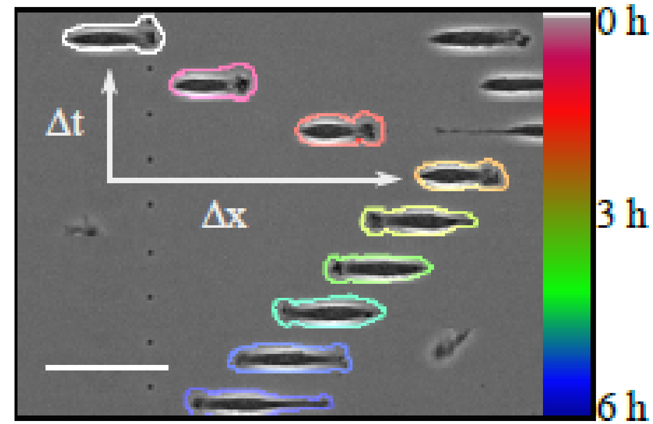
Persistence is an exponential function of speed



micropatterned linetracks

Mesenchymal cells on **1D adhesive** tracks



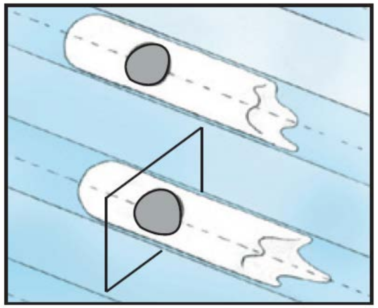


Persistence Time = Δt

Mean Instantaneous Spead = Δx/Δt

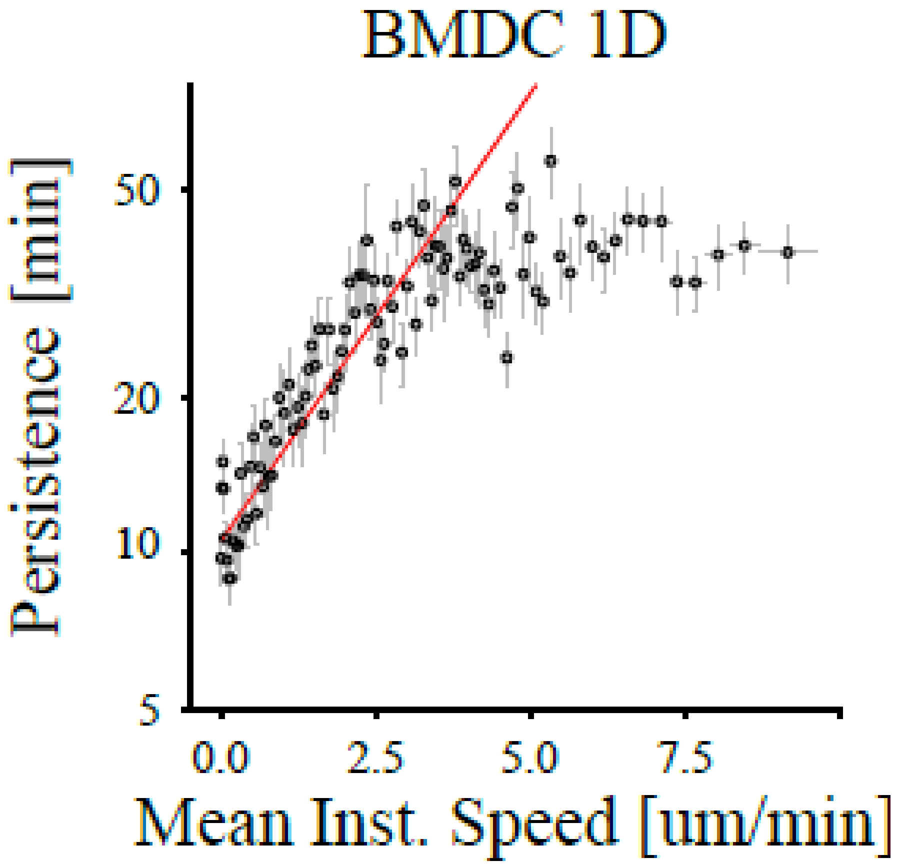
Franziska Lautenschlaeger, Paolo Maiuri (Piel lab)

Persistence is an exponential function of speed

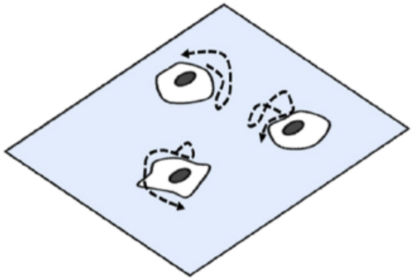


inside microchannels

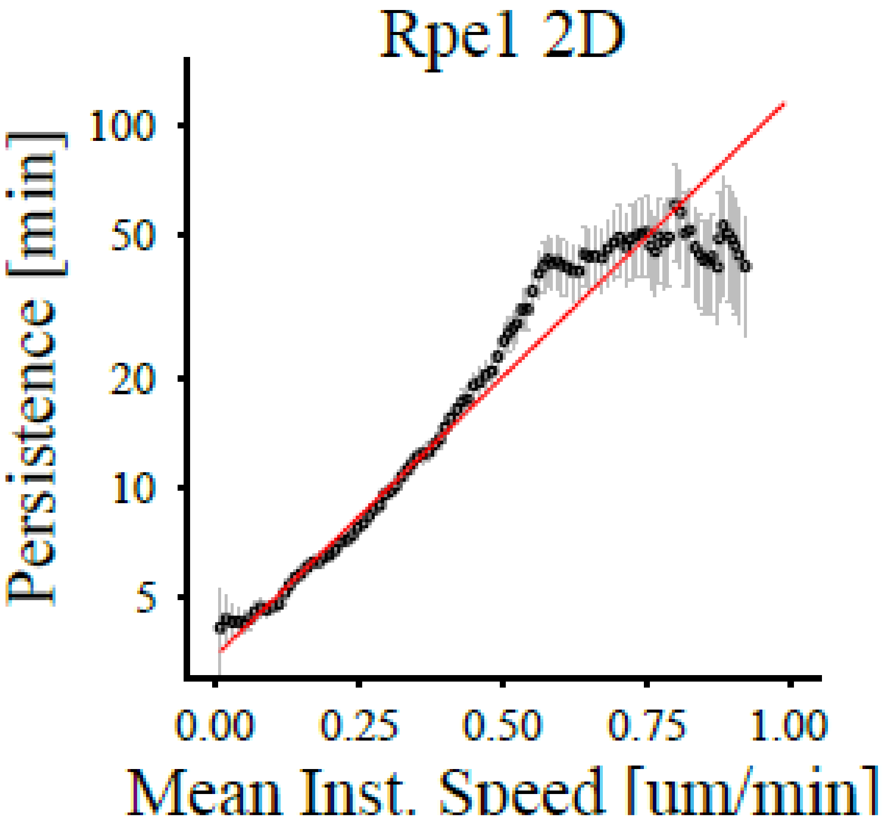
Amoeboid cells inside **1D channels**



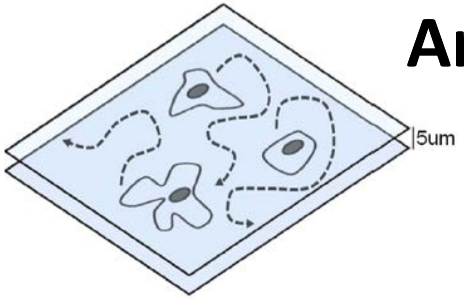
Persistence is an exponential function of speed



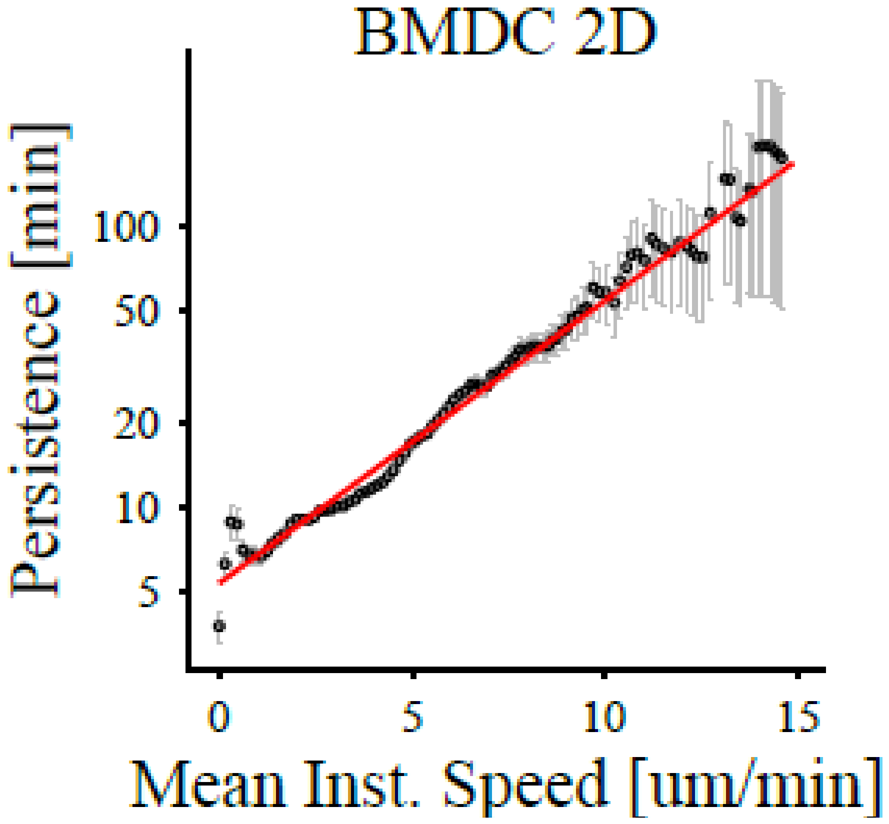
Mesenchymal cells on **2D adhesive** substrate



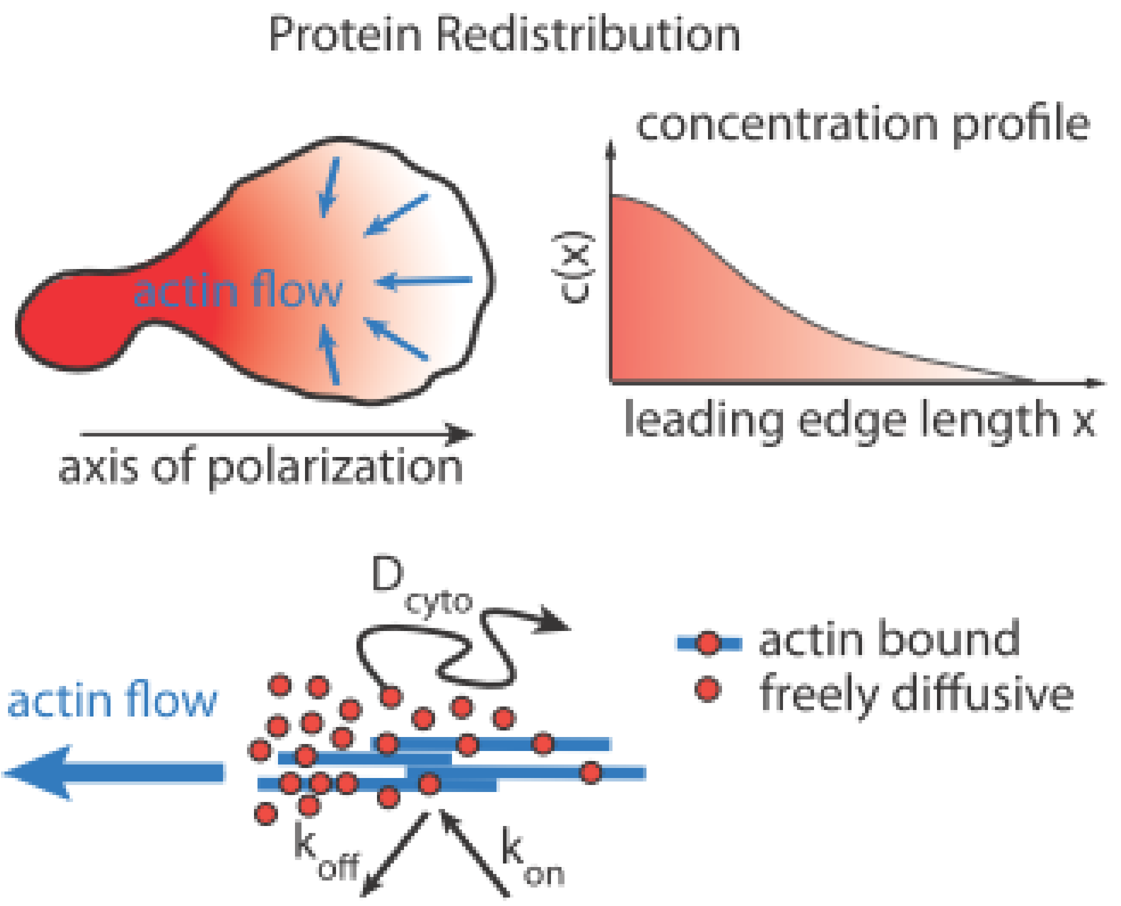
Persistence is an exponential function of speed



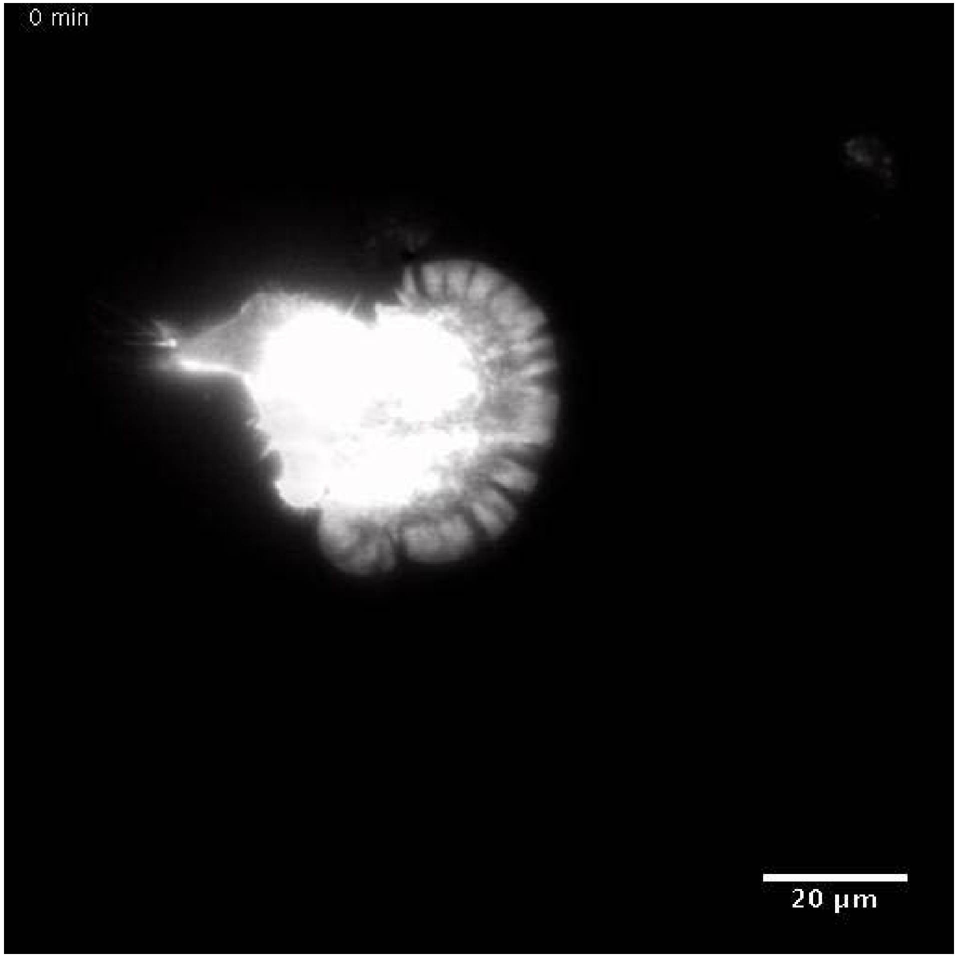
Amoeboid cells on **2D confined** substrate



Coupling speed to persistence: all cells rely on a net flow of actin from front to back in order to move and this flow can transport other proteins

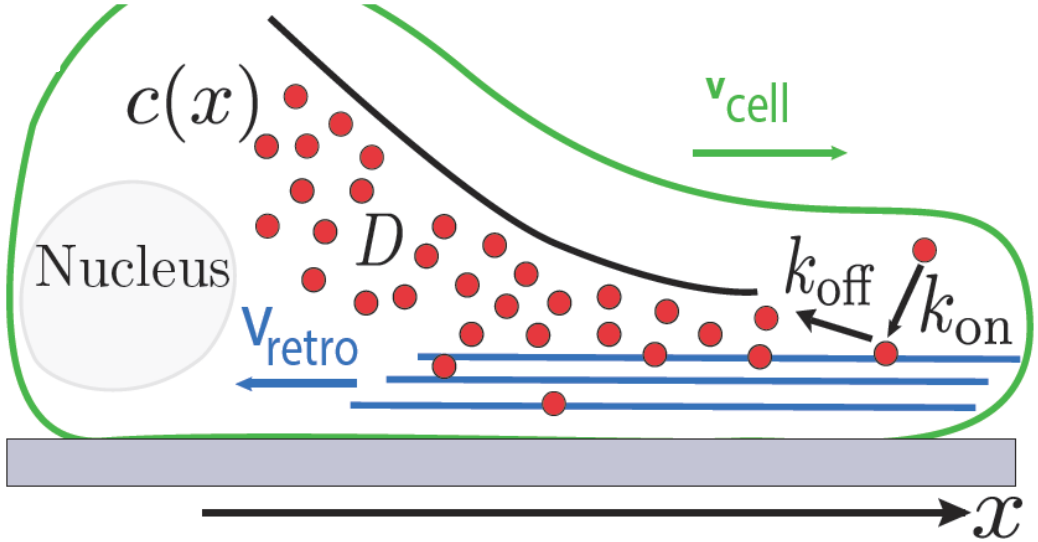


The actin retrograde flow



(BMDC under agarose, Lifeact-GFP, TIRF, from Stefan Wieser, M. Sixt lab)

A simple 1D model for advection of a polarity factor by retrograde flow



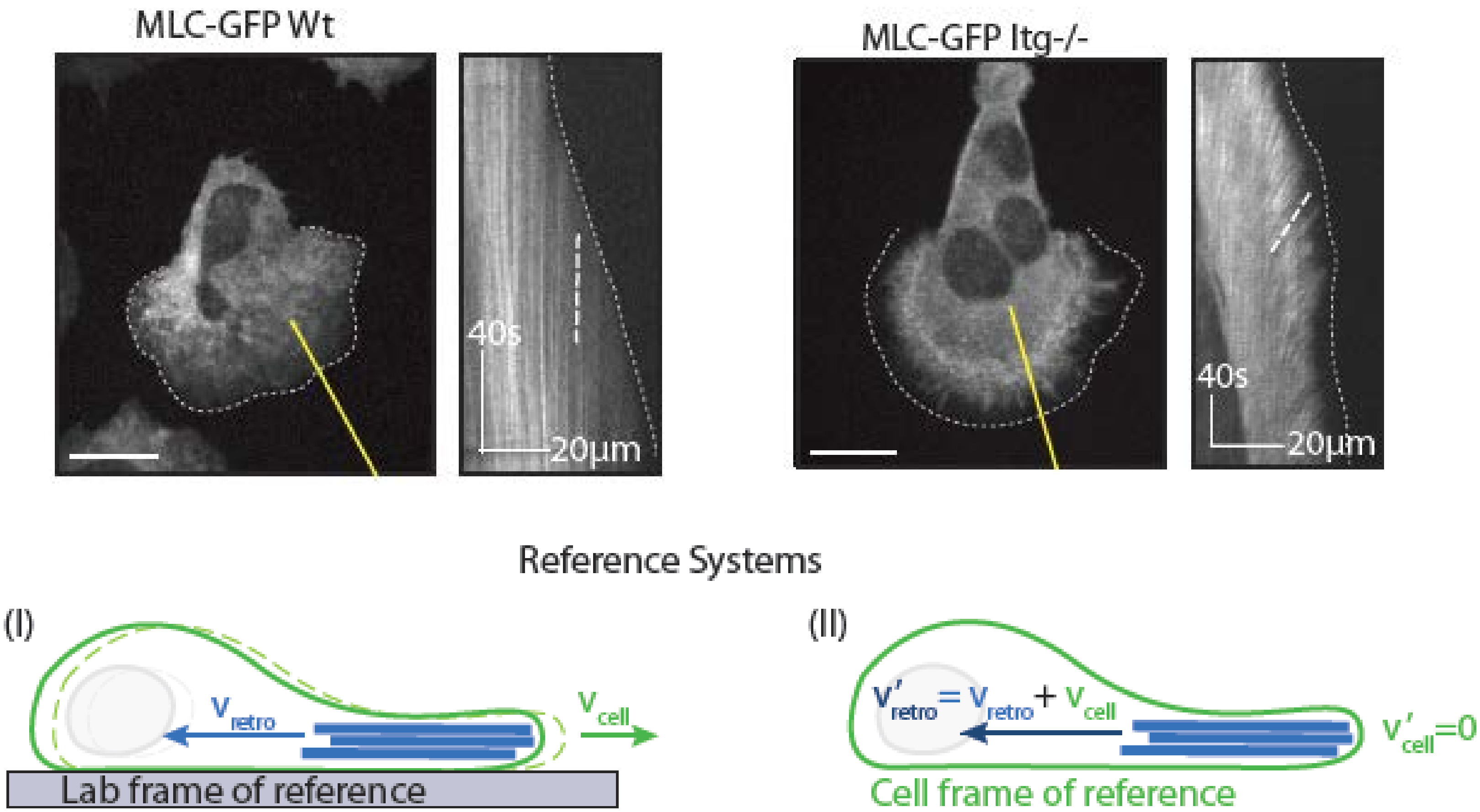
$$\partial_t c(x,t) - \partial_x \left[V c(x,t)\right] = D\partial_x^2 c(x,t) + \partial_x \zeta_c$$

$$V = V_0 k_{on}/(k_{on}+k_{off}) \qquad D = D_0 k_{off}/(k_{on}+k_{off}) \qquad \int_0^L c(x,t)dx = M$$

$$\bar{c}(x) = Ce^{-Vx/D}$$

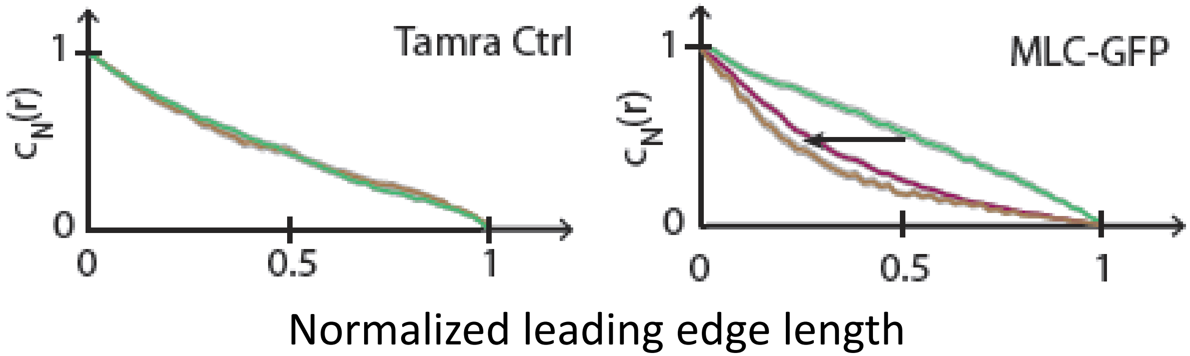
J.F. Rupprecht, Raphael Voirturiez (UPMC, Paris) and Nir Gov (Weizmann Institut, Rehovot)

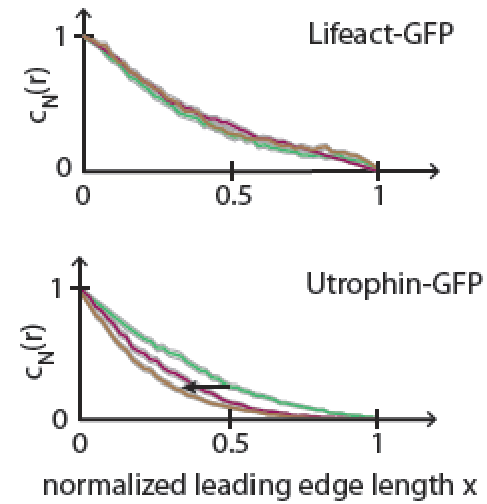
Modulating retrograd flow speed independantly of cell speed

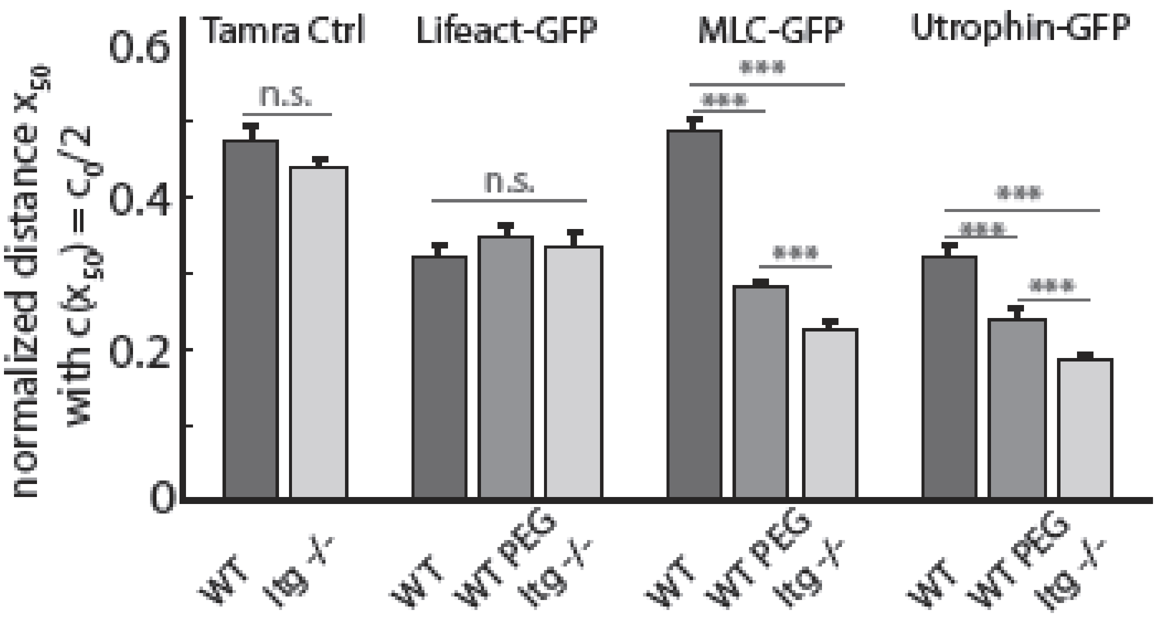


(see Renkawitz et al. NCB 2009, Sixt lab)

Actin flow induces concentration of actin bound proteins







$$\bar{c}(x) = Ce^{-Vx/D}$$

Verena Ruprecht and Stefan Wieser (Sixt and Heisenberg labs, IST Vienna)

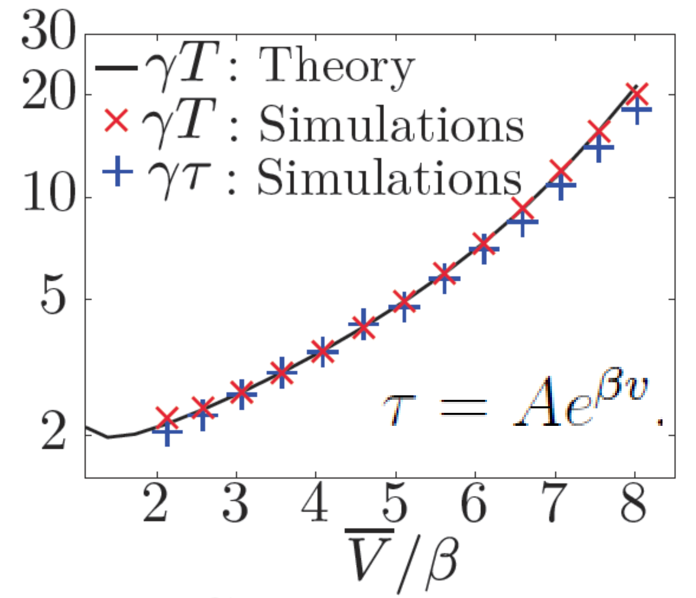
The model captures the exponential relation between persistence and speed

$$\partial_t c(x,t) - \partial_x [V c(x,t)] = D \partial_x^2 c(x,t) + \partial_x \zeta_c$$

$$V^* = \beta \left(\frac{c_0^n(V)}{C_s^n + c_0^n(V)} - \frac{c_L^n(V)}{C_s^n + c_L^n(V)} \right)$$

$$\partial_t V = -\gamma (V - V^*) + \frac{K}{V} + \sqrt{2K}\ \zeta_V$$

$$\partial_t \phi = \frac{\sqrt{2K}}{V}\ \zeta_\phi \qquad L^2/D \ll \gamma^{-1}$$



$$\partial_t V = \gamma \mathcal{F}(V) + \sqrt{2\sigma^2(V)}\ \zeta_V$$

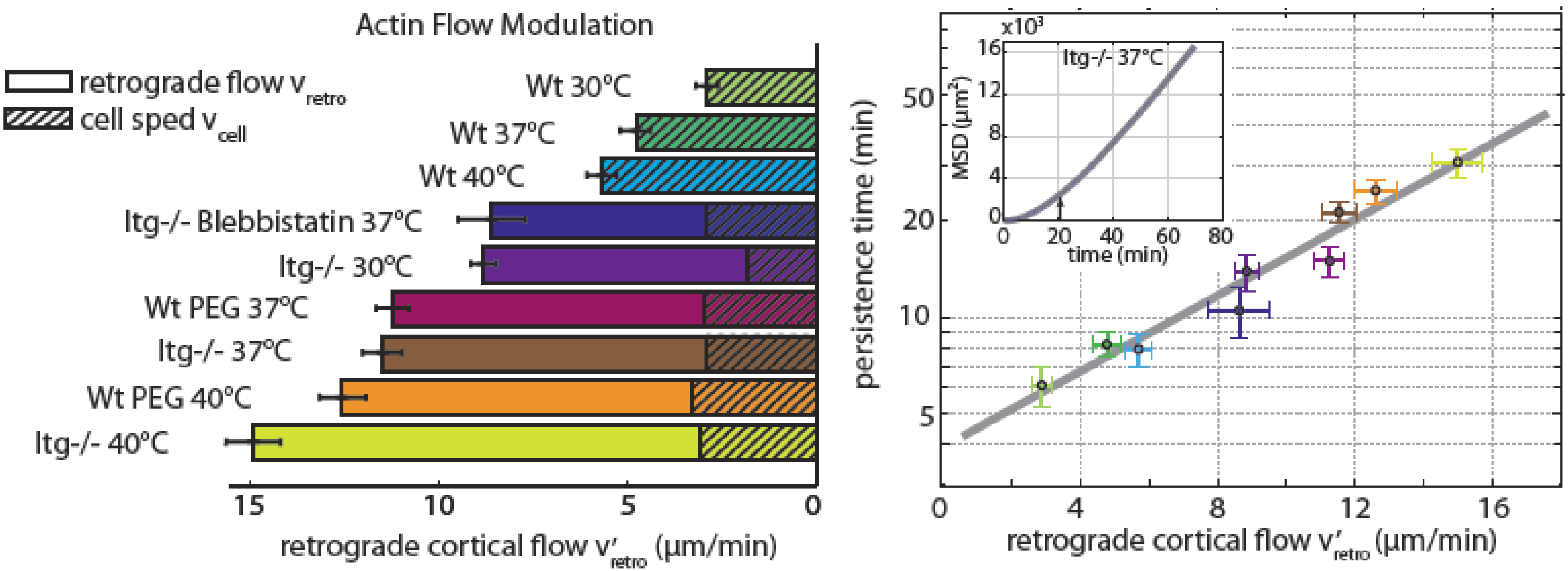
$$\mathcal{F}(V) = -V + \beta \left(\frac{\overline{c}_0^n(V)}{C_s^n + \overline{c}_0^n(V)} - \frac{\overline{c}_L^n(V)}{C_s^n + \overline{c}_L^n(V)} \right) + \frac{K}{\gamma V}$$

$$P(V) = \frac{C}{\sigma^2(V)} \exp\left(\gamma \int_0^V du \frac{\mathcal{F}(u)}{\sigma^2(u)} \right) \equiv C e^{-\gamma W(V)} \qquad \tau_p \simeq A e^{\beta v^\theta}$$

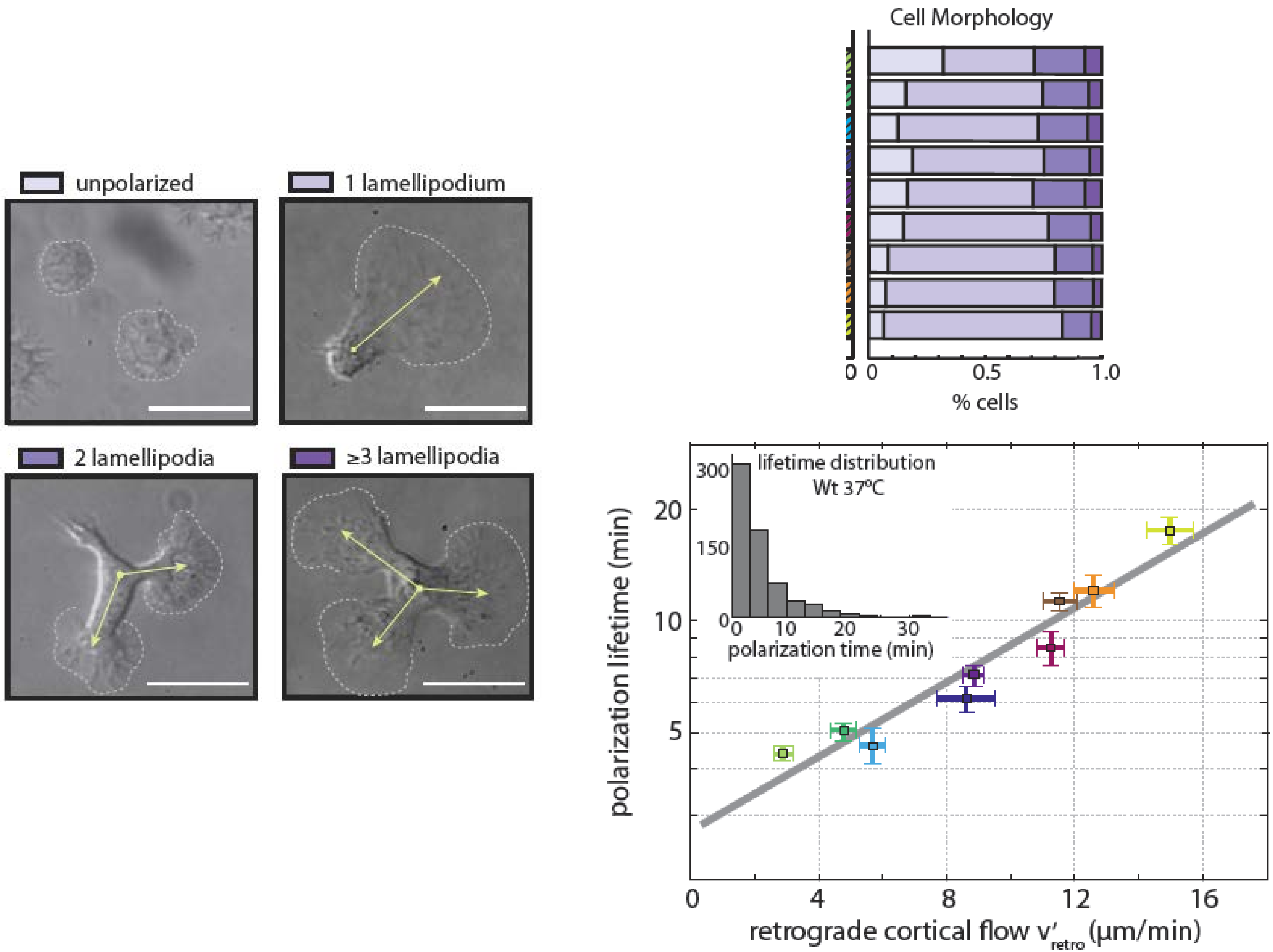
the mean first-passage time at $v = 0$ $\qquad n \simeq 0.9 \qquad \theta \simeq 1$

J.F. Rupprecht, Raphael Voirturiez (UPMC, Paris) and Nir Gov (Weizmann Institut, Rehovot)

Persistence is correlated to retrograde flow speed, independently of cell speed



Verena Ruprecht and Stefan Wieser (Sixt and Heisenberg labs, IST Vienna)



unpolarized
1 lamellipodium
2 lamellipodia
≥3 lamellipodia
Cell Morphology
0
0
0.5
1.0
% cells
lifetime distribution
Wt 37ºC
300
150
0
0
10
20
30
polarization time (min)
polarization lifetime (min)
20
10
5
0
4
8
12
16
retrograde cortical flow v′retro (μm/min)

The model can generate trajectories the cell as an active Brownian particule

$$\partial_t V = \gamma \mathcal{F}(V) + \sqrt{2\sigma^2(V)}\,\zeta_V$$

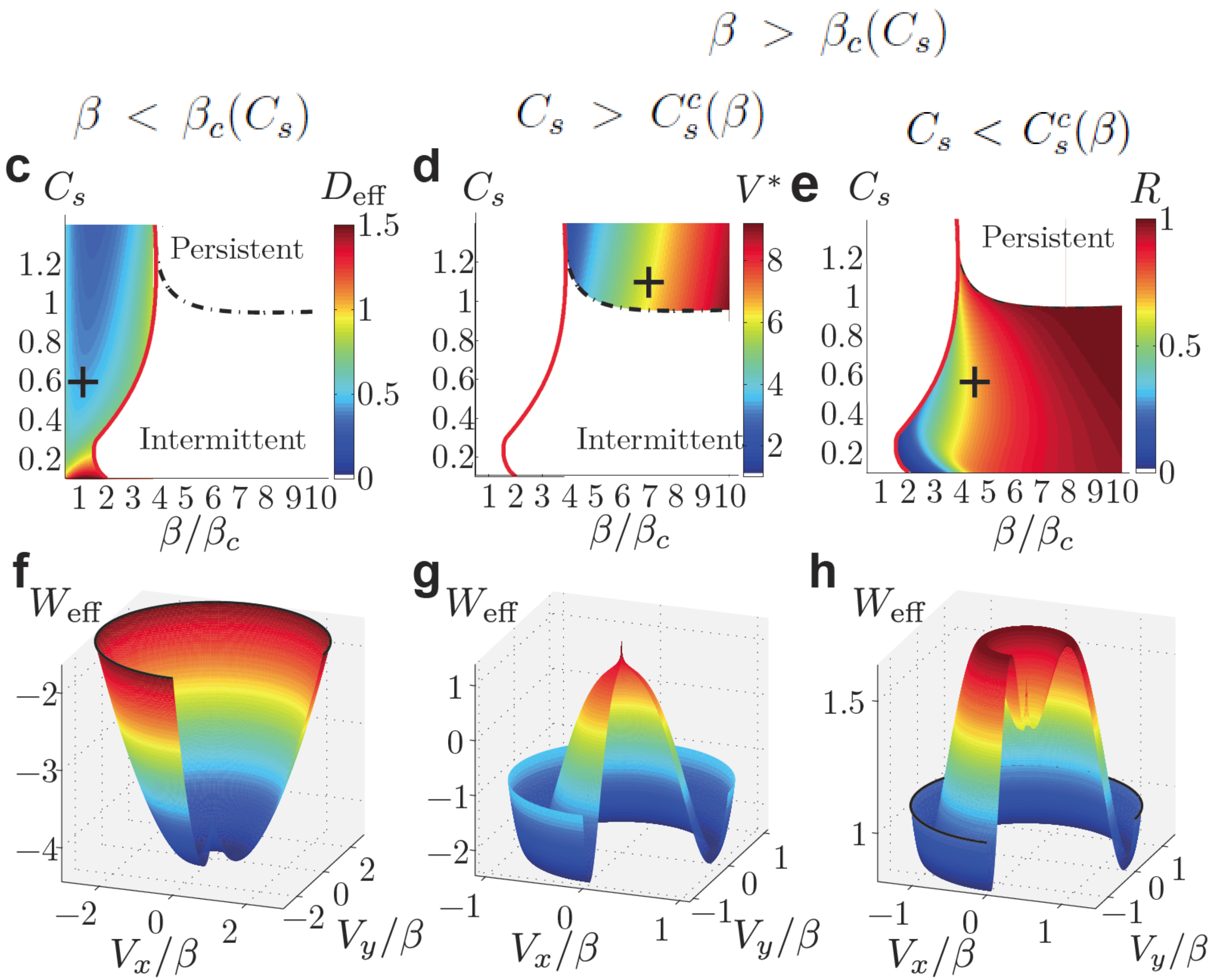
$$\mathcal{F}(V) = -V + \beta\left(\frac{\overline{c}_0^n(V)}{C_s^n + \overline{c}_0^n(V)} - \frac{\overline{c}_L^n(V)}{C_s^n + \overline{c}_L^n(V)}\right) + \frac{K}{\gamma V}$$

$$\sigma^2(V) = K + K_c n^2 \beta^2 C_s^{2n}\left(\frac{\overline{c}_0^{2n-1}(V)}{\left(C_s^n + \overline{c}_0^n(V)\right)^4} + \frac{\overline{c}_L^{2n-1}(V)}{\left(C_s^n + \overline{c}_L^n(V)\right)^4}\right)$$

$$P(V) = \frac{C}{\sigma^2(V)} \exp\left(\gamma \int_0^V du \frac{\mathcal{F}(u)}{\sigma^2(u)}\right) \equiv C e^{-\gamma W(V)}$$

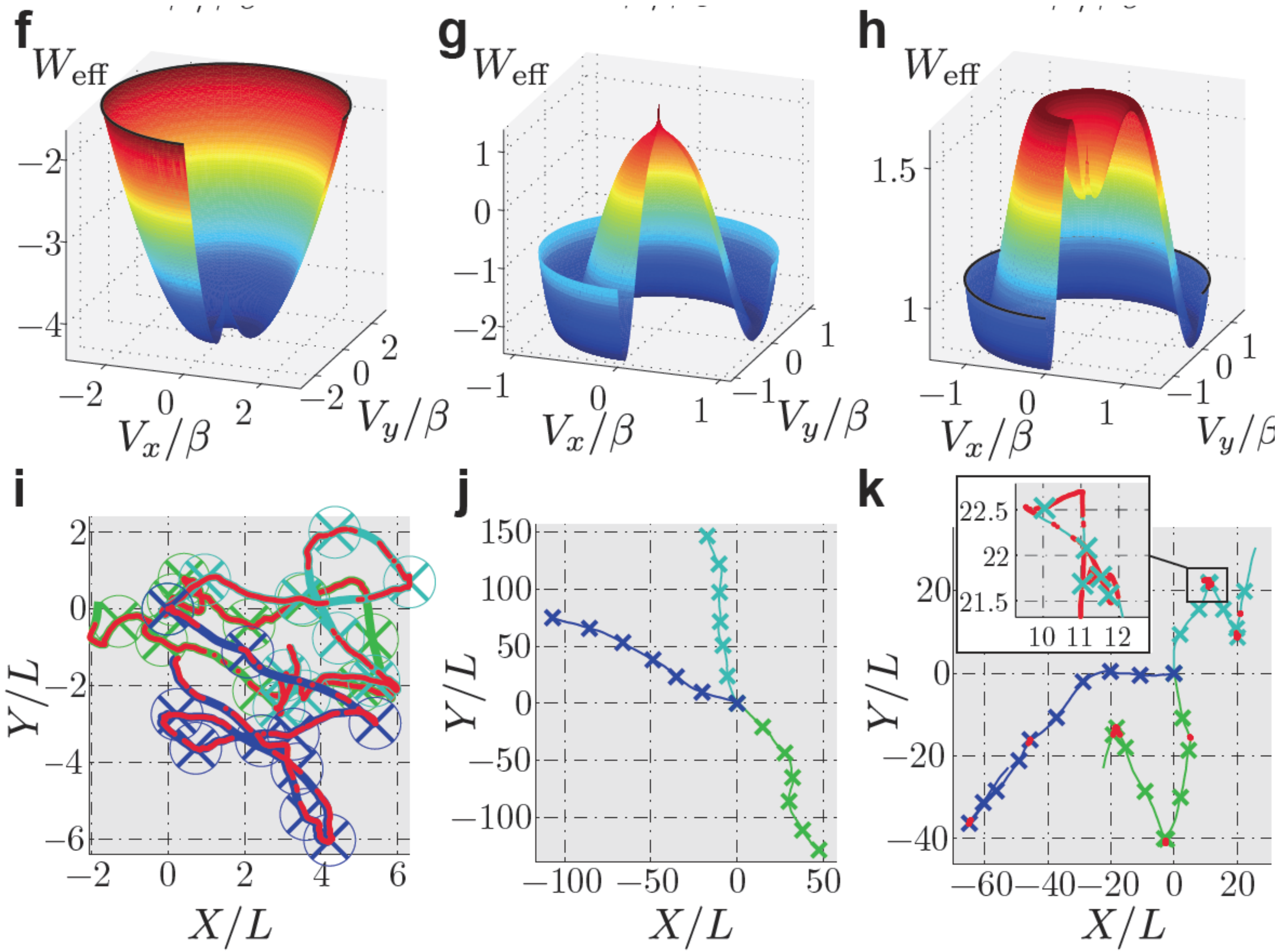
J.F. Rupprecht, Raphael Voirturiez (UPMC, Paris) and Nir Gov (Weizmann Institut, Rehovot)

The model predicts a whole phase diagram of cell behaviors

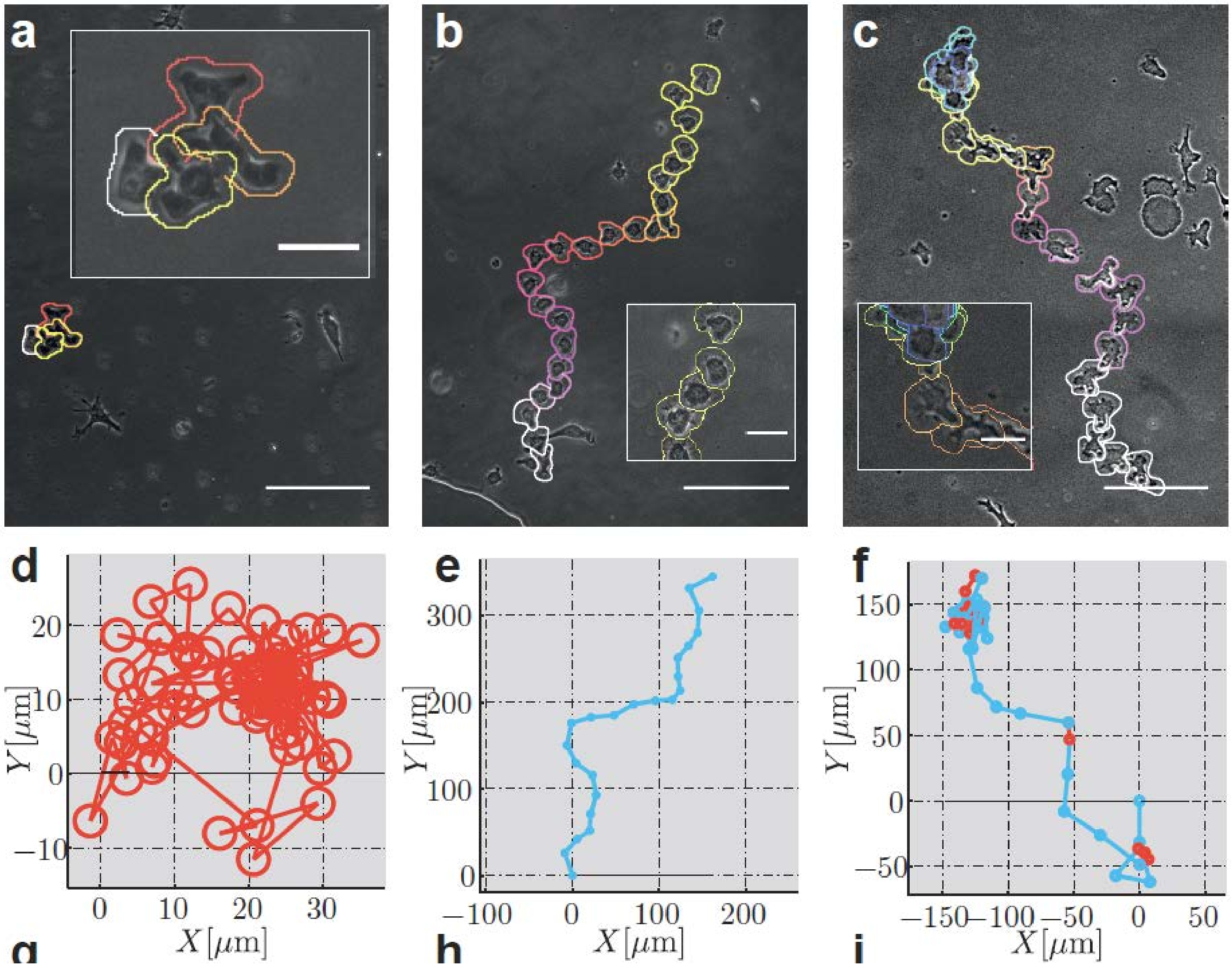


Jean-François Rupprecht (Voituriez lab) Franziska Lautenschlaeger, Paolo Maiuri (Piel lab)

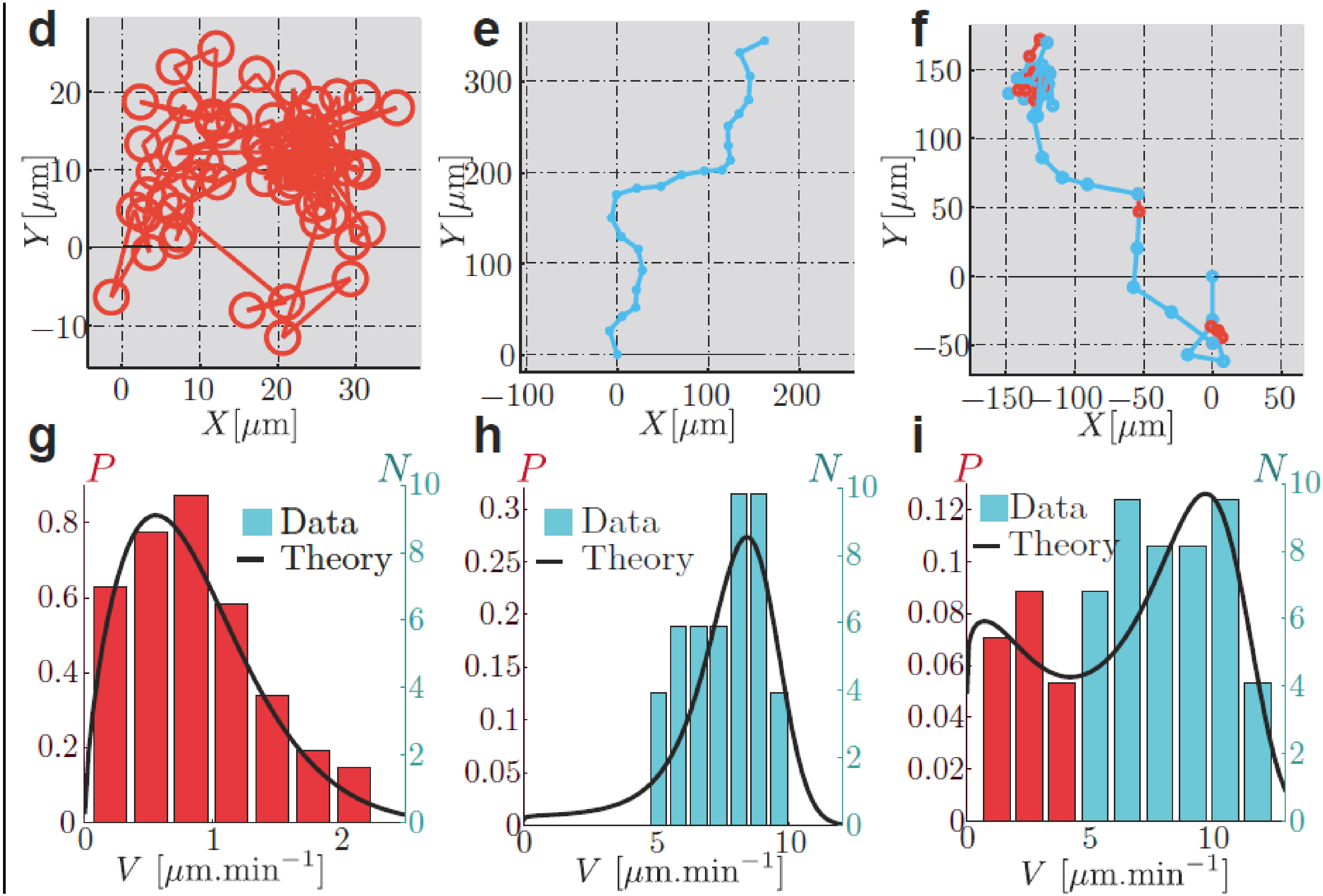
Simulating trajectories from the model



Real cell trajectories



Model fit on real trajectories



Conclusions

1) There is a universal correlation between persistence and speed of migrating cells (the first universal law of cell migrations?)

2) Experiments on BMDCs show that persistence is in fact correlated to retrograde actin flow

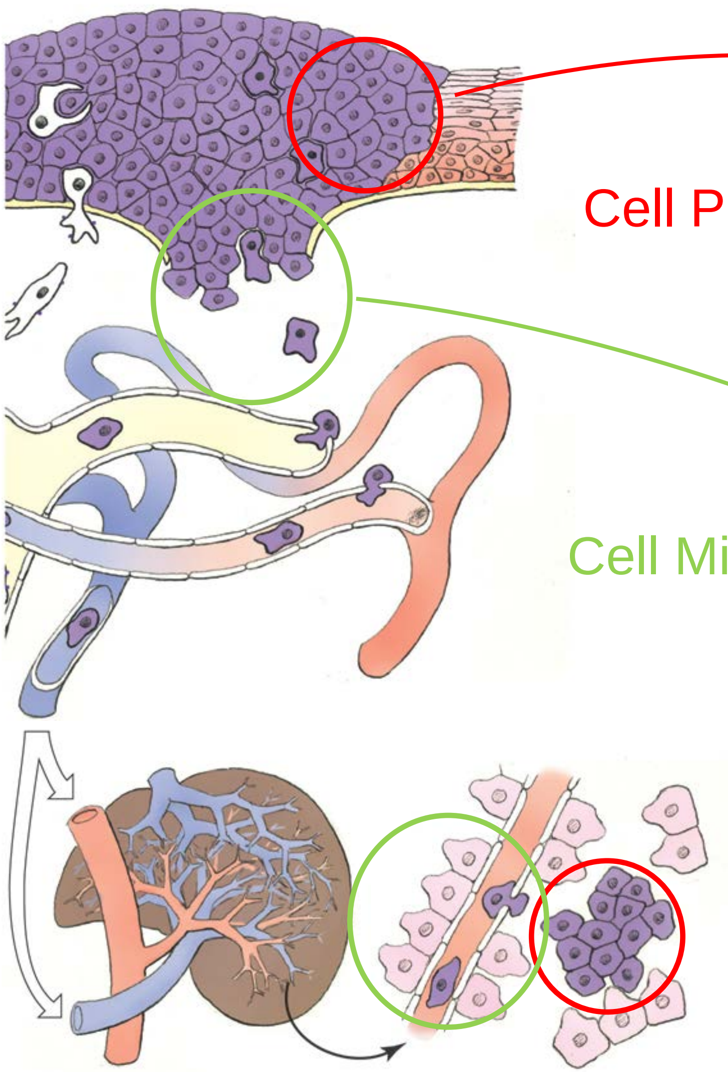
3) A model which assumes advective transport of a polarity factor by the actin flow can predict the exponential relation between persistence and speed

4) The same model, when varying parameters, can generate all observed cell trajectories

5) Extracting model parameters from real trajectories leads to self-consistent predictions

Cells under Constrains

Tumor spreading

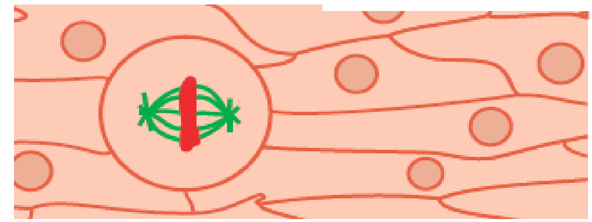


Cell Proliferation

Cell Migration

Art by Renaud Chabrier www.renaudchabrier.com

Division under **constrains**

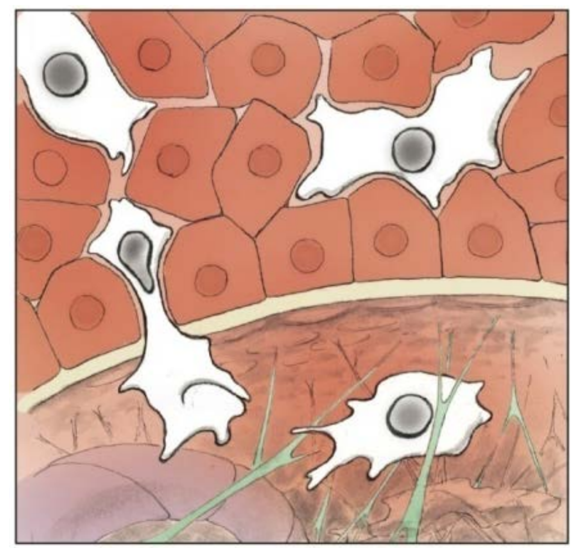


Fink, NCB, 2011

Lafaurie-Janvore, Science, 2013

Lancaster, Dev Cell, 2013

Migration under **constrains**



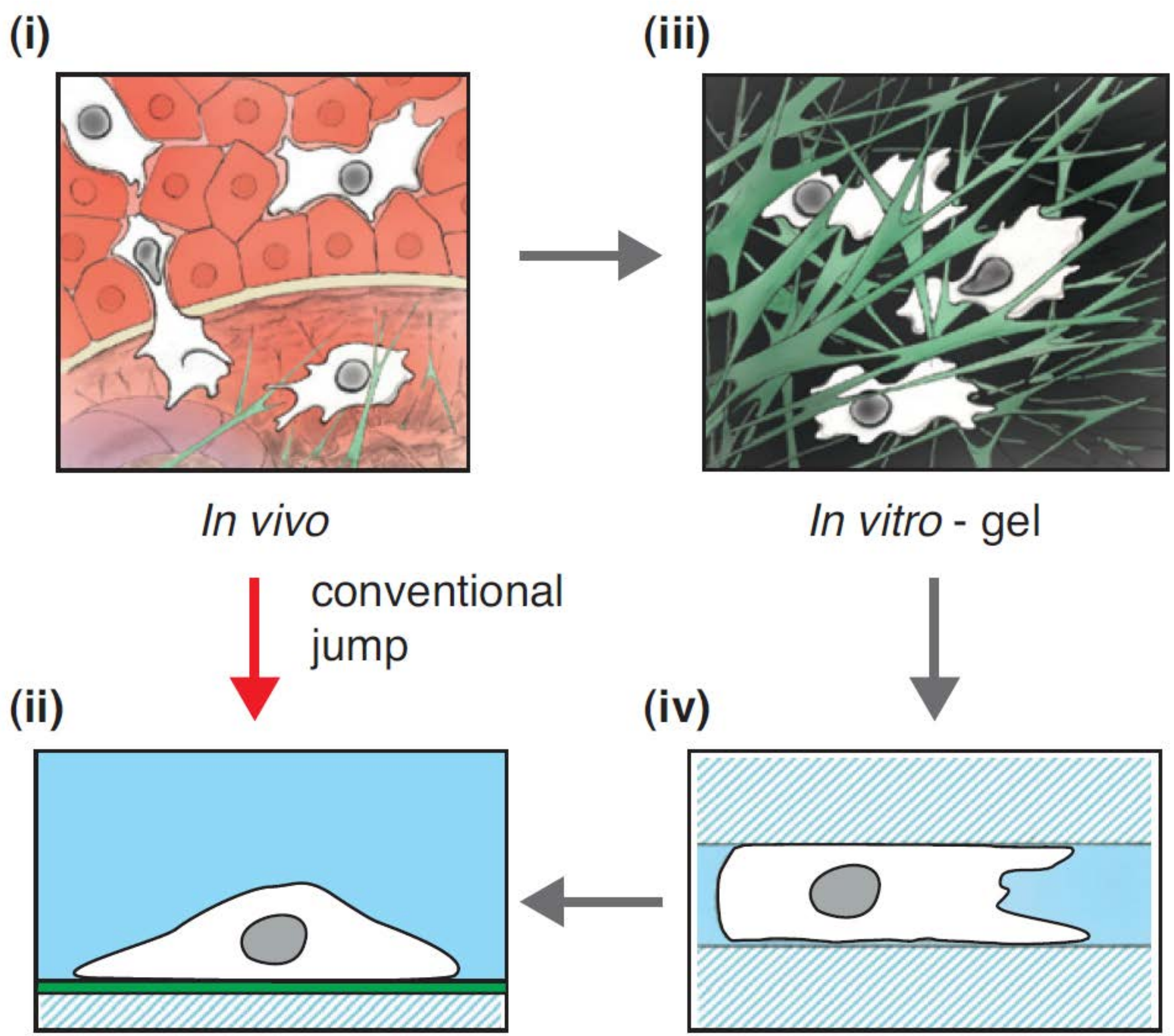
Faure-André, Science, 2008

Hawkins, PRL, 2009

Deconstructing the cell micro-environment

Tissue

3D models



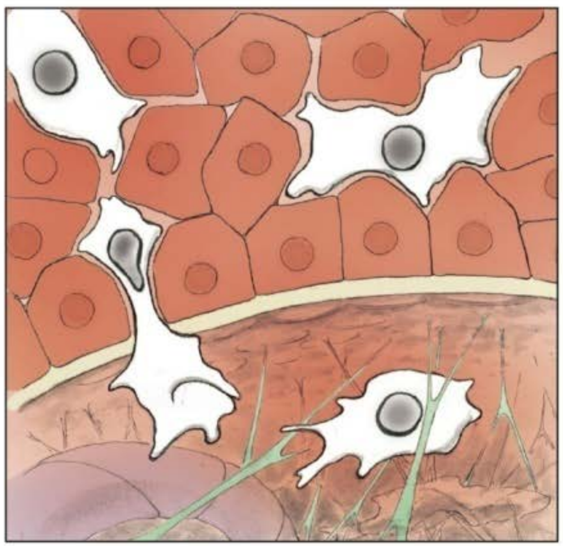
Petri dish

Micro-
controlled
environment

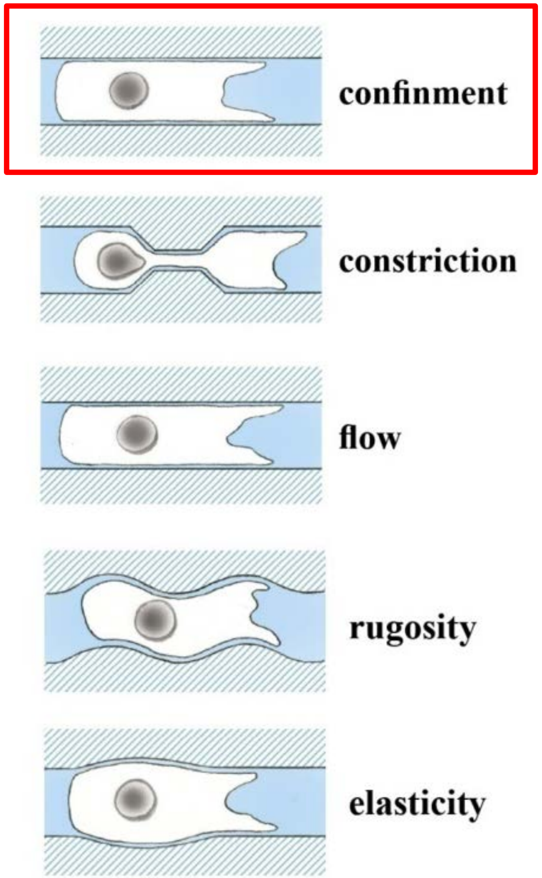
Lautenschlaeger and Piel, COCB, 2012

A reductionist approach to 3D migration

a) *In vivo* interstitial migration



b) *In vitro* migration in 3D

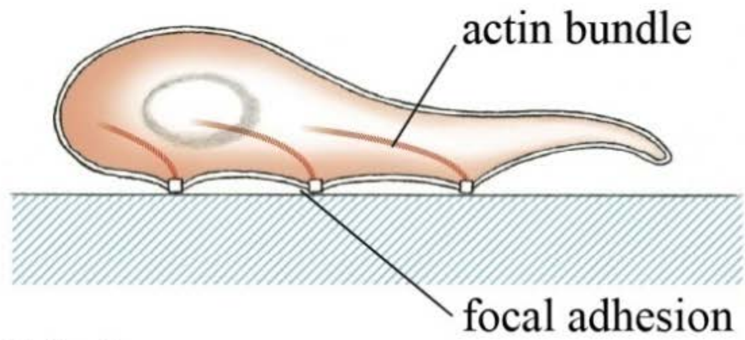


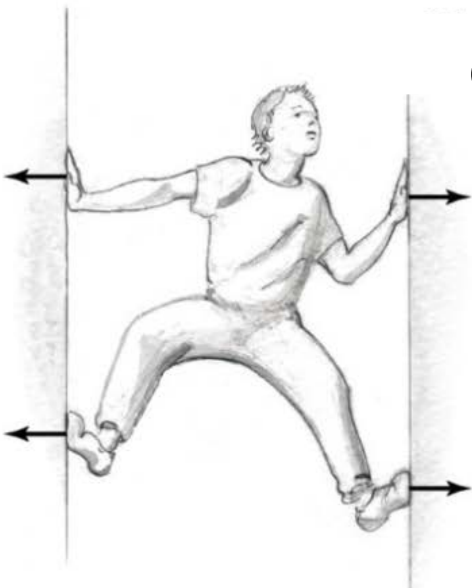
Yanjun Liu

Maël Le Berre

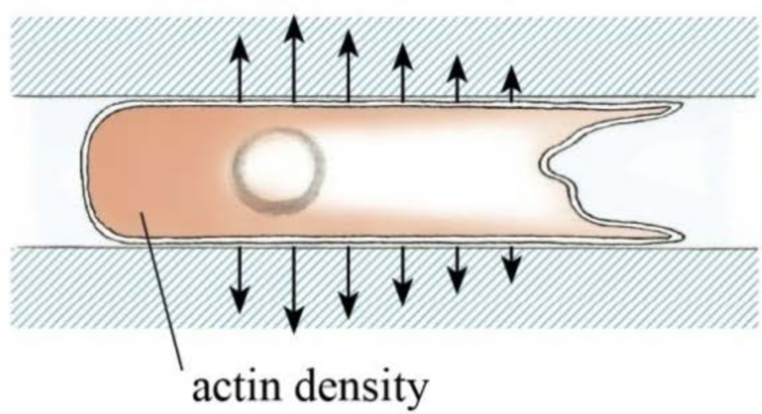
Exerting force on the substrate: Momentum transfer under confinement

Adhesive: mesenchymal migration, protrusive, slow





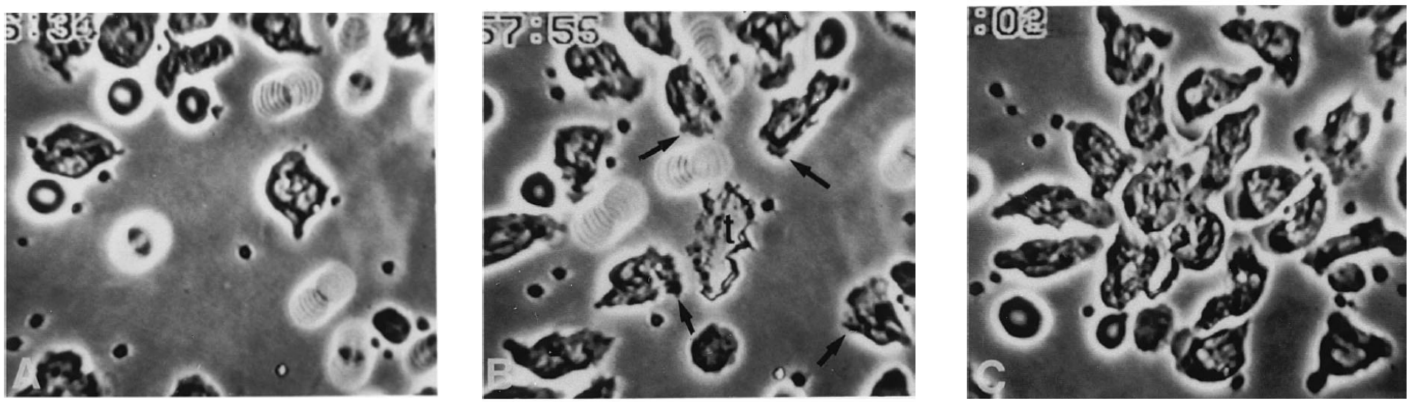
Confined: amoeboid migration, contractile, fast



Hawkins et al., PRL, 2009

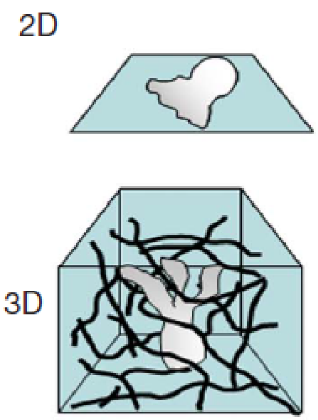
Chemneying (Malawista and de Boisfleury, CMC 2000
Lammerman et al., Nature 2008)

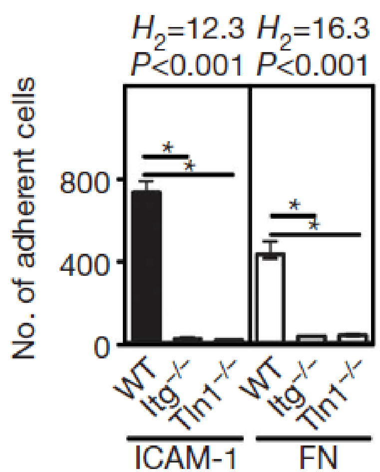
Chemneying: moving without adhering from Malawista and de Boisfleury to Sixt

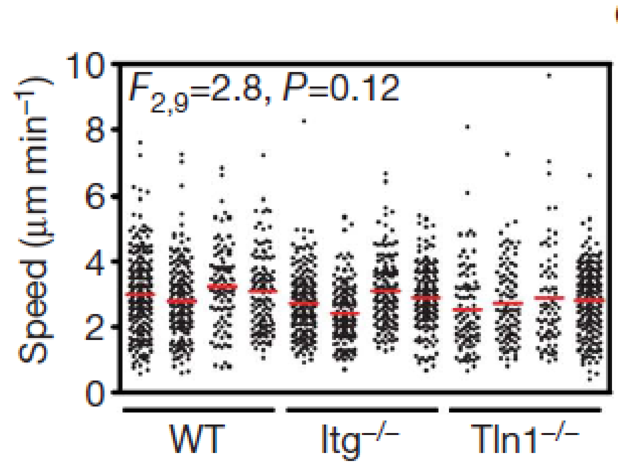


Thin preparation of PMN leukocytes treated with EDTA

Malawista and de Boisfleury, PNAS 1997; Malawista et al. CMC 2000



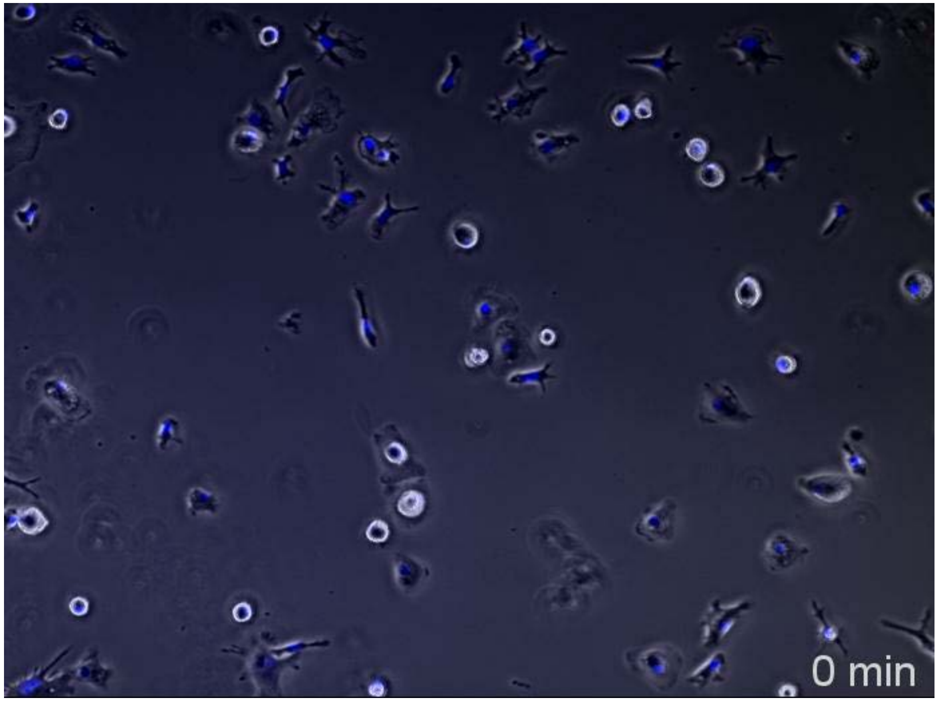




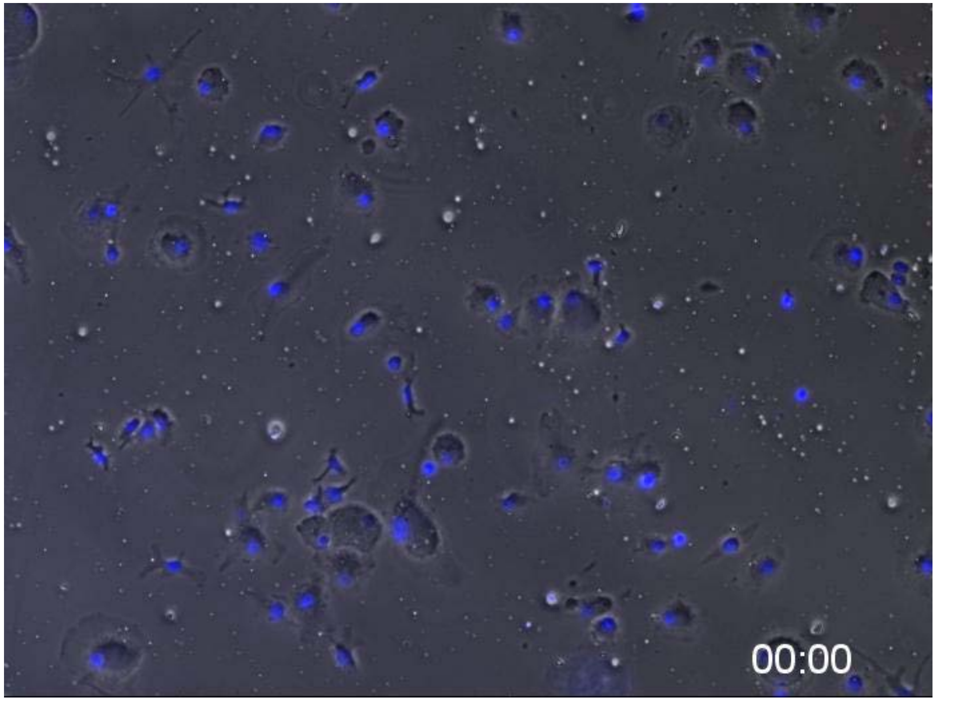
Lämmermann et al., Nature 2008

Leukocytes need to be confined to reveal their migratory potential

No confinement

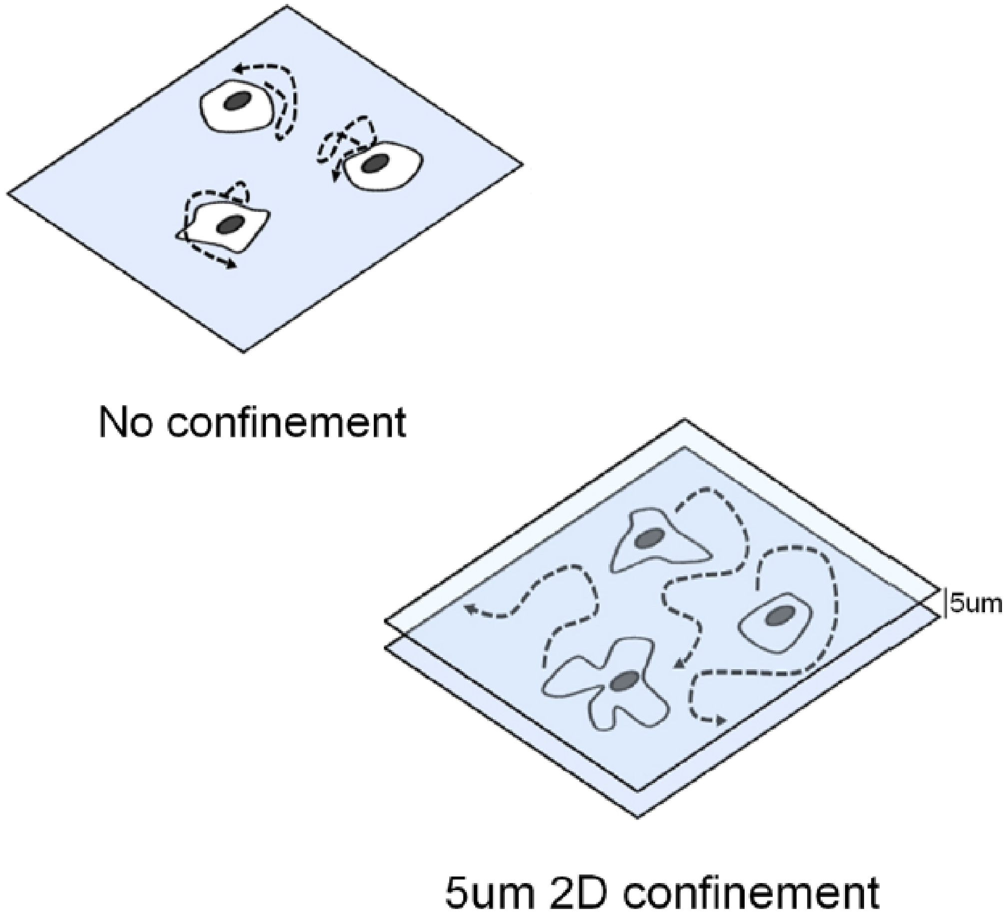


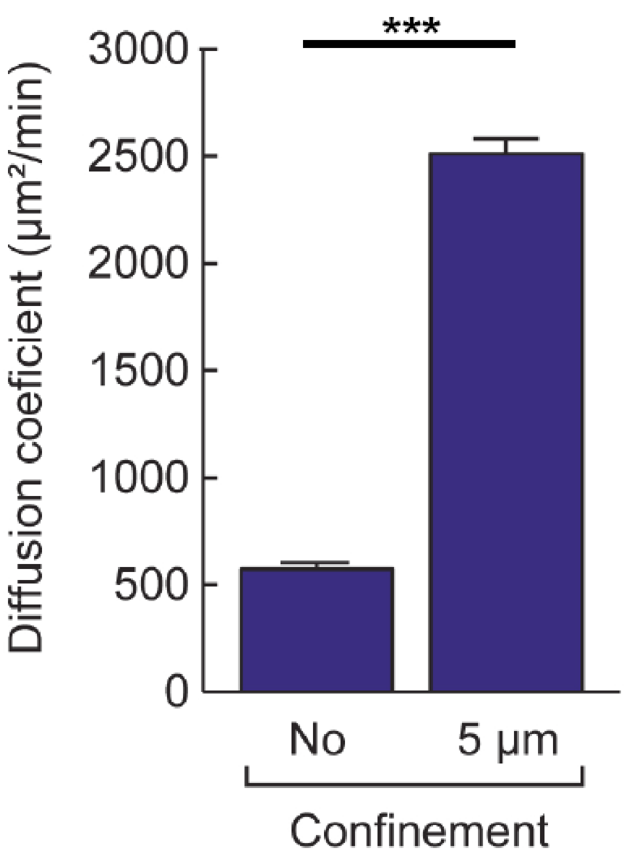
5 µm confinement



BMDCs migrating on FN coated glass surface

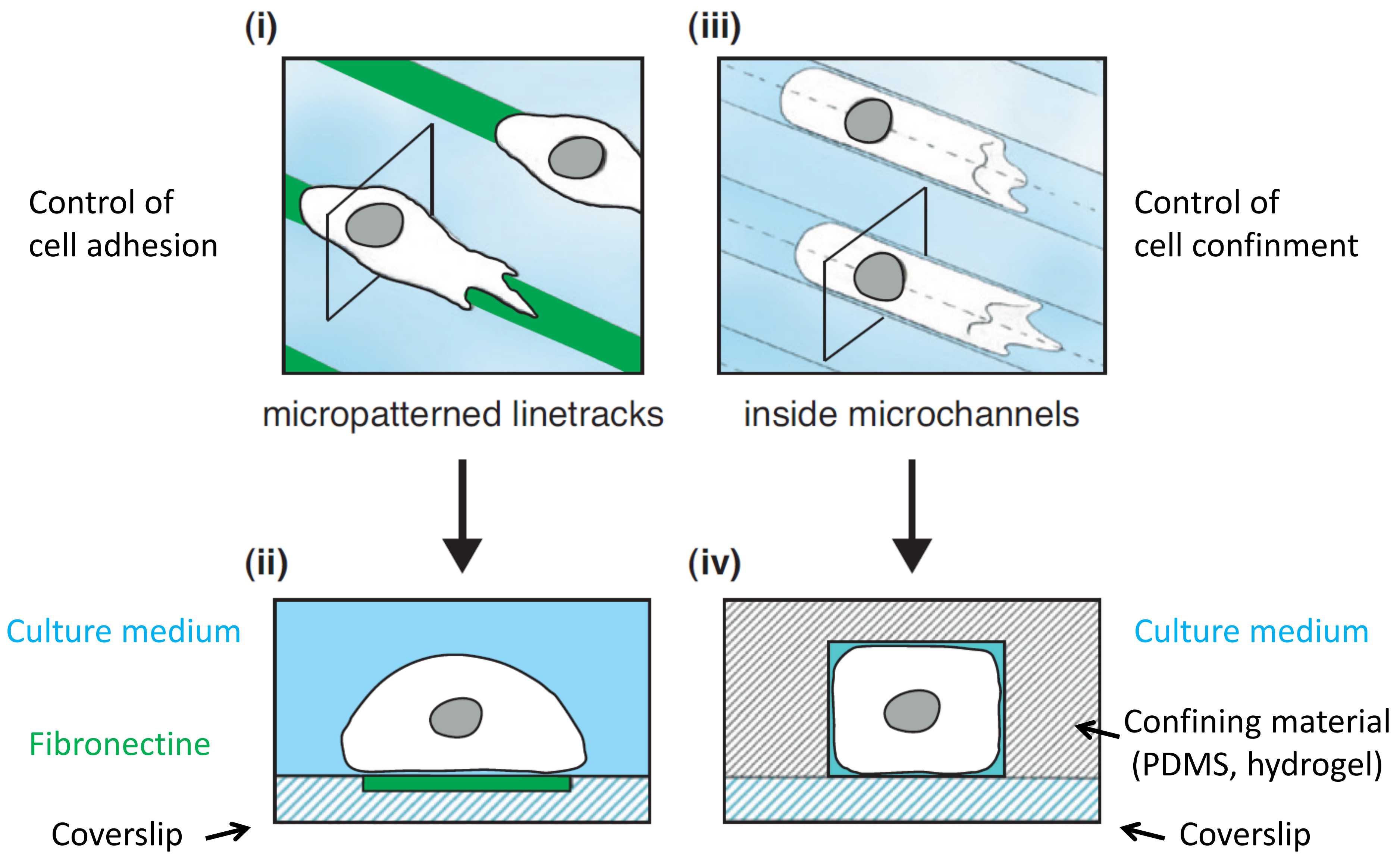
Leukocytes need to be confined to reveal their migratory potential



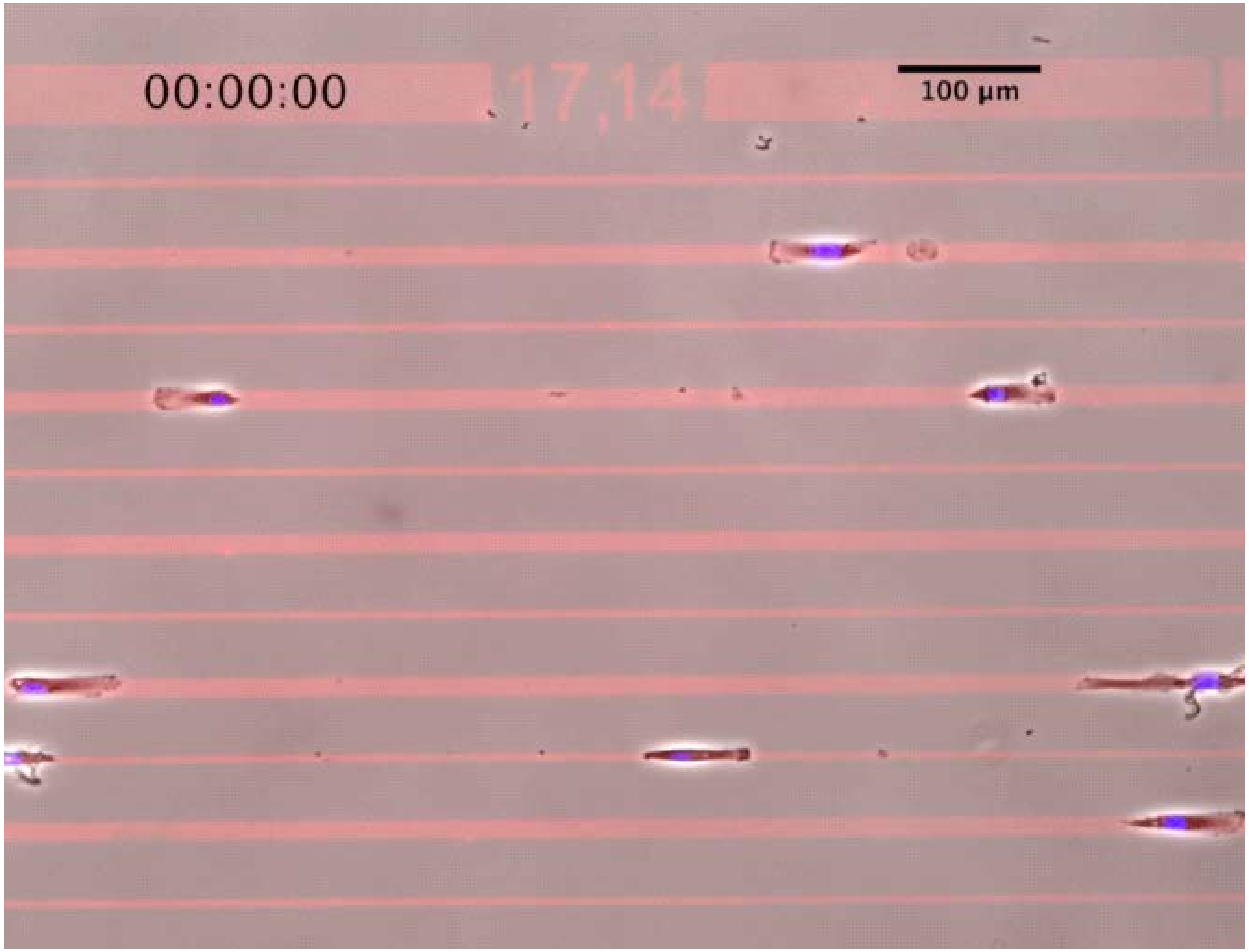


Yanjun Liu/Maël Le Berre/Pablo Vargas

Micro-patterns and micro-channels: two simple tools with multiple applications



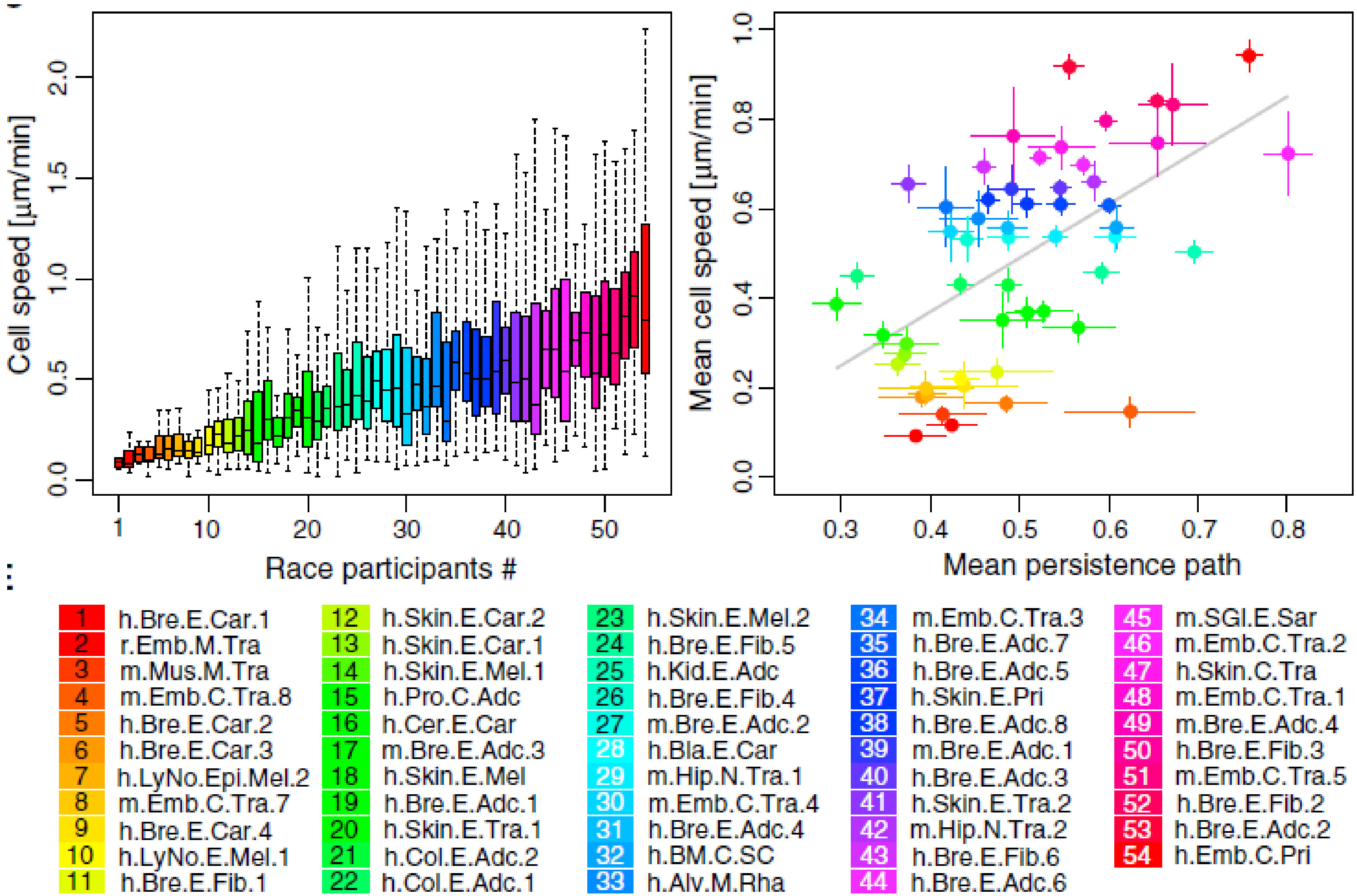
Micropatterns for migrating cells: the First World Cell Race (2011)



Movie: T. Vignault

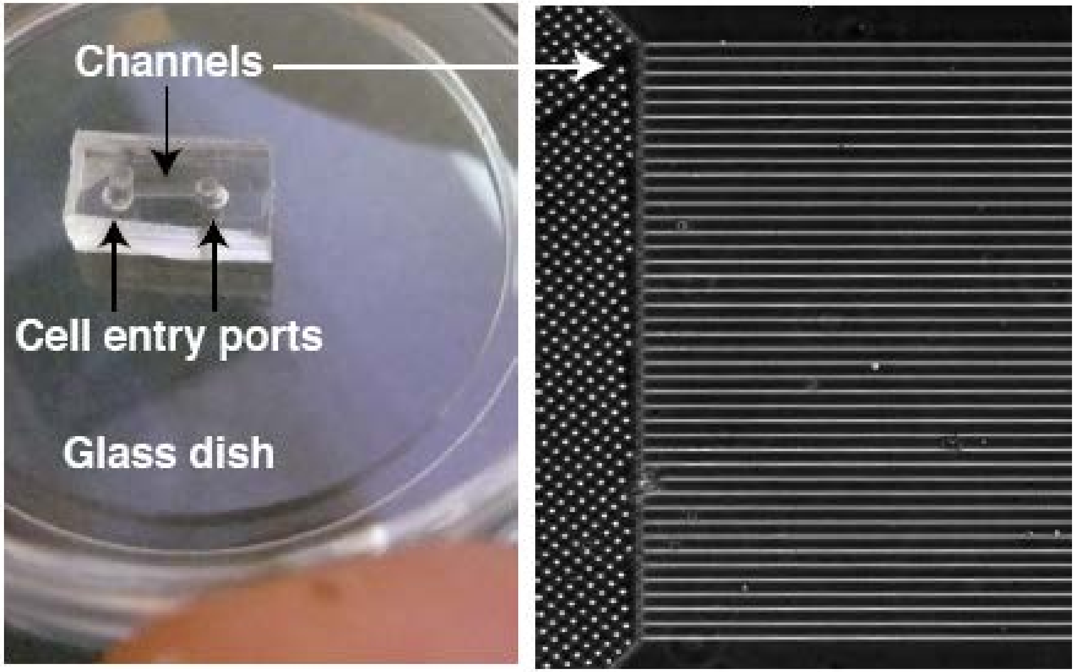
(see also Pouthas et al., JCS 2008 and Doyles et al., JCB 2009)

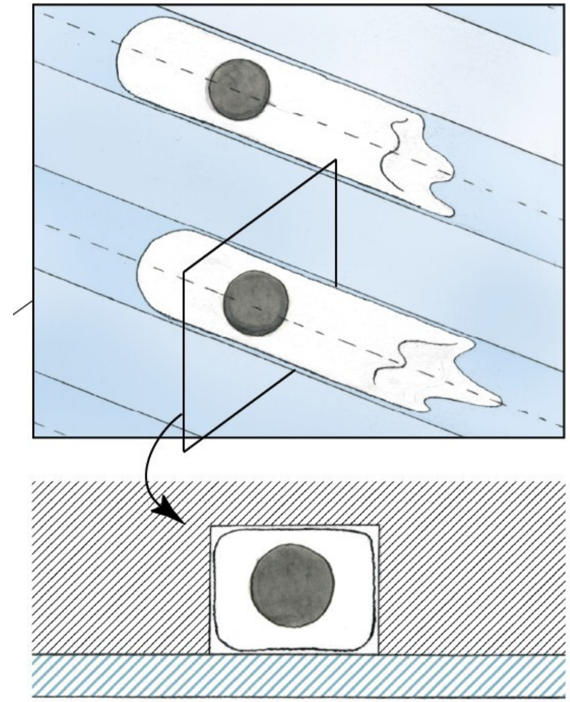
Faster cells are also more persistent, revealing a coupling between the motor and the steering wheel



Maiuri et al., Cur Biol 2012

A model system for migration in a confined space: microchannels with sub-cellular dimension

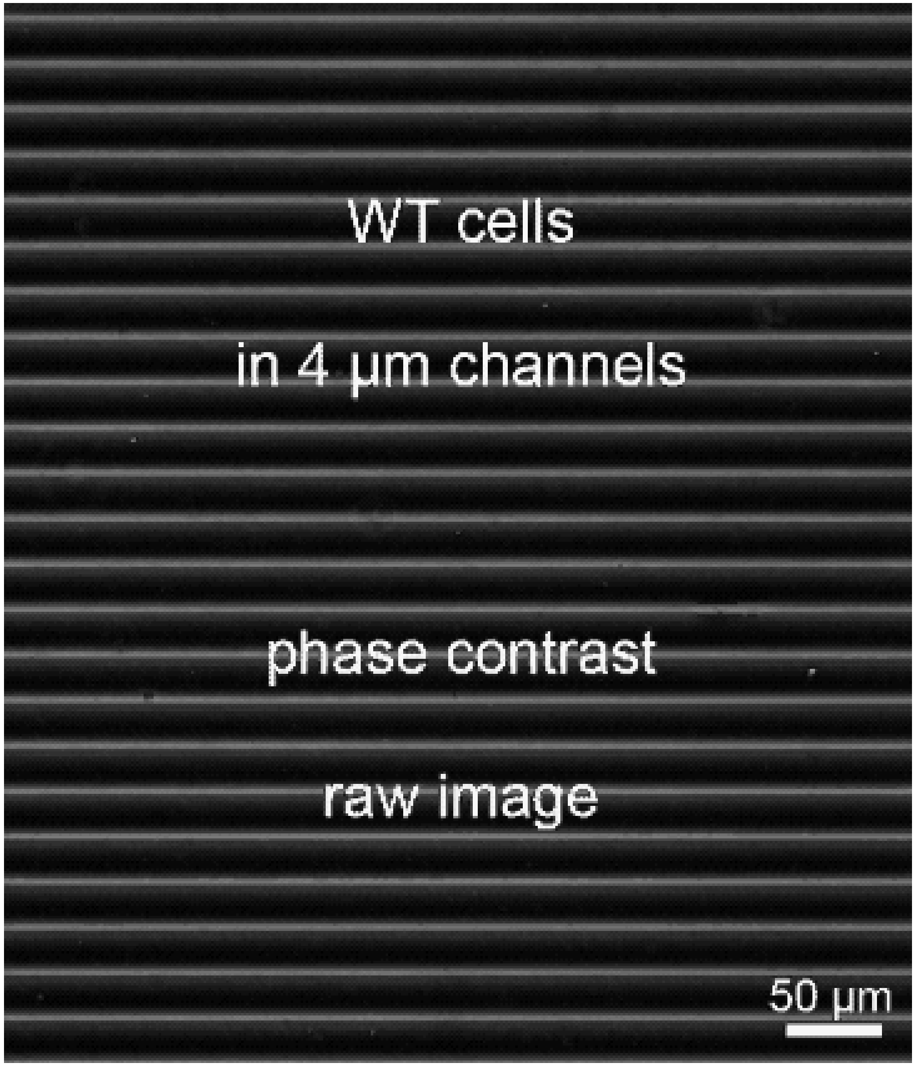




Mice bone marrow derived dendritic cell (BMDC), phase contrast

Faure-André, Science, 2008   Hawkins, PRL 2009   Heuze, Meth MB 2011
(also : Jacobelli, Nat Immunol 2010, Fernandez, Blood 2011, Moreau, Immunity 2012)

Microchannels for migrating amoeboid cells: Another race for immune cells?

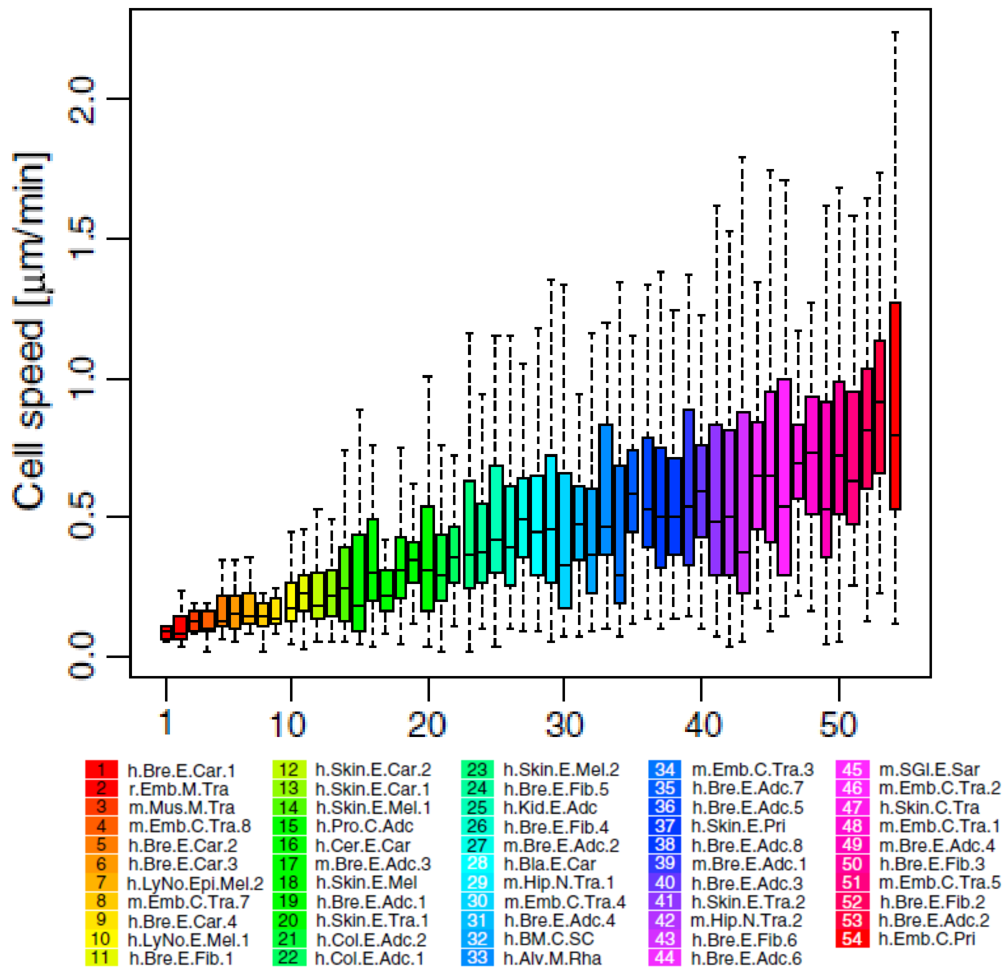


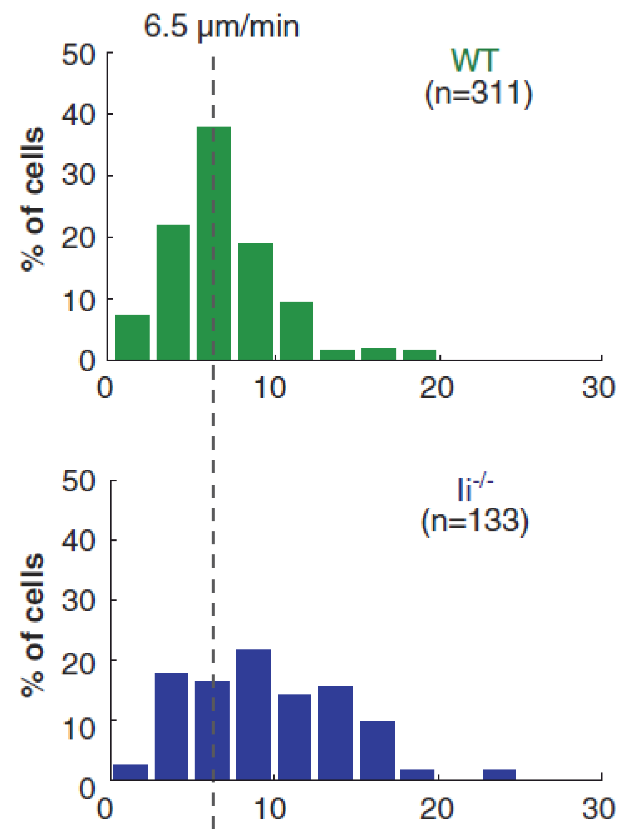
Bone marrow derived dendritic cells from mice (BMDCs)

Amoeboid cells (here BMDCs) in side channels are faster than mesenchymal cells on adhesive lines although they do not move on adhesive lines

WCR cells on lines: **0.1 to 1 µm/min**

BMDCS in channels: **1 to 20 µm/min**





Faure-André et al., Science 2008

Amoeboid versus mesenchymal

Mesenchymal

Proteolysis dependent, high MMP activity

Low Rho-ROCK activity

Elongated morphology with lamellipodial protrusions

Strong attachment to ECM via focal adhesions

Amoeboid

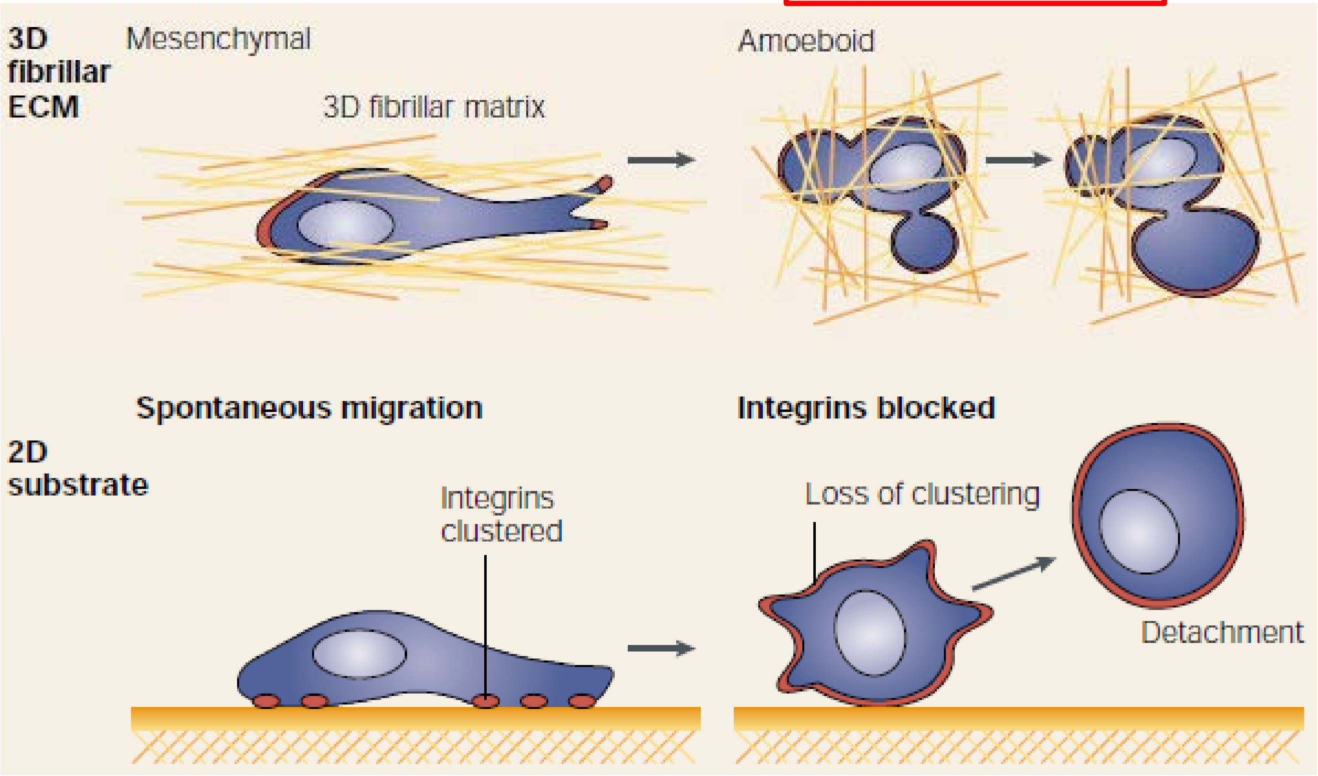
Proteolysis independent, low MMP activity

High Rho-ROCK activity

Rounded morphology with membrane blebbing

High cellular contractility and cortical tension

Weak attachment to ECM



Elongated to Rounded Transition

Summary on Mesenchymal versus Amoeboid:

(see Sanz-Moreno and Marshall, COCB, 2010)

Elongated morphology/mesenchymal migration is favored by

- strong adhesion
- high protrusive activity (Rac1/Wave2/Arp2/3)

Rounded morphology/amoeboid migration is favored by

- low adhesion
- strong contractility (Rho1/ROCK/Formins/Myosin II)

Important point:

- On 2D substrates, both elongated and rounded migration are SLOW
- Inside 3D gels or in vivo, elongated cells are still SLOW (< 1µm/min) and rounded cells are FAST (>1 µm/min)

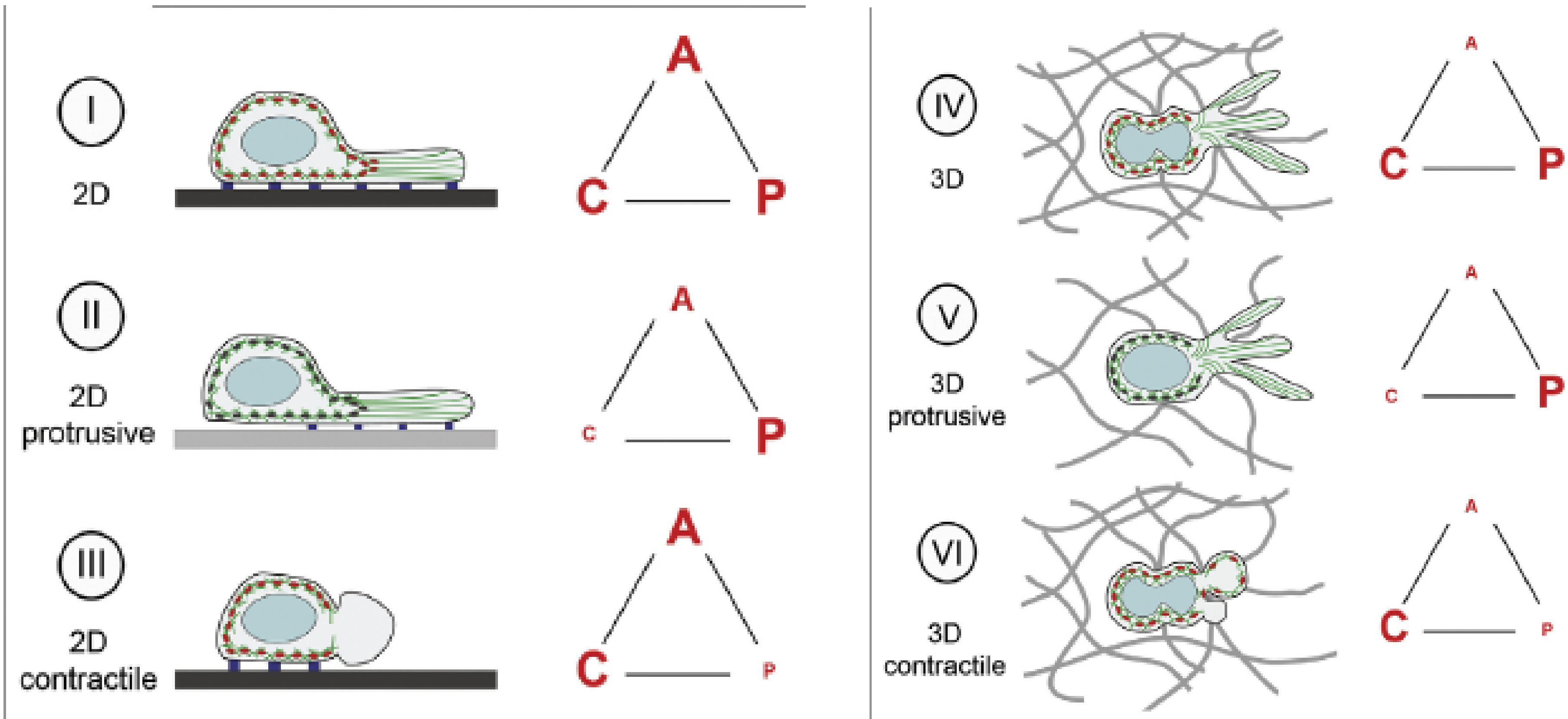
WHY? CONFINEMENT!!

(read Totzluoglu et al. NCB 2013, E. Sahai Lab)

Migration under confinement:
To adhere or not to adhere?

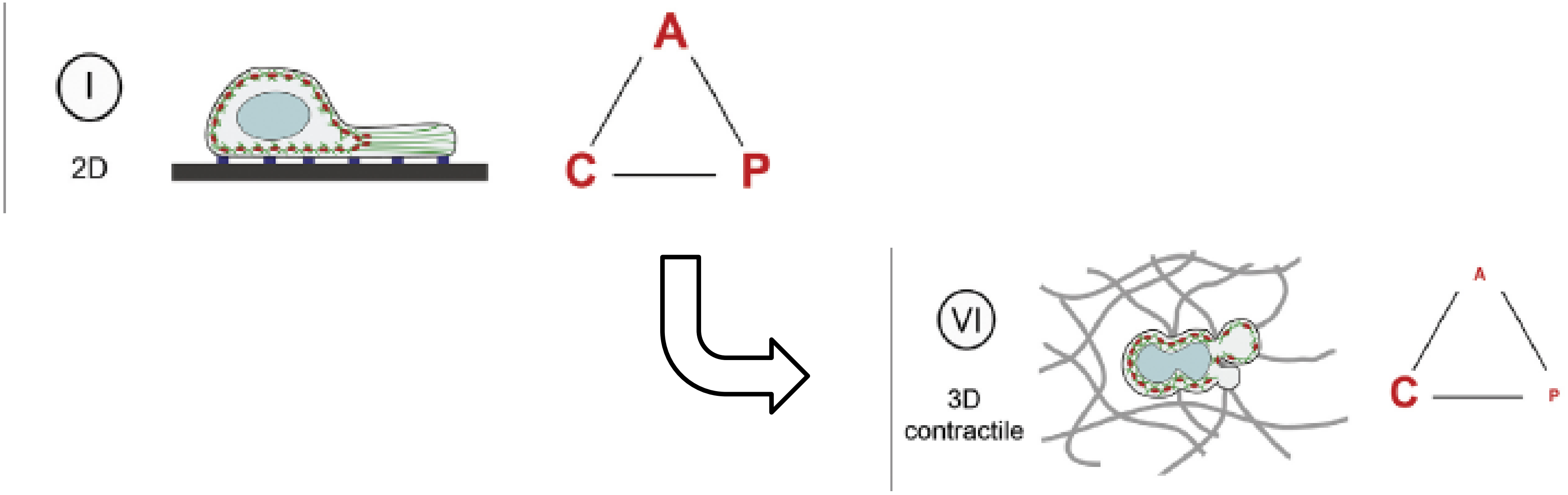
How cells exert force on their surrounding to move?

Mesenchymal | Amoeboid

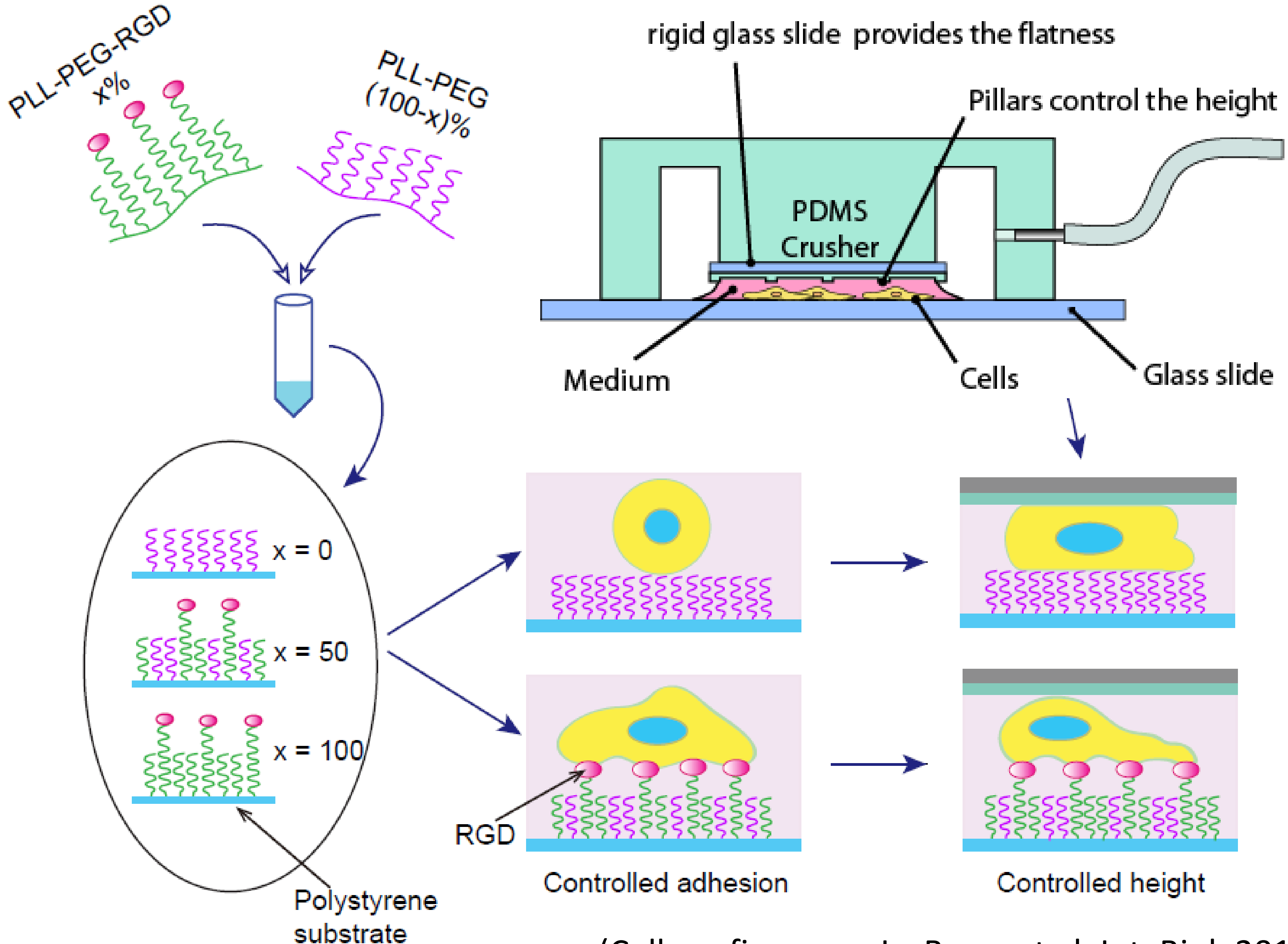


Lämmermann and Sixt COCB 2009

Is it possible, by playing on adhesion, confinement, and contractility to induce mesenchymal cells to move like leukocytes?

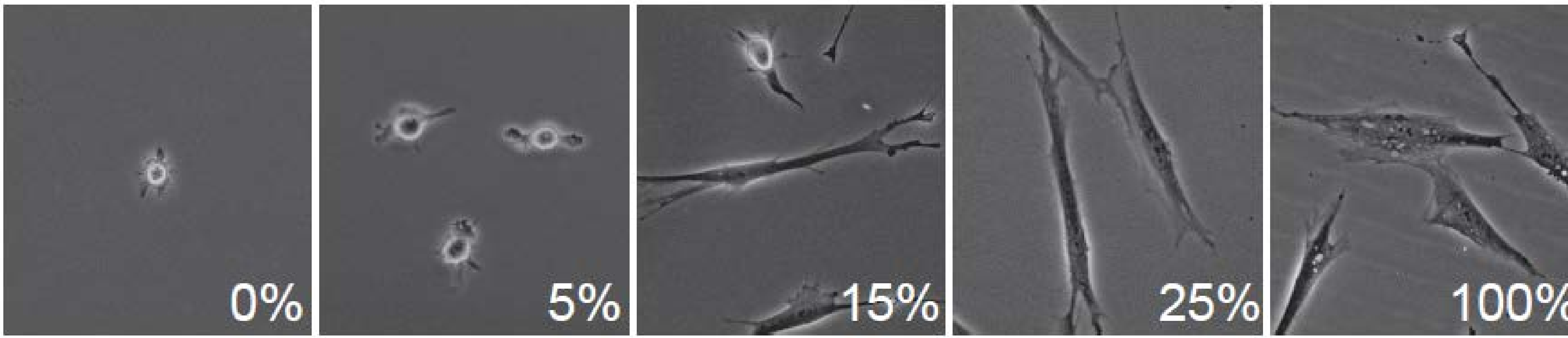


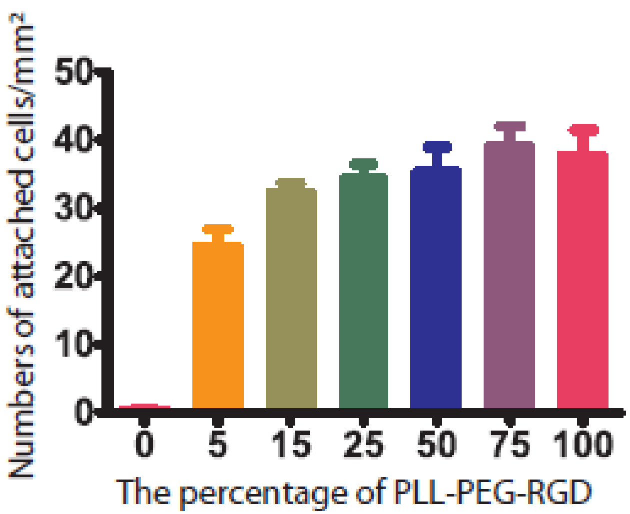
Quantitative control of confinement and adhesion

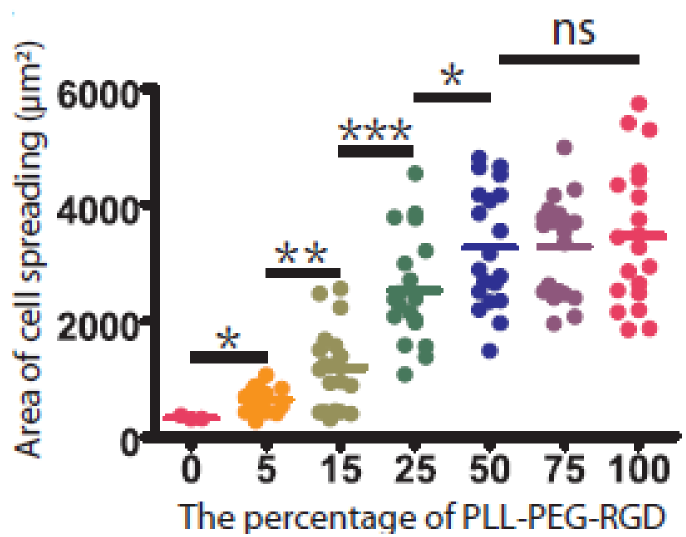


(Cell confiner: see Le Berre et al. Int. Biol. 2012)

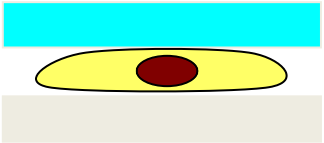
Primary Fibroblasts (NHDFs) on PLL-g-PEG-RGD/Pll-g-PEG surfaces

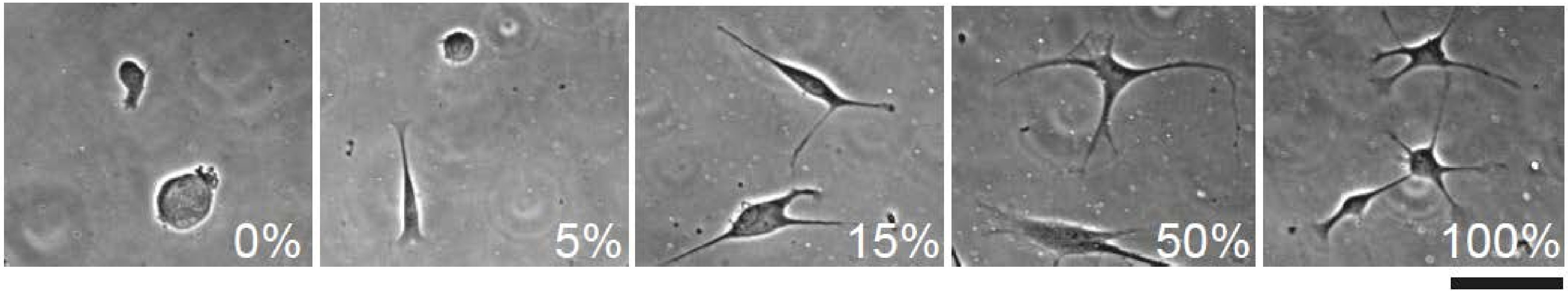


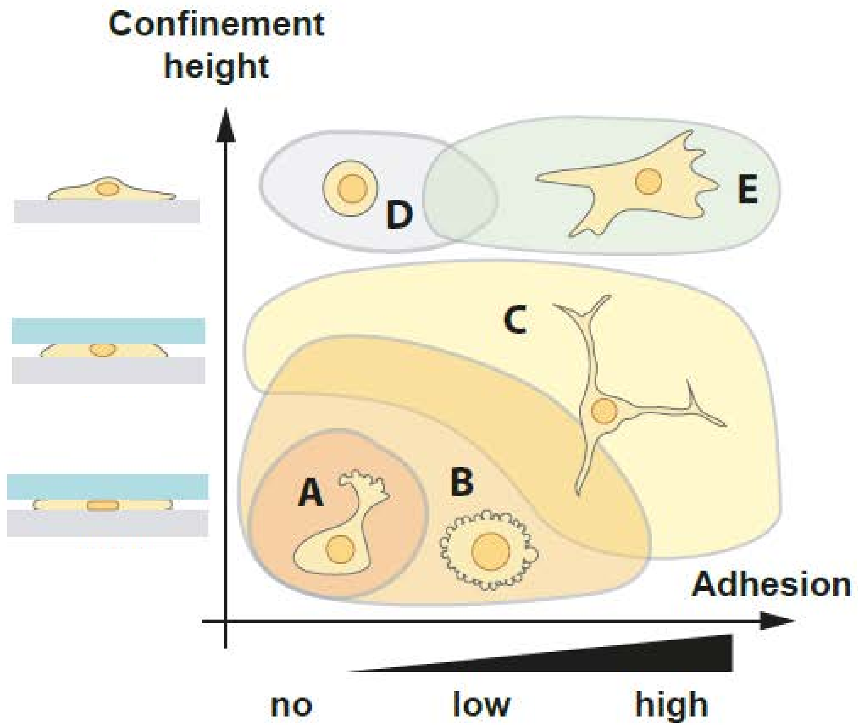


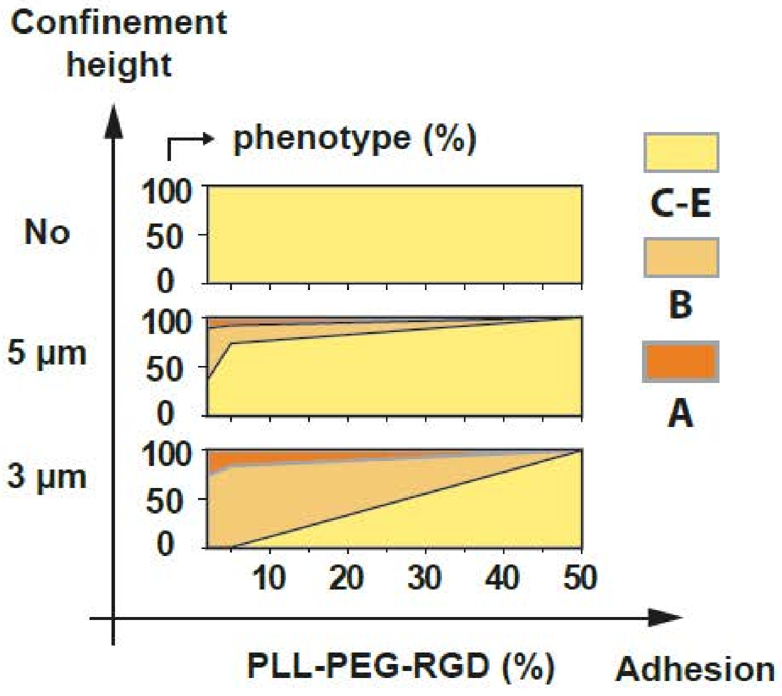


NHDF morphology under confinement

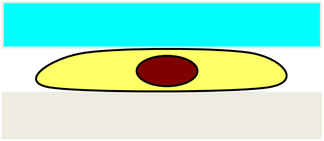




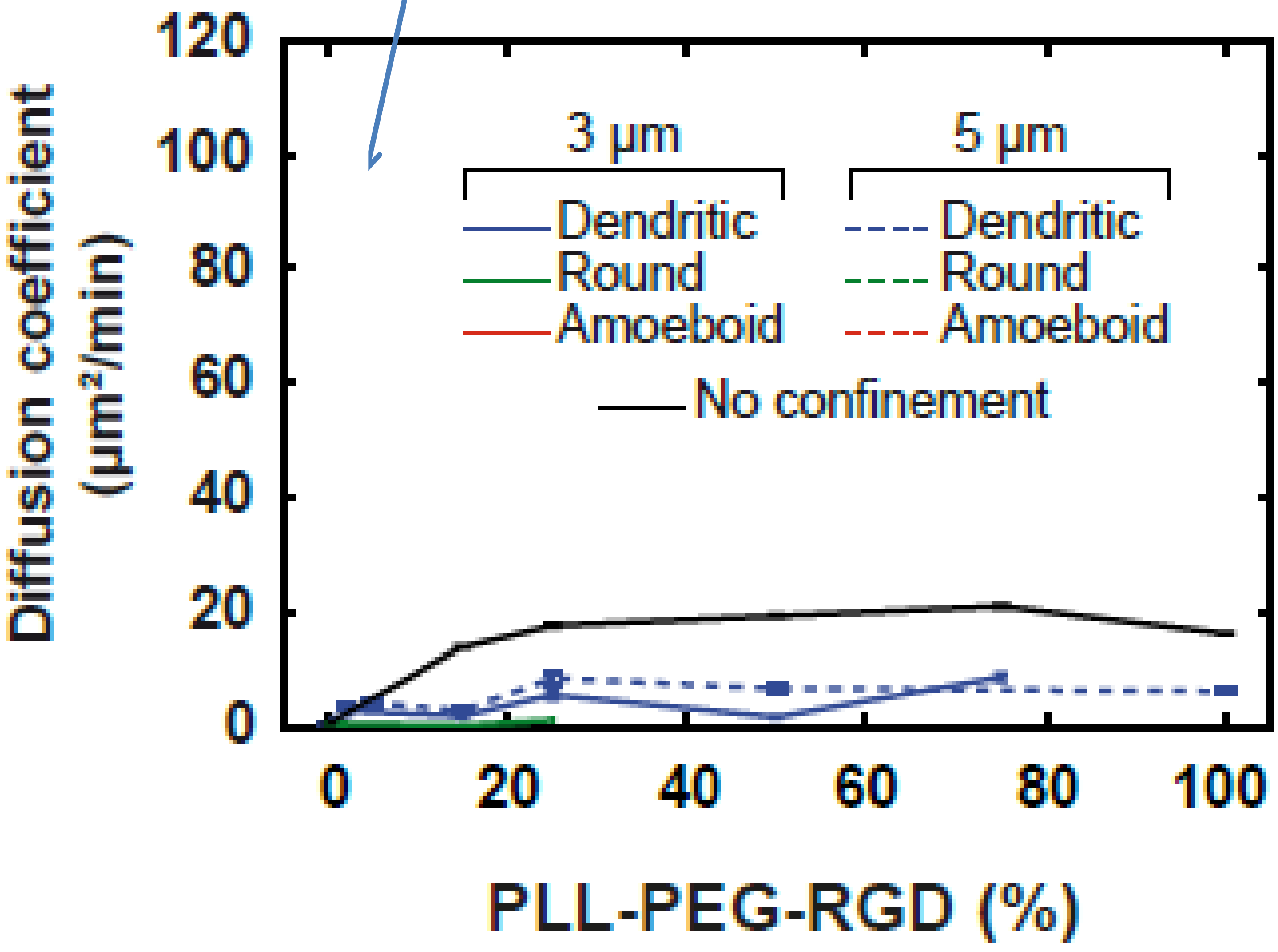




NHDF migration under confinement

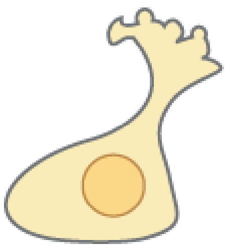


< 5% RGD: cells cannot bind, but move fast!

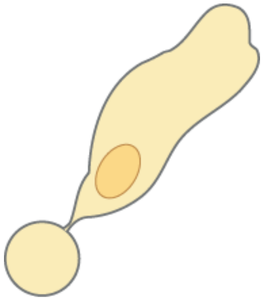


Is it truly a general phenomenon?

Cell lines assayed: NHDFs, HT29, RPE1, 3T3, MDA-MB231, HEK, HeLa

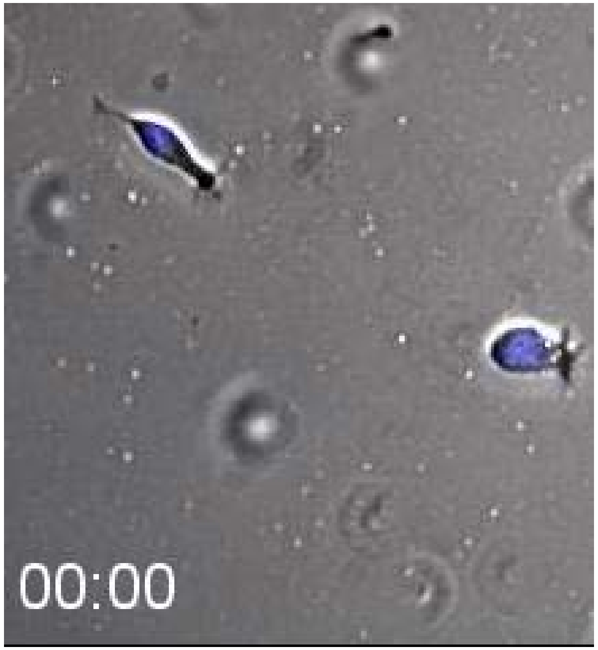


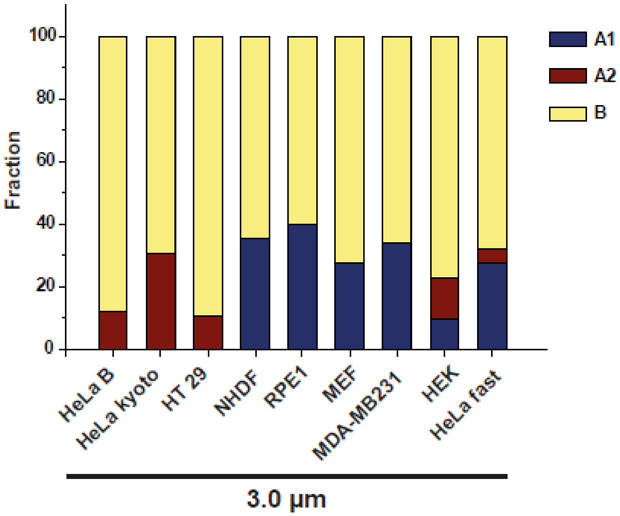
Amoeboid 1 (A1)



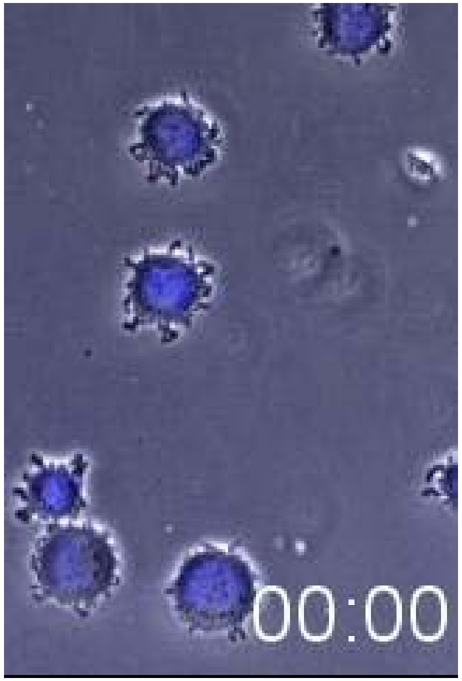
Amoeboid 2 (A2)

RPE1

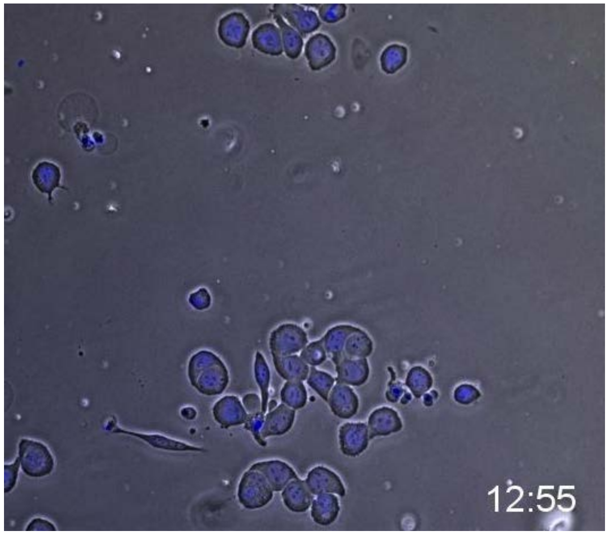




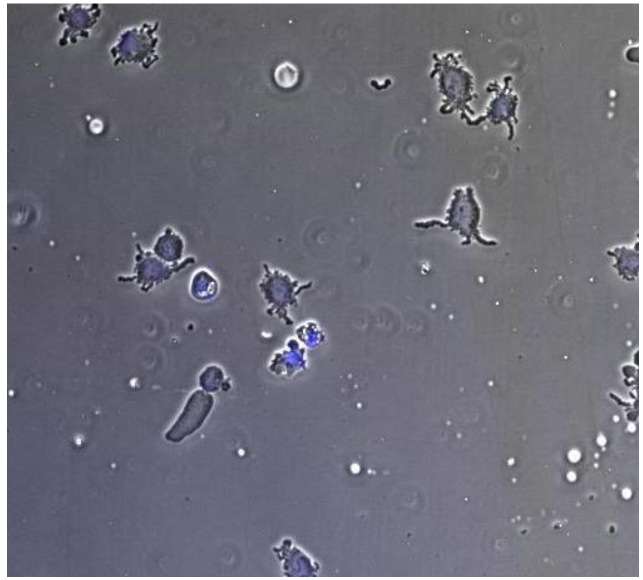
HeLa



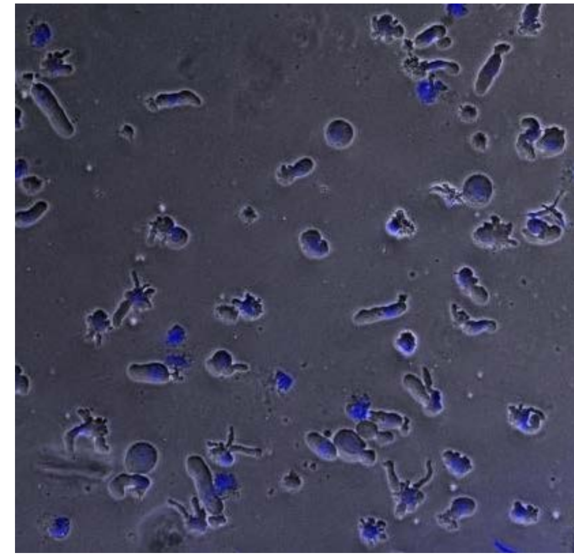
Fraction of A2 increases with contractility, while inhibiting contractility increases A1



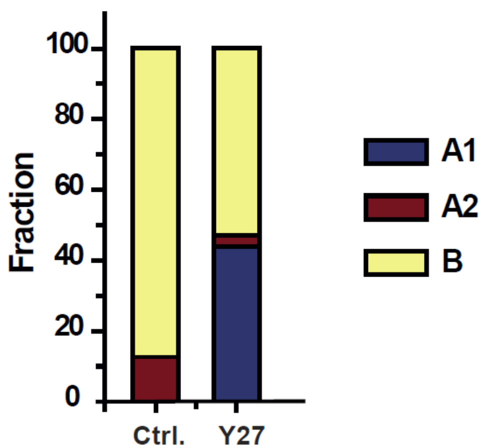
Y27632

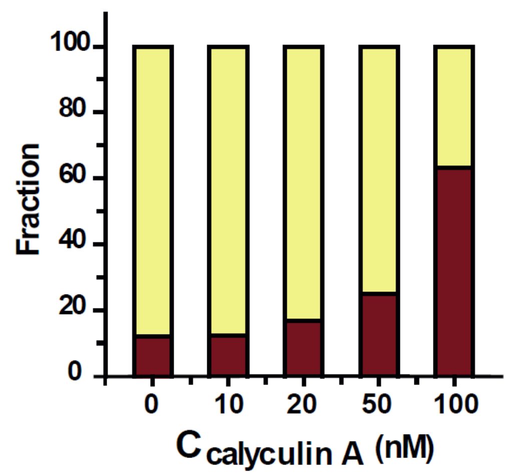


Control



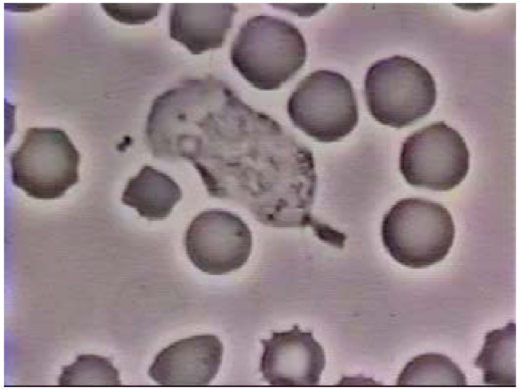
Calyculin A





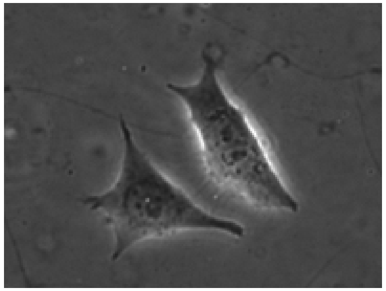
Turning non motile HeLa cells into fast neutrophile-like cells by purely physical means

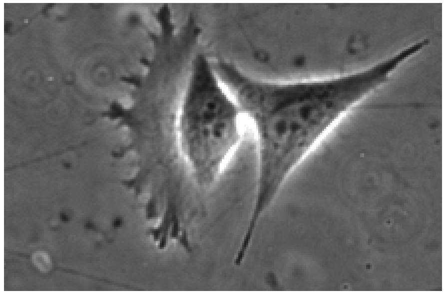
The fastest migrating HeLa cell ever: up to 10 µm/min
Movie: Yanjun Liu

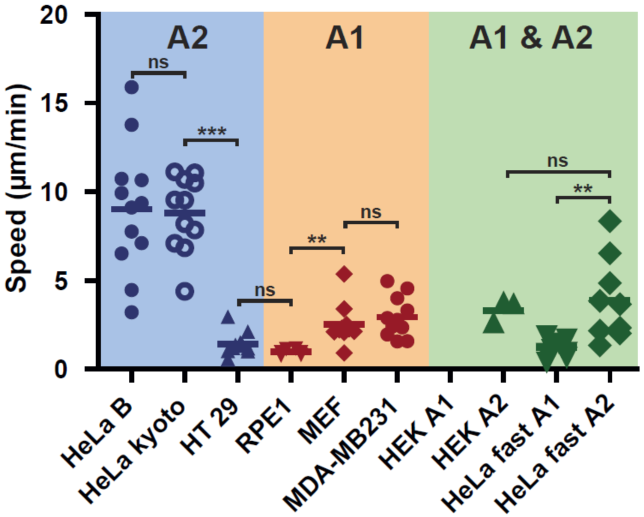


The most famous neutrophile
(Movie: Stossel)

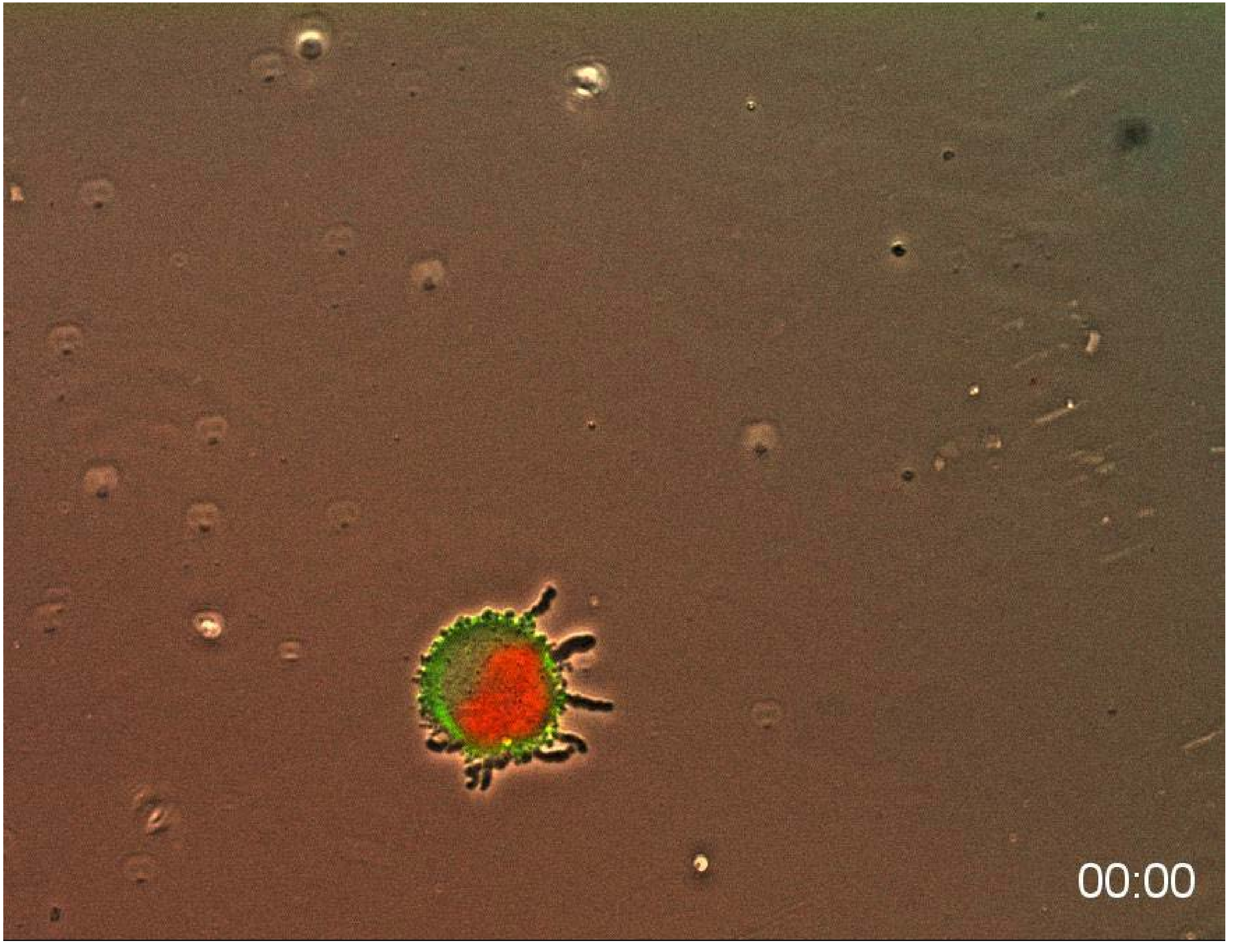
HeLa cells adhesive no confinement







What is going on with these cells?



Myosin II Nucleus

What is going on with these cells?

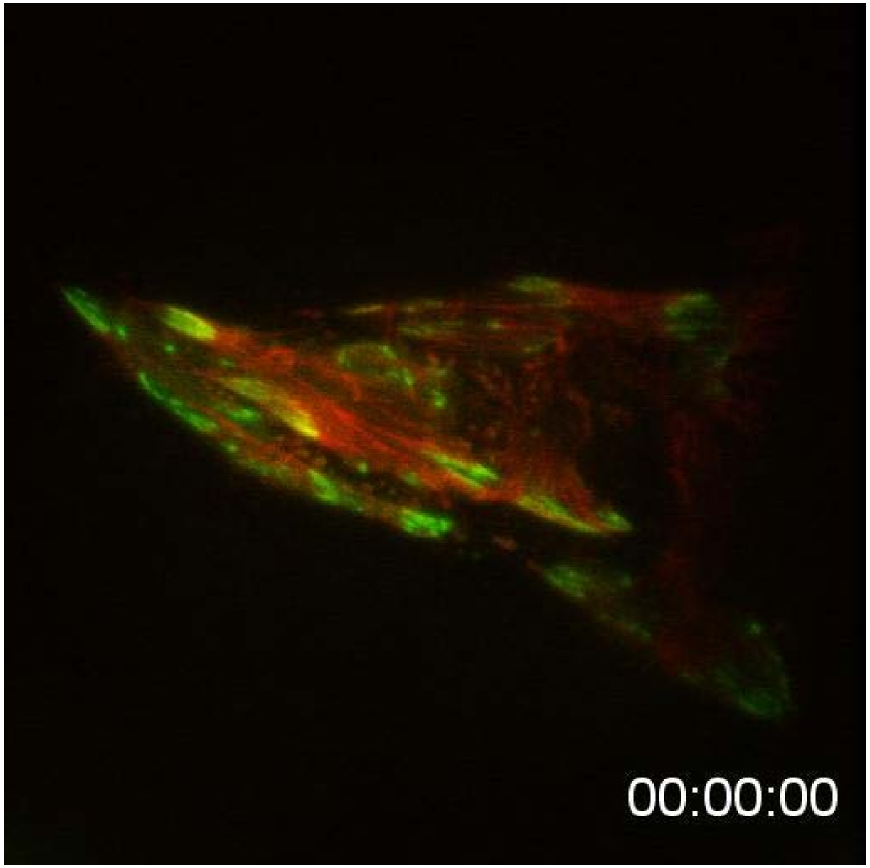
Adhesions (green) plus actin (red)

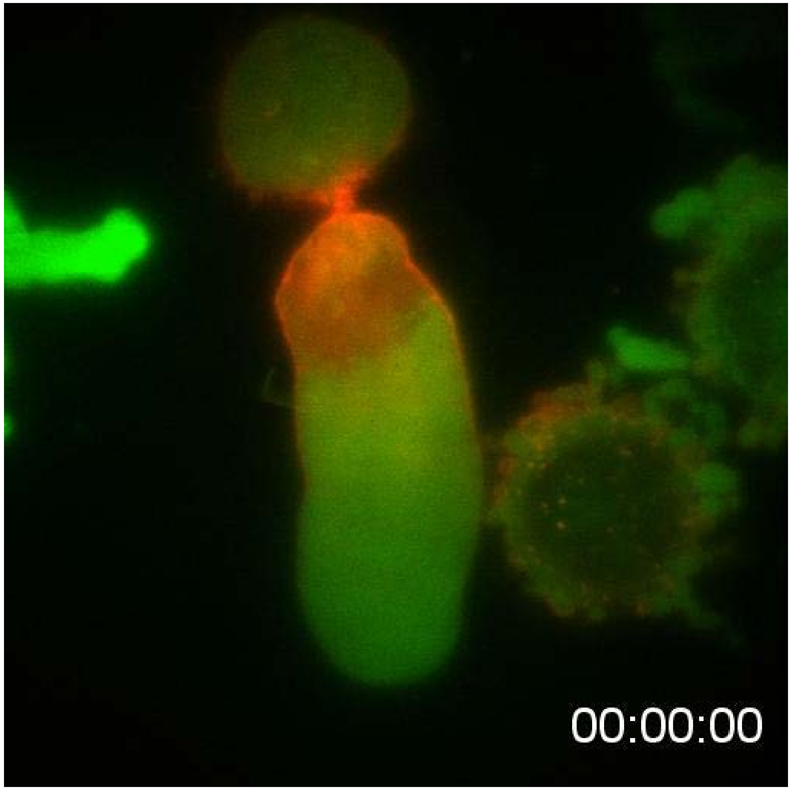
No confinement
Fibronectine

Focal adhesions
Stress fibers

3 µm confinement
0% RGD

No adhesions
Flowing cortex



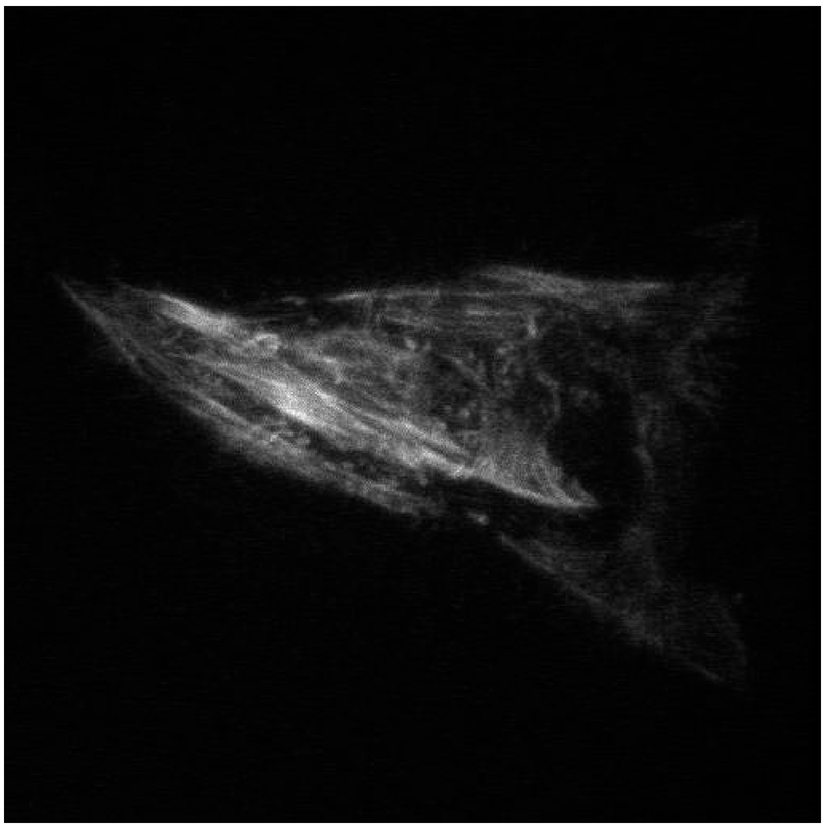


HeLa cells

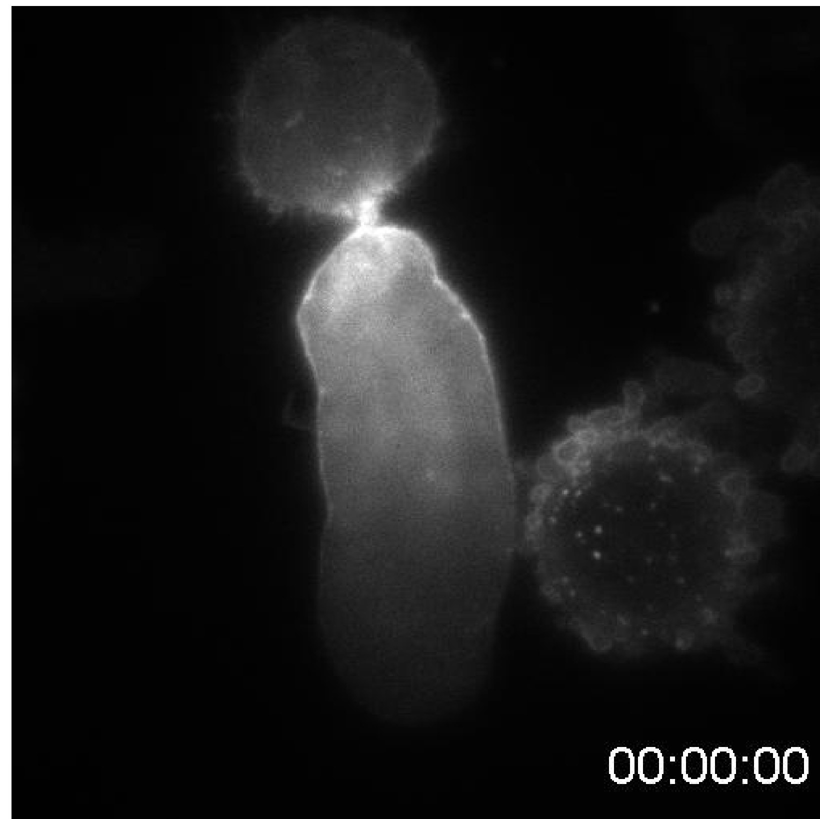
What is going on with these cells?

Actin cytoskeleton: Lifeact-mcherry

No confinement
100% RGD

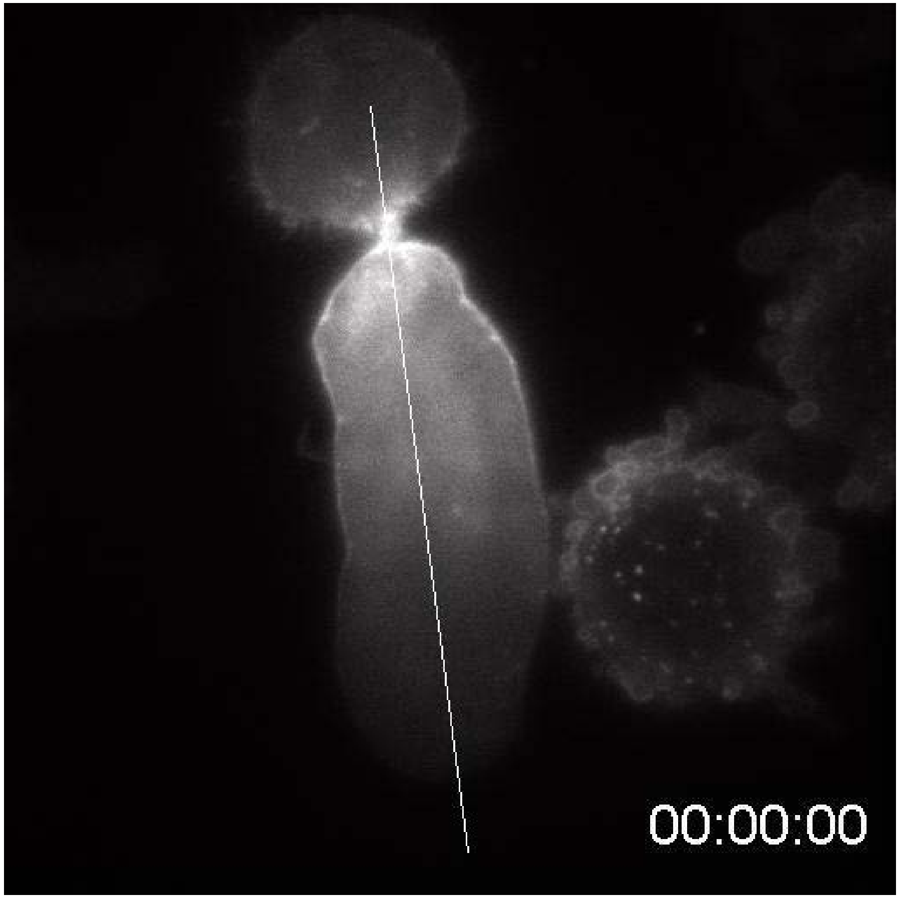


3 µm confinement
2% RGD

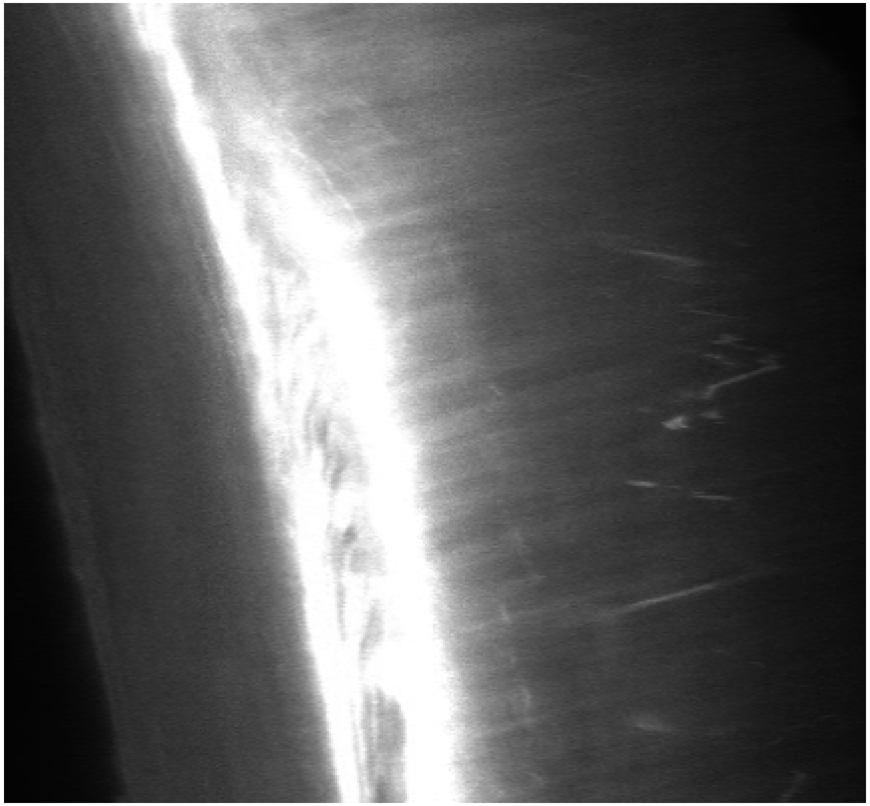


HeLa cells

Actin



Kymograph analysis



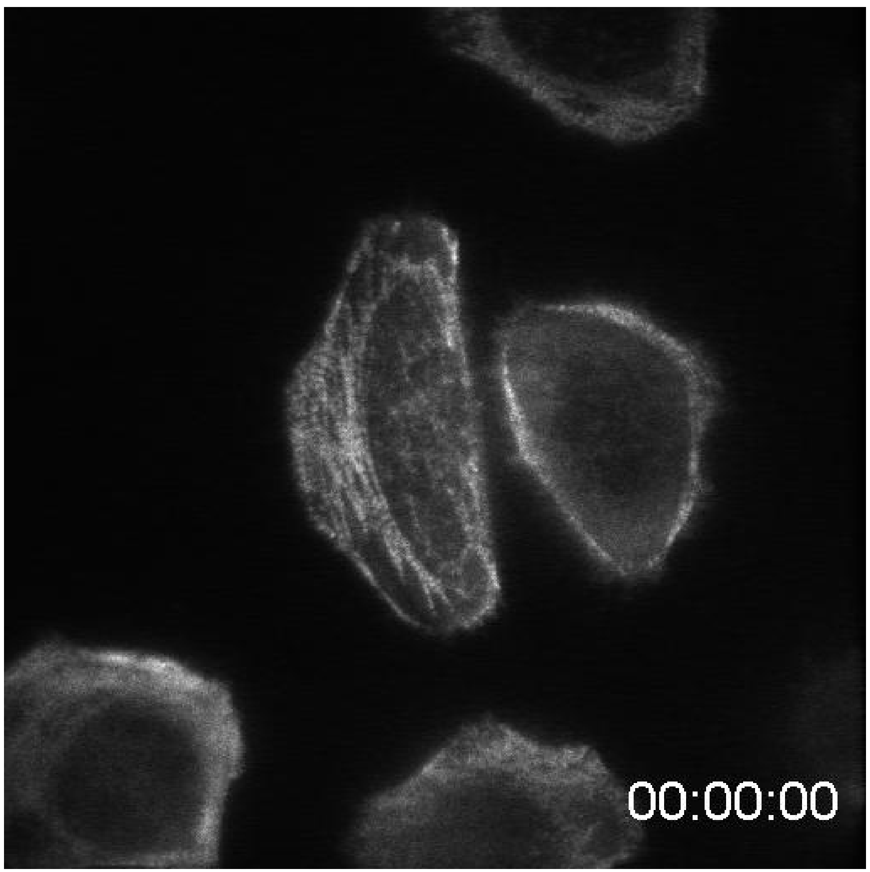
Fast retrograde flow.

Retrograde flow analysis

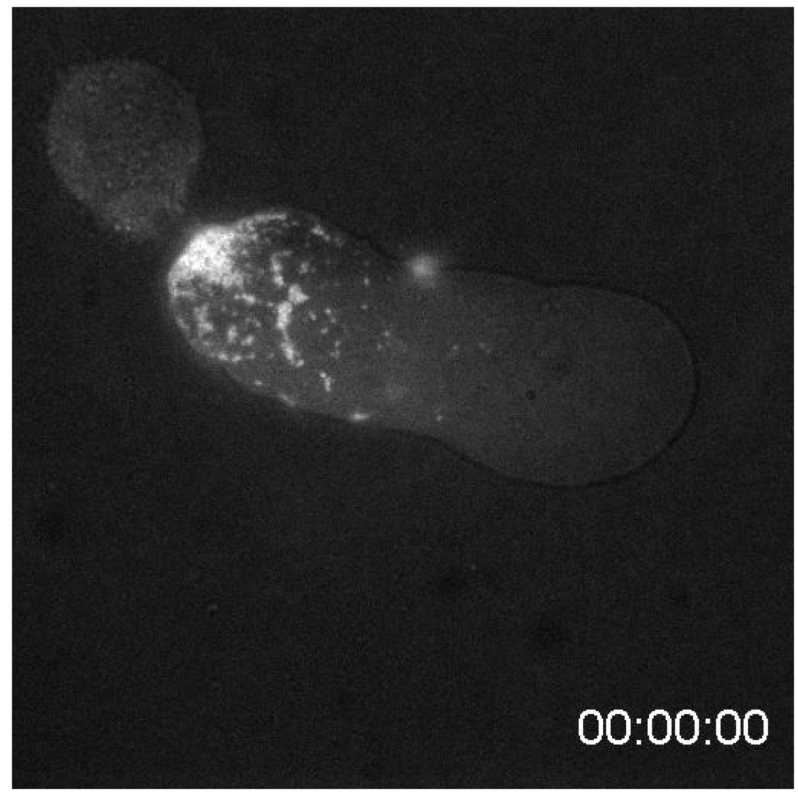
What is going on with these cells?

Myosin motor: MYH9-GFP (Mysoin II A)

No confinement
100% RGD

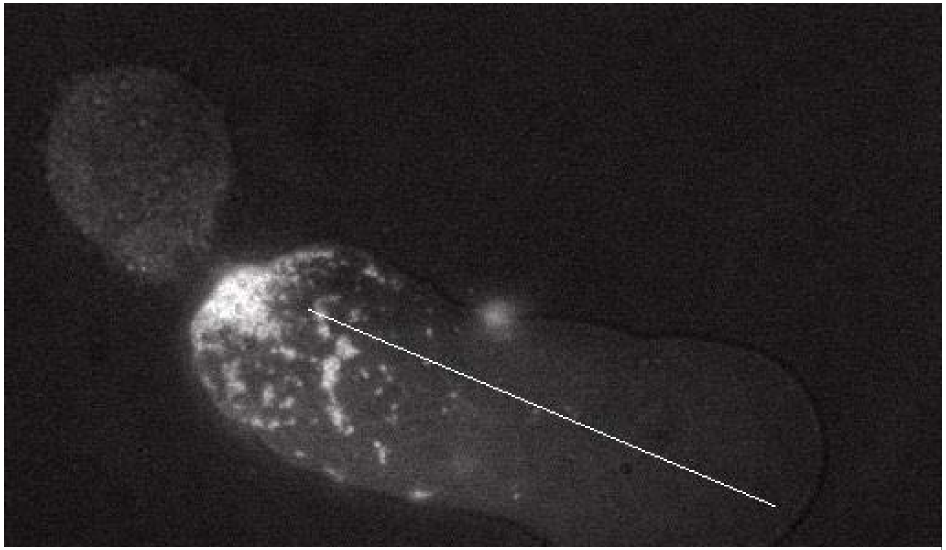


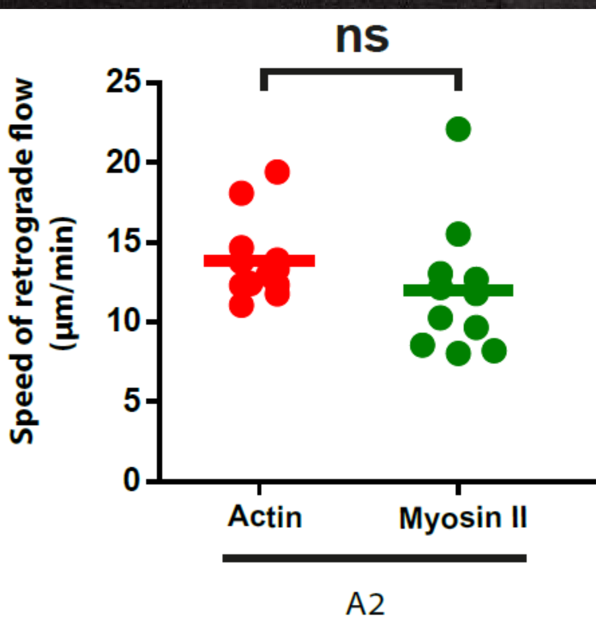
3 µm confinement
2% RGD

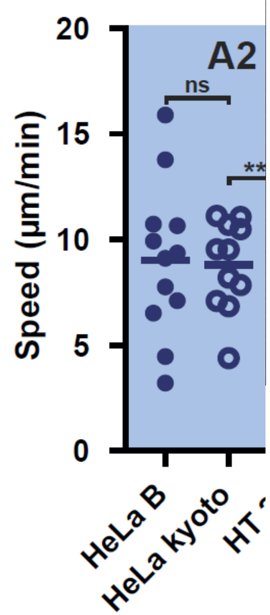


HeLa cells

MyosinII







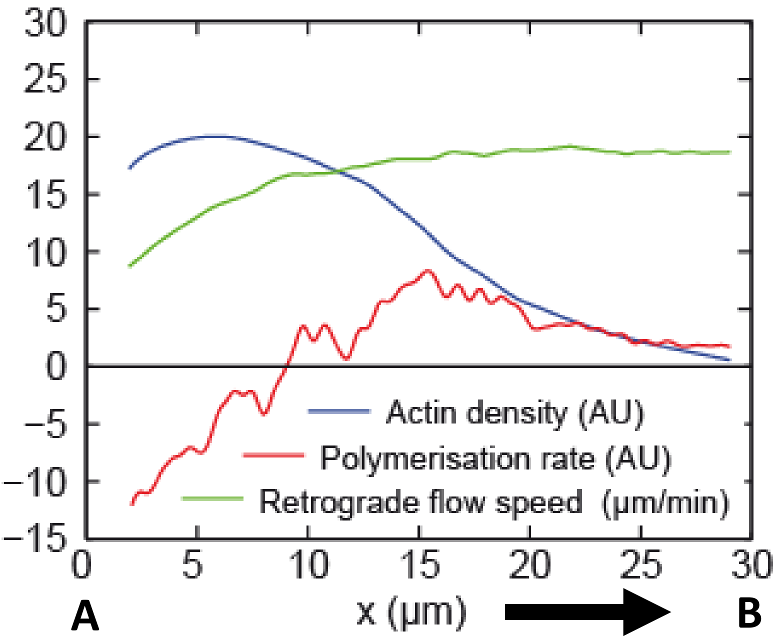
Kymograph analysis

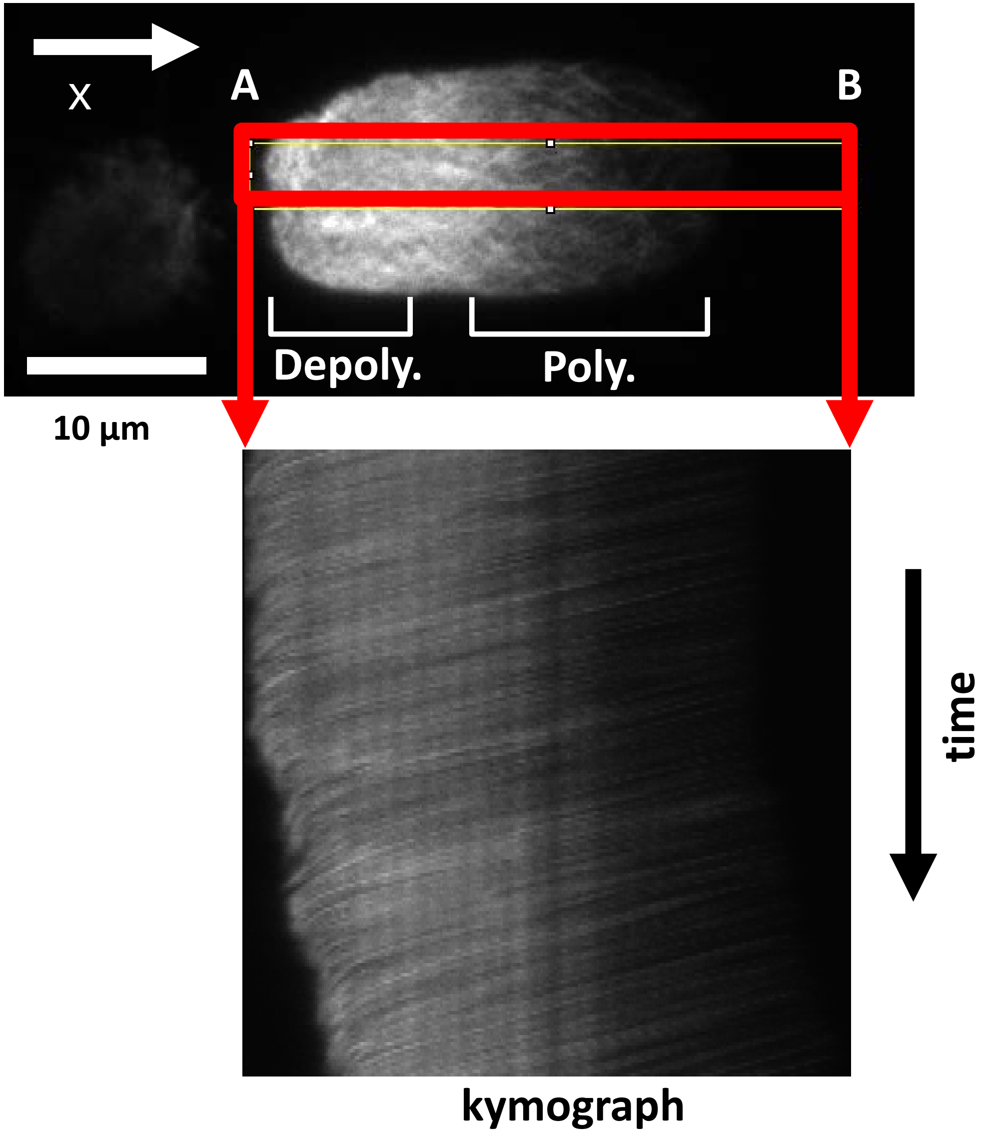
Actin polymerisation

Actin polymerisation rate:

=

Div(Actin density x retrograde flow)

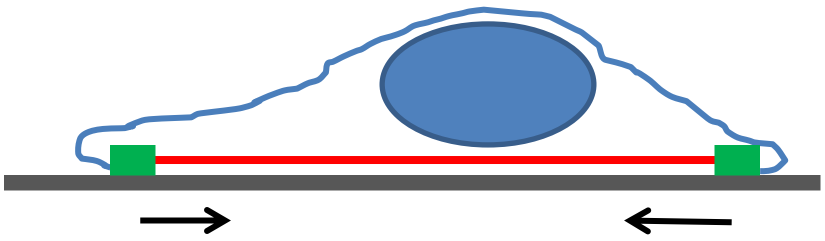




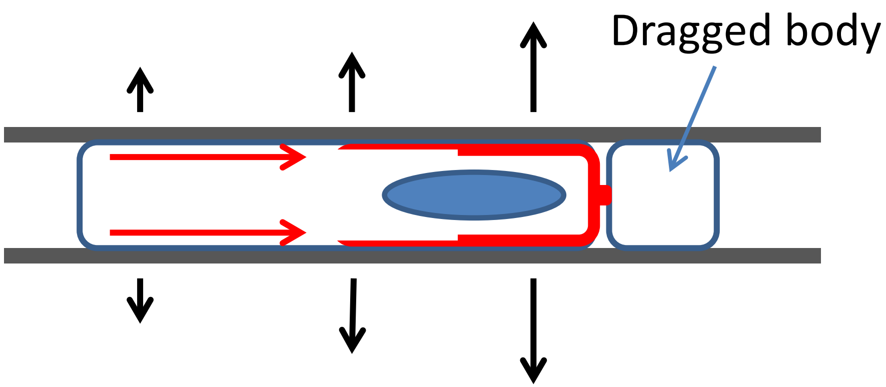
What is going on with these cells?

Focal adhesions
Stress fibers
Pulling
Slow motility (~0.1 μm/min)

No adhesions
Flowing cortex
Pushing
Fast motility (~5-10 μm/min)
Speed and polarity strongly depend on contractility



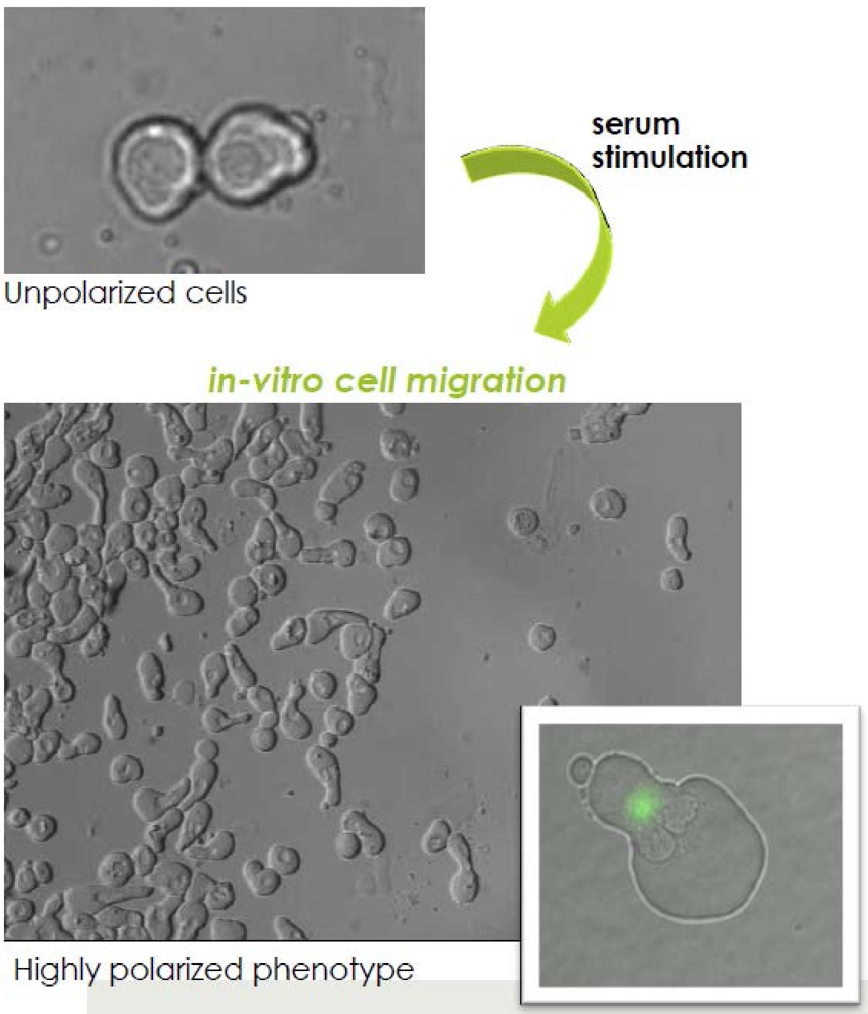
No confinement
100% RGD

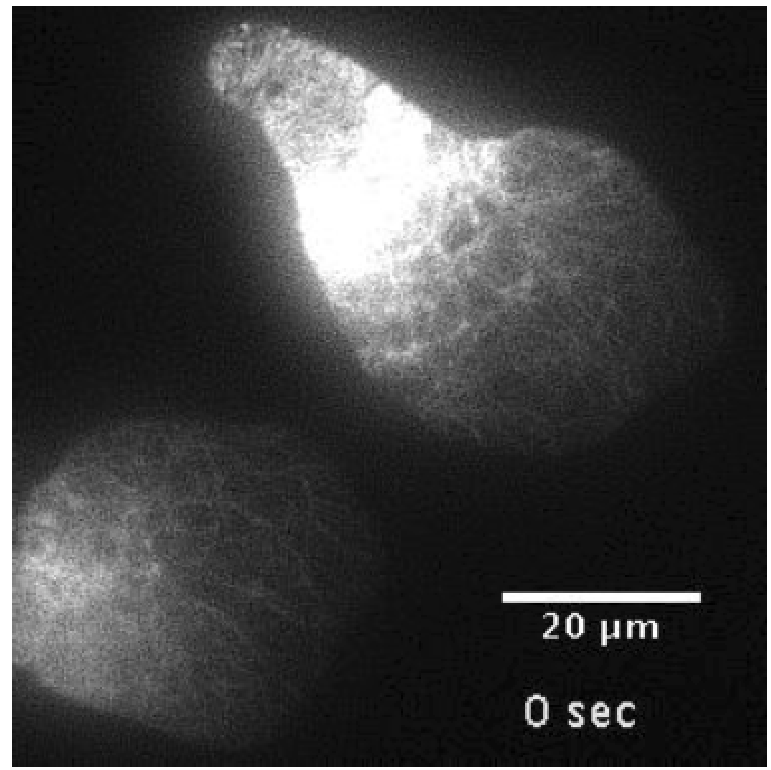


3 μm confinement
0% RGD

(for flow driven migration see also Poincloux et al. PNAS 2011 and Hawkins et al. Bioph J 2011)

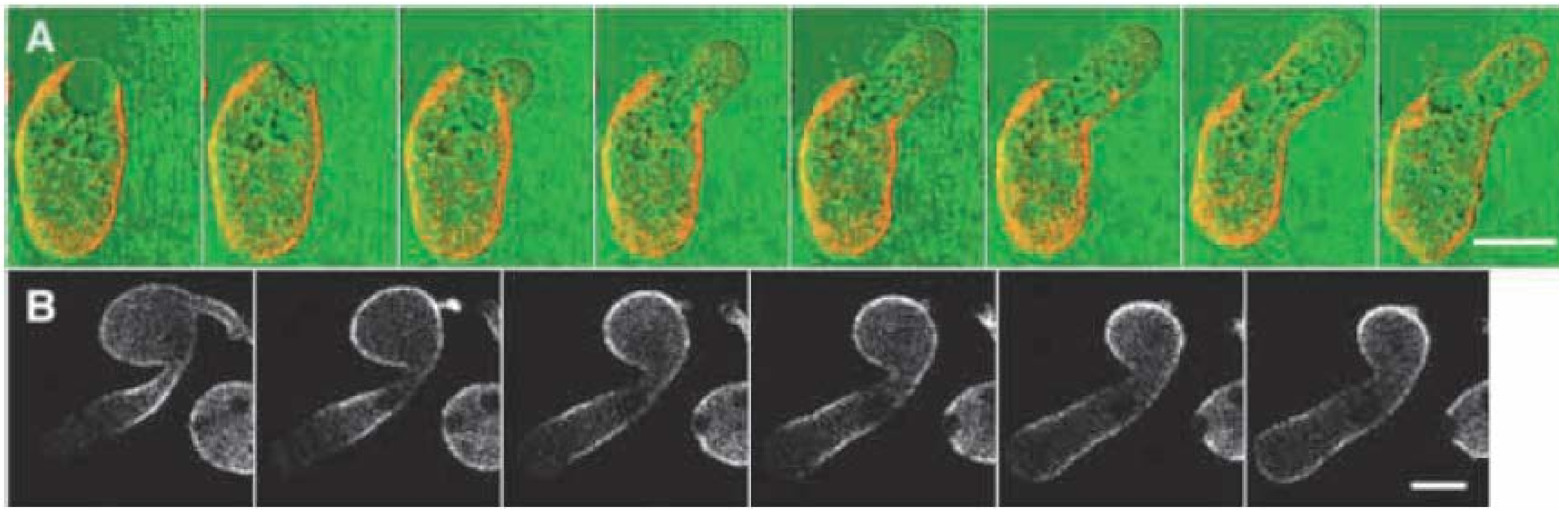
These cells move like neutrophiles and even like… fish embryonic cells (under confinement)



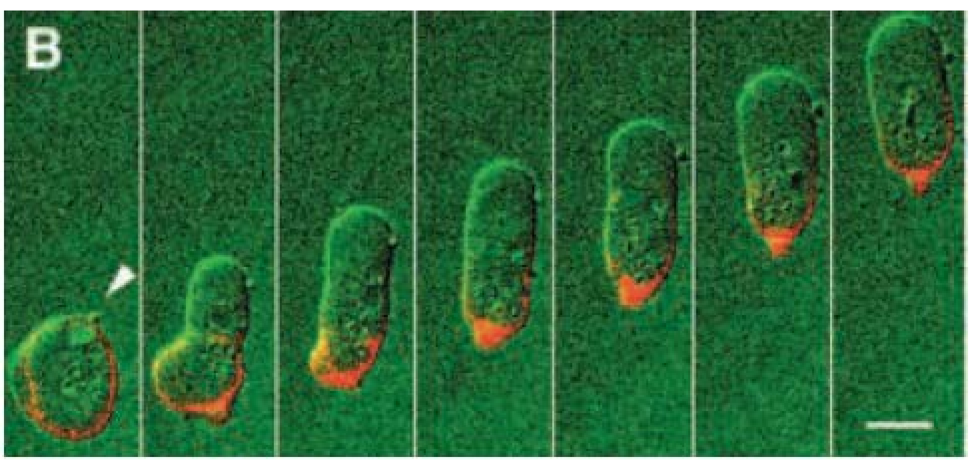


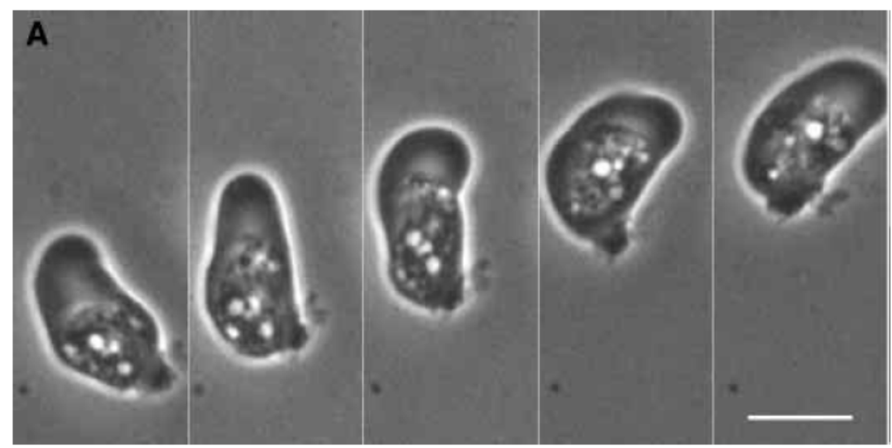
(from Verena Ruprecht,
CP Heisenberg lab, IST, Vienna)

It is really amoeboid migration: Dicty can do it too! (when treated with quinine)



Myo II

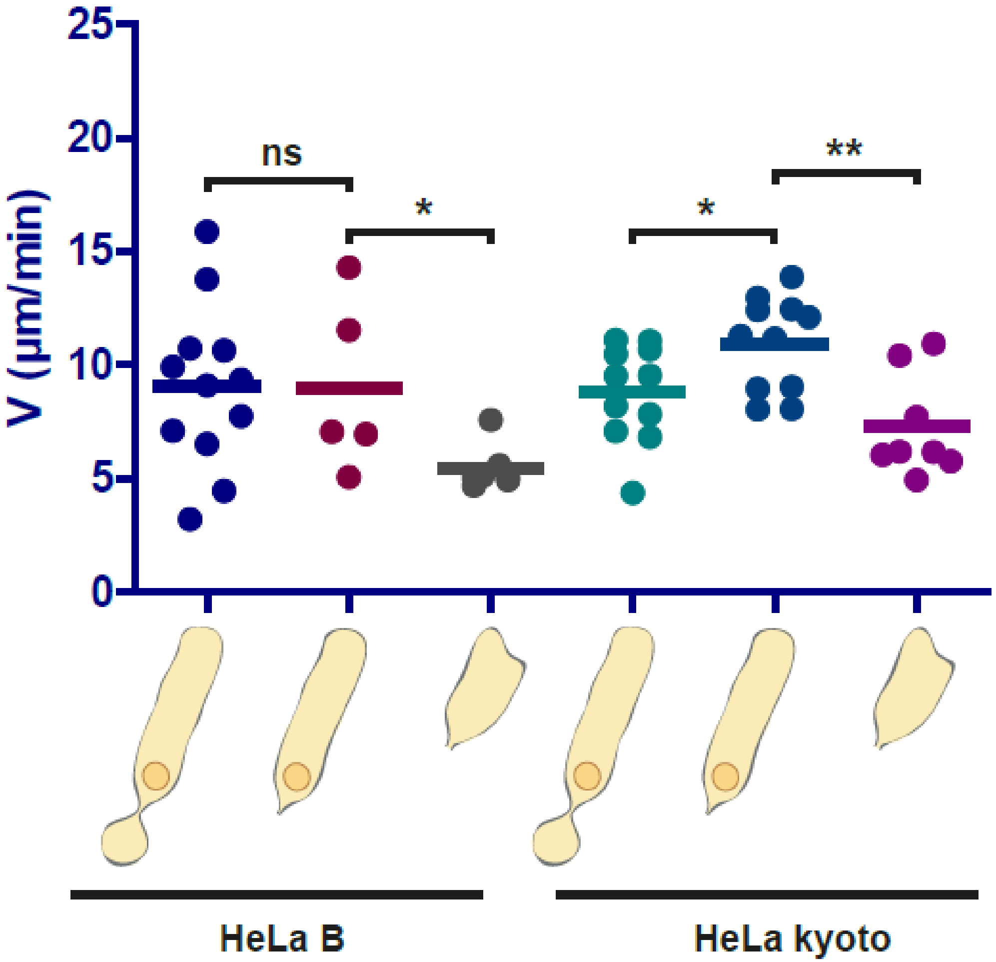




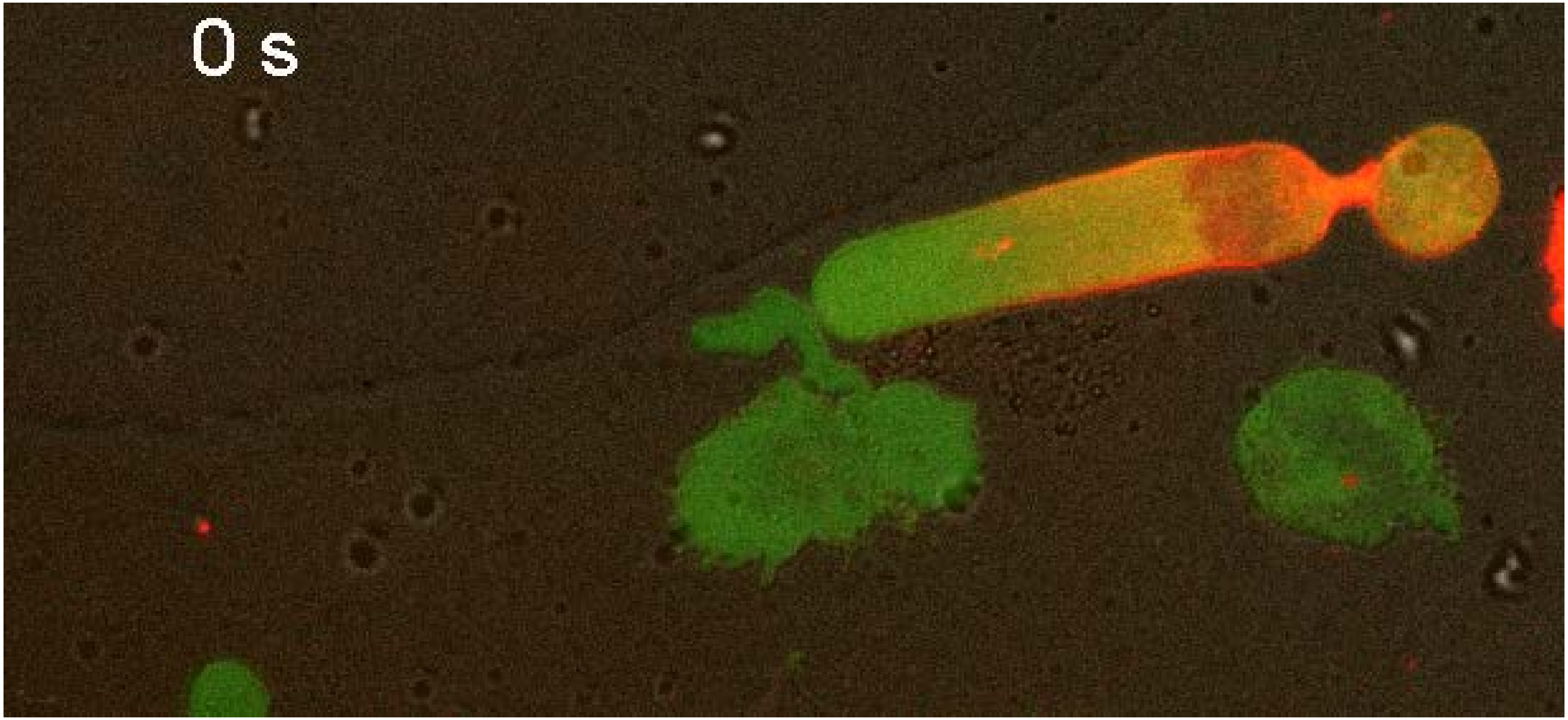
Actin

And Inouye, JCS, 2001

A primitive and universal flow/friction/pressure driven migration?



One more migrating sausage…
HeLa cells as a model system
to study fast amoeboid migration!!

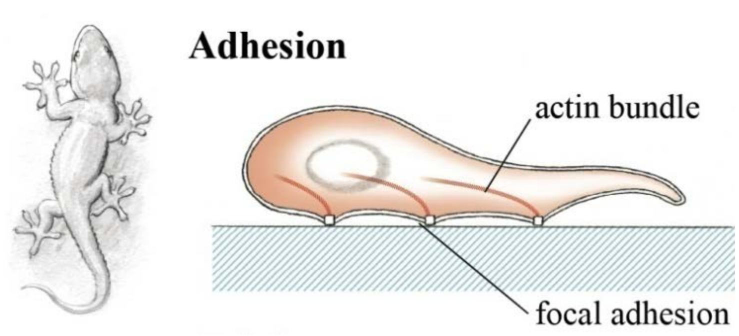


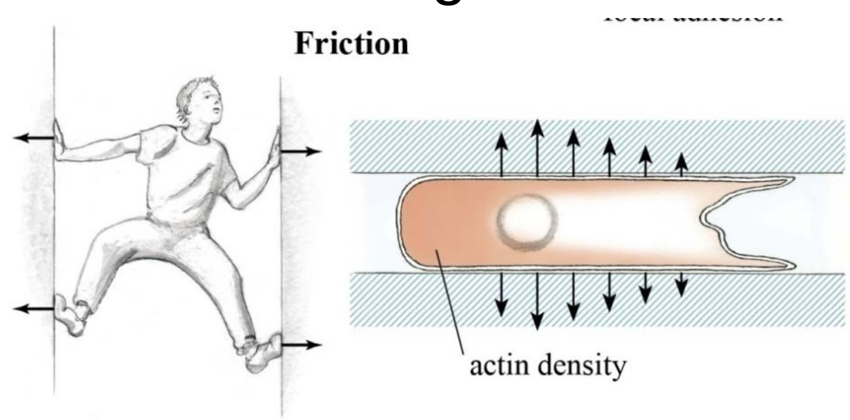
Conclusions

1) At high adhesion, cells migrate slower under confinement (lamelipodial/adhesion driven motility): they use their force to pull on the substrate, not to move

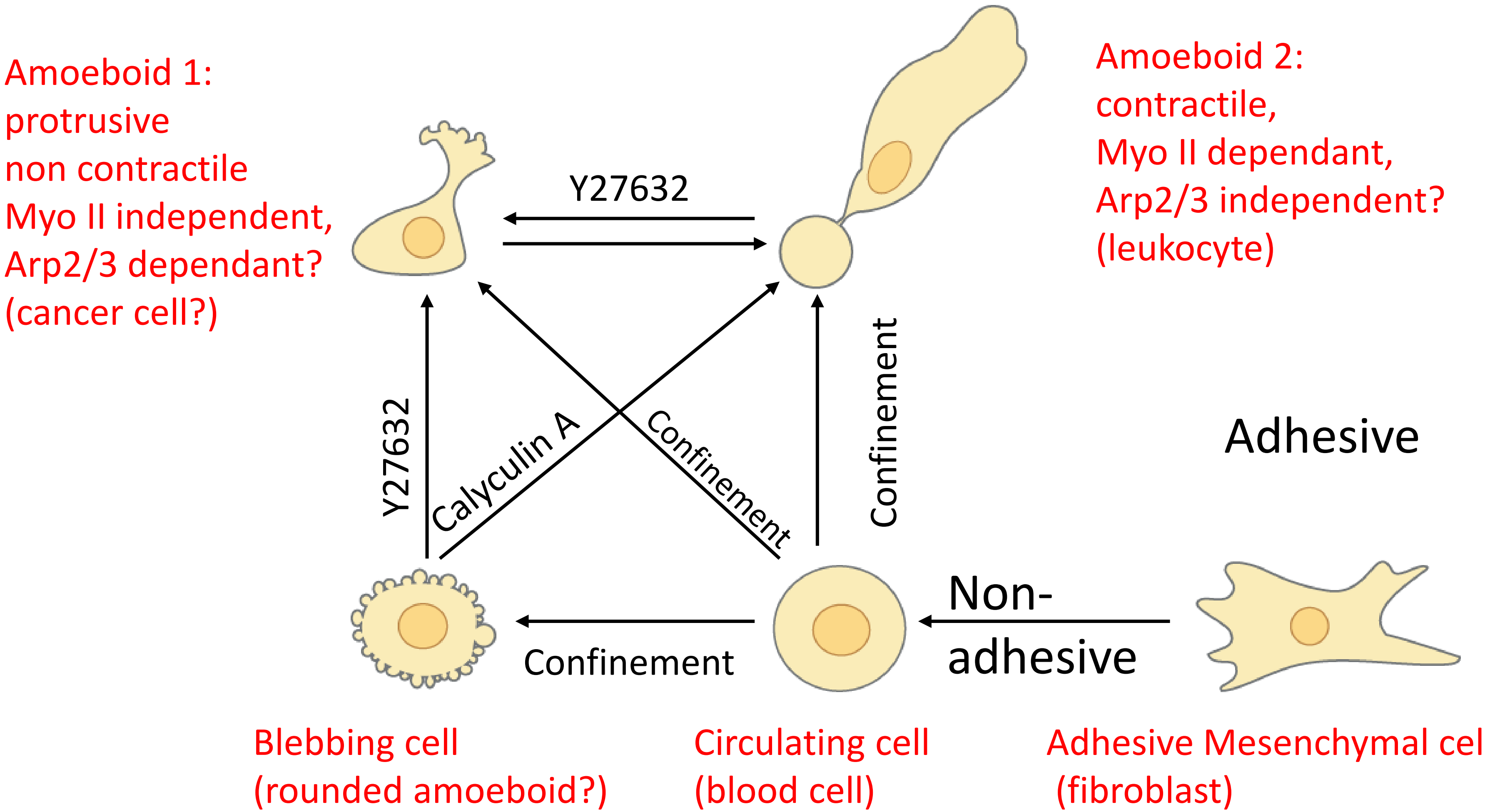
2) At low adhesion, cells migrate faster under confinement (amoeboid/friction driven motility), they use their force to contract, generating a pressure gradient

3) Mesenchymal cells moving under low adhesion/strong confinement display amoeboid morphology and behavior: HeLa as a model system for fast amoeboid migration!!





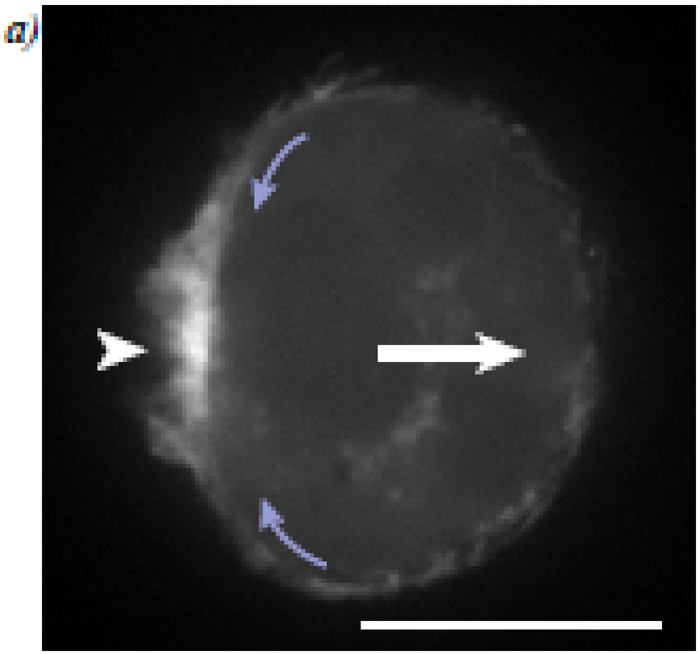
A phase diagram for non-adhesive cell migration?

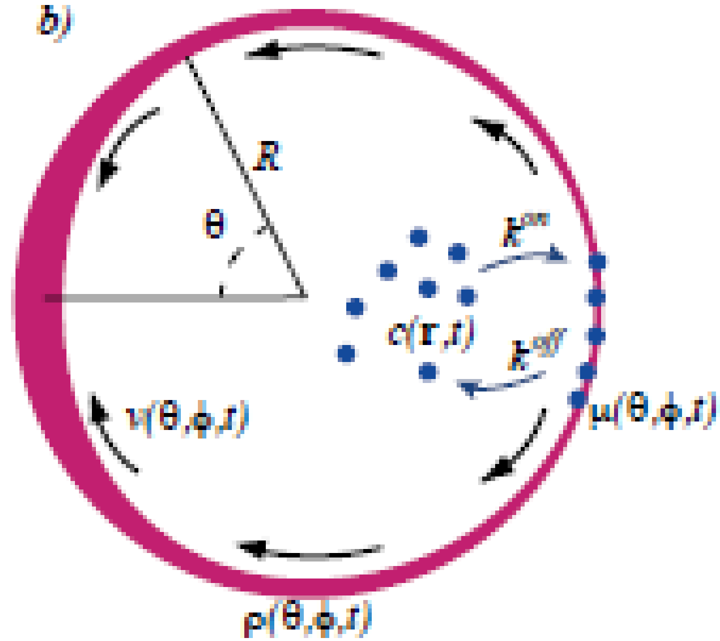


But there is a limit to migration under confinement: the cell nucleus (check Wolf et al., JCB 2013)

The flowing cortex: A spontaneously polarizing motile state

Actin in MDA-MB231 cell migrating inside matrigel



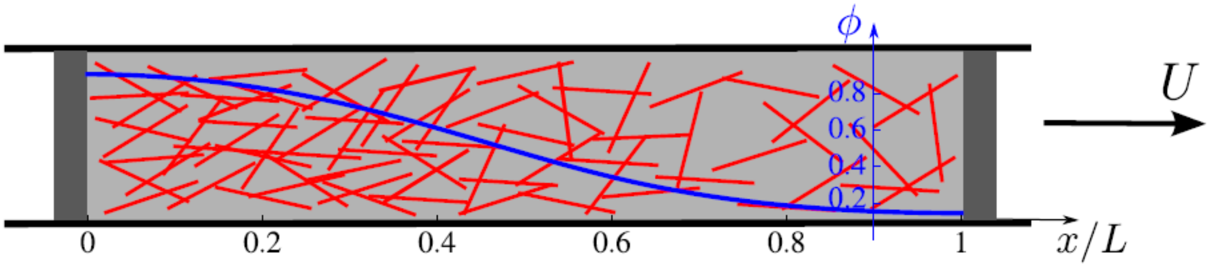


Poincloux, PNAS 2011, Hawkins Biophys J 2011

Raphaël Voituriez (UPMC, Paris)

Rhoda Hawkins (Univ. Sheffield, UK)

The flowing cortex:
A phase diagram of the motile states



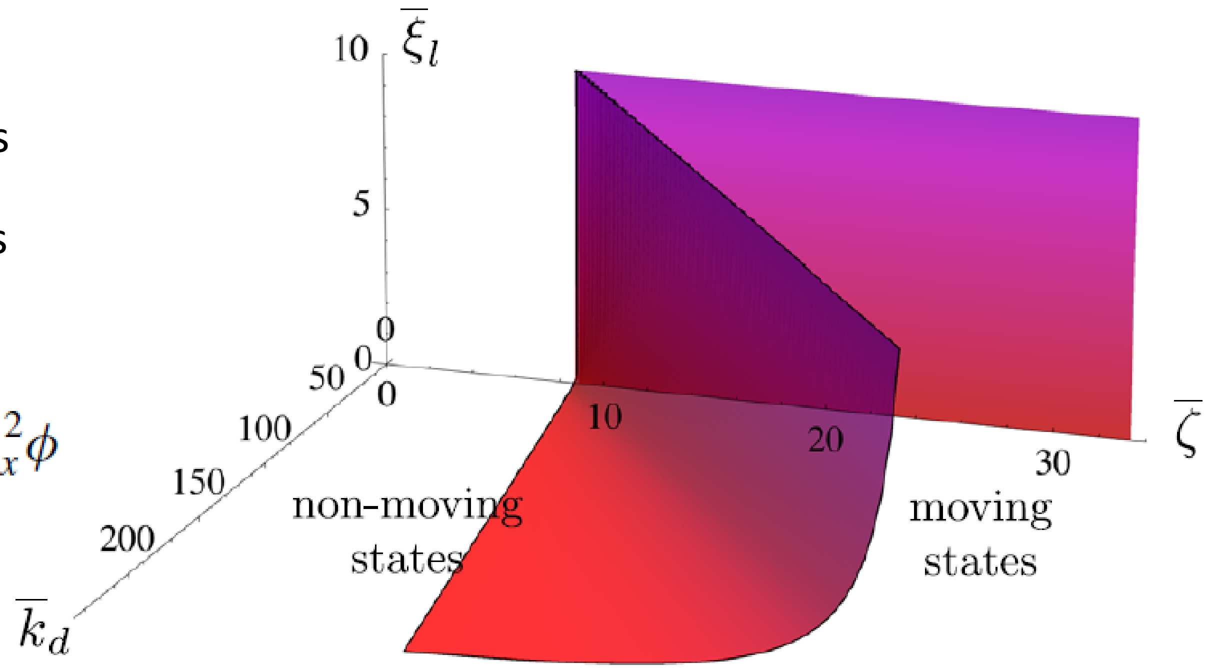
$$\partial_x \left(\sigma^{\mathrm{n}} - \Pi\right) = \xi \, J_{\mathrm{p}}$$

$$\sigma^{\mathrm{n}} = \zeta \phi$$ Active stress

$$\eta_{\mathrm{p}} \partial_x J_{\mathrm{p}}$$ Passive stress

$$\xi \, J_{\mathrm{p}} = \xi \, \phi \, v_{\mathrm{p}}$$

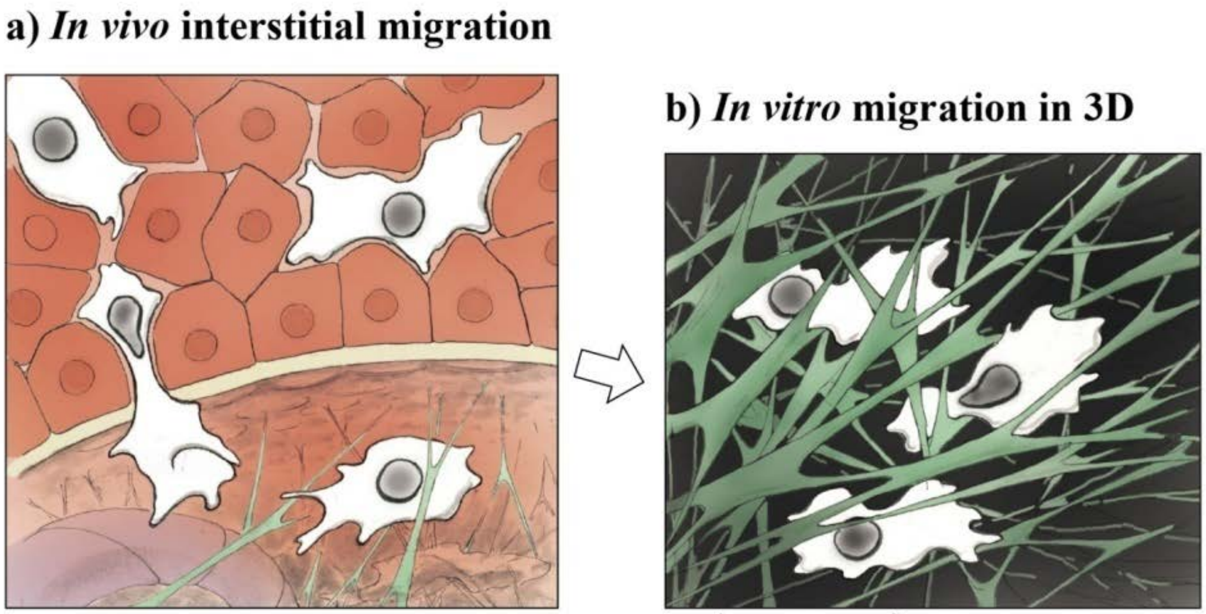
$$\Pi = \alpha(\phi - \phi_0)^3 - \gamma \, \partial_x^2 \phi$$

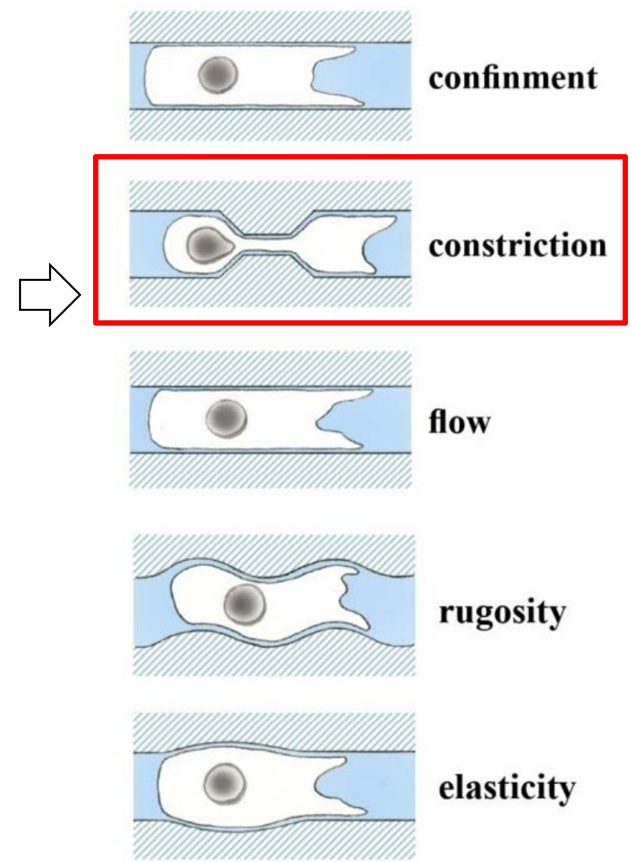


Zeta: activity (contractility)
Xi: friction
Kd: depoly rate

General model (1D): Callan-Jones and Voituriez, N.J.Phys.2013

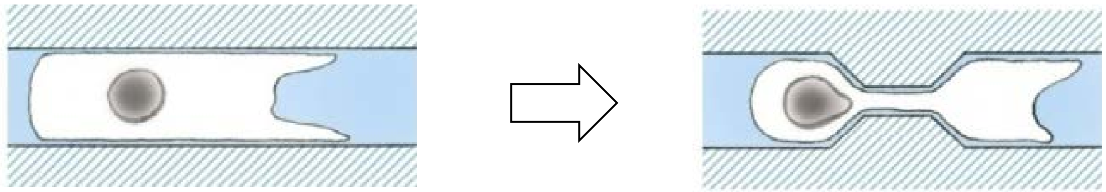
A reductionist approach to 3D migration

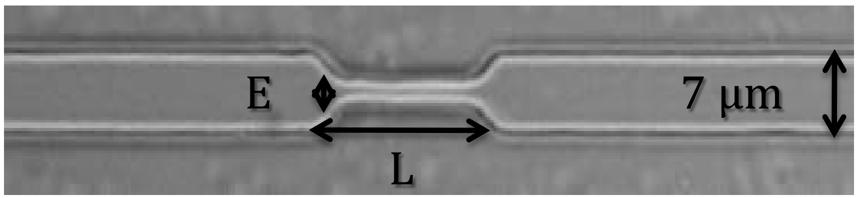




Hawa-Racine Thiam

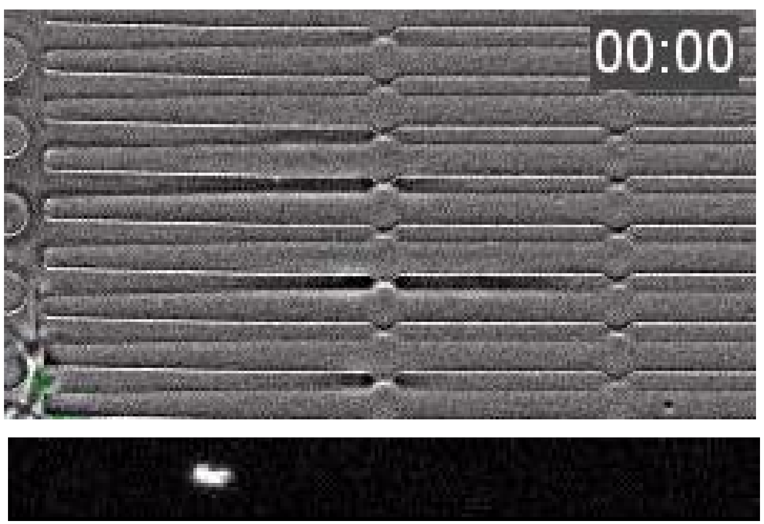
Constrictions in microchannels: a new tool to specifically assay the capacity of cells to deform their nucleus



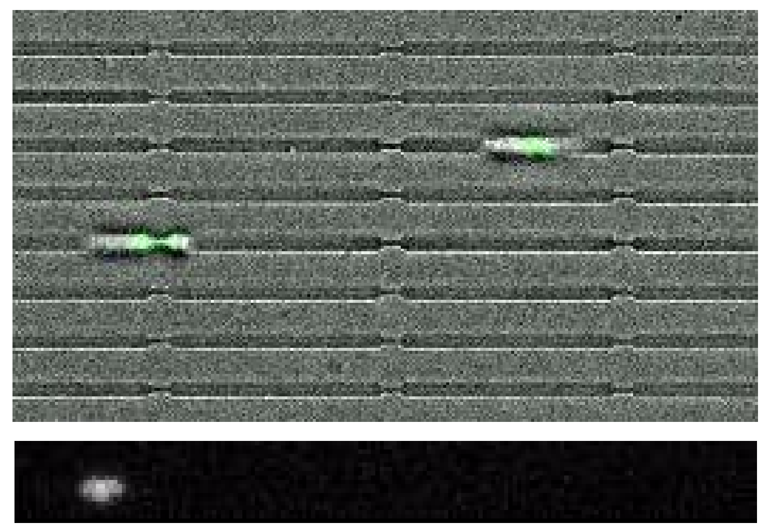


Screening for constrictions sizes :
Length: L = 5; 10; 15; 20µm
Width: E=1; 1,5; 2; 2,5; 3; 3,5; 4; 5µm

L= 5 µm; E= 1µm

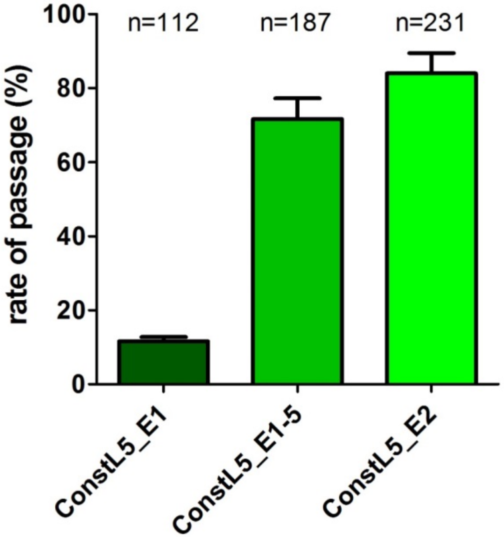


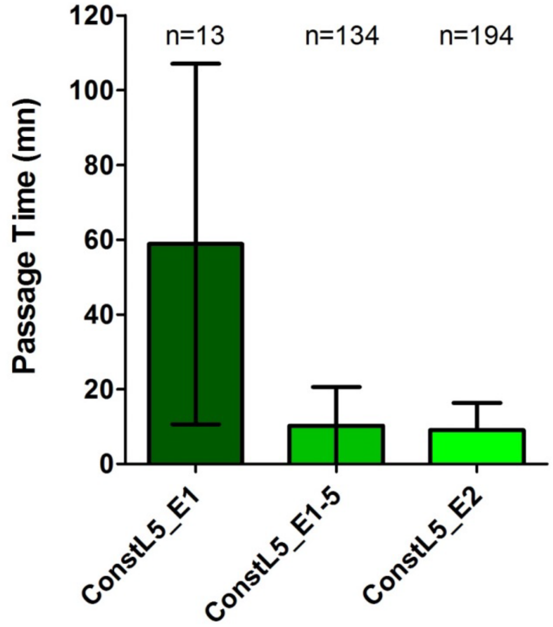
L= 5 µm; E= 2µm

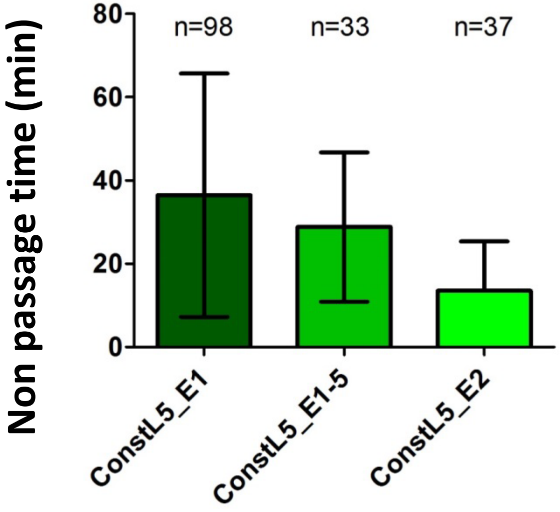


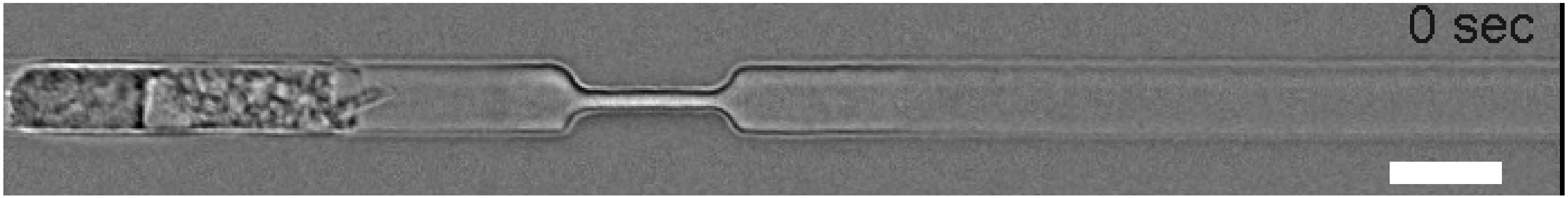
Bone marrow derived dednritic cells (BMDCs); Hoechst

The cell nucleus is limiting transmigration









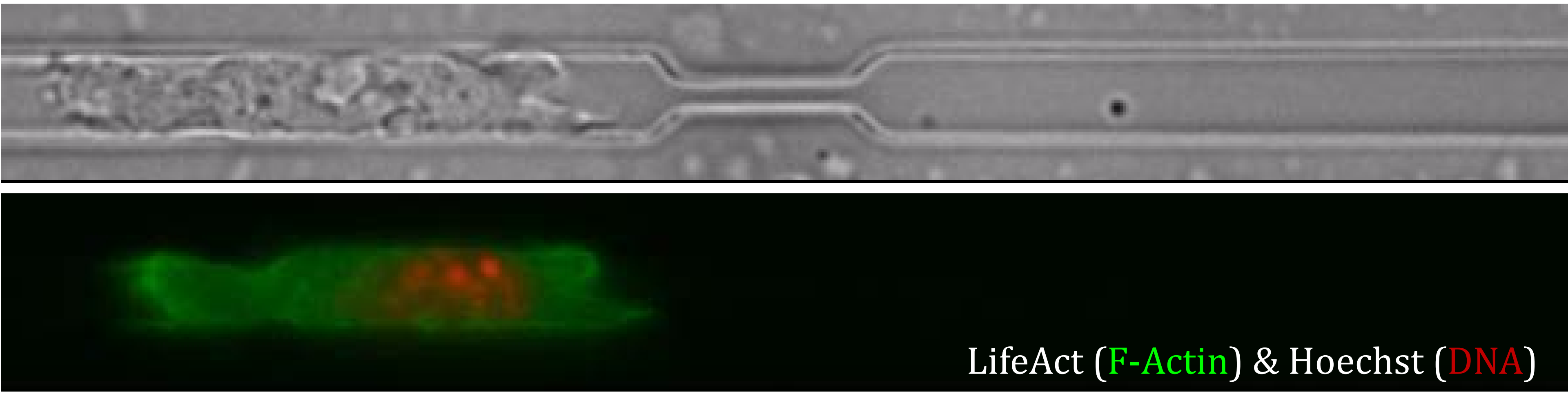
2 µm gap

Conclusions from the size screen:

- DCs can pass down constrictions larger than 1 µm in width
- There is a sharp transition: most cells pass above 1.5 µm
- Cells are slowed down below 4 µm

Actin assembly around squeezed nucleus

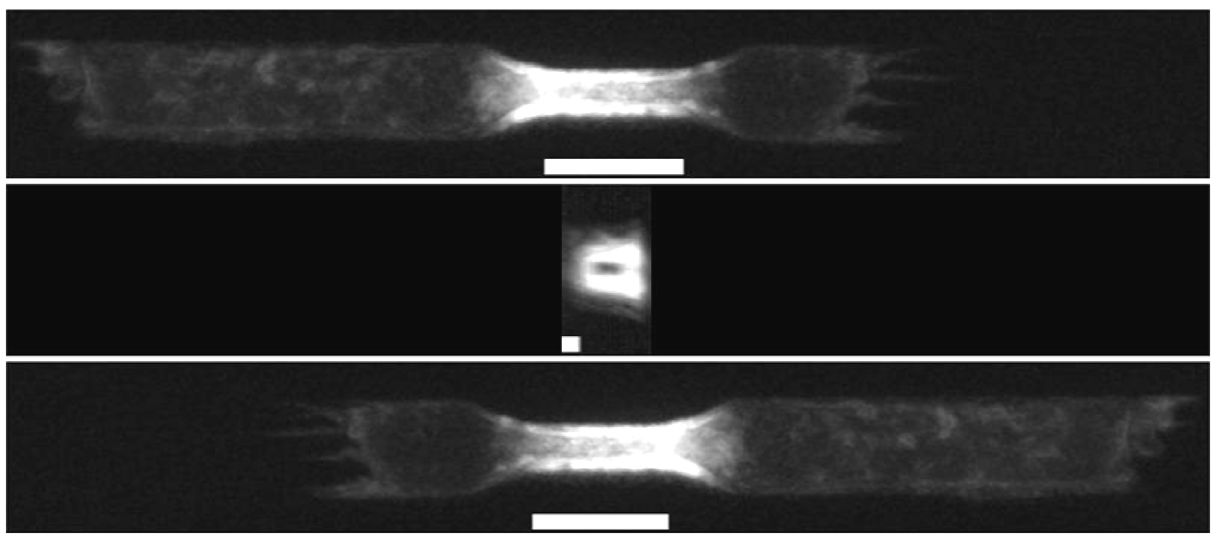
BMDCs (Ii KO) in a 7µm channels with 15µm long and 2µm tickness constriction



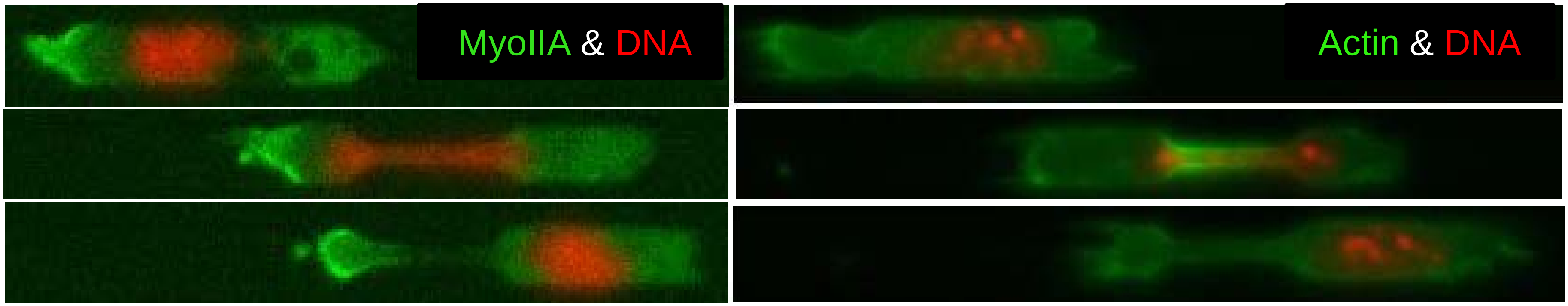
0°

90°

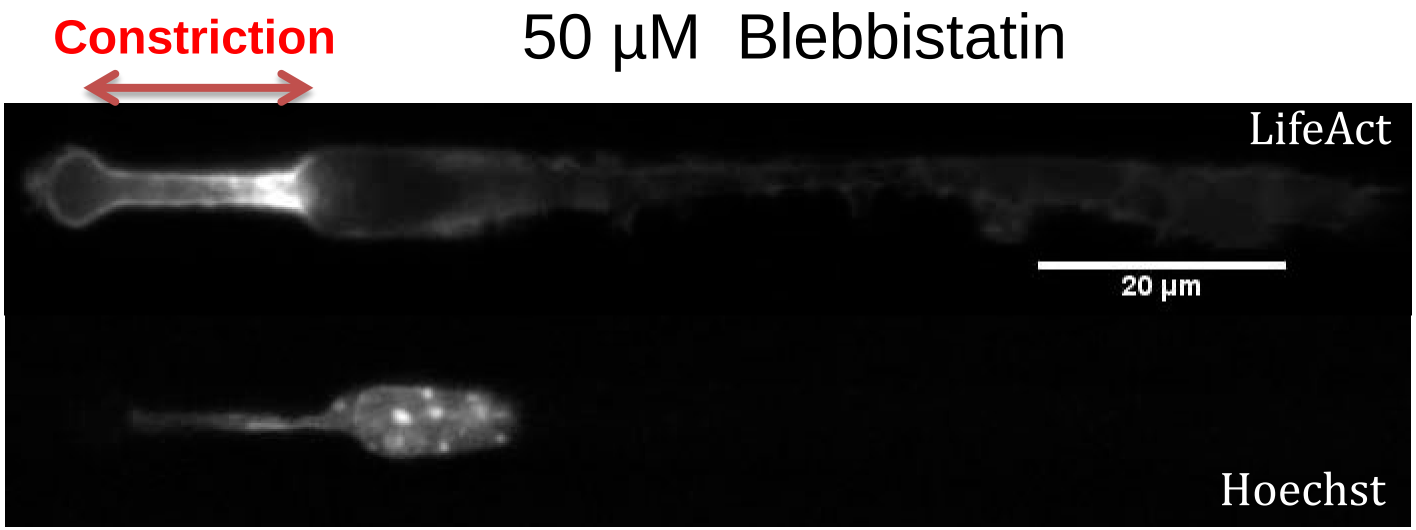
180°



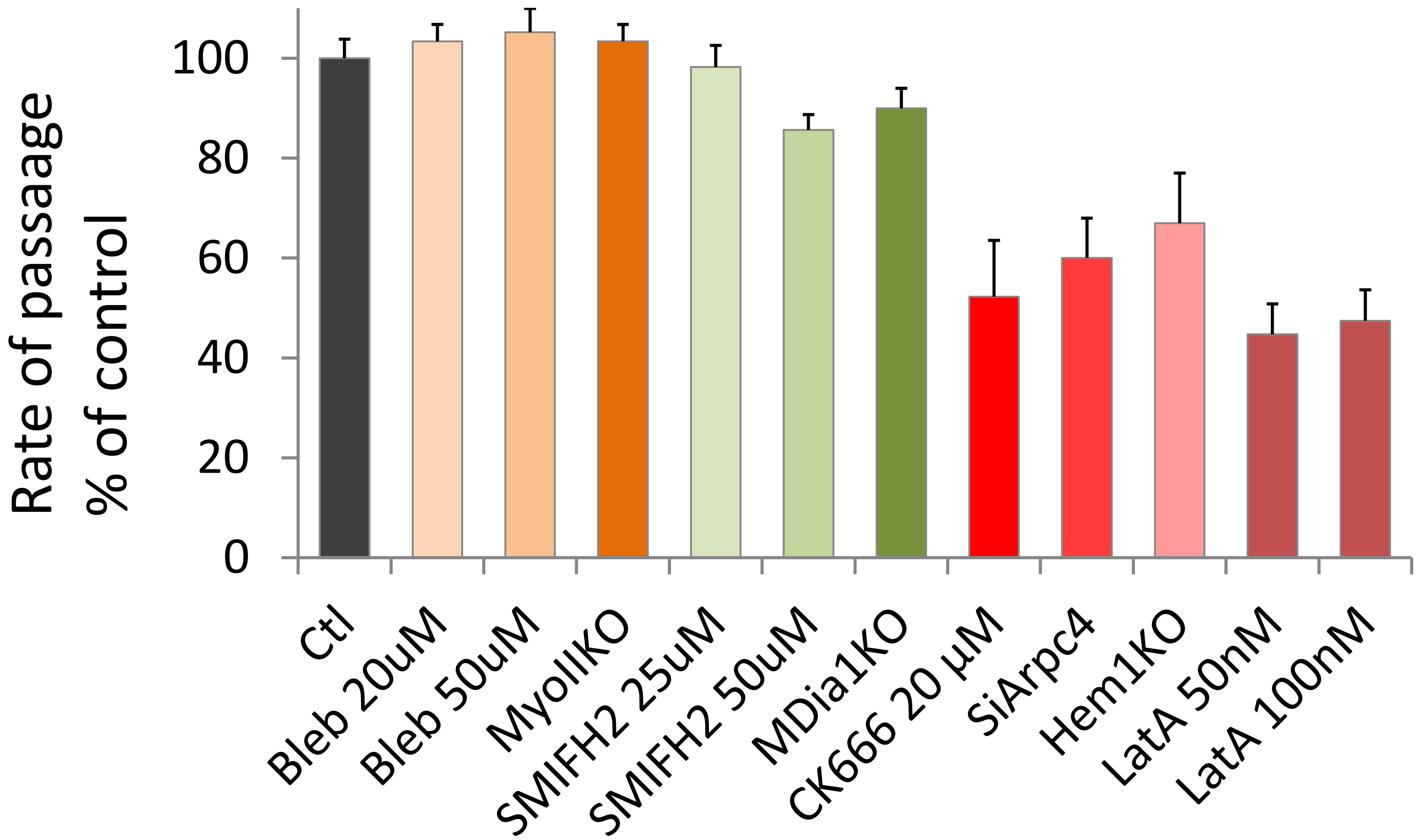
This actin structure does not contain Myo II



50 µM Blebbistatin

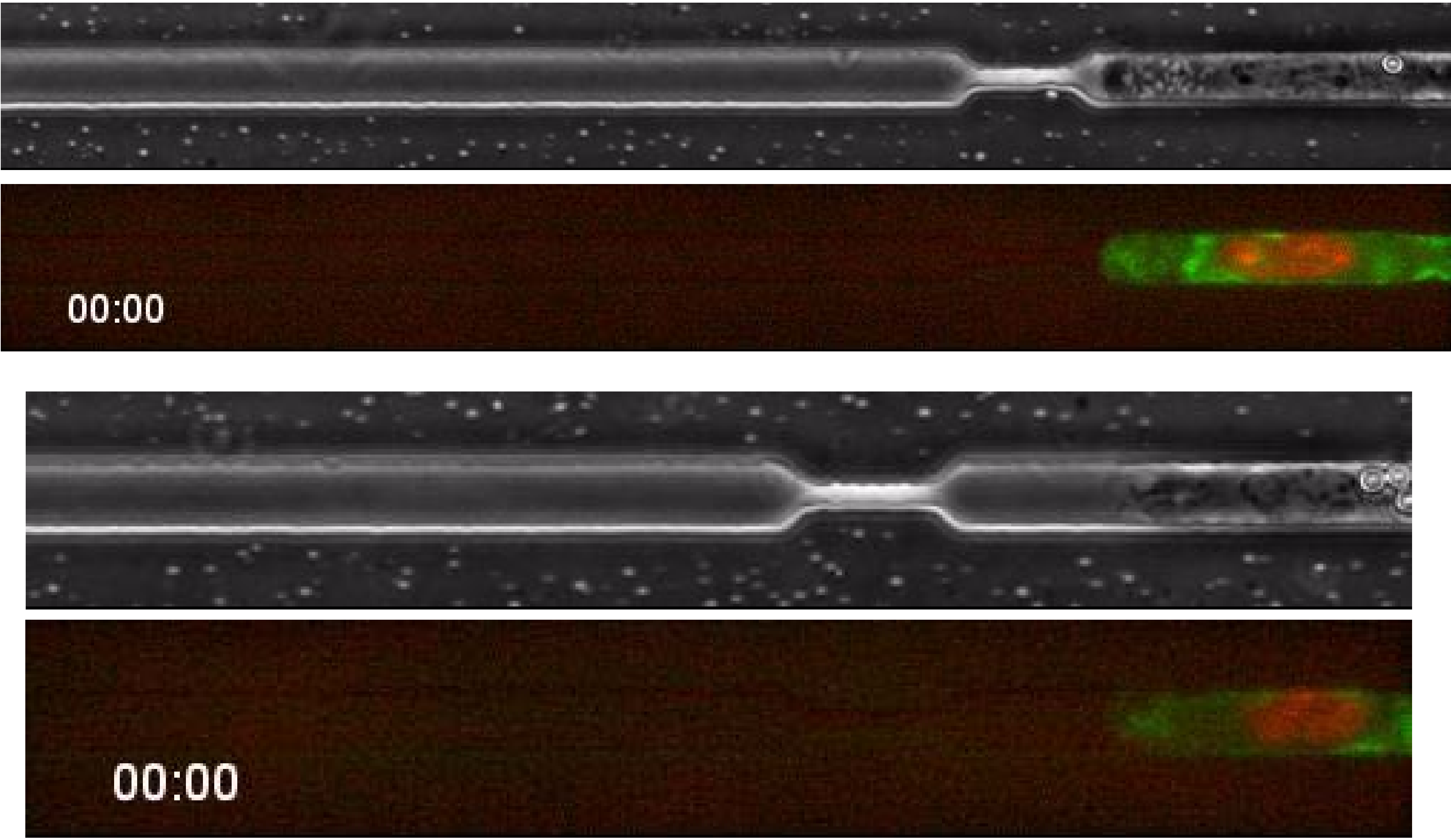


Transmigration of iDCs depends on Hem1 and Arp2/3 but not on Myo II or formins

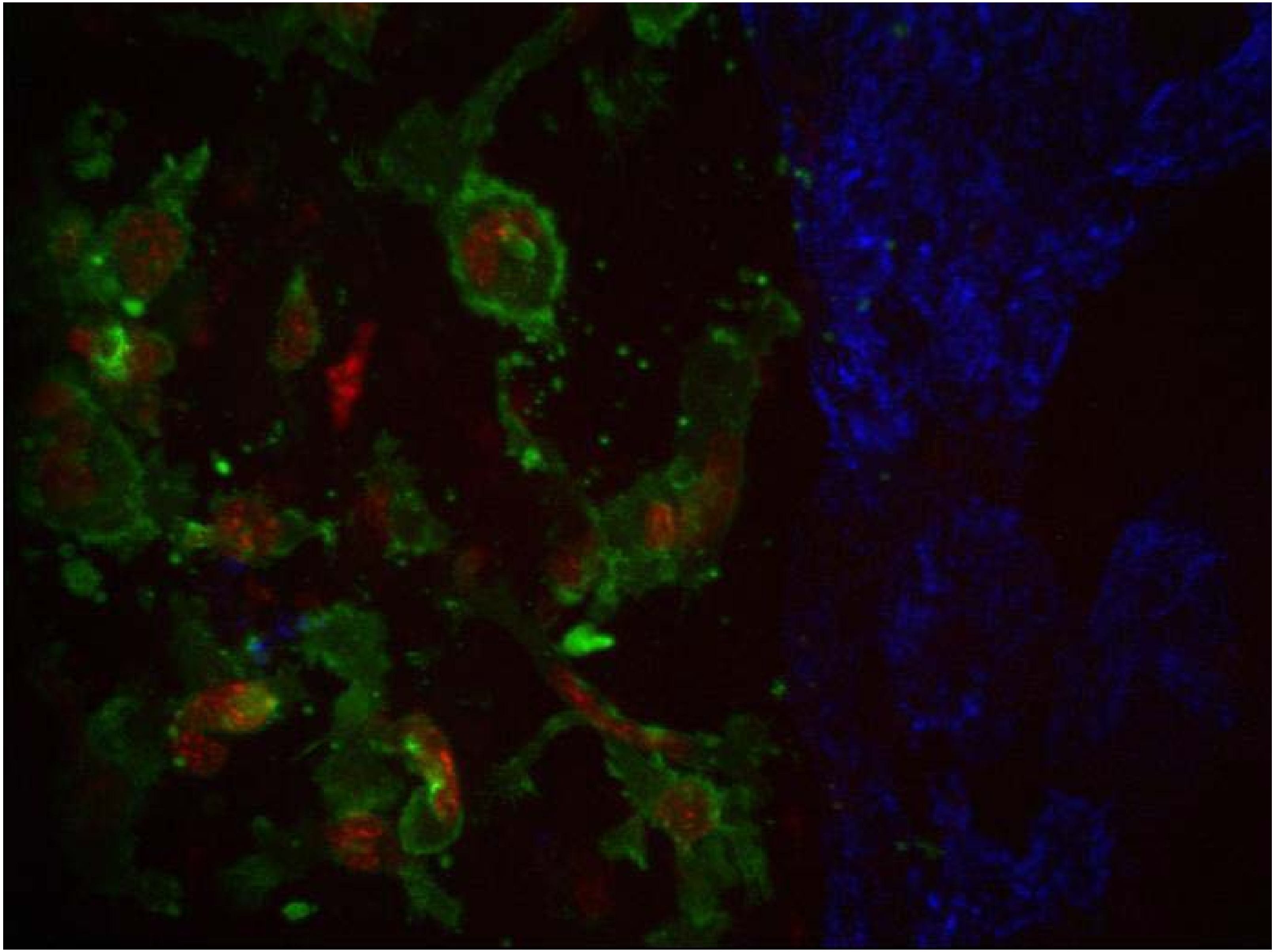


Does not depend either on the LINC complex or the lamina

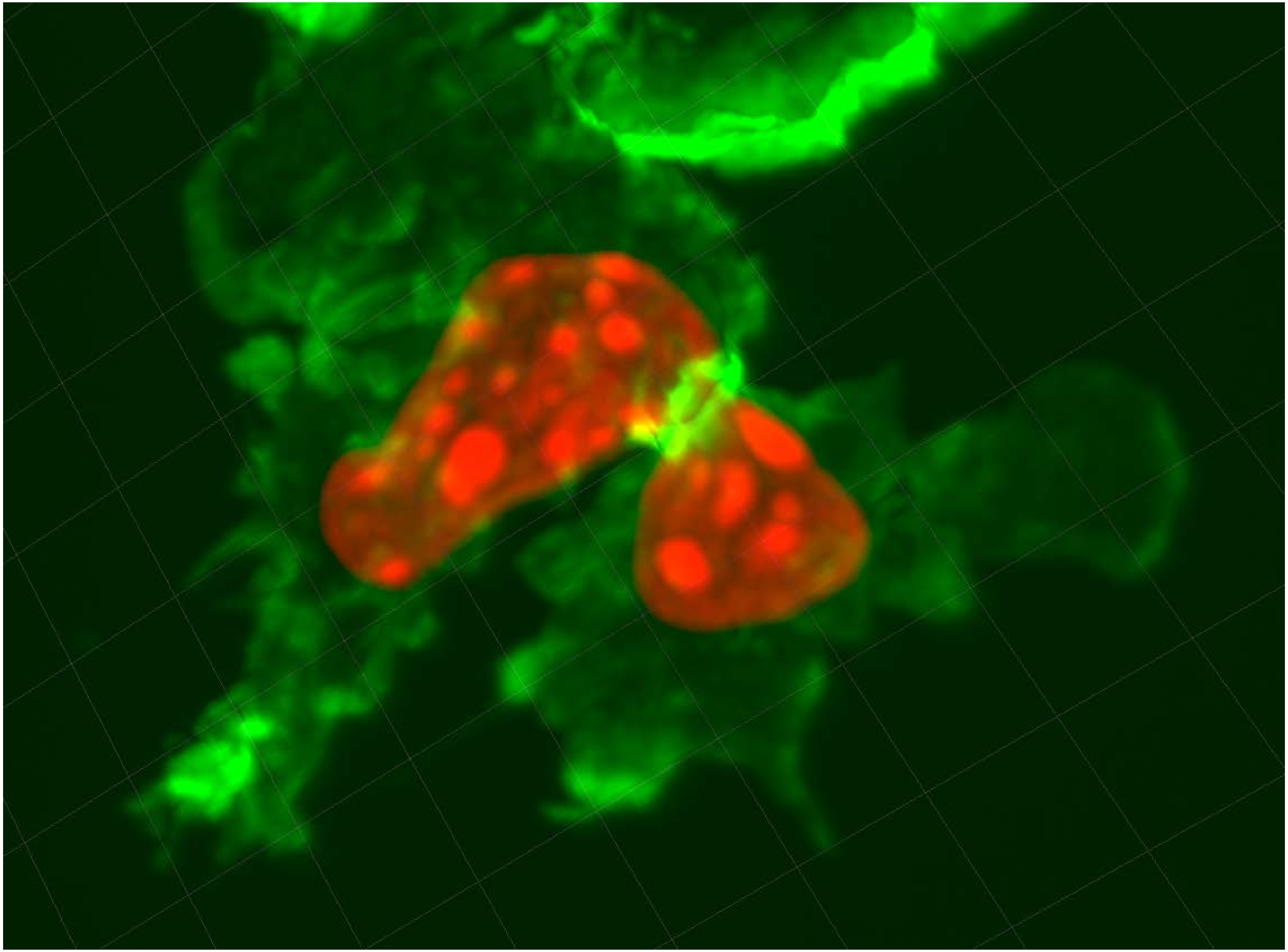
Actin nucleation is specifically induced by the nucleus



This ring exists *in vivo*



Lifeact, Hoechst, LYVE (mouse ear explant, movie: Mattew Raab)



Conclusions

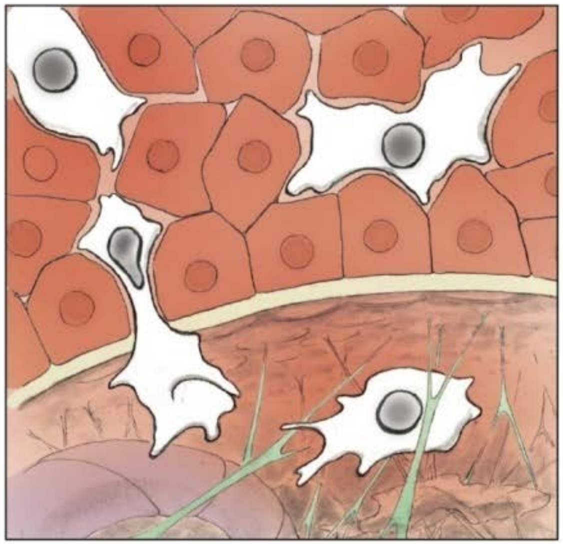
1) Below a minimal size, the nucleus becomes limiting and BMDCs use an Arp2/3 dependant MyoII independent mechanism to squeeze it

2) BMDCs can concentrate antigens via a Myosin II dependant filtering system and they do not push fluid in front of them (‘viscous catching’)

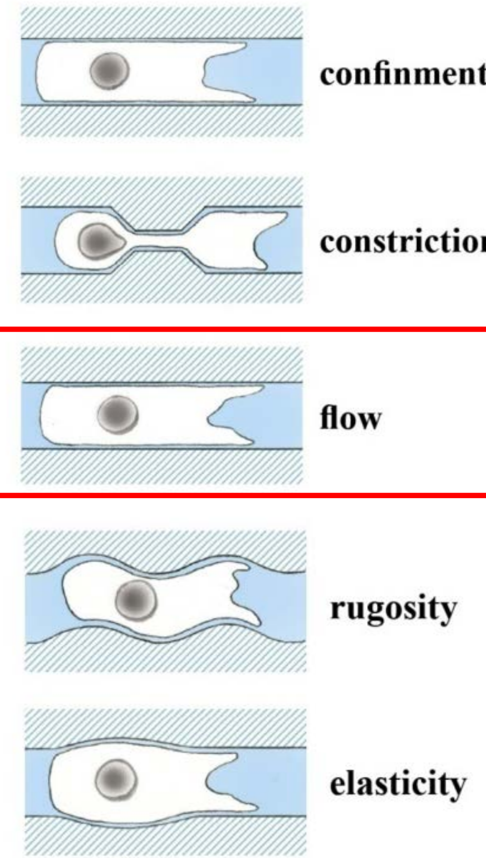
3) Geometric anisotropy is enough to bias cell migration, independently of adhesion, due to deformation of the visco-elastic cell body

A reductionist approach to 3D migration

a) *In vivo* interstitial migration



b) *In vitro* migration in 3D

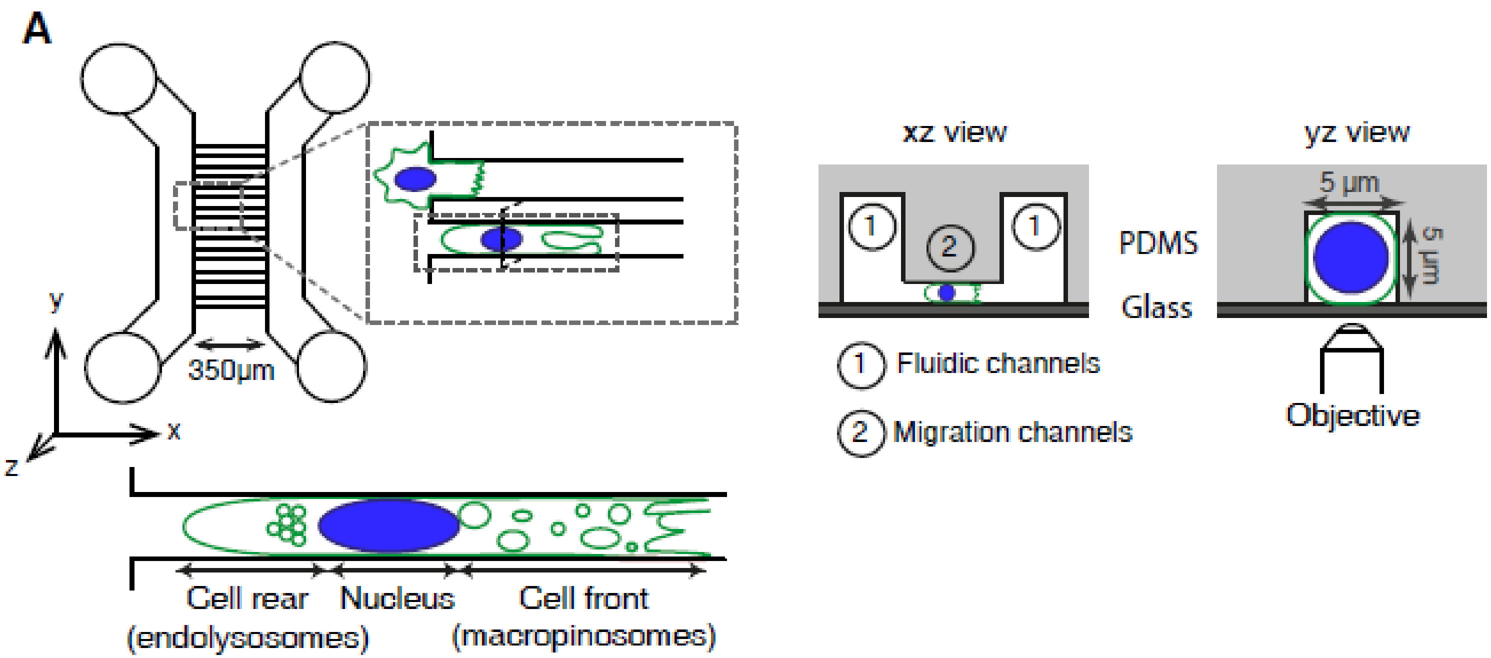


Mélanie Chabaud

Mélina Heuze

Mathieu Pinot

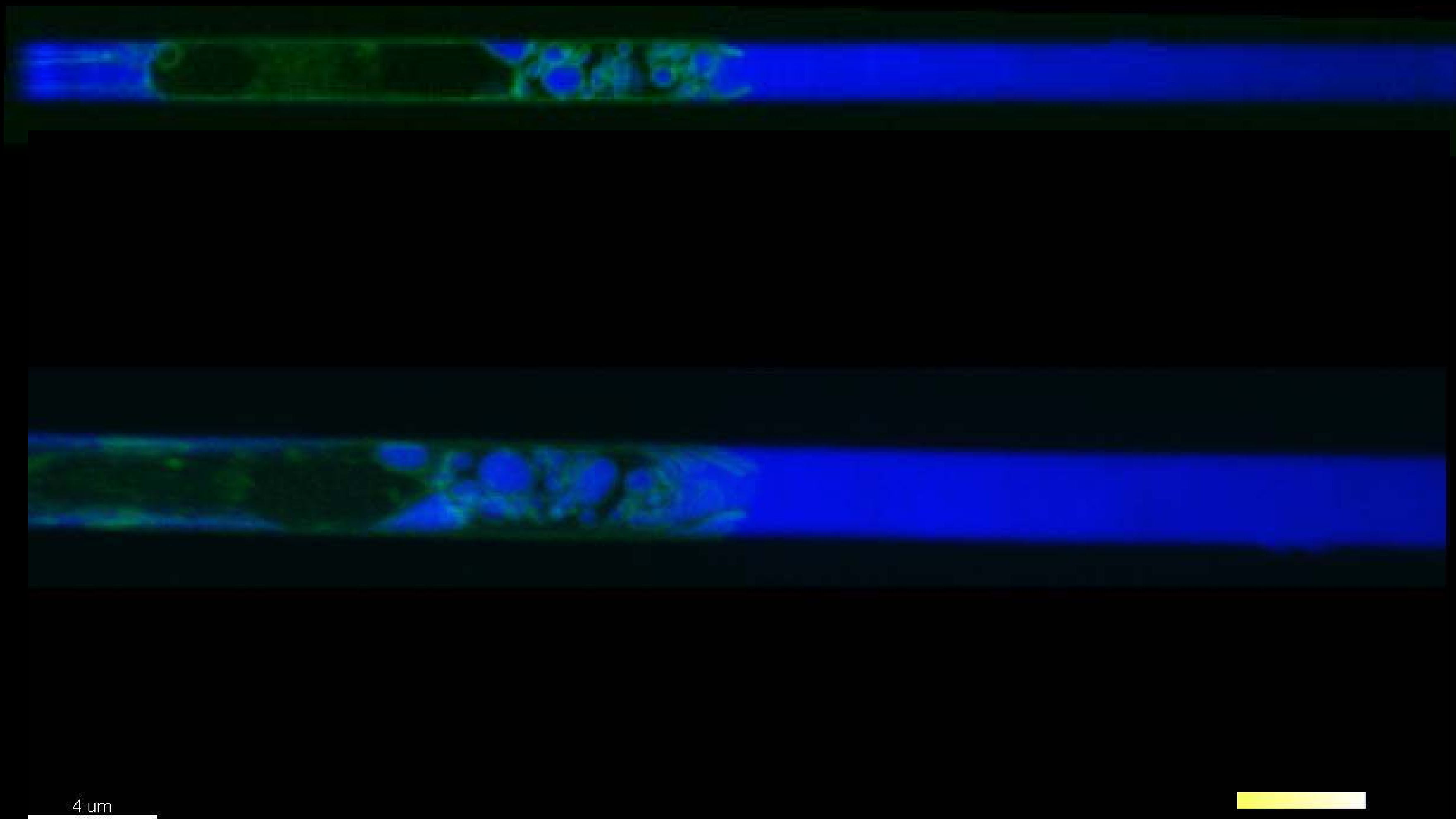
System



Microfluidic device : Normalization of direction and cell shape

Antigen uptake in vitro: DCs are filters

And they do not push the fluid in front

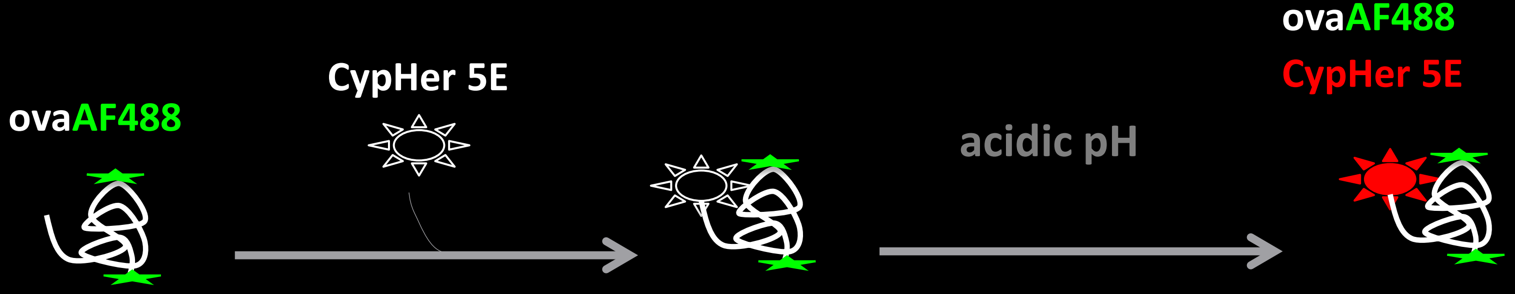


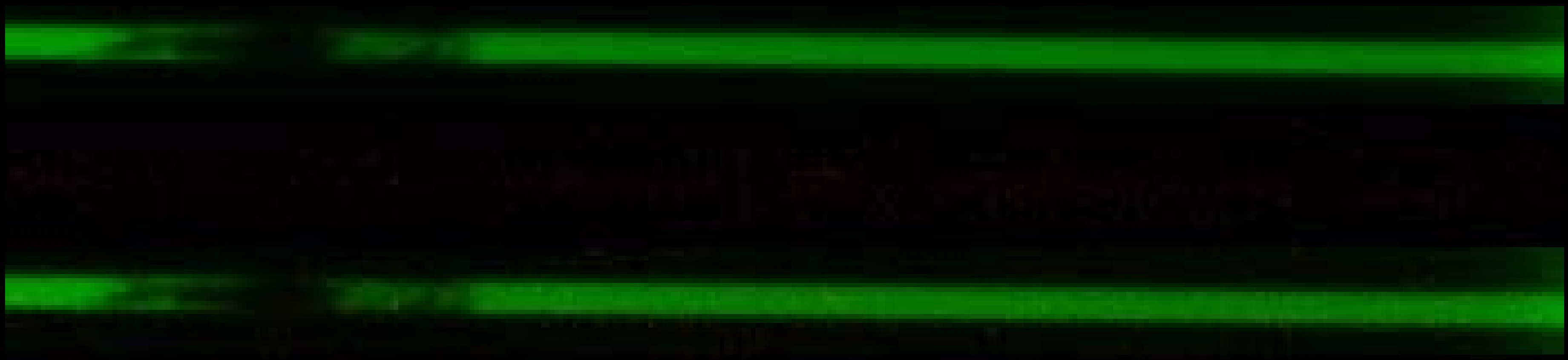
Dextran MHC II

Mélina Heuze and Mélanie Chabaud

Fate of internalized material

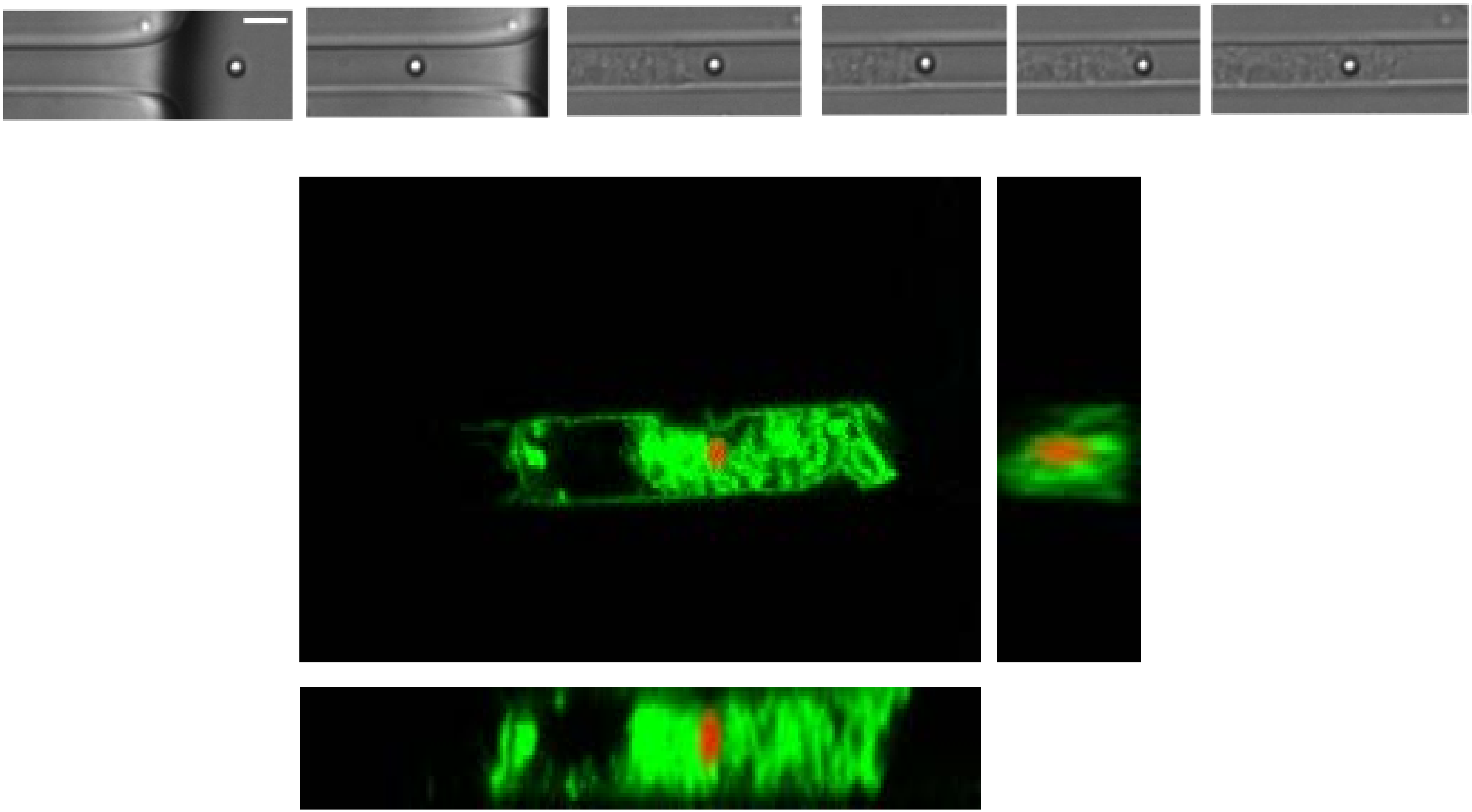
After 20-40min of exposure to the fluid-phase marker…
DCs concentrate it in the lysosomal compartments

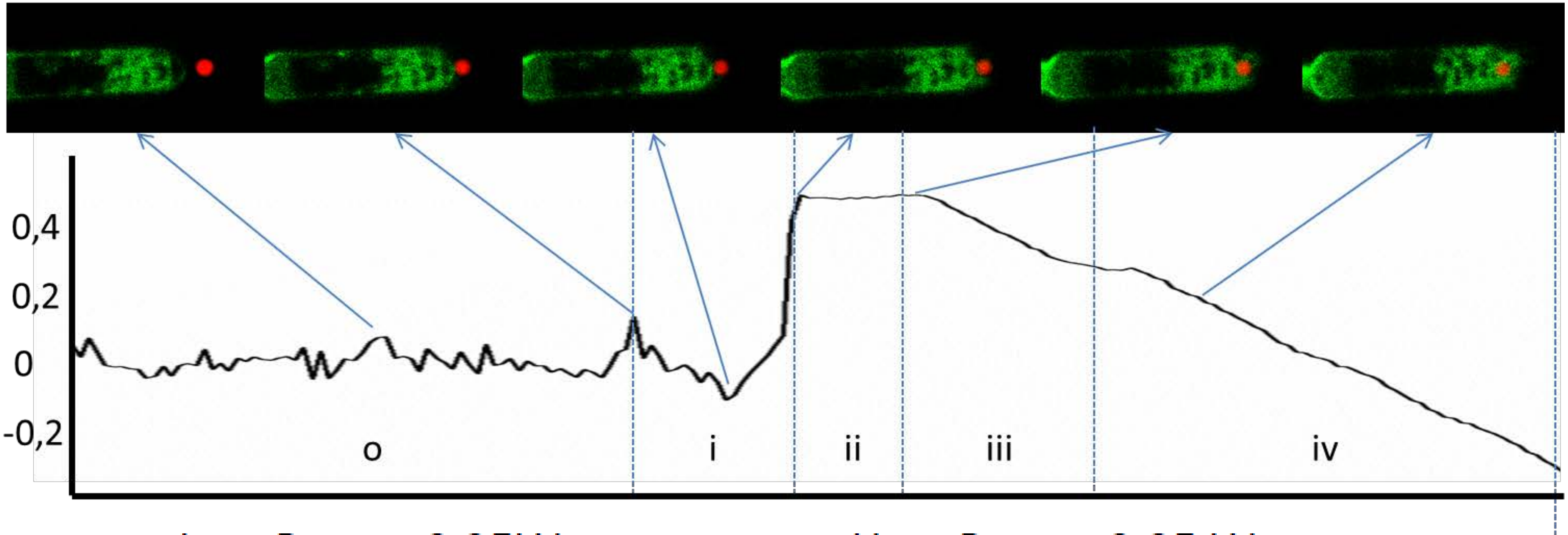




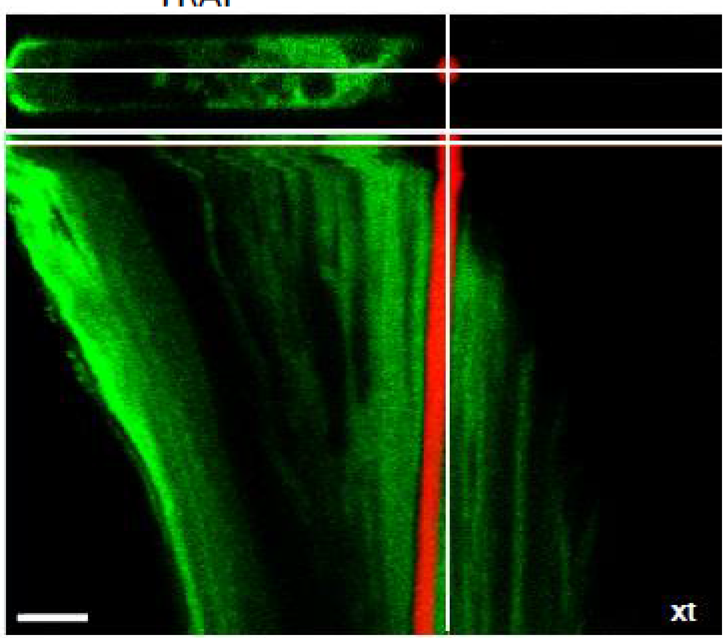
Epi 20X, bin2, 1 image/1min

Eating a bead

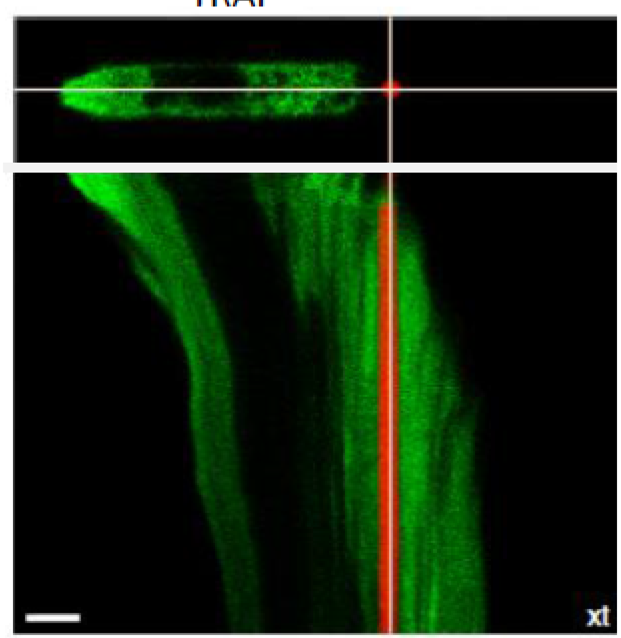




Low P_{TRAP} = 0.25W

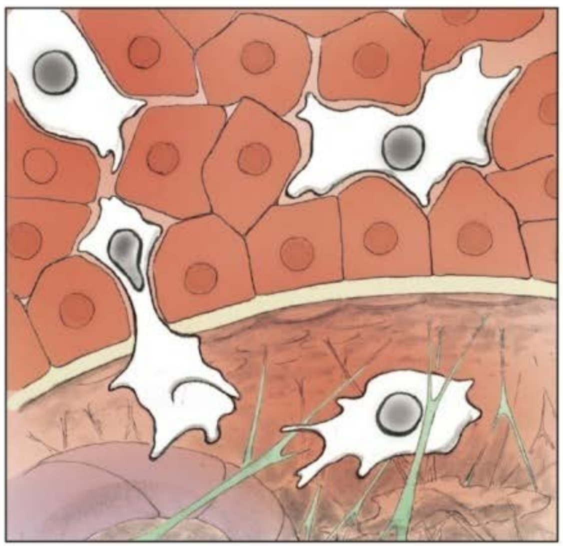


■ High P_{TRAP} = 0.95 W

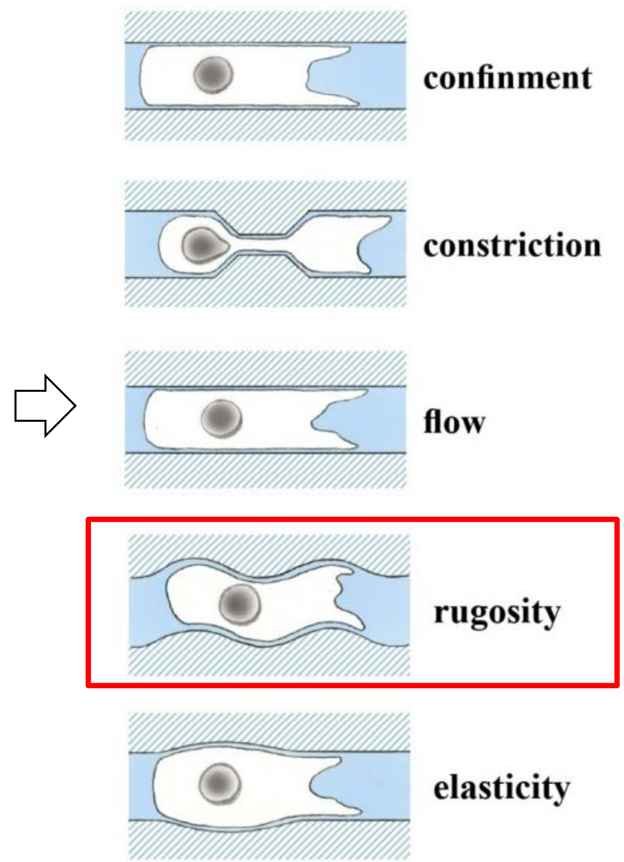


A reductionist approach to 3D migration

a) *In vivo* interstitial migration



b) *In vitro* migration in 3D

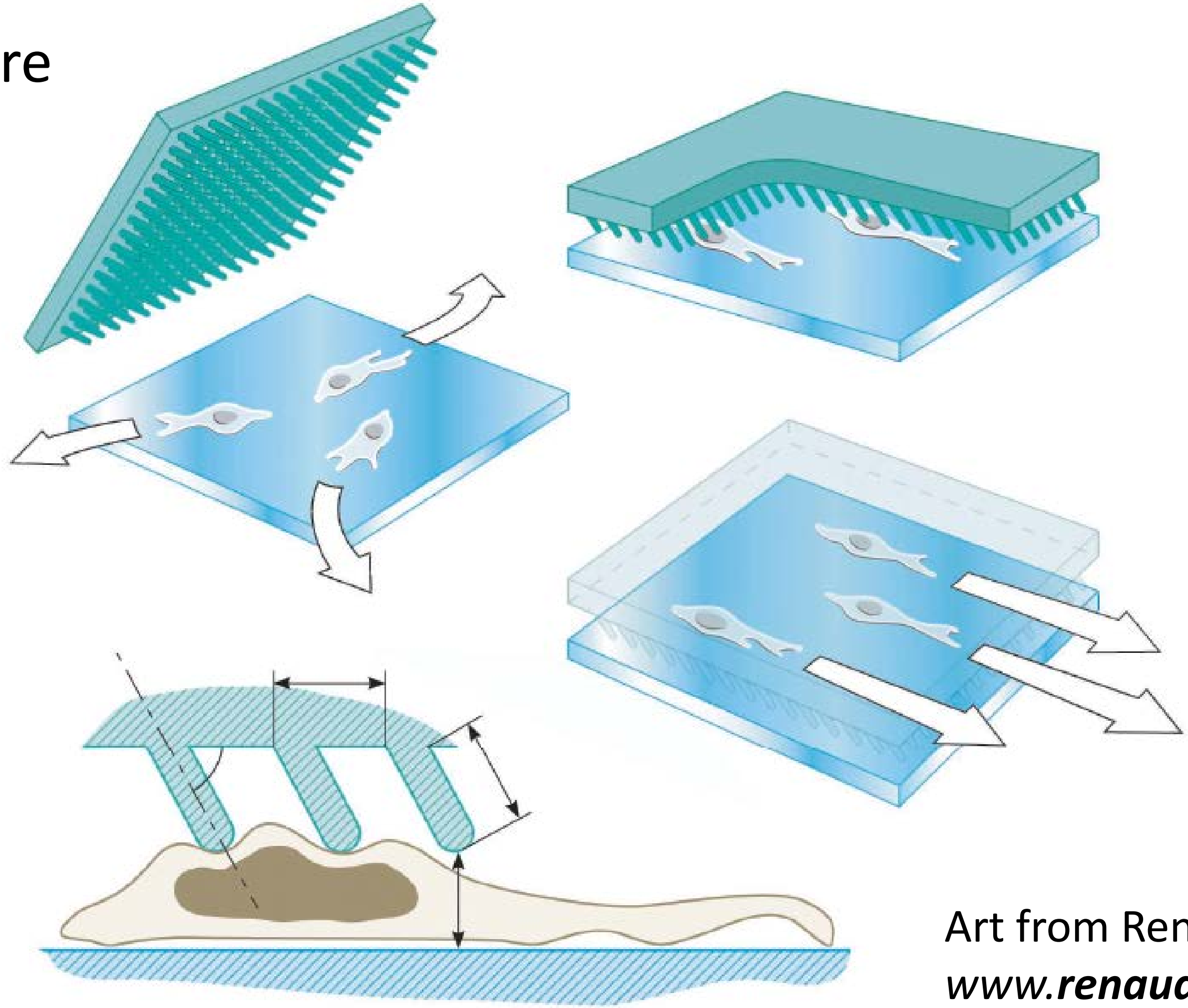


Yanjun Liu

Maël Le Berre

Anisotropic friction: guiding cells with non-adhesive anistropic micro-structures

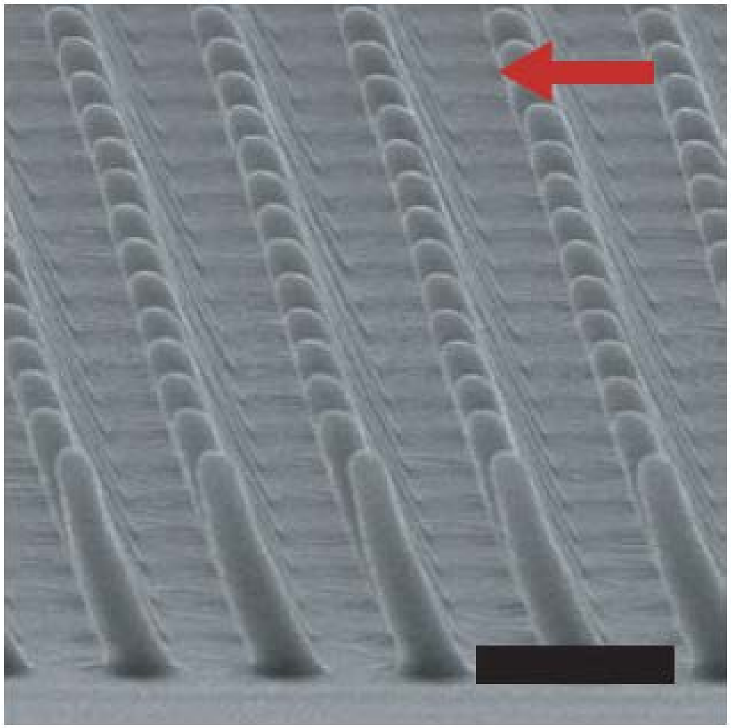
Maël Le Berre
Yanjun Liu

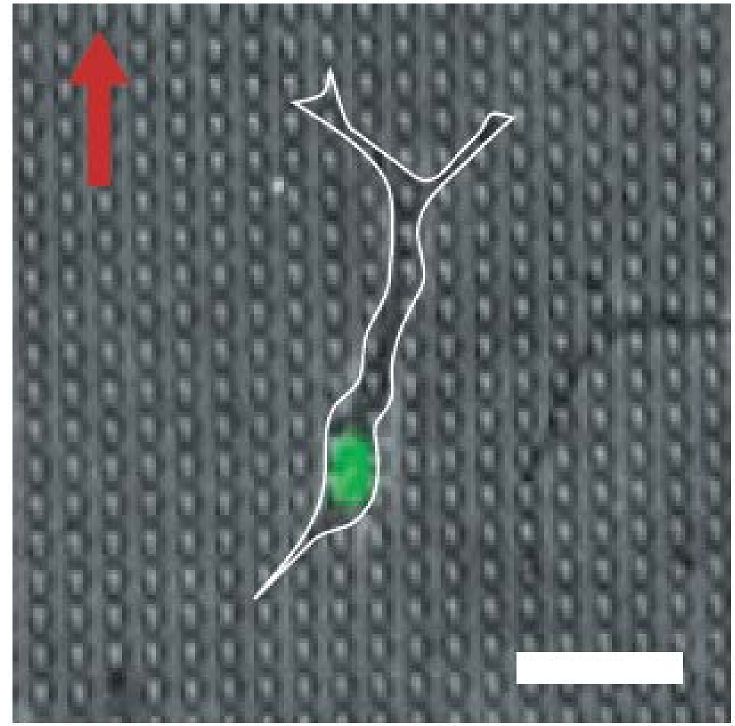


Art from Renaud Chabrier
*www.**renaudchabrier**.com*

Nanofabrication: in collaboration with Y. Chen Lab, ENS Paris

Cells under tilted micro-pillars





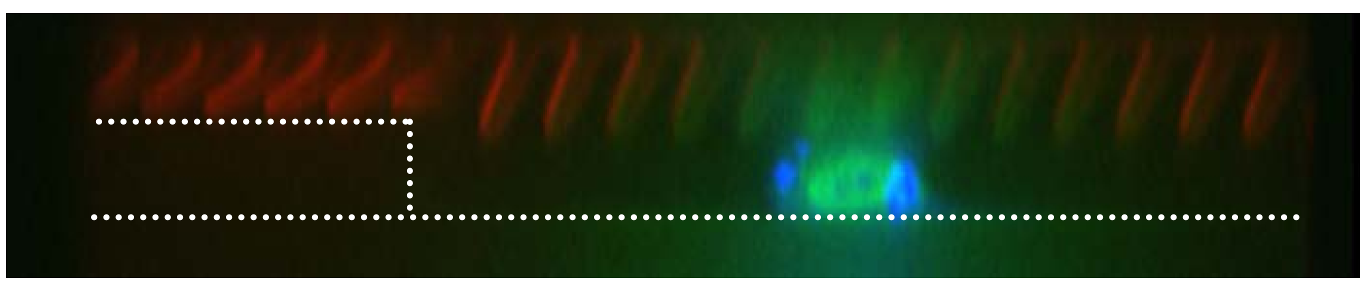
20 µm

30 µm

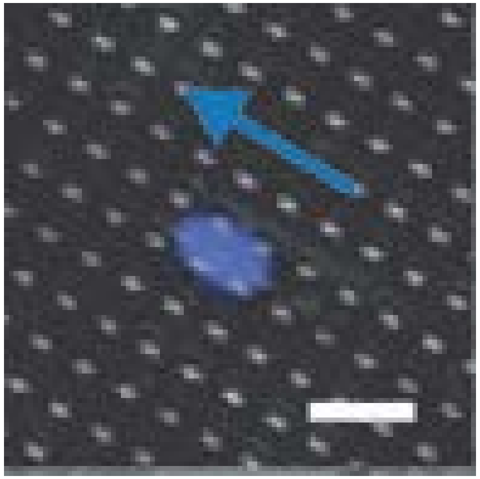
Tilted pillar →

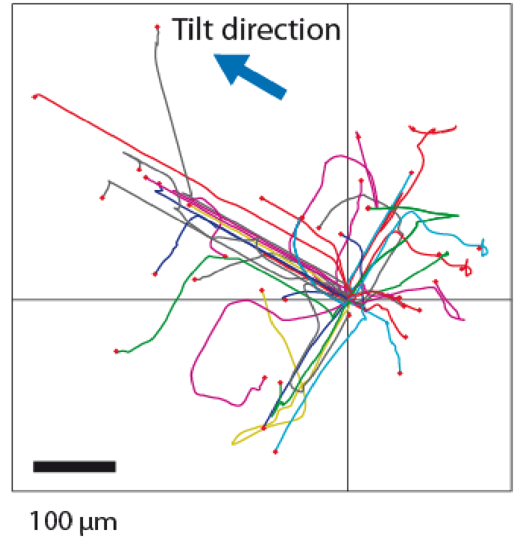
PDMS spacer →

Glass coverslip →

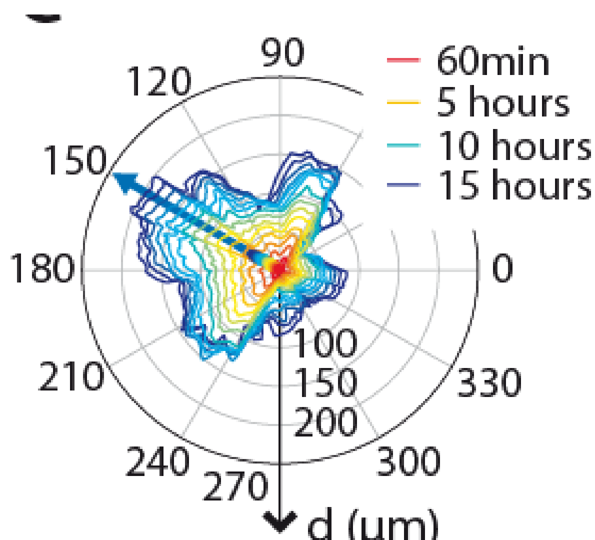


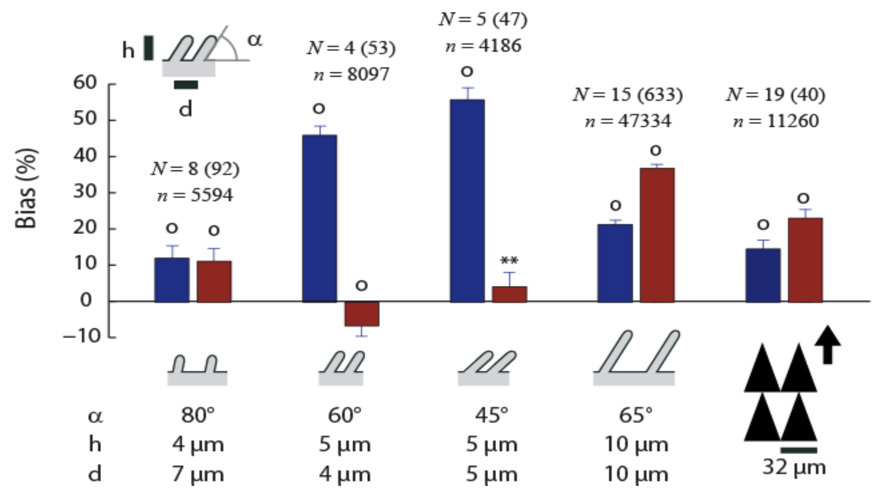
Trajectory analysis reveals a robust biased migration



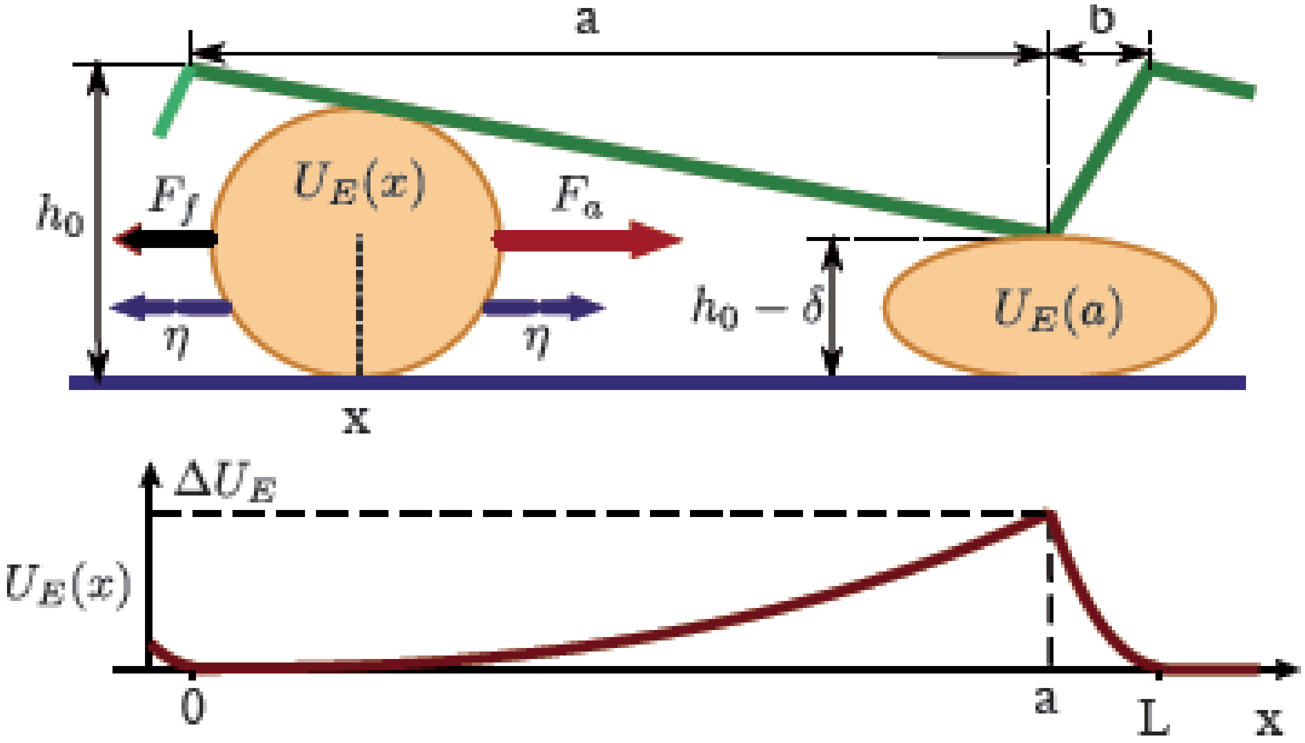


Whole population bias
(50% boundary)





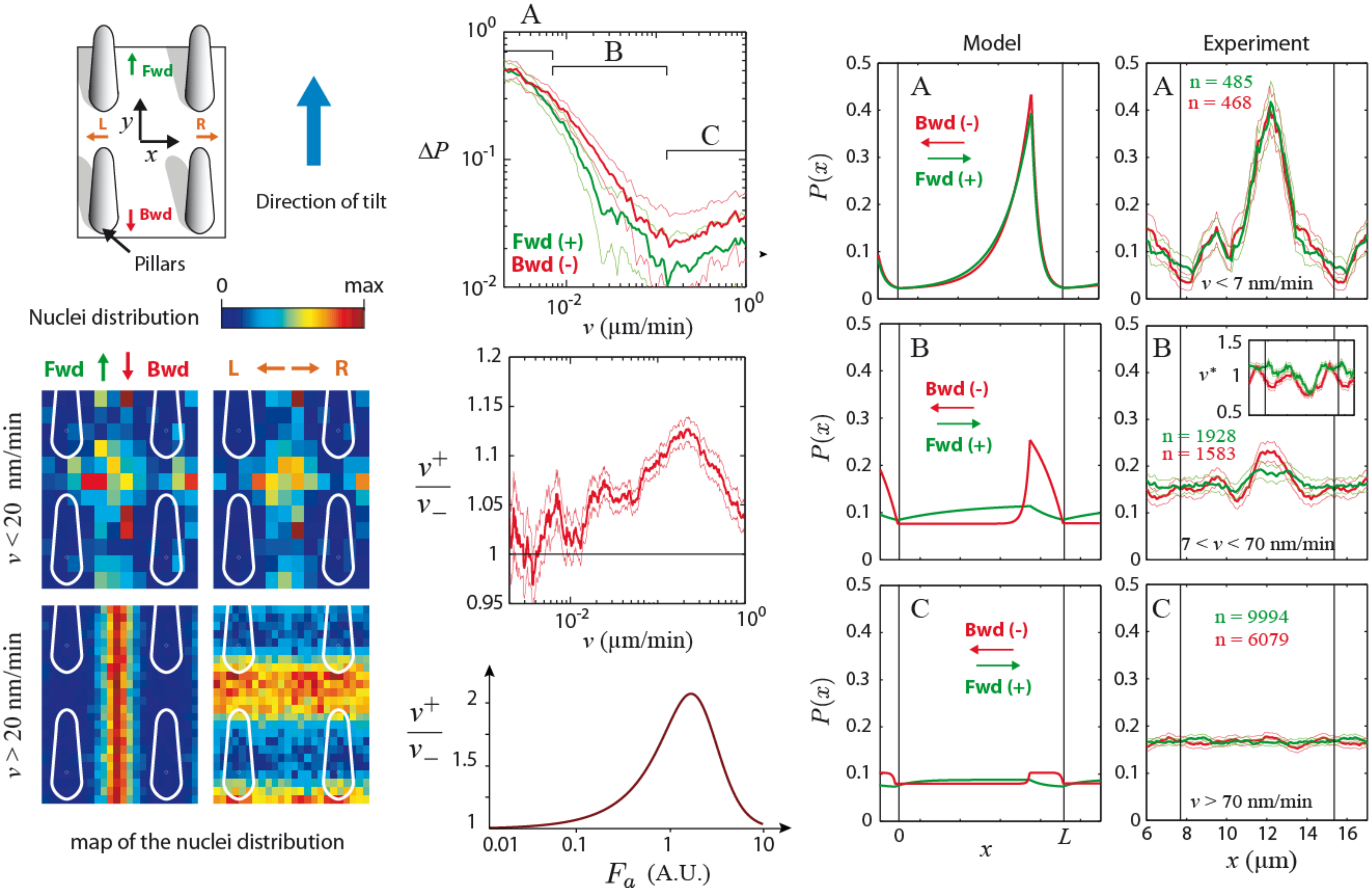
Simple model of an active Brownian particle in a ratchet potential



$$F_a = \epsilon \bar{F} + \eta(t)$$

$$\lambda d_t x = \epsilon F - \partial_x U_E + \eta$$

A simple model qualitatively captures the measured statistics on nuclear position



Conclusions

1) Below a minimal size, the nucleus becomes limiting and BMDCs use an Arp2/3 dependant MyoII independent mechanism to squeeze it

2) BMDCs can concentrate antigens via a Myosin II dependant filtering system and they do not push fluid in front of them (‘viscous catching’)

3) Geometric anisotropy is enough to bias cell migration, independently of adhesion, due to deformation of the visco-elastic cell body


Systems Biology of Cell Division and Cell Polarity
Most wanted Cell Torturers
Franzi
Matthieu
Emmanuel
Hiro
Nicolas
Maël
Nicolas
Daria
Hawa
Ewa
Mélanie
Paolo
Of music before everything—...
For we desire Nuance yet more—
Not color, nothing but Nuance!
Oh! only nuance brings
Dream to dream and flute to horn!
(Verlaine, Art Poétique, tr. Eli Siegel)
Recent alumni
Yanjun
Alexis
Julie

Acknowledgments

MICEMICO: migration under confinement
- Team of Ana-Maria Lennon (IC, Paris)
- Team of Raphael Voituriez (UPMC, Paris)
- Team of Vassili Soumelis (IC, Paris)
- Team of Danijela Vignjevic (IC, Paris)

Micro-fabrication/chemistry:
- Yong Chen (ENS Paris)
- Manuel Théry (CEA Grenoble)

Universal law of cell migration:
- Stefan Wieser, Michael Sixt (IST, Austria)
- Verena Ruprecht, CP Heisenberg (IST)
- Nir Gov (Weizmann Institut, Israel)

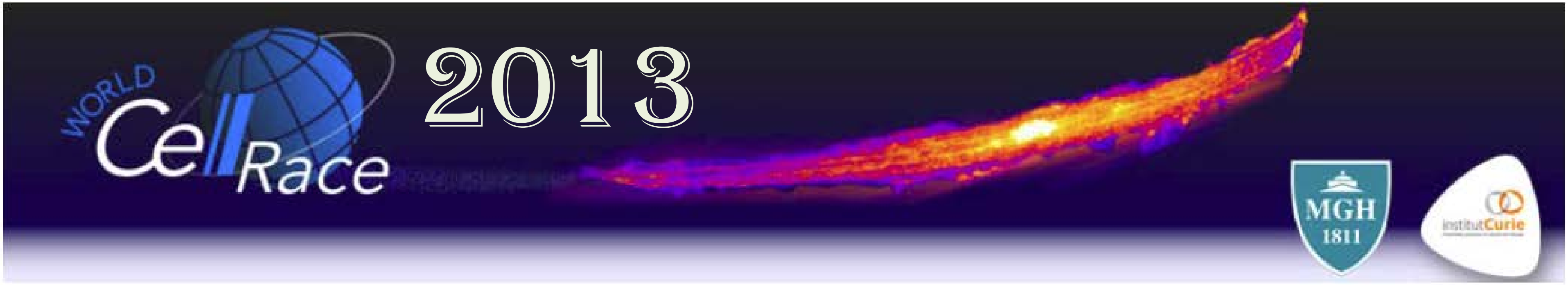
Imaging:
- Imaging Platform PICT IBISA
- Nikon Imaging Center

Plasmids and cells
- Ina Poser (MPI-CBG, Dresden)
- Roland Wedlich-Söldner (MPI, Martinsried)
- more…

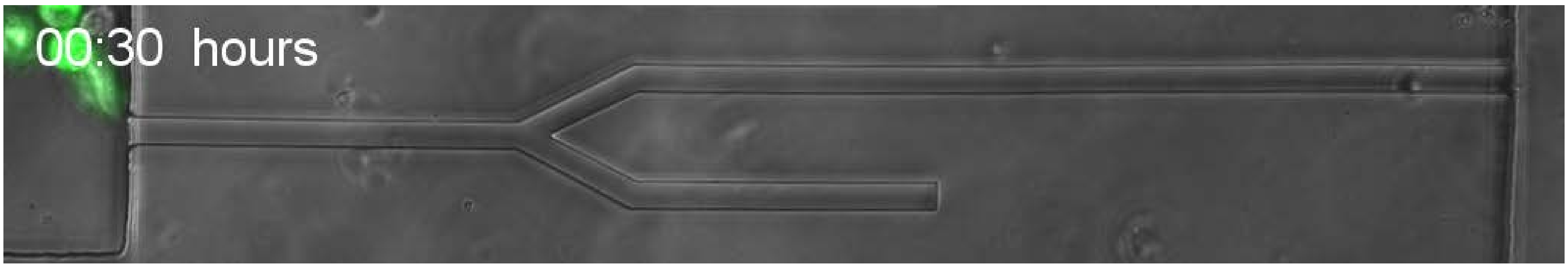
Current funding

Former funding

InNaBioSanté



This year cells will race inside micro-channels, to give a chance to amoeboid cells to win



Be FAST, PERSISTENT and SMART!

Beware of the dead-ends and may the best cell win!

To register or get more information: http://goo.gl/sk3PQ

Sponsors

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
Embassy of France in the United States
Office for Science and Technology

BioMEMS Resource Center

ibidi. cells in focus