Fluids and Structures Interaction and Modeling
Naples, 22-26 May 2017

Flow induced microstructure of emulsions

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Simona Capecchi ©

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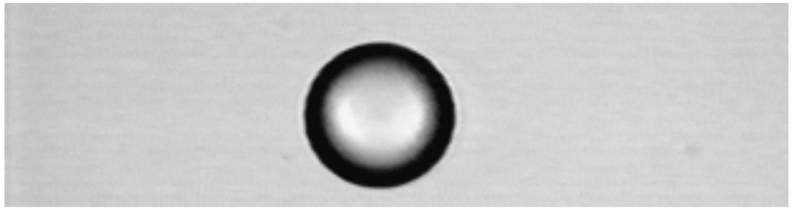
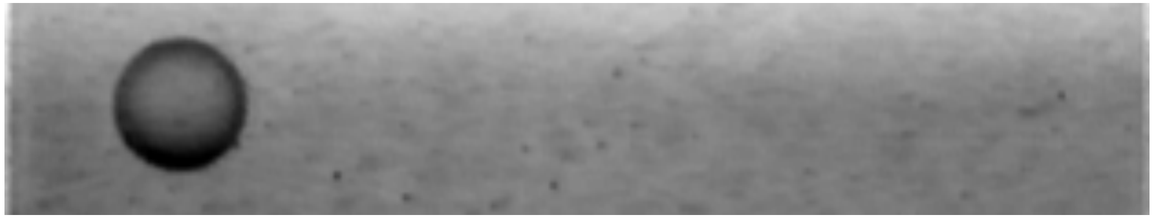
Laboratory of Chemical Engineering @ μ-scale

Flow Induced microstructure of emulsions

Drop deformation & Breakup

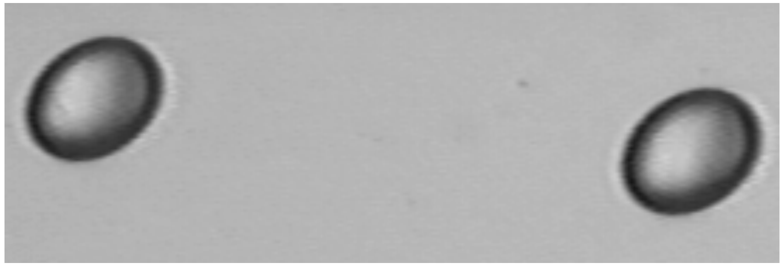


Newtonian

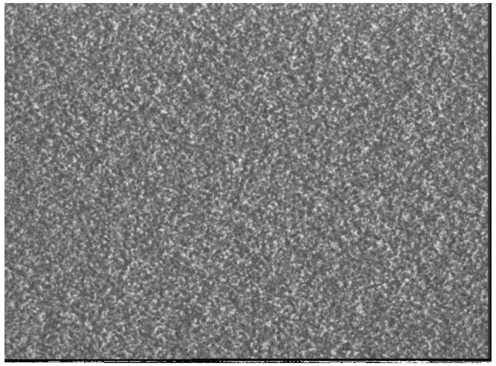


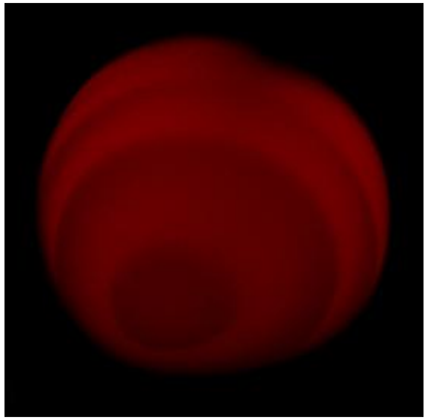
Non-Newtonian

Collision & Coalescence



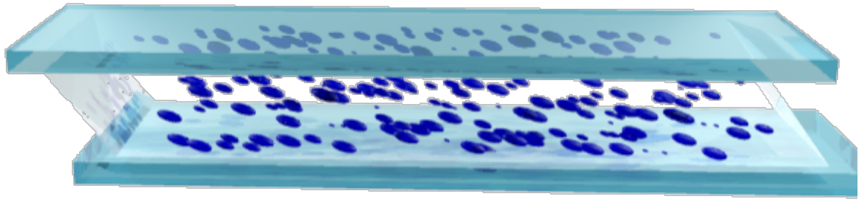
Shear Banding





Multilamellar Vesicles

Shear flow cell

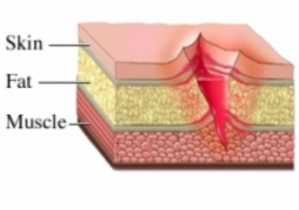


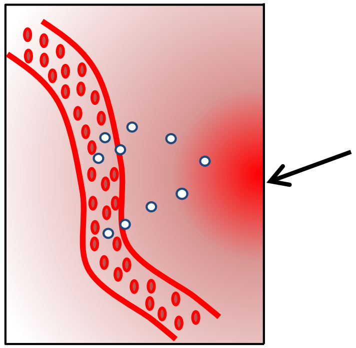
J. Rheol., 2003, 2007, 2016
PRL 2006, 2008, 2012
Soft Matter 2011, 2013
Langmuir, 2012, 2013

Cell dynamic evolution as Active Bio Soft Matter

Physiological and Pathological Processes

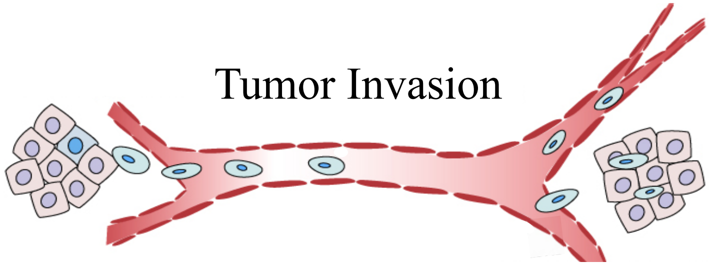
Tissue Repair



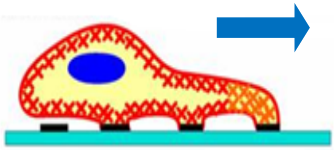


Inflammation

Tumor Invasion

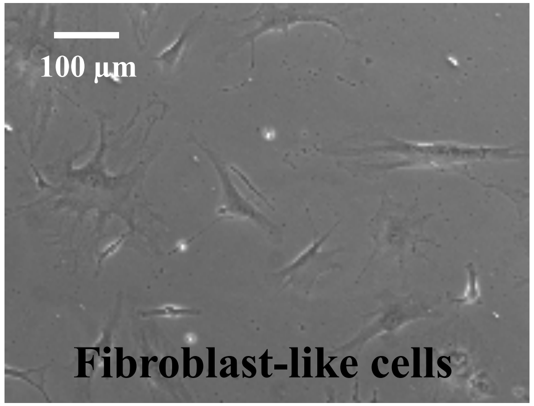


Cell motility

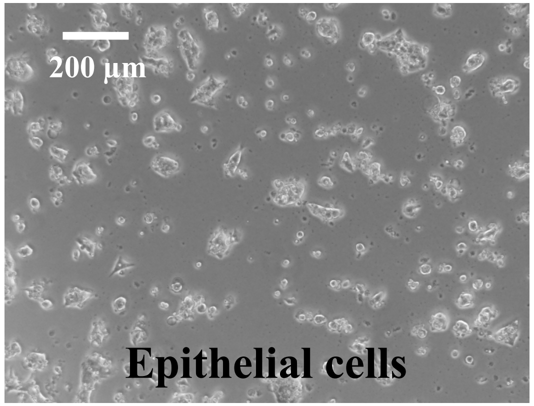


Cell proliferation

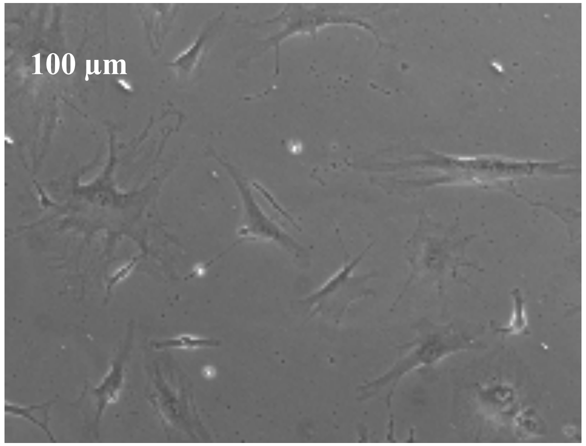
Single Cell Dynamics

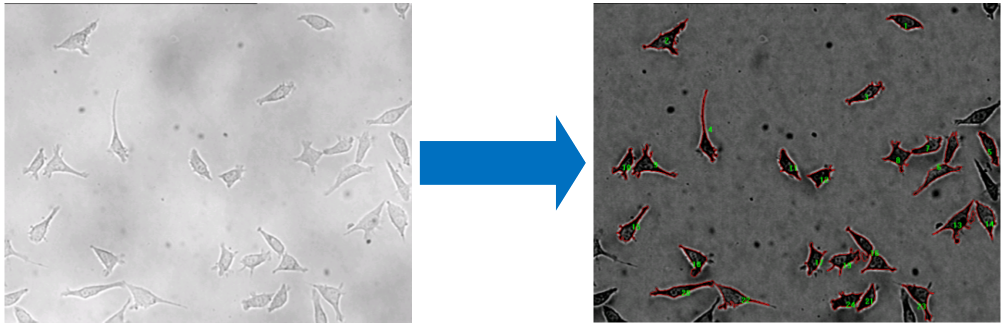


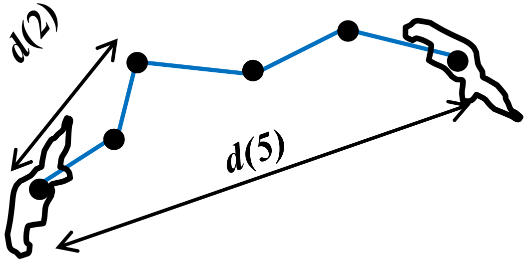
Collective Cell Dynamics



Single Cell Migration Assays







$$< d_i^2 >= \frac{1}{M}\sum_{i=1}^{M}\frac{1}{n_i}\sum_{k=1}^{n_i} d_{i,k}^2$$

n_i= number of Square Displacement
for each cell
M= number of cells

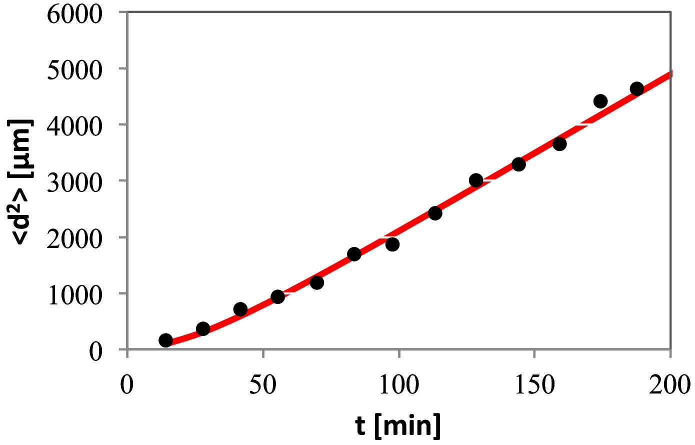
Persistent Random Walk

$$\boxed{\langle d^2(t)\rangle = 4\mu\left[t - P\left(1-e^{-t/P}\right)\ \right]}$$

µ = Random Motility Coefficient

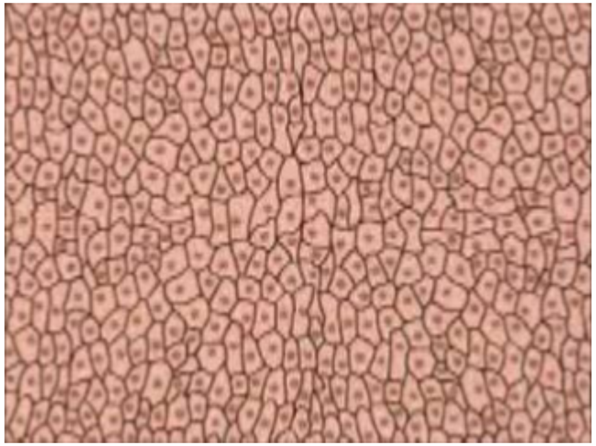
P = Persistence Time

Dickinson & Tranquillo, AIChE J., 1993
Uhlenbeck & Ornstein, Physical R., 1930



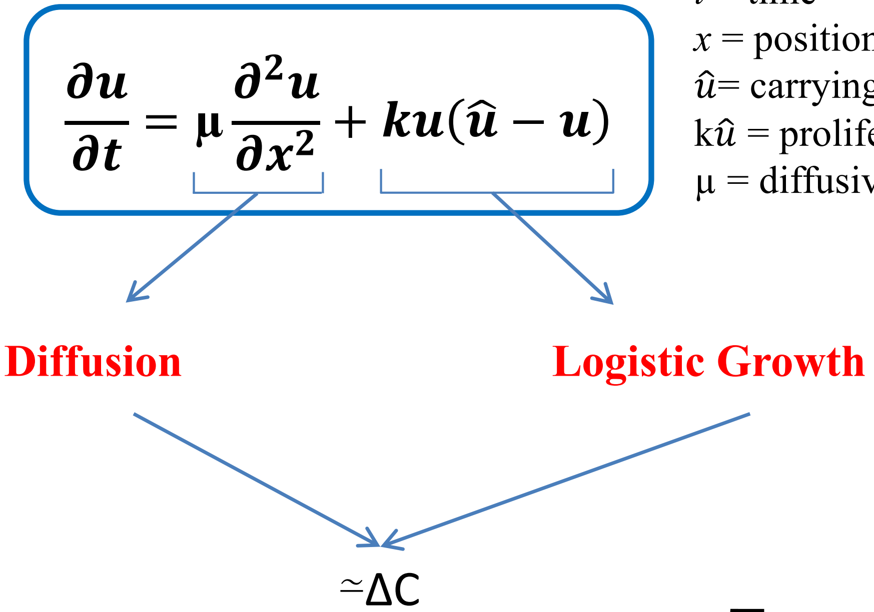
Wound Healing Assay

Wound Healing Assay



Alberts et al. Essential Cell Biology, 2009

Fisher, Ann. Eugenics, 1937



$$\boxed{\frac{\partial u}{\partial t} = \underbrace{\mu \frac{\partial^2 u}{\partial x^2}}_{\text{Diffusion}} + \underbrace{ku(\hat{u} - u)}_{\text{Logistic Growth}}}$$

Diffusion **Logistic Growth**

$\simeq \Delta C$

u = cell density
t = time
x = position
$\hat{u}$= carrying capacity
$k\hat{u}$ = proliferation rate
μ = diffusivity

Thiele Module: $\boldsymbol{\Phi} = \frac{b_0}{2}\sqrt{\frac{k}{\mu}}$

Wound edge speed

$$\mathbf{s} = \sqrt{\frac{\mathbf{4}\,\mu\,\mathbf{ln(2)}}{\mathbf{t_d}}}$$

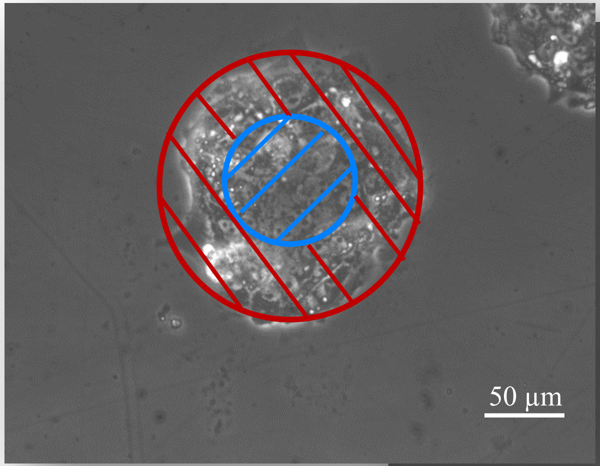
Random motility coefficient

$$\mu = \frac{\mathbf{s^2\ td}}{\mathbf{4ln(2)}}$$

Ascione et al., Chemical Engineering Science, 2017
Ascione et al., Experimental Cell Research, 2017

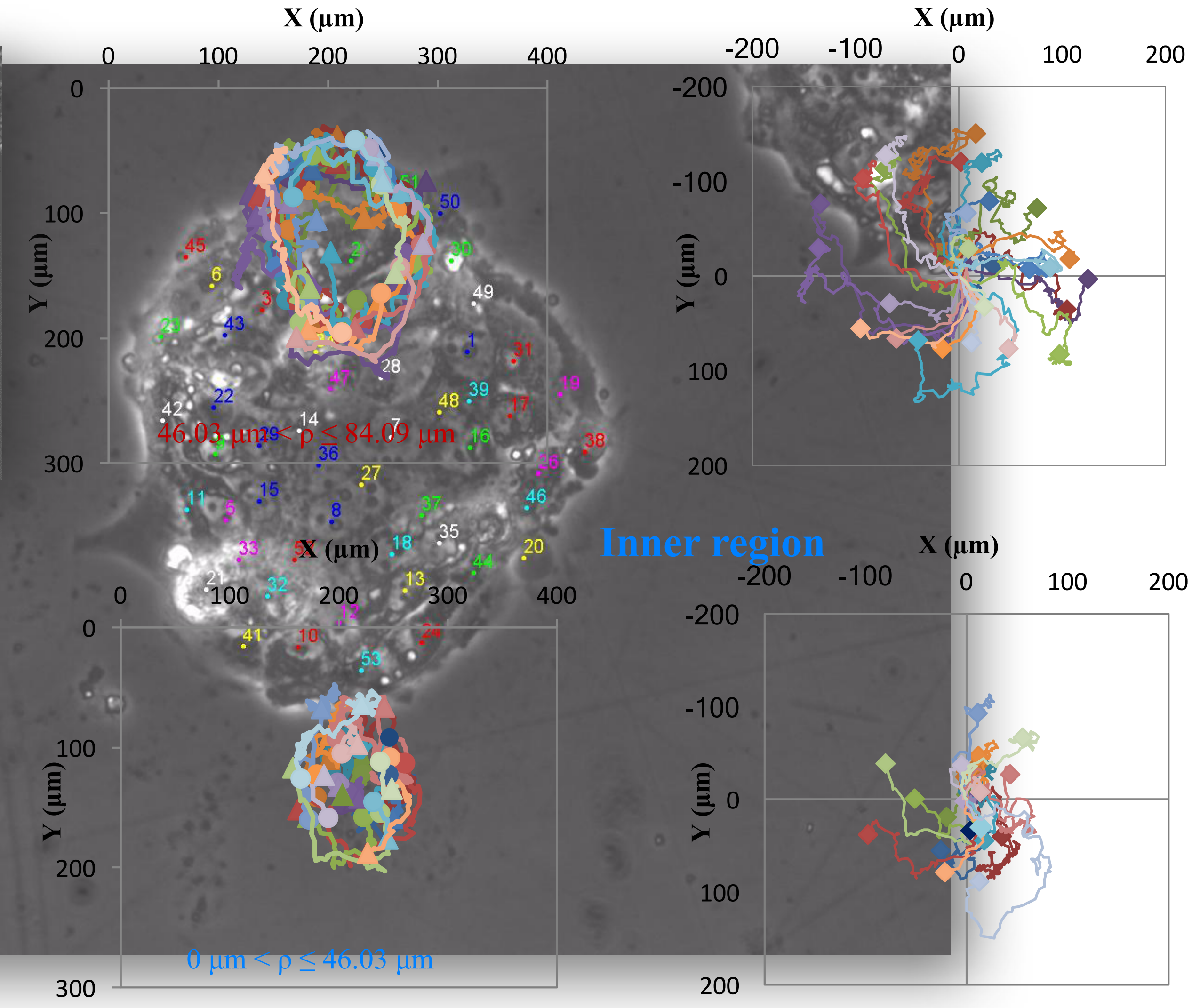
Collective Evolution of Epithelial Cells

R = 89.04 μm



Outer region

Inner region



- Confined movement

- Collective rotation

Collective Evolution of Epithelial Cells

Radial velocity

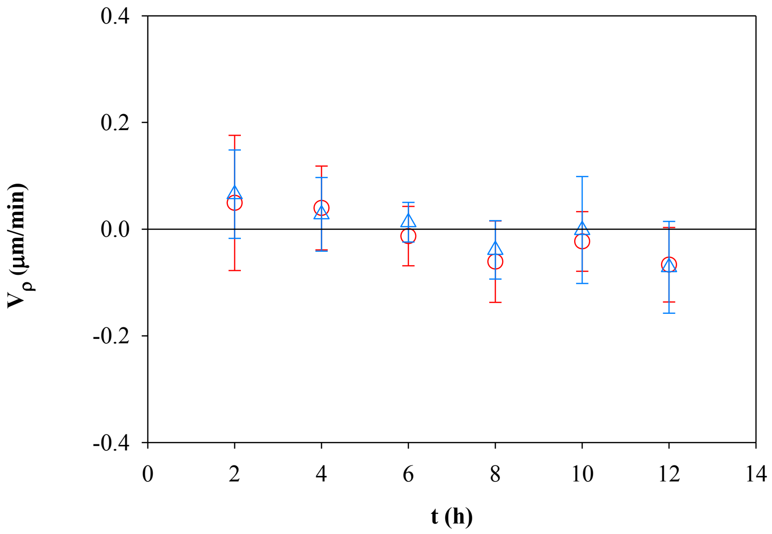
$$V_\rho = \frac{\rho_2 - \rho_1}{t}$$

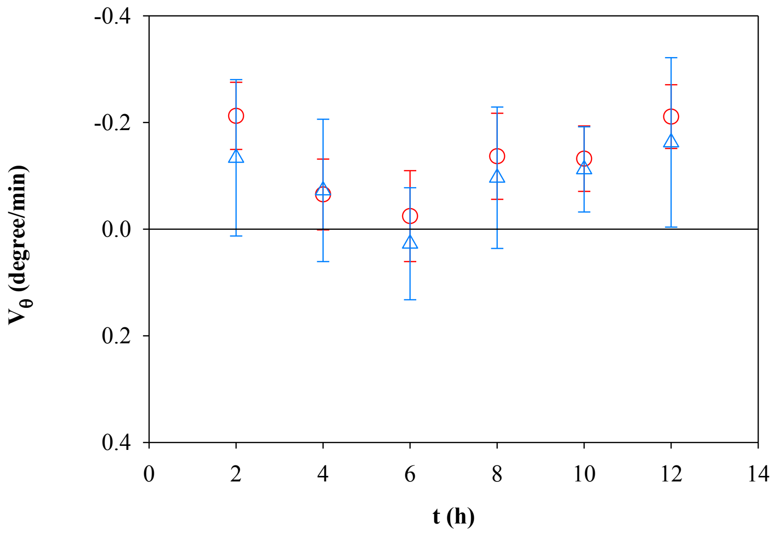
○ Outer region

△ Inner region

Angular velocity

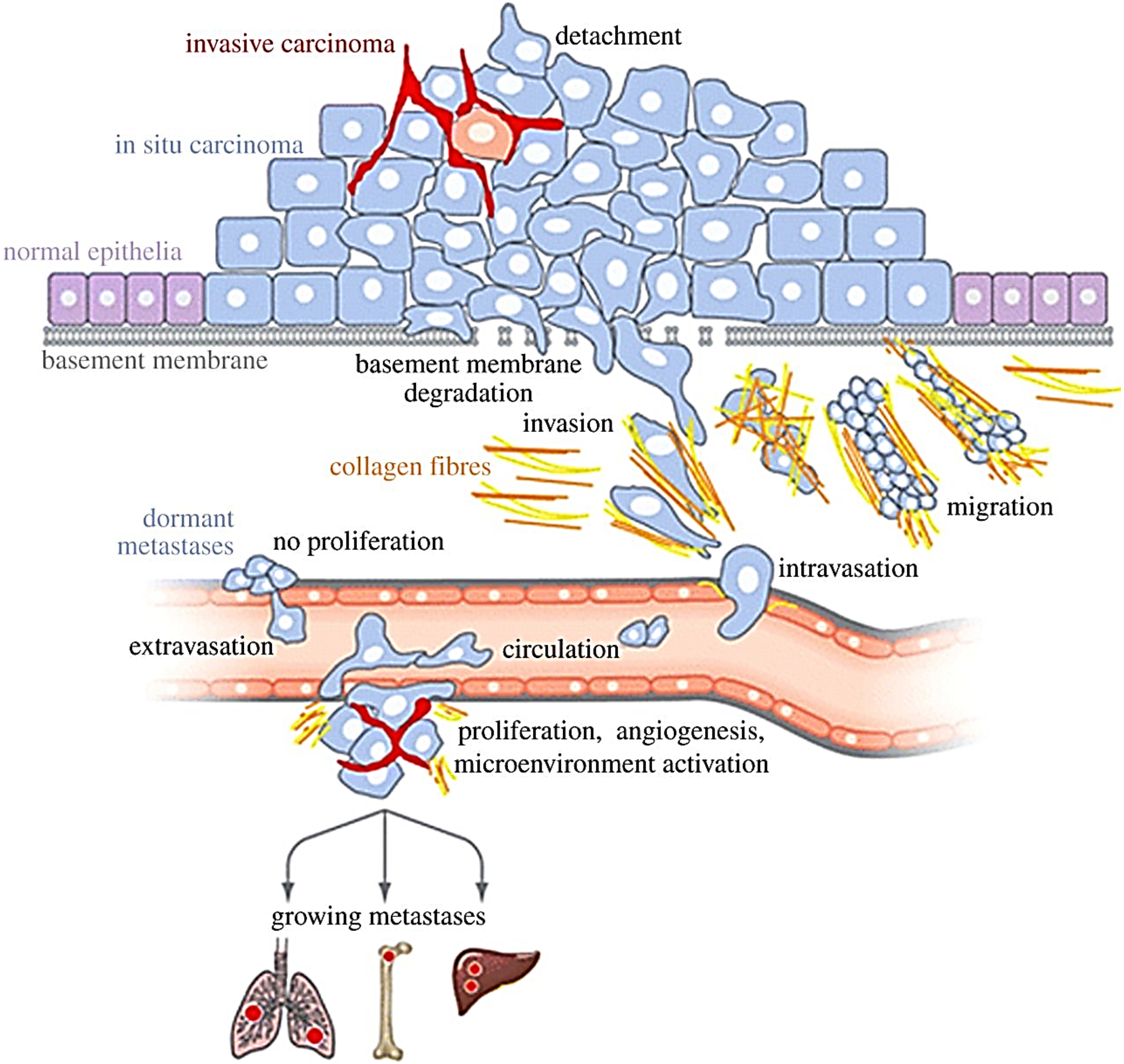
$$V_\theta = \frac{\theta_2 - \theta_1}{t}$$





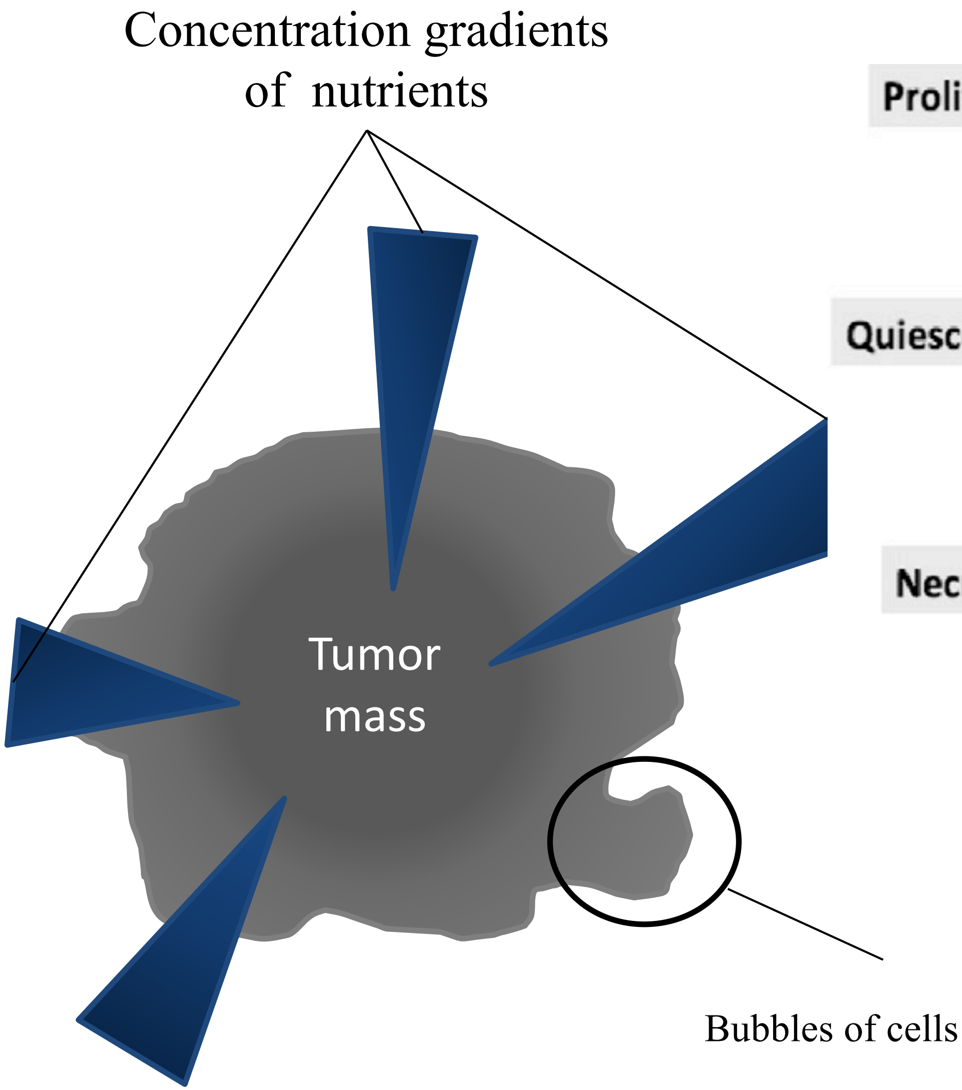
	$V\rho^2$ (μm/min)²	$V\theta^2$ (degree/min)²
Outer region	0.0086 ± 0.0050	0.027 ± 0.016
Inner region	0.0075 ± 0.0039	0.019 ± 0.013

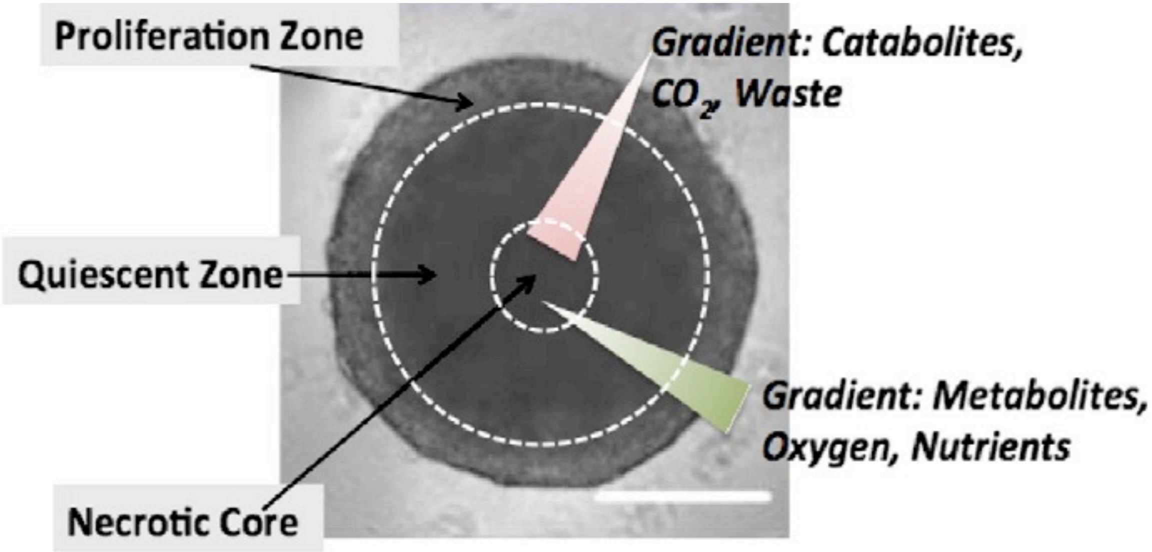
Cancer Growth and Invasion Modelling



M.B.A. Djamgoz et al, Philosophical Transactions of the Royal Society B, 2014

Cancer Growth and invasion: Spheroid Model





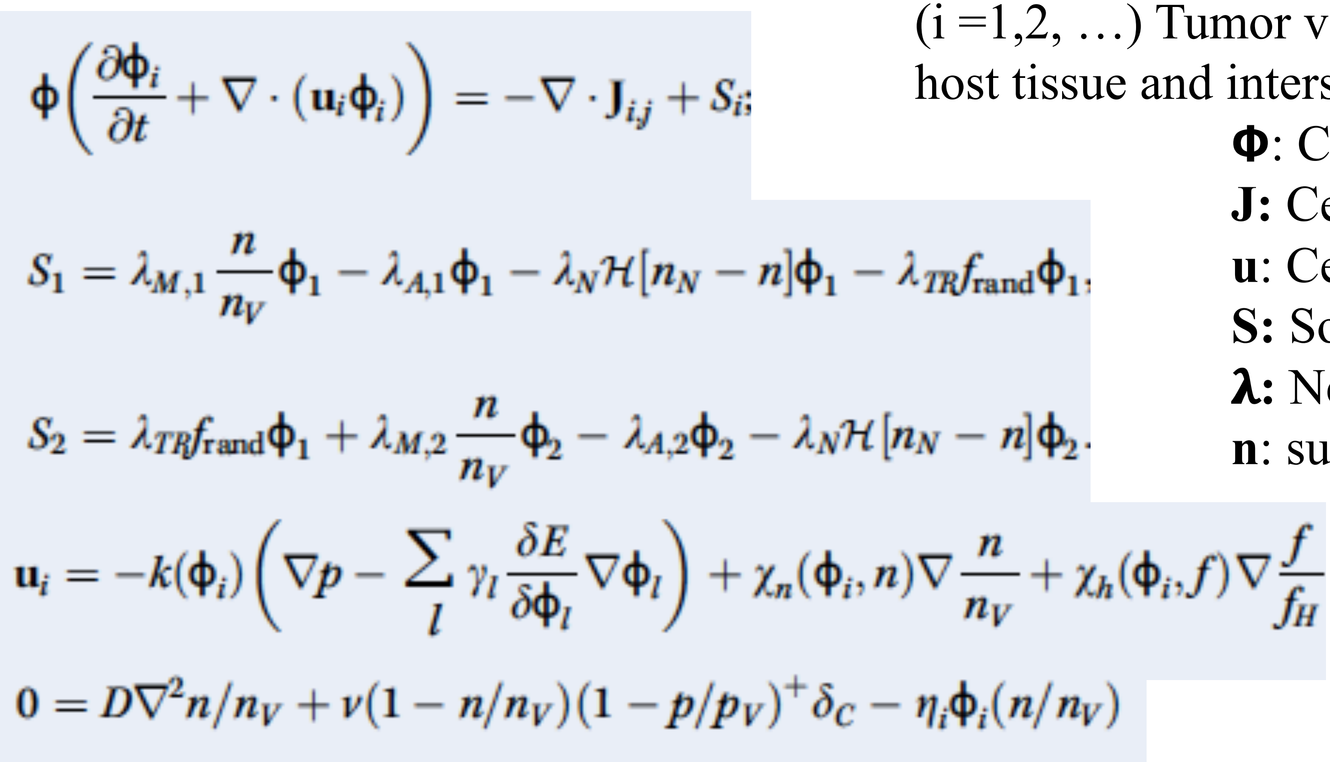
V. Cristini et al., Clinical Cancer Research, 2005

H.B. Frieboes, Cancer Research, 2006

G. Mehta et al., J. Controlled Release, 2012

Cancer Growth and Invasion Modelling

Matematical model + numerical simulations



$$\phi\left(\frac{\partial\phi_i}{\partial t}+\nabla\cdot(\mathbf{u}_i\phi_i)\right)=-\nabla\cdot\mathbf{J}_{i,j}+S_i$$

$$S_1=\lambda_{M,1}\frac{n}{n_V}\phi_1-\lambda_{A,1}\phi_1-\lambda_N\mathcal{H}[n_N-n]\phi_1-\lambda_{TR}f_{\mathrm{rand}}\phi_1$$

$$S_2=\lambda_{TR}f_{\mathrm{rand}}\phi_1+\lambda_{M,2}\frac{n}{n_V}\phi_2-\lambda_{A,2}\phi_2-\lambda_N\mathcal{H}[n_N-n]\phi_2$$

$$\mathbf{u}_i=-k(\phi_i)\left(\nabla p-\sum_l\gamma_l\frac{\delta E}{\delta\phi_l}\nabla\phi_l\right)+\chi_n(\phi_i,n)\nabla\frac{n}{n_V}+\chi_h(\phi_i,f)\nabla\frac{f}{f_H}$$

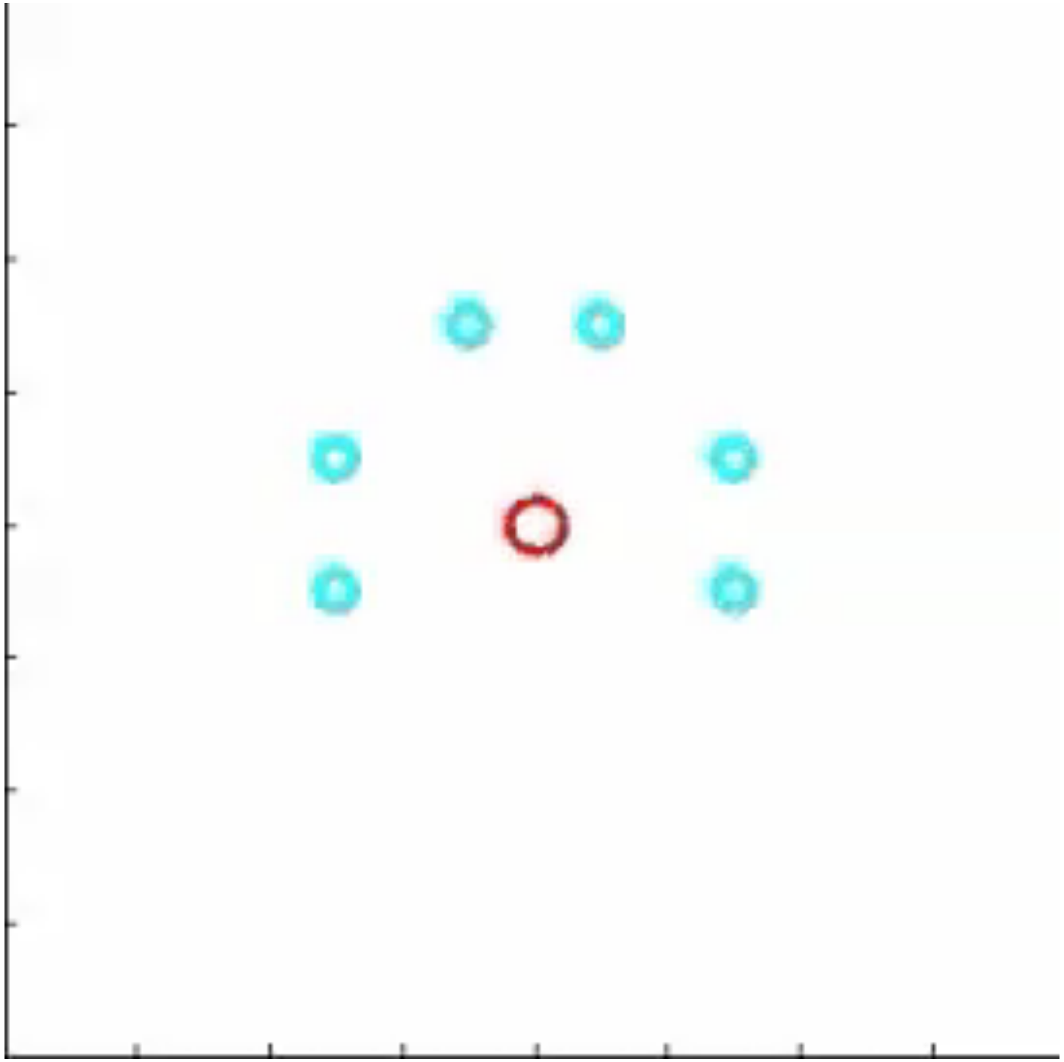
$$0=D\nabla^2 n/n_V+v(1-n/n_V)(1-p/p_V)^+\delta_C-\eta_i\phi_i(n/n_V)$$

(i =1,2, …) Tumor viable species, dead tumor, host tissue and interstitial fluid

Φ: Concentration
J: Cell flux
u: Cell velocity
S: Source of cells
λ: Necrosis/Mitosis/Mutation rates
n: substrate concentration

Cristini et al., Clinical Cancer Research 2005
Bearer et al., Cancer Research 2009

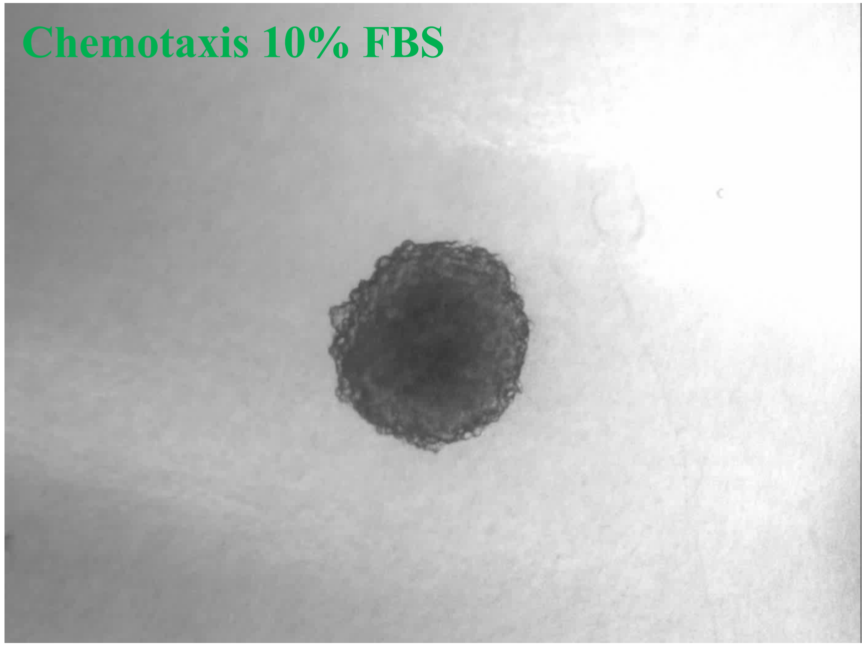
Cancer Growth and Invasion Modelling



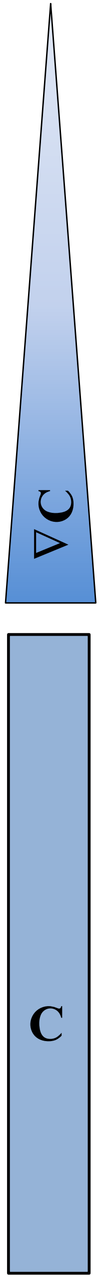
Diffusional Instability model

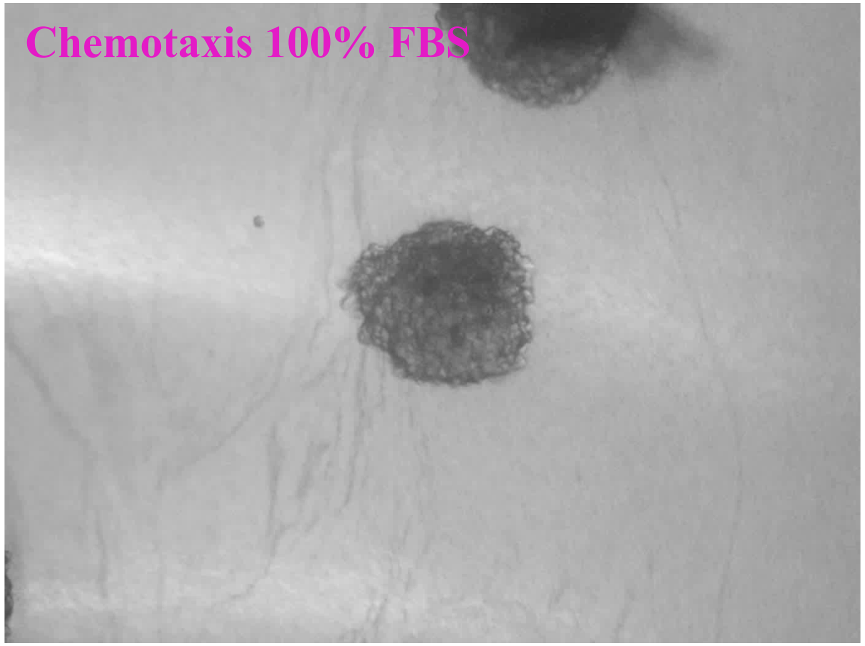
Cristini, Caserta et al., Clinical Cancer Research 2005

Cancer Growth and Invasion: Experiments

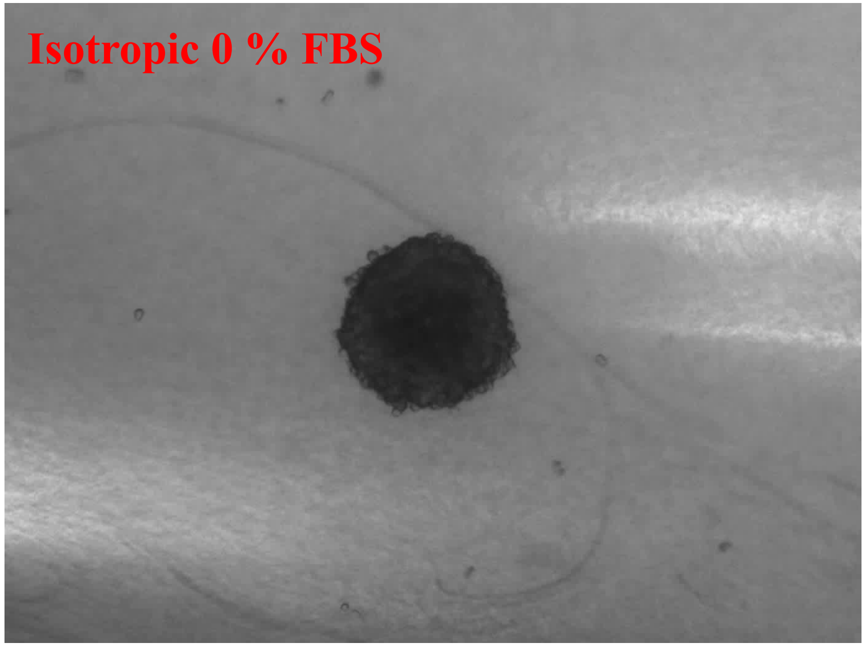


Chemotaxis 10% FBS

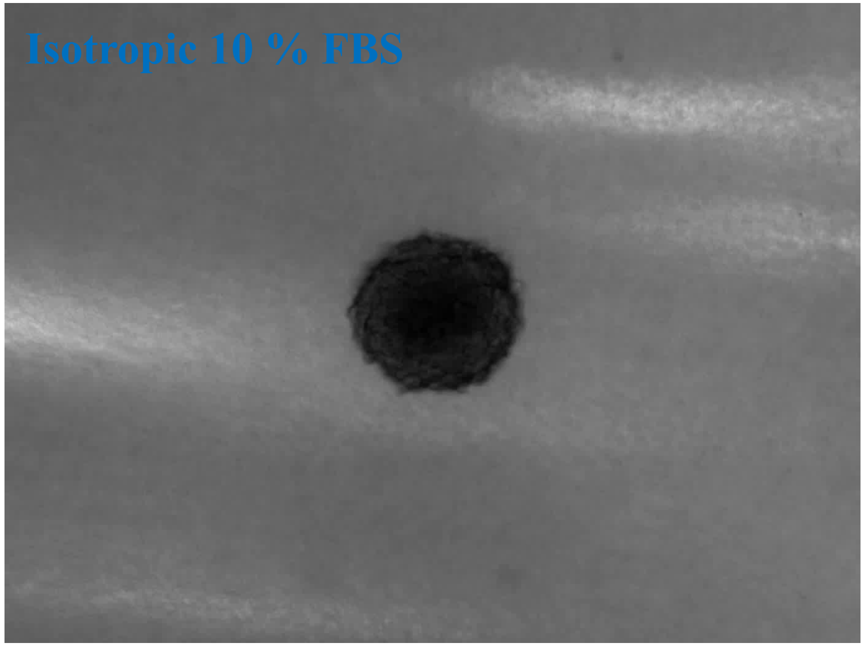




Chemotaxis 100% FBS



Isotropic 0 % FBS



Isotropic 10 % FBS

Main Results

- The dynamic evolution of both isolated and collective cells can be efficiently investigated *in vitro* by Time-lapse Microscopy and image analysis
- A transport phenomena bioengineering approach can be efficiently used to describe the dynamic evolution of cell populations
- Cell dynamic behavior is driven by concentration gradients

… Thank you …

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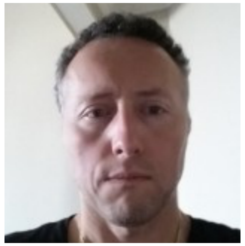

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We are looking forward to welcoming you in Sorrento - Naples

AERC 2018

- Sorrento, April 17– 20, 2018

Abstract deadline: 18th November 2017

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