

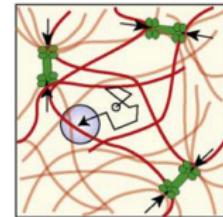
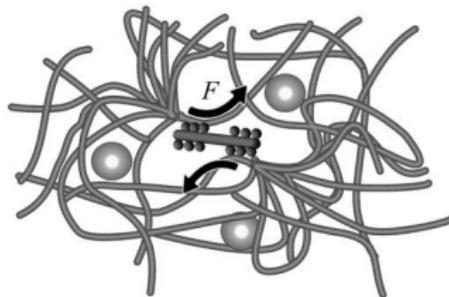
Modeling Active Fluctuations in Living Matter

Étienne Fodor¹, Nir S. Gov², Paolo Visco¹, Frédéric van Wijland¹

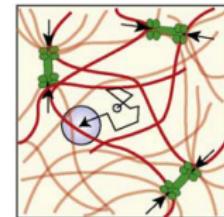
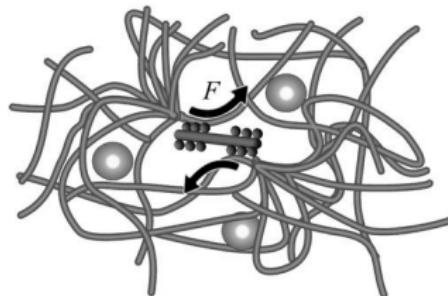
1. Laboratoire Matière et Systèmes Complexes, Université Paris-Diderot
2. Department of Chemical Physics, Weizmann Institute of Science

Group Seminar – Physique du Vivant

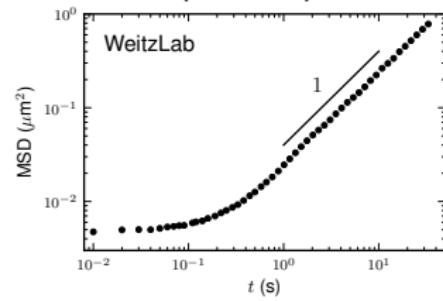
Introduction



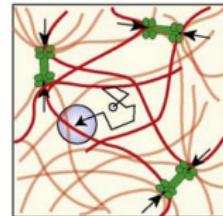
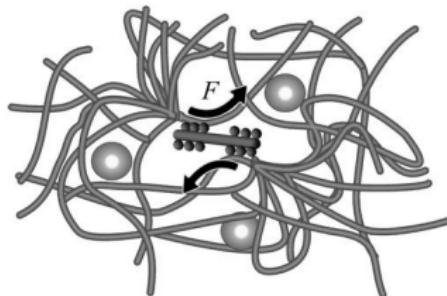
Introduction



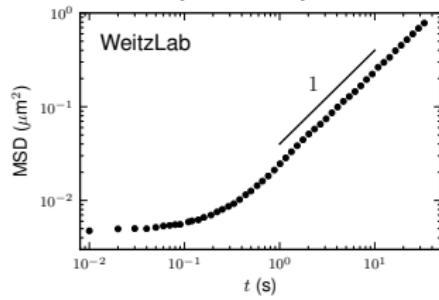
Mean square displacement



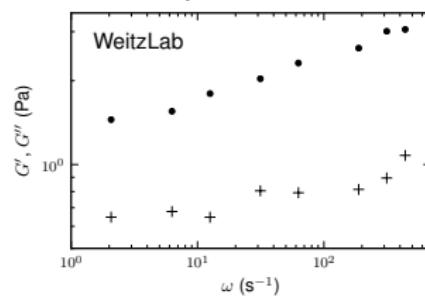
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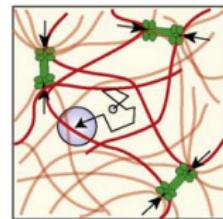
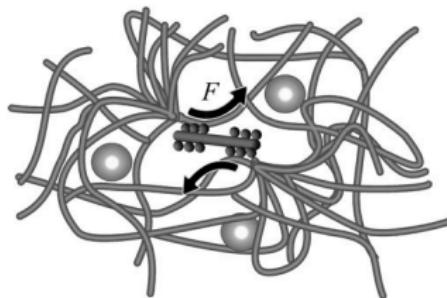
Mean square displacement



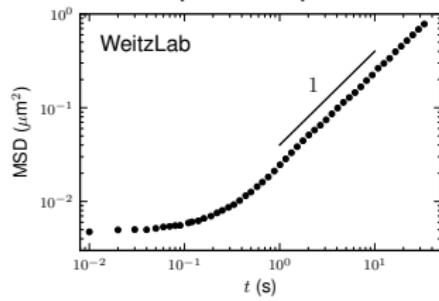
Complex modulus



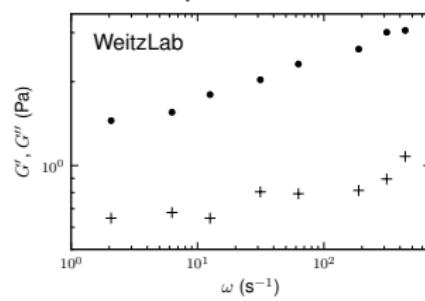
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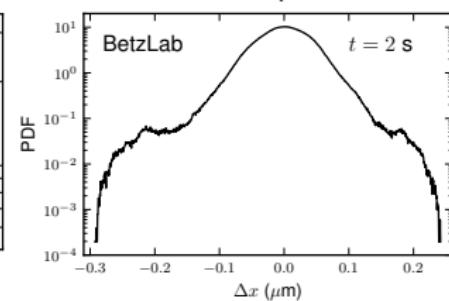
Mean square displacement



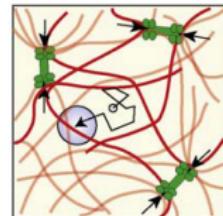
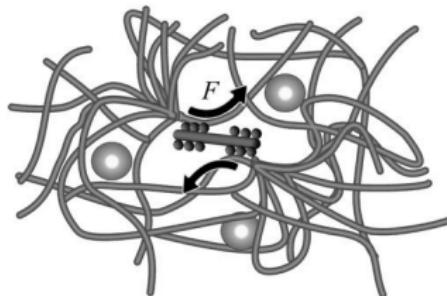
Complex modulus



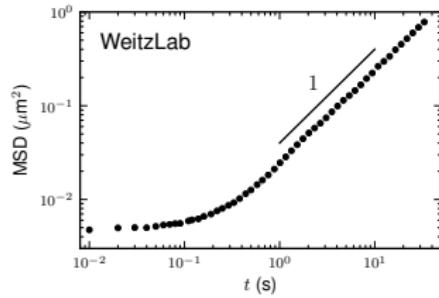
PDF of displacement



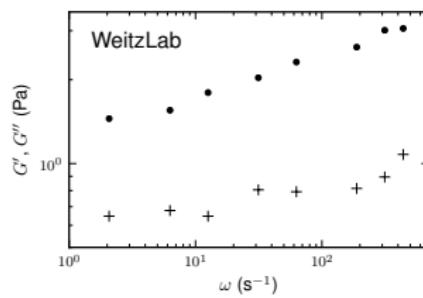
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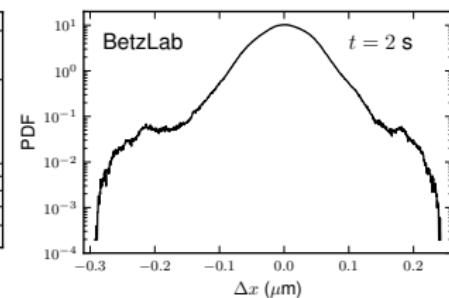
Mean square displacement



Complex modulus



PDF of displacement



Is it possible to extract information about nonequilibrium activity?

Propose a model for the tracers' dynamics

Outline

① Activity driven fluctuations in living cells

Ming Guo, David A. Weitz

School of Engineering and Applied Sciences, Harvard University

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① Activity driven fluctuations in living cells

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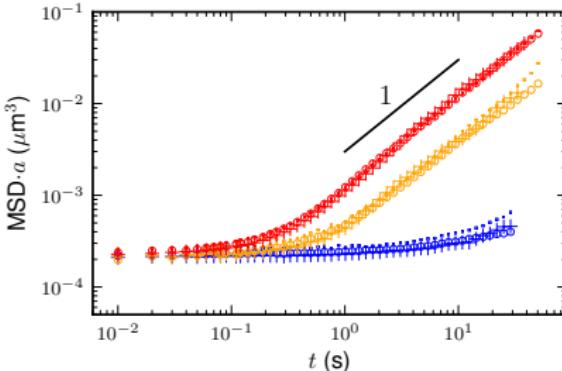
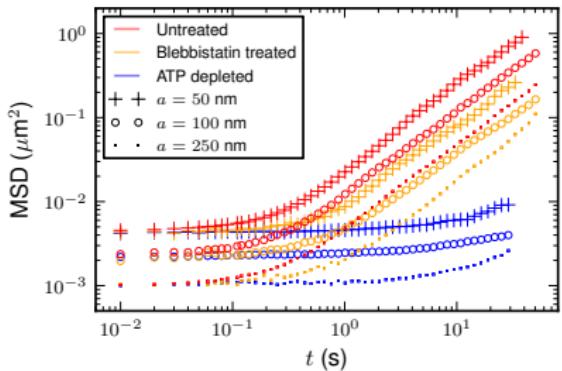
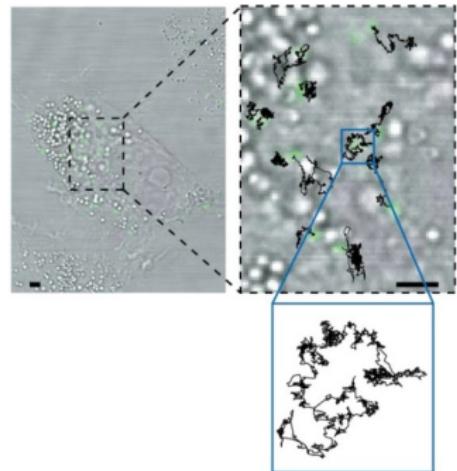
② Epithelial tissues as fluctuating active foams

Vishwajeet Mehandia, Daniel Riveline

Laboratoire de Physique Cellulaire, Université de Strasbourg

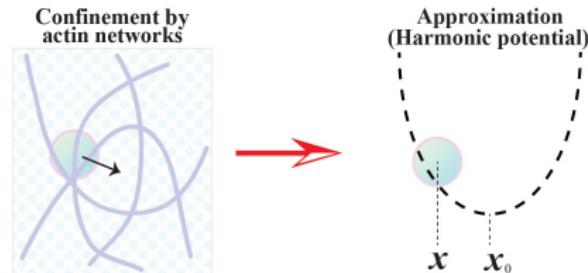
Activity driven fluctuations in living cells

Experimental results



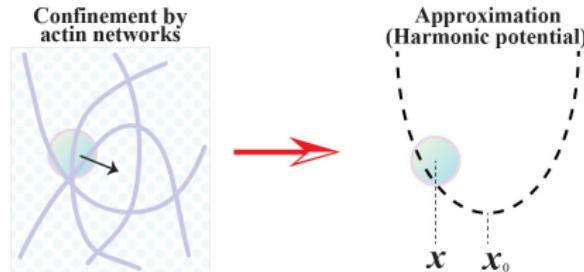
Activity driven fluctuations in living cells

Modeling tracer's dynamics: equation of motion



Activity driven fluctuations in living cells

Modeling tracer's dynamics: equation of motion



Tracer's dynamics

$$m \frac{d^2\mathbf{r}}{dt^2} = -\nabla U + \mathbf{F}_S + \mathbf{F}_{th}$$

Harmonic potential: $U = \frac{k}{2}(\mathbf{r} - \mathbf{r}_0)^2$

Stokes force: $\mathbf{F}_S = -\gamma \frac{d\mathbf{r}}{dt}$

Gaussian white noise: \mathbf{F}_{th}

Activity driven fluctuations in living cells

Modeling tracer's dynamics: equation of motion

Tracer's dynamics

$$\frac{d\mathbf{r}}{dt} = -\frac{1}{\tau_d}(\mathbf{r} - \mathbf{r}_0) + \sqrt{2D_T}\xi$$

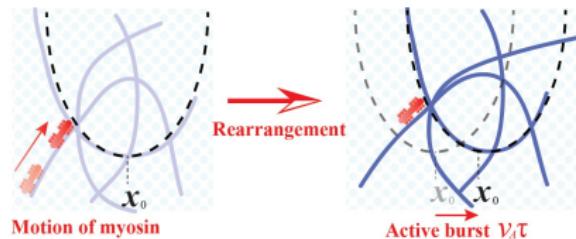
Activity driven fluctuations in living cells

Modeling tracer's dynamics: equation of motion

Tracer's dynamics

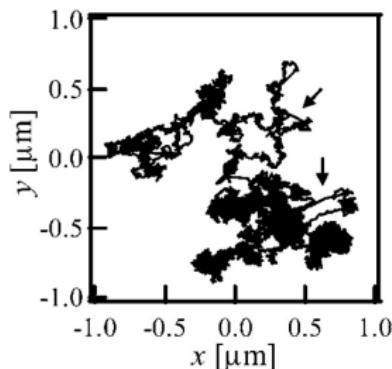
$$\frac{d\mathbf{r}}{dt} = -\frac{1}{\tau_d}(\mathbf{r} - \mathbf{r}_0) + \sqrt{2D_T}\xi, \quad \frac{d\mathbf{r}_0}{dt} = \mathbf{v}_A$$

Active motion of local minimum



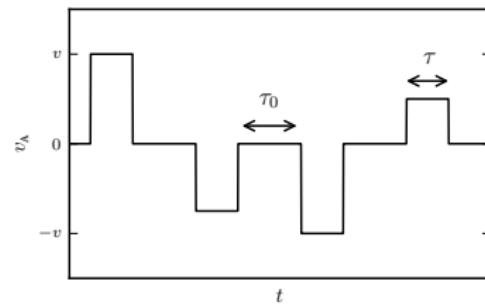
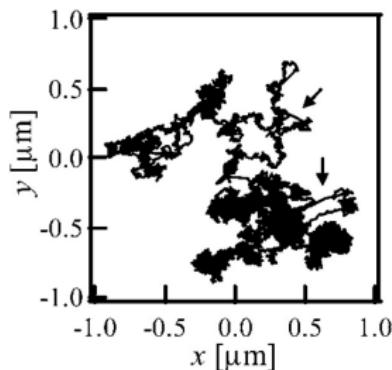
Activity driven fluctuations in living cells

Modeling tracer's dynamics: active burst's statistics



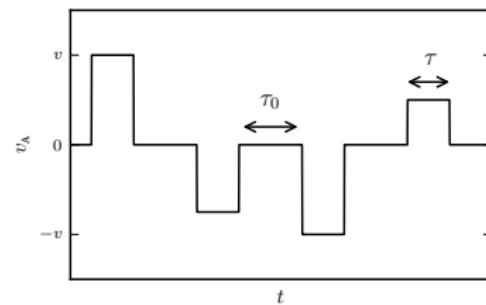
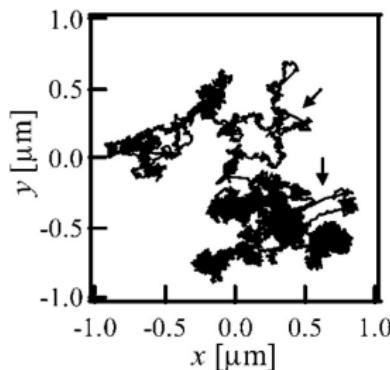
Activity driven fluctuations in living cells

Modeling tracer's dynamics: active burst's statistics



Activity driven fluctuations in living cells

Modeling tracer's dynamics: active burst's statistics



2-time correlation function

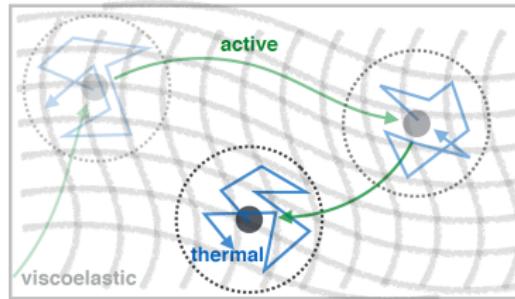
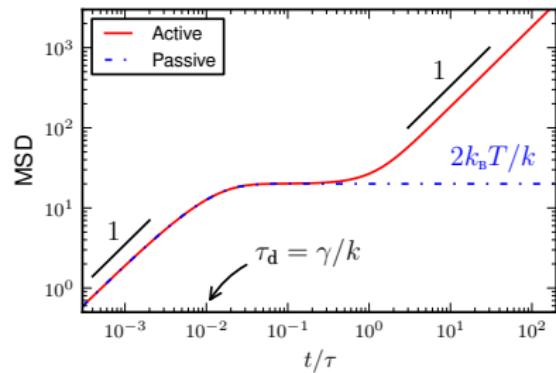
$$\langle v_A(t)v_A(0) \rangle = \frac{D_A}{\tau} e^{-|t|/\tau}, \quad D_A = \frac{(v\tau)^2}{3(\tau + \tau_0)}$$

Activity driven fluctuations in living cells

Modeling tracer's dynamics: tracer's statistics

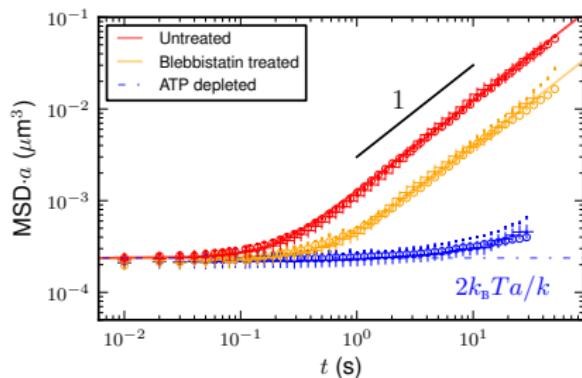
Short time Diffusion + Confinement
 $MSD \sim 2D_T t$

Large time Free diffusion
 $MSD \sim 2D_A t$



Activity driven fluctuations in living cells

Fitting experimental results



Microscopic features

- Typical time of activity

Untreated: $\tau = 0.16 \pm 0.03$ s,

Bleb. treated: $\tau = 0.39 \pm 0.09$ s

- Amplitude of active fluctuations

Untreated: $D_A \simeq 2.8 \cdot 10^{-3} D_T$,

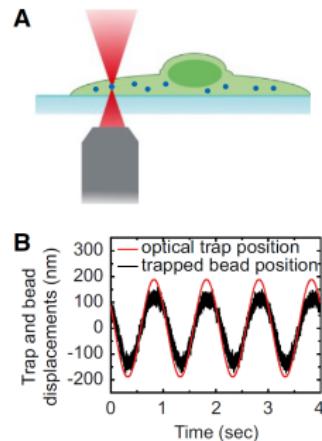
Bleb. treated: $D_A \simeq 9.0 \cdot 10^{-4} D_T$

Activity driven fluctuations in living cells

Nonequilibrium properties

Fluctuation dissipation

$$\chi''(\omega) = \frac{\omega C(\omega)}{2k_B T}$$

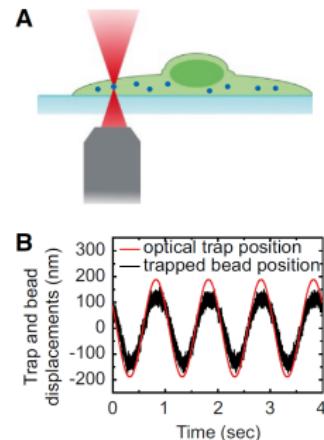
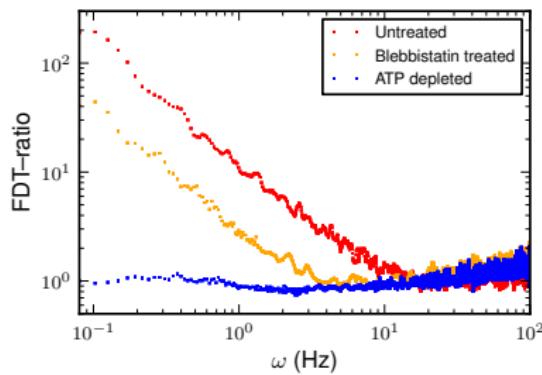


Activity driven fluctuations in living cells

Nonequilibrium properties

Fluctuation dissipation

$$\chi''(\omega) = \frac{\omega C(\omega)}{2k_B T}$$



$$\text{FDT-ratio} = \frac{\omega C(\omega)}{2\chi''(\omega)k_B T}$$

Activity driven fluctuations in living cells

Active force spectrum

Spectrum of stochastic forces

$$S_{\text{tot}}(\omega) = \frac{C(\omega)}{|\chi(\omega)|^2}$$

Activity driven fluctuations in living cells

Active force spectrum

Spectrum of stochastic forces

$$S_{\text{tot}}(\omega) = \frac{C(\omega)}{|\chi(\omega)|^2}$$

Tracer's dynamics

$$\gamma \frac{d\mathbf{r}}{dt} = -k\mathbf{r} + \mathbf{F}_{\text{th}} + \underbrace{\mathbf{F}_A}_{k\mathbf{r}_0} \quad \rightarrow \quad S_{\text{tot}} = S_{\text{th}} + S_A$$

Activity driven fluctuations in living cells

Active force spectrum

Spectrum of stochastic forces

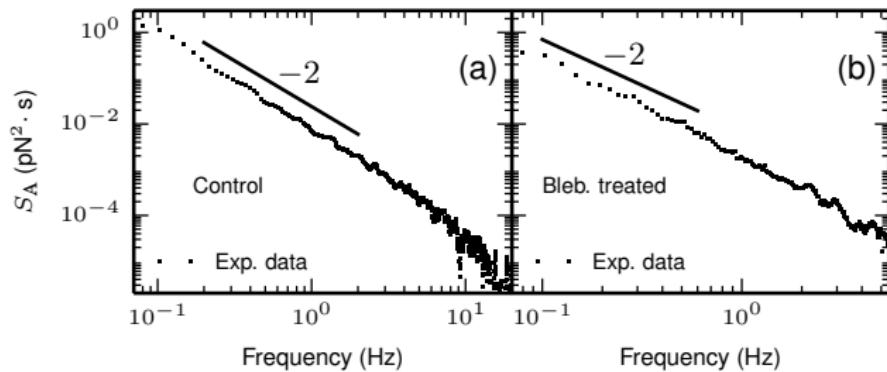
$$S_{\text{tot}}(\omega) = \frac{C(\omega)}{|\chi(\omega)|^2}$$

Tracer's dynamics

$$\gamma \frac{d\mathbf{r}}{dt} = -k\mathbf{r} + \mathbf{F}_{\text{th}} + \cancel{\mathbf{F}_A} \quad \rightarrow \quad \underbrace{S_{\text{tot}} = S_{\text{th}} + \cancel{S_A}}_{\text{ATP depleted}}$$

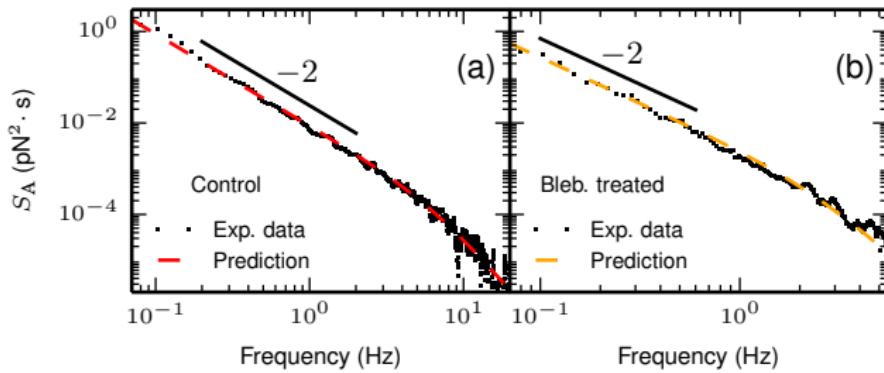
Activity driven fluctuations in living cells

Active force spectrum



Activity driven fluctuations in living cells

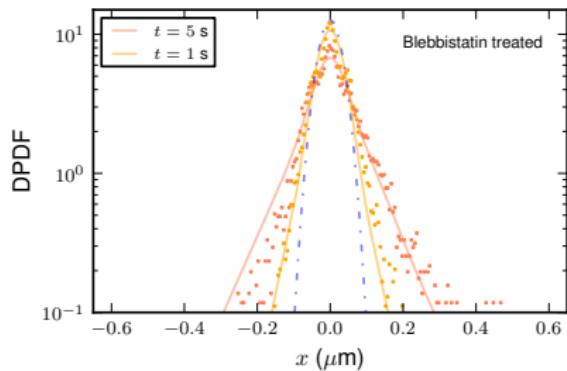
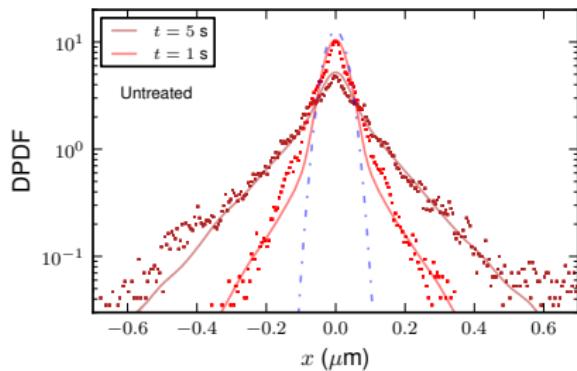
Active force spectrum



$$S_A(\omega) = \left(\frac{k}{\omega} \right)^2 \frac{2D_A}{1 + (\omega\tau)^2}$$

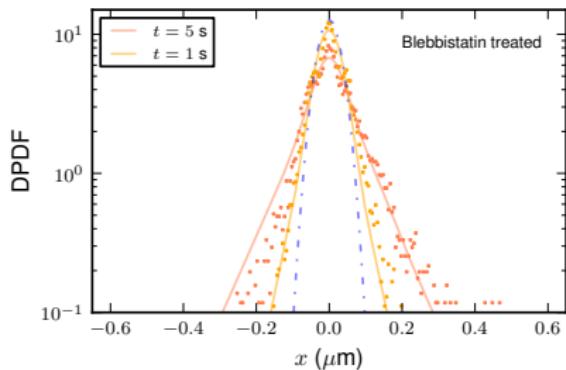
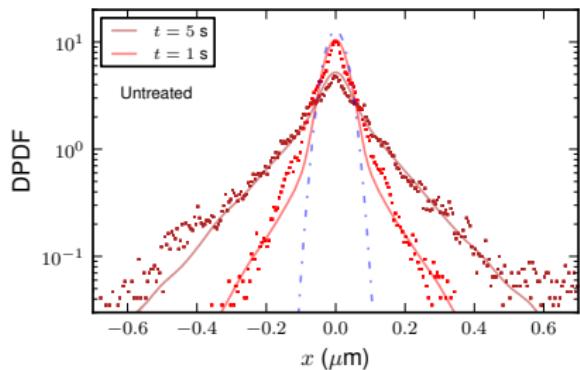
Activity driven fluctuations in living cells

Probability distribution function of displacement



Activity driven fluctuations in living cells

Probability distribution function of displacement



Numerical simulations → Duty ratio: $p_{\text{on}} = \frac{\tau}{\tau + \tau_0}$

Microscopic features

- Untreated: $p_{\text{on}} \simeq 6 \%$, $\tau_0 \simeq 2.5 \text{ s}$
- Blebbistatin treated: $p_{\text{on}} \simeq 15 \%$, $\tau_0 \simeq 2.8 \text{ s}$

Outline

➊ Activity driven fluctuations in living cells

Ming Guo, David A. Weitz

School of Engineering and Applied Sciences, Harvard University

➋ Epithelial tissues as fluctuating active foams

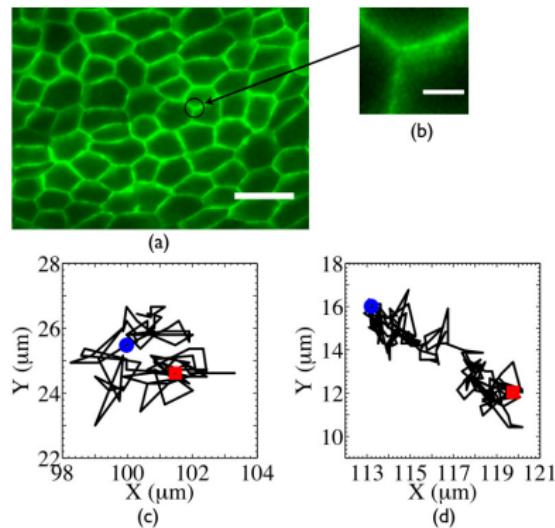
Vishwajeet Mehandia, Daniel Riveline

Laboratoire de Physique Cellulaire, Université de Strasbourg

Epithelial tissues as fluctuating active foams

Experimental results

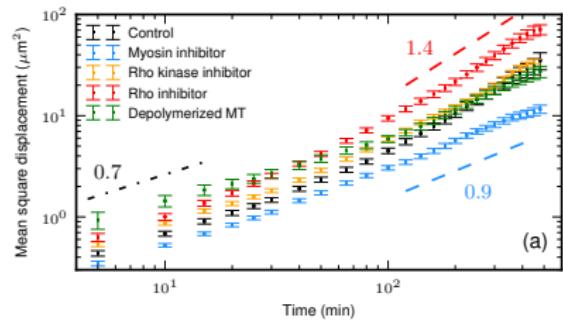
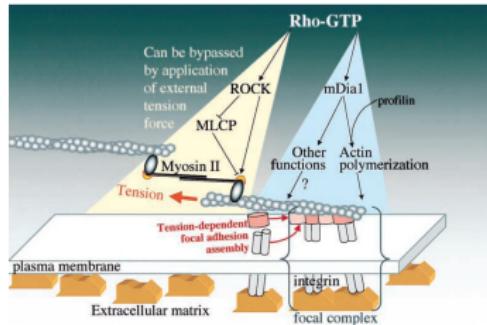
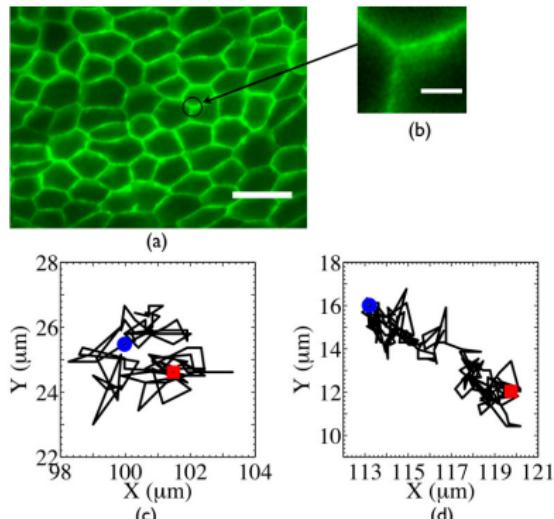
Fluctuations of tricellular junctions



Epithelial tissues as fluctuating active foams

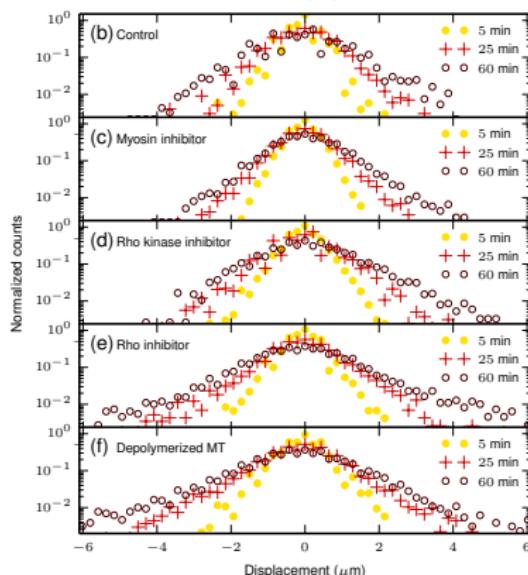
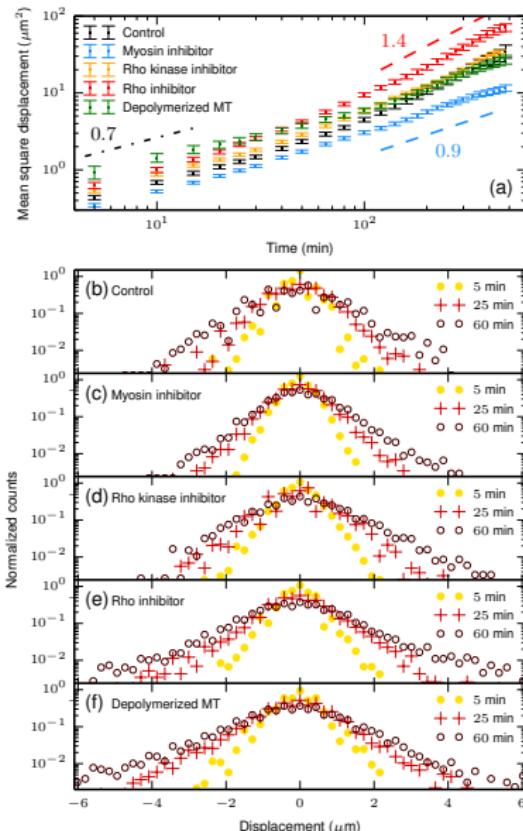
Experimental results

Fluctuations of tricellular junctions



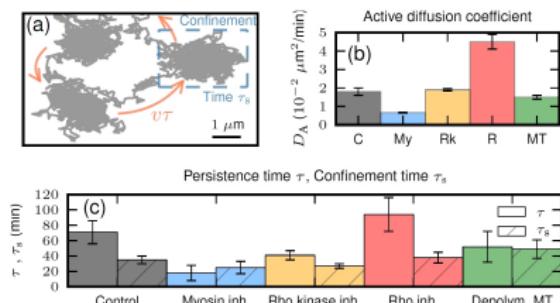
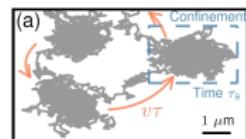
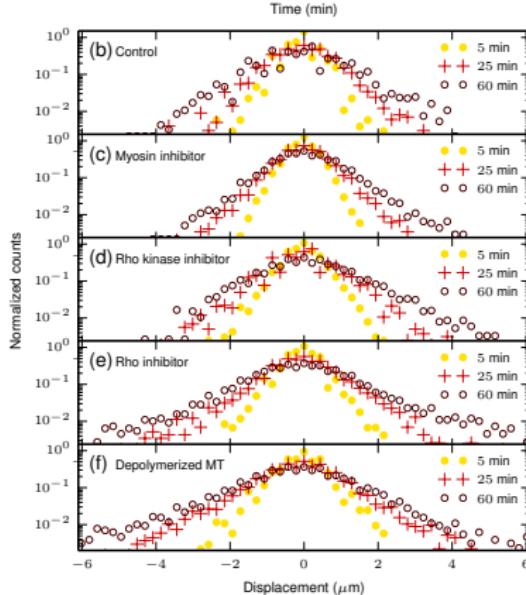
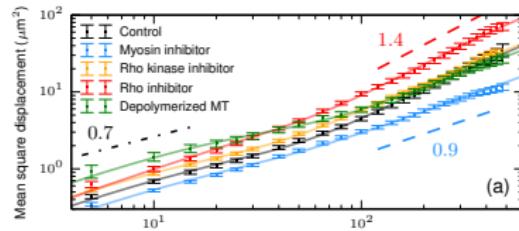
Epithelial tissues as fluctuating active foams

Experimental results



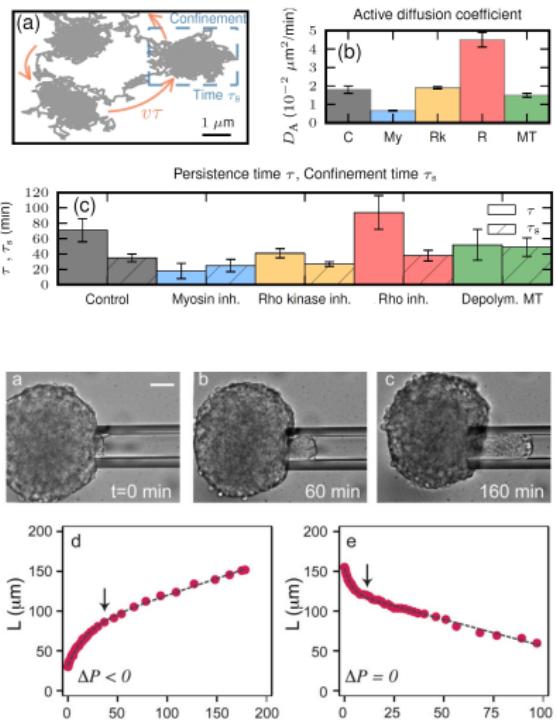
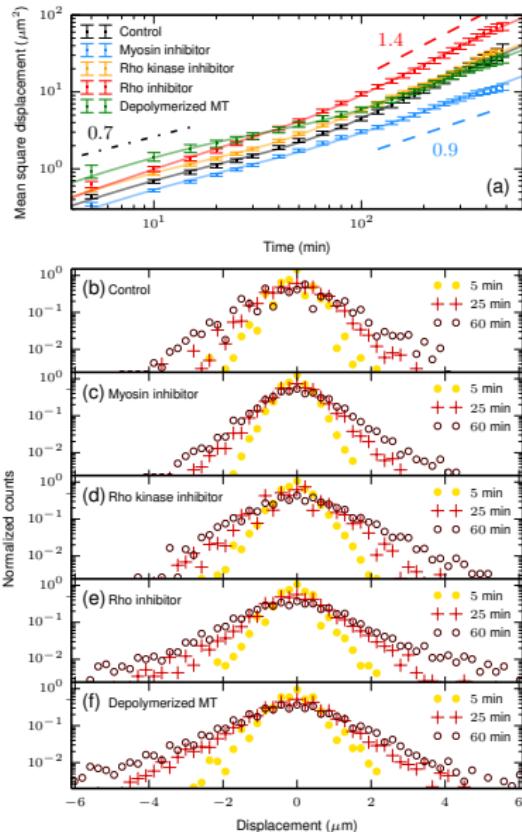
Epithelial tissues as fluctuating active foams

Fitting experimental results



Epithelial tissues as fluctuating active foams

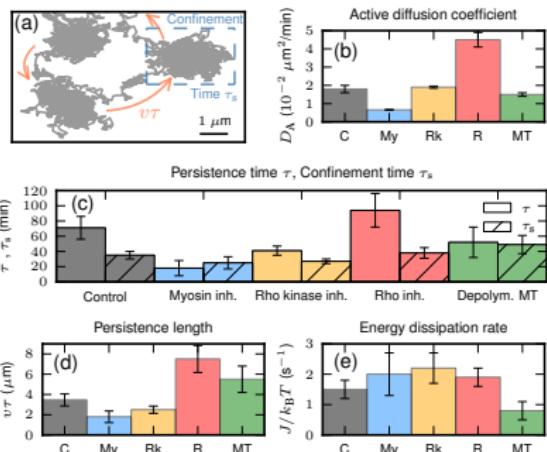
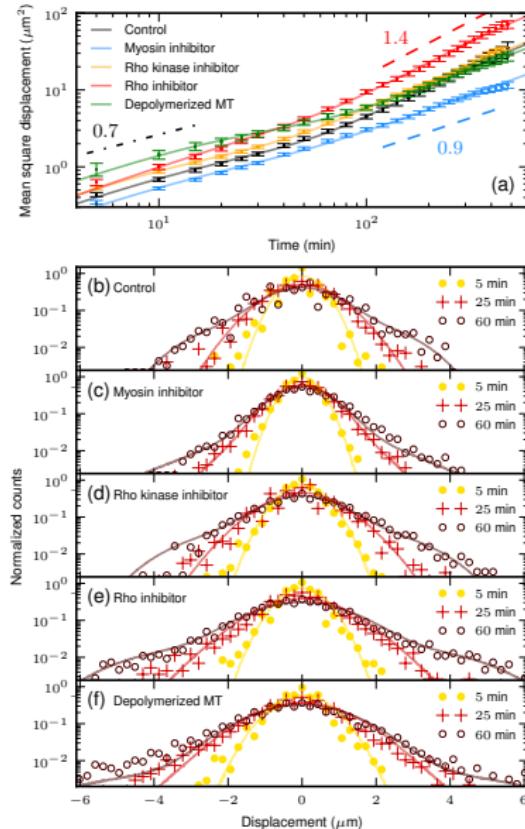
Fitting experimental results



Guevorkian et al., PRL 104, 218101 (2010)

Epithelial tissues as fluctuating active foams

Fitting experimental results



Conclusion

Dynamics in living matter

Two driving forces

- ① Passive, purely thermal, equilibrium
- ② Active, out-of-equilibrium

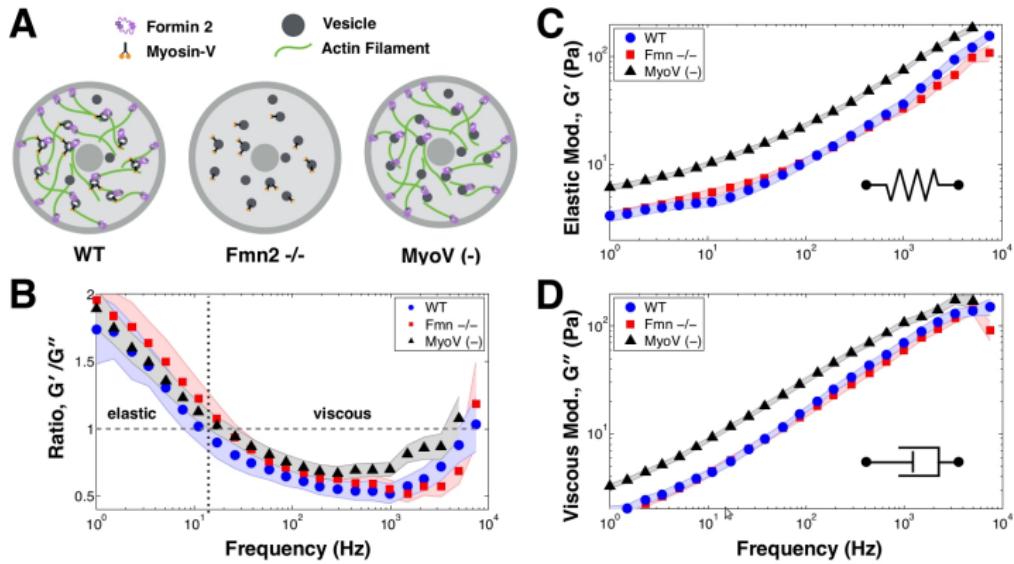
Quantify active features $\{\tau, \tau_0, v\tau, D_A\}$

Outlook

- Rotational dynamics of micro-sized wires
- Spontaneous topological transitions in epithelial tissues

Nonequilibrium mechanics in living oocytes

W. W. Ahmed, M. Almonacid, M. Bussonnier, M.-H. Verlhac, T. Betz



Nonequilibrium mechanics in living oocytes

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