Active fluctuations of a tracer in living matter

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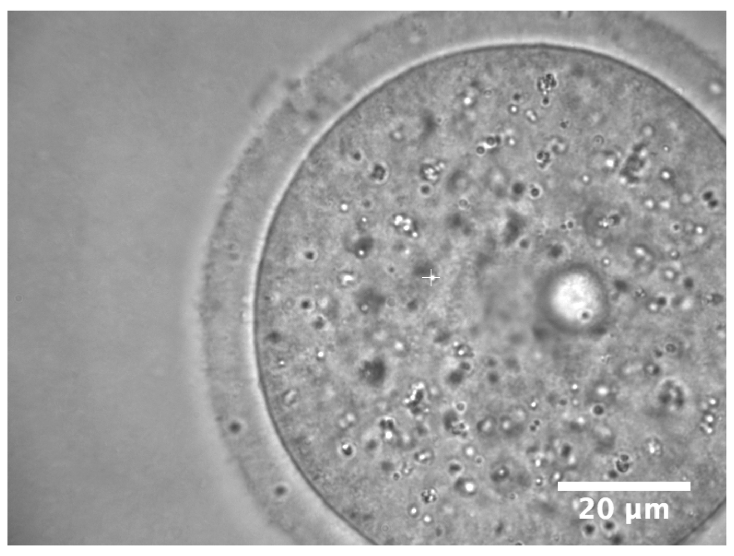
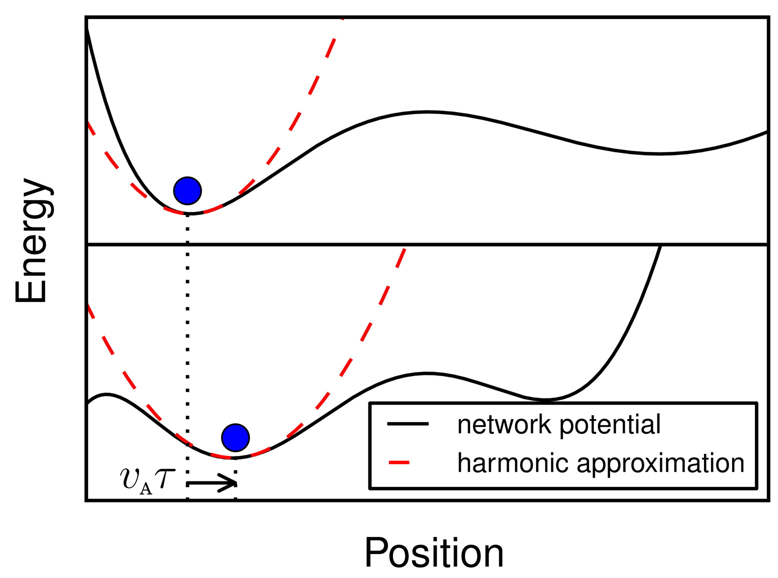
Is it possible to gain information about molecular motor activity from tracers' statistics?

Tracer inside living cell/actin gel: thermal fluctuations and molecular motor activity.



Active motion of local minimum.



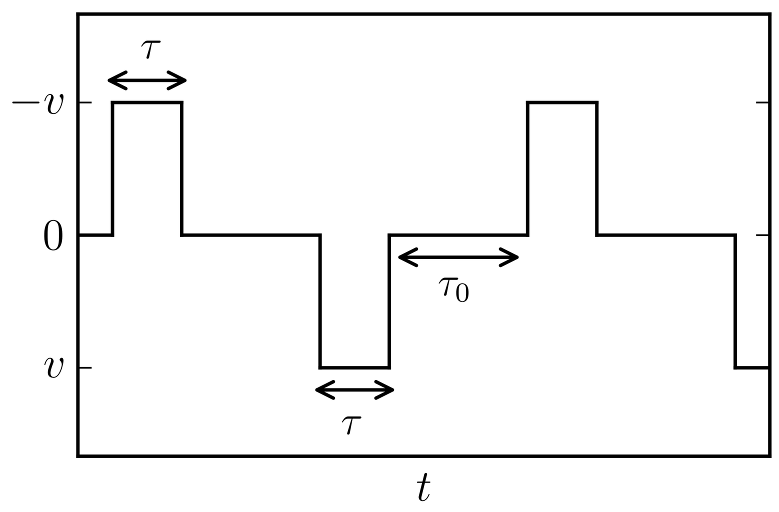
The tracer is trapped in a local mininum of the network potential:

$$\gamma\frac{d\mathbf{r}}{dt} = -k(\mathbf{r}-\mathbf{r}_0) + \sqrt{2T\gamma}\xi \ .$$

$$\frac{d\mathbf{r}_0}{dt} = \mathbf{v}_A$$

$\mathbf{v}_A$ stochastic active burst

- ξ isotropic Gaussian white noise,
- T bath temperature.



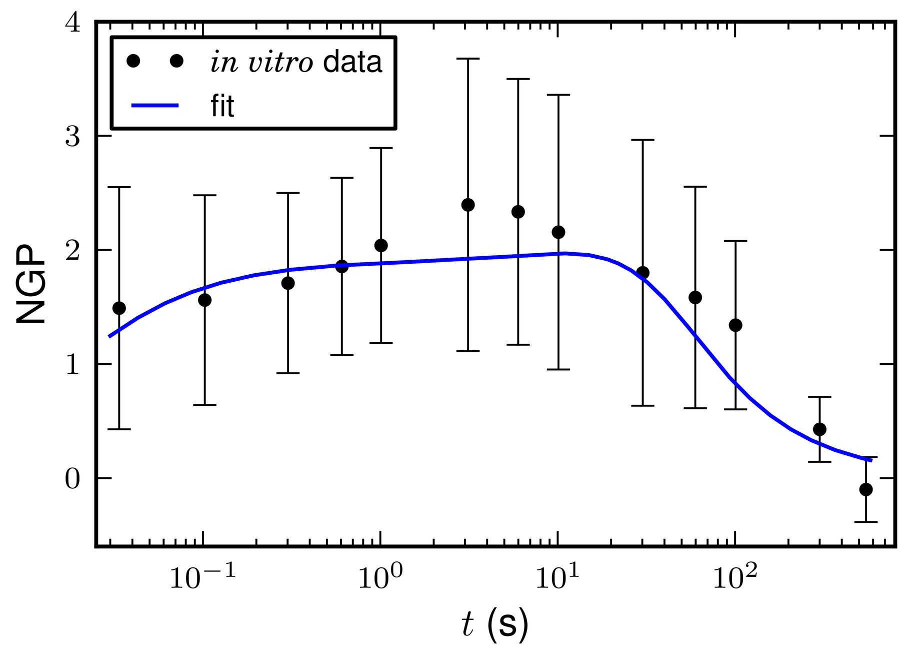
Motor activity induces local rearrangements of the actin network.

Passive case: no motor activity,
Active case: local rearrangements.

Compare predictions with experimental data
→ Extract information about motor activity

Non–Gaussian parameter

Tracers embedded in a reconstituted F–actin gel: Toyota *et al* [1].



$$\text{NGP} = \frac{\langle \Delta x^4\rangle}{3\langle \Delta x^2\rangle^2} - 1 \ .$$

Best fit parameters:

$v \simeq 3\,\mu$m/s, $\tau \simeq 8$ s, $\tau_0 \simeq 30$ s .

→ Active power value:

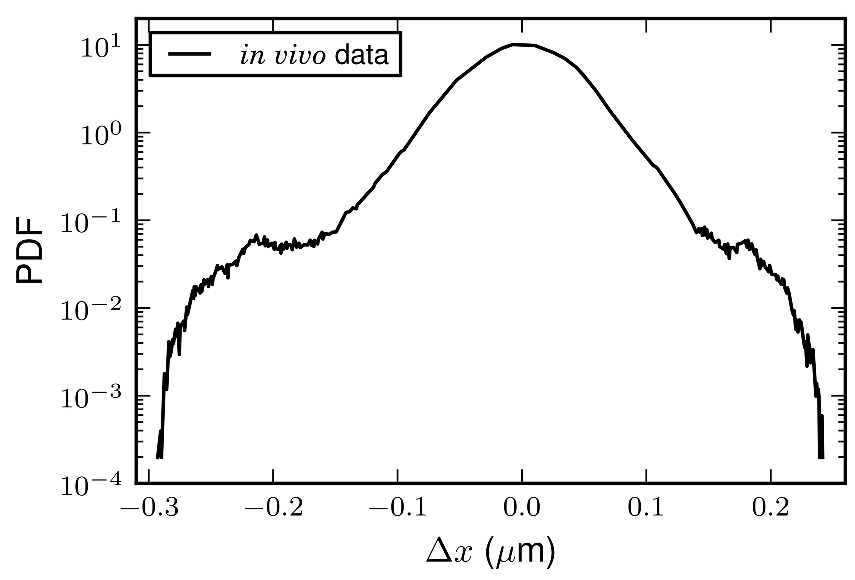
$$P_A = \frac{k_B T_A}{\tau+\tau_0} \simeq 50 P_{ATP} \ ,$$

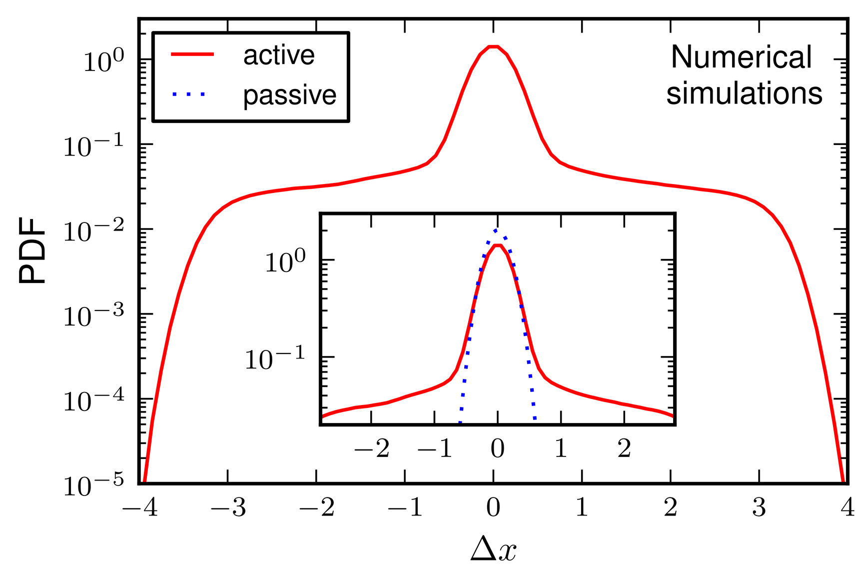
P_{ATP} released by ATP hydrolysis.

Consistent with the expected value: $P_A = NP_{ATP}$, $N \simeq 100$ motors near a tracer.

Probability distribution of displacement

Endogeneous vesicles inside mouse oocytes: BetzLab's measurements.

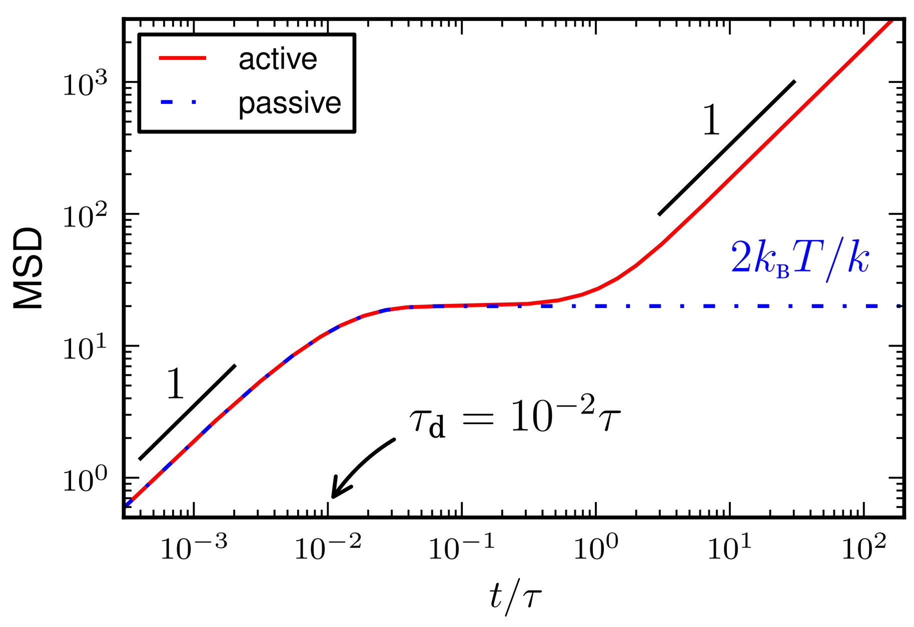




Central part: passive Gaussian → thermal fluctuations
Large Δx: Gaussian-like tails → active fluctuations

Exponential tails are a crossover between two Gaussian distributions.

Mean square displacement

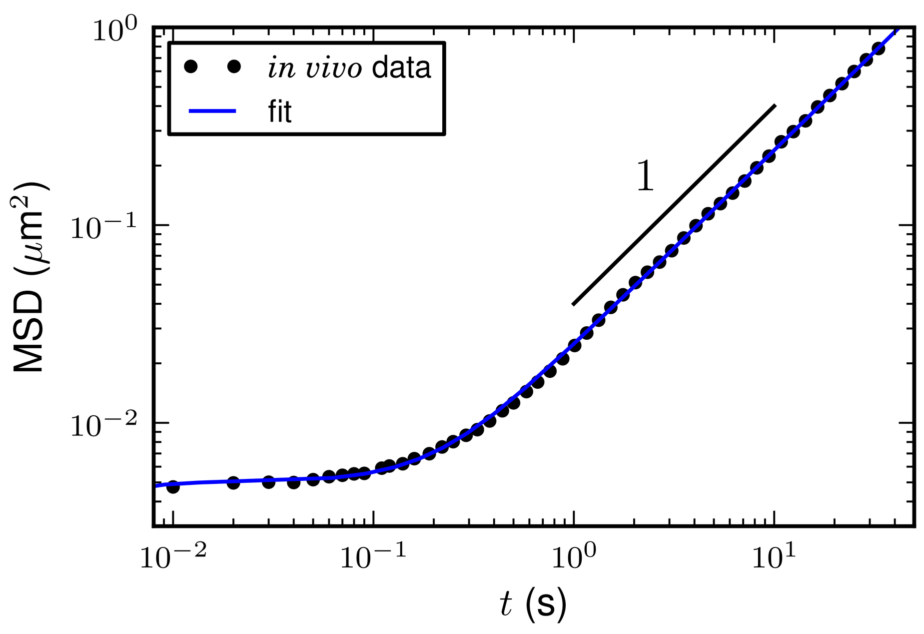


- Passive. The MSD saturates to an equilibrium value $2k_BT/k$ with a relaxation time $\tau_d = \gamma/k$.
- Active. When $\tau \gg \tau_d$, the MSD reaches the equilibrium plateau and then has a diffusive behaviour:

$$\text{MSD} \underset{t\gg\tau}{\sim} \frac{2k_BT_A}{\gamma}t = \frac{2(v\tau)^2}{3(\tau+\tau_0)}t \ .$$

$$\begin{cases} t \ll \tau_d & \text{thermal diffusion} \\ \tau_d < t < \tau & \text{crossover regime} \\ \tau \ll t & \text{active diffusion} \end{cases}$$

Active bursts enable the tracer to visit a large volume via the displacement of $\mathbf{r}_0$.



Microinjected PEG–coated tracers in living A7 cells: WeitzLab's measurements.

Best fit parameters:

$v \simeq 1\,\mu$m/s, $\tau \simeq 0.2$ s, $\tau_0 \simeq 0.5$ s .

→ Active temperature value:

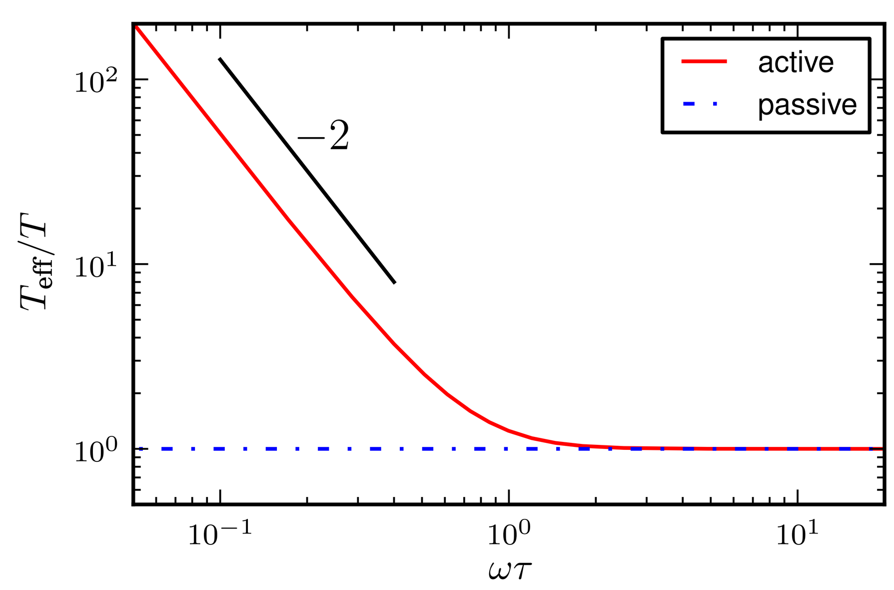
$T_A \simeq T/100$.

Microrheology

Autocorrelation function C: tracking,
Response function χ: microrheology.

$$\rightarrow \quad T_{\text{eff}}(\omega) = -\frac{\omega\tilde{C}(\omega)}{2k_B\tilde{\chi}''(\omega)}$$

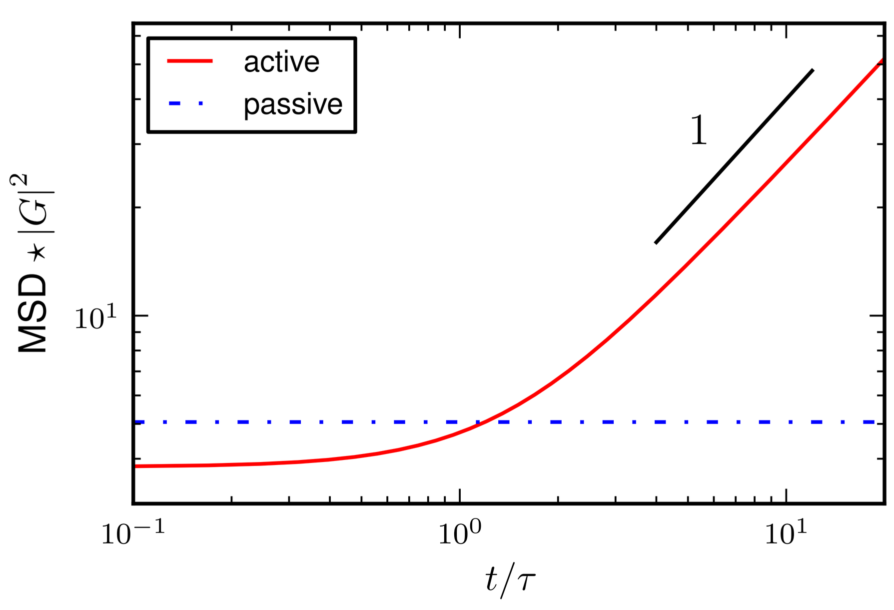
Spectrum of all the forces acting on the particle: $S(\omega) \propto T_{\text{eff}}(\omega)$.



$$T_{\text{eff}}(\omega) = T + \frac{1}{(\omega\tau_d)^2}\frac{T_A}{1+(\omega\tau)^2} \ .$$

- $T_{\text{eff}} \underset{\omega\tau\gg1}{\longrightarrow} T$: thermal fluctuations are predominant.
- $T_{\text{eff}} \underset{\omega\tau\ll1}{\sim} T_A/(\omega\tau_d)^2$: the power law behaviour agrees with experiments.

The force spectrum at low frequency is given by the active bursts' statistics.



Force spectrum in the time domain: MSD $\star\,|G|^2$, shear modulus G.

- Passive. MSD $\star\,|G|^2 \propto k_BTk/R^2$, radius of the tracers R.
- Active. Linear growth:

$$\text{MSD}\star|G|^2 \underset{t\gg\tau}{\sim} \frac{2k_BT_A}{\gamma}\left(\frac{k}{R}\right)^2 t \ .$$

Conclusion

- Agreement with known experimental results: short time scale confinement, large time scale free diffusion, and crossover regime with a PDF broader than Gaussian.
- Access to the basic features of molecular motor activity: **typical times of activity**, **power injected by the motors**, and **amplitude of active fluctuations**.

[1] T. Toyota, D. A. Head, C. F. Schmidt, and D. Mizuno, Soft Matter **7**, 3234 (2011)

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