Energy Dissipation in Adaptive Molecular Circuits

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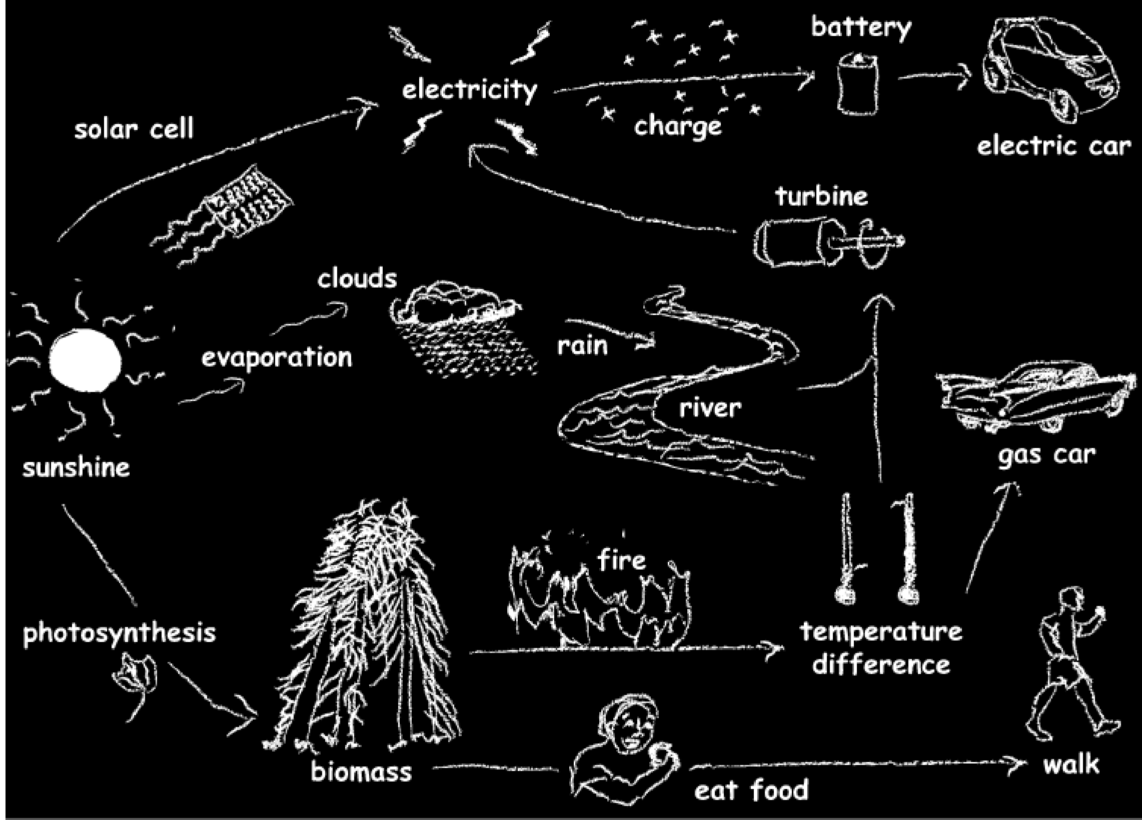
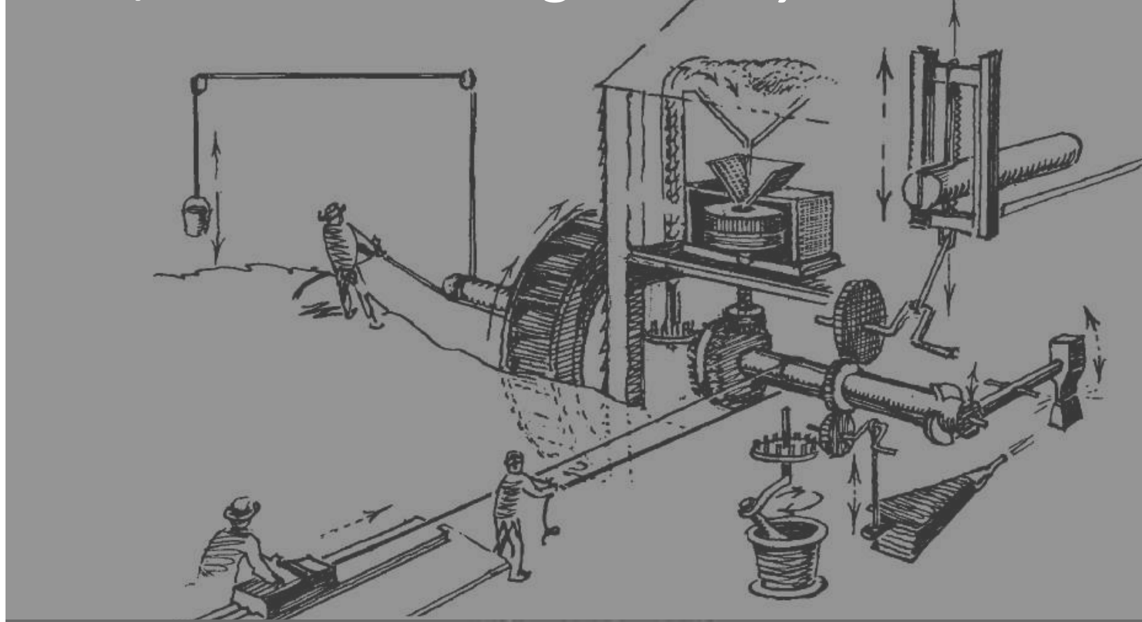
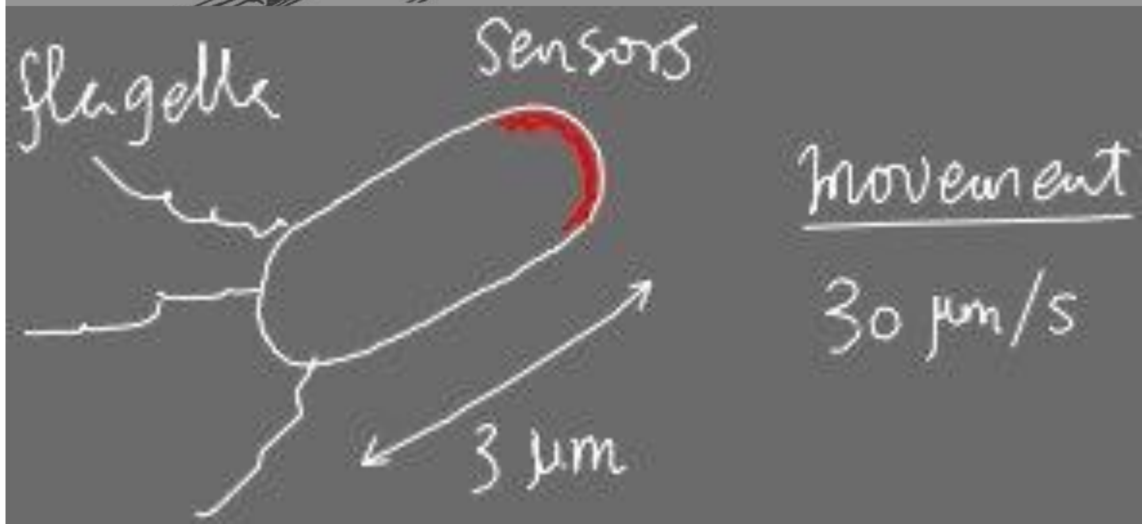


Philip Nelson: *Biological Physics*, 2004





Shou-Wen Wang, et.al., J. Stat. Mech. Theo. Exp., P07025(2015)

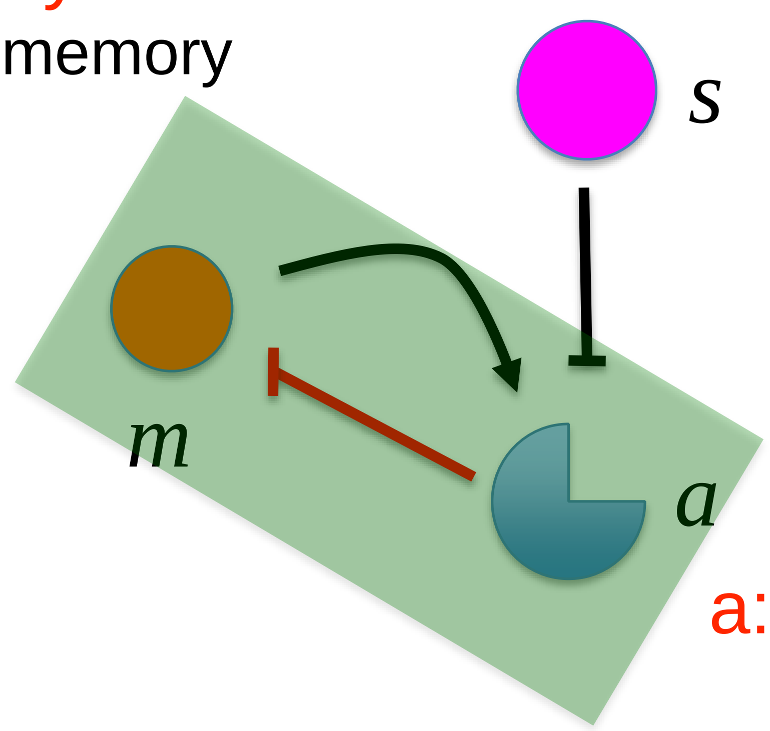
Outline

- Model introduction: sensory adaptation
- Relation between **dissipation** and **adaptation**
- Correlation and respose spectrum

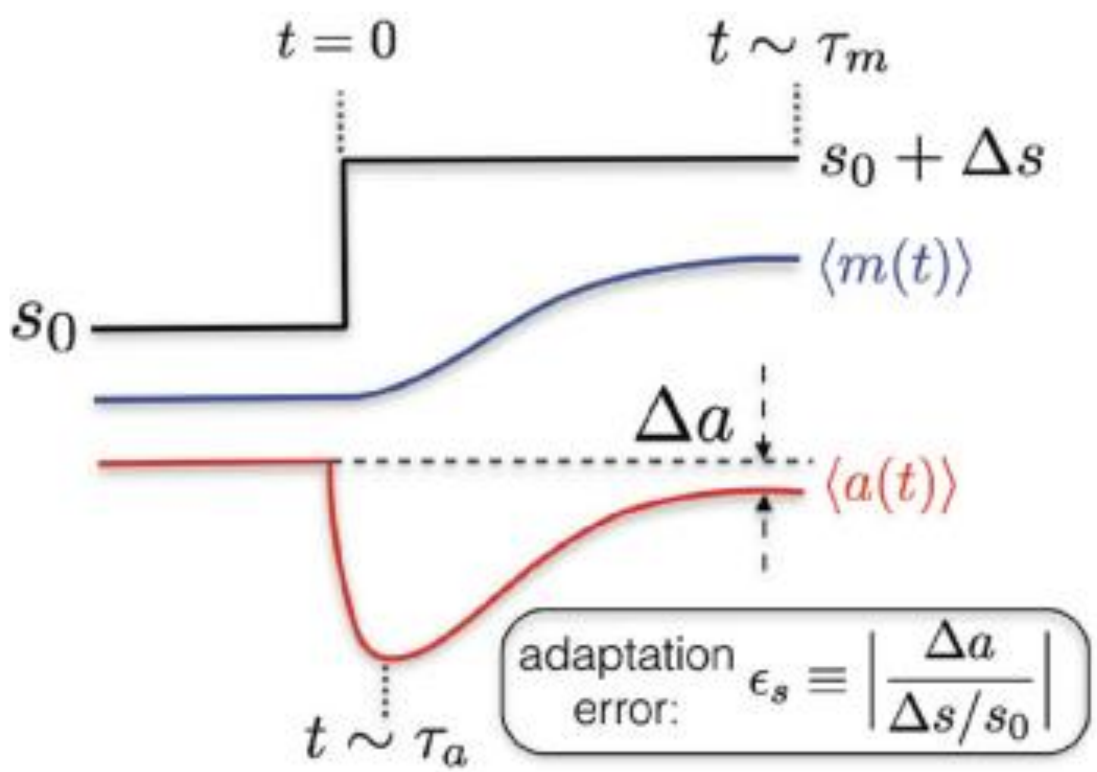
Sensory Adaptation in E.coli

m: methylation
internal memory

signal level: s



a: activity

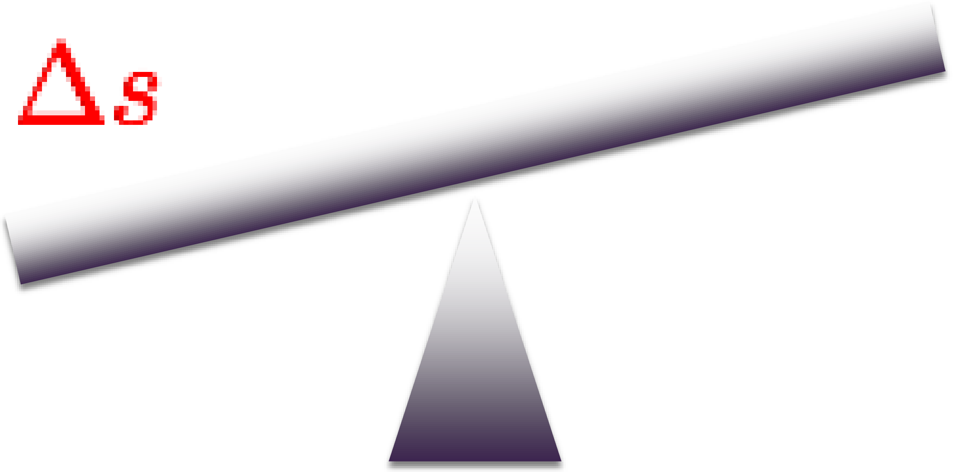


Sensitive tracking at the **short time** scale
Senory Adaptation at the **long time** scale

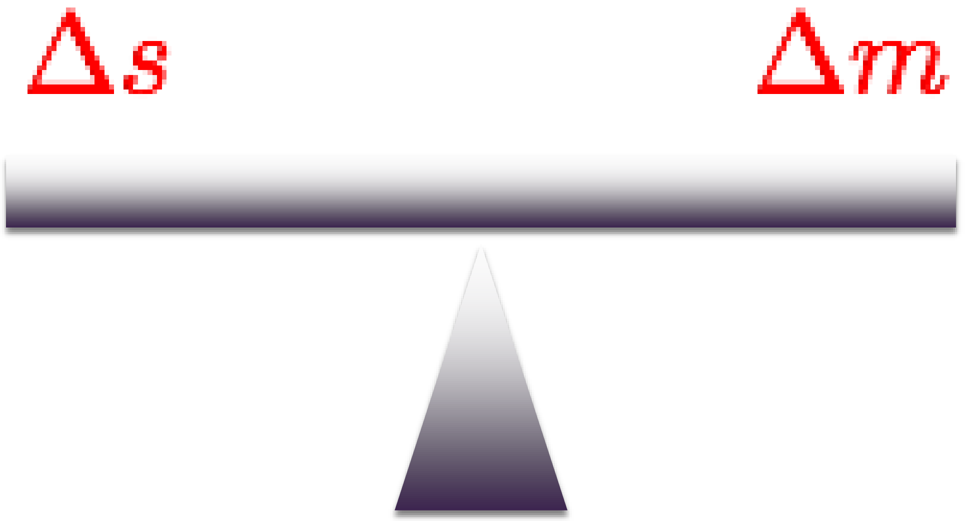
Yuhai Tu, *Annu Rev Biophys* **42**:337-59 (2013)

Adaptation as seesaw balance

Adaptation as seesaw balance

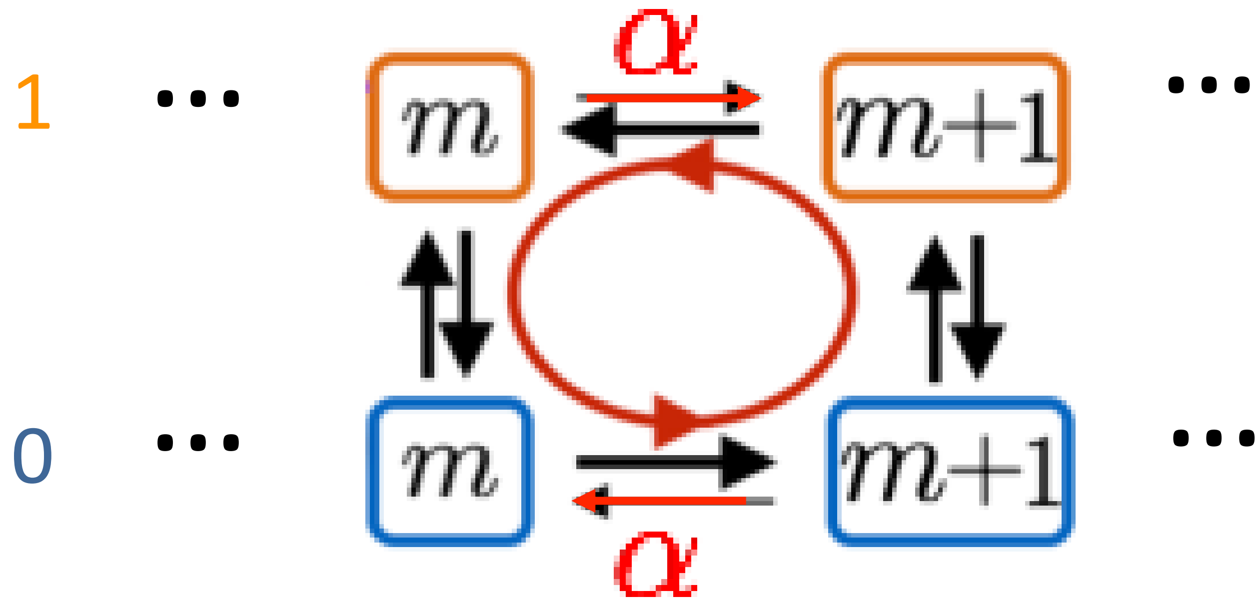


Adaptation as seesaw balance



The Lan *et al.* model

Markov model in phase space **(a,m)**



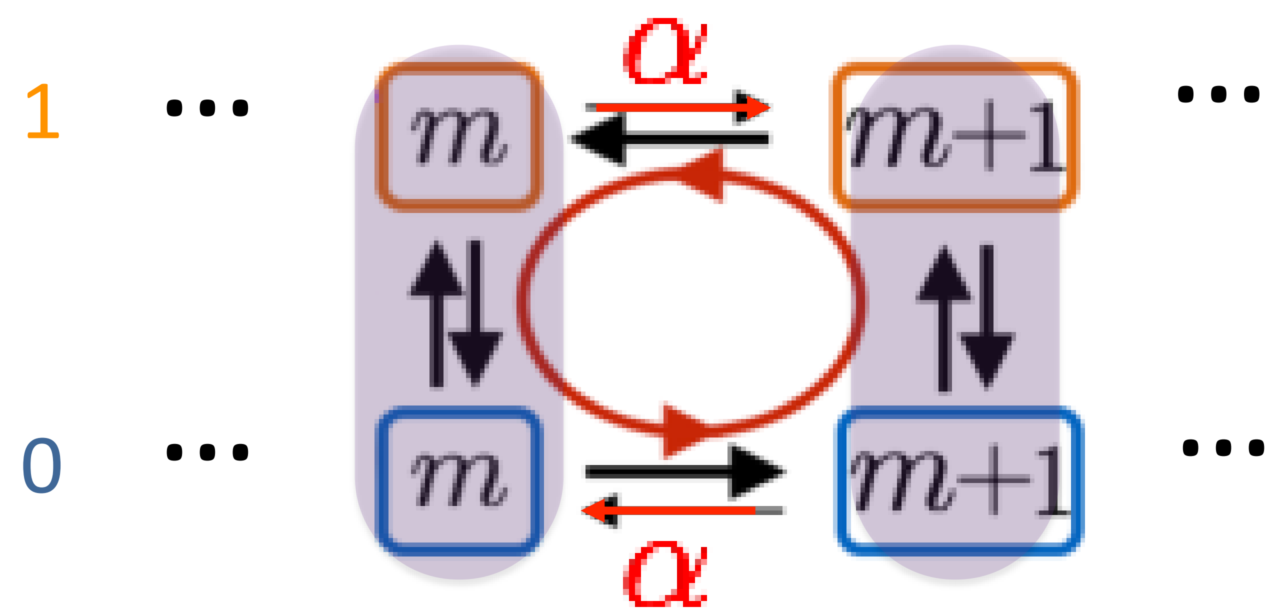
$$0 \le m \le m_0$$

Lan et al., *Nature Physics* 2012, **8**:422

Main Question

Adaptation requries dissipation?

Strategy for solving the model

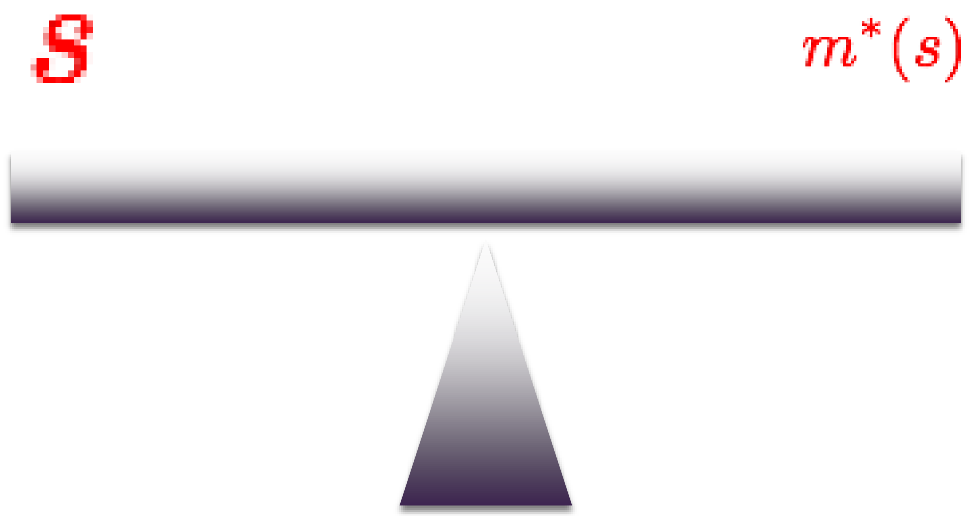


Step 1: **Coarse-graining** fast activity *a*

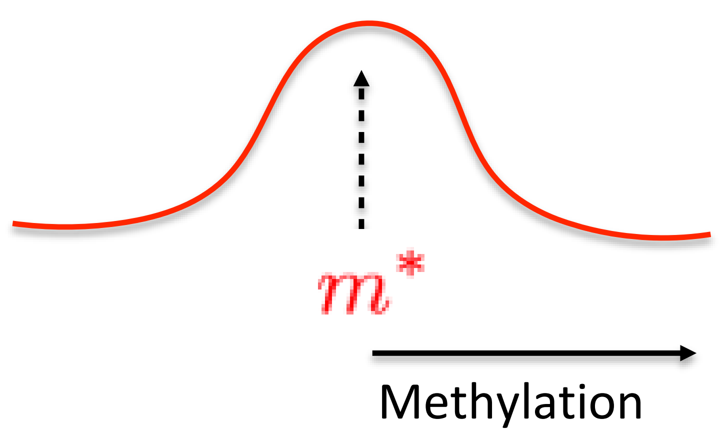
Step 2: **Continuum limit (m),** Fokker-Planck equation

Step 3: Obtain **effective potential** *U(m)*

Non-equilibibirum phase transition

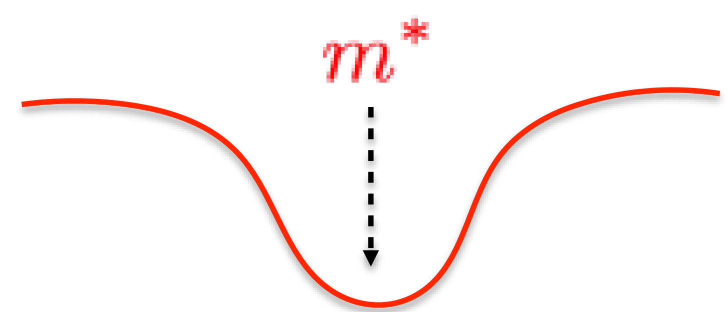


wrong m: fail to adapt



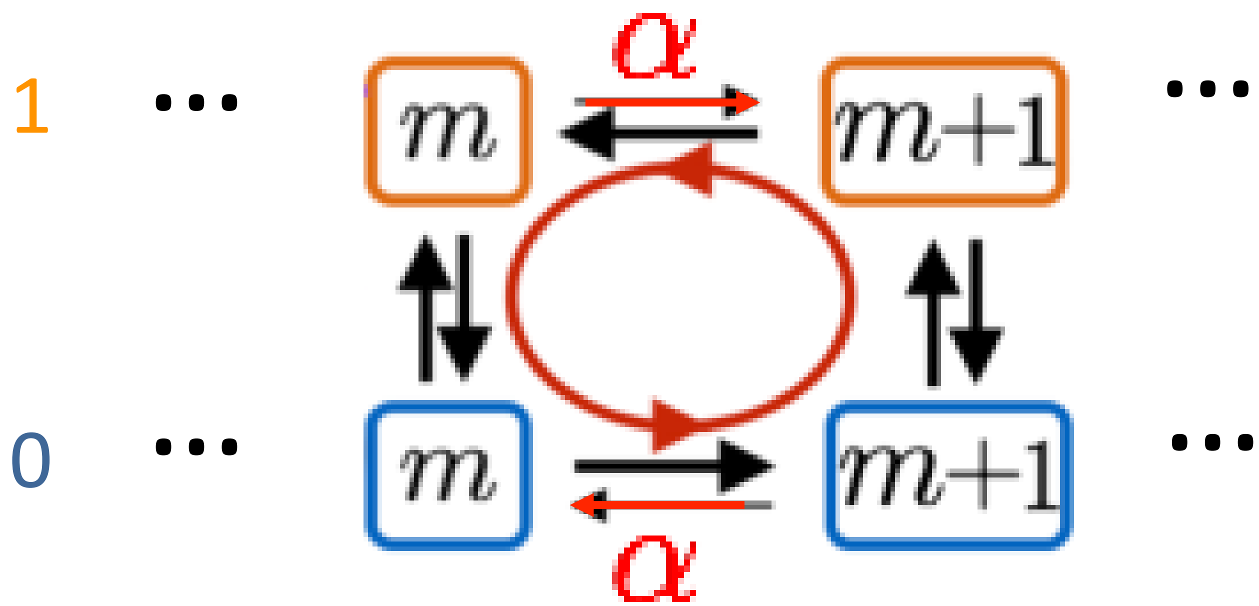
$\alpha \geq 1$ (close to EQ)

Correct m: succeed to adapt



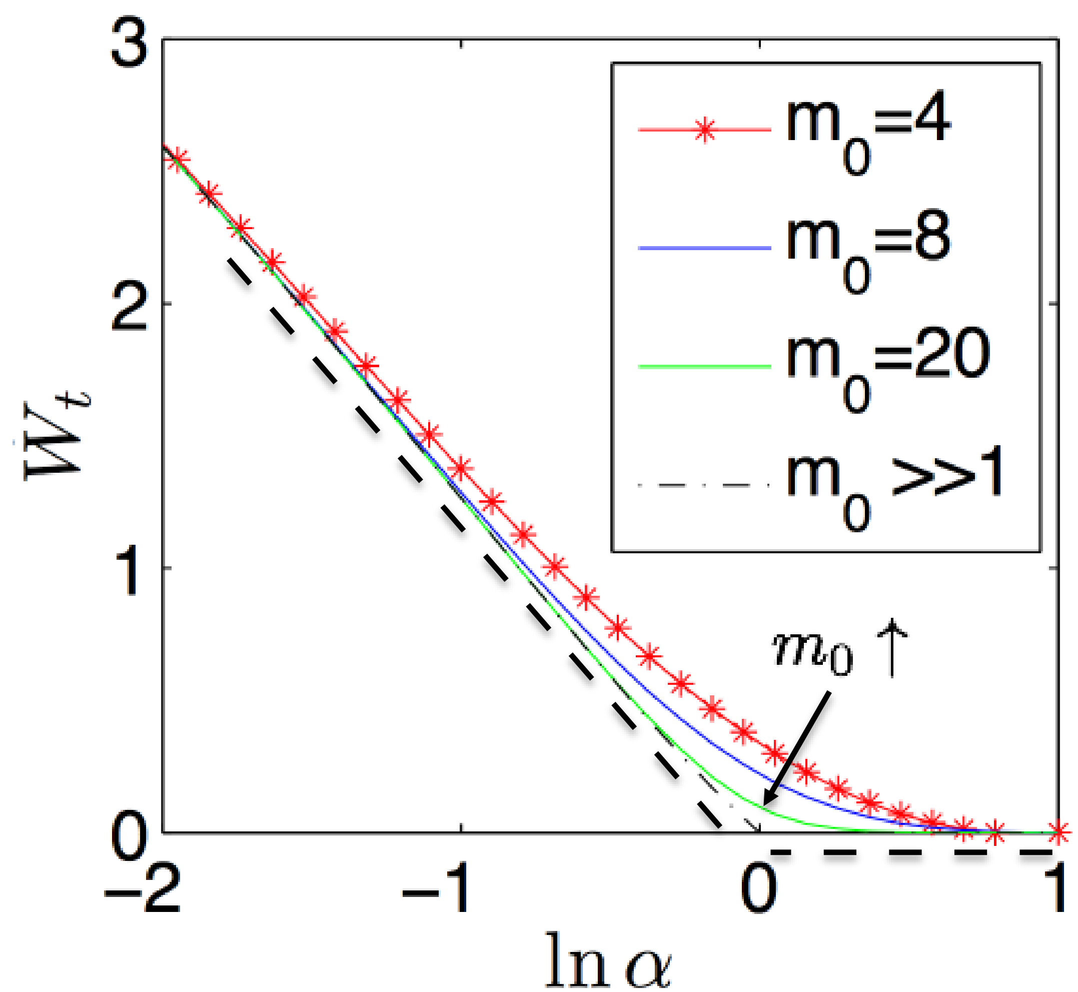
$\alpha < 1$ (far from EQ)

Energy dissipation rate

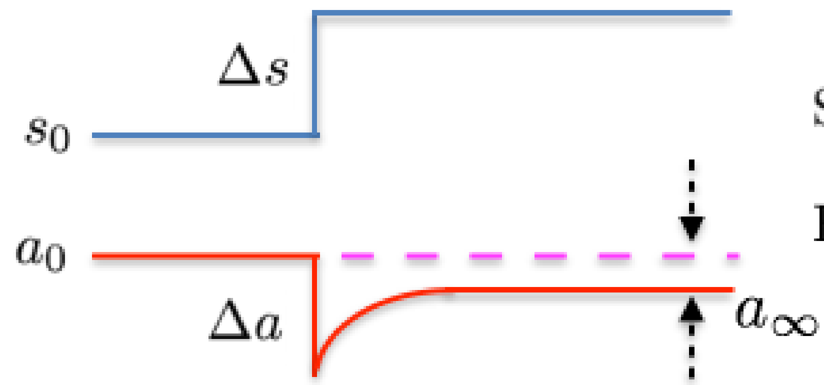


$$0 \le m \le m_0$$

$$\dot{W} = \sum J_c \Delta\mu$$

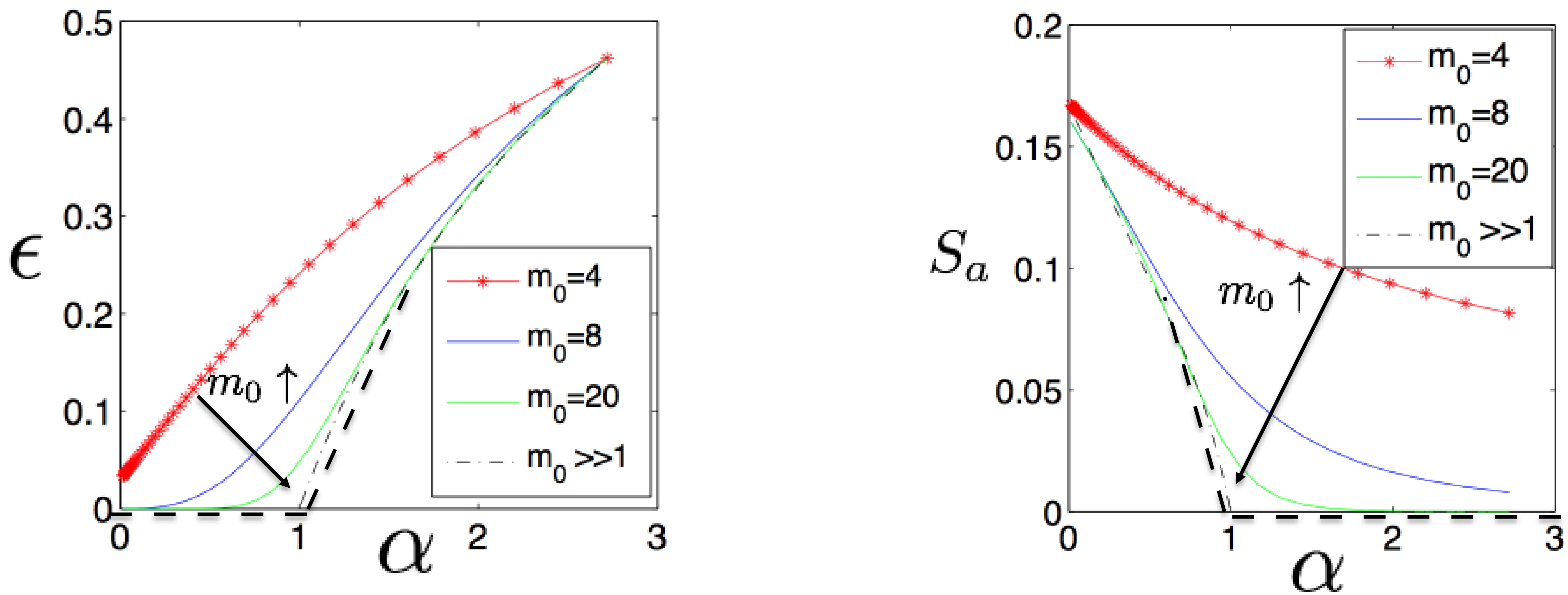


Methylation range reduce both error and sensitivity



Sensitivity: $S_a = \frac{\Delta a}{\Delta s / s_0}$

Error: $\epsilon = |a_\infty - a_0| / a_0$

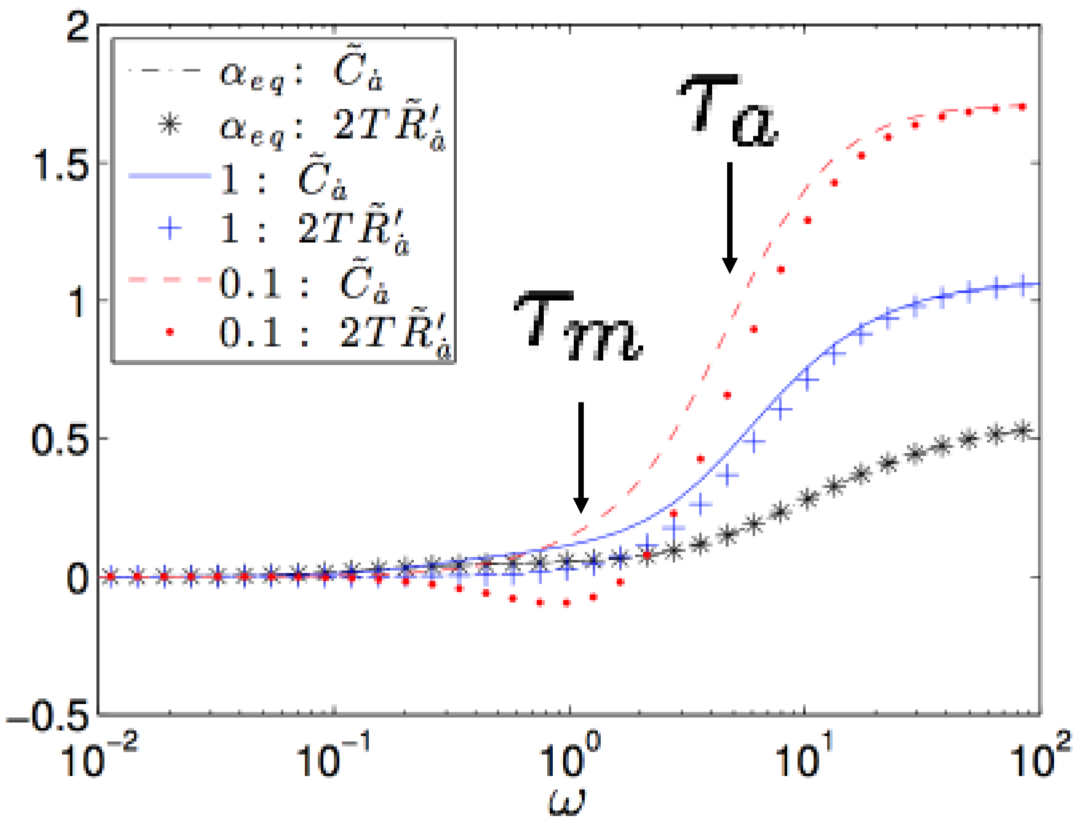


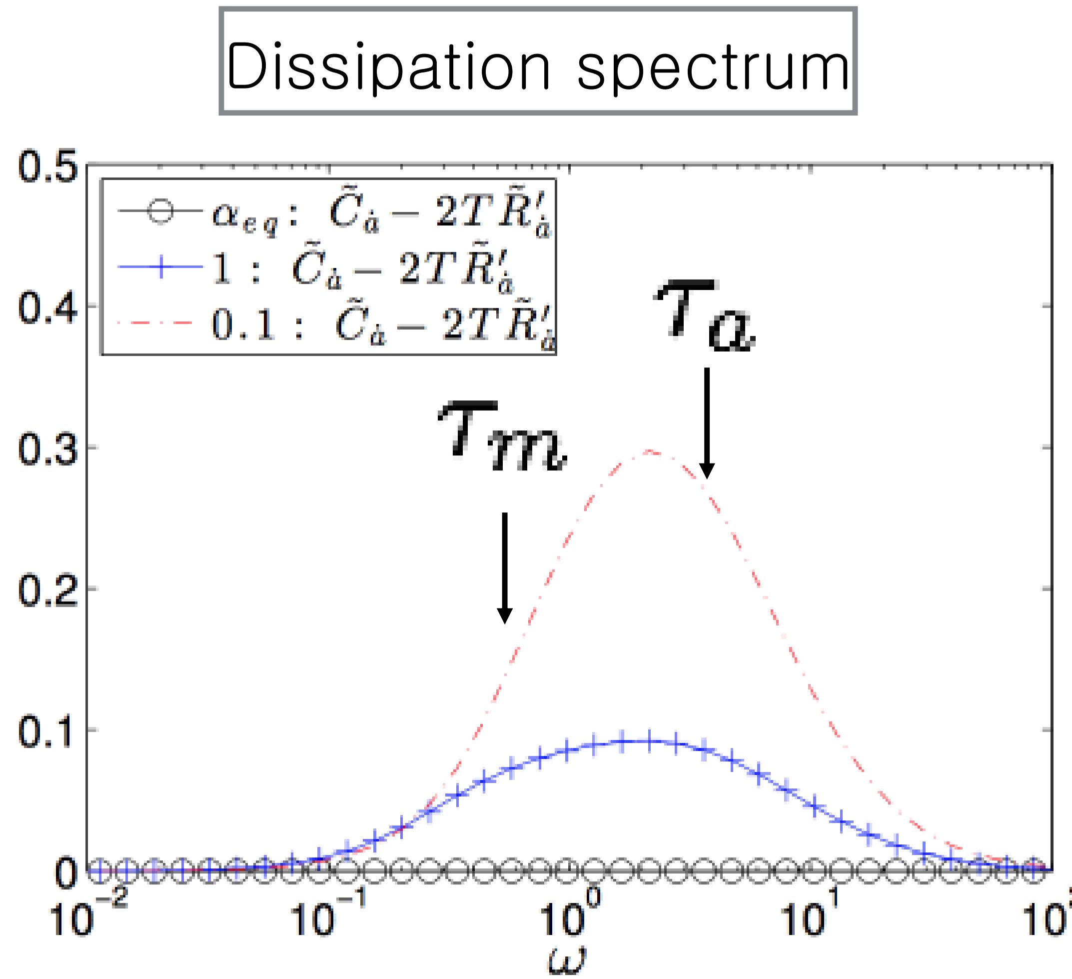
$m_0 \to \infty$: dissipation for higher sensitivity

finite: trade-off between energy, error, and sensitivity

Correlation, Response spectrum and Harada-Sasa equality

observable : $\dot{a}$

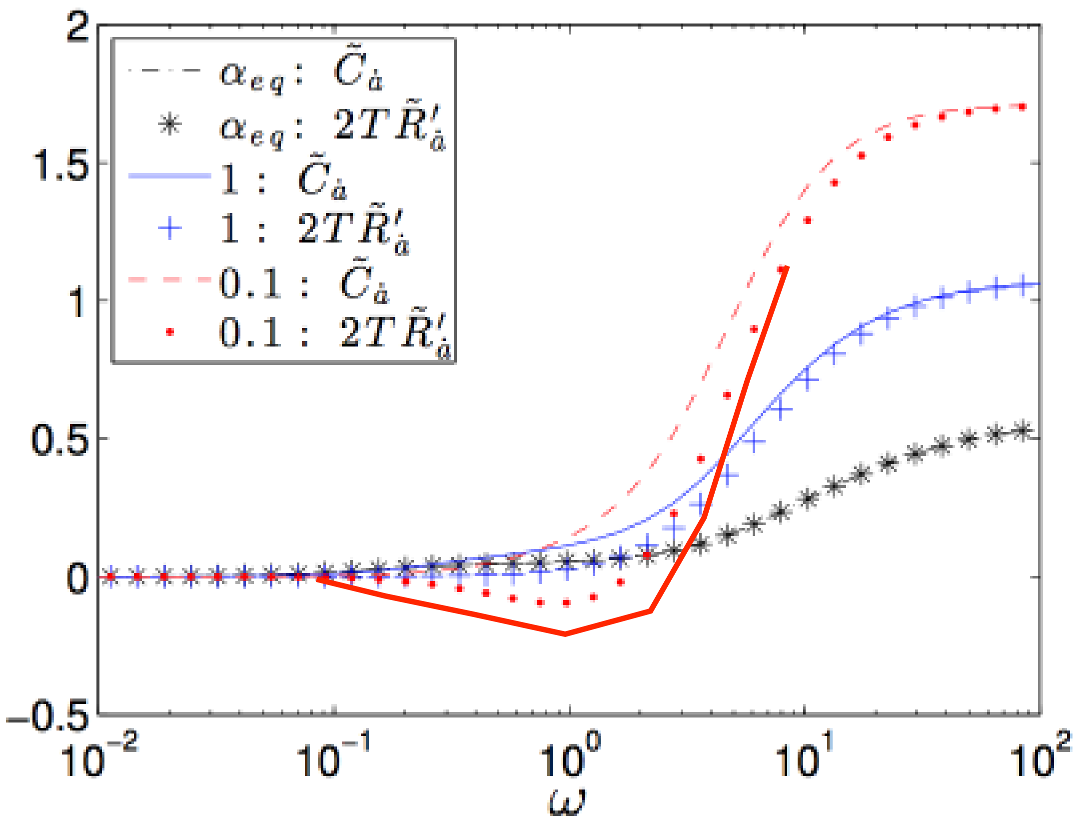




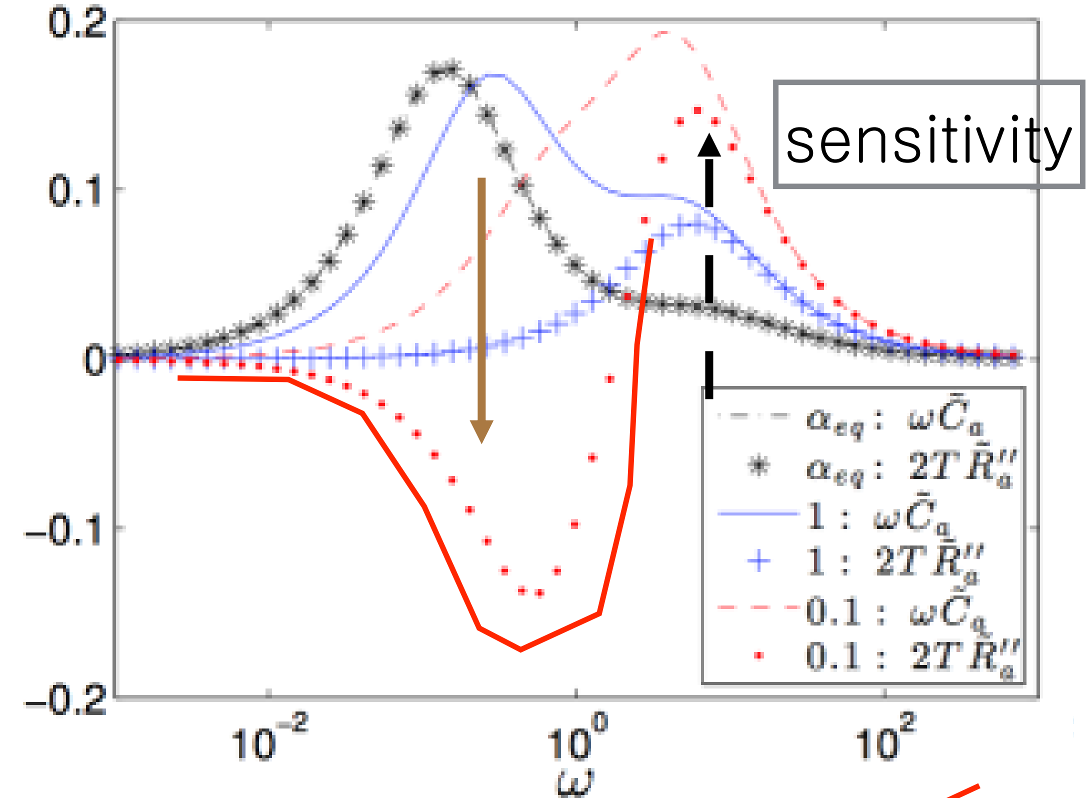
Harada–Sasa equality $W_a = \gamma_a \int_{-\infty}^{\infty} (\tilde{C}_{\dot{a}} - 2T\tilde{R}_{\dot{a}}) \frac{d\omega}{2\pi}$

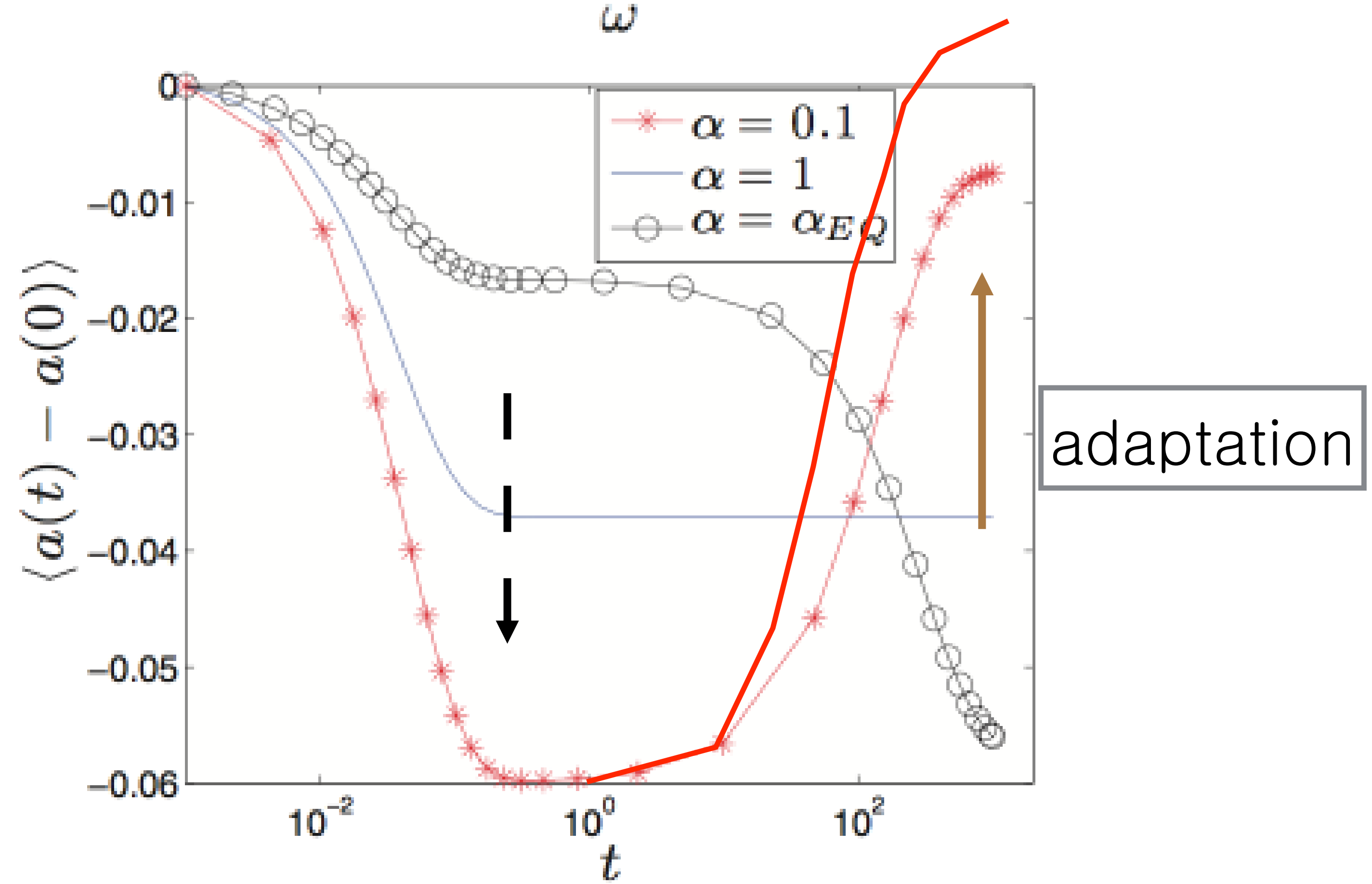
Dissipation spreads in the intermediate frequency window

observable : $\dot{a}$



observable : a





Dissipation is necessary for adaptation due to overshoot

Proposal: More overshoot takes more dissiaption by *a*

Conclusion

Non-equilibrium phase-transition at $\alpha=1$

Trade-off between: cost, error and sensitivity
(methylation range matters)

View from Harada-Sasa equality

- Dissipation spectrum
- Dissipation due to overshoot

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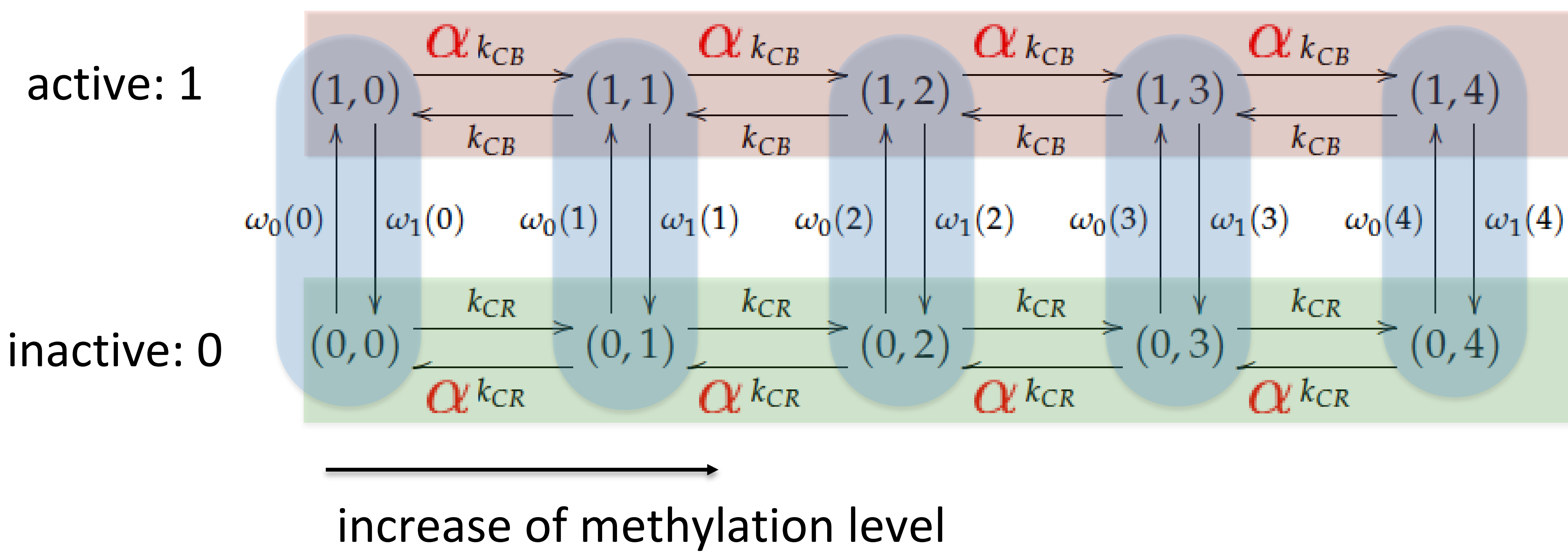

Lan et al., *Nature Physics* 2012, **8**:422