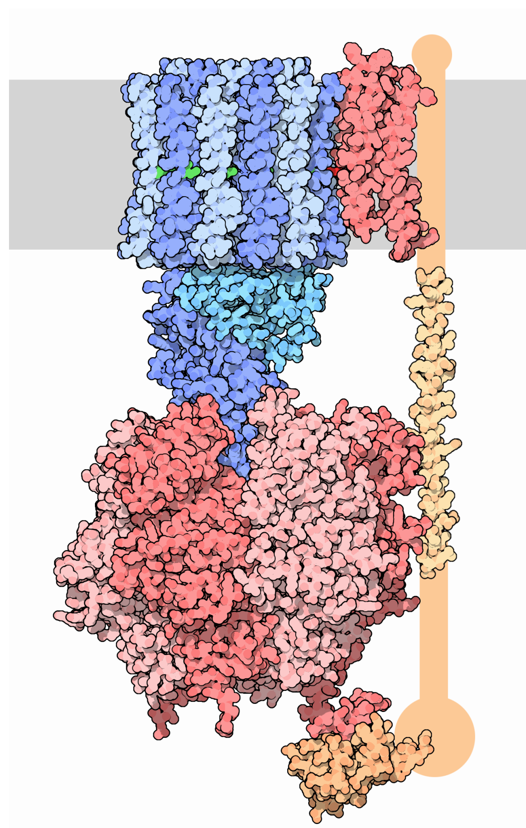
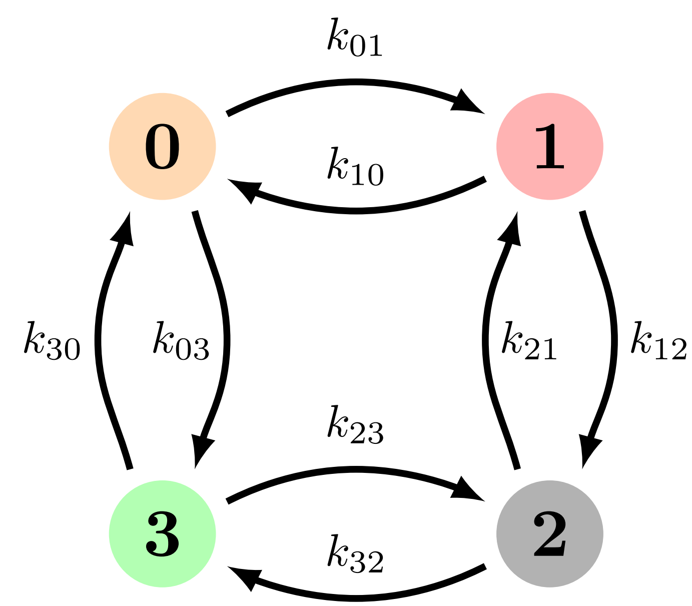
Molecular machinery

Quantifying the energetic cost of controlling nanoscale biological systems





CAP Congress 2019

Steven Large

Department of Physics, Simon Fraser University

Introduction

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- Biophysics: study of biological systems

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- Biophysics: study of biological systems (by physicists)

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- Biophysics: study of biological systems (by physicists) *Quantitative modelling*

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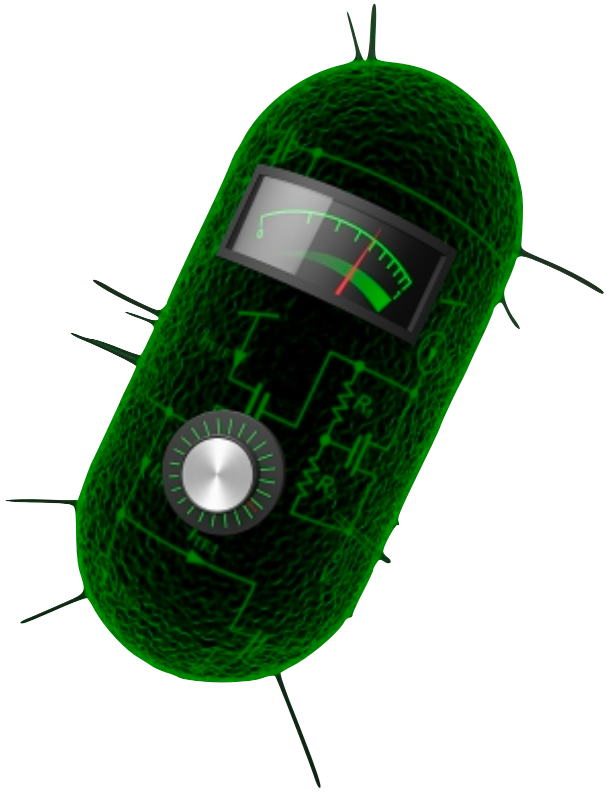

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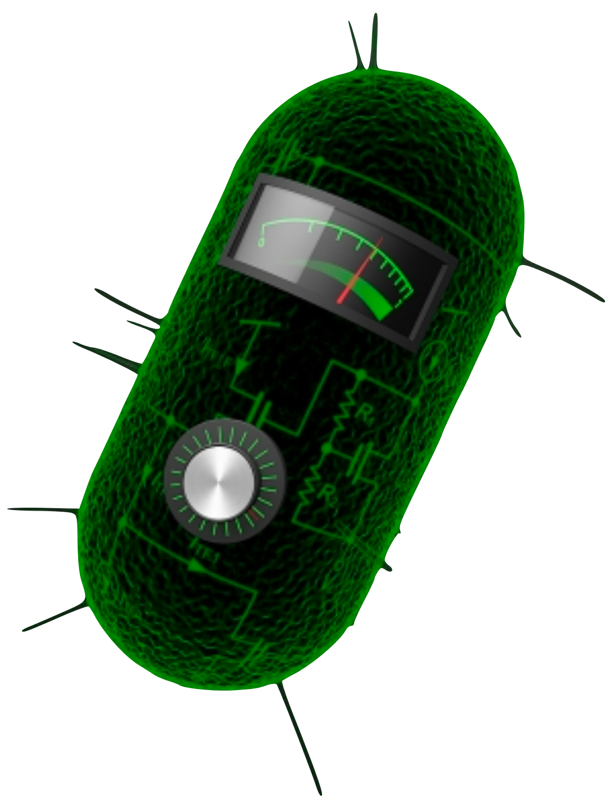
"Nonequilibrium boundary conditions"



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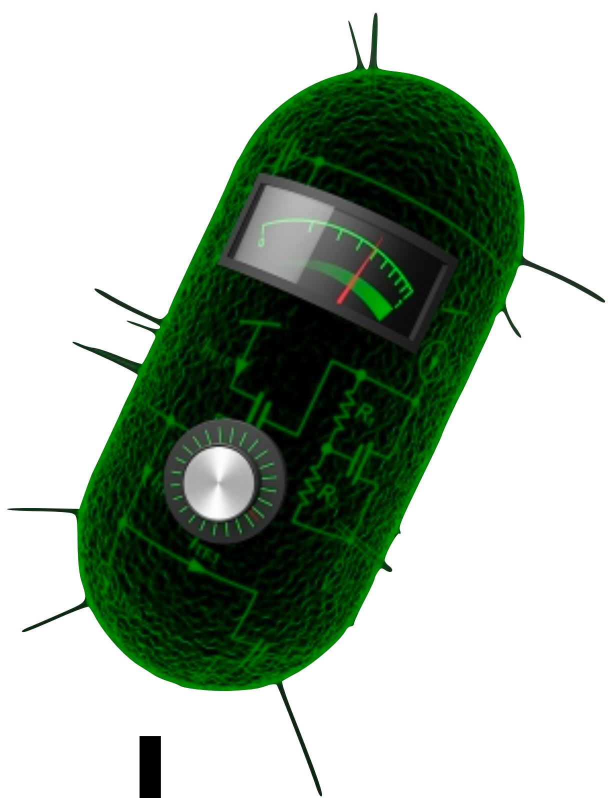

Entropy production

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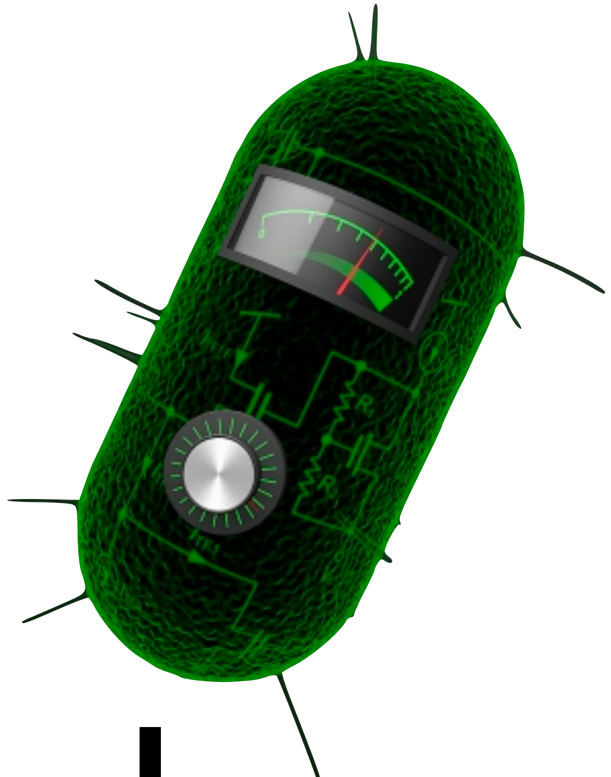

Life

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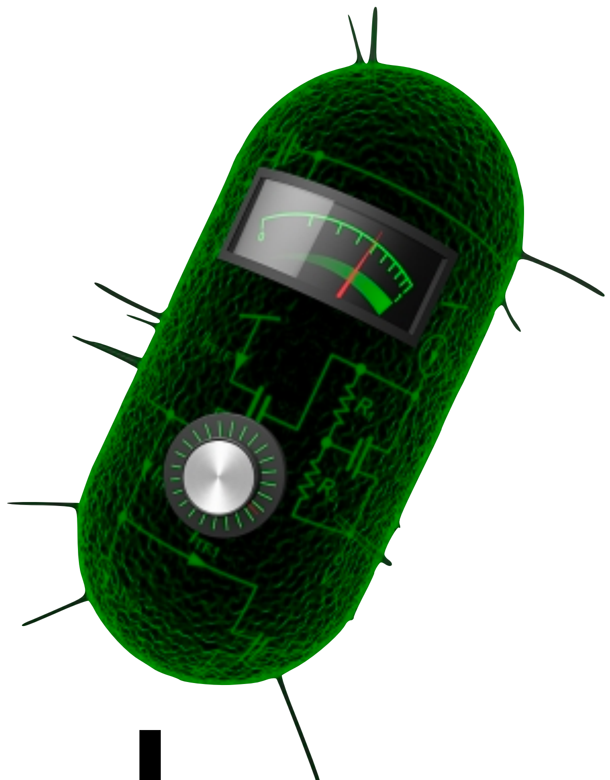

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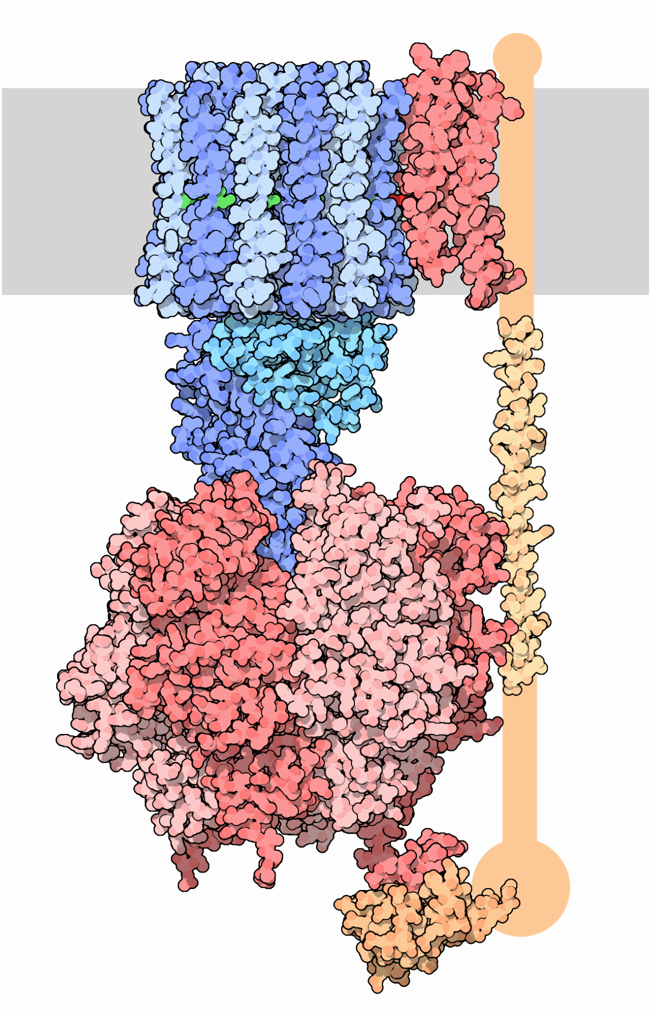

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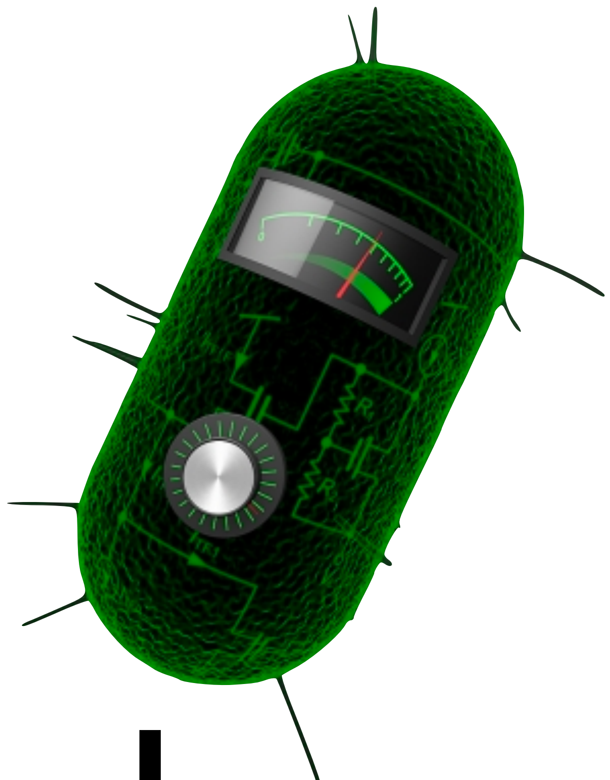

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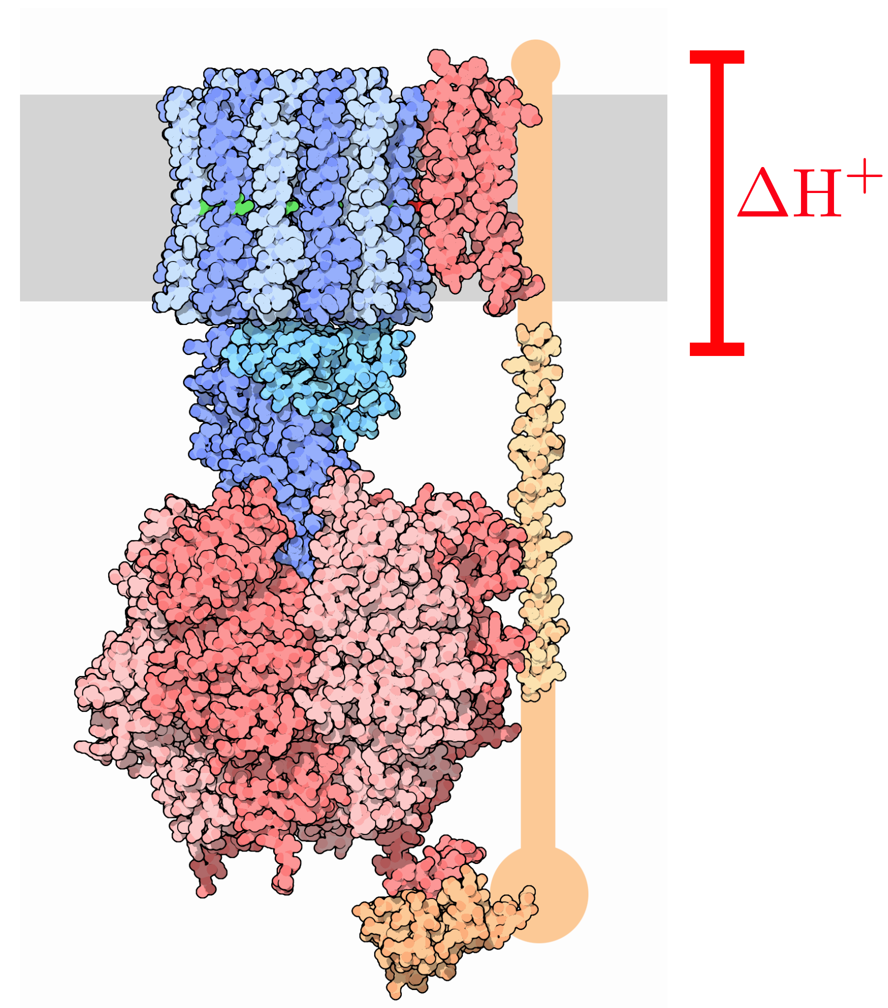

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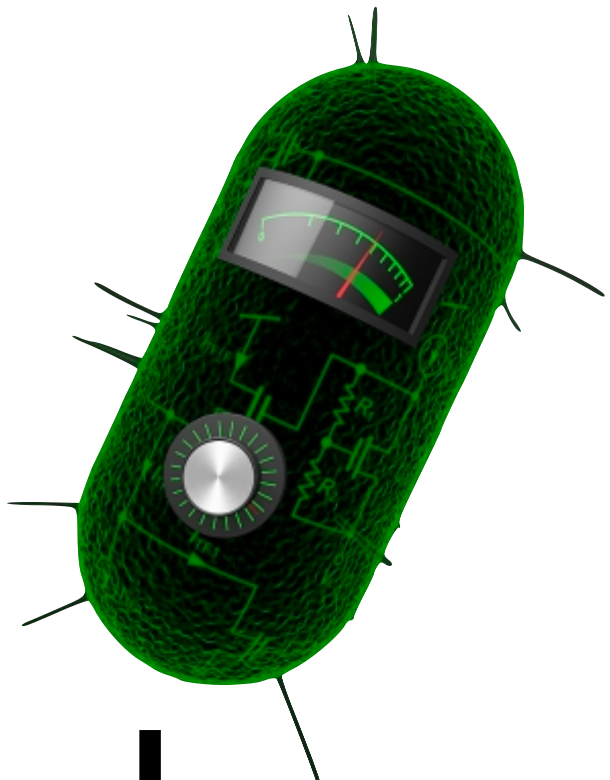

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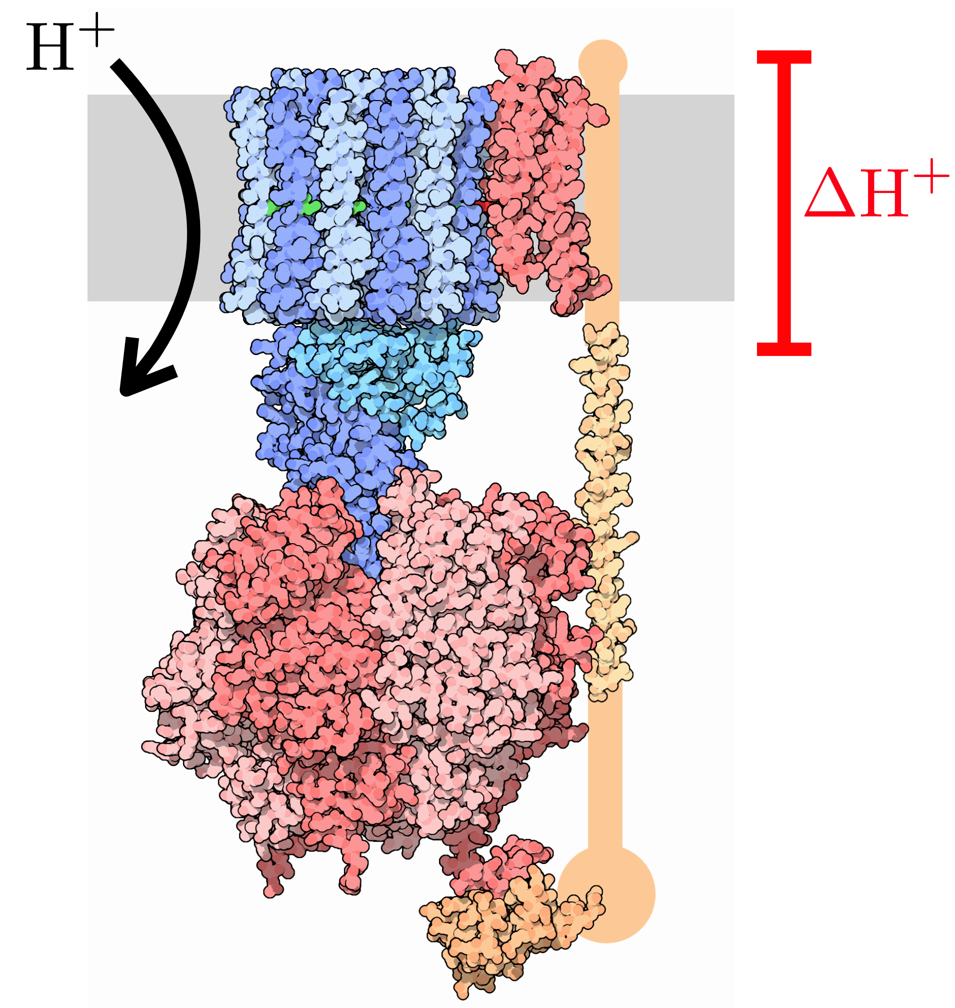

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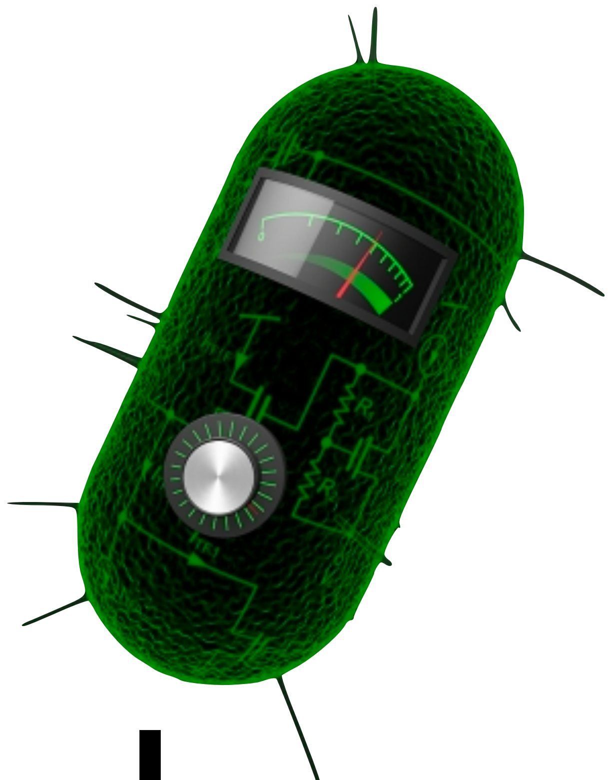

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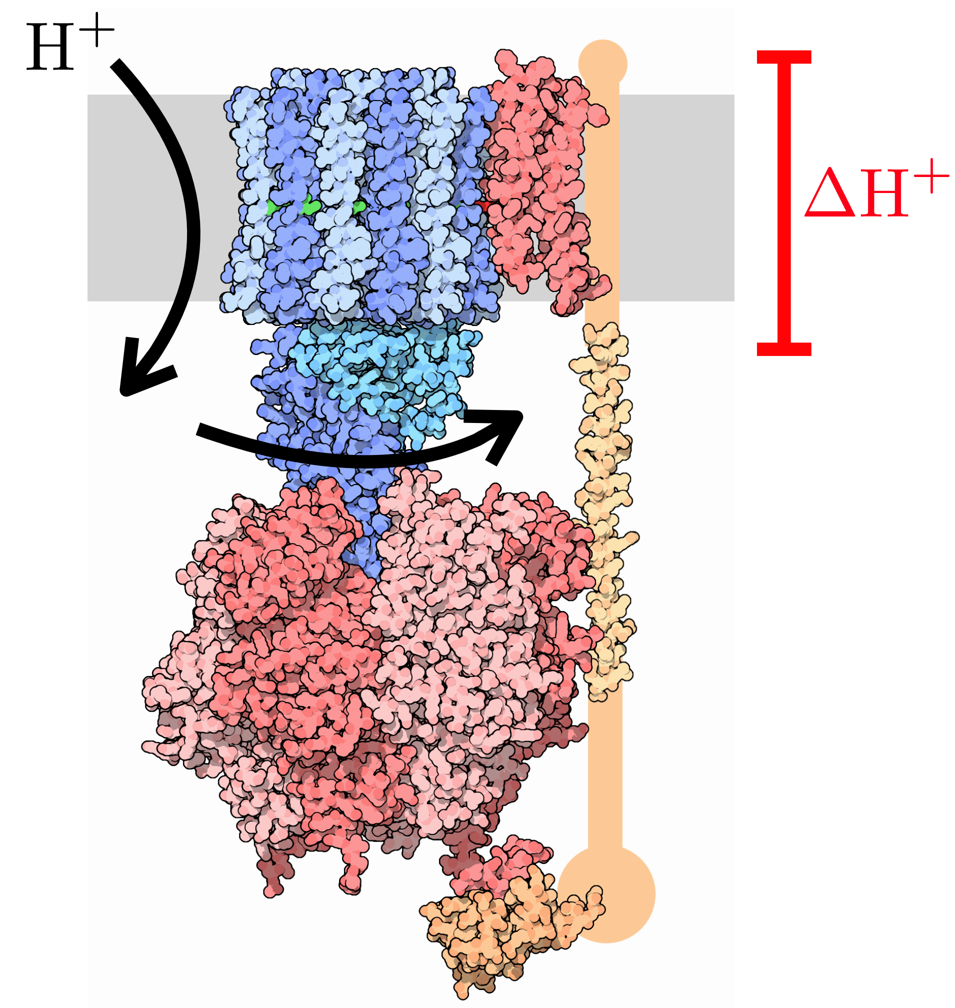

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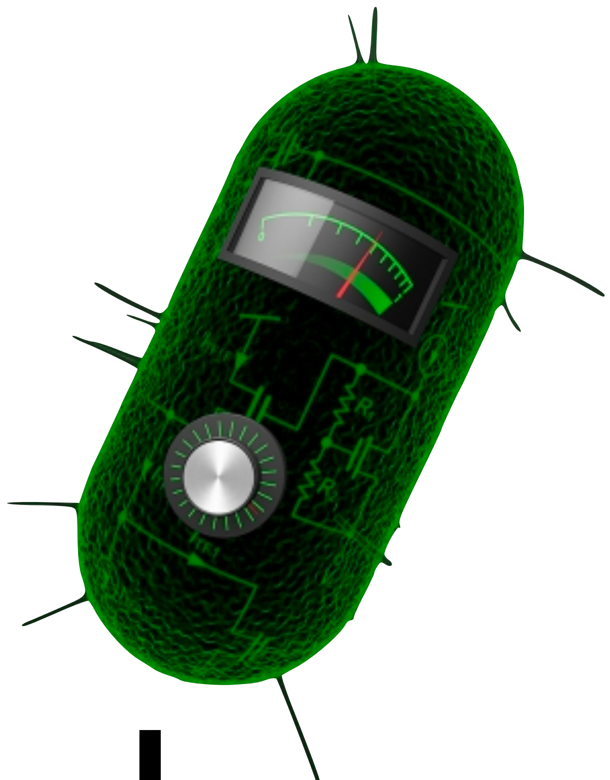

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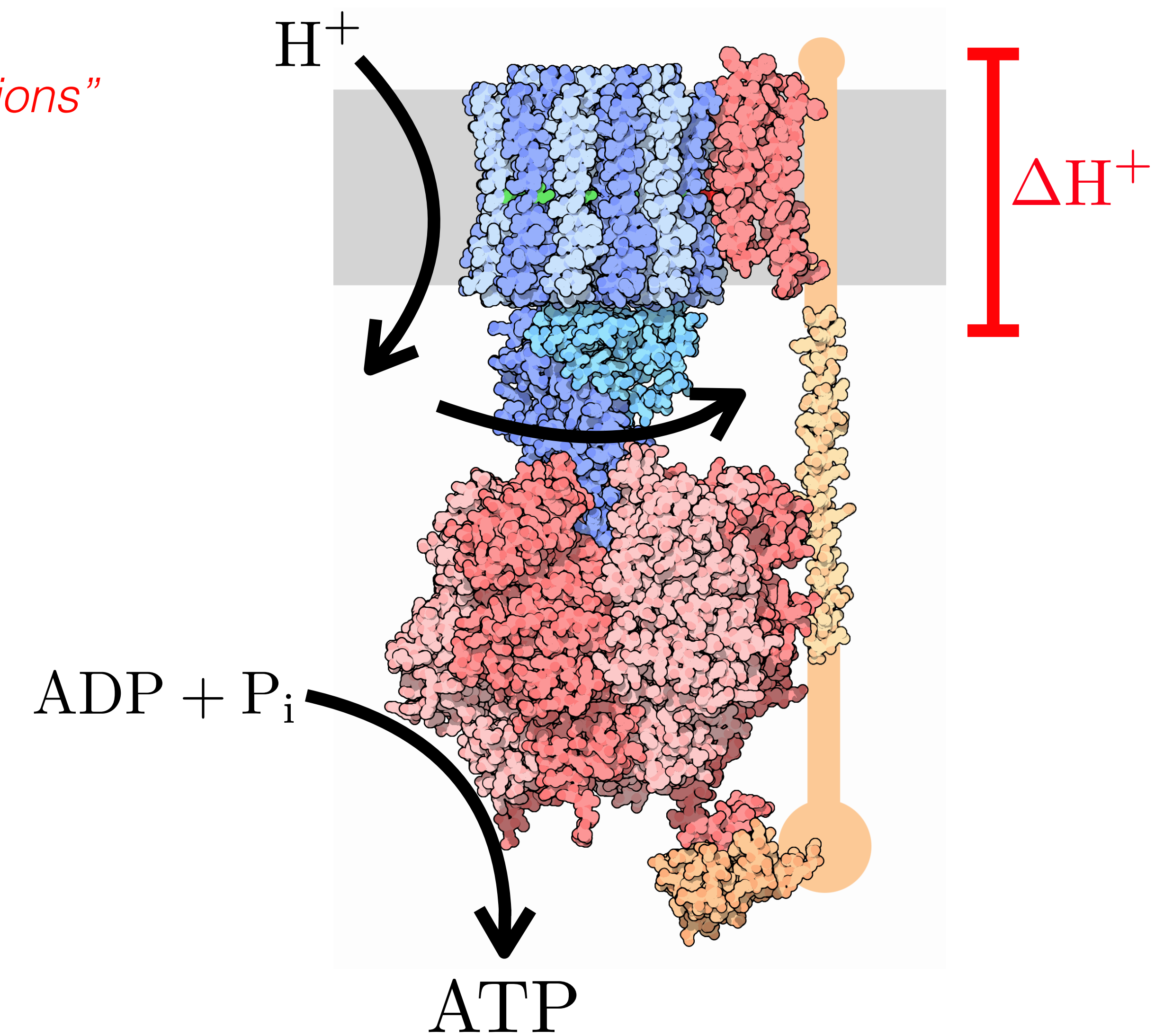

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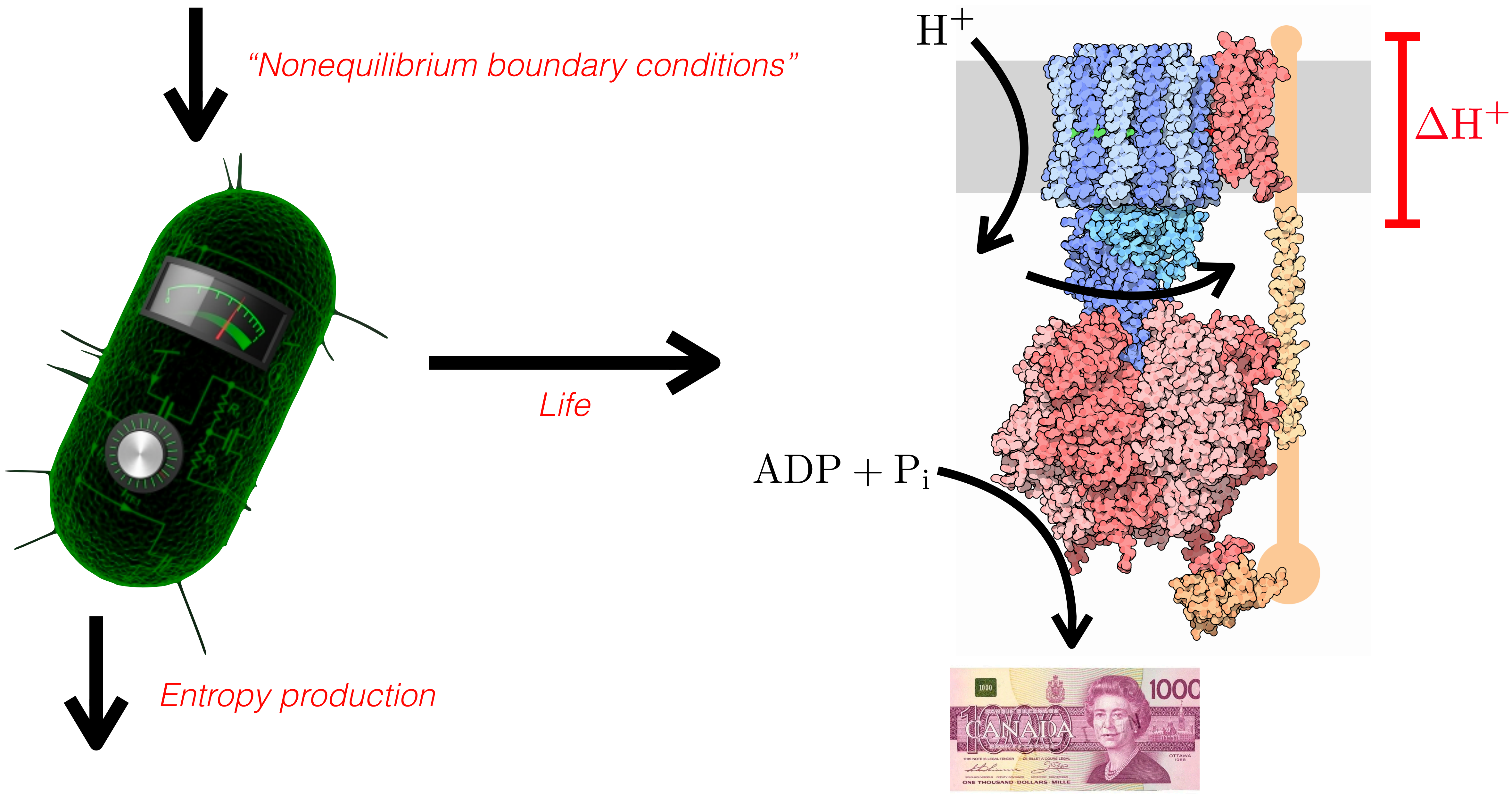

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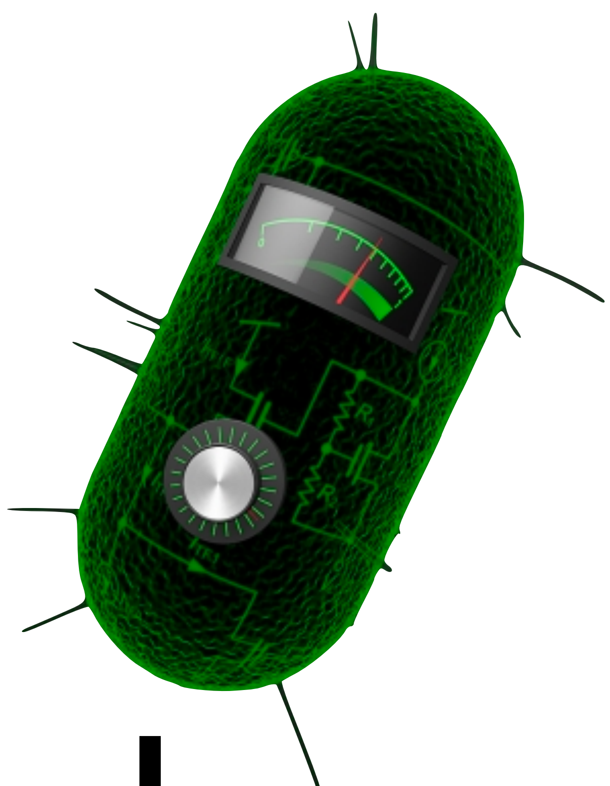

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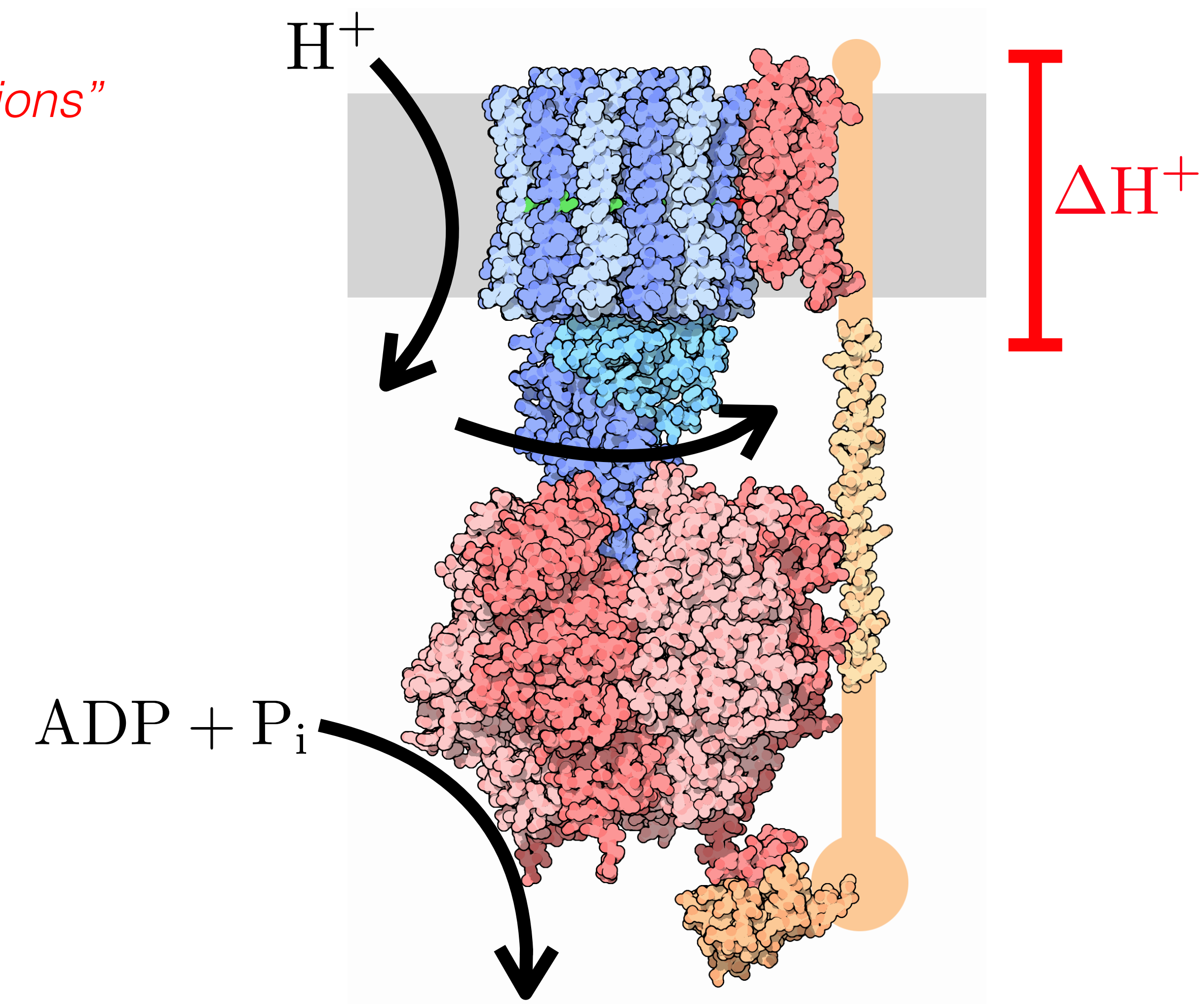

Entropy production

- Quantifying flows of **energy** (and other things) in nanoscale systems is a central challenge to understanding microscopic physics of biological systems

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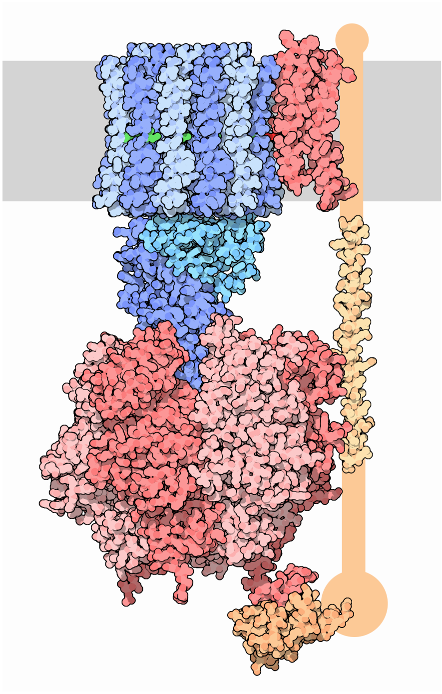

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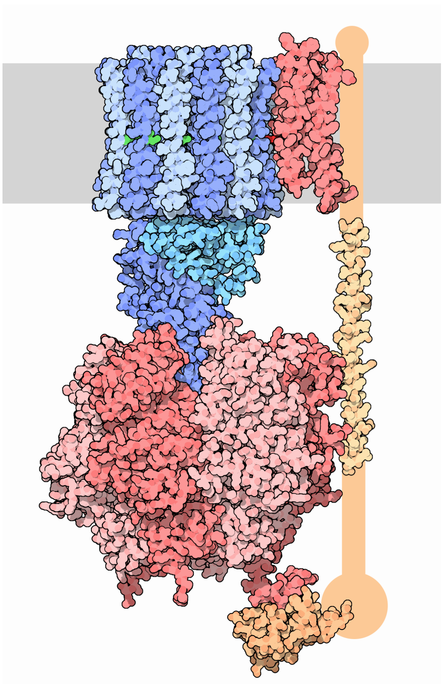

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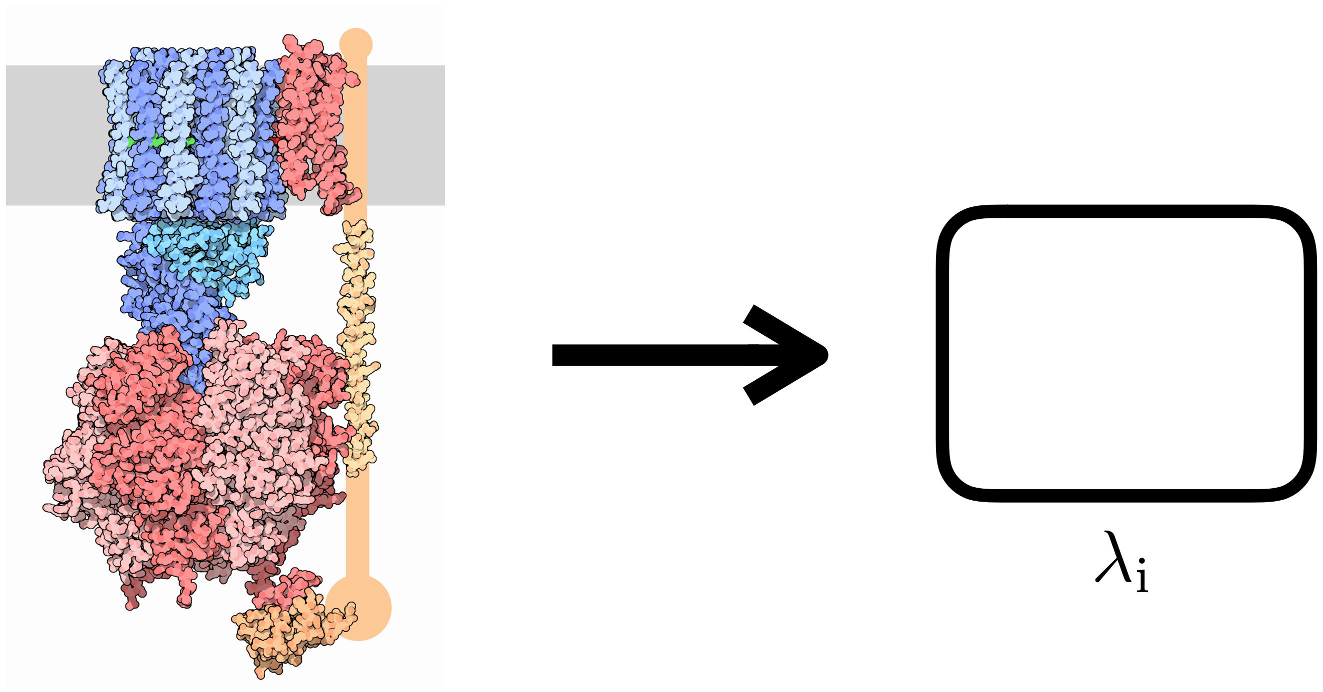

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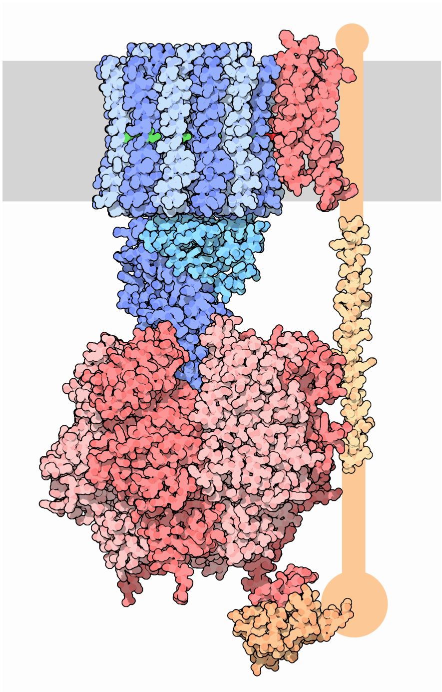

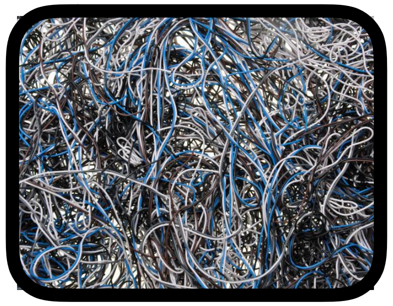

λ_{i}

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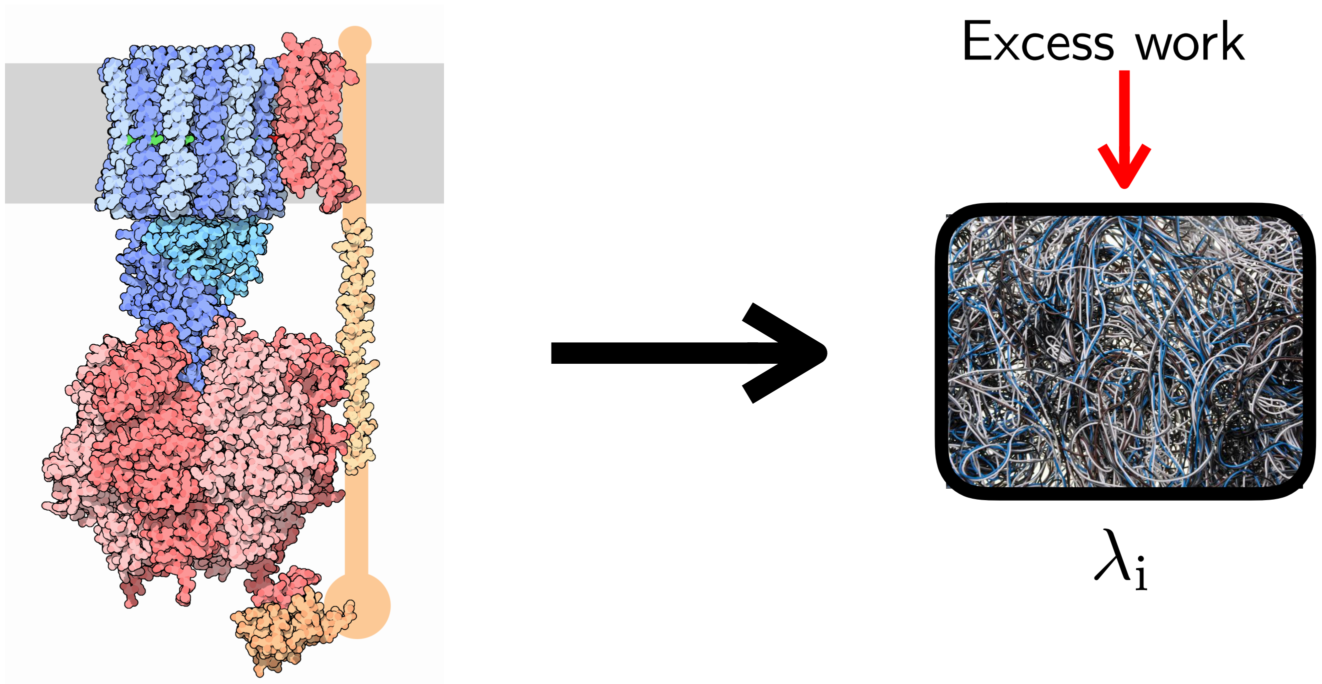

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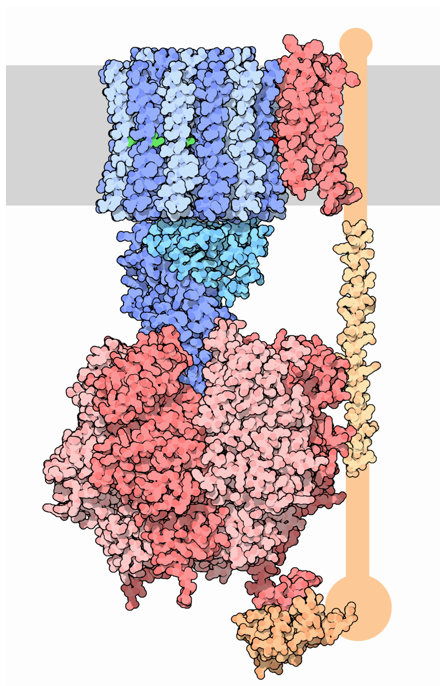

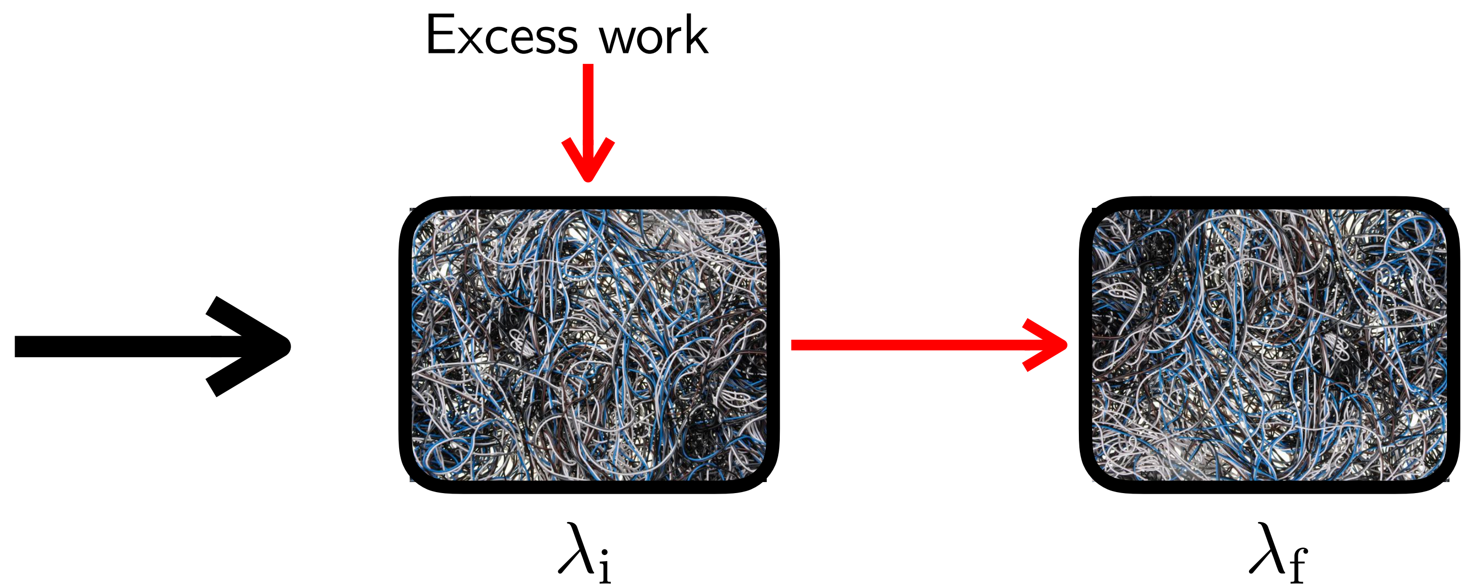

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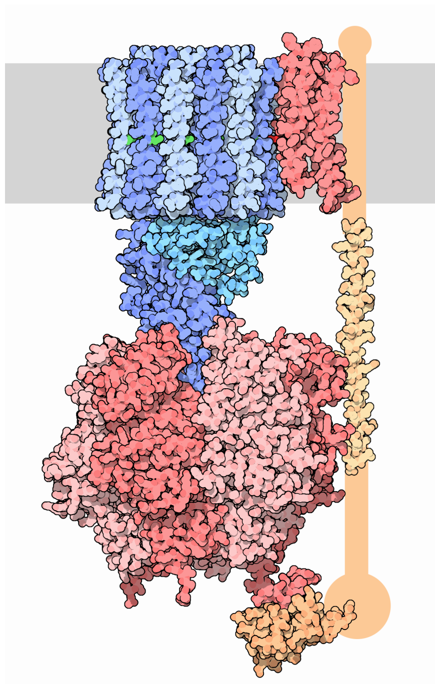
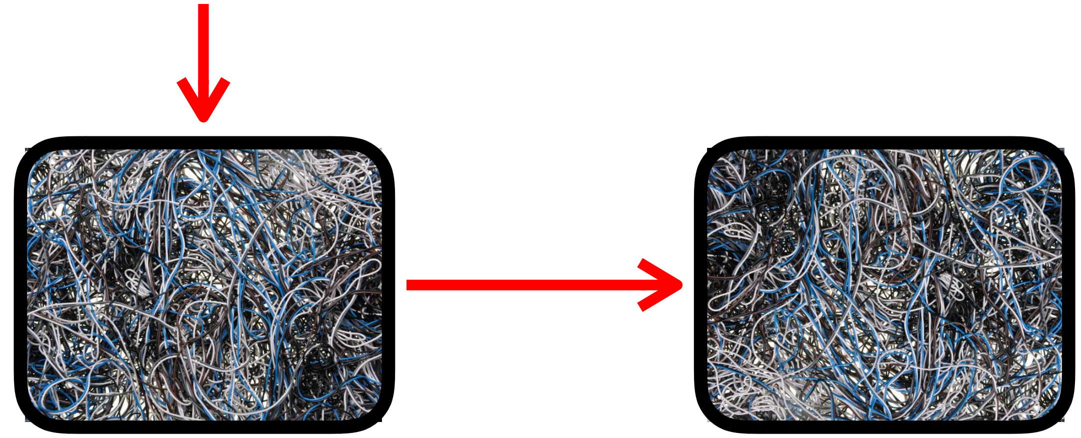


Excess work $\langle W_{\mathrm{ex}} \rangle_{\Lambda} = \langle W \rangle_{\Lambda} - \Delta F$



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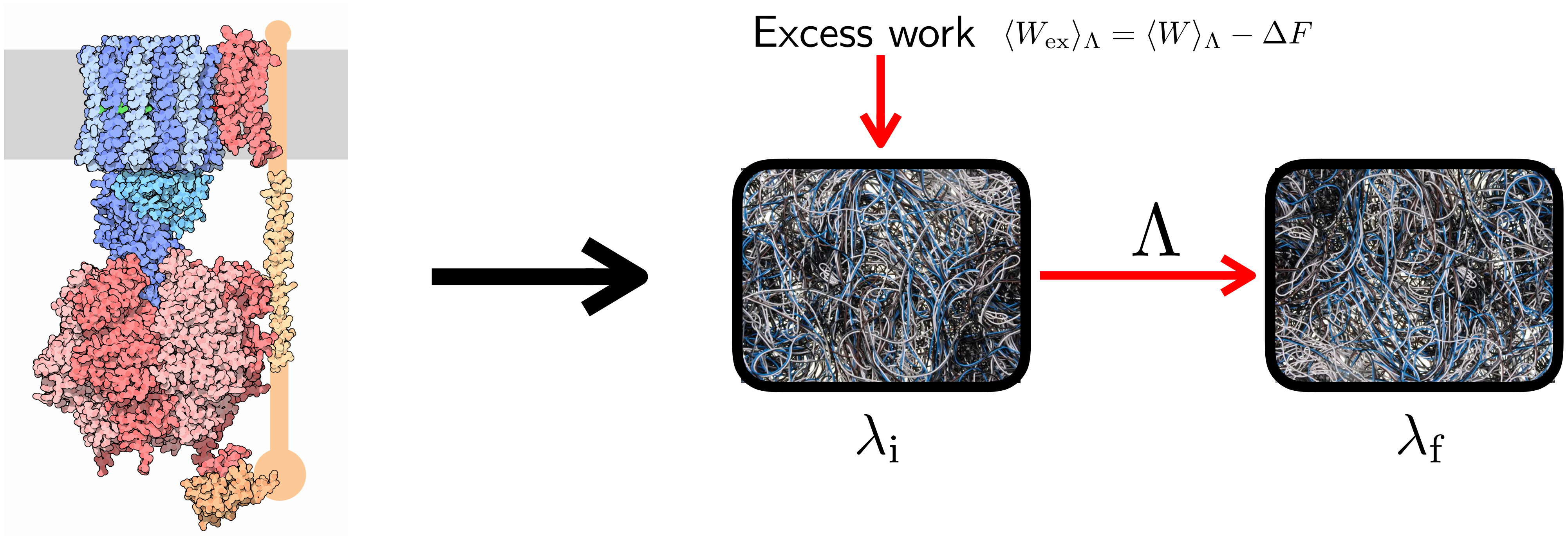

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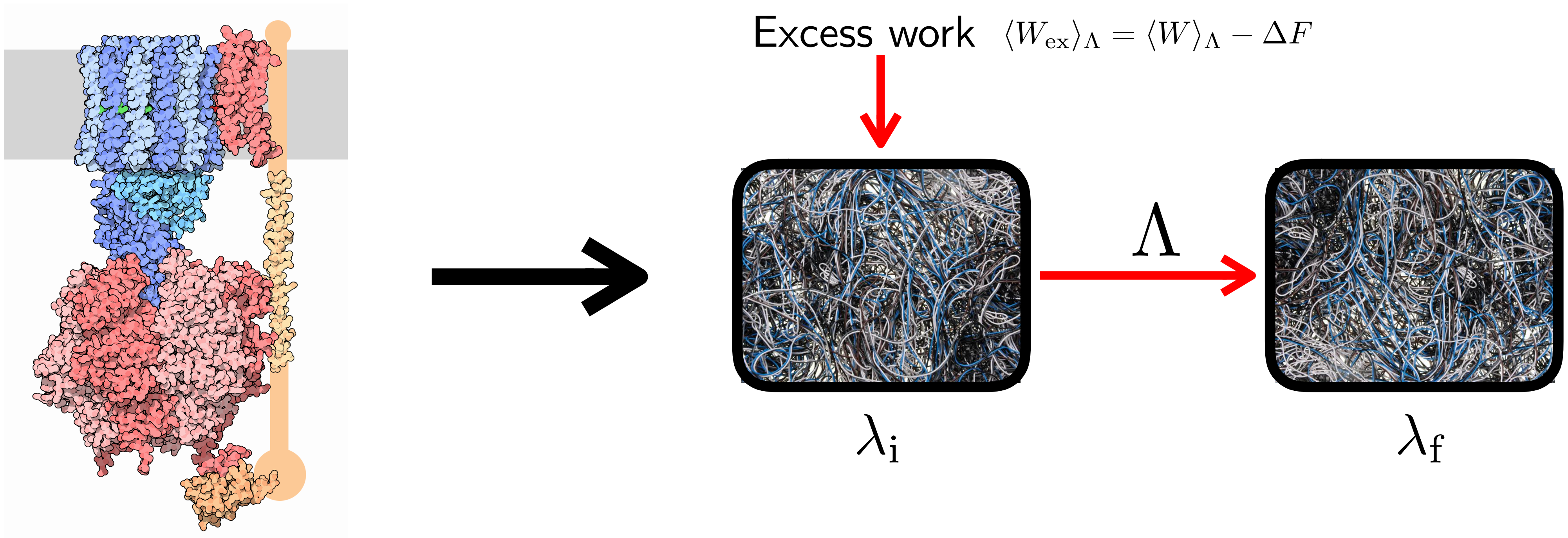

- Average excess work required depends on the particular control protocol

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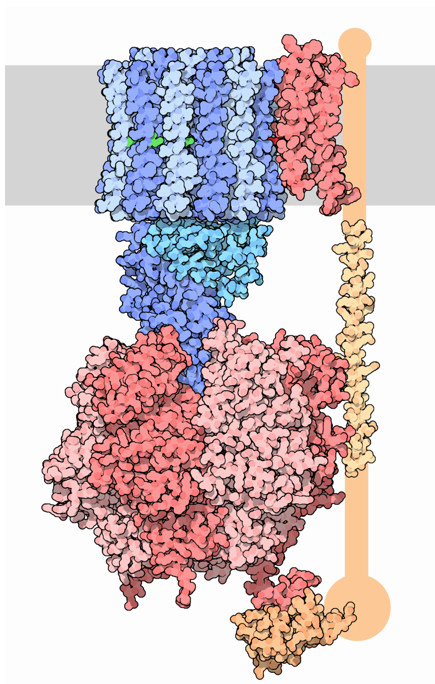

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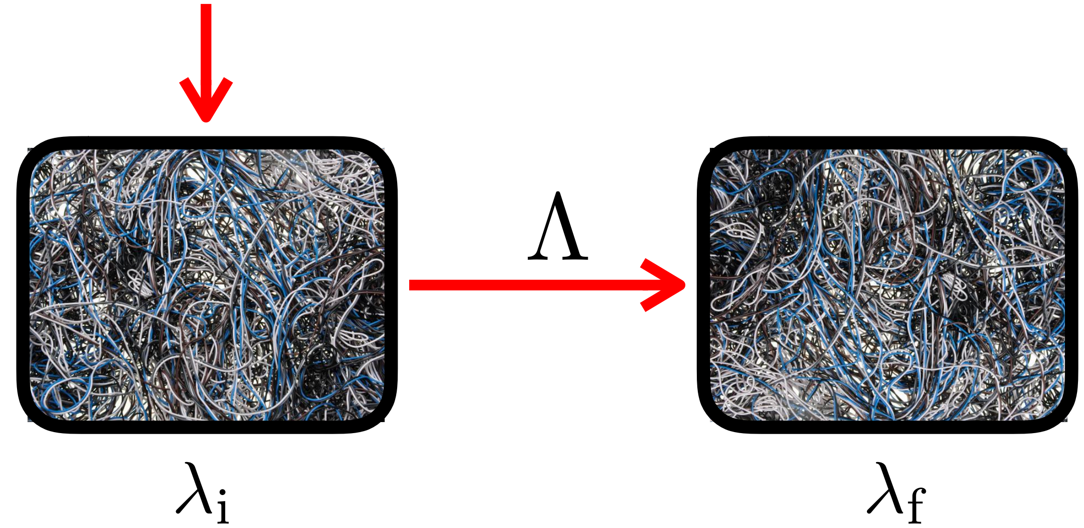

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$$\langle W_{\mathrm{ex}} \rangle_\Lambda = \int_0^\tau \dot{\lambda}^2 \zeta(\lambda) \mathrm{d}t$$

D. A. Sivak & G. E. Crooks, *Phys Rev* Lett, **2012**, 108, 190602

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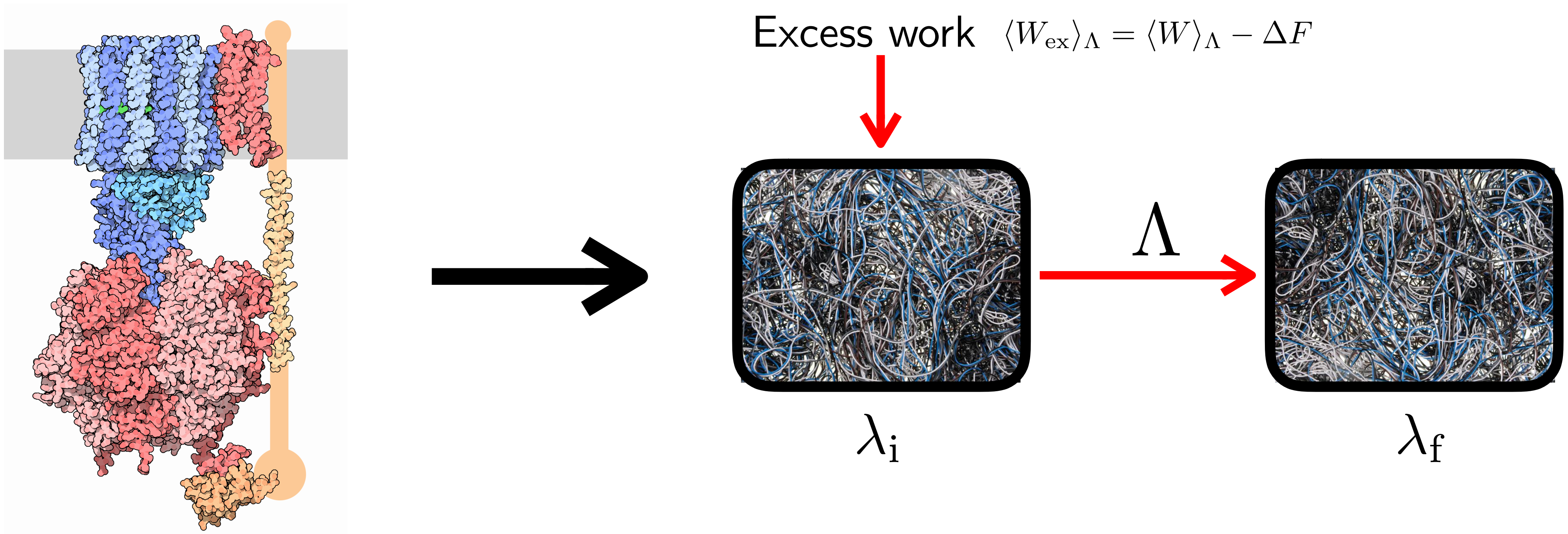

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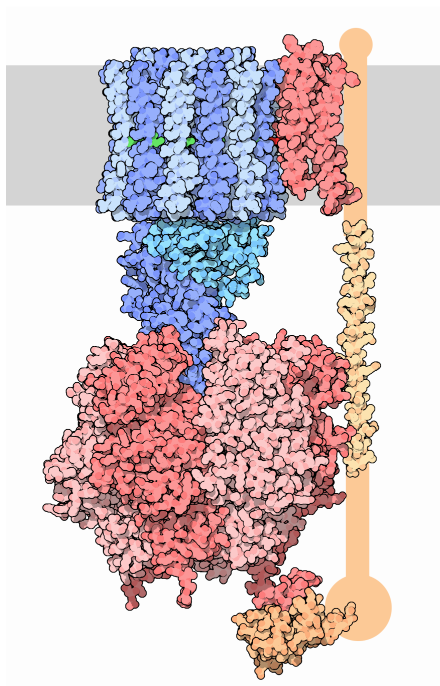

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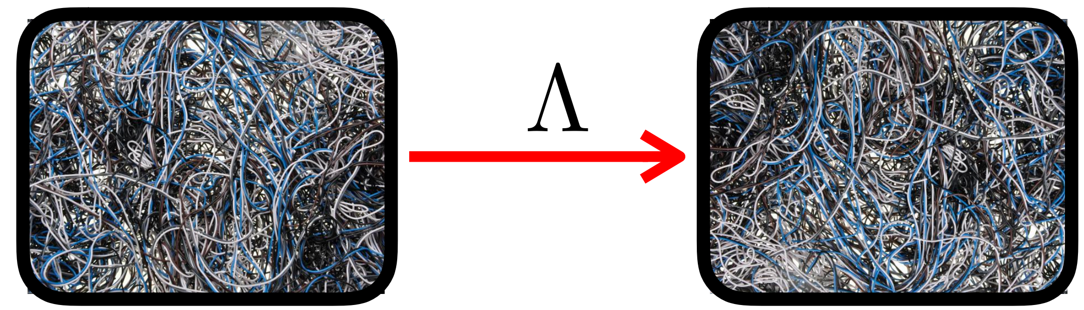

λ_{i} λ_{f}

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Average excess work

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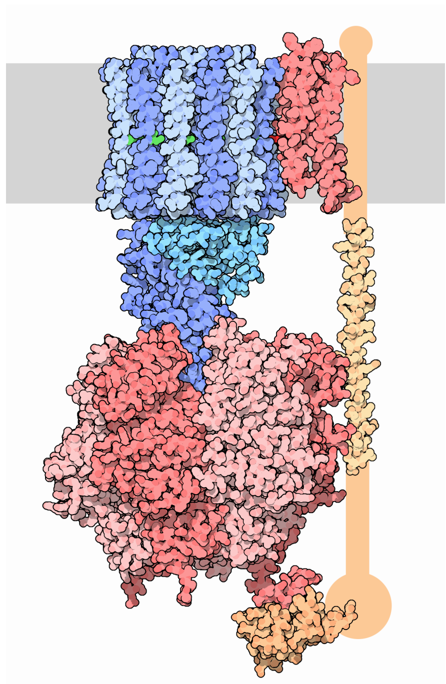

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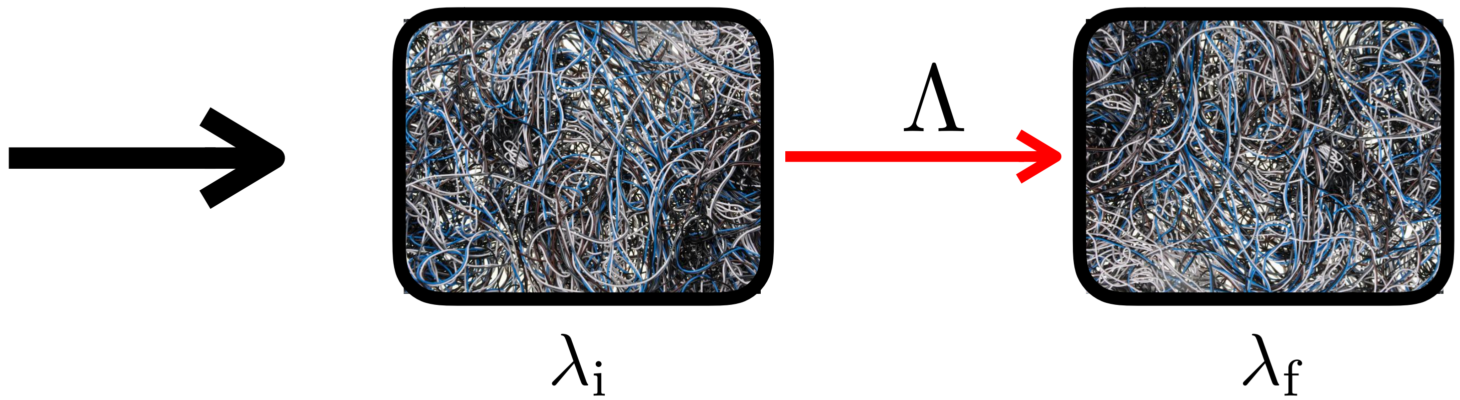

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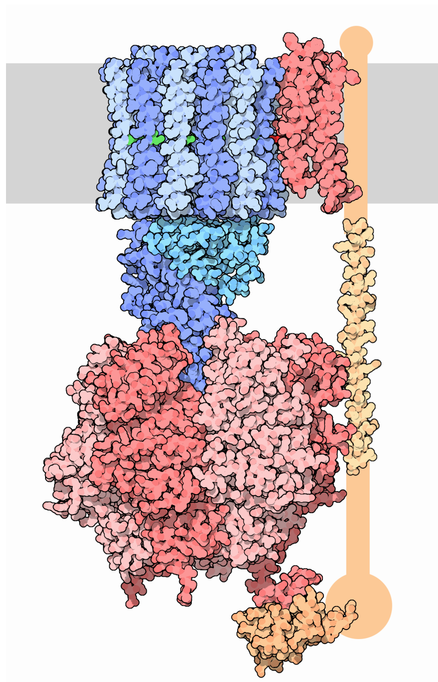

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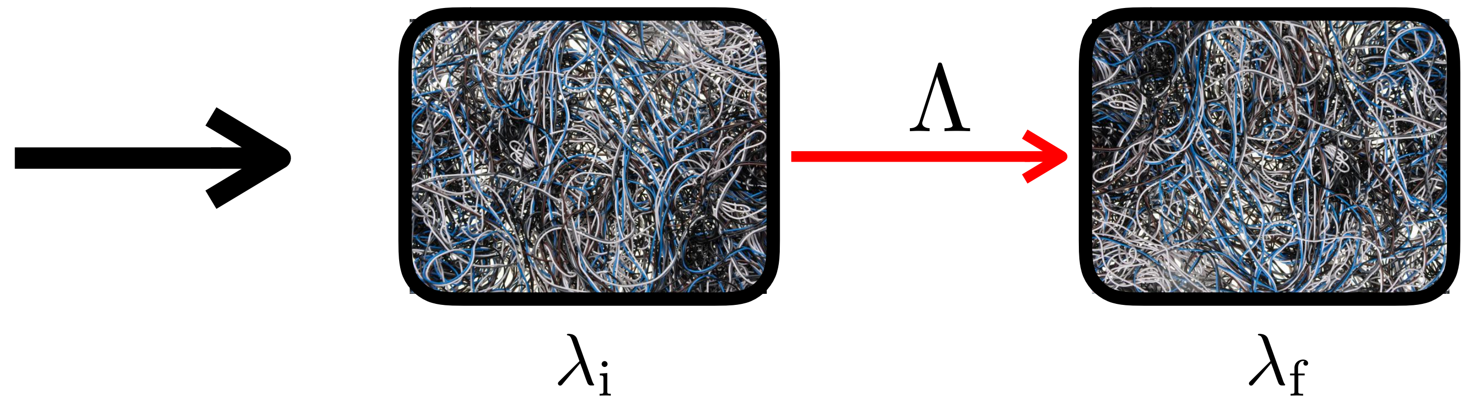

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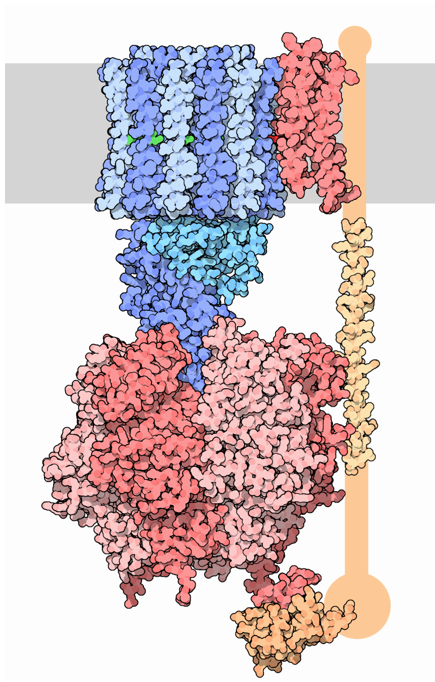

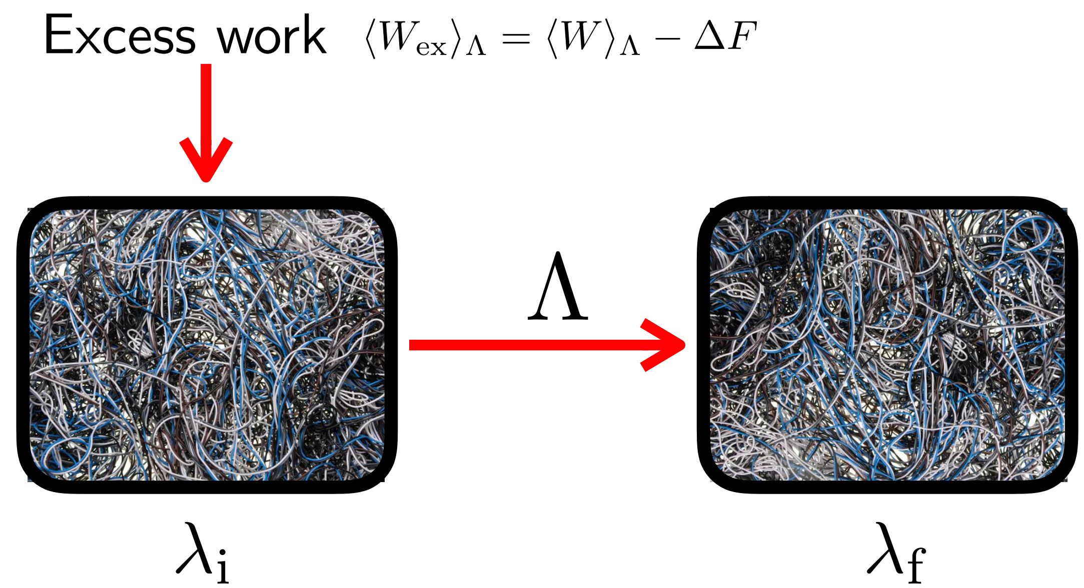

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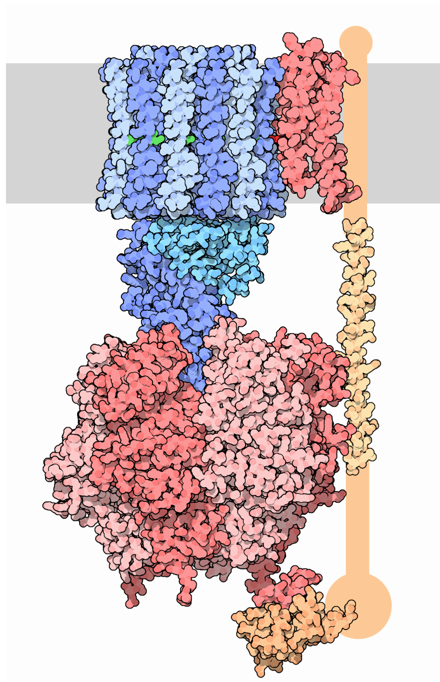

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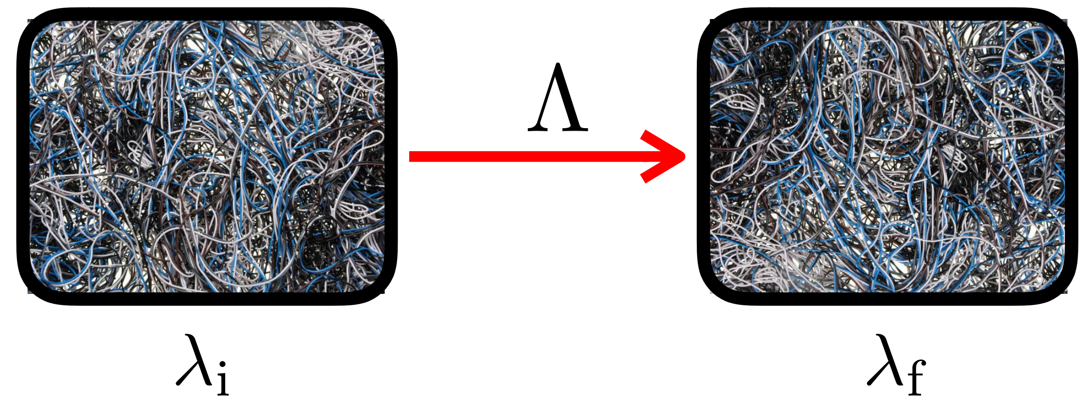

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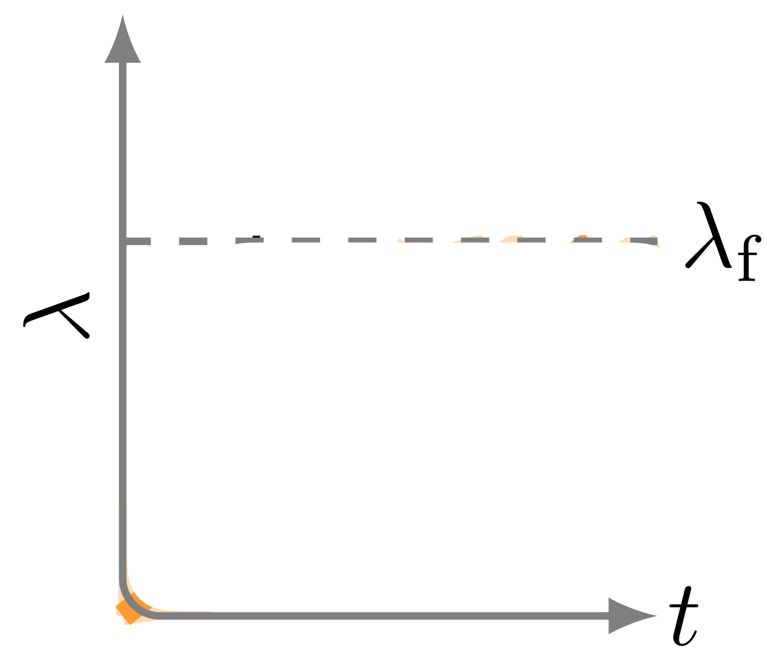

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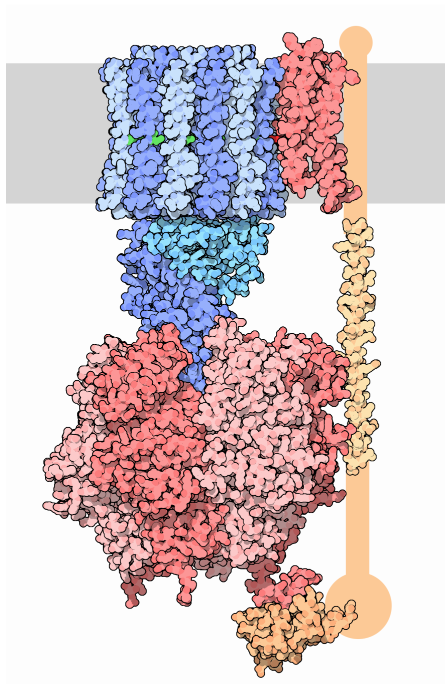

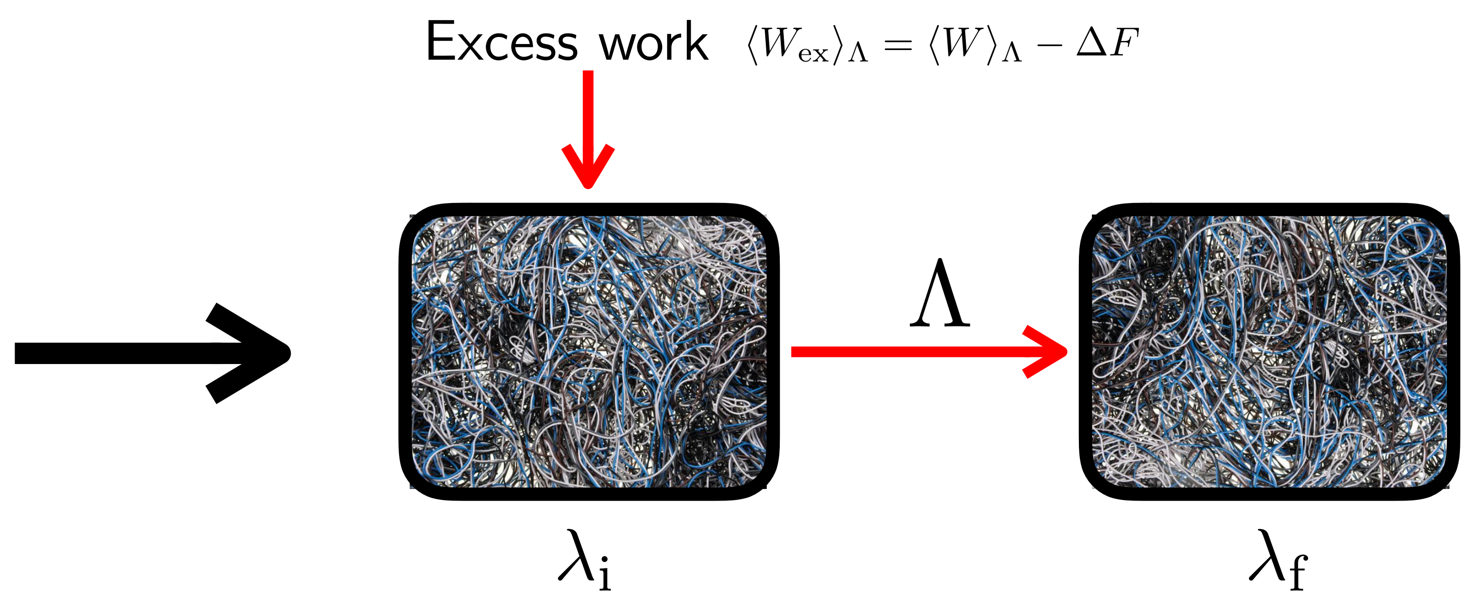

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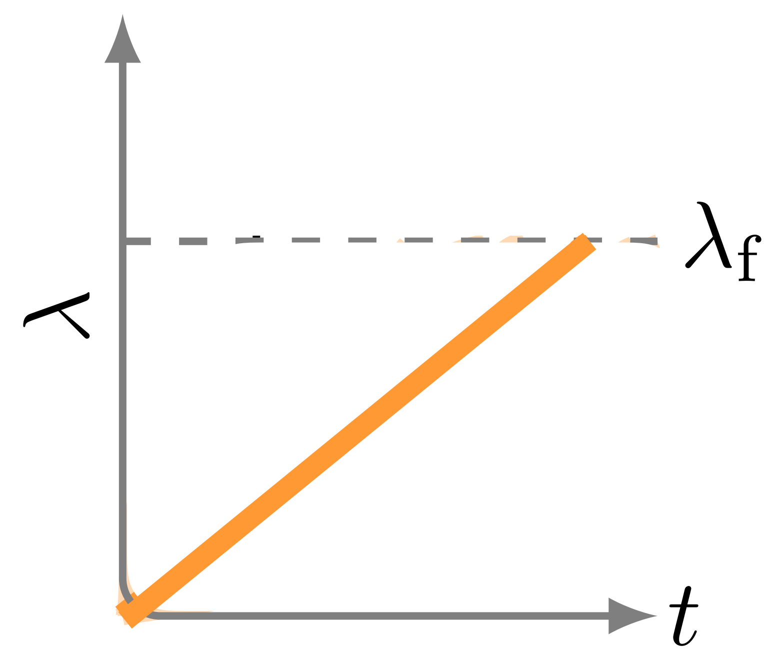

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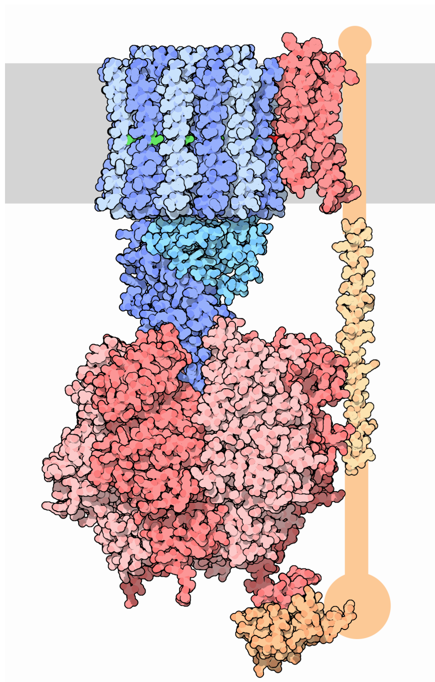

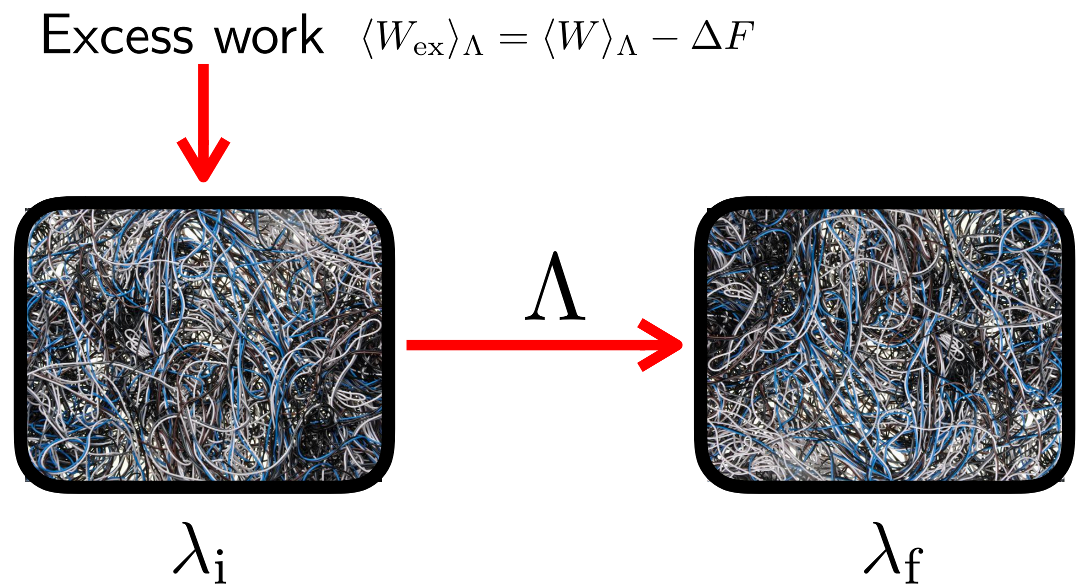

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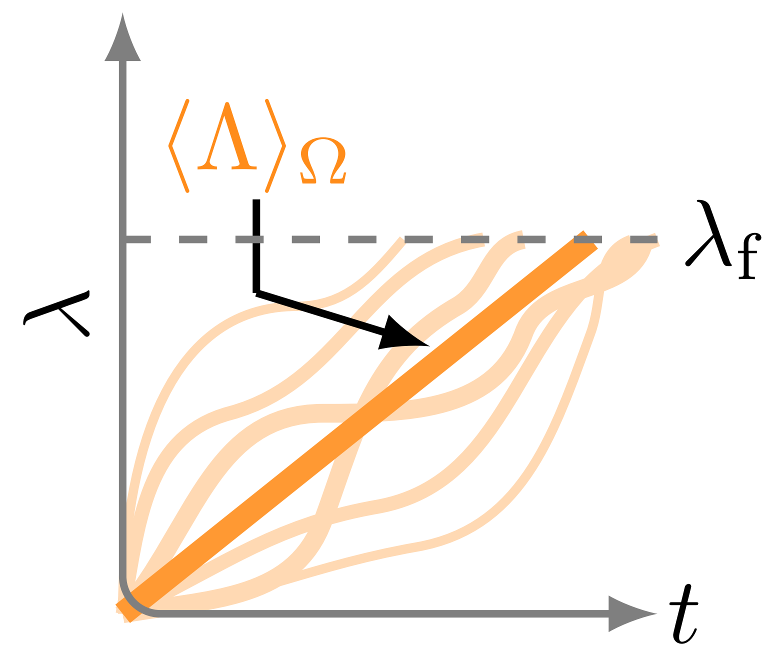

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Stochastic Control

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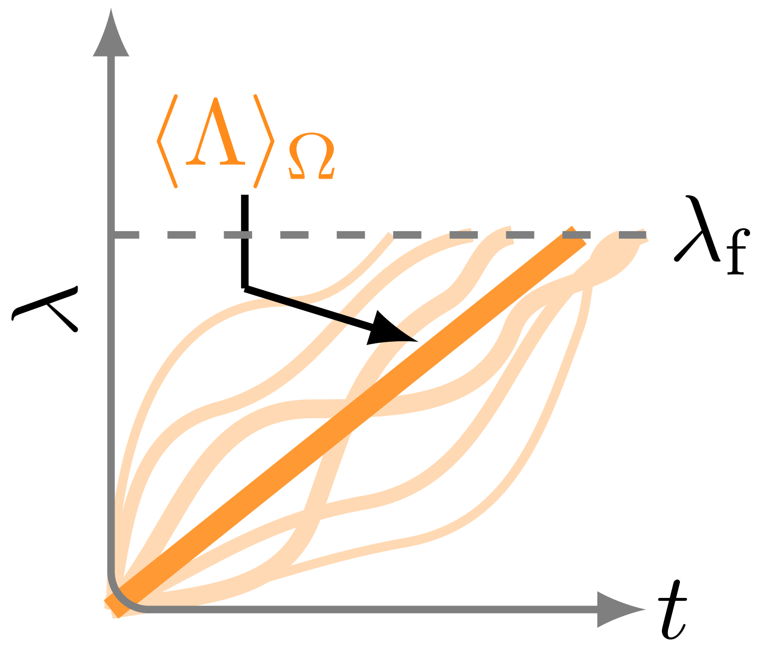
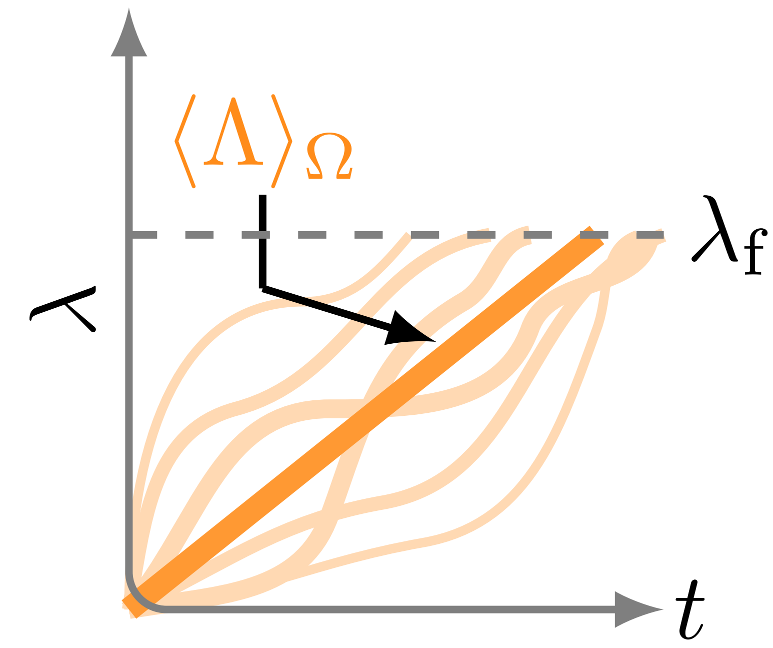


Stochastic Control

- For a stochastically driven process, we are interested in the average excess work, over all possible protocols

$$\langle W_{\mathrm{ex}}\rangle_{\Omega} = \int_0^{\tau} \langle\dot{\lambda}\rangle^2 \zeta(\langle\lambda\rangle)\mathrm{d}t + \int_0^{\tau} \langle\delta\dot{\lambda}^2\rangle \zeta(\langle\lambda\rangle)\mathrm{d}t$$



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Stochastic Control

SFU

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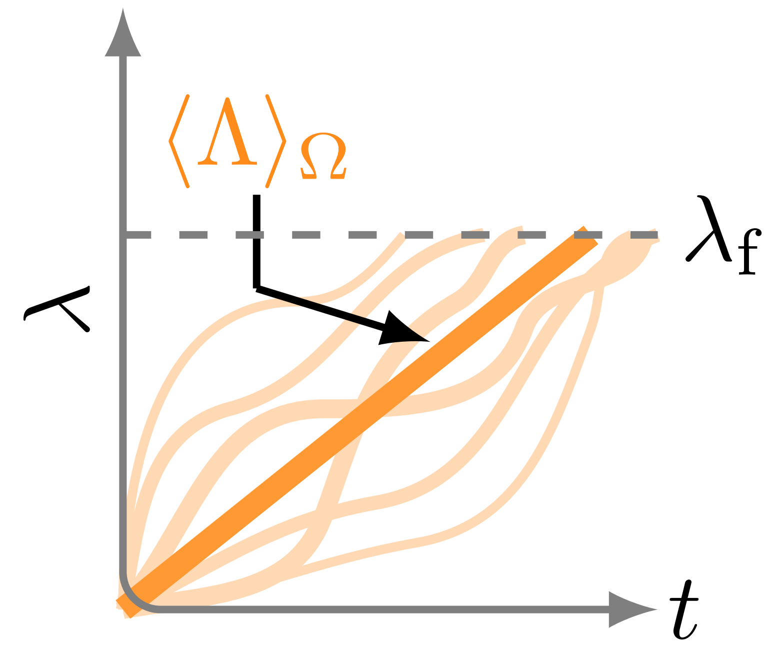
Protocol ensemble average



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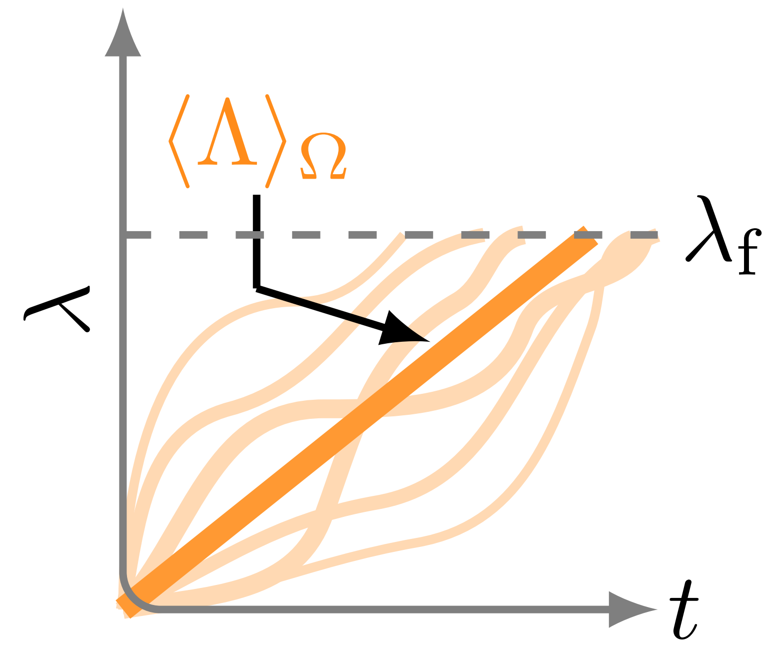

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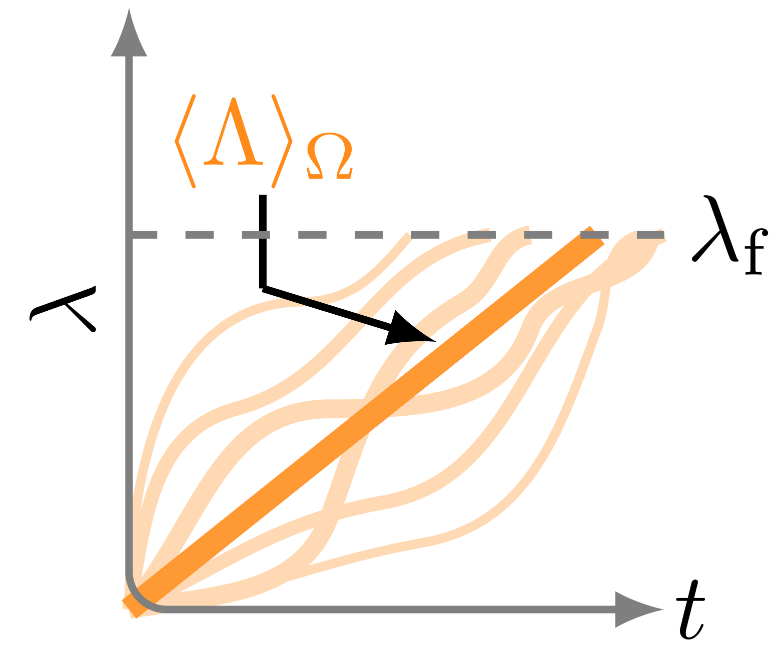

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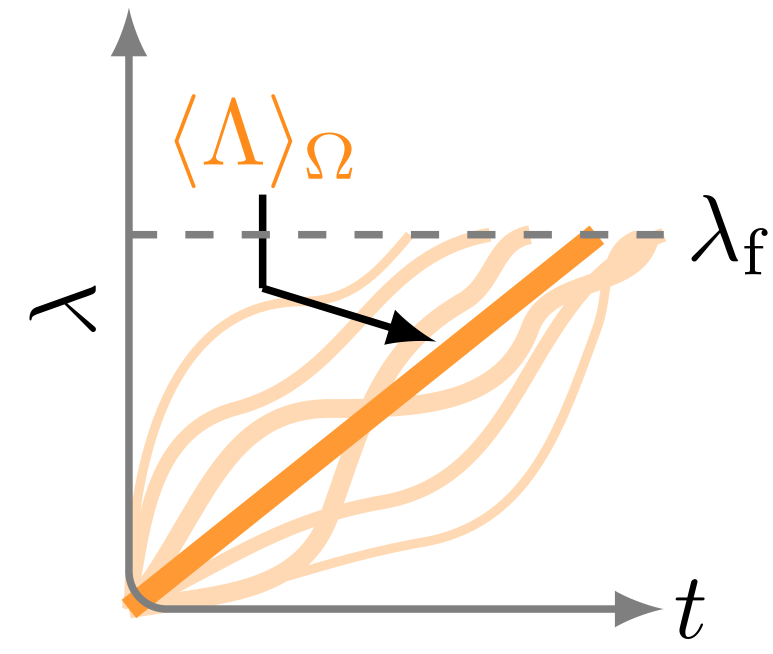

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Protocol ensemble average

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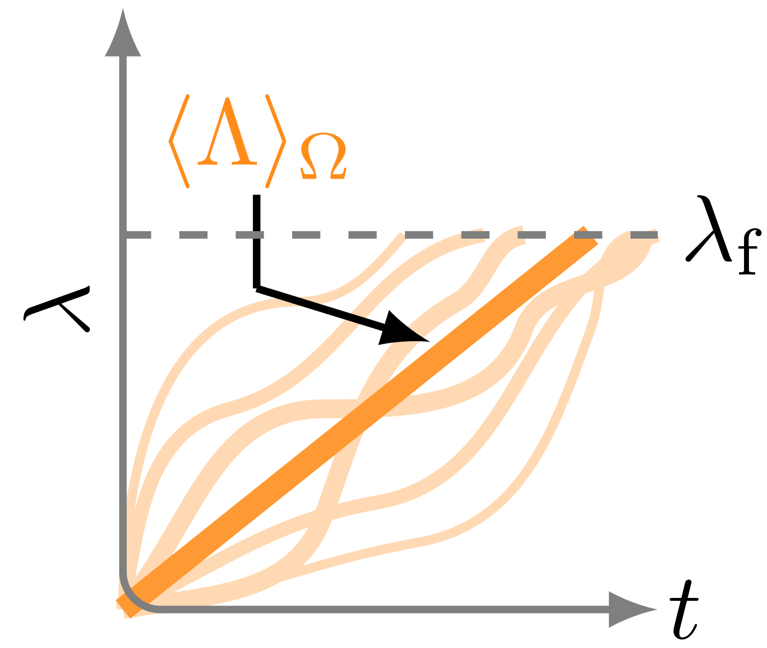
$\propto \tau$



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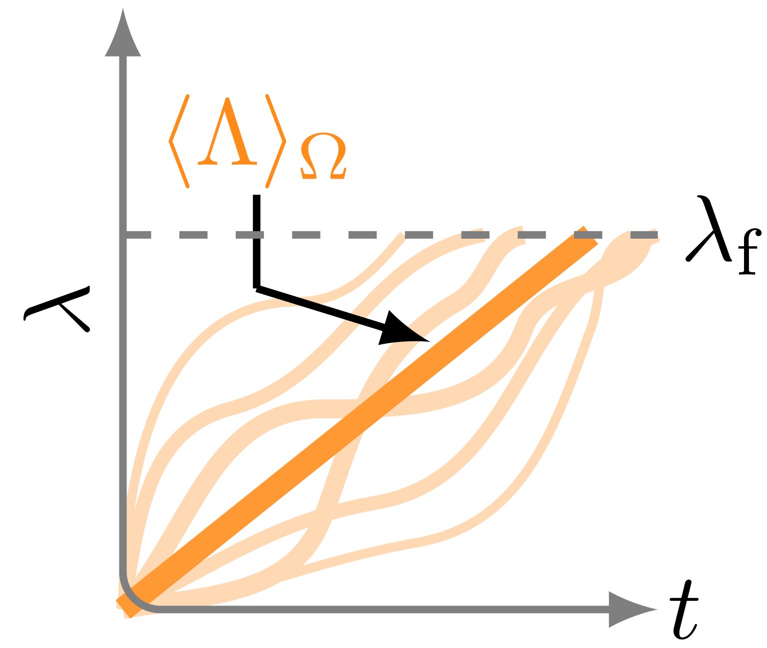

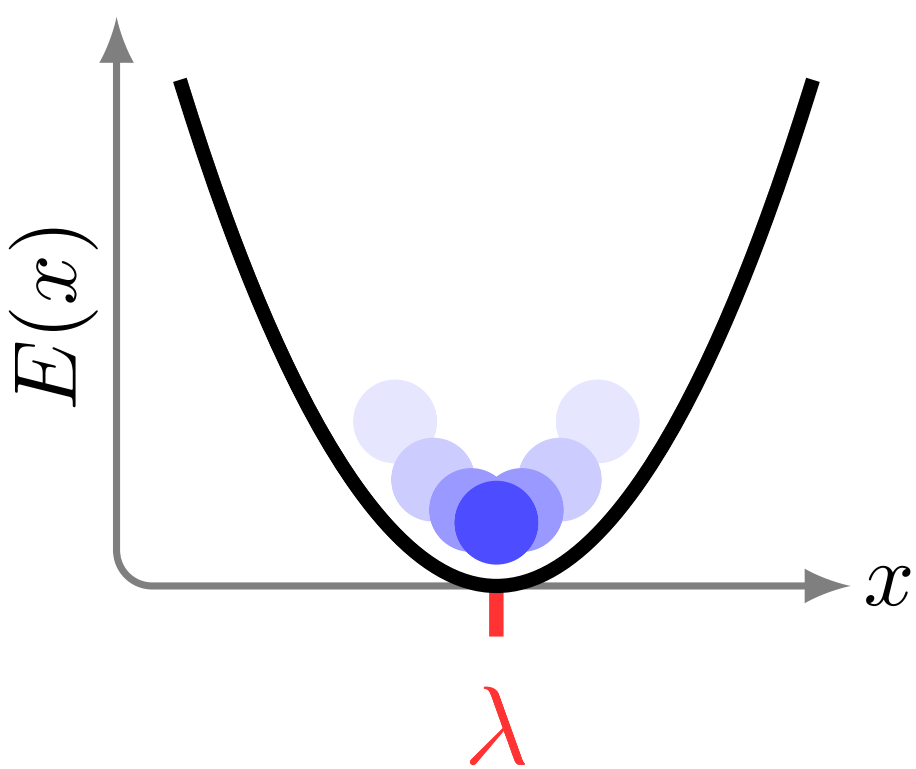

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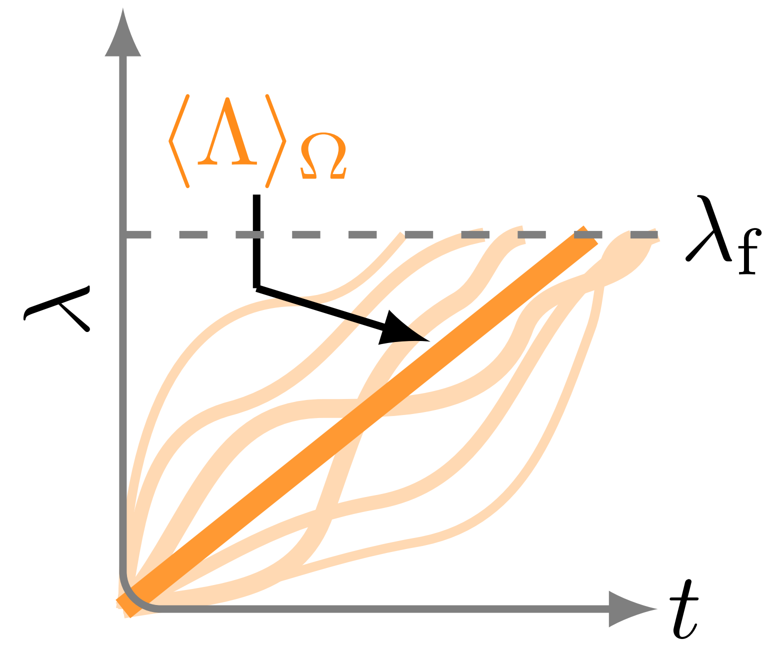

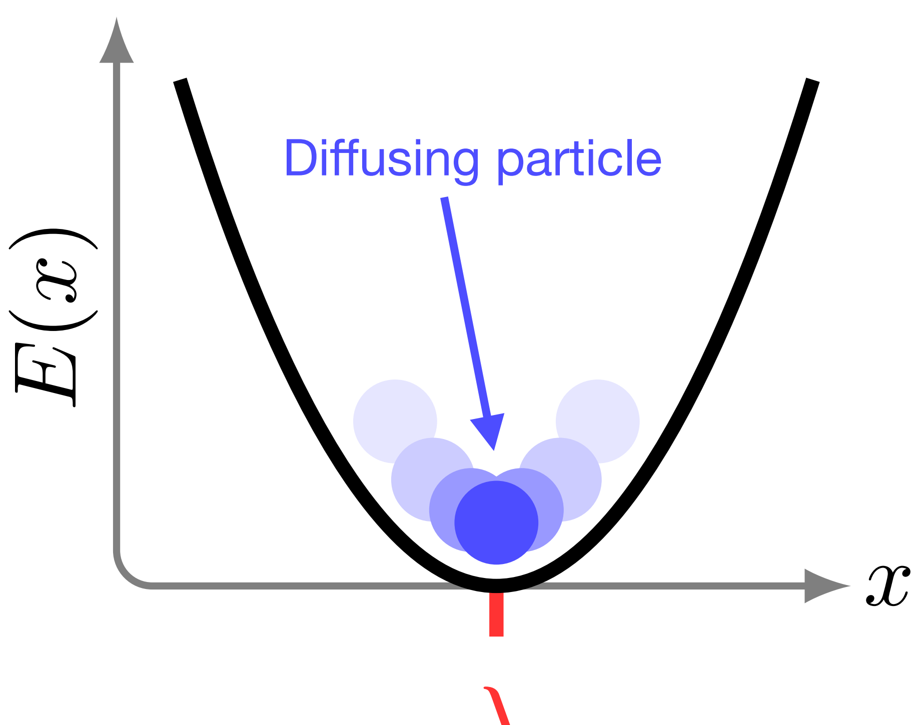

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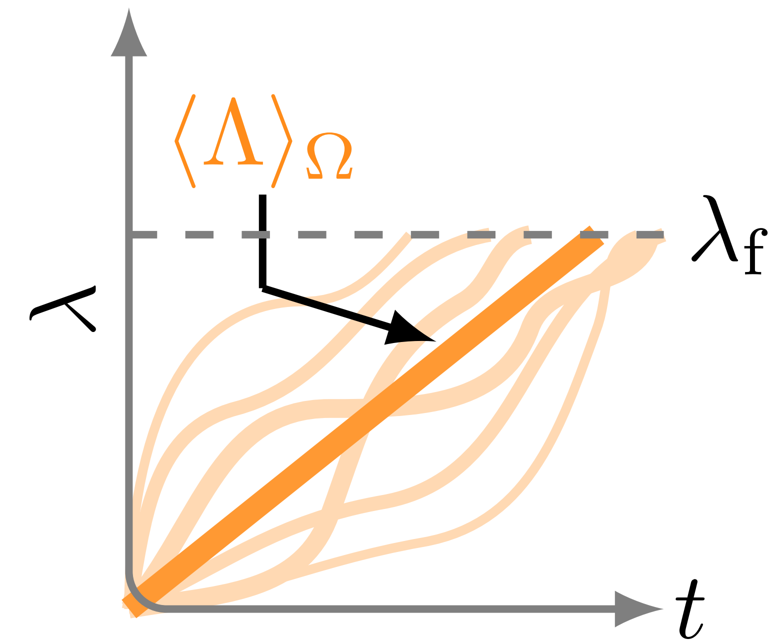

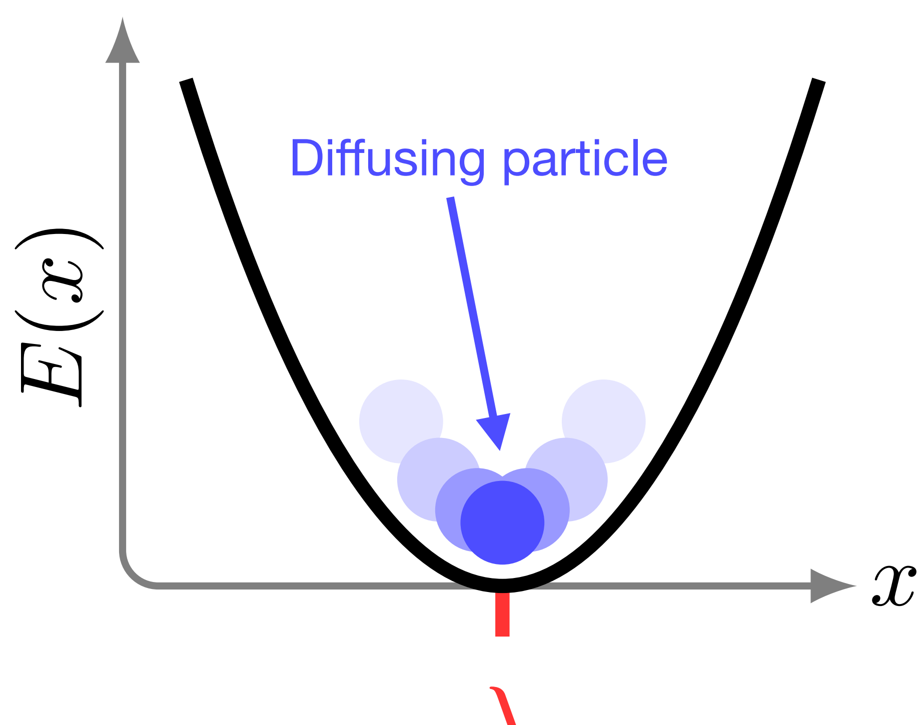

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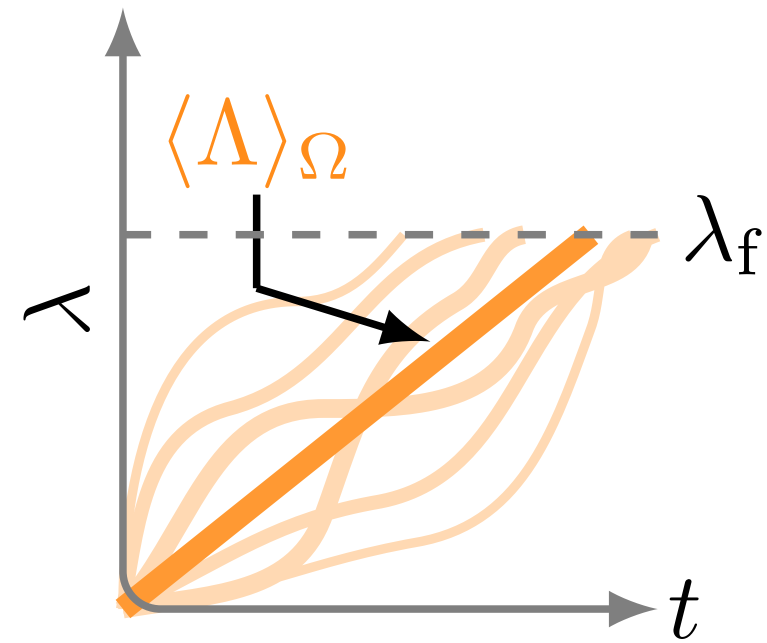

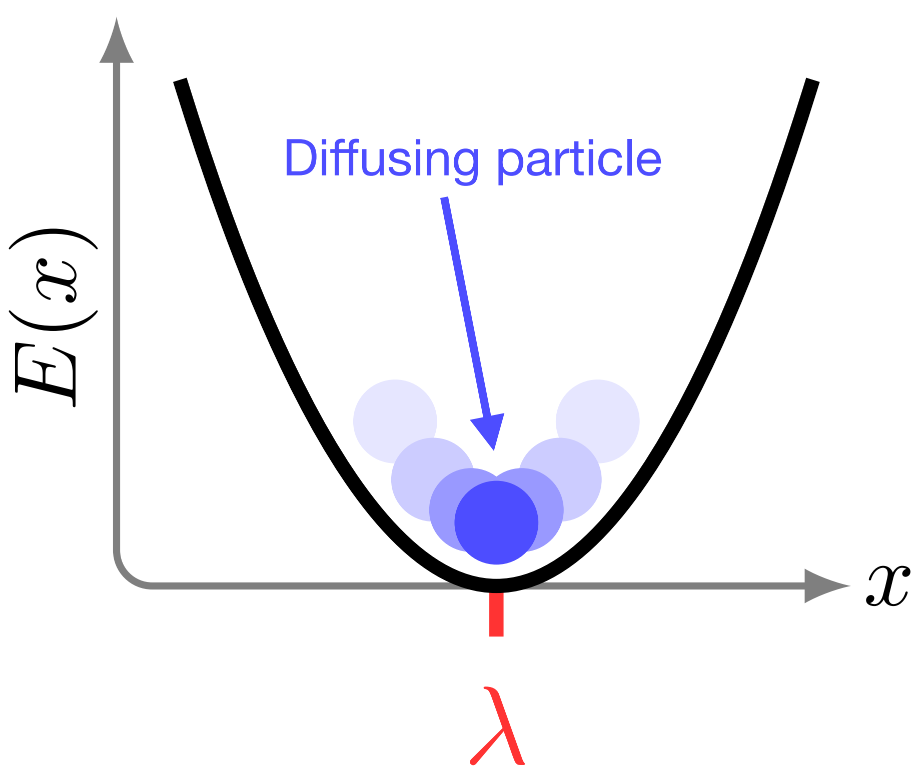

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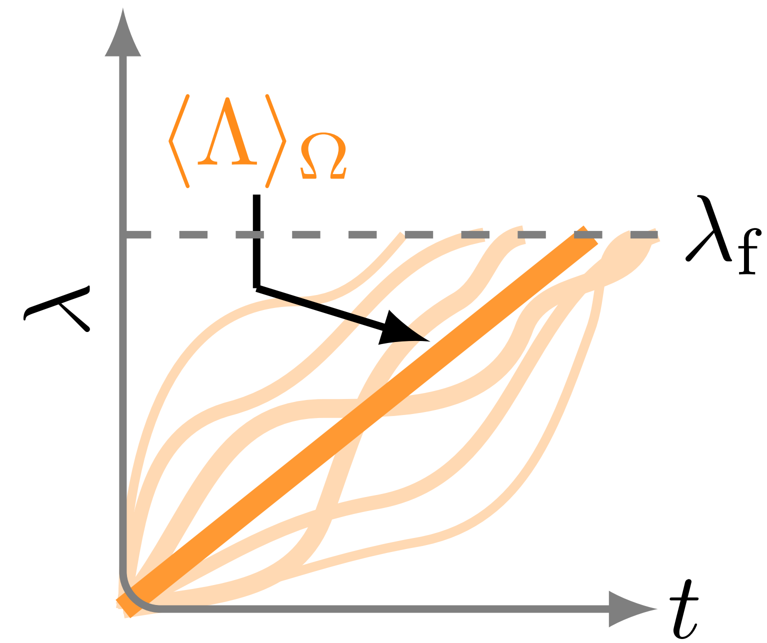

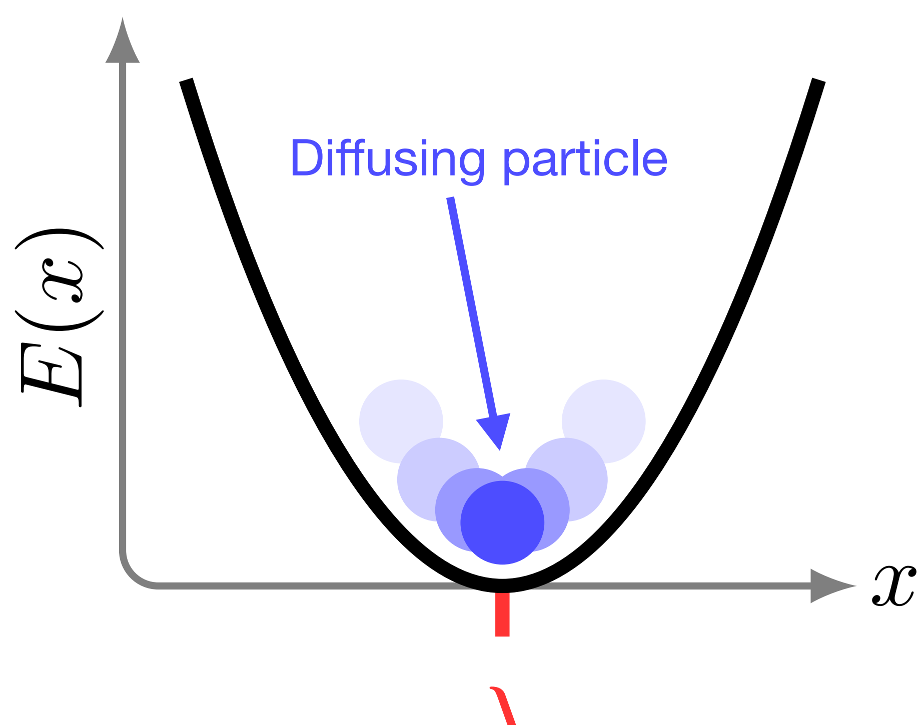

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- Trap minimum evolves under a stochastic dynamics

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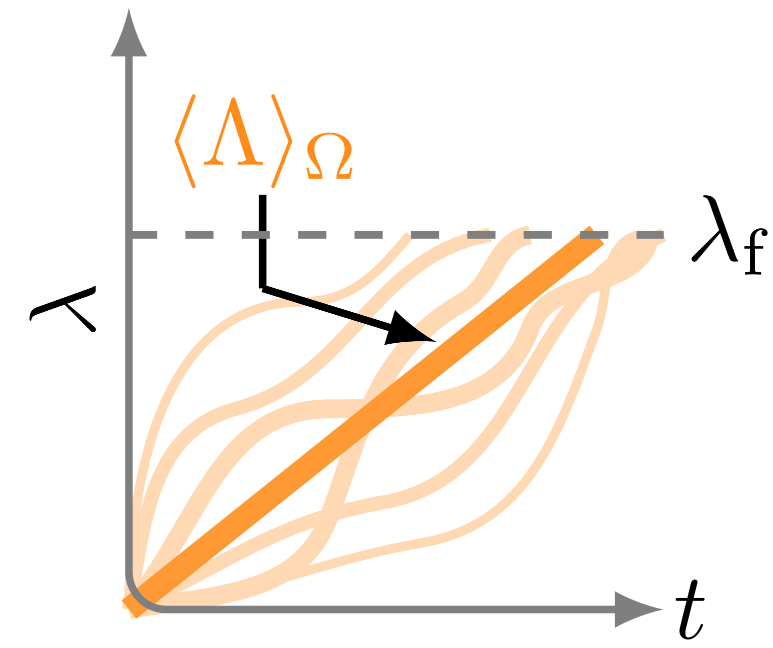

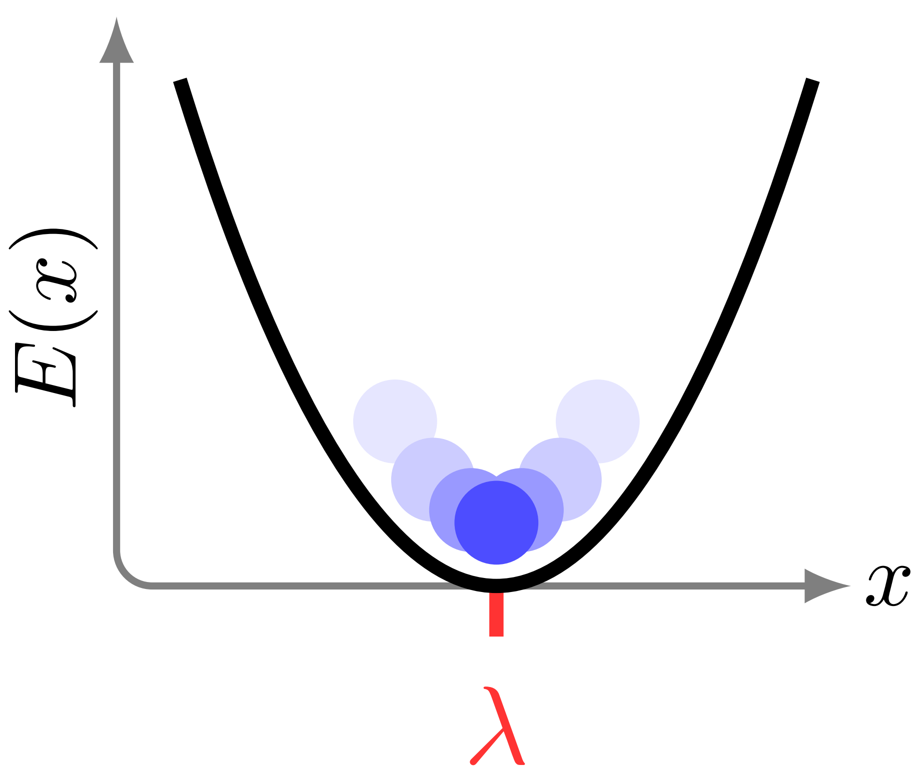

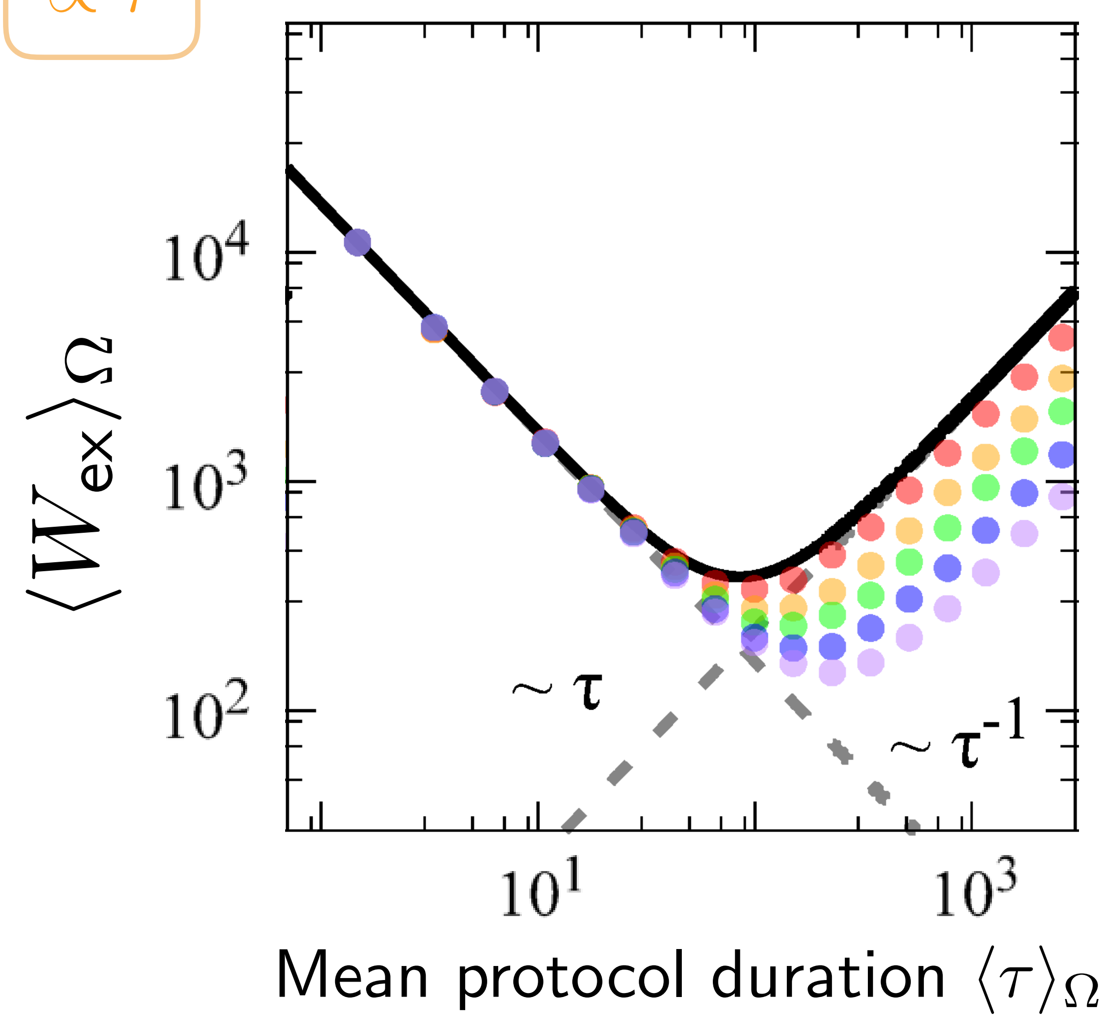

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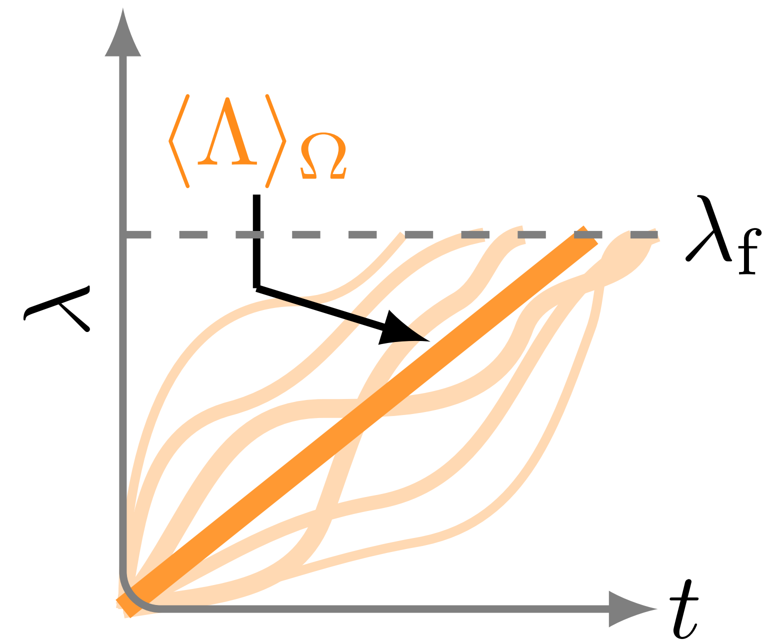

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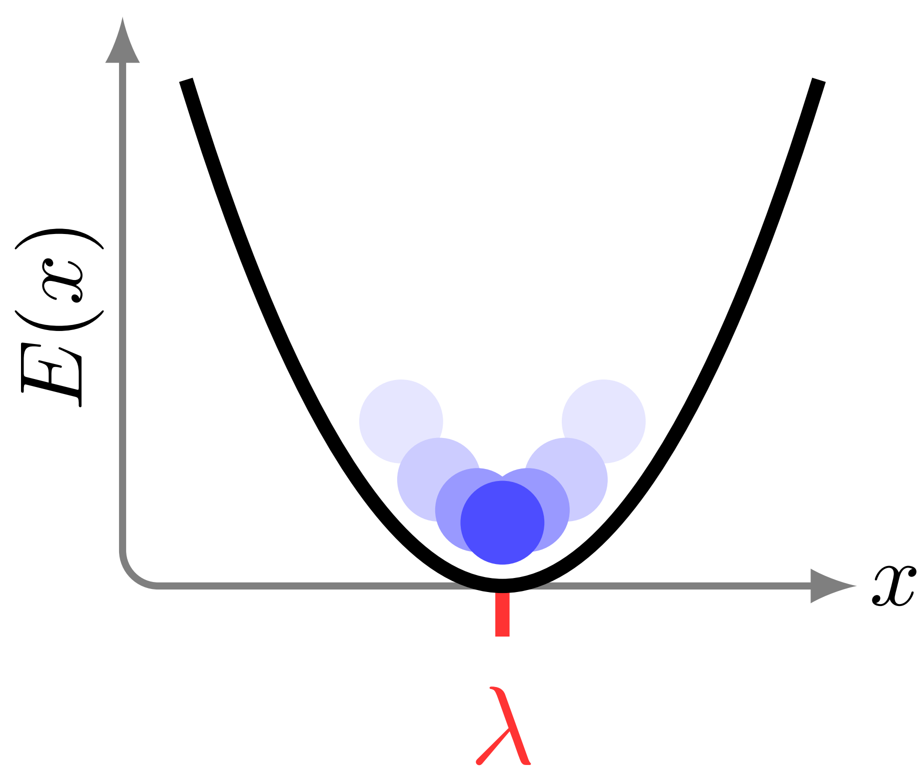

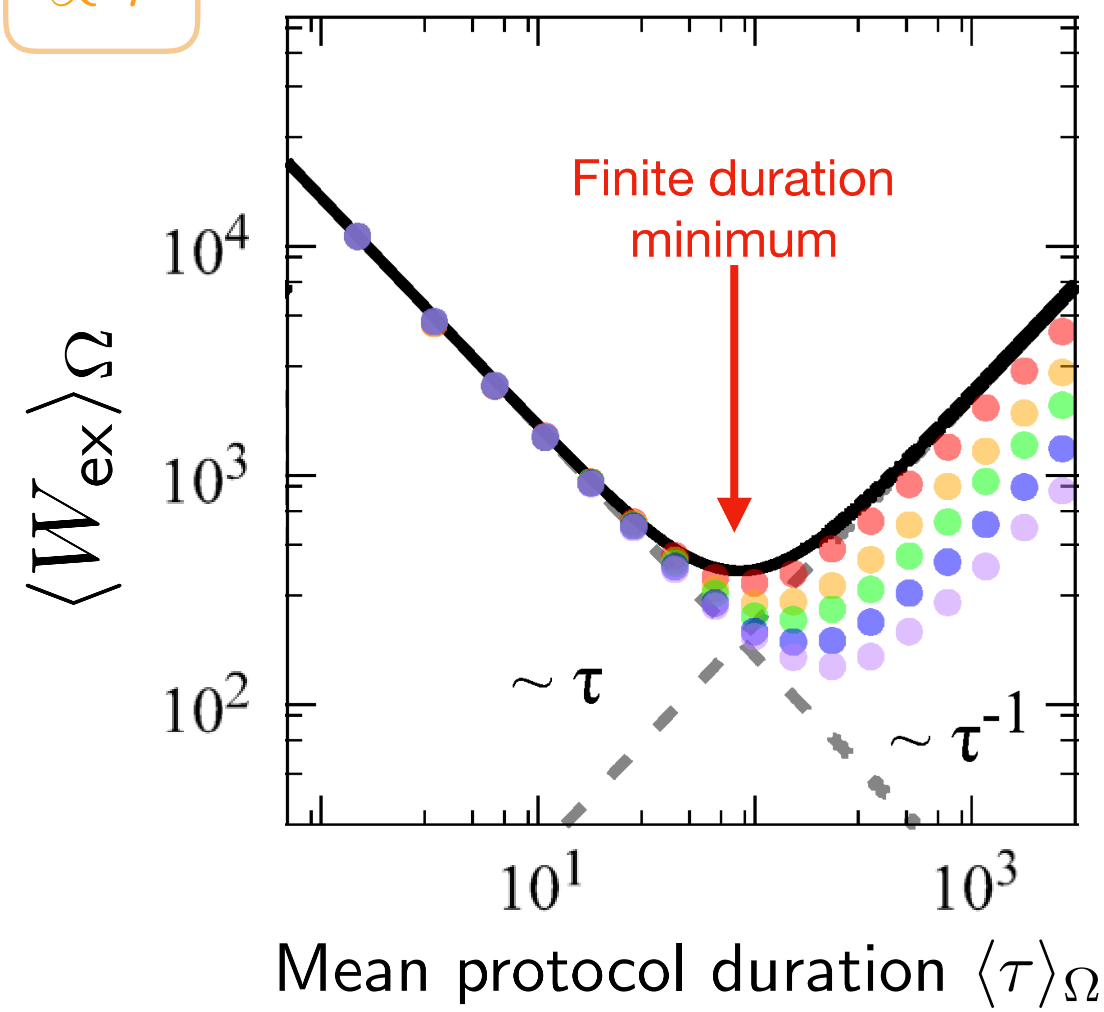

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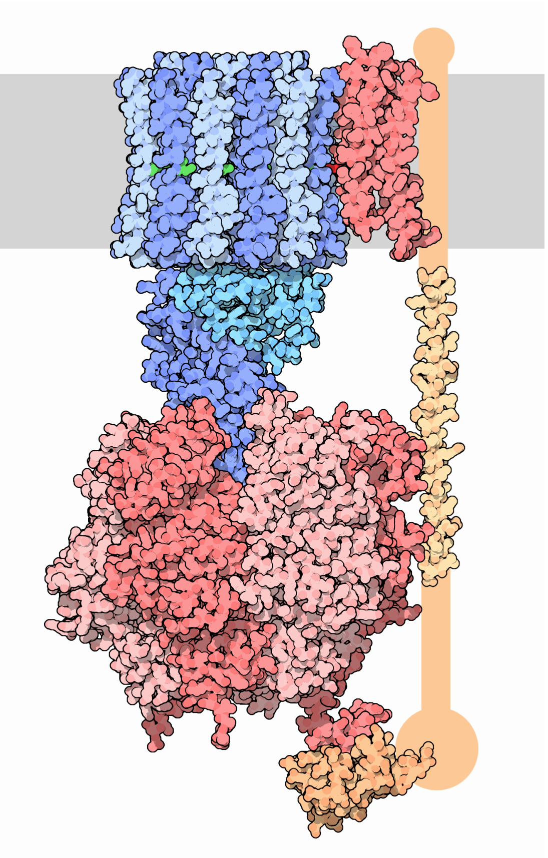
Conclusions/continuing work

- Fluctuations in control parameter dynamics penalize slow operation



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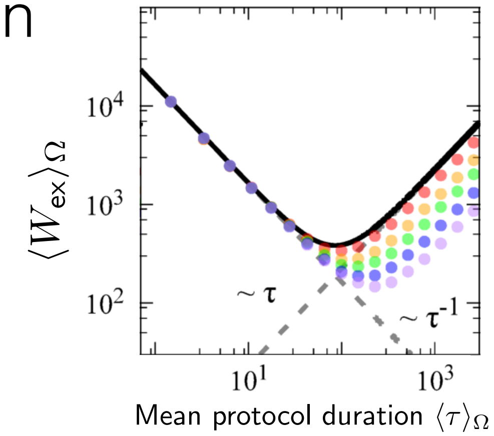

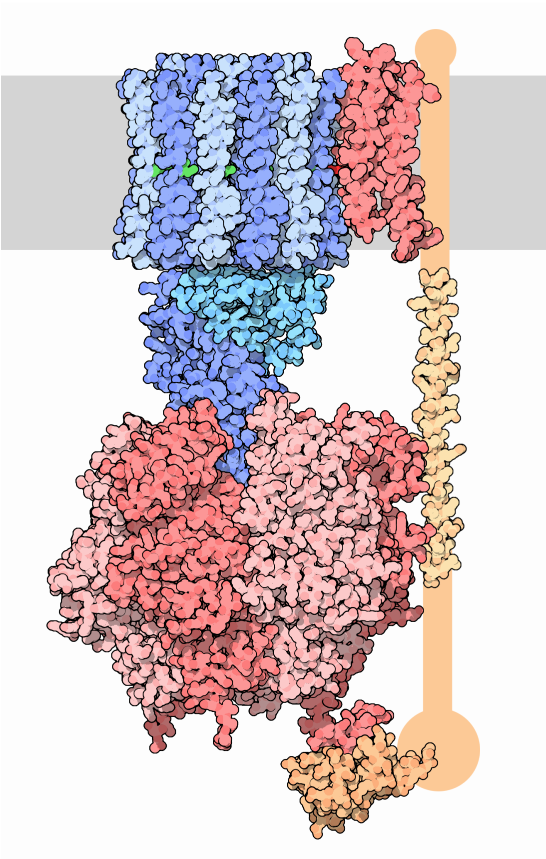

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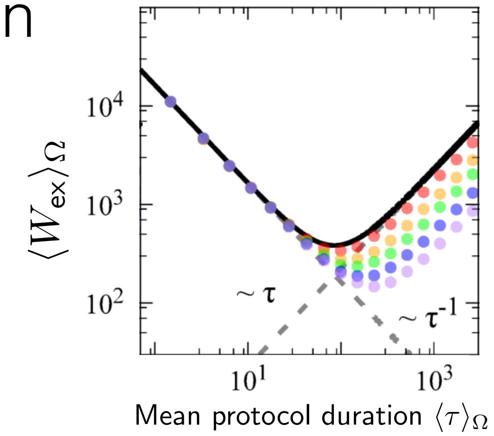
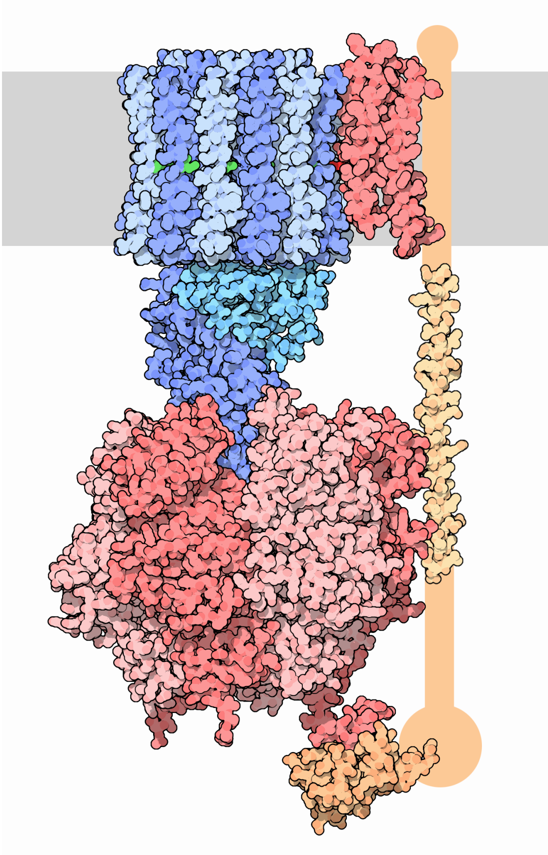


- Finite duration minimum work



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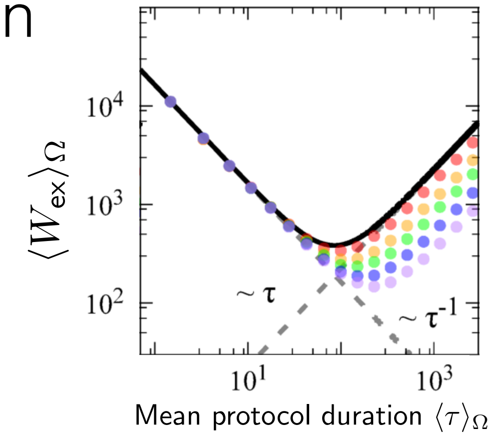

  - Finite duration minimum work
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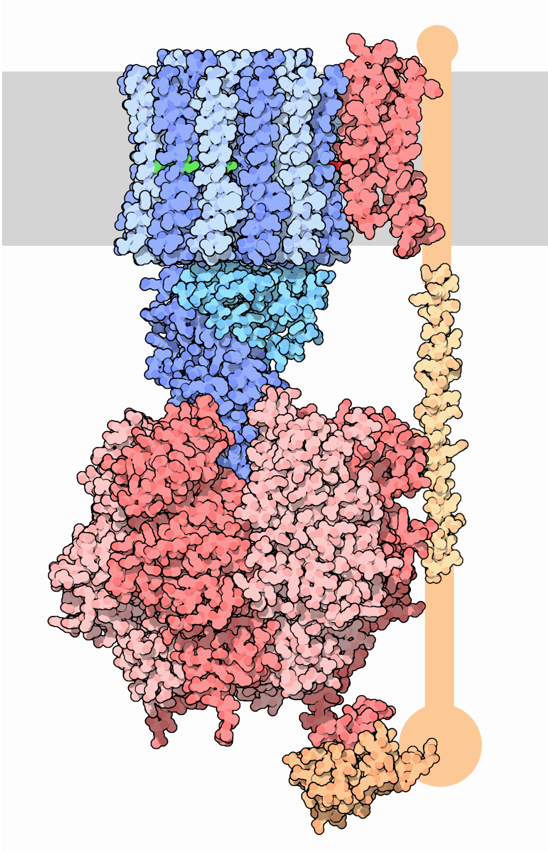

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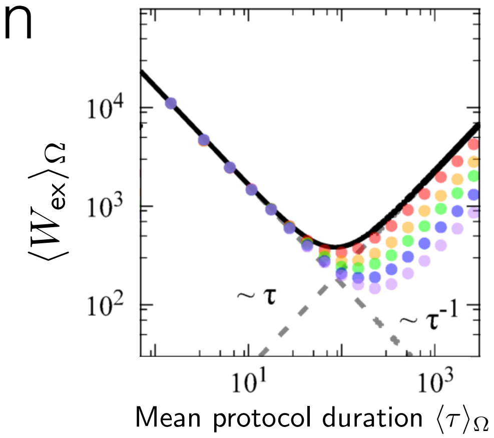

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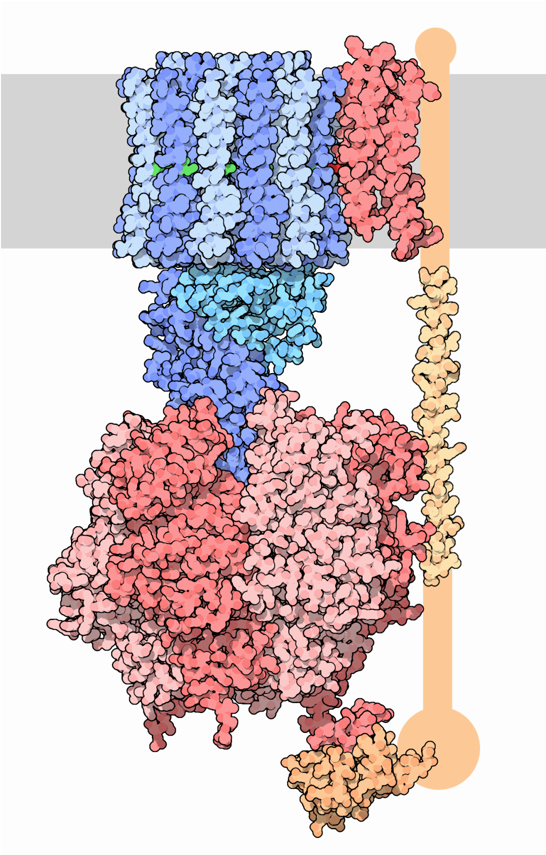

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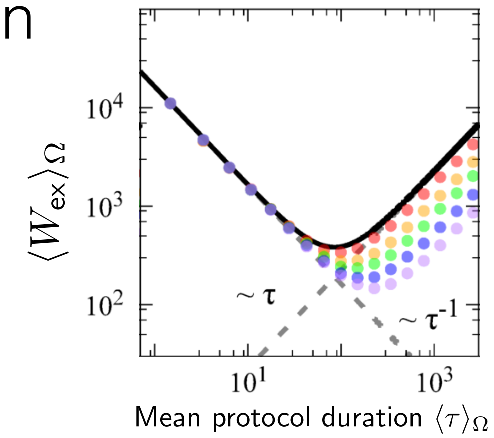

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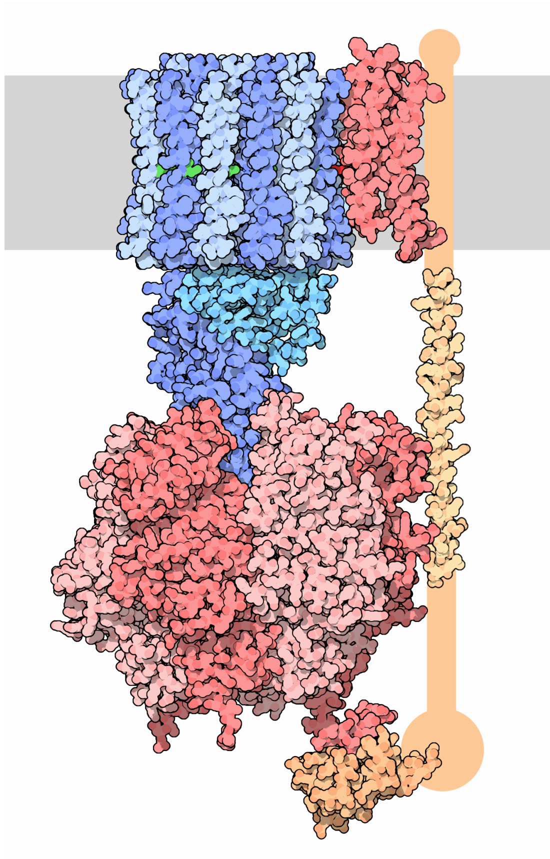

- Molecular machines are driven by chemical reactions, which are modelled as discrete processes

Conclusions/continuing work

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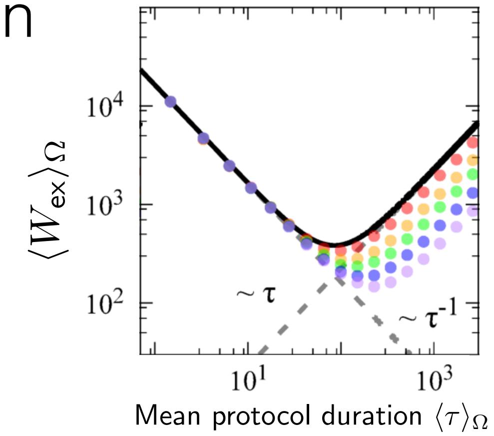

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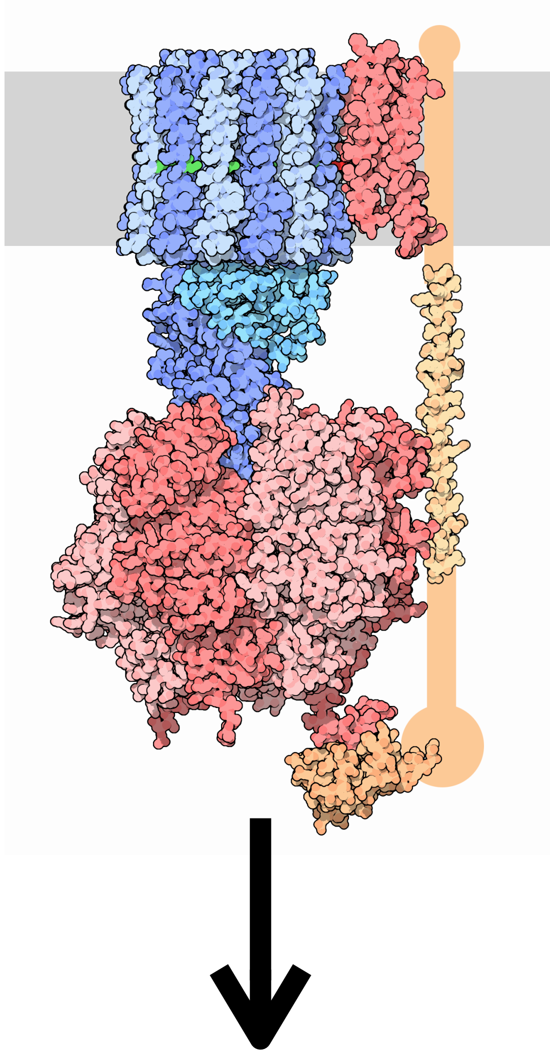

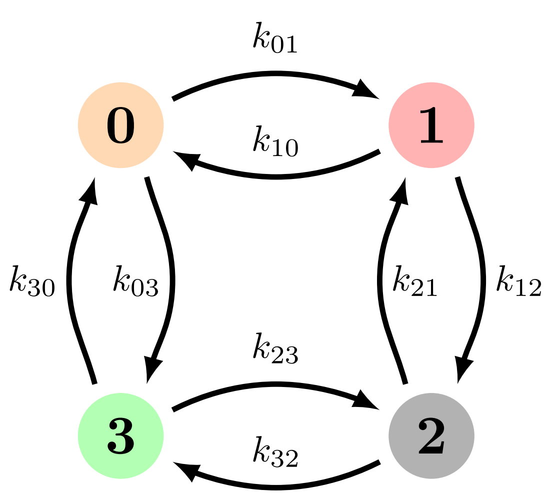

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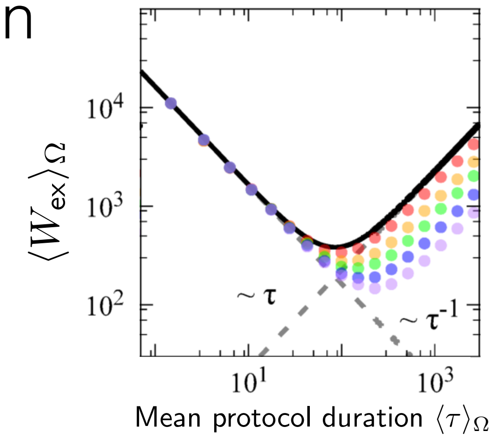

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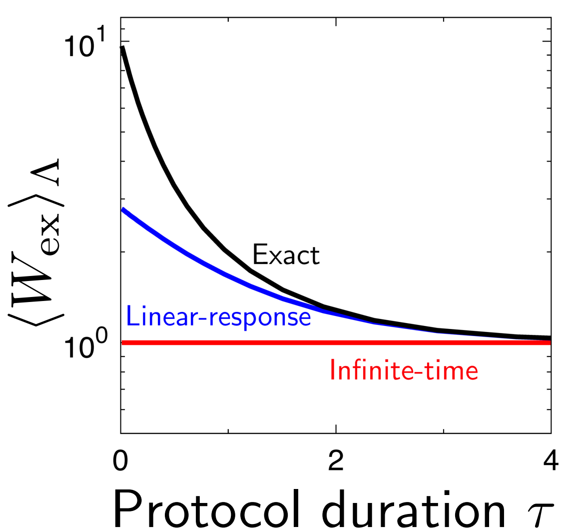

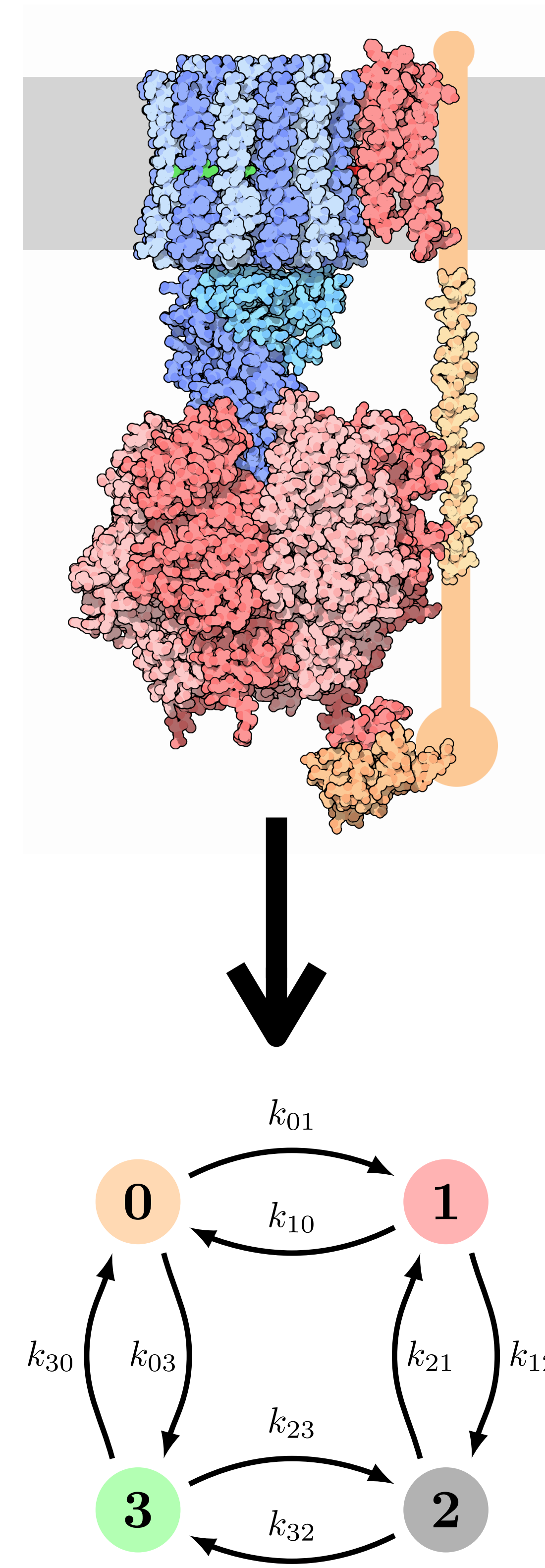

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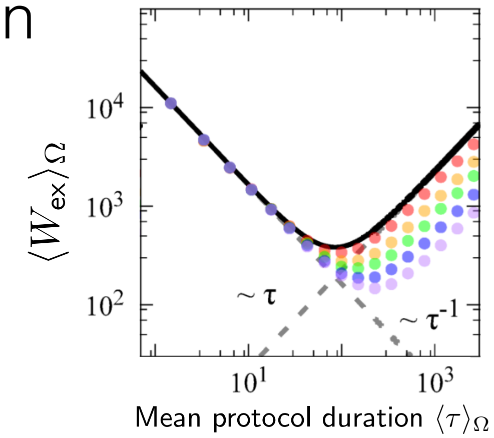

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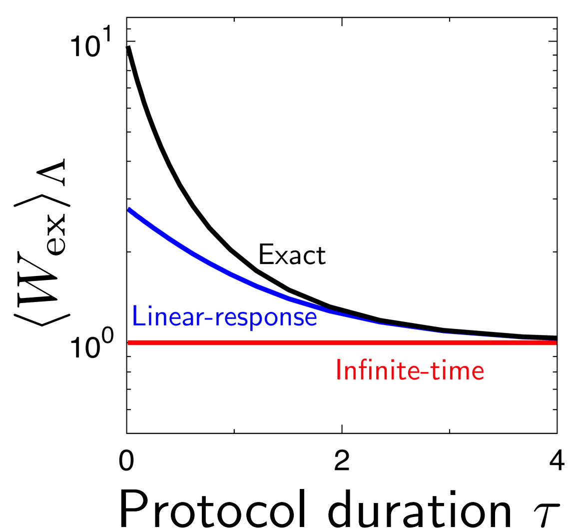

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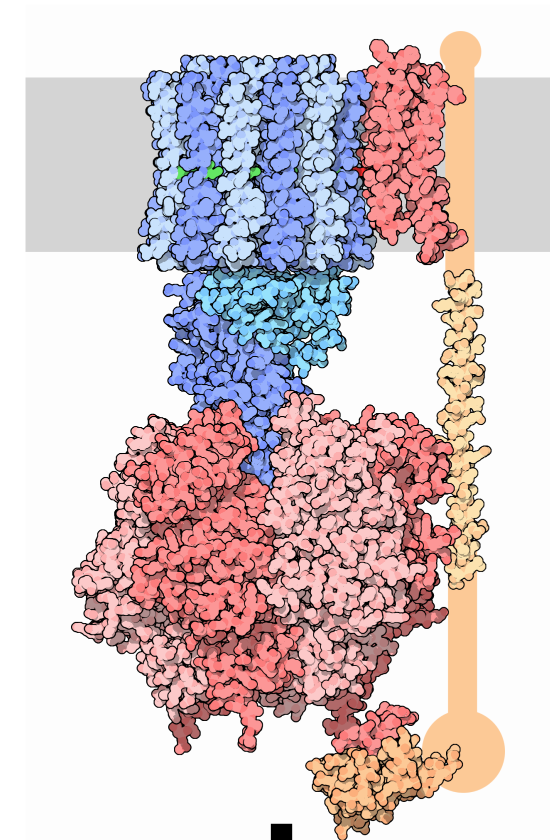

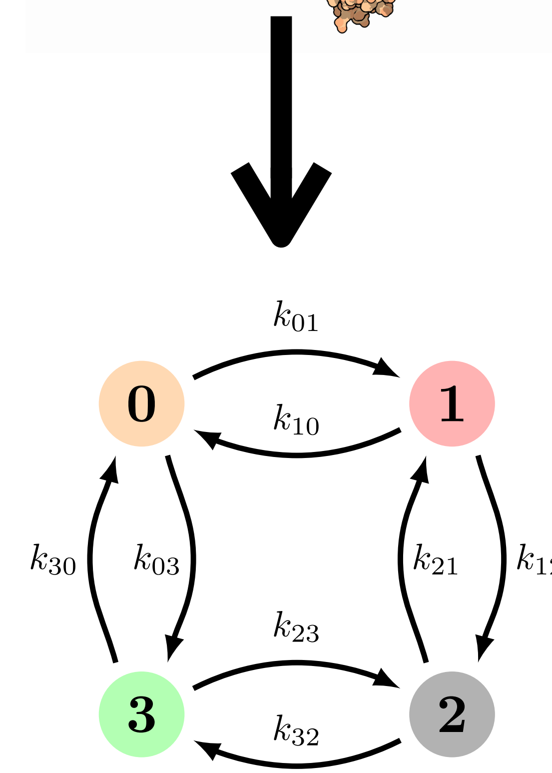

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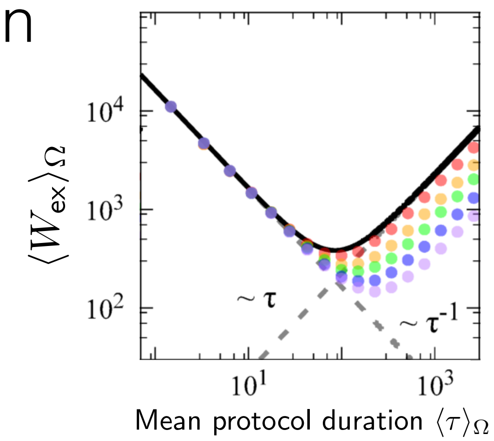

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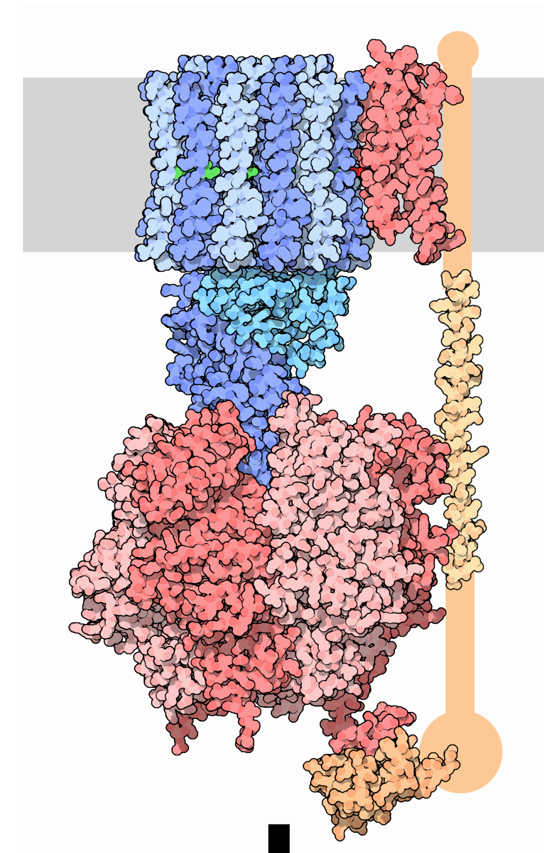
> S. J. Large, R. Chetrite & D. A. Sivak, *EPL*, **2018**, 124, 20001



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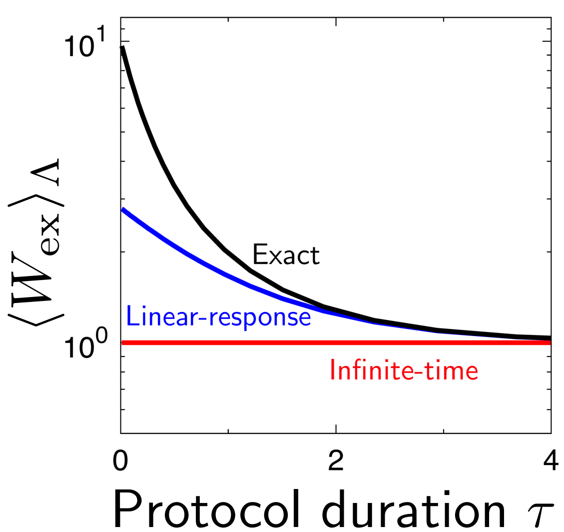

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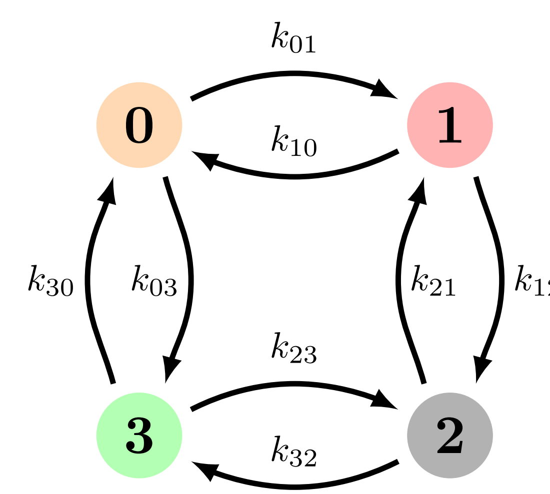

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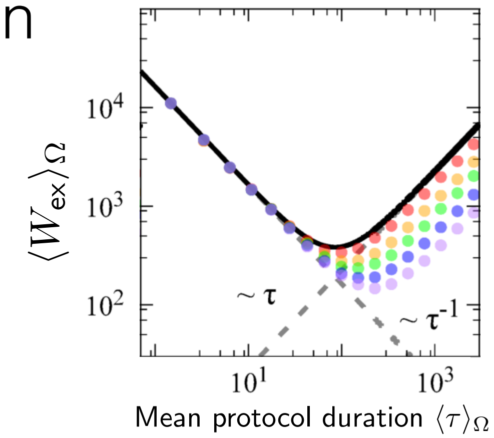

  - Finite duration minimum work
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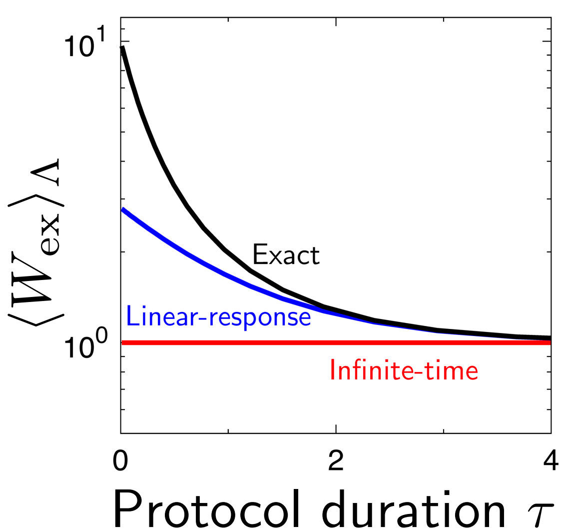
S. J. Large, R. Chetrite & D. A. Sivak, *EPL*, **2018**, 124, 20001

- Molecular machines are driven by chemical reactions, which are modelled as discrete processes



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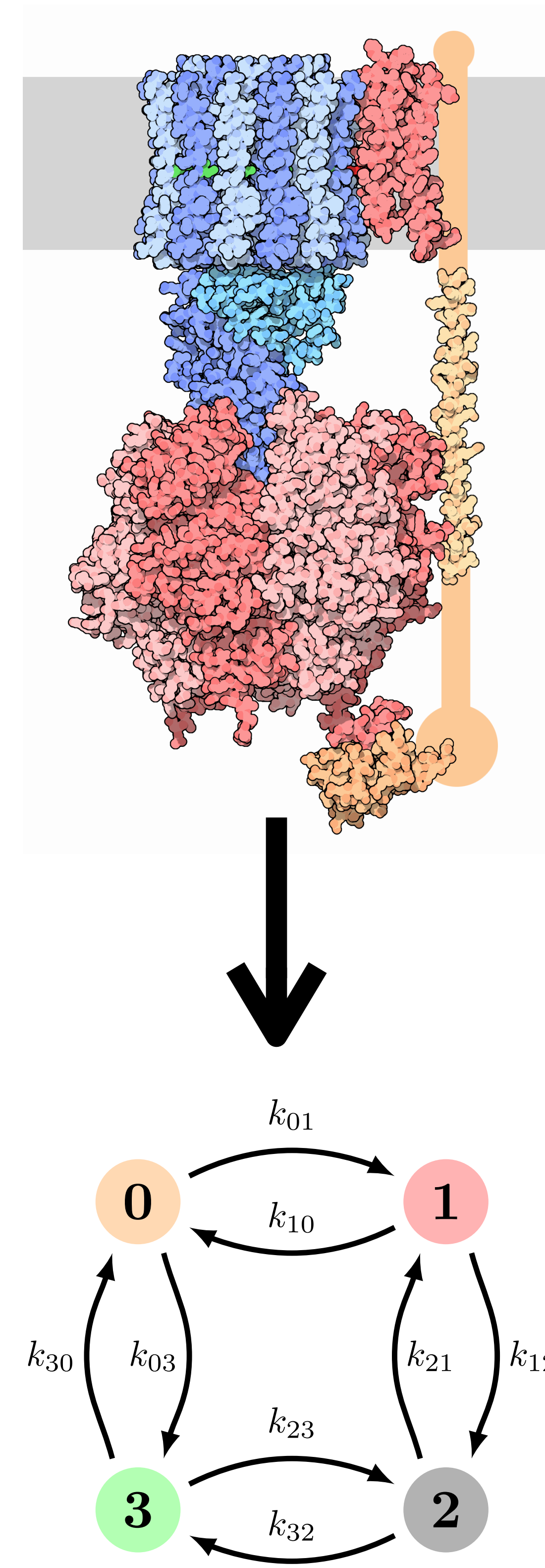

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SFU

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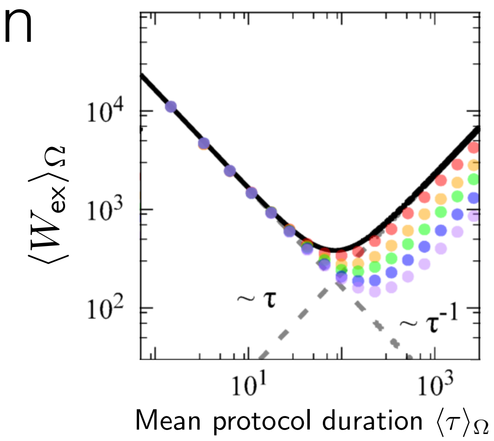

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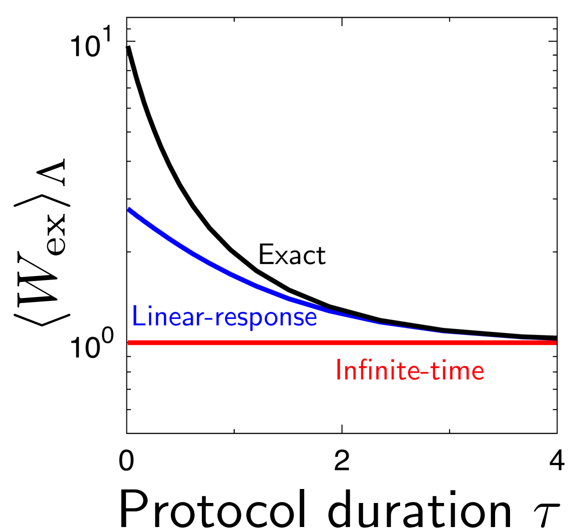

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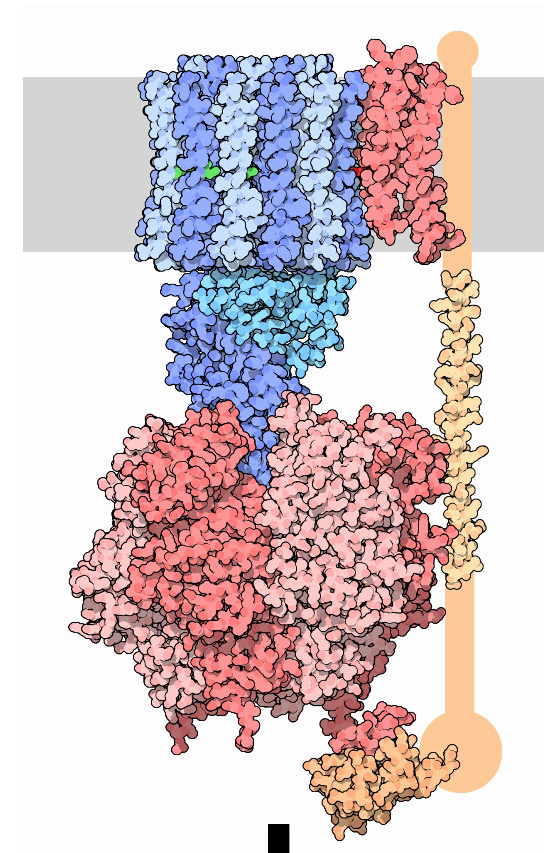

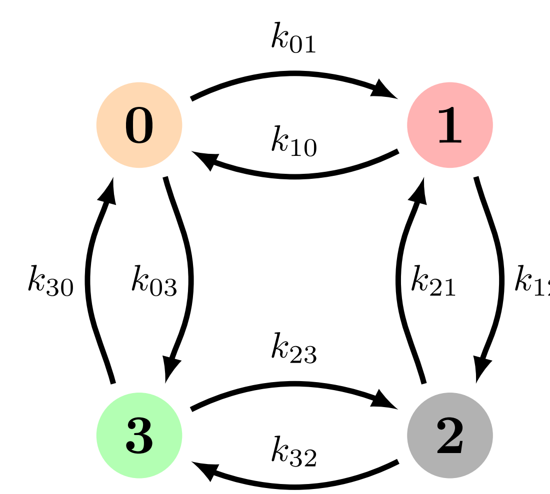

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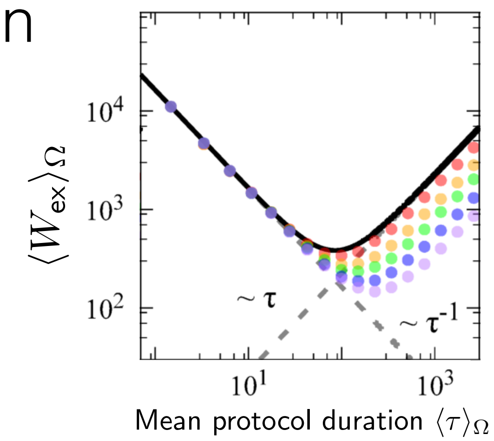

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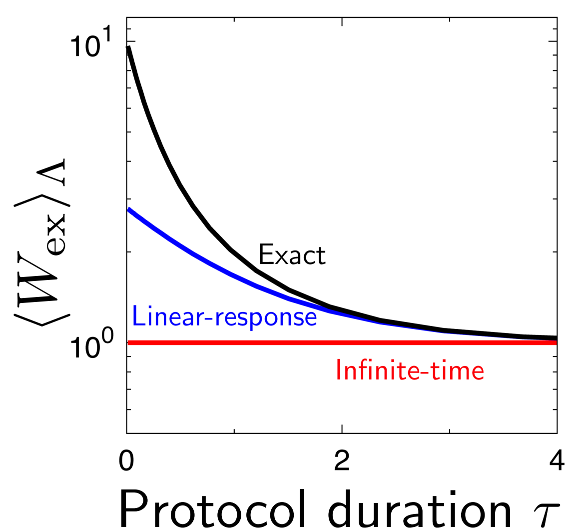

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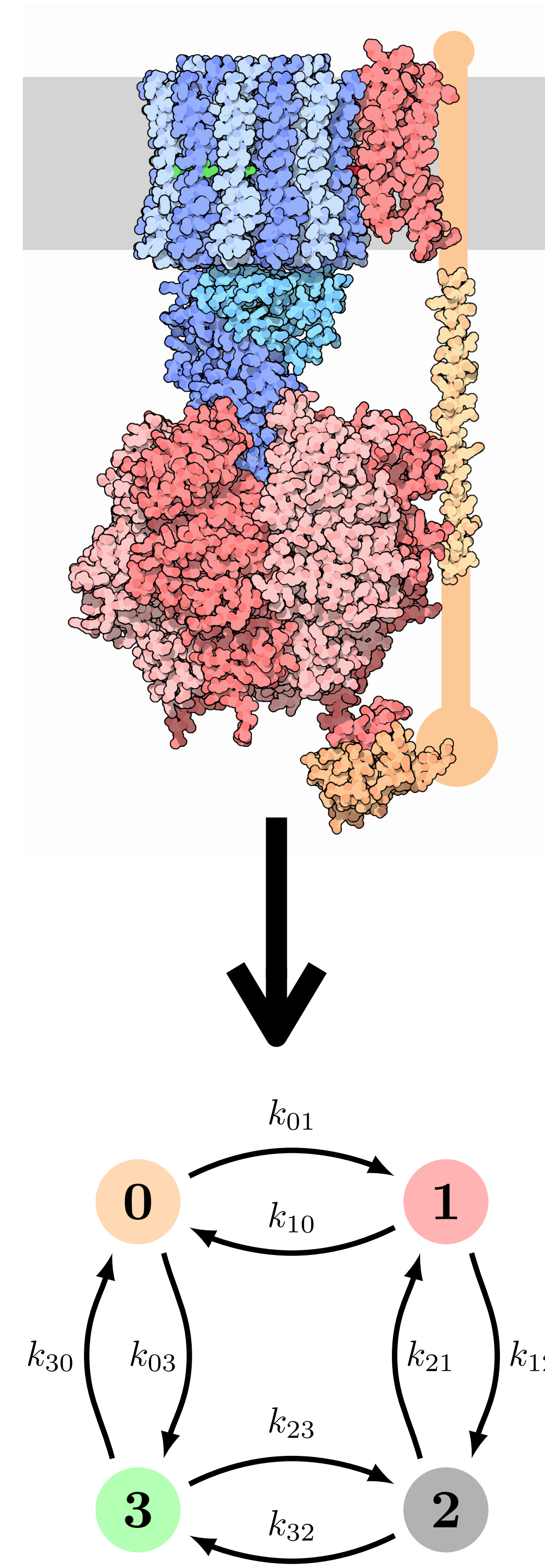

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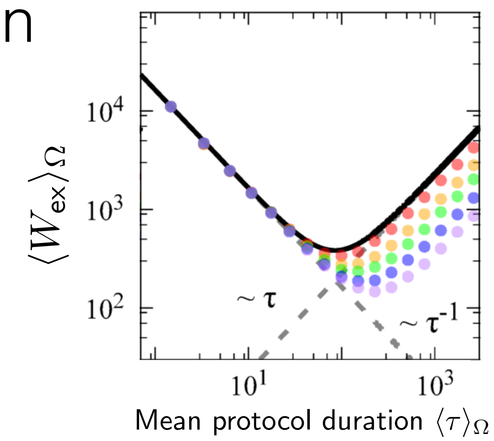

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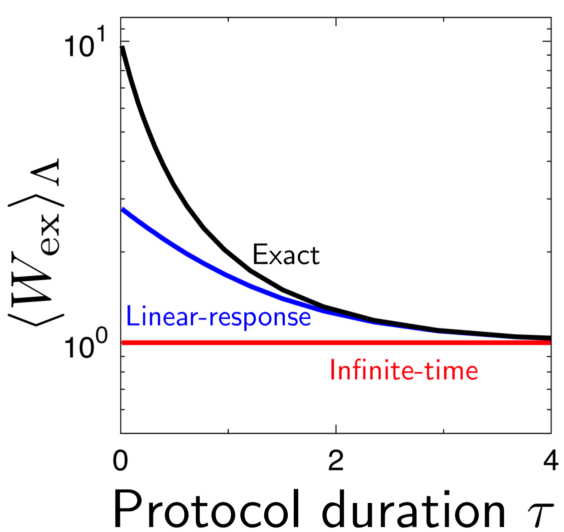

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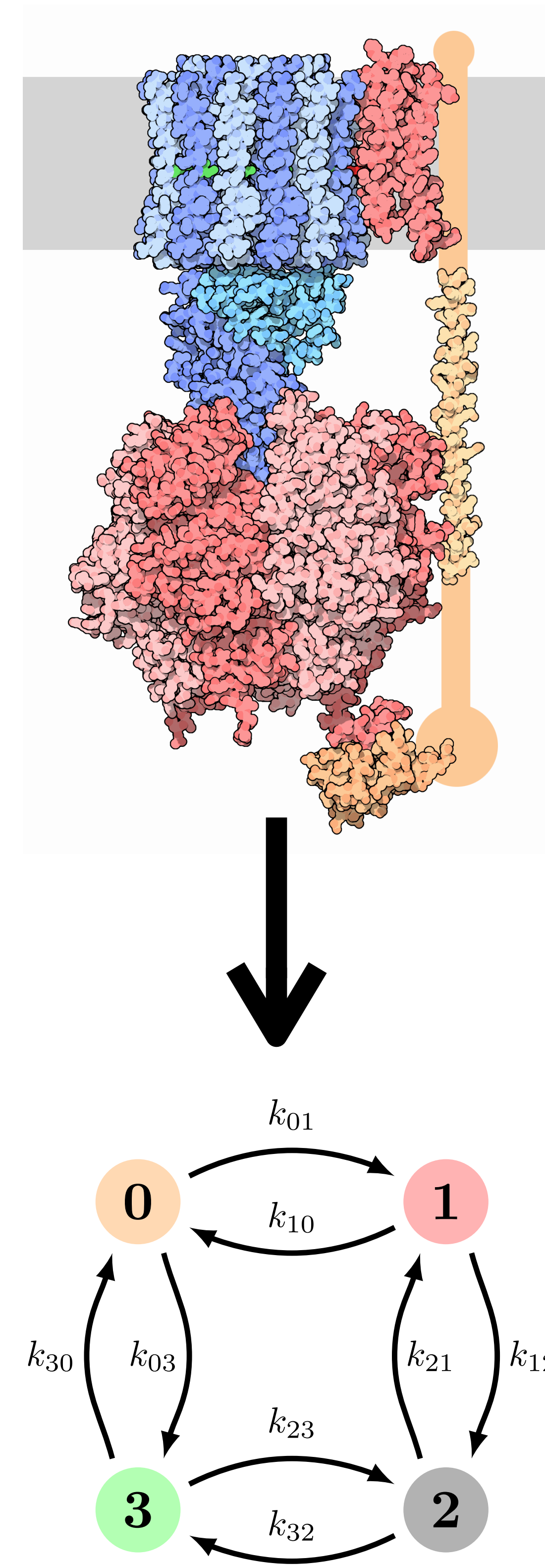
S. J. Large & D. A. Sivak, **2019**, arxiv: 1812.08216



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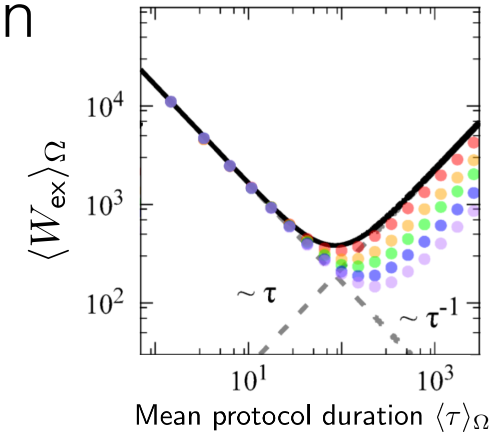

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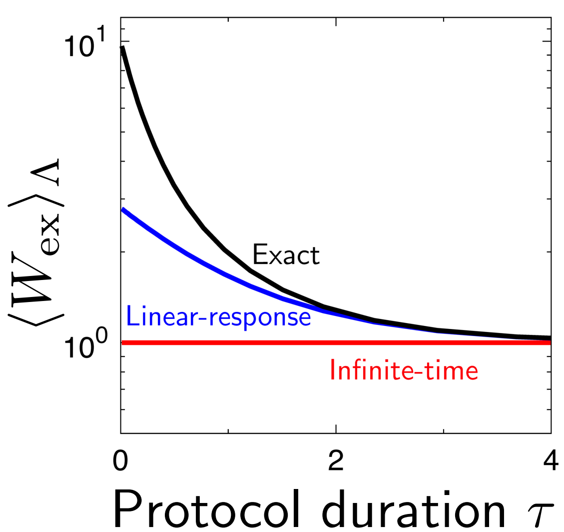

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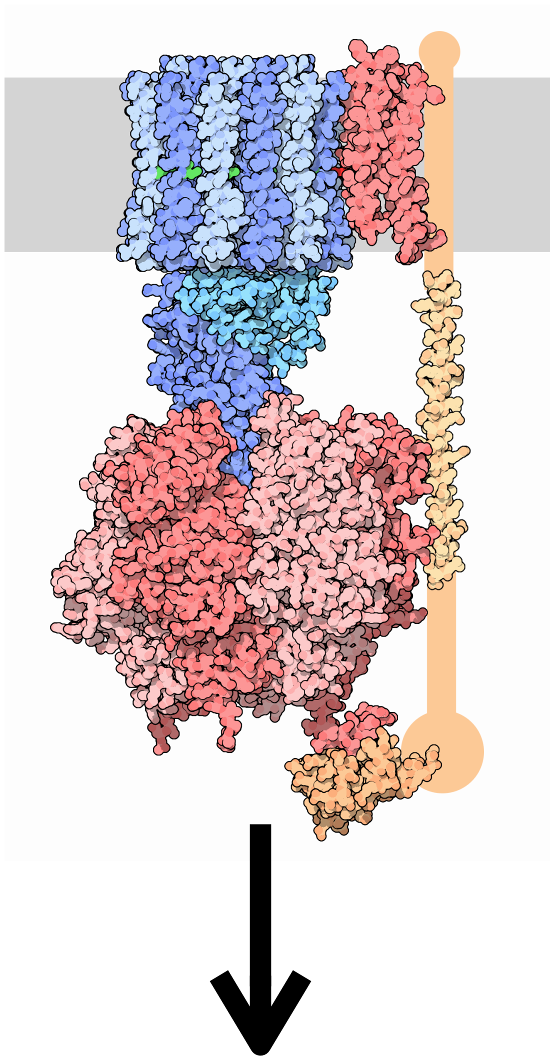
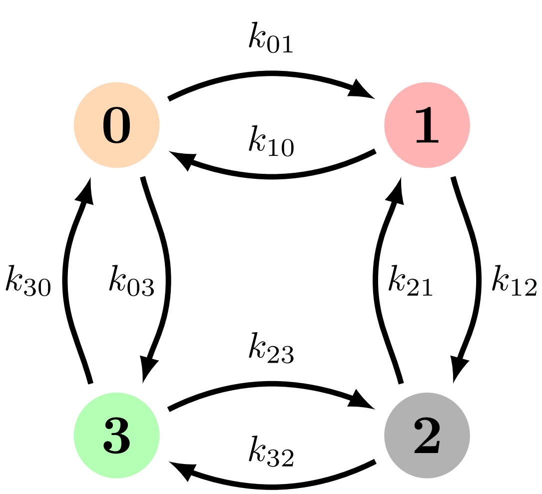
- How do these theories embed themselves into a broader picture of stochastic thermodynamics?





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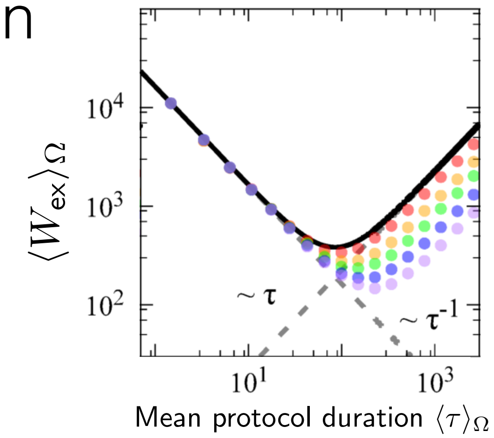

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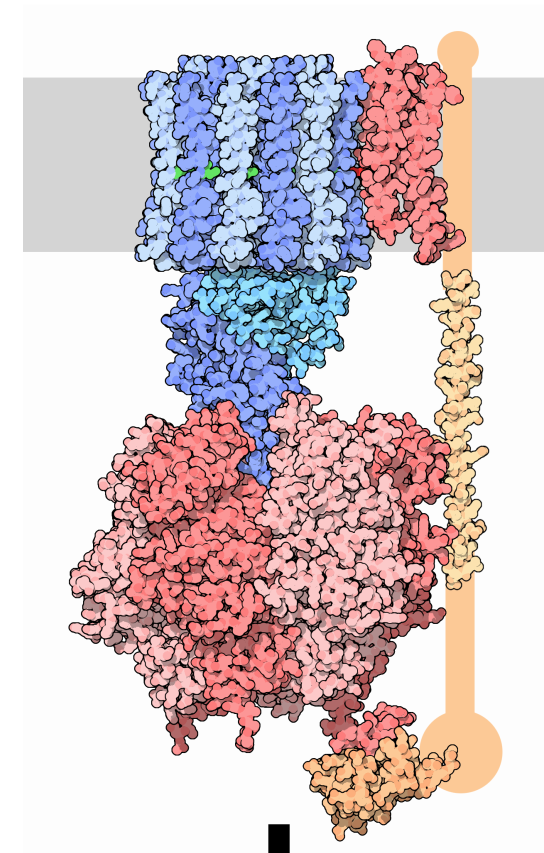

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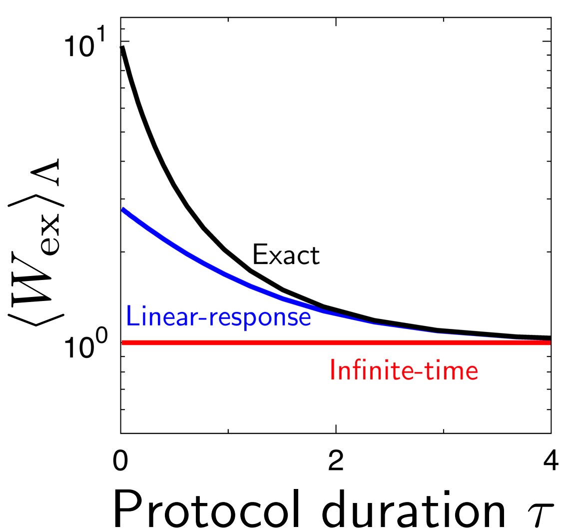

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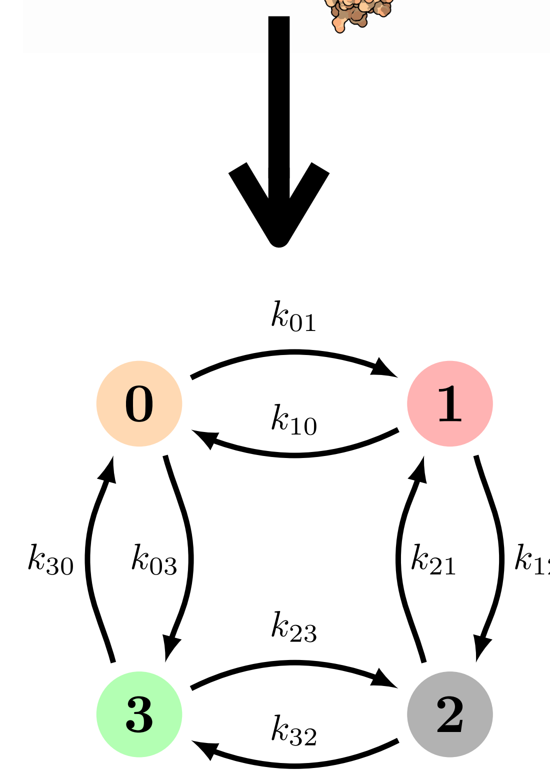

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Acknowledgements

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