Anticipation and Negative Group Delay in a retina

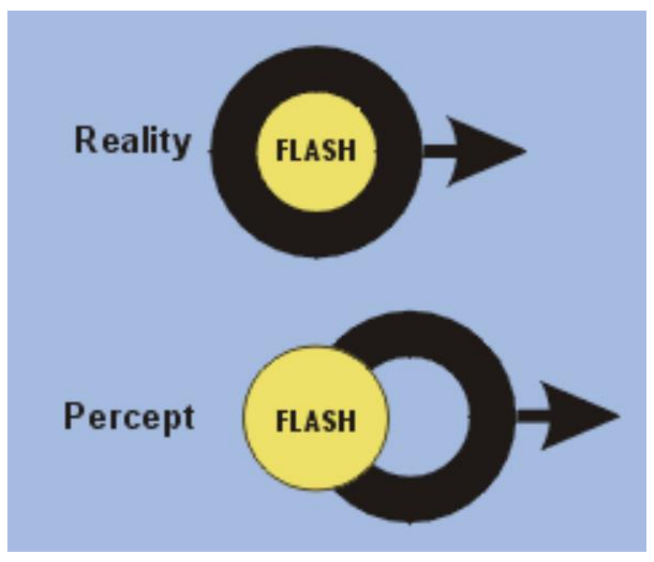
C. K. Chan (陳志強) ckchan@gate.sinica.edu.tw

Institute of Physics, Academia Sinica, Nankang, Taipei, Taiwan

Main points

- Anticipatory dynamics (AD) is unusual in that causality is not ordered by time: a retina can produce AD
- The phenomenon of Negative Group Delay (NGD) in the propagation of a pulsed signal can give rise to AD.
- Our goal: to understand the mechanism of anticipatory dynamics by using the concept of negative group delay in a retina

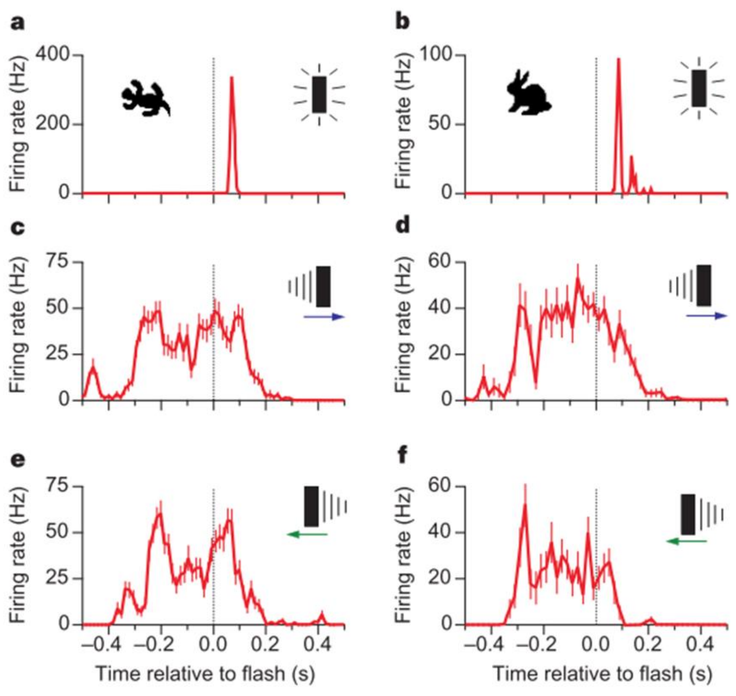
Anticipation in Retina



Flash-lag phenomenon

A moving ring should be at the center of the flash but we see it as moving faster. Motion induces anticipation in our perception

https://slideplayer.com/slide/11470660/



Recording from retina experiments by Berry et al. showed that the anticipation occurs at the retinal network.

https://www.nature.com/articles/18678 [1]

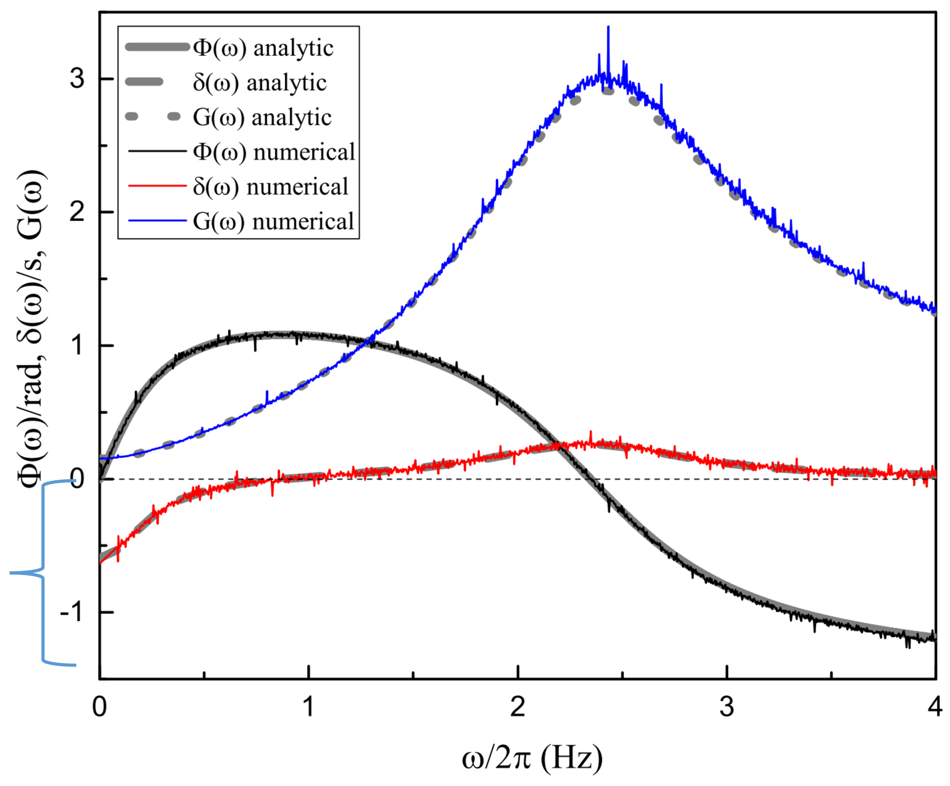
Model Result

$$H(\omega) = Y(\omega)/X(\omega) \equiv G(\omega)e^{i\Phi(\omega)}$$: Response function

$$\Phi(\omega) = -\arctan\left[\frac{w(\beta^2 - gk + w^2)}{\beta gk + \alpha(\beta^2 + w^2)}\right]$$

Group delay : $\delta(\omega) \equiv -d\Phi(\omega)/d\omega$

negative group delay here only



Only slow time varying signal can be anticipated [3]

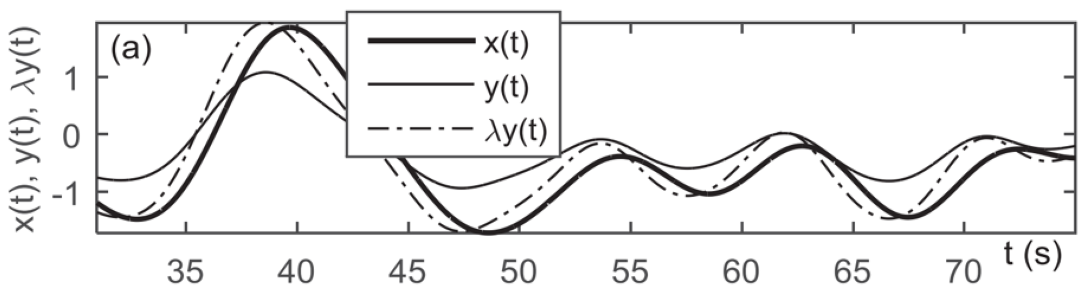
Voss's NGD Model for prediction

Delayed negative feed back can produce prediction

The response y(t) is now ahead of the input x(t) [2]

$$\dot{y}(t) = -\alpha y(t) + K[x(t) - y(t-\tau)]$$

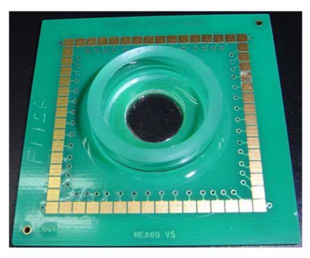
Storage of y(t) needed

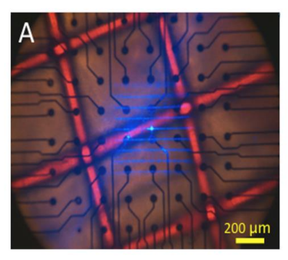


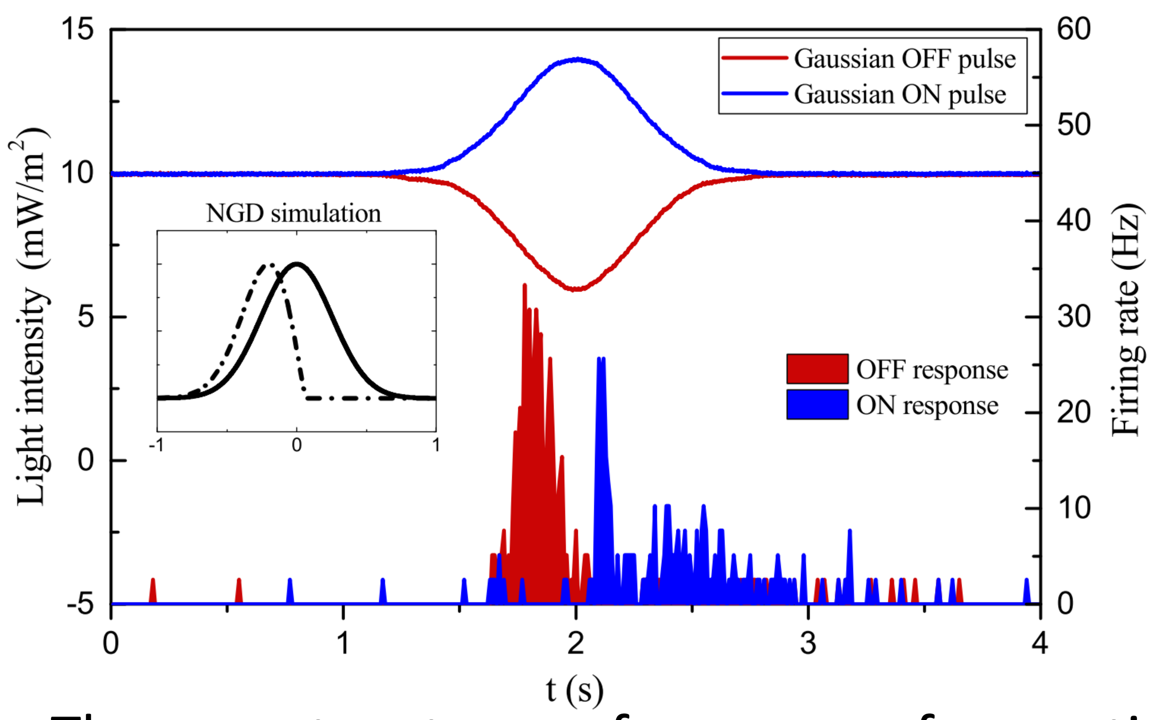
PHYSICAL REVIEW E **93**, 030201(R) (2016)

Experimental Result

- Retina from bull frogs on multi-electrode array
- Whole field stimulation through an LED







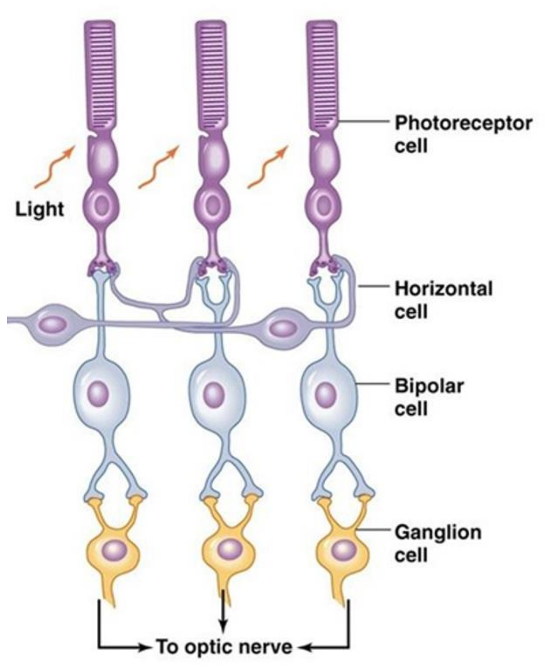
There are two types of responses from retina: ON and OFF

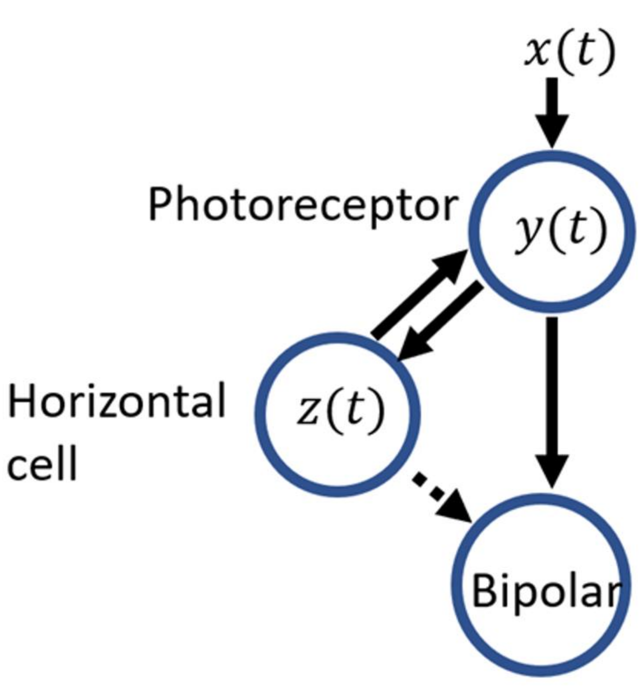
The ON response is delayed

The OFF response is advanced

Only the OFF pathway of a retina is anticipatory

Our NGD model for a Retina





$$\dot{y}(t) = -\alpha y(t) + K\big(x(t) - z(t)\big)$$

$$\dot{z}(t) = -\beta z(t) + g y(t)$$

Summary

1. Anticipatory dynamics in a retina can be understood as a phenomenon of negative group delay
2. Only slow varying signal can be anticipated
3. There is no violation of causality

[1] Berry et al, Anticipation of moving stimuli by the retina, Nature, **1999**, 398, 334

[2] Voss, H.U. Anticipating chaotic synchronization. Physical Review E **2000**, 61, 5115.

[3] C. K. Chan et al, Anticipation and negative group delay in a retina, Physical Review E, **2021,** 103, L020401

3. Relaxational entropy production classifies structures of interaction networks

Yoshiaki Horiike[1, 2], Shin Fujishiro, and Masaki Sasai

[1]Department of Applied Physics, Nagoya University, Nagoya, Japan

[2]Department of Neuroscience, University of Copenhagen, Copenhagen, Denmark

Introduction

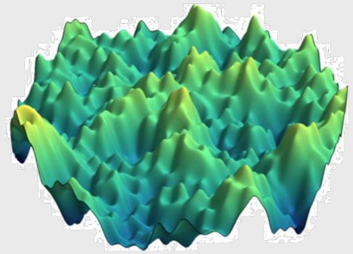
Relaxation ←?→ Interaction networks

e.g.

Glass

Spin glass

Protein folding



Biroli et al. (2018) New J. Phys.

Relaxational entropy production ← Question 1 — Interaction networks

Relaxational pathway ← Question 2 — Interaction networks

Models & Methods

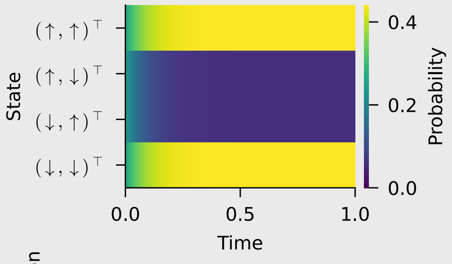
Ising model: up ↑ or down ↓

Interaction: Positive ↑—↑, Negative ↑----↓, No interaction ↑ ↓

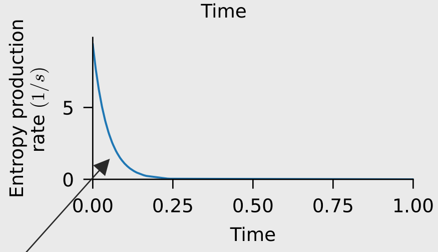
All possible networks

Solving a master equation

(from a uniform distribution)

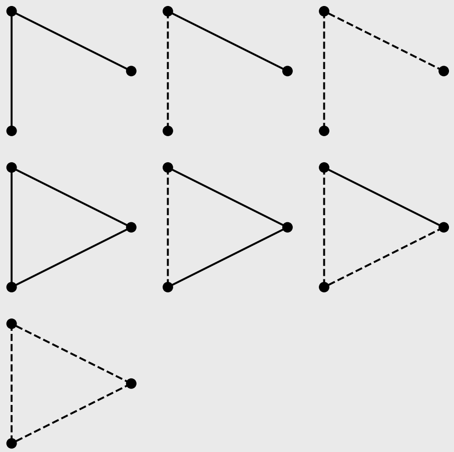


Entropy production rate



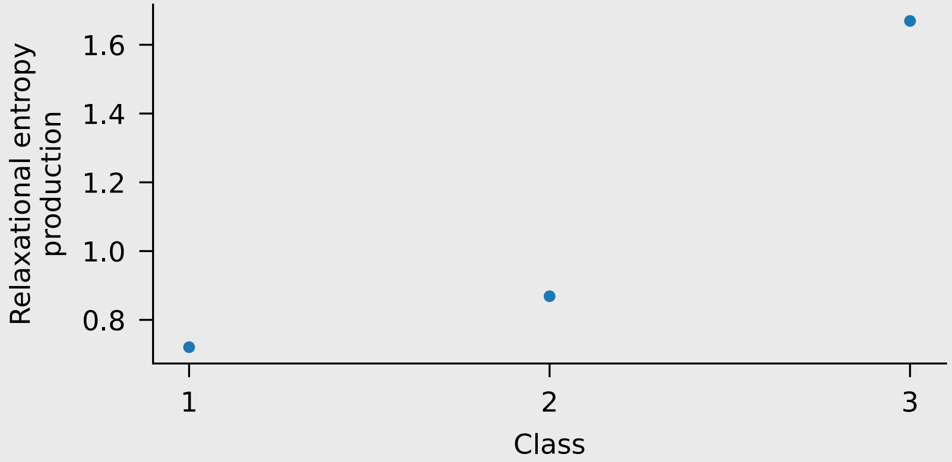
Relaxational entropy production

Results

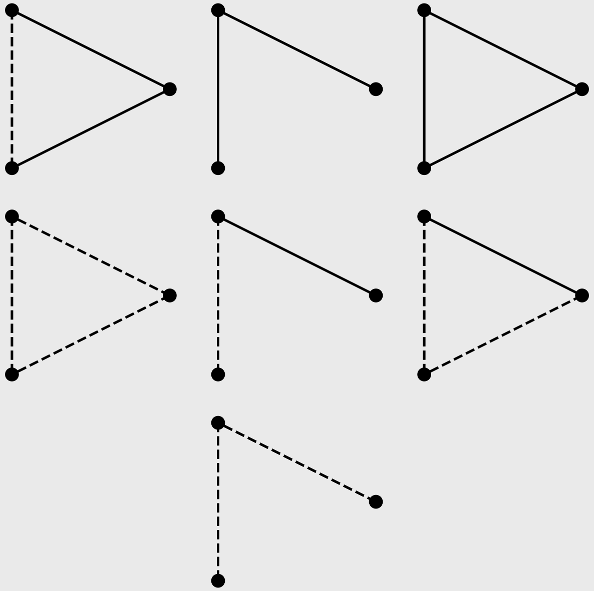


relaxational entropy production of 7 networks

3 classes of relaxational entropy production



sort



In short…

- Relaxational entropy production **can classify** interaction networks
- The classification **reflects structure** of interaction networks

In poster…

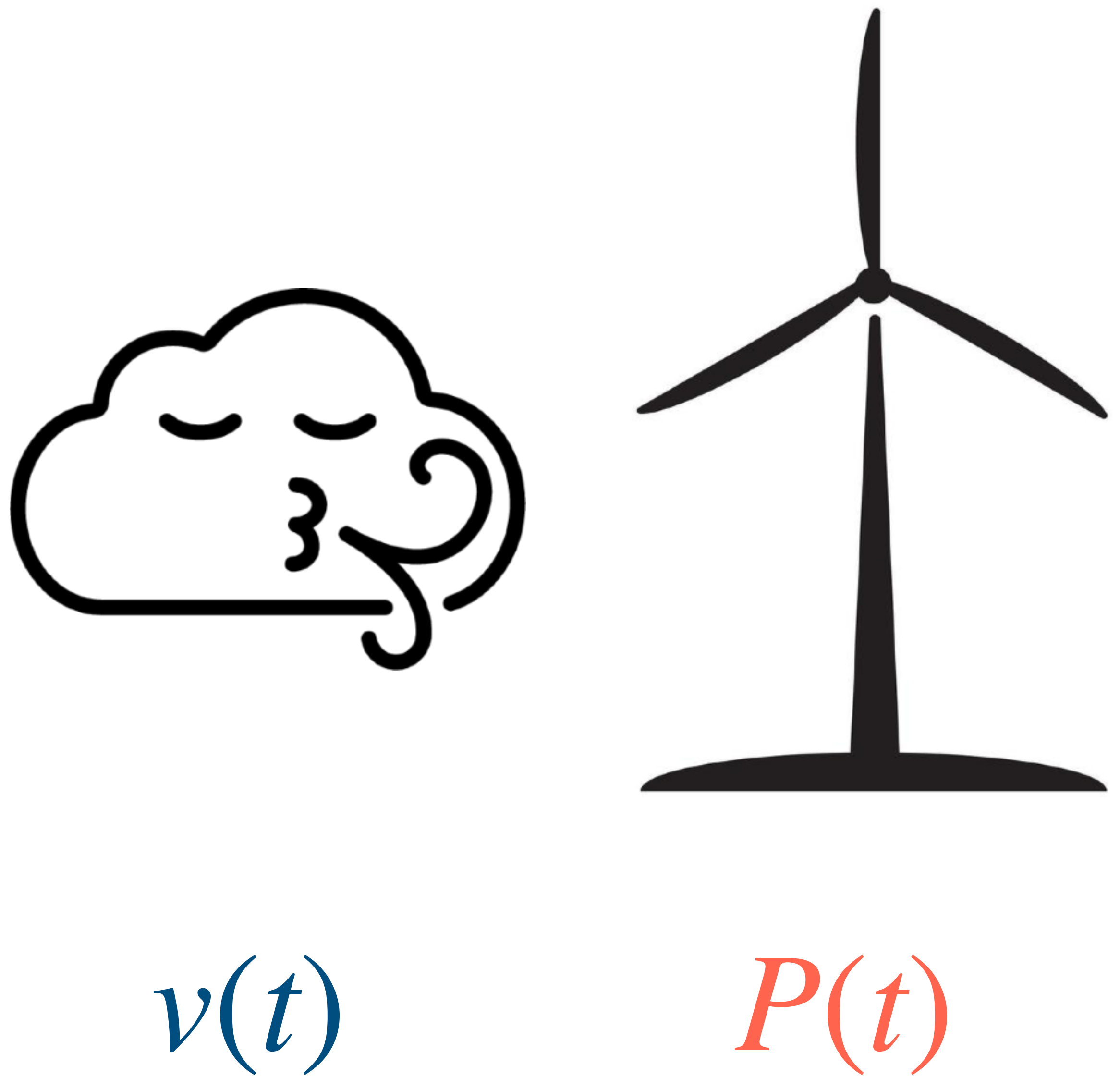
- Pathways of flux
- Quantifying network structure

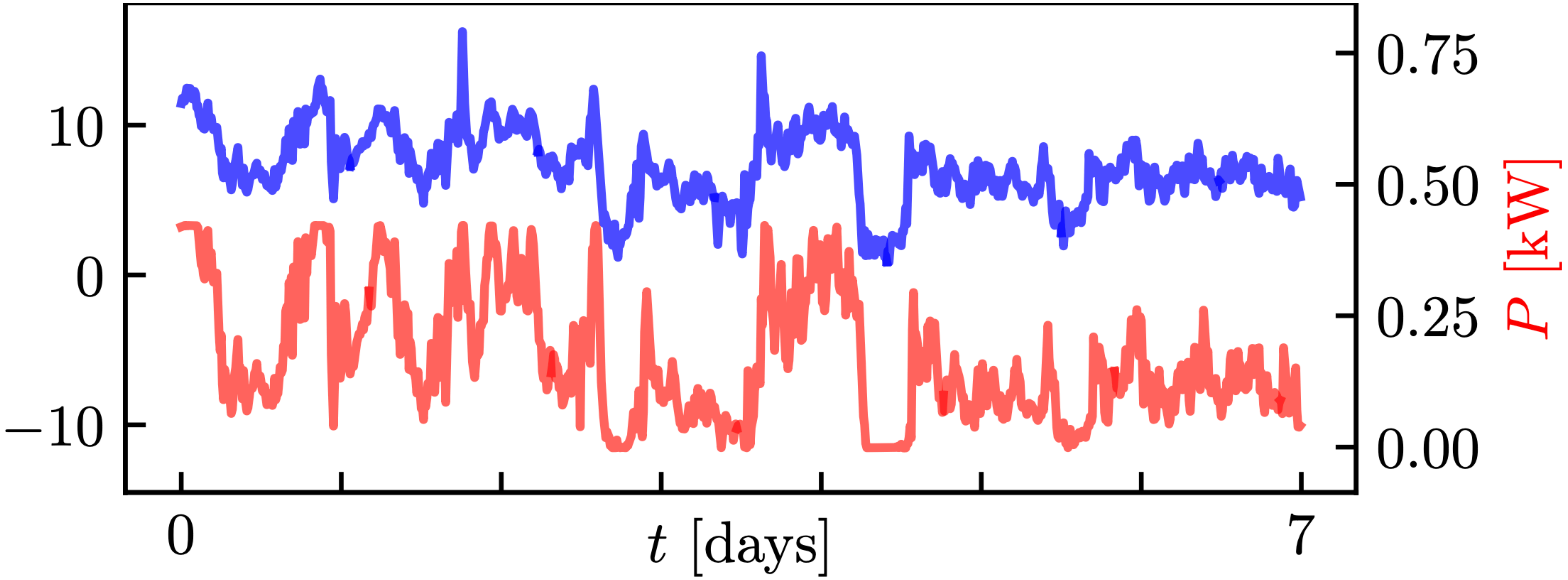
Scaling in Collective Intermittent Wind Power Production

Poster 4.

Samy Lakhal[1], Jim Sardonia[2], Mahesh M. Bandi[1].

Power turbines measure wind speed fluctuations.

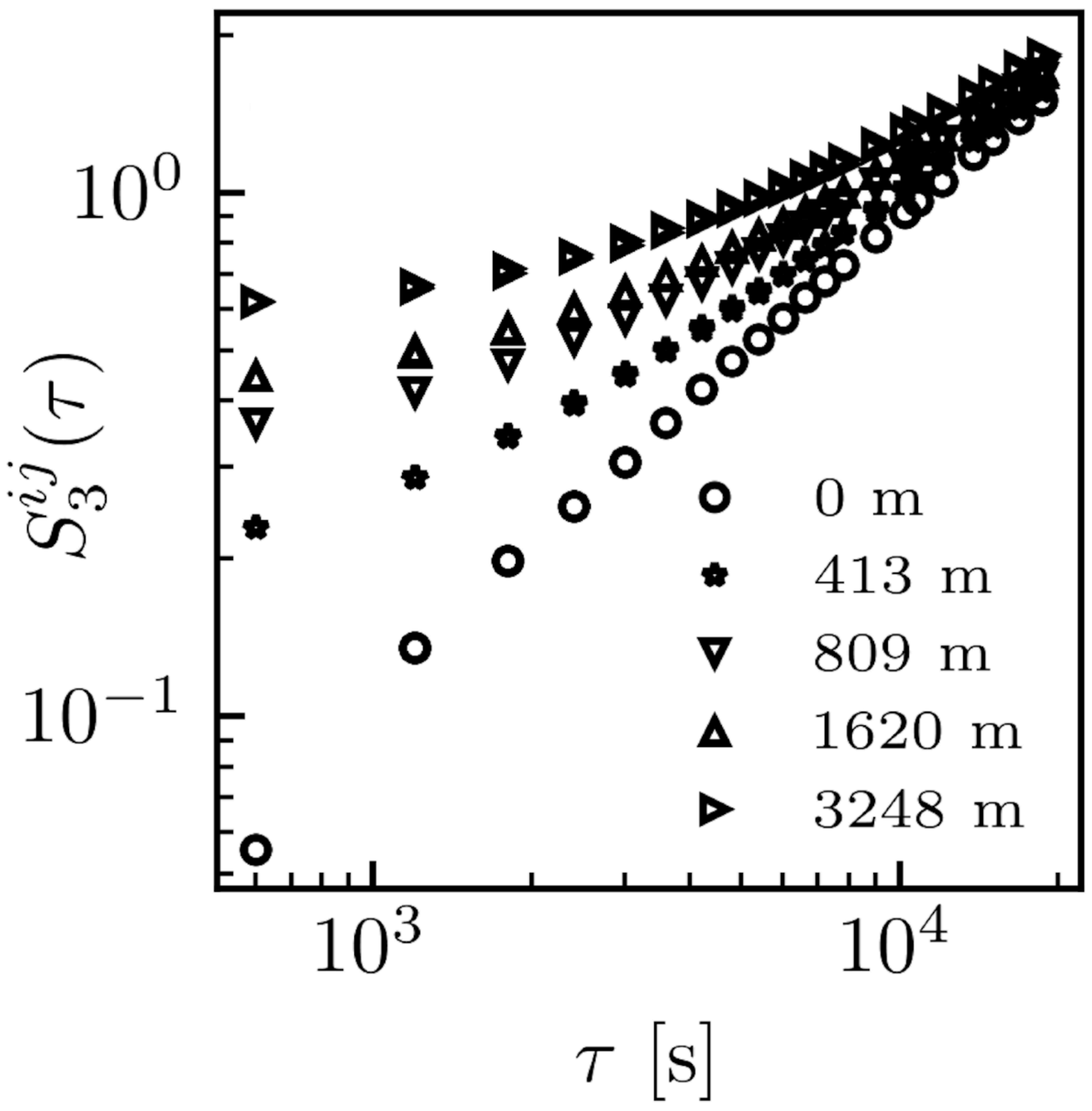




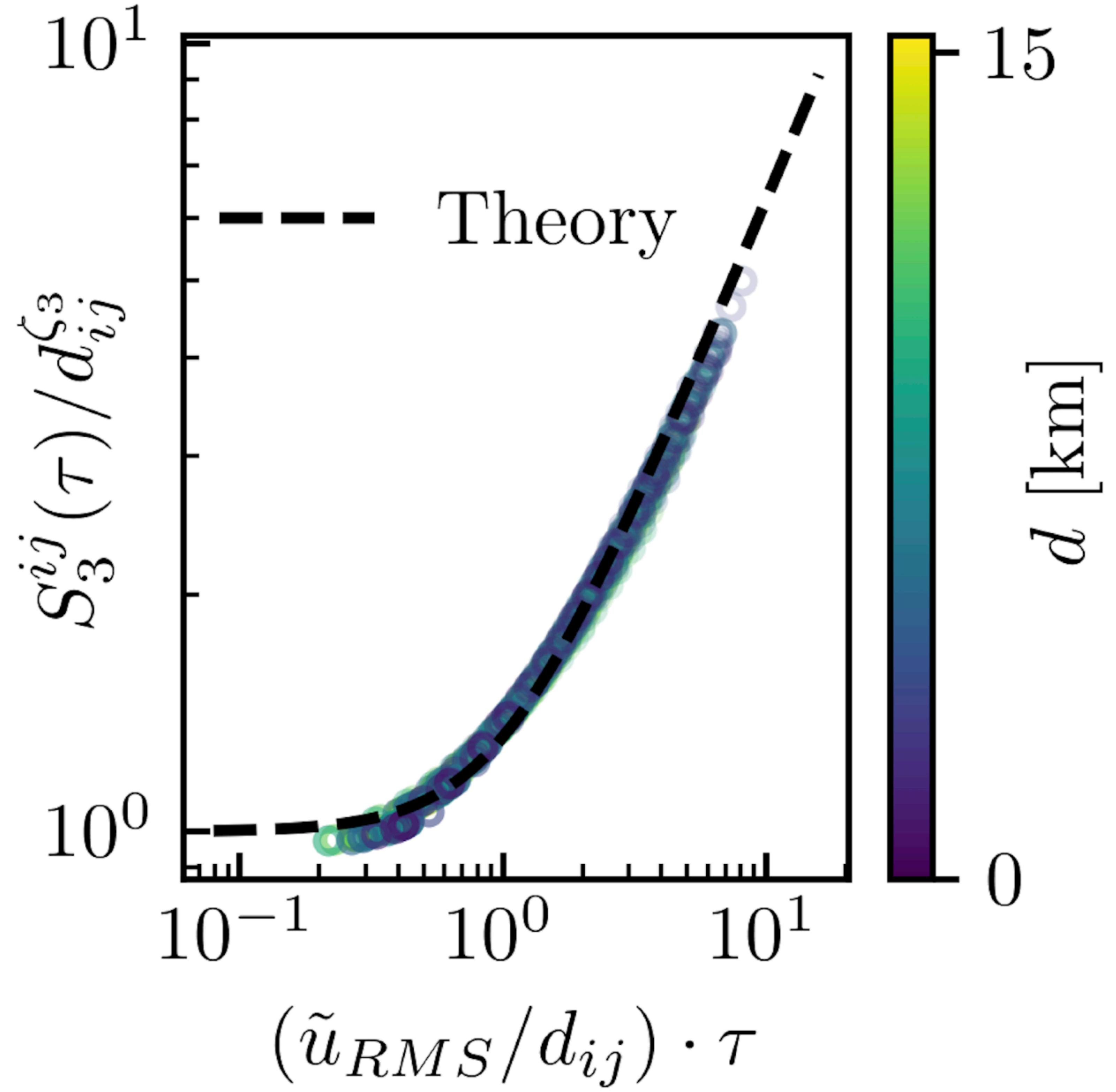
Unexpectedly, total farm power is more intermittent than single turbine.

[1] Nonlinear and Non-equilibrium Physics Unit, OIST Graduate University, Onna 904 0495, Japan
[2] Exus Renewables North America, Pittsburgh, Pennsylvania, USA

An explanation: atmospheric wind is correlated in time and space, and so are power output.
These correlations prevent extreme-events from smoothing out during aggregation.



Spatial Collapse



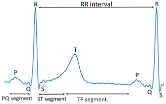
More on Poster 4

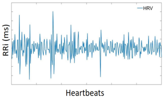
Irreversibility properties of ECGs as indicators of heart conditions

Cesar Maldonado*, Nazul Merino Negrete* & Raúl Salgado-García†
*IPICyT - Mexico. †CInC-UAEM - Mexico

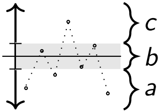
Healthy (& young) bodies produce more entropy than ill (& elder) ones.

We obtain data from PhysioBank





We symbolize ECG signals



We do it for 3, 5, and 7 symbols.

We compute irreversibility indices for those symbolized sequences

$$e_p(P) = \frac{1}{2} \sum_{i,j \in S} (\pi_i p_{ij} - \pi_j p_{ji}) \log \frac{\pi_i p_{ij}}{\pi_j p_{ji}}. \qquad (1)$$

$$D_n\left(\mathbb{P}(X_1^n) | \mathbb{P}(X_n^1)\right) = \sum \mathbb{P}(x_1^n) \log \left(\frac{\mathbb{P}(x_1^n)}{\mathbb{P}(x_n^1)} \right).$$

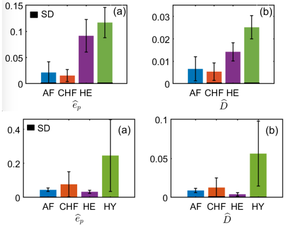
We introduce the Lag irreversibility function given by:

$$L(\tau) = D(\mathbb{P}(X_n = s_0; X_{n+\tau} = s_\tau) | \mathbb{P}(X_n = s_\tau; X_{n+\tau} = s_0))$$

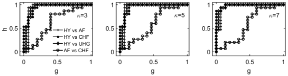
$$= \sum_{s_0} \sum_{s_\tau} \mathbb{P}(X_n = s_0; X_{n+\tau} = s_\tau) \log \left(\frac{\mathbb{P}(X_n = s_0; X_{n+\tau} = s_\tau)}{\mathbb{P}(X_n = s_\tau; X_{n+\tau} = s_0)} \right).$$

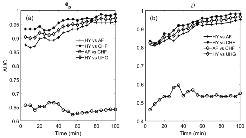
Irreversibility properties of ECGs as indicators of heart conditions

We obtain clearly higher values of EPR and KLD in healthy subjects



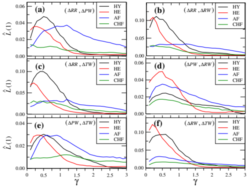
We test the efficiency of our method of discrimination using ROC analysis



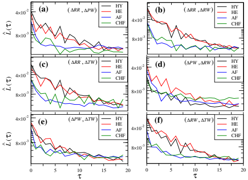


Joint work with Nazul Merino. *Irreversibility indices as indicators of heart conditions from electrocardiographic signals*. Physica A. 2024

We compute the 1-step Lag irreversibility function for joint variability signals



Lag irreversibility as a function of the lag



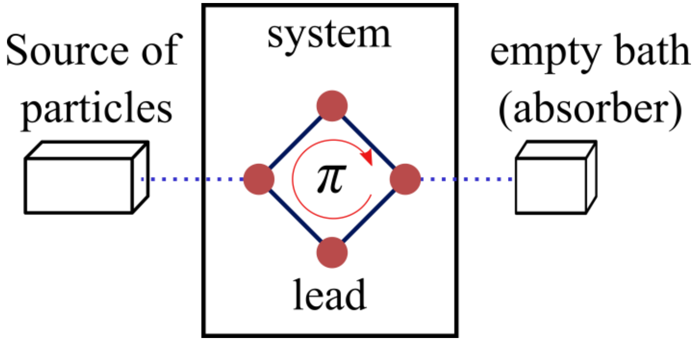
Joint work with Raúl Salgado & Nazul Merino. *Sorting ECGs by lag irreversibilty*. Physica D. 2023

Conductance transition with interacting bosons in an Aharonov-Bohm cage

P. S. Muraev ,[1,2] A. R. Kolovsky ,[2,3] and S. Flach[4]
1 IRC SQC, Siberian Federal University, 660041 Krasnoyarsk, Russia
2 School of Engineering Physics and Radio Electronics, Siberian Federal University, 660041 Krasnoyarsk, Russia
3 Kirensky Institute of Physics, Federal Research Center KSC SB RAS, 660036 Krasnoyarsk, Russia
4 Center for Theoretical Physics of Complex Systems, Institute for Basic Science, 34126 Daejeon, Republic of Korea

Introduction

One of the most famous example of the ABF (all bands are flat) lattices is the π-flux diamond chain. In the present work we address the effect of an interparticle interaction on the transport of Bose particles across the diamond lattice from the viewpoint of laboratory experiments where one injects bosons into the first site of the lattice by using an external coherent driving pump and withdraws them from the last site with a sink.



The Model

The considered setup is described by the following master equation for the reduced density matrix $\hat{\mathcal{R}}(t)$ of microwave photons,

$$\frac{d\hat{\mathcal{R}}}{dt} = -\frac{i}{\hbar_{\rm eff}}[\hat{\mathcal{H}},\hat{\mathcal{R}}] - \frac{\gamma}{2}\left(\hat{a}_L^\dagger\hat{a}_L\hat{\mathcal{R}} - 2\hat{a}_L\hat{\mathcal{R}}\hat{a}_L^\dagger + \hat{\mathcal{R}}\hat{a}_L^\dagger\hat{a}_L\right)$$

where γ is the rate of photon absorption by a measurement device and the Hamiltonian $\hat{\mathcal{H}}$ has the form

$$\hat{\mathcal{H}} = \hbar_{\rm eff}\Delta\sum_{l=1}^{L}\hat{n}_l - \frac{1}{2}\sum_{l,l'=1}^{L} J_{l,l'}\hbar_{\rm eff}\left(\hat{a}_l^\dagger\hat{a}_{l'} + \text{H.c.}\right) + \\ + \frac{g\hbar_{\rm eff}^2}{2}\sum_{l=1}^{L}\hat{n}_l\left(\hat{n}_l - 1\right) + \frac{\Omega\sqrt{\hbar_{\rm eff}}}{2}\left(\hat{a}_1^\dagger + \hat{a}_1\right).$$

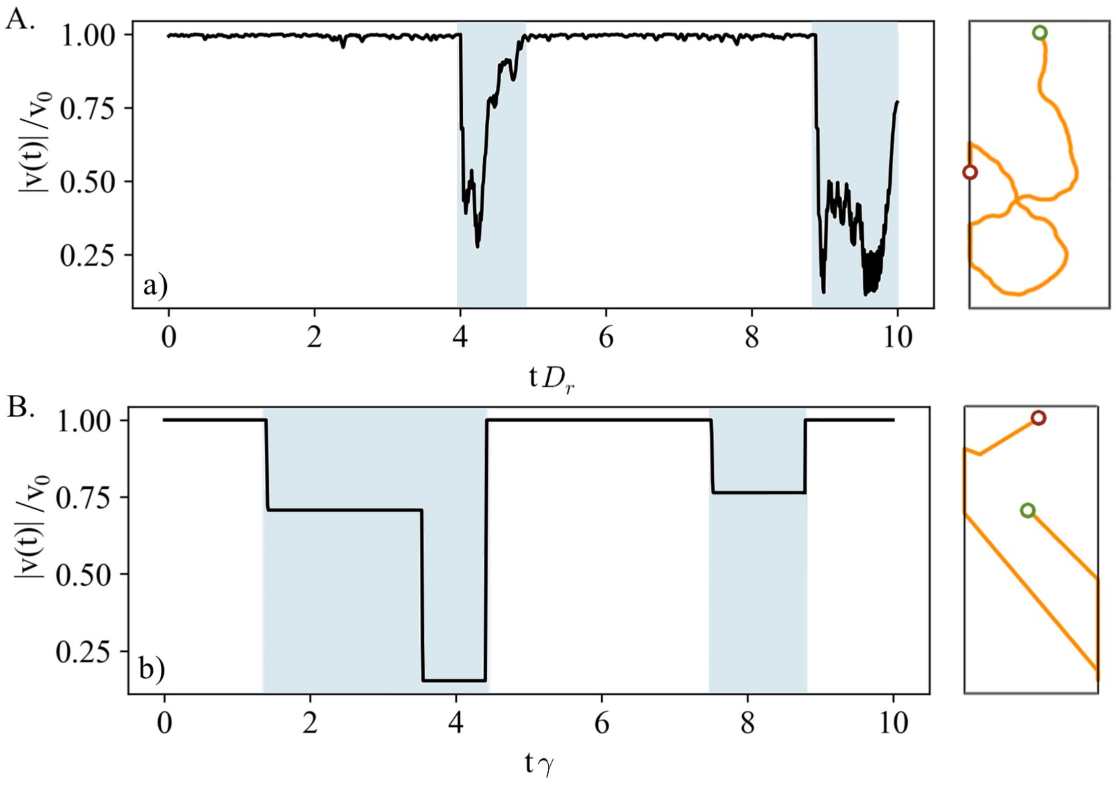
Results

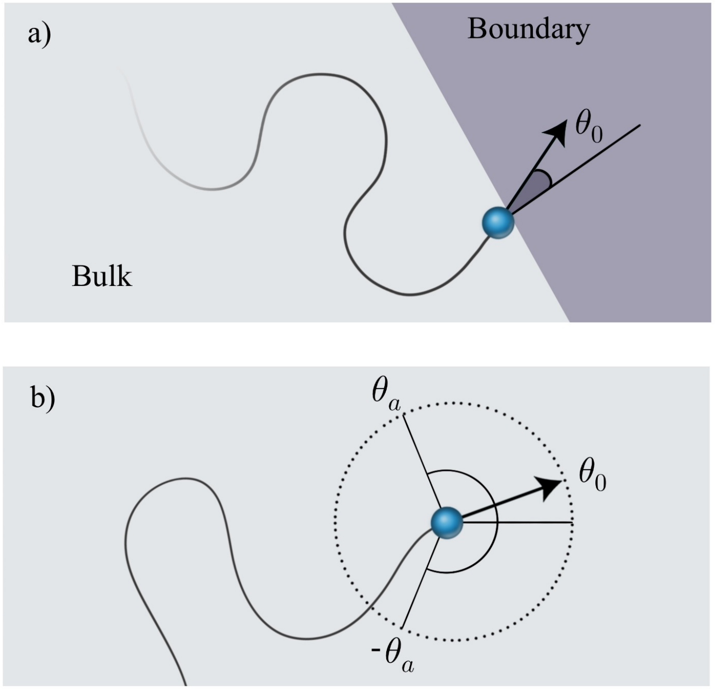
We demonstrate that in the classical regime the system is insulating up to a critical value of the pump strength in the presence of mean-field interactions, while in the quantum regime there is a particle pair transport and weak conductance below the critical pump strength. Additionally, we will show that there is a swift crossover from the quantum into the classical regime by using a pseudoclassical method upon increasing the number of particles or decreasing the effective Planck constant $\hbar_{\rm eff}$.

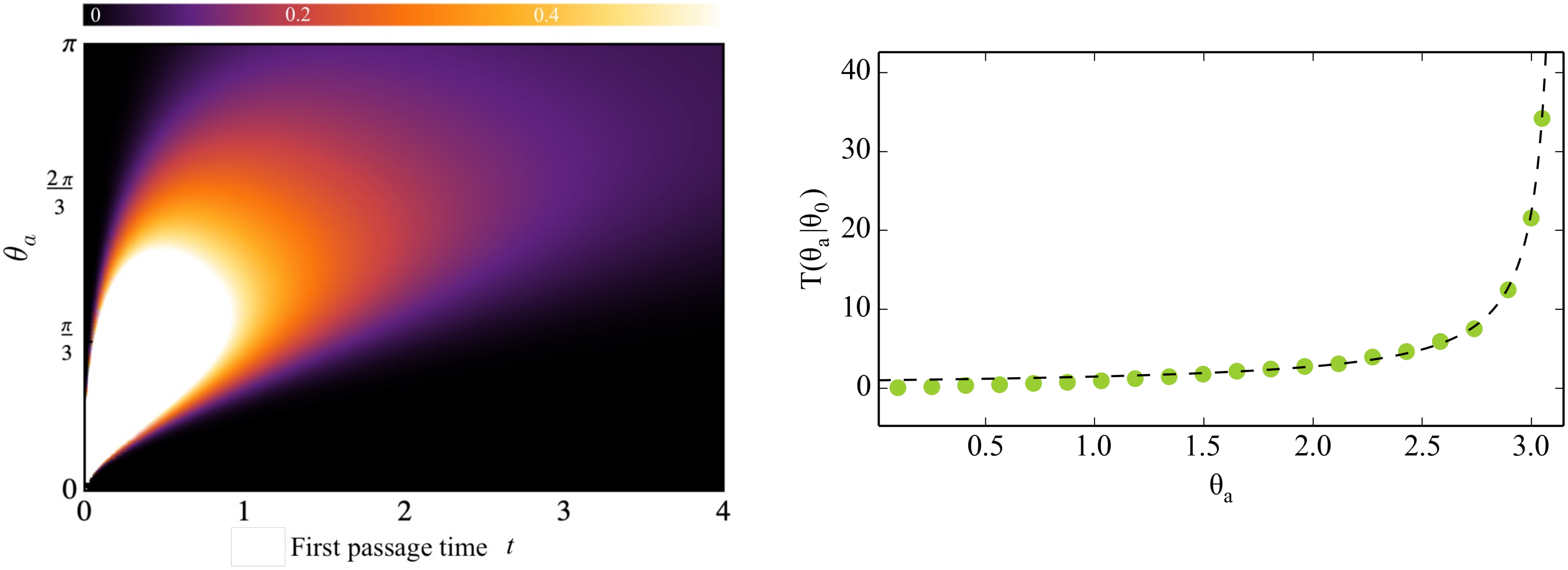
7. Trapping of active Brownian and run-and-tumble particles: A first-passage time approach

E. Q. Z. Moen[1], K. S. Olsen[2], **J. Rønning[3]** and L. Angheluta[1]

1. *The Njord Center, Department of Physics, University of Oslo*
2. *Institut für Theoretische Physik II - Weiche Materie, Heinrich-Heine-Universität Düsseldorf*
3. *Nonlinear and Non-Equilibrium Physics Unit, Okinawa Institute of science and technology*







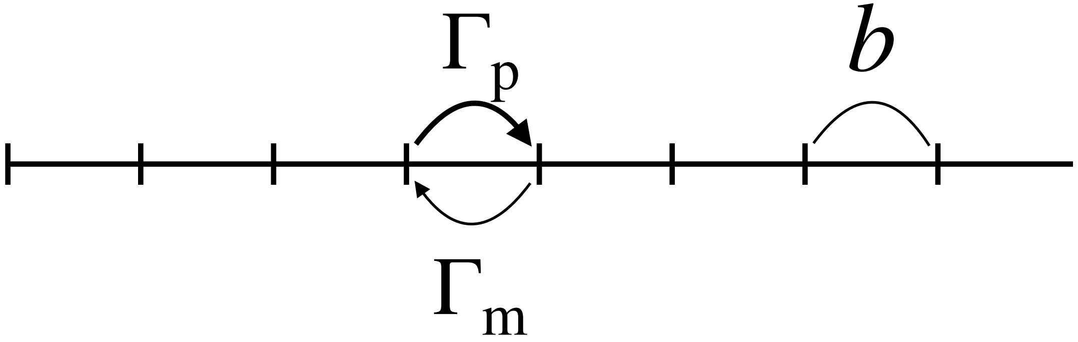
0
0.2
0.4
π
2π/3
π/3
0
θ_a
0
1
2
3
4
First passage time t
40
30
20
10
0
T(θ_a|θ_0)
0.5
1.0
1.5
2.0
2.5
3.0
θ_a

Influence of reflecting boundary on fluctuation relation in a lattice random walk model

Kazuhiko Seki AIST, k-seki@aist.go.jp

https://arxiv.org/abs/2308.13744v2
K. Seki, J. Stat. Mech. (2023) 123207

Random walk model



Local detailed balance

q :Charge

F :External electric field

$$\frac{\Gamma_{\mathrm{p}}(F)}{\Gamma_{\mathrm{m}}(F)} = \exp\left[qFb/(k_{\mathrm{B}}T)\right]$$

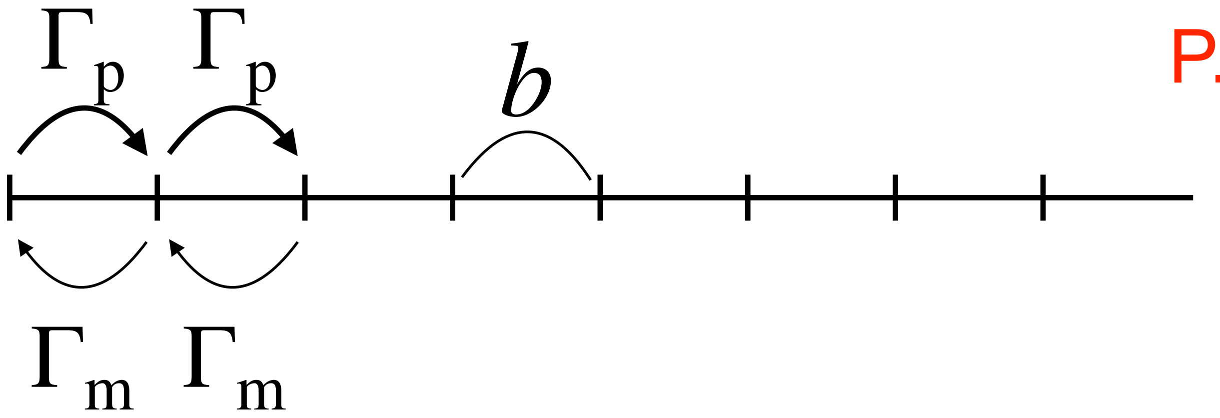
Fluctuation relation

$$\frac{G_0(x_{\mathrm{f}}, x_{\mathrm{i}}, t)}{G_0(x_{\mathrm{i}}, x_{\mathrm{f}}, t)} = \exp\left[(x_{\mathrm{f}} - x_{\mathrm{i}})qF/(k_{\mathrm{B}}T)\right]$$

$G(x, x_{\mathrm{i}}, \tau)$ Conditional probability (Green function)

Reflecting boundary

P. 8 KS

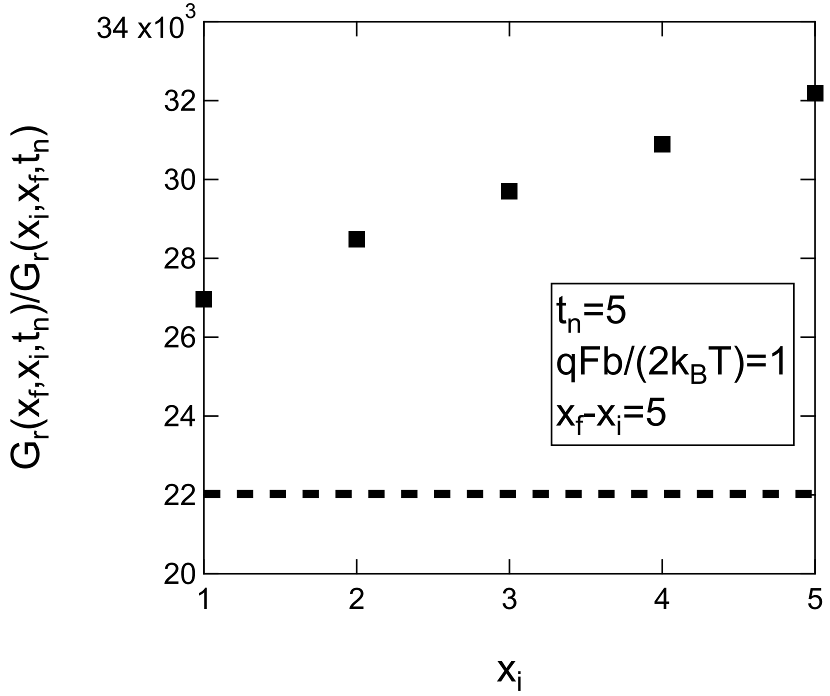


Break-down of Fluctuation relation

$$\frac{G_r(x_f, x_i, t)}{G_r(x_i, x_f, t)} \neq \exp\left[(x_f - x_i)qF/(k_B T)\right]$$

q :Charge

F :External electric field



t_n Dimensionless time =5

$qFb/(2k_B T) = 1$

x_i is normalized by the lattice constant b

← $\exp\left[(x_f - x_i)qF/(k_B T)\right]$

Exact Work Distribution and Jarzynski's Equality of a Relativistic Particle in an Expanding Piston

Tingzhang Shi
Peking University, China
July 2nd, 2024

Xianghang Zhang, Tingzhang Shi, H. T. Quan, arXiv:2403.15986

Outline

- Background and motivation
- Setup of the relativistic piston model
- Trajectory of a particle and verification of the Jarzynski's equality
- Relativistic work distribution and its non-relativistic limit
- Summary

Outline

- Background and motivation
- Setup of the relativistic piston model
- Trajectory of a particle and verification of the Jarzynski's equality
- Relativistic work distribution and its non-relativistic limit
- Summary

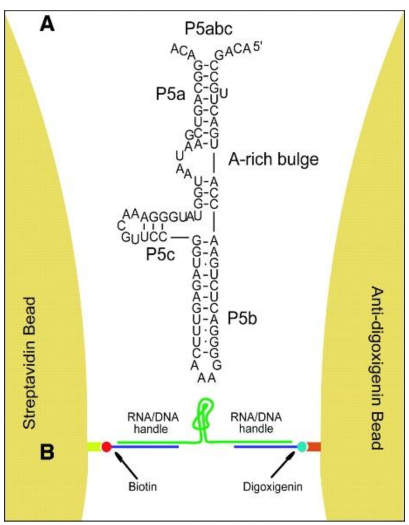
Background and motivation

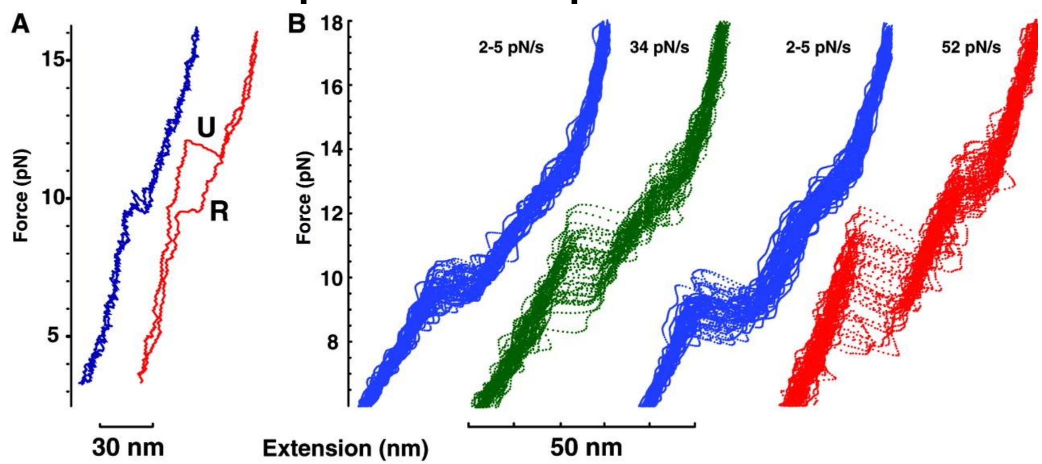
The Jarzynski's equality

- Second law of thermodynamics: $\langle W \rangle \geq \Delta F$
- Jarzynski's equality：

$$\langle e^{-\beta W} \rangle = e^{-\beta \Delta F}$$

- It is possible to obtain equilibrium thermodynamic parameters from non-equilibrium processes.

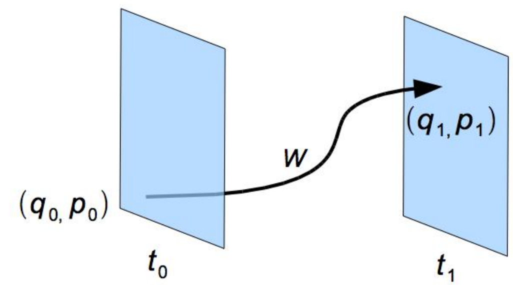




Liphardt, et al., Science 296, 1832 (2002)

Background and motivation
The Jarzynski's equality

- Trajectory work:



$$W(q_0,p_0)=H(q_1,p_1;\lambda_1)-H(q_0,p_0;\lambda_0)$$

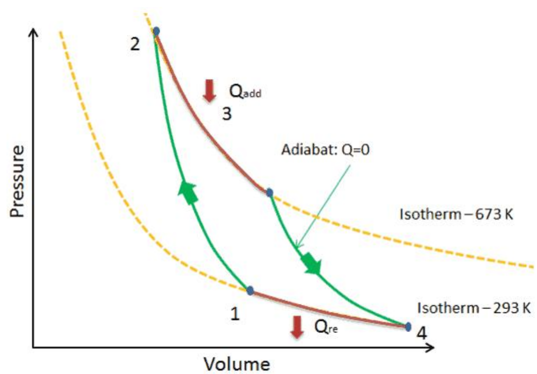
- The proof of Jarzynski's equality:

$$\begin{aligned}
&\left\langle e^{\beta W}\right\rangle \\
&=\int \mathrm{d}p_{i,0}\mathrm{d}q_{i,0}\,\rho(p_{i,0},q_{i,0})e^{\beta W(p_{i,0},q_{i,0},\tau)} \\
&=\frac{1}{Z_0}\int \mathrm{d}p_{i,0}\mathrm{d}q_{i,0}\,e^{-\beta H_{\lambda(\tau)}(p_{i,\tau},q_{i,\tau})} \\
&=\frac{1}{Z_0}\int \mathrm{d}p_{i,\tau}\mathrm{d}q_{i,\tau}\,e^{-\beta H_{\lambda(\tau)}(p_{i,\tau},q_{i,\tau}))} \\
&=\frac{Z_\tau}{Z_0},
\end{aligned}$$

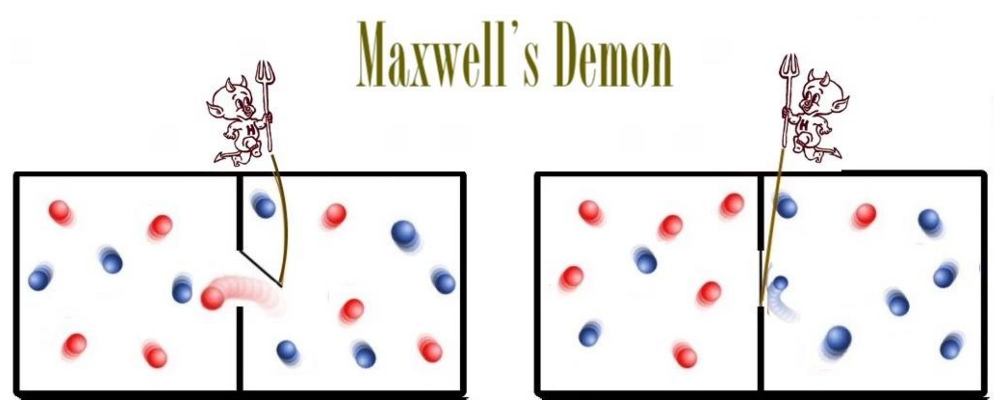
C. Jarzynski, Phys. Rev. Lett. 78, 2690 (1997).

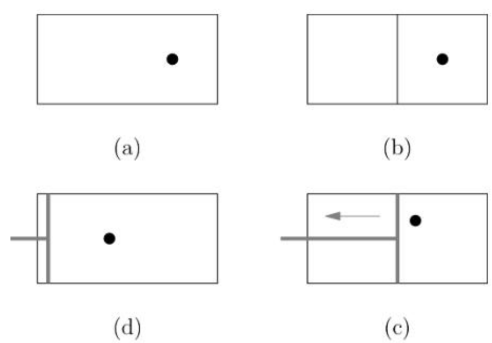
Background and motivation
Piston model

- Piston model: Paradigmatic



Carnot cycle





Landauer Principle

Background and motivation
Piston model

- Piston model: Exact solvable
- Previous work:

Classical Newtonian piston [R. C. Lua and A. Y. Grosberg, 2005]

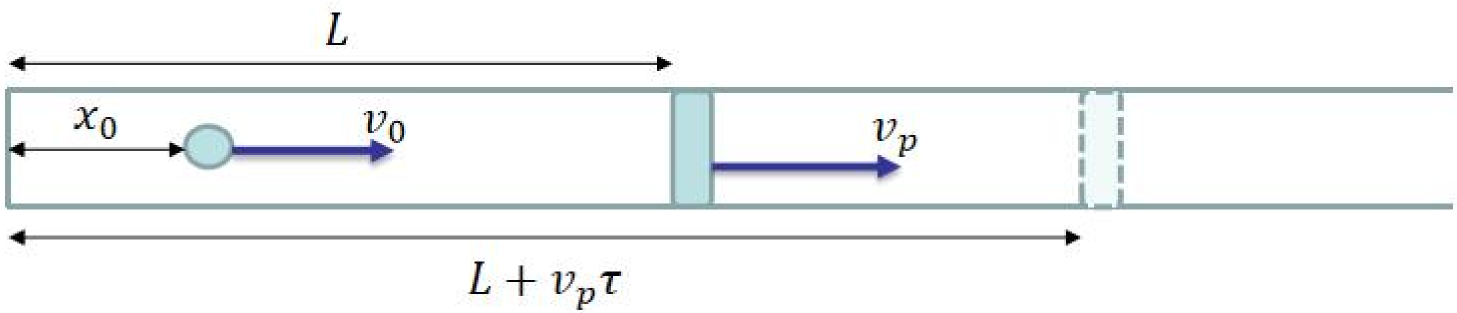
Quantum non-relativistic piston [H. T. Quan and C. Jarzynski, 2012]

Classical relativistic piston (single kick limit) [R. Nolte and A. Engel, 2009]

Outline

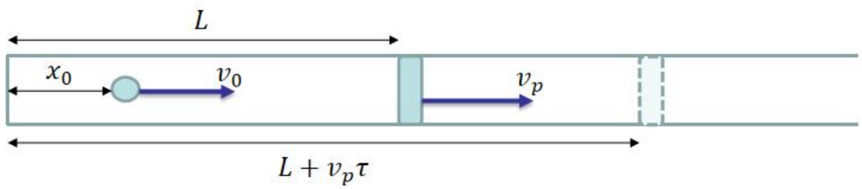
- Background and motivation
- Setup of the relativistic piston model
- Trajectory of a particle and verification of the Jarzynski's equality
- Relativistic work distribution and its non-relativistic limit
- Summary

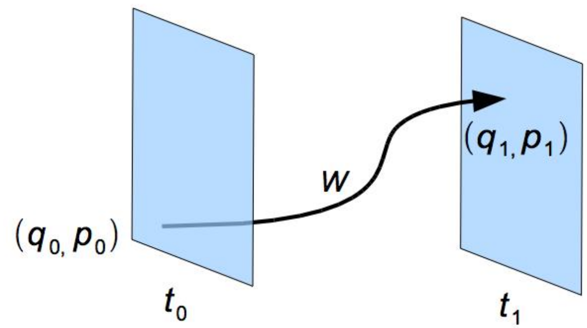
Setup of the relativistic piston model



- A single particle inside a one-dimensional cylinder with a moving piston
- The collision with the piston is elastic.
- The gas is of the inverse temperature β.

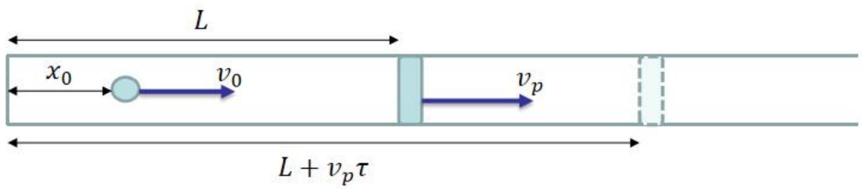
Setup of the relativistic piston model

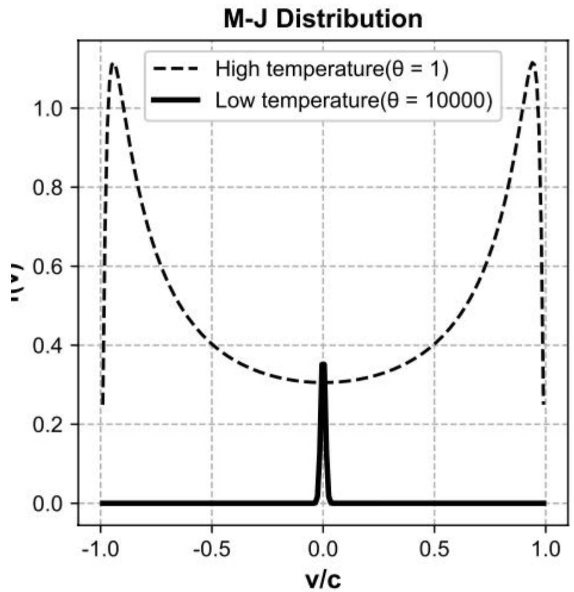




- Elastic collision: in the piston frame, the speed of the particle doesn't change during a collision.
- Trajectory work: $W(q_0, p_0) = H(q_1, p_1; \lambda_1) - H(q_0, p_0; \lambda_0)$
- Time slides are defined in the laboratory frame.

Setup of the relativistic piston model





- Classical
- Relativistic
- Adiabatic

$$f(x,p) = \frac{1}{2K_1(\frac{mc^2}{k_BT})mcL} e^{-\frac{mc^2}{k_BT}\sqrt{1+(\frac{p}{mc})^2}},$$

$$F(x,v) = \frac{1}{2K_1(\frac{mc^2}{k_BT})cL} e^{-\frac{mc^2}{k_BT}\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}} \left(1-\frac{v^2}{c^2}\right)^{-\frac{3}{2}}.$$

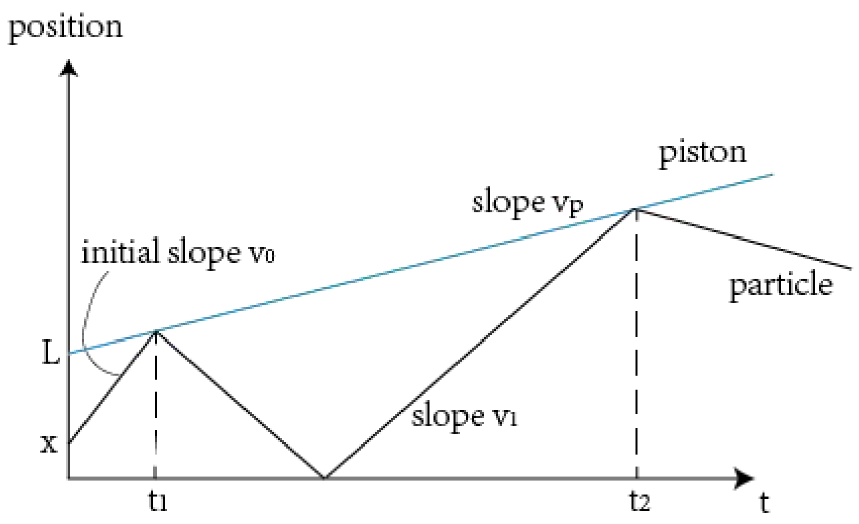
F. Jüttner, Annalen der Physik 339, 856 (1911).

Outline

- Background and motivation
- Setup of the relativistic piston model
- Trajectory of a particle and verification of the Jarzynski's equality
- Relativistic work distribution and its non-relativistic limit
- Summary

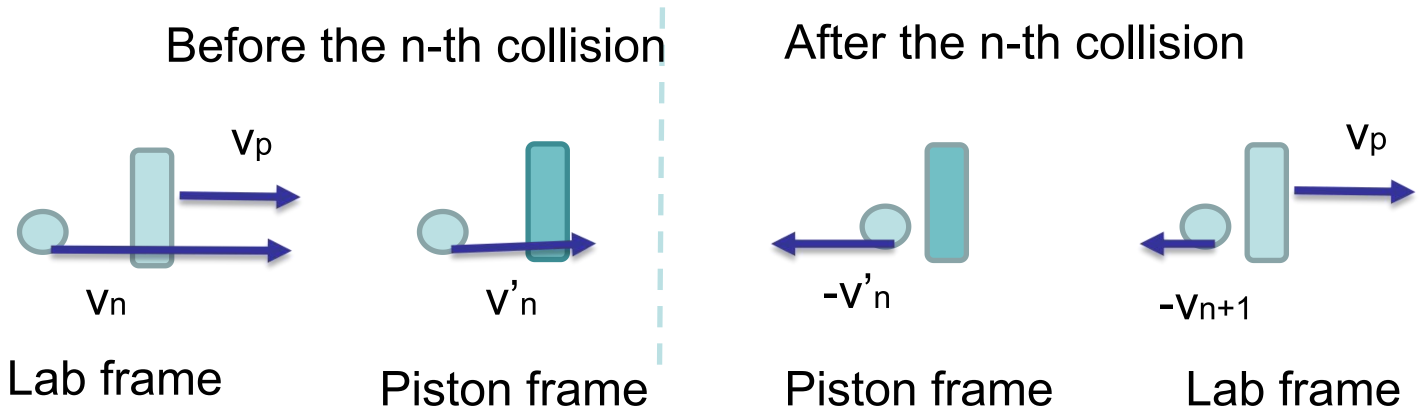
Trajectory of a particle and verification of the Jarzynski's equality

- Trajectory of a particle:



- The key is to obtain the speed after the n-th collision and the time of the n-th collision with the moving piston.

Trajectory of a particle and verification of the Jarzynski's equality



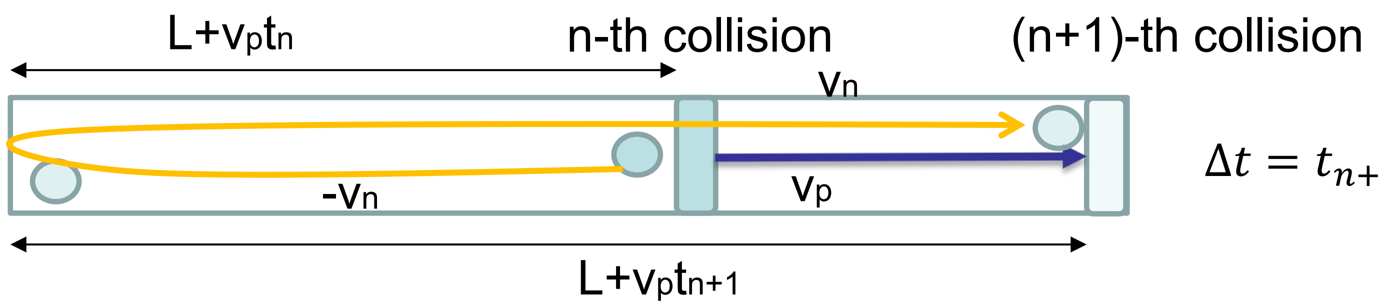
- Recursion relation of the speed :

$$v_{n+1} = \frac{(c^2 + v_p^2)v_n - 2v_p c^2}{c^2 + v_p^2 - 2v_p v_n}.$$

- Solution to the recursion relation:

$$v_n = \frac{(c+v)\alpha_p^{2n} - c + v}{(c+v)\alpha_p^{2n} + c - v} \cdot c, \quad \text{with} \quad \alpha_p = \frac{c - v_p}{c + v_p}.$$

Trajectory of a particle and verification of the Jarzynski's equality

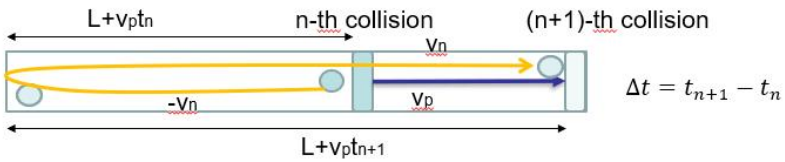


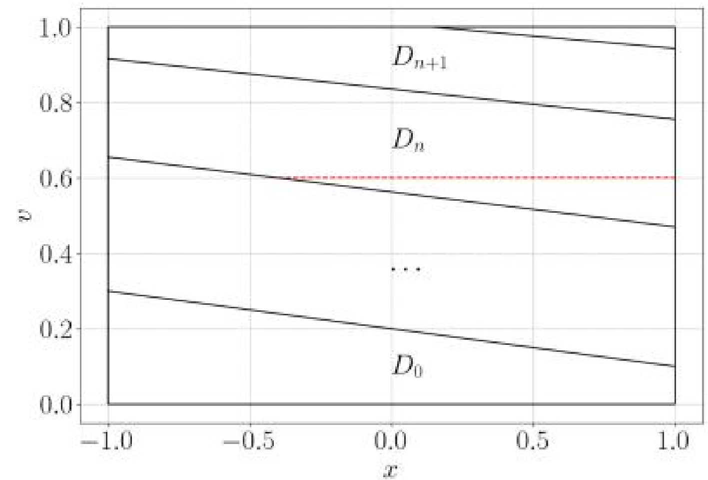
$\Delta t = t_{n+1} - t_n$

- Recursion relation of the time of the n-th collision with the piston: $$t_{n+1} = \frac{2L + (v_p + v_n)t_n}{v_n - v_p},$$
- Solution to the recursion relation:

$$t_n = \left[(-\alpha_p^{2n} - \alpha_p + \alpha_p^{n+1} + \alpha_p^n)\frac{v}{c} + (-\alpha_p^{n+1} + \alpha_p^n)\frac{x}{L} + (\alpha_p - \alpha_p^{2n})\right] \left[-\alpha_p + \alpha_p^{2n} + (\alpha_p + \alpha_p^{2n})\frac{v}{c}\right]^{-1} \cdot \frac{L(1+\alpha_p)}{c(1-\alpha_p)},$$

Trajectory of a particle and verification of the Jarzynski's equality



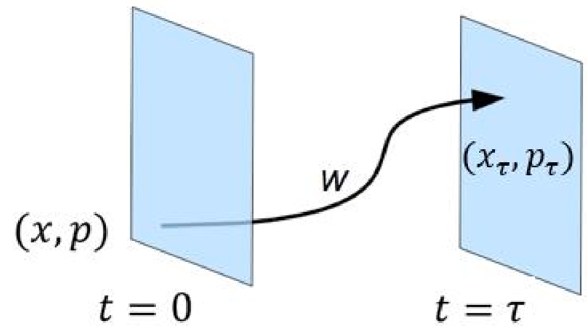


- Solution to the recursion relation:

$$t_n = \left[(-\alpha_p^{2n} - \alpha_p + \alpha_p^{n+1} + \alpha_p^n)\frac{v}{c} + (-\alpha_p^{n+1} + \alpha_p^n)\frac{x}{L} + (\alpha_p - \alpha_p^{2n})\right] \left[-\alpha_p + \alpha_p^{2n} + (\alpha_p + \alpha_p^{2n})\frac{v}{c}\right]^{-1} \cdot \frac{L(1+\alpha_p)}{c(1-\alpha_p)},$$

- Final collision number: $n = \max\{N | t_N \leq \tau\}$

Trajectory of a particle and verification of the Jarzynski's equality



- Final position and momentum:

$$(x_\tau, p_\tau) = (|L - v_n\tau + (v_n + v_p)t_n|, p_n) \quad \text{with} \quad p_n = \frac{mv_n}{\sqrt{1 - \left(\frac{v_n}{c}\right)^2}}.$$

- Liouville's theorem can be proved:

$$\left|\frac{\partial(x_\tau, p_\tau)}{\partial(x, p)}\right| = 1,$$

which verifies the Jarzynski's equality.

Outline

- Background and motivation
- Setup of the relativistic piston model
- Trajectory of a particle and verification of the Jarzynski's equality
- Relativistic work distribution and its non-relativistic limit
- Summary

Relativistic work distribution and its non-relativistic limit

- Non-dimenssionalize: m, L, k_B, c=1.
- Definition of the work distribution:

$$P(W) = \int_{-1}^{1} \mathrm{d}x \int_{0}^{1} \mathrm{d}v \frac{e^{-\frac{\beta}{\sqrt{1-v^2}}} \delta(W - W_\tau(x,v))}{2K_1(\beta)(1-v^2)^{\frac{3}{2}}},$$

- After some tedious calculations, the distribution function of W can be analytically expressed as

$$P(W) = P_0\delta(W) + \frac{1}{2K_1(\beta)} \sum_{n=1}^{N} \varphi_n(v_n(W)) \times \frac{e^{-\beta/\sqrt{1-v_n(W)^2}}}{(\alpha_p^{-n} - 1)\left[1 + \alpha_p^n - v_n(W)(1-\alpha_p^n)\right]}.$$

Relativistic work distribution and its non-relativistic limit

- The work distribution P(W) is:

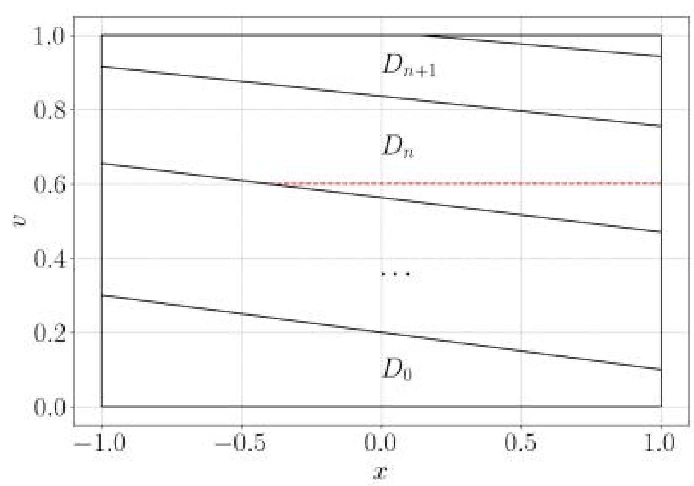
$$P(W) = P_0\delta(W) + \frac{1}{2K_1(\beta)}\sum_{n=1}^{N}\varphi_n(v_n(W)) \times \frac{e^{-\beta/\sqrt{1-v_n(W)^2}}}{(\alpha_p^{-n}-1)\left[1+\alpha_p^n - v_n(W)(1-\alpha_p^n)\right]}.$$

- With

$$v_n(W) = \frac{(1-\alpha_p^n)^3(1+\alpha_p^n) + 4W\sqrt{\alpha_p^{3n}\left((1-\alpha_p^n)^2+\alpha_p^n W^2\right)}}{(1-\alpha_p^{2n})^2 + 4\alpha_p^{2n}W^2},$$

$$\varphi_n(v) = \begin{cases} 1-\xi_n(v), & \frac{X_n-1}{T_n} < v_n(W) \le \frac{X_n+1}{T_n} \\ 2, & \frac{X_n+1}{T_n} < v_n(W) \le \frac{X_{n+1}-1}{T_{n+1}} \\ 1+\xi_{n+1}(v), & \frac{X_{n+1}-1}{T_{n+1}} < v_n(W) \le \frac{X_{n+1}+1}{T_{n+1}} \end{cases},$$

- Overlap factor:



Relativistic work distribution and its non-relativistic limit

- We may recover the dimension of the expressions and let $c \to \infty$, then we have the non-relativistic limit of the work distribution.

$$P(W) = P_0\delta(W) + \frac{\sqrt{\beta}}{\sqrt{2\pi} n v_p} e^{-\frac{\beta}{2}\left(\frac{W}{2nv_p}+nv_p\right)^2} f(W),$$

$$f(W) = \begin{cases} -(n-1)(1+\frac{v_p}{2}) + \frac{W}{4nv_p}, & (n-1)(v_p+2) < \frac{W}{2nv_p} \le (n-1)(v_p+2)+2 \\ 1, & (n-1)(v_p+2)+2 < \frac{W}{2nv_p} \le (n-1)(v_p+2)+2+2v_p \\ (n+1)(1+\frac{v_p}{2}) - \frac{W}{4nv_p}, & (n-1)(v_p+2)+2+2v_p < \frac{W}{2nv_p} \le (n+1)(v_p+2) \end{cases}$$

R. C. Lua and A. Y. Grosberg,
J. Phys. Chem. B 109, 6805 (2005)

The comparison between relativistic work distribution and its non-relativistic limit

$$P(W) = P_0\delta(W) + \frac{1}{2K_1(\beta)}\sum_{n=1}^{N}\varphi_n(v_n(W)) \times \frac{e^{-\beta/\sqrt{1-v_n(W)^2}}}{(\alpha_p^{-n}-1)\left[1+\alpha_p^n - v_n(W)(1-\alpha_p^n)\right]}.$$

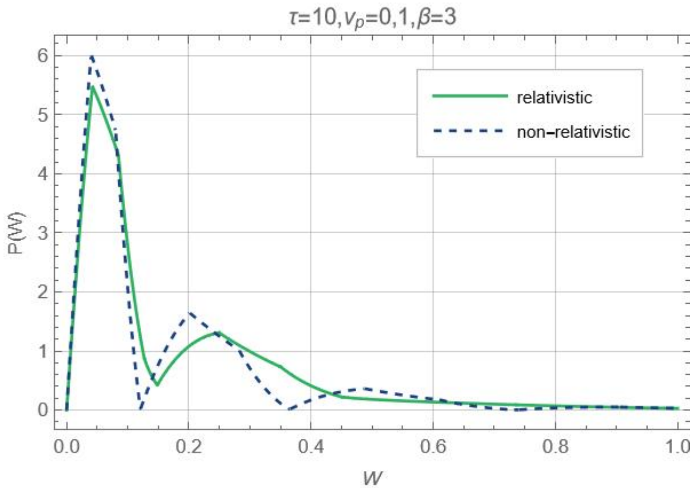
$$v_n(W) = \frac{(1-\alpha_p^n)^3(1+\alpha_p^n) + 4W\sqrt{\alpha_p^{3n}\left((1-\alpha_p^n)^2+\alpha_p^n W^2\right)}}{(1-\alpha_p^{2n})^2 + 4\alpha_p^{2n}W^2},$$

$$\varphi_n(v) = \begin{cases} 1-\xi_n(v), & \frac{X_n-1}{T_n} < v_n(W) \le \frac{X_n+1}{T_n} \\ 2, & \frac{X_n+1}{T_n} < v_n(W) \le \frac{X_{n+1}-1}{T_{n+1}} \\ 1+\xi_{n+1}(v), & \frac{X_{n+1}-1}{T_{n+1}} < v_n(W) \le \frac{X_{n+1}+1}{T_{n+1}} \end{cases},$$

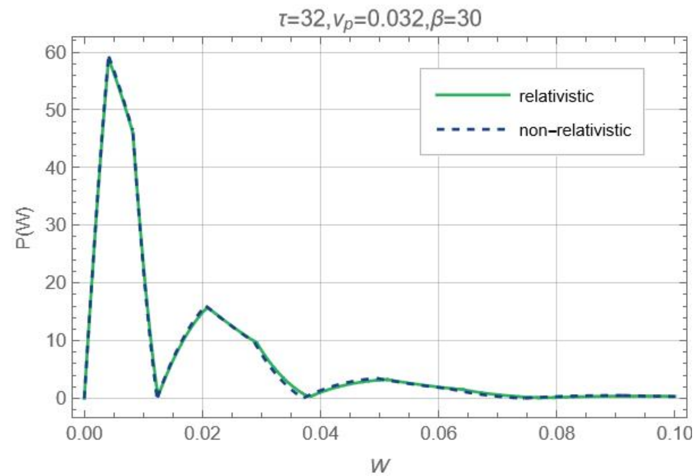
$$P(W) = P_0\delta(W) + \frac{\sqrt{\beta}}{\sqrt{2\pi}nv_p} e^{-\frac{\beta}{2}\left(\frac{W}{2nv_p}+nv_p\right)^2} f(W),$$

$$f(W) = \begin{cases} -(n-1)(1+\frac{v_p}{2}) + \frac{W}{4nv_p}, & (n-1)(v_p+2) < \frac{W}{2nv_p} \le (n-1)(v_p+2)+2 \\ 1, & (n-1)(v_p+2)+2 < \frac{W}{2nv_p} \le (n-1)(v_p+2)+2+2v_p \\ (n+1)(1+\frac{v_p}{2}) - \frac{W}{4nv_p}, & (n-1)(v_p+2)+2+2v_p < \frac{W}{2nv_p} \le (n+1)(v_p+2) \end{cases}$$

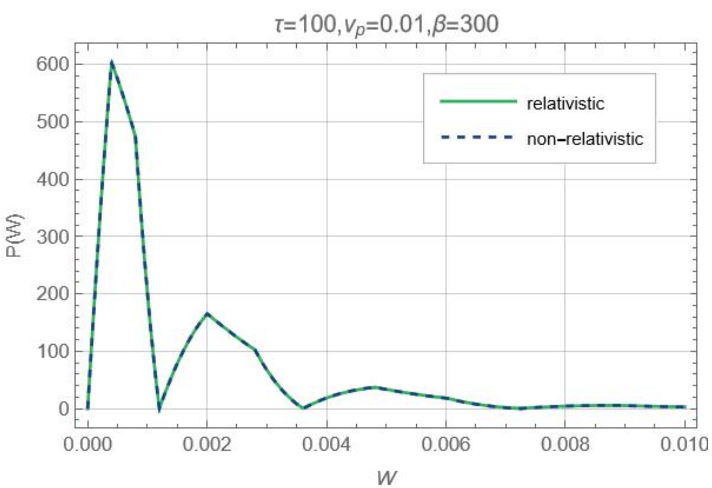
The comparison between relativistic work distribution and its non-relativistic limit



(a)



(b)



(c)

Relativistic and non-relativistic work distribution with different parameters. The initial length is $1cm$. The protocol is:

(a)$\tau = 0.3ns,\ v_p = 3 \times 10^7 m/s, T = 3 \times 10^{12} K$;

$(b)\tau = 1ns,\ v_p = 1 \times 10^7 m/s, T = 3 \times 10^{11} K$;

$(c)\tau = 3ns,\ v_p = 3 \times 10^6 m/s, T = 3 \times 10^{10} K$.

Relativistic work distribution has no zeros, which might be detected.

Outline

- Background and motivation
- Setup of the relativistic piston model
- Trajectory of a particle and verification of the Jarzynski's equality
- Relativistic work distribution and its non-relativistic limit
- Summary

Summary

- 1D classical relativistic piston model is an exact solvable model. We analytical solve the trajectory and the work distributuion of the relativistic piston model, and verify the Jarzynski's equality.

- In the non-relativistic limit, our results recover the non-relativistic results [Lua, & Grosberg, J. Phys. Chem. B, 109, 6805(2005)].

- We also find that, unlike the non-relativistic case, the maximun number of collisions in this relativistic gas model is finite, and the relativistic work distribution no longer has zeros.

- It is difficult to detect the relativistic effects of the work distribution of the ideal gas in a piston system with the current experimental techniques.

Thank you!

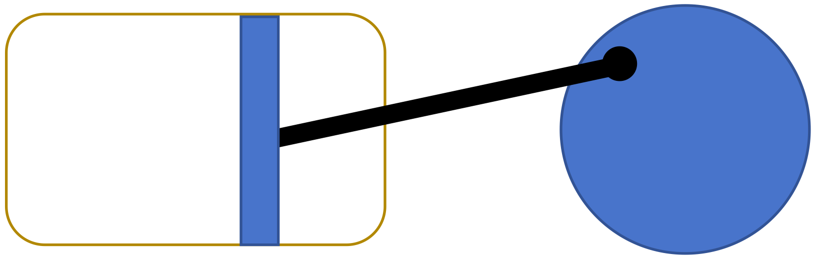
Geometric Thermodynamic Uncertainty Relation for Cyclic Heat Engines

Guo-Hua Xu, Keiji Saito, and Gentaro Watanabe

Motivation

Providing a TUR of cyclic heat engines for general currents including work and heat

Setup: Flywheel as a Degree of Freedom



$$\dot{x} = a(x, y) + \xi_t,$$

$$\dot{y} = \omega,$$

$$\langle \xi_t \xi_s \rangle = 2D\delta(t - s)$$

General current

$$O = \int_0^\tau \mathrm{d}t \Lambda_x(x, y) \circ \mathrm{d}x + \Lambda_y(x, y) \circ \mathrm{d}y$$

Main result I: TUR for cyclic heat engines

Using Cramer-Rao inequality

$$\frac{\mathrm{Var}[O]}{\langle O\rangle^2} \geq \frac{2}{\mathcal{T}\sigma_Q}$$

T. Koyuk, U. Seifert, P. Pietzonka,
J. Phys. A: Math. Theor. **52**, 02LT02 (2018)

σ_Q

Effective entropy production (EP) rate:

EP rate for arbitrary distribution Q(x)

Geometric bound in the linear response regime

$$\sigma_Q \leq \frac{\pi}{2}\mathcal{L}^2$$

$$Q(x) = P_{eq}(\lambda_0, D_0)$$

σ_Q is EP in the fast driving limit

Main result II: geometric TUR

$$\frac{\mathrm{Var}[O]}{\langle O\rangle^2} \geq \frac{4}{\pi\mathcal{L}^2\tau}$$

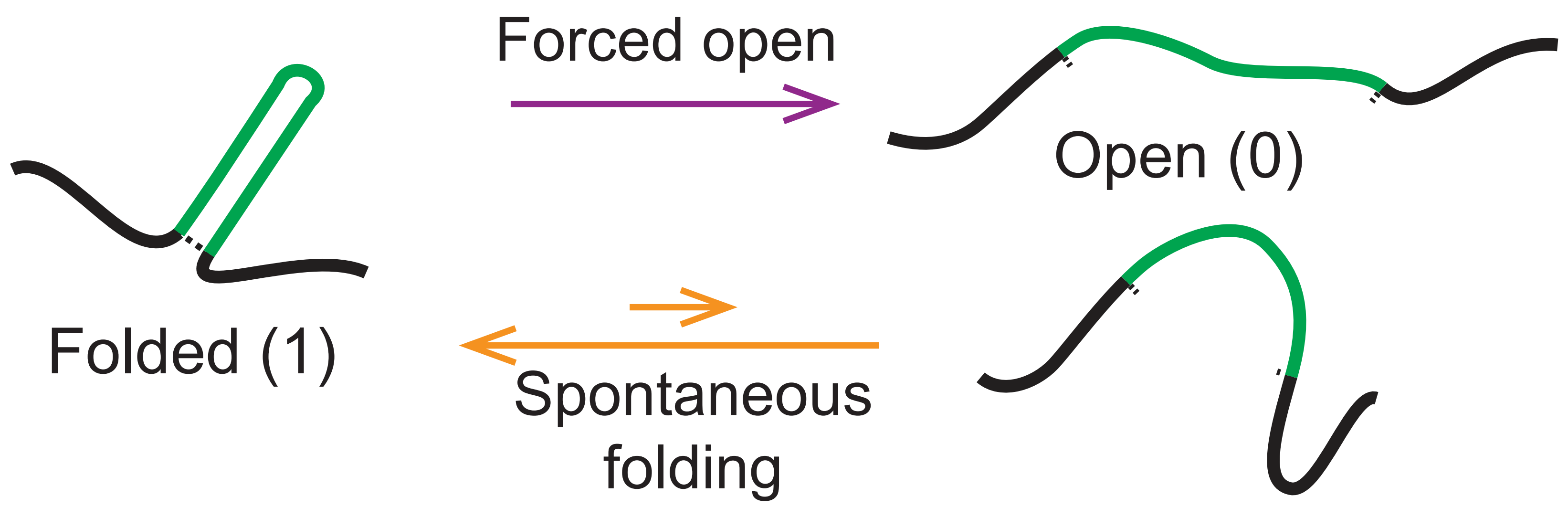
Seeking Postdoctoral Position:

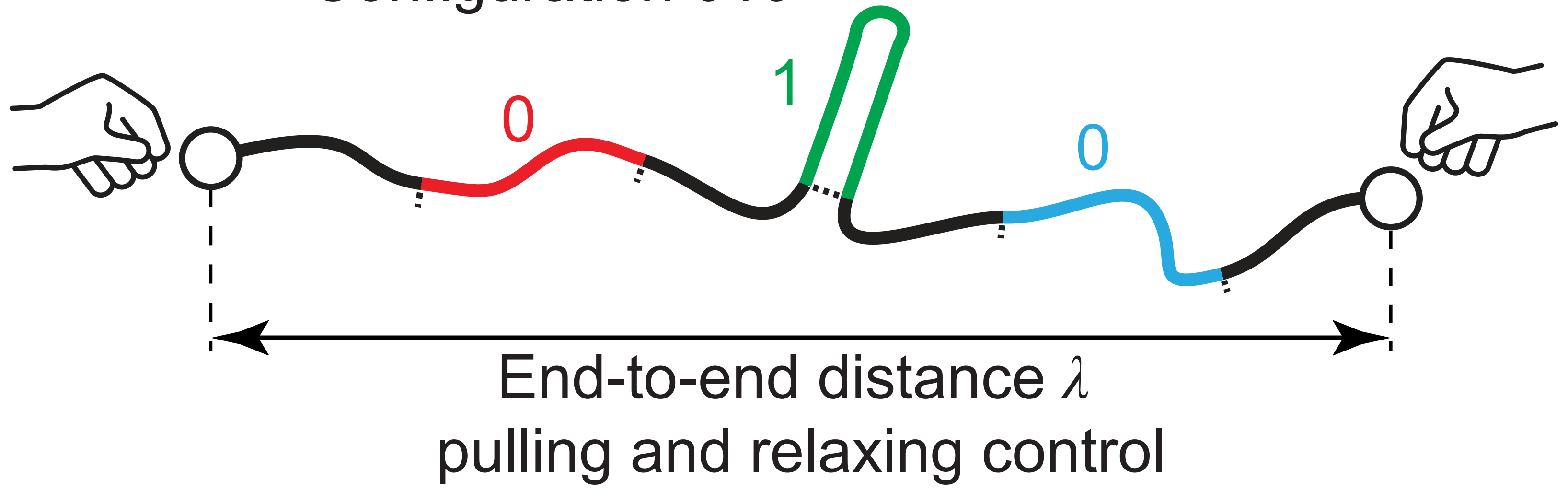
If you know of any opportunities or have suggestions, please feel free to reach out to me. Thank you!

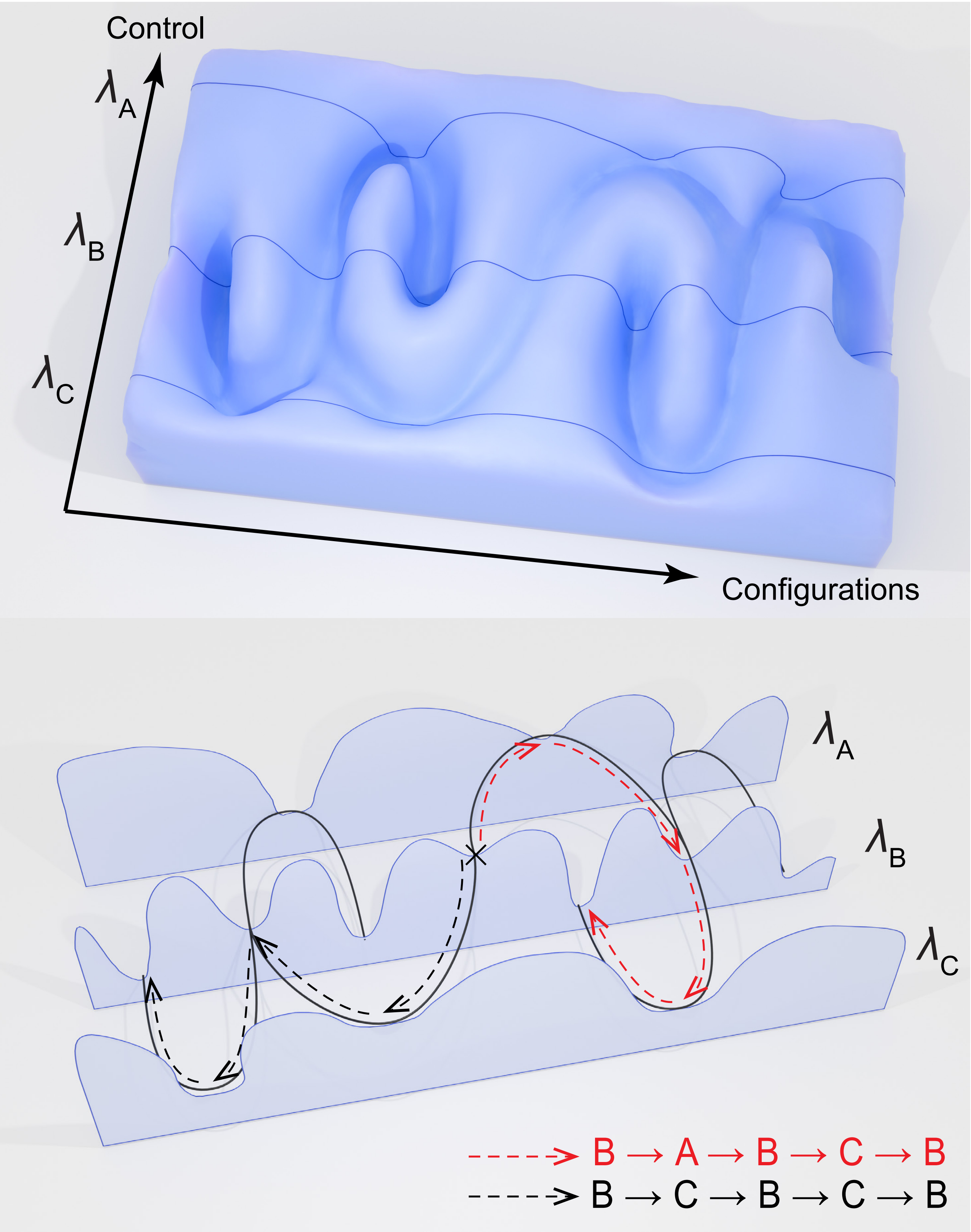
Non-equilibrium Design Principles — Intelligent Molecule for Temporal Pattern Recognition and Computation

Zhongmin Zhang and Zhiyue Lu, Department of Chemistry, University of North Carolina at Chapel Hill

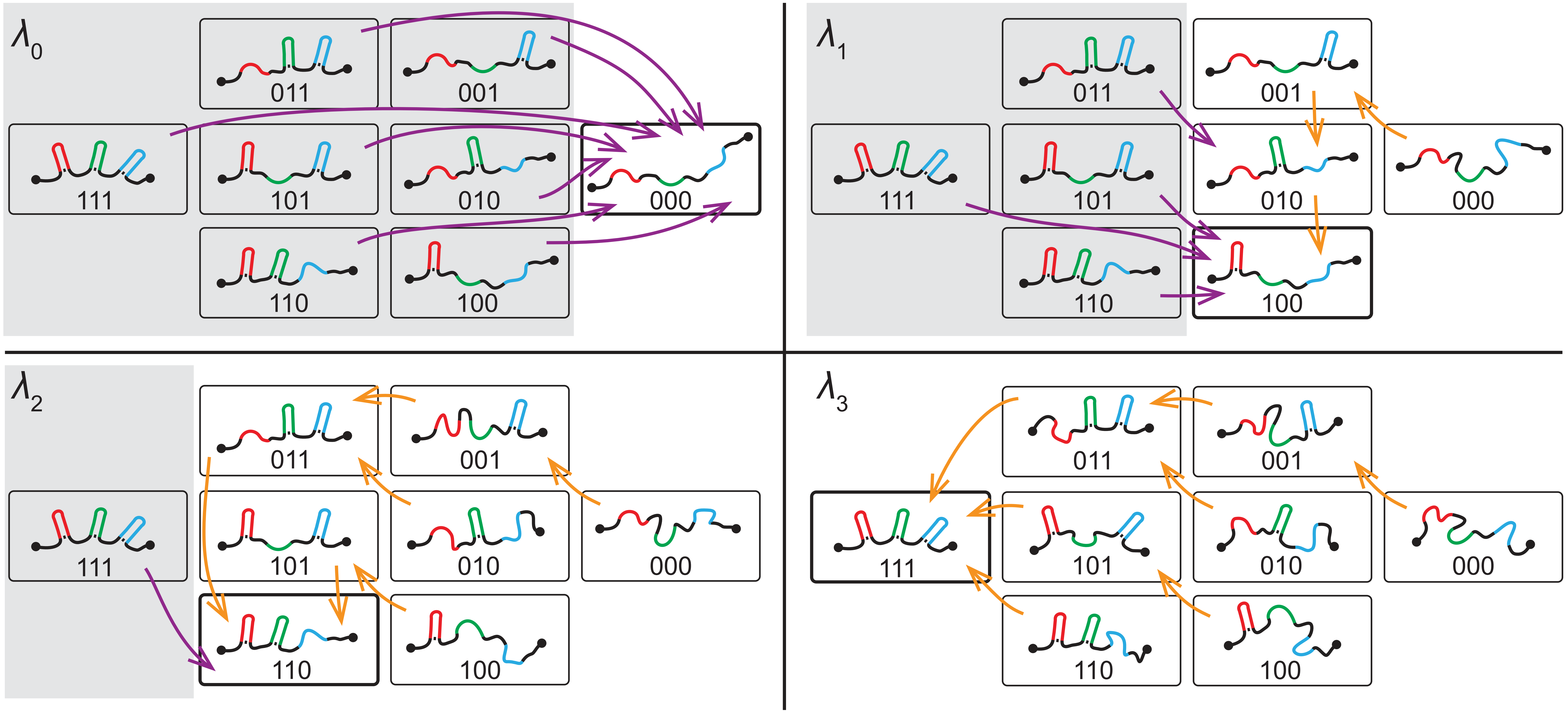
No. 12, 2nd week



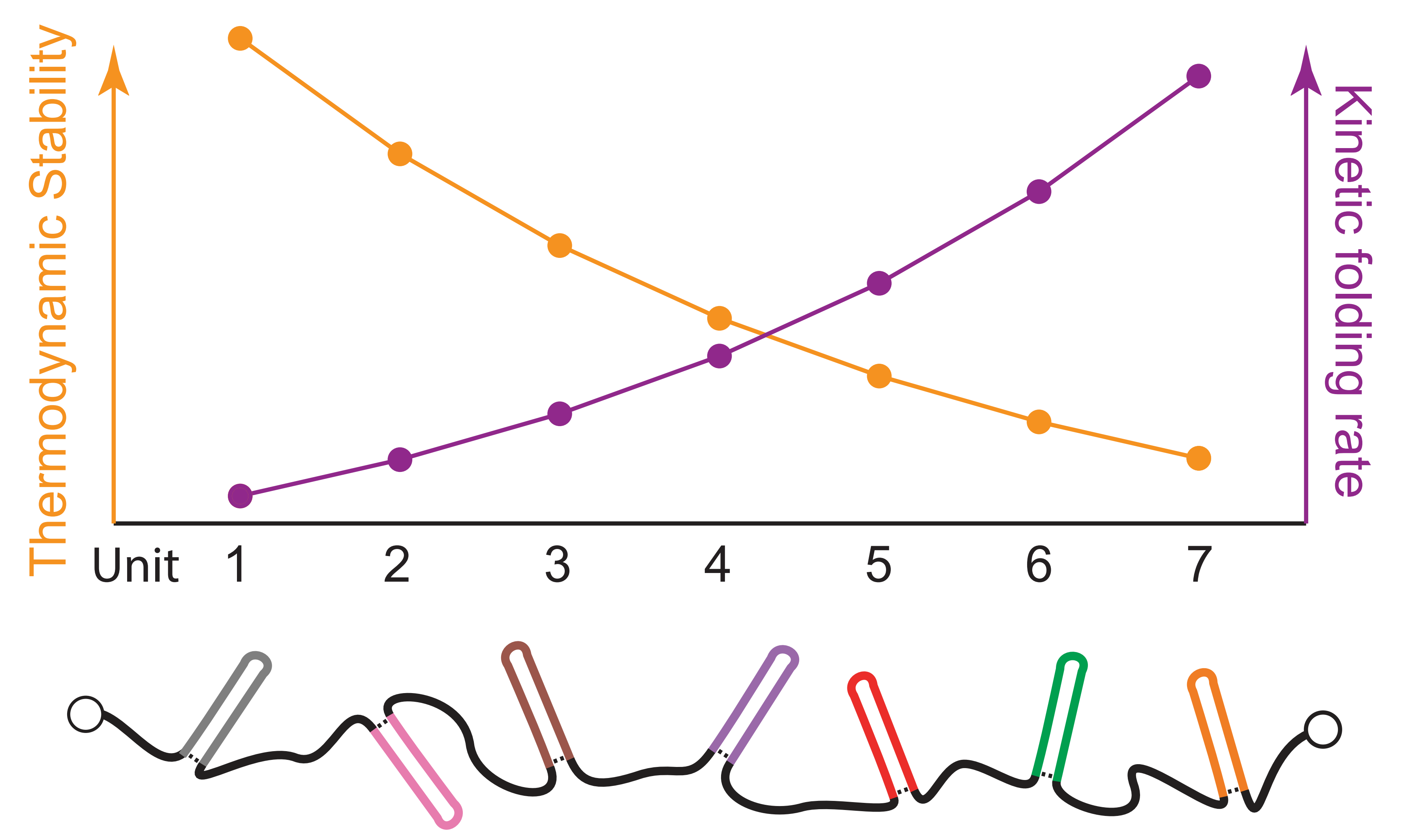




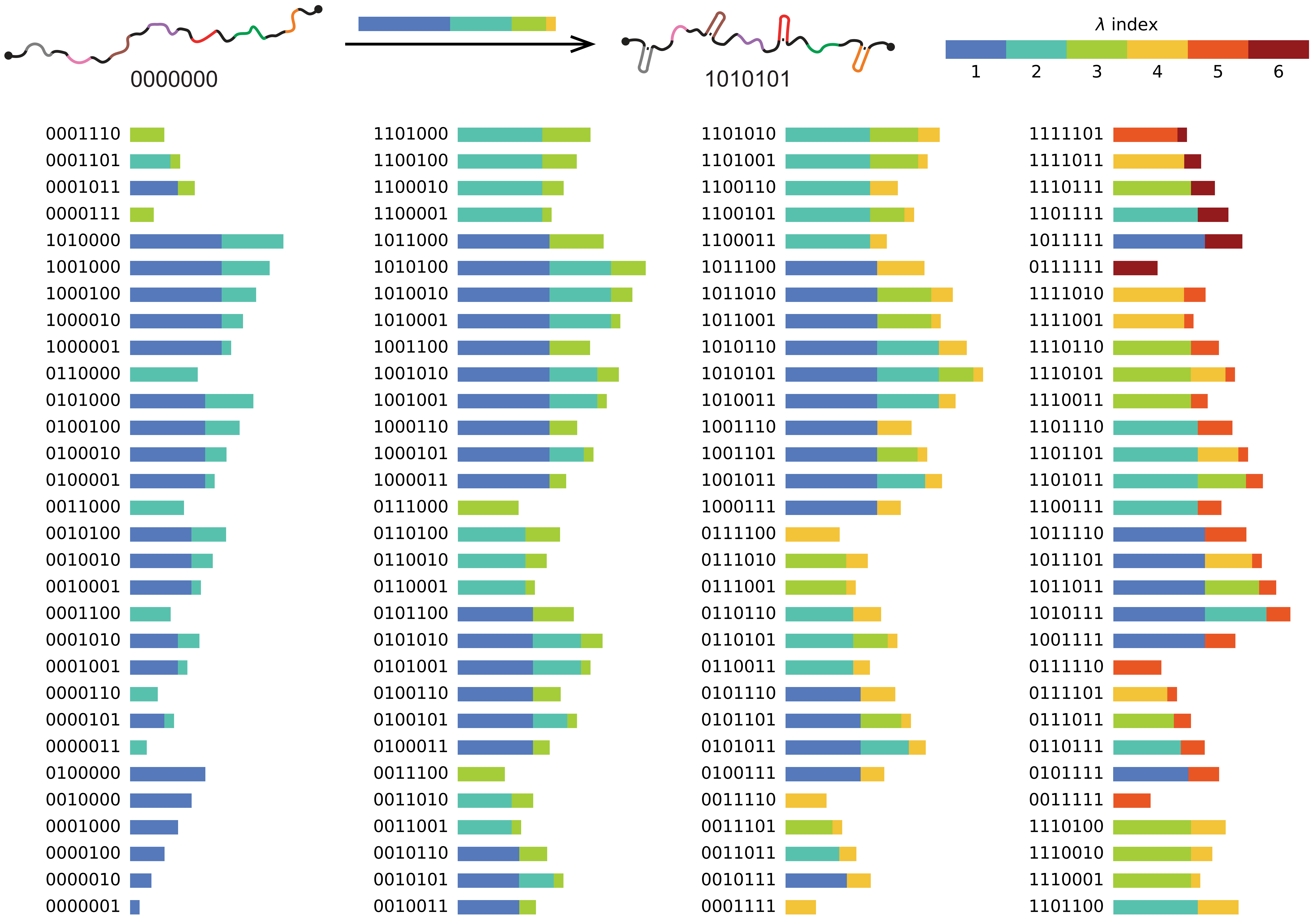
Transition table for the most probable next configuration at control λ_i where at most i units can be folded



Full Non-equilibrium Controllability



Discrepancy design rule: thermally stable states are kineticly slow to reach.

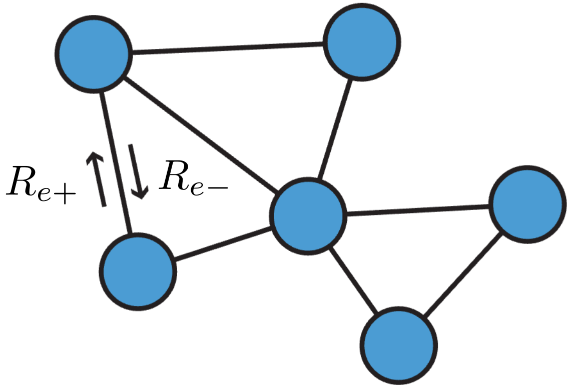


Universal Fluctuation-Response Relations of Non-equilibrium Dynamics: A Trajectory Information Geometry Framework

Jiming Zheng* and Zhuyue Lu†
University of North Carolina at Chapel Hill
Poster Number: #13, 2nd week

arXiv: 2403.10952

System and Setup



Master equation $$\frac{\partial \boldsymbol{p}(t)}{\partial t} = R \cdot \boldsymbol{p}(t)$$

Only Requirement R is irreducible

Control Parameter $$R = R(\boldsymbol{\xi})$$

Modeling Response

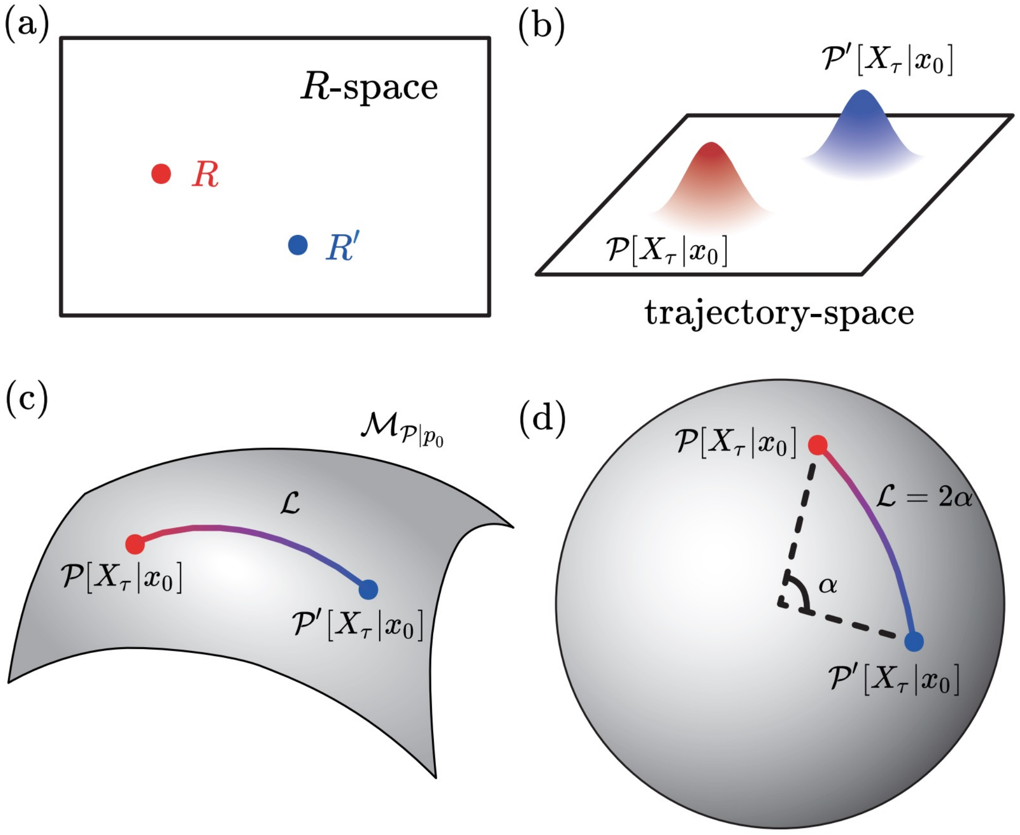
$$\partial_\xi \langle Q \rangle \equiv \frac{\partial \langle Q \rangle}{\partial \xi}$$

Sensitivity

$$\Delta \langle Q \rangle = |\langle Q \rangle' - \langle Q \rangle|$$

Non-perturbative Response

Results



Information geometric structure on the stochastic trajectory level

Cramer-Rao Bound

$$|\partial_{R_{e\pm}}\langle Q\rangle| \leq \sqrt{\mathrm{Var}[Q]}\cdot\frac{\sqrt{\mathcal{A}_{e\pm}}}{R_{e\pm}}$$

Perturbative Response

Geometric Bound

$$|\langle Q\rangle' - \langle Q\rangle| \leq 2\max_{X_\tau}|Q|\cdot\overline{\sin}(G_{e\pm})$$

Non-perturbative Response