SANTA FE INSTITUTE

SECOND WORKSHOP ON STOCHASTIC THERMODYNAMICS (WOST II)

VIRTUAL CONFERENCE AGENDA

Tutorials - May 13, 2021

Main conference - May 17, 2021 – May 21, 2021

Meeting description

Stochastic thermodynamics has revolutionized our understanding of far-from-equilibrium statistical physics over the last few decades. It continues to result in profound, powerful results, including for example the fluctuation theorems, speed-limit theorems, and thermodynamic uncertainty relations, and is being applied to a quickly expanding set of physical systems. The WOST series of annual workshops focus on this fast-developing field, both its theoretical and experimental aspects, as well as its application to other fields of research.

Scope

The workshop's primary aim is to have a wide-ranging cross-section of the stochastic thermodynamics' community present their current research in one forum. The main topics of the workshop include applications of stochastic thermodynamics to:

- Physics and Chemistry
- Biophysics
- Active matter
- Quantum thermodynamics
- Information processing and computation

Mission

The mission of the workshop is:

- To promote the field of stochastic thermodynamics to a broad range of scientists working in many domains
- To foster collaboration on stochastic thermodynamics research among different communities
- To encourage early-career researchers, especially by helping them disseminate their results
- To support academics from underrepresented groups working in the field of stochastic thermodynamics or related fields

Previous workshop

WOST I was organized by the Complexity Science Hub Vienna. It attracted more than 150 participants. The talks can be found at:
https://www.csh.ac.at/event/csh-workshop-stochastic-thermodynamics-complex-systems/.

WOST II Organizing committee

Velimir Ilic	Serbian Academy of Sciences and Arts
Christopher Jarzynski	University of Maryland
Gülce Kardeş	University of Leipzig
Jan Korbel	Medical University of Vienna
Tom Ouldridge	Imperial College London
Jenny Poulton	Imperial College London
Saar Rahav	Technion - Israel Institute of Technology
Udo Seifert	University of Stuttgart
Henrik Wilming	
David Wolpert	Santa Fe Institute
Cigdem Yalcin	Istanbul University

IMPORTANT INFORMATION

Registration
WOST II will be videoconference open to all interested scholars. To partake in WOST II, please register at the conference website.

Zoom
The whole conference will be available through video conferencing software Zoom. The zoom link and the password will be sent to all registered participants.

Talks
There are several types of talks:

- *Tutorials* (13th May): 1hr introductory talks, accessible to non-experts and students
- *Colloquium talks:* 30 min talks describing the current state of art of stochastic thermodynamics research in a range of domains
- *Invited talks:* 20 min talks addressing a particular topic in stochastic thermodynamics
- *Lightning talks:* 10 min talks mainly by junior researchers, chosen from applications, ranging across all aspects of stochastic thermodynamics

Note that no questions will be allowed during a talk (Everyone except the speaker will be muted). Instead, all talks will be followed by a short Q&A period.

Q&A
Participants may ask questions during the Q&A period after each talk. Participants can raise their virtual hand during the talk to indicate that they would like to ask the speaker a question. The session chair will unmute the questioner and they pose the question to the speaker.
Note that after each talk, the first round of questions is dedicated to students.

Recording
All talks will be recorded, and the videos will be published on the SFI webpage.

Video-linked transcript
Thanks to the work of the SFI Applied Complexity Office there will be a video-linked transcript of all talks. participants can search the transcript of the talk, click on a particular word, and the video will jump to the precise part of the talk in which that word was spoken.

Zoom chat on SFI webpage
Another innovation from the SFI Applied Complexity Office is that the Zoom discussion sessions will be ported to a webpage so that participants can easily continue the conversation after the the Zoom discussion session has ended.

Discussion
There is one discussion session each day. Discussion sessions will be moderated by the session chair. If you want to contribute to the discussion, please raise your virtual hand to get the attention of the chair. Discussions will not be recorded.

Website
The workshop website is: https://wiki.santafe.edu/index.php/Stochastic_Thermodynamics_II
We will upload all the relevant information there.

Contact information

You can contact the workshop organizers at the following addresses:

Scientific questions:	David Wolpert	david.h.wolpert@gmail.com
Technical questions:	Della Vigil Gonzales	della@santafe.edu

Tutorials Speakers:

Jordan Horowitz	University of Michigan
Philipp Strasberg	Universitat Autònoma de Barcelona
David Wolpert	Santa Fe Institute

Conference Speakers:

Janet Anders	University of Exeter
Vijay Balasubramanian	University of Pennsylvania
Andre Barato	University Houston
John Bechhoefer	Simon Fraser University
Michael Cates	University of Cambridge
Sergio Ciliberto	CNRS Lyon
Sebastian Deffner	University of Maryland
Andreas Dechant	Kyoto University
Ralf Eichhorn	Nordita
Megan Engel	Harvard University
Jannik Enrich	Simon Fraser University
Nikta Fakhri	MIT
Gianmaria Falasco	University of Luxembourg
Etienne Fodor	University of Luxembourg
Todd Gingrich	Northwestern University
Trevor GrandPre	UC Berkeley
David Hartich	Max Planck Institute for Biophysical Chemistry
Srividya Iyer-Biswas	Purdue University
Frank Jülicher	Max-Planck Institute for the Physics of Complex Systems
Benjamin Kuznets-Speck	UC Berkeley
Kanqiao Liu	University of Tokyo
Eric Lutz	University of Stuttgart
Yosuke Mitsuhashi	University of Tokyo
Florian Oltsch	Max Planck Institute of Molecular Cell Biology and Genetics
Jukka Pekola	Aalto University
Maria Popovic	Trinity College Dublin
Jenny Poulton	Imperial College London
Yuqing Qiu	University of Chicago
Saar Rahav	Technion
Andreu Riera-Campeny	Universitat Autònoma de Barcelona
Felix Ritort	University of Barcelona
Edgar Roldán	ICTP
Shin-Ichi Sasa	Kyoto University
David Sivak	Simon Fraser University
Dominic Skinner	MIT
Thomas Speck	University Mainz
Susanne Still	University of Hawaii
Laura Tociu	University of Chicago
Van Tuan Vo	University of Tokyo
Nicole Yunger Halpern	ITAMP

Final program

Workshop on stochastic thermodynamics II

Note: all times in Santa Fe local time - Mountain Daylight Time (UTC -6h)

Thursday 13th May 2021

Tutorials

Chair: Gülce Kardeş

7:00 AM	**Tutorial**	**Jordan Horowitz**	*Introduction to stochastic thermodynamics*
8:00 AM		Q&A	
8:20 AM		*break*	
8:30 AM	**Tutorial**	**Philipp Strasberg**	*Introduction to quantum stochastic thermodynamics*
9:30 AM		Q&A	
9:50 AM		*break*	
10:00 AM	**Tutorial**	**David Wolpert**	*Stochastic thermodynamics of information processing*
11:00 AM		Q&A	

Monday 17th May 2021

Physics and Chemistry

Chair: Massimiliano Esposito

7:00 AM		Organization committee	*Welcome and introduction*
7:15 AM 7:45 AM	**Colloquium**	**Todd Gingrich** Q&A	*From pair potentials to motors: A simulation saga*
8:00 AM 8:20 AM	**Invited**	**Gianmaria Falasco** Q&A	*Towards a macroscopic limit of stochastic thermodynamics*
8:30 AM 8:50 AM	**Invited**	**Sergio Ciliberto** Q&A	*An out-of-equilibrium Maxwell's demon which controls the energy fluxes*
9:00 AM	**Discussion**		*Discussion session*
9:45 AM		break	
10:00 AM 10:10 AM	**Lightning**	**David Hartich** Q&A	*Emergent memory and kinetic hysteresis in strongly driven networks*
10:15 AM 10:25 AM	**Lightning**	**Megan Engel** Q&A	*Machine learning for optimal control of nonequilibrium systems*
10:30 AM 10:40 AM	**Lightning**	**Benjamin Kuznets-Speck** Q&A	*Dissipation bounds the amplification of transition rates far from equilibrium*
10:45 AM 11:05 AM	**Invited**	**Andre Barato** Q&A	*Precise oscillations in stochastic thermodynamics*
11:15 AM 11:35 AM	**Invited**	**John Bechhoefer** Q&A	*Maximizing the performance of information ratchets*

Tuesday 18th May 2021

Biophysics

Chair: Christopher Jarzynski/Udo Seifert

7:00 AM 7:30 AM	**Colloquium**	**Felix Ritort** Q&A	*Fluctuation theorems for energy and information: theory and experiments*
7:45 AM 8:05 AM	**Invited**	**Saar Rahav** Q&A	*Uncertainty relation for enzymes, resetting systems, and other processes with irreversible transitions*
8:15 AM 8:35 AM	**Invited**	**Frank Jülicher** Q&A	*The physics of active droplets*
8:45 AM		Jenny Poulton	**ST Junior women's caucus announcement**
8:55 AM	**Discussion**		*discussion session*
9:35 AM		break	
9:45 AM 9:55 AM	**Lightning**	**Yuqing Qiu** Q&A	*A strong non-equilibrium bound for sorting of crosslinkers on growing biopolymers*
10:00 AM 10:10 AM	**Lightning**	**Florian Oltsch** Q&A	*Phase separation provides a mechanism to reduce noise in cells*
10:15 AM 10:25 AM	**Lightning**	**Dominic Skinner** Q&A	*Improved bounds on entropy production in living systems*
10:30 AM 10:50 AM	**Invited**	**David Sivak** Q&A	*Nonequilibrium energy transduction is maximized for flexibly linked machine components*
11:00 AM 11:20 AM	**Invited**	**Jenny Poulton** Q&A	*The long and short of templated copying*

Wednesday 19th May

Active matter/Biophysics

Chair: Udo Seifert/Christopher Jarzynski

7:00 AM	**Colloquium**	**Michael Cates**	*Informatic versus thermodynamic entropy production*
7:30 AM		Q&A	*in active systems*
7:45 AM	**Invited**	**Thomas Speck**	*Dissipated heat and entropy production of active Brownian*
8:05 AM		Q&A	*Particles*
8:15 AM	**Invited**	**Nikta Fakhri**	*Irreversibility in living active matter*
8:35 AM		Q&A	
8:45 AM	**Discussion**		*discussion session*
9:30 AM		break	
9:45 AM	**Lightning**	**Laura Tociu**	*Inferring dissipation from static structure in active matter*
9:55 AM		Q&A	
10:00 AM	**Lightning**	**Etienne Fodor**	*Thermodynamic cycles with active matter*
10:10 AM		Q&A	
10:15 AM	**Lightning**	**Trevor GrandPre**	*Entropy production fluctuations encode collective behavior*
10:25 AM		Q&A	*in active matter*
10:30 AM	**Invited**	**Ralf Eichhorn**	*How irreversible are steady-state trajectories of an active particle?*
10:50 AM		Q&A	
11:00 AM	**Invited**	**Srividya Iyer-Biswas**	*The economics of precision and plasticity*
11:20 AM		Q&A	

Thursday 20th May

Quantum stochastic thermodynamics

Chair: Henrik Wilming/Cigdem Yalcin

7:00 AM 7:30 AM	**Colloquium**	**Janet Anders** Q&A	*Energetic footprints of coherence and irreversibility in the quantum regime*
7:45 AM 7:55 AM	**Lightning**	**Yosuke Mitsuhashi** Q&A	*Complete passivity under symmetry constraints*
8:00 AM 8:10 AM	**Lightning**	**Andreu Riera-Campeny** Q&A	*Quantum systems correlated with a finite bath: nonequilibrium dynamics and thermodynamics*
8:15 AM 8:25 AM	**Lightning**	**Maria Popovic** Q&A	*Non-equilibrium quantum thermodynamics with time-evolving matrix product operators*
8:30 AM 8:50 AM	**Invited**	**Jukka Pekola** Q&A	*Stochastic thermodynamics in superconducting circuits*
9:00 AM	**Discussion**		*discussion session*
9:45 AM		break	
10:00 AM 10:20 AM	**Invited**	**Nicole Yunger Halpern** Q&A	*How effectively can a molecular switch switch?*
10:30 AM 10:50 AM	**Invited**	**Eric Lutz** Q&A	*Thermodynamics of weakly measured quantum systems*
11:00 AM 10:20 AM	**Invited**	**Sebastian Deffner** Q&A	*Energetic cost of Hamiltonian quantum gates*

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Friday 21st May

Information processing and computation

Chair: David Wolpert

7:00 AM 7:30 AM	**Colloquium**	**Shin-Ichi Sasa** Q&A	*Non-equilibrium thermodynamics from information theory*
7:45 AM 7:55 AM	**Lightning**	**Kanqiao Liu** Q&A	*Thermodynamic uncertainty relations for arbitrary initial states*
8:00 AM 8:10 AM	**Lightning**	**Van Tuan Vo** Q&A	*Unified approach to classical speed limit and thermodynamic uncertainty relation*
8:15 AM 8:25 AM	**Lightning**	**Jannik Ehrich** Q&A	*Tight bounds on hidden entropy production from partially observed dynamics*
8:30 AM 8:50 AM	**Invited**	**Edgar Roldán** Q&A	*Thermodynamics of gambling demons*
9:00 AM		Organization committee	**WOST III announcement**
9:15 AM	**Discussion**		*Discussion session*
10:00 AM		break	
10:15 AM 10:35 AM	**Invited**	**Vijay Balasubramanian**	*TBA*
10:45 AM 11:05 AM	**Invited**	**Andreas Dechant** Q&A	*Monotonicity of information and correlations in the thermodynamic uncertainty relation*
11:15 AM 11:35 AM	**Invited**	**Susanne Still** Q&A	*Thermodynamics of information processing*
11:45 AM		Organization committee	*Concluding remarks*

ABSTRACTS

Thursday 13th May – Tutorials

Tutorial I - Jordan Horowitz
Title: Introduction to stochastic thermodynamics
Abstract: Introduction to stochastic thermodynamics. Ensemble and trajectory thermodynamics. Second law of thermodynamics. Fluctuation theorems. Applications.

Reference:
C. Van den Broeck, M. Esposito, Ensemble and trajectory thermodynamics: A brief introduction, Physica A 418 (2015) 6-16.

Tutorial II - Philipp Strasberg
Title: Introduction to quantum stochastic thermodynamics
Abstract: Quantum extension of stochastic thermodynamics. Open quantum systems, work fluctuation theorem, (violation of) conservation laws in quantum mechanics, operationalism, Kolmogorov extension theorem, quantum stochastic process.

Reference:
S. Vinjanampathy, J. Anders, Quantum Thermodynamics, Contemporary Physics, 57 (2016) 545.

Tutorial III - David Wolpert
Title: Stochastic thermodynamics of information processing
Abstract: Entropy production in Turing machines and its relation to Kolmogorov complexity. Stochastic thermodynamics of circuits. Stochastic thermodynamics of distributed information processing.

Reference: S. Arora, B. Barak, Computational Complexity: A Modern Approach, CUP (2009), Chapter 1,6.

Monday 17th May – Physics & Chemistry

Colloquium – Todd Gingrich
Title: From pair potentials to motors: A simulation saga
Abstract: Stochastic thermodynamic studies of molecular motors often take as a starting point a Markov description of probabilistic evolution between discrete configurational states. I will describe our efforts to investigate the stochastic thermodynamics of a classical particle-based model of a molecular motor. This model, which could be coarse grained into the discrete-state Markov picture, can be simulated and studied at the fine-grained particle level with explicit particle chemostats providing the thermodynamic potential to generate current. I will discuss our interest in using this model as a playground to numerically explore trade-offs and uncertainty relations.

Invited – Gianmaria Falasco

Title: Towards a macroscopic limit of stochastic thermodynamics

Abstract: When the number of constituents of a nonequilibrium system goes to infinity and the dynamics approaches a deterministic limit, a wealth of new phenomena appear that are qualitatively different from equilibrium phase transitions.

By means of bifurcation theory one can identify multi-stability, limit cycles, and spatial patterns. In large, yet finite systems, thermal noise causes rare random transitions between the latter attractors, which become the macrostates of a coarse-grained stochastic dynamics. Stochastic thermodynamics at this intermediate level of description is still largely unexplored. In my talk I will review these concepts focusing in particular on mean-field interacting systems, chemical reactions, and electronic circuits.

Invited – Sergio Ciliberto

Title: An out-of-equilibrium Maxwell's demon which controls the energy fluxes

Abstract: An autonomous out-of-equilibrium Maxwell's demon is used to reverse the natural direction of the heat flux between two electric circuits kept at different temperatures and coupled by the electric thermal noise. The demon does not process any information, but it achieves its goal by using a frequency-dependent coupling with the two reservoirs of the system. There is no mean energy flux between the demon and the system, but the total entropy production (system + demon) is positive. The demon can be power supplied by thermocouples. The system and the demon are ruled by equations similar to those of two coupled Brownian particles and of the Brownian gyrator. Thus, our results pave the way to the application of autonomous out-of-equilibrium Maxwell demons to coupled nanosystems at different temperatures. Furthermore, we discuss the criterion proposed in Ref. [1] to measure how far a demon is from an ideal one. Finally, a bound on the demon efficiency is given in terms of uncertainty relations.

References:

[1] R. Sánchez, J. Splettstoesser, and R. S. Whitney, Nonequilibrium System as a Demon, Phys. Rev. Lett. 123, 216801 (2019).

Lightning – David Hartich

Title: Emergent memory and kinetic hysteresis in strongly driven networks

Abstract: In the analysis of networks in the context of stochastic thermodynamics the dynamics is typically assumed to obey local detailed balance [1], that is, the dynamics becomes memory-less. Involving prolonged dwells interrupted by instantaneous transitions between nodes such Markov networks stand as a coarse-graining paradigm for chemical reactions, molecular machines, and protein dynamics to name but a few. However, as soon as transitions cease to be negligibly short, as often observed in experiments [2-5], the dynamics develops a memory. That is, state-changes depend not only on the present state but also on the past. In our work we establish the first thermodynamically consistent mapping of an overdamped continuous dynamics onto a network, which reveals three kinds of ingrained dynamical symmetry, two of these being purely kinetic and one relating to thermodynamics [6]. These symmetries impose three independent sources of fluctuations in state-to-state kinetics that determine the flavor of memory. We will restrict the discussion mostly to the symmetry that reflects a generalization of the local detailed balance relation in the absence of a time-scale separation. Comparing our work to recent findings on non-Markovian yet renewal networks dynamics [7], we surprisingly find that the thermodynamically consistent coarse-graining must not commute with the time-reversal, leading to what we call kinetic hysteresis. The hysteresis between the forward/backward in time coarse-graining of continuous trajectories in turn implies a paradigm shift for the thermodynamics of active molecular processes [8{10] beyond the assumption of local detailed balance. Our results provide a new understanding of fluctuations in the operation of molecular machines as well as catch-bonds involved in cellular adhesion [6].

References:

[1] U. Seifert, Rep. Prog. Phys. 75, 126001 (2012).
[2] H. S. Chung, K. McHale, J.M. Louis, W. A. Eaton, Science 335 (2012).
[3] K. Neupane, et al. Phys. Rev. Lett. 109, 068102 (2012).
[4] J. Gladrow J, M. Ribezzi-Crivellari, F. Ritort, U. F. Keyser, Nat. Commun. 10 (2019).
[5] J.Y. Kim, H. S. Chung, Science 368, 1253 (2020).
[6] D. Hartich, A. Godec, arXiv:2011.04628 (2020).
[7] I. A. Martínez, G. Bisker, J. M. Horowitz, and J. M. R. Parrondo, Nat. Commun. 10, 3542 (2019).
[8] I. Neri, E. Roldán, and F. Jülicher, Phys. Rev. X 7, 011019 (2017).
[9] A. C. Barato and U. Seifert, Phys. Rev. Lett. 114, 158101(2015).
[10] J. M. Horowitz and T. R. Gingrich, Nat. Phys. 16, 15(2020).

Lightning – Megan Engel

Title: Machine learning for optimal control of nonequilibrium systems

Abstract: Identifying optimal protocols for driving nonequilibrium processes has broad relevance, from information storage in nanomagnetic systems to the design of efficient nanoengines to interpretation of single molecule force spectroscopy experiments. Errors in free energies derived using the Jarzynski equality, for example, scale with the exponential of nonequilibrium dissipated work, and minimizing this quantity for a given set of experimental or computational constraints is thus highly desirable. Knowledge of how to optimize other quantities, like thermodynamic cyclic efficiency, could lead to engineering insights in the design of DNA or protein nanomachines. Given the practical applicability of finding optimal nonequilibrium driving protocols, much effort has been devoted to the task over the past decade, but existing methods are either limited to the linear response (near-equilibrium) regime or tractable only for very simple systems, such as a Brownian particle in a harmonic potential. A general approach valid for systems of any complexity evolving arbitrarily far from equilibrium has not heretofore been elucidated.

Here, we leverage recent developments in the field of machine learning to find optimal nonequilibrium protocols in the general case, unconstrained by assumptions that have characterized previous efforts. In particular, we use automatic differentiation combined with gradient descent algorithms originally developed to train deep neural networks to reproduce several canonical from the literature. These include (i) the optimal magnetic field and temperature protocols for reversing magnetic bits as represented by an Ising lattice; (ii) the optimal protocol for varying the centre and stiffness of a harmonic potential in which a Brownian colloid is trapped; and (iii) the optimal protocol for driven barrier crossing, representative of biomolecular unfolding experiments. Our results indicate the feasibility of directly differentiating both Monte Carlo and Molecular Dynamics simulations. After thus establishing the validity of the method, we demonstrate how it can be extended to treat cases beyond the scope of previous approaches.

Lightning – Benjamin Kuznets-Speck

Title: Dissipation bounds the amplification of transition rates

Abstract: Nonequilibrium forces shape the behavior of complex stochastic systems by regulating transition rates between long-lived states, but a general theory to connect changes in driven microscopic interactions to emergent rate processes has remained elusive. Working in the transition path ensemble, we use stochastic thermodynamics to develop a theory of rate enhancement, yielding universal relations for and bounds on the ratio of transition rates between the systems with and without a time-dependent driving protocol. We show that the heat dissipated over the course of the transition sets an upper limit on achievable rate enhancement, starting with an exact reweighing scheme rooted in symmetries not limited to time reversal, and simplifying the result in number of limiting, though generic, cases. Canonical examples of rare diffusive events and barrier crossing under time-periodic and autonomous driving illustrate this basic tradeoff between speed and energy consumption.

Invited – Andre Barato
Title: Precise Oscillations in Stochastic Thermodynamics
Abstract: This talk is about the relation between precision and dissipation is system that displays oscillations and pertain to the framework of stochastic thermodynamics. We discuss the following results. A universal bound on the number of coherent oscillations in a biochemical system such as a circadian clock. The relations between precision and dissipation in spatial oscillations of Turing patterns in a simple model. The emergence of subharmonic oscillations in periodically driven systems and a related thermodynamically consistent model of a time-crystal.

Invited – John Bechhoefer
Title: Maximizing the performance of information ratchets
Abstract: Information-engines are the modern realization of the Maxwell demon – a thought experiment that revealed the close connection between thermodynamics and information. We introduce a simple experimental realization of an information engine based on an optically trapped heavy colloidal bead in water. The water functions as a thermal bath, whose fluctuation forces can, via a feedback algorithm, ratchet the bead "up", storing the gravitational energy in a work reservoir (battery). We optimize both the rate of energy storage and the directed velocity and find that big beads store more energy, while small beads go faster. However, increasing trap stiffness improves both criteria, showing the fundamental role of the material parameters of the motor. We analyze our results using a theory based on mean first-passage times. By optimizing the feedback algorithm and trap parameters, we have observed energy storage rates of 1000 kBT/s and directed velocities of 190 μm/s, numbers that exceed previous efforts by an order of magnitude and that are comparable to bacteria, which are of a similar size.

Tuesday 18th May – Biophysics

Colloquium – Felix Ritort
Title: Fluctuation theorems for energy and information: theory and experiments
Abstract: Single-molecule technologies combined with theoretical developments in nonequilibrium physics offer the exciting prospect of experimentally testing fundamental principles of the thermodynamics of information in the nanoscale [1]. In this colloquium, I will start by reviewing a few recent applications of fluctuation theorems to derive molecular free energy differences in biophysics [2,3]. Next, I will present an experimental realization of a Continuous Maxwell Demon using single DNA molecules pulled with optical tweezers under feedback protocols in a novel illustration of the thermodynamics of information [4,5]. Finally, I will introduce feedback protocols for dissipation reduction and improved free energy determination (information-to-measurement conversion), a new applicability domain of the thermodynamics of information to irreversible systems [6]. These studies underline the role of temporal correlations on the information-to-energy conversion efficiency in small systems.

References:
[1] F. Ritort, The noisy and marvelous molecular world of biology, Inventions, 4(2) (2019) 24
[2] A. M. Monge, I. Pastor, C. Bustamante, M. Manosas and F. Ritort, Measurement of the Specific and Non-specific Binding Energies of Mg2+ to RNA, submitted
[3] P. Rissone, C. V. Bizarro and F. Ritort, Stem-loop formation drives RNA folding in mechanical unzipping experiments, submitted

[4] M. Ribezzi-Crivellari and F. Ritort, Large work extraction and the Landauer limit in the Continuous Maxwell Demon, Nature Physics 15 (2019) 660–664.
[5] J. P. Garrahan and F. Ritort, Generalized Continuous Maxwell Demons, http://arxiv.org/abs/2104.12472, submitted
[6] M. Rico-Pasto, R. K. Schmitt, M. R. Crivellari, J. M. Parrondo, H. Linke, J. Johansson and F. Ritort, Dissipation reduction and information-to-measurement conversion in DNA pulling experiments with feedback, submitted

Invited – Saar Rahav
Title: Uncertainty relation for enzymes, resetting systems, and other processes with irreversible transitions
Abstract: The thermodynamic uncertainty relation (TUR) shows that the fluctuations of currents are bounded from below by the inverse entropy production. When one or more transitions are completely irreversible the entropy production diverges, and the TUR becomes non-informative. We show that additional bounds, which mix entropic and dynamic contributions, hold for such processes. Crucially, these new bounds are tighter in the presence of irreversible transitions. A steady-state process with resetting, and a transient first-passage problem are used as examples. We also discuss the connections between the bounds and the Aldous-Shepp bound that is often used in statistical kinetics.

Invited – Frank Jülicher
Title: The physics of active droplets
Abstract: TBA

Lightning – Yuqing Qiu
Title: A strong non-equilibrium bound for sorting of crosslinkers on growing biopolymers
Abstract: Understanding the role of non-equilibrium driving in self-organization is crucial for developing a predictive description of biological systems, yet it is impeded by their complexity. The actin cytoskeleton serves as a paradigm for how equilibrium and non-equilibrium forces combine to give rise to self-organization. Motivated by recent experiments that actin filament growth rates can tune the morphology of a growing actin bundle crosslinked by two competing types of actin binding proteins [Freedman et al. PNAS 116, 16192-16197 (2019)], we construct a minimal model for such a system and show that the dynamics are subject to a set of thermodynamic constraints that relate the non-equilibrium driving, bundle morphology, and molecular fluxes. In particular, we derive a thermodynamic bound of the microscopic driving for sorting of crosslinkers on growing biopolymers and verify that this thermodynamic bound, which has a flavor of non-equilibrium fluctuation dissipation relations, holds arbitrarily far from equilibrium. The thermodynamic constraints reveal the importance of correlations between these molecular fluxes and offer a route to estimating microscopic driving forces from microscopy experiments.

Lightning – Florian Oltsch
Title: Phase separation provides a mechanism to reduce noise in cells
Abstract: Noise in gene expression can cause significant variability in protein concentration. How cells buffer variation in protein concentration is an important question in biology. In this talk, I will show that liquid-liquid phase separation provides an effective mechanism to reduce variability in protein concentration. First, I will introduce our theoretical framework that discusses phase separation in the presence of active protein production and turnover. This stochastic non-equilibrium model allows us to study how fluctuations in protein concentration are affected by phase separation. I will then present under which physical conditions noise buffering by phase separation can be effective. Subsequently, I will show experimental data to test our theoretical predictions.

Lightning – Dominic Skinner
Title: Improved bounds on entropy production in living systems
Abstract: Living systems maintain or increase local order by working against the Second Law of Thermodynamics. Thermodynamic consistency is restored as they dissipate heat, thereby increasing the net entropy of their environment. Recently introduced estimators for the entropy production rate have provided major insights into the thermal efficiency of important cellular processes. In experiments, however, many degrees of freedom typically remain hidden to the observer, and in these cases, existing methods are not optimal. Here, by reformulating the problem within an optimization framework, we are able to infer improved bounds on the rate of entropy production from partial measurements of biological systems. Our approach yields provably optimal estimates given certain measurable transition statistics. In particular, it can reveal non-zero heat production rates even when non-equilibrium processes appear time symmetric and so may pretend to obey detailed balance. We demonstrate the broad applicability of this framework by providing improved bounds on the entropy production rate in a diverse range of biological systems including bacterial flagella motors, growing microtubules, and calcium oscillations within human embryonic kidney cells.

Invited – David Sivak
Title: Nonequilibrium energy transduction is maximized for flexibly linked machine components
Abstract: Living systems at the molecular scale are composed of many constituents with strong and heterogeneous interactions, operating far from equilibrium, and subject to strong fluctuations. These conditions pose significant challenges to efficient, precise, and rapid free energy transduction, yet nature has evolved numerous biomolecular machines that do just this. What are the physical limits on such nonequilibrium performance, and what machine designs actually achieve these limits? In this talk, I discuss a simple model of the ingenious rotary machine that makes ATP (the predominant portable energy currency of the cell), where one can investigate the interplay between nonequilibrium driving forces, thermal fluctuations, and the strength of interactions between strongly coupled subsystems. This model reveals nontrivial yet intuitive design principles for effective molecular-scale free energy transduction. Most notably, while tight coupling between machine components is intuitively appealing, output power is in fact maximized at intermediate-strength coupling, which permits lubrication by stochastic fluctuations with only minimal slippage.

Invited – Jenny Poulton
Title: The long and short of templated copying
Abstract: Templated copying is the central operation by which biology produces complex molecules. Cells copy sequence information from DNA to RNA and into proteins, which are the molecules responsible for the function and regulation of cellular systems. In the templated copying process the template catalyzes the formation of a second molecule carrying the same sequence. Traditionally, people have ignored the separation of the template and copy at the end of the process, but separation is both necessary and fundamentally changes the thermodynamics of the process.

In general, creating an accurate polymer costs free energy. Omitting separation, this can be compensated for by the extra free energy released by "correct" copy/template bonds. Separation requires these bonds be broken, so true copying requires an input of free energy. Copying is a far from equilibrium process. This talk explores the consequences of this observation. We start in the infinite length limit where the costs of accuracy represent hard thermodynamic bounds and then moves to the finite length limit where these same limits can be understood as kinetic barriers. We then discuss copying systems as non-equilibrium steady states, which can be analyzed as information engines moving free energy between out of equilibrium baths.

Wednesday 19th May – Active matter

Colloquium – Michael Cates
Title: Informatic versus thermodynamic entropy production in active systems
Abstract: Stochastic thermodynamics connects the steady-state entropy production rate (EPR) of a system connected to a heat bath with the log ratio of probabilities of forward and time-reversed trajectories. Extending the resulting formula to coarse-grained models of systems much further from equilibrium, such as schools of fish or herds of wildebeest, results in an informatic EPR (IEPR) that is no longer is connected with microscopic heat production, but remains a valuable quantifier of macroscopic irreversibility. In cases where the same coarse-grained models describe microscopic processes (e.g. at subcellular level), a connection to heat flow should be recoverable. To achieve this, we embed the coarse-grained model into a larger model involving explicit (if schematic) chemical reactions such that the whole system is governed by linear irreversible thermodynamics. All the active terms in the order parameter dynamics then become off-diagonal elements of an Onsager matrix whose symmetry determines both the remaining chemical couplings and the noise -- and thus the overall heat production. This full EPR exceeds the IEPR by a term that is a very large constant in uniform systems but contains additional spatial information in nonuniform ones.

Invited – Thomas Speck
Title: Dissipated heat and entropy production of active Brownian particles
Abstract: Active Brownian particles have emerged as a paradigm in active matter, adding directed motion to the arguably simplest model of a passive colloidal suspension. This directed motion needs to be sustained by supplying (free) energy, constantly driving the system away from thermal equilibrium. Living and synthetic active particles are driven not by non-conservative forces but unresolved microscopic processes, for example the local demixing of a binary solvent or the conversion of some fuel chemical. I will present a simple "tight-binding" model mimicking these degrees of freedom, and I will discuss what the model teaches about the actual heat dissipated by active Brownian particles.

Invited – Nikta Fakhri
Title: Irreversibility in living active matter
Abstract: Nonequilibrium dynamics is an essential physical feature of living matter. Living systems harness energy at the molecular scale through ATP hydrolysis and dissipate it on much larger spatiotemporal scales, often in the form of heat. The energetic loss can be cast as an increase in entropy of the environment, and the entropy production is associated with broken time-reversal symmetry and irreversibility in the system's dynamics. In this talk, I will discuss experimental tools and conceptual frameworks we develop to quantify scale-dependent irreversibility in living active matter.

Lightning – Laura Tociu
Title: Inferring dissipation from static structure in active matter
Abstract: Active systems, which are driven by local non-conservative forces, exhibit some unique behaviors and structures for potentially designing novel materials. Towards designing such materials, an important open challenge is to precisely connect the structure of active systems to the dissipation of energy induced by the local driving. We approach this problem by developing a perturbative mean-field theory which requires only static equilibrium measurements to deduce, systematically, how driving forces shape the structure out-of-equilibrium. Based on this theory, we then derive an expression for the dissipation rate, and we show that there exists a robust relation between dissipation and structure which holds even as the system approaches a phase transition far from equilibrium. Finally, we construct a neural network which maps static configurations of active particles to their dissipation rate without any prior knowledge of the underlying dynamics,

consolidating our findings on the connection between static structural information and dissipative work.

Lightning – Etienne Fodor

Title: Thermodynamic cycles with active matter

Abstract: Active matter operates far from equilibrium by constantly dissipating energy at the level of the microscopic constituents to power their self-propulsion. To determine whether, and to what extent, any intuition built from our experience of equilibrium physics is still useful to describe active matter, recent works have strived to build a unifying framework which extends standard thermodynamic notions, such as work, heat and entropy, beyond equilibrium [1-5].

The foundation of equilibrium thermodynamics was largely driven by the search for guiding principles to build efficient and powerful thermal engines. The anomalous properties of active matter now open the door to designing innovative cyclic engines without any equilibrium equivalent. A generic approach is still lacking to quantify and optimize their performances. How do they compare with that of standard thermal engines?

Are there generic relations between their efficiency and power, by analogy with thermal engines?

Based on a minimal model, we put forward a protocol which extracts work by controlling only the properties of the confining walls at boundaries, and we rationalize the transitions between optimal cycles. We show that the corresponding power and efficiency are generally proportional, in contrast with thermal engines, and we provide a generic bound on the maximum power in terms of the microscopic self-propulsion. Altogether, our results offer a systematic method to optimize thermodynamic cycles operating with active matter.

References:

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Lightning – Trevor GrandPre

Title: Entropy production fluctuations encode collective behavior in active matter

Abstract: We derive a general lower bound on distributions of entropy production in interacting active matter systems. The bound is tight in the limit that interparticle correlations are small and short-ranged, which we explore in four canonical active matter models. In all models studied, the bound is weak where collective fluctuations result in long-ranged correlations, which subsequently links the locations of phase transitions to enhanced entropy production fluctuations. We develop a theory for the onset of enhanced fluctuations and relate it to specific phase transitions in active Brownian particles. We also derive optimal control forces that realize the dynamics necessary to tune dissipation and manipulate the system between phases. In so doing, we uncover a general relationship between entropy production and pattern formation in active matter, as well as ways of controlling it.

Invited – Ralf Eichhorn
Title: How irreversible are steady-state trajectories of an active particle?
Abstract: The defining feature of active particles is that they constantly propel themselves by locally converting chemical energy into directed motion. This active self-propulsion prevents them from equilibrating with their thermal environment (e.g. an aqueous solution), thus keeping them permanently out of equilibrium. Nevertheless, the spatial dynamics of active particles might share certain equilibrium features, in particular in the steady state. We here focus on the time-reversal symmetry of individual spatial trajectories as a distinct equilibrium characteristic.
Within the framework of active Ornstein–Uhlenbeck particles we calculate the log-ratio of path probabilities for observing a certain particle trajectory forward in time versus observing its time-reserved twin trajectory, and derive a generalized ``entropy production'', which fulfills an integral fluctuation theorem. Using this ``entropy production'' we then investigate to what extent the steady-state trajectories of a trapped active particle obey or break time-reversal symmetry. We find that the steady-state trajectories in a harmonic potential fulfill path-wise time-reversal symmetry exactly, while this symmetry is typically broken in anharmonic potentials.

Invited – Srividya Iyer-Biswas
Title: The economics of precision and plasticity
Abstract: In this talk we will first summarize emergent simplicities and scaling laws governing stochastic intergenerational growth and division dynamics. Next, the constraints implicit in stochastic intergenerational homeostasis of related quantities. Following which, the generalization to time varying environmental conditions. Finally, a manifesto for a general framework characterizing the tradeoffs between precision, plasticity and energetic costs thereof.

Thursday 20th May – Quantum ST

Colloquium – Janet Anders
Title: Energetic footprints of coherence and irreversibility in the quantum regime
Abstract: In this talk, I will discuss how quantum stochastic thermodynamics can help unravel the fundamental differences between irreversibility in the quantum and classical regime. I will begin with recalling optimal expressions for the work extraction from coherences, i.e. using coherences as "fuel" to convert heat into work [1]. I will then discuss how non-optimal protocols give rise to irreversibility, and how this irreversibility manifests itself in energetic exchanges [2]. We find that, remarkably, these quantum irreversibility footprints differ from those in the classical regime. The analysis is made possible by employing quantum stochastic trajectories to construct distributions for entropic, heat and work exchanges.

References:

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Lightning – Yosuke Mitsuhashi
Title: Complete passivity under symmetry constraints
Abstract: With the rapid improvement in quantum control techniques in recent years, there has been a growing interest in thermodynamics on a small scale. The notion of complete passivity [1,2] is known as a quantum version of the second law of thermodynamics. A state is called completely

passive if one cannot extract work from multiple copies of the state by implementing any unitary operations on them. It is known that completely passive states are only Gibbs ensembles representing thermal equilibrium. Although all unitary operations are supposed to be feasible in the definition of complete passivity, there are constraints such as symmetry in practical experimental situations.
In this work [3], we identify completely passive states when symmetry constraints are imposed on possible unitary operations. Specifically, we prove that completely passive states under continuous symmetry constraints are only generalized Gibbs ensembles (GGEs). We emphasize that this result holds even for non-commutative symmetry, while commutative GGEs have been investigated in the context of thermalization [4]. Moreover, we investigate a setup where we explicitly introduce a quantum work storage system. We also discuss the fundamental difference between our work and a previous study [5].

References:

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Lightning – Andreu Riera-Campeny
Title: Quantum systems correlated with a finite bath: nonequilibrium dynamics and thermodynamics
Abstract: Describing open quantum systems far from equilibrium is challenging, in particular when the environment is mesoscopic, when it develops nonequilibrium features during the evolution, or when memory effects cannot be disregarded. Here, we derive a master equation that explicitly accounts for system-bath correlations and includes, at a coarse-grained level, a dynamically evolving bath. It applies to a wide variety of environments, for instance, those which can be described by Random Matrix Theory or the Eigenstate Thermalization Hypothesis. We obtain a local detailed balance condition which, interestingly, does not forbid the emergence of stable negative temperature states in unison with the definition of temperature through the Boltzmann entropy. We benchmark the master equation against the exact evolution and observe a very good agreement in a situation where the conventional Born-Markov-secular master equation breaks down. Interestingly, the present description of the dynamics is robust, and it remains accurate even if some of the assumptions are relaxed. Even though our master equation describes a dynamically evolving bath not described by a Gibbs state, we provide a consistent nonequilibrium thermodynamic framework and derive the first and second law as well as the Clausius inequality. Our work paves the way for studying a variety of nanoscale quantum technologies including engines, refrigerators, or heat pumps beyond the conventionally employed assumption of a static thermal bath.

Lightning – Maria Popovic
Title: Non-equilibrium quantum thermodynamics with time-evolving matrix product operators
Abstract: We present a numerically exact method to compute the full counting statistics of heat transfer in non-Markovian open quantum systems, which is based on the time-evolving matrix product operator (TEMPO) algorithm. This approach is applied to the paradigmatic spin-boson model in order to calculate the mean and fluctuations of the heat transferred to the environment during thermal equilibration. We show that system-reservoir correlations make a significant contribution to the heat statistics at low temperature and present a variational theory that quantitatively explains our numerical results. We also demonstrate a fluctuation-dissipation relation connecting the mean and variance of the heat distribution at high temperature. Our results reveal that system-bath interactions make a significant contribution to heat dissipation even when the dynamics of the open system is effectively Markovian. The method presented here provides a flexible and general tool to predict the fluctuations of heat transfer in open quantum systems in non-perturbative regimes.

Invited – Jukka Pekola

Title: Stochastic thermodynamics in superconducting circuits

Abstract: I briefly review our activities and achievements on stochastic thermodynamics in mesoscopic electron systems at low temperatures [1]. These classical experiments serve as an accurate test ground of fluctuation relations and a setup to realize Maxwell demons thanks to the possibility to collect large statistics and simple modeling of the system. The second part of the talk focuses on our current activity on using superconducting qubits and ultrasensitive calorimeters to measure heat generation directly in stochastic quantum processes [2,3,4].

References:

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[4] Bayan Karimi and Jukka P. Pekola, Quantum trajectory analysis of single microwave photon detection by nanocalorimetry, Physical Review Letters 124, 170601 (2020).

Invited – Nicole Yunger Halpern

Title: How effectively can a molecular switch switch?

Abstract: Molecular switches called photoisomers surface across nature and technologies, from our eyes to solar-fuel cells. What probability does a switch have of switching? A general answer challenges standard chemistry tools, because molecular switches are small, quantum and far from equilibrium. I will answer by modeling a molecular switch within a resource theory, a simple thermodynamic model from quantum information theory. I will upper-bound the switching probability, then compare the bound with numerical simulations of Lindbladian evolution. The resource-theory bound constrains the yield tightly if a laser barely excites the molecule, as in some experiments. Electronic coherence cannot boost the yield, I will argue, because modes of coherence transform independently via thermal operations. This work illustrates how the intersection of stochastic thermodynamics and quantum information theory can answer questions in other fields.

References:

Yunger Halpern and Limmer, Phys. Rev. A 101, 042116 (2020).

Invited – Eric Lutz

Title: Thermodynamics of weakly measured quantum systems

Abstract: We consider continuously monitored quantum systems and introduce definitions of work, heat and information along individual quantum trajectories that are valid for coherent superposition of energy eigenstates. We use these quantities to extend the laws of stochastic thermodynamics to the quantum domain and analyze a coherent Maxwell demon.
We additionally present corresponding experimental results for a weakly measured transmon qubit.

References:

Thermodynamics of weakly measured quantum systems, Phys. Rev. Lett. 116, 080403 (2016).
Information gain and loss for a quantum Maxwell's demon, Phys. Rev. Lett. 121, 030604 (2018).
Heat and work along individual trajectories of a quantum bit, Phys. Rev. Lett. 124, 110604 (2020).

Invited – Sebastian Deffner
Title: Energetic cost of Hamiltonian quantum gates
Abstract: Landauer's principle laid the main foundation for the development of modern thermodynamics of information. However, in its original inception the principle relies on semiformal arguments and dissipative dynamics. Hence, if and how Landauer's principle applies to unitary quantum computing is less than obvious. In this talk, we prove an inequality bounding the change of Shannon information encoded in the logical quantum states by quantifying the energetic cost of Hamiltonian gate operations. The utility of this bound is demonstrated by outlining how it can be applied to identify energetically optimal quantum gates in theory and experiment. The analysis is concluded by discussing the energetic cost of quantum error correcting codes with non-interacting qubits, such as Shor's code.

Friday 21st May – Information processing

Colloquium – Shin-Ichi Sasa
Title: Non-equilibrium thermodynamics from information theory
Abstract: The critical concept of equilibrium thermodynamics is a transformation with keeping the extent of randomness. The discovery in the 19th century led to the genesis of entropy. Now, studying steady-state systems out of equilibrium, we construct a novel transformation from the steady-state to an equilibrium state with keeping the extent of randomness. We find that the Fisher information of the path probability density with this transformation parameter is equivalent to the entropy production [1]. The formulation provides a new bridge between non-equilibrium thermodynamics and information theory. As an exciting example of steady-state systems out of equilibrium, we illustrate the two-dimensional phase order under shear [2]. We discuss this phenomenon from the viewpoint of information theory.

References:
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Lightning – Kanqiao Liu
Title: Thermodynamic uncertainty relations for arbitrary initial states
Abstract: Over the last two decades, stochastic thermodynamics as a general framework has been greatly developed for understanding dissipation and thermal fluctuations far-away-from equilibrium, such as the celebrated fluctuation theorems. Recently, yet another rigorous principle known as the thermodynamic uncertainty relation (TUR) was discovered [1], stating that, for a nonequilibrium system coupled to several heat reservoirs, there exists a fundamental trade-off relation between the precision of a nonequilibrium accumulated current and the total entropy production. This inequality was originally discovered in biochemical networks and later rigorously proven via large deviation theory. However, currently known TURs require either specific initial states or an infinitely long time and they are only valid for continuous-time Markovian processes, which severely limit the range of its applicability.
In this work [2], we derive several finite-time TURs that are valid for arbitrary initial states in both continuous- and discrete-time Markovian processes. For continuous-time dynamics, we prove that the variance of a time-integrated current is bounded from below by the instantaneous current at the final time, which suggests that “the boundary is constrained by the bulk”. We then apply the obtained result to feedback-controlled processes and successfully explain a violation reported in a recent experiment for a modified TUR with measurement and feedback control. For discrete-time processes, we derive a TUR which is valid for general initial states and linear in the total entropy production, which provides exponential improvement on the existing discrete-time TURs.

References:

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[2] K. Liu, Z. Gong, and M. Ueda, Phys. Rev. Lett. 125, 140602 (2020).

Lightning – Van Tuan Vo

Title: Unified approach to classical speed limit and thermodynamic uncertainty relation

Abstract: The total entropy production quantifies the extent of irreversibility in thermodynamic systems, which is nonnegative for any feasible dynamics. When additional information such as the initial and final states or moments of an observable is available, it is known that tighter lower bounds on the entropy production exists according to the classical speed limits and the thermodynamic uncertainty relations. Here [1], we derive a universal lower bound on the total entropy production involving the probability distributions of an observable in the time forward and backward processes. By choosing an appropriate observable, we show that the universal relation reduces to a classical speed limit, imposing a constraint on the speed of the state transformation in terms of the Hatano-Sasa entropy production and the dynamical activity. It is noteworthy that the newly obtained classical speed limit is tighter than the previously reported bound [2] by a constant factor. As another corollary of the universal relation, we demonstrate that a generalized thermodynamic uncertainty relation can be obtained for systems with time-reversal symmetry breaking. Our uncertainty relation holds for time symmetric or antisymmetric observables and recovers several existing bounds [3,4,5]. Our approach provides a unified perspective on two closely related classes of inequality: classical speed limits and thermodynamic uncertainty relations.

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Lightning – Jannik Ehrich

Title: Tight bounds on hidden entropy production

Abstract: Stochastic Thermodynamics allows us to define heat and work for microscopic systems far from thermodynamic equilibrium, based on observations of their stochastic dynamics. However, a complete account of the energetics of small-scale systems necessitates that all relevant degrees of freedom are resolved, which is not feasible in many experimental situations. A simple approach is to map the visible dynamics onto a Markov model, which produces a lower-bound estimate of the entropy production. The bound, however, can be quite loose, especially when the visible dynamics only have small or vanishing observable currents. Instead, I show an alternative approach which finds an underlying hidden Markov model responsible for generating the observed non-Markovian dynamics. For the setting of masked Markovian kinetic networks, one obtains the tightest possible lower bound on entropy production of the full dynamics that is compatible with the observable data.

Invited – Edgar Roldán

Title: Thermodynamics of gambling demons

Abstract: We introduce and realize demons that follow a customary gambling strategy to stop a nonequilibrium process at stochastic times. We derive second-law-like inequalities for the average work done in the presence of gambling, and universal stopping-time fluctuation relations for classical and quantum nonstationary stochastic processes. We test experimentally our results in a

single-electron box, where an electrostatic potential drives the dynamics of individual electrons tunneling into a metallic island. We also discuss the role of coherence in gambling demons measuring quantum jump trajectories.

References:
G. Manzano, et al., Phys. Rev. Lett. 126, 080603 (2021)

Invited – Vijay Balasubramanian
Title: TBA
Abstract: TBA

Invited – Andreas Dechant
Title: Monotonicity of information and correlations in the thermodynamic uncertainty relation
Abstract: Thermodynamic inequalities, most prominently the thermodynamic uncertainty relation (TUR), have recently attracted much attention in the non-equilibrium statistical mechanics and stochastic thermodynamics communities. Mathematically, many of these inequalities can be derived from the Cramer-Rao bound, a standard result of estimation theory. In this talk, I will discuss the monotonic behavior of the Cramer-Rao bound: More information in the form of additional measurements always results in a tighter bound. Applied to the TUR, we obtain a "correlation TUR" that gives a tighter bound on the entropy production by simultaneously measuring several currents. I will demonstrate a concrete and versatile scheme for exploiting correlations between different observables, thereby improving the estimate with existing trajectory data. For many quasi-one-dimensional systems, such as models of molecular motors, this allows to bound the entropy production to around 90% of its true value, a marked improvement over the bound of around 40% obtained from the TUR.

References:
A. Dechant and S.-I. Sasa, "Fluctuation-response inequality out of equilibrium", PNAS 117 (2020)
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A. Dechant and S.-I. Sasa, "Improving thermodynamic bounds using correlations", arXiv:2104.04169

Invited – Susanne Still
Title: Thermodynamics of information processing
Abstract: Over 150 years ago, Maxwell discussed the interrelatedness of information and work with a thought experiment that is often referred to as "Maxwell's demon". Interest in this subject has surged over the last decade as experimental demonstrations of Szilárd's information engine and of Landauer's bound have become feasible. Szilárd pointed out that the role of the demon is to map measurements onto a decision that persists over the duration of work extraction, i.e., a memory, and that this map can be implemented by machinery. This laid the foundation for information engines, and almost 100 years later, Szilárd's Gedankenexperiment still serves as a canonical example. Until recently, the discussion of information engines was focused on the special case in which the quantities that need to be known in order to extract work are observable, and the observer can, and does, act optimally. Real world observers are not typically in this ideal situation. When the scope is widened to include partially observable scenarios (Still, PRL 2020), an interesting connection emerges between thermodynamic efficiency and predictive inference. The demon's intelligence reflected by the choice of the map from observables to memory can then be mechanized as well. This can be done by finding the map which results in the smallest dissipated energy. An algorithm can be derived from this optimization principle. Information theoretic predictive inference emerges,

specifically the Information Bottleneck method. The framework of generalized, partially observable information engines allows for the combined treatment of heat engines and information engines. Looking at Clausius formulation of the second law from this perspective shows that entropy production in a cyclic process is equal to unusable information created (times the Boltzmann constant).