Thermodynamics and Nonlinear Dynamics in the Information Age

Organizing Committee:
Korana Burke
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July 13 – July 17, 2015

Telluride Elementary School, 477 West Columbia Ave Telluride, CO

Contents

1 Scope

Since its beginnings one of the main purposes of thermodynamics has been the optimization of devices. Commonly, processes are characterized as optimal if they are maximally fast or maximally efficient. Recent years have seen the development of various theoretical tools which tremendously broadened our understanding of such optimal processes, in quantum mechanics and in classical physics. A particular highlight are so-called shortcuts to adiabaticity – finite time processes that mimic adiabatic dynamics without the requirement of slow driving. These exciting new results found relevance and application in a wide variety of fields including Quantum Sensing and Metrology, Finite-Time Thermodynamics, Quantum Simulation, Quantum Computation, Quantum Communication, and Quantum Optimal Control Theory. A second pillar of modern thermodynamic optimization are so-called information engines. In these systems the effects of information gain and its feedback into the dynamics are explicitly studied. As a consequence Maxwell demon-like systems have lost its demonic obscurity and have become an integral part of realistic optimization. All of these processes are frequently governed by inherently nonlinear equations. This conference aims at an exchange of ideas from researchers in Non-Equilibrium Thermodynamics, Atomic, Molecular, and Optical Sciences, Quantum Information and Quantum Technologies, Statistical Mechanics, Optimal Control Theory, and Nonlinear Dynamics.

2 Program

2.1 Overview

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00	badge pick-up	breakfast	breakfast	breakfast	breakfast
8:30		**del Campo**	**Ueda**	**Shabani**	**Steck**
9:00		**Chen**	**Watanabe**	**Orozco**	**Zwolak**
9:30		**Bensey**	**Kim**	**Torrontegui**	**Chien**
10:00		coffee	coffee	coffee	coffee
10:30		**Montangero**	**Deffner**	**Singer**	**Bechhoefer**
11:00	opening	**Boldt**	**Mandal**	**Gardas**	**Mahoney**
11:30	**Burke**	**Salamon**	**Ruppeiner**	**Chamberlin**	closing
12:00	lunch	lunch	lunch	lunch	
12:30					
13:00					
13:30	**Crutchfield**				
14:00	**Boyd**				
14:30	coffee				
15:00	**Hinczewski**				
15:30	**Sivak**				
16:00	**Egusquiza**				
16:30					
17:00					
17:30					
18:00		town talk	TSRC picnic		

2.2 Monday, July 13, 2015: Information Engines

7:30 am – 11:00 am: Badge Pick-Up

Check-In at the Elementary School (available afterwards in the office, room 206)

11:00 am – 12:00 pm: Opening talk

Korana Burke
Sebastian Deffner
Adolfo del Campo

12:00 pm – 1:30 pm: Lunch

Session Chair: **KORANA BURKE**

1:30 pm – 2:00 pm: Structural Thermodynamics of Agency

James P. Crutchfield
Complexity Sciences Center
Physics Department
University of California, Davis, USA

Synthetic nanoscale machines, like their biological counterparts, perform tasks that involve the simultaneous manipulation of energy, information, and matter. In this they are information enginessystems with two inextricably intertwined characters. The first aspect, call it physical, is the one in which the systemseen embedded in a material substrateis driven by, manipulates, stores, and dissipates energy. The second aspect, call it computational, is the one in which the systemseen in terms of its spatial and temporal organizationgenerates, stores, loses, and transforms information. Information engines operate by synergistically balancing both aspects to support a given functionality.

To ground this view, I will show that Szilard's engine is a chaotic dynamical system. This demonstrates that the degree of chaotic instability (determined by the Kolmorogov-Sinai entropy) is the optimum rate at which Maxwellian Demons extract energy from a heat bath. Analyzing a demon's intrinsic computation then gives a quantitative grounding to Maxwell's notion of intelligent control of thermodynamic systems. This suggests a way to analyze a system in terms of its agency—its ability to sense, reflect, decide, and act effectively in an unpredictable environment.

In short, to the degree that nature is structured, it computes.

2:00 pm – 2:30 pm: Exact Information Thermodynamics of an Autonomous Maxwellian Ratchet

Alec Boyd
Complexity Sciences Center
Physics Department
University of California, Davis, USA

We propose a model of Maxwell's demon for which the correlations among the information bearing degrees of freedom can be calculated exactly in a compact analytical form. The model can behave either as an engine, lifting a mass against gravity by extracting energy from a single heat reservoir, or a Landauer eraser, removing information from a sequence of binary symbols by consuming external work. In both cases, the explicit accounting of the correlations among the symbols lead to a stronger bound on the performance of the demon.

2:30 pm – 3:00 pm: Coffee Break

Session Chair: **JOHN BECHHOEFER**

3:00 pm – 3:30 pm: Cellular telephone games: optimizing information transfer through nonlinear, stochastic biological networks

Michael Hinczewski
Department of Physics
Case Western Reserve University, USA

Living cells make crucial decisions — whether to grow, divide, die — based on external signaling molecules in their environment. The biochemical networks which transmit and amplify these signals from receptors on the cell surface are like an elaborate game of telephone: with each stage of the transmission, information is lost through the random nature of the underlying reactions. This talk focuses on how nature can optimize information transfer through the network, taking into account both the discreteness of molecule populations, and the nonlinearity of the dynamical system. We discuss how ideas from statistical physics and signal processing, particularly the theory of Wiener-Kolmogorov filters, can help us understand the fundamental constraints on biological signaling. In the process, we illuminate the striking costs of transmitting even a single bit of information through the tumult of the cell.

3:30 pm – 4:00 pm: Optimal control of microscopic nonequilibrium systems

David Sivak
Department of Physics
Simon Fraser University, Canada

Molecular machines are protein complexes that convert between different forms of energy, and they feature prominently in essentially any major cell biological process. A plausible hypothesis holds that evolution has sculpted these machines to efficiently transmit energy and information in their natural contexts, where energetic fluctuations are large and nonequilibrium driving forces are strong. Toward a systematic picture of efficient, stochastic, nonequilibrium energy and information transmission, I address two related fundamental questions in nonequilibrium statistical mechanics: How do we predict the response of molecular-scale soft-matter systems to rapid nonequilibrium perturbations? And how do we identify the perturbations that most efficiently (yet rapidly) carry such a noisy system from one state to another? I go on to explore the nonequilibrium behavior of some example model systems. These abstract theoretical considerations have fairly immediate consequences for the design of single-molecule biophysical experiments and steered molecular simulations, and potential implications for the design principles of energetically efficient yet stochastic molecular machines.

4:00 pm – 4:30 pm: Quantum memristors

Íñigo Luis Egusquiza
Department of Theoretical Physics and History of Science
University of the Basque Country, Spain

Memristors have attracted a lot of attention as a possible new technology, not least because of the possibility of implementing new computing paradigms. We present here a "quantum memristor", defined as a quantum dissipative device whose decoherence is controlled by a continuous measurement feedback scheme (the memory). We show its characteristic hysteric behaviour, and speculate as to its possible implementation.

2.3 Tuesday, July 14, 2015: Shortcuts to Adiabaticity

Session Chair: **PETER SALAMON**

8:30 am – 9:00 am: Shortcuts to adiabaticity in quantum thermodynamics

Adolfo del Campo
Department of Physics
University of Massachusetts, Boston, USA

A shortcut to adiabaticity (STA) is a non-adiabatic protocol that reproduces the same target state that would result in a strictly adiabatic dynamics. It resorts on an external control to tailor excitations and can be used to induce a "fast motion video of the adiabatic dynamics". STA's have direct applications in finite-time thermodynamics. Ideal reversible engines operate at the maximum efficiency but have zero power. Realistic engines, on the other hand, operate in finite-time and are intrinsically irreversible, implying friction effects at short cycle times. The engineering goal is to find the maximum efficiency allowed at the maximum possible power. In this talk it is shown that, by utilizing STA's in a quantum engine cycle, one can engineer a thermodynamic cycle working at finite power and zero friction. These findings are elucidated using a harmonic oscillator undergoing a quantum Otto cycle.

9:00 am – 9:30 am: Shortcuts to adiabatic trap expansions

Xi Chen
Department of Physics
Shanghai University, China

The expansion of a harmonic potential or trap box that holds a quantum particle may be realized without any final particle excitation but much faster than adiabatically via "shortcuts to adiabaticity" (STA). In this talk I first review the shortcuts to adiabatic expansion for harmonic trap and quantum box. Then I will discuss the role of different time-averaged energies (total, kinetic, potential, non-adiabatic) and of the instantaneous power in characterizing or selecting different shortcut protocols for harmonic trap. Specifically, we prove a virial theorem for STA processes, set minimal energies for specific times or viceversa, and discuss their realizability by means of Dirac impulses or otherwise. The practical limitations and constraints impose minimal finite times, relevant to the third law of thermodynamics, for the externally controlled time-dependent frequency protocols. In addition, I will also briefly discuss the minimize times for fast expansion in trap box, and the role in characterizing the power when shortcuts are applied in the quantum heat engine.

9:30 am – 10:00 am: Spatial adiabatic passage: Shortcuts to adiabaticity and interacting systems

Albert Benseny
Okinawa Institute of Science and Technology, Japan

The spatial adiabatic passage (SAP) technique has been proposed to accurately control the external degrees of freedom of trapped particles in a robust manner, i.e., without requiring an accurate control of the system parameters (1). It considers a system formed by three traps arranged in a straight line, and is a spatial analogue of the quantum-optical stimulated Raman adiabatic passage (STIRAP) technique (2). In its most basic form, it transfers an atom in the ground state of the first trap to the ground state of the third trap. Applications have been suggested for both optically-trapped ultracold atoms (1) and electrons in quantum dots (3)

SAP is an adiabatic technique, which means that it can yield a very high fidelity, but at the cost of being carried out over long time scales (where the inverse of the total time is much larger than all characteristic frequencies of the system). Shortcuts to adiabaticity (STA) techniques (4) allow to speed up adiabatic processes while maintaining their robustness and fidelity. The particular shortcut for a three-level system requires a direct and imaginary coupling between the initial and final states (5). A direct tunnelling coupling, which has no quantum-optical analogue, can be achieved by moving to a two-dimensional trap configuration (6). We have shown that an imaginary coupling (and thus the shortcut) can be achieved by means of a geometric phase which can be implemented through the Aharonov-Bohm effect (7) in a quantum-dot system (8).

Moreover, we have also studied the SAP transport in a triple well for two interacting bosons over the entire range of repulsive interactions (9). We have found that, in addition to the trivial cases of zero and infinite interactions, a large and continuous region for intermediate interactions exist over which high fidelities can be obtained. This is due to the fact that for intermediate values of the interaction strength a decoupled energy band appears, which possess a dark state facilitated by two-particle co-tunneling.

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(2) K. Bergmann, H. Theuer, and B. W. Shore, Rev. Mod. Phys. 70, 1003 (1998).

(3) J. H. Cole, A. D. Greentree, L. C. L. Hollenberg, and S. Das Sarma, Phys. Rev. B 77, 235418 (2008).

(4) E. Torrontegui, S. Ibáñez, S. Martínez-Garaot, M. Modugno, A. del Campo, D. Guéry-Odelin, A. Ruschhaupt, X. Chen, and J. G. Muga, Adv. At. Mol. Opt. Phys. 62, 117 (2013).

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(7) Y. Aharonov and D. Bohm, Phys. Rev. 115 (1959).

(8) A. Benseny, A. Kiely, A. Ruschhaupt, and Th. Busch (2015).

(9) J. Gillet, A. Benseny, and Th. Busch (2015).

10:00 am – 10:30 am: Coffee break

Session Chair: **ADOLFO DEL CAMPO**

10:30 am – 11:00 am: Quantum-classical crossover of the Kibble-Zurek mechanism

Simone Montangero
Institute for Complex Quantum Systems
Ulm University, Germany

Mechanisms of defects formation when dynamically driving a system across a symmetry-breaking phase transitions are an expanding topic in many body physics. Simple and elegant theoretical frameworks, such as the Kibble-Zurek mechanism, often successfully predict scalings of the defects in classical and quantum phase transitions by employing concepts valid at equilibrium. Here, we expand this framework conjecturing that the density of defects after a quench across quantum phase transition, which is classically described by a mean-field model, is governed by the mean-field exponents when the quench speed exceeds a certain value. We quantify this bound and provide numerical support to our conjecture with a many-body out-of-equilibrium simulation of a ϕ^4 lattice theory in 1+1 dimensions. This result contributes to extending the prediction power of the Kibble-Zurek mechanism and to provide insight into recent experimental observations in systems of cold atoms and ions.

11:00 am – 11:30 am: Constructing invariants for ensembles of Hamiltonian systems

Frank Boldt
Institut für Physik
Fakultät für Naturwissenschaften
Technische Universität Chemnitz, Germany

In my talk I will discuss the construction of invariants for Hamiltonian systems following a Lie algebra approach. Further, a generic formalism for constructing invariants for statistical ensembles of such Hamiltonian systems will be laid out. In particular, the famous Ermakov invariant of the harmonic oscillator is compared to the novel Casimir companion exemplifying the proposed approach. Both invariants play a crucial role in finding Shortcuts to Adiabaticity or Fastest Effectively Adiabatic Transitions. Finally, I hope to discuss the term "expanding mode" in the general context of ensemble invariants.

11:30 pm – 12:00 pm: Parasitic oscillations in quantum control

Peter Salamon
Department of Mathematics and Statistics
San Diego State University, USA

Most ways of driving a (classical or quantum) Hamiltonian system leak some of the energy into parasitic modes. It is difficult to extract energy reversibly back out of these modes; it takes something akin to a spin-echo. For quantum control problems, this phenomenon has been dubbed quantum friction and shows up whenever the Hamiltonian of the system at one time does not commute with itself at another time, i.e. $[H(t), H(t')] \neq 0$. Parasitic modes give rise to entropy production by decaying on contact with a heat bath at any temperature. All of these features are illustrated using the problem of controlling the frequency of a harmonic oscillator, which turns out to have a surprisingly rich structure despite its simplicity. The talk concludes with a question: What are general design principles that avoid leaving energy in parasitic modes during control of a conservative system? Going sufficiently slowly may be one answer.

12:00 pm – 1:00 pm: Lunch

6:00 pm – 7:00pm: Town Talk

Town Talk at Telluride Conference Center in Mountain Village

2.4 Wednesday, July 15, 2015: Fluctuation Theorems

Session Chair: **SEBASTIAN DEFFNER**

8:30 am – 9:00 am: Gibbs paradox and fluctuation theorem

Masahito Ueda
Department of Physics
The University of Tokyo, Japan

The Gibbs paradox has a long history of controversy and discussions, and several ideas to resolve it have been put forth. In the talk, we will point out that the Gibbs paradox has a close connection to the fundamental flaw of the fluctuation theorem, and show the way to resolve the paradox.

9:00 am – 9:30 am: Quantum fluctuation theorems and generalized measurements

Gentaro Watanabe
Institute for Basic Science, Korea

The discovery of the transient fluctuation theorems recognized as the Jarzynski equality (1) and the Crooks relation (2) is a recent large development in non-equilibrium statistical mechanics. Originally, these theorems were shown for classical systems and, later on, it was proved that they hold for quantum systems as well (3,4), which we focus on this presentation.

These quantum fluctuation theorems assume that work is determined by projective energy measurements at the beginning and the end of the protocol. However, projective measurements are difficult to implement experimentally. This is a major obstacle to the direct verification of the transient fluctuation theorems in quantum systems. It is thus important to ask whether these projective measurements can be replaced with generalized measurements which could be easier to implement (5-7). First, we prove a kind of no-go theorem that only projective measurements can satisfy the Crooks relation for an arbitrary force protocol (5). Then we show that, however, we can overcome this no-go theorem (7). We will also discuss the future prospects towards the verification of the quantum fluctuation theorems in cold atomic gases.

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(2) G. E. Crooks, Phys. Rev. E 60, 2721 (1999).

(3) J. Kurchan, arXiv:cond-mat/0007360 (2000).

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9:30 am – 10:00 am: A fluctuation relation of work for a quantum system beyond the weak-coupling limit

ILki Kim
Center for Energy Research and Technology
North Carolina A&T State University, USA

We discuss a fluctuation relation of work for a quantum system coupled at an arbitrary strength to a bath. Based on the concept of work for an isolated system prepared in a non-equilibrium state (as well as non-canonical equilibrium one), we first introduce a concept of work for the coupled case, being expressed in terms of the degrees of freedom pertaining to the local system alone (with no bath degrees of freedom). Accordingly, an extraction of its exact (average) amount is practically feasible. Then by successively applying the formulation for an isolated case, we can obtain a fluctuation relation for the coupled case, which has quantum-effect terms. We also discuss its connection to entropy production and information free energy, etc.

10:00 am – 10:30 am: Coffee break

Session Chair: **MASAHITO UEDA**

10:30 am – 11:00 am: Jarzynski Equality in $\mathcal{PT}$-Symmetric Quantum Mechanics

Sebastian Deffner
Theoretical Division and Center for Nonlinear Studies
Los Alamos National Laboratory, USA

For isolated quantum systems fluctuation theorems are commonly derived within the two-time energy measurement approach. In this talk we will discuss recent developments and studies on generalizations of this approach. We will show that the quantum fluctuation theorem generalizes to $\mathcal{PT}$-symmetric quantum mechanics with unbroken $\mathcal{PT}$-symmetry. In the regime of broken $\mathcal{PT}$-symmetry the Jarzynski equality does not hold as also the $\mathcal{CPT}$-norm is not preserved during the dynamics. These findings will be illustrated for an experimentally relevant system - two coupled optical waveguides. It turns out that for these systems the phase transition between the regimes of unbroken and broken $\mathcal{PT}$-symmetry is thermodynamically inhibited as the irreversible work diverges at the critical point.

11:00 pm – 11:30 pm: Reversibility and near-reversibility of steady state processes

Dibyendu Mandal
Department of Physics and Helen Wills Neuroscience Institute
University of California, Berkeley, USA

Within the framework of stochastic thermodynamics, transitions between nonequilibrium steady states are characterized by a modified Clausius inequality. In the quasistatic limit, the inequality turns into an equality, defining the concept of reversibility for steady state processes. We find interesting parallels between this notion of reversible steady state processes and the usual notion of reversible equilibrium processes. We then derive an exact analytical expression for the lowest order correction to the quasistatic limit for slow but finite-rate (near-reversible) processes, discovering a Green-Kubo relation in this far from equilibrium situation.

11:30 pm – 12:00 pm: A thermodynamic alternative to evaluating partition functions for strongly interacting systems

George Ruppeiner
Division of Natural Sciences
New College of Florida, USA

To determine the thermodynamic behavior of a system, we commonly "build up" from the system?s microscopic energy levels, and calculate the partition function Z. Direct calculation of Z is effective for gasses or for simplified models devised for ready summation. Generally, however, for strongly interacting systems, calculating Z is difficult for two reasons: 1) we usually do not know the interparticle interaction potential exactly, and 2) the summation to find Z is intrinsically difficult because large correlated particle clusters are present at mesoscopic size scales. In this talk, I discuss an alternative method of finding the thermodynamic properties of strongly interacting systems, by using a principle resulting from combining hyperscaling with the geometry of thermodynamics. In this method, we "build down" from the macroscopic level to the mesoscopic fluctuations, and the difficulties posed by the large cluster sizes actually prove to be an advantage, as more particles improve the thermodynamic averages. Calculation with this thermodynamic method consists of solving ordinary differential equations for a scaled version of the free energy. Solutions are naturally independent of the details of interparticle interactions, and thus display universal properties. I illustrate with some examples.

12:00 pm – 1:00 pm: Lunch

6:00 pm – 9:00 pm: TSRC Picnic

BBQ under the tent at the Elementary School

2.5 Thursday, July 16, 2015: Nanothermodynamics and Open System

Session Chair: **ÍÑIGO LUIS EGUSQUIZA**

8:30 am – 9:00 am: Artificial Quantum Thermal Bath

Alireza Shabani
Google, USA

Sampling from the Gibbs thermal state of a many-body quantum system is in the core of statistical physics calculations and annealing optimization methods. In this talk, I describe how to simulate thermal equilibrium state of a quantum system via quantum bath engineering. In particular, I show how the effective temperature of a quantum system can be tuned by a driven non-thermal quantum bath. A circuit-QED implementation of such a tunable thermal bath will be proposed.

9:00 am – 9:30 am: Environment assisted speed-up of the field evolution in cavity QED

Burkley D. Patterson and Luis A. Orozco
Joint Quantum Institute
Department of Physics
University of Maryland and NIST
College Park, USA

We measure the quantum speed of the field state evolution in a weakly driven Cavity Quantum Electrodynamics (QED) system. Cavity QED is a superb platform to explore quantum properties of open systems. The system operates in the intermediate regime of cavity QED where the single atom dipole coupling to the mode of the cavity is comparable to the decay rate of the cavity and the spontaneous emission rate. We consider the mode of the electromagnetic field as the quantum system of interest, with a preferential coupling to a tunable environment: the atoms. By changing the number of atoms coupled to the optical cavity mode, we have realized an environment-assisted speed-up: the quantum speed of the state re-population in the optical cavity increases with the coupling strength between the optical cavity mode and this non-Markovian environment (the number of atoms). We find a non-linear relationship between the quantum speed and the number of atoms in the system.

9:30 am – 10:00 am: Activated and non-activated dephasing in NV center dynamics

Erik Torrontegui
Institute of Chemistry
The Hebrew University, Jerusalem, Israel

The origin of decoherence is the interaction of a system with its environment. The process has been studied at least for the past 50 years but there is still a controversy about pure quantum decoherence (pure dephasing). Is initial activation of the bath necessary to observe pure quantum decoherence? We will answer this question introducing different processes in a system consisting of a harmonic oscillator coupled to a spin bath. The processes are also demonstrated in a diamond NV-center.

10:00 am – 10:30 am: Coffee break

Session Chair: **MICHAEL HINCZEWSKI**

10:30 am –11:00 am: Characterization of a single ion heat engine

Kilian Singer
Institut für Physik
Universität Mainz, Germany

An experimental realization of a heat engine with a single ion is presented, which will allow for work extraction even with non-classical thermal reservoirs. To this goal a custom designed linear Paul trap with a single ion performing an Stirling cycle is presented. The radial state of the ion is used as the working gas analogous to the gas in a conventional heat engine. The conventional piston is realized by the axial degrees of freedom and the axial motional excitation stores the generated work, just like a conventional fly-wheel. The heat baths can be realized by tailored laser radiation. Alternatively electrical noise can be used to control the state of the ion. The presented system possesses advantageous properties, as the working parameters can be tuned over a broad range and the motional degrees of freedom of the ion can be accurately determined. Dark resonances allow for fast stroboscopic thermometry during the entire working cycle (1). Monte Carlo simulations are performed to predict the efficiency and the gained work of the working cycle (2). We have also shown how the equations for the Carnot limit have to be modified if a squeezed thermal reservoir is employed (3).

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(2) O. Abah, J. Roßnagel, G. Jacob, S. Deffner, F. Schmidt-Kaler, K. Singer, E. Lutz, Physical Review Letters 109, 203006 (2012).

(3) J. Roßnagel, O. Abah, F. Schmidt-Kaler, K. Singer, E. Lutz, Physical Review Letters 112, 030602 (2014).

11:00 am – 11:30 am: Thermodynamic universality of quantum Carnot engines

Bartłomiej Gardas
Theoretical Division
Los Alamos National Laboratory, USA

Institute of Physics
University of Silesia, Poland

The Carnot statement of the second law of thermodynamics poses an upper limit on the efficiency of all heat engines. Recently, it has been studied whether generic quantum features such as coherence and quantum entanglement could allow for quantum devices with efficiencies larger than the Carnot efficiency. The present study shows that this is not permitted by the laws of thermodynamics. In particular, we will show that rather the definition of heat has to be modified to account for the thermodynamic cost for maintaining coherence and entanglement. Our theoretical findings are numerically illustrated for an experimentally relevant example from optomechanics.

11:30 am – 12:00 am: Nanothermodynamics and nonlinear corrections to statistical mechanics

Ralph V. Chamberlin
Department of Physics
Arizona State University, USA

Standard thermodynamics and thermostatistics are based on the ideal of a homogeneous heat bath that is effectively infinite. However, several experimental techniques have shown that the primary response of most materials comes from a heterogeneous distribution of independently-relaxing nanometer-sized regions. Small-system thermodynamics was originally developed to describe independent nanoparticles and individual molecules. I will discuss how this "nanothermodynamics" may also explain the equilibrium fluctuations and slow dynamics inside bulk materials. One result is the fully-open nanocanonical ensemble, where internal regions are in thermal equilibrium with an ensemble of similar regions. Another result is a nonlinear correction to Boltzmann's factor. This correction can be justified by assuming strict adherence to the laws of thermodynamics at all times in all places: total energy is conserved by including Hill's subdivision potential, local entropy is maximized by transferring information to the thermal bath, and similar states are treated using the statistics of indistinguishable particles. These results provide a common foundation for several empirical formulas, including stretched-exponential relaxation for time-dependent response, non-classical critical scaling for temperature-dependent behavior, and 1/f noise for frequency-dependent fluctuations. I will emphasize how specific models based on nanothermodynamics yield these empirical formulas, plus deviations from the formulas that match the measured behavior in many materials.

12:00 pm – 1:00 pm: Lunch

2.6 Friday, July 17, 2015: Stochastic Processes

Session Chair: **SIMONE MONTANGERO**

8:30 am – 9:00 am: Progress towards a world-line method for electromagnetic Casimir potentials

Daniel A. Steck
Oregon Center for Optics and Department of Physics
University of Oregon, USA

The development of new, general methods for the computation of Casimir potentials in arbitrary geometries and for arbitrary material properties remains a difficult problem. I will review our recent work on the world-line method, previously developed for scalar fields coupled to background potentials. This is a path-integral Monte-Carlo method for computing vacuum- and thermal-state energies of the field. Our work focuses on the generalization of this method to electromagnetism. I will review our recent results in considering a scalar electromagnetic field coupled to dielectrics, where we are able to reproduce a number of classic Casimir-potential results within a general framework. I will also briefly review the path towards a generalization to a full vector-electromagnetism formalism.

9:00 am – 9:30 am: Crossover behavior of the thermal conductance and Kramers' transition rate theory

Michael Zwolak
Nanoscale Science and Technology
National Institute for Standards and Technology, USA

Thermal transport plays opposing roles in nanotechnology, hindering the miniaturization of electronics on one hand and forming the core of novel phononic devices on the other. Moreover, thermal transport in one-dimensional nanostructures has become the paradigmatic example for studying the onset of Fourier's law of heat conduction, an as of yet unresolved puzzle in theoretical physics. We study a paradigmatic setting of heat transport, a one-dimensional lattice coupled to two thermal reservoirs held at different temperatures. Using both numerical and analytical tools we demonstrate that the heat conductance displays a crossover behavior as the coupling to the thermal reservoirs is varied. We provide evidence that this behavior is universal by examining uniform and disordered harmonic lattices, as well as anharmonic systems, and discuss the origin of this effect using an analogy with Kramers' reaction rate theory for chemical transformations. This crossover behavior has important implications in the analysis of numerical results, and suggests a way to tune the conductance in nanoscale devices.

9:30 am – 10:00 am: Quantum transport in ultracold atoms

Chih-Chun Chien
Physics Group
School of Natural Sciences
University of California, Merced, USA

Ultracold atoms confined by engineered magnetic or optical potentials are ideal systems for studying phenomena otherwise difficult to realize or probe in the solid state because their atomic interaction strength, number of species, density, and geometry can be independently controlled. I will briefly review exciting quantum transport phenomena in atomic gases that mirror and oftentimes either better elucidate or show fundamental differences with those observed in mesoscopic and nanoscopic systems. Moreover, I will contrast similarities and differences between transport in cold atoms and in condensed matter systems, and discuss inspiring theoretical predictions that could be difficult to verify in conventional setups. These results further demonstrate the versatility offered by atomic systems in the study of nonequilibrium phenomena and their promise for novel applications.

10:00 am – 10:30 am: Coffee break

Session Chair: **KORANA BURKE**

10:30 am – 11:00 am: Hidden Markov models for stochastic thermodynamics

John Bechhoefer
Deptartment of Physics
Simon Fraser University, Canada

The formalism of state estimation and hidden Markov models (HMMs) can simplify and clarify the discussion of stochastic thermodynamics in the presence of feedback and measurement errors. After reviewing the basic formalism, we use it to shed light on a recent discussion of phase transitions in the optimized response of an information engine, for which measurement noise serves as a control parameter. The HMM formalism also shows that the value of additional information shows a maximum at intermediate signal-to-noise ratios. Finally, we discuss how systems open to information flow can apparently violate causality; the HMM formalism can quantify the performance gains due to such violations.

11:00 am – 11:30 am: Compressing quantum predictive states

John Mahoney
University of California, Davis, USA

Quantum mechanics underlies our classical world, and several of its "structural" features are paramount to our existence. For example, Pauli exclusion is a fundamental feature of atomic physics and chemistry, and it is responsible for the stability of matter itself. Exclusion can be interpreted as a constraint on states, but can easily be recast as a (state-dependent) forbidden transition. Our interest is in structure from this dynamical perspective.

In the study of classical stochastic processes, a natural representation of such a process is given by its ϵ-machine (eM)? its minimal hidden Markov model. An important and well-known measure of the process's structure, easily derived from this representation, is its statistical complexity?a measure of "structural memory" of a stochastic process. We ask, **what is the analog of this structural memory for quantum representations of stochastic processes?** It is first interesting to note that that these measures of memory are not the same. That is, quantum representations are generically more compact. We develop a class of representations that achieves increasing compression, and show that the ultimate level of compression is linked with a topological property of the eM, the cryptic order – a cousin of the Markov order. This work marks progress toward a better understanding of provably minimal quantum representations and quantum causality.

11:30 am – 11:45 am: Closing remarks

Korana Burke
Sebastian Deffner
Adolfo del Campo

3 Conference Venue and Maps

Conference will be held at:
Telluride Elementary School, 477 West Columbia Ave Telluride, CO

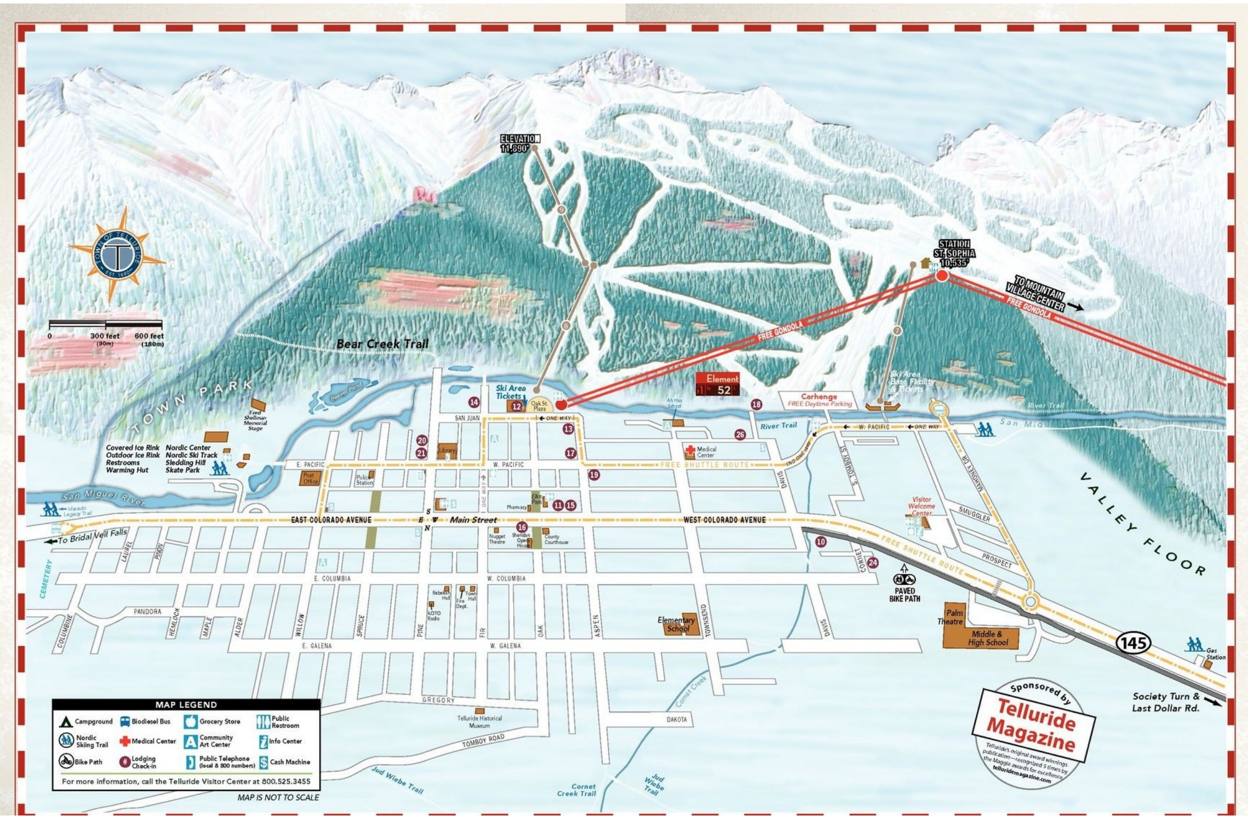

Figure 3.1: Map of the Town of Telluride

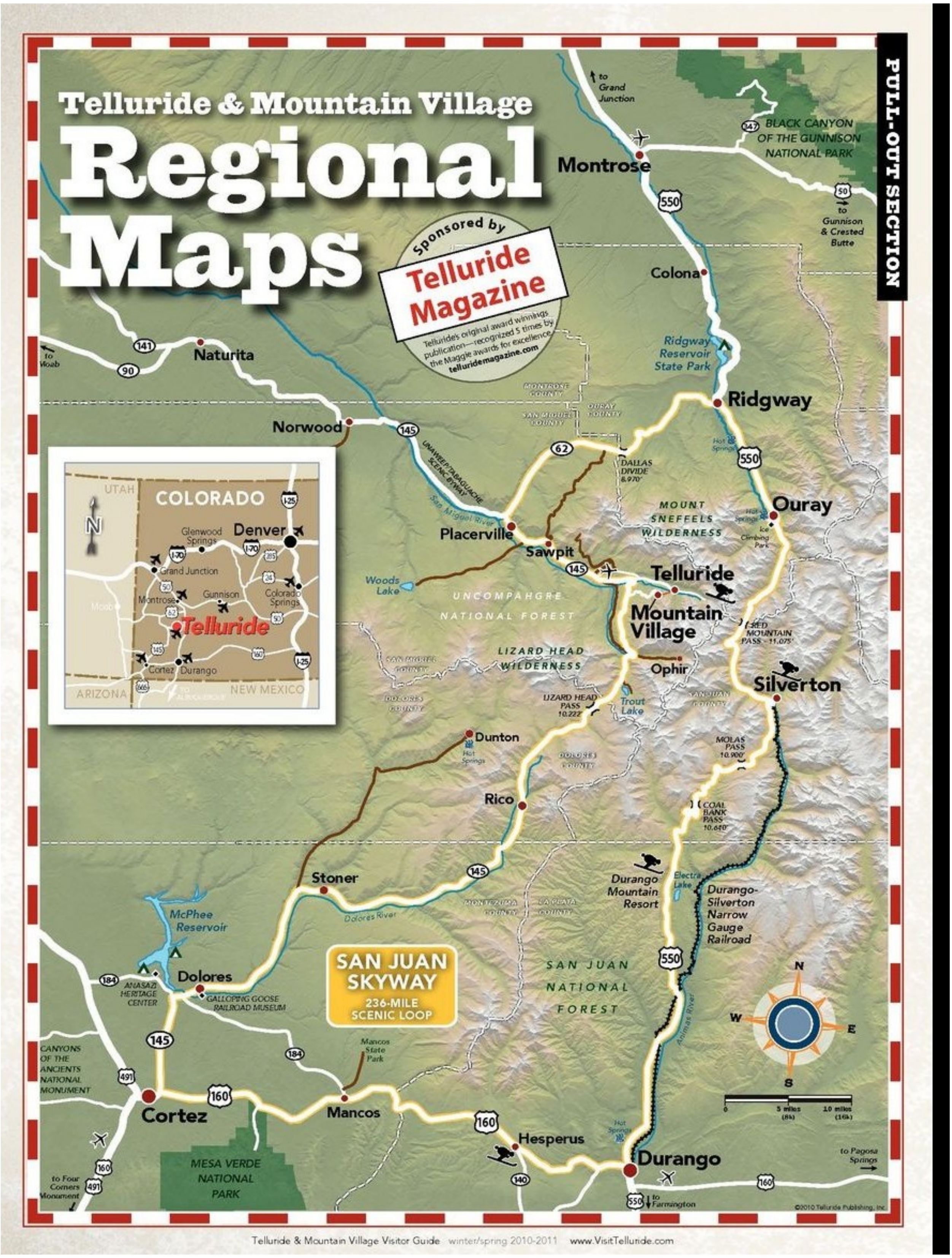

Figure 3.2: Regional Map

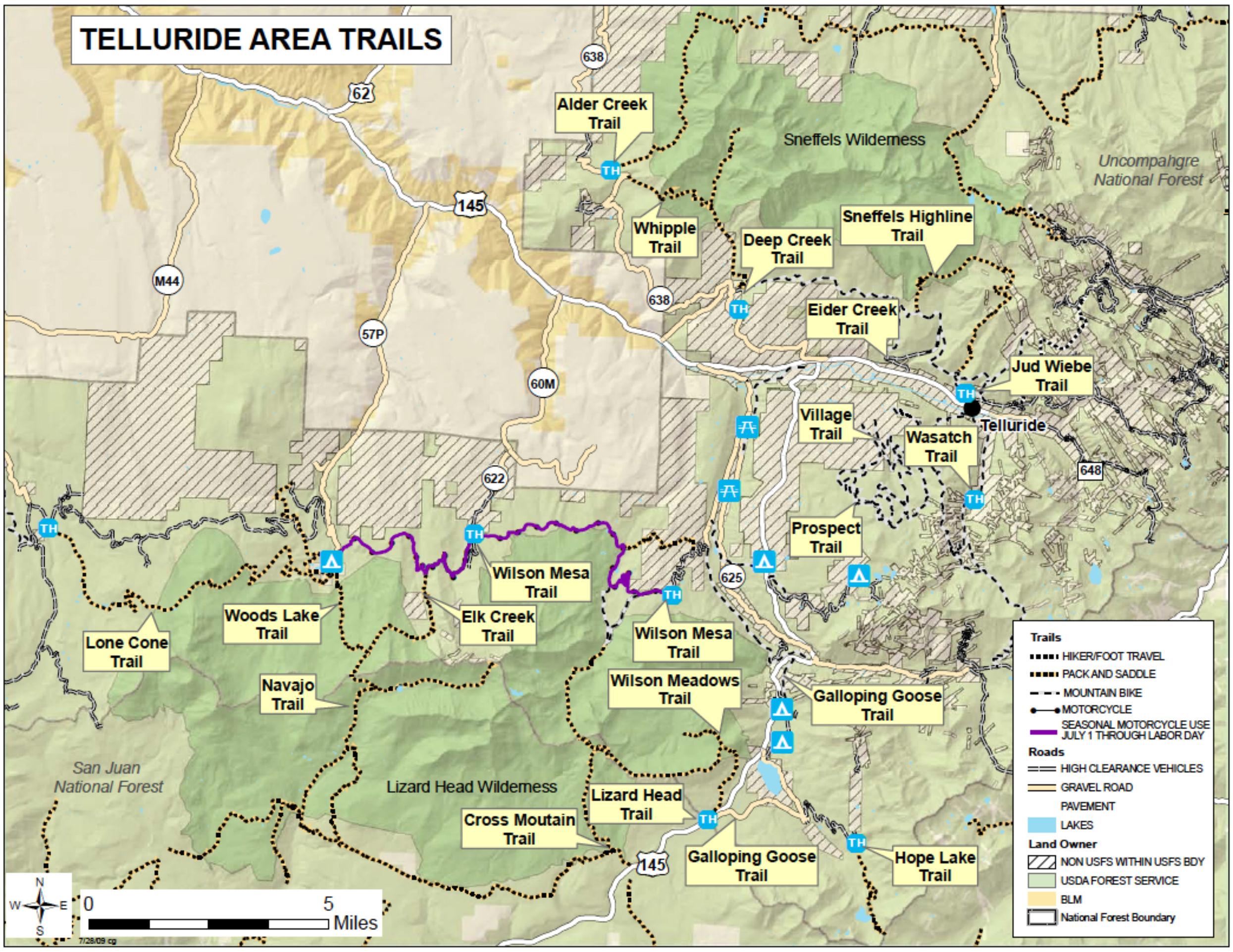

Figure 3.3: Telluride Area Trail Map