19th Symposium on Topological Quantum Information: quantum matter out of equilibrium

April 2, 2016

Monday

09:30-12:30 **Juan Garrahan**: *Aspects of slow relaxation, glasses and non-equilibrium.*
12:30-13:30 **Lunch**
13:30-14:30 **Henning Schomerus**: *Signatures of chaotic scattering from Majorana zero modes.*
14:30-15:30 **Earl Campbell**: *Cellular automata decoders on the toric code.*
15:30-16:00 **Break**
16:00-17:00 **Marta P Estarellas**: *Topologically protected localised states in spin chains.*
17:00-17:30 **Konstantinos Meichanetzidis**: *Topological edge states are monogamous.*
17:30-18:00 **Zlatko Papic**: *Many-bodied localisation*
18:00-19:00 **Poster and Discussion Session**

Tuesday

09:30-12:30 **Andrew Green**: *Combining field theory and tensor networks.*
12:30-13:30 **Lunch**
13:30-14:30 **Aires Ferreira**: *Robustness of topological phases in adatom-decorated graphene.*
14:30-15:30 **James Wootton**: *Quantum computing with parafermions.*
15:30-16:00 **Break**
16:00-17:00 **Adam Stokes**: *Decomposition of Hilbert Spaces and the second law of thermodynamics*
17:00-17:30 **Chris Self**: *Ising anyons at finite temperature.*

Abstracts

Juan Garrahan: *Aspects of slow relaxation, glasses and non-equilibrium.*

I will discuss basic concepts of the physics of many-body systems that display collective dynamics and slow relaxation. In classical statistical physics the paradigm of slow relaxing systems is that of glasses. I will describe the main aspects of the glass transition problem, and briefly review theoretical perspectives on it. I will argue that the complex collective dynamics observed in the phenomenology of glass formers can be seen to be a consequence of local constraints on the relaxation dynamics, and that to understand collective dynamics one has to focus on trajectory, rather than state, space. I will describe how these ideas apply to non-equilibrium in quantum systems, both open (i.e. interacting with an environment), and closed, including issues of quantum metastability and non-ergodicity.

Henning Schomerus: *Signatures of chaotic scattering from Majorana zero modes.*

The formation of Majorana zero modes in topological superconductors can be related either to a charge-conjugation symmetry or to a chiral symmetry. There is a natural desire to detect these modes by considering the conductance, which requires to open up the system to electronic reservoirs. I describe the consequences for disordered systems that can be described by random-matrix theory. For motivation we take the known fact that ballistic couplings eliminate Majorana signatures from systems with charge-conjugation symmetry. I describe that the signatures are preserved for chiral symmetry, and then inspect the role of tunnel barriers.

Background:
H. Schomerus, M. Marciani, C. W. J. Beenakker, Phys. Rev. Lett. 114, 166803 (2015) [arXiv:1412.3998]
M. Marciani, H. Schomerus, C. W. J. Beenakker, Physica E 77, 54-64 (2015) [arXiv:1506.05995]
D. I. Pikulin, J. P. Dahlhaus, M. Wimmer, H. Schomerus, C. W. J. Beenakker, New J. Phys. 14, 125011 (2012) [arXiv:1206.6687]

Earl Campbell: *Cellular automata decoders on the toric code.*

Active error correction of topological quantum codes - in particular the toric code - remains one of the most viable routes to large scale quantum information processing. In this work, we introduce the concept of a dynamical decoder as a promising route for achieving fault-tolerant quantum memories. We analyze a specific dynamical decoder based on a discrete time cellular automaton decoder and provide evidence of a threshold above 0.05% with measurement errors. Without measurement errors, the threshold increases by a factor of roughly 1.5. We stress that (asynchronous) dynamical decoding gives rise to a Markovian dissipative process, hence equating cellular automaton decoding to a fully dissipative topological quantum memory, which removes errors continuously. Finally, we analyze the required resources, and speculate about an ideal constant resource dynamical decoder.

Marta P Estarellas: *Topologically protected localised states in spin chains.*

The SSH model was first presented in 1958 by Su, Schrieffer and Hegger, to describe the soliton formation in polyacetylene. This model predicts the presence of a localised electronic state at the center of an energy gap. In this contribution, we explore this type of localisation in the context of spin chain systems with modulated couplings and their use as quantum devices. We have studied in detail the topologically induced localisation of states by exploring spin chain models with distinct coupling patterns derived from the SSH model. Both dynamical studies and the eigenstate spectrum analysis have been considered, demonstrating the presence of spatial localisation and topological protection of quantum states. We have also investigated the effect of random noise, showing that these characteristics are very robust against noise. We have considered the application of these effects as tool to manipulate the properties and behaviour of spin chains as quantum devices.

Konstantinos Meichanetzidis: *Topological edge states are monogamous.*
Topological phases of matter possess intricate correlation patterns typically probed by entanglement en-

tropies or entanglement spectra. In this work, we propose an alternative approach to assessing topologically induced edge states in free and interacting fermionic systems. We do so by focussing on the fermionic covariance matrix. This matrix is often tractable either analytically or numerically and it precisely captures the relevant correlations of the system. By invoking the concept of monogamy of entanglement we show that highly entangled states supported across a system bi-partition are largely disentangled from the rest of the system, thus appearing usually as gapless edge states. We then define an entanglement qualifier that identifies the presence of topological edge states based purely on correlations present in the ground states. We demonstrate the versatility of this qualifier by applying it to various free and interacting fermionic topological systems.

Andrew Green: *Combining field theory and tensor networks.*

Tensor networks embody deep insights about the entanglement structure of many-body quantum systems. In one dimension, they have led to algorithms that can determine groundstates and follow time evolution with remarkable precision. Entanglement is treated in a very different way in field theories of quantum systems. These are constructed in such a way that the saddle points do not support entanglement which is introduced by instanton or fluctuation corrections. We lift some of the insights about entanglement structure from tensor networks to field theory. Our approach is to explicitly construct a field integral for the partition function over matrix product states, rather than coherent states. The saddle points of such a theory support entanglement in a way that bears interesting comparison with fluctuation and instanton corrections to the usual field theory. In contrast to numerical applications of tensor networks, where the bond order is increased until a certain degree of accuracy is attained, in this field theoretical application, qualitatively new features appear even at low bond order. We demonstrate this by discussing the field theory of certain deconfined quantum critical points.

Aires Ferreira: *Robustness of topological phases in adatom-decorated graphene.*

Spinorbit interactions enable the realisation of topological phases of matter that are gapped in the bulk and display robust spin-helical edge states at the samples boundaries (1,2). This form of quantum Hall topological order, which exists in the absence of external magnetic fields, has been demonstrated in a landmark experiment in mercury-telluride quantum wells (3). On the other hand, the quantum spin Hall effect in graphenethe first theorised topological insulatorremains illusive owing to the extremely small spinorbit-coupling gap in this material. Recently, Weeks et al. proposed that topological gaps in graphene could be elevated up to measurable values through decoration of the sample with a modest concentration (1-5%) of certain nonmagnetic heavy adatomscalculations indicate Thallium and Indium as optimal candidates (4). Despite the great interest generated by this work, transport experiments using the proposed adatom species have failed to observe any signatures of the predicted topological phase (5-8). In this talk, I will argue that topological phases induced by dilute adatoms in graphene are intrinsically fragile. This will be accomplished in two steps. First, I will use symmetry considerations to show that short-range spinorbit interactions activate the inter-valley scattering channel, potentially impacting the spin-helical edge states. Direct evidence of the role of inter-valley scattering will be provided by quantum transport calculations in a representative grapheneThallium system. In the second part, I will present the topological phase diagram of graphene with random spinorbit-coupled adatoms based on a real-space evaluation of the Z2 topological invariant. As the adatom density is lowered, the decay of spin-helical edge states into the bulk is accompanied by a fast suppression of the topological insulator gap, in accordance with the bulk-edge correspondence. Taken together our recent results shed new light onto the experimental findings of Refs. (5-8).

(1) C.L. Kane and E.J. Mele. Phys. Rev. Lett. 95, 226801 (2005)
(2) C.L. Kane and E.J. Mele. Phys. Rev. Lett. 95, 146802 (2005)
(3) M. Konig et al. Science 318, 766 (2007)
(4) C. Weeks et al. Phys. Rev. X 1, 021001 (2011)
(5) U. Chandni et al., Phys. Rev. B 91, 245402 (2015)
(6) Y. Wang et al. Sci. Reports 5, 15764 (2015)
(7) Y. Wang et al. Phys. Rev. B 92, 161411 (2015)

(8) Z. Jia et al. Phys. Rev. B 91, 085411 (2015)

James Wootton: *Quantum computing with parafermions.*

Engineering complex non-Abelian anyon models with simple physical systems is crucial for topological quantum computation. Unfortunately, the simplest systems are typically restricted to Majorana zero modes (Ising anyons). Here, we go beyond this barrier, showing that the 4 parafermion model of non-Abelian anyons can be realized on a qubit lattice. Our system additionally contains the Abelian D(4) anyons as low-energetic excitations. We show that braiding of these parafermions with each other and with the D(4) anyons allows the entire d=4 Clifford group to be generated. The error-correction problem for our model is also studied in detail, guaranteeing fault tolerance of the topological operations. Crucially, since the non-Abelian anyons are engineered through defect lines rather than as excitations, non-Abelian error correction is not required. Instead, the error-correction problem is performed on the underlying Abelian model, allowing high noise thresholds to be realized.

Adam Stokes: *Decomposition of Hilbert Spaces and the second law of thermodynamics*

There are many ways to decompose the Hilbert space of a composite quantum system into tensor product subspaces. Different subsystem decompositions generally imply different interaction Hamiltonians V , and therefore different expectation values for subsystem observables. This means that the uniqueness of physical predictions is not guaranteed, despite the uniqueness of the total Hamiltonian H and the total Hilbert space H. Here we use Clausius version of the second law of thermodynamics (CSL) and standard identifications of thermodynamic quantities to identify possible subsystem decompositions. It is shown that agreement with the CSL is obtained, whenever the total Hamiltonian and the subsystem- dependent interaction Hamiltonian commute (i.e. $[H, V] = 0$). Not imposing this constraint can result in the transfer of heat from a cooler to a hotter subsystem, which could be interpreted as a conflict with thermodynamics. We also investigate the status of the CSL with respect to non-standard definitions of thermodynamic quantities and quantum subsystems.

Chris Self: *Ising anyons at finite temperature.*

Topological quantum computing offers a robust approach to quantum computation using braiding and fusion of anyonic particles. A particular type of anyons called Ising anyons are known to emerge from the microscopics of a spin lattice model called the Kitaev Honeycomb. We study the Ising anyon phase of the Kitaev honeycomb at finite temperature using Monte Carlo methods. We find evidence of the thermal fractionalization of the spins into Majorana modes, similar to the recent results of J. Nasu et al. who studied the non-Ising anyon phases of the model. We relate these findings to the finite temperature stability of the topological characteristics of the model. In addition we probe the thermal edge currents of the Kitaev honeycomb. Analogy to conformal field theory suggests that if the system has a boundary then at very low temperatures there should be a chiral edge current along that boundary that scales with temperature squared. By defining a microscopic current operator and taking its finite temperature expectation value we demonstrate edge currents that obey this scaling.