# GGI Conference: Ergodicity breaking in Quantum Physics, June 3-7, 2019

**Monday June 3**

**9:20-10:00 Ulrich Schneider (Cambridge, UK)**

**Optical quasicrystals and their localization transition**

I will briefly review our experimental realization of many-body localization of interacting fermionic atoms in the presence of quasiperiodic modulations in 1D and 2D. I will discuss the distinction between random disordered potentials and quasiperiodic modulations with a particular focus on slow relaxation dynamics close to the localization transition. Furthermore, I will discuss a recent extension to a 2D quasicrystal with an eightfold rotational symmetry and present first measurements of the localisation transition in this system.

**10:00-10:40 Jens Bardarson (KTH, Stockholm)**

**Multiscale entanglement clusters at the many-body localization phase transition**

We numerically study the formation of entanglement clusters across the many-body localization transition. We observe a crossover from strong many-body entanglement in the ergodic phase to weak local correlations in the localized phase, with continuous clusters throughout the phase diagram. Critical states close to the transition have a structure compatible with fractal or multiscale-entangled states, characterized by entanglement at multiple levels: small strongly entangled clusters are weakly entangled together to form larger clusters. The critical point therefore features subthermal entanglement and a power-law distributed cluster size. Upon entering the localized phase, the power-law distribution seems to persist with a varying power that crosses over into a stretched exponent before eventually becoming exponential deep in the localized phase. These results are in agreement with some of the recently proposed phenomenological renormalization-group schemes characterizing the many-body localized critical point, and serve to constrain other such schemes.

**10:40-11:10 Coffee Break**

**11:10-11:50 Itamar Kimchi (NIST, CU Boulder)**

**RG flows and LSM restrictions for 2D random quantum spin systems**

I will describe how synthesizing ideas from quantum information theory, statistical mechanics, and quantum field theory can give insights into the role of non-MBL randomness in 2D correlated quantum spin systems. First I will outline our results on weak bond-randomness in two theoretically controlled cases ("valence-bond-solids" and classical dimer models) and apply them to random quantum magnets to show that topological defects with free spins necessarily nucleate and control the low energy physics. Second I will describe how the results lead us to conjectures, and a proof in 1D, of general entanglement-based constraints ("LSM theorems") on all possible fates of quantum magnets, that hold even with randomness. Third I will describe how the theory predicts a scaling collapse of the temperature and magnetic-field dependence of thermodynamic quantities that is consistent with experimental observations from multiple disordered materials. Time permitting I will discuss related approaches to other quantum systems.

**11:50-12:30 Anushya Chandran (Boston University)**

**Stability of localization to avalanches**

Rare regions with low disorder are predicted to destabilise localization in one dimension if the bare localization length $\xi$ exceeds a critical value $\xi_c$. Each such region seeds a thermalizing inclusion that `avalanches' and grows without bound by absorbing the localized degrees of freedom at its boundary. I will show strong numerical evidence that an Anderson chain at infinite temperature coupled to an interacting thermal inclusion fails to avalanche at any $\xi$. In contrast, an idealized l-bit model avalanches for $\xi > \xi_c$. The avalanche fails irrespective of bath size and the geometry of the system-bath couplings in both quasi-periodic and random chains.

**12:30-14:20 Lunch**

**14:20-15:00 Konstantin Tikhonov (KIT, Karlsruhe)**

**Anderson localization on random regular graphs**

I will discuss dynamical and spatial correlations of eigenfunctions in the Anderson model on random regular graphs (RRG) at and near the criticality. In the delocalized phase, the observables show a broad critical regime for system sizes N below the correlation volume $N_\xi$ and then cross over to the ergodic behavior. Eigenstate correlations allow to visualize the correlation length $\xi \sim \ln N_\xi$ that controls the finite-size scaling. The critical-to-ergodic crossover is very peculiar, since the critical point is similar to the localized phase, whereas the ergodic regime is characterized by very fast "diffusion," which is similar to the ballistic transport. I will show that results of exact diagonalization agree with those of the solution of the self-consistency equation obtained within the saddle-point analysis of the effective supersymmetric action. Importantly, the analysis of the self-consistency equation allows to reach the critical point closer and reliably extract the critical disorder and critical exponent.

**15:00-15:40 Dmitry Abanin (Geneva)**

**TBA**

**15:40-16:10 Coffee Break**

**16:10-16:50 Silvia Pappalardi (SISSA, BU)**

**Origin of the slow growth of entanglement entropy in long-range interacting systems**

Despite long-range interactions would allow distant degrees of freedom to entangle directly and instantaneously, several numerical simulations have shown that they may result in a dramatic slowdown of entanglement growth after a sudden quantum quench, even in the absence of disorder. In this talk, I will present the general mechanism underlying this counterintuitive phenomenon. We focus on general quantum spin systems with slowly-decaying interactions and demonstrate that entanglement growth is primarily governed by the nonlinear semiclassical dynamics of collective degrees of freedom. We connect bipartite entanglement entropy dynamics with the time-dependent spin squeezing, and show how a universal logarithmic growth emerges in the absence of semiclassical chaos. All our analytical results agree with numerical computations for quantum Ising chains with long-range couplings. Our findings establish a novel viewpoint on entanglement production induced by long-range interactions, and are experimentally relevant for accessing entanglement in highly-controllable platforms, including trapped ions, atomic condensates, and cavity-QED systems.

**16:50-17:30 Elisa Ercolessi (U Bologna)**

**Real-time dynamics in the confined phase of the Z_n Schwinger Lattice Model for QED in 1+1 dimensions**

We will study the real-time dynamics for 1+1 dimensional QED, by simulating it on a lattice with the Schwinger Model with a Z_n gauge symmetry. In particular we will examine the phenomena of pair production and string breaking.

**Tuesday, June 4**

**9:20-10:00 John Imbrie (U Virginia)**

**Dressing up MBL**

I will review what goes into the proof of many-body localization in strongly disordered 1-d spin chains. The level-spacing problem remains open, but I will discuss new methods for tackling it in simpler situations, such as the Anderson model with discrete disorder.

**10:00-10:40 Michael Aizenman (Princeton)**

**TBA**

**10:40-11:10 Coffee Break**

**11:10-11:50 Vieri Mastropietro (U Milano)**

**TBA**

**11:50-12:30 Simone Warzel (TU Munich)**

**TBA**

**12:30-14:20 Lunch**

**14:20-15:00 Valentina Ros (ENS Paris)**

**TBA**

**15:00-15:40 Bryan Clark (UIUC, Urbana-Champaign)**

**Resonances in Many-Body Localization**

**15:40-16:10 Coffee Break**

**16:40-17:10 Frank Pollmann (TU Munich)**

**Far-from-equilibrium dynamics of systems with conservation laws**

Recent years have seen a great deal of effort to understand quantum thermalization: the question of whether closed quantum systems, evolving under unitary dynamics, reach a state of thermal equilibrium. In my talk, I will discuss how the presence of conservation laws affects the dynamics of thermalization. First, we investigate the dynamics of quantum entanglement after a global quench and uncover a qualitative difference between the behavior of the von Neumann entropy and higher Renyi entropies. We argue that the latter generically grow sub-ballistically in systems with diffusive trans- port. We provide strong evidence for this in both a U(1) symmetric random circuit model and in a paradigmatic non-integrable spin chain, where energy is the sole conserved quantity. Second, we show that the combination of charge and dipole conservation leads to an extensive fragmentation of the Hilbert space, which in turn can lead to a breakdown of trhermalization. As a concrete example, we investigate the out-of-equilibrium dynamics of one-dimensional spin-1 models that conserve charge (total Sz) and its associated dipole moment.

**Wednesday, June 5**

**9:20-10:00 Rahul Nandkishore (CU Boulder)**

**Localization beyond locator expansion**

I point out that the failure of a locator expansion does not in itself imply absence of localization. I begin by illustrating this with a discussion of long range interacting systems, where perturbative locator expansions fail. I will present nonperturbative arguments indicating that MBL can arise in systems with long-range (Coulomb) interactions, in one, two and perhaps even three spatial dimensions. The arguments are asymptotic (i.e., valid up to rare region corrections), yet they open the door to investigation of MBL physics in a wide array of long-range interacting systems where such physics was previously believed not to arise. They also open the door to using MBL to stabilize driven superconductivity. I then introduce a model of a `fractonic random circuit' which does not have any time translation symmetry, nor any energy conservation, and hence cannot have any locator expansion. Nonetheless, under certain circumstances this model exhibits localization.

**10:00-10:40 Vedika Khemani (Harvard, Stanford)**

**TBA**

**10:40-11:10 Coffee Break**

**11:10-11:50 Guido Pagano (University of Maryland)**

**Interacting Trapped-Ion Spin Chains: from out-of- equilibrium phenomena to quantum algorithms**

Laser cooled trapped ions offer unprecedented control over both internal and external degrees of freedom at the single-particle level. They are considered among the foremost candidates for realizing quantum simulation and computation platforms that can outperform classical computers at specific tasks. In this talk I will show how linear arrays of trapped 171Yb+ ions can be used as a versatile platform for studying out-of-equilibrium strongly correlated many-body quantum systems. In particular I will describe how to realize time-crystalline phases in a Floquet setting, where the spin system exhibits persistent time-correlations under many-body- localized dynamics [1]. I will also present our observation of a new type of out-of- equilibrium dynamical phase transition in a spin system with over 50 spins [2]. Moreover I will show our latest efforts towards scaling up the trapped-ion quantum simulator [3] using a cryo-pumped vacuum chamber where we can trap more than 100 ions indefinitely. The reliable production and lifetime of large linear ion chains enabled us to investigate quasi-particle excitations showing confinement in the post- quench dynamics [4] and the implementation of Quantum Approximate Optimization Algorithms (QAOA) [5].

References:
[1] J. Zhang et al., Nature, 543, 217 (2017)
[2] J. Zhang, G. Pagano, et al., Nature, 551, 601 (2017)
[3] G. Pagano et al., Quantum Sci. Technol., 4, 014004 (2019) [4] F. Liu, et al., Phys. Rev. Lett. 122, 150601 (2018)
[5] G.Pagano, et al., (in preparation 2019)

**11:50-12:30 Edward Grant (UBC, Vancouver)**

**Quantum disordered dynamics in the arrested relaxation of a molecular ultracold plasma**

Work with: John Sous,[1,2] Kiara Grant,[3] Ruoxi Wang,[1] Kevin Marroquin,[3] Mahyad Aghigh,[3] Rafael Haenel,[1,2] Fernanda Banic Viana Martins,[3,4] Xixi Qi,[3,5] James Keller[3,4] and Edward Grant[1,3]

[1]Department of Physics & Astronomy, [2]Stewart Blusson Quantum Matter Institute, [3]Department of Chemistry, University of British Columbia, Vancouver, BC V6T 1Z1, Canada, [4]Department of Chemistry, Kenyon College, Gambier, OH 43022, USA [5]D´epartement de Chimie, Sorbonne Universit ´e, 75005 Paris, France

Theory points to conditions under which a disordered quantum many-body system can avoid decoherence, preserve spatial order and localize energy. A small number of highly engineered experiments probing the dynamics of ultracold atoms appear to confirm non-ergodicity as a principle in interacting many-body systems held in optical lattices. Such systems have been proposed as analog quantum simulators, or as protected regimes in which to embed atomic or molecular qubits, with perhaps great significance for the field of quantum materials. Here, we look to the quantum mechanical character of the arrested state formed by a quenched ultracold molecular plasma. This novel class of system arises spontaneously, without the deliberate engineering of interactions, and evolves naturally from state-specified initial conditions, to a long-lived final state of canonical density, in a process that conflicts with classical notions of plasma dissipation and neutral dissociation. We take information from elementary theoretical models and experimental observations to develop a conceptual argument that attempts to explain this state of arrested relaxation in terms of a minimal picture of randomly interacting dipoles of random energies. This model of the plasma forms a starting point to describe its observed absence of relaxation as a form of localization. The large number of accessible Rydberg and excitonic states gives rise to an unconventional web of many-body interactions that vastly exceeds the complexity of quantum optics in a conventional few-level scheme. This experimental platform thus opens an avenue for the coupling of dipoles in disordered environments that will demand the development of new theoretical tools.

**12:30-14:20 Lunch**

**14:20-15:00 Alessandro Silva (SISSA, Trieste)**

**Quantum dynamics and chaos in systems long-range interactions**

In this talk I will discuss a variety of interesting phenomena that occur when spin chains with long-range interactions are driven out of equilibrium. In contrast with short range systems, long-range interactions open up the possibility of observing long-range order in non equilibrium conditions in low dimensions. The resulting dynamical critical points turn out to be affected strongly by inhomogeneous fluctuations, giving rise to new chaotic phases. In addition, the presence of periodic drive can stabilise unstable phases of matter against all possible fluctuations, a true many-body analogue of a Kapitza pendulum. The effect of dynamical criticality on the fine structure of the quantum states, described by the OTOC, Fisher information and entanglement entropies, will also be discussed.

**15:00-17:30 Poster Session**

**19:00 Conference Dinner (TBC)**

**Thursday, June 6**

**9:20-10:00 Lev Vidmar (Jožef Stefan Institute, Ljubljana)**

**Quantum chaos challenges many-body localization**

Characterizing states of matter through the lens of their ergodic properties is a fascinating nnew direction of research. In the quantum realm, the many-body localization (MBL) was proposed to be the paradigmatic nonergodic phenomenon, which extends the concept of Anderson localization to interacting systems. At the same time, random matrix theory has established a powerful framework for characterizing the onset of quantum chaos and ergodicity (or the absence thereof) in quantum many-body systems. Here we study a paradigmatic class of models that are expected to exhibit MBL, i.e., disordered spin chains with Heisenberg-like interactions. Surprisingly, we observe that exact calculations show no evidence of approaching MBL while increasing disordered strength in the ergodic regime. Moreover, a scaling analysis suggests that quantum chaotic properties survive for any disorder strength in the thermodynamic limit. Our results are based on calculations of the spectral form factor, which provides a powerful measure for the emergence of many-body quantum chaos.

arXiv:1905.06345

**10:00-10:40 Nicole Fabbri (LENS, Firenze)**

**Experimental test of open-system quantum fluctuation relations with NV centers in diamond**

The connection between statistical properties of out-of-equilibrium dynamical systems, thermodynamics quantities, and information theory, has been deeply investigated in classical and quantum systems, in terms of fluctuation relations [1,2,3]. Open quantum systems, however, pose challenging problems, due to the lack of operative quantum definitions of work and heat flux, and the limited practical access to information on the reservoir.

In this talk, I will present our recent experimental investigations of quantum fluctuation relations, where we employ a Nitrogen-vacancy (NV) center in diamond as a quantum simulator of open quantum system dynamics in the presence of repeated quantum projective measurements and a tunable connection to a heat reservoir. In a first study, we investigate the energy exchange fluctuation relation. Our experimental results suggest an effective reformulation of the energy exchange fluctuation relation including the final out-of-equilibrium steady-state properly defined for a qubit by an effective temperature [4]. In a second study, we investigate a generalized quantum fluctuation relation, related to a spin observable different from the Hamiltonian, enlightening the role of coherences in the process.

[1] C. Jarzynski, Physical Review Letters 78, 2690 (1997)
[2] C. Jarzynski and D. K. Wójcik, Physical Review Letters 92, 931 (2004).
[3] D. Andrieux et al., New Journal of Physics 11, 043014 (2009).
[4] S. Hernández-Gómez et al., in preparation.

**10:40-11:10 Coffee Break**

**11:10-11:50 Chandan Dasgupta (IISc, Bangalore)**

**Vibrational Normal Modes of Disordered Solids**

Properties of the vibrational normal modes of disordered solids and the role of these modes in the dynamics of the system are investigated for two model systems. We first consider [1] a cluster of Coulomb-interacting particles in two-dimensional irregular confinement that leads to the formation of disordered solid structures at low-temperatures. By analyzing the participation ratio and spectral statistics, we characterize the vibrational modes for these clusters as localized, quasi-localized, and delocalized.We further demonstrate that, at a given low temperature, particles exhibiting larger displacement over a time interval comparable to the structural relaxation time are strongly correlated with the low-frequency quasi-localized modes of the inherent structure (local minimum of the potential energy) corresponding to the initial configuration. In the second part, we consider [2] a two-component Lennard-Jones system in three dimensions that forms a glass at low temperatures. Various properties of the harmonic modes associated with inherent structures of different energies are analyzed and related to the thermal conductivity of the system, with emphasis on the dependence of the thermal conductivity on cooling rate and aging time.

This talk is based on work carried out in collaboration with Biswarup Ash, Pranab Jyoti Bhuyan, Rituparno Mandal, Pinaki Chaudhuri, Amit Ghosal and Abhishek Dhar.

References:
[1] B.Ash, C.Dasgupta, and A.Ghosal (2018), Analysis of vibrational normal modes for Coulomb clusters, Phys. Rev. E. 98, 042138.
[2] P.J.Bhuyan, R.Mandal, P.Chaudhuri, A.Dhar and C.Dasgupta (2019), Aging effects in the thermal conductivity of glass-forming liquids, submitted to Phys. Rev. E.

**11:50-12:30 Thibaud Maimbourg (LPTMS Orsay)**

**Low-temperature anomalies in mean-field structural glasses**

In this talk I will present and review recent results for the low-temperature anomalous behaviour of certain quantities (such as the specific heat) in amorphous solids with respect to their ordered crystalline counterparts. The analytic solution of a mean-field model belonging to the same universality class as high-dimensional glasses suggests that there exists a crossover temperature above which the specific heat scales linearly with temperature while below it a cubic scaling is displayed. This novel mechanism relies on two crucial features of the phase diagram: (i) The marginal stability of the free-energy landscape, which induces a gapless phase (ii) The vicinity of a classical jamming critical point. The ensuing scenario arises from the study of the thermodynamics of the system in the quantum regime, where we show that, contrary to crystals, the Debye approximation does not hold.

Main reference: S. Franz, T. Maimbourg, A. Scardicchio, G. Parisi, arXiv:1811.11719.

**12:30-14:20 Lunch**

**14:20-15:00 Arijeet Pal (University College London)**

**Scale Invariant Entanglement Negativity at the Many-body localization transition**

**15:00-15:40 Romain Vasseur (UMass Amherst)**

**KT scaling at the 1D many-body localization transition**

In this talk, I will propose a scaling theory for the many-body localization (MBL) phase transition in disordered one-dimensional systems, building on the idea that it proceeds via a 'quantum avalanche'. I will argue that the critical properties can be captured at a coarse-grained level by a Kosterlitz-Thouless (KT) renormalization group flow. I will also present new results for the universality class of the MBL transition in the presence of quasi-periodic potentials.

**15:40-16:10 Coffee Break**

**16:10-16:50 Gabriel Lemarié (CNRS, Paul Sabatier, Toulouse)**

**Glassy properties of Anderson localization: pinning, avalanches and chaos**

I present the results of extensive numerical simulations which reveal the glassy properties of Anderson localization in dimension two at zero temperature: pinning, avalanches and chaos. I first show that strong localization confines quantum transport along paths which are pinned by disorder but can change abruptly and suddenly (avalanches) when the energy is varied. I determine the roughness exponent \zeta characterizing the transverse fluctuations of these paths and find that its value \zeta=2/3 is the same as for the directed polymer problem. Finally, I characterize the chaos property, namely the fragility of the conductance with respect to small perturbations in the disorder configuration. It is linked to interference effects and universal conductance fluctuations at weak disorder, and more spin-glass-like behavior at strong disorder.

**Friday, June 7**

**9:20-10:00 Anatoli Polkovnikov (Boston University)**

**Nearly adiabatic transformations in chaotic systems**

In this talk I will introduce a general approach for finding gauge potentials (generators of adiabatic transformations) in Hamiltonian systems, both quantum and classical. In particular, I will introduce an expansion in nested commutators, which combined with a variational approach developed earlier allows one to find a local and very efficient approximation for the gauge potential. I will also show that this approximate gauge potential can be realized using a periodic Floquet protocol involving only local terms. I will discuss some applications of these results from constructing heat engines and suppressing dissipation to bounds on quantum speed limits in complex systems.

**10:00-10:40 Sergej Flach (Institute for Basic Science, Daejeon)**

**Dynamical Glass**

Classical many body interacting systems are typically chaotic (nonzero Lyapunov exponents) and their microcanonical dynamics ensures that time averages and phase space averages are identical (ergodic hypothesis). In proximity to an integrable limit the long- or short-range properties of the network of nonintegrable action space perturbations define the finite time relaxation properties of the system towards Gibbs equilibrium. I will focus on short range networks which lead to a dynamical glass (DG), using a classical Josephson junction chain in the limit of large energy densities or small Josephson energies. Close to these limits the Josephson coupling between the superconducting grains induces a short-range nonintegrable network in the corresponding action space. I will introduce a set of quantitative measures which lead to the Lyapunov time TΛ, the ergodization time TE, and to a diffusion constant D. In the DG the system fragments into large patches of nonresonant 'integrable' grains of size l separated by triplets of resonant chaotic patches, all surviving over large times. TE sets the time scale for chaotic dynamics in the triplets. Contrary, TE ≈ l2/D is the much larger time scale of slow diffusion of chaotic triplets. The DG is a generic feature of weakly non-integrable systems with a short range coupling network in action space, and expected to be related to nonergodic quantum metallic states of quantum-many-body systems in proximity to a many-body localization phase.

**10:40-11:10 Coffee Break**

**11:10-11:50 Alberto Rosso (LPTMS, CNRS, Paris-Saclay)**

**Ergodicity breaking in open & driven quantum systems**

**11:50-12:30 Giorgio Parisi (Roma)**

**TBA**

**12:30 Closure**