# Schedule

## Events for:
## Monday, December 11th - Friday, December 15th

### Monday, December 11th

9:30am **Norbert Schuch - SCGP 102**

**Title:** Anyon condensation and topological phase transitions in tensor networks

10:30am **Break - Simons Center**

11:00am **Ian McCulloch - SCGP 102**

**Title:** Matrix product states and symmetry

**Abstract:** I will give an introduction to Matrix Product States and applications, focussing on symmetry aspects, including symmetry breaking and critical phenomena, symmetry protected topological states, and characterization of renormalization group fixed points using finite-size scaling and finite-entanglement scaling.

12:00pm **Lunch - SCGP Cafe**

2:00pm **Glen Evenbly - SCGP 102**

**Title:** Implicit Disentangling for Quantum Many-Body States

**Abstract:** The process of disentangling using properly chosen unitary tensors is key for efficient representations of ground states in quantum many-body systems. In this talk I will discuss a recent work (arXiv1707.05770) where an alternative method for disentangling states called implicit disentangling is introduced. Implicit disentangling, which is based on measurement-type operations as opposed to unitary gates, allows for the removal of entanglement between blocks in a quantum state using only local operators acting within each block. Applications of implicit disentangling towards the study of quantum many-body systems will be discussed, including its use as part of a renormalization group (RG) method to extract conformal data from ground states of quantum critical systems.

3:00pm **Nick Bultinck (short talk) - SCGP 102**

**Title:** Super vector spaces and fermionic tensor networks

**Abstract:** It has almost been ten years since fermionic tensor network states were introduced. Given the great variety of interesting systems containing fermionic degrees of freedom in quantum chemistry, condensed matter and high energy physics, it goes without saying that tensor network states containing fermions are physically very relevant. In this talk a slight reformulation of fermionic tensor networks based on super vector spaces will be presented. Fermionic tensor contraction, the fermionic minus sign bookkeeping, and a graphical tensor notation will be discussed in detail. Using the super vector space formalism canonical forms for fermionic matrix product states are introduced and connected to physical properties such as Majorana edge modes.

4:00pm **Michael Zaletel - SCGP 102**

**Title:** Minimally entangled purifications: algorithms, spins chains and holography

## Tuesday, December 12th

9:15am **Thomas Hartman - SCGP 102**

**Title:** Causal Structure of Emergent Geometries

10:15am **Break - Simons Center**

10:40am **Jens Eisert - SCGP 102**

**Title:** Holography and criticality in matchgate tensor networks

**Abstract:** The AdS/CFT correspondence conjectures a holographic duality between gravity in a bulk space and a critical quantum field theory on its boundary. Tensor networks - which are briefly introduced in the talk - have come to provide toy models to understand such bulk-boundary correspondences, shedding light on connections between geometry and entanglement. We introduce a versatile and efficient framework for studying tensor networks, extending previous tools for Gaussian matchgate tensors in 1+1 dimensions. Using regular bulk tilings, we show that the critical Ising theory can be realized on the boundary of both flat and hyperbolic bulk lattices. Within our framework, we also produce translation-invariant critical states by an efficiently contractible network dual to the multi-scale entanglement renormalization ansatz. Furthermore, we explore the correlation structure of states emerging in holographic quantum error correction. At the end of the talk, we will outline further new connections and perspectives.

11:40am **Lunch - SCGP Cafe**

1:00pm **Weekly Talk: Frank Verstraete**

**Title:** Characterizing phases of matter by symmetries of tensor networks

**Abstract:** We will discuss tensor networks which describe ground states of gapped quantum many body Hamiltonians, and focus on the symmetries in the entanglement degrees of freedom. It will be demonstrated that those symmetries characterize topological phases of matter, and also lead to novel variational algorithms for the quantum many body problem.

2:30pm **Philippe Corborz - SCGP 102**

**Title:** Advances in simulating 2D strongly correlated systems with iPEPS

**Abstract:** In this talk I report on recent progress with infinite projected-entangled pair states (iPEPS) - a two-dimensional tensor network ansatz for 2D ground states in the thermodynamic limit. Thanks to several advances on the methods side, including more accurate and efficient optimization and contraction algorithms, making use of symmetries, and improved extrapolation techniques, iPEPS has become a very powerful tool for the study of 2D strongly correlated systems. I will give an overview of recent developments and simulation results for challenging problems, including the 2D Hubbard model and frustrated spin systems.

3:30pm **Break**

4:00pm **Laurens Vanderstraeten - SCGP 102**

**Title:** Bridging Perturbative Expansions with Tensor Networks

**Abstract:** We demonstrate that perturbative expansions for quantum many-body systems can be rephrased in terms of tensor networks, thereby providing a natural framework for interpolating perturbative expansions across a quantum phase transition. This approach leads to classes of tensor-network states parametrized by few parameters with a clear physical meaning, while still providing excellent variational energies. We also demonstrate how to construct perturbative expansions of the entanglement Hamiltonian, whose eigenvalues form the entanglement spectrum, and how the tensor-network approach gives rise to order parameters for topological phase transitions.

## Wednesday, December 13th

9:30am **Shinsei Ryu - SCGP 102**

**Title:** Topological invariants, entanglement, and partial transpose in topological phases

**Abstract:** I will discuss our recent proposal for the new definition of partial transpose for fermionic systems. As applications, i will discuss the construction of topological invariants and entanglement measure using the fermionic partial transpose. As target systems, I plan to discuss Majorana chains, and, if time allows, (2+1)d fermionic topological phases such as time-reversal symmetric topological insulators.

10:30am **Break - Simons Center**

11:00am **Jutho Haegeman - SCGP 102**

**Title:** Multiresolution decomposition of many-body Hilbert space using tensor networks

**Abstract:** The main part of this talk will be about the use of wavelets to construct a quantum circuit that constructs quantum states for metallic phases of matter, i.e. free fermion systems with a Fermi surface. In 1D, the resulting quantum circuit is a MERA, whereas in 2D (and higher dimensions), a particular type of the so-called branching MERA is obtained. This construction provides analytical error bounds for the quality of the MERA approximation. In the second part of this talk, I will illustrate how also how the MPS approximation of a ground state also provide a multiresolution decomposition of Hilbert space, and briefly discuss some practical applications thereof.

12:00pm **Lunch - SCGP Cafe**

2:00pm **Ying-Jer Kao - SCGP 102**

**Title:** Quantum impurity in a Tomonaga-Luttinger Liquid wire: sub-leading corrections

**Abstract:** We study correlation functions of the spin-1/2 XXZ model with a single impurity. Numerically, by using a finite system with infinite boundary conditions; we can simulate a finite region of the impurity systems in the thermodynamic limit. Analytically, we use bosonization and boundary conformal field theory to obtain the leading and sub-leading exponents of the correlation functions.We find excellent agreements between numerical and analytical results. This demonstrates that infinite boundary conditions can be a powerful tool to study quantum impurity systems.

3:00pm **Break - SCGP 102**

3:30pm **Sujeet Shukla (short talk) - Simons Center**

**Title:** Instability in tensor network representations of topological phases

**Abstract:** The Tensor Network (TN) representation of many-body quantum states, given by local tensors, provides a promising numerical and conceptual tool for the study of strongly correlated topological phases in two dimension. However, TN representations may be vulnerable to instabilities caused by small variations of the local tensor, especially when the local tensor is not injective. For example, the topological order in TN representations of the toric code ground state has been shown to be unstable: the topological order is stable under variations if and only if the variations respect a $Z_2$ symmetry of the local tensor. In this work, we ask whether other types of topological orders suffer from similar kinds of instability and if so, what is the underlying physical mechanism and whether we can protect the order by enforcing certain symmetries on the variations. We answer these questions by showing that the tensor network representation of all string-net models are indeed unstable and though enforcing the so-called matrix product operator (MPO) symmetries (which can be thought of as the generalization of the $Z_2$ symmetry of the toric code local tensor) on the local tensors is sufficient for stability, it is not a necessary condition. We show that if a small variation cannot "stand alone" in the tensor network, it also cannot cause instability, even if it breaks the MPO symmetry. In fact, a variation is unstable if and only if it breaks the MPO symmetry and can also stand alone, and this explains all instability behavior observed numerically. The physical reason of instability is found to be the fact that unstable variations induce the condensation of bosonic quasi-particles and destroy the topological order in the system. Therefore, MPO symmetry breaking variations that can stand alone should be forbidden for the encoded topological order to be reliably extracted from the local tensor. On the other hand, if a TN based variational algorithm is used to simulate the phase transition due to boson condensation, then such variation directions must be allowed in order to access the continuous phase transition process correctly.

4:10pm **Nicholas Pomata - SCGP 102**

**Title:** Phase transitions of a 2D deformed-AKLT model

**Abstract:** We study deformed-AKLT models on the square lattice, via a two-parameter family of O(2)-symmetric ground-state wavefunctions as defined by Niggemann, Kl\"umper, and Zittartz, who found previously that the phase diagram consists of a N\'eel-ordered phase and a disordered phase which contains the AKLT point. Using tensor-nework methods, we not only confirm the N\'eel phase but also find an XY phase with quasi-long-range order, and investigate the consequences of a seemingly isolated product-state point at the boundary of the phase diagram.

## Thursday, December 14th

9:30am **Didier Poilblanc - SCGP 102**

**Title:** Chiral topological spin liquids with PEPS

**Abstract:** A simple spin-1/2 frustrated antiferromagnetic Heisenberg model (AFHM) on the square lattice - including chiral plaquette cyclic terms - was argued [Anne E.B. Nielsen et al., Nature Communications 4, 2864 (2013)] to host a bosonic Kalmeyer-Laughlin (KL) fractional quantum Hall ground state [V. Kalmeyer and R. B. Laughlin, Phys. Rev. Lett. 59, 2095 (1987)]. Here, I construct generic families of chiral projected entangled pair states (chiral PEPS) with low bond dimension (D=3,4,5) which, upon optimization, provide better variational energies than the KL ansatz. The optimal PEPS exhibits (at D=3) chiral edge modes described by the Wess-Zumino-Witten SU(2)1 model, as expected for the KL spin liquid. However, I find evidence that, in contrast to the KL state, the PEPS spin liquids have power-law dimer-dimer correlations and exhibit a gossamer long-range tail in the spin-spin correlations. I conjecture that these features are genuine to local chiral AFHM on bipartite lattices.

10:30am **Break - Simons Center**

11:00am **Shuo Yang - SCGP 102**

**Title:** Lattice model constructions for gapless domain walls of topological phases

**Abstract:** Lattice models of gapless domain walls between twisted and untwisted quantum double models are constructed systematically. As a simple example, we numerically study the gapless domain walls between toric code model and double semion model using the state-of-art Loop tensor network renormalization (Loop-TNR) algorithm. Surprisingly, we find a conformal field theory described by the orbifold double su(2)_1 Wess-Zumino-Witten model even in the absence of global SU(2) symmetry for such a gapless domain wall. By taking advantage of the systematic classification and construction of twisted quantum double models and their corresponding SPT phases using group cohomology theory, we formally constructed general lattice models of these domain wall models for arbitrary finite symmetry group. Finally, we generalize the constructions in arbitrary dimensions and discuss potential physical interpretations for gapless domain walls in higher dimensions.

12:00pm **Lunch - SCGP Cafe**

2:00pm **Miles Stoudenmire - SCGP 102**

**Title:** Learning Relevant Features of Data Using Multi Scale Tensor Networks

**Abstract:** Tensor networks have been very successful in the field of many-body physics, since they underpin powerful algorithms and also give qualitative insights into different phases of matter. But more abstractly, tensor networks are simply a tool to compress tensors with a very large number of indices. Using them in the context of models for machine learning allows one to efficiently parameterize very expressive and interesting models. Previous applications include supervised learning and generative modeling of real-world data sets. But tensor networks are also used in physics to implement the idea of coarse graining, that is the renormalization group. In a renormalization group process, one is interested in keeping the most relevant fluctuations of a statistical ensemble while reducing the space of the problem by removing unimportant fluctuations. I will show how similar ideas can be realized for an ensemble of data using layered or multiscale tensor networks. The resulting algorithm leads to a model where most of the parameters are found in an unsupervised algorithm. Optimizing only the parameters at the coarsest scales for a specific task nevertheless results in excellent performance. I will conclude by discussing extensions of the idea and future directions.

3:00pm **Break - Simons Center**

3:30pm **Xiaoliang Qi - SCGP 102**

**Title:** Emergent gauge field and geometry in random tensor networks

4:30pm **Break - Simons Center**

5:00pm **Banquet - SCGP Cafe**

## Friday, December 15th

9:30am **Tomotoshi Nishino - SCGP 102**

**Title:** Entanglement entropy of the boundary spin configuration of a random 2D statistical system

**Abstract:** A classical analogue of the entanglement entropy is calculated on the system boundary of the +-J Ising model. The boundary spin distribution is obtained by means of the time-evolving block decimation (TEBD) method, where the random ensemble is created from the successive multiplications of position-dependent transfer matrices. The random average of the entanglement entropy is calculated on the Nishimori line, and it is confirmed that the entanglement entropy shows critical singularity at the Nishimori point.

10:30am **Break - Simons Center**

11:00am **Mehmet Burak Sahinoglu (short talk) - SCGP 102**

**Title:** Matrix Product Representation of Locality Preserving Unitaries

**Abstract:** I'll show recent results about characterization and classification of matrix product unitary operators (MPUOs). After reviewing why one may be interested in MPUOs, we'll start with minimal basics of matrix product states. Then we'll build up the results that end up with fixed-point equations that characterize MPUOs and we'll discuss the implications. Furthermore, we'll go beyond characterization and define an index called 'Rank-Ratio index' that classifies MPUOs. We'll see that it's related to the index that classifies one dimensional quantum cellular automata, introduced by Gross, Nesme, Vogt, Werner. We'll finish the talk with future directions. This is a work in collaboration with Sujeet Shukla, Feng Bi and Xie Chen. You can find our work at arXiv:1704.01943 [quant-ph] and a similar work at arXiv:1703.09188 [cond-mat.str-el].

11:40am **Andrej Gendiar (short talk) - SCGP 102**

**Title:** Quantum phase transitions in AdS_2 and fractals: Tensor-network studies

12:20pm **Lunch and Departure - SCGP Cafe**