Ergodicity, entanglement, and many-body localization

Abanin, Dmitry
(Perimeter Institute for Theoretical Physics, Condensed matter physics, Waterloo, Canada)

We are used to describing systems of many particles by statistical mechanics. However, the basic postulate of statistical mechanics – ergodicity -- breaks down in so-called many-body localized systems, where disorder prevents particle transport and thermalization. In this talk, I will present a theory of the many-body localized (MBL) phase, based on new insights from quantum entanglement. I will argue that, in contrast to ergodic systems, MBL eigenstates are not highly entangled. I will use this fact to show that MBL phase is characterized by an infinite number of emergent local conservation laws, in terms of which the Hamiltonian acquires a universal form. Turning to the experimental implications, I will describe the response of MBL systems to quenches: surprisingly, entanglement shows logarithmic in time growth, reminiscent of glasses, while local observables exhibit power-law approach to "equilibrium" values. I will support the presented theory with results of numerical experiments. I will close by discussing experimental implications and other directions in exploring ergodicty and its breaking in quantum many-body systems.

A new path towards universal topological quantum computation

Alicea, Jason
(California Institute of Technology, Physics, Pasadena, CA 91107, USA)

The realization of a quantum computer poses a grand outstanding challenge that promises technological advances in areas ranging from cryptography to quantum simulation and beyond. Typically decoherence--whereby environmental perturbations corrupt quantum information--presents the chief obstacle. Topological quantum computation, however, cleverly sidesteps decoherence at the hardware level by non-locally manipulating quantum information using emergent particles known as non-Abelian anyons. Considerable progress has recently been made towards stabilizing the simplest non-Abelian anyons (particles binding Majorana zero-modes) by judiciously combining well-understood materials. This 'engineering' approach has inspired a wave of experiments, though such Majorana-based platforms require unprotected gates to run general quantum computing algorithms, thus entailing significant overhead. A natural question therefore arises: can one combine ordinary ingredients to synthesize a fully fault-tolerant, universal quantum computer? I will answer this question in the affirmative. More precisely, I will describe how one can combine simple fractional quantum Hall states and conventional superconductors to realize a novel superconducting phase that harbors so-called Fibonacci anyons. These particles constitute the 'holy grail' for topological quantum computing in that they allow for computational universality via a single elementary gate generated by braiding the anyons around each other.

Universal dynamics and topology in many-body localized states

Altman, Ehud
(The Weizmann Institute of Science, Condensed Matter Physics, Rehovot, Israel)

It has been argued recently that, through a phenomenon of many-body localization, closed quantum systems subject to sufficiently strong disorder would fail to thermalize. In this talk I will discuss the nature of the dynamics in the localized state. I will show that rather than being a dead state, the localized phase supports highly non trivial modes of quantum dynamics. Most spectacularly, many-body localization can facilitate the existence of topological order in the entire many-body spectrum rather than in the ground state alone. I will demonstrate with a concrete model of a quantum magnet how this leads to protected quantum-bits that retain perfect coherence even when the system is at arbitrarily high energy.

Phase-junctions in one-dimensional topological superconductors

Ardonne, Eddy
(Stockholm University, Department of Physics, Stockholm, Sweden)

In this talk, we consider junctions in superconducting wires. In particular, we will study the difference `real' junctions, and so-called `phase-winding' junctions, and investigate the role topology plays. We briefly comment on some potential experimental setups, which could be used to test our results.

Entanglement Spectra of Interacting Fermions in Quantum Monte Carlo Simulations

Assaad, Fakher
(University of Würzburg, Institut für Theoretische Physik und Astrophysik, Würzburg, Germany)

In a recent article T. Grover [Phys. Rev. Lett. {bf 111}, 130402 (2013)] introduced a simple method to compute Renyi entanglement entropies in the realm of the auxiliary field quantum Monte Carlo algorithm. Here, we further develop this approach and provide a stabilization scheme to compute higher order Renyi entropies and an extension to access the entanglement spectrum. The method is tested on systems of correlated topological insulators.

Optical Flux Lattices for Ultracold Neutral Atoms

Aycock, Lauren
(Joint Quantum Institute, National Institute of Standards and Technology, Physical Measurement Laboratory, Gaithersburg, MD, USA)

The fractional quantum Hall effect arises in strongly interacting systems of electrons at high magnetic fields when the ratio of the magnetic flux to the electronic density is of order unity [1]. Ultracold neutral atoms are ideal systems to study such strongly correlated many-body physics in contexts – such as for bosonic systems – that are impossible for electrons [2]. The ability to measure local correlation functions in cold atom systems may allow for new understanding of these many-body states and their interesting emergent phenomena. We are implementing an experiment to achieve the required high magnetic flux densities with an "optical flux lattice" based on recent proposals [3-5] that use a spin dependent optical lattice to realize a band structure with nontrivial topological order. I will comment on experimentally realizable parameters for such a system and potential measurement techniques to probe interaction driven bosonic fractional quantum hall states.

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[3] N. R. Cooper, Phys. Rev. Lett. 106, 175301 (2011).
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Many-body localization and entanglement

Bardarson, Jens H
(Max Planck Institute for the Physics of Complex Systems, Dresden, Germany)

In this talk I will discuss the entanglement properties of the exact eigenstates of many-body localized systems. In particular, I will discuss two entanglement properties that are promising for the study of the many-body localization transition: the variance of the half-chain entanglement entropy of exact eigenstates and the long time change in entanglement after a local quench from an exact eigenstate. These quantities are then used to numerically study a disordered quantum Ising chain and to estimate the critical disorder strength and its energy dependence. In addition, I give an analysis of a spin-glass transition at large disorder strength and provide evidence for it being a separate transition. Together, this thereby gives numerical support for a recently proposed phase diagram of many-body localization with localization protected quantum order [Huse et al. Phys. Rev. B 88, 014206 (2013)].

Ref: J.A. Kjall, J.H. Bardarson and F. Pollmann, arXiv:1403.1568

Coherent transmutation of electrons into fractionalized anyons

Barkeshli, Maissam
(Microsoft Research Station Q, University of California, Santa Barbara, Santa Barbara, USA)

Majorana fermions in magnetic atomic chains

Bernevig, B. Andrei
(Princeton University, Department of Physics, Princeton, USA)

Quasiholes in certain fractional quantum Hall states are promising candidates for the experimental realization of non-Abelian anyons. They are assumed to be localized excitations, and to display non-Abelian statistics when sufficiently separated, but these properties have not been explicitly demonstrated except for the Moore-Read state. We apply the newly developed matrix product state technique to examine these exotic excitations. For the Moore-Read and the $mathbb{Z}_3$ Read-Rezayi states, we estimate the quasihole radii, and determine the correlation lengths associated with the exponential convergence of the braiding statistics. We provide the first microscopic verification for the Fibonacci nature of the $mathbb{Z}_3$ Read-Rezayi quasiholes. We also present evidence for the failure of plasma screening in the non-unitary Gaffnian wave function. We compute topological entanglement entropies of these states and bound their correlation lengths.

New quantum dimer models with a twisted Z_2 spin liquid phase

Buerschaper, Oliver
(Perimeter Institute for Theoretical Physics, Waterloo, Canada)

We present new quantum dimer models on the Kagome lattice which exhibit an usual Z_2 spin liquid phase. In contrast to previous models, this phase corresponds to a U(1)times U(1) Chern-Simons theory rather than ordinary Z_2 gauge theory. We give both an exactly solvable and a minimal model and investigate possible realizations in microscopic Hamiltonians of quantum magnets.

Anomalous symmetry fractionalization in topologically ordered surface states

Burnell, Fiona
(University of Minnesota (UMN), Physics and Astronomy, USA)

TBA

Accessing topological order in fractionalized liquids with gapped edges

Chamon, Claudio
(Boston University, Physics, Boston, USA)

We consider manifestations of topological order in time-reversal-symmetric fractional topological liquids (TRS-FTLs), defined on planar surfaces with holes. We derive a general formula for the topological ground state degeneracy of such a TRS-FTL, which applies to cases where the edge modes on each boundary are fully gapped by backscattering terms. The degeneracy is exact in the limit of infinite system size, and is given by q^N , where N is the number of holes and q is an integer that is determined by the topological field theory. When the degeneracy is lifted by finite-size effects, the holes realize a system of N coupled spin-like q-state degrees of freedom. In particular, we provide examples where “artificial” Z_q quantum clock models are realized. We also investigate the possibility of measuring the topological ground state degeneracy with calorimetry, and briefly revisit the notion of topological order in s-wave BCS superconductors.

A Memory of Majorana Modes through Quantum Quench

Chung, Ming-Chiang
(National Chung Hsing university, National Chung Hsing university, Department of Physics, Taichung City, Taiwan)

We study the sudden quench of a one-dimensional p-wave superconductor through its topological signature in the entanglement spectrum. The long-time evolution of the system and its topological characterization depend on a pseudomagnetic eld Re(k), which connects both the initial and the final Hamiltonians, hence exhibiting a memory effect etc. In particular, we explore the robustness of the Majorana zero-mode associated with the entanglement cut in the topologically nontrivial phase and identify the parameter space in which the mode can survive in the infinite-time limit.

Symmetries and boundary theories for chiral projected entangled pair states

Cirac, Ignacio
(Max Planck Institut of Quantum Optics, Theory, Garching, Germany)

We investigate the topological character of lattice chiral Gaussian fermionic states in two dimension possessing the simplest descriptions in terms of projected entangled-pair states (PEPS). As for (non-chiral) topological PEPS, it can be traced down to the existence of a symmetry in the virtual modes that are used to build the state. Based on that symmetry, we construct string-like operators acting on the virtual modes that can be continuously deformed without changing the state. On the torus, the symmetry implies that the ground state space of the local parent Hamiltonian is two-fold degenerate. By adding a string wrapping around the torus one can change one of the ground states into the other. We use the special properties of PEPS to build the boundary theory and show how the symmetry results in the appearance of chiral modes, and a universal correction to the area law for the zero R'enyi entropy. We also report on some results for non-Gaussian states.

TBA

Cooper, Nigel
(University of Cambridge, Cavendish Laboratory, Physics Department, Cambridge, United Kingdom)

TBA

Interacting Hamiltonians for topological insulator surfaces

Essin, Andrew
(California Institute of Technology, Institute for Quantum Information and Matter, Physics, Pasadena, USA)

There has been much recent activity concerning the fate of the topological insulator surface states in the presence of strong interactions. Most notably, two-dimensional topological orders have been proposed that are only consistent with the relevant symmetries when placed at the surface of a three-dimensional system. I will discuss present gapped, symmetric Hamiltonians for topological insulator surfaces and the extent to which we can determine the topological order present.

Stability of Topological Superconductors to Interactions and Surface Topological Order

Fidkowski, Lukasz
(Stony Brook University, Physics and Astronomy, Stony Brook, USA)

Three-dimensional topological superconductors protected by time reversal symmetry are characterized by gapless Majorana cones on their surface. Free-fermion phases with this symmetry (class DIII) are indexed by an integer nu, of which $nu=1$ is realized by the B phase of superfluid $^3 He$. Previously, it was believed that the surface must be gapless unless time-reversal symmetry is broken. In this talk, we argue that a fully symmetric and gapped surface is possible in the presence of strong interactions, if a special type of topological order appears on the surface. The topological order realizes time reversal symmetry in an anomalous way, one that is impossible to achieve in purely two dimensions. For odd nu, the surface topological order must be non-Abelian, and propose the simplest non-Abelian topological order that contains electronlike excitations, $SO(3)_6$, with four quasiparticles, as a candidate surface state. We also discuss Abelian theories for the surface $nu=2,4,8$; one particular consequence of our scheme is that $nu=16$ admits a trivially gapped time reversal symmetric surface.

Non-Abelian statistics in one dimension: Majorana fermions, topological momentum spacings, and SU(2) level k fusion rules

Greiter, Martin
(Julius-Maximilians-Universität Würzburg, Lehrstuhl für Theoretische Physik 1, Fakultät für Physik und Astronomie, Würzburg, Germany)

We use a family of critical spin chain models discovered recently by one of us [M. Greiter, emph{Mapping of Parent Hamiltonians}, vol. 244 of Springer Tracts in Modern Physics, Springer, Berlin/Heidelberg 2011] to propose and elaborate that non-Abelian, SU(2) level k anyon statistics manifests itself in one dimension through topological selection rules for the fractional momentum spacings, which yield an internal Hilbert space of in the thermodynamic limit degenerate states. These spacings constitute the equivalent to fractional relative angular momentum for anyons in two dimensions. We derive the rules first for Ising anyons, which are quantized according to what we call Majorana spacings, and then generalize them to SU(2) level k anyons. Finally, we establish a one-to-one correspondence between the topological choices for the momentum spacings and the fusion rules of spin half spinons in the SU(2) level k Wess--Zumino--Witten model.

Stability of Chern and Fractional Chern Insulators

Grushin, Adolfo González
(Max Planck Institute for the Physics of Complex Systems (MPIPKS), Max Planck Institute for the Physics of Complex Systems, Condensed Matter, Dresden, Germany)

The experimental realization of Chern insulators (CI) and fractional Chern insulators (FCI), zero field lattice analogues of the integer and fractional quantum Hall effects respectively, is still a major open problem in condensed matter. For the former, it was proposed that short range interactions at the mean-field level can drive a trivial insulator into a CI. For the latter, the effect of band dispersion and sizes of the single-particle gaps with respect to the interaction strength have been argued to be important to stabilize an FCI state. In this talk we will examine the robustness and fate of these statements with exact diagonalization and infinite density matrix renormalization group (iDMRG).

Emergence of p+ip topological superconducting ground state in infinite-U Hubbard model on honeycomb lattice

Gu, Zheng-Cheng
(Perimeter Institute for Theoretical Physics, Waterloo, Canada)

In this talk, I will show the emergence of p+ip topological superconducting ground state in infinite-U Hubbard model on honeycomb lattice, from both state-of-art Grassmann tensor-network numerical approach and quantum field theory approach.

Bulk-boundary correspondence in fractional quantum Hall effect

Gurarie, Victor
(University of Colorado, Physics, Boulder, USA)

Quantum Hall physics with photons: from observation of non-interacting edge states

towards simulating many-body physics

Hafezi, Mohammad
(University of Maryland, Joint Quantum Institute,)

I demonstrate how topological physics can be observed for photons; specifically, how various quantum Hall Hamiltonians can be simulated with photons. I talk about the observation of topological photonic edge state using the silicon-on-insulator technology. Furthermore, the addition of optical nonlinearity to the system leads to the possibility of implementing fractional quantum Hall states of photons and anyonic states. In particular, I discuss a scheme to engineer three-body interaction, which is absent in nature, to implement some of the fractional quantum Hall models, in the context of circuit-QED. In the end, I discuss various schemes to implement such many-body states by either synthesizing chemical potential for photons or benefiting from the compressibility of gapped states.

Unexpected pairing of electrons in the IQHE regime

Heiblum, Moty
(Weizmann Institute of Science, Condensed matter physics, Rehovot, Israel)

Electron pairing is a rare phenomenon appearing only in a few unique physical systems, such as superconductors or Kondo-correlated quantum-dots. Here, we report on an unexpected 'pairing' of electrons in the integer-quantum Hall effect (IQHE) regime. The pairing takes place in the interfering most outer edge channel within an electronic Fabry-Perot interferometer at a bulk filling factor . We note three clear observations: (a) Aharonov-Bohm oscillations with magnetic-flux periodicity v , with the electron charge and Planck's constant; (b) An interference charge - revealed by shot noise measurements; and (c) Entanglement between the two most outer edge channels. While the exact mechanism of the pairing is not understood, we show that this unique phenomenon results from inter-edge channels interactions.

Long-range Coulomb interactions and the quadratic band touching in two and three dimensions

Herbut, Igor
(Simon Fraser University, Physics, Burnaby, Canada)

In two-dimensional systems with a quadratic band touching, such as the celebrated bilayer graphene, the short-range repulsion is a marginally relevant perturbation that may lead to the spontaneous formation of the topological insulating ground state, for example. The long-range component of the Coulomb interaction is in general assumed to be screened, and not to change the result qualitatively. In three dimensions, on the other hand, after the work of Abrikosov in the `70s, the long-range Coulomb interaction is believed to turn the electronic system with the quadratic band touching into a non-Fermi liquid. I will discuss the renormalization group flow of the irreducible Hamiltonian with a quadratic band touching and with the Coulomb repulsion in general dimension, and consider what turns out to be a non-trivial interplay of the long-range and the short-range components of the interaction. This more complete treatment indicates that a single quadratic point may in fact be unstable towards the formation of the gap both in two and three dimensions, in the latter case contradicting the Abrikosov's classic result. It will be argued that the non-Fermi liquid in three dimensions obtains only for the number of fermionic components larger than a critical number, which is estimated to be somewhat bigger than two.

Quantum spin liquid with a Majorana Fermi surface on the three-dimensional hyperoctagon lattice

Hermanns, Maria
(University of Cologne, Physics, Theoretical physics, Köln, Germany)

Motivated by the recent synthesis of β-Li_2IrO_3 -- a spin-orbit entangled $j=1/2$ Mott insulator with a three-dimensional lattice structure of the Ir^{4+} ions -- we consider generalizations of the Kitaev model believed to capture some of the microscopic interactions between the Iridium moments on various trivalent lattice structures in three spatial dimensions.
Of particular interest is the so-called hyperoctagon lattice -- the premedial lattice of the hyperkagome lattice, for which the ground state is a gapless quantum spin liquid where the gapless Majorana modes form an extended two-dimensional Majorana Fermi surface.
We demonstrate that this Majorana Fermi surface is inherently protected by lattice symmetries and discuss possible instabilities.
We thus provide the first example of an analytically tractable microscopic model of interacting SU(2) spin-1/2 degrees of freedom in three spatial dimensions that harbors a spin liquid with a two-dimensional spinon Fermi surface.

Topological Phases on Hyperhoneycomb and Pyrochlore lattices

Kim, Yong-Baek
(University of Toronto, Physics, Toronto, Canada)

Motivated by recent experiments on three-dimensional versions of honeycomb iridates, we consider possible quantum spin liquid and topological insulator phases on three-dimensional hyperhoneycomb and related lattices. Both strong-coupling and weak-coupling limits are analyzed to provide a comprehensive picture. We also consider the possibility of a spin liquid phase with charge fractionalization in partially-filled correlated electron systems on the pyrochlore lattice. Connections between these models of interacting electrons on the pyrochlore lattice and quantum-spin-ice models are pointed out. Applications of these ideas to possible materials are discussed.

Spin structure factor in Abelian and non-Abelian Kitaev spin liquids and the effect of disorder

Knolle, Johannes
(Max-Planck-Institut für Physik komplexer Systeme, Condensed Matter, Dresden, Germany)

Topological states of matter present a wide variety of striking new phenomena, most prominently is the fractionalization of electrons. Their detection, however, is fundamentally complicated by the lack of any local order. While there are now several instances of candidate topological spin liquids, their identification remains challenging. We provide a complete and exact theoretical study of the dynamical structure factor and the inelastic Raman scattering response of a two-dimensional quantum spin liquid in Abelian and non-Abelian phases. We show that there are salient signatures of the Majorana fermions and gauge fluxes emerging in Kitaev's honeycomb model. Our analysis identifies new varieties of the venerable X-ray edge problem and explores connections to the physics of quantum quenches. Finally, we discuss the effect of bond disorder on the dynamical response.

Topological order from strong interactions in two-dimensional lattice models of spinless fermions

Kourtis, Stefanos
(Leibniz Gemeinschaft, Leibniz Institute for Solid State and Materials Research Dresden, Institute for Theoretical Solid-State

Physics, Dresden, Germany)

The formation of fractional quantum-Hall (FQH) states in lattice systems without externally applied magnetic fields -- dubbed fractional Chern insulators (FCI) -- is a recent and promising theoretical proposal that has the potential to render the FQH effect experimentally more accessible. The paradigmatic FCIs are found when interacting electrons with frozen spin degree of freedom populate relatively flat topological bands, with the interaction strength being smaller than the gap to other bands. In this talk, I will show that this limit is adiabatically connected to the opposite one, in which the interaction strength goes to infinity, thus exceeding the gap to other bands. Electrons then become extended hard-core particles, the notion of bands becomes meaningless and the connection to Landau level physics of the FQH effect is practically lost. FCI states are very robust in this hardcore limit, reaching up to, or possibly beyond, the non-interacting topological phase transition. Strong interactions may also give rise to competition between topological and conventional charge order. After discussing this competition, I will introduce a class of states in which the FCI topological order is induced by the presence of a charge-density wave and will present numerical evidence for this coexistence. Finally, based on these compositely ordered states, I will provide a recipe for topological order out of a topologically trivial band structure.

Condensate-induced transitions and critical spin chains: Construction of exactly solvable spin chains with so(N)_1 critical points

Lahtinen, Ville
(University of Amsterdam, Institute of Physics, Physics, Amsterdam, Netherlands)

We argue that condensate-induced transitions between two-dimensional topological phases provide a general framework to relate also one-dimensional spin models at their critical points [1]. This connection is based on both being described by a conformal field theory (CFT). In a two-dimensional topological phase the possible bulk quasiparticles are given by the CFT describing the edge, while the spectrum of a one-dimensional spin chain is known to be fully conformal. In condensate-induced transitions the condensation of a bosonic quasiparticle leads to redefinition of the vacuum state and to the confinement of some other quasiparticles. We show that the counterpart of this mechanism in critical spin chains is a non-local “confining” Hamiltonian term that constrains the CFT sectors accordingly.

We exploit this insight to construct a hierarchy of exactly solvable spin-1/2 chains with so(N)_1 critical points [2]. First we construct a confining Hamiltonian term to couple together N transverse field Ising chains and verify that the resulting theory is critical and described by the predicted so(N)_1 CFT. Then we employ spin duality transformations to cast these spin chains for arbitrary N into translationally invariant forms that all allow exact solution by the means of a Jordan-Wigner transformation. For odd N our models generalize the phase diagram of the transverse field Ising chain, the simplest model in our hierarchy. For even N the models can be viewed as longer ranger generalizations of the XY chain, the next model in the hierarchy.

References:
[1] T. Månsson, V. Lahtinen, J. Suorsa and E. Ardonne, Phys. Rev. B 88, 041403(R) (2013)
[2] V. Lahtinen, T. Månsson and E. Ardonne, Phys. Rev. B 89, 014409 (2014)

Braiding statistics and symmetry-protected topological phases

Levin, Michael
(University of Chicago, USA)

Symmetry-protected topological (SPT) phases can be thought of as generalizations of topological insulators. Just as topological insulators have robust boundary modes protected by time reversal and charge conservation symmetry, SPT phases have boundary modes protected by more general symmetries. In this talk, I will describe a method for analyzing 2D and 3D SPT phases using braiding statistics. More specifically, I will show that 2D and 3D SPT phases can be characterized by gauging their symmetries and studying the braiding statistics of their gauge flux excitations. The 3D case is of particular interest as it involves a generalization of quasiparticle braiding statistics to three dimensions.

Light induced topological phenomena

Lindner, Netanel
(Technion - Israel Institute of Technology Institute of Technology, Physics, Haifa, Israel)

Entanglement spectroscopy of 1+1D CFT systems

Läuchli, Andreas
(University of Innsbruck, Institute for Theoretical Physics, Innsbruck, Austria)

In this talk I will present Exact Diagonalization results for several S=1/2 models on the kagome lattice and provide new insights into proposed spin liquid phases.

Dynamical correlations of a quantum spin liquid

Moessner, Roderich
(Max Planck Institute for Physics of Complex Systems, Dresden, Germany)

Non-Abelian topological order from symmetrization

Mong, Roger
(California Institute of Technology, PMA, Physics, Pasadena, USA)

By symmetrizing two copies of some Abelian phase, we can often obtain an exotic topological phase with non-Abelian anyons. Here we analyze the symmetrization of two copies of the toric code.

Connecting experimental observables to entanglement growth in many-body localization

Moore, Joel
(University of California, Berkeley, Department of Physics, Berkeley, USA)

One way in which the many-body localized (MBL) state is known to differ from single-particle Anderson localization is that it shows a slow but unbounded increase of the entanglement entropy from an initially unentangled state. We discuss a picture of this increase in terms of dephasing from pairwise interactions without delocalization and explain how (a) the dynamics of a single spin in the MBL phase can be interpreted, using statistics of "revivals", as reflecting this same process, and (b) how aspects of the MBL phase still appear in simple translation-invariant models of heavy and light particles.

Joint work with C. Laumann, S. Parameswaran, R. Vasseur, and N. Yao.

Model Realization and Numerical Study of a Three-Dimensional Bosonic Topological Insulator

Motrunich, Olexei
(California Institute of Technology, Physics Department, Pasadena, USA)

We study a topological phase of interacting bosons in (3+1) dimensions which is protected by charge conservation and time-reversal symmetry. We present an explicit lattice model which realizes this phase and which can be studied in sign-free Monte Carlo simulations. The idea behind our model is to bind bosons to topological defects called hedgehogs. We determine the phase diagram of the model and

identify a phase where such bound states are proliferated. In this phase we observe a Witten effect in the bulk whereby an external monopole binds half of the elementary boson charge, which confirms that it is a bosonic topological
insulator. We also study the boundary between the topological insulator and a trivial insulator. We find a surface phase diagram which includes exotic superfluids, a topologically ordered phase, and a phase with a Hall effect
quantized to one-half of the value possible in a purely two-dimensional system. We also present models that realize symmetry-enriched topologically-ordered phases.

Realizations of synthetic gauge fields in the dice lattice geometry

Möller, Gunnar
(University of Cambridge, Theory of Condensed Matter (TCM), Cavendish Laboratory, Cambridge, United Kingdom)

The dice lattice with pi-flux per plaquette realises the physics of Aharonov-Bohm cages that yield entirely flat bands [1]. Consequently, this model supports collective states driven entirely by interactions. Prominently, these states include a supersolid phase arising near half filling of the lowest band, and complex vortex lattices at large particle density [2]. Motivated by these exciting target phases, we discuss realisations of synthetic gauge fields in systems with dice lattice geometry. We show two distinct realisations of the dice lattice in cold atomic gases: A first realisation is based on optical flux lattices and exploits the Berry phase of atoms moving in a shallow optical lattice. We contrast this approach with a second realisation in terms of an `anti-magic' optical lattice for two-state systems such as Yb. Here, we start from a tight binding limit and induce hopping elements that simulate the presence of the desired magnetic flux. We discuss possible implications of these distinct realisations for the ensuing many-body physics.

[1] J. Vidal, R. Mosseri, and B. Doucot, Phys. Rev. Lett. {bf 81}, 5888 (1998).
[2] G. M"oller and N.R. Cooper, Phys. Rev. Lett. {bf 108}, 045306 (2012).
[3] G. M"oller and N.R. Cooper, in preparation.

Interacting surface states of three-dimensional topological insulators

Neupert, Titus
(Princeton University, Princeton Center for Theoretical Science, Princeton, USA)

We numerically investigate the surface states of a strong topological insulator in the presence of strong electron-electron interactions. We choose a spherical topological insulator geometry to make the surface amenable to a finite size analysis.
The single-particle problem maps to that of Landau orbitals on the sphere with a magnetic monopole at the center that has unit strength and opposite sign for electrons with opposite spin. Assuming density-density contact interactions, we find superconducting and anomalous (quantum) Hall phases for attractive and repulsive interactions, respectively. Our setup design is ideally adapted to the search for topologically ordered surface terminations that could be microscopically stabilized by tailored surface interaction profiles.

Fractional quantum Hall lattice models from conformal field theory

Nielsen, Anne Ersbak Bang
(Max-Planck-Institut für Quantenoptik, Garching, Germany)

We propose a method to construct spin models with interesting physical properties and only local

interactions, and we apply it to obtain a lattice model with a fractional quantum Hall like ground state. The first step is to use conformal fields to build a wave function, which is an infinite-dimensional-matrix product state. Then, the mathematical structure of the state is used to derive a (nonlocal) parent Hamiltonian. Finally, the Hamiltonian is transformed into a local Hamiltonian without crossing a phase transition. For the example considered, we demonstrate explicitly that the model has the expected topological properties. The nature of the model differs from the flat band models proposed previously as a general recipe to obtain fractional quantum Hall like lattice states.

References: Nat. Commun. 4, 2864 (2013); J. Stat. Mech. P11014 (2011).

Symmetry-protected topological phases and transitions in frustrated spin-1/2 chains

Onoda, Shigeki
(RIKEN (The Institute of Physical and Chemical Research), Condensed Matter Theory Laboratory, Wako, Japan)

Frustrated spin-1/2 XXZ chain models are revisited in the light of symmetry-protected topological phases. Using iDMRG technique and clarifying the projective representations, we fully categorize the previously obtained gapped ground states with the time-reversal invariance as SPT phases: the Haldane-dimer phase near the SU(2)-symmetric case and the even-parity dimer phase with large easy-plane exchange anisotropy both of which have the inversion symmetry, as well as two topologically distinct parity-broken vector-chiral dimer phases. In particular, a small nearest-neighbor bond alternation destabilizes the gapless vector-chiral phase which occupies a large region in the space of J1/J2 and the XXZ anisotropy in between the above two dimer phases, and it allows for a topological transition between the two parity-broken vector-chiral dimer phases. A possible relevance to quasi-one-dimensional cuprates is discussed.

Fractional Majoranas and the Wires' approach for Fractional Topological Insulators

Oreg, Yuval
(Weizmann Institute of Science, Rehovot, Israel)

We study a one dimensional wire with spin-orbit coupling and show that in the presence of Zeeman field and strong electron-electron interaction a clean wire may support fractional Majoranas when the system is proximity-coupled to a superconductor. We discuss how disorder destabilizes these fractional phases in the 1D limit and how it is possible to connect few wires and create an effective 2D system which is topologically stable against disorder. The construction (of an array of alternating wires that contain electrons and holes, correlated with an alternating magnetic field without the need of superconductors) is valid for a large class of topological states including Chern Insulator. We show how electron-electron interactions can stabilize fractional Chern insulators (Abelian and non-Abelian). In particular, we construct a relatively stable non-Abelian Z3 parafermion state. Our construction is generalized to wires with alternating spin-orbit couplings, which give rise to integer and fractional (Abelian and non-Abelian) topological insulators. The possibility of experimental realization of our construction is addressed.

Symmetry-protected "trivial" phases in one dimension (tentative)

Oshikawa, Masaki
(University of Tokyo, Institute for Solid State Physics, Kashiwa, Japan)

(tentative)
Classification of quantum phases is one of the most important topics in statistical mechanics and condensed matter physics. Traditionally, distinct phases were characterized by the presence of various long-range orders. However, recently it has been recognized that there are various phases which cannot be characterized by any long-range order in the conventional sense. Nontrivial quantum phases without any conventional order are generally called topological phases. There are two classes of topological phases: (genuine) topologically ordered phases, which are distinct from a trivial phase without imposing any symmetry, and symmetry-protected topological phases.
In one dimension, there is no genuine topologically ordered phase, but there are symmetry-protected

topological phases. One of the examples is the well-known Haldane phase. It is characterized by an exact double degeneracy of the entanglement spectrum. Because of this, the Haldane phase cannot adiabatically connected to a trivial state, namely a simple product of local spin states, in the presence of the appropriate symmetry.
However, the symmetry protection also works between trivial phases, which include product states without any entanglement. Namely, there are several distinct "trivial" phases protected by symmetries. We demonstrate this in a simple S=1 chain with on-site anisotropies and a staggered field, using field theory and matrix product state representation.

Quantum critical behavior of the Hubbard and Hubbard-Kane-Mele model on the honeycomb lattice

Parisen Toldin, Francesco
(University of Wuerzburg, Institut fuer theoretische Physik I, Abteilung Assaad, Wuerzburg, Germany)

We numerically investigate the critical behavior of the Hubbard model, with and without pi fluxes, and of the Kane-Mele-Hubbard model at half-filling and at zero temperature. By means of Auxiliary-Field Projective Quantum Monte Carlo and a careful Finite-Size Scaling analysis which exploits Renormalization-Group invariant observables, we are able to extract an estimate of the value of the critical couplings and of the critical exponents. Our results confirm that the critical behavior of the Hubbard model and of the Hubbard model with the insertion of pi fluxes, i.e., the so-called pi-flux-Hubbard model, belongs to the Gross-Neveu-Yukawa universality class. In the presence of spin-orbit coupling, the resulting Hubbard-Kane-Mele model exhibits a phase transitions in the XY universality class.

Ref.:
F. Parisen Toldin, M. Hohenadler, F. F. Assaad, I. Herbut, in preparation

Superfluids and superconductors from Projected Entangled Pair States

Poilblanc, Didier
(C.N.R.S. & UNIVERSITE DE TOULOUSE, I.R.S.A.M.C., LABORATOIRE DE PHYSIQUE THEORIQUE, TOULOUSE, France)

Topological gapped Z_2 spin liquids have been proposed as candidates for the ground-state of the S=1/2 quantum antiferromagnet on frustrated lattices (like the Kagome lattice). We use Projected Entangled Pair States (PEPS) to construct (on the cylinder) Resonating Valence Bond (RVB) spin liquids. By considering the presence or the absence of spinon and vison lines along an infinite cylinder, we explicitly construct four orthogonal RVB Minimally Entangled States. The spinon and vison coherence lengths are then extracted from a finite size scaling w.r.t the cylinder perimeter of the energy splittings of the four sectors.

A large enough magnetic field can generically induce "doping" of polarized S=1/2 spinons or triplons (i.e. spinon bound pairs). We show that simple PEPS can describe Bose condensed spinons (RVB) superfluids with transverse staggered (Néel) magnetic order associated to the (spontaneous) breaking of the U(1)-symmetry around the magnetic field direction.

Lastly, we consider the doping of RVB spin liquids by charge carriers (holes) within the framework of an extended (frustrated) t--J model. The new U(1) symmetry associated to charge conservation can be spontaneously broken leading to a superconducting state. Using fermionic PEPS, we give strong evidence that a RVB superconductor emerges immediately under doping the RVB insulator. The simplicity of the PEPS ansatz enables to fully investigate the properties of this unconventional superconductor (pairing symmetry, etc...).

From correlated topological insulators to spin liquids and iridates

Rachel, Stephan
(TU Dresden, Institute for Theoretical Physics, Dresden, Germany)

When Holes Lose Their Statistics

Ralko, Arnaud
(University Joseph Fourier - CNRS, Institut NEEL, MCBT, Grenoble, France)

The discovery of exotic quantum spin liquids is one of the challenges of modern condensed matter physics. Resonating Valence bond (RVB) liquids, made of spin singlet pairs, exhibit, once broken, a separation of the spin and the charge degrees of freedom (and superconductivity) into two emergent particles, a holon carrying the charge quantum and a spinon carrying the spin quantum. Although the original electron is a fermion, the question of the actual statistics of holons and spinons in such a "deconfinement" scenario remains an open issue.

In that context, Quantum Dimer Models (QDM) arise as low energy effective models for frustrated magnets. Some of these models have proven successful in generating a scenario for such exotic spin liquid phases with deconfined spinons and topological properties.

We evidence the existence of a dynamical statistical transmutation in doped quantum dimer models. The dimer quantum dynamics experienced by the holons can transmute their original statistics, e.g. from fermions to bosons. This exact transformation enables to define duality equivalence classes (or families) of doped QDM, and provides a kind of dynamical realization of a Chern-Simon theory.

As a result, it will be shown how the parent insulating state and the original lattice geometry can influence the nature of the hole doped phases: phase separation, superfluidity, supersolidity, and fermionic phases. In particular, some evidences for an exotic superconducting phase originating from the condensation of (bosonic) charge-e holons will be given.

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The Hilbert-glass transition: new universality of many-body dynamical quantum criticality

Refael, Gil
(California Institute of Technology, Physics, Pasadena, USA)

We study a new class of unconventional critical phenomena that is characterized by singularities only in dynamical quantities and has no thermodynamic signatures. I will develop a real-space renormalization group method for excited state (RSRG-X) that allows us to analyze such transitions, and will focus on the 1D disordered transverse field Ising model with generic interactions. While thermodynamic phase transitions are generally forbidden in this model, using RSRG-X we find a finite-temperature dynamical transition between two localized phases. The transition is characterized by non-analyticities in the low

frequency heat conductivity and in the long-time (dynamic) spin correlation function. The latter is a consequence of an up-down spin symmetry that results in the appearance of an Edwards-Anderson-like order parameter in one of the localized phases.

Matrix Product States and the Fractional Quantum Hall Effect

Regnault, Nicolas
(CNRS - Princeton University, Ecole Normale Superieure Paris, Paris, France)

The understanding and simulation of quantum many-body states in one space dimension has experienced revolutionary progress with the advent of the density matrix renormalization group. In modern language, this method can be viewed as a variational optimization over the set of matrix product states (MPS). Due to their perimeter law entanglement, 2-D systems such as the fractional quantum Hall effect are harder to simulate by MPS.

We will show that many fractional quantum Hall states have an exact infinite MPS representation. We will discuss how a controlled truncation can be performed on this representation and we will give a natural interpretation from the entanglement spectrum perspective. Through the MPS, We will give evidences why certain model states related to non-unitary conformal field theories, are pathological. We will also show the direct characterization of the Read-Rezayi quasihole excitations from their MPS description.

Dephasing suppression and phase lapses: signatures of entanglement in the fractional quantum Hall regime

Rosenow, Bernd
(Universität Leipzig, Institut fuer Theoretische Physik, Fakultät für Physik und Geowissenschaften, Leipzig, Germany)

A charge fluctuator which is electrostatically coupled to a conducting channel may fully dephase quantum transport through the latter. Here, we address the case where a quantum dot (QD), playing the role of a charge fluctuator, is tunnel-coupled to an additional channel. In the case where the latter may support fractional charge, distinct differences from the integer case arise : Abrupt phase lapses of the transmission through the conducting channel occur (which may or may not be equal to pi). This is accompanied by a cusp-like suppression of the interferometer's visibility, yet no full dephasing. We interpret our findings in terms of the entanglement between the fluctuator and the conducting channel as measured by the concurrence of the density matrix.

Effective theory of surface states in topological Kondo insulator SmB6

Roy, Bitan
(Condensed-Matter Theory Group, CMTC, University of Maryland, Physics, College Park, USA)

Three dimensional topological insulators stand as examples of novel state of matter, that supports robust-gapless surface states. These surface states are topologically protected by the Z2 bulk topological invariant. Although the topological invariant is strictly defined in a system of non-interacting quasi-particles, recently its extension even to strongly correlated systems has been demonstrated. Following the theoretical proposal, there has been a surge of experimental works suggesting samarium hexaboride (SmB6) as a promising candidate of topological Kondo insulators. In this work, I will present the effective theory of the surface states in this system. I will discuss its experimental ramifications, and universal properties. I will also present the generic form of a model bulk Hamiltonian, which can capture various universal and topological properties in multi-band strongly correlated Kondo topological systems. Role of topological defects and strong correlations in these systems will be addressed as well.

Symmetry protected topoloigcal phases and orientifolds

Ryu, Shinsei
(University of Illinois at Urbana-Champaign, Department of Physics, Urbana, USA)

We generalize Laughlin's flux insertion argument, originally discussed in the context of the quantum Hall effect, to topological phases protected by non-on-site unitary symmetries, in particular by parity symmetry or parity symmetry combined with an on-site unitary symmetry. As a model, we discuss fermionic or bosonic systems in two spatial dimensions with CP symmetry, which are, by the CPT theorem, related to time-reversal symmetric topological insulators (e.g., the quantum spin Hall effect). In particular, we develop the stability/instability (or "gappability"/"ingappablity") criteria for non-chiral conformal field theories with parity symmetry that may emerge as an edge state of a symmetry-protected topological phase. A necessary ingredient, as it turns out, is to consider the edge conformal field theories on unoriented surfaces, such as the Klein bottle, which arises naturally from enforcing parity symmetry by a projection operation.

Floquet Topological Spin Liquid in a Driven Kitaev Honeycomb Model

Sato, Masahiro
(Aoyama Gakuin University, Department of Physics and Mathematics, Sagamihara, Japan)

Recently theoretical studies of periodically-driven quantum states have made much progress [1-6]. This is mainly because it becomes widely recognized that such a nonequilibrium system can be reduced to an effective static system by using Floquet theory. Through the mapping, we can apply various theoretical techniques for static systems. In the experimental side, the laser science of manipulating quantum states is rapidly developed and it gradually becomes possible to realize various nonequilibrium states by using laser [3].

Theoretical studies for driven many-body systems have concentrated on non-interacting fermion systems so far. For instance, a theoretical study [1,2] shows that when a circularly polarized laser is applied to two-dimensional (2D) Dirac electron systems on lattices, a topologically-insulating state with a gapless chiral edge mode emerges. Furthermore, experimental signatures of laser-driven electron states in band-insulating materials have been reported very recently [3].

On the other hand, nonequilibrium states in strongly correlated many-body systems are still open. We are therefore exploring novel nonquilibrium phenomena in correlated systems. In particular, we are focusing on quantum antiferromagnets [4,6] and multiferroic models [5], which are typical simple models for strongly correlated systems in solid. In this conference, we would like to discuss one of our recent results for a laser-driven topological state [6] in the Kitaev honeycomb lattice model [7] that is a low-energy effective model for Mott insulators with strong spin-orbit interaction [8]. We show that when we apply an elliptically (or circularly) polarized laser to a gapless spin liquid ground state of the Kitaev model with a magnetoelectric coupling between spin exchange and electric polarization, the ground state changes into a topological gapped spin liquid with a gapless chiral edge mode. This edge mode can be viewed as a Majorana edge mode [9] like topological superconductor and its rotating direction can be switched by changing the helicity of the laser. This theoretical result provides the first concrete example for a topological quantum phase transition in strongly correlated systems.

I will discuss the above result for the Kitaev model in detail in the conference.

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Supersymmetric quantum wires

Schoutens, Kareljan
(University of Amsterdam, Institute for Theoretical Physics, Faculty of Science, Amsterdam, Netherlands)

We explore supersymmetric lattice models for charges on a 1-D chain, subject to an exclusion rule that allows up to k particles on neighboring sites. The order-k clustering property turns out to be similar to the clustering property of electrons in a $nu={k over k+2}$ Read-Rezayi fractional quantum Hall state. In particular, the two systems are both linked to the number k minimal model of $N=2$ superconformal field theory (SCFT).

Interplay of topological order and symmetry breaking

Schulz, Marc Daniel
(University of Minnesota, College of Science and Engineering, School of Physics and Astronomy, Minneapolis, MN, USA)

We consider the string-net model on the honeycomb lattice for Ising anyons in the presence of different string tensions.
The resulting phase diagram includes several phases, including phases harboring Abelian and non-Abelian anyons as well as different topologically trivially phases.

We investigate the location and critical properties of phase transitions between these phases by means of high-order series expansions and exact diagonalizations.
Different phase transitions of first and second order are found, including different second-order transitions out of the non-Abelian topological phase.

From solitons to Majorana bound states in a one-dimensional interacting model

Seabra, Luis
(Technion - Israel Institute of Technology, Physics Department, Physics Department, Haifa, Israel)

The effects of interactions on topological systems is one of the most active research topics in condensed matter physics. Here, we investigate the Creutz ladder model, a one-dimensional fermionic system which supports zero-energy solitonic modes locked to open ends. Augmenting the model with induced superconducting pairing leads either to a topological superconductor with edge Majorana bound states, or to a trivial superconductor with edge chiral bound states. We establish the stability of these phases in the presence of Hubbard repulsive interactions with matrix-product-state DMRG calculations and mean-field theory. While interactions leave the Majorana states intact, the edge chiral states are removed, revealing another topologically non-trivial phase.

Anyonics: Designing exotic circuitry with non-Abelian anyons

Shtengel, Kirill
(University of California, Riverside, Department of Physics and Astronomy, Riverside, USA)

Non-Abelian anyons are widely sought for the exotic fundamental physics they harbour as well as for their possible applications for quantum information processing. Currently, there are numerous blueprints for stabilizing the simplest type of non-Abelian anyon, a Majorana zero energy mode bound to a vortex or a domain wall. One such candidate system, a so-called "Majorana wire" can be made by

judiciously interfacing readily available materials; the experimental evidence for the viability of this approach is presently emerging.
Following this idea, we introduce a device fabricated from conventional fractional quantum Hall states, s-wave superconductors and insulators with strong spin-orbit coupling. Similarly to a Majorana wire, the ends of our “quantum wire” would bind "parafermions", exotic non-Abelian anyons which can be viewed as fractionalised Majorana zero modes.
I will discuss their properties and describe how such parafermions can be used to construct new and potentially useful circuit elements which include current and voltage mirrors, transistors for fractional charge currents and "flux capacitors".

More about entanglement spectra of fractional quantum Hall states

Simon, Steve
(University of Oxford, Oxford, United Kingdom)

Topological Matter and Why You Should Be Interested

Simon, Steve
(University of Oxford, Oxford, United Kingdom)

In two dimensional topological phases of matter, processes depend on gross topology rather than detailed geometry. Thinking in 2+1 dimensions, particle world lines can be interpreted as knots or links, and the amplitude for certain processes becomes a topological invariant of that link. While sounding rather exotic, we believe that such phases of matter not only exist, but have actually been observed in quantum Hall experiments, and could provide a uniquely practical route to building a quantum computer. Possibilities have also been proposed for creating similar physics in systems ranging from superfluid helium to strontium ruthenate to semiconductor-superconductor junctions to quantum wires to spin systems to cold atoms.

Non-abelian physics between one and two dimensions

Stern, Ady
(Weizmann Institute, Condensed Matter Physics, Rehovot, Israel)

In my talk I will discuss non-abelian defects on the edge of a bi-layer electron-hole system in the fractional quantum Hall regime. I will examine what happens to these defects as the system is deformed to being quasi one dimensional. In particular, I will search for aspects of non-abelian statistics that survive the reduction to one dimension.

Wire deconstructionism of topological phases

Thomale, Ronny
(Universität Würzburg, Theoretische Physik 1, Würzburg, Germany)

A scheme is proposed to classify integer and fractional topological quantum states of fermions in two spatial dimensions. We devise models for such states by coupling wires of non-chiral Luttinger liquids of electrons, that are arranged in a periodic array. Which inter-wire couplings are allowed is dictated by symmetry and the compatibility criterion that they can simultaneously acquire a finite expectation value, opening a spectral gap between the ground state(s) and all excited states in the bulk. First, with these criteria at hand, we reproduce the tenfold classification table of integer topological insulators, where their stability against interactions becomes immediately transparent in the Luttinger liquid description. Second,

we expand the table to long-range entangled topological phases with intrinsic topological order and fractional excitations.

Interacting electronic topological insulators in 3 dimensions

Todadri, Senthil
(Massachusetts Institute of Technology, Physics, Cambridge, USA)

I will describe recent progress in understanding interacting SPT phases of spin-orbit coupled insulators in three dimensions. The Z2 classification of such insulators in band theory is modified to a Z2^3 classification with interactions. I describe the properties of the corresponding 8 distinct insulators. If time permits I will describe other interacting electronic insulating/SPT phases with other symmetries in 3d.

Symmetry-protected topological Mott insulators of ultra-cold fermions in one dimension --entanglement and non-local order parameters

Totsuka, Keisuke
(Kyoto University, Yukawa Institute for Theoretical Physics, Kyoto, Japan)

There are a variety of states of matter called "topological", that defy the traditional Landau-type description. Among them, a class of topological phases, now dubbed "symmetry-protected topological (SPT)", is stable only in the presence of certain symmetries (e.g., time-reversal, reflection, space groups). In this talk, I show how various SPT phases appear in SU(N)-symmetric ultra-cold alkaline-earth fermions on an optical lattice in 1D and characterize these phases by using entanglement spectrum and other methods. Specifically, on top of the nuclear SU(N), we introduce two orbital degrees of freedom either by picking up two atomic states (1S0 and 3P0) or by using p-bands. The phase diagram of the two-orbital SU(N) fermion model at half-filling is mapped out [2,3,4] using weak-coupling bosonization, DMRG, strong-coupling expansion, etc. to find several featureless topological phases as well as conventional symmetry-broken phases (e.g. CDW, spin-Peierls, etc.). Then, we investigate [3,4] the nature of the new SU(N) topological phase by using the parent-Hamiltonian appraoch and spectroscopy of entanglement spectrum. Last, we explicitly construct [4] a set of string order parameters which distinguishes between the N different SPT phases. An interesting connection between the group-cohomology approach to SPT and the characterization by non-local (string) order parameters will be discussed as well.

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Quantum spin liquids and Majorana metals

Trebst, Simon
(University of Cologne, Institute for Theoretical Physics, Köln, Germany)

One of the most intriguing phenomena in strongly correlated systems is the fractionalization of quantum numbers — familiar examples include the spin-charge separation in one-dimensional metallic systems, the fractionalization of the electron in certain quantum Hall states or the emergence of monopoles in spin ice.

In this talk, I will discuss the fractionalization of magnetic moments in a certain class of Mott insulators, in which the emergent degrees of freedom are Majorana fermions that form an (almost) conventional metal. The origin of such a dichotomous state is elucidated by a family of exactly solvable models of frustrated quantum magnets in three dimensions, which might be realized in a class of recently

synthesized Iridate compounds. These models thereby provide the first analytical tractable examples of long sought-after quantum spin liquids with a spinon Fermi surface and even an entire new class of quantum spin liquids — a Weyl spin liquid, in which the fractionalized degrees of freedom form a topological semi-metal.

Infinite-dimensional-matrix product states from conformal field theories

Tu, Hong-Hao
(Max Planck Insititute for Quantum Optics, Theory Division, Garching, Germany)

We propose 1D and 2D lattice wave functions constructed from the SU(n)_1 and SO(n)_1 Wess-Zumino-Witten models. These states can be defined in both 1D and 2D lattices and their parent Hamiltonians are derived systematically using CFT techniques. In 1D, the parent Hamiltonians are long-ranged Haldane-Shastry-type models. In 2D, the wave functions describe chiral topological states. For SU(n) spins in 2D lattices transform under SU(n) fundamental representations, we show that the wave functions converge to a class of Halperin's multilayer fractional quantum Hall states. For the 2D SO(n) wave functions, we show that they can be viewed as projected p+ip states and support Kitaev's 16-fold way of anyonic properties.

Spin Fluctuations and Entanglement

Turner, Ari
(Johns Hopkins U., Physics and Astronomy, Baltimore, MD, USA)

I will compare the effects of quantum and thermal fluctuations in a spin chain by calculating the probability distribution for spin fluctuations in a segment.

The calculation will use the concept of an "entanglement Hamiltonian." It is an imaginary system that describes the correlations of the ground state. It cannot be measured directly, but it is related to the statistics of the fluctuations, so measuring the spin fluctuations of the atoms on the sites of an optical lattice is an indirect way of measuring the entanglement Hamiltonian.

Fibonacci Anyons From Abelian Bilayer Quantum Hall States

Vaezi, Seyyed Mir Abolhassan
(Cornell University, Physics, Ithaca, USA)

The possibility of realizing non-Abelian statistics and utilizing it for topological quantum computation (TQC) has generated widespread interest. However, the non-Abelian statistics that can be realized in most accessible proposals is not powerful enough for universal TQC. In this talk, I consider a simple bilayer fractional quantum Hall (FQH) system with the 1/3 Laughlin state in each layer, in the presence of interlayer tunneling. I show that interlayer tunneling can drive a continuous phase transition to an exotic non-Abelian state that contains the famous `Fibonacci' anyon, whose non-Abelian statistics is powerful enough for universal TQC. The analysis towards this result rests on startling agreements from a variety of distinct methods, including thin torus limits, effective field theories, and coupled wire constructions. The charge gap remains open at the transitions while the neutral gap closes. This raises the question of whether these exotic phases may have already been realized at nu=2/3 in bilayers, as past experiments may not have definitively ruled them out. I finally discuss the global phase diagram at total filling fraction nu= 2/3, which, including the results of previous works, now includes several distinct non-Abelian FQH states.

Ground state degeneracy of non-Abelian topological phases with boundaries

Wan, Yidun
(Perimeter Institute for Theoretical Physics , Waterloo, Canada)

In this talk, we shall study the ground state degeneracy of non-Abelian topological phases in 2+1 dimensions with two or multiple boundaries. To this end, we generalize the Laughlin-Wu-Tao argument and extend the concept of Lagrangian subset to the non-Abelian case, via the method of anyon condensation. We show that a particular boundary condition/type corresponds to a particular anyon condensation, and that the ground state degeneracy with the boundary condition coincides with the number of confined particles due to the anyon condensation.

The universal SPT invariants and SPT states beyond group cohomology

Wen, Xiao-Gang
(Perimeter Institute for Theoretical Physics, Waterloo, USA)

I plan to describe some recent progresses in topological order and SPT order, such as algebraic topology approach and their realizations.

Interacting Weyl semimetals: characterization via the topological Hamiltonian and its breakdown

Witczak-Krempa, William
(Perimeter Institute for Theoretical Physics, Waterloo, Canada)

Weyl semimetals (WSMs) constitute a 3D phase with linearly-dispersing Weyl-like excitations at low energy. Unusual properties arise from the latter, such as anomalous electrodynamic responses and open Fermi arcs on boundaries. We derive a simple criterion to identify and characterize WSMs in an interacting setting using the exact electronic Green's function at zero frequency, which defines a topological Bloch Hamiltonian. We apply this criterion by numerically analyzing, via cluster and other methods, interacting lattice models with and without time-reversal symmetry. We thus identify various mechanisms for how interactions move and renormalize Weyl fermions. Our methods remain valid in the presence of long-ranged Coulomb repulsion, although the latter destroys the Weyl quasiparticles. Finally, we introduce a WSM-like phase for which our criterion breaks down, due to fractionalization of the electron.
http://arxiv.org/abs/1406.0843

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Violation of Entanglement Area Law in Fermionic and Bosonic Systems

Yang, Kun
(Florida State University, Physics Department, Tallahassee, USA)

Entanglement is perhaps the most counter-intuitive aspect of quantum mechanics, and provides the sharpest distinction between quantum and classical descriptions of nature. The most widely used measure of entanglement is the entanglement entropy. For extended quantum systems, ground states of all gapped local Hamiltonians, as well as a large number gapless systems, are known to follow the so called ”area law”, which states that the entanglement entropy is proportional to the surface area of the subsystem. However, violations of the area law, usually in a logarithmic fashion, do exist in various systems. They are found to be associated with quantum criticality in certain one dimensional systems. Until recently the only established examples of such violation in higher dimensions are free fermion ground states with Fermi surfaces, where it is found that the area law is enhanced by a logarithmic factor. In Ref. [1], we explored the relation between logarithmic divergence in one-dimensional
fermionic systems and that of free fermions in higher dimensions. We showed that both logarithmic factors share the same origin - the singularity at the Fermi points or Fermi surface. We then make use of the tool of multi-dimensional bosonization to re-derive the entanglement entropy of free

fermions in high dimensions in a simpler way. Furthermore the bosonization technique allows us to take into account the Fermi liquid interactions, and obtain the leading scaling behavior of the entanglement entropy of Fermi liquids. The central result of our work is that Fermi liquid interactions do not alter the leading scaling behavior of the entanglement entropy, and the logarithmic enhancement of area law is a robust property of the Fermi liquid phase.

In sharp contrast to the fermioic systems with Fermi surfaces, quantum critical (or gapless) bosonic systems do not violate the area law above 1D (except for the case discussed below). The fundamental difference lies in the fact that gapless excitations live near a single point (usually origin of momentum space) in such bosonic systems, while they live around an (extended) Fermi surface in Fermi liquids. In Ref. [2], we studied entanglement properties of some specific examples of the so called Bose metal states, in which bosons neither condense (and become a superfluid) nor localize (and insulate) at T=0. The system supports gapless excitations around ``Bose surfaces", instead of isolated points in momentum space. We showed that similar to free Fermi gas and Fermi liquids, these states violate the entanglement area law in a logarithmic fashion. Our results demonstrate that perhaps area-law violation in high dimensions is more common than previously thought; in particular the existence of Fermi surface(s) is not a prerequisite for it.

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Emergent space-time supersymmetry in 3+1D Weyl and 2+1D Dirac semimetals

Yao, Hong
(Tsinghua University, Institute for Advanced Study, Beijing, China, People's Republic of)

We introduce a new class of superconductors (SCs) in two spatial dimensions with time reversal symmetry and reflection (i.e., mirror) symmetry. In the absence of interactions, topological classes of these SCs are distinguished by an integer-valued ($mathbb{Z}$) topological invariant. When interactions are included, we show that the topological classification is modified to $mathbb{Z}_8$. This clearly demonstrates that interactions can have qualitative effect on topological classifications of gapped states of matter in more than one dimension.

Tunable symmetry breaking and helical edge transport in a graphene quantum spin Hall state

Young, Andrea
(Massachusetts Institute of Technology ,)

I will discuss experiments on charge neutral monolayer graphene at high magnetic fields, in which the electron system can be made to display a quantum spin Hall (QSH) effect. Unlike the case of time reversal symmetry topological insulators, the QSH presented here is protected by a spin-rotation symmetry that emerges as electron spins in a half-filled Landau level are polarized by the combination of a large in-plane magnetic field and their mutual interactions. The properties of the resulting helical edge states can be modulated by balancing the applied field against an intrinsic antiferromagnetic instability, which tends to spontaneously break the spin-rotation symmetry. In the resulting canted antiferromagnetic (CAF) state, we observe transport signatures of gapped edge states, which constitute a new kind of one-dimensional electronic system with tunable band gap and associated spin-texture.

Towards a full measurement of symmetry fractionalization with applications to the

Kagome quantum spin liquid

Zaletel, Michael
(University of California, Berkeley, Department of Physics, Physics, Berkeley, USA)

In addition to braiding and statistics, topological phases can be more finely distinguished by the action of symmetries on the anyons. For many spin liquids, the action of time reversal and SU(2) is fixed, and the interesting symmetries are the crystal symmetries of the lattice. For example, even if the Kagome Heisenberg spin liquid observed in recent numerics is indeed a Z_2 spin liquid, there are a number of competing proposals, such as the zoo of bosonic and fermionic parton constructions, which differ in their realization of the crystal symmetries.
These distinctions have important consequences for the edge states, neighboring ordered phases, and spinon spectra.
I will explain how to measure what type of 2D spin liquid you've discovered given data available to finite and infinite DMRG, with preliminary applications to the Kagome Heisenberg model.

Unexpected pairing of electrons in the IQHE regime

Moty Heiblum

Electron pairing is a rare phenomenon appearing only in a few unique physical systems, such as superconductors or Kondo-correlated quantum-dots. Here, we report on an unexpected 'pairing' of electrons in the integer-quantum Hall effect (IQHE) regime. The pairing takes place in the interfering most outer edge channel within an electronic Fabry-Perot interferometer at a bulk filling factor $\boldsymbol{\nu_B} > \mathbf{2}$. We note three clear observations: (a) Aharonov-Bohm oscillations with magnetic-flux periodicity $\boldsymbol{\phi_0^*} = \frac{\boldsymbol{h}}{\mathbf{2}\boldsymbol{e}}$, with $\boldsymbol{e}$ the electron charge and $\boldsymbol{h}$ Planck's constant; (b) An interference charge $\boldsymbol{e}^* \sim \mathbf{2}\boldsymbol{e}$ - revealed by shot noise measurements; and (c) Entanglement between the two most outer edge channels. While the exact mechanism of the pairing is not understood, we show that this unique phenomenon results from inter-edge channels interactions.