New Frontiers:
Interactions between
Quantum Physics and Mathematics

June 20-23, 2022

American Academy of Arts and Sciences, June 20

Harvard University, Jefferson Laboratory, June 21–23

Cambridge, Massachusetts

*** If you any questions or need assistance, please call Crystal Stillman at 617-495-2895 or email cstillman@fas.harvard.edu.

New Frontiers: Interactions between Quantum Physics and Mathematics

		Monday June 20: American Academy	Tuesday, June 21: Jefferson 250	Wednesday, June 22: Jefferson 250	Thursday, June 23: Jefferson 250
8:15		*coffee-breakfast*	*coffee-breakfast*	*coffee-breakfast*	*coffee-breakfast*
8:45		**Jaffe, Myers, Stubbs**			
	chair	**Bert Halperin**	**Zhenghan Wang**	**Dietmar Bisch**	**Andrei Ruckenstein**
9:00	talk	**Mikhail Lukin**	**Michael Freedman**	**Peter Shor**	**Hari Arthanari**
9:30	discussion				
9:35	talk	**Zhenghan Wang**	**Jiaoyang Huang**	**Zhengwei Liu (r)**	**Elchanan Mossel**
10:05	discussion				
10:15		*coffee*	*coffee*	*coffee*	*coffee*
10:45	talk	**Roberto Longo**	**Yury Polyanskiy**	**Shawn Cui**	**Marius Junge**
11:15	discussion				
11:20	talk	**Xiao-Gang Wen**	**Yasu Kawahigashi**	**Julia Plavnik**	**Nilanjana Datta**
11:50	discussion				
12:00		*lunch*	*lunch*	*lunch*	*lunch*
	chair	**Zhenghan Wang, Mikhail Lukin**	**Renato Renner**	**Pavel Etingof**	
1:30	talk	**Renato Renner**	**Leonard Susskind (r)**	**Victor Ostrik**	
2:00	discussion				
2:05	talk	**Hans Wenzl**	**Guoliang Yu**	**Kaifeng Bu**	
2:35	discussion				
2:45		*coffee*	*coffee*	*coffee*	
3:15	talk	**Daniel Loss**	**Steven Flammia**	**Jun Yang**	
3:45	discussion				
3:50	talk	**Problems: Seth Lloyd, Michael Freedman, Pavel Etingof**	**Dave Penneys**	**Aram Harrow**	
4:20	discussion				
4:45		*Welcome Reception**	**Edward Farhi**	**Terry Gannon**	
6:00		Concert* **Ya-Fei Chuang**	*Conference Banquet**		

**Registration with Crystal Stillman required.*

Monday, June 20, American Academy of Arts and Sciences

8:45 Conference Welcome: Arthur Jaffe, Harvard University
Joe Myers, US Army Research Laboratory
Christopher Stubbs, Harvard University

Morning Session Chair: Bert Halperin

9:00 Mikhail Lukin, Harvard University

Exploring new scientific frontiers using programmable atom arrays

We will discuss the recent advances involving programmable, coherent manipulation of quantum many-body systems using neutral atom arrays excited into Rydberg states, allowing the control of over 200 qubits in two dimensions. These systems can be used for realization and probing of exotic quantum phases of matter and exploration of their non-equilibrium dynamics. Recent advances involving the realization and probing of quantum spin liquid states —the exotic topological states of matter have thus far evaded direct experimental detection— and the observation of quantum speedup for solving optimization problems will be described. In addition, the realization of novel quantum processing architecture based on dynamically reconfigurable entanglement and the steps towards quantum error correction will be presented. Finally, we will discuss prospects for using these techniques for realization of large-scale quantum processors.

9:35 Zhenghan Wang, Microsoft

Spaces of Hamiltonians, symmetries of topological order, and Floquet codes

Given a topological order, there should be a space of gapped physical Hamiltonians that realize this topological order. In two spatial dimensions, we conjecture that the space of Hamiltonians behaves like the classifying space of the categorical symmetry group of an anyon model. Nontrivial loops of the Hamiltonian space can be used to explain the new Floquet quantum error correction codes. This talk is based on the joint work with Aasen and Hastings arxiv:2203.11137.

10:15 Break

10:45 Roberto Longo, University of Rome Tor Vergata

Entropy and the modular Hamiltonian

I present the key concept of entropy of a vector in a complex Hilbert space with respect to a real linear subspace. The entropy is related to the Tomita-Takesaki modular theory. I compute the local entropy of a classical or quantum wave packet in certain cases. If time permits, I will explain the relation with the quantum energy inequalities.

11:20 Xiao-Gang Wen, MIT

Phases and Phase transition from categorical symmetry

We study possible phases and possible continuous phase transitions in 1+1D systems with a given finite symmetry. We use the corresponding categorical symmetry and its condensable algebras to classify the possible gapped phases and possible gapless critical points, as well as determine the CFT of the critical points.

12:00 Lunch

Afternoon Session Chair: Mikhail Lukin, Zhenghan Wang

1:30 Renato Renner, ETH Zurich

A quantum information perspective on black holes

Recent calculations based on gravitational path integrals provide strong support for the hypothesis that the entropy of Hawking radiation follows the Page curve, indicating that the underlying time evolution is unitary (and thus in principle reversible). In this talk I will revisit these calculations from a quantum information-theoretic perspective. Specifically, I will show that the quantum de Finetti theorem can provide insights on the precise nature of the entropy measure that is actually computed by gravitational path integrals. One of the conclusions is that this entropy is best understood as the regularised joint entropy of the radiation emitted by a collection of many identical black holes, rather than the entropy of the radiation emitted by a single black hole. There is evidence that the latter is strictly larger than the former. This would imply that the Hawking radiation emitted by multiple black holes is correlated, even if they were prepared independently.

2:05 Hans Wenzl, University of California, San Diego

Module Categories for WZW-Models

Non-exceptional module categories are obtained via orbifolds and Dynkin diagram automorphisms, such as charge conjugation. We propose a rigorous construction and explicit description of such categories in general via q-deformations of embeddings of Lie groups. This would allow for a conceptual description of algebras and fusion rules for such module categories. This program has already been successfully carried out for many cases in type A and is consistent with various checks for other Lie types. This talk is based in part on joint work with Cain Edie-Michell.

2:45 Break

3:15 Daniel Loss, University of Basel

From Fractional Spin to Topological Magnons

Topological quantum matter with exotic excitations has attracted a lot of attention in recent years, prime examples being states with fractional charges and non-abelian braiding statistics that hold promise for topological quantum computation. The focus has been mostly on systems with itinerant particles. In this talk I will present some extensions to insulating spin systems such as spin ladders and show that such systems in the presence of strong interactions can host excitations that carry fractional spin 1/n with n odd. The presence of these excitations can be seen in the magnetization behavior and gives rise to fractional spin conductances in units of (1/n)(gmu_B)^2/h (in analogy to the quantum Hall conductance (1/n)e^2/h in charged systems).

3:50 Open Questions Session: Seth Lloyd, MIT
Michael Freedman, Microsoft
Pavel Etingof, MIT

4:45 Reception in Lobby

6:00 Ya-Fei Chuang piano concert

Tuesday, June 21, Harvard University, Jefferson Laboratory 250

Morning Session Chair: Zhenghan Wang

9:00 Michael Freedman, Microsoft

Smallest Interacting Universe

I will explain a spontaneous symmetry breaking which picks out a tensor decomposition on a finite dimensional Hilbert space and interpret this as creating many particles from one. This was work with Modj Shokrian-Zini. Then with Adam Brown, we considered the simultaneous emergence of a preferred initial state. This package is really a small interacting universe.

9:35 Jiaoyang Huang, Courant Institute, NYU

Random Matrix Statistics

The success of random matrices in modeling physical systems lies in the universality phenomenon of their eigenvalue statistics. The general belief is for systems with a lot of independence, we expect to see the Gaussian distribution. However, for systems with many strongly interacting components, we expect to see random matrix statistics. In this talk, I will first discuss some background concerning random matrix statistics. Beyond matrix setting, random matrix statistics are conjectured to govern the asymptotic behavior of various random growth models and interacting particle systems. However, this was only proven for some exactly solvable models. I will discuss a general strategy to prove the universality of random matrix statistics, and our recent result proving that for random lozenge tilings of polygons, the scaling limit of the extreme path is given by random matrix statistics.

10:15 Break

10:45 Yury Polyanskiy, MIT

Information propagation in low dimensions

In this talk we will survey some old and new results (and conjectures) about information propagation in 1D, 2D and 3D. An example of the result is the following. Consider a 2D square lattice with edges oriented away from the origin and represent noisy communication channels (for simplicity, suppose that the flip the input bit with a small probability δ). At time 0 an information bit gets broadcasted from the origin and an ``information wave'' starts spreading with each node processing its incoming (one or two messages) and broadcasting a function of it along its (one or two) outgoing edges. We show that for any arbitrarily small δ and any choice of the broadcasting functions, the information contained in the wavefront is vanishing. On the contrary, in 3D we conjecture that information is retained indefinitely.

11:20 Yasuyuki Kawahigashi, University of Tokyo

A characterization of a finite-dimensional commuting square producing a subfactor of finite depth

We give a characterization of a finite-dimensional commuting square with a normalized trace that produces a hyperfinite type II_1 subfactor of finite index and finite depth in terms of Morita equivalence of fusion categories. This type of commuting squares were studied by N. Sato, and we show that a slight generalization of his construction covers the fully general case of such commuting squares. We also give a characterization of such a commuting square that produces a given hyperfinite type II_1 subfactor of finite index and finite depth. These results also give a characterization of certain 4-tensors appearing in recent studies of matrix product operators in 2-dimensional topological order in condensed matter physics.

12:00 Lunch

Afternoon Session Chair: Renato Renner

1:30 Leonard Susskind, Stanford University (remote)

Infinite Temperature's not so hot.

I will explain how the double-scaled limit of the SYK theory describes de Sitter space.

2:05 Guoliang Yu, Texas A&M University

An index theorem for manifolds with corners and scalar curvature rigidity

In this talk, I will discuss an index theorem for manifolds with corners and its application to Gromov's dihedral rigidity conjecture on scalar curvature. This is joint work with Jinmin Wang and Zhizhang Xie.

2:45 Break

3:15 Steven Flammia, AWS Center for Quantum Computing

A Constructive Approach to Zauner's Conjecture via the Stark Conjectures

We propose a construction of d^2 complex equiangular lines in C^d, also known as SICs or SIC-POVMs, which were conjectured by Zauner to exist for all d. The construction gives a putatively complete list of SICs with Weyl-Heisenberg symmetry in all dimensions d > 3. Specifically, we give an explicit expression for an object that we call a ghost SIC which is constructed from the real multiplication values of a special function and which is Galois conjugate to a SIC. The special function, which we call the Shintani-Faddeev modular cocycle, is a family of meromorphic functions parameterized by congruence subgroups of SL_2(Z) and may be of independent interest. We prove that our construction gives a valid SIC assuming two conjectures: first, we conjecture that the ghost SIC is idempotent, and second, we require Tate's refinement of the rank-1 abelian Stark conjecture for real quadratic fields. The latter condition allows us to prove that the ghost and the SIC are Galois conjugate over an extension of Q(sqrt{D}) where D = (d+1)(d-3). We provide computational tests of our SIC construction by cross validating it with known exact solutions, with the numerical work of Scott and Grassl, and by constructing four numerical examples of SICs in d=100, three of which are new. We further consider rank-r generalizations of SICs given by equiangular configurations of r-dimensional complex subspaces, known also as MEFFs (maximal equichordal tight fusion frames). We give similar conditional constructions for MEFFs for all r, d such that r(d-r) divides (d^2-1). Finally, we study the structure of the field extensions conjecturally generated by the SICs and MEFFs. If K is any real quadratic field, then either every ray class field over K, or else every ray class field for which 2 is unramified, is generated by our construction.

3:50 Dave Penneys, Ohio State University

Composing topological domain walls and anyon mobility

We study the concatenations of topological domain walls and their decompositions into superselection sectors. Our approach uses a description of particle mobility across domain walls in terms of tunneling operators. These are formalized in a 3-category of (2+1)D topological orders with a fixed anomaly described by a unitary modular tensor category A, algebraically characterized by the 3-category of A-enriched unitary fusion categories. This is joint work with Fiona Burnell, Peter Huston, and Corey Jones.

4:45 Edward Farhi, MIT

An overview of the Quantum Approximate Optimization Algorithm

I will review recent progress in understanding the performance of the QAOA.

6:00 Conference Banquet at the Fly Club (for registered guests)

Wednesday, June 22, Harvard University, Jefferson Laboratory 250

Morning Session Chair: Dietmar Bisch

9:00 Peter Shor, MIT

Quantum Money

Quantum money is a quantum cryptographic protocol that allows for the creation of verifiable but uncopyable states. The requirements are A) One player (the mint) must be able to produce a quantum money state, along with a serial number. B) The serial number gives a verification test, and the quantum money state must pass this test with very high probability. C) If some aspiring counterfeiter has the quantum money state and knows the verification test, they cannot create two quantum states that both pass the verification test. Quantum money was first proposed in 2009. Since then, several protocols for quantum money have been proposed. We will discuss these protocols, and give a new protocol based on the difficulty of finding short vectors in lattices.

9:35 Zhengwei Liu, Tisnghua University and BIMSA (remote)

Quantum Fourier Analysis for Quantum Channels

Fourier Analysis has been widely used in classical information processing. We investigate quantum Fourier analysis and its application to quantum information processing. In this talk, we will analyze the Fourier duality of quantum channels and study the fixed points of a quantum channel, beginning with a quantization of the Perron-Frobenius theorem. We will discuss its application to quantum error correction.

10:15 Break

10:45 Shawn Cui, Purdue University

Trisection invariants of 4-manifolds from Hopf algebras

The Kuperberg invariant is a topological invariant of closed 3-manifolds based on finite-dimensional Hopf algebras. Here we initiate the program of constructing 4-manifold invariants in the spirit of Kuperberg's 3-manifold invariant. We utilize a structure called a Hopf triplet, which consists of three Hopf algebras and a bilinear form on each pair subject to certain compatibility conditions. In our construction, we present 4-manifolds by their trisection diagrams, a four-dimensional analog of Heegaard diagrams. The main result is that every Hopf triplet yields a diffeomorphism invariant of closed 4-manifolds. In special cases, our invariant reduces to Crane-Yetter invariants and generalized dichromatic invariants, and conjecturally Kashaev's invariant. As a starting point, we assume that the Hopf algebras involved in the Hopf triplets are semisimple. Time permitting, we also sketch an ongoing effort to generalize the invariant using non-semisimple Hopf algebras.

11:20 Julia Plavnik, Indiana University, Bloomington

Zesting, condensation and gauging as quantum symmetries

In this talk, we will present the zesting construction for modular categories. Zesting was first introduced in 2012 and further developed for applications to fermionic theories in 2016. We will give some examples and properties of this construction and, if time permits, we will compare it with other constructions of modular categories like gauging and condensation.

12:00 Lunch

Afternoon Session Chair: Pavel Etingof

1:30 Victor Ostrik, University of Oregon

Frobenius exact symmetric tensor categories.

I will report on a joint work with K.Coulembier and P.Etingof. We give a characterization of symmetric tensor categories over fields of positive characteristic which admit an exact tensor functor to the Verlinde category; in particular we give a characterization of Tannakian categories similar to characterization by Deligne and Doplicher-Roberts in characteristic zero. A crucial ingredient of this characterization is exactness of the Frobenius twist functor which mimics the Frobenius twist for representations of algebraic groups.

2:05 Kaifeng Bu, Harvard University

Quantum circuit complexity and quantum resource

Quantum circuit complexity—a measure of the minimum number of gates needed to implement a given unitary transformation—is a fundamental concept in quantum computation, with widespread applications ranging from determining the running time of quantum algorithms to understanding the physics of black holes. In this talk, we will talk about the complexity of quantum circuits via different quantum resource.

2:45 Break

3:15 Jun Yang, Harvard University

The Plancherel Measure of an Adelic Group is the von Neumann Dimension

For a number field F and a simply connected semisimple F-group G, we prove that the Plancherel measure of the adelic group G(A_F) is the von Neumann dimension over G(F).

3:50 Aram Harrow, MIT

Quantum walks on hierarchical graphs

There are few known exponential speedups for quantum algorithms and these tend to fall into even fewer families. One speedup that has mostly resisted generalization is the use of quantum walks to traverse the welded-tree graph, due to Childs, Cleve, Deotto, Farhi, Gutmann, and Spielman. We show how to generalize this to a large class of hierarchical graphs in which the vertices are grouped into a d-dimensional lattice of "supervertices." Supervertices can have different sizes, and edges between supervertices correspond to random connections between their constituent vertices. The hitting times of quantum walks on these graphs is mapped to the localization properties of zero modes in certain disordered tight binding Hamiltonians. The speedups range from superpolynomial to exponential, depending on the underlying dimension and the random graph model.

4:45 Terry Gannon, University of Alberta

Exotic quantum subgroups for any Lie algebra

In 1986, Cappelli-Itzykson-Zuber classified the conformal field theories built from affine sl(2), finding an A-D-E pattern. In modern language, these are the module categories for sl(2) quantum groups at roots of unity. The hardest part of this classification is determining the module categories of extension type, corresponding to the extensions of sl(2) vertex operator algebras; these are called the sl(2) quantum subgroups. The same questions can be asked for any simple Lie algebra, although only for sl(3) do we have published proofs -- Ocneanu has announced without details the results for a couple other algebras. In this talk I introduce the problem, and then establish for any Lie algebra a bound growing like the rank-cubed; when the root of unity has order beyond that bound, any quantum subgroup will be trivial (of simple-current type). I then use this to classify all quantum subgroups for all Lie algebras of rank less than 7.

Thursday, June 23, Harvard University, Jefferson Laboratory 250

Morning Session Chair: Andrei Ruckenstein

9:00 Hari Arthanari, Harvard Medical School/DFCI

Emerging frontiers in computational drug discovery

The most common form of drug discovery involves finding a small molecule that binds to the Achilles heel of a biomolecule (protein/nucleic acid) and inhibits its function in a disease state. The binding strength, also known as affinity, is dictated by the laws of thermodynamics. The tighter the binding of the small molecule to its target biomolecule, the lower the dose that is required, thus fewer side effects. Though we can deconvolute and computationally calculate the individual thermodynamic parameters that are involved in the process of the small molecule engaging the target, the computational costs associated with the process preclude the application to a large library of molecules, to find the needle in the haystack. We have developed an open-source platform VirtualFlow that harnesses the power of computing clusters to screen ultra-large libraries of druglike molecules, thus compensating for the inaccuracies in a simplified and computationally fast docking algorithm, based on classical physics. We will present the architecture of the platform and some examples of therapeutic use cases with experimental validation.

9:35 Elchanan Mossel, MIT

Variations of Hyper-contraction

Hypercontractive inequalities are a fundamental analytical tool. I will survey some recent variations and their (classical) applications.

10:15 Break

10:45 Marius Junge, University of Illinois at Urbana-Champaign

Entropy decay in large open systems

From a physical point of view our estimates describe the return to equilibrium after an electric field acting on an array of particles is turned off. Mathematically, we show concentration inequalities (a la Talagrand) for matrix valued functions on compact Lie groups with respect to sublaplacians. We also indicate why quantum information theoretical formulations naturally lead to larger function spaces typically considered in noncommutative geometry. This is joint work with Haojian Li, Li Gao, Nick LaRacuente and Yidong Chen.

11:20 Nilanjana Datta, University of Cambridge

Universal proofs of entropic continuity bounds via majorization flow

We employ majorization theory to obtain a powerful tool for deriving simple and universal proofs of continuity bounds for various entropies which are relevant in information theory. In obtaining this, we first state a more general result which may be of independent interest: a necessary and sufficient condition under which a state maximizes a concave, continuous, Gateaux-differentiable function in an epsilon-ball in trace distance. Examples of such a function include the von Neumann entropy, Renyi entropies, and the conditional entropy. In particular, by introducing a notion of majorization flow, we prove that the alpha-Rényi entropy is Lipschitz continuous, for alpha > 1, thus resolving an open problem and providing a substantial improvement over previously known bounds. This is joint work with Eric Hanson.

12:00 Lunch

END OF CONFERENCE