Workshop on the Frontiers of Quantum Information and Computer Science

College Park Marriott and Conference Center
3501 University Blvd., East Hyattsville, Maryland 20783

All speaker sessions will be held in the Chesapeake Ballroom, Salon C

Lunch will be in the Patuxent Room

The poster session on Wednesday, September 30 will be held 2–5 p.m. in the Computer and Space Sciences Building, room 3100, College Park, Maryland 20742

Monday, September 28

8–9:30 a.m.	Registration/Continental Breakfast
9:30–9:40 a.m.	Opening Remarks
9:40–10:25 a.m.	Robin Kothari- "Quantum Linear Systems Algorithms with Exponentially Improved Dependence on Precision"
10:25–11 a.m.	Coffee Break
11 a.m.–12 p.m.	Seth Lloyd- JQI Seminar: "Universal Deep Quantum Learning"
12–1:30 p.m.	Lunch
1:30–2:15 p.m.	Graeme Smith- "Additivity in Classical and Quantum Shannon Theory"
2:15–3 p.m.	James Whitfield- "Applications of Chemical Group Theory to Quantum Simulation"
3–3:30p.m.	Coffee Break
3:30–4:15 p.m.	Mark Zhandry- "Quantum Query Solvability: A Refinement of Quantum Query Complexity and Applications"
4:15–5 p.m.	Edward Farhi- "A Quantum Approximate Optimization Algorithm"

Tuesday, September 29

8–9:30 a.m.	Registration/Continental Breakfast
9:30–10:15 a.m.	Beni Yoshida- "Classifying Fault-tolerant Logical Gates by Group Cohomology (or SPT Phases)"
10:15–11 a.m.	Coffee Break
11–11:45 a.m.	Jeongwan Haah- "Optimal Tomography of Quantum States"
11:45 a.m.–12:30 p.m.	David Gosset- "Gapped and Gapless Phases of Frustration-free Spin-1/2 chains"
12:30–2 p.m.	Lunch
2–2:45 p.m.	Debbie Leung- "On the Power of PPT-preserving and Non-signalling Codes"
2:45–3:30 p.m.	Steve Flammia- "Sparse Quantum Codes with (Almost) Good Distance"
3:30–4:15 p.m.	Coffee Break
4:15–5 p.m.	Māris Ozols- "Entropy Power Inequalities for Qudits"

Wednesday, September 30

8–9:30 a.m.	Registration/Continental Breakfast
9:30–10:15 a.m.	Michael Bremner- "Average-case Complexity Versus Approximate Simulation of Commuting Quantum Computations"
10:15–11 a.m.	Coffee Break
11–11:45 a.m.	Scott Aaronson- "Black Holes, Firewalls, and the Complexity of States and Unitaries"
11:45 a.m.–12:30 p.m.	Daniel Gottesman- "Stabilizer Codes for Prime Power Qudits"
12:30–2 p.m.	Lunch
2–5 p.m.	Poster Session/Lab Tours

Thursday, October 1

8–9:30 a.m.	Registration/Continental Breakfast
9:30–10:15 a.m.	Lorenza Viola- “Fixed-point Engineering in Quasi-local Open-system Dynamics”
10:15–11 a.m.	Coffee Break
11–11:45 a.m.	Daniel Nagaj- “Very Entangled Spin Chains”
11:45 a.m.–12:30 p.m.	Robin Blume-Kohout- “Gate Set Tomography: 2 Qubits and 10^{-5} Error Bars”
12:30–2 p.m.	Lunch
2–2:45 p.m.	Norbert Schuch- “Topological Phase Transitions in Tensor Networks: A Holographic Perspective”
2:45–3:30 p.m.	Mario Szegedy- “Issues Concerning the Area Law in Quantum Physics”
3:30–4:15 p.m.	Coffee Break
4:15–5 p.m.	Thomas Vidick- “A Multiprover Interactive Proof System for the Local Hamiltonian Problem”

Friday, October 2

8–9:30 a.m.	Continental Breakfast
9:30–10:15 a.m.	Martin Roetteler- “Reversible Circuit Compilation with Space Constraints”
10:15–11 a.m.	Coffee Break
11–11:45 a.m.	Chris Monroe- “Time to Build a Real Quantum Computer”
11:45 a.m.–12:30 p.m.	Aram Harrow- “Local Hamiltonians with No Low-energy Trivial States”
12:30–1:30 p.m.	Lunch

Monday, September 28, 2015

Robin Kothari, MIT
9:40 a.m.

"Quantum Linear Systems Algorithms with Exponentially Improved Dependence on Precision"

Consider the linear system of equations $Ax = b$. Harrow, Hassidim, and Lloyd showed that if A and b satisfy appropriate conditions, it is possible to output a quantum state whose entries are proportional to the entries of x. Their algorithm runs in time polynomial in $\log N$ and $1/\epsilon$, where N is the size of A, and ϵ is the desired precision in the output state. We present an improved algorithm whose running time is polynomial in $\log N$ and $\log(1/\epsilon)$, exponentially improving the dependence on precision while keeping the same dependence on other parameters.

Seth Lloyd, MIT
11 a.m.

"Universal Deep Quantum Learning"

Quantum systems can generate non-classical correlations that can't be generated by classical systems. This talk investigates whether quantum devices can recognize patterns that can't be recognized classically. Deep quantum learning architectures are compared with deep classical learning architectures, and conditions are identified under which universal deep quantum learners can recognize patterns that can't be recognized by classical learners.

Graeme Smith, IBM
1:30 p.m.

"Additivity in Classical and Quantum Shannon Theory"

Most capacities in quantum and classical information theory are given as regularized limits of linear combinations of entropies of the subsystems involved in the communication protocol. In some auspicious cases, e.g. classical Shannon capacity or entanglement-assisted quantum capacity, the combination of entropic quantities is additive, so the capacity is given by a single-letter formula, without need of regularization. We exhibit an easily-evaluated sufficient condition for a linear combination of entropies to be additive. It captures all known additive quantum formulas and lets us identify new and intriguing additive quantities.

James Whitfield, University of Vienna
2:15 p.m.

"Applications of Chemical Group Theory to Quantum Simulation"

In order for quantum computational simulations to advance to a competitive point, many techniques from classical simulations must be imported into the quantum domain.

In this talk, I will explore some applications of symmetry in the context of quantum simulation. I will motivate and detail algorithms for the application of well-established ideas from computational chemistry to the first and second quantized formulations of quantum simulation, as well as applications to the black-box formulation of quantum simulation of fermionic systems.

Mark Zhandry, Stanford University
3:30 p.m.

"Quantum Query Solvability: A Refinement of Quantum Query Complexity and Applications"

The standard notion of "difficulty" for quantum oracle problems is that of quantum query complexity, which measures how many quantum queries to an oracle are required to solve a given problem.

In this talk, I will argue that quantum query complexity results typically hide important relationships between quantum queries and the ability to solve problems. Instead, I will argue for a more refined notion of difficulty, called quantum query solvability, which measures how easy it is to solve a given problem using a prescribed number of queries.

To motivate this notion, I will then describe several settings arising from cryptography where quantum query solvability is important/useful. One such setting is that of finding collisions in a function $f: [M] \rightarrow [N]$. The quantum query complexity of the so-called quantum collision problem has been established in the setting where $N \geq M$, but it is unclear how to extend these results to the case $N < M$, which is the cryptographically interesting setting. I will show how to solve this problem for arbitrary M, N. The idea is to first determine the quantum oracle solvability of the problem for the regime $N \geq M$, after which a simple reduction extends the result to the case $N < M$ (such a reduction does not apply for quantum query complexity). The quantum oracle solvability when $N < M$ implies an optimal quantum query complexity in that regime, thus resolving the quantum query complexity problem for all domain/range sizes.

Edward Farhi, MIT
4:15 p.m.

"A Quantum Approximate Optimization Algorithm"

I will describe a quantum algorithm for approximate optimization and explain how to analyze its performance on all instances of particular combinatorial optimization problems. I will also explain why this algorithm is well suited to be run on small-scale quantum computer that will be developed in the near term because of its low circuit depth and simple gate structure.

Tuesday, September 29, 2015

Beni Yoshida, Caltech
9:30 a.m.

"Classifying Fault-tolerant Logical Gates by Group Cohomology (or SPT Phases)"

We present a systematic framework of finding/classifying fault-tolerantly implementable logical gates in topological quantum codes by using the duality map between topological gauge theories and bosonic SPT phases. As a concrete application of the framework, we demonstrate that the transversal R_d in the d-

dimensional color code, belonging to the d^{th} level of the Clifford hierarchy, can be constructed from a d-cocycle function.

Jeongwan Haah, MIT
11 a.m.

"Optimal Tomography of Quantum States"

It is a fundamental problem to decide how many copies of an unknown mixed quantum state are necessary and sufficient to determine the state. Previously, it was known only that estimating states to error ϵ in trace distance required $O(dr^2/\epsilon^2)$ copies for a d-dimensional density matrix of rank r. Here, we give a theoretical measurement scheme (POVM) that requires $O((dr/\delta)\ \ln\ (d/\delta))$ copies of ρ to error δ in infidelity, and a matching lower bound up to logarithmic factors. This implies $O((dr/\epsilon^2)\ln(d/\epsilon))$ copies suffice to achieve error ϵ in trace distance. For fixed d, our measurement can be implemented on a quantum computer in time polynomial in n.

David Gosset, Caltech
11:45 a.m.

"Gapped and Gapless Phases of Frustration-free Spin-1/2 chains"

We consider a family of translation-invariant quantum spin chains with nearest-neighbor interactions and derive necessary and sufficient conditions for these systems to be gapped in the thermodynamic limit.

More precisely, let $|\psi\rangle$ be an arbitrary two-qubit state. We consider a chain of n qubits with open boundary conditions and Hamiltonian, which is defined as the sum of rank-1 projectors onto $|\psi\rangle$ applied to consecutive pairs of qubits. We show that the spectral gap of the Hamiltonian is upper bounded by $1/(n-1)$ if the eigenvalues of a certain two-by-two matrix simply related to $|\psi\rangle$ have equal non-zero absolute value. Otherwise, the spectral gap is lower bounded by a positive constant independent of n (depending only on $|\psi\rangle$).

A key ingredient in the proof is a new operator inequality for the ground space projector, which expresses a monotonicity under the partial trace. This monotonicity property appears to be very general and might be interesting in its own right. As an extension of our main result, we obtain a complete classification of gapped and gapless phases of frustration-free translation-invariant spin-1/2 chains with nearest-neighbor interactions.

This is joint work with Sergey Bravyi of IBM.

Debbie Leung, University of Waterloo
2 p.m.

"On the Power of PPT-preserving and Non-signalling Codes"

We will start by considering the general problem of transmitting quantum information over multiple uses of a memoryless quantum channel, which encompasses several rich but challenging areas of study including quantum error correcting codes, entanglement purification, and quantum channel capacity.

We will then discuss recent development in optimal finite block-length communication, a refinement to the study of quantum channel capacity. To approach this difficult problem we consider a relaxation of the optimization that corresponds to channel codes assisted by operations that are non-signalling between the sender and the receiver, and that are PPT-preserving (cannot create entanglement). The optimal rate-distortion tradeoff can be formulated as a semidefinite program and can be precisely computed. We will discuss several applications of our results.

This is joint work with William Matthews of the University of Cambridge.

Steve Flammia, University of Sydney
2:45 p.m.

"Sparse Quantum Codes with (Almost) Good Distance"

Sparse error correcting codes, where every parity check involves only a small (constant) number of bits, have become ubiquitous because they can be generated easily and decoded efficiently, even when a constant fraction of bits are in error. These properties do not carry over easily to the quantum case, however.

In this talk, I will discuss a family of quantum sparse codes that can correct a nearly constant fraction of errors. The codes are sparse enough that each syndrome measurement involves just three qubits at a time. The construction is very general, and proceeds by transforming any other quantum code into a sparse one. The price we pay for this transformation is some extra qubits and that the new code is a more general subsystem code. If time permits, I will also discuss the connection between these new codes and the physics of self-correcting quantum memories.

Joint work with D. Bacon, A. Harrow, and J. Shi (arXiv:1411.3334).

Māris Ozols, University of Cambridge
4:15 p.m.

“Entropy Power Inequalities for Qudits”

Shannon's entropy power inequality (EPI) for continuous random variables can be stated as concavity of von Neumann entropy or its power under a certain scaled addition rule. König and Smith obtained quantum analogues of these inequalities for continuous-variable quantum systems, where random variables are replaced by bosonic fields and the addition rule corresponds to the action of a beamsplitter on those fields.

We consider d-level quantum systems (qudits) and establish analogues of EPIs for a large class of functions. In particular, we prove a qudit analogue of the entropy photon number inequality, which is still open in the bosonic case. The addition rule underlying our inequalities is given by a partial swap channel that acts as a finite-dimensional analogue of a beamsplitter. Contrary to previous work, our proofs rely on majorization.

This is joint work with Koenraad Audenaert of Royal Holloway and Nilanjana Datta of University of Cambridge (arXiv:1503.04213).

Wednesday, September 30, 2015

Michael Bremner, University of Technology, Sydney
9:30 a.m.

"Average-case Complexity Versus Approximate Simulation of Commuting Quantum Computations"

We use the class of commuting quantum computations known as IQP (Instantaneous Quantum Polynomial time) to strengthen the conjecture that quantum computers are hard to simulate classically.

We show that, if either of two plausible average-case hardness conjectures holds, then IQP computations are hard to simulate classically up to constant additive error. One conjecture relates to the hardness of estimating the complex-temperature partition function for random instances of the Ising model, while the other concerns approximating the number of zeroes of random low-degree polynomials.

We observe that both conjectures can be shown to be valid in the setting of worst-case complexity. We arrive at these conjectures by deriving spin-based generalisations of the Boson Sampling problem that avoid the so-called permanent anticoncentration conjecture.

Scott Aaronson, MIT
11 a.m.

"Black Holes, Firewalls, and the Complexity of States and Unitaries"

I will discuss some recent results, motivated by the black-hole firewall paradox and the AdS/CFT correspondence, about the quantum circuit complexity of preparing certain entangled states and implementing certain unitary transformations.

One result is a strengthening of an argument by Harlow and Hayden. I will show that, under plausible assumptions, "decoding" useful information from Hawking radiation, as called for by the AMPS "firewall" thought experiment, requires the computational power to invert arbitrary cryptographic one-way functions, something we think not even quantum computers could do in sub-astronomical time.

A second result, joint with Lenny Susskind of Stanford University, considers the circuit complexity of the kinds of states that could arise in AdS/CFT and shows that, under a reasonable conjecture about complexity classes (PSPACE is not in PP/poly), the complexity indeed becomes superpolynomially large, as predicted by a conjectured relationship between complexity and geometry.

I will also discuss more general problems about the complexities of states and unitary transformations, which I find fascinating even apart from the quantum-gravity motivation.

Daniel Gottesman, Perimeter Institute for Theoretical Physics
11:45 a.m.

Stabilizer Codes for Prime Power Qudits

There is a standard generalization of stabilizer codes to work with qudits which have prime dimension, and a slightly less standard generalization for qudits whose dimension is a prime power. However, for prime power dimensions, the usual generalization effectively treats the qudit as multiple prime-dimensional qudits instead of one larger object. There is a finite field GF(q) with size equal to any prime power, and it makes sense to label the qudit basis states with elements of the finite field, but the usual stabilizer codes do not make use of the structure of the finite field.

I introduce the true GF(q) stabilizer codes, a subset of the usual prime power stabilizer codes which do make full use of the finite field structure. The true GF(q) stabilizer codes have nicer properties than the usual stabilizer codes over prime power qudits and work with a lifted Pauli group, which has some interesting mathematical aspects to it.

Poster Session/Lab Tours
2–5 p.m.

Computer and Space Sciences Building, room 3100, 4254 Stadium Dr., College Park, Maryland 20742

Eugene Dumitrescu: "Direct Characterization of Quantum Dynamics with Noisy Ancilla"

Bill Fefferman: "The Power of Quantum Fourier Sampling"

Michael Jarret: "Optimal Spectral Gap Bounds, Adiabatic Optimization, and Graph Theory"

John Myers: "Logical Synchronization in Classical and Quantum Computing"

Peter Johnson: "Fixed-point Engineering with Quasi-local Frustration-free Markovian Dynamics"

Jianxin Chen: "Necessary Conditions for the Overlapping Quantum Marginal Problem"

Michael Gullans: "Sisyphus Thermalization of Photons in a Semiconductor Double Quantum Dot"

Andrew Childs and David Gosset: "Complexity of the XY Antiferromagnet"

Andrew Childs, David Gosset and Daniel Nagaj: "Momentum Switches"

Zhexuan Gong: "Topological phases with Long Range Interactions"

Shelby Kimmel: TBA

Michael Goerz: "Charting the cQED Design Landscape Using Optimal Control"

Davide Venturelli: "Quantum Relaxation and Quantum Annealing in the Dissipative Ising Chain"

Charles Clark: "Neutron Quantum Information Science"

Saurabh Paul: "Effective 3-body Interactions in a Double-well Optical Lattice"

Mohammad Maghrebi: "Entanglement Entropy from Thermodynamic Entropy in One Higher Dimension"

Bill Fefferman and Shelby Kimmel: "QMA vs. QCMA and Subset State Verification"

Chiao-Hsuan Wang: "A Quantum Model for Entropic Springs"

Steven Flammia: "Ribbon Operators for Topologically Ordered 2D Systems"

Christopher Chubb: "Polynomial-time Degenerate Ground State Approximation of Gapped 1D Hamiltonians"

Christopher Granade: "Practical Bayesian Tomography"

Chris Ferrie: "Self-guided Quantum Systems"

Xiaopeng Li: "Chiral Density Waves and Spontaneous Topological Phases in a Rydberg Atomic Gas"

Andrew Glaudell: "Near GHz Bandwidth Quantum Repeaters Using a Serialized Quantum Error Correction Protocol"

Stephen Ragole: "Cold Atoms in One-dimensional Rings: A Luttinger Liquid Approach to Precision Measurement"

Pavel Lougovsky: "Simulating Universal Quantum Computers on Hybrid Quantum-classical Hardware"

Yi-Kai Liu: "Tamper-resistant Cryptographic Hardware in the Isolated Qubits Model"

Shihhan Hung: "Optimal Quantum Algorithm for Polynomial Interpolation"

Howard Barnum: "Entropy, Majorization, and Thermodynamics in Quantum Theory and Beyond"

Yichen Huang: "Correlation Length Versus Gap in Frustration-free Systems"

Yudong Cao: "Efficiently Optimizing Perturbative Gadgets Using Cellular Automata"

Thursday, October 1, 2015

Lorenza Viola, Dartmouth College
9:30 a.m.

"Fixed-point Engineering in Quasi-local Open-system Dynamics"

Techniques for quantum reservoir and dissipation engineering are playing an increasingly important role in controlling open quantum systems. Implications range from dissipative quantum state preparation and quantum computation, to non-equilibrium quantum phases of matter and quantum thermodynamics.

In this talk, I will describe progress toward developing a general control-theoretic framework for designing open quantum system dynamics that admits a desired (pure or mixed) quantum state as its unique fixed point, subject to physical quasi-locality constraints.

In particular, I will present rigorous results and illustrative examples for asymptotic dissipative state preparation using a natural class of frustration-free Lindblad dynamics. Time permitting, I will also describe ongoing work on discrete-time dynamics, in which case the possibility of finite-time stabilization additionally arises.

Daniel Nagaj, University of Vienna
11 a.m.

"Very Entangled Spin Chains"

We will look at various fun examples of how ground states of spin chains in 1D can be *very* entangled, especially for systems with polynomially small gaps. In particular, we will show an extension of earlier work on the bracket model that does not need endpoint terms, so it can be truly translationally invariant on a line/cycle.

Based on joint work with Ramis Movassagh and Peter Shor of MIT.

Robin Blume-Kohout, Sandia National Library
11:45 a.m.

"Gate Set Tomography: 2 Qubits and 10^{-5} Error Bars"

Four years ago, there was no reliable way to characterize and debug quantum gates. Process tomography required perfectly pre-calibrated gates, while randomized benchmarking only yielded an overall error rate. Gate-set tomography (GST) emerged around 2012-13 in several variants (most notably at IBM; see PRA 87, 062119) to address this need, providing complete and calibration-free characterization of gates.

At Sandia, we have pushed the capabilities of GST well beyond these initial goals. In this talk, I'll demonstrate our open web interface, show how we characterize gates with accuracy at the Heisenberg limit, discuss how we put error bars on the results, and present experimental GST estimates with 10^{-5} error bars. I'll also present preliminary results of GST on 2-qubit gates, including a brief survey of the tricks we use to make it possible.

Norbert Schuch, Aachen University
2 p.m.

"Topological Phase Transitions in Tensor Networks: A Holographic Perspective"

We investigate topological phases and phase transitions in the framework of tensor network models. We discuss the role of symmetries in this description, and show how it allows to relate topological phases and transitions between them to symmetry broken and symmetry protected phases exhibited by the transfer operator of the system, i.e., at the boundary.

We will also discuss how topological excitations in the 2D bulk and can be understood as domain wall excitations, order parameters, and string order parameters of the symmetry broken or symmetry protected 1D boundary, respectively, and show that this yields a natural holographic picture for topological phase transitions induced by condensation and confinement of anyons.

Mario Szegedy, Rutgers University
2:45 p.m.

"Issues Concerning the Area Law in Quantum Physics"

Several versions of the area law of quantum physics have been proposed and different results (both positive and negative) were obtained. We survey them.

Thomas Vidick, Caltech
4:15 p.m.

"A Multiprover Interactive Proof System for the Local Hamiltonian Problem"

In this talk I will introduce a variant of the "quantum PCP conjecture" formulated in terms of multiplayer games, and provide a first step toward the proof of the new conjecture.

For this, I will describe a quantum interactive proof system for the local Hamiltonian problem on n qubits in which the verifier has a single round of interaction with three entangled provers, receiving only a constant number of qubits from each prover. Completeness and soundness of this protocol are separated by an inverse polynomial in n, and the conjecture is that this can be improved to a constant.

This result provides the first indication that quantum multiprover interactive proof systems with entangled provers may be strictly more powerful than unentangled-prover interactive proof systems. A distinguishing feature of our protocol is that the completeness property requires honest provers to share a large entangled state, obtained as the encoding of the ground state of the local Hamiltonian via a simple error-correcting code.

Based on joint work with Joseph Fitzsimons of the Centre for Quantum Technologies.

Friday, October 2, 2015

Martin Roetteler, Microsoft Research
9:30 a.m.

"Reversible Circuit Compilation with Space Constraints"

I will present REVS, a tool for resource-aware compilation of higher-level, irreversible programs into lower-level, reversible circuits over a universal gate set such as the Toffoli gates. Our main focus is on optimizing the memory footprint of the resulting reversible networks. This is motivated by the limited availability of qubits for the foreseeable future. REVS can translate programs that are expressed in a subset of the functional programming language F# into Toffoli networks which can then be further processed.

We employ three main ideas to optimize the number of required ancilla qubits: (1) whenever possible, we allow the compiler to make use of in-place functions to compute expressions; (2) we introduce an intermediate representation that allows tracking data dependencies within the program. This allows identifying subsets of qubits that are no longer needed for subsequent parts of the computation, allowing those qubits to be cleaned up early; (3) we use a heuristic which corresponds to pebble games played on the dependency graph to transform irreversible programs into reversible circuits under an overall space constraint.

We discuss a number of examples to illustrate our compilation strategy for problems at scale, including a reversible implementation of hash functions such as SHA-256, automatic generation of reversible integer arithmetic from irreversible descriptions, as well as a test-bench of Boolean circuits that is used by the classical Circuits and Systems community.

Our main findings are that, when compared with Bennett's original "compute-copy-uncompute," it is possible to reduce the space complexity by 75 percent or more, at the price of having an only moderate increase in circuit size as well as in compilation time.

Chris Monroe, University of Maryland

11 a.m.

“Time to Build a Real Quantum Computer”

I will concentrate on how superconductors and trapped ions seem to be sticking out of the pack and are ready to be built up. I will cover their complementary characteristics, and speculate wildly on what they might look like, especially the ion version. I will try to encourage "co-design" where theorists and experimentalists work together on this venture.

Aram Harrow, MIT
11:45 a.m.

Local Hamiltonians with No Low-energy Trivial States

We prove the NLTS (No Low-energy Trivial States) conjecture of Hastings and Freedman. Specifically, we construct a family of O(1)-local Hamiltonians for which no low-energy states (i.e. states whose energy is a constant fraction of the number of terms in the Hamiltonian) can be prepared with a circuit of sub-logarithmic depth.

Our Hamiltonian is based on applying the Tillich-Zemor code construction to classical locally testable codes. Indeed as a corollary we also obtain the first quantum locally testable codes. A key tool in our proof is a new isoperimetric inequality for the output of low-depth quantum circuits.

Joint work with Lior Eldar at MIT.

QuICS is grateful for workshop sponsorship from CyberPoint