

# **Quantum Information Science for Fundamental Physics**

## **Report of Contributions**

Contribution ID: 1

Type: **not specified**

# Perspectives on Quantum Information Science for Fundamental Physics

*Tuesday, 18 February 2020 08:00 (40 minutes)*

**Presenter:** PRESKILL, John (Caltech)

**Session Classification:** Morning session

Contribution ID: 2

Type: **not specified**

## **Quantum electromagnetic sensors and the search for axion dark matter below 1 micro-eV**

*Tuesday, 18 February 2020 08:40 (40 minutes)*

**Presenter:** IRWIN, Kent (Stanford University)

**Session Classification:** Morning session

Contribution ID: 3

Type: **not specified**

## **New Ideas in Dark Matter Detection**

*Tuesday, 18 February 2020 09:40 (40 minutes)*

**Presenter:** ZUREK, Kathryn

**Session Classification:** Morning session

Contribution ID: 4

Type: **not specified**

# Quantum technologies for gravitational wave detectors

*Tuesday, 18 February 2020 10:20 (40 minutes)*

**Presenter:** MAVALVALA, Nergis (MIT)

**Session Classification:** Morning session

Contribution ID: 5

Type: **not specified**

## **Comments on QI in accelerating cosmology (phenomenological and thought-experimental)**

*Tuesday, 18 February 2020 16:30 (30 minutes)*

**Presenter:** SILVERSTEIN, Eva (Stanford)

**Session Classification:** Evening session

Contribution ID: 6

Type: **not specified**

## Quantum entropy generated by dynamical evolution

*Tuesday, 18 February 2020 17:00 (30 minutes)*

We introduce the notion of a time density matrix which captures a probabilistic ensemble of systems in specified states at different times. The quantum entropy of a time density matrix quantifies the information needed to track the unitary evolution of an arbitrary quantum system. As such it can grow with time, and is a finer probe of the dynamics of the system than the quantum entropy of a regular density matrix. This dynamical quantum entropy is expected to be useful in characterizing chaotic quantum systems, as well as in studying how certain quantum systems are encoded in dual gravity theories.

**Presenter:** SUH, Josephine

**Session Classification:** Evening session

Contribution ID: 8

Type: **not specified**

## Sensing, Entanglement, and Scrambling

*Wednesday, 19 February 2020 08:00 (30 minutes)*

We will begin by discussing optimal entanglement-based protocols for measuring spatially varying fields with a sensor network. We will then discuss fast protocols for preparing the required entangled states and lower bounds on the preparation time. Finally, we will discuss applications of these and related bounds to quantum information scrambling.

**Presenter:** GORSHKOV, Alexey

**Session Classification:** Morning session



Contribution ID: 9

Type: **not specified**

## Advanced Characterization and Sensing with Squeezed Optomechanical Systems

*Wednesday, 19 February 2020 08:30 (30 minutes)*

In this talk I will outline quantum-enhanced sensing modalities for nanoscale displacement and phase sensing. Optomechanical devices use optical readout of micro/nano-electromechanical systems (MEMS) displacement in order to transduce displacement and phase signals. New detection modes that focus on ultrasonic measurements have brought the shot noise of the optical field into play when transducing signals near resonance, allowing for shot noise limited measurements even at room temperature. However, state of the art approaches to date have been unable to leverage the lower noise floor away from the mechanical resonance frequency because minimum resolvable signals fall below the noise floor off-resonance. As a result, many MEMS measurement techniques can only probe the RF responses of materials or fields at discrete mechanical frequencies, with slow measurements associated with micromechanical ringdown times that are highly susceptible to nonlinear dynamics. In the shot noise limited regime, far below the back-action limit, these devices are good candidates for quantum sensing, where quantum effects like entanglement are used to enhance the readout of optical beam displacements, revealing signals that were previously buried in the noise. For example, in the case of atomic force microscopy, the ability to lower the noise floor beyond current classical limits enables broadband materials characterization critical to describing electronic dynamics in complex materials with orders of magnitude faster acquisition times than are currently available. I will compare and contrast two common readout techniques, with added quantum enhancement: direct detection readout and interferometric readout. I will outline a new scheme that relies on squeezed light and nonlinear interferometry to move nanoscale displacement sensing, phase sensing, and quantum imaging below the shot noise limit.

**Presenter:** POOSER, Raphael (Oak Ridge National Laboratory)

**Session Classification:** Morning session

Contribution ID: 10

Type: **not specified**

# Cavity Optomechanics: Generating Mechanical Interference Fringes and Brillouin Optomechanical Strong Coupling

*Wednesday, 19 February 2020 09:30 (30 minutes)*

Cavity quantum optomechanics utilizes electromagnetic fields to generate and study quantum states of motion of macroscopic mechanical oscillators. The field has undergone significant growth recently owing to its significant promise for both quantum technology development and to test the foundations of physics. Our new team at Imperial College London - the Quantum Measurement Lab - pursue a combination of experiment and theory in these directions with key interests including quantum-state engineering of mechanical systems and exploring the quantum-to-classical transition. In this talk, results from two of our research programs will be presented. Firstly, our work towards creating a mechanical superposition state will be described including experimentally generating interference fringes in the motion of a mechanical oscillator using single-photon detection [1], and theoretical work proposing how to grow a mechanical superposition state using a sequence of pulsed interactions and single-photon measurements [2]. Secondly, our experimental work on Brillouin optomechanics with high-frequency phonons (~10 GHz) will be presented including the first observation of Brillouin optomechanical strong coupling [3]. This observation provides a powerful new direction that unites several favorable properties for mechanical quantum state engineering including very low optical loss and absorption, and back-scatter operation to allow the signal to be easily separated from the pump.

[1] Ringbauer et al, *New J. Phys.* 20, 053042 (2018).

[2] Clarke and Vanner, *Quantum Sci. Technol.* 4, 014003 (2019).

[3] Enzian et al, *Optica* 6, 7 (2019).

<https://groups.physics.ox.ac.uk/QMLab/>

**Presenter:** VANNER, Michael (Imperial College, London)

**Session Classification:** Morning session

Contribution ID: 11

Type: **not specified**

# Quantum Control of Harmonic Oscillator Motional States of Ions

*Wednesday, 19 February 2020 10:00 (30 minutes)*

This talk will give an overview of recent work on quantum control of the harmonic oscillator states of motion realized with trapped ions at NIST. We prepare non-classical states of the motion of a single Be<sup>+</sup> or Mg<sup>+</sup> ion, such as approximately pure number states of ion motion up to  $n = 100$  [1], coherent superpositions of the ground state with number states up to  $n = 16$  [1] and squeezing to more than 20 dB over a motional ground state [2]. These states are useful to characterize ion motional excitation and frequency noise over a wide range of time-scales, with a quantum advantage over more traditional approaches.

Besides being useful for exploring quantum control of harmonic oscillators, atomic ions are also sensitive to coherent electric fields, such as those that may result from hidden photons or from axions in the presence of a magnetic field. The motional frequencies of ions in the quantum regime typically range from 100 kHz - 10 MHz and can be tuned by changing their confining potential. Harmonic oscillator quality factors of at least 10<sup>5</sup> have been observed and even better quality factors may be realized by more careful elimination of noise and drifts in the system. Therefore, it could be interesting to use ions as field-sensors for searches of axions and hidden photons in a frequency range where electrical circuits may be limited by thermal noise. Similar experiments can also be done in a Penning trap with hundreds of ions [3]. Penning trap operation requires a strong magnetic field that can potentially serve to convert axion fields into electric fields and the larger number of ions allows for faster averaging of projection noise during readout of the ion state.

[1] K. C. McCormick, J. Keller, S. C. Burd, David J. Wineland, A. C. Wilson, and D. Leibfried, *Nature* 572, 86 (2019).

[2] S. C. Burd, R. Srinivas, J. J. Bollinger, A. C. Wilson, D. J. Wineland, D. Leibfried, D. H. Slichter, and D. T. C. Allcock, *Science* 364, 1163 (2019).

[3] K. A. Gilmore, J. G. Bohnet, B. C. Sawyer, J. W. Britton, and J. J. Bollinger, *Phys. Rev. Lett.* 118, 263602 (2017).

This work was supported by the NIST Quantum Information Program.

**Presenter:** LEIBFRIED, Dietrich

**Session Classification:** Morning session

Contribution ID: 12

Type: **not specified**

## Replica Wormholes and the Black Hole Interior

*Thursday, 20 February 2020 08:00 (30 minutes)*

Naïve semiclassical arguments suggest that the entropy of Hawking radiation should continue to grow even at very late times, a result that is inconsistent with the unitarity of quantum mechanics. In this talk, I will argue that a more careful replica trick calculation shows that the gravitational path integral becomes dominated (at late times) by saddles containing spacetime wormholes. These wormholes cause the entropy to decrease after the Page time, consistent with unitarity, and allow information to escape from the interior of the black hole.

**Presenter:** PENINGTON, Geoff (Stanford University)

**Session Classification:** Morning session

Contribution ID: 13

Type: **not specified**

## **A Traversable Wormhole Teleportation Protocol in the SYK Model**

*Thursday, 20 February 2020 08:30 (30 minutes)*

**Presenter:** GAO, Ping

**Session Classification:** Morning session

Contribution ID: 14

Type: **not specified**

# **Superconducting Kinetic Inductance Technologies for Submillimeter Single-Photon Detection and Quantum-Limited Amplification for Spectroscopy in Space**

*Thursday, 20 February 2020 10:00 (30 minutes)*

**Presenter:** NOROOZIAN, Omid

**Session Classification:** Morning session

Contribution ID: 15

Type: **not specified**

## **Superconducting Nanowire Detectors for rare event searches**

*Thursday, 20 February 2020 10:30 (30 minutes)*

**Presenter:** NAM, Sae Woo

**Session Classification:** Morning session

Contribution ID: 16

Type: **not specified**

## **Axion Searches from Micro-eV to Milli-eV**

*Saturday, 22 February 2020 09:30 (30 minutes)*

**Presenter:** SONNENSCHNEIN, Andrew

**Session Classification:** Morning session



Contribution ID: 17

Type: **not specified**

## Axion and Gravitational Waves from Black Hole Superradiance

*Thursday, 20 February 2020 16:30 (30 minutes)*

Theories beyond the Standard Model of particle physics often predict new, light, feebly interacting particles whose discovery requires novel search strategies. A light particle, the QCD axion, elegantly solves the outstanding strong-CP problem of the Standard Model; cousins of the QCD axion can also appear, and are natural dark matter candidates. I will show how rotating black holes turn into axionic and gravitational wave beacons, creating nature's laboratories for ultralight bosons. When an axion's Compton wavelength is comparable to a black hole size, energy and angular momentum from the black hole source exponentially-growing bound states of particles, forming 'gravitational atoms'. These gravitational atoms emit monochromatic gravitational wave signals, enabling gravitational wave observatories to discover ultralight axions. If the axions interact with one another, instead of gravitational waves, black holes populate the universe with axion waves.

**Presenter:** BARYAKHTAR, Masha (NYU)

**Session Classification:** Evening session

Contribution ID: 18

Type: **not specified**

## Searching for Dark Matter with Athermal Phonon Detectors Throughout the Mass Range from 50meV through 500MeV

*Thursday, 20 February 2020 17:00 (30 minutes)*

Substantial astronomical observations have established that approximately 25% of the energy density of the universe is composed of cold non-baryonic dark matter, whose detection and characterization could be key to improving our understanding of the laws of physics. Over the past three decades, physicists have largely focused on searching for dark matter within the 10 GeV-1 TeV range (WIMPs), unfortunately without success. These experimental failures and recent theoretical realizations, have motivated new experimental searches for dark matter with much lower masses.

In this talk, we'll discuss the experimental requirements when searching for dark matter throughout the mass range from 50meV- 500 MeV. We'll also discuss recent R&D breakthroughs in athermal phonon sensor technology that will enable experiments that are being proposed using silicon, polar crystal and superfluid He as the detector material.

**Presenter:** PYLE, Matt (Berkeley)

**Session Classification:** Evening session

Contribution ID: 19

Type: **not specified**

## **ABRACADABRA-10cm: Searching for Axions and Preparing for DMRadio-m3**

*Thursday, 20 February 2020 17:30 (30 minutes)*

**Presenter:** WINSLOW, Lindley (MIT)

**Session Classification:** Evening session

Contribution ID: 20

Type: **not specified**

## **Dark Matter Detection with Magnons and Phonons**

*Thursday, 20 February 2020 18:30 (30 minutes)*

**Presenter:** ZHANG, K.

**Session Classification:** Evening session

Contribution ID: 21

Type: **not specified**

## Plasmons and Excesses in Low-Threshold Dark Matter Experiments

*Thursday, 20 February 2020 19:00 (30 minutes)*

Spectacular advances in dark matter detection experiments, using a variety of detector materials, have pushed energy thresholds below 60 eV and charge detection to single-charge resolution. Eleven such low-threshold experiments have observed an unexplained excess of events at low energies. Surprisingly, the excess rates of  $\sim 10$  Hz/kg in semiconductor detectors are the same to within a factor of a few, independent of exposure, overburden, shielding, or detector location, while the rates at noble liquid detectors are much smaller but are also consistent to within an order of magnitude. Taken together, I will argue that these disparate results can be explained if some external source is exciting a plasmon resonance in the semiconductor detectors, which is absent in disordered materials. If the external source happens to be dark matter, the couplings and masses required to explain the observed rate are consistent with standard thermal mechanisms for obtaining the correct relic abundance. I will mention numerous testable predictions for this scenario, many of which imply interesting new detector physics whether or not dark matter is the source of the observed events.

**Presenter:** KAHN, Yoni (UIUC)

**Session Classification:** Evening session

Contribution ID: 22

Type: **not specified**

## Quantum Gravity in the Lab

*Friday, 21 February 2020 10:00 (30 minutes)*

The trend of theoretical advances in AdS/CFT suggests that quantum gravity is broadly applicable as an effective description of chaotic many-body physics. Experimental realizations of such systems are now coming online, with more progress expected in the next few years. We can and should use tools of quantum gravity to describe the physics of these experiments. I will sketch one possible experiment exhibiting nontrivial behavior which, though perfectly understandable in hindsight using conventional methods, is motivated entirely by the physics of wormholes.

**Presenter:** LEICHENAUER, Stefan**Session Classification:** Morning session

Contribution ID: 23

Type: **not specified**

## Hidden Space-times in Quantum Spin Chains

*Friday, 21 February 2020 10:30 (30 minutes)*

It has been suggested that space-time geometries can emerge from quantum entanglement in the context of AdS/CFT and beyond. Inspired by travel-time tomography in seismology, we construct a geometry detector that quantitatively determines whether classical space-times can actually emerge from certain entanglement patterns. Then we explicitly reconstruct the best-fit emergent holographic geometries from various entanglement data extracted from a 1-dimensional quantum system, such as a quantum spin chain at criticality, for both static and dynamical cases. Finally, we discuss how this approach may be used for understanding simulated classical/quantum gravitational dynamics in a laboratory setting.

**Presenter:** CAO, Charles

**Session Classification:** Morning session

Contribution ID: 24

Type: **not specified**

## Mechanical architectures for fundamental physics detection

*Friday, 21 February 2020 08:30 (30 minutes)*

Mechanical sensing technologies in the classical and quantum regimes have been demonstrated across an enormous range of frequency and mass scales. I'll overview some ideas about using these sensing techniques to look a diverse variety of dark matter candidates, including ultra-light ( $m < \text{meV}$ ) and ultra-heavy ( $m > m_{\text{GUT}}$ ) fields. The theory of quantum backaction-evading measurements, especially of the momentum of a device, will play a key role in the more ambitious examples.

**Presenter:** CARNEY, Dan

**Session Classification:** Morning session



Contribution ID: 25

Type: **not specified**

## A Supersonically expanding BEC: An expanding universe in the lab

*Friday, 21 February 2020 09:00 (30 minutes)*

The massive scale of the universe makes the experimental study of cosmological inflation difficult. This has led to an interest in developing analogous systems using table top experiments. One possible system for such simulations is an expanding atomic quantum gas. In recent experiments, we have modeled the basic features of an expanding universe by drawing parallels with an expanding ring-shaped Bose Einstein Condensate (BEC). The Bose-Einstein condensate can be thought of as a vacuum for phonons, and used in analogy to the quantum field proposed to have driven the expansion of the early universe. Here, while the ring-shaped BEC serves as the background vacuum, the phonons are the analogue to photons in the expanding universe. We have studied the dynamics of a supersonically expanding ring-shaped

BEC both experimentally and theoretically. I will present our results and discuss prospects for future experiments.

**Presenter:** CAMPBELL, Gretchen

**Session Classification:** Morning session

Contribution ID: 26

Type: **not specified**

## Synthesis of Quantum-Noise-”Free” Systems

*Friday, 21 February 2020 08:00 (30 minutes)*

The sensitivity of quantum-noise limited systems can be greatly increased by engineering the quantum correlations of the probing field either externally (e.g. squeezed light) or internally (e.g. strong nonlinearities and/or coherent quantum control). Techniques used in the optimization of classical electrical circuits can be applied to the maximization of SNR in the context of the quantum Rao-Cramer bound, including losses, and thereby minimize the impact of decoherence on the reconstruction of the desired signal (e.g. LIGO, ADMX, etc). Not only can this approach be used for linear measurements of classical fields, but also for hypothesis testing of deviations from QM and GR.

**Presenter:** ADHIKARI, Rana**Session Classification:** Morning session

Contribution ID: 27

Type: **not specified**

## **Precision searches for new physics using optically levitated sensors**

*Friday, 21 February 2020 16:30 (30 minutes)*

**Presenter:** MOORE, David (Yale)

**Session Classification:** Evening session

Contribution ID: 28

Type: **not specified**

## **Exploring sensing and quantum measurement with membrane cavity optomechanics**

*Friday, 21 February 2020 17:00 (30 minutes)*

**Presenter:** REGAL, Cindy (University of Colorado)

**Session Classification:** Evening session

Contribution ID: 29

Type: **not specified**

## Quantum metamaterial for nondestructive microwave photon detection

*Friday, 21 February 2020 18:00 (30 minutes)*

Detecting traveling photons is an essential primitive for many quantum information processing tasks. We propose a single-photon detector operating in the microwave domain based on a nonlinear metamaterial built from a large number of coupled Josephson junctions. By trading local nonlinearity for large spatial extent, this approach allows for a large detection bandwidth. Using numerical simulations based on many-body physics methods, we show that the single-photon detection fidelity increases with the length of the metamaterial to approaches one. The photon is not destroyed and the photon wavepacket is only minimally disturbed by the detection, in stark contrast to conventional photon detectors operating in the optical domain. The proposed detector thus offers new possibilities for quantum information processing with superconducting qubits, as well as fundamentally new experiments exploring single-photon physics and phenomenology.

**Presenter:** BLAIS, Alexandre**Session Classification:** Evening session

Contribution ID: **30**

Type: **not specified**

**TBD**

*Friday, 21 February 2020 18:30 (30 minutes)*

**Presenter:** SCHUSTER, Dave (Chicago)

**Session Classification:** Evening session

Contribution ID: 31

Type: **not specified**

## **HAYSTAC and the Search for Dark Matter Axions above 10 micro-eV**

*Friday, 21 February 2020 19:00 (30 minutes)*

**Presenter:** MARUYAMA, Reina (Yale)

**Session Classification:** Evening session

Contribution ID: 32

Type: **not specified**

## **Quantum algorithms for pattern recognition in high-energy physics experiments**

*Saturday, 22 February 2020 08:00 (30 minutes)*

**Presenter:** GRAY, Heather

**Session Classification:** Morning session



Contribution ID: 33

Type: **not specified**

# Quantum Algorithms for High Energy Physics Simulations

*Saturday, 22 February 2020 08:30 (30 minutes)*

**Presenter:** BAUER, Christian

**Session Classification:** Morning session

Contribution ID: 34

Type: **not specified**

## **First results of DarkSRF: a dark photon search using SRF cavities**

*Saturday, 22 February 2020 10:00 (30 minutes)*

**Presenter:** GRASSELINO, Anna (Fermilab)

**Session Classification:** Morning session

Contribution ID: 36

Type: **not specified**

## **Entanglement normalization in effective field theories**

**Presenter:** ALVES, Daniele

**Session Classification:** Morning session

Contribution ID: 37

Type: **not specified**

## **Panel discussion: Strategies for Advancing QIS and Fundamental Science (Raphael Bousso, Joe Lykken, Yoshihisa Yamamoto, Maria Spiropulu + ...)**

*Saturday, 22 February 2020 10:30 (1 hour)*

Gathering the perspective of leaders in quantum computing, quantum gravity, HEP theory and experiment. Where do we think each of the fields is going? What are near-term opportunities for cross-fertilization? How can we make best use of the opportunities offered by the National Quantum Initiative, by investments made by industry, and by the HEP Snowmass process? What are the long-term prospects for advancing scientific knowledge and technical capabilities if we are allowed to dream?

**Presenters:** CHOU, Aaron; LYKKEN, Joe (Fermilab); ZUREK, Kathryn; LEHNERT, Konrad; SPIROPULU, Maria (Caltech); BOUSSO, Raphael (Berkeley)

**Session Classification:** Evening session

Contribution ID: 38

Type: **not specified**

## **Summary/reflection (Aaron Chou, Konrad Lehnert, Brian Swingle, Kathryn Zurek)**

**Session Classification:** Evening session

Contribution ID: 39

Type: **not specified**

# Quantum Computing and the Entanglement Frontier

*Wednesday, 19 February 2020 17:30 (1 hour)*

**Presenter:** PRESKILL, John (Caltech)

**Session Classification:** Public Event at Aspen Center for Physics