Quantum Africa
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INVITED TALKS: Titles and Abstracts

The European Quantum Initative
- from a Flagship to a Fleet -

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Abstract

As the first applications leap out of research laboratories towards commercialization, the global race for leadership in the maturing field of quantum technologies is becoming ever fiercer. To retain its historical lead, kick-start a continent-wide quantum-driven industry and accelerate market uptake, the European Commission launched in 2018 the Quantum Technology (QT) Flagship, an ambitious €1 billion initiative spanning a ten year period of R&D&I. Since then, the QT Flagship has been sided by many other funding instruments, initiatives and actions, which have basically more than doubled its initial budget effectively transformed it in a whole 'quantum fleet'.

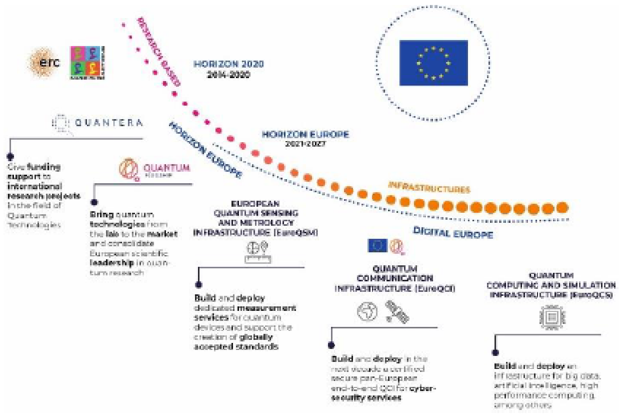

Figure 1: From a Flagship to a Fleet

This presentation will provide a broad view of the existing and planned Quantum Fleet components highlighting how the envisaged actions will realise the vision of placing Europe as a worldwide knowledge-based industrial and technological leader in the QT field.

Superconducting Quantum Circuit

Jaw-Shen Tsai

Tokyo University of Science, and Riken

Josephson is a macroscopic object. Well-designed Josephson superconducting circuits exhibit pronounced quantum coherent property [1]. In this talk, physics of such circuits as well as their application to quantum computer will be discussed.

[1] Y. Nakamura, Yu. A. Pashkin, J. S. Tsai, Nature, 398, 786, 1999

Spin qubits in hole quantum dots

Daniel Loss

RIKEN and Univ. Basel, Switzerland

Quantum Plasmonics

Mark Tame

Stellenbosch, S. Africa

Integrated photonics is an attractive platform for quantum technologies as it enables the building of compact and scalable quantum devices. Recent studies have shown that by using metallic materials one can build ultra-compact integrated photonic devices for realizing quantum applications at the nanoscale. I will talk about some of these applications, many of which have been experimentally demonstrated, including single-photon sources, quantum sensing, quantum random number generation, and the production and distillation of entanglement.

Convergence properties of the Quantum Approximate Optimization Algorithm for the number partitioning problem

Wilhelm-Mauch, Frank

Julich, Germany

with Dmitry Bagrets, Aditi Misra-Spieldenner, Tim Bode, Tobias Stollenwerk, and David Headley

Combinatorical optimization is a central problem in modern computer science and thus approaches to speed up its hard instances is of central interest in quantum computing. The Quantum Approximate Optimization Algorithm (QAOA) is a near-term hybrid quantum-classical algorithm that is believed to have high potential for solving this problems - yet, a detailed understanding of its potential for speedup is hard to come by. In this talk, I will present two results towards this goal: On the one hand, I will present a quantum-inspired classical version of this algorithm, called Mean-Field-AOA, which can be shown to be an excellent approximation to QAOA under a number of efficiently testable conditions. We will also show that QAOA with a Grover driver can be reduced to a single-round sampling task from a distribution characteristic for the optimization problem.

Introduction to Quantum Error Correction with

Superconducting Qubits and Microwave Photons

Steven M. Girvin

Yale University

This talk will provide an elementary introduction to the concepts behind quantum error correction and describe the advantages of bosonic codes (that store information in microwave photon states) over traditional qubit codes. Recent experimental results on bosonic codes will be presented.

Giant Artificial Atoms and Waveguide QED

William D. Oliver

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Models of light-matter interaction with natural atoms typically invoke the dipole approximation, wherein atoms are treated as point-like objects compared with the wavelength of their resonant driving fields. In this talk, we present a demonstration of "giant artificial atoms" realized with superconducting qubits in a waveguide QED architecture. The superconducting qubits couple to the waveguide at multiple, well-separated locations. In this configuration, the dipole approximation no longer holds, and the giant atom may quantum mechanically self-interfere. This system enables tunable qubit-waveguide couplings with large on-off ratios and a coupling spectrum that can be engineered by design. Multiple, interleaved qubits in this architecture can be switched between protected and emissive configurations, while retaining qubit-qubit interactions mediated by the waveguide. Using this architecture, we generate a Bell state with 94% fidelity, despite both qubits being strongly coupled to the waveguide. Time permitting, we also discuss recent advances in 3D integration of superconducting quantum circuits.

Moving Quantum from POC towards Production Readiness

Helmut G. Katzgraber
Senior Practice Manager, Amazon Quantum Solutions Lab

The mission of the Amazon Quantum Solutions Lab is to help AWS customers accelerate their use of quantum technologies in their products and operations. We strive to build scalable, hardware-agnostic solutions today, while preparing our customers for a fault-tolerant quantum future. In this presentation I will give an overview of the quantum efforts at Amazon, and showcase some recent customer use cases we have worked on.

Fault tolerant Quantum Computing with bosonic systems

Fernando Brandao

AWS

Time-Crystalline Eigenstate Order on a Quantum Processor

Pedram Roushan

Google Quantum

Quantum many-body systems display rich phase structure in their low-temperature equilibrium states . However, much of nature is not in thermal equilibrium. Remarkably, it was recently predicted that out-of-equilibrium systems can exhibit novel dynamical phases that may otherwise be forbidden by equilibrium thermodynamics, a paradigmatic example being the discrete time crystal (DTC). Concretely, dynamical phases can be defned in periodically driven many-body localized (MBL) systems via the concept of eigenstate order. In eigenstate-ordered MBL phases, the entire many-body spectrum exhibits quantum correlations and long-range order, with characteristic signatures in late-time dynamics from all initial states. It is, however, challenging to experimentally distinguish such stable phases from transient phenomena, or from regimes in which the dynamics of few select states can mask typical behavior. Here we implement tunable CPHASE gates on an array of superconducting qubits to experimentally observe an MBL-DTC and demonstrate its characteristic spatiotemporal response for generic initial states. Our work employs a time-reversal protocol to quantify the impact of external decoherence, and leverages quantum typicality to circumvent the exponential cost of densely sampling the eigenspectrum. Furthermore, we locate the phase transition out of the DTC with an experimental fnite-size analysis. These results establish a scalable approach to studying non-equilibrium phases of matter on quantum processors.

Floating electrons as qubits

Erika Kawakami

Floating-Electron-Based Quantum Information Hakubi Research Team, Center for Quantum Computing and Cluster for Pioneering Research, RIKEN, Wako, Japan

Realizing long-lived qubits is one of the fundamental requirements to build a reliable quantum computer. I will introduce a physical system called electrons on helium. In this physical system, the electrons float in vacuum and thus are free from the noisy environment that would shorten the qubits' lifetime.

Quantum Error Mitigation: An open-source software approach

Nathan Shammah

Unitary Fund

Abstract

I will provide an overview of recent advancements in quantum error mitigation, the collection of techniques developed to reduce the impact of errors in quantum computers. Mitiq is an open-source toolkit in Python built with the community of developers that implements techniques such as zero-noise extrapolation and probabilistic error cancellation, dynamical decoupling, and learning-based techniques, integrated with most quantum-circuit front-ends (Qiskit, Cirq, Braket, Pyquil) and any back-end processors or simulators. I will also briefly introduce Unitary Fund (https://unitary.fund/), a non-profit that supports the community of explorers in quantum technology with grants and community events (such as hackathons). It also performs research on quantum error mitigation [1-3].

References

[1] "Mitiq: A software package for error mitigation on noisy quantum computers", R. LaRose et al., https://arxiv.org/abs/2009.04417 Quantum 6, 774 (2022)

[2] "Digital zero noise extrapolation for quantum error mitigation", T. Giurgica-Tiron *et al.*, https://arxiv.org/abs/2005.10921, 2020 IEEE Int. Conf. Quant. Comp. Eng.

[3] "Extending quantum probabilistic error cancellation by noise scaling", A. Mari, N. Shammah, and W. Zeng, https://arxiv.org/abs/2108.02237 Phys. Rev. A 104, 052607 (2021)

Formation of robust bound states of interacting photons

Trond Andersen

Google Quantum AI

Systems of correlated particles appear in many fields of science and represent some of the most intractable puzzles in nature. The computational challenge in these systems arises when interactions become comparable to other energy scales, which makes the state of each particle depend on all other particles. The lack of general solutions for the 3-body problem and acceptable theory for strongly correlated electrons shows that our understanding of correlated systems fades when the particle number or the interaction strength increases. One of the hallmarks of interacting systems is the formation of multi-particle bound states. In a ring of 24 superconducting qubits, we develop a high fidelity parameterizable fSim gate that we use to implement the periodic quantum circuit of the spin-1/2 XXZ model, an archetypal model of interaction. By placing microwave photons in adjacent qubit sites, we study the propagation of these excitations and observe their bound nature for up to 5 photons. We devise a phase sensitive method for constructing the few-body spectrum of the bound states and extract their pseudo-charge by introducing a synthetic flux. By introducing interactions between the ring and additional qubits, we observe an unexpected resilience of the bound states to integrability breaking. This finding goes against the common wisdom that bound states in non-integrable systems are unstable when their energies overlap with the continuum spectrum. Our work provides experimental evidence for bound states of interacting photons and discovers their stability beyond the integrability limit.

Quantum Computing and Quantum Communications at JPMorgan Chase

Marco Pistoia

JPMorgan Chase & Co

Embedding theories for quantum simulations on hybrid classical-quantum architectures

Giulia Galli
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University of Chicago & Argonne National Laboratory

We discuss a quantum embedding theory that we have recently developed [1] to study spin-defects and impurities in solids, which is scalable to large systems. We compare the theory (which we call quantum defect embedding [QDET]) with other embedding frameworks, pointing out differences and similarities and target applications. We also present calculations on classical and quantum computers of the electronic structure of qubits performed with QDET [2].

[1] He Ma, Marco Govoni and Giulia Galli, npj, Comput. Mat., 6 (85), (2020); He Ma, Nan Sheng, Marco Govoni and Giulia Galli, J. Chem. Theory Comput., 17, 2116-2125 (2021); Nan Sheng, Christian Vorwerk, Marco Govoni and Giulia Galli 2022: https://arxiv.org/abs/2203.05493).
[2] Benchen Huang, Marco Govoni and Giulia Galli, PRX-Quantum 3, 010339 (2022).

Averaged Circuit Eigenvalue Sampling

Steve Flammia

AWS

We introduce ACES, a method for scalable noise metrology of quantum circuits that stands for Averaged Circuit Eigenvalue Sampling. It simultaneously estimates the individual error rates of all the gates in collections of quantum circuits, and can even account for space and time correlations between these gates. ACES strictly generalizes randomized benchmarking (RB), interleaved RB, simultaneous RB, and several other related techniques. However, ACES provides much more information and provably works under strictly weaker assumptions than these techniques. Finally, ACES is extremely scalable: we demonstrate with numerical simulations that it simultaneously and precisely estimates all the Pauli error rates on every gate and measurement in a 100 qubit quantum device using fewer than 20 relatively shallow Clifford circuits and an experimentally feasible number of samples. By learning the detailed gate errors for large quantum devices, ACES opens new possibilities for error mitigation, bespoke quantum error correcting codes and decoders, customized compilers, and more.

Fault-Tolerant Quantum Computing with photons

Mercedes Gimeno-Segovia,

PsiQuantum

Quantum computers promise a new paradigm of computation where information is processed in a way that has no classical analogue. However, the known problems for which quantum computers offer a computational advantage require long gate sequences and large number of qubits, which means that effective methods of noise mitigation and error correction must be at the core of the architectural design of any useful quantum computer. Photons make great qubits, they are cheap to produce, resilient to noise and the only known option for quantum networks. Most crucially, they can be efficiently manipulated with silicon photonics, an intrinsically scalable and manufacturable platform in which all the fundamental quantum gates can be implemented. In this talk, I will describe an architecture for universal fault-tolerant quantum computing supported by a silicon photonics platform. In particular, I will describe how its unique networking capabilities enable modular architectures with high thresholds.

Quantum Computing at the Speed of Light

Terry Rudolph

PsiQuantum

Quantum stochastic resonance of individual Fe atoms

Susan N Coppersmith

UNSW Sydney

Stochastic resonance, where noise synchronizes a system's response to an external drive, is a phenomenon that occurs in a wide variety of noisy systems ranging from the dynamics of neurons to the periodicity of ice ages. This talk will present theory and experiments on a quantum system that exhibits stochastic resonance — the quantum tunneling of the magnetization of a single Fe atom measured using spin-polarized scanning tunneling microscopy. Stochastic resonance is shown deep in the quantum regime, where fluctuations are driven by tunneling of the magnetization, as well as in a semi-classical crossover region where thermal excitations set in. An analytic theory with no adjustable parameters agrees quantitatively with experiment, and provides a path towards probing dynamics on time scales shorter than can be resolved experimentally.

Reference:

Max Hänze, Gregory McMurtrie, Susanne Baumann, Luigi Malavolti, Susan N. Coppersmith and Sebastian Loth, "Quantum stochastic resonance of individual Fe atoms," Science Advances 7, eabg2616 (2021).

Rydberg topological quantum memories and toric code dynamics

Marcello Dalmonte,

ICTP, Trieste Italy

Recent atomic physics experiments and numerical works have reported complementary signatures of the emergence of a topological quantum spin liquid in models with blockade interactions. Those states are promising candidates for robust quantum information storage, as they realize a dynamics that is akin to that of Kitaev's toric code. However, the specific mechanism stabilizing such phases remains unclear. Here, we introduce an exact relation between an Ising-Higgs lattice gauge theory on the kagome lattice and blockaded models on Ruby lattices. This relation elucidates the origin of previously observed topological spin liquids by directly linking the latter to a deconfined phase of a solvable gauge theory. We show that the deconfined phases extend in a broad region of the parameter space; these states are characterized by a large ground state overlap with resonating valence bond wavefunctions. These blockaded models include both creation/annihilation and hopping dynamics, and can be experimentally realized with Rydberg-dressed atoms, offering novel and controllable platforms for the engineering and characterisation of spin liquid states and toric code dynamics.

Bad vibrations: Quantum Tunnelling and SARS-CoV-2 infections

Francesco Petruccione

Stellenbosch, S. Africa

Quantum photonics using non-linear integrated optics and pulsed light

Christine Silberhorn

Paderborn Univ. Germany

Quantum technologies promise a change of paradigm for many fields of application, for example in communication systems, in high-performance computing and simulation of quantum systems, as well as in sensor technology. They can shift the boundaries of today's systems and devices beyond classical limits and seemingly fundamental limitations. Current efforts in photonic quantum target the implementation of high dimensional and scalable systems, where the realization of controlled quantum network structures is key for many applications.

Here we present three approaches to advance current experimental approaches for multi-dimensional photonic quantum systems: non-linear integrated quantum optics, pulsed temporal modes and time-multiplexing. Non-linear integrated quantum devices with multiple channels enable the combinations of different functionalities, such as sources and fast electro-optic modulations, on a single compact monolithic structure. Pulsed photon temporal modes are defined as field orthogonal superposition states and can constitute a high dimensional quantum system. They occupy only a single spatial mode and thus they can be efficiently used in single-mode fibre communication networks. Finally, time-multiplexed quantum walks are a versatile tool for the implementation of a highly flexible simulation platform with many modes and dynamic control of the underlying graph structures and coherence properties of the quantum network.

A Mitigated Path to Quantum Advantage

Oliver Dial

IBM
Yorktown Heights

Demonstrating quantum advantage requires solving a concrete problem with a quantum computer that is impossible on any classical computer. Two possible paths to quantum advantage are to use an approximate quantum computer to directly run the circuits involved, or building a large fault tolerant quantum computer. I'll discuss a middle ground, using error mitigation to allow a smooth transition between these approaches. I'll then briefly discuss IBM's current quantum hardware and software research in the context of this approach, and how researchers outside of IBM can make use of these resources.

Entanglement versus quantum computers

B. Vermersch
LPMMC Univ Grenoble Alpes and IQOQI Innsbruck

First, I will introduce the concept of entanglement in relation with quantum computers and quantum simulators. I will then present some protocols to measure quantities related to entanglement, and illustrate those with recent experimental works performed on quantum computers.

Non-Bloch parity-time symmetry and exceptional points

Peng Xue

CSRC, China

Parity-time(PT)-symmetric non-Hermitian Hamiltonians arise in open systems and, for thepast two decades, have stimulated immense interests across many physical communities including photonics, phononics, and cold atoms. A central feature of a PT-symmetric Hamiltonian is the presence of exceptional points, which occur in betweenthe exact PT phase (with entirely real eigen spectrum) and the broken PT phase(with complex eigen spectrum). At these exceptional points, the Hamiltonian features coalescing eigenstates and eigenenergies, and acquires a host of critical behaviors with abundant potentials for application. Since PT-symmetric systems are often implemented with spatially periodic structures, the location and critical phenomena of exceptional points are all characterized using the Bloch band theory therein.
Here, we report the first experimental observation of PT symmetry and exceptionalpoints beyond the Bloch band theory in spatially periodic systems, thus unveiling an entirely new class of exceptional points. Our “non-Bloch PT symmetry” and “non-Bloch exceptional points” originate from the non-Hermitian skin effect, which is a unique non-Hermitian phenomenon that has fundamentally changed our understanding of non-Hermitian topology very recently. The scope of our work goes far beyond the topological phenomena and renews a central non-Hermitian concept: PT symmetry. Our work shows that non-Hermitian skin effect can be exploited as a general mechanism of PT symmetry and exceptional points.

Exotic states in quantum many-body open systems

Rosario Fazio

The *Abdus Salam* International Centre for Theoretical Physics (ICTP), Trieste Italy

I will briefly discuss some properties of open system quantum simulators. I will concentrate on the rich phase diagram that can observed in few case and on the possibility to observe complex state of matter. I will discuss, as an example, the possibility to realize dissipative time crystals.

The US National Quantum Initiative

Charles Tahan

White House Office for Quantum, USA

Computer-aided quantization and numerical modeling of superconducting circuits with "scqubits"

Jens Koch

Northwestern Univ.

Superconducting circuits have emerged as one of the most versatile platforms in the development of hardware for quantum information applications. Exploring new superconducting circuits and optimizing existing ones naturally relies on accurate modeling. In this talk, I will focus on the open-source package "scqubits" which offers functionality that simplifies the simulation of superconducting qubits and coupled circuit QED systems. A recent addition to the package facilitates automatic circuit quantization of custom circuits. I will highlight the ideas behind automating this analysis and give an outlook on the challenges yet to be addressed.

Title: *TBA*

Meigan Aronson

UBC, Vancouver

What quantum computer science teaches us about chemistry and quantum advantage in learning from experiments

Jarrod McClean

Google Quantum

With the rapid development of quantum technology, one of the leading applications is the simulation of chemistry. Interestingly, even before full scale quantum computers are available, quantum computer science has exhibited a remarkable string of results that directly impact what is possible in chemical simulation with any computer. Some of these results even impact our understanding of chemistry in the real world. In addition, quantum technology has the potential to revolutionize how we acquire and process experimental data to learn about the physical world. We show that an experimental setup that transduces data from a physical system to a stable quantum memory, and processes that data using a quantum computer, could have significant advantages over conventional experiments in which the physical system is measured and the outcomes are processed using a classical computer. We prove that, in various tasks, quantum machines can learn from exponentially fewer experiments than those required in conventional experiments. The exponential advantage holds in predicting properties of physical systems, performing quantum principal component analysis on noisy states, and learning approximate models of physical dynamics. Conducting experiments with up to 40 superconducting qubits and 1300 quantum gates, we demonstrate that a substantial quantum advantage can be realized using today's relatively noisy quantum processors.

Unsupervised learning universal critical behavior via the intrinsic dimension

Tiago Mendes Santos
University of Augsburg

Identifying universal properties from minimally processed data sets is one goal of machine learning techniques applied to statistical physics. Here, we study how the minimum number of variables needed to accurately describe the important features of a data set—the intrinsic dimension (ID)—behaves in the vicinity of quantum phase transitions. We employ state-of-the-art ID estimators to compute the ID of data sets generated by quantum Monte Carlo and experiments with quantum simulators. For the considered cases, we find the finite-size analysis of the ID allows us to characterize critical properties associated with quantum criticality. Our work reveals how generic features of raw data sets display unique signatures of universal behavior of quantum many-body systems.

Attractor Neural Networks: storage capacity and learning

Anna Sanpera Trigueros

Authors: Carlo Marconi, Pau Colomer-Saus, Maria García-Díaz, Anna Sanpera Trigueros

One way to understand quantum neural networks is to adapt classical cases into the quantum regime. Attractor neural networks are able to retrieve different configurations after they are applied several times allowing to associate each initial state with the closest stable configuration of the network. The quantum case is obtained by studying which are the completely positive trace preserving (CPTP) maps that hold the larger number of stationary states. I will show that in this case, the attractor associated with an arbitrary input state is the one minimizing their relative entropy. We will discuss why this network outperforms the classical ones.