SWISS QUANTUM DAYS

Swiss Quantum Days 2025
Program Booklet

Arosa
January 29 to 31, 2025

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The Swiss Quantum Initiative is one of the measures adopted by the Federal Council in 2022 to support research and innovation. Its mission is to consolidate Switzerland's excellent position in the field of quantum science and technologies.

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ZuriQ is an ETH spin-off developing a utility-scale quantum computer using novel ion-trap methods to overcome challenges in scaling quantum computers.

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Stephanie Parker
Prof. Vincenzo Savona

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Dr. Géraldine Haack
Dr. Rob Thew

Agenda

Time	Wednesday, **January 29, 2025**
12:00	Arrival & Posters Up
12:30	Lunch
13:45	Welcome
13:55	Invited Talk Wolfgang Tittel (Unige & CIT)
14:30	Christoph Wildfeuer (FHNW)
14:50	Jef Pauwels (Unige)
15:10	Coffee Break
15:40	Invited Talk Philipp Treutlein (Basel)
16:15	Victor Helson (CSEM)
16:35	Justynia Stefaniak (ETH)
16:55	Gaia Bolognini (EPFL)
17:15	Poster Session
19:00	Dinner
21:00	Keynote Talk Ana Maria Rey (JILA & Univ. Colorado)

Scan to read the Abstracts of the Invited and Contributed Talks

Time	Thursday, **January 30, 2**
08:30	Invited Talk Mitali Banerjee (E
09:05	Robert Chapman
09:25	Andreas Elben (PS
09:45	Giacomo Sala (Ur
10:05	Coffee Break
10:35	Invited Talk Chetan Nayak (Mi Station Q)
11:10	Yu Yang (ETH)
11:30	Rahel Baumgartn
11:50	Stefan Woerner (I
12:10	Begoña Abad (Ba
12:30	Swiss Quantum In Nicolas Gisin
13:00	Lunch & Free Afte
18:00	Year of Quantum: Discussion
19:30	Dinner

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Time	Friday, **January 31, 2025**
08:30	Invited Talk Juan Carrasquilla (ETH)
09:05	Towsif Taher (Unige)
09:25	Uto Takahiro (ETH)
09:45	Tobias Nadolny (Basel)
10:05	Coffee Break
10:35	Gianmichele Blasi (Unige)
10:55	Joao Pinto Barros (ETH)
11:15	Christoph Galland (EPFL)
11:35	Minghao Li (Basel)
11:55	Baptiste Coquinot (EPFL)
12:15	Prize Announcements & Closing Remarks
12:40	Lunch & Departure

Our Keynote Speaker

Professor
Ana Maria Rey

JILA, NIST and University of Colorado, USA

Adjoint research Professor
JILA and NIST Fellow

Rey Theory Group

New frontiers in quantum simulation and sensing via cavity mediated interactions

Atoms and photons are the fundamental building blocks of our universe. Their interactions rule the behavior of our physical world but at the same time can be extremely complex, especially in the context of many-body quantum systems. Understanding and harnessing them is one of the major challenges of modern quantum science. In recent years, ultracold atomic systems have emerged as a pristine platform for the exploration of atom-light of interactions. In this talk, I will discuss the potential of atomic systems loaded in optical cavities as a resource to push experiments into a regime where they can take advantage of quantum entanglement, advance the frontier of quantum simulation, and, overcome physical constraints currently limiting the performance of state-of-the-art atomic clocks and interferometers.

Our Invited Speakers

Professor
Wolfgang Tittel

University of Geneva & CIT

Quantum Networks group

Professor
Philipp Treutlein

University of Basel

Quantum Optics Lab

Professor
Mitali Banerjee

EPFL

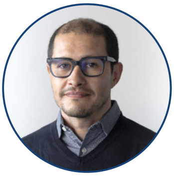
Laboratory of Quantum Physics, Topology & Correlation

Professor
Chetan Nayak

Microsoft Station Q and UCSB

Chetan Nayak Research

Professor
Juan Carrasquilla



ETH Zurich

Quantum Center at ETH Zurich

Abstracts of Invited & Contribute

Wednesday, January 29

Session chair:

13:55 – 14:30 Wolfgang Tittel **Invited Talk**

Quantum network technology – the second life of rare-earth crystals

Starting with the demonstration of lasing more than 50 years ago, the special properties of rare-earth ion doped crystals and glasses have given rise to the development of solid-state lasers and amplifiers, which are crucial for the functioning of today's world-wide Internet. As a fascinating generalization of their use in optical communication infrastructure, it became clear during the past decade that, when cooled to cryogenic temperatures of a few Kelvin, rare-earth crystals also promise the creation of technology for quantum communication networks. I will discuss recent advances towards the development of key ingredients of such networks: the creation of single photons using individual rare-earth ions coupled to nano-photonic cavities, as well as the reversible storage of quantum states of light in large ensembles of rare-earth ions. This work is not only interesting from a fundamental point of view, but furthermore paves the path towards a quantum repeater, which will ultimately enable quantum communications over arbitrary distances.

14:30 – 14:50 Christoph Wildfeur

Towards long-range free-space optical quantum communication with drones and high-altitude platforms

Establishing a global quantum network requires transmitting quantum states through free space due to the limitations of terrestrial fiber-optic links. Understanding and mitigating atmospheric effects on these delicate signals, and robust communication protocols, are crucial steps towards achieving secure, high-speed global quantum communication. The research of Christoph Wildfeuer at FHNW in near-space flights, in partnership with the National University of Singapore (NUS), has fostered significant advancements. Notably, FHNW has operated the ground control station for the SpooQy-1 nanosatellite, achieving groundbreaking results in entangled photon generation and quantum random number distribution in space, with findings published in Optica and Nature Communications.

At FHNW we play a crucial role in operating drones and high-altitude balloon platforms (HAPS) equipped with a custom-made 2-axis gimbal for coarse pointing and a MEMS mirror device for fine pointing to simulate ground-to-satellite quantum communications. Many successful HAPS launches in Switzerland have been carried out over the the past decade. We provide an overview of past, current, and planned activities to advance free-space optical quantum communications with drones and high-altitude platforms.

14:50 – 15:10 Jef Pauwels

Impossible measurements in Quantum Field Theories, localized measurements and classification of Joint quantum measurements

For decades, the scientific community has explored entanglement in composite systems, leading to foundational insights like Bell's theorem and technological advancements such as device-independent cryptography. Our understanding of quantum measurements on composite systems lags far behind, particularly outside the well-studied cases of maximally entangled and completely separable measurements. Joint quantum measurements are essential for multiparty correlation experiments, but their role and potential remain largely unexplored. Recent discoveries show that partially entangled measurements reveal new phenomena and enable applications like genuine network nonlocality, exposing a significant gap in our knowledge. To address this, we develop a new approach to classify joint measurements based on the entanglement cost of performing them locally—without bringing subsystems together or exchanging information. This classification, inspired by the longstanding question of how relativistic causality constrains quantum operations, establishes a hierarchy of measurements according to their complexity. Our approach opens up a promising avenue for understanding the structure of joint measurements and discovering new types of measurements for multiparty scenarios.

Abstracts of Invited & Contribute

Wednesday, January 29

Session chair:

15:40 – 16:15 Philipp Treutlein **Invited Talk**

In quantum metrology, entangled states of many-particle systems are investigated to enhance measurement precision of the most precise clocks and field sensors. While single-parameter quantum metrology is well established, many metrological tasks require joint multiparameter estimation, which poses new conceptual challenges that have so far only been explored theoretically. We experimentally demonstrate multiparameter quantum metrology with an array of entangled atomic ensembles. By splitting a spin-squeezed ensemble, we create an atomic sensor array featuring inter-sensor entanglement that can be flexibly configured to enhance measurement precision of multiple parameters jointly. Using an optimal estimation protocol, we achieve significant gains over the standard quantum limit in key multiparameter estimation tasks of relevance for field sensor arrays and

16:15 – 16:35 Victor Helson

Development of an industrial two-photon Rb atomic clock for timekeeping applications

Optical atomic clocks based on hot atomic vapor cells have recently gained an increased attention due to their capacity to outperform traditional microwave atomic clocks while keeping a limited SWaP budget. Among the possible atomic transitions, the Rb two-photon transition at 778 nm offers a particularly interesting combination of intrinsic stability, reduced complexity, and high reliability. In this contribution, we report on the performance of a 2-photon atomic clock currently developed at CSEM with Rolex. This clock, designed in view of its integration in a 19-inch rack-mount enclosure, is intended for 24/7 operation as a timescale master clock. The clock design, based on a standard architecture, takes advantage of the reliability and availability of fibred telecom C-band components. A 1556 nm narrow-linewidth laser is used as local oscillator. The laser light is amplified with an EDFA and frequency-doubled to address the 52S1/2 □ 52D5/2 two-photon transition of 87Rb within an evacuated glass-blown cell. The wavelength of the laser is controlled by electro-optic modulation and synchronous detection of the 420 nm fluorescence light arising from the atomic deexcitation. The stability of the locked optical reference is finally transferred to the RF domain using a 100 MHz repetition rate self-referenced fibred frequency comb. The system presented here demonstrates a long-term stability limited to a few 10^-15 by the cell helium permeation drift. A drift-removed relative frequency stability in the 10^-15 range at 10^5 s is moreover achieved, limited by the residual AC Stark-shift. Details of the clock architecture and an instability budget will be presented. A development plan, ultimately targeting the declaration of this clock by METAS to the BIPM for the generation of UTC will also be described.

16:35 – 16:55 Justynia Stefaniak

Observing mode coalescence in a driven-dissipative quantum many-body system

In recent years, ultra-cold atom research has driven significant advancements in quantum optics, condensed matter physics, and quantum information processing, leading to the discovery of novel states of matter and new quantum simulation platforms. While many studies have focused on weakly interacting, short-range systems, there is a growing interest in systems with long-range interactions, especially those involving dissipation, which leads to complex dynamics. Understanding these systems can reveal new quantum phenomena and advance both quantum technology and fundamental physics. Our experiment investigates the collective phenomena of a Bose-Einstein Condensate (BEC) of rubidium atoms trapped in two crossed high-finesse cavities. The coupling between the BEC and the cavity produces long-range interactions, resulting in two roton-like excitation modes corresponding to exotic superradiant phases [1,2]. The tunability of our system allows us to examine a parameter regime where the energy of two modes would cross in a closed system. However, the inherent dissipation makes their fate less trivial and causes the coalescence of these two modes in energy. This also leads to dissipation-induced instability in the system. By performing cavity Bragg spectroscopy we can observe the coalescing modes and dynamical instability.

16:55 – 17:15 Gaia Bolognini

Microscopy of density-wave ordering in strongly interacting Fermi gases

We investigate the formation of density-wave order in a strongly interacting Fermi gas in a high-finesse cavity, where photons mediate a long-range interaction between atoms. We combine real-time observation of the amplitude and phase of the cavity field with high-resolution microscopy to reveal the details of the ordering dynamics. In particular, we will present the first direct, in-situ imaging of the charge density waves. Our study shows new light on phase transitions induced by long-range interactions, and on the competition between superfluidity and charge ordering in quantum matter.

Thursday, January 30

Session chair:

08:30 – 09:05 Mitali Banerjee **Invited Talk**

Unconventional superconductivity in twisted magic angle trilayer

Moire superlattices provide a unique avenue for exploring unconventional superconductivity, allowing precise manipulation of electronic properties and revealing novel emergent phenomena. In this talk, I will discuss how twisted trilayer graphene has become a key platform for investigating exotic quantum phases due to its tunable flat bands.

09:05 – 09:25 Robert Chapman

Lithium niobate-on-insulator photonics for optical quantum

Lithium niobate-on-insulator (LNOI) is an emerging platform that has enabled significant advancements in classical photonics technology including telecommunications modulators, frequency combs and frequency converters. Here, we utilize the benefits of LNOI photonics for quantum information science and technology, using the strong second order nonlinearity in periodically poled waveguides for entangled photon-pair generation and programmable circuits for quantum state preparation and tomography. LNOI overcomes many of the challenges of silicon photonics such as two-photon absorption, slow thermo-optic reconfigurability, and weak optical nonlinearity. We firstly used LNOI photonics to generated path entangled photons in N00N and Bell states with very high brightness in a dual-rail encoding that is ideally suited for linear optical quantum computing. We next demonstrated time-bin Bell state generation and tomography, as an encoding for quantum communication and key distribution. Finally, we control the dispersion of the waveguides to generate spectrally uncorrelated photons that are essential for efficient heralded photon generation.

09:25 – 09:45 Andreas Elben

Benchmarking Many-Body Quantum

In the era of intermediate-scale quantum devices, a key challenge is scaling up quantum systems while enhancing the control and quality of their individual components. This necessitates efficient protocols for probing and benchmarking many-body quantum devices at scale. In this talk, I will focus on the use of engineered and emergent randomness for benchmarking quantum systems. I will discuss a new kind of maximum entropy principle, manifesting in universal ensembles of pure states that naturally emerge in ergodic quantum dynamics. I will show how this principle gives rise to benchmarking protocols through fidelity estimation for highly entangled quantum states. Furthermore, I will present experimental results from a 60-atom Rydberg quantum simulator operating beyond the capabilities of exact classical simulation, demonstrating, in addition, the ability to use the estimated fidelity for efficient probing of entanglement.

09:45 – 10:05 Giacomo Sala

Quantum materials are characterized by electromagnetic responses intrinsically linked to the geometry and topology of the electronic wavefunctions. These properties are encoded in the quantum metric and Berry curvature. While Berry curvature-mediated transport effects such as the anomalous and nonlinear Hall effects have been identified in several magnetic and nonmagnetic systems, quantum metric-induced transport phenomena remain limited to topological antiferromagnets. Here we show that spin-momentum locking -- a general characteristic of the electronic states at surfaces and interfaces of spin-orbit coupled materials -- leads to a finite quantum metric. This metric activates a nonlinear in-plane magnetoresistance that we measure and electrically control in 111-oriented LaAlO3/SrTiO3 interfaces. These findings demonstrate the existence of quantum metric effects in a vast class of materials and provide new strategies to design functionalities based on the quantum geometry.

Session chair:

10:35 – 11:10 Chetan Nayak

Invited Talk

Title: TBC

Abstract: TBC

11:10 – 11:30 Yu Yang

A mechanical qubit

Whilst strong nonlinear interactions between quantized excitations are an important resource for quantum technologies based on bosonic oscillator modes, most electromagnetic and mechanical nonlinearities are far too weak to allow for nonlinear effects to be observed on the single-quantum level. This limitation has been overcome in electromagnetic resonators by coupling them to other strongly nonlinear quantum systems such as atoms and superconducting qubits. I will present the realization of the single-phonon nonlinear regime in a solid-state mechanical system. The single-phonon anharmonicity in our system exceeds the decoherence rate by a factor of 6.8, allowing us to use it as a mechanical qubit and demonstrate initialization, readout, and single qubit gates. Our approach provides a powerful quantum acoustics platform for quantum simulations, sensing, and information processing.

11:30 – 11:50 Rahel Baumgartner

Quantum simulation of SYK using time-dependent disorder in optical cavities

In this work we propose a digital-analog scheme for the quantum simulation of the complex Sachdev-Ye-Kitaev model in a single-mode optical cavity, implementable on currently existing infrastructure. This implementation is based on a general scheme for densifying the coupling distribution of random disorder Hamiltonians, using time dependent disorder realizations. The scheme applies to the Sachdev-Ye-Kitaev class of models, but also extends to spin glasses, spin liquids, and related disorder models, bringing them into reach of quantum simulation using single-mode cavity-QED setups.

11:50 – 12:10 Stefan Woerner

Recent progress and the path to quantum advantage at IBM

This talk will provide an update on IBM's recent announcements, IBM Quantum Development & Innovation Roadmaps, and research toward quantum advantage. We will highlight advancements in hardware, algorithms, and quantum-centric supercomputing, showcasing how these synergies are unlocking new possibilities for practical applications and shaping the future of computing.

12:10 – 12:30 Begoña Abad

Exploring phonon dynamics by pump-probe spectroscopy

Semiconductor devices are the building blocks of most modern technologies and rely on energy transfer dictated by charge and heat carrier dynamics and their interaction. Therefore, the description of the energy flow in these materials is of critical importance to understanding the fundamental mechanisms that govern their macroscopic physical properties. A fundamental understanding of energy decay channels after an excitation enables the improvement of device performance. Time-resolved pump-probe technique is a powerful tool to investigate carrier and phonon dynamic information as well as thermal transport. We use a pump-probe setup capable of performing both time-resolved Raman spectroscopy (TRRS) and transient reflectivity (TR) measurements, where we monitor either changes in Raman spectra or in reflectivity, respectively, as a function of time after ultrafast excitation. In the TRRS scheme, we track the time evolution of optical phonon properties and temperature. Instead, in the TR configuration we probe different energy transfer mechanisms given by electron-phonon and phonon-phonon interactions. We carried out TRRS and TR measurements at room temperature in germanium. We observe rich dynamics by TRRS: a rise of the optical phonon temperature due to the energy relaxation of the photoexcited carriers with a subsequent temperature decay time of 3 ps as well as other nonthermal contributions to the optical phonon mode properties. Additionally, TR measurements reveal coherent acoustic phonon oscillation. Correlating these two techniques provides a full picture of the energy decay mechanisms in classic semiconductors.

12:10 – 12:30 Nicolas Gisin

Swiss Quantum Initiative

An update on the Swiss Quantum Initiative (SQI) including current and planned funding instruments. The quantum community is invited to a dialogue on views and priorities for the upcoming years.

Abstracts of Invited & Contribute

Friday, January 31

Session chair:

08:30 - 09:05 Juan Carrasquilla **Invited Talk**

Language models for the simulation of quantum many-body systems

In this talk, I will discuss our work on using models inspired by natural language processing in the realm of quantum many-body physics. I will demonstrate their utility in solving ground states of quantum Hamiltoniansreal-time dynamics of open quantum systems and characterization of quantum states from measurements. Our findings highlight the potential of using language models to explore many-body physics and beyond.

09:05 - 09:25 Towsif Taher

Superconducting nanowire single-photon detector architectures for photon-number resolution and beyond

Superconducting nanowire single-photon detector (SNSPD) development in recent years has culminated in demonstrations of single-photon sensitivity from X-Ray to beyond 29 µm, which makes them the only time-resolved single-photon detector to operate across such a broad range of wavelengths. Other attractive characteristics include intrinsic photon-number resolution (PNR), ultra-low dark count rates and scalability to cameras approaching megapixel scales. One of the key areas of research in this field is the multiplexing architecture, which allows for connectivity between the detector´s cryogenic environment to the outside world. Here, we report on a 28-pixel SNSPD with a dedicated parallel architecture that, while maintaining a simple readout with a single coaxial line, enables the detector to operate at high speed with low performance degradation. The device shows a single-photon detection efficiency (SDE) of 88% and is able to maintain its SDE above 50%, coupled with a timing jitter lower than 80 ps, up to a detection rate of 200 million counts per second (Mcps). The detector also provides state-of-the-art PNR performances with a 2-photon efficiency of 75% and a 3-photon efficiency of 60%. This talk will also review other promising multiplexing architectures which can be adopted for future quantum optics applications.

09:25 – 09:45 Takahiro Uto

Quantum optical twist and scan microscope

Two dimensional materials and their van der Waals (vdW) heterostructures have emerged as a promising platform for realization of strongly correlated matter. Introduction of a twist angle in stacking two monolayers effects a moire potential for electrons that allowed for the observation of new physics, ranging from Mott-Wigner states through fractional Chern insulators to kinetic magnetism. Even though this platform allows for tunability of system parameters that is unprecedented for condensed-matter, further advances would be enabled through introduction of further control knobs, such as in-situ continuously tunable twist angle or applied pressure.
In this talk, we introduce a novel microscopy technique that combines confocal optical microscopy with the recently developed quantum twisting microscopy. The setup we designed and implemented allows us to create twisted interfaces between vdW materials with high tunability. In particular, in the context of Fermi Hubbard model with layer pseudo-spin degree of freedom, our set-up would allow us to tune the ratio of interaction strength to kinetic energy, as well as the bandwidth and topology of the emerging moire bands. Leveraging this new capability, we aim to explore previously inaccessible phases and phase transitions in strongly correlated systems.
The quantum optical twist microscope we realize could also be used to implement super-resolution microscopy and sensing of electric and magnetic fields with unprecedented spatial resolution. To this end, we are investigating the possibility of creating quantum emitters in few nanometer thick boron nitride.

09:45 – 10:05 Tobias Nadolny

Nonreciprocal Synchronization of Active Quantum Spins

Nonreciprocal interactions between two agents, A and B, indicate that A exerts an influence on B different from the influence that B exerts on A. For instance, A may chase B which in turn runs away from A.
We present a quantum model of two spin species that interact in a nonreciprocal way. One species tends to synchronize in phase with the other species which in contrast tends to synchronize with a phase shift of pi. We show that a dynamical state analogous to chase-and-run-away dynamics emerges. Our work extends the study of nonreciprocal interactions to the quantum domain.

Session chair:

10:35 – 10:55 Gianmichele Blasi

Extending Dynamical Activity in Quantum Coherent Transport

Kinetic Uncertainty Relations (KURs) impose fundamental limits on the precision of quantum transport observables by linking signal-to-noise ratios to system activity, a measure of the rate of particle exchange between the system and its environment. While KURs are well-defined in weak coupling regimes, where particle-like behavior dominates, extending these relations to strong coupling regimes remains a challenge due to coherent electron transport effects. Here, we develop a generalized definition of activity for strong coupling simply based on a Hamiltonian description, adapting KURs to generic quantum coherent mesoscopic conductors. Our findings allow us to account for quantum coherent effects in deriving fundamental bounds for quantum sensing.

10:55 – 11:15 Joao Pinto Barros

Quantum Many-Body Scars in Abelian Gauge Theories

Systems exhibiting quantum many-body scars challenge established notions of thermalization. They fail to thermalize after a long time when starting from a small subset of initial states. This talk discusses the emergence of quantum many-body scarring in Abelian gauge theories in (2+1)-d and arbitrary dimension of the gauge links. We uncover an analytical structure that allows for the construction of scar states. These results shed light on how many-body systems may fail to thermalize and can guide near-term experimental characterization of novel phenomena in gauge theories.

11:15 – 11:35 Christophe Galland

Toward indistinguishable single photons with tailored spectra from commercial fluorophores

Indistinguishable single photons are key resources for quantum technologies, but solid-state sources suffer from the fast dephasing of optical excitations at finite temperature. A promising solution is to embed the quantum emitter in a cavity to modify its local photonic environment and thereby tailor its properties [1]. Here, we precisely position a single commercial fluorophore inside a plasmonic nanocavity with the help of DNA origami and study this hybrid system from 4K

11:35 – 11:55 Minghao Li

Optical charge state conversion and stabilization of shallow SiV centers in diamond

Both negatively and neutrally charged Silicon vacancy centers (SiV) in diamond are promising spin defects with significant potential in various quantum applications. A key challenge for these applications is reliable control and stabilization of the charge state of near-surface defects.

11:55 – 12:15 Baptiste Coquinot

Bridging nanofluidics and quantum condensed matter

Nanofluidics, the study of liquid (water) flows at nanometer scales, has until recently been rooted in the classical framework of hydrodynamics. Exotic phenomena observed in the experiments have challenged this view, revealing the importance of couplings between the liquid and the solid-state systems at its boundaries. This presentation explores fluctuation-induced couplings at the solid-liquid interface and their emerging applications [1]. These van der Waals-like interactions emerge from spectral overlap between the solid's and the liquid's charge excitations, leading to a 'quantum friction force' and energy transfer. Using non-equilibrium perturbation (Keldysh) theory, we show that the solid's internal state is impacted by a liquid flowing on its surface, which drives it out of equilibrium and induces an electric current along the direction of the flow [2]. This amounts to the conversion of hydrodynamic friction into electrical power, and represents a promising mechanism for nanoscale hydroelectric energy conversion [3]. We further predict and quantify the reciprocal effect, dubbed 'quantum osmosis', which consists in driving a liquid flow using a solid-state electric current. Finally, merging these two phenomena, we predict an effective 'flow tunneling' - momentum transfer between two liquids through a solid boundary, forbidden by standard hydrodynamics [4]. Altogether, I will illustrate how at the nanoscale liquid and electron flow are intertwined, allowing for the exotic phenomenology of quantum condensed matter to be used for nanofluidic applications.