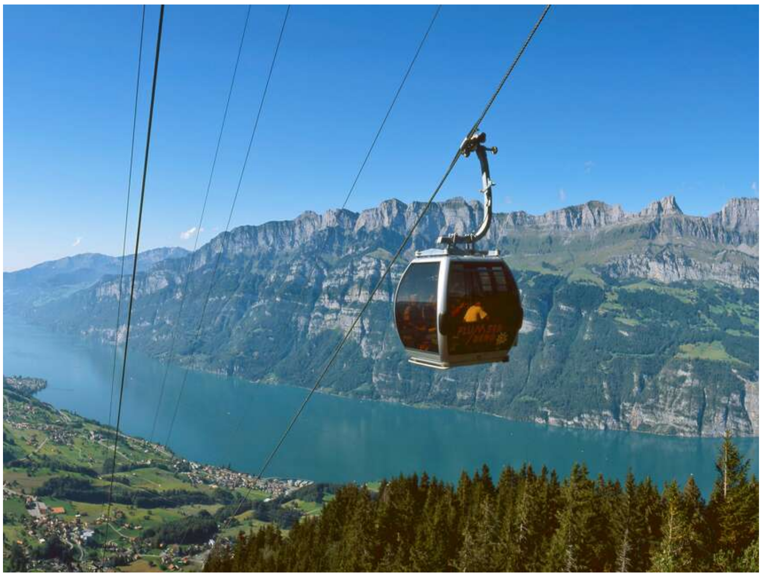
NCCR QSIT Junior Meeting 2022

Flumserberg, June 7-10th 2022



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10:00		Tobias Nadolny	Simon Wili	Nicola Reiter
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11:10		Matteo Simoni	Qblox sponsor talk	Diego Visani
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Abstracts

Session 1

Ivan Rojkov

Bias in error-corrected quantum sensing

Quantum-enhanced sensors use quantum systems and effects to sense an external signal in their environment, such as electromagnetic fields, temperature or pressure. They also, however, experience decoherence due to this same environment, which limits their sensitivity in practice. Quantum error correction (QEC) can enhance this sensitivity by suppressing decoherence [1]. We demonstrate that, in addition, error correction of a quantum sensor introduces a side-effect: in realistic settings, the finite strength of QEC biases the sensor's output [2]. If unaccounted for, this bias can systematically reduce the sensor's performance in experiment, and give misleading values for the minimum detectable signal in theory. We analyze this effect in the setting of continuous- and discrete-time QEC, showing both how one can remedy the bias through post-processing of measurement data, and how incorrect results can arise when one does not.

[1] F. Reiter, A. S. Sørensen, P. Zoller, and C. A. Muschik. Dissipative quantum error correction and application to quantum sensing with trapped ions, Nat. Commun. 8, 1822 (2017).
[2] I. Rojkov, D. Layden, P. Cappellaro, J. Home, and F. Reiter, Bias in error-corrected quantum sensing, arXiv: 2101.05817 (Accepted in Phys. Rev. Lett.)

Lorenzo Graziotto

Characterization and analysis of a symmetry-breaking THz chiral metamaterial

The ultra-strong coupling between the cyclotron resonance of a 2D electron gas in a static perpendicular magnetic field and an antenna-based metamaterial that can sustain chiral electromagnetic modes gives rise to polaritonic states with opposite circular polarizations, thus providing a way to break time-reversal symmetry. To further investigate polaritons dressed by the electromagnetic vacuum in the cavity, highly subwavelength interacting volumes along with high electron densities are needed. Therefore, planar cavities on a GaAs/AlGaAs heterostructure are engineered and characterized through THz time-domain spectroscopy, and the coupling mechanism and its limitations are understood straightforwardly via classical circuit theory.

Shobhna Misra

Design of a voltage-controllable magnetic tip for membrane-based scanning force microscopy

Our group has recently reported the development of a scanning force microscope based on an ultrasensitive silicon nitride membrane optomechanical transducer [1]. This development was made possible by inverting the standard force microscope geometry—in our instrument, the substrate is vibrating and the scanning tip is at rest. The stationary scanning tip opens up a multitude of possibilities that are difficult to achieve with a vibrating tip. In particular, we are investigating the possibility of a voltage-controlled magnetic tip (VCMT) for differential imaging modalities in magnetic force microscopy (MFM). In collaboration with the group of Prof. Hans J. Hug at EMPA, we have started with the basic design of a device that combines a sharp magnetic tip and a coil with a magnetizable core. We have performed simulations in COMSOL to determine the design parameters of the first prototype. The VCMT has the potential to enable better contrast in images of complex magnetic structures, such as the ones used for the study of artificial spin ice, patterned ferromagnetic layers, and magnetic topological structures. Ultimately, we hope that the VCMT will allow for rapid modulation of the spin force in nanoscale magnetic resonance force microscopy, similar to the MAGGIC protocol in nanowire-based scanning microscopy [2].

[1] D. Halg, T. Gisler, Y. Tsaturyan, L. Catalini, U. Grob, M. D. Krass, M. Héritier, H. Mattiat, A. K. Thamm, R. Schirhagl, E. C. Langman, A. Schliesser, C. L. Degen, and A. Eichler, Phys. Rev. Applied 15, L021001 (2021).
[2] J. M. Nichol, E. R. Hemesath, L. J. Lauhon, and R. Budakian, Phys. Rev. B 85, 054414 (2012).

Richard Karl

Laser cooling of ions in inhomogeneous B-fields

The increasing control over ions, atoms and molecules, allow for collision experiments and studies of chemical reactions at temperatures that are less than a few millikelvin. Interesting quantum phenomena occur at such temperatures and intermolecular interactions as well as reaction mechanisms can be studied with high precision. At the frontier of cold collision experiments are hybrid traps in which charged and neutral species are trapped simultaneously. In an experiment that aims to combine neutral molecules and molecular ions in a hybrid trap, a RF trap for the ions and a magnetic trap for the neutral species are used. The molecular ions are sympathetically cooled by a Coulomb crystal of laser-cooled calcium ions. After overlapping the RF trap with the magnetic trap, each calcium ion in the Coulomb crystal experiences a different Zeeman shift which causes laser-cooling to be inefficient in the hybrid trap. Molecular-dynamics-typed simulations of laser-cooled ions in inhomogeneous B-fields reveal an inefficient repumping and the occurrence of dark resonances. To overcome those challenges, a cooling scheme inspired by magneto-optical traps is explored for ions in inhomogeneous B-fields.

Marcelo Janovitch

Breakdown of wave-particle duality in the classical limit of a quantum heat engine

Quantum heat engines have spurred a lot of interest in the recent years, and, although their classical counterparts have been thoroughly investigated in the last centuries, the quantum-to-classical transition remains elusive. In this ongoing investigation, we consider a quantum heat engine based on photon-assisted Cooper pair tunnelling. Its quantum description exhibits a dual wave-particle behaviour, but a comparison with viable classical models has been lacking. Here, we derive different classical limits: (i) A particle model, where photons hop between two neighbouring resonators; (ii) a wave model, in which electromagnetic waves interfere. We contrast these with the quantum model at the level of current fluctuations, where non-classical features usually emerge.

Session 2

Alfredo Ricci Vasquez

Quantum information processing of trapped ions using integrated photonics

The use of surface-electrode ion traps with integrated photonics is a promising approach for manipulating the quantum states of individual or multiple ions: it reduces the complexity of the system, achieves higher coherence times by increasing the phase stability between the ion and the laser beam, and it can be used to generate light fields with non-trivial spatial structure. In our work we show the manipulation of the electronic and motional energy levels of an individual Ca+ ion, in a multizone surface-electrode trap where light at 729 nm 854 nm and 866 nm is delivered to the ion using integrated photonics. We addressed a dipole-forbidden transition in Ca+ using two counter-propagating light beams emitted from the trap, forming a passively phase stable standing wave which interacts with the ion. By positioning the ion with resolutions well below the standing wave periodicity we show that it is possible to modulate the strength of the electronic or motional excitation as well as the AC Stark shift, a key feature for performing faster entangling gates using trapped ions. Finally, we present advances towards performing multizone operations in the trap, including the transport of ions between zones and light delivery in multiple zones.

Elsa Jöchl

An ultrastrongly coupled single THz meta-atom

In order to approach the regime of THz spectroscopy at a single electron level, we developed an asymmetric lens setup that makes the far-field resolution of a single, strongly subwavelength meta-atom possible for the first time. The measured structures consist of optical cavities comprised of complementary split ring resonators (cSRR) on top of two-dimensional electron gases (2DEG), which couple strongly confined electrons and photons to create new quasi-particles called cavity polaritons. As the coupling strength in such systems is inversely dependant on the cavity volume, it becomes necessary to achieve the resolution of highly subwavelength structures. Utilizing a pair of Si THz lenses we were able to focus the incident waves enough to resolve single cSRR meta-atoms, decreasing the number of electrons taking part in the interaction We report normalized coupling ratios of $\Omega/\omega = 0.33$ (GaAs quantum well), $\Omega/\omega = 0.47$ (InSb quantum well) and $\Omega/\omega = 0.66$ (InSb quantum well, cSRR with smaller gap). Further, we can experimentally verify the quenching of superradiance in the single resonator system by quantifying the quality factors of the cavity resonances in arrays with decreasing resonator numbers down to a single element. The outlook of this project is very promising, as it grants access to a different quantum regime and paves the way to couple sub-THz radiation to high quality, exfoliated 2D materials.

Jonas Gerber

Spin relaxation (T1) time in bilayer graphene quantum dots

A promising qubit type for quantum computing are graphene-based spin qubits due to the expectation of long coherence times. One characteristic figure of metric is the spin relaxation time T1. We measured the T1 time via time-resolved electronic transport in electrostatically defined bilayer graphene quantum dots. Our sample structure allows the quantum dot to be probed by a nearby detector, which enables us to detect electrons tunneling in and out of the quantum dot. Using a three-level pulse, T1 is accessed by the Elzerman readout technique. We measured relaxation times of up to 50 ms, which is far higher than the lower limits reported in state-of-the-art literature [Banszerus et al. arXiv 2210.13051 (2021)]. A strong dependence between the relaxation time and the magnetic field B is extracted. This dependence enables us to envision relaxation times far higher than the measured 50 ms. These results are consequently a major milestone in realizing spin qubits for graphene-based quantum computing.

Laric Bobzien

Internal degrees of freedom of levitated objects

Levitated objects can mechanically move, rotate, and internally vibrate. These acoustic vibrations are of special interest, since they exhibit large quality factors and can be coupled to external degrees of freedom. These are important prerequisites for achieving the big promise in levitodynamics of macroscopic quantum superposition. Acoustic vibrations can be excited in materials weakly interacting with light such as silica via stimulated Brillouin scattering. In materials interacting strongly with light such as noble metals acoustic vibrations can be excited by a strong single laser pulse. So far, the feasibility of acoustic vibration as an internal degree of freedom in levitodynamics remained unexplored. Thus, we aim to show that we can control the acoustic vibration of a gold nanoparticle as a first step.Therefore, we combine ultrafast pump-probe spectroscopy with electrical levitation to study the acoustic vibrations of single gold nanospheres in air and vacuum. We aim to characterize particle sizes from 100 nm - 250 nm at different pressures and laser powers. Our experiment allows us to directly infer the intrinsic damping of the particles with nearly no coupling to its environment in the GHz regime.

Elias Zapusek

Nonunitary multi-qubit operations and mixed-state expressibility in variational quantum algorithms

Variational quantum algorithms (or VQA) are promising applications of noisy intermediate-scale quantum (NISQ) information processing. Using the variational principle, variational quantum eigensolvers (VQE) compute the energy of the (pure) ground state of a Hamiltonian – a central problem in condensed matter physics and quantum chemistry. In contrast, variational quantum thermalizers (VQT) aim to prepare (mixed) thermal states [1]. To achieve this, parameterized unitaries are combined with nonunitary circuit elements. Different circuit designs for VQA have been extensively studied. Expressibility has been introduced to judge the representational power of the ansatz [2], judging how uniformly the produced states span across the target Hilbert space. Available expressibility descriptors are not applicable to VQT as the target states are mixed. We extend the concept of expressibility by identifying a suitable measure on the space of mixed states. These resulting descriptors are studied performing simulations for a variety of circuit fragments, which could add to novel variational toolboxes. Specifically, we engineer multi-qubit nonunitary operations to achieve more expressible circuits. Based on these, we aim to better approximate thermal states of a variety of problem Hamiltonians. There is also potential to generate fundamentally interesting mixed states such as generalized Gibbs ensembles [3]. The methods and descriptors developed in this study can be used to improve VQTs applied to quantum machine learning and the simulation of open quantum systems.

[1] G. Verdon, J. Marks, S. Nanda, S. Leichenauer, and J. Hidary, Quantum Hamiltonian-Based Models and the Variational Quantum Thermalizer Algorithm, arXiv:1910.02071 (2019).
[2] S. Sim, P. D. Johnson, and A. Aspuru-Guzik, Expressibility and Entangling Capability of Parameterized Quantum Circuits for Hybrid Quantum-Classical Algorithms, Adv Quantum Tech 2, 1900070 (2019).
[3] See poster by K. Kirova, E. Zapusek, Z. Lenarčič, and F. Reiter, Variational preparation of generalized Gibbs ensembles

Session 3

Alexandra Mestre Tora

Gate-defined ring in magic-angle twisted bilayer graphene

We fabricate a ring in magic-angle twisted bilayer graphene (MATBG) encapsulated in hexagonal boron nitride. By electrostatically gating the structure, we are able to locally tune the charge density and observe resistive states at multiples of a quarter-filling of the magic-angle Moiré unit cell. With that, we can define a conducting ring-shape region where the bulk is gated to be resistive. With the device, we attempt to tune the ring region to a superconducting state and use it as an interferometer to study the nature of superconductivity in MATBG.

Alessio Cargioli

Characterization of QCL Frequency Combs under Strong Injection Locking

Dual comb spectroscopy has established itself as a powerful tool to explore the properties of organic molecules mainly in the near (NIR) and mid (MIR) infrared region. Compared to mode-locked lasers, quantum cascade laser frequency combs (QCL-FC) have the advantage of being compact, high brightness and tunable sources. On the other hand, they still present quite large mode spacing (tens of GHz) and relative narrow bands up to tens of $cm^{-}1$ which significantly limits their application for molecular spectroscopy. To this purpose, we propose a new way of operating these kind of devices under strong electrical injection in a subharmonic of the repetition rate frequency in order to increase their emission bandwidth and coherence. The coherence properties of the QCL-FC are investigated through Fourier Transform Interferometry (FTIR) and heterodyne measurements using a single line QCL as a local oscillator.

Richard Hess

Local and nonlocal quantum transport due to Andreev bound states in finite Rashba nanowires with superconducting and normal sections

We analyze Andreev bound states (ABSs) that form in normal sections of a Rashba nanowire that is only partially covered by a superconducting layer. These ABSs are localized close to the ends of the superconducting section and can be pinned to zero energy over a wide range of magnetic field strengths even if the nanowire is in the nontopological regime. For finite-size nanowires (typically $\lessapprox 1\mu m$ in current experiments), the ABS localization length is comparable to the length of the nanowire. The probability density of an ABS is therefore nonzero throughout the nanowire and differential-conductance calculations reveal a correlated zero-bias peak (ZBP) at both ends of the nanowire. When a second normal section hosts an additional ABS at the opposite end of the superconducting section, the combination of the two ABSs can mimic the closing and reopening of the bulk gap in local and nonlocal conductances accompanied by the appearance of the ZBP. These signatures are reminiscent of those expected for Majorana bound states (MBSs) but occur here in the nontopological regime. Our results demonstrate that conductance measurements of correlated ZBPs at the ends of a typical superconducting nanowire or an apparent closing and reopening of the bulk gap in the local and nonlocal conductance are not conclusive indicators for the presence of MBSs.

Tobias Nadolny

Quantum Synchronization and Chimera States

Synchronization, the tendency of coupled oscillators to adjust their phases and frequencies, occurs abundantly in nature. It has been widely studied in biology, mathematics and classical physics. We explore synchronization in systems of quantum oscillators, such as spins, or particles in a potential close to the ground state.
Previous work in our group includes a digital simulation of phase locking of a spin-1 oscillator on a quantum computer. Quantum synchronization has also been observed experimentally in an ensemble of laser-cooled spin-1 atoms. Both works considered synchronization of one quantum oscillator to an external signal.
Here, we explore more complex synchronization effects in systems of multiple quantum oscillators, such as frustration and symmetry breaking Chimera states. Apart from their theoretical study, we are working towards a simulation or a direct experimental demonstration of these effects.

Gabriel Margiani

State Lifetime of a Synthetic Two-Level System

We compare the suitability of several mathematical methods to characterize the lifetime of two-level systems. The methods deal in different ways with random-walk fluctuations during a switch. Such fluctuations are not captured by a simple telegraph-noise picture and can lead to a significant overestimation of the switching rate. We show that this problem can be avoided by choosing the correct counting method. In addition to known methods relying on thresholds and the power spectral density of fluctuations, we establish that a peak in the Allan variance of fluctuations can be used to determine the lifetime. As a simple, classical test system, we utilize a nonlinear Kerr resonator driven into parametric oscillations regime, whose stable solutions mimic the physics of a single spin.
Fabrication was performed in nano@Stanford labs, which are supported by the National Science Foundation (NSF) as part of the National Nanotechnology Coordinated Infrastructure under Award No. ECCS-1542152, with support from the Defense Advanced Research Projects Agency's Precise Robust Inertial Guidance for Munitions (PRIGM) Program, managed by Ron Polcawich and Robert Lutwak. This work was further supported by the Swiss National Science Foundation through grants (CRSII5 177198/1) and (PP00P2 163818), a DFG Heisenberg grant, and SFB 1432.
Margiani G , Guerrero S , Heugel T , Marty C , Pachlatko R , Gisler T , Vukasin G , Kwon H , Miller J , Bousse N , Kenny T , Zilberberg O , Sabonis D , Eichler A.

Session 4

Matteo Simoni

Towards a toolbox for QCCD architecture with mixed species ion crystals

Trapped ions constitute one of the most promising platforms for quantum computing thanks for example to their high fidelities and to long range interactions. Nonetheless, long strings of ions seem difficult to scale up because because the complexity of the physical system under control increases, reducing control. One promising alternative is provided by the so called QCCD architecture: in this framework, the quantum computer is broken down into multiple modules, each occupied by a small number of ion; the modules are then connected by moving selected ions between the crystals. In order for the scheme to work, it is necessary to obtain reliable shuttling, merging and splitting of ion crystals, while not introducing excessive energy to the ion chains such that cooling to temperatures required for multi-ion gates does not take too long. I will describe work on implementing these tasks with mixed species ion crystals composed by Beryllium and Calcium ions and to demonstrate proofs of principle of QCCD architecture schemes. While one species is used to store information, the other can be used either as an ancilla for syndrome readout in error correction or for re-cooling. Thanks to the optical isolation between the species, cooling can be performed without scattered light destroying stored quantum information. To optimise control, a better understanding of the potentials in our trap is required, particularly close to the crossing point of oscillation modes. The work contributes towards a fully formed toolbox for implementing the QCCD architecture, for which all other elements exist in our experimental apparatus. Other research directions we are pursuing are the study of dissipative quantum systems of mixed species ions crystals and the application of QEC schemes by encoding quantum information in the motional state of a Calcium ion.

Théo Sanchez Mejia

Difference Frequency Generation and Spectral Filtering for Quantum Frequency Conversion

Quantum communication, the use of quantum bits rather than classical bits, can allow for the increased security of messages between two parties. The limitation of quantum communication is that the quantum bits cannot be amplified to be sent longer distances, which is why quantum repeaters using quantum memories are used. The quantum memories, however, do not absorb or emit light at the wavelengths which have the lowest attenuation in optical fibers. Therefore, light from quantum memories has to be converted to the appropriate wavelength, the telecom C-band, to allow for long distance communication. This work is on the experimental setup for conversion of quantum memory light to the telecom C-band through difference frequency generation. 580 nm light compatible with a $Eu^{3+} : Y_2SiO_5$ quantum memory was pumped with a 930 nm laser into a periodically-poled lithium niobate crystal waveguide and was converted to 1540 nm with an interaction efficiency of 89.5 $\frac{\%}{Wcm^2}$ and a maximum conversion efficiency of 80.5 %. Spectral filtering was applied to reduce noise induced by spontaneous parametric down-conversion of the 930 nm pump, which was achieved by combining a volume bragg grating and a Fabry-Pérot cavity. The characterized noise was fit to be 10 $\frac{Hz}{Wcm}$ after filters, or 52 $\frac{Hz}{Wcm}$ at the crystal face. A method for increasing the signal-to-noise ratio between the converted light and the broadband noise is thought to be found through the use of simulations, though experimentally unproven in this work.

Alexa Herter

Measusring the correlation of vacuum field fluctuations in causally disconected space-time points

Despite the absence of photons, the ground state of light still contains energy manifesting itself in fluctuating electro-magnetic fields. These so called vacuum field fluctuations are causing several phenomena such as Casimir force or spontaneous emission, but a direct access to the ground state is demanding. Moreover quantum field theory predicts a correlation of the ground state between space-time points, which are causally disconnected according to special relativity. The technique of Electro-optic sampling directly measure the electric field of light in the THz range instead of its intensity. Consequently it overcomes the challenge of directly measuring the vacuum field fluctuations. By the use of electro-optic with two separated probe beams one can map the ground state vacuum field onto the polarization state of two laser pulses choosing their distance in space and time. We could measure correlation of two 195 fs separated by a distance corresponding to a time of flight of 470 fs introduced by the vacuum field.

Maria Ana de Matos Afonso Pereira

Dual Anode SPADs for High Speed Applications

High count rates and low noise are critical for an enhanced secure key rate in Quantum Key Distribution (QKD), therefore, progress in QKD has been strongly tied with technical advances in single-photon detectors. Because of their inexpensive cost and minimal implementation complexity, InGaAs/InP Single-Photon Avalanche Diodes (SPADS) have been frequently employed for QKD applications. However, afterpulsing effects are a hurdle in high-speed semiconductor-based SPADs since extensive hold-off times are required after each avalanche event to minimize these spurious events, therefore limiting the maximum count rate of SPADs. Afterpulsing can be decreased by reducing the number of free carriers produced by each avalanche event. This is achieved by reducing the avalanche signal to a minimal level. This reduction is however limited by the parasitic capacitive response of the SPAD, that determines the lowest avalanche amplitude that can be differentiated in gate-mode operation. A dual anode SPAD with the capacitive response eliminated by a subtraction circuit can be used to discern these weak avalanche signals. This SPAD features a common cathode and two anodes. One anode solely generates a capacitive response while the other generates the capacitive response as well as the avalanche signal from photon detection. Results show that this approach reduces the capacitive response signal and allows for the detection of weak avalanches. With a gating frequency of 100MHz, for a detection efficiency of 10.5

Nicholas Meinhardt

Time-resolved scanning diamond magnetometry of dynamic domain walls

Understanding the micromagnetics of current-induced motion of domain walls (DW) in thin magnetic films is crucial for the development of novel spintronic devices. While electric measurement techniques are well-established in this field, they only provide a macroscopic picture. In contrast, scanning diamond magnetometry has proven itself a suitable platform for nanoscale imaging of the internal DW structure, benefiting from its compact table-top setup under ambient conditions. This technique measures the local magnetic stray field by optically detecting magnetic resonances of a nitrogen-vacancy (NV) defect in diamond. However, it is inherently not a single-shot method, which is why scanning NV magnetometry has so far been restricted to static measurements. The goal of this project is to overcome this limitation and enable time-resolved magnetometry, which would be an important step towards imaging moving DWs. We start from a Co/Pt multilayer, which exhibits strong Dzyaloshinskii-Moriya interactions at the interface and allows us to move DWs via spin-orbit torque by applying a current. Afterwards we will proceed towards time-resolved measurements by driving DWs with AC currents and synchronizing the stray field readout with the DW's motion.

Session 5

Nathan Lacroix

Realizing Repeated Quantum Error Correction in a Distance-Three Surface Code

Quantum computers hold the promise of solving computational problems which are intractable using conventional methods [1]. For fault-tolerant operation quantum computers must correct errors occurring due to unavoidable decoherence and limited control accuracy [2]. Here, we demonstrate quantum error correction using the surface code, which is known for its exceptionally high tolerance to errors [3–6]. Using 17 physical qubits in a superconducting circuit we encode quantum information in a distance-three logical qubit building up on recent distance-two error detection experiments [7–9]. In an error correction cycle taking only 1.1 μs, we demonstrate the preservation of four cardinal states of the logical qubit. Repeatedly executing the cycle, we measure and decode both bit- and phase-flip error syndromes using a minimum-weight perfect-matching algorithm in an error-model free approach and apply corrections in postprocessing. We find a low error probability of 3% per cycle when rejecting experimental runs in which leakage is detected. The measured characteristics of our device agree well with a numerical model. Our demonstration of repeated, fast and high-performance quantum error correction cycles, together with recent advances in ion traps [10], support our understanding that fault-tolerant quantum computation will be practically realizable.

Ina Heckelmann

Measurement of the sub-poissonian shot noise in a Quantum Cascade Detector

Quantum Cascade Detectors (QCD) utilise stacking of thin semiconductor layers and careful engineering of the band structure for the detection of mid-infrared light via intraband transitions. This process is expected to exhibit sub-poissonian noise statistics due to the reduced effective charge transported through the device upon photon absorption. According to the Shockley-Ramo theorem, this noise gain is inversely proportional to the number of layers in the QCD. In the present work, the agreement of the theory with experimental results will be tested for the first time. For this purpose, a high-intensity Quantum Cascade Laser at 4.5 um was used to illuminate the QCD. In order to make the minute contribution of the shot noise to the total noise detectable, an external amplifier was used in addition to the internal amplification of the spectral analyser to record the AC signal detected by the QCD. Correction for dark and thermal noise and the selection of a coherent and stable multi-mode state of the laser allowed for quantitative measurements of the shot noise. The retrieved experimental result underpins the sub-poissonian character of QCDs and yields a shot noise 90 times lower than expected for a conventional detector at the same photocurrent.

Lorenzo Stasi

High efficiency and fast photon-number resolving parallel superconducting nanowire single-photon detector

Photon number resolving (PNR) detectors represent a key element in many quantum optics application such as linear optics quantum computing, purity characterization of single-photon sources and quantum imaging. Here, we explore the PNR capabilities of the parallel superconducting nanowire single-photon detectors (P-SNSPDs) architecture and we assess them by developing an unbounded model that describes all the n-click probabilities for a m-photon event. To make the model as general as possible, we do not take assumptions such as uniform spacial distribution of light or equal efficiencies for the different SNSPDs. We apply our model on a 4-pixel P-SNSPDs with a system detection efficiency of 92.5%, full recovery time in 40 ns and 42.3 ps jitter. We report a fidelity probability of 92% on 1-photon event and of 48.3% on 2-photon event. Lastly, we evaluate the possibility to reconstruct the statistic of unknown light sources.

Laura van Schie

NV imaging of Domain Walls in Ferrimagnetic RETM alloy with room temperature compensation points.

Current Induced Domain Wall motion (CIDWM) has proven to be an essential step in the development of data storage and transfer in spintronics devices. Though CIDWM has been well studied on the macroscopic scale, a more thorough understanding of the internal structure of domain walls during motion can be achieved by studying these systems via diamond nitrogen-vacancy (NV) magnetometry. To achieve this imaging of dynamic fields, the NV measurement protocol must be enhanced from a single-shot to a stroboscopic readout of a repeatable signal. This study focuses on CIDWM via spin-orbit torque in ferrimagnetic GdFeCo. This system has been chosen as it hosts highly mobile domain walls in ambient conditions. Moreover, the properties of the system can be tuned by tuning the composition of Gd to and away from the ferrimagnetic compensation point. The initial stages of this project have worked to characterise CIDWM in GdFeCo racetrack devices via MOKE imaging. This, combined with static imaging and modelling of domain walls in samples of varying compositions of Gd and racetrack geometries, form the groundwork of understanding and creating a reproducible system that will aid in improving temporal resolution of scanning NV magnetometry.

Kacper Prech

Violations of the Thermodynamic Uncertainty Relation and Entanglement - Two Manifestations of Quantum Coherence

Entanglement, a form of correlation that is stronger than what classical systems are capable of, is a prominent manifestation of quantum coherence. Recently, a different manifestation of coherence has been discovered: systems exhibiting quantum coherence have been found to violate inequalities that bound the signal-to-noise ratio of any current in classical systems, so-called thermodynamic uncertainty relations (TURs) [1]. We systematically analyze the relation between these two different manifestations of coherence in a serial double quantum dot. In this system, entanglement can be generated by driving a charge current through the double dot [2]. That same current may exhibit a suppression of fluctuations due to quantum coherence, allowing for TUR violations. We find that TUR violations and entanglement are present for the same range of tunnel-couplings. However, while TUR violations require small bias voltages (keeping dissipation small), entanglement is maximized in the large bias limit. Increasing the bias voltage, we observe a cross-over from TUR violations to entanglement with a window of co-existence for intermediate voltages. Coulomb interactions between the dots enhance coherence resulting in larger TUR violations, stronger entanglement, and, in the case of strong interactions, non-local quantum states.

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Huber Luca Immanuel

Low-crosstalk individual addressing for cryogenic ion trapping

Authors: L. Huber, R. Matt, R. Oswald, J. Flannery, K. Wang, C. Decaroli, C. Axline, J. Home
We present experimental work performed in a cryogenic ion trap architecture for the implementation of quantum error correction and quantum algorithms. The quantum register consists of a linear string of Ca40 ions, where single-qubit quantum operations are realised by an array of individually controllable tightly focused laser beams perpendicular to the ion string axis. A narrower ion spacing generally allows for faster and higher fidelity quantum gates, given stronger ion-to-ion coupling and a more favourable motional frequency spectrum. However, closely spaced ion strings necessitate tightly focused individual beams. While multi-core waveguide arrays can be used to produce the required array of beams at each ion location, the narrow spacing of laser beams easily leads to crosstalk at the neighbouring ion locations. Here, crosstalk inside the waveguide array has to be traded off against diffraction due to a subsequent optical demagnification step. We present results of a laser written waveguide array, which will allow us to reach intensity crosstalk on the order of $10^{-}4$. To reduce remaining crosstalk, we implement a novel coherent optical cancellation method by applying parallel compensation pulses on spectator ions. Given the high phase stability requirements of our method, we develop calibration experiments and procedures to characterize and mitigate phase drifts in the different optical paths. Our findings are not only relevant to free-space single ion addressing but also to future ion traps with integrated waveguides, which require phase-stable operation.

Session 6

Sebastián Guerrero Soriano

Cryogenic NV Magnetometry applied to Multiferroics

Imaging weak magnetic fields using the electronic spin of a nitrogen-vacancy (NV) defect in diamond is a well-established, versatile technique for the study of magnetic materials, mainly due to exceptionally long spin-coherence times. The quantum sensor based on the NV center has been an active field of research, widening its capabilities to obtain information of weak magnetic fields with sensitivities in the nanotesla regime and nanometric resolution. In recent years, further uses for these sensors, such as in Gradiometry, electric field imaging or its extension towards cryogenic temperatures have been explored with promising results. A combination of the mentioned techniques could be of great interest towards understanding the fundamental nature of more complex systems, such as those present in multiferroics. There, more than one ferroic order, for instance, ferroelectric and antiferromagnetic, coexist. The interest in such systems relies on their potential use for more efficient, smaller and reliable magnetic devices, for instance, a low energy switching, non-volatile nanoscale magnetic memory. Imaging magnetic and electric domains of such materials simultaneously, which is one of the main goals of the project, will be a breakthrough which pushes our understanding of the physics underlying those systems a step further.

Giulia Mazzola

On the Black Hole War: A quantum information view to reconcile Hawking's prediction of information loss with unitarity of quantum theory

A major discovery by Hawking was that the interplay between general relativity and quantum theory leads to the prediction that black holes must radiate. In Hawking's original calculation however, the black hole radiation was found to be of thermal character thus leaving behind a mixed state describing the radiation as soon as the black hole has fully evaporated. This conclusion stands in apparent contradiction to the reversibility of time evolution in quantum theory which predicts a pure final state of the radiation, thereby giving rise to the famous black hole information puzzle. This discrepancy can be more concretely illustrated in terms of (von Neumann) entropy: Hawking's prediction leads to a continuously increasing entropy during the black hole evaporation while quantum theory instead dictates that the entropy should decrease in the final stages of the evaporation. Recent calculations based on random unitary models or using the gravitational path-integral integral formalism have shed new light on this puzzle, supporting the latter behavior of the radiation entropy in favor of the unitary evolution picture. Hence, was Hawking's conclusion wrong? In analyzing this question, it turns out that information-theoretic tools allow us to interpret the different behaviors of the black hole radiation entropy during evaporation and therefore might help in understanding the relations between recent results and Hawking's conclusions. In this talk, I will mainly focus on the random unitary model for black hole evaporation and, as an outlook, present a recently suggested framework in which Hawking's original predictions and the unitary picture of quantum theory may be reconciled.

Lara Ostertag

Silicon MOSFET gate stack optimization for FinFET quantum dots

As the race to build a quantum computer intensifies, technologies such as superconducting circuits, trapped ions, and semiconductor quantum dots are crystalising themselves as strong contenders in reaching this goal. Due to advanced silicon fabrication technologies, and suppressed hyperfine-induced decoherence due to few nuclear-spins, silicon quantum dots in particular are a promising way to create scalable qubits for quantum computers. In these devices, a qubit is formed using the spin state of an electron or a hole confined in a quantum dot, which can be formed using non-planar fin field-effect transistors (FinFETs).
In efforts to optimize FinFET quantum dots, silicon metal-oxide-semiconductor field-effect transistors (MOSFET) gate stacks are studied. The following work analyses the peak mobility, density of interface and percolation threshold of different Hall bars, capacitance devices and quantum dots and thereby shows how varying the thickness and materials of oxide layers makes it possible to optimize silicon quantum dots by increasing peak mobility and decreasing percolation thresholds.

Rebecka Sax

High-speed integrated QKD system

Confidentiality and protection of the transmission of online data is becoming a more and more relevant area of concern. Today, algorithms used to encrypt and decrypt data are based on computationally hard problems. However, with the advancement of quantum computers such algorithms will no longer be secure, ergo an urgent need of an alternative solution. One such is the use of quantum key distribution (QKD), which, with the help of the laws of quantum mechanics, is proven to be information- theoretically secure. QKD has been extensively experimentally demonstrated, from the first one with users separated on an optical table using the free space as the quantum channel, to their separation at distances of hundreds of kilometers through optical fibers and even to the usage of satellites. The setups have gone from bulk to integrated, to allow for a straight-forward and cost-friendly integration of QKD into existing metropolitan fiber-networks. We present a time-bin encoding QKD setup using several different integrated photonic technologies for the transmitter (Alice) and receiver (Bob). A secret key exchange is performed at a rate of 2.5 GHz, which is the fastest (to our knowledge) rate performed using integrated QKD. Secret keys with low QBERs at reasonable metropolitan distances were obtained, applying the three-state BB84 protocol with 1- decoy state. The integrated part of Alice is based on silicon and consists of an interferometer, an intensity modulator and variable attenuators, all integrated onto one chip. Regarding Bob, two integrated versions were made, both consisting of a passive beam splitter and an interferometer, one of which is based on silica (planar light circuit, PLC) or fabricated using a femtosecond laser micromaching technique. Bob is polarization insensitive, and Alice and Bob are separated with dedicated optical fibers.

Marius Gächter

Breakdown of quantisation in a Hubbard-Thouless pump

Cold atoms in a periodically varying lattice potential can serve as a platform to study quantum transport. By adiabatically varying certain parameters of such a one dimensional lattice system, a fermionic cloud of atoms can realize the paradigmatic Thouless pump. The slow variation then leads to the atoms being transported an integer number of lattice sites per pump cycle. The quantisation of transport solely depends on the topology of the trajectory in parameter space and is therefore robust against disorder and other perturbations. Here we investigate the competition between this topological protection and on-site interactions in a system of ultra-cold fermionic atoms.

Session 7

Zhewen Xu

Scanning Nitrogen Vacancy Magnetometer and its Spatial Resolution

Quantum sensor based on the optical detected magnetic resonance (ODMR) of nitrogen vacancies (NV) in diamond is a great instrument to investigate complex magnetic textures, such as chiral domain wall and skyrmion. The limitations of this magnetometer to reconstruct the magnetization of magnetic sample from the magnetic field measured by NV centre are the spatial resolution and ODMR signal sensitivities. My project focuses on the topic of spatial resolution of scanning NV magnetometer from the three different aspects, i.e., magnetic stand-off distance measured by scanning the edge of ferro-magnetic sample, dynamic stand-off distance extracted from atomic force microscopy (AFM) measurement and the NV depth gained from dynamic decoupling spectroscopy. By well studying these aspects, we most probably have the access to improve the spatial resolution of scanning NV magnetometer. Finally, we will apply this improved quantum sensor to image room temperature skyrmions and other novel and interesting magnetic textures.

Marta Perego

Developing tunnelling spectroscopy in magic angle twisted bilayer graphene

Magic-angle twisted bilayer graphene is a highly tunable two-dimensional material, exhibiting a wide range of phases, including superconductivity [1]. Although its superconductivity has been extensively examined, no definite conclusion on its type or pairing mechanism has been reached. One way to answer these questions is to use tunneling spectroscopy to measure the superconducting gap. We have developed a fabrication technique which allows us to carry out tunnelling spectroscopy in conjunction with transport measurements. Patterned electrons are embedded in hexagonal boron nitride, which is used as the first layer in the stacking procedure [2]. Few-layer hexagonal boron nitride is employed as tunneling barrier, only a few layers are used so that defect-mediated tunnelling is suppressed [3]. Our results are the initial steps toward the development of a tunneling spectroscopy technique to measure the superconducting gap in twisted bilayer graphene.

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Alex Gómez Salvador

Optical signatures of periodic magnetization: the moiré Zeeman effect

There has recently been an increased interest in two-dimensional systems, such as graphene or transition metal dichalcogenides (TMDs), both at the monolayer and few layer level. In particular, TMD monolayers present a unique combination of fascinating features, such as direct semiconductor bandgap, strong spin-orbit coupling and tightly bound excitons with valley dependent optical selection rules among many others. Consequently, they have been stablished as remarkable platforms for the study of fundamental physics and cutting-edge traditional and exotic electronics. Here, we discuss the possibility of using TMD excitons to optically determine periodic charge order and periodic magnetic fields at the 10 nm length scale. For small electron doping, we show that the spin-valley dependent exciton-electron interactions in TMDs allow for probing the spin-valley order of electrons and demonstrate the appearance unique optical signatures for different lattices and spin order. Furthermore, we extend this technique to probe interesting semiclassical magnetic structures appearing in twisted bilayers of magnetic semiconductors.

Simon Wili

Observing Superfluid Current Through a Dissipative Quantum Point Contact

We experimentally and theoretically investigate the robustness of fermionic superfluidity to spin-dependent dissipation in a unitary Fermi gas. With a focused laser resonant with one of the two spin states, we introduce a controllable particle loss at a quantum point contact connecting two superfluid reservoirs. We measure the influence of the dissipation on the superfluid flow between the reservoirs, characterized by a non-Ohmic current-bias relation due to multiple Andreev reflections (MAR). A mean-field model in the Keldysh formalism qualitatively reproduces our observations, showing that there is no critical dissipation strength where the supercurrent vanishes. Instead, it decays smoothly with increasing dissipation while the current-bias relation approaches an Ohmic scaling, indicating a surprising robustness of MAR. Our current work extends to pure spin transport under local dissipation. These results are relevant for dissipative engineering of transport properties and understanding dissipative non-equilibrium superfluid systems.

Jingjing Chen

Towards an atomic frequency comb memory in europium-doped yttrium orthosilicate under moderate magnetic bias field

Rare-earth ion crystals have proven to be a promising platform for quantum memories. Our group has shown that $Eu^3+ : Y2SiO5$ in particular can achieve qubit storage for up to 20 ms based on the atomic frequency comb (AFC), at a weak magnetic field of about 1 mT. However, the price to pay when working at this weak field is a reduced efficiency, due to interferences between different quantum paths due to small Zeeman splits of the hyperfine levels. The goal of my project is to work in a new regime of moderate field (250 mT). Under these conditions we believe this problem can be solved, as the Zeeman split is larger than the memory bandwidth, thereby avoiding the multiple paths of excitations. I will present first results towards an AFC memory at moderate field. I will show the experimental setup allowing the application of 200 mT in the cryostat, some hyperfine spectroscopy results, and the complete optical control of spin population in the six Zeeman-split hyperfine levels. These results should soon lead to preliminary AFC storage experiments at moderate fields.

Session 8

Bhavesh Kharbanda

Spin Detection using Ultra-coherent Silicon Nitride String Resonators

In my project, I will employ quasi-1D soft-clamped silicon nitride resonators for cavity-based opto-mechanical sensing. These resonators feature Q-factors up to $\approx 10^9$ at room temperature, which makes them very sensitive to small forces. They are arranged as strings in a polygon configuration and integrated with photonic cavities on a chip. The photonic cavities allow compact read-out of the mechanical motion with high precision through a tapered optical fiber. The goal of the project is to use these mechanical resonators as force sensors. In particular, they are envisaged as a new tool to detect individual spins, and to map out the positions of spins in a complex sample behaving as a nanoscale variant of magnetic resonance microscopy (MRI). For this application, it will be necessary to cool the resonators to very low temperatures (<100 mK) in order to suppress thermo-mechanical fluctuations.

Max Ruckriegel

Towards dispersive charge sensing of graphene quantum dots with microwave resonators

Electrostatically defined quantum dots (QD) in bilayer graphene are an increasingly promising platform to host spin qubits. Further investigation of qubits in graphene QDs requires high-fidelity charge sensing. Fast charge sensing can be performed by dispersively coupling electrons in a double QD to microwave photons. Here we report on progress towards integrating graphene QD devices with on-chip superconducting microwave resonators. We outline the main advances in design and fabrication of graphene-based hybrid devices and highlight the key challenges. We show first device characterizations and proof-of-priciple measurements towards dispersive charge sensing.

Scarato Colin

Training a Quantum Convolutional Neural Network on a Superconducting Processor

Quantum machine learning aims at combining machine learning techniques with quantum computing hardware, and is considered a promising tool to study complex quantum systems. A common approach is to train a quantum neural network, by implementing it as a parameterised quantum circuit and optimising its parameters. To date, most experimental realisations of such circuits have been run on a quantum processor only after pre-training with classical simulations, which is not scalable due to an exponentially growing Hilbert space. In our previous work, we pre-optimised a Quantum Convolutional Neural Network (QCNN) [1], to classify if the quantum state of a spin chain belongs to a symmetry-protected topological phase (cluster state). Here, we discuss the first steps towards training a QCNN directly on a superconducting quantum processor, where a classical computer iteratively measures and optimises the circuit. To this end, we plan to extend the resonant-interaction two-qubit gate [2] to a continuous set of conditional phase gates with arbitrary angles, which reduces the number of gates necessary to run the circuit [3]. We will then optimise the two-qubit gate angles as part of the QCNN training procedure. We also present the electronic and cryogenic setup built to run this experiment, and discuss prerequisites to train quantum neural networks faster, including the need for high repetition rate of the measurement as well as small control overhead.

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Session 9

Andraz Omahen

Electrostatically Defined Quantum Dots in Bilayer Graphene

Quantum dots are a platform that represents potential candidate for quantum computing. They can be implemented in several materials, with the leading one being Si, followed by Ge. A very promising material for implementation of quantum dots is bilayer graphene due to small spin-orbit and hyperfine interactions, which lead to long coherence times.
To understand the bilayer graphene quantum dots, we want to measure degeneracy of the first charge carrier (either an electron or a hole). However, the tunnelling rates of charges in and out of the dot are too high for the detector's bandwidth at zero magnetic field. By applying a finite field, the tunnelling rates get lower, but the degeneracy of the charge carriers also changes, making the measurement ineffective for observing the degeneracy at zero field. Therefore, one either needs to increase the bandwidth of the detector or optimize the dot geometry, such that the tunnelling barriers provide better control of the tunnelling rates. Optimizing the quantum dot geometry is the main subject of my master's thesis and would enable us to perform more elaborate charge detection experiments.

Völker Laura Alicia

Exploring Nitrogen–Vacancy Centers in Diamond as Sensors of Chiral-Induced Spin Selectivity (CISS) in Photoinduced Electron Transfer

Chiral-induced spin selectivity (CISS) refers to spin-dependent interactions between electrons and inversion asymmetric materials: electrons exhibit preferred spin polarization in transmission through a chiral molecule or crystal. Numerous experimental studies on CISS have been demonstrated, most often by measuring electron transport at the interface of chiral molecular assemblies and ferromagnetic electrodes. Despite concurrent advances in theoretical models to describe the effect, open questions remain, such as the role of spin coherence and the extent to which spin polarization may be perturbed at the ferromagnetic interface. Novel measurement techniques are necessary that enable tracking of spin polarization lifetimes in the chiral molecules and deconvolution of ferromagnetic interface effects. Here, we propose to utilize near-surface NV centers in diamond as innocent, nano-scale magnetic field sensors for detection of CISS in adsorbed donor-chiral bridge-acceptor (D-B-A) molecules. In these systems, photoexcitation of the donor species and subsequent electron transfer via a chiral bridge to the acceptor moiety generates a radical pair. Due to CISS, this transfer is hypothesized to result in spin polarization, which can be read-out by tracking the magnetic resonance frequency shifts of proximal NV reporters. Importantly, this strategy enables probing electron transfer and ultimately spin coherence lifetime in D-B-A molecules without charge injection from ferromagnetic electrodes. Overall, the NV center could thus be exploited as an innocent sensor for CISS at the single-molecule level to provide novel understanding of the effect and a complementary approach to existing experimental schemes.

Tabea Bühler

Self-organization of a strongly interacting Fermi gas

Quantum-gas-cavity systems offer a possibility to experimentally implement and study non-trivial Hamiltonians which emerge, for example, in solid state physics [1].
In the talk I will present an experimental setup that is used to produce a Fermi gas consisting of 6Li atoms cooled down to the degenerate regime inside a high-finesse optical cavity [2]. I will explain how the particle to particle interactions can be tuned by the use of a Feschbach resonance. Having control over the inter-particle interactions, this setup allows to combine the study of strong particle to particle interactions and the strong coupling of those particles to light [3].
The project currently being carried out on this setup is the study of self-organization of the system due to cavity mediated interactions. Being pumped from the side the system undergoes a transition into a super radiant phase for a critical strength of the pump field. With our experimental apparatus we aim at characterizing how the onset of the phase transition changes as we vary the particle to particle interactions.

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Nicola Reiter

Atomic parametric down-conversion with a spinor quantum gas coupled to a cavity

Parametric down-conversion (PDC) is a paradigmatic process in optical systems, which is employed for the fast generation of correlated pairs of photons (signal, idler) from a laser pump beam incident on a nonlinear crystal. In our experiment, we realize an atomic analogue of PDC by coupling a Bose-Einstein condensate of 87Rb atoms to a high-finesse optical cavity. The atoms are initialized in the $|F = 1, mF = 0\rangle$ level (pump mode) and illuminated by a running-wave transverse drive. Correlated production of pairs of atoms in $mF = \pm 1$ (signal and idler mode) is induced by four-photon processes, which involve off-resonant scattering of virtual cavity photons from and into a transverse laser drive. This process is highy non-linear, as demonstrated by the scaling of the number pairs with the number of atoms in the pump mode. The emerging spin-pairs are ejected out of the BEC with opposite relative momentum in resemblance to PDC, facilitating direct observation of the four-photon process by spin- and momentum-resolved time-of-flight measurements. The resemblance to spin-changing collisions and the comparably faster dynamics provide near prospects for fast entanglement production and detection in cold atom experiments.

Leonardo Massai

Noise mitigation in silicon quantum devices

Superconducting circuits and spins confined in semiconductor structures represent two leading qubit implementations. Continuous fabrication improvements and a better understanding of semiconductor-oxide interfaces are crucial to enhancing qubit performance. We use noise spectroscopy in silicon quantum dots to evaluate the substrates and oxides. Furthermore, we present a novel design for superconducting resonators, aiming to improve their internal quality factor by modifying the conductor geometry and minimizing the presence of oxides at the relevant interfaces. We study the reproducibility of the fabrication and explore the properties of different superconducting materials. Addressing these sources of noise and reducing their impact on qubits will be critical for future development of scalable quantum-computing platforms.

Session 10

Diego Visani

NanoMRI with a membrane-based scanning force microscope

The ability to observe extremely small features in a non-destructive way is capital in understanding our surrounding environment. For instance, the direct three-dimensional (3D) observation of folded proteins or viruses can be a paradigm changer in structural biology and medical research. Magnetic resonance force microscopy (MRFM) is a promising technique to achieve these goals. Like conventional MRI, MRFM allows non-destructive 3D imaging of nuclear spin densities. However, by replacing the inductive coil detector with a nanomechanical force sensor, the pixel side length can be reduced from the 100 micrometer range to a few nanometers. Even so, current experiments are not yet sensitive enough to reveal new structural information. By combining nanomechanical membranes with low dissipation, advanced scanning techniques, and very low temperatures, we expect a further enhancement of the sensitivity by an order of magnitude beyond the state of the art. Our work would open the door to using cutting-edge nanomechanical resonators for single nuclear spin detection.

Christoph Adam

Measuring Entropy of Mesoscopic Systems

We measure the degeneracy of the ground state in an electrostatically defined quantum dot hosted on a two dimensional electron system in GaAs/AlGaAs. The dot is in thermal equilibrium with a reservoir and its states are weakly coupled to it allowing for exchange of particles and energy. The electronic temperature in the reservoir can be changed by applying a current. Electrons hopping onto the dot are detected with a quantum point contact used as a charge detector. The change of the mean particle number on the dot with respect to temperature is related to the change in entropy with respect to the electrochemical potential of the quantum dot. This relation enables us to learn something about the degeneracies of the dot states involved. The principle can be extended to any material system, in which one can have quantum dots, in particular bilayer graphene. The ground state degeneracy of an electron in a bilayer graphene quantum dot is something still debated among experts and this method provides means to access it.

Tristan Kuttner
Implementation of a SNAIL parametric amplifier

High-fidelity single-shot measurement of qubits is an important requirement for many quantum information processing applications. In superconducting circuits this is enabled through near quantum-limited parametric amplifiers which make use of the strong nonlinearity of Josephson junctions.
This type of amplifiers can be realized by embedding an array of superconducting nonlinear asymmetric inductive elements (SNAILs) in the center of $\lambda/2$ microstrip transmission lines. The resulting nonlinear mode can then be used to realize parametric amplification processes of the input signal, by driving it with a strong microwave pumping tone. These devices can operate in a broad bandwidth and achieve quantum-limited amplification, while in particular not sacrificing their quantum-limited noise performance.
During this project, the aim is to simulate and produce these SNAIL parametric amplifiers (SPA) for their use in bosonic quantum error correction. I will present the theory of three-wave mixing amplifiers as well as the methods of simulating and tuning the design and layout of SPAs, and finally iterate through the different fabrication processes and quality assurance steps that need to be taken in order to maximize the yield and quality of production.