QSIT Junior

Collection of Abstracts

for the

QSIT Junior Meeting 2020

11.06.2020

QSIT Quantum Science and Technology

National Centre of Competence in Research

Invited Speakers

Viktoria Yurgens:

Laser writing of nitrogen-vacancy centers in diamond for applications in open microcavites

Uwe von Lübke:

Quantum music

Fons van der Laan:

An optically levitated rotor at its thermal limit of frequency stability

Christa Zoufal:

Quantum Machine Learning on Near-Term Quantum Devices

Participants

Adelsberger, Christoph (Loss, University of Basel):

In my research I theoretically explore ways to combine spin qubits and topological qubits for future universal quantum computers. My first project is focused on the topological part, where I numerically analyze holes in silicon and germanium nanowires with strong direct Rashba spin-orbit interaction proximitized to a s-wave superconductor with a tight-binding model. Under the application of electric and magnetic fields we can observe a pair of topologically protected Majorana bound states at zero energy at the ends of the nanowire. The Zeeman gap size is a crucial parameter for the observation of Majorana bound states. In order to understand it, one needs to understand the effective g-factor which depends on orbital effects. I apply analytical and numerical methods to derive an effective description of the g-factor and to find its maximum for given material parameters.

Antoniadis, Nadia (Warburton, University of Basel):

Due to the scalability of their generation, single-photons are a promising candidate for qubits in quantum technology. We use a gated InAs QD coupled to a tunable optical microcavity as an on-demand source of single-photons. Our source's efficiency is the highest ever reported (57%). Moreover, the generated photons are coherent over long timescales and the source is stable and reproducible. The coupled QD-cavity system can further be extended with lateral excitation of the QD. This extension, combined with the high efficiency and coherence, would allow for generation of a string of entangled photons as required for cluster-state computation.

Gao, Jialiang (Novotny, ETH Zürich)**:**

I am studying the optical levited system. In this system, silicon particles can be trapped and levited by optical force. The aim of my project is to build an inertial sensor (more specifically, a rotation sensor) based on this optical levitation system. Due to the perfect isolation through levitation, sensing noise can be reduced and sensitivity can be could be improved.

Geyer, Simon (Warburton, University of Basel)**:**

Quantum information can be encoded in the spin state of a single electron or hole confined to a semiconductor quantum dot. Silicon is a particularly promising platform for scalable spin-based quantum computing due to its fully developed, industrial manufacturing processes. We create single and double quantum dots in silicon fin-field-effect transistors (FinFETs), which are fabricated using a self-alignment technique. Quantum transport measurements reveal signatures of Coulomb blockade and Pauli spin blockade at ‘hot’ temperatures of up to 10K. The strong spin-orbit coupling for holes in silicon allows for coherent hole spin manipulation via electric dipole spin resonance (EDSR) and thus to create a hole spin qubit.

Helmrich, Felix (Imamoglu / Faist, ETH Zürich)**:**

Ultrastrong coupling of electromagnetic vacuum fields to matter excitations has been predicted to influence the ground state phase diagram of the matter component. In this project, we investigate how the excitonic insulator phase is affected by ultrastrong coupling to a resonator in the THz frequency range. As a first step towards this goal, we develop on-chip THz time-domain spectroscopy (THz-TDS). THz radiation is generated optically using a photoconductive switch and guided to the resonator in a transmission-line geometry. The transmitted field is detected by electro-optic sampling.

Herb, Konstantin (Degen, ETH Zürich)**:**

70 years ago, Erwin Hahn published the first experimental demonstration of a Free Induction Decay (FID) experiment. Advances in quantum optics and material science enable us today to record the free precession signal of single ^{13}C nuclear spins inside a diamond crystal. The experimental instrumentation to achieve this sensitivity is not of a classical and macroscopic scale as in Hahn’s experiment, but rather of a microscopic scale. Indeed, the sensor is an electron spin: the electron spin of the Nitrogen-Vacancy (NV) center in diamond. The NV center platform aims at bringing NMR spectroscopy to the single molecule level with numerous applications in life science and fundamental physics.

Herman, Frantisek (Sigrist, ETH Zürich)**:**

The study itself is focused on experimental interpretation of transport measurements in metamagnetic system $Ca_{1.8}Sr_{0.2}RuO_4$. The metamagnetic transition is reached by tuning a van Hove singularity to the Fermi level at a critical magnetic field H_m. In $Ca_{1.8}Sr_{0.2}RuO_4$, we report across H_m a strong decoupling of inelastic electron scattering, measured by resistivity, and electronic mass, inferred from density-of-state probes. As a result, we observe - in contrast to conventional correlated Fermi liquids - a strong variation of the Kadowaki-Woods ratio. Fermi-liquid and non-Fermi-liquid properties associated with van Hove singularities are discussed in terms of disorder and dimensionality.

Herter, Alexa (Faist, ETH Zürich)**:**

My research aims to increase the sensitivity of weak electrical field measurements in the spectral range of THz radiation. Electo-optic sampling enabled to detect the electric field correlation of vacuum fluctuations, but for significant signal-to-noise ratios long integration times of several weeks are required. To decrease the measuring time, a promising approach is to increase the coupling between THz fields and probe beams by spatial confinement of the modes. Therefore I will try to implement a correlation measurement based on homodyne detection of the electrical field in on-chip antenna structures. Besides gaining deeper understanding on quantum states of light, these detectors offer many further applications, for example in the telecommunication.

Hess, Richard Gerhard (Klinovaja, University of Basel)**:**

Modelling of one-dimensional semiconducting Rashba nanowires proximity coupled to s-wave superconductors in the framework of tight binding simulations. Andreev bound states in the topological trivial phase. Examination of the influence of a step like Reproduction of the results concerning Rashba coupling. Investigation of the g-factor renormalization in one- and two-dimensional quantum dot systems.

Kreis, Carla (Merkt, ETH Zürich)**:**

My research focuses on the investigation of long-lived ion-pair states of small polyatomic molecules. The goal is to produce such state with photoexcitation with a narrow band dye laser and to determine their structure with threshold ion-pair production spectroscopy. This not only allows to get a better understanding of the long-range interaction of a system bound by a coulomb potential, but also to determine bond energies and electron affinities of those molecules with high accuracy.

Laubscher, Katharina (Klinovaja, University of Basel)**:**

We study topological phases in systems with strong electron-electron interactions. Particular focus lies on the emergence of exotic quasiparticles, such as parafermions, and their possible applications to topological quantum computation. In two recent works [Phys. Rev. Research 1, 032017(R) (2019) and Phys. Rev. Research 2, 013330 (2020)], we introduce models that realize second-order topological superconducting phases with Majorana corner states in the non-interacting case and and exotic parafermion corner states in the presence of strong electron-electron interactions

Mattana, Maria Luisa (Novotny, ETH Zürich)**:**

My project revolves around optomechanics and levitodynamics. Our main experiment consists in trapping a silica nanosphere with optical tweezers and analyzing its dynamics. The short-term goal is to bring this mesoscopic particle to its energetic ground state by cooling its center of mass motion with laser beams. The experiment is performed in a vacuum chamber inside a cryostat, taking advantage of very low environmental temperatures and pressures. Our research is important for sensing applications, and in general to advance research in the field of levitodynamics.

Nam, Nguyen (Warburton, University of Basel)**:**

Optical characterization measurements were performed using a dark-field microscope to resonantly excite single GaAs quantum dots. We demonstrate the successful charge-tuning of GaAs quantum dots. From resonance fluorescence measurements, we obtain emission linewidths as narrow as 850MHz and confirm the predicted decreased fine structure splitting of the GaAs quantum dots compared to InAs quantum dots. Furthermore, we confirm photon antibunching behavior through autocorrelation measurements and demonstrate spin-pumping into the dark state for the negatively and positively charged trion, yielding spin-pumping fidelities above 96%.

Piotrowski, Johannes (Novotny, ETH Zürich)**:**

At the intersection between micro- and macroscopic physics, levitated nanoparticles present an opportunity to observe quantum phenomena at mesoscopic scales. To reach the quantum regime, we trap particles in the field of an optical tweezer and cool their center of mass state via coupling to a microcavity. This opens further channels of nonlinear optomechanical interactions. We measure cross-coupling effects between different motional axes for accurate 3D thermometry, levelling the way to ground state cooling.

Portolés, Elias (Ensslin, ETH Zürich)**:**

When two layers of graphene are twisted by a small angle, a Moiré pattern appears. The coupling between the layers depends on the twist angle. With twisted double bilayer graphene, similar effects hold while a band gap can be opened in each bilayer by an out-of-plane electric field. Using local gates in devices with different twist angles we define junctions between electrons and/or holes in different bands. We then define cavities leading to Fabry-Pérot oscillations. For low enough twist angles, we reach the characteristic Van Hove singularity. This allows us to probe junctions and cavities between gamma-electrons (holes) and kappa-electrons (holes). We furthermore engineer regions in which one of the bilayers is gapped, thus leading to the definition of interlayer junctions. At some gating configurations, we observe gaps due to correlations or due to crystal field effects.

Prumbaum, Nils (Degen, ETH Zürich)**:**

Magnetic Resonance Force Microscopy (MRFM) is a scanning probe technique used to image objects at a nanometer scale resolution, by exciting spatially localized nuclear spins and measuring the resulting magnetic force acting on a ultra-sensitive force transducer. With this technique, one-dimensional resolutions of less than one nanometer were achieved. To achieve such high resolutions and high signal-to-noise ratios compared to classical Magnetic Resonance Imaging (MRI), the signal pick-up coils are replaced by a highly sensitive force transducer. Instead of induction currents, here, the response of a micromechanical cantilever to magnetic forces is detected which leads to a significantly higher signal-to-noise ratio. The cantilever motion is precisely measured by an fiber-based Fabry-Pérot interferometer. For very small spin volumes it is beneficial to detect the statistical spin polarization instead of the thermal Boltzmann polarization. In order to enable this measurement scheme, active feedback-damping is applied to the cantilever to achieve sufficiently large bandwidths.

Reiter, Nicola (Brantut, EPFL)**:**

We are setting up a new type of microscope, which consists of an ultra-cold Fermi gas in a high-finesse cavity, combined with a high-numerical-aperture lens (0.38). While atoms in the cavity can be detected through their dispersive interactions with light, a second laser beam focused tightly onto the atom cloud locally enhances the atom-cavity coupling and allows for non-destructive measurements of the atomic density with sub-micron resolution. Having control over the coupling, cavity-mediated interactions can be modified temporally as well as spatially. Currently, we are at the end of setting up the experiment and we expect to start trapping atoms in the cavity soon. In the course of my master´s thesis which aims at conducting first experiments on the cavityenhanced microscope, I have set up an experiment control system called labscript suite, allowing for the hardware-timing of our cold atom experiment. At the moment I am working on determining the wave front aberrations of the cavity lense, using phase retrieval techniques.

Roguski, Mikolai Franciszek (Willitsch, University of Basel)**:**

We are currently working on an experiment on the quantum control and precision spectroscopy of single ground-state cooled nitrogen ions, N_2^+, in an ion trap using quantum logic via co-trapped atomic ions, Ca^+. Recently, our group demonstrated a quantum-nondemolition state-detection scheme, which steps up the level of control over the trapped molecular ions. In order to further improve the accuracy of precision measurements and the fidelity of the molecular qubit that can be used for quantum experiments, I am currently working on the implementation of an EIT cooling scheme within the existing setup. This would allow us to simultaneously cool several vibrational modes of the ion Coulomb crystal, increase the cooling rate and achieve a lower minimum temperature of the trapped species.

Ruckriegel, Max (Ensslin, ETH Zürich)**:**

Atoms in one-dimensional free space can interact strongly with propagating photons. Kockum et al. recently proposed the notion of "giant atoms“ that connect to a waveguide at more than one point and thus have a physical dimension on the order of the wavelength. Intricate interference effects between the connection points lead to frequency dependent relaxation rates and interactions of giant atoms that can be engineered to a high degree. We demonstrate a successful implementation of giant atoms with transmon qubits in a microwave transmission line. We confirm that the frequency dependence of both, decay rates and exchange interactions can be engineered with high precision. At specifically designed frequencies we measure complete decoupling from radiation in the transmission line with T1 times approaching the natural lifetimes of transmons in the absence of the waveguide. In particular, we also observe waveguide-mediated exchange interactions between braided giant atoms at the points where the qubits are protected from energy relaxation.

Stocker, Lidia (Zilberberg, ETH Zürich)**:**

Quantum engineered mesoscopic devices composed of quantum dots coupled to electronic cavities have showcased fascinating many-body physical phenomena. We investigate dot-cavity devices analytically and, with Numerical Renormalisation Group and Matrix Product States techniques, numerically. Our results for the quantum dot and dot-cavity systems corroborate previous observations. In our analytical investigation of the dot-cavity-dot setup, we find signatures for a molecular Kondo formation and long-range dot-dot hybridisation. Our numerical agreements pave the way to extend the work in [G. Nicoli et al. Phys. Rev. Lett. 120, 236801 (2018).] with the experimental hunt for non-local Kondo impurities.

Swiadek, François (Wallraff, ETH Zürich)**:**

I do experimental research in the group of Prof. Andreas Wallraff on superconducting quantum devices. The concept of universal quantum computing requires an extensible and scalable platform of qubits, combined to quantum error correction (QEC) to achieve fault-tolerancy. My research focuses on the design of noisy intermediate-scale quantum (NISQ) devices on which we study the Surface code for QEC. In particular, my work includes simulations and tests of the interdependencies between qubits, couplers between qubits, and the readout circuitry of such a device, from a design perspective.

Talebi, Mohsen (Esslinger, ETH Zürich)**:**

The main aim of the research in the Quantum Optics group is to investigate the many body quantum phenomena in atomic thermodynamic systems. To reach the quantum limit, the temperature of the system is decreased using laser-cooling methods (Doppler cooling methods, evaporative cooling, ...). In the Lithium lab, we decrease the temperature of a gaseous cloud of fermionic lithium-6 to the tens of nanokelvin. After these steps, we manipulate the structure of the cloud using the potential landscapes created by the dipole force of far-detuned laser beams and tune the interatomic interactions using a magnetic Feshbach resonance. The main physical motivation in this experiment is to investigate the transport phenomena in interacting, degenerate fermionic matter.

Varghese, Blesson Sam (Schönenberger, University of Basel)**:**

The field of 2d materials is advancing a lot after the discovery of graphene. Strain engineering is a new field that explores the effect of strain on different material properties like optical, electrical transport etc. Optical studies are carried out on different 2d materials with strain as a parameter to understand the band structure changes of the material. The work focuses on the effect of strain on the electrical transport through the materials and the underlying mechanisms involved.

Zheng, Han (Schönenberger, University of Basel)**:**

My project is mainly on quantum transport with 1D Ge/Si core/shell nanowire. According to the theory of Kiteav's chain, 1D nanowire with p-wave coupling could host Majorana zero mode at the two end of the wire. Intrinsic p-wave coupling material is not common in nature. However, a one-dimension topological superconductor can be engineered in semiconducting nanowires (NWs) with strong spin-orbit inter-action (SOI) coupled to a "normal" BCS-type superconductor in magnetic field. Most of the work in this area has been performed with III-V semiconductors, e.g. with InAs and InSb. In this project, the use of holes in Ge/Si is motivated by a recent prediction that these holes have a large SOI which is tunable.

Zhu, Zijie (Esslinger, ETH Zürich):

My master thesis is mainly about preparations for future experiments on Bose-Fermi mixtures in optical lattices. On theoretical side, we study the geometry of the trapping potential in the presence of gravity and the density profiles of bosonic and fermionic clouds in the trap. In addition, we study the Bose-Fermi-Hubbard model and how its parameters depend on interaction strengths. On the experimental side, we focus on the stabilization of the current which generates the magnetic fields for a Feshbach resonance, where we realize mains synchronization which can greatly reduce the shot-to-shot noise induced by 50 Hz noise and its higher harmonics. We also discover another, previously unknown, noise source in the experiment by analyzing the results of Ramsey and Spin-Echo experiment and comparing them with simulations.

Zwettler, Timo (Brantut, EPFL):

Quantum-degenerate atomic gases represent paradigmatic systems for the study of many-body and fundamental physics applications, as extreme quantum conditions can be engineered with remarkably high precision. By the use of Feshbach resonances, we can investigate the strong interaction regime in an ultracold gas. In our experiment, we combine a quantum degenerate, unitary Fermi gas of ^{6}Li with a high finnesse optical cavity, greatly enhancing the atom-photon coupling. We demonstrate strong coupling of the Fermi gas to light by measuring the transmission spectrum of the coupled system for both the spin-polarized and spinbalanced case. For the spin-polarized case, we find the well-known anti-crossing of the excitations of the strongly coupled light-matter system. In the spin-balanced case, we find the two anti-crossings of both spin components and additional signals originating from the presence of strong inter-atomic interactions. Our system provides exceptionally good and simultaneous control over atom-atom and atom-light interactions and paves the way for continuous quantum non-demolition measurements of fermionic transport in strongly correlated systems as well as the creation of novel light-induced phases of matter.