VCQ SUMMER SCHOOL
2021
QUANTUM SENSING & IMAGING

BOOK of ABSTRACTS

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About the Summer School

The 14th edition of the Vienna Center for Quantum Science & Technology (VCQ) summer school takes place from 6th to 10th of September 2021 at the Atominstitut of TU Wien in Vienna, Austria.

Four distinguished professors will deliver lecture series on the basics of quantum sensors and imaging techniques and their applications in various fields. During the summer school, the participants will have the opportunity to interact and discuss their research in multiple occasions. Seven Participants will give a 20 minutes presentation of their work and 50 other participants will present posters in two dedicated poster sessions (on Monday the 6th and Thursday the 9th) In addition to these presentations, there will be a VCQ Special lecture for general audience.

About VCQ

The Doctoral Program of the Vienna Center for Quantum Science and Technology, is a continuation of the former doctoral college on Complex Quantum Systems (CoQuS), and it holds an annual summer school for international young researchers interested in several fields of quantum physics. The school is organised by PhD candidates of the doctoral program. Over the past 14 years, highly distinguished international experts have given introductions into ground-breaking theoretical concepts and experimental approaches in fundamental and applied quantum science which they pioneered in their own research. The VCQ doctoral program is funded by the Austrian Science Fund (FWF) and it is a joint initiative of the Vienna University of Technology (TU Wien), the University of Vienna, the Institute of Science and Technology Austria (IST) and the Austrian Academy of Sciences (ÖAW). It acts as a training centre for more than 100 early stage researchers who are selected from an international pool of applicants, based on their academic excellence, scientific success and ambition.

Contents

Lecture Series

Quantum sensors with colds atoms: from basic principles to recent developments

Philippe Bouyer

CNRS, Institut d'Optique, Bordeaux, France

The remarkable success of atom coherent manipulation techniques has motivated competitive research and development in precision metrology. Matter-wave inertial sensors – accelerometers, gyrometers, gravimeters – based on these techniques are all at the forefront of their respective measurement classes. Atom inertial sensors provide nowadays about the best accelerometers and gravimeters and allow, for instance, to make the most precise monitoring of gravity or to device precise tests of general relativity. They also offer an opportunity to push forward new applications such as underground survey, GPS-free navigation, gravitational wave detection. In this lecture series, I will present the basic concepts behind these quantum sensors and introduce some recent developments, such as space or large scale sensors for fundamental physics or new concepts for future, compact, sensors.

Zero- to ultralow-field nuclear magnetic resonance and other atomic-magnetometry adventures from chemistry to dark matter

Dmitry Budker

Johannes Gutenberg University Mainz, Germany

Atomic magnetometers are sensitive quantum sensors that have undergone several decades of development and have been used in myriad applications, from geophysics to tests of fundamental symmetries of Nature. In this series of lectures, we will discuss how the magnetometers work and explore one of their relatively recent applications—nuclear magnetic resonance without magnets, which is now a multidisciplinary branch of science in itself.

Quantum sensing enabled by diamond spin qubits

Fedor Jelezko
Universität Ulm, Germany

We will review modern developments in quantum technologies based on diamond colour centres. The physics of colour centres and methods for detection of individual defects will be introduced. We will also discuss realisation of spin based quantum processors and elements of quantum repeaters based on colour centres. Applications of diamond spin qubits for sensing and metrology will be introduced.

A particularly interesting application of diamond based quantum sensing is the detection of nuclear magnetic resonance on nanometer scales, including the detection of individual nuclear spins or small ensembles of external nuclear spins. Single nitrogen vacancy (NV) color centers in diamond currently have sufficient sensitivity for detecting single external nuclear spins and resolve their position within a few angstroms. The ability to bring the sensor close to biomolecules by implantation of single NV centers and attachment of proteins to the surface of diamond enabled the first proof of principle demonstration of proteins labelled by paramagnetic markers and label-free detection of the signal from a single protein. Single-molecule nuclear magnetic resonance (NMR) experiments open the way towards unraveling dynamics and structure of single biomolecules. However, for that purpose, NV magnetometers must reach spectral resolutions comparable to that of conventional solution state NMR. New techniques for this purpose will be discussed.

Most of the mentioned above results obtained so far with diamond centers are based on optical detection of single NV color centers. We will also show how photo-electrical detection of NV centres based on spin selective photoionization can provide robust and efficient access to spin state of individual colour centre.

Imaging with entangled photons

Miles Padgett
University of Glasgow, UK

Quantum Technologies hold the promise to revolutionise imaging, pushing the boundaries of what is possible beyond traditional limits. This series of lectures will present a personal view of recent developments, especially those which use detector arrays to take advantage of the correlations between entangled photon pairs. Camera technologies range from electron multiplying CCDs which boast extremely high quantum efficiency and image intensified CCDs which although having much lower efficiency can be run with sub nanosecond timing resolution, to the latest generation of CMOS cameras that can count the number of photons in each pixel. Alongside these spatial detection technologies are technologies for spatially shaping both light beams and individual photons. These shaping technologies are based on both liquid crystal phase modulators with high diffraction efficiency and digital mirrors that are less efficient but much higher speed. The lectures will explain the role and choices of these technologies in various demonstrations of different quantum enhanced imaging schemes.

VCQ Special Lecture

Squeezed light – now exploited by all gravitational-wave observatories

Roman Schnabel

Institut für Laserphysik, Universität Hamburg, Germany

Light with squeezed quantum uncertainty allows for the sensitivity improvement of laser interferometers. Since 2010, the gravitational-wave (GW) detector GEO600 has been using squeezed light in all of its searches for GWs [1]. The successful sensitivity improvement triggered the implementation of squeezed light sources also in Advanced LIGO and Advanced Virgo. On April 1st, 2019 these observatories started their third observational run. Since then, they have been detecting more than one GW event per week. An increased event rate of up to 50 is due to the exploitation of squeezed states of light[2] [3]. Squeezed light is fully described by quantum theory; however, observations on squeezed light represent physics that is not self-evident. I present a clear description of why a squeezed photon-counting statistic is rather remarkable[4].

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[1]LIGO Scientific Collaboration, Nature Physics 7, 962 (2011)

[2]M. Tse et al., Phys. Rev. Lett. 123, 231107 (2019)

[3]F. Acernese et al., Phys. Rev. Lett. 123, 231108 (2019)

[4]R. Schnabel, Annalen der Physik 532, 1900508 (2020)

Student Talks

A Compact Atom Interferometer with Tunable Interactions

Sep 7th
3:00 PM

Benedikt Gerstenecker, Maximilian Lerchbaumer, Shreyas Gulhane, Christian Altvater, Florian Honz, Stephanie Manz and Thorsten Schumm

Atominstitut, Technische Universität Wien (TU Wien), Austria

The matter-wave properties of atoms and the macroscopic behavior of Bose-Einstein condensates make interference experiments with ultracold atoms a useful tool for both fundamental research and metrology applications. My talk will motivate the implementation of a compact interferometer using Caesium atoms, report the current progress of our experiment, and outline its main prospects.

I will show how our unique design allows us to combine the advantages of atomchip technology with the flexibility of optical traps and furthermore the favorable magnetically induced Feshbach resonances in Caesium, which are well-suited for interaction-tuning and therefore enable condensation of this challenging atomic species. The tunability of the atoms' scattering length and the convenient access to the trap characteristics of the optical potential will give us full control over the crucial parameters, allowing for the simulation of different regimes of two-mode systems as well as for competing with the sensitivity of large interferometric sensors.

Spectroscopic studies of aluminium monofluoride with relevance for laser cooling and trapping

Sep 7th
3:20 PM

Maximilian Doppelbauer[1], Nicole Walter[1], Simon Hofsäss[1], Silvio Marx[1], Christian Schewe[1], Sebastian Kray[1], Jesús Pérez Ríos[1], Boris Sartakov[2], Stefan Truppe[1], Gerard Meijer[1]

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[2]Prokhorov General Physics Institute, Russian Academy of Sciences, Moscow, Russia

The aluminium monofluoride (AlF) molecule has proven favourable properties for laser cooling and trapping experiments at high densities. Recently, it has been shown that all Q-lines of the $A^1\Pi$-$X^1\Sigma^+$ transition can be used for rapid optical cycling. AlF is sensitive to variations in the proton-to-electron mass ratio μ and the proton EDM. Because AlF can be trapped, long coherence times can be exploited for these studies.

The triplet manifold of AlF is being studied for several reasons. The long lifetime of

the $a^3\Pi$ state allows to precisely determine line positions and spectroscopic parameters and serves as a starting point for the investigation of the singlet cooling cycle. We determined the energy levels within each Ω manifold of the $a^3\Pi, v = 0$ state with a relative accuracy of a few kHz, using laser-radio-frequency multiple resonance and ionization detection schemes in a jet-cooled, pulsed molecular beam. The $a^3\Pi$-$X^1\Sigma^+$ transition can be used for narrow linewidth cooling of pre-cooled AlF molecules to the recoil limit (1.5 µm).
The $b^3\Sigma^+$ state serves for hyperfine-resolved fluorescence detection of triplet molecules; it interacts with the singlet manifold via spin-orbit coupling. The hyperfine structure in the $b^3\Sigma^+, v = 0$ state and the interaction with the $A^1\Pi$ state were investigated in high-resolution continuous wave laser spectroscopy experiments.

Sep 7th
3:40 PM

Modeling and observation of nonlinear damping in dissipation-diluted nanomechanical resonators

Letizia Catalini, Massimiliano Rossi, Eric C. Langman, Albert Schliesser
Niels Bohr institute, University of Copenhagen, Denmark

In the last decades, significant progress in engineering micro- and nanomechanical resonators has resulted in a rich number of applications in sensing experiments and quantum science, where high coherence has critical role. To this end, the introduction of the dissipation dilution enables extremely low linear loss in stressed nanomechanical resonators, such as strings or membranes. In the last decades, significant progress in engineering micro- and nanomechanical resonators has resulted in a rich number of applications in sensing experiments and quantum science, where high coherence has critical role. To this end, the introduction of the dissipation dilution enables extremely low linear loss in stressed nanomechanical resonators, such as strings or membranes. The low mass of these resonators, combined with their high quality factors, makes them a promising platform for magnetic resonance force microscopy (MRFM) experiments, by enabling force sensitivity on the order of the order of $\mathrm{aN}/\sqrt{\mathrm{Hz}}$. Here, we report on the observation and theoretical modelling of nonlinear dissipation in such structures. We introduce an analytical model based on von Kármán theory, which can be numerically evaluated using finite-element models for arbitrary geometries. Through this approach, we predict both nonlinear loss and (Duffing) frequency shift in ultracoherent phononic membrane resonators. A set of systematic measurements on a range of complex mode shapes, geometric parameters, and temperatures shows good agreement with the model for low-order soft-clamped modes. Our analysis also reveals quantitative connections between these nonlinearities and dissipation dilution. This is of interest for future design of novel resonators geometries and the characterization of the performance of dissipation-diluted devices, yielding otherwise inaccessible insight when diagnosing their performance in an experimental setting.

Optimised Nitrogen-vacancy Spin-state Initialisation and Manipulation for DC Magnetometry

Sep 7th
4:00 PM

Nimba Oshnik[1,2], Phila Rembold[3,4,5], Matthias M. Müller[6], Simone Montangero[4,5], Tommaso Calarco[6], and Elke Neu[1]

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[2]Universität des Saarlandes, Faculty of Natural Sciences and Technology, Physics, Campus E2.6, D-66123 Saarbrücken, Germany
[3]Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany
[4]Dipartimento di Fisica e Astronomia "G. Galilei", Università degli Studi di Padova, I-35131 Padua, Italy
[5]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Padova, I-35131 Padua, Italy
[6]Forschungszentrum Jülich GmbH, Peter Grünberg Institute - Quantum Control (PGI-8), D-52425 Jülich, Germany

Nitrogen-vacancy (NV) centers in diamond are one of the cornerstones of the emerging and fast-growing field of quantum technology[5]. The potential for efficient optical spin-state initialisation & coherent, microwave-based manipulation of NV spin qubits are fundamental to it's versatile applicability as a quantum sensor. This naturally offers a prospective two-way approach to optimise spin manipulation schemes for improved NV based magnetometers; optimisation of pulsed laser assisted spin-state initialisation/readout process, along with optimisation of microwave-based spin control gates can be interpreted as quantum optimal control problems[6]. In this context, this work investigates closed-loop based optimisation of DC magnetometry methods with shallow-single NV centers in diamond. The optimisation goal here is to enhance the spin readout contrast and incorporate robustness against power variation in the control pulses. Such goal functions under the feedback based optimization strategy inherently undermine the limitations imposed by experimental imperfections, unknown system parameters and finite dephasing times. This work reports enhanced sensitivity of sub-$\mu THz^{-\frac{1}{2}}$ with the pulsed-ODMR experiments, and sensitivity of the order $10^2 nTHz^{-\frac{1}{2}}$ with the Ramsey protocol for DC magnetic field sensing. Such optimised sensing schemes are suitable for a variety of magnetometry applications, e.g. those involving ensemble of NV centers or scanning NVs, as well as other quantum systems where the lack of complete knowledge about the system Hamiltonian and associated experimental parameters adheres the scope of simulation based optimisation.

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[5]Rembold, P., Oshnik, N. et al. Introduction to quantum optimal control for quantum sensing with Nitrogen-vacancy centers in diamond, AVS Quantum Sci. 2, 024701 (2020)

[6]Glaser, S., Boscain, U., Calarco, T. et al. Training Schrödinger's cat: quantum optimal control. Eur. Phys. J. D 69, 279 (2015)

Sep 8th
4:20 PM

Decoherence in superconducting circuits based on fluxonium architecture

Larisa-Milena Pioras-Timbolmas[1 2], Liviu Zarbo[1]

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Because of the scalability towards larger systems, the good capability for external manipulation, high anharmonicity with multiple accessible levels, while suppressing the effect of offset charges, the fluxonium qubit is an excellent choice of a superconducting qubit.[7] We evaluate and characterize an artificial atom based on superconductors, using the fluxonium qubit architecture in the regime in which the flux noise is minimized. We perform numerical calculations for the system coupled to a readout resonator in order to allow a precise characterization.

Sep 8th
4:40 PM

Scaling nuclear magnetic resonance to the single spin level

Konstantin Herb, John Abendroth, Erika Janitz and Christian Degen

Department of Physics, ETH Zürich, Otto-Stern-Weg 1, 8093 Zurich, Switzerland

The structure elucidation of macromolecules and molecular complexes is an important topic in molecular biology and biochemistry. The nitrogen vacancy center (NV center), one of the numerous color defects in diamond is seen as a promising platform for scaling nuclear magnetic resonance down to the single molecule level and to perform high-resolution spectroscopy.

In this talk, we report on our recent attempts to map the nuclear spin signals of individual ^{13}C atoms the in the atomistic environment of the NV center and to measure their inter-nuclear couplings at room temperature. The sparse ^{13}C nuclei serve as an ideal test bed for the long-term goal of imaging individual molecules that are attached to the diamond surface. Towards that goal, we report on our ongoing work on bringing NV centers close to the surface and preparing the surface in a controlled manner. We show fluor signals obtained by a systematic functionalization of the diamond surface.

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[7]Vool U.,Devoret M.,Introduction to Quantum Electromagnetic Circuits, Int.J.Circ.Theor.Appl. 45:897-934,(2017)

Tunable directional scattering from a pair of superconducting qubits

Sep 8th
5:00 PM

E.S. Redchenko[1], Alexander V. Poshakinskiy[2], Alexander N. Poddubny[2], and J.M. Fink[1]

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[2] Ioffe Institute, St. Petersburg 194021, Russia

The ability to control the direction of scattered light in integrated devices is crucial to provide the flexibility and scalability for a wide range of the on-chip applications, such as integrated photonics, quantum information processing and nonlinear optics. Nonreciprocal devices can be realized using magnetic field, nonlinear effects, stimulated Brillouin scattering, or parametrically driven mechanical systems. Here we demonstrate tunable directional scattering with just two transmon qubits with periodically modulated transition frequency coupled to a transmission line. Such a device could be used for the design of topologically protected states and to route microwave radiation for the realization of chiral networks.

Posters (Monday Session)

Towards deterministic generation of time-bin entangled photons from GaAs quantum dots **P1**

Florian Kappe[1], Yusuf Karli[1], Vikas Remesh[1], Santanu Manna[2], Armando Rastelli[2] and Gregor Weihs[1]

[1]Institute for Experimental Physics, University of Innsbruck, Austria
[2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University of Linz, Austria

Semiconductor quantum dots are bright, on-demand single photon sources suitable for realising quantum communication devices. We present our progress towards the deterministic generation of time-bin entangled photon states utilizing single GaAs/AlGaAs quantum dots. Our scheme relies on the use of highly chirped picosecond laser pulses and an optically dark exciton state acting as a metastable state. Numerical simulations of the quantum dot dynamics yield predictions of the state preparation fidelity. To demonstrate the efficacy of chirped excitation pulses we present results of an adiabatic-rapid-passage excitation scheme acting on a two-photon resonant transition to the neutral biexciton state. This scheme allows the implementation of a deterministic two-photon source insensitive to power fluctuations of the pump laser.

Coherent control of ion motion via Rydberg excitation **P2**

Marion Mallweger, Harry Parke, Shalina Salim, Chi Zhang and Markus Hennrich
Stockholm University (SU)

Trapped Rydberg ions are a novel approach to quantum information processing. This idea combines qubit rotations in the ions' ground states with entanglement operations via the Rydberg interaction. Importantly, the combination of quantum operations in ground and Rydberg states requires the Rydberg excitation to be controlled coherently. In the experiments presented here a trapped strontium ion was excited from the metastable 4D to Rydberg states. The excitation to Rydberg states modifies the electric trapping fields. Continuous transitions between the ground and the Rydberg states can therefore cause a geometric phase accumulation via the ion motion. We investigate this effect and perform coherent Rydberg excitation using stimulated Raman adiabatic passage (STIRAP). Such control of the ion motion would allow us to investigate the dynamics at a conical intersection of the trapping

potential, and thus enable quantum simulations of molecular dynamics. Additionally, the excitation of motional modes via Rydberg excitation could be used for realizing a fast quantum phase gate.

P3

Photon pair generation in ultra-thin carbon nanotube films without phase-matching

Philipp K. Jenke[1], Irati Alonso Calafell[1], Alessandro Trenti[1], Kimmo Mustonen[2], Lee A. Rozema[1], Philip Walther[1]

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In sufficiently thin nonlinear materials, the phase-matching condition of four-wave mixing (FWM) relaxes. We characterize the resulting broadband biphoton states by stimulated emission tomography, and present progress towards photon pair generation in ultra-thin carbon nanotube films.

Our 200 nm thick single-walled carbon nanotube films (much smaller than the pump wavelength of around 810nm) impose energy conservation as the only requirement in the nonlinear interaction, resulting in strong two-photon energy correlations.[8] Additionally, the absence of phase-matching means that the photon pairs are highly entangled in frequency and separable in all other degrees of freedom.[9]

Using stimulated emission tomography[10] we characterize the joint spectral intensity of the generated biphoton state. We keep the pump wavelength constant and stimulate the FWM process with different wavelengths. The measured spectral width of the state extends over more than 50 THz. To conclude, broadband stimulated emission tomography measurements on single-walled carbon nanotubes have been successfully demonstrated, which shows the potential to generate photon pairs with broadband entanglement.

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[8]C. Okoth, et al., "Microscale Generation of Entangled Photons without Momentum Conservation", Phys. Rev. Lett. 123, 263602 (2019).

[9]C. Yuan, et al., "Spatiotemporally Separable Biphoton State Generated by Spontaneous Four Wave Mixing in Ultrathin Nonlinear Films", arXiv:1903.10936

[10]B. Fang, et al., "Fast and highly resolved capture of the joint spectral density of photon pairs", Optica 1, 281-284 (2014).

Scalable Quantum State Tomography with Artificial Neural Networks **P4**

Tobias Schmale[1], Moritz Reh[1], Martin Gärttner[1,2,3]

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[2]Physikalisches Institut, Universität Heidelberg

[3]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg

Modern day quantum simulators can prepare a wide variety of quantum states but extracting observables from this "quantum data" often remains a challenge. We tackle this problem by developing a quantum state tomography scheme for open quantum systems, which relies on approximating the target POVM (positive operator valued measurement) distribution in a variational manifold represented by a convolutional neural network. We show an excellent representability of typical ground- and steady states within the network, often requiring only a polynomial scaling in the number of variational parameters. This compressed representation allows us to achieve RMS (root mean square) errors of experimentally interesting observables that are up to an order of magnitude smaller than what is obtainable via standard methods for identical sample sizes.

Ultrafast Molecular Dynamics in Suprafluid Helium Droplets **P5**

Michael Stadlhofer, Kerstin Absenger, Bernhard Thaler, Markus Koch

Institute for Experimental Physics, Graz University of Technology, Austria

Suprafluid helium droplets offer fascinating opportunities for ultrafast time-resolved studies of molecular dynamics. However, the influence of the quantum-solvent helium on molecular properties and dynamics, such as potential energy curves and their couplings, or the alteration of intramolecular relaxation pathways, still needs to be explored. With my PhD thesis I aim to develop time-resolved He droplet spectroscopy into a powerful tool, which will then be used to investigate complex molecular systems with technological or biological relevance. Aluminum dimers and iodine molecules form the starting point of this development. The simple molecules serve as model systems for the investigation of the helium solvent influence on dopants. As experimental methods, time-resolved photoelectron and ion spectroscopy are utilized for examining the doped helium droplets. More advanced techniques such as coincidence / covariance detection and velocity map imaging can be used to gain information about electron-ion correlation and the electron momentum distribution respectively. Experimental results are compared to ab-initio wavepacket simulations which enable a clear assignment of the observed phenomena to particular molecular states.

P6 Quantitative study of the response of a single NV defect in diamond to magnetic noise

Maxime Rollo[1], Aurore Finco[1], Rana Tanos[1], Florentin Fabre[1], Thibaut Devolder[2], Isabelle Robert-Philip[1], Vincent Jacques[1]

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The dynamical study of the nitrogen-vacancy (NV) defect is a powerful tool to image randomly fluctuating magnetic signals. The longitudinal spin relaxation of the NV center is indeed accelerated in the presence of magnetic noise featuring a spectral component at its spin resonance frequency. Instead of recording this relaxation time to probe the magnetic noise, we here propose a novel strategy which relies simply on the measurement of the NV center photoluminescence (PL) level. By applying a calibrated and tunable magnetic noise on a single NV defect, we show that the reduction of the relaxation time, also comes with a reduction of the PL level, which we explain by use of a simplified three level model of the defect[11]. This PL variation with the magnetic noise at the spin resonance frequency offers a simple, all-optical method to detect the magnetic noise at the nanoscale[12].

P7 Phonon-assisted transport in a quantum dot coupled to a Majorana bound state

Levente Máthé[1,2], Doru Sticlet[1] and Liviu P. Zârbo[1]

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We study quantum transport through a quantum dot connected to the one of Majorana bound states located at the ends of a topological superconductor nanowire in the presence of electron-phonon interaction. The localized electrons in the dot interact with a single long-wave optical phonon mode. The electron-phonon interaction is treated by using the canonical transformation within the nonequilibrium Green's function formalism. The retarded Green's functions are determined by applying the equation of motion method. We find that when the two Majorana bound states do not overlap, the zero-temperature linear conductance is independent of the quantum dot energy, the finite values of dot-Majorana coupling, or the strength of electron-phonon interaction. Moreover, the zero-temperature linear conductance changes significantly when the Majorana bound states overlap. The differential conductance spectra consist of phonon-assisted satellite peaks due to the electron-phonon interaction. We hope that our results will provide insight into phonon-assisted Majorana-induced transport signatures.

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[11]M. Rollo et al. Phys. Rev. B 103, 235418 (2021)

[12]A. Finco et al. Nat. Commun.12 (2021), 767

Heterodyne sensing of microwaves with a quantum sensor **P8**

Jonas Meinel[1,2] , Vadim Vorobyov[1], Boris Yavkin[1], Durga Dasari[1,2], Hitoshi Sumiya[3], Shinobu Onoda[4], Junichi Isoya[5] & Jörg Wrachtrup[1,2]

[1] 3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany.
[2] Max Planck Institute for Solid State Research, Stuttgart, Germany.
[3] Advanced Materials Laboratory, Sumitomo Electric Industries Ltd., Itami, Japan.
[4] Takasaki Advanced Radiation Research Institute, National Institutes for Quantum and Radiological Science and Technology, Takasaki, Japan.
[5] Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan

The nitrogen vacancy center in diamond (NV) is sensitive to static and time varying signals. If the signal of interest is longer as the fundamental lifetime of the quantum sensor, for the NV spin typically 1 ms, it requires support by a quantum memory or synchronized measurements techniques to catch the dynamics. The latter can by achieved by applying a synchronized dynamical decoupling sequence (DD), creating a lock-in response. However it fails for frequencies larger than ≈ 10 MHz. Here we present a method to detect a 4 GHz microwave (MW) signal[13]. We mix the MW signal with a reference MW source in the rotating frame of the sensor and optically readout the relative phase via the NV fluorescence. This heterodyne response allows to demodulate the MW signal to low frequencies and make it accessible for detection. Further we show that the interaction of the reference and the signal can be controlled by dressed states, like pulsed Mollow triplets or Floquet dynamics. While pulsed Mollow triplet increase the sensitivity, Floquet dynamics allow control independent of the system's resonance. This work is of importance for studies of weak and coherent oscillating signals in the MW regime.

Inverse design of artificial two-level systems with Mössbauer nuclei in thin-film cavities **P9**

Oliver Diekmann, Dominik Lentrodt and Jörg Evers

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We theoretically investigate the platform of Mössbauer nuclei in thin-film cavities for applications in x-ray quantum optics. Thin-film cavities are stacks of layers of different materials. One or several of the layers consist of a Mössbauer isotope (typically Fe57), i.e. the nuclei within this layer have a spectrally very narrow nuclear transition. At low probing intensities, the nuclei-cavity system is equivalent to a quantum few-level scheme, e.g. a single, thin layer of Mössbauer nuclei in the cavity forms an artificial two-level system (TLS) whose transition frequency and decay constant we can tune by e.g. modifying the surrounding cavity. The capabilities of the platform have already been hinted in a number of experiments.

While it is possible to ab initio calculate the quantum optical system simulated by a cavity structure, the inverse problem of finding the cavity structure to realize a desired level scheme is an open problem. Using a quantum optical framework based

[13]Meinel, J., et al., Nature comm. 12.1 (2021): 1-8.

on the electromagnetic Green's function, we could recently solve this problem for the TLS case, and determined its full tuning capabilities while taking into account practical considerations. The approach will also allow for extensions to multi-level schemes, otherwise inaccessible at hard x-ray energies, and, thus, promises to further the field of x-ray quantum optics towards applications in spectroscopy and x-ray based quantum technologies.

P10

Zero-field nuclear magnetic resonance spectroscopy with the use of atomic sensors

Piotr Put[1], Seyma Alcicek[1], Vladimir Kontul[1], Szymon Pustelny[1]

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In recent years zero- to ultralow-field (ZULF) nuclear magnetic resonance (NMR) emerged as a new portable, and cost-effective technique enabling high-precision chemical analysis through a direct observation of spin interactions in the absence of large external magnetic field. The method relies on a direct access to indirect spin—spin interactions (J-coupling) due to a vanishing Zeeman interaction in the absence of an applied magnetic field and averaged out direct spin—spin couplings occurring in isotropic liquids. This J-coupling yields, rich in useful information about the electronic structure, spectra with remarkably narrow resonance lines as a result of the high absolute field homogeneity and long spin coherence times under ultra-low field conditions. To observe a zero-field NMR spin dynamics occurring up 1 kHz, one need to replace inductive detection with a sensor sensitive in a near DC frequency range. We employ atomic magnetometers for this purpose characterized by low-price, small size, and noncryogenic operation. Basics of zero-field NMR experiments will be presented as well as obtained spectra for a range of small biomolecules ranging from metabolites, sugars to amino acids. Method for simulation and interpretation of the spectra will be shown and the influence of the chemical environment (i.e. chemical exchange) on the biomolecular spectra will be discussed. We plan to present prospects of chemical identification based on the biomolecular zero-field spectra library and consider a way towards measurements in biological samples with the use of hyperpolarization techniques.

Optimized Planar Microwave Antenna for Nitrogen Vacancy Center based Sensing Applications

P11

Oliver Roman Opaluch, Nimba Oshnik, Richard Nelz and Elke Neu

Department of Physics, University of Kaiserslautern, Germany

Individual nitrogen vacancy (NV) color centers in diamond are versatile, spin-based quantum sensors. Coherently controlling the spin of NV centers using microwaves in a typical frequency range between 2.5 and 3.5 GHz is necessary for sensing applications. In this work, we present a stripline-based, planar, Ω-shaped microwave antenna that enables to reliably manipulate NV spins. We find an optimal antenna design using finite integral simulations. We fabricate our antennas on low-cost, transparent glass substrate. We demonstrate highly uniform microwave fields in areas of roughly 400×400 μm^2 while realizing high Rabi frequencies of up to 10 MHz in an ensemble of NV centers.

Collective radiative dynamics of an ensemble of cold atoms coupled to an optical waveguide

P12

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We experimentally and theoretically investigate collective radiative effects in an ensemble of cold atoms coupled to a single-mode optical nanofiber. Our analysis unveils the microscopic dynamics of the system, showing that collective interactions between the atoms and a single guided photon gradually build-up along the atomic array in the direction of propagation of light. These results are supported by time-resolved measurements of the light transmitted and reflected by the ensemble after excitation via nanofiber-guided laser pulses, whose rise and fall times are shorter than the atomic lifetime. Superradiant decays more than one order of magnitude faster than the single-atom free-space decay rate are observed for emission in the forward-propagating guided mode, while at the same time no speed-up of the decay rate are measured in the backward direction. In addition, position-resolved measurements of the light that is transmitted past the atoms are performed by inserting the nanofiber-coupled atomic array in a 45-m long fiber ring-resonator, which allow us to experimentally reveal the progressive growth of the collective response of the atomic ensemble. Our results highlight the unique opportunities offered by nanophotonic cold atom systems for the experimental investigation of collective light-matter interaction.

P13

Certification of High-Dimensional Entanglement in Ultracold Atom Systems

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Quantum entanglement has been identified as a crucial concept underlying many intriguing phenomena in condensed matter systems such as topological phases or many-body localization. Recently, instead of considering mere quantifiers of entanglement like entanglement entropy, the study of entanglement structure in terms of the entanglement spectrum has shifted into the focus leading to new insights into fractional quantum Hall states and topological insulators, among others. What remains a challenge is the experimental detection of such fine-grained properties of quantum systems. Here we present a method to bound the width of the entanglement spectrum or entanglement dimension of cold atoms in lattice geometries, requiring only measurements in two experimentally accessible bases and utilizing ballistic time-of-flight (ToF) expansion. We first consider entanglement between two atoms of different atomic species and later generalize to higher numbers of atoms per species and multispecies configurations showing multipartite high-dimensional entanglement. Through numerical simulations of a Fermi-Hubbard system we demonstrate that our method is robust against typical experimental noise effects and the required measurement statistics is manageable.

P14

Optical cycling of AlF molecules

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Aluminium monofluoride (AlF) is a promising candidate for a high density magneto-optical trap (MOT) of molecules. Here, we show that AlF can be produced efficiently in a bright, pulsed cryogenic buffer gas beam, and demonstrate rapid optical cycling on the Q rotational lines of the $A^1\Pi \leftrightarrow X^1\Sigma^+$ transition at 228nm. We measure the brightness of the molecular beam to be $> 10^{12}$ molecules per steradian per pulse in a single rotational state and present a new method to determine its velocity distribution accurately in a single molecular pulse. The photon scattering rate is measured using three different methods and compared to theoretical predictions of the optical Bloch equations and a rate equation model. An exceptionally high scattering rate of up to 42(7) x $10^6 s^{-1}$ can be sustained despite the large number of Zeeman sublevels (up to 216 for the Q(4) transition) involved in the optical cycle. We demonstrate that losses from the optical cycle due to vibrational branching to $X^1\Sigma^+, v = 1$ can be addressed efficiently with a repump laser, allowing us to scatter

about 10^4 photons using two lasers. Further, we investigate two other loss channels, photo-ionisation and parity mixing by stray electric fields. The upper bounds for these effects are sufficiently low to allow loading the molecules into a MOT.

Toward on-demand control of charge state dynamics and spin manipulation in diamond NV color center for quantum information processing

P15

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Nitrogen-Vacancy (NV) color center, a vacancy of a missing carbon atom combined with substitutional nitrogen impurity in diamond crystal lattice, is an atomic scale optically accessible spin qubit system. NV color center have different charge states depending on the configuration of spins. However, the negatively charged state (NV-) is mainly preferred for coherent spin manipulation and detection, optimal operating regime of NV- center, optical nanoscopy, charge-based memories, and electrical spin detection [14], because it has longer electron spin relaxation and dephasing time than other charged state as spin-1 triplet electronic ground state. In this research, first, we studied photo-induced interconversion between charge states. On top of that, the post-selection analysis of emitted photons counts from projective observation on spin states was developed to contribute to the high fidelity measurement of spin along with understanding charge state dynamics in NV color center. Based on the above research, furthermore, with the current emergent researches for highly controllable quantum information processor and experimental quantum simulator [15], we investigated the quality control of spin polarization in electron-nuclear spin system in single NV center at room temperature and ambient condition. We designed effective flip-flop interaction of spins by engineering effective Hamiltonian with home-built experiment setup combined with confocal microscope, microwave and radio-frequency wave operation. Combinatory array of electron rotation gates periodically flipped electron spin in single NV center. NV electron spin drives flipping of nuclear spin due to hyperfine coupling with dynamical decoupling from environmental spin bath[16]. We also programmed simple quantum circuits and selectively harness the various neighbor nuclear spins by central NV electron spin to build quantum simulator to test interaction Hamiltonians. The experiment significantly contributes to understand energy conversion and polarization transfer between electron and nuclear spins system. The study crucially promotes the apprehension about NV charge state dynamics, quantum information processing, high resolution microscopy and nanoscale sensing. (E-mail: minsik.kwon@ pi3.uni-stuttgart.de)

References:

[14] 1,2,3,4
[15] 5,6
[16] 7

[1] D. D. Awschalom et al., Nature Photonics 12, 516–527 (2018)
[2] M. Pfender et al., Nano lett. 17, 5931 (2017)
[3] N. Aslam et al., New J. Phys. 15, 013064 (2013)
[4] M. Pfender et al., PNAS, 111, 14669 (2014)
[5] G.Waldherr et al., Nature 506, 204-207 (2013).
[6] D. D. Bhaktavatsala Rao et al., Phys.Rev. A 100, 022307 (2019).
[7] I. Schwartz et al., Science Advances 4, eaat8978 (2018)

P16

Fabrication of diamond nano-pillars with shallow ensemble of NV centers using He-ion implantation

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Nitrogen-Vacancy (NV) color centers in diamond are excellent quantum sensors due to their high sensitivity and nanoscale spatial resolution. Embedding NV centers in nano-pillars allows to increase the collection efficiency of emitted photons, which is otherwise limited by total internal reflection caused by the high refractive index of diamond (2.42). These structures can also serve as scanning probes for nanoscale magnetic field imaging. We present here the fabrication of diamond nano-pillars with an ensemble of shallow NV centers (average depth around 14 nm) using low energy (E = 10 keV) helium ion implantation in nitrogen rich diamonds (type Ib) with [100] and [111] crystal orientations. The former pillars show diameters between 600 and 1000 nm, containing on average $N_{[100]} = 1590$ NVs, for the latter the diameter is between 100 and 600 nm, with an average number of NVs $N_{[111]} = 770$. NV's excited state lifetime measurement is fitted with a bi-exponential decay with time constants $\tau_1 \approx 2$ ns and $\tau_2 \approx 8$ ns, which are shorter compared to a single color center in a bulk crystal ($\tau = 10\,\text{ns}$). These shortened lifetimes and normalized second-order fluorescence auto-correlation measurement showing values around 1.8 at zero-time delay suggest that a collective emission process is present (e.g. superradiance). Optically detected magnetic resonance measurements reveal a contrast of about 4.7% and a coherence time of the NV's electron spin $T_2 = 450$ ns. These pillars with ensemble NV centers could be used for magnetic field imaging and nano-scale NMR, where the sensitivity would be improved by a factor of $\sqrt{N}$, compared to a single NV having the same coherence time.

Probing for causal non-linear corrections to quantum mechanics using trapped ions **P17**

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It has recently been shown that non-linear and state-dependent terms can be consistently added to quantum field theory to yield causal non-linear time evolution in quantum mechanics[17]. Causal non-linear theories have the unavoidable feature that their quantum effects are dramatically sensitive to the full physical spread of the quantum state of the system. As a result, such theories are not well tested by conventional atomic and nuclear spectroscopic tests of quantum mechanics. In these theories, non-linear evolution causes self-interaction in the wave-function of a quantum system with the self-interactions being mediated by conventional interactions of the quantum system such as electromagnetism. These effects can be effectively tested in ion interferometers where these self interactions would cause two arms of an ion interferometer to interact with each other via the Coulomb interaction and cause contrast dependent phase-shifts in the experiment. Ions are ideal testbeds to probe these effects since they permit long interrogation times and allow the different arms of the interferometer to be controllably placed close to each other maximizing the effect of the hypothesized Coulombic self-interaction. In this poster, we describe the first experiment designed to probe for these effects and share preliminary results.

Optimization of telecom quantum dots single-photon sources for quantum communication **P18**

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Poisson Distributed Sources (PDS) such as parametric conversion or weak laser pulses, play a central role in the field of photonic quantum information processing. However, these sources emit photons in a probabilistic manner and their Poisson-distributed multi-photon components limits the overall efficiency. Semiconductor Quantum Dots (QDs), which can in principle deliver on-demand high-purity non-classical states of light, hold the promise to overcome these issues. Most of the existing QDs technologies emit near-infrared light whereas most of the current infrastructures for the information transmission are based on silica fiber networks. It's

[17]David E. Kaplan, & Surjeet Rajendran. (2021). A Causal Framework for Non-Linear Quantum Mechanics.

well known that these fibers display their lowest transmission losses in the so called "Telecom C-Band", namely for wavelength $\lambda = 1530 - 1565\,\text{nm}$. Our work aims at extracting polarization-entangled states from InAs/InGaAs/GaAs dots, emitting in the C-band, to perform quantum cryptography protocols such as Quantum Key Distribution (QKD). In order to generate entangled pairs, we pump the exciton-biexciton 4-level system under Two Photon Excitation (TPE), which presents two decay cascades in which the emitted photons are both H or V polarized. The main issue is related to the dots' structure: the lack of a perfect spherical symmetry is responsible for the rise of the so-called Fine Structure Splitting (FSS) that limits the purity of entangled states and consequently affects the protocols' security figures of merit, such as secret key rate in QKD. We are working on the characterization of our QDs' sample and on the improvement of our setup to achieve high performance in terms of entanglement visibility. Our experiment introduces QDs to the quantum-secure telecommunication realm, exploring their advantages over well-established Poisson-distributed photonic sources.

P19 Coherent Backscattering of Entangled Photon Pairs

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When coherent light passes through a multiply scattering media, it travels through many different paths which interfere and produce a speckle pattern. Coherent backscattering (CBS) is the phenomenon where the paths come in pairs, and every path has a time-reversed counterpart. This results in a pronounced 2-to-1 peak in the backscattering direction that prevails disorder averaging, owing to the constructive interference of these paths. In this work, we study coherent backscattering of entangled photon pairs occupying multiple transverse modes and report its first observation. We analyze the non-classical CBS lineshape theoretically in a multiply scattering media, which is further supported by numerical simulations. We also demonstrate two-photon CBS experimentally by utilizing the double-passage geometry consisting of a random phase screen and a mirror. We show that although the entangled photon pairs are backscattered by a dynamically changing random medium, they exhibit a 2-to-1 enhancement in the backscattering direction that is narrower than the classical lineshape at the same wavelength.

Towards RbSr dipolar rovibronic ground-state molecules **P20**

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Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam, The Netherlands

Ultracold dipolar molecules offer an ideal platform for investigations in the fields of quantum simulation, precision measurement and quantum chemistry. The range of possibilities provided by ultracold molecules could be substantially extended by employing the previously unexplored open-shell molecules. Unlike bialkali molecules, open shell molecules possess both a magnetic and an electric dipole moment offering an additional level of control. Here we present our novel quantum-engineering approach towards the production of ultracold open-shell RbSr molecules using an ultra-narrow Feshbach resonance at 1311 G. Our dual stabilization approach for controlling magnetic fields enables us to achieve a relative magnetic field stability ¬on the order of 1 ppm at fields as high as 1300G. We benchmark our system through the production of Rb2 Feshbach molecules in a 3D lattice using a comparably narrow Feshbach resonance at 911 G with high efficiency.

Posters (Thursday Session)

Imaging and Localizing Individual Atoms Interfaced with a Nanophotonic Waveguide **P1**

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Single particle-resolved fluorescence imaging is an enabling technology in cold-atom physics. However, so far, this technique has not been available for nanophotonic atom-light interfaces. Here, we image single atoms that are trapped and optically interfaced using an optical nanofiber. Near-resonant light is scattered off the atoms and imaged while counteracting heating mechanisms via degenerate Raman cooling. We detect trapped atoms within 150 ms and record image sequences of given atoms. Building on our technique, we perform two experiments which are conditioned on the number and position of the nanofiber-trapped atoms. We measure the transmission of nanofiber-guided resonant light and verify its exponential scaling in the few-atom limit, in accordance with Beer-Lambert's law. Moreover, depending on the interatomic distance, we observe interference of the fields that two simultaneously trapped atoms emit into the nanofiber. The demonstrated technique enables postselection and possible feedback schemes and thereby opens the road toward a new generation of experiments in quantum nanophotonics.

NV center based super resolution Nano-NMR **P2**

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NV center based room-temperature spectrometer is a promising tool for performing NMR in nanoscale volume at low field. However, poor spectral resolution

is one of the major challenges in NV Nano-NMR. In this work, we try to investigate the correlation function of the temporal magnetic field noise induced by the diffusing spins at the NV centre and thereby understanding the line shape of the NMR spectrum. We show that the magnetic noise power spectrum can be deviated from the Lorentzian noise spectrum due to diffusion, and this can lead to an improved resolution.

P3

Signal and Image Processing Inspired by Quantum Mechanics: Application to Denoising

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Decomposition of digital signals and images into other basis or dictionaries than time or space domains is a very common approach in digital signal and image processing and analysis such as denoising. Such a decomposition is commonly obtained using fixed transforms (e.g., Fourier, DCT or wavelet) or data-driven dictionaries learned from example databases or from the signal or image itself (e.g., by exploiting the redundancy within patches extracted from one or several images). In this work, we investigate a new idea of constructing such a signal or image-dependent bases inspired by quantum mechanics tools, i.e., by considering the signal or image as a potential in the discretized Schrödinger equation[18]. This quantum signal or image processing method based on the theory of single particle quantum systems is further generalized to patch-wise image representation using the concepts of quantum many-body interaction. The similarity between two image patches is introduced in the formalism through a term akin to interaction terms in quantum mechanics[19].

Interactions in quantum physics correspond to two or more quantum particles present in the system that can influence each other's quantum state. From an image processing perspective, we propose to adapt this theory to extend the idea of interaction between image patches, classically used by non-local mean filters. More precisely, the proposed framework consists in placing a quantum particle in every image-patch, i.e., every image-patch acts as a single particle system, and the whole collection of patches, i.e. the image, behaves as a many-body system where interactions describe local similarities in the neighboring patches. Schrödinger's equation makes it possible to implement this interaction. Mathematically, this interaction is defined as inversely proportional to the square of the Euclidean distance and linearly proportional to the absolute value of the pixel-wise difference between the patches, thus transposing an inverse-square law in quantum physics to image processing.

[18]Sayantan Dutta, Adrian Basarab, Bertrand Georgeot, and Denis Kouamé, "Quantum mechanics-based signal and image representation: Application to denoising," *IEEE Open Journal of Signal Processing*, vol. 2, pp. 190–206, 2021.

[19]Sayantan Dutta, Adrian Basarab, Bertrand Georgeot, and Denis Kouamé, "Image denoising inspired by quantum many-body physics," in *2021 28th IEEE International Conference on Image Processing (ICIP)*, IEEE, 2021.

The potential of the proposed adaptive decomposition is illustrated through image denoising, in particular, despeckling real-life cancer and non-cancer ultrasound imaging applications[20]. Simulation results show that the proposed decomposition technique outperforms other existing standard state-of-the-art methods.

Nanoscale magnetic imaging at room temperature using single spins in diamonds

P4

Tetyana Shalomayeva[1], Jianpei Geng[1], Qi-Chao Sun[1], Abhay Kant Srivastava[3], Stuart Parkin[3], Rainer Stöhr[1] and Jörg Wrachtrup[1,2]

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Due to the significant development of compounds hosting skyrmions at ambient conditions [21] the need of the quantitative real-space imaging of the magnetic textures is high nowadays. As an atomic-sized magnetic field sensor we use the point lattice defect in diamond, which consists of carbon vacancy and substitutional nitrogen atom (NV centre). For the scanning probe experiments single NV centre is integrated into the monolithic nanopillar, which plays the role of the sharp end of the AFM tip.

In this contribution we demonstrate the scanning probe measurement of the magnetic helical structure on the surface of thin $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ lamellae via off-axial fluorescence quenching at room temperature and further numerical extraction of B-field.

Fermi polaron in the presence of a scattering phase shift resonance

P5

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In three dimensions, a single mobile impurity immersed into a dilute Fermi gas induces screening by bath excitations, what leads to the formation of the Fermi polaron quasiparticle. Quasiparticle properties, such as effective mass or energy, are derived from the impurity-mediated fermion-fermion interaction, which, in its turn, is related to the density profile of the Fermi gas. In the presence of an impurity, the many-body density function exhibits Friedél oscillations that can be described in terms of the scattering phase shift of the single-fermion wave function. At low temperatures, only low-energy bath excitations are relevant, thus the value of the

[20] Sayantan Dutta, Adrian Basarab, Bertrand Georgeot, and Denis Kouamé, "Despeckling Ultrasound Images Using Quantum Many-Body Physics" in *2021 IEEE International Ultrasonics Symposium (IUS)*, IEEE, 2021.

[21] A.K. Nayak et al. Nature 548, 561-566 (2017)

phase shift at the Fermi surface already defines the macroscopic behavior of the system. This simplification is not valid if the momentum dependence of the phase shift exhibits any abrupt changes. *We considered a heavy mobile impurity with a resonant scattering cross section coupled to a dissipationless Fermi gas.* We applied mean-field approximation to obtain single-particle fermionic wave functions in the presence of the impurity. We calculated the ground state energy of the emergent Fermi polaron using Fumi's theorem. Additionally, we calculated the many-body density function of the bath and discovered the deformation of Friedél oscillations that is induced by the non-smooth behavior of the scattering phase shift. We further investigated time-evolution of the deformation domain in a simple quench experiment. Our findings are beneficial to the studies of emergent interactions that follow RKKY mechanism in ultracold bosonic and fermionic systems.

P6

A Quantum Network Node Based on a Nanophotonic Interface for Atoms in Optical Tweezers

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We demonstrate a method for interfacing neutral atom arrays with optical photons. In our approach, atomic qubits trapped in individually controlled optical tweezers are moved in and out of the near-field of a nanofabricated photonic crystal cavity. With this platform, we demonstrate full quantum control, efficient quantum non-destructive readout, and entanglement of atom pairs strongly coupled to the cavity. By encoding the qubits into long-lived states and employing dynamical decoupling, the entangled state is verified in free space after being transported away from the cavity. The combination of a compact, integrated optical link and entanglement transport paves the way for quantum networking with neutral atom quantum processors.

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^{75}As NQR study of quasi one-dimensional $A_2Mo_3As_3$ superconductors

P7

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$A_2Mo_3As_3$, where A stands for K, Rb or Cs, is a family of quasi one-dimensional conductors, where MoAs form quasi one-dimensional double-walled subnanotubes, with A ions in between chains. It is isostructural to the $A_2Cr_3As_3$ family, which was shown to be superconducting at low temperatures, with $T_c = 6.1$ K, $T_c = 4.8$ K and $T_c = 2.2$ K, for A = K, Rb and Cs respectively. The Molybdenum family achieves higher critical temperatures of 10.4 K, 10.5 K and 11.5 K for A = K, Rb and Cs respectively.

A comprehensive ^{75}As NMR study of $A_2Mo_3As_3$ for A= K, Rb, Cs is presented. The ^{75}As NQR spectra show surprising results, indicating four NQR lines, not conforming to the generally accepted structure and space group ($P\bar{6}m2$), which suggests just two chemically inequivalent As sites. Recent density functional theory and neutron total scattering studies of $K_2Cr_3As_3$ propose structural instability in the original structure and a local deformation to a space group Amm2. A possibility of a similar occurrence in $K_2Mo_3As_3$ is thus explored here.

Both $A_2Cr_3As_3$ and $A_2Mo_3As_3$ show a power-law temperature dependencies of spin-lattice relaxation rates, which are fingerprints of the Tommonaga-Luttinger liquid behaviour above T_c. However, there is an important difference between the two families of materials with $A_2Cr_3As_3$ showing repulsive interactions and $Rb_2Mo_3As_3$ showing attractive interactions. Interestingly, ^{75}As NQR and 87Rb NMR show different spin-lattice relaxation rate dependence with temperature in $Rb_2Mo_3As_3$. In the $K_2Mo_3As_3$, even the different As sites show different spin-lattice relaxation rates, suggesting the importance of multi-orbital physics.

The importance of multi-orbital physics is again shown in the superconducting state. No Hebel-Slichter cohrenece peak was observed in both $Rb_2Mo_3As_3$ and $K_2Mo_3As_3$, the first sign of unconventional superconductivity. ^{75}As NQR in $Rb_2Mo_3As_3$ shows BCS gap, while 87Rb NMR shows a reduced gap. In the $K_2Mo_3As_3$ again, even different As sites show different behaviour in the superconducting state, with one site observing the BCS gap, and the others following the Korringa relation even below T_c.

P8

Geometrical description of the argument of weak values in terms of SU(N) generators

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[2]Philosophical space of Namur (ESPHIN) & Namur Institute for Complex Systems (naXys), University of Namur, Belgium

Measurements play an important role in quantum mechanics. Amongst them, weak measurements have attracted much interest, for both theoretical and experimental reasons. Weak measurements are feasible when the interaction between a system and an ancilla is weak. After applying pre- and post-selection (which is equivalent to imposing initial and final conditions to the system evolution), the ancilla wavefunction is shifted by an amount dependent on a quantity called the weak value, multiplied by the coupling constant. Weak values depend on the initial and final states of the system, as well as on the weakly probed observable. As weak values are complex and unbounded numbers, they give rise to many applications, especially related to metrology (due to their amplification power) and to probing foundational issues in quantum mechanics (due to the non-perturbative features of weak measurements). Usually, weak values are studied in terms of their real and imaginary parts. Nonetheless, to understand their geometrical properties (related to geometric phases), their study in terms of modulus and argument becomes crucial[22][23]. In this work, we have studied the argument of the weak values of general observables in N-dimensional quantum systems. This argument describes the area of a geodesic triangle created by three vectors representing the pre-selected state, the observable and the post-selected state on CP^{N-1}. The area of this geodesic triangle characterizes the generalization of a solid angle. This scheme can be applied in the case of $N = 3$ to measure 3D Stokes parameters in terms of Gell-Mann matrices. Our work extends significantly previous results that were limited to weak values of qubit observables and to projectors.

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[22]Revealing geometric phases in modular and weak values with a quantum eraser. Mirko Cormann, Mathilde Remy, Branko Kolaric, and Yves Caudano 2016 Phys. Rev. A 93, 042124

[23]Geometric description of modular and weak values in discrete quantum systems using the Majorana representation. Mirko Cormann and Yves Caudano 2017 J. Phys. A: Math. Theor. 50, 305302

Imaging magnetic van der Waals crystals with a single spin microscope

P9

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Although magnetic van der Waals (vdW) crystals where known since decades, two-dimensional (2D) magnetism has been obtained experimentally only a few years ago[24]. This discovery in Cr2Ge2Te6 and CrI3 has triggered an intense research effort due to their high potential in studying 2D magnetic states[25][26][27]. A wide range of new physical properties emerging from the reduced dimensionality can be explored and exploited, like the control of magnetic properties through gating. New devices based on vdW magnetic heterostructures have also been proposed, such as spin-filter magnetic tunnel junctions based on CrI3, showing a tunneling magnetoresistance higher than their bulk counterparts based on conventionally grown magnetic thin films. The potential of 2D magnets in topological spintronics is also under investigation, with for example recent works on the stabilization of skyrmions in Fe3GeTe2[28]. However, to make further progress in this field, quantitative magnetic imaging techniques with a nanoscale spatial resolution is required.

Here, I will discuss two different approaches towards magnetic imaging of 2D magnets, which are based on solid-state quantum sensors. First, I will introduce nanoscale magnetic imaging with a single Nitrogen-Vacancy (NV) defect in diamond, a magnetic microscopy technique which provides quantitative magnetic field measurements with an unprecedented combination of sensitivity and spatial resolution under ambient conditions. Using this technique, I will demonstrate that exfoliated flakes of the CrTe2 vdW magnet with thicknesses down to 20 nm exhibit an in-plane ferromagnetic order at room temperature with a typical magnetization in the range of M=27 kA/m[29]. These results make CrTe2 a unique system in the growing family of vdW ferromagnets, because it is the only material platform known to date which offers an intrinsic in-plane magnetization and a Curie temperature above room temperature in thin flakes. In a second part, I will present our work on the optical and spin properties of the recently discovered negatively-charged Boron-Vacancy in hexagonal boron nitride[30][31][32], a layered material which is a key building block of vdW heterostructures. This defect is a promising quantum sensor, which could be directly integrated into vdW heterostructures in order to probe, in situ, the

[24] N. Samarth, Nature 546, 216 (2017)
[25] K. S. Burchet al., Nature 563, 47 (2018)
[26] X. Z. Cheng Gong, Science 363, 6428 (2019)
[27] M. Gibertini et al., Nature Nanotechnology 14, 408 (2019)
[28] Y. Wu et al., Nature Communications 11, 3860 (2020)
[29] F. Fabre et al., Physical Review Materials 5, 034008 (2021)
[30] V. Ivády et al., npj Computational Materials 6, 41 (2020)
[31] A. Gottscholl et al., Science Advances 7, 14 (2021)
[32] A. Gottscholl et al., Nature Materials 19, 540-545 (2020)

physics occurring at the interfaces between atomically-thin 2D materials assembled in vertical stacks.

P10 Hybrid quantum sensors: AFM probes, tellurium glass rods, and microstructured optical fibres with NV^- color centers

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The negatively charged (NV^-) color centers in diamond are arguably one of the most promising and studied systems due to their long coherence time and sensitivity to magnetic and electric fields, temperature, and mechanical stress. As such, these diamond-based sensors have find application in many fields such as quantum computing, bio-imaging, ultra-high spatially resolved temperature and magnetic field sensing and imaging and as a basis for single-photon sources.

Based on the optically detected magnetic resonance (ODMR) technique we investigated three approaches to create diamond-based sensors that can compete with already known diamond magneto- and thermometers. The first one, the atomic force microscopy (AFM) probe with tip coated with a nanodiamond (with NV^- color centers) suspension is a promising solution for fluorescent AFM bio-applications. The use of an AFM probe with the fluorescing tip can be an advantageous for precise localizing the position of the scanning probe over the particular cell organelle, which can also be specifically stained. Moreover, by improving the developed method of depositing diamonds on the tip area, a useful and inexpensive method can be introduced for producing magnetic field sensitive probes for nano-scale spatial magnetic field mapping.

Independently, we are working on the efficient integration of NV-rich nanodiamonds with photonic devices. This demands optimized NV^- fluorescence-light coupling to the guided modes in optical fibers and larger optical structures. With a tellurite glass rod doped in a bulk with nanodiamonds, we demonstrate the magnetic-field gradient and temperature measurements. Additionally, we present a way to control the NDs distribution within an optical fiber core by using a nanostructured lead-silicate optical fiber. With a 40-cm-long fiber section, we demonstrate its B-field sensing capabilities in a MW-free protocol with a dynamic range of 35 mT.

Sensitivity of a spinor condensate comagnetometer to exotic spin-dependent forces **P11**

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A Spinor Bose-Einstein condensate (SBEC) comagnetometer consists of co-located magnetometers employing $f = 1$ and $f = 2$ ground state hyperfine manifolds of ^{87}Rb [33]. These states have nearly opposite gyromagnetic ratios, which makes their net rotation angle insensitive to the magnetic field but sensitive to other effects that produce a relative rotation of the two states. We propose the potential application of SBEC comagnetometer as an instrument to search for exotic spin-dependent forces mediated by *axions* or *axion-like particles* (ALPs) or by spin-gravity coupling. We estimate the statistical sensitivity of the SBEC comagnetometer to ALP-mediated monopole-dipole coupling to protons, after a week of averaging and compare to the state of the art [34]. The SBEC comagnetometer has the potential to improve sensitivity by several orders of magnitude for the forces in the sub-mm length scale.

Towards a cold atom experiment with potassium for realizing the "Quantum Klystron" and levitated atom interferometry **P12**

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Technische Universität Wien (TU Wien), Atominstitut

We develop a setup suitable for cavity enhanced levitated atom interferometer which is capable of interaction times of several seconds (V. Xu et al., Science 2019) and for investigating interactions between atoms and electrons (the *Quantum Klystron*, D. Rätzel et al., Phys.Rev.Research 2021). Atom interferometry enables high precision experiments allowing for search for new physics. The Quantum Klystron mimics electromagnetic radiation by the non-radiating near-field of a density modulated electron beam to coherently manipulate atoms in the $|F = 1\rangle$ and $|F = 2\rangle$ hyperfine groundstates. The experiment consists of a *transfer chamber* separated by a valve to a *science chamber*, which facilitates the exchange of the electron beam source. This also offers the possibility to insert samples, e.g. test masses, and measure their effect on the potassium atoms for further interferometry experiments.

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[33]Gomez, Pau, et al. "Bose-Einstein condensate comagnetometer." Physical review letters 124.17 (2020): 170401.

[34]Safronova, M. S., et al. "Search for new physics with atoms and molecules." Reviews of Modern Physics 90.2 (2018): 025008.

P13

Atomic motion in a quadrupole magnetic trap for cavity QED experiments

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We are trapping neutral Rb cold atoms in a quadrupole magnetic trap to interact with an optical cavity mode, where we investigate the collective dynamics of the atom cloud. For our measurements, it is essential to understand the distribution of a gas in an axially symmetric, approximately conservative magnetic trap.
To model this, I examine the classical particle trajectories, starting from an initial set showing thermal distribution. I also simulate the magnetic field of a quadrupole magnetic trap.
Using the potential of the magnetic field, I give the thermal distribution of the atoms in the trap. Using the obtained distribution, I determine the trajectory of an atom by examining the differential equation system obtained on the basis of the one-particle Hamiltonian equation written in cylindrical coordinates.

P14

Exploring the interaction tuning in the Caesium matter-wave interferometry.

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A Cesium (Cs) Bose-Einstein Condensate in an optical trap with the magnetic field as free tuning parameter offers exciting possibilities including tunable matter-wave interferometry using optical double-well potential. The scattering length of Cs near one of many Feshbach resonances can be controlled using magnetic field of practical values for tuning the atom-atom interactions. Atomchip in the experiment ensures compactness and increases the control by virtue of steep trap parameters. Cs being heavier than other possible candidates like Rubidium associates shorter De Broglie wavelength indicating sensitive interferometer which can probe change in gravity for fundamental and environmental research.

Wide-field magnetic imaging using nanodiamonds with nitrogen-vacancy centers

P15

Saravanan Sengottuvel, Mariusz Mrózek, Wojciech Gawlik and Adam Wojciechowski

Jagiellonian University, Krakow, Poland

The negatively charged Nitrogen-Vacancy center (NV) in diamond lattice is a prominent quantum system commonly used as a sensor for detection and imaging of weak magnetic fields. Due to its outstanding optical and spin properties at room temperature, there has been tremendous advances in using the NV centers for magnetic field imaging. For mapping the magnetic fields, typically either a bulk diamond with a very thin NV layer or a scanning probe diamond tip is used, which requires a smooth sample surface and the proximity of the probing device, often limiting the sensing capabilities. Here we propose an alternative approach with nanodiamonds (NDs) deposited on a planar surface and discuss the viability of optical read-out of the spin state of NV center by recording the ODMR signals in arbitrarily spatially oriented nanocrystals. Our goal is to use the wide-field microscopy for magnetic imaging and sensing. In addition, we study the NDs deposited at the facet of an imaging fiber bundle that may find applications in the high spatial-resolution endoscopic magnetic imaging. In principle, this approach can be extended to irregular surfaces which shows a promising path to nanodiamond-based photonic sensors.

Fast and Simple One-Way High-Dimensional Quantum Key Distribution

P16

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In the early quantum key distribution (QKD) protocols each bit of the key was encoded using a quantum state belonging to a binary Hilbert space. High-dimensional QKD protocols were introduced more recently, based on preparing a set of states belonging to a d-dimensional Hilbert space, called qudits. The higher information capacity of qudits allows a higher secure key rate and improves the robustness to noise, leading to higher threshold values of the quantum bit error rate (QBER).

Time-bin encoding of weak coherent laser pulses is the most popular technique for implementing QKD over single-mode fibers. Recent demonstrations of high-dimensional temporal encoding showed significant improvements of the secure key rates. However, implementation of high-dimensional QKD protocols in commercial systems is still held back, since present high-dimensional schemes require significantly higher experimental resources.

In this work we present a novel approach for high-dimensional QKD with time-bin encoding, which can be implemented using a standard QKD system without any hardware modifications [35]. Instead, we show that Eve's information can be bounded by randomizing the time-bins order. We further analyze the security and expected secure key rate for optimized Eve's strategy. Finally, we experimentally demonstrate a 32-dimensional protocol over a 40 km long fiber using only two single-photon detectors and one interferometer at the receiver end. We demonstrate the improved performance of our protocol in comparison to a binary protocol using the same experimental setup, and show more than a two-fold increase in the asymptotically secure key rate. Our work paves the way towards a wider use of high-dimensional encoding in quantum communication.

P17

Creating spatial modes with photonic lanterns in an all-fiber platform

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We take advantage of the well-known linearly polarized (LP) spatial modes in optical fibers and their coherent superpositions to create several photonic quantum states, where the Orbital Angular Momentum (OAM) modes stand out. Contrary to previously presented techniques to generate and measure OAM modes, our experimental setup adopts an all in-fiber approach relying on photonic lanterns and few-mode fibers. We then prepared, propagated, and detected coherent superpositions of qubits encoded over LP modes in few-mode fibers demonstrating the feasibility to carry out quantum cryptography with this setup. Furthermore, our scheme takes advantage of being fully compatible with optical networks hardware by using off-the-shelf components operating at the 1550nm telecom window.

P18

NV biosensing in diamond: toward intra-cellular measurement

Giulia Petrini[1,2], Ekaterina Moreva[2], Ettore Bernardi[2], Paolo Traina[2], Ivo Pietro Degiovanni[2,3] and Marco Genovese[2,3]

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Nitrogen-vacancy centers in diamond allow measurement of environment properties such as temperature, magnetic and electric fields at the nanoscale level, of utmost relevance for several research fields, ranging from nanotechnologies to biosensing. The working principle is based on the measurement of the resonance frequency shift of a single nitrogen-vacancy center (or an ensemble of them), usually detected by monitoring the center photoluminescence emission intensity. Still many issues must be overcome to obtain either a sensitivity capable of revealing the very weak

[35]Sulimany, Kfir, et al. "Fast and Simple One-Way High-Dimensional Quantum Key Distribution." arXiv preprint arXiv:2105.04733 (2021).

electromagnetic fields generated by neurons (or other excitable cells) during their firing activity or a spatial resolution sufficient to measure intracellular thermal gradient due to biological processes. However, over the last few years, significant improvements have been achieved in this direction, thanks to the use of innovative techniques. Here we present a simple and effective continuous-wave lock-in-based technique able to reach high sensitivity in temperature (4.8 mK/Hz$^{1/2}$ in m^3) measurement at microscale or nanoscale volumes. This technique usis a small magnetic field orthogonal to NV axis in order to create a quantum superposition which lead to an increase in temperature sensitivity by a factor of 3 and reduces sensitivity to magnetic noise. In addition, the necessary conditions of biocompatibility will be discussed.

A versatile platform for spin-mechanical coupling **P19**

Felix Hahne, Lucio Stefan, Letizia Catalini, Albert Schliesser

Niels Bohr Institute, University of Copenhagen, Denmark

We report on the layout of a versatile platform for coherent spin-mechanical coupling among a single nitrogen-vacancy (NV) defect in diamond attached to an ultra-coherent silicon nitride membrane oscillator ($Qf \sim 10^{14}$ Hz). The membrane senses the spin-gradient force between the NV and a nearby scanning tip, while the resulting displacement is read out by an interferometer. By cooling the system down to cryogenic temperatures, we plan to perform real-time detection of the spin state at moderate field gradients ($\sim$ kT/m) and expect detection of non-classical spin states with sufficiently high gradients ($\sim$ MT/m). The ultimate goal is to generate Schrödinger cat states of millimeter-sized mechanical systems with dedicated spin excitation schemes, and parametric amplification and squeezing protocols. In this poster we elaborate on several planned versions of our experiment and discuss their key components including the membrane sensor itself, parametric protocols and readout.

Open quantum evolution from thermodynamic collision models **P20**

Felix Hubmann, Philip Taranto, Felix Binder, Simon Milz

Institute for Quantum Optics and Quantum Information - IQOQI Vienna

Thermal operations are those that can be realised by coupling a system of interest to a thermal bath and performing an energy-conserving unitary. These provide a viable tool to understand which transformations between pairs of states are possible within the resource theory of athermality. Such operations are an important subset of those possible within the general theory of open quantum evolutions. Here, by invoking the Born-Markov approximation, one can describe the continuous-time evolution of the system in terms of a master equation. Particular properties of the master equation arise when thermodynamic assumptions are further imposed. A priori, it is not clear that invoking thermodynamic assumptions before and after the Born-Markov approximations lead to the same description. In this work, we begin with a collision model based on sequences of thermal operations and take the continuous-time limit to yield a master equation, which we show to have similar properties as that derived in the work of others. An advantage of our approach is the ability to compute properties (such as decay rates) in terms of relevant Hamiltonians, which offers additional insights on how thermodynamic processes can be tuned.

P21

Experimental quantum memristor

Michele Spagnolo, Joshua Morris, Simone Piacentini, Micheal Antesberger, Francesco Massa, Francesco Ceccarelli, Andrea Crespi, Roberto Osellame and Philip Walther

University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ)

Quantum computer technology harnesses the features of quantum physics for revolutionizing information processing and computing. As such, quantum computers use physical quantum gates that process information unitarily, even though the final computing steps might be measurement-based or non-unitary. The applications of quantum computers cover diverse areas, reaching from well-known quantum algorithms to quantum machine learning and quantum neural networks. The last of these is of particular interest by belonging to the promising field of artificial intelligence. However, quantum neural networks are technologically challenging as the underlying computation requires non-unitary operations for mimicking the behavior of neurons. A landmark development for classical neural networks was the realization of memory-resistors, or “memristors”. These are passive circuit elements that keep a memory of their past states in the form of a resistive hysteresis and thus provide access to nonlinear gate operations. The quest for realising a quantum memristor led to a few proposals, all of which face limited technological practicality. Here we introduce and experimentally demonstrate a novel quantum-optical memristor that is based on integrated photonics and acts on single photons. We characterize its memristive behavior and underline the practical potential of our device by numerically simulating instances of quantum reservoir computing, where we predict an advantage in the use of our quantum memristor over classical architectures. Given recent progress in the realization of photonic circuits for neural networks applications, our device could become a building block of immediate and near-term quantum neuromorphic architectures.

Company Flash Talks

Pioneering premium lighting and electronic systems by ZKW

Sep 6th
4:00 PM

Christian Knobloch

ZKW Lichtsysteme GmbH, Wieselburg, Austria

Nowadays sensing and imaging are vital instruments not only in quantum science/mechanics, but also in the classical regime. Our daily life as well as the automotive customers benefit from various sensors, especially when driving a car during dark hours. ZKW develops on one hand innovative and premium lighting systems and on the other hand the corresponding electronics for different mobility concepts. One of the corner stones of ZKW's development lies in mastering the illumination of sustainable automobile/vehicle headlights. This aligns with the engineering of sensors and information beams for passive and active communication all around future cars. In this talk, I will briefly present the company fact sheet and then go through the cutting-edge technologies applied in vehicle headlights by ZKW.

Introducing IMS Nanofabrication

Sep 8th
4:00 PM

Stefan Kuhn

IMS Nanofabrication GmbH, Vienna, Austria

Industries and consumers around the world are currently affected by a global shortage of high-end chips. In order to meet this growing demand, the semiconductor industry is investing billions of US dollars to ramp up their production capacities. In recent years, IMS Nanofabrication has become the technology and market leader in the semi-conductor industry for supplying Multibeam Maskwriter to the largest chip manufacturing companies in the world. Our multi-electron beam technology enables patterning of the most complex layouts for the 5nm node and beyond. This technology is one of the key ingredients for the continuous improvement in computational power and energy consumption of computer chips, still following Moore's law. In this talk, we will introduce IMS Nanofabrication as attractive and competitive employer for physicists in Vienna, East Asia and the US. Furthermore, we will outline our unique technology concept, which allows us play an important role in the development of the semiconductor industry. Join our rapidly growing teams and help us to tackle the rising demand of high-end chips.

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