VCQ 2021 SUMMER SCHOOL

QUANTUM SENSING & IMAGING

BOOKLET

TU WIEN
TECHNISCHE UNIVERSITÄT WIEN

IST AUSTRIA
Institute of Science and Technology

universität wien

ÖAW
ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

Institutions

Sponsors

IMS Nanofabrication
www.ims.co.at

ZKW

BLUEFORS

Table of Content

VCQ

Vienna Center for Quantum Science and Technology

Timetable

	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00
Monday	Opening / Jelezko	Break	Padgett	Lunch	Padgett	Break	Jelezko	CFT 1 / Poster session		Social Event
Tuesday	Jelezko	Break / Jelezko		Lunch	Bouyer	Break	Student Talks			Conference Dinner
Wednes-	Budker	Break / Bouyer		Lunch	Padgett	Break	Bouyer	CFT 2 / Student Talks		
Thursday	Bouyer	Break / Budker		Lunch	Budker	Break	Poster session			VCQ Special Lecture
Friday	Budker	Break / Padgett		Lunch		Lab Tours				

CFT 1 Company Flash Talk: ZKW

CFT 2 Company Flash Talk: IMS

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 Technische Universität Wien (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 150 early stage researchers who are selected from an international pool of applicants, based on their academic excellence, scientific success and ambition.

Statement of Inclusiveness

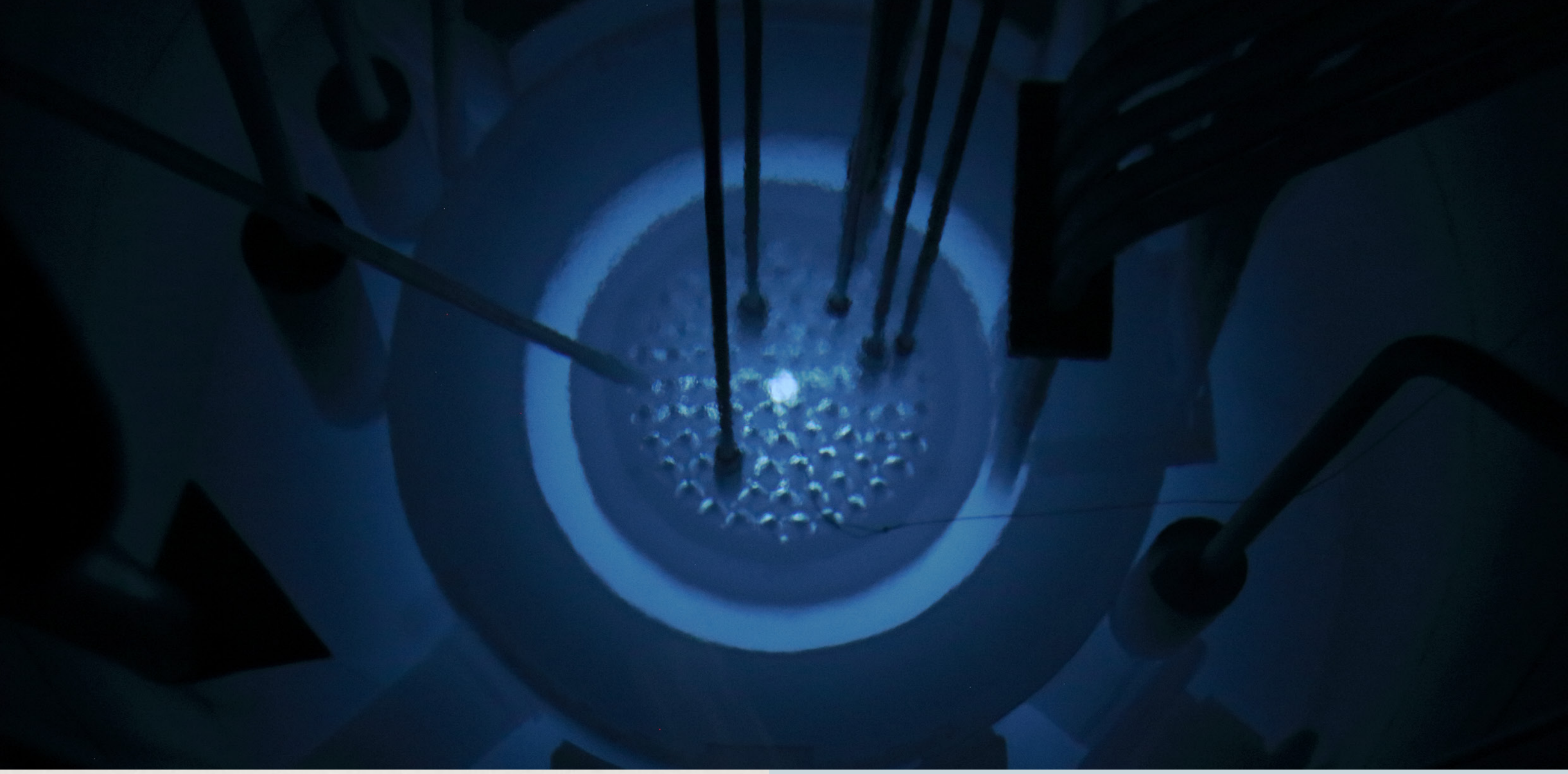
We refuse to compromise the ideals of academic freedom and open exchange. We affirm that scientific events have to be open to everybody, regardless of class, financial situation, race, sex, religion, national origin, sexual orientation, gender identity, disability, age, pregnancy, immigration status, academic affiliation, or any other aspect of identity.

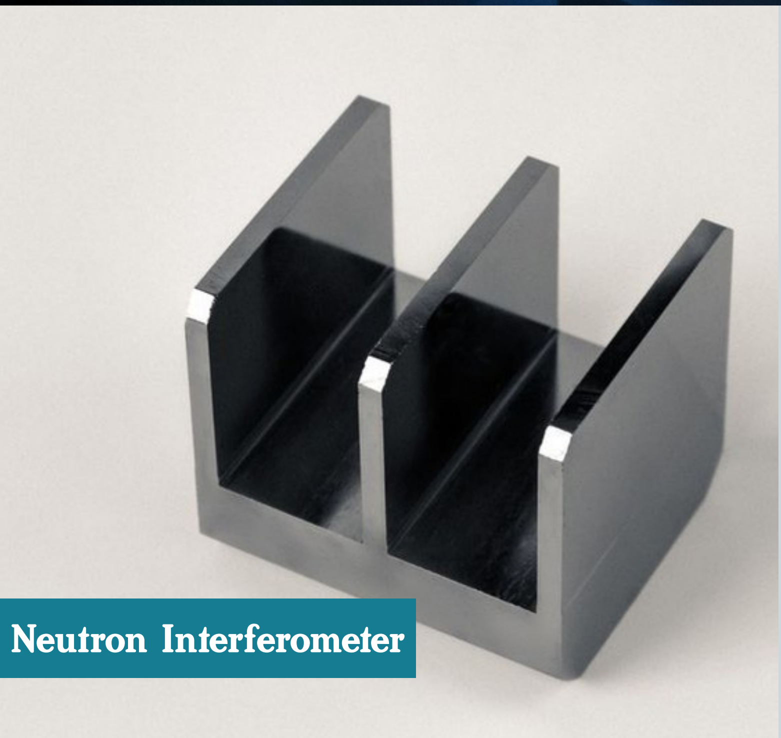
We believe that such events have to be supportive, inclusive, and safe environments for all participants. We believe that all participants are to be treated with dignity and respect. Discrimination and harassment cannot be tolerated. We are committed to ensuring that the scientific events in which we participate follow these principles.

Original source: www.math.toronto.edu/~rafi/statement/

Atominstitut

The Atominstitut is the largest of the four research institutes of the Faculty of Physics at Technische Universität Wien (TU Wien). About 150 employees together with 100 students perform cutting-edge research on a broad range of scientific problems. The spectrum ranges from radiation physics to nuclear and particle physics, includes archaeometry, radiochemistry, quantum optics, ultra-cold atoms, environ mental physics, precision measurements and more.
The institute was founded in 1958 as an inter-university institute and opened in 1962 at its current location at the Prater, in the course of the university reform the Atominstitut was integrated into the Faculty of Physics at the TU Wien. Centre piece of the Atominstitut is the research reactor TRIGA Mark Ii. It serves as a reliable neutron source, enables a plathora of research opportunities i n the field of forensic science/trare analytics and provides short-lived isotopes for use as markers in medical physics- to name just a few examples. We cooperate closely with the International Atomic Energy Agency (IAEA), eg. in the training of nuclear safeguard inspectors which are active all over the globe. The Atominstitut is also involved in monitoring the Nuclear-Test-Ban Treaty (CTBTO).
Besides world-class research, the Atomistitut has a focus on training and educating the next generation of physicists: In numerous lectures, courses, seminars, but also practical courses and hands-on laboratories we pass on our knowledge, our experience, and our enthusiasm for physics. And last but not least, more than





Neutron Interferometer

Perfect crystal neutron interferometry was invented at this institute in 1974 by Helmut Rauch together with Wolfgang Treimer and Ulrich Bonse and carried forward by Gerald Badurek with polarized neutrons. In the year after the invention, neutron interferometry was applied for a direct test of the 4 symmetry of spin / particle wave functions and the quantum spin superposition law. These concepts are now widely used in fundamental science and in technological applications of quantum physics. Helmut Rauch's experiments crucially contributed to the rise of activities in quantum physics and quantum information in Austria and inspired new generations of physicists worldwide. Graduates of Helmut Rauch are, among others, Kurt Binder, Heinrich Kurz, and Anton Zeilinger, pioneers in the fields of statistical mechanics, nanotechnology, and quantum optics and quantum information.

Helmut Rauch

Helmut Rauch (born 22.01.1939 in Krems an der Donau) is an Austrian physicist. He is specially known for his pioneering experiments on neutron interference. Rauch studied Physics at TU Wien and worked at Atominstitut. He has also been affiliated with Forschungszentrum Jülich and Institut Laue-Langevin in Grenoble. In 1974, Rauch, together with Ulrich Bonse and Wolfgang Treimer, demonstrated the first matter wave interference of Neutrons. This demonstrated the wave-like nature of neutrons for the first time and was another experimental proof that not only photons can be described by waves, but also massive particles. Further they demonstrated the fundamental symmetry of spin 1/2 particles under rotations.

fLtR: Riya, Pra, Nadine, Amin, Fede

Organizers

Barbara Stros

Evgeniya Schimpf

Nadine Hilmar

Nadine has studied Structural Engineering in Germany but has changed career after she has moved to Vienna in 2008. She has been working as a Science Communicator in the group of thorsten Schumm since 2020 and is also the coordinator of the VCQ PhD-program at the TU Wien.

Federica Cataldini

Federica Cataldini studied in Italy at Università del Salento in Lecce. For her master thesis project she joined the group of Prof. Massimo Inguscio at LENS, in Florence, where she worked on one-dimensional ultracold superfluids on optical lattices under the supervision of Prof. Giovanni Modugno. In 2015 she moved to Vienna to join the CoQuS doctoral school in the group of Prof. Jörg Schmiedmayer. Her current research is focused on the out of equilibrium dynamics of one-dimensional quasi-BEC realised on atomchip.

Pradyumna Paranjape

After finishing his bachelor's degree in physics at the University of Pune, he continued his master's studies at the same university. However, after a year, he moved to LMU Munich to pursue a master's degree in physics. For his master's thesis, he joined the group of Prof Theodor Hänsch. After completion of his master's studies, he did three research internships at MPQ Garching (with Prof Immanuel Bloch), at IST Austria (with Prof Johannes Fink) and Heidelberg University (with Prof Markus Oberthaler and Prof Fred Jendrzejewski), respectively. Since June 2017, Pradyumna is a PhD student in the group of Prof Jörg Schmiedmayer at Atominstitut TU Wien.

Organizers

Riya Sett

Riya completed her MSc. in Photonics from Aix-Marseille University, Marseille and Universitat Politècnica de Catalunya, Barcelona through the Erasmus Mundus Europhotonics Masters program. As a scientific assistant at the Karlsruhe Institute of Technology, Germany, she worked on superconducting microwave resonators in a flip-chip geometry under the supervision of Dr. Martin Weides in the Ustinov group. During her master thesis in the Quantronics group at CEA Saclay, she worked on Josephson parametric amplifiers with flux-tunable SQUID arrays under the supervision of Dr. Denis Vion. Riya joined IST as a PhD student in October 2018.

Mohammad Amin Tajik

Amin is a PhD student in the group of Jörg Schmiedmayer, where he works on quantum simulations using one-dimensional (1D) quasi-condensates. He joined the group in 2015 as a master student to build a new setup for designing arbitrary optical dipole potintials on an atom chip. Amin finished his bachelor's degree in 2013 at the University of Tehran. For his bachelor's thesis he worked on post processing of the molecular dynamics simulations using pizza.py.

Lecturers

Philippe Bouyer

Philippe Bouyer is research director at CNRS and deputy director of the Institut d'Optique Graduate School in Bordeaux. He received his doctorate at Ecole Normale Supérieure in 1995 and was then a postdoctoral fellow at Stanford during which he worked on atom interferometer-based inertial sensor experiments. He joined CNRS and the Institut d'Optique Graduate School in 1996, where he worked on atom lasers and Anderson localization with cold atoms. His current interests are the study of quantum simulators with ultracold atoms and the development of atom interferometers for testing general relativity in space or detecting gravity fields and gravitational waves underground. He is the recipient of the 2012 Louis D award of the French academy, APS fellow and OSA senior member.

Dmitry Budker

Dmitry Budker was born in USSR and graduated from Novosibirsk State University in 1980. He obtained his PhD in Physics in 1993, from the University of California at Berkeley, USA, where he has been on the faculty since 1995. From 2014, he is leading the Matter-Antimatter Section of the Helmholtz Institute at Mainz, Germany and a Professor at the Johannes Gutenberg University. Budker's research interest ranges from precision measurement and dark matter research to biomagnetic sensing and measuring magnetic fields in the mesosphere. He is an author of several textbooks and the recipient of the 2021 Norman F. Ramsey Prize of the American Physical Society.

Fedor Jelezko

Fedor Jelezko is a director of the Institute of Quantum Optics and fellow of the Center for Integrated Quantum Science and Technology (IQST) at Ulm University. He studied in Minsk (Belarus) and received his Ph.D. in 1998. After finishing the habilitation in 2010 at Stuttgart University he was appointed as a professor of experimental physics in Ulm in 2011. His research interests are at the intersection of fundamental quantum physics and application of quantum technologies for information processing, communication, sensing, and imaging.

Miles Padgett

Miles Padgett is a Royal Society Research Professor and also holds the Kelvin Chair of Natural Philosophy in the School of Physics and Astronomy at the University of Glasgow. He leads an optics research team covering a wide spectrum from blue-sky research to applied commercial development, funded by a combination of government, charity and industry. He is currently the Principal Investigator of QuantIC, the UK's Centre of excellence for research, development and innovation in quantum enhanced imaging, bringing together eight Universities with more than 40 industry partners. He is a Fellow both of the Royal Society of Edinburgh and the Royal Society. Among many other prizes, he has won the Rumford Medal of the Royal Society and the Quantum Electronics and Optics Prize of the European Physical Society.

Roman Schnabel

Roman Schnabel graduated from the University of Hannover in the fields of plasma physics and atomic spectroscopy. He was a Juniorprofessor and then a University Professor at Leibniz Universität Hannover, from where he finally moved to Hamburg University in 2014. Since 2002, he has been working on-squeezed light for gravitational-wave detectors and other applications such as quantum cryptography. He was awarded the 2013 Joseph F. Keithley Award of the American Physical Society, an ERC advanced grant, the 2016 Special Breakthrough Prize in Fundamental Physics (as a member of the LIGO team), and the QCMC 2018 Award for Outstanding Achievements in Quantum Experimentation, amongst others.

Lecture Series

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

Philippe Bouyer

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

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.

Lecture Series

Quantum sensing enabled by diamond spin qubits

Fedor Jelezko

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 photoelectrical 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

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

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].

[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)

- Pioneering premium lighting and electronic systems by ZKW Lichtsysteme GmbH (Knobloch, Christian)
- Introducing IMS Nanofabrication (Kuhn, Stefan)
- Introducing Bluefors

Company Presentations

Student Talks

- A Compact Atom Interferometer with Tunable Interactions (Gerstenecker, Benedikt)
- Spectroscopic studies of aluminium monofluoride with relevance for laser cooling and trapping (Doppelbauer, Maximilian)
- Modeling and observation of nonlinear damping in dissipation-diluted nanomechanical resonators (Catalini, Letizia)
- Optimised Nitrogen-vacancy Spin-state Initialisation and Manipulation for
- DC Magnetometry (Oshnik, Nimba)
- Decoherence in superconducting circuits based on fluxonium architecture (Pioras-Timbolmas, Larisa-Milena)
- Scaling nuclear magnetic resonance to the single spin level (Herb, Konstantin)
- Tunable directional scattering from a pair of superconducting qubits (Redchenko, Elena)

Posters (Monday Session)

1. Towards deterministic generation of time-bin entangled photons from GaAs quantum dots (Kappe, Florian)

2. Coherent control of ion motion via Rydberg excitation (Mallweger, Marion)

3. Photon pair generation in ultra-thin carbon nanotube films without phase-matching (Jenke, Philipp K.)

4. Scalable Quantum State Tomography with Artificial Neural Networks (Schmale, Tobias)

5. Ultrafast Molecular Dynamics in Suprafluid Helium Droplets (Stadlhofer, Michael)

6. Quantitative study of the response of a single NV defect in diamond to magnetic noise (Rollo, Maxime)

7. Phonon-assisted transport in a quantum dot coupled to a Majorana bound state (Máthé, Levente)

8. Heterodyne sensing of microwaves with a quantum sensor (Meinel, Jonas)

9. Inverse design of artificial two-level systems with Mössbauer nuclei in thin-film cavities (Diekmann, Oliver)

10. Zero-field nuclear magnetic resonance spectroscopy with the use of atomic sensors (Put, Piotr)

11. Optimized Planar Microwave Antenna for Nitrogen Vacancy Center based Sensing Applications (Opaluch, Oliver Roman)

12. Collective radiative dynamics of an ensemble of cold atoms coupled to an optical waveguide (Lechner, Daniel)

13. Certification of High-Dimensional Entanglement in Ultracold Atom Systems (Euler, Niklas)

14. Optical cycling of AlF molecules (Hofsäss, Simon)

15. Toward on-demand control of charge state dynamics and spin manipulation in diamond NV color center for quantum information processing (Kwon, Min-Sik)

16. Fabrication of diamond nano-pillars with shallow ensemble of NV centers using He-ion implantation (Volkova, Kseniia)

17. Probing for causal non-linear corrections to quantum mechanics using trapped ions (Broz, Joseph)

18. Optimization of telecom quantum dots single-photon sources for quantum communication (Giorgino, Francesco)

19. Coherent Backscattering of Entangled Photon Pairs (Safadi, Mamoon)

20. Towards RbSr dipolar rovibronic ground-state molecules (Thekkeppatt, Premjith)

Posters (Thursday Session)

1. Imaging and Localizing Individual Atoms Interfaced with a Nanophotonic Waveguide (Pucher, Sebastian)

2. NV center based super resolution Nano-NMR (Vijayakumar Sreeja, Anjusha)

3. Signal and Image Processing Inspired by Quantum Mechanics: Application to Denoising (Dutta, Sayantan)

4. Nanoscale magnetic imaging at room temperature using single spins in diamonds (Shalomayeva, Tetyana)

5. Fermi polaron in the presence of a scattering phase shift resonance (Maslov, Mikhail)

6. A Quantum Network Node Based on a Nanophotonic Interface for Atoms in Optical Tweezers (Grinkemeyer, Brandon)

7. ^{75}As NQR study of quasi one-dimensional $A_2Mo_3As_3$ superconductors (Gosar, Žiga)

8. Geometrical description of the argument of weak values in terms of SU(N) generators (Ballesteros Ferraz, Lorena)

9. Imaging magnetic van der Waals crystals with a single spin microscope (Fabre, Florentin)

10. Hybrid quantum sensors: AFM probes, tellurium glass rods, and microstructured optical fibres with NV− color centers (Orzechowska, Zuzanna)

11. Sensitivity of a spinor condensate comagnetometer to exotic spindependent forces (Gugnani, Stuti)

12. Towards a cold atom experiment with potassium for realizing the “Quantum Klystron” and levitated atom interferometry (Kolb, Matthias)

13. Atomic motion in a quadrupole magnetic trap for cavity QED experiments (Dániel, Varga)

14. Exploring the interaction tuning in the Caesium matter-wave interferometry (Gulhane, Shreyas)

15. Wide-field magnetic imaging using nanodiamonds with nitrogenvacancy centers (Sengottuvel, Saravanan)

16. Fast and Simple One-Way High-Dimensional Quantum Key Distribution (Sulimany, Kfir)

17. Creating spatial modes with photonic lanterns in an all-fiber platform (Alarcón, Alvaro)

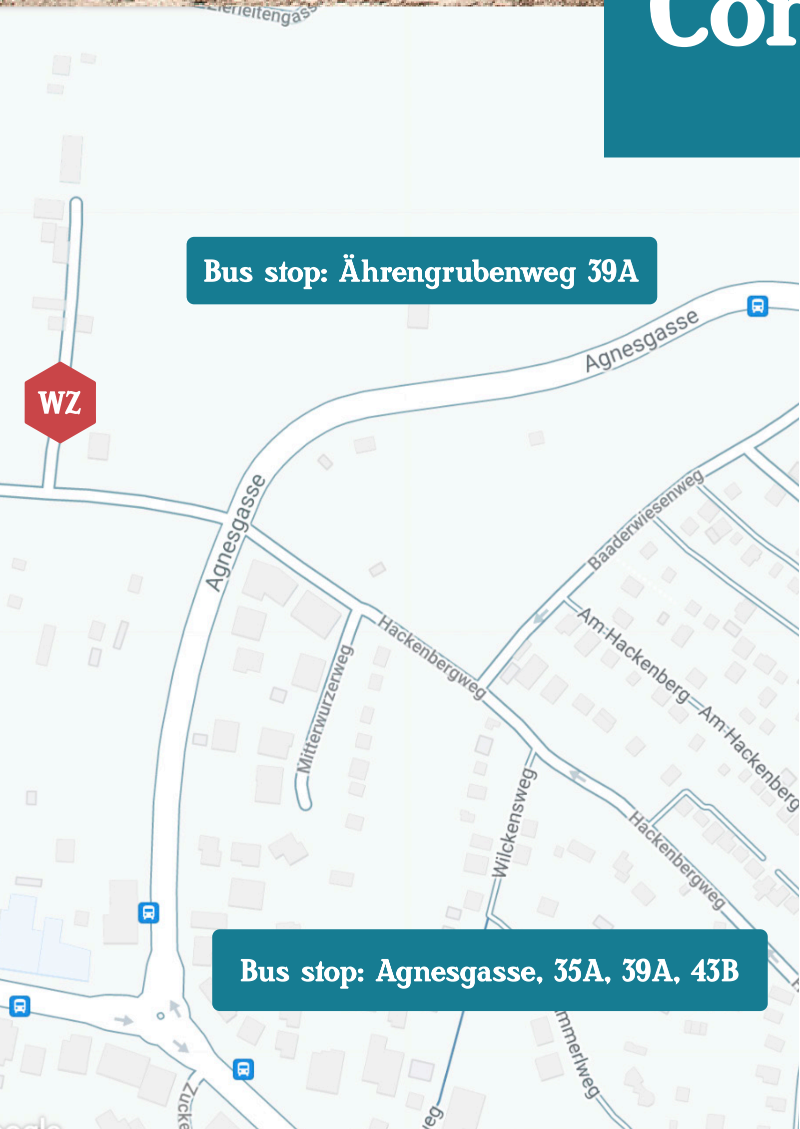
18. NV biosensing in diamond: toward intra-cellular measurement (Petrini, Giulia)

19. A versatile platform for spin-mechanical coupling (Hahne, Felix)

20. Open quantum evolution from thermodynamic collision models (Hubmann, Felix)

21. Experimental quantum memristor (Spagnolo, Michele)

Conference Dinner



We will enjoy Tuesday evening in Weinhof Zimmermann, a typical Austrian "Heuriger" in the 19th district of Vienna.

Heuriger is the abbreviation of "heuriger Wein" (this year's wine) in Austrian and Bavarian German. Originally, they were simple open-air taverns on the premises of winemakers, where people would bring along food and drink the new wine. Nowadays, the taverns are often situated at a distance from the wineyards and offer both food and drinks.