MCQST

Munich Conference on Quantum Science and Technology

Deutsches Museum, 8/9 July 2019

Welcome...

Welcoming Message

... to the first Munich Conference on Quantum Science and Technology at the Center for New Technologies in the Deutsches Museum! It is organized in the framework of the Cluster of Excellence "Munich Center for Quantum Science and Technology" (MCQST, EXC 2111) funded by the German Research Foundation (DFG, Deutsche Forschungsgemeinschaft). The event marks the starting point of an annual conference series and brings together quantum scientists from Munich.

With 22 invited speakers from Munich and abroad, the talks at the conference cover all Research Units (RUs) present in MCQST: RU-A: Quantum Information Theory, RU-B: Quantum Simulation, RU-C: Quantum Computing, RU-D: Quantum Communication, RU-E: Quantum Metrology and Sensing, RU-F: Quantum Matter, RU-G: Explorative Research Directions. A total of 55 contributed posters by local scientists with a wide variety of topics are an expression of the rich research environment in Munich.

On Monday night, we invite you to get together at the Quantum Science Slam that Microsoft is hosting for us in their Atrium in Schwabing. We have recruited four local quantum scientists for the event. They will talk about their research in an entertaining way, and in the end, the audience's applause will determine a favorite.

Tuesday afternoon is reserved for two special sessions. First, the topic of gender and physics is addressed. It is important for us to reach many of you with this topic, since one of the main structural goals of MCQST is to increase the proportion of female scientists on all levels. Second, we are getting in dialog with industry on strategies in quantum science and technology. In a panel discussion with attocube, Google, Huawei, Microsoft, and NVision we are addressing their plans, visions, and expectations.

We hope that we have put together an interesting and diverse program for you, and that you will enjoy the conference! We are looking forward to many exciting presentations and interesting discussions, which will create new links between scientists from the Munich QST community!

With kind regards from

Tatjana Wilk and the MCQST Office Team

Content

Organizer

Munich Center for Quantum Science und -Technology (MCQST)
Schellingstraße 4
D-80799 Munich, Germany
www.mcqst.de
e-mail: info@mcqst.de

Venue

Deutsches Museum
Museumsinsel 1
80538 München

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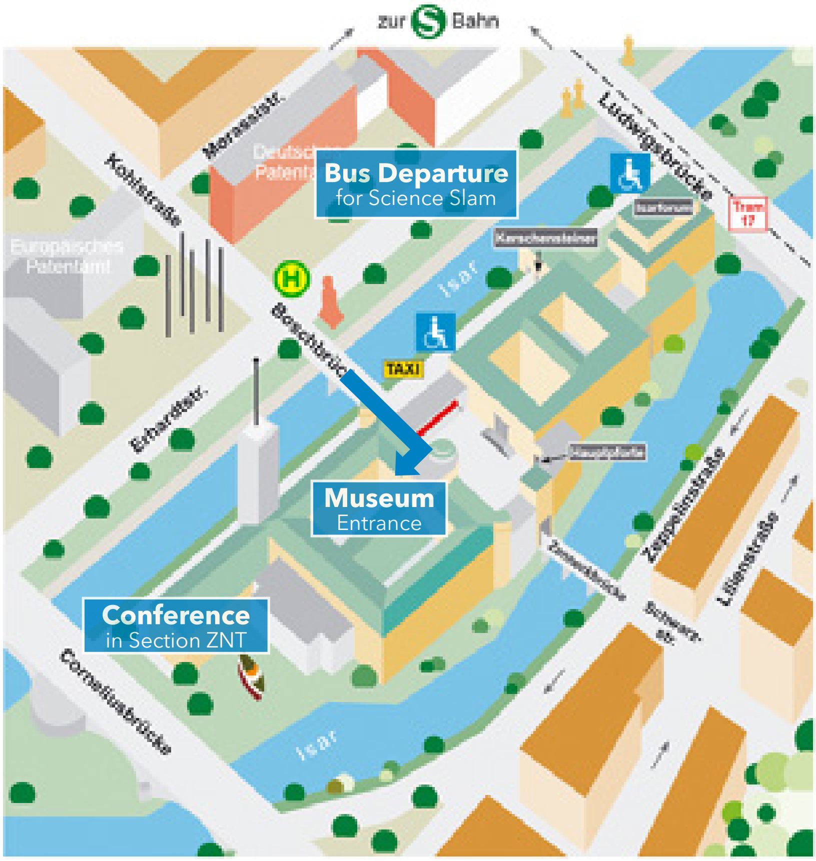
Map



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Map of the Museumsinsel

Deutsches Museum

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www.deutsches-museum.de

Museumsinsel 1
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In other cases of urgency you may call the conference organizer on mobile phone:

+49 176 78266509

Disclaimer

The organizers do not hold any liabilities on damages, losses, health issues, etc.. All participants are advised to take care about their travel and health insurances related to this conference.

Invited Talks

Talks

- Research Unit A - **Quantum Information Theory**
- Research Unit B - **Quantum Simulation**
- Research Unit C - **Quantum Computing**
- Research Unit D - **Quantum Communication**
- Research Unit E - **Quantum Metrology and Sensing**
- Research Unit F - **Quantum Matter**
- Research Unit G - **Explorative Research**

Overview

Invited Talks

Mon, 9:00

TBA

Boris Altshuler
Physics Department, Columbia University, New York, NY 10027, USA

notes

Atomistic defect states as quantum emitters in monolayer MoS_2

Alexander W. Holleitner
Walter Schottky Institut and Physics Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

We demonstrate the deterministic generation of single defect emitters in a monolayer MoS_2 van der Waals heterostructure [1]. We bombard monolayer MoS_2 with helium ions to generate optically active defect luminescence [2] and encapsulate the defective MoS_2 within hBN to greatly enhance their optical quality [3,4]. We spectroscopically investigate single emitters by performing photoluminescence excitation spectroscopy and temperature dependent measurements. The line shape reveals a strong asymmetry resembling the interaction with LA/TA phonons. Employing the independent Boson model to our emission lines, we find that the emitters are spatially localized to a length scale of 2 nm. We attribute the emission to atomistic defects induced by the helium ion bombardment and discuss their origin in the light of scanning tunneling microscopy measurements [5]. The demonstrated methodology allows positioning quantum emitters with a precision of a few nanometers. Our work paves the way towards the controlled and deterministic generation of single quantum emitters in monolayer TMDC van der Waals heterostructures.

I thank my collaborators J. Klein, M. Lorke, M. Florian, F. Sigger, L. Sigl, S. Puentes, J. Wierzbowski, A. Hötger, K. Barthelmi, P. Zimmermann, E. Mitterreiter, J. Cerne, K. Müller, T. Taniguchi, K. Watanabe, U. Wurstbauer, M. Kaniber, M. Knap, R. Schmidt, and J. J. Finley for a very fruitful collaboration.

References

[1] J. Klein et al., Nature Comm. (2019).

[2] J. Klein et al., 2D Mater. 5, 1 (2017).

[3] J. Wierzbowski et al., Sci. Rep. 7, 12383 (2017).

[4] B. Miller et al. Nature Comm. 10, 807 (2019).

[5] J. Klein et al., arxiv 1905.01242 (2019).

notes

Mon, 10:10

Charge density wave quantum criticality in two dimensional metals

Johannes Halbinger, Dimitri Pimenov, Matthias Punk
Fakultät für Physik, LMU München, Germany

While ordinary metals are very well described within Landau's Fermi liquid theory, various strongly correlated electron materials exhibit strange metallic phases which do not fit into the Fermi liquid framework. Such non-Fermi liquids are often found in the vicinity of quantum phase transitions and their theoretical description remains a challenging open problem in condensed matter physics. After a short introduction to the problem we will discuss the specific example of charge density wave quantum critical points in quasi two-dimensional metals [1], which have been observed in a variety of materials such as transition metal dichalcogenides and rare-earth tellurides. We characterize the quantum critical point using a controlled renormalization group approach and show that the continuous transition is stabilized by a dynamical nesting of the Fermi surface.

References

[1] J. Halbinger, D. Pimenov, and M. Punk, Phys. Rev. B 99, 195102 (2019).

notes

Mon, 11:00

Magnetism and frustration in quantum gases

Dan M. Stamper-Kurn
Department of Physics, University of California, Berkeley, CA 94720, USA

Ultracold atomic gases and the methods of atomic physics allow us to create many-body quantum systems whose microscopic construction is exactly known. These systems allow us to study phenomena that appear typically in solid-state materials, but, now, in an experimental setting that is precisely characterized and controlled. I will present three applications of ultracold atomic gases toward studies of magnetism and geometric frustration: the realization of magnon condensation in a quantum gas, the construction of lattices characterized by geometric frustration, and a new effort to produce ultracold gases of transition-metal elements.

notes

Mon, 11:45

New routes to probe the two-dimensional Fermi-Hubbard model

A. Bohrdt, F. Grusdt, C. S. Chiu, G. Ji. M. Xu, D. Greif, M. Greiner, E. Demler, and Michael Knap
Department of Physics and Institute for Advanced Study, Technical University of Munich, Germany

The phase diagram of the two-dimensional Fermi-Hubbard model and its connection to high-temperature superconductivity have been the subject of a vast amount of theoretical and experimental studies in the past decades. Here, we present recent results motivated by the new perspective quantum gas microscopes provide. In particular, we develop matrix product state based algorithms to study the dynamics of a single hole in the anti-ferromagnetic background and identify the relevant scales both at low and high temperatures [1]. The effective dynamics can be well captured by a doped hole moving in an anti-ferromagnetic environment as a bound state of spinons and chargons. We furthermore compare this simple effective picture for spin correlations in the finite temperature and finite doping regime of a cold atom experiment and find remarkable agreement [2]. For an unbiased comparison of theories and experiment, we develop a machine learning approach to classify experimental data at finite doping into different theoretical categories in order to determine which theory describes the system best on the microscopic level [3].

References

[1] A. Bohrdt, F. Grusdt, MK (2019)

[2] C. Chiu, et al. ArXiv:1810.03584 (2018); accepted in Science

[3] A. Bohrdt, et al. ArXiv:1811.12425 (2018); accepted in Nature Physics

notes

Mon, 12:10

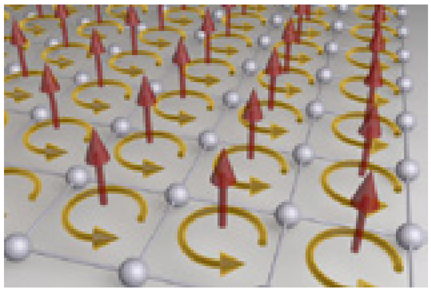
Synthetic gauge fields with ultracold atoms in periodically-driven lattices

Monika Aidelsburger
Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 Munich, Germany
Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Ultracold atoms in optical lattices are powerful experimental platforms to study a variety of phenomena ranging from condensed-matter to statistical physics. Recently, a promising new direction emerged after the successful realization of paradigmatic topological lattice models [1]. Topological states of matter exhibit unique conductivity properties. One of the most prominent examples is the quantum Hall effect.

A widespread technique for generating topological band structures is Floquet engineering [2]. It relies on periodic modulation of the systems' parameters to emulate the properties of a non-trivial static system. This method facilitated the direct observation of bulk topological properties and chiral currents in optical lattices with synthetic gauge fields. Floquet techniques have further been proposed to engineer density-dependent gauge fields or even complete gauge theories, which require an interaction between matter and gauge fields. Inspired by these ideas, we have developed and implemented a minimal model of a Z2 lattice gauge theory coupled to matter [3].

The rich properties of Floquet systems, however, go well beyond those of their static counterparts [4]. The quasienergy spectrum can exhibit a non-trivial winding number, which leads to the appearance of anomalous chiral edge modes. For



instance, an anomalous Floquet insulator with topologically trivial bulk bands is characterized by topologically protected chiral edge modes. Cold atoms have the potential to reveal these intriguing phases through direct measurements of the bulk and edge-state properties of the system.

References

[1] N. R. Cooper et al., Phys. Mod. Phys. 91, 015005 (2019).

[2] A. Eckardt, Phys. Mod. Phys. 89, 311 (2017).

[3] C. Schweizer et al., arXiv:1901.07103 (2019).

[4] T. Kitagawa et al., Phys. Rev. B 82, 235114 (2010).

notes

Mon, 14:30

Quantum computation and quantum simulation with strings of trapped Ca^+ ions

Rainer Blatt
Institute for Experimental Physics, University of Innsbruck, Technikerstrasse 25, A-6020 Innsbruck, Austria
Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Otto-Hittmair-Platz 1, A-6020 Innsbruck, Austria

The state-of-the-art of the Innsbruck trapped-ion quantum computer is briefly reviewed. We present an overview on the available quantum toolbox and discuss the scalability of the approach. Fidelities of quantum gate operations are evaluated and optimized by means of cycle-benchmarking [1] and we show the generation of a 16-qubit GHZ state. Entangled states of a fully controlled 20-ion string are investigated [2] and used for quantum simulations.

In the second part, we present both the digital quantum simulation and a hybrid quantum- classical simulation of the Lattice Schwinger model, a gauge theory of 1D quantum electrodynamics. Employing universal quantum computations, we investigate the dynamics of the pair-creation [3] and using a hybrid-classical ansatz, we determine steady-state properties of the Hamiltonian. Hybrid classical-quantum algorithms aim at solving optimization problems variationally, using a feedback loop between a classical computer and a quantum co-processor, while benefitting from quantum resources [4].

References

[1] A. Erhard et al., arXiv:1902.08543 (2019).

[2] N. Friis et al., Phys Rev X. 8 021012 (2018).

[3] E. A. Martinez et al., Nature 534, 516 (2016).

[4] C. Kokail et al., Nature 569, 355–360 (2019).

notes

Mon, 15:15

Quantum microwaves: Secure communication, cryogenic LAN cables, and illumination

Frank Deppe[1,2,3]
[1]*Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany*
[2]*Physik-Department, Technische Universität München, 85748 Garching, Germany*
[3]*Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany*

The research on quantum microwaves emitted from superconducting circuits has advanced from the realm of pure basic research to the demonstration of first protocols employing nonclassical correlations. After a brief recap of the WMI activities in this field, a recent result on the nonlocal preparation of a squeezed state and its intricate relation to one-time pad cryptography will be discussed [1]. In the outlook, ideas on distributed quantum computation, quantum microwave communication, and quantum radar targeted within the European Flagship project "Quantum Microwaves for Communication and Sensing (QMiCS)" [2] are presented.

We acknowledge support by the Germany's Excellence Strategy EXC-2111-390814868, Elite Network of Bavaria through the program ExQM, the European Union via the Quantum Flagship project QMiCS (Grant No. 820505).

References

[1] S. Pogorzalek et al., Secure quantum remote state preparation of squeezed microwave states, Nat. Commun. 10, 2604 (2019).

[2] https://qmics.wmi.badw.de/

notes

Mon, 15:40

Neural-network approach to dissipative quantum many-body dynamics

Michael J. Hartmann[1,2,3] **and G. Carleo**[4]
[1] *Department of Physics, University of Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany*
[2] *Google Research, Erika-Mann-Str. 33, 80636 München, Germany*
[3] *Institute of Photonics and Quantum Sciences, Heriot-Watt University Edinburgh EH14 4AS, United Kingdom*
[4] *Center for Computational Quantum Physics, Flatiron Institute, 162 5th Avenue, New York, NY 10010, USA*

Quantum many-body systems are hard to simulate with classical computers and are thus a good candidate for interesting first applications of quantum computers. In both scenarios, variational algorithms play a significant role, classically in the form of variational Monte Carlo approaches and quantum mechanically in the form of variational hybrid algorithms. In this talk I will introduce a classical variational algorithm that is based on machine learning techniques [1]. In particular I will focus on the experimentally relevant situation of quantum systems that are not perfectly isolated and take their coupling to an environment into account. The algorithms thus represents the mixed many-body quantum states with neural networks in the form of restricted Boltzmann machines and integrates its time evolution using a variational Monte-Carlo technique. I illustrate the accuracy of the approach with numerical examples for a dissipative spin lattice system.

References

[1] M. J. Hartmann and G. Carleo, Phys. Rev. Lett., in print, arXiv:1902.05131.

notes

Mon, 16:30

TBA

Stephanie Wehner
QuTech, Delft University of Technology, Delft, Netherlands

notes

Mon, 17:15

Quantum advantage with noisy shallow circuits in 3D

Sergey Bravyi, David Gosset, Robert König and Marco Tomamichel
IBM Watson
University of Waterloo, Canada
TU München, Germany
University of Technology Sydney, Australia

Prior work has shown that there exists a relation problem which can be solved with certainty by a constant-depth quantum circuit composed of geometrically local gates in two dimensions, but cannot be solved with high probability by any classical constant depth circuit composed of bounded fan-in gates. Here we provide two extensions of this result. Firstly, we show that a separation in computational power persists even when the constant-depth quantum circuit is restricted to geometrically local gates in one dimension. The corresponding quantum algorithm is the simplest we know of which achieves a quantum advantage of this type. It may also be more practical for future implementations. Our second, main result, is that a separation persists even if the shallow quantum circuit is corrupted by noise. We construct a relation problem which can be solved with near certainty using a noisy constant-depth quantum circuit composed of geometrically local gates in three dimensions, provided the noise rate is below a certain constant threshold value. On the other hand, the problem cannot be solved with high probability by a noise-free classical circuit of constant depth. A key component of the proof is a quantum error-correcting code which admits constant-depth logical Clifford gates and single-shot logical state preparation. We show that the surface code meets these criteria. To this end, we provide a protocol for single-shot logical state preparation in the surface code which may be of independent interest.

notes

Mon, 17:40

From quantum mechanics to probability theory - and back?

Sabine Jansen
LMU München, Mathematisches Institut, Theresienstr. 39, 80333 München, Germany

Many-body systems - quantum, but also classical - are challenging. Many methods originated in quantum mechanics prove helpful in understanding classical systems: Metastability and the rigorous proof of Arrhenius laws build on the semi-classical limit and WKB expansions; spatial correlations are studied by investigating operators (Stein operators, infinitesimal generators) and their spectral gap; duality of Markov processes, a notion related to unitary equivalence of Hamilton operators and different representations for algebras of creation and annihilation operators, is tremendously helpful in mathematical population genetics. Conversely, probability theory sometimes helps address problems in quantum statistical mechanics, e.g. via path integrals. The talk highlights some of those possible points of contacts between and probablity theory and quantum theory.

References

[1] S. Jansen, E. H. Lieb, R. Seiler:
Symmetry breaking in Laughlin's state on a cylinder
Commun. Math. Phys. 285, 503-535 (2009).

[2] S. Jansen, P. Jung:
Wigner crystallization for the quantum 1D jellium at all densities
Commun. Math. Phys. 331, 1133-1154 (2014).

[3] S. Jansen, N. Kurt:
On the notion(s) of duality of Markov processes
Probab. Surveys 11, 59-120 (2014).

notes

General Information

Science Slam

Mon, 19:30 - 21:30

Talking Quantum – Science Slam

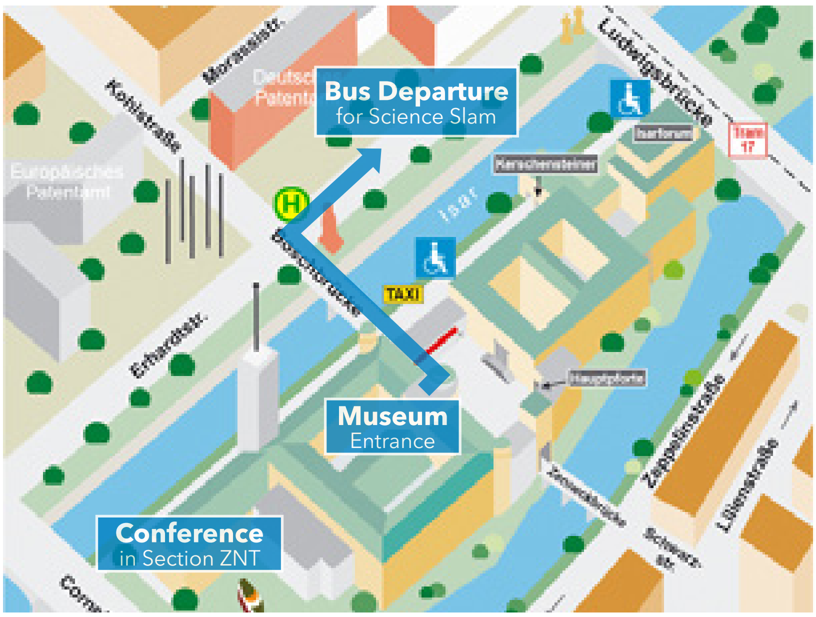
MCQST proudly presents its first Quantum Science Slam organized in collaboration with Microsoft Germany. A science slam consists of a series of talks in which scientists present complex issues and state-of-the-art research in 10-minutes in an entertaining and comprehensive way. In the end, the audience's applause will evaluate the presentations and determine a favourite. Since MCQST is all about quantum science and technology, the talks will focus primarily on quantum related themes. With this event, MCQST aims to bring quantum science into focus in an understandable and engaging way.

Our Quantum Slammers

- **Markus Hasenöhrl** | TU Munich | *Defusing a bomb - the quantum way*
- **Ivana Kurečić** | Max Planck Institute of Quantum Optics | *Quantum Policy Control Theory*
- **Frauke Seeßelberg** | Science Slammer | *AlkaLove*
- **Nicolas Tolazzi** | Max Planck Institute of Quantum Optics | *A Photon Love Story*

Host

- **Matthias Mader** | LMU München



Departure via Bus between 18:15 and 18:50

Destination:
Microsoft Atrium
Walter-Gropius-Str. 5, 80807 Munich

Tue, 9:00

Quantum sensing enabled by diamond

Fedor Jelezko
Institute of Quantum Optics, Ulm University, Germany

Electron and nuclear spin resonance is a spectroscopic technique that provides very detailed information on almost every possible substance but also as very insensitive. This may be contrasted to the excellent sensitivity of optical single molecule spectroscopy which is able to demonstrate the detection of single molecules in condensed matter. A recent development is a combination of these techniques making it possible to detect magnetic resonance transitions of single quantum systems. While first experiments were done with aromatic molecules at low temperatures, recently single spin magnetic resonance techniques were also applied to the study of defect centers in diamond allowing coherent single spin control and readout under ambient conditions. This new approach opened a number of interesting applications, such as quantum information processing and communication, secure quantum communication and sensing with nanometer resolution.

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 labeled 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 were proposed for this purpose and realized recently including technique that employs quantum entanglement. The ability to sense nuclear spins by NV centers also enables the transfer of polarization from optically polarized spins of NV centers to external nuclear spins. Such diamond based techniques for dynamic nuclear spin polarization are very promising for the enhancement of sensitivity of conventional MRI imaging.

Most of mentioned above results obtained so far with diamond centers are based on optical detection of single NV color centers. Recently it was shown that photoelectrical detection of NV centers base on spin selective photoionization can provide robust and efficient access to spin state of individual color centers

notes

Tue, 9:45

Quantum sensors for microwave radiation

T. Joas, A.M. Waeber, D.M. Irber, G. Braunbeck, Friedemann Reinhard
TU München, Walter Schottky Institut and Physik-Department, 85748 Garching, Germany

Magnetic field sensors based on spin qubits have become a front-runner candidate for real-world applications of quantum technology. In flagship experiments, Nitrogen-Vacancy centers are being used to image the magnetic field of hard drive write heads [1], and atomic vapor cells detect currents in a living brain [2].

Interestingly, virtually all existing sensors are targeting fields at low frequencies (DC - 10 MHz). Quantum sensing of GHz-frequency signals has remained under-explored, which is surprising given that the qubit transitions themselves happen to live in this range.

I will discuss the reasons for this white spot on the sensing map, and review the efforts of our group and others to fill it. This includes work on dedicated protocols for high-frequency sensing [3,4], as well as novel sensing hardware based on room-temperature cavity-QED devices that could provide sensitive detectors and amplifiers for microwave radiation.

References

[1] S. Knappe, T. Sander, L. Trahms in Magnetoencephalography, 993 (2014).

[2] I. Jakobi et al., Nature Nanotechnology 12, 67 (2017).

[3] T. Joas et al., Nature Communications 8, 964 (2017).

[4] A. Stark et al., Nature Communications 8, 1105 (2017).

[5] J.D. Breeze et al., Nature 555, 493 (2018).

notes

Tue, 10:10

Challenging QED with atomic hydrogen

L. Maisenbacher, A. Beyer, V. Andreev, A. Grinin, A. Matveev, K. Khabarova, N. Kolachevsky, R. Pohl, D. Yost, T. Hänsch and Thomas Udem
Max-Planck Institute of Quantum Optics, 85748 Garching and Ludwig-Maximilians-Universität München

Precise determination of transition frequencies of simple atomic systems are required for a number of fundamental applications such as tests of quantum electrodynamics (QED), the determination of fundamental constants and nuclear charge radii. The sharpest transition in atomic hydrogen occurs between the metastable 2S state and the 1S ground state with a natural line width of only 1.3 Hz. Its transition frequency has been measured with almost 15 digits accuracy using an optical frequency comb and a cesium atomic clock as a reference [1]. A measurement of the Lamb shift in muonic hydrogen is in significant contradiction to the hydrogen data if QED calculations are assumed to be correct [2]. In order to shed light on this discrepancy the transition frequency of one of the broader lines in atomic hydrogen has to be measured with very good accuracy. For this purpose, we have employed our previous 1S-2S apparatus as a cold source of laser excited 2S atoms in order to perform spectroscopy on the 2S-4P transitions. With a natural line width of 12.7 MHz, large Doppler effects, quantum interference etc. a good line shape analysis is mandatory to identify the true transition frequency. Our result on this transition yields a value for the proton radius that is compatible with the value obtained from muonic hydrogen with an uncertainty that is comparable to the previous hydrogen world data [3]. Meanwhile Hélène Fleurbaey and her team at the Laboratoire Kastler Brossel, Paris have re-measured the 1S-3S transition frequency with a significantly improved accuracy and find the previous "regular hydrogen charge radius" [4]. At our lab, we have also been working on this transition with a different method. We hope to be ready to report a result soon. This will provide a unique opportunity to compare two highly accurate measurements obtained at different labs.

References

[1] C. G. Parthey et al., Phys. Rev. Lett. 107, 203001 (2011).

[2] A. Antognini et al., Science 339, 417, (2013).

[3] A. Beyer et al., Science 358, 79 (2017).

[4] H. Fleurbaey et al. PRL 12).0, 183001 (2018).

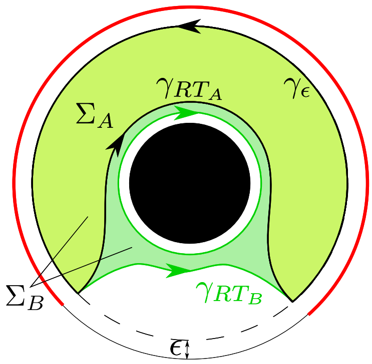
notes

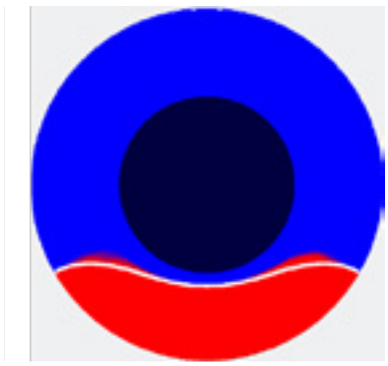
Tue, 11:00

New insights into quantum information from black holes

R. Abt, Johanna Erdmenger, M. Gerbershagen, H.Hinrichsen, C.M. Melby-Thompson, R.Meyer, C. Northe, I. A. Reyes
Lehrstuhl für Theoretische Physik III, Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg

I will give an overview over new developments that relate concepts of quantum information theory to the properties of black holes in hyperbolic space-times, in the context of generalizations of the AdS/CFT (Anti-de Sitter space/Conformal field theory) correspondence. AdS/CFT provides a new duality relation between quantum field theory and gravity. This duality is based on the holographic principle, which states that the information stored in a *d+1*-dimensional volume is encoded in its d-dimensional boundary, in analogy to the Bekenstein formula that gives the entropy of a black hole in terms of its horizon area. As proposed by Ryu and Takayanagi, the entanglement entropy of a *d*-dimensional conformal field theory may be mapped to the area of a minimal surface in *d+1*-dimensional AdS space that shares the boundary of the entangling region. In the talk I will focus in particular on recent results for *complexity*, i.e. the number of quantum gates that need to be applied to a given reference state in order to reach any other state in the Hilbert space, and on recent proposals for providing a dual realization of complexity using black holes. Results involving the topology of the hyperbolic space are reproduced in a tensor network approach.





Left: Phase transition of the Ryu-Takayanagi (RT) surface for three-dimensional black holes: The RT surface has two phases, a connected and a disconnected one.

Right: A simulation of the black-hole geometry using Ising spins in which the predicted transition between both phases is observed.

References

[1] R. Abt, J. Erdmenger, H. Hinrichsen, C. M. Melby-Thompson, R. Meyer, C. Northe and I. A. Reyes, Topological Complexity in AdS3/CFT2 , Fortsch. Phys. 66 (2018) no.6, 180003 [arXiv:1710.01327 [hep-th]].

[2] R. Abt, J. Erdmenger, M. Gerbershagen, C. M. Melby-Thompson and C. Northe, Holographic Subregion Complexity from Kinematic Space, JHEP 1901 (2019) 012 [arXiv:1805.10298 [hep-th]].

notes

Tue, 11:45

Analog Quantum Chemistry Simulation with Cold Atoms

J. Arguello-Luengo[1], Alejandro González-Tudela[2], Tao Shi[3], P. Zoller[4], J. I. Cirac[5]

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[4] *Center for Quantum Physics, University of Innsbruck, A-6020 Innsbruck, Austria*
[5] *Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany*

Solving quantum chemistry problems with a quantum computer is one of the most exciting applications of future quantum technologies. Current efforts are focused on finding on efficient algorithm that allow the efficient simulation of chemistry problems in a digital way. In this talk [1], I will present a complementary approach to the problem which consists in simulating quantum chemistry problems using ultra-cold atoms. I will first show how to simulate the different parts of the Hamiltonian, and then benchmark it with simple molecules.

References

[1] arXiv:1807.09228.

notes

Tue, 12:10

Using tensor network states for lattice gauge theories

Mari Carmen Bañuls
Max-Planck-Institut für Quantenoptik, Hans Kopfermann Str. 1, 85748 Garching (Germany)

Tensor Network (TN) techniques have demonstrated their power for strongly correlated quantum many body systems. Lattice Gauge Theories, in their Hamiltonian version, offer a challenging scenario for them. While the dimensions and sizes of the systems amenable to TN studies are still far from those achievable by Monte Carlo simulations, Tensor Networks can be readily used for problems which more standard techniques cannot easily tackle, such as the presence of a chemical potential, or out-of-equilibrium dynamics. The last years have seen an increasing interest in this particular application of Tensor Network methods. In this talk I will present some of the recent work in this area, in particular targeting the solution of continuum field theories through their discrete lattice formulation.

notes

Tue, 14:30

What does gender have to do with physics?

Tomas Brage
Division of Mathematical Physics, Department of Physics, Lund University, 221 00 Lund, Sweden

Physics is often seen, by Physicists not the least, as an objective Science and we believe we are surrounded by a "culture without culture". At the same time our history, class- and board rooms are dominated by men. This is a clear paradox that should awaken the curiosity of anyone. In this talk I will give some examples on how you can approach the question in the title. There have been several studies of Physicists and I will combine a discussion of these with some general theory and personal experiences, to paint a picture on how gender transgresses Physics, like all other fields. By using the three levels of change introduced by Schiebinger, I refer to studies of e.g. Anthropologists and Psychologists. The bias against women, due to the fact that Physics is stereotypically male, combined with the "myth of meritocracy" could be one key to understand the lack of women in the field. The talk is intended as a translation of results from recent progress in Gender Science to an audience of non-experts in the field, especially people within STEM-fields. The aim is to give some answers, but also to show that this is an extremely interesting and active research field.

notes

Tue, 15:15

Panel Discussion

"Challenges in quantum science and technologies from basic research to applications"

Companies all over the world are currently investing in quantum technologies. We have invited a few guests from industry and will ask them to share with us their companies' interest in quantum science and technology (QST) and to tell us about their activities. We will talk about the companies' aims and expectations, short- and long-term goals and their QST business model: When (and how) are they expecting to make profit from their QST branch?

Moreover, we would like to discuss how academia and industry can work together towards the goals in QST. What does industry expect from scientists? And how can scientists gain from collaboration with industry? Can Europe compete with USA and China?

Further, we would like to know if the companies are interested in forming a QST community. How should this community look like? Do companies have expectations on the skills of future QST graduates?

Our guests

- **Sella Brosh** | Chief Executive Officer at NVision Imaging Technologies GmbH
- **Markus Hoffmann** | Global Quantum Computing Practice Lead at Google Germany GmbH
- **Khaled Karrai** | Co-Founder & Scientific Director at attocube systems AG
- **Natalie Kilber** | Technical Consultant at Microsoft Deutschland GmbH
- **Walter Weigel** | Vice-President of the Huawei European Research Institute

Host

- **Jonathan Finley** | Professor at TU Munich

Tue, 16:30

Quantum Communications in Space: new opportunities for basic science and applications

Paolo Villoresi
Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Padova, Padova, Italy

Quantum Communications are based on degrees of freedom (DoF) of light that allow for the sharing of quantum states over long distances. The DoF for Space links are of interest to address the interplay of Quantum Physics and Gravity as well as the applications as QKD on very long scales.

We shall describe some steps forward in the use of temporal modes for free-space Quantum Communications (QC). These were initially used to investigate the superposition principle on a Space channel [1,2] and are recently considered for an Optical Test of the Einstein Equivalence Principle [3].

A relevant development in the Lab use of the temporal modes includes the introduction of a scheme free from the post-selection loophole, when entangled stated, that may be extended to free-space channels [4]. Moreover, the experimental efforts to improve both the resolution in the temporal detection and the photon exchange scale has now reached the level of 250 ps along a real space channel [5] and the altitude of 20000 km [6] respectively, as well the Space extension of the John Wheeler wave-particle gedankenexperiment [7].

The QC experiments along Space channels were realized at MLRO - Matera Laser Ranging Observatory of the ASI Italian Space Agency, in Matera, Italy.

notes

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Tue, 17:15

Towards quantum networks with Erbium dopants

B. Merkel, L. Weiss, A. Gritsch, P. Cova Fariña, Andreas Reiserer
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A future quantum network will consist of quantum processors that are connected by quantum channels, just like conventional computers are wired up to form the Internet. In contrast to classical devices, however, the entanglement and non-local correlations available in a quantum-controlled system facilitate novel fundamental tests of quantum theory and numerous applications in distributed quantum information processing, quantum communication, and precision measurement.

While pioneering experiments have demonstrated the entanglement of two quantum nodes separated by up to 1.3 km [1,2], accessing the full potential of quantum networks requires scaling of these prototypes to more nodes and larger distances. To this end, a new technology that overcomes the bottlenecks of existing physical seems mandatory.

In this context, our group explores individual erbium ions doped into silicate crystals. This system combines second-long ground-state coherence [3] with optical transitions in the telecommunications frequency window [4] where loss in optical fibers is minimal. However, harnessing individual erbium ions has been hampered by the ms-long lifetime of their optically excited states.

We plan to overcome this challenge using optical resonators [1]. We target an unprecedented lifetime reduction by several orders of magnitude using resonators of high quality factor with ultra-small optical mode volume. In a first experimental approach, we embed micrometer thin silicate crystals into cryogenic Fabry-Perot resonators. In a second approach, we combine silicon nano-photonic structures with erbium dopants [4]. I will present the current status of these experiments and give an outlook towards realizing global quantum networks with erbium-doped crystals.

References

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notes

Tue, 17:40

Qubit memories for quantum networks

<u>Olivier Morin</u>, M. Körber, S. Langenfeld, and G. Rempe
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Qubit memories are of a tremendous importance for the development of quantum information protocols. In the context of quantum networks, where qubits are carried and transferred by single photons, quantum memories need to be built from systems offering an efficient light-matter interaction. Systems based on cavity quantum electrodynamics have been shown to be promising platforms. However, for such systems as well as others, a thorough understanding and control of the various physical effects is necessary. For a qubit memory, essentially two challenges have to be addressed: efficiency and fidelity. In this talk, starting from those two requirements, I will present our recent progresses on the development of photonic qubit memories for quantum network applications. In particular, I will show how we can extend the storage time up to more than 100ms and thus opening up global scale quantum communication [1]. In addition, I will discuss the role of single photon temporal modes in quantum information protocols and show how it can be handled by our system [2].

References

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notes

Poster **Session**

Session A

Monday, 13:30 - 14:30

Overview A

01 Nanomechanical strings in superconducting hybrid quantum systems

Daniel Schwienbacher[1,2,3], P. Schmidt[1,2,3], N. Segercrantz[1], M. Pernpeintner[1,2,3], F. Wulschner[1,2], F. Deppe[1,], A. Marx[1], R. Gross[1,2,3], and H. Huebl[1,2,3]
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In nano-electromechanics, quantum mechanical phenomena can be studied in the literal sense. For example, the coupling of nanomechanical elements to superconducting resonators allows to cool the mechanical mode to its ground state as well as squeeze its motion. The preparation of mechanical (phonon) Fock states comes into reach by combining the circuit with a sufficiently nonlinear circuit element. In this context, a superconducting qubit is one obvious choice.

Here, we present two approaches for the design of such a hybrid system consisting of a superconducting coplanar microwave resonator, a transmon qubit, and a nanomechanical string resonator, for which we discuss design considerations as well as spectroscopy data. To be specific, we present two device types: one device (type 1), where the nano-string is integrated into a superconducting coplanar waveguide resonator at a voltage antinode, while a transmon qubit is situated at another voltage antinode, and a second device (type 2), where the nano-string is integrated into the shunt capacitance of a transmon qubit which itself is located at the voltage antinode of the superconducting coplanar waveguide resonator.

While device type 1 allows for the investigation of photon and phonon numbers in the system, device type 2 is dedicated for the investigation of mechanical ground state cooling using a transmon and the initialization of phonon Fock states.

Superconducting planar microwave resonators for high-sensitivity magnetic resonance applications 02

Stefan Weichselbaumer[1,3], P. Natzkin[1,3], C. W. Zollitsch[1,3], M.Weiler[1,3], M. S. Brandt[2,3], R. Gross[1,3], H. Huebl[1,3]
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Microwave resonators are widely used in magnetic resonance experiments to concentrate the magnetic field at the sample location and therefore increase the sensitivity. This is in particular useful in electron spin resonance (ESR) applications, where one investigates paramagnetic spin ensembles. For high-sensitivity magnetic resonance applications, one wants to optimize both the filling factor as well as the quality factor of the resonator in use. Three-dimensional cavities offer excellent quality factors, but at the cost of reduced filling factors for small sample sizes. In contrast, the use of planar superconducting microwave resonators enable both ultra-high quality factors as well as large filling factors due to the small mode volume.

We present three designs for planar superconducting microwave resonators for electron spin resonance (ESR) experiments [1]. We implement finite element simulations to calculate the resonance frequency and quality factors as well as the three-dimensional microwave magnetic field distribution of the resonators. Continuous-wave ESR experiments of phosphorus donors in natSi demonstrate the feasibility of our resonators for magnetic resonance experiments. We extract the collective coupling rate between the spin ensemble and the microwave resonator and find a good agreement with our simulation results, corroborating our model approach.

We use these planar microwave resonators to investigate the dynamics of a strongly coupled ^{28}Si:P spin ensemble at Millikelvin temperatures [2]. In particular, we use Hahn echos and observe multiple unexpected echo signatures after the first conventional echo. We present experimental data within and outside the strong coupling regime and discuss a model predicting and corroborating the amplitude evolution of the echos based on the echo separation time, the dephasing rate of the spin ensemble, and the linewidth of the microwave resonator. These measurements allow a single-shot measurement of the coherence time T2 of the spin ensemble.

References

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03 Non-local emergent hydrodynamics in a long-range interacting spin chain

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Short-range interacting quantum systems with a conserved quantity show universal diffusive behaviour at late times in the absence of quasiparticle excitations. We show how this universality is replaced by a more general transport process in the presence of long-range interactions decaying algebraically, as $r^{(-\beta)}$, with distance r. While diffusion is recovered for large exponents $\beta>1.5$, longer-ranged interactions with $0.5<\beta<1.5$ give rise to effective classical Lévy flights, a random walk with step sizes following a heavy-tailed distribution. We demonstrate this phenomenon in a long-range interacting XY spin chain, conserving the total magnetization Sz, at infinite temperature by employing non-equilibrium quantum field theory and semi-classical phase-space simulations. We find that the space-time dependent spin density profiles show a self-similar behaviour, with a scaling function smoothly covering all stable symmetric distributions as a function of β for $0.5<\beta<1.5$. In particular, the spin autocorrelation function decays algebraically, with the exponent given by $1/(2\beta-1)$. Our findings can be readily verified with current trapped ion experiments and may also be observable in critical itinerant ferromagnets.

Return probability for the Anderson model on the random regular graph and generalized Rosenzweig-Porter random matrix ensemble 04

Giuseppe De Tomasi, M. Amini, B. Soumya, I. M. Khaymovich, V. E. Kravtsov, A. Scardicchio
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We study the return probability for the Anderson model on the random regular graph (RRG) [1] and on Generalized Rosenzweig-Porter random matrix ensemble (RP) [2].

We give evidence of the existence of two distinct phases: a fully ergodic and non-ergodic one. In the ergodic phase the return probability has a standard form, characterized by a polynomial decay with time with periodic oscillations, which are attribute of the Wigner-Dyson-like behaviour. Moreover, we study the full propagation of an initially localized wave packet on the RRG, showing that it can host a sub-diffusive phase [3].

References

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[3] In preparation.

05 Numerical study of the many body localization transition

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The many body localization (MBL) phase of matter provides a robust alternative to thermalization and ergodicity in quantum systems. It has gained considerable attention in the last few years due to its fundamental importance in the understanding of statistical physics as well its experimental relevance (for example in cold atom systems). Despite many efforts, a complete understanding of the MBL-ergodic transition is still missing. We study the transition using the recently developed DMRG-X method [1]—a matrix product state method well suited to extract excited states of MBL Hamiltonians. Thanks to this technique, we can reach system sizes far beyond what is achievable using exact diagonalization techniques [2]. Motivated by a hypothesised thermalization avalanche process, our approach is to analyse the entanglement structure of these states as we approach the transition.

References

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06 Towards an efficient quantum memory at telecom wavelength

Benjamin Merkel, **P. Cova Fariña, A. Reiserer**
MPI of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Global quantum networks will require efficient interfaces between long-lived memory nodes and photons at a telecommunications wavelength, where loss in optical fibers is minimal. In this context, ensembles of Erbium ions doped into suited crystals are a promising candidate, as they exhibit both an optical transition at 1.5 μm and spin lifetimes exceeding 100 ms [1]. Unfortunately, dipole-dipole interactions between neighboring Erbium ions limit the ground-state spin coherence times and restrict the experiments to crystals with low dopant concentration. This severely limits the efficiency of quantum memories. We study two approaches to overcome this challenge: First, we have assembled high-finesse cavities that enhance the optical depth 10000 fold. This should allow us to implement efficient quantum memories in crystals with extremely low dopant concentration. To facilitate cryogenic operation, the disturbance of mechanical vibrations, which are abundant in closed-cycle cryostats, were minimized by an optimization of the cavity mount. Second, we also investigate the effect of microwave pulses on ensembles of Erbium spins and explore the potential of dynamical decoupling to increase coherence times. To this end, we have implemented a resonator on a printed circuit board whose microwave field is very homogeneous over the crystal. We will present the current status of the mentioned experiments.

References

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07 Towards single-shot readout of NV centers in diamond by low-temperature spin-to-charge conversion

Dominik M. Irber[1], **F. Kong**[2], **F. Shi**[2], **M. Kieschnick**[3], **J. Meijer**[3], **J. Du**[2] **and F. Reinhard**[1]
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We present our recent progress in implementing an improved readout scheme for the nitrogen-vacancy (NV) center's spin-state combining resonant excitation at low temperature with spin-to-charge conversion. Resonant excitation exploits that the optical excitation spectrum at low temperature has sufficiently narrow linewidths [1,2] to selectively address the spin-sublevels. In combination with a second laser pulse, a spin-to-charge conversion [3,4] protocol can be implemented, where the NV center is spin-selectively excited and converted to different charge-states. These are more stable than the initial spin-state and can currently be read-out with near single-shot fidelity.

Compared to the state-of-the-art readout [5], this work promises to accelerate readout by a factor of up to 100. Besides, laser power in the optical regime can be reduced by orders of magnitude. This reduces the risk of photodamage for future sensing experiments with biological samples.

References

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08 Simulating quantum many-body dynamics on a current quantum computer

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Universal quantum computers are potentially an ideal setting for simulating many-body quantum dynamics that is out of reach for classical digital computers. We use state-of-the-art IBM quantum computers to study paradigmatic examples of condensed matter physics – we simulate the effects of disorder and interactions on quantum particle transport, as well as correlation and entanglement spreading. Our benchmark results show that the quality of the current machines is below what is necessary for quantitatively accurate continuous time dynamics of observables and reachable system sizes are small comparable to exact diagonalization. Despite this, we are successfully able to demonstrate clear qualitative behaviour associated with localization physics and many-body interaction effects.

A strengthened data processing inequality for the Belavkin-Staszewski relative entropy 09

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In this work, we provide a strengthening of the data processing inequality for the relative entropy introduced by Belavkin and Staszewski (BS-entropy). This extends previous results by Carlen and Vershynina for the relative entropy and other standard f-divergences. To this end, we provide two new equivalent conditions for the equality case of the data processing inequality for the BS-entropy. Subsequently, we extend our result to a larger class of maximal f-divergences. Here, we first focus on quantum channels which are conditional expectations onto subalgebras and use the Stinespring dilation to lift our results to arbitrary quantum channels.

10 Quantum error-detection at low energies

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Motivated by the close relationship between quantum error-correction, topological order, the holographic AdS/CFT duality, and tensor networks, we initiate the study of approximate quantum error-detecting codes in matrix product states (MPS). We first show that using open-boundary MPS to define boundary to bulk encoding maps yields at most constant distance error-detecting codes. These are degenerate ground spaces of gapped local Hamiltonians. To get around this no-go result, we consider excited states, i.e., we use the excitation ansatz to construct encoding maps: these yield error-detecting codes with distance $\Omega(n^{1-\nu})$ for any $\nu \in (0,1)$ and $\Omega(\log n)$ encoded qubits. This shows that gapped systems contain - within isolated energy bands - error-detecting codes spanned by momentum eigenstates. We also consider the gapless Heisenberg-XXX model, whose energy eigenstates can be described via Bethe ansatz tensor networks. We show that it contains -within its low-energy eigenspace- an error-detecting code with the same parameter scaling.All these codes detect arbitrary d-local (not necessarily geometrically local) errors even though they are not permutation-invariant. This suggests that a wide range of naturally occurring many-body systems possess intrinsic error-detecting features.[1]

11 Secure quantum remote state preparation of squeezed microwave states

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Quantum communication protocols employ nonclassical correlations as a resource for an efficient transfer of quantum states. As a fundamental protocol, remote state preparation (RSP) aims at the preparation of a known quantum state at a remote location using classical communication and quantum entanglement. We use flux-driven Josephson parametric amplifiers and linear circuit elements in order to generate propagating two-mode squeezed (TMS) microwave states acting as our quantum resource. Combined with a feedforward, we use the TMS states to experimentally demonstrate the continuous-variable RSP protocol by preparing single-mode squeezed states at a distant location. Finally, security of RSP is investigated by using the concept of the one-time pad and measuring the von Neumann entropies.

We acknowledge support by the Excellence Cluster MCQST, the Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No. 820505).

Coupling of atomically thin semiconductors to plasmonic nanoantennas 12

Marko M. Petric[1,2], A. Nolinder[1], A. Lyamkina[1], M. Kaniber[1], A. V. Stier[1], K. Müller[2], and J. J. Finley[1]

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Combining nano-optical systems with optically active two-dimensional materials has recently emerged as a fascinating topic to achieve new optical functionalities at the nanoscale [1]. In this contribution, we present investigations of light-matter interactions between transition metal dichalcogenide (TMD) monolayers and lithographically defined gold bowtie nanoantennas. By performing 3D-FDTD calculations, we tuned the design of the bowtie nanoantennas to match the dipolar resonance with the fundamental exciton transitions in a proximal $MoSe_2$ monolayer. Fabricated bowtie nanoantennas show quality factors of Q = 5 and sub-10nm feed-gaps with estimated mode volumes as small as V_m = 2000 nm^3. Typical differential reflectance spectra recorded from individual TMD-bowtie nanostructures at room temperature reveal low- and high-energy peaks separated by a dip at the energy of the uncoupled exciton. To elucidate the nature of characteristic spectral features, we use the coupled oscillator model [2], which result in coupling constants at zero detuning of g = 55 meV. This places our hybrid system in the weak-coupling regime with spectra exhibiting Fano-like behavior. Furthermore, we demonstrate active control of the optical response by varying the polarization of the excitation light. The methods developed in our work contribute to on-demand realization of optimally coupled TMD-nanoantenna systems that can be site-selectively addressed. This type of nanostructure could pave the way for on-chip actively controlled hybrid devices operating at elevated temperatures.

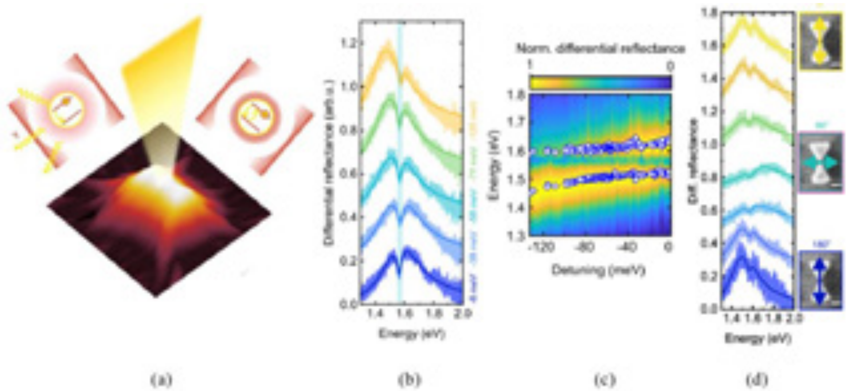

Figure 1: (a) Schematic representation of a TMD-bowtie hybrid nanostructure. (b)(c) Differential reflectance spectra recorded from single nanoantennas ordered by detuning to the exciton transition. Data reveals an anti-crossing-like behaviour. (d) Control of the optical response by tuning the polarization of the excitation light.

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13 Understanding the spin physics of donors

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We present Auger-electron-detected magnetic resonance (AEDMR) experiments on phosphorus donors in silicon, where the selective optical generation of donor-bound excitons is used for the electrical detection of the electron spin state [1]. Because of the long dephasing times of the electron spins in isotopically purified 28Si, weak microwave fields are sufficient for these experiments [2]. Implementing Auger-electron-detected electron nuclear double resonance (ENDOR), we further demonstrate the optically assisted control of the nuclear spin under conditions where the hyperfine splitting is not resolved in the optical spectrum [3]. Compared to previous studies, this significantly relaxes the requirements on the sample and the experimental setup, e.g., with respect to strain, isotopic purity, and temperature. The technique is also applicable to donors such as As, Sb or Bi with nuclear spin higher than 1/2, which opens up the possibility of examining the quadrupolar spin interaction and its dependence on strain in more detail [4].

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Decoherence dynamics of electron spins in an optically active quantum dot 14

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Semiconductor self-assembled quantum dots (QDs) offer a manifold of possibilities to realize interacting quantum systems for quantum information elements such as qubits, gates and spin-photon interfaces. However, assessing the suitability for applications requires a detailed understanding of the decoherence dynamics and exploring ways to extend the obtainable coherence times.

For electron spin in QDs two basic types of spin relaxation routes are recognized in phenomenological models of decoherence: fast ensemble dephasing due to the coherent precession of spin qubits around nearly static but randomly distributed hyperfine fields (~2ns) and a much slower process (>1μs) of irreversible monotonic relaxation of the spin qubit polarization due to nuclear spin co-flips with the central spin or due to other complex many-body interaction effects [1]. Here, we demonstrate experimentally and theoretically that not only two but three distinct stages of decoherence can be identified in the relaxation of a QD electron spin qubit. Measurements and simulations of the spin projection without an external field clearly reveal an additional decoherence stage at intermediate timescales [2]. The additional stage corresponds to the effect of coherent dephasing processes that occur in the nuclear spin bath itself induced by quadrupolar coupling of nuclear spins to strain-driven electric field gradients, leading to a relatively fast but incomplete non-monotonic relaxation of the central spin polarization (~750ns).

A system which promises significantly longer T2* times consists of logic singlet-triplet qubits formed in vertically stacked pairs of QDs, so called QD-molecules. Here, a specific "sweet spot" in the applied gate voltage can be realized in which the singlet-triplet energy splitting is in first order independent to electric and magnetic field fluctuations [3]. To these ends, we present our results towards realizing a structure where the two-electron spin states will be all-optically prepared such that the electric control of the electric field applied along the growth direction can be independently used to tune the system to the "sweet spot". Realizing such a promising system requires a systematic engineering of the growth process in order to precisely control parameters such as transition energies of the two QDs and tunneling rates.

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15 Single atoms in crossed fiber cavities

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In general, to observe an interaction between an atom and a photon, an extremely large number of either are required. Cavity quantum electrodynamics, however, provides a rich toolbox for utilizing single atoms and single photons to investigate fundamental phenomena in quantum physics through an increased light-matter coupling which is inversely proportional to the square root of the cavity mode volume. Traditional manufacturing processes of high-finesse cavity mirrors have reached the limits of the reduction of the cavity mode volume, but the introduction of mirrors fabricated by means of CO2 laser ablation has allowed for smaller radii of curvature and smaller mode volumes. CO2 laser ablation has also enabled the creation of high quality mirrors on nontraditional substrates including the ends of optical fibers [1]. The smaller dimensions of optical fiber cavities also enable new cavity geometries, including coupling a single emitter to two independent and perpendicular cavity modes. We have set up a new experiment consisting of two crossed fiber cavities which realizes this unique cavity geometry and will present measurements on trapped atoms coupling to both cavities including first results of a new quantum memory scheme.

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Studying the Coulomb glass phase on the Bethe lattice 16

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We study the Coulomb glass behavior emerging from the interplay of interactions and disorder, by examining a model of spinless fermions at half filling on the Bethe lattice [1,2]. We consider the limit of infinite coordination number, where we combine dynamical mean field theory with a Hartree-Fock approximation to investigate the glass phase transition, as well as the properties of the glassy phase in the presence of full replica symmetry breaking. This approximation, becoming exact at the classical limit where the hopping between lattice sites vanishes, allows us to study the opening of the Efros-Shklovskii pseudogap in the glassy phase, and also grants us access to the spectral function. In particular, we examine the scaling of the pseudogap at close to zero temperatures, where the melting of the Coulomb glass is governed by the quantum fluctuations induced by the hopping of fermions between lattice sites. Turning to the spectral function, interestingly we find that a significant correlation dip is formed around the Fermi energy already in the high temperature phase, before entering the glassy phase. Our results should be relevant for understanding the glassy dynamics observed in Si inversion layers, persisting in the metallic phase [3].

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17 Stability of symmetries in quantum mechanics

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The presence of symmetries in quantum mechanics allows in many cases to obtain exact solutions that is difficult to conceive a theory without them. In this series of work [2,3], we study how almost-symmetries can be approximated by exact symmetries and provide bounds on the quality of these approximations. On the one hand, we study the linear stability of the celebrated Wigner theorem [1] which tell us how we mathematically represent symmetries in quantum mechanics. More precisely, we show [2] that any transformation that preserves transition probabilities up to an additive error in a separable Hilbert space admits a weak linear approximation, i.e. one relative to any fixed observable. Furthermore, we prove that a linear approximation that is close in norm and independent of the dimension of the underlying Hilbert space does not exist in general. On the other hand, we present a new characterization of Gaussian bosonic states - an ubiquitous set of states in continuous quantum information- which has a simple symmetry interpretation. We show how stable is this symmetry characterization when the underlying conditions are almost satisfied [3].

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18 New probes of the Fermi-Hubbard model

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The phase diagram of the Fermi-Hubbard model and its connection to high-temperature superconductivity have been the subject of a vast amount of theoretical and experimental studies in the past decades. Here, we present recent results motivated by the new perspective quantum gas microscopes provide. Our theoretical approach, the geometric string theory, describes doped holes moving in an AFM environment as meson-like bound states of spinons and chargons [1]. Matrix product state based simulations of the ground state show convincing evidence for this scenario. We numerically study the dynamics of a single hole created in the ground state for a dimensional crossover from one to two dimensions and are able to explain our findings in the framework of geometric string theory.

We furthermore compare geometric string theory predictions for spin correlation functions as well as string patterns at finite temperature and finite doping to experimental data of a cold atom experiment and find remarkable agreement [2]. For an unbiased comparison of theories and experiment, we apply machine learning to classify experimental data at finite doping into different theoretical categories in order to determine which theory describes the system best on the microscopic level [3].

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19 Universality of local weak interactions and its application for interferometric alignment

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Postselection of quantum systems is used in many quantum applications and can lead to intricate novel effects. The two-state vector formalism developed by Aharonov and Vaidman [1] represents and elegant and intuitive way to describe pre- and postselected quantum systems. Its key element are weak values of observables, which are empirically accessible via weak measurements and can lead to results that lie far outside the usual spectrum of the measured observables [2]. This property of weak values became the basis of several successful applications in precision measurement techniques [3] and further applications still emerge [4].

In this work we investigate the fundamental properties of pre- and postselected systems and show both theoretically and experimentally that the weak value of local projection represents a universal description of how an effect due to any interaction of the particle is modified. Since the totality of the particle's interactions at this location is affected in the same manner, in this sense the effective presence of the particle can be seen as altered.

We demonstrate our findings experimentally by considering pre- and postselected photons passing through a Mach-Zehnder interferometer. By characterizing the effects due to various, different interactions in one of the interferometers arms, we are able to show how different degrees of freedom are influenced in the same manner.

Apart from this foundational result our findings lead to a novel, simple, and efficient alignment technique for interferometers, which harnesses the benefits of weak value amplification and the fact that weak values can be complex in general. Based on this, the phase dependence of the image on only a single detector in the output of an interferometer allows to extract misalignment parameters.

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New microscopic paradigms in the doped Fermi-Hubbard model 20

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The interplay of mobile dopants with anti-ferromagnetic spin correlations is at the heart of high-temperature superconductivity. Here we present a microscopic trial wavefunction describing individual dopants as spinon-chargon composites [1]. We derive the correlations of the charges with their spin environment and reveal short-range hidden string order, which manifests in genuine higher-order correlations developing around the dopants and can be directly observed in state-of-the-art quantum simulations. The trial wavefunction is used to analyze the spectral weight, and we argue that it provides indications that spinons have fermionic statistics. Our microscopic model explains the observations of string patterns [2,3] and the dressing cloud of magnetic polarons [4] in recent measurements performed with ultracold atoms in optical lattices. Our approach can be applied at finite doping and paves the way for a microscopic description of the exotic metallic phases in strongly correlated cuprate compounds.

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21 Quantum key distribution with small satellites

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QKD to satellites can enable global secure communication. After the first successful demonstration by the Chinese satellite MICIUS [1], the question arises how small a satellite can be designed. We show our concept for a BB84 QKD payload [2] for the nano-satellite mission QUBE. Faint laser pulses from four VCSELs at 850 nm are polarized using an array of polarizer foils and focused into a waveguide chip, which couples the four input modes into a single mode fiber. The optical QKD-unit will be hermetically sealed and mounted onto a 9x9 cm^2 PCB. Together with a second quantum payload to evaluate CV-QKD [3] and quantum random number generation [4], this mission will study the feasibility of cost effective QKD with nano-satellites in low-earth-orbits (~ 500 km altitude). In the first phase, the satellite with a planned size of only 30x10x10 cm^3 will use an optical terminal (OSIRIS - Optical Space Infrared Downlink System) with an aperture of 20 mm for downlink to the optical ground station with a planned telescope size of 80 cm to achieve high coupling efficiency.

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22 Quantized corner charge: Topological invariant for higher order symmetry protected topological phases in the 2D superlattice Bose Hubbard Model

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Topological insulators combine an insulating bulk with gapless edge states at their boundaries. Recently, higher-order topological insulators (HOTI's) have been discovered. In contrast to conventional topological insulators, an n-th higher-order topological insulator in d dimensions hosts (d-n) dimensional topological protected gapless boundary modes, but (d-1) dimensional gapped boundary states. The gapless boundary states are protected by symmetries [1]. These features even survive in the presence of interactions [2].

Here we study the 2D superlattice (SL) Bose Hubbard (BHM) at half-filling on a square lattice with open boundaries at various values for the on-site interaction strength. Beside the spatial C4 symmetry there is also a global U(1) symmetry associated with particle number conservation. We show that the 2D SL BHM can realize two inequivalent HOTI's as long as the bulk stays incompressible. We argue that the topologically inequivalent classes can be labelled by the fractional part of the corner charge which is quantized to Q=0 or Q=0.5. The fractional part of the corner charge cannot change as long as any perturbation respects the symmetries and does not close the bulk gap. To support our analytical arguments, we use the density renormalization group ansatz (DMRG) [3] on a finite 2D system, where we determine the phase diagram of the 2D SL BHM and calculate the full counting statistic of the fractional part of the corner charge Q.

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23 Simultaneous transmission of classical and quantum information under channel uncertainty and jamming attacks

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We derive universal codes for simultaneous transmission of classical messages and entanglement through quantum channels, possibly under the attack of a malignant third party. These codes are robust to different kinds of channel uncertainties. To construct such universal codes, we invoke and generalize the properties of random codes for classical and quantum message transmission through quantum channels. We show these codes to be optimal by giving a multi-letter characterization of regions corresponding to capacity of compound quantum channels for simultaneously transmitting and generating entanglement with classical messages. In addition, we give dichotomy statements in which we characterize the capacity of arbitrarily varying quantum channels for simultaneous transmission of classical messages and entanglement. These include cases where the malignant jammer present in the arbitrarily varying channel model is classical (chooses channel states of the product form) and fully quantum (is capable of general attacks not necessarily of the product form).

Periodically driven Sachdev-Ye-Kitaev models 24

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Periodically driven quantum matter can realize exotic dynamical phases. In order to understand how ubiquitous and robust these phases are, it is pertinent to investigate the heating dynamics of generic interacting quantum systems. Here we study the thermalization in a periodically-driven generalized Sachdev-Ye-Kitaev (SYK)-model, which realizes a crossover from a heavy Fermi liquid (FL) to a non-Fermi liquid (NFL) at a tunable energy scale. Developing an exact field theoretic approach, we determine two distinct regimes in the heating dynamics. While the NFL heats exponentially and thermalizes rapidly, we report that the presence of quasi-particles in the heavy FL obstructs heating and thermalization over comparatively long time scales. Prethermal high-frequency dynamics and possible experimental realizations of non-equilibirum SYK physics are discussed as well.

25 Photonic crystal cavities for efficient coupling to individual Erbium ions

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Erbium ions trapped in suited host crystals are promising candidates for large-scale quantum networks since they can combine second-long ground state spin coherence times with coherent optical transitions at telecommunication wavelengths. Unfortunately, the extremely long lifetime of the excited state (10 ms) makes it difficult to spectrally resolve and control individual ions in order to harness them for quantum networks.

To overcome this challenge, we design and fabricate Photonic Crystal Cavities (PCC) on one-dimensional silicon waveguides that can then be transferred to a suited substrate material1. At cryogenic temperature, we thus expect to shorten the radiative lifetime of the optical transitions by more than three orders of magnitude via the Purcell effect. This will enable deterministic interactions between individual spins and single telecom photons, opening unique prospects for the realization of entanglement between spins over distances exceeding 100 km. We will present simulations and the current status of the experiment towards single-ion spectroscopy and control.

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26 Giant enhancement of Imbert Fedorov shift (Spin Hall effect of light) in metals through confocal microscopy

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Confocal microscope is widely used in quantum optics for studying resonant fluorescence properties of semiconductor quantum dots [1], transition metal dichalcogenides (TMD) monolayers [2], etc… .

Such an experiment requires a high polarization rejection of the strong excitation laser beam. However, a confocal microscope contains multiple depolarizing optical elements (like mirrors and beam splitters) that makes the detection of resonance fluorescence challenging. To overcome this challenge, we have explored the limits of laser rejection with a transmitted and reflected light through two crossed polarizers. In particular, a high polarization extinction ratio of 109 was reached using a mirror reflectivity of a linearly polarized Gaussian laser beam. Whereas the polarization extinction ratio of a transmitted light through two crossed polarizers is limited to only 105 -106 range. This unexpected enhancement is due to Imbert Fedorov shift (Spin Hall effect of light) which manifests itself when a light beam reflects at air-metal interface.

With these investigations based on a single mirror reflectivity, we intend to provide progress towards a high-polarization extinction confocal microscope based on compensated two-mirror arrangement as well as compensated beam splitter arrangement.

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Optomechanics and Quantum Optics 27

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Our group focuses on Quantum Technologies. We make chips using state-of-the-art nanofabrication techniques to study quantum effects in a variety of systems. One main topic is integrated quantum optics, where photonic chips with functionality to generate, manipulate, and detect single photons are designed, made, and measured. Another field that we focus on is optomechanics. When such devices are cooled to their quantum ground state they become quantum mechanical objects. These devices will be based on photonic and phononic crystal cavities where confinement and coupling between phonons and photons takes place. We are currently fabricating and measuring our first chips while optimizing the nanofabrication techniques. Two new vacuum chambers for optomechanical studies are currently set up and will allow measurements on micrometer scale membranes and double clamped bars containing both photonic and phononic crystals. We also perform device simulations to predict designs that are promising to fabricate and study.

Poster **Session**

Session B

Tuesday, 13:30 - 14:30

Overview B

Poster **Session**

Poster No #

Poster No #

28 Secure quantum remote state preparation of squeezed microwave states

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Quantum communication protocols employ nonclassical correlations as a resource for an efficient transfer of quantum states. As a fundamental protocol, remote state preparation (RSP) aims at the preparation of a known quantum state at a remote location using classical communication and quantum entanglement. We use flux-driven Josephson parametric amplifiers and linear circuit elements in order to generate propagating two-mode squeezed (TMS) microwave states acting as our quantum resource. Combined with a feedforward, we use the TMS states to experimentally demonstrate the continuous-variable RSP protocol by preparing single-mode squeezed states at a distant location [1]. Finally, security of RSP is investigated by using the concept of the one-time pad and measuring the von Neumann entropies.

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Planar scanning probes 29

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Scanning probe microscopy (SPM) is traditionally based on very sharp tips, where the small size of the apex is critical for resolution, as in for example atomic force microscopy. This paradigm is about to shift, since a new generation of planar probes, such as SQUIDs [1], scanning SETs [2] and nitrogen-vacancy (NV) color centers in diamond [3, 4], promises to image hitherto inaccessible quantities such as very small magnetic and electric fields. So far, much effort is put into fabricating these planar sensors on tip-like structures, to be compatible with traditional SPM techniques and to bring the sensor close to the sample surface. This poses a significant engineering challenge, which is mastered by only a few groups.

On this poster, we present a novel, tipless approach - a technique to scan a planar probe parallel to a planar sample at a distance of few tens of nanometers. The core element of our scheme are optical far-field techniques to measure both distance and tilt between the two surfaces of probe and sample with 1 nm position and sub-1 mrad tilt resolution.

We use shallow NV centers at the planar surface of a bulk diamond as scanning probes. This can simultaneously lower the fabrication complexity, improve the sensor quality and reduce the sensor-sample distance compared to existing tip-based schemes. Employing the optical far-field measurements as a feedback signal we demonstrate scanning near-field optical microscopy of plasmonic modes in silver nanowires by a single NV center [5].

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30 Towards quantum simulation with $^{23}Na^{40}K$ molecules in optical lattices

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Ultracold polar molecules are promising for studying quantum many-body physics and as scalable quantum computers [1]. Strong dipolar interactions and long single-particle lifetimes make it feasible to observe exotic phases of matter [2].

We have developed a few new tools to manipulate the rotational states of our ground state molecules. The rotational structure is particularly important for controlling the mediated interactions but also adversely couples to the trapping light field. We disentangle this problem by using a spin-decoupled magic trap [3] which extends the coherence time of rotational states by one order of magnitude to about 10 ms in a bulk gas of polar molecules. Additionally, we observed density-dependent decoherence manifested by the molecules' dipolar character and we demonstrated a rotation-dependent dipole trap that can be tuned between magic, tune-out, and anti-magic by changing the laser detuning.

For quantum simulation, it is still challenging and necessary to produce a degenerate cloud of polar molecules. With our recent upgrade to the atomic transport, we can create 10^5 deeply degenerate atoms of Na and K. It brings us to a regime where we could produce a low-entropy cloud of polar molecules by magnetically associating atoms into Feshbach molecules and subsequently transferring them into the rovibronic ground state.

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Quantum engineering taken to the limits of quantum systems theory 31

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Quantum optimal control is often key to exploiting the full potential of experimental set-ups pertinent to quantum emerging technologies [1,2].

We sketch a unified comprehensive Lie frame for quantum systems theory [3,4], where symmetries and conservation laws are now in a quantum Noether-type 1:1 correspondence. Thus, one gets a full assessment of controllability, observability, and accessibility in quantum engineering. We now see which symmetries to break for more control and we show how to apply optimal control to exploit quantum dynamics within the enlarged accessible territory.

Our recent proposal [5] for an optomechanical oscillator extended by a two-level atom perfectly illustrates these principles: without breaking the system symmetries of the optomechanical oscillator one can only interconvert within the equivalence class of states of the same Wigner negativity. Coupling to the atom breaks the symmetry and thus allows to cross between these classes, e.g., from Gaussian states to non-classical ones.

The example thus elucidates guiding principles for quantum technologies 2.0.

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32 Quantum electronic circuit simulation of generalized sine-Gordon models

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Investigation of strongly interacting, non-linear quantum field theories (QFT-s) remains one of the outstanding challenges of modern physics. Here, we describe analog quantum simulators for nonlinear QFT-s using mesoscopic superconducting circuit lattices. Using the Josephson effect as the source of nonlinear interaction, we investigate generalizations of the quantum sine-Gordon model. In particular, we consider a two-field generalization, the double sine-Gordon model. In contrast to the sine-Gordon model, this model can be purely quantum integrable, when it does not admit a semi-classical description - a property that is generic to many multi-field QFT-s. The primary goal of this work is to investigate different thermodynamic properties of the double sine-Gordon model and propose experiments that can capture its subtle quantum integrability. First, we analytically compute the mass-spectrum and the ground state energy in the presence of an external `magnetic' field using Bethe ansatz and conformal perturbation theory. Second, we calculate the thermodynamic Bethe ansatz equations for the model and analyze its finite temperature properties. Third, we propose experiments to verify the theoretical predictions.

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High-finesse tunable cavity on a closed-cycle cryostat 33

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The light-matter interactions in a solid-state based quantum emitter combined with an optical cavity is a vital tool for realization of quantum technologies, as well as fundamental studies in field of cavity quantum electrodynamics. A promising platform has emerged based on Fabry-Perot cavity combined with capability for spectral and spatial tuning, which enables tuning cavity resonance for effective photon confinement and interaction with individual quantum emitter over large areas [1 - 3]. We will show our recent progress towards achieving high-Finesse stable cavity at low temperature in a closed-cycle cryostat integrated with an optical table. We will discuss various aspects of setup, particularly mechanical stability and show recent measurements characterizing the performance of the setup.

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34 A sustainable sub-Kelvin cooling technology for quantum electronics

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Cooling devices providing temperatures well below 1 K are a key prerequisite for modern research and development, e.g., in materials science, quantum electronics and the cooling of sensors and detectors. Commercially available state-of-the art cooling solutions require typically the rare and costly helium isotope, helium-3. Here we present a versatile and compact demagnetization refrigerator for the cryogen-free, continuous generation of sub-Kelvin temperatures based on prevalent and affordable solid-state cooling media.

35 Floquet approach to Z_2 lattice gauge theories with ultracold atoms in optical lattices

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Z_2 lattice gauge theories (LGTs) are of high interest in condensed matter physics and topological quantum computation. The investigation of strongly-interacting regimes, however, is especially challenging and in general difficult to access with conventional numerical methods. Here, we take a first step using analog quantum simulations and present an approach to realize Z_2 LGTs. We use a two-component mixture of ultracold bosonic atoms with strong on-site interactions in an optical two-site potential together with resonant periodic driving. For particular driving parameters, the effective Floquet Hamiltonian exhibits Z_2 symmetry. We study the dynamics of the system for different initial states and find that it is well described by a full time-dependent description. Moreover, it is non-trivial due to the imposed gauge constraints and in agreement with predictions from the ideal Z_2 LGT. We reveal challenges that arise due to symmetry-breaking terms, which may be relevant for any experimental implementation, and outline potential pathways to overcome them. The results provide important insights for studies of LGTs based on Floquet techniques and the two-site model constitutes a minimal instance for extended LGTs coupled to matter.

Symmetries of Liouvillians for Markovian dynamics and their relation to quantum information protection 36

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Invariant or decoherence-free subspaces (DFS) as well as the more general concept of noiseless subsystems are among various schemes devised for the stabilization of quantum information which can be treated in a unified algebraic framework. Within the setting of dissipative processes modeled by quantum dynamical semigroups, we explore the role of symmetries characterized by the commutants to the Lindbladian semigroup generators and their relation to DFS and fixpoint spaces. We present new results concerning the connection between these subspaces and properties of the Lindbladians, concluding with several applications.

37 Ergodicity-breaking arising from Hilbert space fragmentation in dipole-conserving Hamiltonians

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We show that the combination of charge and dipole conservation---characteristic of fracton systems---leads to an extensive fragmentation of the Hilbert space, which in turn can lead to a breakdown of thermalization. As a concrete example, we investigate the out-of-equilibrium dynamics of one-dimensional spin-1 models that conserve charge (total Sz) and its associated dipole moment. First, we consider a minimal model including only three-site terms and find that the infinite temperature auto-correlation saturates to a finite value---showcasing non-thermal behavior. The absence of thermalization is identified as a consequence of the \emph{strong fragmentation} of the Hilbert space into exponentially many invariant subspaces in the local Sz basis, arising from the interplay of dipole conservation and local interactions. Second, we extend the model by including four-site terms and find that this perturbation leads to a \emph{weak fragmentation}: the system still has exponentially many invariant subspaces, but they are no longer sufficient to avoid thermalization for typical initial states. More generally, for any finite range of interactions, the system still exhibits non-thermal eigenstates appearing throughout the entire spectrum. We compare our results to charge and dipole moment conserving random unitary circuit models for which we reach identical conclusions.

38 Towards quantum simulation of light-matter interfaces with strontium atoms in optical lattices

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In the last two decades, quantum simulators based on ultracold atoms in optical lattices have successfully emulated strongly correlated condensed matter systems. With the recent development of quantum gas microscopes, these quantum simulators can now control such systems with single-site resolution. Within the same time period, atomic clocks have also started to take advantage of optical lattices by trapping alkaline earth metal atoms such as Sr, and interrogating them with precision and accuracy at the 10^{-18} level. Here, we report on progress towards a new quantum simulator that combines quantum gas microscopy with optical lattice clock technology. We aim to trap ultracold Sr atoms in large-mode-volume and state-dependent optical lattices to emulate strongly-coupled light-matter-interfaces in parameter regimes that are unattainable in real photonic systems. We also report on a narrow-line magneto-optical trapping technique that outperforms standard techniques in terms of speed, robustness, and capture fraction.

Reachability in infinite-dimensional unital open quantum systems with switchable GKS-Lindblad generators 39

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In quantum systems theory one of the fundamental problems boils down to: given an initial state, which final states can be reached by the dynamic system in question?

Here we consider infinite dimensional open quantum dynamical systems following a unital Kossakowski-Lindblad master equation extended by controls. More precisely, their time evolution shall be governed by an inevitable (potentially unbounded) Hamiltonian drift term, finitely many bounded control Hamiltonians allowing for (at least) piecewise constant control amplitudes plus a bang-bang switchable noise term in GKS form (generated by some compact V).

Generalizing standard majorization results from finite to infinite dimensions, we show that such bilinear quantum control systems allow to approximately reach any target state majorized by the initial one as up to now only has been known in finite dimensional analogues.

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40 Probing many-body correlations in Fermi gases using Rydberg excitations

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We investigate correlation functions of a Fermi gas by exciting an atom to a Rydberg state. Atoms of the background gas can form bound molecular states with the Rydberg atom via the scattering with its electron. These molecules have a well-defined internuclear spacing. By introducing approximate wave functions we connect the molecular production rates of Rydberg molecules with different principal quantum numbers to the corresponding correlation functions evaluated at length scales of the associated Rydberg radius.

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41 Single-photon distillation with a cavity QED system

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Custom-shaped single photons are an indispensable tool for many quantum communication applications. We distill them out of incoming coherent optical pulses that are reflected from an atom-cavity system [1]. A suitable measurement on the atom is employed to herald the suppression of unwanted higher Fock components. Out of vacuum-dominated light pulses, we distill single photons with fidelity of 66%. Applying our protocol to state-of-the-art fiber cavities would allow to reach single-photon fidelities of up to 96%.

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Quantum gas microscopy of Rydberg macrodimers 42

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The sub-nanoscale size of typical diatomic molecules hinders direct optical access to their constituents. Rydberg macrodimers – bound states of two highly-excited Rydberg atoms [1,2,3] – feature interatomic distances easily exceeding optical wavelengths. Here we report the direct microscopic observation and detailed characterization of such molecules in a gas of ultracold atoms in an optical lattice [4]. The bond length of about 0.7 μm, comparable to the size of small bacteria, matches the diagonal distance of the lattice. By exciting pairs in the initial two-dimensional atom array, we resolve more than 50 vibrational resonances. Using our spatially resolved detection, we observe the macrodimers by correlated atom loss and demonstrate control of the molecular alignment by the choice of the vibrational state. Our results allow for rigorous testing of Rydberg interaction potentials and highlight the potential of quantum gas microscopy for molecular physics.

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43 MBL to diffusive phase transition in the strongly coupled disordered t-V chain

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We study the disordered t-V chain in the limit of infinite interactions V. In this limit the Hamiltonian of interest describes constraint dynamics where a fermion is only allowed to hop left or right if the total number of adjacent fermions is unchanged. This divides the full Hilbert space into unconnected blocks. Despite the infinitely strong interaction term, we identify an MBL phase for sufficiently strong but finite disorder values W > W_c in the largest sector of the Hilbert space. This can be understood by the fact that in our model interactions effectively only enter by additional constraints on the dynamics. Interestingly, for W < W_c, the growth of bipartite entanglement entropy indicates that the delocalized part of the phase diagram obeys diffusive transport properties. This is notable because most systems showing a MBL to delocalized transition behave subdiffusively in the extended phase.

44 In-plane anisotropy of the photon-helicity induced linear Hall effect in few-layer WTe_2

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Using Hall photovoltage measurements, we demonstrate that a linear transverse Hall voltage can be induced in few-layer WTe2 under circularly polarized light illumination [1,2]. By applying a bias voltage along different crystal axes, we find that the photon-helicity induced Hall effect coincides with a particular crystal axis. Our results are consistent with the underlying Berry curvature exhibiting a dipolar distribution due to the breaking of crystal inversion symmetry. Using time resolved optoelectronic autocorrelation spectroscopy [3], we find that the decay time of the detected Hall voltage exceeds the electron-phonon scattering time by orders of magnitude but is consistent with the comparatively long spin lifetime of carriers in the momentum-indirect electron and hole pockets in WTe2. Our observation suggests that a helicity induced non-equilibrium spin density on the Fermi surface after the initial charge carrier relaxation gives rise to a linear Hall effect [1,4].

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Magnetic polarons and dynamical spin-charge separation under the microscope 45

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The Fermi-Hubbard model offers an intriguing playground to explore strongly correlated many-body systems. Much of its complexity arises from the interplay of spin and charge degrees of freedom. We report on the experimental study of one- and two-dimensional synthetic Hubbard systems implemented on the optical lattice platform. We discuss our recent observations of spin-charge separation in one dimension [1] and the imaging of magnetic polarons in two dimensions [2]. Due to our spin and charge resolved imaging technique, our measurements are largely independent of presumed models. Future extensions of these experiments may allow one to study the interaction of polarons as a precursor to collective many body physics in the Hubbard model.

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46 Hybridized indirect excitons in MoS_2/WS_2 heterobilayers

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Ensembles of indirect or interlayer excitons (IXs) are intriguing systems to explore classical and quantum phases of interacting bosonic ensembles. IXs feature enlarged lifetimes due to the reduced overlap of the electron-hole wave functions [1,2]. A field effect structure with few layer hexagonal boron nitrite (hBN) as insulator and few-layer graphene as gate-electrodes facilitates an electric field control of the IXs in a MoS_2/WS_2 heterobilayer [2]. A multiplet structure in the IX emission band can be observed even at room temperature. Stark shift measurements reveal the presence of a finite out-of plane dipole of the IXs. Due to a different strength of the dipole and a distinct temperature dependence, we identify the IXs to stem from optical interband transitions with electrons and holes in different valleys of the heterostructures [2]. We observe a field dependent level anti-crossing for the energetically lowest emission line, forming hybridized indirect excitons at low temperatures [2,3]. We discuss this behavior in terms of a finite coupling of the electronic states of the two TMDC monolayers. Our results demonstrate the design of novel nano-quantum materials prepared from artificial van der Waals solids with the possibility to in-situ control their physical properties via external stimuli such as electric fields.

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Quantum optoelectronics in materials with topological order 47

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Crystals with symmetry-protected topological order, such as topological insulators or Weyl semimetals, promise coherent spin and charge transport even in the presence of disorder at room temperature. Here, we explore light-matter interactions in topological materials, and we probe the interplay of non-trivial spin-momentum textures, optical excitation, and non-equilibrium spin and charge carrier dynamics. We find an optoelectronic quantum conductance e^2/h of topological insulator surface states, which is described within the Shockley-Ramo theorem [1]. In Weyl semimetals, instead, the optoelectronic conductance is governed by non-zero Berry curvature, which results in an anomalous Hall-effect [2]. The non-equilibrium dynamics are dominated by coupling of spin and charge excitations and by ultrafast relaxation via the gapless surface states [3,4]. Our work elucidates fundamental properties of topological materials towards their integration in novel quantum electronic circuits.

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48 Interorbital interactions in Yb-171

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Ytterbium is an alkaline-earth-like atom with a metastable clock state in addition to the stable ground state. In neutral ytterbium, state-dependent lattices using these states can be employed for the realization of two-orbital magnetic Hamiltonians, including Kondo impurity and Kondo lattice models [1-3]. A fundamental parameter for Kondo models is the spin-exchange interaction, which is known to be ferromagnetic for ytterbium-173 [4], and whose dynamics in state-dependent lattices has already been observed [5]. In our experiment, we investigate the interorbital scattering properties of ytterbium-171. Using clock-line spectroscopy in a three-dimensional optical lattice, we find an antiferromagnetic spin-exchange interaction and long lifetimes of the interacting states in the lattice. Ytterbium-171 and ytterbium-173 should then make accessible quantum simulation of various and diverse regimes of Kondo-type models.

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49 Bridging the THz gap: Toward ultrafast coherent on-chip electronics up to 10 THz

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Classical electronics allows frequency components below hundreds of GHz and photonics uses phenomena starting at 10 THz with the so-called THz gap in between, where components for signal generation, conversion and detection remain difficult to implement. A promising way to access this frequency range is combining femtosecond optics and on-chip electronics to generate electric pulses in the THz domain. For information processing applications, it is essential to guide such THz pulses in integrated on-chip circuits. We study a commonly used implementation for on-chip signal transmission, so-called coplanar striplines, which in combination with photoconductive semiconductor (Auston) switches [1] allow the generation and detection of THz signals. We show the numerical computation of the effective refractive index and attenuation of coplanar stripline circuits with microscale lateral dimensions on various substrates including sapphire, GaN, silica glass, and CVD-grown diamond. We show how to include dielectric, radiative and ohmic losses to describe the pulse propagation in the striplines with frequency components up to 10 THz [2]. Our study gives a guideline to design coplanar striplines compatible with on-chip time-resolved pump-probe spectroscopy with sub-picosecond time resolution [3]. Consequently, we implement such on-chip spectroscopy scheme driven by the high peak electric fields provided by a 5 fs (FWHM) laser pulse with central wavelength 800 nm. We aim to further decrease the overall switching time and increase the resolution of the time-resolved measurements, for instance by plasmonic effects [4], and to exploit the carrier envelope phase of the laser for controlling the electronic response.

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50 Exploring mobility edges and many-body localization in a 1D quasiperiodic optical lattice

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A single-particle mobility edge (SPME) marks a critical energy separating extended from localized states. Certain one-dimensional systems with correlated disorder such as the generalized Aubry-André (GAA) model are known to have SPMEs in the corresponding single-particle spectrum. In this work, we realize the GAA model with ultracold fermionic atoms in optical lattices. We find experimental evidence for the existence of an SPME in this system. Specifically, we find a regime where extended and localized single-particle states coexist, in good agreement with theoretical simulations.

In the corresponding interacting system we find that the dynamics is continuously slowing down upon approaching a critical disorder strength, indicating that the system exhibits many-body localization (MBL) despite the presence of an SPME. Moreover, we compare and contrast two models with and without an SPME and experimentally and numerically explore their dynamics on short and long timescales. We discuss our results with respect to the potential existence of a many-body intermediate phase.

Towards a suburban quantum network link 51

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Quantum repeaters will allow scalable quantum networks, which is essential for large scale quantum communication and distributed quantum computing. Yet, still missing on the road towards a quantum repeater, is to achieve entanglement between quantum memories over long distances. Currently, we operate an experimental setup which employs the entanglement swapping protocol to generate heralded entanglement between two Rubidium 87 atoms separated by a distance of 400 meters [1]. Here we report on results towards increasing this distance by at least an order of magnitude.

Fiber based photonic quantum state distribution beyond a few kilometres makes conversion to telecom wavelengths indispensable. For this purpose, we use quantum frequency conversion, where the spontaneously emitted photon at 780 nm is mixed with a strong pump field at 1600 nm inside a nonlinear waveguide crystal in a Sagnac-type interferometer configuration [1,2]. Furthermore, to overcome losses during the frequency conversion and increase the event rate, we implemented a custom designed high-NA microscope objective, increasing the photon collection efficiency by a factor of 2.5. This now enabled the observation of atom-photon entanglement over a 10 km optical fiber with a fidelity of 85%.

Another crucial point is improving the coherence time of the atomic state. We present a method using a standing-wave dipole trap to suppress longitudinal field components introduced by the strong focussing and applying a coherent Raman transfer to the entangled atomic state to make the atomic state combination 500 times less sensitive to magnetic-field fluctuations [4]. We expect the atomic coherence time to increase by two orders of magnitude, which is sufficient for communication over more than 100 km.

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52 Lattice-trapped lithium as tunable Floquet matter

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Degenerate lithium in modulated optical lattices makes a near-ideal testbed for the experimental study of quantum matter driven far from equilibrium. We present a sequence of recent experimental results: flexible Floquet engineering of band structure and transport properties [1], direct imaging of Floquet-Bloch bands using position-space Bloch oscillations [2], detailed experimental mapping of the properties of prethermal Floquet matter [3], and an indication of anomalously slow heating in a rapidly driven interacting gas.

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Site-selectively generated photon emitters in monolayer MoS_2 via helium ion irradiation 53

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Atomically thin TMDCs are well known for their strong light matter interaction and exciton dominated spectral response. Here, we demonstrate the deterministic and site-selective generation of single defect emitters in a monolayer MoS_2 van der Waals heterostructure by bombarding it with a nanometer-focused beam of helium ions. [1] Encapsulation of the defective MoS_2 within hBN greatly enhances the optical quality and reveals narrow spectral lines with emission energies 100-220 meV below the neutral 2D exciton. [2] We spectroscopically investigate single emitters by performing photoluminescence excitation spectroscopy. The emitter line shape reveals a strong asymmetry resembling the interaction with LA/TA phonons. We attribute the emission to atomistic defects induced by the helium ion bombardment and discuss their origin in the light of ab-initio calculations and scanning tunneling microscopy measurements. Finally, we demonstrate the deterministic positioning of optically active defects within the monolayer.

We acknowledge financial support by the DFG via the German Excellence Strategy 'Munich Center for Quantum Science and Technology' (MCQST).

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54 Trions in two-dimensional semiconductors - implications for exciton-polaron physics

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We study the bound and excited states of a system composed of three charge carriers in two-dimensional semiconductors. Our approach yields accurate results for the binding energies of excitons and trions in monolayers and heterostructures of transition metal dichalcogenides (TMD) [1]. Furthermore, it allows one to infer the scattering properties of excitons and electrons based on an exact solution of the three-body problem. The predicted effective phase shift implies that range corrections cannot be neglected in the low-energy exciton charge carrier scattering. We discuss the resulting implications for the observation of exciton-Fermi polarons, a many-body system consisting of a single exciton interacting with a Fermi sea of charge carriers [2,3,4]. In particular, we find that effective range corrections have a substantial effect on the optical absorption spectrum of charge-doped TMDs, which have to be included in an accurate description of Fermi polaron formation in two-dimensional semiconductors.

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Emergent Glassy Dynamics in a Quantum Dimer Model 55

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We consider the quench dynamics of a two-dimensional quantum dimer model and determine the role of its kinematic constraints. We interpret the non-equilibrium dynamics in terms of the underlying equilibrium phase transitions consisting of a BKT-transition between a columnar ordered valence bond solid (VBS) and a valence bond liquid (VBL), as well as a first order transition between a staggered VBS and the VBL. We find that quenches from a columnar VBS are ergodic and both order parameters and spatial correlations quickly relax to their thermal equilibrium. By contrast, the staggered side of the first order transition does not display thermalization on numerically accessible timescales. Based on the model's kinematic constraints, we uncover a mechanism of relaxation that rests on emergent, highly detuned multi-defect processes in a staggered background, which gives rise to slow, glassy dynamics at low temperatures even in the thermodynamic limit [1].

References

[1] JF, F. Pollmann, M. Knap, arXiv:1901.07597.

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MCQST Munich Conference on Quantum Science & Technology

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9:00	**Boris Altshuler** (p.08) Quantum Many-Body Systems between Localization and Ergodicity	**Fedor Jelezko** (p.21) Quantum sensing enabled by diamond
9:45	**Alexander W. Holleitner** (p.09) Atomistic defect states as quantum emitters in monolayer MoS_2	**Friedemann Reinhard** (p.22) Quantum sensors for microwave radiation
10:10	**Matthias Punk** (p.10) Charge density wave quantum criticality in two dimensional metals	**Thomas Udem** (p.23) Challenging QED with atomic hydrogen
10:35	Coffee Break	Coffee Break
11:00	**Dan M. Stamper-Kurn** (p.11) Magnetism and frustration in quantum gases	**Johanna Erdmenger** (p.24) New insights into quantum information from black holes
11:45	**Michael Knap** (p.12) New routes to probe the two-dimensional Fermi-Hubbard model	**Alejandro González-Tudela** (p.25) Analog Quantum Chemistry Simulation with Cold Atoms
12:10	**Monika Aidelsburger** (p.13) Synthetic gauge fields with ultracold atoms in periodically-driven lattices	**Mari Carmen Bañuls** (p.26) Using tensor network states for lattice gauge theories
12:35	Lunch	Lunch
13:30	Poster Session A	Poster Session B
14:30	**Rainer Blatt** (p.14) Quantum computation and quantum simulation with strings of trapped Ca^+ ions	**Tomas Brage** (p.27) What does Gender have to do with Physics?
15:15	**Frank Deppe** (p.15) Quantum microwaves: Secure communication, cryo-genic LAN cables, and illumination	**Panel Discussion** (p.28) Challenges in quantum science and technologies from basic research to applications
15:40	**Michael J. Hartmann** (p.16) Neural-network approach to dissipative quantum many-body dynamics	with guests from industry
16:05	Coffee Break	Coffee Break
16:30	**Stephanie Wehner** (p.17) tba	**Paolo Villoresi** (p.29) Quantum Communications in Space: new opportunities for basic science and applications
17:15	**Robert König** (p.18) Quantum advantage with noisy shallow circuits in 3D	**Andreas Reiserer** (p.30) Towards quantum networks with Erbium dopants
17:40	**Sabine Jansen** (p.19) From quantum mechanics to probability theory - and back?	**Olivier Morin** (p.31) Qubit memories for quantum networks
18:15 - 18:50	Bus departures at Deutsches Museum	
19:00	Arrival at Microsoft Atrium München	
19:30 - 21:30	**Science Slam** (p.20)	

- Research Unit A - **Quantum Information Theory**
- Research Unit B - **Quantum Simulation**
- Research Unit C - **Quantum Computing**
- Research Unit D - **Quantum Communication**
- Research Unit E - **Quantum Metrology and Sensing**
- Research Unit F - **Quantum Matter**
- Research Unit G - **Explorative Research**
- **Special Sessions**