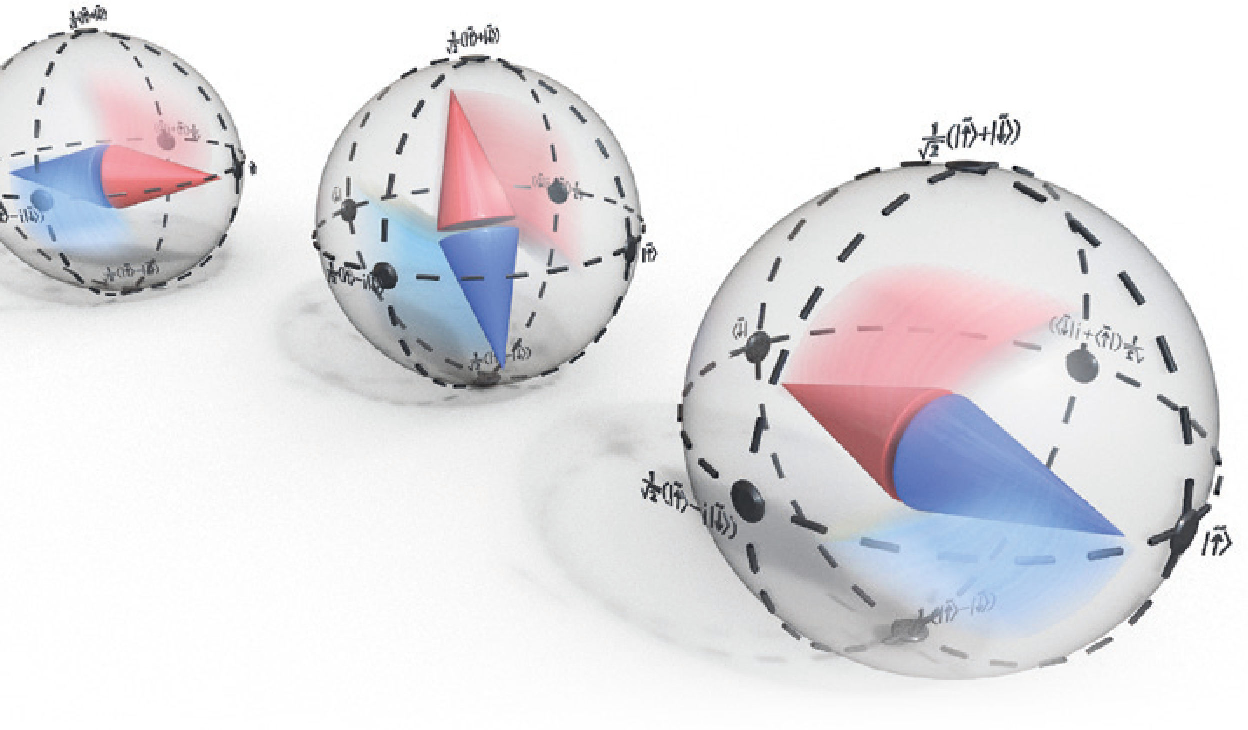
MID-TERM REPORT

Munich Center for Quantum Science and Technology

2019 – 2022 – 2025



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Introduction

>500 Scientists

including doctoral students, postdocs, staff scientists, and principal investigators are part of our active research community today.

Dear Reader,

The first four years of MCQST have passed by swiftly. Taking the cluster from its initial conceptualization on paper to its vibrant existence has been a challenging yet exceptionally rewarding experience. It's been truly gratifying to observe the tremendous passion that our members, colleagues, and friends have dedicated to supporting us in this endeavor.

Together, we have created a vibrant community, which attracts students and scientists from around the globe, and entices the general public with the world of quantum physics. By offering a large variety of support measures and educational programs, we open up new opportunities for talented researchers at all career levels. We also bring the community together at multiple events, which facilitates new connections and serves as a cornerstone for collaborative initiatives. In addition, with its flexible funding schemes, the cluster provides a fertile soil for new research ideas.

To give you a glimpse into our life at MCQST, the research done here, and the scientists doing research, we have compiled this report summarizing our activities in the first four years of the cluster's funding period. We are happy and proud of what we have achieved already together with our members, colleagues, and friends. And we are excited about what is to come within the next years in this very dynamic field of science. We warmly invite you to accompany us on this transformative journey.



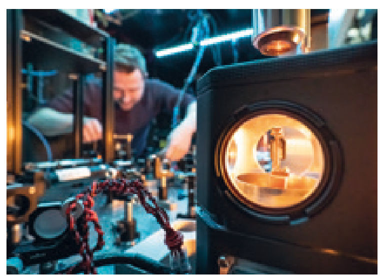
Immanuel Bloch (LMU / MPQ)
Ignacio Cirac (MPQ)
Rudolf Gross (TUM / WMI (BADW))

Discover the Cluster of Excellence MCQST –
the Munich Center for Quantum Science and Technology.

About Our Cluster

PROMOTING SCIENTISTS ON ALL CAREER LEVELS

COMMUNICATING SCIENCE TO DIFFERENT TARGET GROUPS



PROVIDING INFRASTRUCTURE, INSTRUMENTATION, AND EQUIPMENT

Uniting Munich's Quantum Scientists

Researchers from all Munich institutions active in quantum science related basic research have come together to form MCQST.

Beginning as a grassroots initiative by researchers in Munich, the MCQST officially started its work in January 2019. Now, about four years later, the cluster plays a pivotal role in quantum science in Munich and on an international scale. MCQST is composed of all institutions in Munich that are active in basic research in quantum science and technology: the Ludwig-Maximilians-Universität München (LMU), the Technical University of Munich (TUM), the Max Planck Institute of Quantum Optics (MPQ), the Walther-Meißner-Institute (WMI), as well as the Deutsches Museum (DM), which serves as an outreach partner. We bring together physicists, mathematicians, computer scientists, chemists, and electrical engineers to work jointly on our structured long-term research program covering all fields of quantum science and technology.

Enabling research

The cluster is an essential part of Munich's quantum ecosystem, enabling and supporting research by:

i. promoting scientists on all career levels,

ii. providing infrastructure, instrumentation, and equipment, and

iii. communicating science to various target groups.

With funding from the German Research Foundation (DFG) we were able to establish MCQST as a strong home base for all quantum researchers in Munich, supporting them through funding, support programs, outreach, and events.

Flexible funding

MCQST members appreciate the flexible funding we can provide over the cluster's lifetime. A considerable share of our total budget is reserved for internal support programs. The budgets are allocated to projects following tailor-made rules set by the community. The flexible funding allows us to accelerate the scientific innovation process, since it allows us to reorient our research program when needed, to follow new trends, to immediately pursue a research idea and test it, or to support talent when we find it.

The vibrant community we have created here over the past few years is transforming Munich into an attractive hub for quantum science research. Step-by-step we continue to advance towards our objective of establishing a world-leading center in quantum science.

OUR MISSION

Discover and **understand** the **novel and unifying concepts** in the interdisciplinary research fields of quantum science and technology. Make them **tangible and practical**, to develop the extraordinary applications within reach by building **next-generation quantum devices.**

EXPLORING ENTANGLEMENT

Scientific Goals

In the proposal submitted to DFG in 2018, we outlined the scientifc goals the cluster would aim to achieve, which include:

Advance the foundations of quantum information theory

to characterize new ways of processing and transmitting information using quantum devices, describe and characterize the complex entanglement present in multi-particle systems, and to further unify quantum physics and information science.

Engineer extended quantum systems

and the complex entanglement structure present therein across different time, length, and energy scales. Our research ranges from materials to artificial quantum systems, as well as explorative regimes of cosmology such as black hole physics.

Exploit unique control of quantum entanglement

for applications in computing, communication, metrology and sensing, material science, chemistry, and fundamental science.

Build the hardware and software for prototypes

of quantum devices across all thematic areas of QST: from quantum sensing to quantum communication, quantum computing, and quantum simulation.

Indentify and develop important links

between research areas and extend the reach of QST into new fields, such as high-energy physics, quantum cosmology, and quantum chemistry.

ADVISORY BOARD

Dan Stamper-Kurn (UC Berkeley): quantum simulation, quantum optics

Rainer Blatt (UIBK/IQOQI): quantum computing, quantum optics

Pascale Senellart (CNRS/C2N): quantum communication, solid state quantum devices

Markus Aspelmeyer (Univ. of Vienna): quantum sensing & metrology

Erez Berg (Weizmann Institute): quantum materials

Frank Verstraete (Ghent Univ.): quantum information theory, quantum many-body systems

Khaled Karrai (attocube): quantum metrology, supporting quantum technologies

Andrea Binder (Humboldt Foundation): international outreach, research management

Jeanne Rubner (Bayrischer Rundfunk): media & press (until 2022)

To give a first impression on the cluster's activities, we have compiled several key figures that define our community and reflect our priorities.

MCQST in Numbers

685 Scientists

…have been active in MCQST for at least 6 weeks. This includes PhD students, postdocs, staff scientists, and principal investigators.

923 Publications

…have been published by MCQST-affiliated researchers between 2019 and 2022.

124 Events

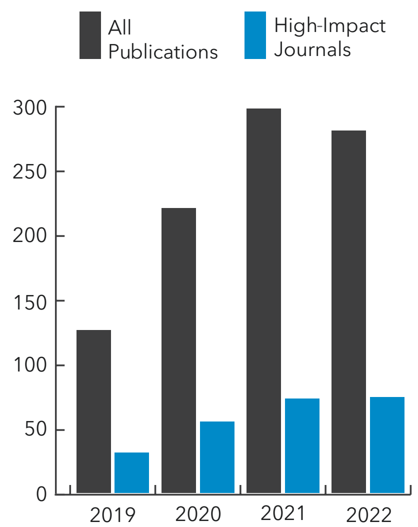
…including scientific events (conferences, scientific workshops, and colloquium talks), networking meetings, soft skill trainings, DEI (Diversity, Equity, and Inclusion) workshops, and events for the general public.

2.7 M€ for START Fellows

We are committed to support scientists at all stages of their careers. To date, a substantial sum of 2.7 million euros has been invested in the program.

419 Scientific Talks

…from specialist talks to public lectures. The majority of talks are recorded and published online to help make quantum science accessible to a global audience.



Publications

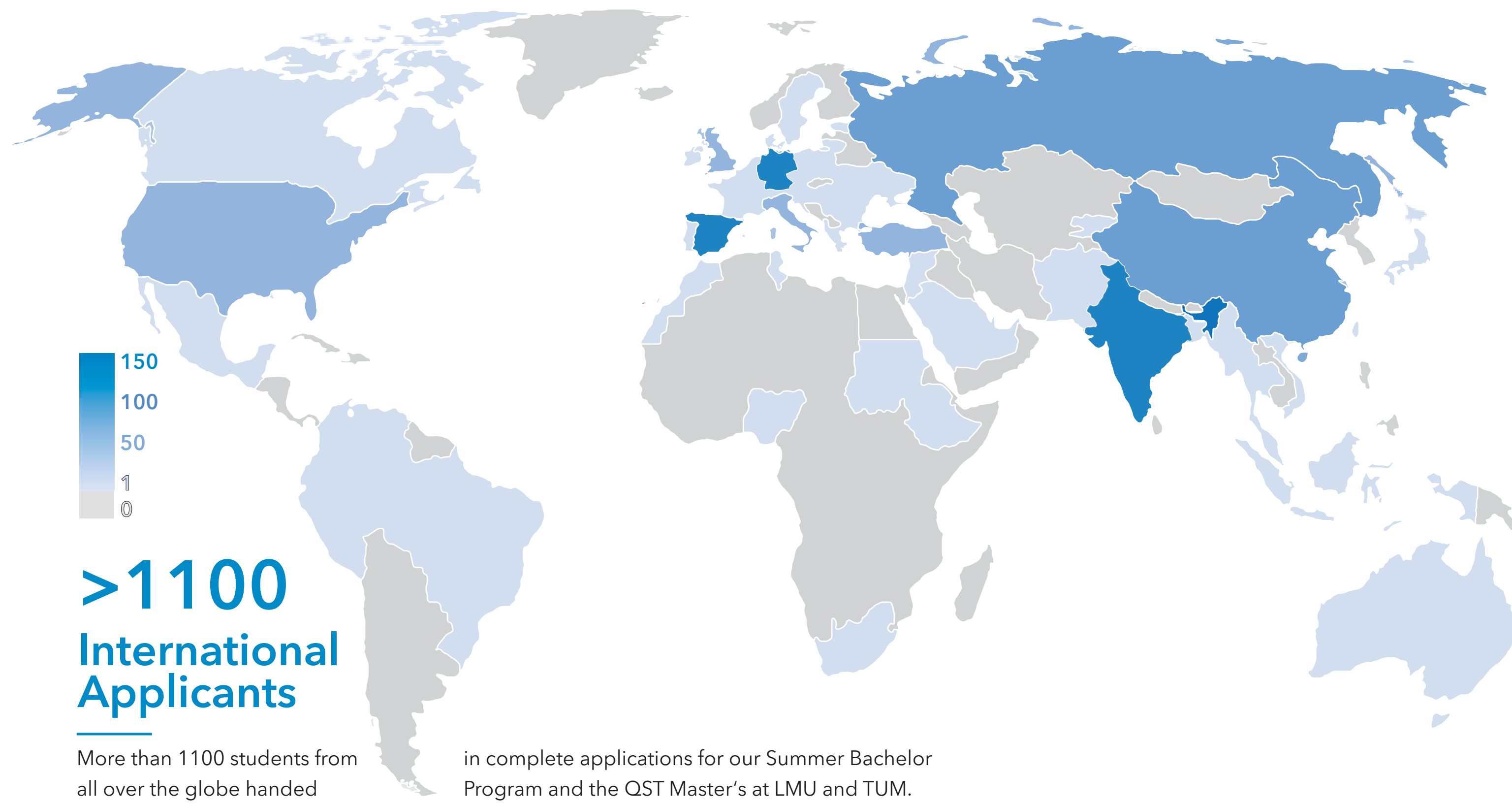
Pioneering research in top journals

Results from the excellent research by our groups are regularly featured in high-impact journals, such as Nature, Science, Physical Review Letters, Phys. Rev. X, Nature Physics, Review of Modern Physics, or Nano Letters, just to name a few. MCQST-supported papers drive progress and inspire new discoveries across disciplines worldwide.

>120 hours

DEI workshops & talks

DEI: Diversity, Equity & Inclusion



>1100 International Applicants

More than 1100 students from all over the globe handed in complete applications for our Summer Bachelor Program and the QST Master's at LMU and TUM.

40% International

MCQST has a high percentage of international scientists, with 23% coming from Europe and the remaining 17% coming from the rest of world.

9 ERC Grants

Multiple grants by the European Research Council from 2019-2022.

15 Appointments

15 professors active in QST have been appointed at LMU and TUM.

61 Scientific Guests

…were invited via the MQC Guest Program, including 37 colloquium speakers and 24 international guests carrying out extended research visits within our research groups.

+50% Female PhDs

The success of our DEI measures is demonstrated by the increase of female PhDs in the cluster from 12 to 18% in the last 4 years. But with 14.3 % female researchers in total we still have a long way to go!

Curious? Find the stories behind the numbers throughout this report.

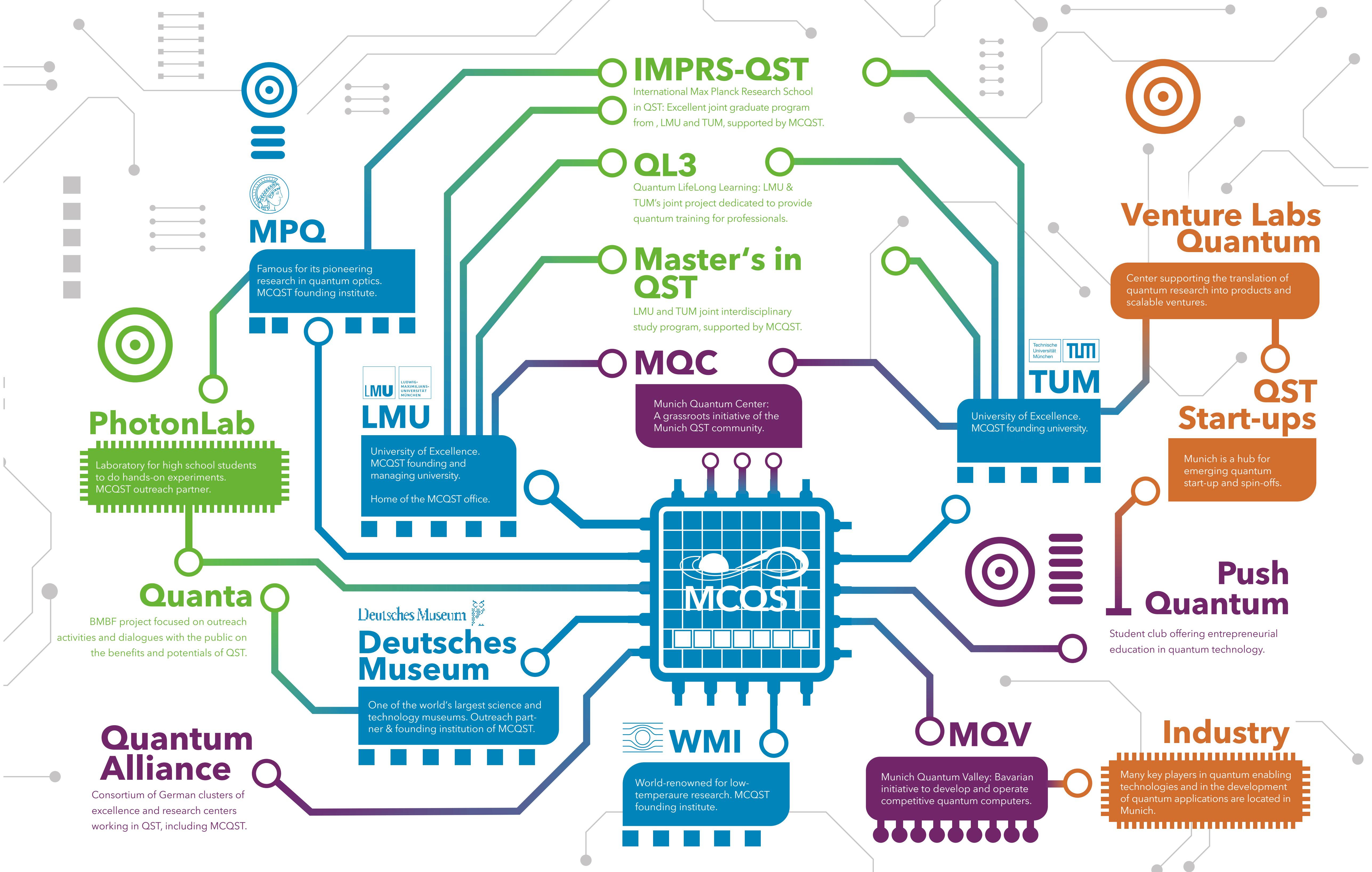
7 M€ Support Programs

We provide an extensive selection of support programs for QST researchers, fostering collaboration and providing funding and opportunities for quantum scientists at all career levels.

Early Career Support

We place a major emphasis on supporting early-career researchers, facilitating their journey towards independence, supporting them in establishing their own research groups, and promoting their visibility through outreach.

Munich's Integrated Quantum Network



In addition to MCQST's strong ties with its founding institutions, we have established a large network spanning institutes and clusters across Munich, Bavaria, and the entire country. MCQST has actively co-founded and supported various programs aimed at nurturing young talents within the QST community. We also maintain robust connections with industry and start-ups, fostering entrepreneurial education and facilitating job opportunities for our members.

Ludwig-Maximilians-Universität München (LMU)

LMU is one of the top European research university, excelling in teaching and pioneering research. Its diverse disciplines and exceptional faculty create a strong foundation for outstanding research and academic achievements.

Technical University of Munich (TUM)

TUM is one of the leading European universities focused on research, teaching, and innovation in engineering, natural sciences, life sciences, medicine, and social sciences. It fosters entrepreneurship, talent, and societal value creation.

Max Planck Institute of Quantum Optics (MPQ)

MPQ is a top institute for quantum optics research, pioneering advancements in quantum computing while exploring new forms and states of quantum matter.

Walther-Meißner-Institute (WMI)

WMI of the Bavarian Academy of Sciences and Humanities (BAdW) is renowned for low-temperature research. WMI excels in exploring physics at ultra-low temperatures and is a global leader in quantum technology advancements.

Deutsches Museum (DM)

The DM is one of the world's largest and most successful natural sciences and technology museums, known for its commitment to connecting cutting-edge research with a diverse public of all ages and educational backgrounds.

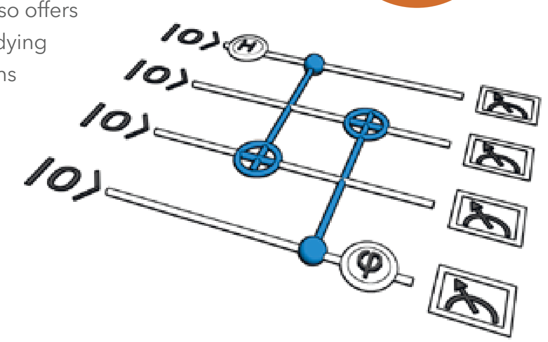
Scientists from various disciplines work together across all core areas of quantum science and technology.

Our Research Program

Research Unit A
Quantum Information Theory

RU-A

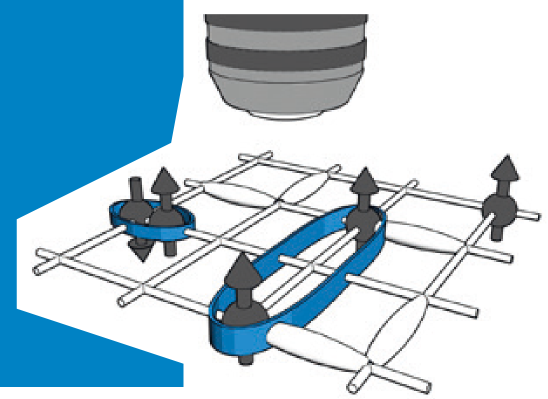
Quantum information theory revolutionizes information processing using quantum physics. It enables secure communication, powerful algorithms surpassing classical computers, and applications like sensitive sensors. Being complex and interdisciplinary, it involves physicists, computer scientists, and mathematicians. It also offers new perspectives for studying complex quantum systems in various fields beyond information processing, such as new materials, high energy problems, black holes, and holographic principles.



Research Unit B
Quantum Simulation

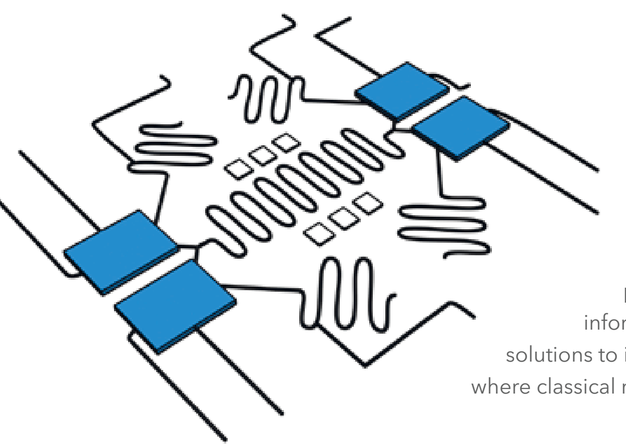
RU-B

Quantum simulation focuses on understanding and controlling complex quantum systems. It enables the preparation of many-body wave functions for challenging problems, surpassing classical computational resources. Experimental control and purity allow for simulations with hundreds of qubits, achieving 'quantum advantage'. RU-B's expertise in theory and experimentation drives advancements in quantum simulations, improving algorithms, gaining conceptual insights, and proposing new protocols.



Research Unit C
Quantum Computing

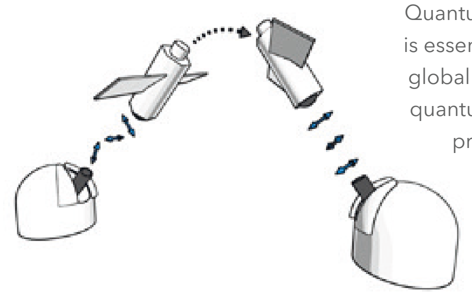
RU-C



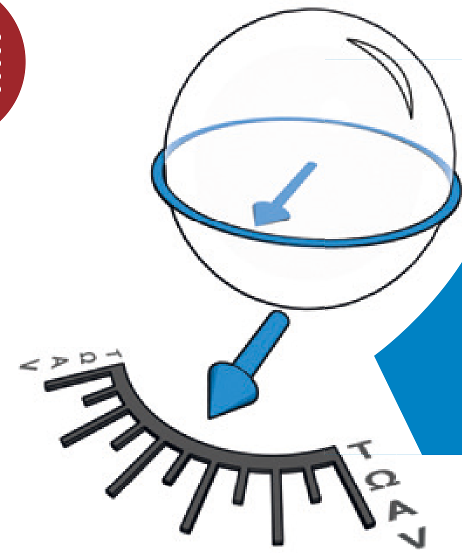
Quantum computers leverage the principles of quantum physics to process information, providing solutions to intricate problems where classical methods fall short. While prototypes using different physical implementations exist, the development of scalable devices remains a significant challenge. In addressing this obstacle, RU-C collaborates closely with other Research Units within MCQST, exploring innovative concepts involving topological matter and quantum control to tackle the issue of decoherence.

Research Unit D
Quantum Communication

RU-D



Quantum communication is essential for secure and global connectivity, while quantum key distribution provides unmatched security against future quantum computers. Its integration into networks but also the development of quantum repeater networks are vital for a quantum internet. Therefore Research Unit D: Quantum Communication focuses on advancing these crucial technologies.



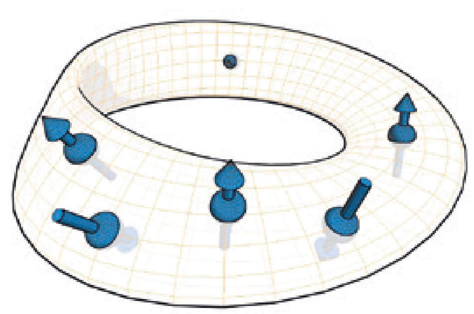
Research Unit E
Metrology and Sensing

RU-E

Utilizing optical frequency combs, spin qubits, and entanglement, Quantum Metrology and Sensing explores the frontier of precision measurement. Applications span all fields of science and technology, requiring collaboration between theoretical and experimental groups to optimize sensing protocols and control strategies.

Research Unit F
Quantum Matter

RU-F

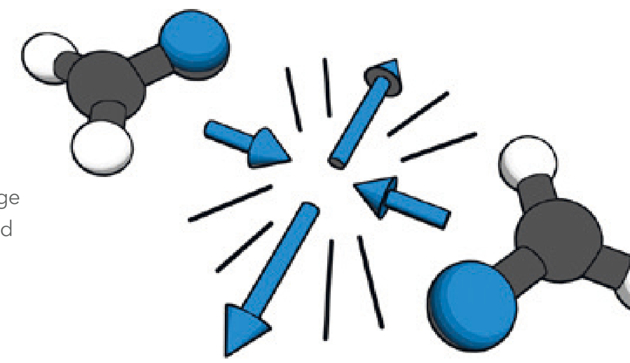


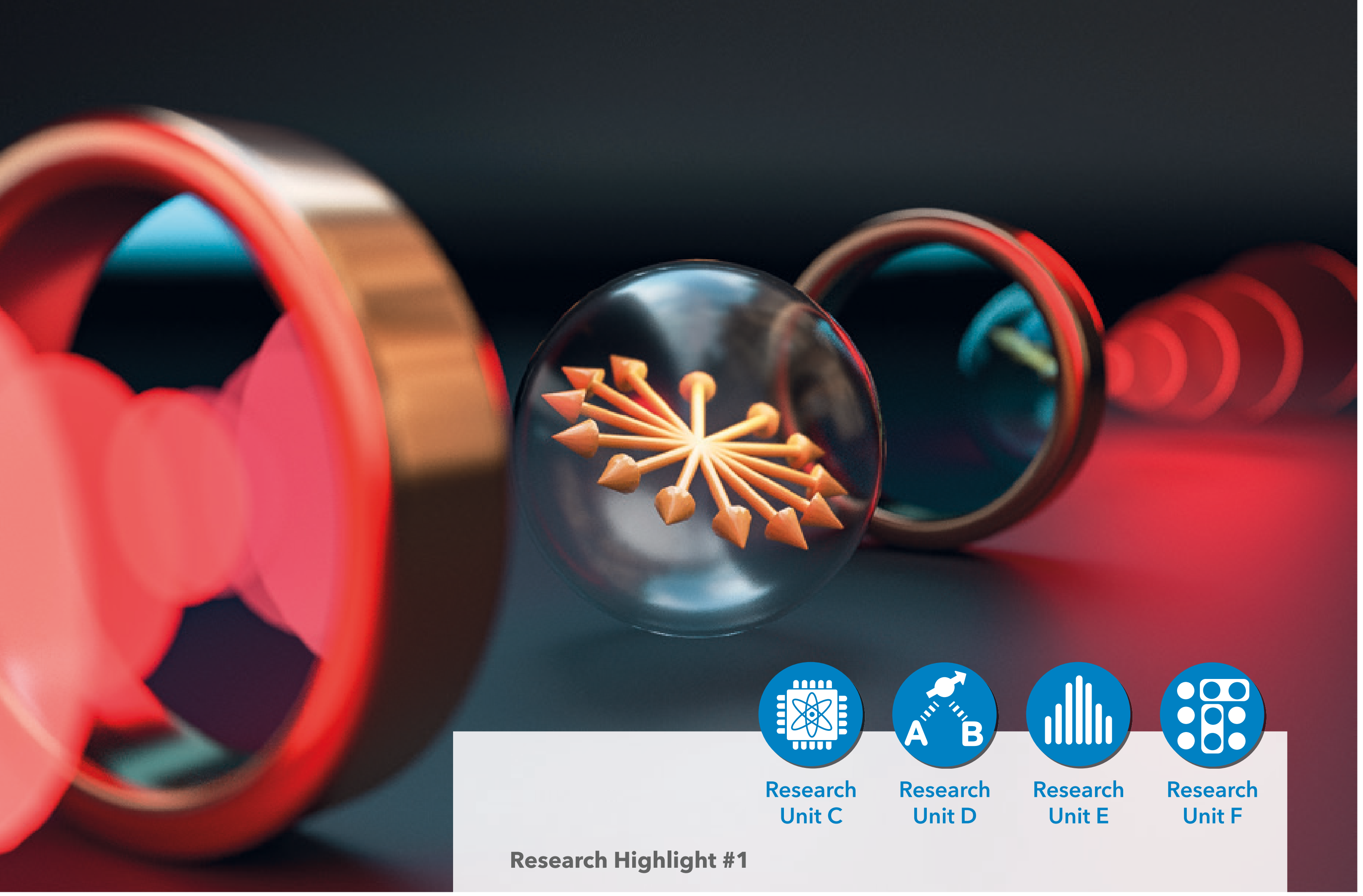
RU-F's central goal is to experimentally create tailored quantum materials and customized many-body systems. It aims to understand quantum phases of matter, control their properties, and develop theoretical tools. This research holds transformative potential for advanced electronic, spintronic, and photonic devices with unprecedented functionalities.

Research Unit G
Explorative Directions

RU-G

In recent years, various disciplines in quantum science have found common ground, creating exciting connections with high-energy physics, quantum gravity, cosmology, and quantum chemistry. Entanglement serves as a bridge, offering fresh perspectives on fundamental problems in these fields. This Research Unit aims to explore these frontiers and leverage quantum information concepts and methods to revolutionize multiple scientific domains.



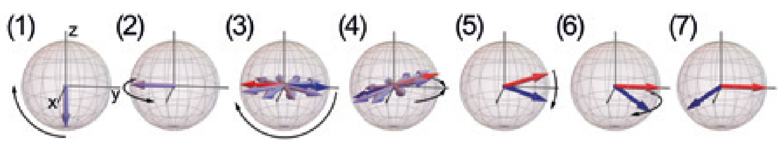


Research Unit C
Research Unit D
Research Unit E
Research Unit F

Research Highlight #1

The Return of the Spin Echo

Spin echoes (also known as Hahn echoes) hold significant importance in the natural sciences and are also useful in medical imaging, such as MRIs. In quantum sciences, they are vital for determining coherence time, representing the "quantum memory time" of a state. This study explored the intricate dynamics resulting from a Hahn echo sequence applied to a hybrid system consisting of a superconducting microwave resonator and an ultra-long coherent spin ensemble. Remarkably, this experiment revealed that the hybrid system emits a sequence of spin echoes, due to the strong coupling between the microwave circuit and the spins. This discovery raises intriguing questions about utilizing this effect for long-term quantum state storage, which is crucial for quantum communication, computing, and sensing applications. The success of this research is thanks to the collaboration of MCQST researchers from various areas of expertise, specifically Hans Huebl (spins and microwave circuits), Martin Brandt (coherent control of spin ensembles with electrical readout), and Rudolf Gross (microwave quantum circuits), supported by theoretical insights from Stefan Rotter at TU Vienna.



ABOVE FIGURE

Spin echo sequence of a spin ensemble strongly interacting with a superconducting microwave circuit.

3 M€
Follow-up Funding

S. Weichselbaumer, M. Zens, C. W. Zollitsch, M. S. Brandt, S. Rotter, R. Gross, and H. Huebl

Phys. Rev. Lett. **125**, 137701 (2020)

PAVING THE PATH

The results shown in Research Highlight #1 serve as a pivotal puzzle piece for projects originating out of MCQST. They act as a centerpiece for the storage of quantum tokens in a project funded by BMBF within the grand challenge of quantum communications (1.8M€), represent a prototypical system for the understanding and spectroscopy of quantum matter funded via the DFG collaborative research center (TRR360) constrained quantum matter (0.6M€), and are a building block for projects pursued within the lighthouse projects NEQUS and IQ-Sense (0.6M€).

Research Highlight #2

Atomistic Defects as Single-Photon Emitters in Atomically Thin MoS_2

For potential applications in quantum technologies, single-photon emitters need to exhibit a high position accuracy, a significant long-term stability, and a clear path for scalability. By irradiating hBN-encapsulated monolayers of MoS_2 with a focused He-ion beam, MCQST researchers demonstrated that quantum emitters based on single sulfur vacancies can deterministically be generated in a maskless (and therefore scalable) fashion. Due to the nanometer resolution of the He-ion lithography, the position accuracy was below 10 nm, limited only by back-scattering of secondary electrons. Long-term studies have shown that the atomistic quantum emitters are stable for several months. Moreover, the method allows introducing such atom-scale quantum emitters in already assembled heterostructures of 2D materials, paving the way toward future gate-tunable optoelectronic quantum circuits based on single defects.

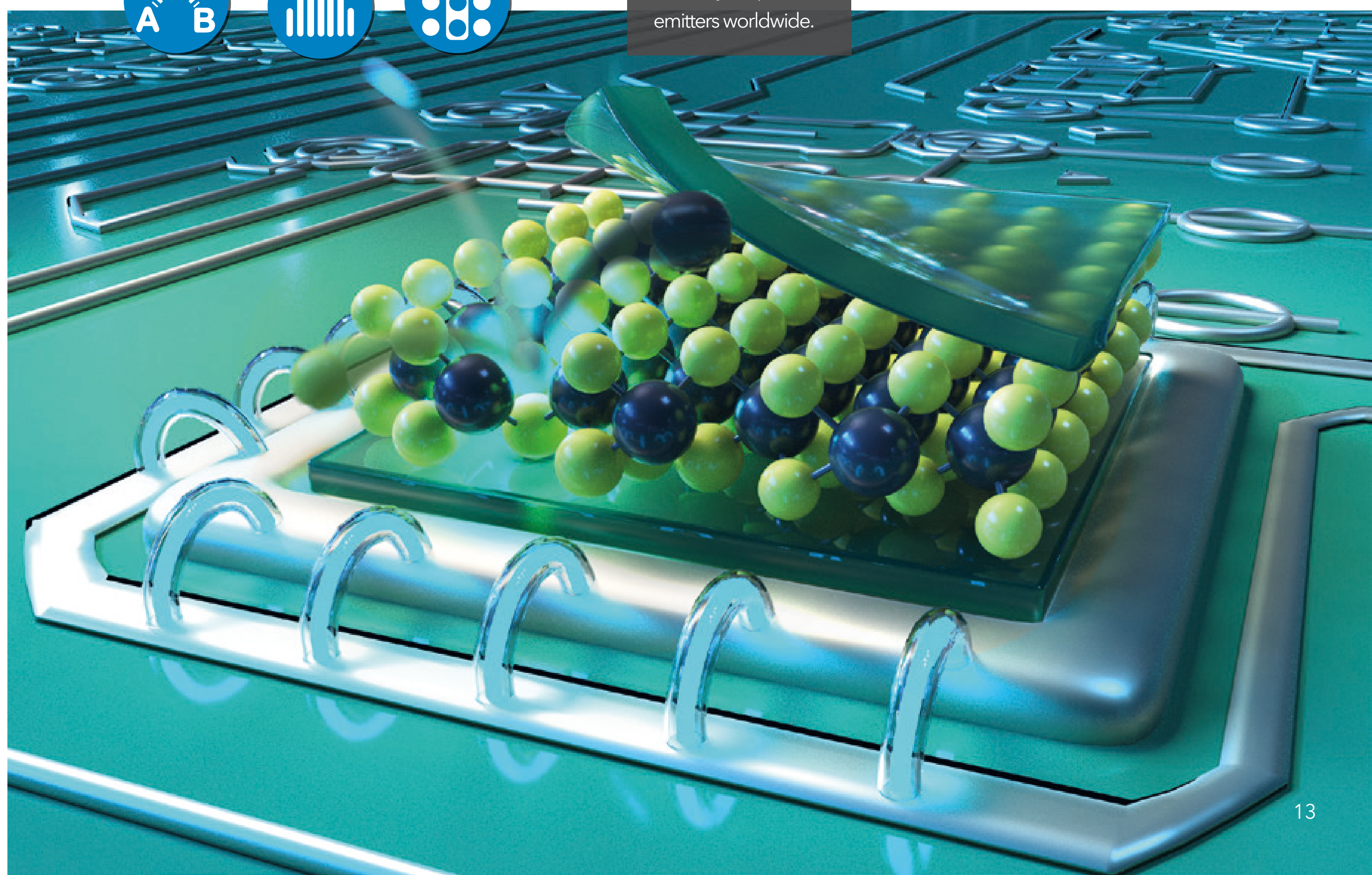
K. Barthelmi, J. Klein, A. Hötger, L. Sigl, F. Sigger, E. Mitterreiter, S. Rey, S. Gyger, M. Lorke, M. Florian, F. Jahnke, T. Taniguchi, K. Watanabe, V. Zwiller, K. D. Jöns, U. Wurstbauer, C. Kastl, A. Weber-Bargioni, J. J. Finley, K. Müller, A. W. Holleitner

Appl. Phys. Lett. **117**, 070501 (2020)
Perspective Article

Research Unit D
Research Unit E
Research Unit F

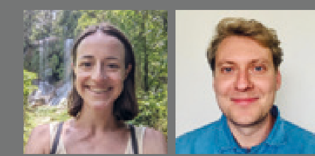
TOP-NOTCH POSITIONING

The Holleitner chair has achieved the highest position accuracy of quantum emitters worldwide.



THE LINK BETWEEN RESEARCH GROUPS

Both Katja Barthelmi and Julian Klein have been working between the groups of the MCQST-PIs Holleitner, Finley, Müller, and Knap, exploiting the groups' complementary expertise across various areas, including nanoscopic He-ion lithography, quantum optics and communication, as well as theory.



Katja Barthelmi and former PhD Student Julian Klein.

Research Highlight #3

Floquet Approach to Z2 Lattice Gauge Theories with Ultracold Atoms in Optical Lattices

Coupling matter to gauge fields can fundamentally alter its physical properties. Once the gauge fields themselves behave quantum mechanically, the physics become even richer. Indeed, the resulting models – known as lattice gauge theories – have a similar fundamental structure to the Standard Model of particle physics. In this work, scientists from MCQST, together with collaborators from the Université Libre de Bruxelles and Harvard University, have devised a feasible scheme to perform quantum simulations of lattice gauge models coupled to dynamical matter. In a proof-of-principle experiment using mixtures of ultracold atoms in optical lattices, the team demonstrated the practical feasibility of their approach in the laboratory. They implemented a minimal lattice gauge theory – with a local Z2 symmetry – which plays an important role in condensed matter physics and quantum computation. To this end, the team combined lattice shaking techniques with strong local interactions of ultracold atoms. By coupling the underlying building blocks realized in their work, the authors described how extended versions of their model can be realized in the future.

Theoretical proposal:

L. Barbiero, C. Schweizer, M. Aidelsburger, E. Demler, N. Goldman, & F. Grusdt

Science Advances, **5**, 7444 (2019)

Experimental realization:

C. Schweizer, F. Grusdt, M. Berngruber, L. Barbiero, E. Demler, N. Goldman, I. Bloch & M. Aidelsburger

Nature Physics, **15**, 1168-1173 (2019)

The last of many...

This study was also the last experiment performed on a record-breaking setup before it was decommissioned. During its lifetime, the experimental apparatus was used in research representing an estimated:

27k Citations

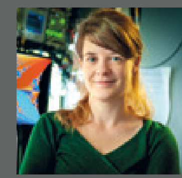
19 Year Lifetime

5 Generations of PhD students, constantly increasing its capabilities

46 Publications published in 9 different scientific journals

Kicking off a new initiative to simulate larger lattice gauge theories

The prospect of realizing lattice gauge theories using quantum simulation platforms has generated enormous interest around the world, not least for the fact that the Standard Model of particle physics is ultimately a gauge theory. While first extensive theoretical studies of such endeavors were performed in the early 2000s, the demonstration of experimental feasibility in building-block experiments like the one described here at MCQST sparked a new flame. To further concentrate their joint efforts, the team from MCQST together with colleagues from around Europe created a new consortium funded by QuantERA: Next Generation Quantum Simulators: From DYNAMIcal Gauge Fields to Lattice Gauge ThEory (DYNAMITE).



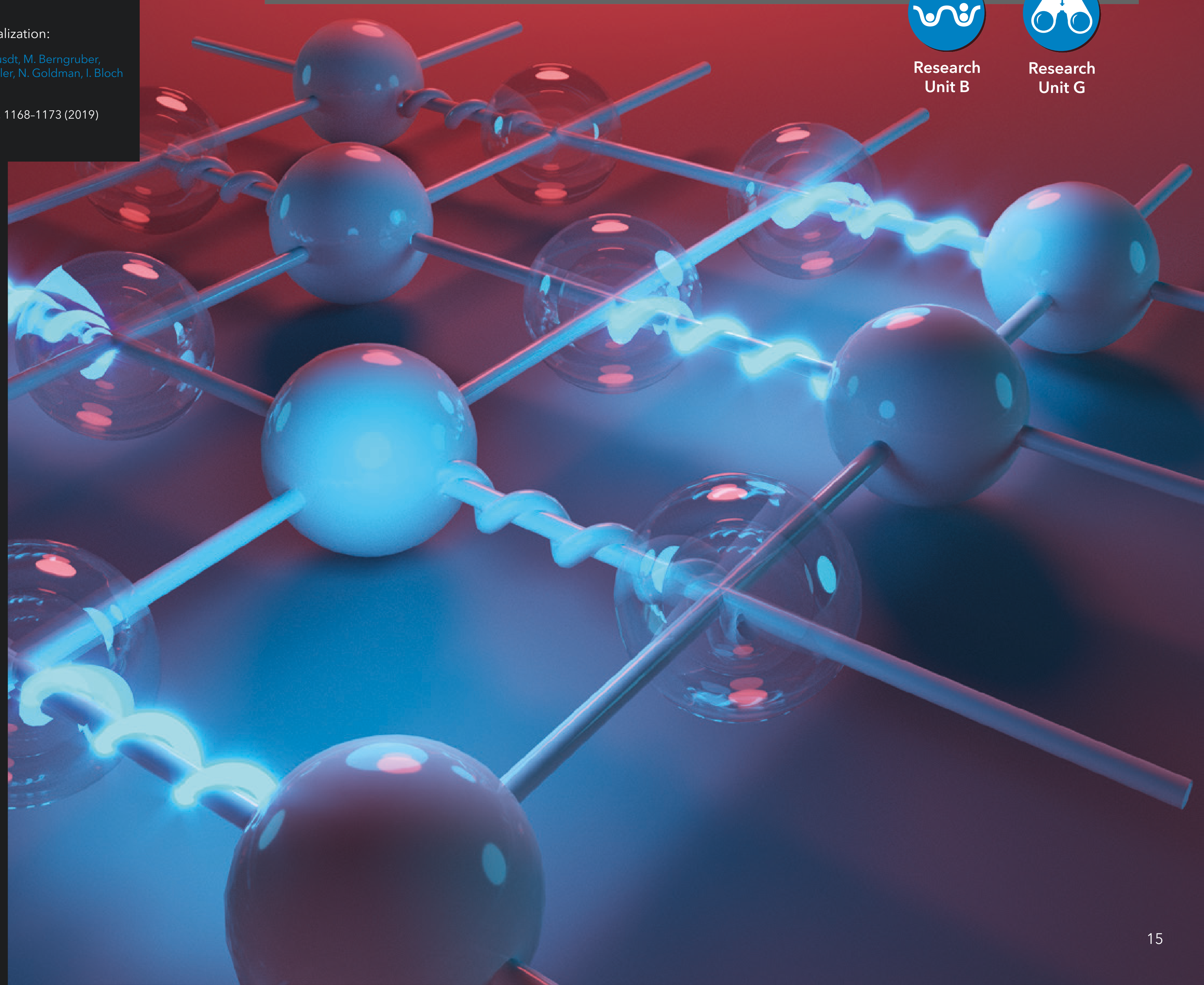

Monika Aidelsburger and Fabian Grusdt combined their experimental and theoretical expertise to realize lattice gauge fields with ultracold atoms.

THEORY MEETS EXPERIMENT

Theoretical and experimental teams led by MCQST PIs joined forces to devise, analyze, and subsequently realize a new building block for the simulation of lattice gauge theories coupled to dynamical matter. On the experimental side, inhomogeneous broadening was among the main challenges, which could be verified by detailed theoretical simulations including disorder averaging. On the theoretical side, the scalability beyond the two-site building block constituted a central question, which was ultimately solved in a concerted effort in which the experimental input played a decisive role. Furthermore, the team's analysis identified a key future challenge: to protect the local gauge invariance for sufficiently long times.

Research Unit B

Research Unit G



Research Highlight #4

Nondestructive Detection of Photonic Qubits

Researchers at the Max Planck Institute of Quantum Optics have developed an extremely subtle optical detector that can detect single photon qubits without destroying the photon or the encoded quantum state. The detector is based on a single atom trapped at the center of two crossed optical resonators. Photonic qubits are reflected in one of the resonators while leaving a trace on a quantum superposition state of the atom. This change in the atomic superposition state occurs without energy exchange, in such a way that the photon qubit is still alive after the interaction with the detector. The change in the atomic state can be then measured using cavity-enhanced fluorescence with the second crossed resonator, indicating the presence of the reflected photonic qubit.

This nondestructive detector can be used to track quantum transmissions, aiming to improve the efficiency of quantum communication. In this type of communication, quantum bits of information are encoded in single photons, but the loss of these photons poses limitations. Therefore, being able to identify whether photonic qubits are still on their way or have been lost during communication, can significantly reduce the effort required for the subsequent information processing.

D. Niemietz, P. Farrera, S. Langenfeld the G. Rempe

Nature **591**, 570-574 (2021)

Research Unit D

7 Years

to develop and manufacture the optical cavities and assembling the setup

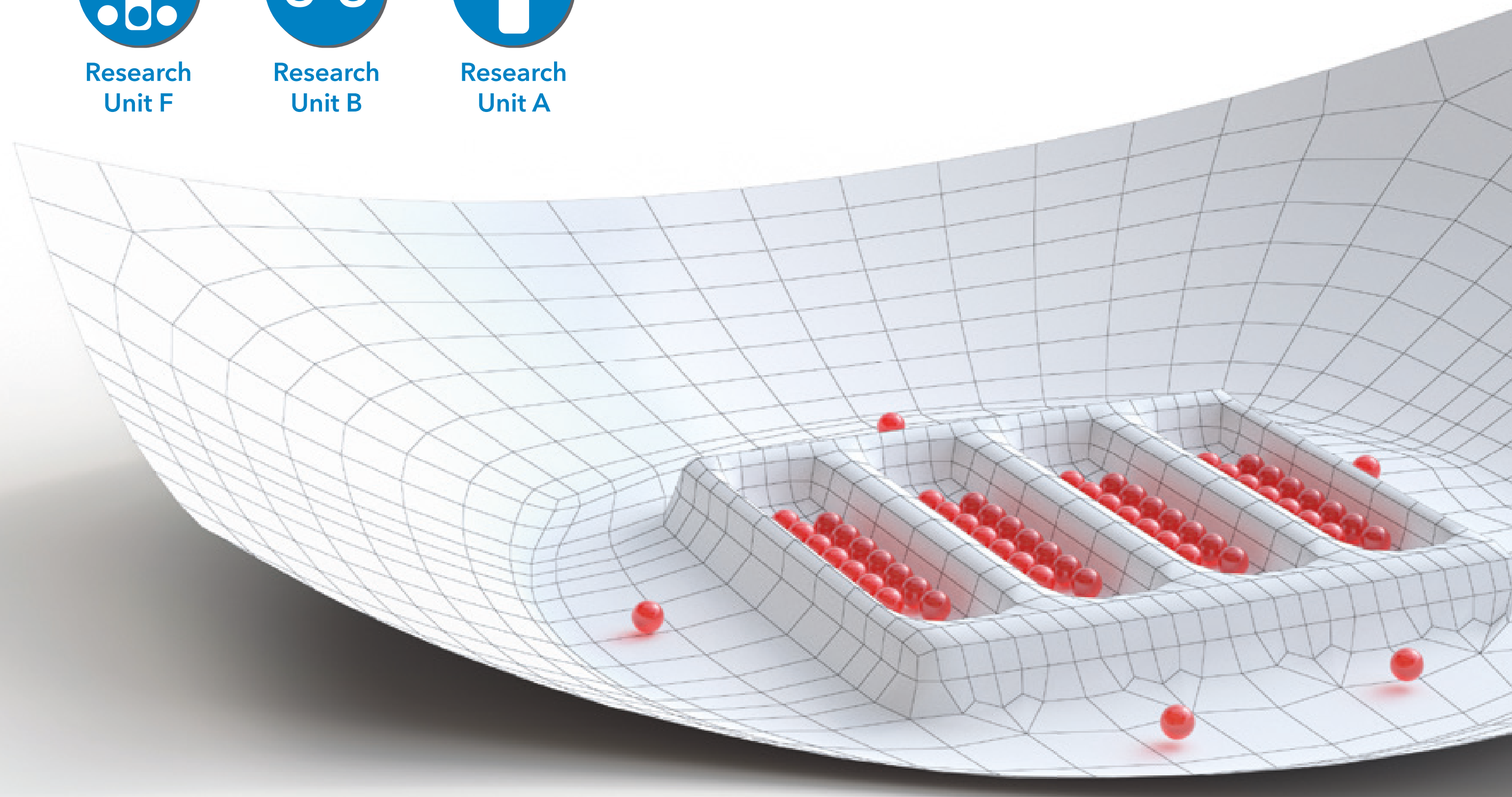
1 Atom
2 Cavities

Two independent cavities are strongly coupled to a single atom

VISIT THE ACTUAL LAB IN 360°
www.mcqst.de/crossfibre

Take a 360° lab tour in the cross fibre cavity lab at the Quantum Dynamics Division at MPQ led by Gerhard Rempe.

Research Unit F | Research Unit B | Research Unit A



Research Highlight #5

Realizing the Symmetry-Protected Haldane Phase in Fermi-Hubbard Ladders

Topology has revolutionized how we grasp quantum phases of matter. An influential model is the antiferromagnetic spin-1 Haldane chain, which describes a perfect one-dimensional row of interacting quantum particles with three internal states each. It displays unusual magnetic order and surprising states at its edges. Recently, it became clear that this chain represents a specific instance of a broader classification scheme for symmetry-protected topological phases, linked to quantum information and entanglement. MCQST researchers achieved a finite-temperature version of this topological Haldane phase using Fermi-Hubbard ladders in an ultracold-atom quantum simulator.

By employing single-site and particle-resolved measurements, along with non-local correlation functions, scientists directly observed both edge and bulk properties. Varying the interaction strength allowed them to explore the magnetic phase's resilience to charge fluctuations with a novel correlator.

P. Sompet, S. Hirthe, D. Bourgund, T. Chalopin, J. Bibo, J. Koepsell, P. Bojović, R. Verresen, F. Pollmann, G. Salomon, C. Gross, T. A. Hilker & I. Bloch

Nature **606**, 484-488 (2022)

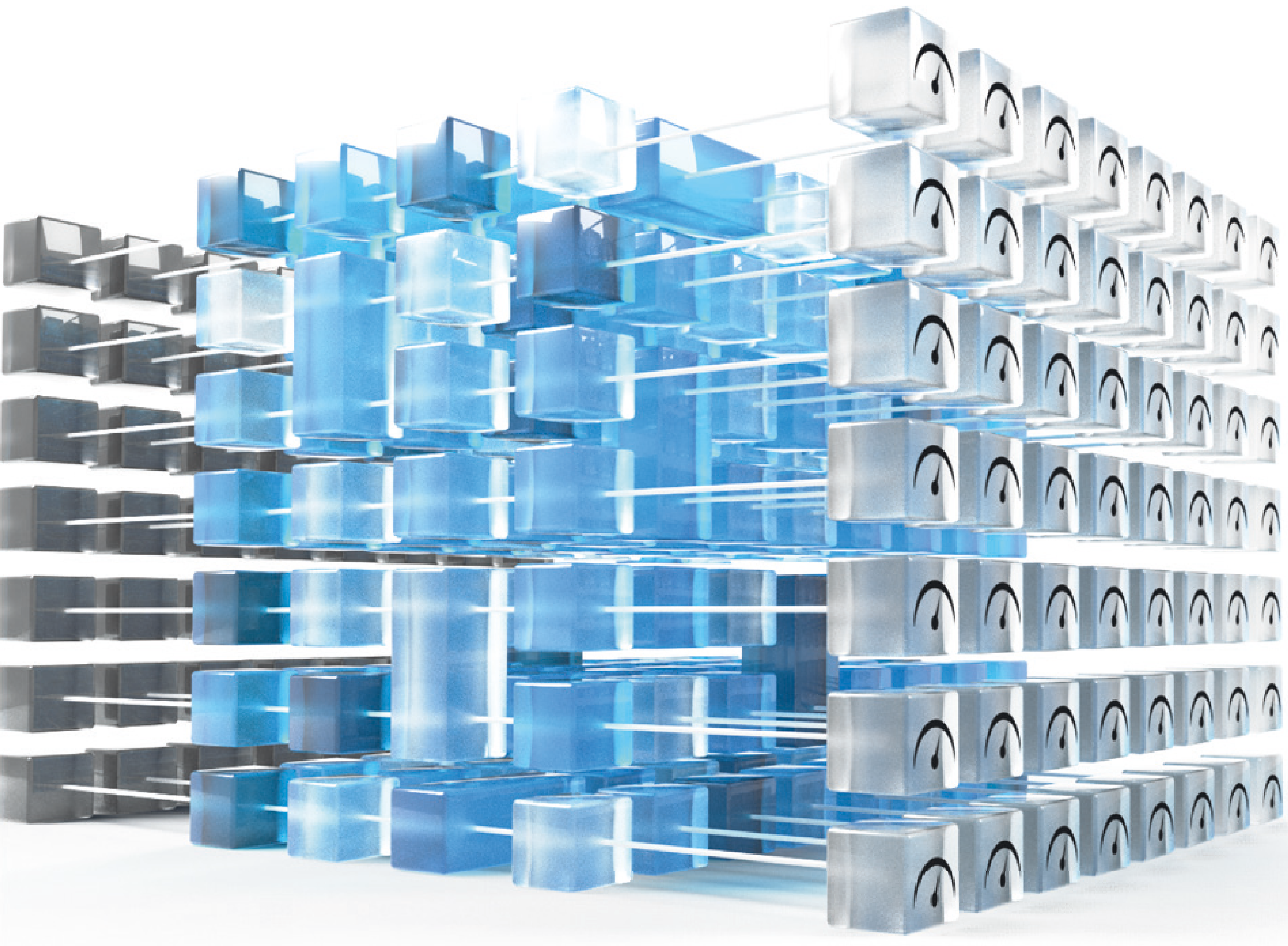
3 nK

Nanokelvin - Just Cold Enough

The experiment is performed at temperatures as cold as a few billionths of a degree above absolute zero. While the topological Haldane phase is strictly only defined at zero temperature, its striking signatures could still be observed because of the finite system size.

TRAVELING THROUGH THE DECADES

Duncan Haldane puzzled the community in 1983 with his conjecture that integer spin chains are topologically fundamentally different from half-integer spin chains. After much debate, Ian Affleck and co-authors developed the exactly solvable AKLT model in 1987 which beautifully illustrates Haldane's claims. More than two decades later, a mathematical framework was derived in 2010 that allows for a complete classification of 1D symmetry-protected topological phases.



Research Highlight #6

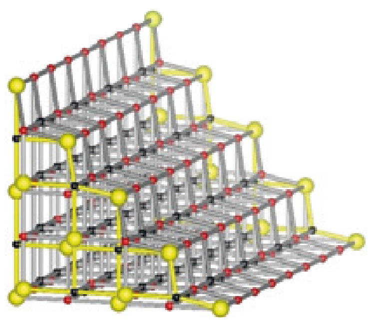
Quantum Advantage With Shallow Noisy Circuits

Together with colleagues from IBM Watson, the University of Waterloo, and the National University of Singapore, Robert König from the Technical University of Munich showed that noisy quantum computers are computationally more powerful than noise-free classical ones. The study was published in Nature Physics on July 6, 2020.

A primary challenge in quantum computing is demonstrating its computational superiority over classical devices. Previous work by three of the authors involved in the study showed that shallow quantum circuits are more powerful than classical ones, but assumed perfect execution without noise.

The recent breakthrough overcomes this limitation by proving that even faulty shallow quantum circuits outperform their noise-free classical counterparts. The team identified a computational problem which is solvable by imperfect shallow quantum circuits but is beyond the computational reach of ideal shallow classical circuits.

This advance opens the possibility of quantum advantage experiments with noisy intermediate-scale quantum (NISQ) computers and provides new building blocks for NISQ applications. Future work may aim to further reduce architectural requirements for experiments.



ABOVE FIGURE

The proposed three-dimensional architecture for noise-tolerant quantum advantage demonstrations (created used VESTA).

S. Bravyi, D. Gosset, R. Koenig, M. Tomamichel.

Nature Physics,**16**, 1040–1045 (2020)

A Visit in Munich Triggered a Multinational Collaboration

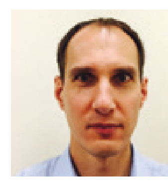
This collaboration began with discussions between König and Tomamichel, who had been invited to Munich in December 2019 as part of the MCQST Guest Program.

An earlier result had established a quantum advantage only in an experimentally unrealistic, academic scenario where quantum circuits can be realized perfectly. Nagging questions remained: Was this complexity-theoretic result of any real-world relevance? Could the quantum advantage be observed in the lab?

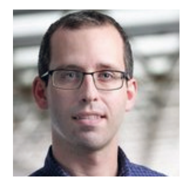
While mulling over an earlier failed, but conceptually appealing, attempt at demonstrating a quantum advantage based on entanglement-swapping, the two researchers realized that the so-called magic square game could be leveraged to make the approach work. This resulted in the simplest known circuit for demonstrating a quantum advantage.

This simplicity was key for the subsequent development – together with Bravyi and Gosset – of fault-tolerance methods rendering the construction noise-resilient. The project thus brought together four researchers in their shared passion for trying to understand the power of quantum computing.

4 Researchers 4 Countries



Sergey Bravyi



David Gosset

Robert König

Marco Tomamichel

THE HOLY GRAIL IN QUANTUM COMPUTING

Are there computational problems that can be solved by efficient (polynomial-time) quantum computations, but are beyond any classical efficient computation? Unfortunately, despite decades of efforts, an answer to this question remains elusive. Since a resolution of this problem would resolve long-standing complexity-theoretic conjectures in (classical) theoretical computer science, an answer is not expected anytime soon without a major breakthrough.

The question addressed by this collaboration is therefore more specific: The study compares constant-depth (so-called shallow) quantum and classical circuits instead of polynomial-time computations. Such computations can be executed in a constant time and can be seen as a model for parallel computing. An unconditional proof of a quantum advantage was found in this more restricted context.

Journal Covers

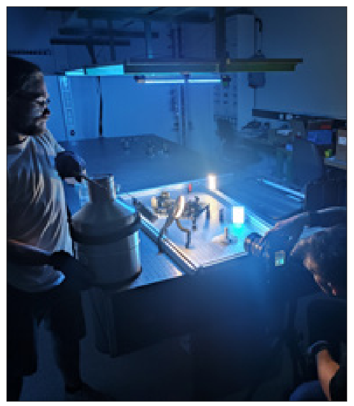
Cover and Feature Images by MCQST (2019 – 2022)

MCQST frequently designs cover art for its researchers' publications featured in major scientific journals, further elevating the visibility of their research and making it easier for them to obtain additional funding for their innovative work.

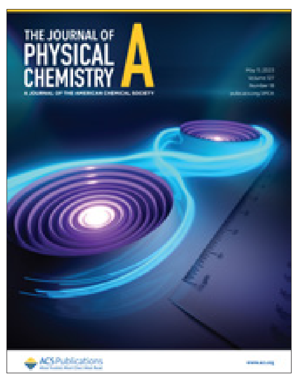
Cover Image
Nature, 2022

The Underdog Experiment

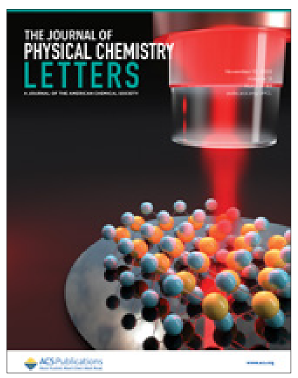
The cover to the left demonstrates that patience pays off. Two generations of PhD students fought for about 10 years to bring molecules to record low temperatures, at which point their state of matter develops quantum mechanical properties. What started as a challenge to assemble molecules from ultracold laser-cooled atoms turned into a grand challenge as scientists around the world found that even supposedly stable molecules undergo mysterious reactions at ultracold temperatures. After the team studied the origin of these fatal reactions, they realized a universal technique to shield the molecules from reactive collisions with the help of rotating microwave fields. The final breakthrough – the microwave antenna that was added to the experiment – made it on the cover of Nature.



Making of: Photoshoot for the cover at MPQ in Garching.



Cover Image
The Journal of Physical Chemistry A, 2022



Back-Cover Image
The Journal of Physical Chemistry Letters, 2022

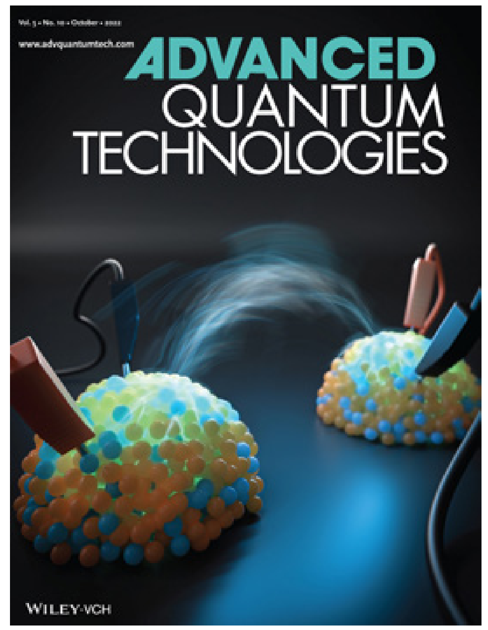
Cover Image
Chem Comm, 2022

Cover Image
Lab on a a Chip, 2022

Cover Image
Nature, 2019

Cover Image
Optica, 2021

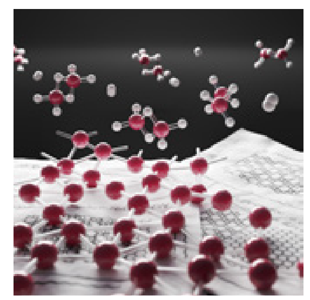
Cover Image
Reviews of Modern Physics, 2021



Cover Image
Advanced Quantum Technologies, 2022

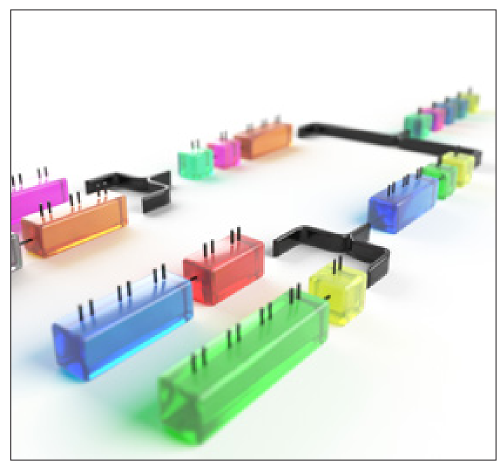
Cover Image
Science Advances, 2022

Cover Image
Physical Review Letters, 2019

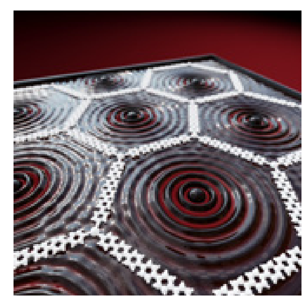


Web Feature Image
Science Advances, 2021

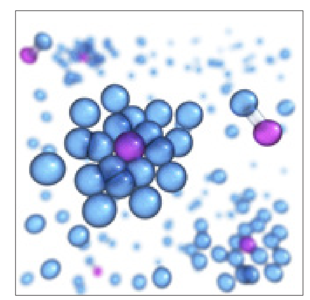
Web Feature Image
Science Advances, 2021



Web Feature Image
PRX Quantum, 2020



Web Feature Image
Reviews of Modern Physics, 2022



Web Feature Image
PRX, 2020

Many scientists have joined us over the past years, bringing in new expertise and triggering new collaborations, while others left us seeking new challenges.

Hello & Goodbye

People Joining MCQST

Since 2019, we have welcomed many scientists joining our cluster as principal investigators (PIs).

Munich remains an attractive hub for quantum research, with its world-renowned institutions, top-notch educational programs, excellent infrastructure, and a vibrant community. At MCQST, we are thrilled to have embraced numerous dedicated researchers and are committed to collaborating toward our shared objectives, while further shaping the local quantum ecosystem.

Monika Aidelsburger

LMU München → LMU München

Fabian Bohrdt-Grusdt

LMU München → LMU München

Dominik Bucher

Harvard Univ. → TU München

Dmitri Efetov

ICFO → LMU München

Stefan Filipp

IBM Research → TU München

Christian Hainzl

Univ. Tübingen → LMU München

Johannes Knolle

Imp. College London → TU München

Barbara Kraus

Univ. Innsbruck → TU München

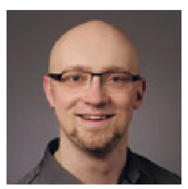
Christian Mendl

TU Dresden → TU München

Kai Müller

TU München → TU München

Janis Nötzel



TU München → TU München

Philipp Preiss

Univ. Heidelberg → MPQ Garching

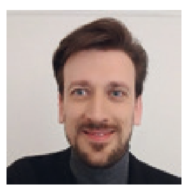
Peter Rabl

TU Vienna → TU München

Andreas Reiserer

MPQ Garching → TU München

Christian Schilling



Uni Aalborg → LMU München

Eva Weig

Univ. Konstanz → LMU München

© Photo: ICFO

"The vibrant network of highly motivated quantum scientists, the focus on fundamental research, and the immense opportunities for young researchers make MCQST a unique and special center in the world."

Dmitri K. Efetov holds the Chair of Solid State Physics at LMU Munich since August 2021. Before coming to Munich, he was Assistant Professor at ICFO Barcelona, Spain. His group is a leading team pioneering exotic quantum effects in graphene, a two-dimensional carbon material.

More about Dmitri Efetov at www.mcqst.de/efetov

"I am very proud to join TUM and MCQST, both worldwide renowned institutions, and hope to be able to contribute to our common goals within quantum science and technology."

Barbara Kraus holds the Chair of Quantum Algorithms and Applications of TUM School of Natural Sciences since January 2023. Previously she was Professor at the Institute for Theoretical Physics at University of Innsbruck, Austria. Her research group is working on identifying new, feasible applications within quantum information processing, as well as the verification of quantum processors.

More about Barbara Kraus at www.mcqst.de/kraus

© Photo: TUM | A. Heddergott

People Leaving MCQST

For some PIs, our cluster served as an important stepping stone in their careers.

Sergej Moroz

TU München → Karlstad Univ.

Peter Pickl

LMU München → Univ. Tübingen

Matthias Punk

LMU München → Patent Professional

Friedemann Reinhard

TU München → Univ. Rostock

Richard Schmidt

MPQ → Univ. Heidelberg

Norbert Schuch

MPQ Garching → Univ. Vienna

Thomas Weitz

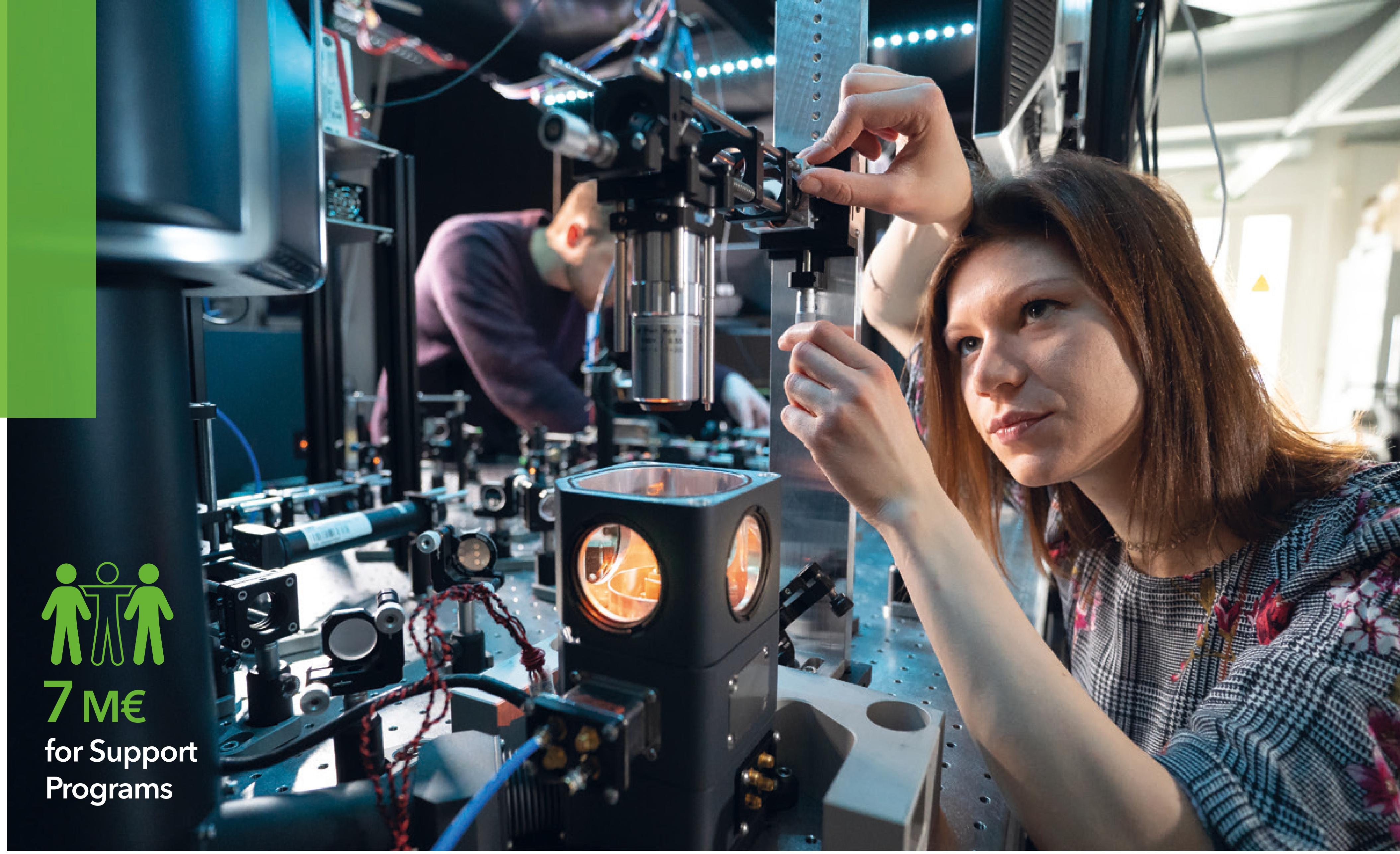
LMU München → Univ. Göttingen

"MCQST gave me and my team an excellent platform to establish long-lasting collaborations with experts across the field of quantum science and technology."

Richard Schmidt, now professor at Heidelberg University

Leading the way and enbling people for a career in quantum with our

Support Programs



7 M€
for Support Programs

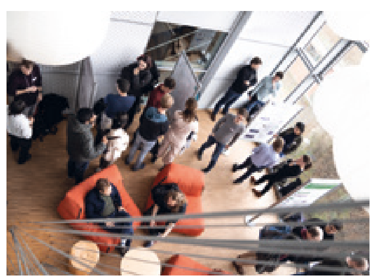
Empowering and Guiding Excellence

A roadmap of our support programs for all career levels

Our goal is to build and strengthen an infrastructure that promotes researchers from different research directions and different faculties to work together on key challenges in QST. To do so, we established new opportunities for Bachelor's, Master's, and PhD students, while also offering various funding opportunities for junior researchers, such as the START Fellowship, or seed funding for high risk, high reward projects.

In addition, we set out to attract scientists throughout the world to come together in Munich to accelerate progress in research and technological developments. Programs like the MCQST Summer Bachelor Program demonstrate our dedication to starting this process at an early career stage.

We are committed to establishing and maintaining a culture of fairness and respect. Furthermore, we are actively implementing measures to assist the career advancement of people belonging to marginalized groups. Our Distinguished Postdoc Fellowship is evidence that Diversity, Equity, and Inclusion (DEI) measures can have a strong impact even on a relative short-term scale, while the Diversity in Leadership Program has supported a growing awareness of DEI topics within our community.



Conference support

Our annual conference provides internal exchange and networking and develops connections with internationally renowned guest speakers. We also provide financial and organizational support for other international conferences relevant to MCQST researchers, such as the QIP 2021.

Looking for a job?

Our job portal offers an overview of career opportunities in our research groups, at partner institutes, or in industry. Interested? Then check out our support website at:

www.mcqst.de/jobs

MCQST AWARDS

The MCQST Master's & PhD Awards acknowledge exceptional early-career research and encourage recipients to pursue a career in science. The prizes are presented during the annual MCQST conference, where we also honor three outstanding posters for their scientific excellence, presentation, and design.

Is that all? No! In fact, we're just getting started. Take a closer look at our support programs in the upcoming pages.

Viviana Villafañe on the Various MCQST Support Programs

Viviana is an MCQST Distinguished Postdoc at TUM and Walter Schottky Institute.

How have our support programs helped you in your career so far?

Viviana: I arrived in Munich in September 2019 after finishing my PhD in Argentina. Since then, MCQST has greatly supported me in my career development by providing funds for my salary and research equipment, facilitating international collaborations relevant to my research, and organizing workshops that improved my leadership and communication skills. MCQST also connected me with a mentor who guided me to enhance my CV, thus becoming a permanent member of the cluster. Furthermore, it has actively promoted my scientific visibility by featuring my work on their website and podcasts.

Is there something in particular you found unique or especially helpful?

Viviana: MCQST has a strong positive impact on both individual members and the quantum science community in Munich as a whole. Their targeted policies promoting women and minorities in science are evident in daily conversations. As a foreign female scientist, it is truly gratifying to overhear my colleagues (including professors, postdocs, PhDs, and master's students) engaging in relaxed discussions about equal opportunities, strategies to combat discrimination, and the promotion of a healthy work environment. This unique aspect of the cluster reflects their successful implementation of measures that foster a positive atmosphere for all community members, regardless of their position.

What are you focusing on now?

Viviana: With the support of MCQST, I can focus on doing quantum science. Right now, we are mounting optical spin control techniques for silicon vacancies in diamond (SiV). This involves preparing short resonant optical pulses to initialize and read the spin state in diamond, as well as preparing optical access to a newly acquired ~mK dilution cryostat hosting our diamond samples.

More about Viviana at www.mcqst.de/villafane

Nurturing Young Quantum Talents

~300 Students

apply for the MCQST Summer Bachelor Program each year

The MCQST Summer Bachelor Program

International undergraduates work on hands-on research projects in MCQST groups.

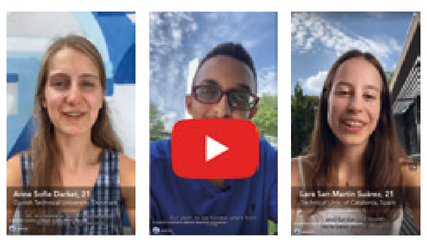
Every year, we invite 15-20 outstanding students from all over the world to spend a quantum summer in Munich. The four-week program gives participants the opportunity to deepen their theoretical and practical knowledge in QST. The special feature of the program compared to other summer schools is the three-week research project that the participants carry out under the guidance of a mentor in an MCQST research group. By the end of the program, participants have gained first-hand expert knowledge in quantum science and technology.

Quantum research in all its breadth: promoting Munich

Some candidates have remained in contact with our research teams beyond the completion of their project and continue to participate in ongoing projects. In addition to working on a topic within the framework of the research project, the program offers a broad insight into research within MCQST and our participating institutions through lectures, laboratory visits, and smaller experiments.

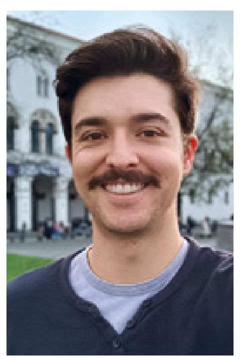
Direct impact on career paths

We believe the program can provide the foundation for personal and professional networks that benefit individual participants – as well as MCQST itself. We are especially pleased to have had former summer students in the Master's program and we're dedicated to making our community grow and flourish even more.



A quantum summer in Munich
www.mcqst.de/summer

Students from Denmark, Ethiopia, and Spain share their experiences of the program.



"The summer student program was an amazing experience, and it reinforced in me the idea of coming to Munich!"

Juan Baratech Soriano, Spain

Juan is a former summer program participant and now QST Master's student and works in the Quantum Networks group at MPQ.

4 Reasons to Enroll in the QST Master's Program

01 **Numerous specialized courses on QST**

MCQST scientists teach specialized courses covering their research fields.

02 **Being part of the MCQST family**

QST students perform their one-year research phase within the group of any of the ~60 MCQST PIs.

03 **Exchange fellowships**

Exchange visits of up to a year to other QST centers worldwide are possible and can be supported financially by exchange fellowships.

04 **Industrial internships**

QST students can engage in entrepreneurial training and have direct access to internships at several companies with QST activities in Munich.

70 students / year
with >200 applicants per year

32% female students

>30 different nationalities

October 2021: first QST graduate receives his certificate

Jan von Delft (L), Sirui Lu, Alexander Holleitner, and Tatjana Wilk

Two Questions for the Creators of the QST Master's Program

Jan von Delft (LMU) and Alexander Holleitner (TUM)

Why would you study QST in Munich, if you were a student again?

Alexander: Once our QST students have passed the mandatory courses, one on quantum hardware and one on quantum information theory, they can choose among dozens of special courses on cutting-edge quantum research topics. The offer is simply astounding! Moreover, Munich is a beautiful city to boot!

What impressed you about the first few generations of QST-Master students?

Jan: Our student body is very international, and many students have strong entrepreneurial aspirations. Moreover, I am delighted to see that the percentage of female students is steadily increasing, having reached 32% for the most recent cohort.

Graduate Schools at MCQST

High-Level Training at Renowned Institutions

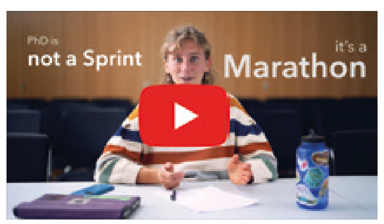
Exploring Quantum Matter (ExQM) and the International Max Planck Research School for Quantum Science and Technology (IMPRS-QST)

MCQST provides optimal conditions for a PhD in quantum science and technology. Currently, more than 250 doctoral students are part of our lively scientific community, working in a wide variety of subjects across different fields. Our associated graduate programs, ExQM and IMPRS-QST, are hosted at top universities and research institutions in Munich. The research focus of ExQM is centered on quantum optics, numerical tensor network methods, and the study of open quantum system, while IMPRS-QST covers a much broader research spectrum in QST.

Together with our associated programs, MCQST offers many benefits for PhD students, from funding possibilities to a structured framework with a set curriculum and high-level training options tailored to their interests and needs. Through soft skills courses and workshops, the programs ensure the acquisition of essential skills for building a successful career in science or industry, such as science communication, presentation techniques, conflict management, mental health, diversity, and leadership. In addition, professional development is supported through mentoring programs, industry visits, and career talks. Networking and scientific exchange are promoted within and beyond the institutional borders of the Munich quantum community, We cooperate and exchange extensively with other graduate programs and renowned institutions. Moreover, our doctoral students are members of the TUM Graduate School or the LMU Graduate Center, profiting from their services and offers.

> "The IMPRS events are exciting and unique opportunities to learn directly from some of the top scientists in the world."
> Matthew Kiser (PhD student at VW & MPQ)

Students can shape their own education by actively participating in the organization of the activities.



PHD Survival Tips on Youtube

www.mcqst.de/survival

From managing time to balancing research and life, these videos are packed with valuable advice for anyone pursuing a PhD.

© Photo: MPQ | J. Greune

260
PhD students

Among the 500 scientists affiliated with MCQST, half of them are currently pursuing their doctoral degrees. They are distributed across the 60 research groups operating within MCQST.

IMPRS at a Glance

female students	25
international students	54
alumni	40
associated PIs	38
applications overall	370

Status: March 2023

Since 2016, the international graduate program IMPRS-QST unites the competencies of more than 20 research groups in a common platform, offering doctoral students exciting opportunities and an exceptionally broad, yet focused training. Within the framework of the IMPRS, PhD students are supported in developing research at the highest quality level while also receiving a structured education in quantum science and technology. The curriculum includes basic and specialized courses, annual summer schools, and scientific workshops on different topics, as well as soft skill courses and networking opportunities with industry contacts. IMPRS-QST also cooperates with other graduate programs and renowned institutions such as ICFO, ETH Zurich, Berkeley, and Harvard, organizing regular joint activities to encourage better networking and scientific exchange as an integral part of the doctoral training.

>100 students

The MCQST Distinguished Postdoc Fellowship awards outstanding female Postdocs with two years of funding.

Our Distinguished Postdocs

33%
have been offered group leaderships or **professorships**

ABOUT THE FELLOWSHIP

Bringing the brightest minds to MCQST is a central goal of the MCQST Support Programs. MCQST aims to boost female representation in QST at all career levels.

To proactively recruit and attract excellent female scientists, MCQST awards up to three Distinguished Postdoc Fellowships annually. The Fellowship provides two years of funding, split equally between the hosting group and MCQST.

The next call for applications will be in the fall of 2023.

Ángela Capel on the Impact of the Fellowship on her Career.

After her position as Distinguished Postdoc with MCQST, Ángela is now a Junior Professor in the Mathematics Department at University of Tübingen.

How has the Distinguished Postdoc Fellowship impacted your career?

Ángela: The Distinguished Postdoc Fellowship has been essential for my career in various aspects: On the one hand, being selected for such a prestigious fellowship gave me enough confidence to believe in myself, while continuing to pursue my research and bring it to the next level. On the other hand, it provided me with quite some visibility from outside MCQST, which certainly helped me obtain my current position as a Junior Professor at the University of Tübingen.

What was the best aspect of it?

Ángela: The best aspect was the possibility to have access to all the resources provided by MCQST in the form of materials, workshops, contacts with internationally renowned researchers, etc, as well as the freedom given by MCQST in all matters related to research, teaching and, in general, career development.

More about Ángela at www.mcqst.de/capel

Climbing the ladder of academia

START Fellowships

One Step Further on the Way to Becoming an Independent Group Leader

PROGRAM BENEFITS

Independence
Fellows have their own budget, office, and lab space to pursue independent research and build their profile for a future group. The two-year term allows raising third party funding.

Developing leadership skills
With their own budget, fellows have the opportunity to build a small research group and gain experience in managing their own team.

Mentoring
START Fellows have a hosting and mentoring PI who offers lab/office space and academic advice along with extra resources.

Benefiting from the cluster
The fellows are integrated into the cluster and benefit from its programs, like Seed Funding, workshops, and collaborations.

The START Fellowship offers a unique opportunity for postdocs on their transition to independent researchers. With a total budget of 300,000 € for a funding period of two years, the fellows have the opportunity to start their own scientific project. The first cohort of fellows is in the process of becoming independent and have already obtained permanent positions or professorships. We look forward to supporting more young researchers in this way and following their career paths

“Having my own research group is an important step for me. I have more ideas than I can implement on my own right now.“

Björn Sbierski, Group Leader at LMU

Already **5 professorships** or permanent positions

- 2019 | Jasmin Meinecke (LMU/MPQ)
- 2019 | Fabian Grusdt (LMU)
- 2020 | Cambyse Rouzé (LMU)
- 2020 | Nadezhda Kukharchyk (LMU)
- 2020 | Nathan Wilson (TUM)
- 2021 | Björn Sbierski (LMU)
- 2021 | Aisha Aqeel (TUM)
- 2022 | Pau Farrera (MPQ)
- 2022 | Annabelle Bohrdt (LMU)

Professors / Permanent — Fixed Term

More about our START Fellows:
www.research-in-bavaria.de/quantum-science-fellowship-at-mcqst

2.7 M€

We are committed to supporting scientists at all stages of their careers. To date, a substantial sum of 2.7 million euros has been invested in the program.

Reaping the Rewards

69 Projects

were funded between 2019 and 2022 with budgets ranging from 10,000 to 50,000 €.

How Seed Funding Projects Add Major Value to the Cluster

Researchers report here about the impact the Seed Funding had for their projects.

Shaping the group profile

Andreas Reiserer (MPQ/TUM)

The results from the project shaped the main research direction (quantum networks) of Andreas' group. Moreover, the project enabled a successful major grant application (BMBF) targeting portable quantum network nodes based on erbium-doped silicon.

Establishing long-term collaborations

Amanda Young (TUM)

The project has helped solidify Amanda's research relationship with her collaborator Angelo Lucia. The two scientists have already planned future projects. It is a collaboration that Amanda expects to continue for years to come.

Scientific breakthrough

Xinyu Luo (MPQ)

Facilitated by the flexible funding, the group was able to produce the so-far coldest Fermi gas of polar molecules thus far. The groundbreaking results were published in Nature and featured on the magazine's cover.

Kick-starting a new laboratory

Kirill Fedorov (WMI)

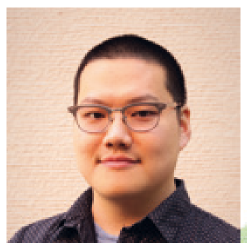
The seed funding project has provided Kirill with an essential experimental and theoretical basis for the follow-up project on "Quantum Microwave Tokens & Memories" (QuaMToMe) funded by BMBF with a total budget of 1.9 M€.

Encouraging innovative ideas

Samarth Vadia (LMU)

A follow-up project was recently awarded additional funding by SPRIND (Federal Agency for Disruptive Innovation in Germany). This agency supports radical new ideas and technologies in Germany. The group became the first successful SPRIND awardees at LMU.

Exploring new directions



Martin Lee (LMU)

The funding enabled the exploration of a new research direction focused on mechanical tuning of electronic properties in twisted 2D systems. Now, the group is close to harnessing both the in-plane and out-of-plane strain as tuning parameters.

About the program

The Seed Funding Program is aimed at principal investigators, junior group leaders and postdocs at MCQST and supports exceptional and unconventional project ideas. It is designed to foster collaboration within and between research units, and to support ideas with a high risk and high reward potential. The program is particularly well-received by postdocs and junior research group leaders. Often, it is their first project as independent researchers, helping support junior researchers in the cluster on their journey to independence.

The provided funds have not only led to new collaborations: often, the project results have also been used as a basis for attracting further third-party funding, as impetus for new ideas or research directions, or have been published in high-ranking journals.

Seed Funding proposals of MCQST members

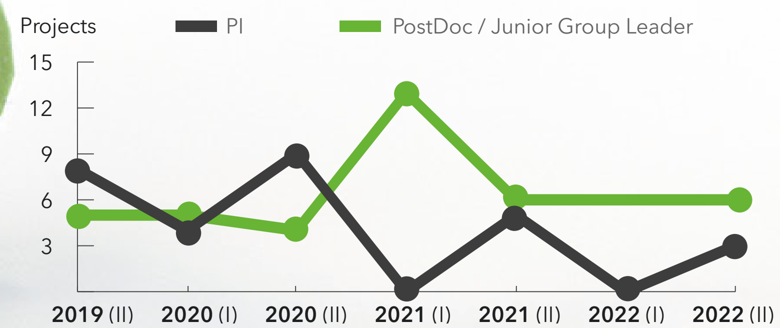
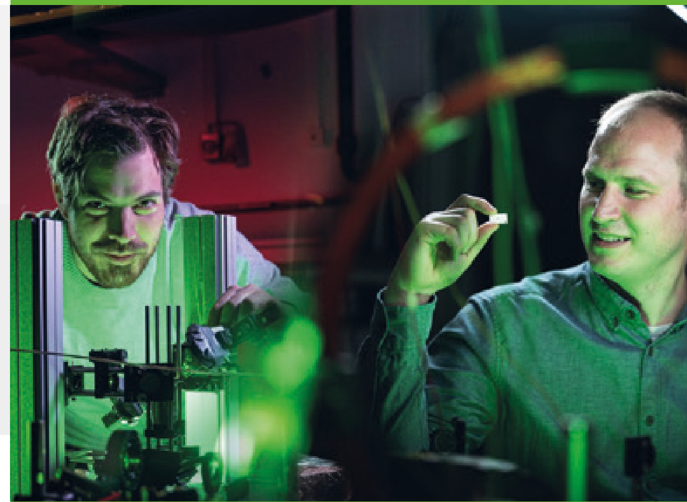


Chart Info

While at the beginning of the funding period most proposals were submitted by PIs, the majority of projects now involve postdocs and junior group leaders. Over the years Seed Funding has thus developed into an important tool for promoting the work of young researchers, enabling them to develop projects with their very own funds.

Joining forces across disciplines and creating a whole new line of research.



A MATCH MADE IN MUNICH

A physicist and a chemist, who unexpectedly crossed paths thanks to the Munich Center for Quantum Science and Technology (MCQST), embarked on a groundbreaking venture to develop a revolutionary quantum camera. Andreas Stier and Dominik Bucher have forged a unique partnership, motivated by their shared passion for exploring the properties of ultra-thin 2D materials. The allure of these materials lies in their remarkable characteristics, with graphene, one such material, even earning a Nobel Prize in Physics in 2010. The serendipitous collaboration was born during a meeting on quantum sensors, where Dominik Bucher showcased his work on diamonds, and Andreas Stier realized the potential of studying magnetic 2D materials. Recognizing their compatibility both professionally and personally, the scientists were eager to venture into uncharted territory together.

Read the full story:
www.mcqst.de/match-made-in-munich

Three Questions to Our Equal Opportunity Managers

Mari Carmen Bañuls (MPQ), Simone Warzel (TUM), and Immanuel Bloch (LMU/MPQ)

Why is diversity, equity, and inclusion (DEI) important to you?

Mari-Carmen: We all know by now that a diverse working environment has plenty of benefits. In particular, it gives us the chance to incorporate different perspectives, something that is crucial for scientific progress.

But diversity without inclusion only looks good in numbers.

Because inclusion means that we create an environment where everyone can feel like they belong, like they are a part of the common endeavour. In this situation it is when people are happier and capable of giving their best.

What do you think is the greatest challenge regarding diversity, equity and inclusion in quantum physics?

Simone: The biggest challenges continue to be the situation of minorities of all kinds, especially female minorities. Moreover, the extraordinary workload, often in the form of irregular hours, that young scientists need to invest in order to make progress, is not easy to square with family life. On the positive side, in terms of international diversity, our field is doing quite well. Most of our research groups attract many students and scientists from abroad. In such an environment, being non-native is the rule rather than the exception.

In the future, where would you like MCQST to be in regard to DEI?

Immanuel: We want to attract even more of the exceptional, creative, and diverse talents from all over the world to be inspired and work together with us here at MCQST in shaping the future of quantum science and technology.

FAMILY & CAREER

We offer several programs to support our researchers with care responsibilities: childcare scholarships for excellent researchers (from 2020-2022) as well as home office equipment. Childcare is also available during our events, and a KidsBox provides a mobile children's room. People with other care responsibilities can work with us to develop individual solutions for their situations. Official events are scheduled in family-friendly times whenever possible. These initiatives help ensure that researchers with care responsibilities can balance their personal and professional lives.

Raising awareness of unconscious bias and countering gender stereotypes to establish an atmosphere that welcomes everyone.

Diversity, Equity, & Inclusion

Pictured right: At a Women in QST event with Marissa Giustina in 2019

This series regularly features inspiring female researchers in quantum science and technology and offers informal networking opportunities.

© Photo: MPQ | Mirjam Krieger

30+ Workshops
e.g. Mental Health, Active Bystander Training, ...

44% Female START Fellows

Mentoring future quantum leaders

MENTORING PROGRAM

Our Mentoring Program matches female and gender minority early career researchers with mentors from academia or industry. It also offers many networking and development opportunities for the mentees. The goal is to provide young scientists from Master's to postdoc level with role models and an extended network at an early stage of their career.

Support and awareness

DIVERSITY IN LEADERSHIP

Our Diversity in Leadership Program (DIL) consists of a series of workshops on DEI topics that evoke questions and offer future leaders in QST the opportunity to reflect on their own leadership values. Moreover, participants learn methods and approaches to implement diversity aspects into their own leadership style.

"DIL gave me tools to recognize and solve interpersonal issues and helped me make my research group more inclusive."

Dr. Daniel Malz (MPQ)

130+ Participants
in total in all DEI Workshops

Our Guest Program is funded by the Munich Quantum Center (MQC) and is part of the support infrastructure offered by MCQST.

International Guest Program

Exchange With International Renowned Researchers

Together MQC and MCQST bring top-level international experts to the QST network in Munich. Implementing a vibrant guest program is a core element of both MCQST and MQC's collaboration strategy.

Strengthening the stream of prominent scientists who come to the Munich area for short- and long-term visits contributes to promoting international collaborations. Furthermore, it raises the visibility of QST research in Munich and supports junior researchers in building their own international research network.

A colloquium series sparking international exchange

Our colloquium series features interdisciplinary talks given by outstanding international scientists from the field of quantum science and technology. The monthly colloquia talks cover topics spanning all MCQST research units. The main goal is to create a framework for an exchange of ideas, deepen links with leading QST groups worldwide, and act as an integral part of the local educational offers. In order to facilitate this, MCQST organizes informal lunch meetings with the speakers for PhDs and Postdocs and arranges a visiting program including lab tours as well as one-on-one and group meetings. During the pandemic, the colloquia changed from in-person presentations to online-only streams, and are now all offered as hybrid talks with recordings. Throughout these challenging times, the colloquium has strengthened the internal network of our researchers and helped them to establish international cooperation.

31
Colloquium Talks
from November 2019 until Dec 2022

PICTURED ABOVE

MCQST Speaker Ignacio Cirac introduces 2022's Distinguished Lecturer Mikhail Lukin

DON'T MISS THE NEXT TALK
Join our mailing list

MCQST Newsletter
www.mcqst.de/newsletter

MCQST Colloquia Videos
www.mcqst.de/colloquia-playlist

WHAT IS MQC?

Founded in 2014, the Munich Quantum Center (MQC) is the first initiative that united the quantum scientists from all Munich research institutions: LMU, TUM, MPQ, and WMI. The idea was to pool together their efforts and increase the visibility of Munich as a center for QST research. Regular exchanges and discussions among the members led to the idea of submitting a proposal to the call for clusters of excellence by the DFG. This is how the idea of MCQST was born.

Distinguished Lecturer

Every year we honor outstanding QST scientists for their engagement with the public.

The MCQST Distinguished Lecturer Award acknowledges high-achieving scientists in the field of quantum science and technology who have demonstrated a high commitment to communicating their research developments to the broader public. To share their knowledge and expertise with different audiences, the awardees give a public talk, contribute to the MCQST Colloquium, and present a seminar for a more specialized audience. The public talks, which attract up to 200 audience members, promote discussions on QST topics within the Munich area, emphasizing its wider significance for society and potential impact on future technologies. Moreover, the colloquium and specialized seminar help inspire new thoughts and ideas within the MCQST research community.

5 Awardees

2019 | John Preskill (Caltech)
2020 | Pascale Senellart (CNRS / C2N)
2021 | Dorit Aharonov (HU Jerusalem)
2022 | Mikhail Lukin (Harvard Univ.)
2023 | Andreas Wallraff (ETH Zurich)

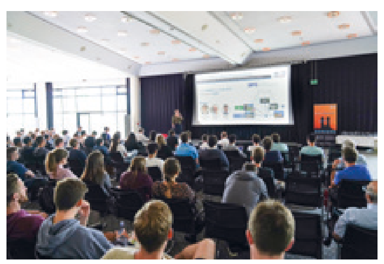
Quantum Eraser

Beware of quantum erasers!

Andreas Wallraff warned Distinguished Lecturer **John Preskill** (2019) about our quantum erasers on Twitter only to become Distinguished Lecturer himself in 2023.

Fostering interdisciplinary exchange for scientific excellence.

Scientific Events



GROUP PHOTO, AWARD CEREMONY, POSTER SESSION, AND TALKS

—

Impressions of the MCQST Conference 2022 in Sonthofen, Germany

124 Events

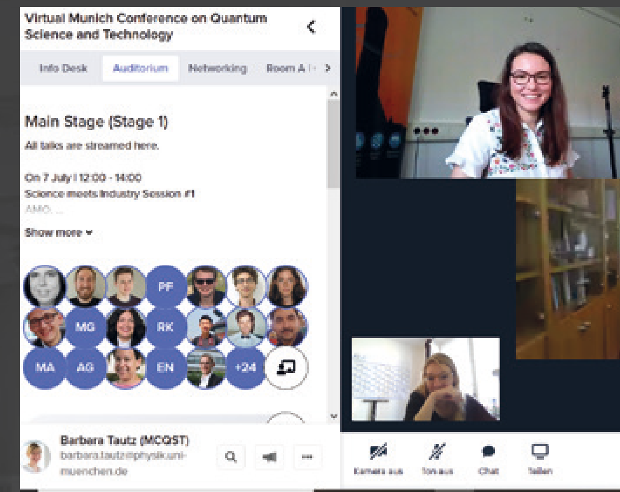
communicating quantum to scientists and a general public (2019 - 2022)

~200h Watchtime

of over 370 recorded scientific talks on our YouTube channel: **youtube.com/@mcqst**

Virtual Spaces for Scientific Exchange and Remote Learning

Virtual Poster Session in 3D room (MCQST Conference 2020 & 2021)



Informal discussions and mingling via video chat

ENGAGING OUR COMMUNITY & THE PUBLIC IN NEW WAYS

The Covid-19 pandemic brought the world to a standstill, compelling MCQST to seek innovative and creative solutions for maintaining networking opportunities and scientific exchange. To address this challenge, we created a customized digital space that facilitated talks, poster sessions, and networking among scientists. This early adaptation allowed us to not only sustain a similar level of interaction as before the pandemic, but also attract an even wider audience to our online events. For instance, our MCQST 2020 conference saw a significant increase in participation, with 900 attendees compared to the previous year's in-person event (150 participants). Furthermore, our digital space served as a platform for other major conferences, including the Conference on Quantum Information Processing (QIP) 2021, which boasted an impressive 3600 participants. Additionally, MCQST supported remote learning by organizing three young DPG Student Conferences and establishing a digital PhotonLab 3D environment, ensuring high school students could explore the world of quantum science from the comfort of their homes.

Networking and Collaborating Through All Core Areas of QST

We create the framework for scientific exchange. We foster cross-disciplinary cooperation. We boost international collaborations.

Events lie at the heart of the MCQST community. We recognize recognizes the importance of scientific exchange and actively create the framework to facilitate it through its conference support measures. Scientific events help nurture international cooperation and leverage the diverse expertise from other groups that is translated into successful collaborations. This continuous learning and exchange of knowledge enable MCQST to stay at the forefront of scientific advancements, while strengthening Munich's position as an international hub for excellent research.

qip/21 **~3800 Participants** at QIP Conference 2021

The MCQST Conference

The Munich Conference on Quantum Science and Technology brings together our community with academia and industry experts spanning all fields of Quantum Science and Technology (QST), an exchange of ideas, providing networking opportunities, and fortifying the international quantum science and technology community. The annual conference connects scientists from various disciplines, including physicists, chemists, mathematicians, computer scientists, and engineers, spanning all career levels. Dedicated poster sessions provide young researchers with a platform to showcase their own research and gain valuable insights into the work of their peers.

105 Invited Speakers

Unique conference lineup: MCQST speakers and international experts.

© Photo: T. Sommer

Fostering a sense of wonder and curiosity.

Outreach and Media

~16k Followers on Social Media

14 Public Talks

Get entangled with us!

- @MCQST_cluster
- mcqst
- @MCQST@wisskomm.social
- @MCQST

PICTURED ABOVE

MCQST Media Designer Christoph Hohmann lighting and photographing the surface of a quantum chip by using a macrolens

Bringing Quantum Science to the World

Engaging the public and sparking excitement for quantum science at all ages.

At MCQST, we are passionate about science communication and public engagement. We engage with the public at various scientific fairs, regularly organize events to inspire young students (Girls' Day, Maustag), and participate in national and international conferences where we get to network with the scientific community and with representatives from industry.

We also employ a wide range of media and storytelling techniques to offer an immersive experience that goes beyond traditional modes of scientific communication.

We work hand-in-hand with researchers to develop new outreach content, translating their expertise and insights in a way that captivates and educates the public.

In the video series Quantum Minutes, our researchers explain complex quantum phenomena in just a few minutes. From quantum communication to the exploration of black holes to quantum simulation, the series aims to allow a wider audience to envision how quantum technologies have the potential to revolutionize our daily lives.

Quantum Minutes
www.mcqst.de/q-minutes

Breaking down complex quantum phenomena for general audiences.

Why outreach? Outreach helps bridge scientists and the public, fostering understanding and appreciation for quantum science.

Public Engagement

Public talks

Our members are committed to science communication and actively offer public talks as part of our public engagement efforts. The talks are designed for diverse audiences and convey the researchers' knowledge and discoveries in an accessible and captivating manner. Our public talks take place at various venues such as museums, theaters, in pubs, and online platforms, and are always inspiring and engaging.

We are particularly fond of the science slam format, which combines science communication with elements of performance and public speaking. In science slams, scientists have just a few minutes, to present their topics or research to a general audience.

Science fairs & festivals

Science fairs and festivals (e.g. FORSCHA, World of Quantum), provide an excellent platform for us to interact with people of all ages and backgrounds. We use hands-on experiments and demonstrations to illustrate complex quantum phenomena, and with the help of VR headsets, visitors can actually step in our laboratories. It is always a joy to witness the "aha" moments when someone finally grasps a challenging idea.

We believe that the interactions at these events are mutually enriching – the public is informed and gets excited about new technologies, while the researchers gain new perspectives and are motivated to continue pushing the boundaries of knowledge.

Diving deeper into our research

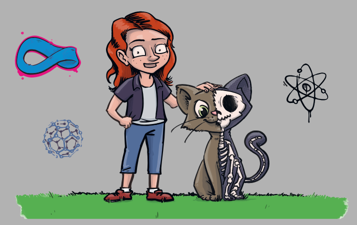
During the Covid-19 pandemic, we seized the opportunity to re-think how to open up our labs to the public. With the help of a 360° camera we filmed virtual lab tours for researchers who could no longer travel to Munich. Moreover, at science fairs, we have introduced the use of VR headsets to elevate the experience, further immersing visitors in the world of quantum science.

On our Quantum Science Blog, we tell stories of the people behind the research. The blog regularly features MCQST community members as well as inspiring international experts, such as our Distinguished Lecturers.

The Munich Quantum Stammtisch is a series of live panel discussions where we set out to bring together experts in the field of quantum science. Just like at a traditional "Stammtisch", our guests cover the latest in QST in an informal atmosphere.

MCQST Advent Calendar
www.mcqst.de/calendar

Meet members of the MCQST Community in our annual advent calendar.

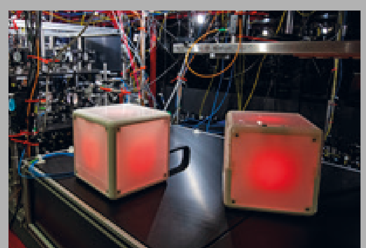


Podcast / Audio Play:

Alice im Quantenland

Embark on a journey through the quantum realm alongside Alice and the enigmatic cat Schrödinger in our captivating audio play. Tailored for children aged 6 to 12, this story is available for free download on your preferred podcast app (in German).

Hands-on Demonstration



Entanglement is explained colorfully using the „Quantum Dice" developed in the framework of the BMBF-project Quanta. Strong correlation between the entangled particles are demonstrated by showing the same colors on each dice.

Interactive Learning Resources

To prepare for the visit of a school class, teachers can use our introduction video, a 360° view into the lab, as well as our interactive books. Have a look:

www.mcqst.de/photonlab

Hands-on experiments, teacher's trainings, and science communication.

PhotonLab

Over 25
Experiments

Hands-on experiments for lasers, optics, and quantum science.

~2000
Students / Year

Students have the opportunity to perform experiments autonomously and visit research laboratories.

~40
Interns / Year

One-week internships give a deeper insight into photonics and quantum science.

EXPERIENCING QUANTUM SCIENCE

For more than12 years, Silke Stähler-Schöpf, the head of PhotonLab, has inspired high school students with hands-on experiments in optics and photonics. Funding from MCQST enabled her to broaden the spectrum of experiments towards quantum science. Silke also engages in many other outreach activities, e.g., in collaboration with Deutsches Museum.

Engaging the Next Generation

The PhotonLab is a laser laboratory specifically designed for high school students and is located at MPQ. Since 2011, it has been a focal point for anyone who wants to learn about light. It was designed to show that optics and photonics is fun.

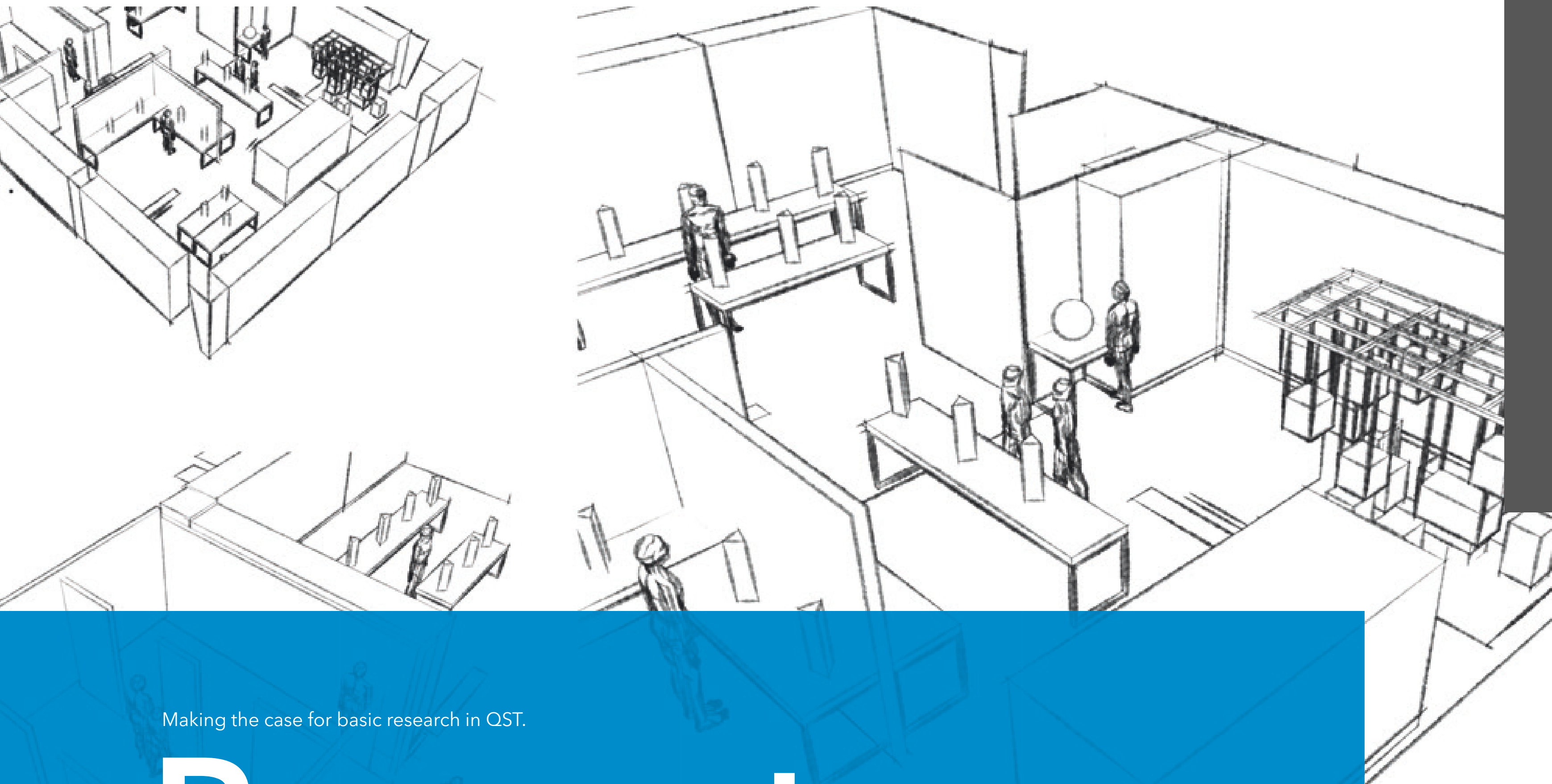
Over 17,000 visitors have already taken the opportunity to learn and experiment in the lab. The first offered experiments were in optics and included: measuring the thickness of a hair, determining the sugar concentration of a liquid using refraction, or how to transmit music using light. Now, the offer has been extended to quantum analogy experiments with attenuated lasers and students can experiment with, e.g., a quantum eraser, a bomb tester, quantum key distribution, and a quantum random number generator. With this setup students can observe the wave and particle behaviors of light at the same time: interference in combination with photon counting statistics.

> "Your workshop is the best school outreach experience I have ever been to (...)."
>
> **Ben Simmons, Teacher at Abingdon School, UK**

The PhotonLab regularly offers teacher trainings, internships for high-school students, support in more advanced experiments at schools, or guidance in entering experiments in competitions, such as the German Young Physicist Tournament (www.gypt.org). Moreover, the PhotonLab contributed to two BMBF projects: (1) Quanta – for developing hands-on materials together with Deutsches Museum and other partners, and (2) ease-Corona – for giving repeated workshops for schoolchildren who lost motivation during the Covid-19 pandemic. Together with the MCQST office, the PhotonLab is present at different fairs such as FORSCHA, Festival der Zukunft, Day of Hope, and more. In addition the PhotonLab offers digital material, such as interactive books, to prepare the school students for the visit, following the flipped classroom method.

PICTURED BELOW

A hand-drawn sketch of the upcoming MCQST Exhibiton "Light & Matter," which will open in 2024 at the Deutsches Museum in Munich.



Making the case for basic research in QST.

Prospects

of Our Cluster of Excellence

Is there a future for basic research in quantum science and technology?

On the balance between curiosity-driven and target-driven research in quantum.

With activities in quantum science and technology, our cluster is working in a research field that has recently gained the general interest of policy makers, politicians, investors, and the public. Large investments have been made for technology development in this area, and record funding has reached research groups as well as start-ups active in the field. However, most of these projects are target driven and have clear goals for developing quantum devices. They strictly aim at milestones and deliverables all set to fulfill the promise of developing products with a high technological readiness level in order to keep pace with other nations. In contrast, MCQST stands for basic research and its research program is mainly curiosity driven. Our freedom to invest in fundamental science and to follow research ideas that the community is striving for, creates a dynamic and vivid research atmosphere which attracts scientists from around the globe. On the one hand, such curiosity driven research leaves space for unorthodox ideas apart from predefined roadmaps and has the potential to inspire true innovation. On the other hand, target driven research can give a research field orientation towards questions with relevance for society. In the end, both forms of doing research are important, and in the ideal case, as it is in Munich, they coexist and mutually stimulate each other.

MUNICH: A BLUEPRINT FOR QUANTUM HUBS

The thriving Munich quantum ecosystem has gained a lot of international visibility. This was further reinforced by the creation of the Munich Quantum Valley as counterpart to MCQST. Delegations from Brazil, Canada, Denmark, France, and other countries visited our sites to understand the factors that have brought our community together and made it so strong.

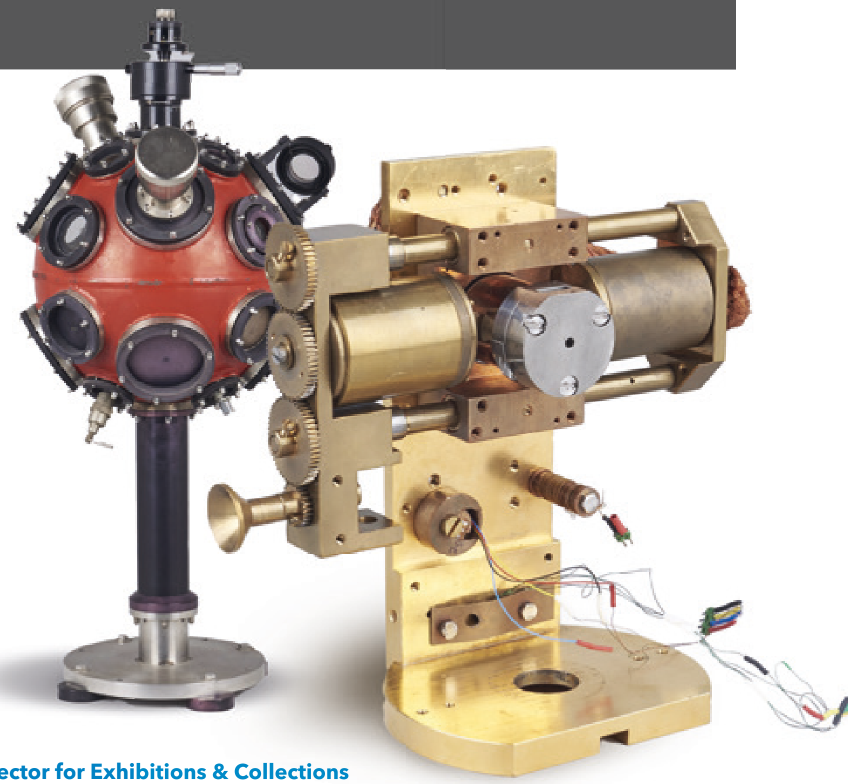
LIGHT & MATTER EXHIBITION

at the Deutsches Museum – public engagement with research

The Deutsches Museum is one of the largest science and technology museums in the world. Every year, more than 1 million visitors of all backgrounds and ages engage with interactive exhibits and unique historical artifacts of research. The exhibition "Light & Matter" guides visitors through the development of our changing understanding of light and the foundations of quantum mechanics in the 20th century. Tracing advances in spectroscopy and laser physics, the gallery highlights how their convergence enabled the control of quantum physics with light and thus broke ground for quantum technologies. In the gallery, visitors also have opportunities for virtual interaction with researchers from the MCQST community, thus enabling a platform for dialogue on present day science-in-the-making. The exhibition will open in 2024 and remain open until the end of 2025. After visitor evaluation, the exhibition will become a permanent gallery at the Deutsches Museum in 2028.

INTERACT WITH UNIQUE ARTIFACTS

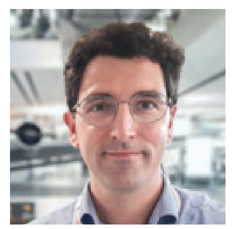
The Garching micromaser (right) and the NIXE laser plasma target chamber (left) are two of the highlights in the exhibition.



3 questions for one of the curators of the Deutsches Museum and his team

Johannes-Geert Hagmann, Deutsches Museum, Deputy Director for Exhibitions & Collections

Why is a quantum exhibition necessary?



Johannes: We need to recognize that quantum science has a profound impact on the world we live in. Quantum science and technology are in the focus of research funding worldwide and the media today. Museums have a vital and complementary role here: First, they act as translators for public engagement with contemporary research. Second, they provide a wide-impact forum for dialogue on science in and for society. And third but not least, the exhibitions can inspire future generations of creative minds to participate in the journey of quantum research.

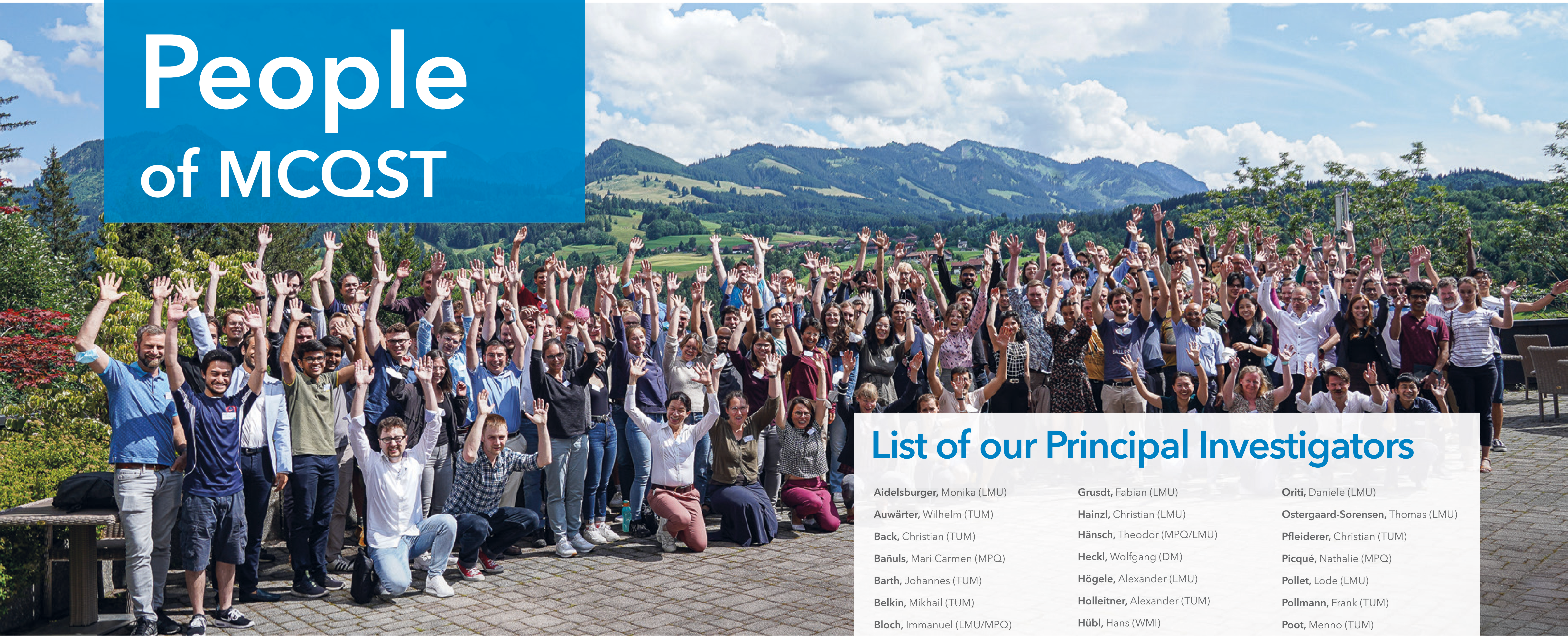
Are there special challenges?

Johannes: I believe we are often unaware of quantum science as many phenomena are hidden from human perception. The laws of quantum physics defy our intuition. To establish a connection with science, an exhibition can go beyond what textbooks and classrooms; however, it needs to do so for a broad range of audiences. Furthermore, there are hardly any existing examples of interactive exhibitions on quantum science and technology. We therefore had to develop new interactive exhibits and experiments that we will test and evaluate together with the public through visitor research.

Which highlights are you personally looking forward to the most?

Johannes: One of my favorite features is the storytelling approach called "scenorama" that has been newly developed by our museum workshops. Blending museographic elements from dioramas, graphic novels, and artifacts displays, these exhibits provide a unique medium to narrate intricate and often surprising human endeavors in scientific research. In addition, I am very much looking forward to the dialogues mediated by the exhibition as a platform in the International Year of Quantum Science and Technologies: with broad audiences including visitors, researchers, and museum colleagues alike.

People of MCQST



PICTURED ABOVE

Group photo at the MCQST Conference in Sonthofen 2022

Supporting Excellence

Outstanding scientific research owes its success to exceptional scientists and visionary leaders. The principal investigators (PIs) and their groups play a pivotal role in fostering excellence, embracing new and diverse ideas, and shaping the educational environment in Munich. The diverse MCQST community is characterized by strong interdisciplinary collaborations, international partnerships, a thirst for scientific discovery, and a passion for outreach.

The MCQST office is delighted to support the people within our cluster and drive various initiatives within the organization.

The MCQST Office Team: Michelle Lorenz, Brigitte Voß, Anca Ionescu, Claudia Leonhardt, Tatjana Wilk, Barbara Tautz, Christoph Hohmann

List of our Principal Investigators

Aidelsburger, Monika (LMU)
Auwärter, Wilhelm (TUM)
Back, Christian (TUM)
Bañuls, Mari Carmen (MPQ)
Barth, Johannes (TUM)
Belkin, Mikhail (TUM)
Bloch, Immanuel (LMU/MPQ)
Boche, Holger (TUM)
Brambilla, Nora (TUM)
Brandt, Martin (TUM)
Bucher, Dominik (TUM)
Cirac, Ignacio (MPQ)
Deppe, Frank (WMI)
Dürr, Stephan (MPQ)
Dvali, Georgi (LMU/MPP)
Efetov, Dmitri (LMU)
Filipp, Stefan (TUM/WMI)
Finley, Jonathan (TUM)
Frank, Rupert (LMU)
Glaser, Steffen (TUM)
Gross, Rudolf (TUM/WMI)
Grusdt, Fabian (LMU)
Hainzl, Christian (LMU)
Hänsch, Theodor (MPQ/LMU)
Heckl, Wolfgang (DM)
Högele, Alexander (LMU)
Holleitner, Alexander (TUM)
Hübl, Hans (WMI)
Jansen, Sabine (LMU)
Kienberger, Reinhard (TUM)
Knap, Michael (TUM)
Knolle, Johannes (TUM)
Koblmüller, Gregor (TUM)
König, Robert (TUM)
Kraus, Barbara (TUM)
Mendl, Christian (TUM)
Mukhanov, Viatcheslav (LMU)
Müller, Peter (LMU)
Müller, Kai (TUM)
Nam, Phan Thanh (LMU)
Nötzel, Janis (TUM)
Ochsenfeld, Christian (LMU)
Oriti, Daniele (LMU)
Ostergaard-Sorensen, Thomas (LMU)
Pfleiderer, Christian (TUM)
Picqué, Nathalie (MPQ)
Pollet, Lode (LMU)
Pollmann, Frank (TUM)
Poot, Menno (TUM)
Preiss, Philipp (MPQ)
Rabl, Peter (TUM/WMI)
Reiserer, Andreas (MPQ/TUM)
Rempe, Gerhard (MPQ)
Schilling, Christian (LMU)
Schollwöck, Ulrich (LMU)
Schulte-Herbrüggen, Thomas (TUM)
Siedentop, Heinz (LMU)
Udem, Thomas (MPQ)
von Delft, Jan (LMU)
Warzel, Simone (TUM)
Weig, Eva Maria (TUM)
Weinfurter, Harald (LMU)
Wolf, Michael (TUM)

Get entangled with us!

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LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN · Technical University of Munich TUM · MAX-PLANCK-INSTITUT FÜR QUANTENOPTIK · WMI · Deutsches Museum

MCQST is funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) under Germany's Excellence Strategy (EXC 2111 – 390814868).