Annual Report | 2023

Center for Quantum Spintronics

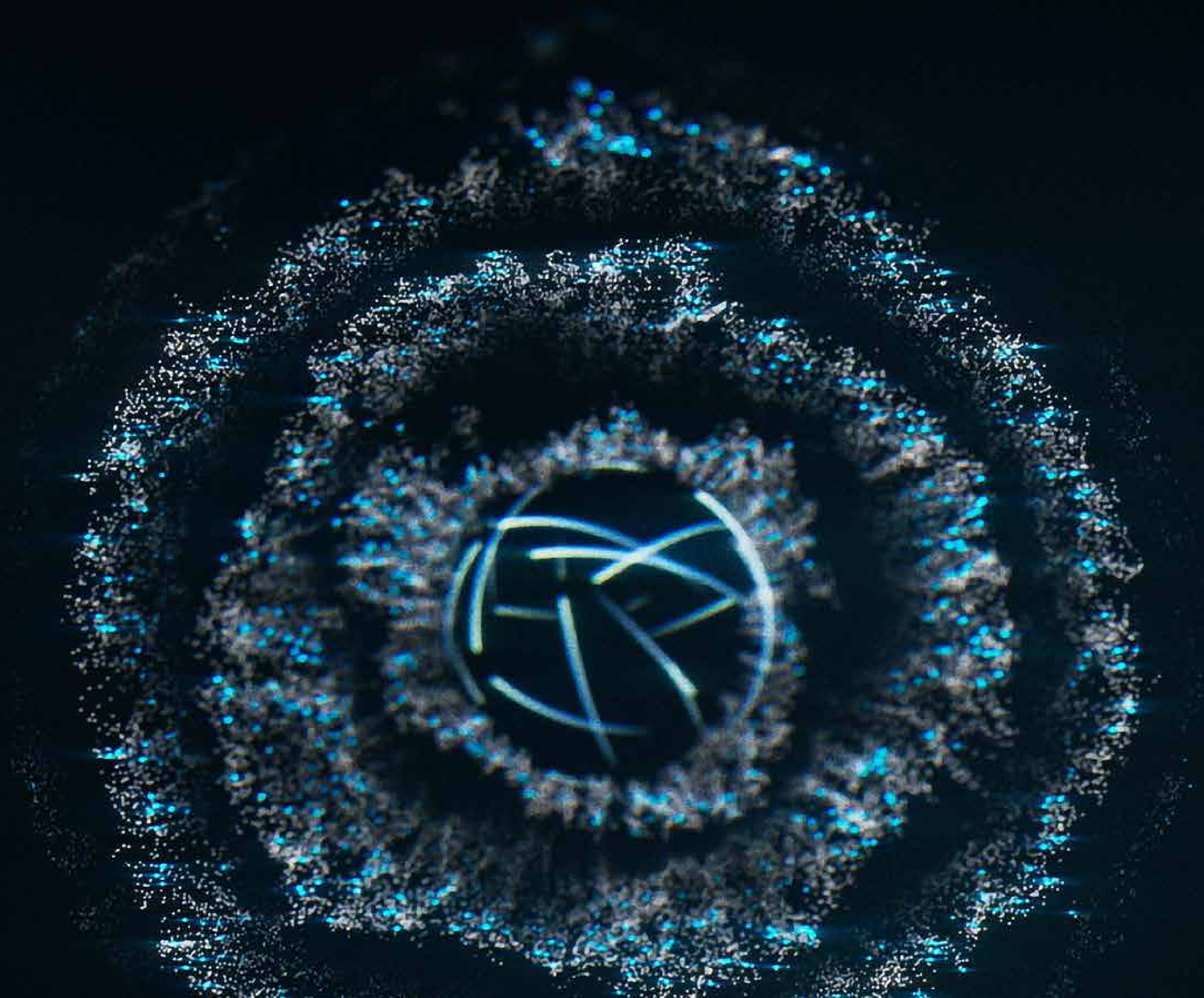
QuSpin

Norwegian Centre of Excellence
The Research Council of Norway

NTNU
Norwegian University of Science and Technology

Our Vision

is to trigger a revolution in low-power information and communication technologies in an energy-efficient society.



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THE ELECTRON SPIN: *The electron spin, the electron's magnetic moment, is a prime example of a quantum entity. Classically, when the earth orbits around the sun, it has an orbital angular momentum. The spin is the electron's intrinsic angular momentum. It is as if something orbits inside the electron. While such an analogue can be useful, it is not what really happens. Instead, the spin is an intrinsic property of the electron. Furthermore, in measurements, there are only two possible outcomes of the spin, clockwise rotation or counter-clockwise rotation. We denote these states as spin-up and spin-down.*

CENTER DIRECTOR ASLE SUDBØ

QuSpin entering its second period as an SFF

At the heart of Quantum Spintronics lies the manipulation and control of electron spin, a quantum property that serves as the fundamental building block for novel electronic devices. Unlike classical electronics, which relies solely on the charge of electrons, spintronics exploits both the charge and spin of electrons to encode and process information with unprecedented efficiency and speed. This paradigm shift not only promises breakthroughs in computing and data storage but also opens doors to entirely new avenues of scientific inquiry.

QuSpin embodies the collaborative spirit that drives scientific progress. Through shared expertise, our Center fosters synergistic collaborations, and researchers within the Center are poised to unravel the mysteries of quantum spin and pave the way for transformative technologies.

In 2023, QuSpin completed 6 years of full activity, and the Center is entering the second part of its lifespan. The Center has been able to keep up the excellent publication rate in the world's premier research journals in the field of condensed matter physics, and continues to consistently educate PhD candidates and Postdocs for the benefit of the global science community. Although the announced midterm evaluation from the Research Council of Norway (RCN) this year was not executed, our activities and results were approved by the RCN. QuSpin has outlined the activity for the final 4 years thoroughly, and will continue to produce high-quality high-impact science.

In September 2023, QuSpin organized its second collaboration workshop involving all members of the Center, including associate PI's and members of their groups both in Mainz University and Utrecht University. This workshop was a success and has yielded several new collaboration projects within the Center.

One major goal of QuSpin is to serve as a hub for nurturing the next generation of scientific leaders. Through mentorship programs, collaborative projects, and educational initiatives, the Center cultivates a vibrant intellectual environment where aspiring researchers can thrive and innovate. By fostering a culture of curiosity, creativity, and excellence, the Center empowers young minds to push the boundaries of knowledge and drive forward the frontiers of Quantum Spintronics.

As QuSpin embarks on its final part of exploration and discovery, we will continue to embrace the challenges and opportunities that lie ahead. Together, we will chart a course towards a future where the principles of quantum spin propel us towards new horizons of technological innovation and scientific understanding. QuSpin stands ready to lead the way, guided by a steadfast commitment to excellence, collaboration, and the relentless pursuit of knowledge.

> *Our primary mission is to contribute to the world's scientific endeavors with high-quality research in the field of quantum spintronics.*

Center of Excellence

SFF QuSpin's Principal Investigators (from left): Asle Sudbø, Arne Brataas, Hendrik Bentmann and Jacob Linder.

To innovate in the field of spintronics, our research center will be receiving funding throughout its ten-year lifetime. QuSpin will receive part of the total funding of 1.5 billion Norwegian Kroner for the Centers of Excellence. We are now halfway in our project and we look forward to the next half period of our research period up till the autumn of 2027.

By the end of 2023, our Center had developed into around sixty-people strong team with members from twelve different countries. QuSpin now has nine permanent professors and associate professors, two senior researchers, three postdocs, twenty-two PhD candidates, fourteen master's students, and one administrator. In addition, we have one position on twenty five percent as finance controller, two positions on twenty percent as Co-Principal Investigators and one professor II position and two lab engineers.

From 2023 we were happy to welcome Associate Professor Hendrik Bentmann as Principal Investigator and member of our leader group. He is heading the ARPES lab and has established a new highly international research team.

As an international research center, QuSpin values its highly professional international advisory board of researchers as well as an experienced board with senior researchers from NTNU.

In bringing together Norwegian experts with their international counterparts, the Center puts Norway at the forefront of quantum spintronics research. In turn, our research will enable innovative applications.

QuSpin, recognized in 2017 as one of ten new Centers of Excellence by the Research Council of Norway, carries the responsibility to provide the resources and space for international researchers, to delve into and unravel the beautiful complexities of condensed matter physics to further our understanding and control of quantum physics in the pursuit of innovations.

Here is a fraction of the members from our center. Many missing were on research stays or visiting other experimental labs.

Our new Principal Investigator heading the ARPES lab

> *Handling this working style requires certain skills and a certain attitude. I was happy to find people with the right expertise and experience.*

This article is based on a conversation with Associate Professor Hendrik Bentmann, facilitated by Karen-Elisabeth Sødahl.

From left: Chu-Lee Min, Anders Mathisen, Hendrik Bentmann, Stefanie Brinkman and Xin Tan.

Our new Principal Investigator Associate Professor Hendrik Bentmann got onboard QuSpin mid-August 2022. He has now had some time getting to know the Center and its people, and he has established a new research team. We asked him about his reflections from heading the ARPES team, working in the lab and his research.

What was your scientific background and motivation for starting at QuSpin?
I was working as an "Akademischer Rat» at the Department of Physics at the University of Würzburg in Germany, the equivalent of an assistant professor. As principal investigator in a collaborative research center, I was leading an experimental project on magnetic and topological materials.

There were a couple of reasons for taking on this new position at QuSpin. I was at a stage in my career where I wanted to get more international experience and a broader view of the research landscape and of how things work elsewhere. This specific QuSpin announcement was a perfect match for my expertise. I could not let this opportunity pass. I have always liked teamwork, interacting with people with similar interests and from complementary fields of expertise. I hoped that this would also be possible here.

The strong international standing of QuSpin was definitely a big motivation, as well as the ARPES equipment that was already available here. I have a longstanding background in doing experiments at synchrotronic facilities. The equipment in the QuSpin ARPES lab is a challenge because it is not yet a mature technique in the photoemission community. But I have had previous collaborations with groups that pioneered this technique, i.e. this particular approach of doing ARPES.

How did your family react to the possibility to move to Northern Europe?
I didn't really have strong connections to Norway, not even to Scandinavia. When I first looked at the map I thought: Wow, this is quite far up north, but eventually this didn't hold us back. I was really excited about this opportunity but it was a tough decision to move as a whole family with wife and three kids ranging from one to eight years old away from immediate family and friends to a place with a different language, kindergarten and school system. But it has worked out very well. My wife has a part-time job, and the children thrive in their daily life here.

How did you recruit and establish your ARPES research team?
Bentmann now has a team of five people including himself, and it is a very international one: Chul-Hee Min from South-Korea, Xin Tan from Malaysia, Stefanie Brinkman from the Netherlands, and Anders Christian Mathisen from Norway.

As an experimental research team we have a rather close working style. We are very dependent on each member individually and as a team. The experiments, and the development and maintenance of equipment cannot be accomplished by a single person. We must be able to rely on each other and work together on a common goal. Particularly during beamtimes at international synchrotron facilities, we are working very closely together for five or six days, and essentially around the clock with little sleep in between. That is an additional challenge, I would say.

Handling this working style requires certain skills and a certain attitude. I started out by looking for relevant skills. I was happy to find people with the right expertise and experience. In addition, their personalities played an important role, especially their enthusiasm for science in general, and for basic research in particular. We also needed collaborative team players who can stand pressure and are willing to «fill the gaps», sometimes taking the lead, and other times not.

A team with experienced members complementing each other
Our lab engineer Chul-Hee Min, who previously worked in Würzburg and then Kiel (Germany), has experience with various types of ARPES instruments and more than 20 years of experience with photoemission spectroscopy. Postdoc-to-be Xin Tan comes from a renowned research facility in Jülich (Germany) and was a member of the group that invented and pioneered the type of spin detection that we use. They are both great reinforcements for QuSpin, coming from world-leading groups. PhD Candidate Stefanie Brinkman completed her master's with the QuSpins MBE group growing materials, and PhD Candidate Anders Christian Mathisen's master's at the TEM group here at the Department of Physics has given him experience with electron microscopy. Moreover, PhD Candidate Øyvind Finnseth, from Associate Professor Ingrid Hallsteinsen`s group, works in the ARPES lab, where he learned about the technique during his bachelor's. It is obviously important to have experienced experimentalists, especially since the technique we use is still under development. Worldwide, still only just a little handful of groups are working with it, but the number is growing. Together, this team builds a strong basis for the next four years of research activity at QuSpin.

What are the main methods and focus for the research in your team?
ARPES stands for angle-resolved photoelectron spectroscopy. The basic idea of ARPES is that we kick out electrons from a sample by monochromatic light, and then analyze the energy and angular distribution of the electrons that come out of the sample. Moreover, we aim to detect the spin of the excited electrons. The implementation we use for this analysis, i.e. the way we detect the electrons, is a rather new technique compared to more traditional ARPES approaches that are used in many other places worldwide. I believe that ARPES provides fundamental and comprehensive information about the electronic and magnetic properties of complex materials.

Associate Professor Hendrik Bentmann working in the ARPES lab.

In QuSpin the research focus is on the behavior of three main materials: superconductors, magnetic insulators, and topological insulators. Within this framework, our current interest is on the electronic structure of antiferromagnets and non-centrosymmetric topological semimetals. A common scheme here is that the crystal structure, i.e. the precise way in which the atoms are arranged in the material, can have a profound influence on the electron spin and the electron (orbital) motion. We try to image these effects in our experiments.

Sometimes it can be a challenge to concentrate on the details of the running projects and at the same time keep an overview of the bigger picture and the developments in the research field. The workshops and conferences we organize at QuSpin are very valuable in this regard. Long-term planning is tricky, but you need to make choices, and the field is very competitive.

> *Our ARPES group is running a few interesting projects that are yielding their first competitive results, which we hope will attract even more international attention to QuSpin.*

We have had some technical problems with the equipment which prevented us from making major progress in the laboratory. These instruments have many fragile components, which makes them prone to different kinds of malfunction. At the moment we are slightly slowed down but we are able to compensate this by reinforcing our activities at international facilities, such as DESY in Hamburg.

How do you supervise and work with your PhD candidates to generate scientific results, to be able to write articles and to prepare for their defense?
We have regular group and individual meetings where we discuss organizational matters, plans for the laboratory, data analysis, progress of projects, and so on. Almost all our projects involve collaboration with other groups. For example, we often rely on samples synthesized in other groups, such as the MBE group of Associate Professor Christoph Brüne at QuSpin. It is important to initiate such collaborations, keep them running and identify and cross-correlate this with our interests. I also need to assess the risk of projects; it may be wise to combine a risky project with a more «bread-and-butter» project for a particular PhD candidate.

Do you actively seek collaboration with the theorists at QuSpin or do they come to you?
As an experimental group, we most often obtain new results and then seek support from theorists to understand and describe them better, to properly put them into context. Vice versa we might get inspired by new theoretical developments, either from theorists at QuSpin or from external groups, to carry out experiments in a new direction.

Our first paper is up for review now. There we have a successful experiment-theory collaboration, including our experimentalists Xin Tan and Stefanie Brinkman, and theorist PhD Candidate Bjørnulf Brekke as co-authors. This was really a nice example where we had experimental results, which we understood to some extent, but got a better and deeper understanding of them through collaboration with Bjørnulf.

If experimental results are particularly clear or well-understood from previous theory, they may well stand on their own. But if this is not the case, it is often essential to have theory support to complement the experiments.

What inspires you for your future research at QuSpin?
Having a collaborative team, with various research groups working on the same vision, puts a strong base motivation on every day's work and the overall spirit. QuSpin workshops, the conferences, seminars, and collaboration and financial opportunities are also important. Our ARPES group is running a few interesting projects that are yielding their first competitive results, which we hope will attract even more international attention to QuSpin.

Main Research Themes, Goals and Activities

The principal goal of the Center is to describe, characterize and develop recently identified quantum approaches to control electric signals in advanced nanoelectronics, conceptually different from those existing today.

The research focuses on three judiciously chosen low-dissipation systems: magnetic insulators, topological insulators, and superconductors which correspond to three research themes: insulator spintronics, topological matter, and super spintronics.

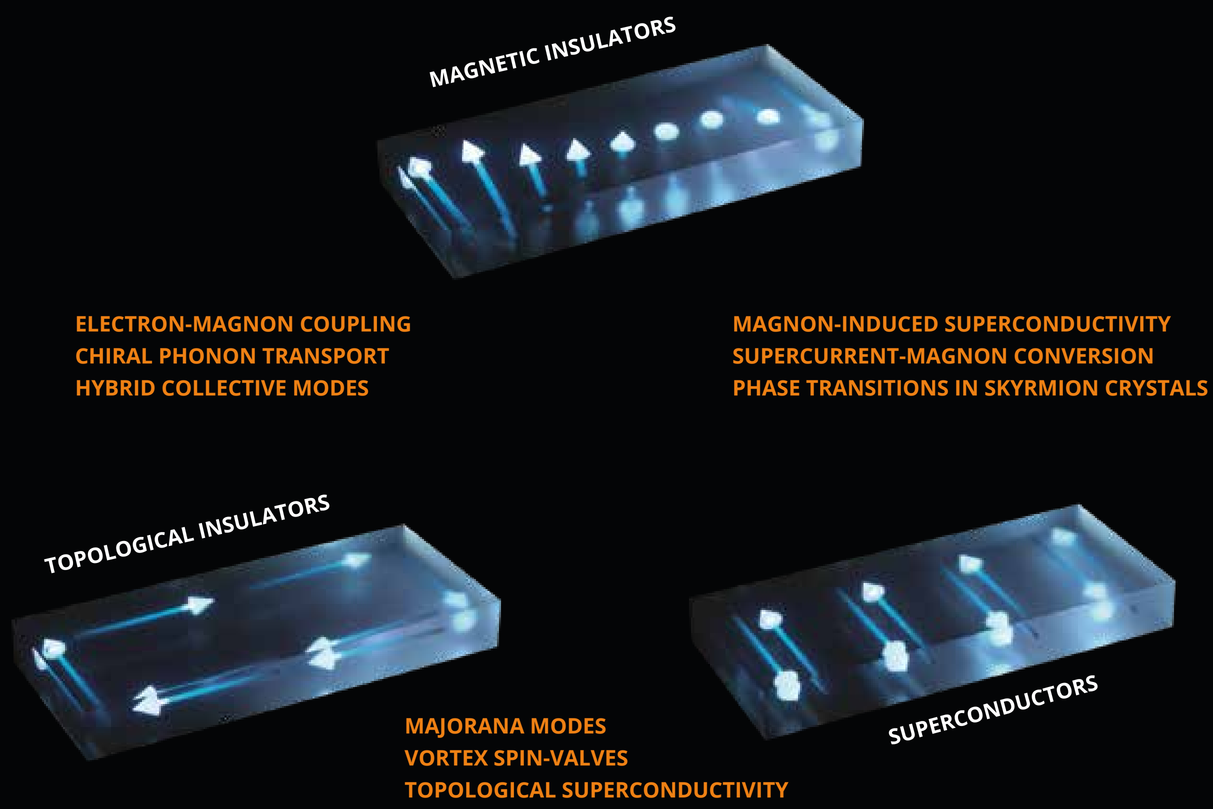
Our unique competitive edge is addressing the ultra-low power innovations by uniting expertise from insulator spintronics, topological matter, and super spintronics. Although these themes are individually exciting, we combine them to generate significant added value.

Electrons can move in free air. In materials, their motion can differ significantly. In metals, the collective flow of the electrons resembles that of particles, but with dramatically altered properties. Their mass, charge, and even spin can be modified. This dressed behavior resembles new particles, so-called quasi-particles, that require new models and new concepts.

We address how such quasi-particles can convey spin information with exceptional tiny energy losses. Also, we consider the dynamical evolution of the spin states for high-speed electronics. A supercurrent is a remarkable phenomenon where a current can flow in a supercurrent with no electrical resistance and no energy loss. New material combinations with such properties would revolutionize electronics and have a significant impact on society at large. We consider how spin can flow via supercurrents.

Successfully meeting these challenges has the potential to transform electronic data transmission, storage, and processing. Ultimately, dissipationless spin transport would solve the problem of energy waste to the environment with potential uses in disruptive technologies.

Overlapping research themes within the different research areas



MAGNETIC INSULATORS: *Magnetic insulators are excellent conductors of spin while forbidding the energy-consuming process of charge transport. In magnetic insulators, the quanta of the spin vibrations can act as new low power dissipation information carriers.*

TOPOLOGICAL INSULATORS: *Topological insulators allow ultra-low dissipation transport of charge and spin at the surface but inhibit lossy processes in the bulk. An important aspect is the exceptionally strong coupling between charge and spin signals.*

SUPERCONDUCTORS: *Superconductors have exactly zero electrical resistance and expel magnetic fields. Cleverly designed nanostructured superconductors in combination with magnetic materials exhibit intriguing new electrical and magnetic phenomena coupling charge and spin information.*

ASLE SUDBØ

Topological Quantum Matter

Theme and goal

Topological quantum matter is a fascinating field that lies at the intersection of quantum mechanics and topology, exploring properties of materials that exhibit unique quantum states. Unlike conventional materials, topological quantum matter exhibits electronic behavior that is robust against small perturbations. An intriguing aspect is the emergence of nontrivial topology in the electronic band structure, yielding protected surface or edge states. These topologically protected states are akin to quantum anomalies that persist despite external disturbances, offering potential applications in quantum computing and information processing.

In superconductors, electrons form pairs and move without resistance, enabling the efficient transmission of electrical currents. This phenomenon holds immense potential for revolutionizing power transmission and creating advanced electronic devices. Superfluids exhibit zero viscosity, allowing them to flow without any energy loss, and are observed in certain quantum fluids and even in ultra-cold gases. Superconductivity and superfluidity both highlight the extraordinary capabilities of matter when subjected to extreme conditions, offering a glimpse into the quantum world's remarkable and counterintuitive nature.

The overarching goal of our research is to understand how collective effects in quantum systems with topologically protected physical properties, both with and without strong correlation effects, conspire to produce novel and emergent physics. This research is likely to shed light on other areas of physics as well, such as high-energy physics and high-temperature superconductivity. Systems that we study with this in mind are heterostructures of topological insulators and magnetic insulators, topological insulators, superconductors, and chiral p-wave superconductors.

Activity in 2023

One major focus of the activities in 2023 has been exploring novel platforms for quantum computing, utilizing quantum spin-fluctuations in topological magnetic ground states. Building on research carried out in 2022 on quantum skyrmion crystals, we computed and predicted superconducting instabilities in hybrid quantum system consisting of quantum fluctuating skyrmion crystals and normal metals. Due to the noncollinearity and noncoplanarity of the quantum spins in the ground state (a quantum fluctuating analog of a classical skyrmion crystal) the spin-structure of the computed effective electron-electron interaction is sufficiently rich to permit fully spin-polarized Cooper-pairs. Furthermore, due to the features of the Dzyaloshinskii-Moriya interaction responsible for the non-collinear ground state, the superconductivity is endowed with a non-trivial topological invariant. These results have also been generalized to a wider (and simpler) class of magnetic systems involving quantum fluctuating spiral ground states that are noncollinear, but coplanar. Our results propose a simpler path for realizing topological superconductivity than previous proposals involving skyrmions and superconductors, by obviating the need for a priori having superconductors in the hybrid quantum system.

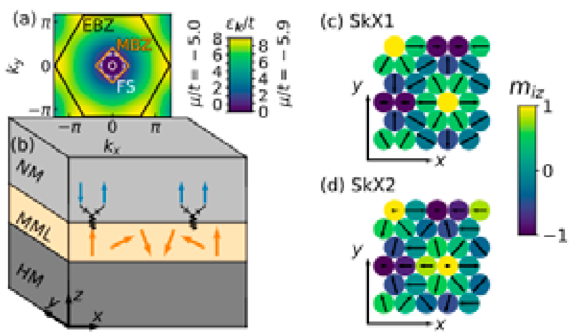


Figure caption: (a) Plot of the electron energy showing the electron first Brillouin zone (EBZ) in black, the magnetic first Brillouin zone (MBZ) in orange and the Fermi surface (FS) in white. Two choices of the chemical potential μ are shown, where the solid FS corresponds to μ/t = -5.9 and the dashed FS corresponds to μ/t = -5.0. (b) An illustration of the system under consideration. The itinerant electrons (blue arrows) in a normal metal (NM) are coupled to the spins (orange arrows) in a magnetic monolayer (MML). The MML is deposited on a heavy metal (HM) such that skyrmion crystal (SkX) ground states (GSs) are preferred. The (c) SkX1 and (d) SkX2 GSs are shown with periodic boundary conditions. Colors give the z-component of the spins, and arrows show their inplane component.

ARNE BRATAAS

Spin Transport and Spin Dynamics

Theme and goal

An electron has a spin in addition to its electric charge. The spin is the source of magnetism. The motion of the mobile charge carriers is the basis of conventional electronics and spintronics. In metals and semiconductors, electric fields induce currents. In magnetic materials, a spin current occurs naturally as well. Spin currents also appear in non-magnetic materials where the spin is significantly coupled to electron motion. In superconductors in contact with magnetic materials, charge and spin can flow without dissipation. In insulators, there are no moving-charges. Spin information can, nevertheless, propagate. While electrons are immobile in insulators, another entity conveys information. At equilibrium, the electron spins become ordered. In response to external forces, the ordered pattern of the spins can be disturbed. The disturbance can take forms like waves, spin waves, or other dynamical spin textures.

We aim to determine how spin in antiferromagnetic and ferromagnetic materials connects to mobile electrons in adjacent conductors or superconductors. We will utilize this coupling to control electric signals. One aspect is to replace moving charges with magnetic insulators´ dynamic low-dissipation coherent and incoherent spin excitations. Another is to utilize superconductors in contact with magnetic materials to enable new ways of dissipationless flow of spin and charge. Additionally, coupling THz spin dynamics in antiferromagnets with conductors can facilitate new ways of creating THz electronics. In these systems, we can also enable unprecedented control of electron-electron, electron-magnon, and magnon-magnon interactions. These features can open doors toward creating new paths for magnon and exciton condensation, superfluidity, and superconductivity. Furthermore, since spin signals in many of these systems have extremely low power dissipation, overcoming the limitations can enable low-power technologies such as oscillators, logic devices, non-volatile random access memories, interconnects, and even quantum information processing.

Key questions

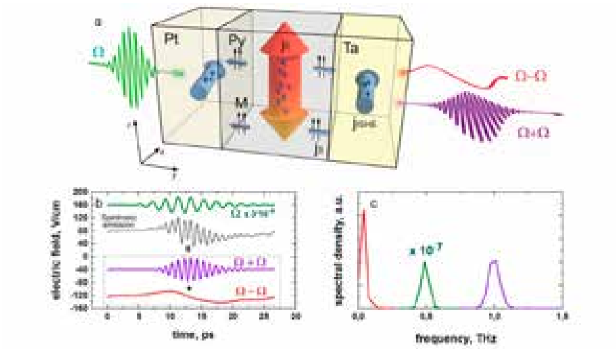
We focus on the fundamental challenges facing quantum spintronics. Key questions are how spin can transfer from magnetic materials to conductors and superconductors, how far and how spin propagates in insulators, conductors, and superconductors, how we can control electron and magnon correlations that cause new states of matter, and how to detect these phenomena's signatures.

Activity in 2023

We have contributed to understanding how THz light can efficiently drive coherent angular momentum transfer in nanometer-thick ferromagnet/heavy-metal heterostructures. The coherently driven spin currents originate from the ultrafast spin Seebeck effect, caused by a THz-induced temperature imbalance in electronic and magnonic temperatures and fast relaxation of the electron-phonon system. Because the electron-phonon relaxation time is comparable with the period of a THz wave, the induced spin current results in THz second harmonic generation and THz optical rectification.

Finally, we have also participated in other developments with partners at QuSpin, such as supercurrents through antiferromagnets, Andreev reflection in antiferromagnets, magnon-plasmon interaction in ferromagnets, spin transport in antiferromagnetic insulators, and cavity spintronics.

We have published 11 papers, two in Physical Review Letters, one in Materials Research Letters, two in Nature Communications, five in the Physical Review B, and one in the Physical Review Applied.



Spintronics THz second harmonic generation and optical rectification in ferromagnet-heavy metal trilayers.

JACOB LINDER

Superconducting Spintronics

Theme and goal

In classical physics, matter exists as a gas, liquid, solid, or plasma. However, this classification is too crude to capture the fascinating physics that emerges within each of these states. For instance, not all solid states behave the same way. According to quantum physics, various solid materials will behave very differently. Some are magnetic, some do not conduct electric currents, while others can carry currents of not only charge but also a property known as spin. This property is closely related to magnetism and is a fundamental trait of most elementary particles.

It turns out that some materials can conduct electric currents without any energy loss: so-called super-conductors. The origin of superconductivity is quantum mechanical, but that does not mean superconductivity only occurs at microscopic length scales invisible to the naked eye. Large chunks of materials can be superconducting, making this phenomenon a macroscopic manifestation of quantum physics. Magnetism is another example of a phenomenon which originates from quantum physics. When different materials such as superconductors and magnets are combined, new physics can emerge that is more than just the sum of properties of the materials. This is one of the motivations behind the field of superconducting spintronics where one studies spin-dependent quantum effects in superconductors.

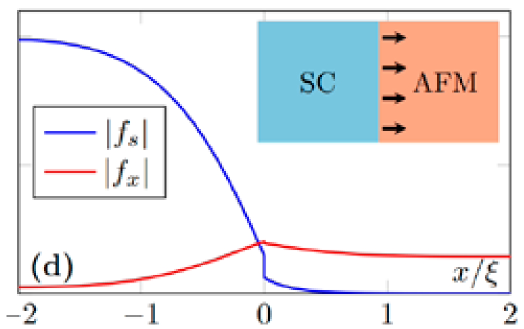
Two main goals guide our research. The first one is to discover new quantum phenomena that transpire when combining superconductors with materials that have fundamentally different properties, such as magnetic ones. Secondly, we focus on discovering phenomena that are relevant to the development of cryogenic information transfer, generation, and storage based on super-conductors. This is closely related to the transport of charge, spin, and heat in hybrid structures. We use a variety of analytical and numerical tools to address the research questions above, depending on which method is the most appropriate for the system at hand. Some of our theoretical approaches include lattice models, quasiclassical Keldysh theory, Green function techniques, scattering theory, and Landau-Lifshitz-Gilbert phenomenology.

Key questions

The main research problems we are focusing on solving are related to the functional properties of materials and how they can be controlled and altered by combining several materials or by applying external stimuli. For instance, is it possible to use magnetic materials to control when superconductivity appears and even enhance its properties? How can one use superconductors to generate and detect transport of not only charge, but also other degrees of freedom such as spin and heat, with minimal energy loss? Finally, we are interested in understanding the quantum dynamics of various types of long-range order in solid-state systems when quenches are applied in interaction parameters, to see if novel meta-stable quantum phases can be accessed.

Activity in 2023

One of our research highlights in 2023 was the prediction of 0-pi oscillation in a new class of magnetic materials called altermagnets. Despite the lack of net magnetization in altermagnets, we showed that both the Josephson effect and Andreev reflection can display similar spin-dependent effects as conventional magnetic materials, but importantly without any disturbing stray field. We also developed a theory for spin pumping with unconventional superconductors and for altermagnetic metals and insulators. Moreover, we collaborated with experimentalists and reported the observation of magnetic state dependent thermoelectricity in superconducting spin valves. Our publications in 2023 include three papers in PRL, one paper in Science Advances, and six papers in PRB.



Contrary to what might be expected at first glance, antiferromagnets distinguish between Cooper pairs with different spins, permitting long-ranged spin-polarized superconductivity.

HENDRIK BENTMANN

Spectroscopy of Quantum Materials

Theme and goal

The recent decades have seen the rise of modern information and communication technologies, largely based on the use of semiconductors in transistors and integrated electronic circuits. This era is sometimes referred to as the „silicon age", highlighting the importance of the material silicon in this context. The properties of silicon are well understood on fundamental grounds. However, there are classes of materials whose physical behaviour is vastly more complex and less understood, including superconductors, magnets, and topological systems. In these „quantum materials" the quantum-mechanical nature of the electrons and their mutual interactions come to the forefront and remain manifest over a wider range of energy and length scales. Researchers envision that proper control of these quantum effects and resolving some of their puzzles could enable new technologies beyond the silicon age. Understanding the physics of quantum materials is challenging, however, and involves the development and application of sophisticated experimental and theoretical techniques.

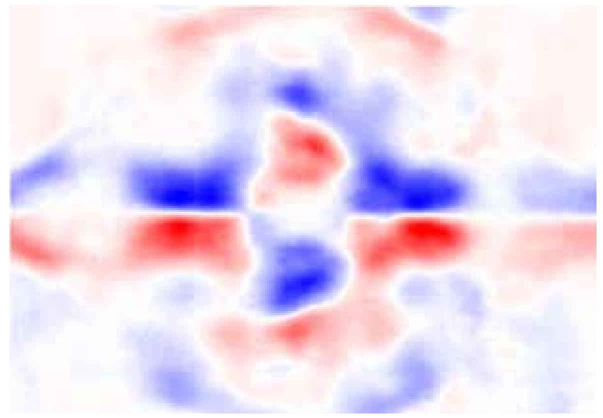
We use a method called spin- and angle-resolved photoelectron spectroscopy (spin-ARPES) to investigate magnetic and topological materials. Spin-ARPES is based on the photoelectric effect, i.e. the excitation of photoelectrons at a material surface upon irradiation with monochromatic light. The effect has long been known and constitutes one of the key observations that paved the way from classical electrodynamics to quantum mechanics. Use of modern spectrometers and light sources allows us to study the spatial, angular and spin distributions of photoemitted electrons as well as their dependence on energy and polarization of the exciting light, providing detailed information about electronic and magnetic properties. With this, our goal is to contribute to the discovery and to a refined microscopic understanding of quantum states in new and complex materials.

Key questions

Our primary focus lies on the investigation of electronic states with so-called topological properties which give rise to unusual spin textures in momentum space. We are interested in how topological properties and spin textures are related to or modified by ferromagnetic or antiferromagnetic order, specific crystalline symmetries, quantum confinement in atomically thin crystals and proximity coupling in heterostructures. Spin-ARPES allow us to directly address these points experimentally. Our experiments are performed in the laboratory at NTNU and at international synchrotron radiation facilities, such as PETRA III at DESY (Hamburg).

Activity in 2023

A new head engineer and a new Postdoc-to-be (2024) started working in the lab in late 2023. Moreover, a new PhD candidate joined the group in the autumn semester. The activities in the lab were delayed by necessary repairs of the ARPES instrument. Yet, initial experiments on films grown in the groups of C. Brüne (QuSpin) and I. Hallsteinsen (FACET) we carried out. We performed successful synchrotron-based measurements on chiral topological semimetals and different magnetic systems.



Circular dichroism in the angular distribution (CDAD) of photoemitted electrons for a topological semimetal, probing the chirality of Weyl nodes in the band structure.

CHRISTOPH BRÜNE

Molecular Beam Epitaxy of Antiferromagnets

Theme and goal
Access to high quality magnetic materials is essential for spintronics research. Especially magnetic thin films are of great interest. These are layers of magnetic materials with thicknesses in the nm range. We are developing thin film synthesis of magnetic materials with large potential for spintronics research and applications.

To do this, we rely on a technique called molecular beam epitaxy. This technique uses an ultra-high vacuum environment to guide atoms or molecules onto a target, where a crystalline layer will grow under the right conditions. Using this method, we can create high-quality crystals with thicknesses down to a single atomic layer. It is also possible to combine different materials in complex layer structures to create new physical properties and control them in detail. Furthermore, we can also create nano-objects like nano- wires and quantum dots using molecular beam epitaxy.

Key questions
Our first key project area is the growth of so-called antiferromagnetic semiconductors. These materials combine the potential for new spintronics applications with the possibility to manipulate the material properties using electric fields (similar to today's semiconductor technology). This will enable the integration of established semiconductor techniques and spintronics applications.

Here we are currently concentrating our efforts on the growth of $CuFeS_2$, an antiferromagnetic semiconductor with a very high Néel temperature of 823 K. This work is done in collaboration with Arne Brataas' and Mathias Kläuis' group in QuSpin. We are also collaborating with Morten Kildemo and Magnus Nord for optical and structural studies of our thin films.

Helimagnetic systems are the group's second research area. These materials are very interesting for their complex magnetic structures, based on a spiraling (helical) order of the spins in the material. This includes so-called 'Skyrmions', stable magnetic whirls inside the material. Skyrmions are promising for their potential as

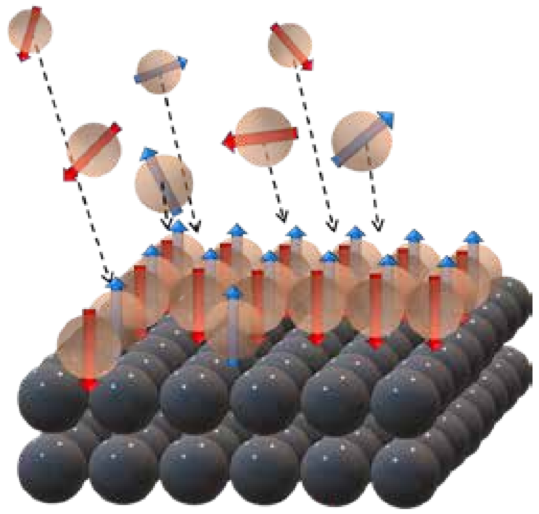


Illustration of molecular beam epitaxy growth of an antiferromagnetic layer on a non-magnetic substrate.

nano-objects for future low-energy memory devices. We are currently developing the growth of materials in the Fe-Sn and Mn-Sn family of materials. These materials are known for their Kagome lattice type spin structures and are hosting helical and skyrmionics states. These investigations are conducted in close collaboration with Dennis Meiers' group, with two PhD candidates shared between the two groups.

Activity in 2023
In 2023 we continued growth optimization of our materials. For the $CuFeS_2$ thin films, we concentrated on investigation of different growth phases and directions as well as developing an annealing procedure. Both steps resulted in improved film quality and better control over the growth. Finally, we also investigated structural, optical, electronic and magnetic properties together with our collaborators.

For the Kagome materials we focused on the investigation of different substrate materials and successfully improved growth starting conditions. Furthermore, we optimized towards larger island/domain sizes in the thin films and we further characterized the layers magnetically and structurally.

JEROEN DANON

Spin-based Quantum Computation

Theme and goal
The quest for the optimal physical qubit (it should be stable, controllable, and scalable) is at full speed, and by now the research has been narrowed down to a handful of very promising approaches. My research is theoretical, but focuses on practical aspects of such qubit implementations, usually in close collaboration with experimentalists.

A large part of my work is in the field of spin qubits in semiconductor quantum dots (small potential traps inside a semiconductor), where the basic idea is to use the spin degree of freedom of localized electrons as a qubit basis. Attractive features of such qubits are that they are small, fast, and potentially easily scalable. Since they are very similar in design to regular microchip transistors, one could imagine leveraging industrial fabrication techniques to massively scale up spin-based quantum processors.

A promising recent development in the field is a successful shift from GaAs-based spin qubits to devices that are hosted in group-IV materials, such as Si and Ge. An intrinsic problem with GaAs is that both Ga and As atoms carry finite nuclear spin, which results effectively in randomly fluctuating magnetic fields acting on the qubit spins, which causes fast qubit decoherence (loss of the quantum aspect of the information). Both Si and Ge can be isotopically purified to be nearly nuclear-spin-free, and are thus much better host materials in that sense. Practical problems with the more complex conduction-band structure in Si and Ge turned out to be avoidable by using the spin of *holes* ("missing" electrons) in the valence band as quantum information carriers. This shift has yielded qubits that operate below the fault-tolerant threshold.

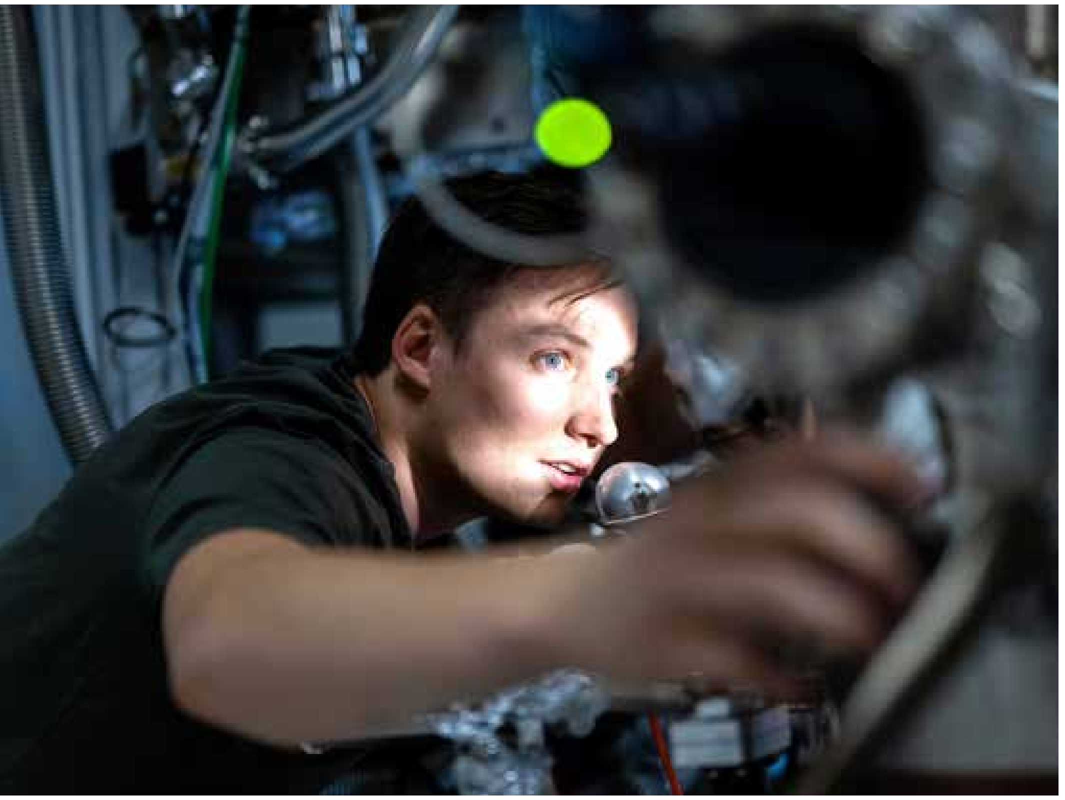
Key questions
Most problems my group is working on are related to questions such as: How can we further improve qubit initialization, control, or read-out in a specific setup? What processes dominate qubit decoherence? How can we further reduce the effect of these processes? How can we achieve a significant scale-up of spin-qubit devices, including coherent qubit-qubit coupling between distant qubits?

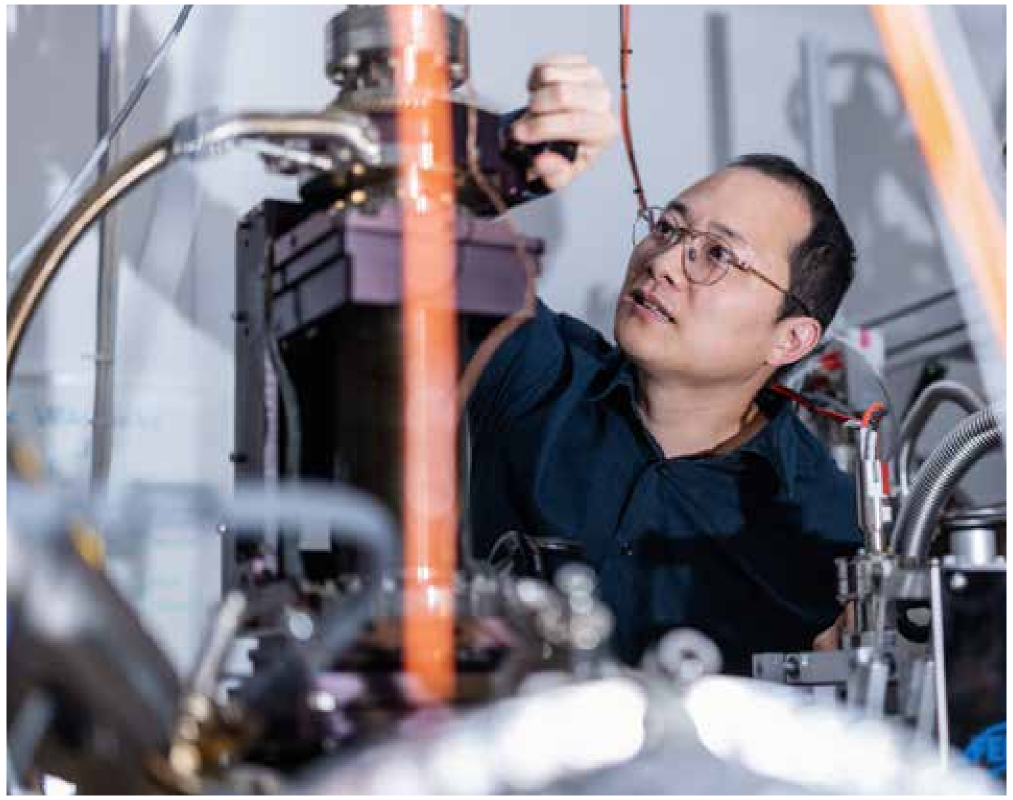
Activity in 2023
Currently, one of the core activities of my group is developing a detailed understanding of the properties of the valence-band holes in materials such as Si and Ge and their behavior when proximitized by a superconducting material. Due to the underlying p-type nature of the wave functions in the valence band, the spin and orbital degrees of freedom of confined holes can become strongly mixed, resulting in complex spin dynamics that depend intricately on the interplay between the applied magnetic field, electric field, and the band structure itself. Understanding this physics is crucial for the further development of fast electrically controllable spin qubits, reliable superconducting spin-qubit couplers, "artificial Kitaev chains" comprised of proximitized quantum dots, gate-tunable Josephson junctions, SQUIDs, and superconducting qubits, as well as superconducting diodes.

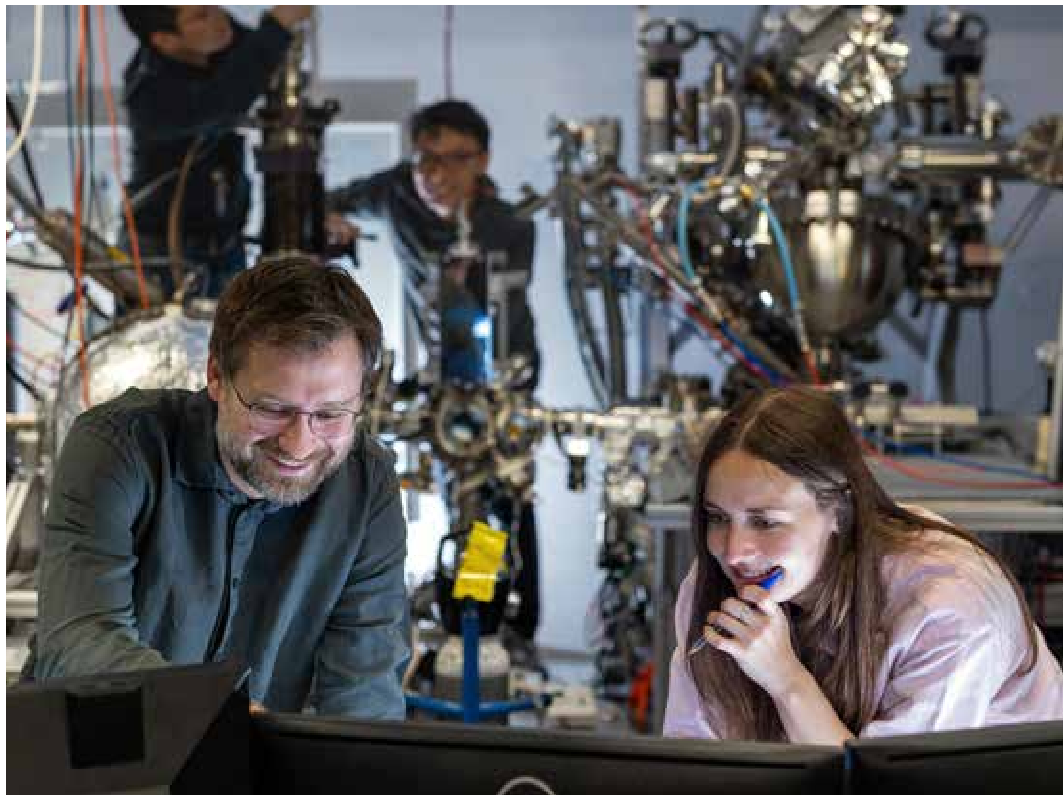
Another direction of research in my group is to investigate methods to implement machine-learning techniques for the automated tuning, stabilization, and operation of quantum devices such as solid-state qubits. One example is the development and experimental realization of fast protocols for active monitoring of the fluctuations of the nuclear fields in GaAs-based spin qubits, using adaptive Bayesian estimation methods combined with neural-network-based machine learning techniques.

EXPERIMENTALISTS AT WORK

The ARPES team in action in the lab.







JOHN OVE FJÆRESTAD

Frustrated Quantum Antiferromagnets

Theme and goal

Our group's research centers around lattice models of quantum antiferromagnets, especially models with competing (aka "frustrated") interactions. In combination with strong quantum fluctuations, frustration may prevent magnetic order and instead lead to other, magnetically disordered, phases that possess more exotic types of order that are of great fundamental interest.

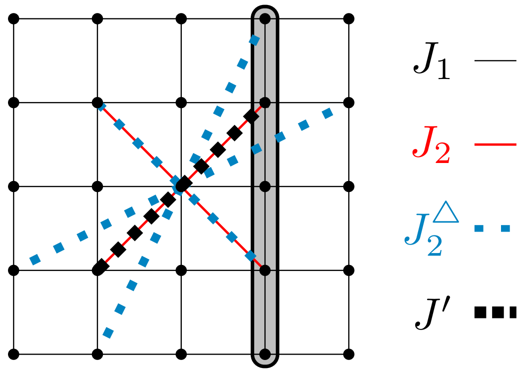
Of particular interest are phases known as quantum spin liquids, whose order is not described by broken symmetries but may instead be of a topological nature. In recent years, new materials have been discovered which exhibit evidence of unconventional behavior pointing towards spin-liquid physics.

In recent years it has also become clear that various concepts and quantities originating in quantum information theory, like entanglement entropy and fidelity, may be very useful for characterizing quantum many-body phases and the quantum phase transitions between them. Different types of order may give rise to characteristic "signatures" in such quantities and their behavior as a function of various parameters.

The overall goal is to get a better understanding of the "zoo of phases" that may arise in frustrated quantum antiferromagnets, and contribute towards their description and classification.

Key questions

Key questions include whether/where quantum spin liquids arise the phase diagram of various lattice quantum spin models, what types of quantum spin liquids can arise, and how various types of order can manifest themselves through signatures in quantities like entanglement entropy (including both orders that are and are not described by broken symmetries).



Examples of model interactions for calculations of entanglement entropy of magnetically ordered frustrated quantum Heisenberg antiferromagnets (subsystem in grey).

ERIK WAHLSTRÖM

Local and Global Magneto-dynamic Properties of Oxides

Theme and goal

Our primary theme is to probe and understand excitations in the charge, spin and lattice, and their interactions at the atomic scale. Our primary method is through developing excitation spectroscopy techniques, primarily scanning-based probe techniques and other experiments that provide insights into the fate of charge and spin in materials.

Our short-term goal is to explore the magnetoelectronics and magnonics of oxide ferromagnets and antiferro-magnets. In a more applied context, the long-term goal is to understand and control coupling in the thermal energy scale in order to contribute to the use of thermal energy to communicate information. The long-term goal on the method side is to develop STM-based point-contact techniques to explore mesoscopic and magnetodynamic physics at a very local scale.

Key questions

We primarily study the excitations and coupling between magnons, phonons and charge carriers at an energy scale that ranges from sub-thermal energies to electron volts. In the spin domain, the prime motive is to understand magnons, and the expression in the form of propagating magnons and their interaction with charge and phonons.

In the phonon regime, we are interested in understanding size and material control and tunability in coupling to the charge and spin excitations.

We are primarily investigating model systems in oxide materials, developing an understanding of perovskite-type ferromagnets and antiferromagnets, mainly seeking collaboration with groups on the material synthesis side to address our key questions.

Activity in 2023

We have continued our project on phonon-magnon coupling in oxide heterostructure. This is an internationally collaborative effort where THz characterization (Stefano Bonetti, Stockholm), PEEM imaging of excited structures (Ferran Macia, Barcelona) and development of point contact spectroscopy (NTNU and Toshu An, Kanasawa) will be used to probe structures grown in collaboration with the oxide electronics group at NTNU. Travis Gustafsson is the first to join our team as PhD candidate. He has worked hard within the project with a main focus on establishing a versatile platform for electric measurements on combined surface acoustic wave and magneto dynamic wave mixing. He has also participated in dynamic PEEM experiments at ALBA. We also worked on initiating the other parts of the project in close collaboration with Prof. Thomas Tybell in the Electronics Department at NTNU.

DENNIS MEIER

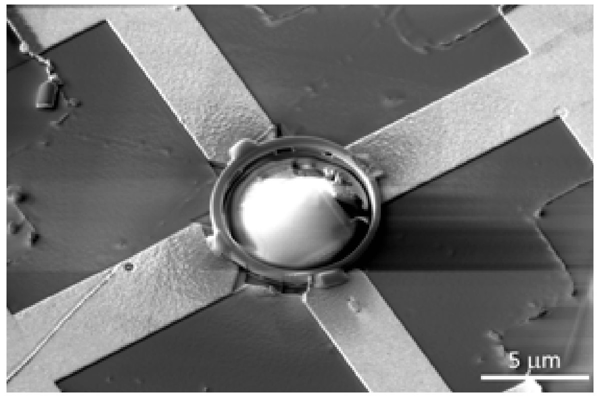
Topological Spin Textures

Theme and goal

Topological spin textures, such as magnetic skyrmions and domain walls, are a rich source for emergent physical phenomena and promising functional nanoscale systems for future technologies, enabling conceptually new approaches towards low-energy information processing and data storage. Application opportunities range from logic gates and memory devices to unconventional computing and sensing.

Our research studies the fundamental physics that give rise to the unique properties and dynamical responses of topological spin textures in ferroic materials. We are particularly interested in the unusual local responses of these special magnetic defects, their scaling behavior and how they can be created on demand, controlled, and read out. For this purpose, we apply different advanced microscopy and nano-structuring tools which allow us to investigate the topological defects spatially resolved in device-relevant geometries.

The goal of our research is to understand and utilize the emergent functional phenomena associated with topological spin textures, developing current device paradigms into new realms of magnetism.



Ring-shaped device structure prepared from an Fe-Sn based material using a focused ion beam. The ring is placed on contact pads, which can be used to inject electrical current and control the material´s topological spin textures. (Courtesy of E. D. Roede)

Key questions

Many developments in the field have occurred only recently, and it has become clear they only scratched the surface regarding topological textures that form in magnetically ordered materials. Specifically, controlling such textures remains a major challenge. We investigate new magnetic materials that host topological spin textures and study their functional responses at the nanoscale. For this purpose, we apply different microscopy and nano-structuring methods, such as magnetic force microscopy (MFM) and focused ion beam (FIB).

For example, we use FIB to shape materials of interest into device-relevant structures. Based on these structures, we study, e.g., the impact of reduced physical dimensions on the magnetic order and how electrical currents and magnetic fields control the position and movement of individual spin textures. Ultimately, we want to understand the new degrees of flexibility topological spin textures can offer and demonstrate new opportunities that arise for future applications, including Green-IT (i.e. low-power technologies) and modern concepts for unconventional computing.

Activity in 2023

One of the key events in 2023 was the start of our network project "TOPOCOM" (Topological Solitons in Ferroics for Unconventional Computing), for which we received funding from the European Union's Horizon 2020 research and innovation programme. TOPOCOM is a network of leading groups from different disciplines and sectors selected to provide a unique training for 11 PhD candidates. Together with other QuSpin members, including the team of Mathias Kläui, we ensured that the network spans the whole range from fundamental physics and applied materials science - linking both experimental and theoretical aspects - to industrial-scale production and evaluation. The scientific part ("Training through Research") is complemented by advanced transferable business and cultural skills training ("Training for Life"), providing Europe with a unique training programme at the forefront in unconventional computing based on electric and magnetic solitons. Furthermore, we organized a focus issue on topological solitons for neuromorphic systems and wrote a perspective article, promoting the field and innovative magetnism-based computing paradigms.

SOL H. JACOBSEN

Triplet Spintronics

Theme and goal

Superconducting spin-polarized triplets carry coherent quantum information. A component of their correlation does not decay in either ferromagnets or superconductors, even with impurities. This makes them a primary candidate for low-dissipation information transport in spintronics. We examine the interplay of magnetism and superconductivity in emerging spintronic systems, using theoretical and numerical techniques.

Key questions

Our research considers atypical geometries and model setups for examining the conversion mechanisms, manipulation and detection of superconducting singlets and triplets in spintronic devices, including magnets. We primarily consider the effect of curvature and/or strain, as well as cavity-mediated effects, which may enable new superconducting spintronic device design and control.

Activity in 2023

I am delighted that our work on geometric control of spin-orbit coupling will feature in the Emerging Leaders of 2023 special issue of the Journal of Physics: Condensed Matter. We highlight geometry as a designable and controllable way to manipulate spin transport, and we show how to wield chirality in mixed-geometry junctions (see figure) [1]. This year we have also shown that curvature and torsion can be used to probe the quality of a buried, uncompensated antiferromagnetic interface [2].

We continue to progress in our quest to understand the quantum details of photonic cavity coupling to a range of materials and systems. We proposed a remote sensing scheme where the superconducting transition is detected at a remote ferromagnet, through a change in its anisotropy field, chosen as an Editor's Suggestion in Phys. Rev. B [3]. Using the same cavity-coupling mechanism, we showed that circularly polarized light gives a dichroic response when the cavity contains a spin-split material, which may be used as a novel way to estimate a material's exchange splitting in equilibrium [4].

I had the honour of giving a keynote presentation at the international conference of the Grete Hermann Network for women in condensed matter physics, held in Würzburg, Germany. With a great lineup of inspiring speakers and featuring fascinating condensed matter projects, the conference stood out for its exceptionally engaged and enthusiastic audience, with great questions and discussions. As a member of the QuSpin Balance Project Group, I also helped report on our activities in diversity training and awareness, and look forward to continuing that important work in 2024.

Our group enjoyed visits from prominent scientists, with stimulating discussions with Norman Birge, and PhD opponents Paola Gentile and Denys Makarov. It was a joy to attend Tancredi Salamone's defence, a crowning achievement after three years of dedicated work. We also congratulate Eirik Høydalsvik and Magnus Skjærpe on successful Master's theses, and we welcome three new students to the group: Henrik Kaarbø, Maxim Tjøtta and Kjell Heinrich.

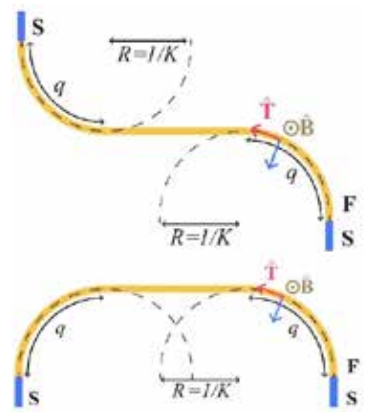


Illustration: Comparing mixed-chirality junctions with non-constant geometric curvature [1]. Fig. by A.J.Skarpeid.

[1] Skarpeid, A.J. et al, J.Phys.:Condens.Matter. 36, 235302 (2024). [2] Salamone, T. et al, PRB 109, 094508 (2024). [3] Janssønn, A.T.G. et al, PRB 107, 035147 (2023) [Editors' Suggestion]. [4] Hugdal, H.G. et al, arXiv: 2401.01929.

Website: sites.google.com/view/soljacobsen
X/Twitter: @SpintronicMum

ALIREZA QAIUMZADEH

Emergent Phenomena in Quantum Matters

Theme and goal

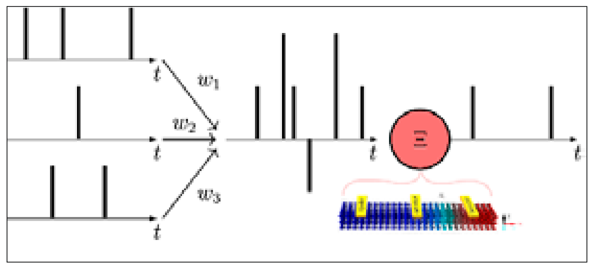
Our group conducts basic research over a wide swath of theoretical condensed matter physics, including *quantum spintronics and magnetism* (topological magnetic textures, superconducting spintronics, and neuromorphic spintronics); *quantum transport phenomena; topological phases of matter and quantum matter; ultrafast and nonequilibrium phenomena;* and *quantum field-theory of many-body systems.* Our goal is to understand and engineer emergent and exotic phenomena in novel quantum materials, such as 2D magnetic and topological materials. We are interested in investigating potential applications of these phenomena in quantum technology. Novel quantum materials have interesting, exotic behaviours. For example, in 2D systems, quantum fluctuations and interactions are usually strong and cannot be neglected, whereas in novel 3D topological materials, like Weyl and Dirac semimetals, emergent low-energy massless quasiparticles provide a testbed for investigating new phenomena beyond conventional relativistic quantum field theory and the Landau Fermi liquid paradigm. Developing theories to predict and explain exotic equilibrium and nonequilibrium states of novel quantum materials with an ultimate application beyond the state-of-the-art quantum devices is among our goals.

Key questions

Interplay between spin, charge, orbital, and lattice degrees of freedom; hybridization and scattering between different quasiparticles and collective excitations such as magnons, spinons, phonons, and plasmons lead to emerging phenomena. Microscopic understanding of these phenomena is a challenging problem in theoretical physics for which we need to develop and apply sophisticated analytical and advanced numerical techniques. We are interested in studying the effect of quantum and thermal fluctuations by stabilizing different topologically nontrivial magnetic phases and exotic spin, charge, and orbital transport in novel quantum systems.

Activity in 2023

In 2023 we published 11 papers. We continued our collaboration with A. Brataas as our main internal collaborator and several other world-leading experimental and theoretical groups. In collaboration with the experimental group of K. Ando in Japan, we found emergence of tunnelling spin-orbit torques at magnetic-metal/semimetal heterojunctions (Nat. Commun.). In collaboration with our master student T. Ballestad, and A. Cortijo and M. Vozmediano in Spain, we proposed a method to investigate quantum conformal anomaly in tilted Weyl semimetals (PRB). In collaboration with J. Linder's group, we introduced a formalism to describe transport in dirty superconductor-antiferromagnet junctions (PRL and PRB). In another achievement, our PhD Candidate V. Brehm uncovered the underlying mechanism of spin transport in easy-plane antiferromagnetic insulators based on coherent beating oscillation mechanism (PRB). We have proposed a non-volatile leaky integrate-and-fire neuron based on antiferromagnetic domain walls in collaboration with our master student J. Austefjord (Sci. Rep.). Our former Postdoc M. Barbeau has, in collaboration with M. Katsnelson and M. Titov in the Netherlands, developed a new quantum kinetic formalism for nonthermal magnons generated by hot electrons in an antiferromagnetic metal under strong laser irradiation (PRR Letter). In collaboration with our MSc student, J. Kløgetvedt, we investigated topological magnon-polarons in 2D systems. Together with our Polish collaborators, under the 2Dtronics project, we proposed mechanisms for magnon-plasmon hybridizations (PRB) and tuning spin interactions (Sci. Rep) in 2D magnets. In another work, we have proposed a mechanism for generating the bilinear planar Hall effect in topological insulators (PSS-RRL).



Schematic of a spiking neural network. A leaky integrate-and-fire neuron, Ξ, receives input spikes from several presynaptic neurons. We model Ξ by an antiferromagnetic domain-wall. [Sci. Rep. 13, 13404 (2023)]

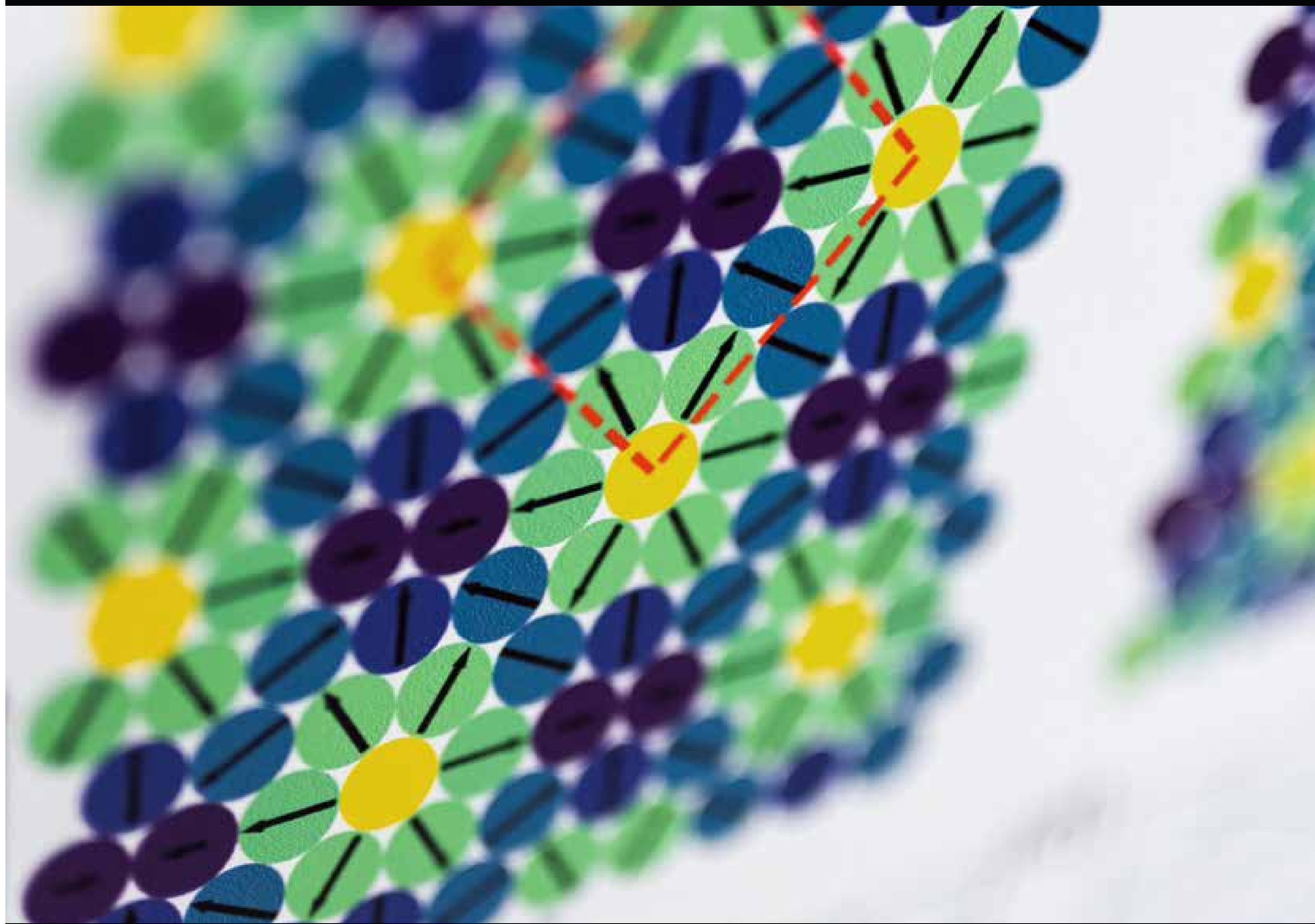


Photo from an illustration by Kristian Mæland from one of our featured articles.

International Partners and Research Network

We are continuing the long-term collaboration with our Co-Principal Investigators and their groups, Professor Mathias Kläui at the Institute of Physics at Johannes Gutenberg University of Mainz in Germany, and Professor Rembert Duine at the Institute for Theoretical Physics at the University of Utrecht in the Netherlands.

Professor Mathias Kläui

Professor Mathias Kläui is a leading experimental scientist, and a Professor II at QuSpin. A central theme of the collaboration has been spin transport in antiferromagnetic insulators, where we have established fruitful synergies between experimental and theoretical developments. Combining the work of young and dynamic experimentalists in Trondheim and Mainz, with the support of our excellent theory activity, QuSpin is taking its experimental activity to the next level. In particular, the collaboration with JGU Mainz gives QuSpin access to state-of-the-art materials growth, characterization and transport measurements. Recently, exciting predictions on magnetic 2D materials have been corroborated in joint activities between Mainz and Trondheim. To strengthen our collaboration, joint PhD work where one student from Mainz will spend some time in has recently been initiated with further support from a recently started EU project between QuSpin members in Trondheim and Mainz.

Professor Rembert Duine

Professor Rembert Duine is a leading theoretician scientist in the quantum many-body physics of spin transport and spin excitations, and a Professor II at QuSpin. Landmark publications by Rembert Duine and his collaborators have led to the opening of new subfields of physics, such as magnetic skyrmion spintronics, antiferromagnetic spintronics, and cold spintronics. The insights gained in these developments give QuSpin complementary expertise in theoretical developments on magnetic insulators and topological matter. Most of the collaborations over the past year have focused on quantum magnonics, involving also the group of Professor Kläui, and on interactions in ultrapure conductors.

The QuSpin Center is grateful for its opportunities to host visiting researchers that allow for interactions on a personal level, bolstering the professional work and exposure to new, ongoing, and past projects. In addition, we collaborate with internationally leading theoretical and experimental groups in many places around the world (See map next page).

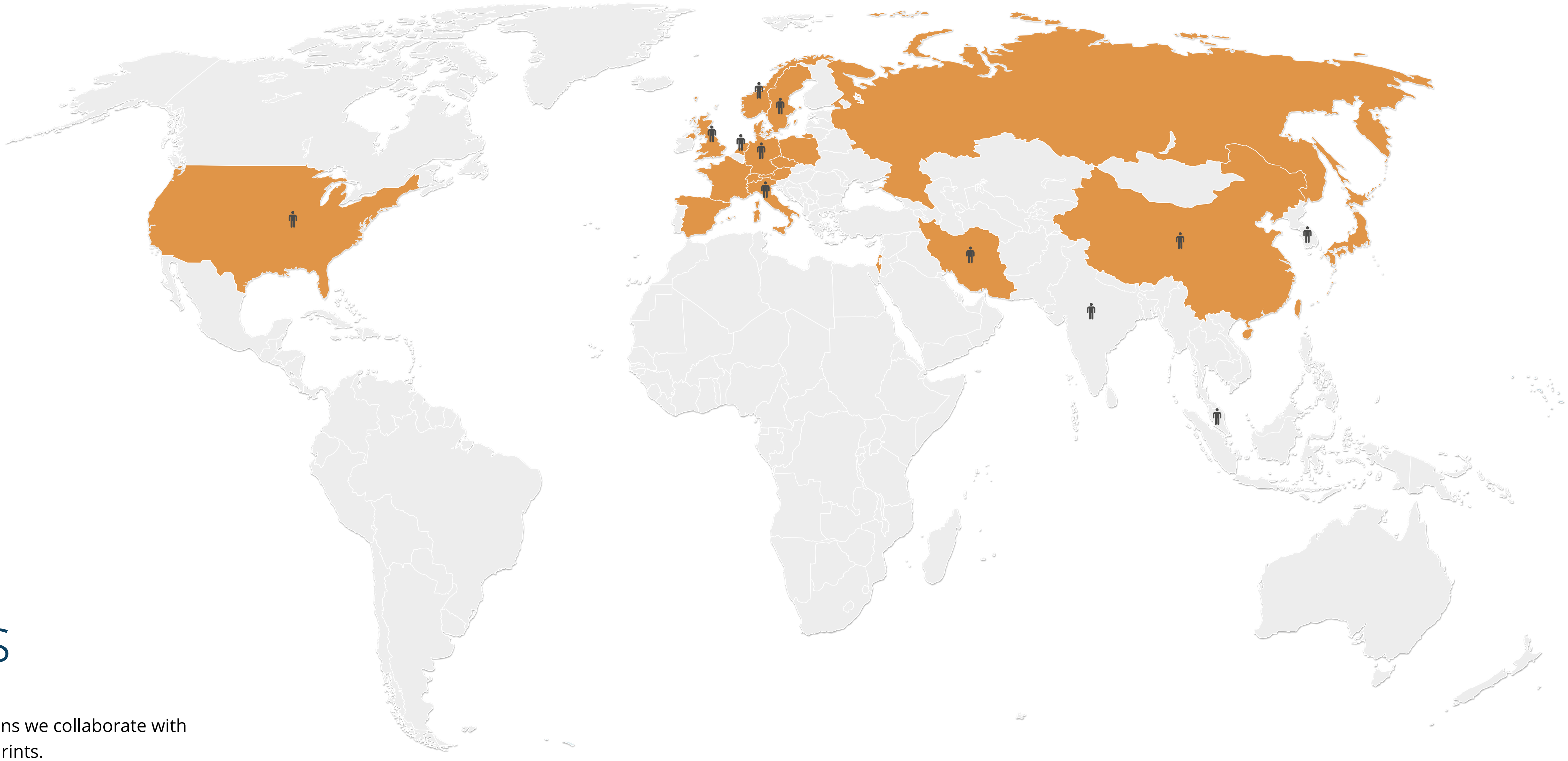
THE RESEARCH TEAM OF PROFESSOR MATHIAS KLÄUI *is part of the Institute of Physics at Johannes Gutenberg-Universität Mainz with more than 50 faculty members and more than 300 members in total. The Kläui lab has 10 permanent staff and about 50 members including junior researchers and staff in total.*

THE GROUP OF PROFESSOR REMBERT DUINE *at the Institute for Theoretical Physics (ITP) is part of the Department of Physics, at the Science Faculty at the Utrecht University. The ITP hosts over 10 faculty members and 70 members including junior researchers in total. Professor Duine's group has one permanent staff, one Postdoc and 4 PhD candidates, as well as master and bachelor students.*

Countries with collaborators

Nationality of our staff members

China	Norway
Germany	South-Korea
India	Sweden
Iran	The Netherlands
Italy	United Kingdom
Malaysia	USA



Collaborators

The list below is an overview of the institutions we collaborate with as co-authors on published papers and preprints.

AUSTRIA
Graz University of Technology, Graz

CHINA
Central South University, Changsha
China Academy of Engineering Physics, Beijing
Chinese Academy of Sciences, Beijing
University of Chinese Academy of Sciences, Beijing
Beijing University of Technology, Beijing
Southern University of Science and Technology, Shenzhen
Shenzhen University, Shenzhen

CZECH REPUBLIC
Czech Academy of Sciences, Prague

DENMARK
University of Copenhagen, Copenhagen

FRANCE
Nancy Universitè, Nancy
Universite Grenoble Alpes, Saint-Martin-d'Hères
Universite Paris-Saclay, Saint-Aubin
Université de Strasbourg, Strasbourg
Unité Mixte de Physique CNRS/Thales, Palaiseau

GERMANY
Fritz-Haber-Institute of the Max-Planck Society, Berlin
Johannes Gutenberg University Mainz, Mainz
Karlsruhe Institute of Technology, Karlsruhe
Leibnizs Institute, Dresden
TU Kaiserslautern, Kaiserslautern
Technical University of Munich, Munich
University of Augsburg, Augsburg
University of Cologne, Cologne
University of Konstanz, Konstanz
University of Regensburg, Regensburg
University of Würzburg, Würzburg
Walther Meissner Institute for Low Temperature Research, Munich
University of Kiel (Germany)
Deutsches Elektronen-Synchrotron (DESY), Hamburg

HONG KONG
The Hong Kong Polytechnic University, Hung Hom, Kowloon

IRAN
Institute for Research in Fundamental Sciences, Teheran
Institute for Advanced Studies in Basic Sciences, Zanjan

ISRAEL
Hebrew University of Jerusalem, Jerusalem

ITALY
University of Genova, Genova
Universitá di Milano-Bicocca, Milan
University of Salerno, Fisciano
University of Bologna, Bologna

JAPAN
RIKEN Center for Emergent Matter Science, Saitama
Keio University, Tokyo

NORWAY
University of Oslo, Oslo

POLAND
Polish Academy of Sciences, Warzaw
Adam Mickiewicz University, Poznań

ROMANIA
Technical University of Cluj-Napoca, Cluj-Napoca

RUSSIA
Russian Academy of Sciences, Moscow

SPAIN
Instituto de Física Fundamental, Madrid
Donostia International Physics Center, Donostia-San-Sebastian
Universidad Autónoma de Madrid, Madrid
Instituto de Ciencia de Materiales de Madrid (CSIC)

SWEDEN
KTH Royal Institute of Technology, Stockholm
Uppsala University, Uppsala

SWITZERLAND
ETH Zürich, Zürich

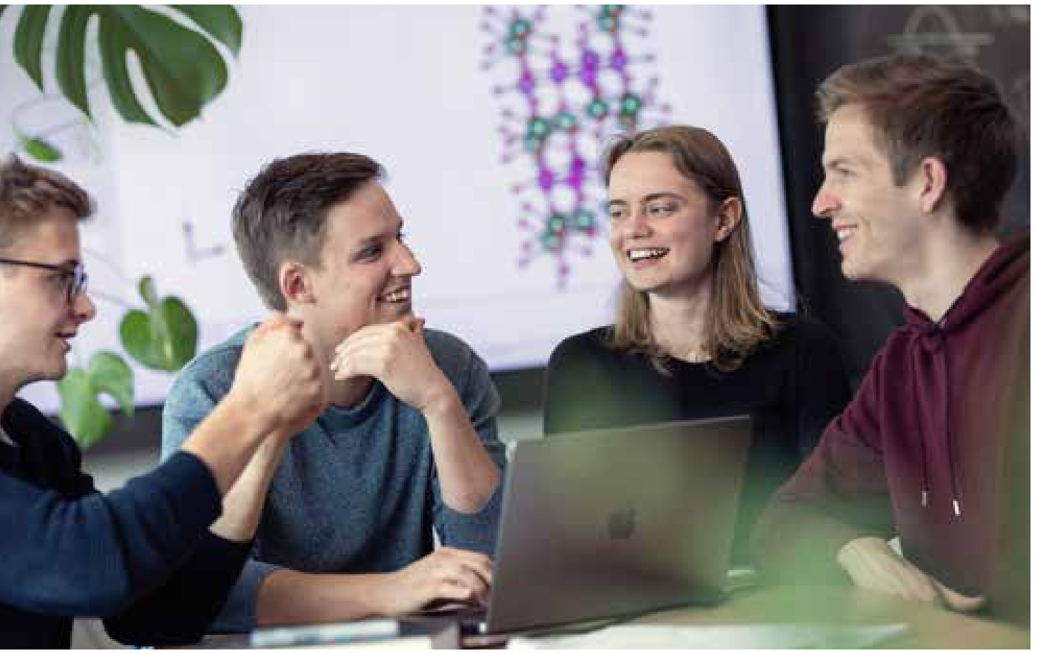
THE NETHERLANDS
Radboud University, Nijmegen
Utrecht University, Utrecht
University of Groningen, Groningen

UK
Cambridge Graphene Centre, Cambrigde
Hitatchi Cambridge Laboratory, Cambrigde
Loughborough University, Loughborough
University of Cambridge, Cambridge
University of York, York
Swansea University, Swansea
University of Central Lancashire
University of Edinburgh

USA
Cubic Carbon Ceramics, Huntingtown
Harvard University, Cambridge, MA
University of California, Riverside
University of California, Berkeley
University of Central Florida, Orlando
University of Chicago, Chicago
Massachusetts Institute of Technology, Cambridge
University at Buffalo, State University of New York
National High Magnetic Field Laboratory, Tallahassee

Research Training of our PhD candidates and Postdocs

We wish to train the next generation of researchers within our field so that they can take on leadership for new projects of their own, s well as gain experience by co-supervising our PhD candidates and Master's students.



Glimpses from various collaboration settings at our center.

We give a range of workshops and seminars at the Center. At the seminars the speakers present their work, share ideas and discuss the challenges they face. Our regular Journal Club provides training in presenting a scientific article and its essence for discussion. These are valuable experiences in the process of their work and in writing articles for publication as well as giving talks at international conferences and workshops.

In addition, guest researchers are giving interesting talks. This gives an opportunity to extend our understanding of ongoing work by colleague researchers and opportunities for fruitful collaborations.

We also have a self-organized Idea Forum for the younger researchers, where projects, ideas, and research challenges are shared, stimulating collaboration across both the theoretical and experimental fields, as well as between PhD candidates, Postdocs and researchers.

The professors' teaching, supervision, and curriculum is still the primary source for each PhD candidate research training. However, we see that all the other activities have a significant added value.

The QuSpin Mobility Grant

Encouraging our PhD candidates to seek international research experience, broaden their cultural outlook and extend their network.

In 2022 we established the QuSpin Mobility Grant which our PhD candidates can apply for in connection with research stays abroad if their application provides a clear explanation on how the research stay will benefit their current project and QuSpin.

The purpose of this grant is to learn and transfer research methods or techniques relevant to the project and QuSpin as a whole. We emphasize that these research stays should create stronger professional relationships between the host, the PhD candidate and QuSpin, and that it should result in a joint publication.

The grant will typically cover travel and accommodation costs. Candidates can apply for financial support for up to three months for a research stay. After the completion of the research term the applicant is required to present findings and experiences during the annual research conference. In addition, a presentation will be required at the Center and on our webpage.

PhD candidates to receive this grant 2023-2024
In September 2023 two candidates applied and received this three-months mobility grant. PhD Candidate Stefanie Brinkman will during spring 2024 have a research stay at the Hiroshima Synchrotron Radiation Center (HiSOR) at the Hiroshima University, Japan. And PhD Candidate Jacob Daniel Benestad will have a research stay during late summer 2024 in Prof. Ferdinand Kuemmeth's group at the University of Copenhagen, Denmark.

PhD Candidate
Stefanie Brinkmann off to Japan.

PhD Candidate
Jacob Benestad off to Denmark.

Photo from the ARPES lab showing a detail in the instrument.

In September, we arranged our second three-day internal collaboration workshop. It was a kick-off for our research activities for 2024-2027.

International Collaboration Workshop

We opted once more for Bjerkeløkka Conference Center at Oppdal, a two-hour drive south of Trondheim. The place is rich in traditional architecture and local food, and offers a relaxed atmosphere for formal and informal interaction and dialogue. There were forty participants from QuSpin, Trondheim, and our partners in Mainz and Delft, as well as an Advisory Board member.

Our focus was on generating new ideas and collaboration between theory and experimental research activities that will generate publications in leading scientific journals. We arranged speed clobbering sessions on the following research themes: Dissipationless Quantum Spin Transfer, Quantum Spin Dynamics, and Spin and Topology, followed up by parallel workshops. During in-depth discussions, several new ideas for collaborative projects were born, and we exchanged ideas on how to prioritize future work.

In addition to the intensive scientific work, we had a great time with various activities. We went mountain hiking in the warm autumn weather, and the evenings were spent playing various games, having relaxed conversations and fun. The Northern lights on the dark evening sky added a magical touch to our stay.

QUSPIN COLLABORATION WORKSHOP 2023

Here are some glimpses from the workshop showing our researchers at work as well as enjoying social activities.












QuSpin Balance Project Film

Sharing learning experiences from the QuSpin Balance Project 2021-2022. The project was funded by RCN as part of the RCN Balance Program on "How to get more females into top positions in Academia. About Gender Balance and Diversity".

This article is facilitated and edited by Karen-Elisabeth Sødahl.

Project Background
We hold a diverse Center of permanent and temporary research positions with people from twelve different countries, from various walks of life and cultures. But female researchers are totally absent from permanent positions as professors and associate professors. In other words, our Center is strongly male-dominant, setting the premises for our leadership, strategy, research, culture and recruitment. The permanent top positions are few and the competition and qualification requirements tough.

We want to change this situation. Our goal is for 1/3 of all new recruitment to be females. We need to understand what hinders this today and how to reach this goal in the future. It is necessary to analyze today's situation, and work on change processes to raise everyone's awareness, clarify requirements and expectations, and take specific measures on all levels in QuSpin, for females and males alike.

We need more female candidates and applicants, and we need to understand how we can make an academic career more attractive. We have several female researchers with the competence and personnel skills whom we want to help qualify for future top positions. To further develop their careers towards top positions, their competence as well as individual skills and mentoring are important tools. We want to actively communicate and share experiences from our project.

Project Activities
We have performed a range of activities, taking experience and learning from each activity into the next:
- Internal Survey on Gender Balance and Diversity
- In-depth Dialogue and Interactive Workshops
- International Mentor Group, Mentoring and Recommendations
- QuSpin Cafés for Recruiting Female Students
- A course, a seminar and several ad-hoc activities

Results
QuSpin has moved from having 1 female PhD candidate to 6, from 1 female Postdoc to 2, plus 1 female senior researcher (2017-2022). And through this project we have, for the first time in our history, achieved having had 50% female master students, equivalent to 8 female students out of a total of 16 students (2022).

QuSpin wants to build on the experiences from the Balance Project and continue the work for increased gender balance and inclusion.

Launching a film in 2023 sharing some important learning experiences
In addition to publishing a glossy report with detailed information from this project, we saw the potential of a short film for reaching a wider audience both internally at QuSpin, and more broadly at NTNU, the RCN and others interested in the development for change.

Below, project group members, mentors, and mentees in our project share learning experiences and reflections.

Raising the awareness
"Diversity and gender balance is important in Academia to reflect the whole society in finding solutions. At QuSpin we have zero female professors and associate professors, and we want to change this. This was our motivation for joining the Balance Program of the Research Council of Norway. The participation was supported by the whole leader group", says Project Manager/Center Coordinator Karen-Elisabeth Sødahl.

"We experience built-in biases within our society and within the culture of our field, and that is something we somehow need to correct. So of course we would like to attract more female students to our field, and to QuSpin, to get more diversity, to get more different kinds of ideas, but also to create a completely different social environment", says Project Owner/Professor Arne Brataas.

Female researchers at QuSpin. From left: Atousa Ghanbari (PhD Candidate), Payel Chatterjee (PhD Candidate), Lina Grøvan Johnsen (PhD Candidate), Verena Brehm (PhD Candidate), Marion Barbeau (Postdoc), Anna Cecilie Åsland (PhD Candidate) and Dr. Sol H. Jacobsen (senior researcher). Postdoc Chi Sun and PhD Candidate Therese Frostad were not present when the picture was taken.

QUSPIN BALANCE PROJECT GROUP

Center Director/Professor Arne Brataas
(project owner, QuSpin/NTNU)

Center Coordinator Karen-Elisabeth Sødahl
(project manager, QuSpin/NTNU)

Principal Investigator/Professor Asle Sudbø
(QuSpin/NTNU)

Professor Vivian Anette Lagesen
(Department of Interdisciplinary Studies of Culture/NTNU)

Principal Investigator/Professor Jacob Linder
(QuSpin/NTNU)

Senior Researcher Dr. Sol H. Jacobsen
(QuSpin/NTNU)

MENTORS

Professor Jason Robinson
Cambridge University, UK
(Chair QuSpin Advisory Board)

Professor Daniela Pfannkuche
Hamburg University, Germany
(Member QuSpin Advisory Board)

Professor Siri Fjellheim
Norwegian University of Life Sciences, Norway

Professor Kathrine Røe Redalen
Department of Physics, NTNU, Norway

Leadership coach/therapist Signe Johanne Haver
3B, Norway

MENTEES

Senior researcher Sol H. Jacobsen
(QuSpin/NTNU)

Postdoc Chi Sun
(QuSpin/NTNU)

Postdoc Marion Barbeau
(QuSpin/NTNU)

PhD Candidate Payel Chatterjee
(QuSpin/NTNU)

PhD Candidate Lina Johnsen Kamra
(QuSpin/NTNU)

PhD Candidate Atousa Ghanbari
(QuSpin/NTNU)

"There's something called unconscious bias. And this is, of course, not only true in grading, but it is also true in choosing people for a job. We cannot deny that they still have a steeper path to go", says Mentor/Professor Daniela Pfannkuche, "Equal opportunities does not necessarily mean equal treatment. For me it is always a lot of fun because it is so interesting to work with young, female researchers".

And Project Member/Professor Jacob Linder shares his thoughts; "If all female physics students at NTNU see during their years of studies are males lecturing, giving talks, getting attention for their research results, and being promoted in the media, it is natural that they're going to think: Is there really a place for me as a woman in physics?. So we need to take the female researchers we already have and lift them up and show them off. Listening to how female researchers experience interactions with male researchers in academia was really useful for me. It opened my eyes to some things that I hadn't thought about".

And "Listening to people and hearing their stories and what they are concerned about is always an eye opener. Let's say a refresher, it reminds you to be open-minded to people's needs", says Project Member/Professor Asle Sudbø. "What we saw is that we needed to increase the recruitment of female master's students, PhDs and postdocs and to help them qualify to apply for permanent positions", says Karen-Elisabeth Sødahl.

Mobilizing for change
"Overwhelmingly I think everybody here has a good experience of the work environment. But that's not to say that there aren't differences in how groups interact", says Mentee/Project member/Senior Researcher Sol Jacobsen. "The work of the Balance Project is trying to gently show those who are not aware, how it can be perceived from people on the outside. For me the biggest take-aways from it, were where we created these spaces to share experience and learn from each other".

"I came to Academia with hopes that everybody was equal, and everything was just judged on performance alone, but that is not the case", says Mentee/Postdoc Marion Barbeau. "We all knew about this problem, but I don't think we had much of a dialog about it", says Mentee/PhD Candiate Payel Chatterjee. And she continues, "My initial motivation to choose physics was that I wanted to be a scientist. I wanted people to call me a scientist. I realized that I really love magnetism and that I really love spending time in the lab. I found this position here, which was very relevant to the work I was doing back in India".

"The most important criteria for getting a permanent position have to be hard work, publishing good research, being an excellent educator and speaker, and especially not least networking, getting the right connections", says Professor Jacob Linder. "I think perhaps one of the key challenges women face in science is the lack of other women they can closely interact with", says Mentor/Professor Jason Robinson.

In addition to these challenges, Project Member/Professor Vivian Lagesen adds, "I think many leaders will welcome more knowledge and more input about how they should go about to do diversity management, because it is not given. It's not something that everyone knows, it's not necessarily intuitive".

Mentoring female researchers in temporary positions
"We launched something similar in Cambridge, but it is more low-key. QuSpin was very deliberately targeting international mentorship, which I think is a really amazing opportunity both for the individual, and of course for the mentee", says Professor Jason Robinson.

"There is a lot to gain from being a mentee. And even if you don't learn that much, it is still good to give it a try. It's worth it, like for developing connections. One can discuss with someone who already knows a lot about the industry or knows a lot about academia", says Postdoc Marion Barbeu.

And she continues, "My mentor gave me a lot of incredibly useful advice on how to handle some situations. These mentoring sessions have been greatly valuable for me. Thanks to her, my transition from academia to the research industry was much smoother and exciting".

"I think the most I got out of it for my career is the advice that you don't usually get from anyone around you - concrete advice on what I should do and when I should do it", says Mentee/PhD Candidate Lina Johnsen Kamra, "I got a lot out of this. I held my first invited seminar for the "Oxide Superspin International Network" which is a collaboration between several universities in the UK, Italy, Japan, and South-Korea. I also got the opportunity to visit Jason Robinson's group in Cambridge and take part in interesting discussions. Thank you to the Balance project for opening these opportunities for me".

"My mentor Daniela is a lovely person. She was very supportive and she is also from a different country, and she gave me a broader perspective about what it is to work in academia. She introduced me to other female researchers working in the same field", says PhD Candidate Payel Chatterjee, "I hope that in the future other researchers also will get the benefit of this program".

Development for change
"We think it's important to continue the activities from the Balance Project, to increase the diversity and gender balance within physics. This requires having a safe space for dialog, interaction and inclusion. Having arenas where we specifically discuss these types of issues is important in that work", says Center Coordinator Karen-Elisabeth Sødahl, "In addition, we would like to see gender balanced recruitment committees and training of leaders and supervisors in diversity and gender balance competence".

"But it doesn't help to only increase the number of doctoral students. You have to increase the number of postdocs, and you have to increase the number of female professors", Professor Daniela Pfannkuche points out.

"The is a gap between postdoc and associate professor, and there are no measures to cater to that group, and that's where we see people fall off", Senior Researcher Sol Jacobsen points out. "It is important to offer support to the temporary staff as well as professors on their career path".

"Focusing on gender balance in recruiting new students to the Center has had a very positive effect", says Professor Asle Sudbø, "I believe that this center does physics which can be of great societal impact, and we should therefore recruit students actively, in particular female students for the years ahead. If it turns out that we are losing 50% of the talents, because they think this is not interesting, we're making it difficult for ourselves".

"You can only really have a positive change if you have a constant dialog around these issues, such as mentorship, staff review and development", says Professor Jason Robinson, "If you could have that pool of alumni that are willing to support your current staff or students for mentorship, then that's a great opportunity, both for you as an institution and most certainly for your staff".

"We shouldn't underestimate the amount of effort that is necessary to succeed with such a project because there are no quick fixes", says Professor Vivian Lagesen. "And there is still some work to be done for sure, but it seems that we're going on the right path", Postdoc Marion Barbeu concludes.

Read more about the project and see the whole film @ https://www.ntnu.edu/quspin/quspin-balance-project1

Glimpses from Our Center

Diversity leadership is about the strength we find in our differences and fostering that potential.

Our Center's researchers have their roots in twelve different countries. They come from various walks of life, cultures, and ethnicities. They speak a variety of languages and are of diverse genders.

We spend time and resources on developing a prosocial and robust culture. We build arenas where people can meet, create, and interact. We also arrange cafés for younger female students to attract more of them to write their project or master thesis at our Center. We are also fortunate to have had Phd candidates presenting our Center and researchers to curious students visiting NTNU's Researchers Night and to a school class visiting from Ole Vig's High School, situated close to Trondheim.

We seize every opportunity to have social gatherings, celebrating successful publications in the Physical Review Letter (PRL), various holidays, as well as wishing good colleagues and friends all the best on their journey to the next phase in their careers, i.e. master's students and PhD candidates moving on to positions within academia, the industry, research institutes or the public sector.

Like every year, we welcomed the summer season with a game of boccia in the center coordinater's garden before moving on to Lille-Skansen restaurant by the fjord. In December we celebrated our great scientific work and results of the year with a nice dinner at the historical Tavern restaurant.

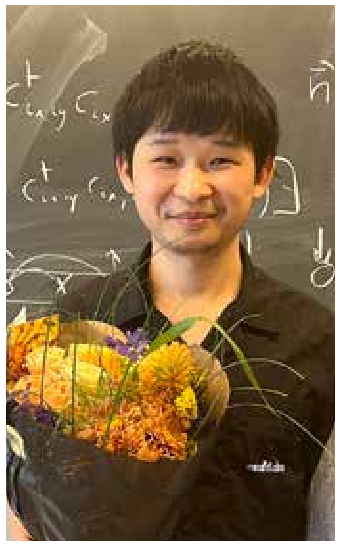
This year, the PhD Candidates Kristian Mæland, Anna Cecilie Åsland and Verena Brehm were awarded QuSpin Diplomas. The diploma is a recognition of effort at the Center for scientific and social contributions to our working culture:

Honoring PhD Candidate Kristian Mæland for publishing outstanding research in PRL, getting media coverage through APS Physics and Editors' Suggestion, generously giving his time to assist others at QuSpin with his expertise, and for taking on research problems of substantial complexity.

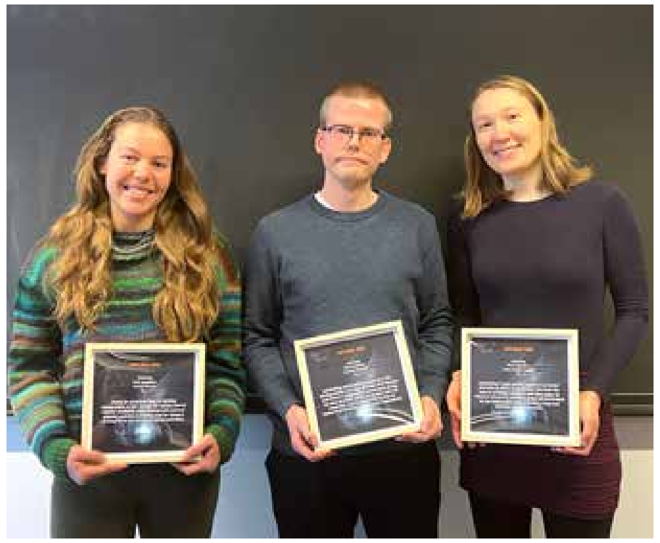
Honoring PhD Candidate Anna Cecilie Åsland for publishing five high-quality papers in premier journals in 2023. She particularly took the lead in writing a complex and long paper in Physical Review B, showing great perseverance as the corresponding author during a long and arduous referee process.

Honoring PhD Candidate Verena Brehm for being an excellent host for visiting researchers at our Center, for taking care of master's students, contributing with several popular science activities, and for being a driving force for inclusive social activities.

We also had the pleasure of welcoming three new PhD Candidates: Sondre Duna Lundemo, Johanne B. Tjernshaugen, Anders Christian Mathisen, Postdoc Morten Amundsen and guest researcher Xin Tan starting his postdoc position in 2024. We hope that our newcomers feel welcome, and that all our colleagues thrive in our research environment, and we are very happy that initiatives for social interaction and fun are being taken outside of QuSpin as well.




Some glimpses from various activities like guest seminar, school visit presentations, farewell gathering for Postdoc's, celebrating a PhD defense, QuSpin Awards recipients, bocchia game, and relaxed scientific discussion on our balcony.

PhD Defenses and Completed Master Theses

We congratulate our PhD candidates who successfully completed their defenses and our Master's students who completed their theses. We wish them all the best in the next phase of their journey!

COMPLETED PHD'S

Fyhn, Eirik Holm. PhD Defense August 11th, 2023. Title: *Green's Function Approach to Quantum Phenomena in Heterostructures with Spin-Polarization and Coherence.*
Supervisor professor Jacob Linder. Co-supervisor Justin Wells.

Haugen, Håvard Homleid. PhD Defense February 24th, 2023. Title: *Monte Carlo studies of phase transitions in unconventional and two-dimensional superconductors.*
Supervisor professor Asle Sudbø. Co-supervisor professor Jeroen Danon.

Kamra, Lina Johnsen. PhD Defense June 29th, 2023. Title: *Proximity effects, spin transport, and phase transitions in superconducting hybrids.*
Supervisor professor Jacob Linder. Co-supervisor associate professor John Ove Fjærestad.

Lidal, Jonas. PhD Defense September 7th, 2023. Title: *Hybrid devices for protected quantum information processing.*
Supervisor professor Jeroen Danon. Co-supervisor professor Arne Brataas.

Salamone, Tancredi. PhD Defense September 22nd, 2023. Title: *Proximity effects in nanostructures with geometric curvature for superconducting spintronics.* Supervisor Dr. Sol Jacobsen. Co-supervisor professor Jacob Linder.

COMPLETED MASTER THESES

Abnar, Sara. Title: *Magnon-Mediated Superconductivity: Investigating the Emergence of Strong Topological Superconductivity Mediated by Magnons in a Coplanar, Non-Collinear Magnet.* Professor Asle Sudbø.

Aunsmo, Sigrid. Title: *Supercurrent Induced Proximity Effects at Spin-Orbit Coupled Interfaces.*
Supervisor: Professor Jacob Linder.

Beronio, Ellaine R. A.. Title: *Plasmons and Magnons in Antiferromagnetic FeSn: A Time-Dependent Density Functional Theory Study.*
Supervisor: Senior researcher Alireza Qaiumzadeh.

Ekrheim, Stine. Title: *Ginzburg-Landau Theory for Charge Density Waves and Superconductivity.* Professor Asle Sudbø.

Falch, Håvard. Title: *Paramagnetic Meissner Effect and Non-Equilibrium Vortices in Superconductor/Normal-Metal Structures.* Supervisor: Postdoc Jabir Ali Ouassou.

Høydalsvik, Eirik Jaccheri. Title: *Circular dichroism in cavities coupled to ferromagnetic metals and superconductors.*
Supervisor: Senior researcher Sol Jacobsen.

Kløgetvedt, Jostein N. Title: *Topological Magnon-Phonon Hybrid Excitations and Hall Effects in Two-Dimensional Ferromagnets.* Supervisor: Senior researcher Alireza Qaiumzadeh.

Kristoffersen, Anne Louise. Title: *Magnon Condensation in Magnetic Insulators.* Supervisor: Senior researcher Alireza Qaiumzadeh.

Lind-Olsen, Jesper. Title: *Topological Transport Properties of Non-Abelian Magnons in a Spiral Phase Ferromagnetic Insulator.*
Supervisor: Senior researcher Alireza Qaiumzadeh

Lundemo, Sondre Duna. Title: *The Effective U(1)×O(3) Theory of Superconductivity and Antiferromagnetism - Derivation and Critical Properties.*
Supervisor: Professor Asle Sudbø.

Lyngaas, Jens A.. Title: *Neuromorphic computing with ferromagnetic nano-oscillators.*
Supervisor: Senior researcher Alireza Qaiumzadeh

Roheim, Marthe Elise Fiskarstrand. Title: *Ginzburg-Landau Theory for Charge Density Waves and Superconductivity.* Supervisor: Professor Asle Sudbø.

Rørbakken, Øyvind B. Title: *Second order coherence of squeezed magnons in a thermal environment.*
Supervisor: Senior researcher Alireza Qaiumzadeh.

Skjærpe, Magnus Svenøy. Title: *Superconducting Proximity Effects in Diffusive, Curved Antiferromagnet.*
Supervisor: Senior researcher Sol Jacobsen.

Tietjen, Finja. Title: *RKKY Interaction in Unconventional Superconductors.* Supervisor: Professor Jacob Linder.

Tjernshaugen, Johanne Bratland. Title: *Beyond the Chandrasekhar-Clogston limit in a spin-split superconductor driven out of equilibrium by a spin-accumulation.*
Supervisor: Professor Jacob Linder.

Sol H. Jacobsen and Tancredi Salamone.

Håvard Homleid Haugen and Asle Sudbø.

Jacob Linder and Eirik Holm Fyhn.

Jeroen Danon and Jonas Lidal.

Lina Johnsen Kamra and Jacob Linder.

Some of our master students celebrating having received their Master's degree.

Honors and Grants

We had a great year with several honors and grants to our researchers. We highly appreciate the acknowledgment of our colleagues work, and the opportunities this represents for the further development of our center.

EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME

Our QuSpin members Professor Dennis Meier and Professor Mathias Kläui have initiated a network of leading European groups from different disciplines and sectors to provide comprehensive training on the integrative concepts underlying the science of topological solitons in ferroic materials and their application in unconventional computing.
The NTNU coordinated project **Topological Solitons in Ferroics for Unconventional Computing (TOPOCOM)** is funded via the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie action (Grant Agreement 101119608 – EU contribution € 2.683.972). European Partners involved are the Luxembourg Institute for Science and Technology, IBM Research Zurich, Singulus, University of Groningen, Johannes Gutenberg University Mainz, University of Crete, Infineon, and the University of Messina.

EMERGING LEADERS 2023

Senior researcher **Sol H. Jacobsen** has been chosen for Emerging Leaders 2023 by Journal of Physics: Condensed Matter.
JPCM represents the condensed matter physics community, and as such, they are publishing a special issue bringing together the best early-career researchers from all areas of condensed matter physics.
An emerging leader is defined as a top researcher who completed their PhD in 2013 or later (10 years excluding career breaks). A limited number of early career researchers have been nominated by the journal's Editorial Board as the most talented and exciting researchers in their generation.

ELECTED ORGANIZER

PhD Candidate Verena Brehm was elected organizer of the seminar series "*Spin dynamics In nanostructures*" at the Gordon Research seminar 2025 that is associated with the Gordon Research Conference with the same name.

IEEE FELLOW

Co-PI professor Mathias Kläui became an IEEE Fellow 2023 for his contribution to the next generation magnetic solid-state memory, logic and sensor devices.
The IEEE Fellow is one of the most prestigious honors of the IEEE, and is bestowed upon a very limited number of Senior Members who have contributed importantly to the advancement or application of engineering, science and technology bringing significant value to our society. The number of IEEE Fellows elevated in a year is no more than one-tenth of one percent of the total IEEE voting.

NORSK FYSISK SELSKAP AWARD

MSc graduate **Thorvald Ballestad** received 2023 **Martin Landrø's award for an excellent master's thesis** in physics from Norsk Fysisk Selskap. Thorvald finished his master's thesis spring 2022 under the supervision of Senior Researcher Alireza Qaiumzadeh at QuSpin. Title of the thesis is *Anomalous Thermoelectric Effect in Tilted Dirac and Weyl Semimetals: Contribution to the Nernst Effect from the Conformal Anomaly.*

BEST MASTER PRIZES AT THE FACULTY OF NATURAL SCIENCES, NTNU

Sondre Duna Lundemo received the prize for the best Master of Technology (teknologimaster) with the title *The Effective U(1)×O(3) Theory of Superconductivity and Antiferromagnetism - Derivation and Critical Properties.* And **Johanne Bratland Tjernshaugen** received the prize for best Master of Science (master i fysikk) with the title *Beyond the Chandrasekhar-Clogston limit in a spin-split superconductor driven out of equilibrium by a spin-accumulation.* The advisors have been the Professors Asle Sudbø (Sondre) and Jacob Linder (Johanne).

Talks and Presentations

One of our key goals is to make physics in general, and the research at our Center in particular, attractive to other researchers and students. And by sharing the work through accessible language and tangible examples, illustrating why our research is crucial and worth funding. This year our researchers were giving various talks and presenting posters, both locally and internationally.

JANUARY

Materials Chain Seminar Series - Materials and Energy. Challenges and Opportunities, Ruhr University Bochum (webinar), Germany.
Talk by Professor Dennis Meier. Title: *Ferroic domain walls for next-generation nanotechnology.*

FEBRUARY

University of Cambridge, UK
Guest talk by PhD Candidate Lina Johnsen Kamra.
Title: *Spin-triplet superconductivity: Controllable enhancement and coupling to magnon spin currents.*

MARCH

DPG Conference, Dresden, Germany.
Talk by Professor Dennis Meier. Title: *Ferroelectric and multiferroic domain walls for nanotechnology.*

DPG spring meeting Dresden, Germany.
Talk by PhD Candidate Verena Brehm. Title: *Impact of DM on magnonic antiferromagnetic leaky integrate-and-fire neuronal networks.*

Realfagsdagene, NTNU
PhD Candidate Verena Brehm and PhD Candidate Bjørnulf Brekke. Participants at the *Table of talk with PhD candidates within maths and physics.*

DPG Meeting, Dresden, Germany
Talk by PhD Candidate Niels Henrik Aase. Title: *Dominant superconducting correlations in a Luttinger liquid induced by spin fluctuations.*

German Physical Society The DPG Spring Meeting of the Condensed Matter Section, Dresden, Germany.
Talk by Senior researcher Alireza Qaiumzadeh.
Title: *Nonequilibrium Magnons from Hot Electrons in Antiferromagnetic Systems.*

German Physical Society The DPG Spring Meeting of the Condensed Matter Section, Dresden, Germany.
Talk by Senior researcher Alireza Qaiumzadeh.
Title: *Novel thermo-electric transport channel in the conformal limit of tilted Weyl semimetals.*

APS March meeting, Las Vegas, USA.
Talk by PhD Candidate Lina Johnsen Kamra. Title: *Magnon spin current induced by triplet Cooper pair supercurrents.*

Massachusetts Institute of Technology. Boston, USA
Guest talk by PhD Candidate Lina Johnsen Kamra.
Title: *Spin-triplet superconductivity: Controllable enhancement and coupling to magnon spin currents.*

APS March Meeting, Las Vegas, USA
Talk by PhD Candidate Kristian Mæland. Title: *Topological superconductivity mediated by magnons of a skyrmion crystal.*

APS March Meeting, Las Vegas, USA
Talk by PhD Candidate Bjørnulf Brekke. Title: *Interfacial Magnon-Mediated Superconductivity in Twisted Bilayer Graphene.*

APRIL

WE Hereaus Seminar (784) - Microstructure, Magnetic and Electric Ordering: Interplay and Interactions, Bad Honnef, Germany
Talk by Professor Dennis Meier. Title: *Emergent functional properties and advanced characterization of ferroelectric domain walls.*

EuroMBE2023, the ETSI de Telecomunicación (Telecommunication Engineering School), Universidad Politécnica de Madrid, Madrid (Spain)
Poster presentation by PhD Candidate Payel Chatterjee.
Title: *MBE growth of Fen Kagome lattice on GaAs (111) substrate.*

I0P Magnetism Manchester, United Kingdom.
Poster presentation by PhD Candidate Verena Brehm.
Title: *Non-volatile leaky integrate-and-fire neurons with domain walls in antiferromagnetic insulators.*

MAY

Nordita BalCon TP 2023, Stockholm, Sweden
Talk by Professor Asle Sudbø. Title: *Spin-fluctuations and unconventional superconductivity in heterostructures of magnetic insulators and gapless fermion systems.*

WE Hereaus Seminar (788) - Beyond Imperfection: New Structure-Property Relationships in Ceramics and Glasses, Bad Honnef, Germany
Talk by Professor Dennis Meier. Title: *Structure-property relations at charged interfaces in ferroelectric and multiferroic oxides.*

8th International Conference on Superconductivity and Magnetism, Fethiye, Turkey.
Talk by Senior researcher Alireza Qaiumzadeh.
Title: *Electrically Controlled Crossed Andreev Reflection in Two-Dimensional Antiferromagnets.*

JUNE

Materials for Neuromorphic Circuits (MANIC), Cambridge, UK.
Talk by Professor Dennis Meier. Title: *Ferroelectric domain walls - functional electronic properties and opportunities for unconventional computing.*

TNNN conference, Vestfold, Norway.
Talk by Professor Dennis Meier. Title: *Ferroelectric and multiferroic domain walls for nanotechnology.*

BalCon, TP, Dynamical and Hidden Orders. Nordita, Stockholm, Sweden.
Talk by Professor Asle Sudbø. *Title: Spin-fluctuations and unconventional superconductivity in heterostructures of magnetic insulators and gapless fermion systems.*

13th International Conference on Intrinsic Josephson effect, University of Glasgow, Scotland.
Talk by Professor Jacob Linder. Title: *Spin-polarized superconductivity in antiferromagnets and altermagnets.*

Max Planck Institute for the Structure & Dynamics of Matter, Munich, Germany.
Guest seminar by Postdoc Henning Goa Hugdal.
Title: *Superconductors in spintronics.*

JULY

Grete Hermann Network Workshop, Würzburg, Germany.
Talk by Senior researcher Sol H. Jacobsen.
Title: *New perspectives in combining superconductivity and magnetism for spintronics.*

GRS/GRC Spin Dynamics in Nanostructures Les Diablerets, Switzerland.
PhD Candidate Verena Brehm. Leader in Session *Spin Textures, Magnetism and Topology in Low-Dimensional Systems.* Poster: *Micromagnetic study of spin transport in easy-plane antiferromagnetic insulators.*

AUGUST

European Magnetism Association Joint European Magnetic Symposia (JEMS), Madrid, Spain.
Talk by Senior researcher Alireza Qaiumzadeh.
Title: *Magnon-Plasmon Hybridization Mediated by Spin-Orbit Interaction.*

Colloquium, Department of Physics and Astronomy,
Talk by Associate Professor Hendrik Bentmann.
Title: *Imaging topological quantum states by angle-resolved photoelectron spectroscopy.*

JEMS Madrid, Spain.
Poster presentation by PhD Candidate Verena Brehm.
Title: *Atomistic spin simulation of magnon dispersion relations and spin transport in Cris and Young.*
Researchers flash talk by PhD Candidate Verena Brehm.
Title: *A little story about Hall effects when they should not be there.*

SEPTEMBER

Researchers Night 2023 (Ungdommens forskernatt), NTNU, Trondheim, Norway
Associate Professor Hendrik Bentmann and his team participating with inviting students to the ARPES lab.
Title: *Kom og se hvordan vi jobber med kvantefysikk i lab'en vår på QuSpin. Der forsker vi på hvordan elektroner oppfører seg i nye materialer eller superledere gjennom å se på dette i mikroskop. Dette er viktig i utviklingen av nye energieffektive løsninger for et «grønnere» samfunn.*

EMRS Fall Meeting, Warsaw, Poland.
Talk by Professor Dennis Meier. Title: *Anti-polar order at domain walls in uniaxial ferroics.*

International Workshop on Quantum Magnonic Hybrid Systems, Korea (online).
Talk by Professor Asle Sudbø. Title: *Topological superconductivity mediated by quantum fluctuations in non-colinear spin states.*

Researchers' Night - Ungdommens forskernatt ved NTNU Trondheim, Norway.
PhD Candidate Verena Brehm. Stand: Outreach to pupils. Title: *Big brain time hierneinspirert databehandling.*

OCTOBER

Another physics is possible Uppsala, Sweden.
PhD Candidate Verena Brehm. Active participation workshop about *inclusive teaching and equity in physics didactics.*

NOVEMBER

MRS Fall Meeting, Boston, USA
Talk by Professor Dennis Meier. Title: *Structure-property relations at charged interfaces in ferroic oxides.*

Annual Conference on QUANTUM CONDENSED MATTER (QMAT2023), Bhubaneswar, India.
Talk by Senior researcher Alireza Qaiumzadeh. Title: *Magnon-plasmon hybridization in 2D magnetic systems.*

Workshop Soft X-ray Science at PETRA, DESY, Hamburg, Germany
Talk by Associate professor Hendrik Bentmann. Title: *Dichroism in soft X-ray photoemission: phase-sensitive contrast in topological quantum materials.*

School visit from Ole Vig's High School.
Talk by PhD Candidate Bjørnulf Brekke. Title: *Jakten på fremtidens materialer.*

Nordic UK Condensed Matter Seminar (online), Stockholm, Sweden/ London,UK.
Talk by Professor Asle Sudbø. Title: *Spin-fluctuations and unconventional superconductivity in heterostructures of unconventional magnetic insulators and gapless fermion systems.*

Nicolás Cabrera Colloquium Series, Frontiers in Materials Science, Madrid, Spain.
Talk by Professor Jacob Linder. Title: *Utilizing spin and orbital angular momentum with superconductors.*

Workshop on active learning Trondheim, Norway.
PhD Candidate Verena Brehm. Active participation workshop about *inclusive teaching and equity in physics didactics.*

DECEMBER

PetaSpin School, Messina, Italy.
Talk by Professor Dennis Meier. Title: *Non-collinear magnetism - from spin spirals to topological phenomena.*

Trinity College Dublin, Irland (virtual seminar).
Talk by Professor Jacob Linder. Title: *Combining superconductors and magnetic materials.*

KUJI QMAT Seminar Series, Japan/Korea/Italy (online)
Talk by Professor Jacob Linder. Title: *Interplay between superconductors and altermagnets.*

In the Media

GEMINI. JUNE 23, 2023.
Article by Jacob Linder, Asle Sudbø, Arne Brataas and Karen-Elisabeth Sødahl.
Title: *Kvantesensorer åpner nye muligheter på mange områder*.
English version: *Quantum sensors open up new possibilities in many areas.*

MORGENBLADET. AUGUST 2023.
Interview with Asle Sudbø. *Har LK-99, materialet som skulle forandre alt, rent bort i ingenting?*

NRK P2, AT 3.45 PM. AUGUST 14, 2023.
Interview with Asle Sudbø. *Har LK-99, materialet som skulle forandre alt, rent bort i ingenting?*

UNIVERSITETSAVISA. NOVEMBER 14, 2023.
Statement (ytring) by Sudbø,Asle; Arne Brataas; Jacob Linder and Hendrik Bentmann. *Nedleggelse av bachelorprogrammet i fysikk er destruktivt.*

MINERVA. NOVEMBER 21, 2023.
Feature with Asle Sudbø. *Fysikk foreslås erstattet med «bærekraft» på NTNU.*
Title: *Omfattende kutt kan føre til at en ren fysikklinje på bachelornivå må legges ned ved Norges «teknisk-naturvitenskapelige universitet.*

KIFINFO.NO (ONLINE NEWSLETTER), DECEMBER, 2023
Videos produced by Karen-Elisabeth Sødahl (9- and 3- minute video versions) of the QuSpin Balance Project. This was profiled through the kifinfo.no website (the Committee for Gender Balance and Diversity in Research, Norway).
Video title: *To help get more female researchers into top positions in academia.*
Balanseprosjektet QuSpin ved NTNU har laget en video om hvordan få flere kvinnelige fysikere i toppstillinger i akademia.

Highlights

PhD Defense
Håvard Homleid Haugen

FEBRUARY

Elected organizer at the Gordon Research Seminar
Verena Brehm

Best Master of Technology
Sondre Duna Lundemo
Best Master of Science
Johanne Bratland Tjernshaugen

JULY

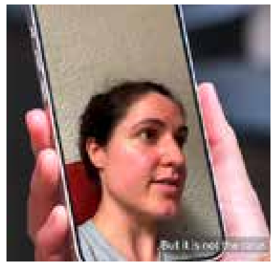
PhD Defense
Eirik Holm Fyhn

Norsk Fysisk Selskap Award
Thorvald Ballestad

AUGUST

Emerging Leaders 2023
Sol H. Jacobsen

QuSpin
Balance Film



DECEMBER

JUNI

IEEE Fellow
Professor Mathias Kläui

European Union's Horizon funding
Professor Dennis Meier and Professor Mathias Kläui

PhD Defense
Lina Johnsen Kamra

SEPTEMBER

PhD Defense
Jonas Lidal

PhD Defense
Tancredi Salamone

QuSpin Collaboration Workshop

Scientific Publications

We are privileged to have the work of our researchers published in journals such as Physical Review Letters, Physical Review B, Nature, Nature Physics, Nature Materials, Science Advances and the following listed publications.

1. van Weerdenburg, Werner M.J.; Kamlapure, Anand; Fyhn, Eirik Holm; Huang, Xiaochun; van Mullekom, Niels P.E.; Steinbrecher, Manuel; Krogstrup, Peter; Linder, Jacob Wüsthoff; Khajetoorians, Alexander Ako.
Extreme enhancement of superconductivity in epitaxial aluminum near the monolayer limit.
Science Advances ;Volum 9.(9). 101126

2. Mæland, Kristian; Sudbø, Asle.
Topological Superconductivity Mediated by Skyrmionic Magnons. **Physical Review Letters**. Volume 130. 156002

3. Ouassou, Jabir Ali; Brataas, Arne; Linder, Jacob Wüsthoff.
Dc Josephson Effect in Altermagnets. **Physical Review Letters** ;Volum 131.(7). 076003

4. Fyhn, Eirik Holm; Brataas, Arne; Qaiumzadeh, Alireza; Linder, Jacob Wüsthoff.
Superconducting Proximity Effect and Long-Ranged Triplets in Dirty Metallic Antiferromagnets.
Physical Review Letters ;Volume 131.(7). 076001.

5. Gonzalez-Ruano, C.; Caso, D.; Ouassou, Jabir Ali; Tiusan, C.; Lu, Y.; Linder, Jacob Wüsthoff; Aliev, Farkhad G..
Observation of magnetic state dependent thermoelectricity in superconducting spin valves.
Physical Review Letters; Volum 130. 237001

6. Aase, Niels Henrik; Johnsen, Christian Svingen; Sudbø, Asle.
Constrained s-wave weak-coupling superconductivity in multiband superconductors.
Physical Review B (PRB) ;Volum 108.(2). 024509

7. Aase, Niels Henrik; Mæland, Kristian; Sudbø, Asle.
Multiband strong-coupling superconductors with spontaneously broken time-reversal symmetry.
Physical Review B (PRB);Volum 108.(21). 214508

8. Ballestad, Thorvald M.; Cortijo, Alberto; Vozmediano, M. A. H.; Qaiumzadeh, Alireza.
Unconventional thermoelectric transport in tilted Weyl semimetals. **Physical Review B (PRB)** 107. 014410

9. Brehm, Verena Johanna; Gomonay, Olena; Lepadatu, Serban; Kläüi, Mathias; Sinova, Jairo; Brataas, Arne; Qaiumzadeh, Alireza.
Micromagnetic study of spin transport in easy-plane antiferromagnetic insulators.
Physical Review B (PRB) 107. 184404

10. Brekke, Bjørnulf; Brataas, Arne; Sudbø, Asle.
Two-dimensional altermagnets: Superconductivity in a minimal microscopic model.
Physical Review B (PRB);Volum 108.(22). 224421

11. Chourasia, Simran; Kamra, Lina Johnsen; Bobkova, Irina V.; Kamra, Akashdeep.
Generation of spin-triplet Cooper pairs via a canted antiferromagnet. **Physical Review B (PRB)** ;Volume 108.(6). 064515

12. Dyrdał, Anna; Qaiumzadeh, Alireza; Brataas, Arne; Barnaś, Józef.
Magnon-plasmon hybridization mediated by spin-orbit interaction in magnetic materials.
Physical Review B (PRB);Volum 108.(4). 045414

13. Fyhn, Eirik Holm; Brataas, Arne; Qaiumzadeh, Alireza; Linder, Jacob Wüsthoff.
Quasiclassical theory for antiferromagnetic metals. **Physical Review B (PRB)** 107. 174503.

14. Hodt, Erik Wegner; Linder, Jacob Wüsthoff.
On-off switch and sign change for a nonlocal Josephson diode in spin-valve Andreev molecules.
Physical Review B (PRB) 174502

15. Hodt, Erik Wegner; Ouassou, Jabir Ali; Linder, Jacob Wüsthoff.
Transient dynamics and quantum phase diagram for the square lattice Rashba-Hubbard model at arbitrary hole doping.
Physical Review B (PRB). 224427

16. Janssønn, Andreas T. G.; Hugdal, Henning G.; Brataas, Arne; Jacobsen, Sol H..
Cavity-mediated superconductor-ferromagnetic-insulator coupling. **Physical Review B (PRB)** 107. 035147.

17. Kamra, Lina Johnsen; Chourasia, Simran; Bobkov, G. A.; Gordeeva, V. M.; Bobkova, I. V.; Kamra, Akashdeep.
Complete Tc suppression and Néel triplets mediated exchange in antiferromagnet-superconductor-antiferromagnet trilayers. **Physical Review B (PRB)** ;Volum 108. 144506

18. Kløgetvedt, Jostein N.; Qaiumzadeh, Alireza. (2023)
Tunable topological magnon-polaron states and intrinsic anomalous Hall phenomena in two-dimensional ferromagnetic insulators. **Physical Review B (PRB)**; Volume 108. 224424.

19. Mæland, Kristian; Sudbø, Asle.
Exceeding the Chandrasekhar-Clogston limit in flat-band superconductors: A multiband strong-coupling approach.
Physical Review B (PRB); Volum 108.(21). 214511

20. Salamone, Tancredi; Hugdal, Henning Goa; Jacobsen, Sol Hernæs; Amundsen, Morten.
High magnetic field superconductivity in a two-band superconductor. **Physical Review B (PRB)** ;Volume 107.(17)

21. Sun, Chi; Brataas, Arne; Linder, Jacob Wüsthoff.
Andreev reflection in altermagnets. **Physical Review B (PRB)** ;Volum 108.(5). L060508.

22. Sun, Chi; Linder, Jacob Wüsthoff.
Spin pumping from a ferromagnetic insulator to an unconventional superconductor with interfacial Andreev bound states.
Physical Review B (PRB) ;Volume 107.(14). 144504

23. Sun, Chi; Mæland, Kristian; Sudbø, Asle.
Stability of superconducting gap symmetries arising from antiferromagnetic magnons.
Physical Review B (PRB) ;Volum 108.(5). 054520

24. Åsland, Anna Cecilie; Bakkelund, Johannes; Thingstad, Even; Røst, Håkon; Cooil, Simon Phillip; Hu, Jinbang; Vobornik, Ivana; Fujii, Jun; Sudbø, Asle; Wells, Justin William; Mazzola, Federico.
One-dimensional spin-polarized surface states: A comparison of Bi(112) with other vicinal bismuth surfaces.
Physical Review B (PRB) ;Volum 108.

25. Barbeau, Marion; Titov, Mikhail; Katsnelson, Mikhail I.; Qaiumzadeh, Alireza.
Nonequilibrium magnons from hot electrons in antiferromagnetic systems.
Physical Review Research (PRResearch);Volum 5.(2). L022065

26. Boventer, I.; Simensen, Haakon Thømt; Brekke, Bjørnulf; Weides, M.; Anane, A.; Kläui, Mathias Michael; Brataas, Arne; Lebrun, R..
Antiferromagnetic Cavity Magnon Polaritons in Collinear and Canted Phases of Hematite. **Phys. Rev. Applied** 19. 014071

27. Røst, Håkon; Cooil, Simon Phillip; Åsland, Anna Cecilie; Hu, Jinbang; Ali, Ayaz; Taniguchi, Takashi; Watanabe, Kenji; Belle, Branson Delano; Holst, Bodil; Sadowski, Jerzy; Mazzola, Federico; Wells, Justin William.
Phonon-Mediated Quasiparticle Lifetime Renormalizations in Few-Layer Hexagonal Boron Nitride.
Nano Letters ;Volume 23.(16) p. 7539-7545. 3c02086

28. Røst, Håkon; Tosi, Ezequiel; Strand, Frode Sneve; Åsland, Anna Cecilie; Lacovig, Paolo; Lizzit, Silvano; Wells, Justin William.
Probing the Atomic Arrangement of Subsurface Dopants in a Silicon Quantum Device Platform.
ACS Applied Materials & Interfaces ;Volum 15.(18) s. 22637-22643

29. Franziska Martin, Kyujoon Lee, Maurice Schmitt, Anna Liedtke, Aga Shahee, Haakon Thømt Simensen, Tanja Scholz, Tom G. Saunderson, Dongwook Go, Martin Gradhand, Yuriy Mokrousov, Thibaud Denneulin, András Kovács, Bettina Lotsch, Arne Brataas & Mathias Kläui
Strong bulk spin-orbit torques quantified in the van der Waals ferromagnet Fe3GeTe2.
Materials Research Letters ;Volume 11. 2119108.

30. Gao, Tenghua; Qaiumzadeh, Alireza; Troncoso, Roberto E.; Haku, Satoshi; An, Hongyu; Nakayama, Hiroki; Tazaki, Yuya; Zhang, Song; Tu, Rong; Asami, Akio; Brataas, Arne; Ando, Kazuya.
Impact of inherent energy barrier on spin-orbit torques in magnetic-metal/semimetal heterojunctions.
Nature Communications;Volume 14.(1). 5187.

31. Ilyakov, Igor; Brataas, Arne; de Oliveira, Thales V. A. G.; Ponomaryov, Alexey; Deinert, Jan-Christoph; Hellwig, Olav; Fassbender, Jurgen; Lindner, Jürgen; Salikhov, Ruslan; Kovalev, Sergey.
Efficient ultrafast field-driven spin current generation for spintronic terahertz frequency conversion.
Nature Communications; Volum 14.(7010)

32. Brehm, Verena Johanna; Austefjord, Johannes Wiger; Lepadatu, Serban; Qaiumzadeh Javinani, Alireza.
A proposal for leaky integrate-and-fire neurons by domain walls in antiferromagnetic insulators.
Scientific Reports 13.(1). 13402

33. Ebrahimian, Ali; Dyrdał, Anna; Qaiumzadeh, Alireza.
Control of magnetic states and spin interactions in bilayer CrCl3 with strain and electric fields: an ab initio study.
Scientific Reports 13, Article number: 5336

34. Hale, Nathan; Hartl, Matthias; Humlíček, Josef; Brüne, Christoph; Kildemo, Morten.
Dielectric function and band gap determination of single crystal CuFeS2 using FTIR-VIS-UV spectroscopic ellipsometry.
Optical Materials Express;Volum 13.(7) s. 2020-2035. 493426.

35. Xu, Zhonghui; Yuan, Qiuming; Siu, Zhuo Bin; Rafi-Ul-Islam, S.M.; Sun, Chi; Zhao, Shuliang; Jalil, Mansoor B. A..
Photoelectric current generation in a monolayer MoSe<inf>2</inf>-WS<inf>2</inf> lateral heterojunction.
Journal of Physics D: Applied Physics ;Volum 56.(6). O65304

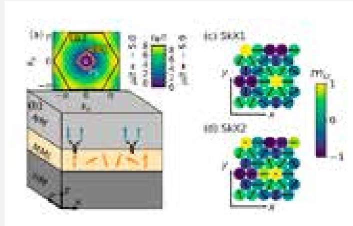
36. Mamedov, Damir; Åsland, Anna Cecilie; Cooil, Simon Phillip; Røst, Håkon; Bakkelund, Johannes; Allaniyazov, Atabek; Wells, Justin William; Karazhanov, Smagul.
Enhanced hydrophobicity of CeO2 thin films: Role of the morphology, adsorbed species and crystallography.
Materials Today Communications. 106323

37. Zarezad, Amir N.; Barnaś, Józef; Qaiumzadeh, Alireza; Dyrdał, Anna.
Bilinear planar Hall effect in topological insulators due to spin-momentum locking inhomogeneity.
Physica Status Solidi. Rapid Research Letters. 05971.

38. Paulsen, Michael; Lindner, Julian; Klemke, Bastian; Beyer, Jörn; Fechner, Michael; Meier, Dennis; Kiefer, Klaus.
An ultra-low field SQUID magnetometer for measuring antiferromagnetic and weakly remanent magnetic materials at low temperatures. **Review of Scientific Instruments 2023 ;Volume 94.**(10)

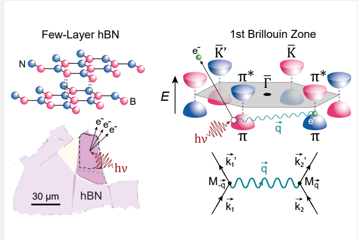
Featured Articles

This was yet another year where QuSpin Researchers published groundbreaking results in the world's premier physics journals. We have chosen to highlight three of them: Two of the works are theoretical, and the third paper is an experimental work.



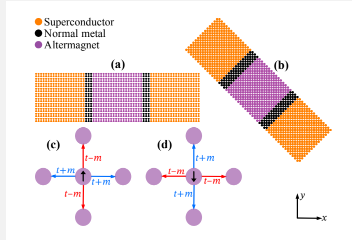
Topological Superconductivity Mediated by Skyrmionic Magnons
Kristian Mæland and Asle Sudbø.
Phys. Rev. Lett. 130, 156002 – Published 13 April 2023

Abstract
Topological superconductors are associated with the appearance of Majorana bound states, with promising applications in topologically protected quantum computing. In this Letter, we study a system where a skyrmion crystal is interfaced with a normal metal. Through interfacial exchange coupling, spin fluctuations in the skyrmion crystal mediate an effective electron-electron interaction in the normal metal. We study superconductivity within a weak-coupling approach and solve gap equations both close to the critical temperature and at zero temperature. Special features in the effective electron-electron interaction due to the noncolinearity of the magnetic ground state yield topological superconductivity at the interface.



Phonon-Mediated Quasiparticle Lifetime Renormalizations in Few-Layer Hexagonal Boron Nitride
Håkon I. Røst, Simon P. Cooil, Anna Cecilie Åsland, Jinbang Hu, Ayaz Ali, Takashi Taniguchi, Kenji Watanabe, Branson D. Belle, Bodil Holst, Jerzy T. Sadowski, Federico Mazzola and Justin W. Wells.
Nano Lett. 2023, 23, 16, 7539–7545 - Published 10 August 2023.

Abstract
Understanding the collective behavior of the quasiparticles in solid-state systems underpins the field of nonvolatile electronics, including the opportunity to control many-body effects for well-desired physical phenomena and their applications. Hexagonal boron nitride (hBN) is a wide-energy-bandgap semiconductor, showing immense potential as a platform for low-dimensional device heterostructures. It is an inert dielectric used for gated devices, having a negligible orbital hybridization when placed in contact with other systems. Despite its inertness, we discover a large electron mass enhancement in few-layer hBN affecting the lifetime of the π-band states. We show that the renormalization is phonon-mediated and consistent with both single- and multiple-phonon scattering events. Our findings thus unveil a so-far unknown many-body state in a wide-bandgap insulator, having important implications for devices using hBN as one of their building blocks.



dc Josephson Effect in Altermagnets
Jabir Ali Ouassou, Arne Brataas, and Jacob Linder.
Phys. Rev. Lett. 131, 076003 – Published 17 August 2023

Abstract
The ability of magnetic materials to modify superconductors is an active research area for possible applications in thermoelectricity, quantum sensing, and spintronics. We consider the fundamental properties of the Josephson effect in a class of magnetic materials that recently have attracted much attention: altermagnets. We show that despite having no net magnetization and a band structure qualitatively different from ferromagnets and from conventional antiferromagnets without spin-split bands, altermagnets induce 0−π oscillations. The decay length and oscillation period of the Josephson coupling are qualitatively different from ferromagnetic junctions and depend on the crystallographic orientation of the altermagnet. The Josephson effect in altermagnets thus serves a dual purpose: it acts as a signature that distinguishes altermagnetism from ferromagnetism and conventional antiferromagnetism and offers a way to control the supercurrent via flow direction anisotropy.

Facts

As of 2023.12.31.

9
PROF/ASSOC.PROF

2
SENIOR RESEARCHERS

3
POSTDOCS

22
PHD CANDIDATES

14
MASTER STUDENTS

1
ADMINISTRATOR

11
DIFFERENT NATIONALITIES

21
VISITING RESEARCHERS

38
PUBLICATIONS

* Note: In addition we have a 25 % Finance Officer position, Head Engineer from the Department of Physics/NTNU, two Co-Principal Investigators in 17% and 20% positions, and one Prof. II position.

Funding

FUNDING 2023 (NOK)

The Research Council of Norway, Center of Excellence	16 169 000
Norwegian University of Science and Technology	9 168 000
SUM	**25 337 000**
The Research Council of Norway (Center of Excellence)	6 691 000
International Funding	4 494 000
Other Public	200 000
SUM	**11 385 000**
TOTAL FUNDING	**36 722 000**

People Overview

Colleagues who left QuSpin before 2023.12.31 are marked with an *

QUSPIN LEADER GROUP

Center Director till April 30th/ Professor/Principal Investigator
Arne Brataas

Center Director from May 1 st/ Professor/Principal Investigator
Asle Sudbø

Professor/Principal Investigator
Jacob Linder

Associate Professor/ Principal Investigator
Hendrik Bentmann

Center Coordinator
Karen-Elisabeth Sødahl

ASSOCIATED MEMBERS

Associate Professor
Christoph Brüne

Professor
Jeroen Danon

Associate Professor
John Ove Fjærestad

Professor (Onsager Fellow)
Dennis Gerhard Meier

Professor/Head of Department of Physics
Erik Wahlström

SENIOR RESEARCHERS

Senior Researcher
Sol H. Jacobsen

Senior Researcher
Alireza Qaiumzadeh

PROFESSOR II

Professor
Justin Wells

POSTDOCS


Morten Amundsen


Jinbang Hu*


Henning Goa Hugdal


Jabir Ali Ouassou*


Chi Sun


Xin Tan (Guest researcher 2023, starting as a Postdoc in 2024.)

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Erik Hodt


Jacob Daniel Benestad


Verena Brehm


Bjørnulf Brekke


Payel Chatterjee


Niels Henrik Aase


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Therese Frostad


Matthias Hartl


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Leraand, Kristoffer
Matre, Bjarte
Mykland, Olai Breivik
Schenk, Richard Justin
Syljuåasen, Erlend
Tjøtta, Maxim
Ursin, Sofie Helene

Photo from the ARPES lab showing a detail.

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The Netherlands

Professor
Mathias Kläui, Johannes Gutenberg
University Mainz, Germany

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Chul-Hee Min
Department of Physics, NTNU

Head Engineer MBE lab
Geir Myrvågnes
Department of Physics, NTNU

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Tohoku University, Japan

Professor
Daniela Pfannkuche
University of Hamburg, Germany

QuSpin Alumni

Here are the members of our QuSpin Alumni. They are previous researchers at our Center, who are now in new positions within academia, research institutions, and industry.

Dr. Lina Johnsen Kamra
PhD 2023
Next position: Postdoc at the IFIMAC - Condensed Matter Physics Center, Universidad Autónoma de Madrid, Madrid, Spain

Dr. Jonas Lidal
PhD 2023
Next position: Researcher at Norwegian National Security Authority (NSM), Oslo, Norway

Dr. Tancredi Salamone
PhD 2023
Next position: TBA

Dr. Håvard Homleid Haugen
PhD 2023
Next position: Researcher at Norwegian Meteorological Institute, Oslo, Norway.

Dr. Eirik Holm Fyhn
PhD 2023
Next position: Reseracher at SINTEF Energy, Department of Gas Technology, Trondheim, Norway.

Dr. Sverre Aamodt Gulbrandsen
PhD 2022
Next position: Researcher at Optonor AS, Trondheim, Norway

Dr. Atousa Ghanbari Birgani
PhD 2022
Next position: Data Scientist at Startuplab, Oslo, Norway

Dr. Jonas Blomberg Ghini
PhD 2022
Next position: Power engineering consultant at Multiconsult, Trondheim, Norway

Dr. Håkon Ivarssønn Røst
PhD 2022
Next position: Postdoctoral Fellow at the Department of Physics and Technology, University of Bergen, Norway

Dr. Jørgen Holme Qvist
PhD 2022
Next position: Research Scientist at Voca AS, Kristiansand, Norway

Dr. Eirik Erlandsen
PhD 2022
Next position: Data Analyst at the Norwegian Bank (DnB), Oslo, Norway

Dr. Andreas T. G. Janssønn
PhD 2022
Next position: TBA

Dr. Markus Althaler
PhD 2022
Next position: TBA

Dr. Marion Barbeau
PostDoc 2019-2022
Next position: Researcher in Photonics for Health, Imec, Eindhoven, The Netherlands

Akashdeep Kamra
Researcher 2021
Next position: Junior Group Leader at the IFIMAC - Condensed Matter Physics Center, Universidad Autónoma de Madrid, Madrid, Spain

Dr. Vasil Saroka
PostDoc 2018-2021
Next position: Tor Vergata University of Rome, Italy

Dr. Mariia Stepanova
PostDoc 2019-2021
Next position: Materials Engineer and Data Analyst, Norsk Titanum AS, Hønefoss, Norway

Dr. Martin Fonnum Jakobsen
PhD 2021
Next position: Researcher at the Norwegian Defence Research Establishment (FFI), Oslo, Norway

Dr. Even Thingstad
PhD 2021
Next position: Postdoctoral Fellow at Universität Basel, Switzerland

Dr. Fredrik Nicolai Krohg
PhD 2021
Next position: Security Analyst at Orange Cyberdefense, Norway

Dr. Erik Nikolai Lysne
PhD 2021
Next position: Fullstack Developer at Fink, Oslo, Norway

Dr. Haakon Krogstad
PhD 2021
Next position: Consultant at McKinsey, Oslo, Norway

Dr. Simon Coill
Associate professor II 2018-2020
Next position: Postdoc at the Department of Physics, University of Oslo, Norway

Dr. Xiansi Wang
PostDoc 2018-2020
Next position: Professor at Hunan University, Changsa, China

Dr. Junhui Zheng
PostDoc 2020
Next position: Associated Professor at the Institute of Modern Physics, Northwest University, Xi'an, China

Dr. Rui Wu
PostDoc 2020
Next position: Associate Professor in colleague of physics at University of Electronic Science and Technology of China (UESTC)

Dr. Roberto Troncoso
PostDoc 2020
Next position: Associate Professor at the Faculty of Engineering of University Adolfo Ibánez, Santiago, Chile

Dr. Morten Amundsen
PhD 2020
Next position: Postdoc at NORDITA, Stockholm, Sweden

Dr. Arnau Sala
PhD 2020
Next position: PostDoc at Interuniversity Microelectronics Centre (IMEC), Leuven, Belgium

Dr. Niklas Rohling
Researcher 2019
Next position: PostDoc at Universität Konstanz, Konstanz, Germany

Dr. Alex Schenk
PostDoc 2019
Next position: La Trobe University, Melbourne, Australia

Dr. Maximillian Kessel
PostDoc 2019
Next position: Scientist at Fraunhofer-Institute for Applied Solid State Physics in Freiburg, Germany

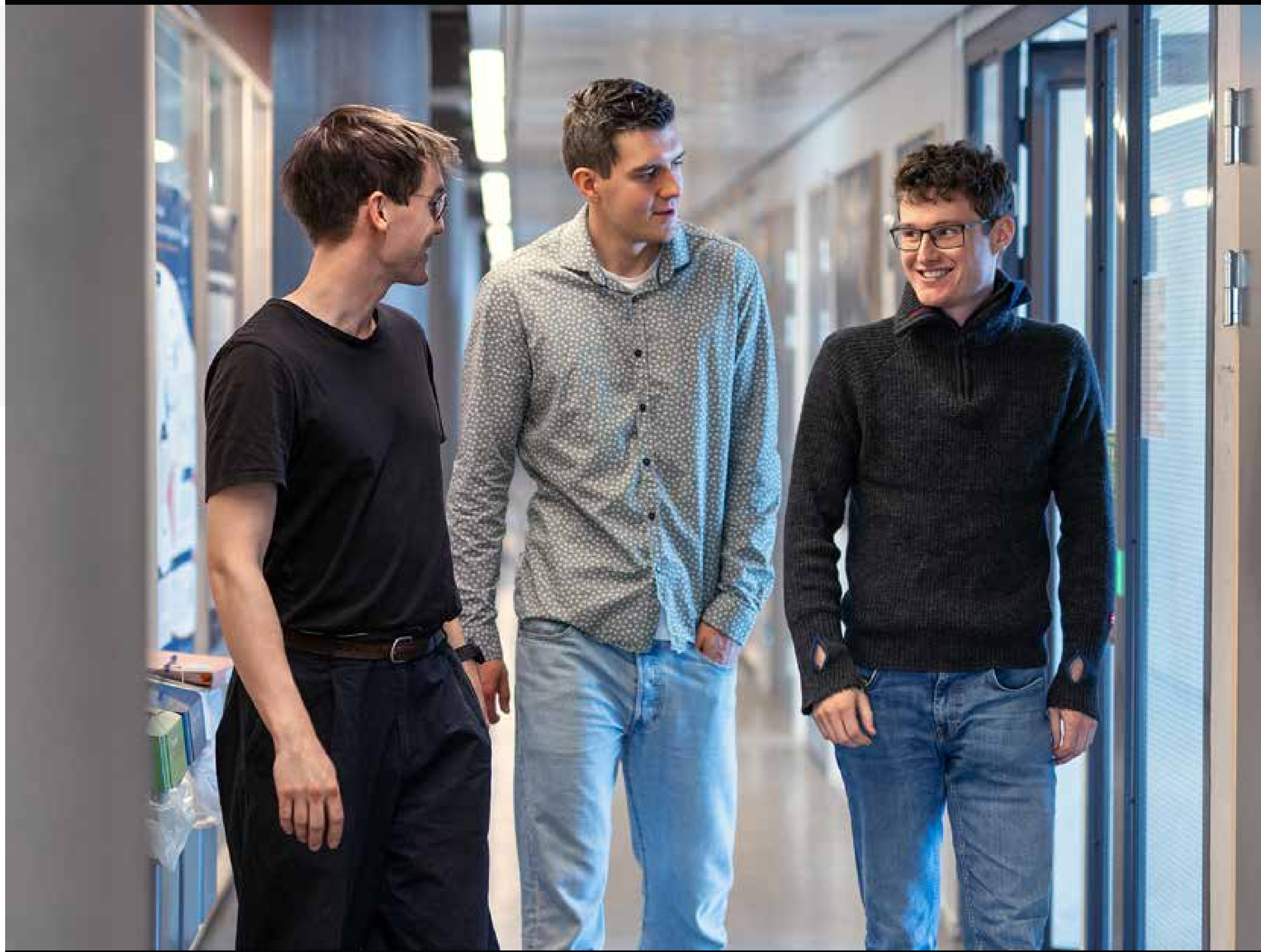
Dr. Rajesh Kumar Chellappan
PostDoc 2019
Next position: Technical Reviewer/Assessor, DNV Product Assurance AS, Høvik, Norway

Dr. Vetle Kjære Risinggård
PhD 2019
Next position: Researcher at Norwegian Research Centre (NORCE), Kristiansand, Norway

Dr. Øyvind Johansen
PhD 2019
Next position: Service Consultant at Matrix Technology AG, Munich, Germany

Dr. Eirik Løhaugen Fjærbu
PhD 2019
Next position: Data Scientist at Deepinsight AS, Oslo, Norway

Dr. Camilla Espedal
PhD 2013-2017
Next position: Research Scientist at SINTEF Energy Research, Trondheim, Norway



Erik Hodt, Hans Gløckner Gill and Jacob Benestad taking a stroll in our corridor.

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Karen-Elisabeth Sødahl

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Dennis Meier
Sol H. Jacobsen
Alireza Qaiumzadeh
Karen-Elisabeth Sødahl

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Frode Myhren /Vinnvinn Reklame (page): 57
NTNU (pages): 4-5

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Arne Brataas (page): 17
Eirik Holm Fyhn (page): 18, 61
Hendrik Bentmann (page): 19
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A.J. Skarpeid (page): 27
Alireza Qaiumzadeh (page): 28
Kristian Mæland (page): 61 (article 1)
Håkon Røst (page): 61 (article 2)
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