Annual Report | 2021

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 ARNE BRATAAS

Foreword

QuSpin started in September 2017 is scheduled to finish in 2027. We are now close to midterm. We see significant spin-offs regarding the personnel we train, the global impact through our publications, and the improved synergetic strategy for experimental and theoretical condensed matter physics. In 2022, the research council will evaluate the Centers of Excellence that began in 2017. We need to pass the evaluation to get continued support for the final years.

The most important output of QuSpin is the trained personnel that either continue to work in academia and or move on to working in industry. Our first generation of Ph.D. students that spent their entire training period with us finished in 2021. It is great to see their achievements and how they have matured as researchers. We look forward to seeing the contributions in the years to come.

We believe we are in a good position for the midterm evaluation. The pro-rector of our university recently highlighted the *Nature Index* ranking in the university newspaper *Universitetsavisa*. It showed that NTNU ranks globally as 22 of 150 new universities. QuSpin is proud to contribute to about 25% of the total rating points for NTNU in this ranking. QuSpin also excels on other scales. Two of our PIs are on the top-100 list of researchers based on gathered publication points in any field in Norway in 2021.

To prepare for the midterm evaluation, we are very grateful that our advisory board came to Trondheim to evaluate our activities in late November. Their constructive feedback will assist in bringing QuSpin forward. Encouragingly, the advisory board concludes that "QuSpin continues to deliver world-leading research on cutting-edge topics of quantum spintronics."

The spin-ARPES is the most significant experimental investment at QuSpin. We want to thank Justin Wells for his outstanding contributions to QuSpin and his group's tremendous effort in purchasing and installing the spin-ARPES laboratory. We are pleased that Justin Wells will continue in a 20% position as a professor II for the next three years and wish him the best of luck with his primary function at the University of Oslo. The department has finished the evaluation of the candidates for the job of associate professor in charge of the spin-ARPES laboratory. We look forward to welcoming one of the top-ranked candidates at QuSpin soon, as well as the continued positive integration trend between the different experimental and theoretical activities at QuSpin.

> *QuSpin continues to deliver world-leading research on cutting-edge topics of quantum spintronics.*

We successfully arranged our annual workshop Quantum Spintronics 2021, on 1 and 2 December. Alas, Covid-19 restrictions were imposed before the workshop. Nevertheless, we managed to organize a hybrid version where most speakers appeared digitally while the QuSpin members were physically present. After a long period with Covid-19 restrictions, we very much look forward to meeting and interacting with our scientific colleagues.

We focus on gender balance at our center because diversity stimulates creativity. While we have kept our promise of hiring 1/3 female among the QuSpin-funded post-docs and Ph.D. students, the gender imbalance remains among the permanent staff. QuSpin participates in the Gender Balance program funded by the Research Council of Norway to further increase attention on this central issue. We hope that the trained personnel and insights we have gained will improve the gender balance among the permanent staff in the longer run.

Center of Excellence

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.

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.

By the end of 2021, our Center had developed into the more than sixty-people strong team with members from thirteen different countries. QuSpin now has eight permanent professors and associate professors, two researchers, three postdocs, twenty-three PhD students, eighteen master's students, and one administrator. In addition, we have one position on twenty five percent as finance controller, and two positions on twenty percent as Co-Principal Investigators.

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.

QUSPINERS 2021:
QuSpiners working from their home offices during the pandemic.

The Journey of SFF QuSpin

At the end of the year 2021, we sat down around the table and reflected on the Center´s journey so far. How did the Center start? What did it take to become successful? And what have we learnt from our experiences so far?

Dialogue between the three Principal Investigators Arne Brataas, Asle Sudbø and Jacob Linder, facilitated by Karen-Elisabeth Sødahl. The fourth original Principal Investigator, Justin Wells, had already started in his new position at the University of Oslo.

Carrying out research at the department before the foundation of the Center for Quantum Spintronics
It is common practice for researchers to work by themselves within well-defined research areas at universities. The research culture allows for a high degree of freedom and independence. Researchers are focused specialists who operate in separate or parallel "silos." The university and public funding system reward individual researchers for articles published and cited and for project funding they attract.

The motivation for applying for a Center of Excellence (SFF)
"We wanted to make a more extensive scientific impact, securing long-term funding and resources by joining forces and developing new ways of working together. Therefore, we developed a set of coherent research fields toward a shared vision to trigger a revolution in low-power information and communication technologies in an energy-efficient society," says Arne Brataas.

The four professors, Arne Brataas, Asle Sudbø, Jacob Linder, and Justin Wells, cover the theoretical and the experimental fields within physics. They sat down to explore if they could form a strong enough team with a chance to succeed with their ambitions. Their track records, coherent research themes, and complementary competencies were crucial. After challenging discussions at many meetings and compromises on which research to prioritize, writing and re-writing the application tenfold times, they handed in a solid application to the Research Council of Norway (RCN), which succeeded.

In September 2017, the Research Council of Norway awarded the Center of Quantum Spintronics (QuSpin) the Center of Excellence (SFF) status. A ten-year journey started. Besides the PIs, the Center includes a center coordinator, associated members, Postdocs, Ph.D. and master's students. At the end of 2021, the Center counted sixty members from thirteen different nations. Twenty-five researchers from 2017-2021 have moved on from QuSpin to careers within academia or the industry.

The importance of a joint location in developing the research culture
"We believed in the importance of being close together to create an environment for formal and informal collaboration and meetings. So, the priority was to gather everyone in the same corridor," says Arne Brataas. *"We designed a common room, the heart of the Center, where the researchers can meet for lunch, seminars, journal clubs, idea forums, workshops, meetings, cultural feasts, and birthday celebrations."*

"Gathering many researchers on one physical location has been a success," says Asle Sudbø. *"As a result, everybody easily finds colleagues who work in closely related scientific fields to talk to and discuss with. This environment is enriching both scientifically and socially."*

Quspin has people with various backgrounds, competencies, and personalities. An important aim is that everyone should be seen and heard.

> *Gathering many researchers on one physical location has been a success. – Asle Sudbø*

Covid-19 and research at QuSpin
During the past two years, the covid-19 pandemic has affected people both at work and in their private lives. The home office has been the main rule for a long time. Therefore, covid-19 has put a new kind of stress on the organization. The physical meeting places and activities were canceled or moved to digital platforms such as Teams and Zoom.

"Looking at the number of publications and distribution between the researchers," Jacob Linder says, "*it shows that we have been able to keep the research going. What we see is a small dip in collaborations in 2021, but this is an effect of not being together, and the labs have had a delay in ongoing activity*."

"The corona pandemic has put people's mental and physical conditions to the test," Asle Sudbø comments. *"At the same time, we were optimistic that as soon as society would open up again and people would be back to work, we would be able to regain the motivation and interaction we had before the lockdown."*

> *We see a gradual increase in collaboration between theorists and experimentalists and between the various experimental labs. – Arne Brataas*

The effect the center has had on collaborations between the researchers and across theoretical and experimental fields
One of the Center's goals was to increase the collaborations. Therefore, the Center invested 16 MNOK in a new ARPES lab, developed and set up by Justin Wells and his team. The associate professor Christoph Brüne did the same with the MBE lab, while Professor Dennis Meier headed the Scanning Probe Microscopy lab. The developments of the experimental capacity have been vital to increased interaction and collaboration between both fields at QuSpin. In addition, the Center collaborates with the international partners Professor Mathias Kläui (Mainz) and Rembert Duine (Delft) and their lab teams.

"We see a gradual increase in collaboration between theoreticians and experimentalists and between the various experimental labs," says Arne Brataas. *"There is a 30% increase in collaboration on articles over the years 2017-2021. Furthermore, according to the latest ranking in the Nature Index measures, QuSpin's publications represent 25% of the total rating points for NTNU in this ranking."*

The benefit of co-location and joint activities where the researchers learn more about each other's activities has been instrumental in making this happen. Learning from others is not something the Principal Investigators force but primarily facilitate. *"The Principal Investigators must lead the way and be examples to the other researchers,"* says Jacob Linder.

Training of young researchers is one of the major tasks at the Center
The center is publicly funded and is responsible for training younger researchers. They receive training in research and methods. Increased competence and skills are valuable for their next position and contributions to society, whether in Norway or abroad.

"The environment seems to be positive for their learning and experiences, and we are happy to see how well they are all doing. The degree of completion of their studies at QuSpin is high," says Jacob Linder. *"And our master students seem to thrive from being part of the Center. Many are inspired to do an outstanding master thesis as well as apply for Ph.D. studies at QuSpin."*

"Role models are also important and to build a network of people for their future career inside or outside Academia," says Asle Sudbø.

The researchers were also recognized outside of QuSpin in 2021. They have received grants from RCN/FRINATEK, Yara's Birkeland Prize, The Netherlands Science Foundation, and the RCN Balance Program.

Basic research and discovering new grounds at QuSpin
The typical research collaboration is between a principal researcher and Ph.D. students. Researchers and postdocs collaborate in the same way, and sometimes the projects involve researchers from all levels.

The more senior the researchers, the more self-driven they tend to be. Groundbreaking results may come about from a specific idea that is being explored or by unexpected discoveries via a side-track.

"As mentioned earlier, we see that the research and production of results and publications have improved

significantly by working together in a Center like ours," says Jacob Linder. *"Everyone at the Center plays a role and is crucial to what we are trying to achieve."*

Developing new curriculums at the department
The development of new knowledge is part of the Center's strategy to make this available as enhanced content and training in physics courses at the department and faculty.

"We have an old course called quantum materials. The whole section at QuSpin works with modern quantum materials in different ways. We have modified the content to focus on forefront research. This motivates and attracts many more students these days," says Asle Sudbø.

Increased international recognition amongst other researchers
The annual international workshop and conference "Quantum Spintronics" has many international speakers. This event allows the researchers to meet, interact, share, and find common ground for future collaborations.

"We managed to arrange the workshop in 2021 as well, even though we had to redesign it at the last minute due to the new omicron virus," says Arne Brataas. *"We ended up with a hybrid workshop, but we were delighted that we were able to kick this off. Next year we will expand the conference from two to three days."*

An SFF Center also gives access to increased human and financial resources. The diversity within the group of researchers and the group's size also enhances international collaboration. *«The presence of 30-40 researchers, as opposed to five or six, more easily attracts international researchers to visit and give seminars»,* says Asle Sudbø. *«We mostly get immediate, positive responses to speaker invitations."*

How QuSpin actively participates in a diverse society
Researchers impact the focus and funding of research in society. As a result, there is a growing trend on the importance of having a group of researchers who represent all of society, not just one major group.

Historically, male researchers dominate the field of theoretical physics. Therefore, the Center has a goal that females hold a minimum of one-third of all new positions at QuSpin. We have met this goal on the Ph.D. level.

"But we experience a clear challenge here," says Jacob Linder. *"What to do when the recruitment process shows mostly male applications?"*

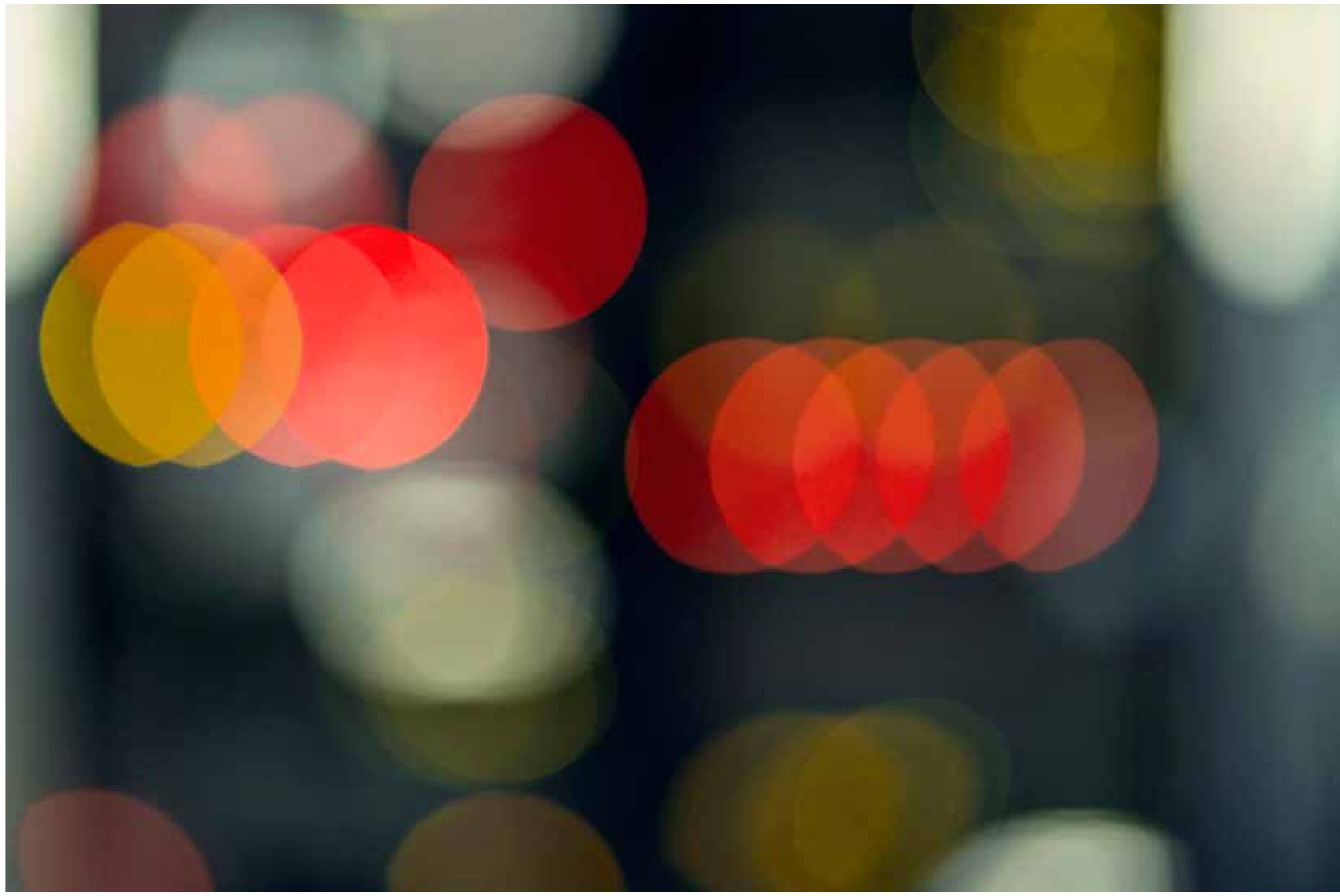
"We have started addressing this more actively," says Arne Brataas. *"The Center received the Balance Program Grant 2021-2022, a gender balance project headed by coordinator Karen-Elisabeth Sødahl.* The Research Council of Norway's Balance program aims to increase the number of female researchers in top positions in Academia.

An internal survey in QuSpin in late 2021 showed the potential for increased awareness of status, challenges, and possibilities in the way we recruit, work, communicate, collaborate, support, and train our researchers in their career development.

There are different measures to be taken. The Center has taken its first steps on a much longer journey to increased gender balance at our Center and in permanent positions in Academia. QuSpin must do what they can, while the responsibility on a systemic and structural challenge lies at the university level.

The journey towards the mid-term evaluation in 2022-2023 and beyond
All principal investigators share the wish to develop collaboration in all areas and on all levels. They look forward to more discussions on in-depth research to open up to even more groundbreaking ideas and continuously keep the Center's vision alive.

They wish to continue the development of an open, creative, social, and collective robust research culture that will motivate and engage our researchers and attract the most engaging and motivated new colleagues, collaborators, and guests.



The environment seems to be positive for their learning and experiences, and we are happy to see how well they are all doing. – Jacob Linder

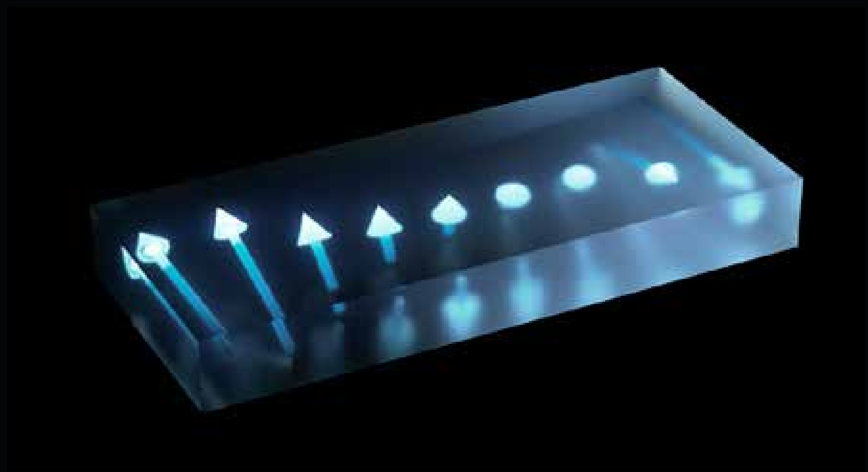
Main Research Themes, Goals and Activities

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.

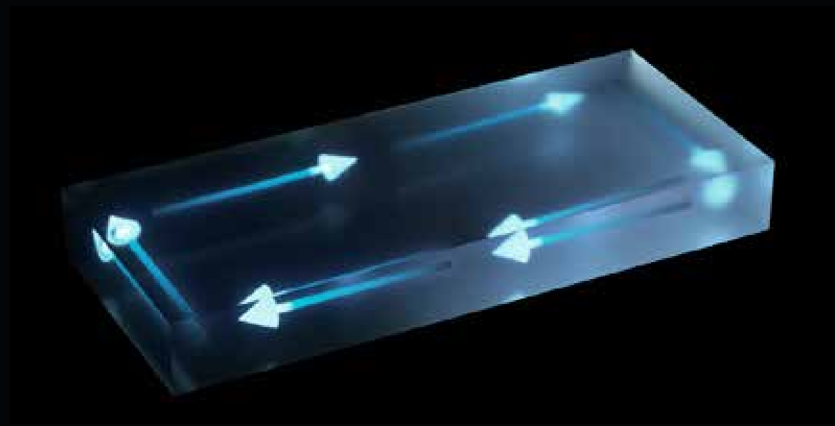
The research focuses on three judiciously chosen low- dissipation systems: magnetic insulators, topological insulators, and superconductors which correspond to three research themes: insulator spintronics, topological matter, and super spintronics.

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.

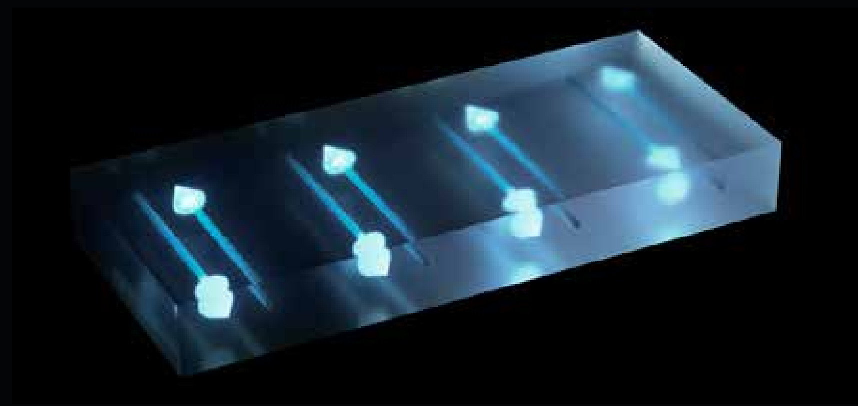
Electrons can move in free air. In materials, their motion can differ significantly. In metals, the collective flow of the electrons resembles that of particles, but with dramatically altered properties. Their mass, charge, and even spin can be modified. This dressed behavior resembles new particles,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



MAGNETIC INSULATORS



TOPOLOGICAL INSULATORS



SUPERCONDUCTORS

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.*

We will address how such quasi-particles can convey spin information with exceptional tiny energy losses. Also, we will 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 will 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.

ARNE BRATAAS

Spin Insulatronics

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 significantly couples to electron motion.

Spin Insulatronics is profoundly different because there are no moving charges. In magnetic insulators, 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 such as waves, spin waves, or other dynamical spin textures.

Controlling electric signals through the deployment of magnetic insulators can facilitate a revolution in information and communication technologies. We aim to determine the extent to which spin in antiferromagnetic and ferromagnetic insulators couple to mobile electrons in adjacent conductors. We will utilize this coupling to control electric signals. We will replace moving charges with magnetic insulators' dynamic low-dissipation coherent and incoherent spin excitations. These features also imply that we can enable unprecedented control of electron-electron correlations. In turn, these features can open the doors towards creating new paths for magnon and exciton condensation, superfluidity, and superconductivity. Furthermore, since spin signals in insulators 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 perhaps even quantum information processing.

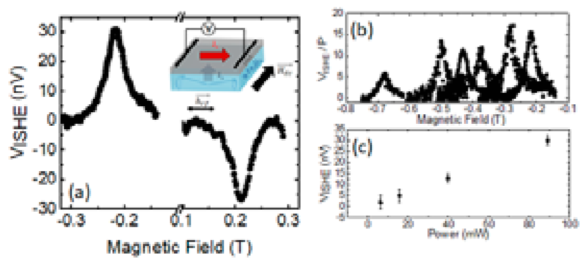
Key questions

We focus on the fundamental challenges facing Spin Insulatronics. Key questions are how spin can transfer from electrical conductors to insulators, how far and how spin propagates in insulators, how we can control correlations that cause new states of matter, and detect these phenomena's signatures.

Activity in 2021

Antiferromagnets are promising in high-frequency electronics since their spin dynamics is in the THz range, orders of magnitude faster than ferromagnets. Spin transfer torque and spin Hall effects combined with their reciprocal phenomena, spin pumping, and inverse spin Hall effects enable reading and controlling magnetic moments in spintronics. In 2020, we reported the direct observation of these central effects in the journal Science. We assisted Enrique del Barco's experimental team at the University of Florida in Orlando with our theoretical input. They observed subterahertz spin pumping at the interface of the uniaxial insulating antiferromagnet manganese difluoride and platinum.

In 2021, we went one step further. Romain Lebrun's experimental team at the University of Paris-Saclay, assisted with our theoretical input, observed spin-pumping in a different class of antiferromagnets, canted antiferromagnets. The canted moments arise due to the Dzyalonshinskii-Moriya interaction. Intriguingly, the canting enhances spin-pumping at relatively low resonance frequencies. These results open new means to generate and detect spin currents at THz frequencies by functionalizing antiferromagnets with low damping and canted moments. Furthermore, our results highlight that canted antiferromagnets embrace the rich dynamics of antiferromagnets while keeping a net moment and more considerable temperature stability than ferrimagnets with compensated angular momentum.



We have also contributed to developing a theory of magnon spin currents driven by supercurrents, RKKY interactions via Kitaev spin liquids, crossed Andreev reflection in antiferromagnet-superconductor junctions, cross-sublattice spin pumping in antiferromagnets, and spin-pumping in ferromagnet-super-conductor systems.

ASLE SUDBØ

Topological Quantum Matter

Theme and goal

In recent years, matter in the quantum domain harboring particularly intriguing and useful physical properties that are protected against destruction by some global robust properties of the eigenstates of the system, has garnered considerable attention. It turns out that the protection of the useful physical properties is facilitated by certain topological properties of the space of eigenstates of the system. Topology was originally a branch of mathematics that investigates global geometric properties of objects. These could be physical objects, but also much more abstract objects defined in an abstract space of mathematical functions. In recent years, physics has seen a sharp rise of interest in topological properties of matter in the quantum domain.

Topological quantum matter features certain robust and very useful physical properties protected by non-trivial topological properties of the quantum states of the system, involving the "geometry" of the quantum states. Topological phase transitions are phase transitions whose ordered state cannot be characterized by a standard simple local order parameter. Rather, the ordered state has a lack of topological defects, while the disordered state has proliferated large amounts of topological defects "ripping" the ordered state apart".

Superfluidity and superconductivity are the phenomena that fluids in the quantum regime may flow without any dissipation. Superconductivity, superfluidity, and magnetism are phenomena in which enormous numbers of degrees of freedom spontaneously self-organize themselves into various ordered states of matter.

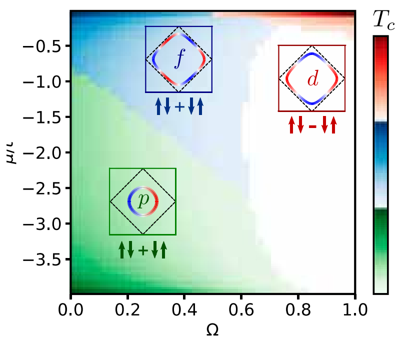
Key questions

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. Such effects are of interest from a fundamental physics point of view, and the 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 and superconductors, and chiral p-wave superconductors.

Activity in 2021

The research carried out in 2021 has been an extension and continuation of research from 2019 and 2020, namely to compute and predict how magnetic quantum fluctuations at the interface between metals or topological insulators on the one hand, and ferromagnets or quantum antiferromagnets on the other hand, may induce superconductivity in the metal or topological insulator. An important aspect of this has been to extend previous investigations into the strong coupling regime. This necessitates taking into account how the fluctuations causing superconductivity also affect the very nature of the fermionic quasiparticles that pair into Cooper-pairs. This is facilitated by an Eliashberg strong-coupling approach to superconductivity. We have performed detailed calculation showing how magnons in quantum antiferromagnets (squeezed magnons) lead to superconductivity in the strong-coupling regime. Concomitant with this, we also carried out detailed calculations of many-body effects caused by ferromagnetic and antiferromagnetic magnons on the spectra and lifetimes of topological Dirac matter. The results of these calculations have been presented in a form that allows direct comparison with ARPES -experiments, and are indeed carried out in collaboration with the ARPES-group.

This line of investigation will be carried further, considering quantum magnets with non-collinear (possibly chiral) ground states. We have also carried out detailed large-scale Monte Carlo calculations of the character of thermally-driven phase transitions in chiral p-wave superconductors both in zero and finite magnetic field.



Phase diagram for superconductivity as a function of chemical potential and coupling-asymmetry parameter. The plot is colored according to which of the three possible superconducting orders in our calculations that give the larges (upper) critical temperature. The intensity of the color within each phase corresponds to the critical temperature normalized to its maximum value for that phase.

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, 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 of a quantum property known as spin as well. 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 superconductors. 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, things get interesting. This is one of the motivations behind the field of superconducting spintronics where we study spin-dependent quantum effects in superconductors.

Two goals guide our research. The main goal is to discover new quantum phenomena that emerge when combining superconductors with materials that have very different properties, in particular magnetic ones. Secondly, we focus on discovering phenomena that may be relevant to the development of memory technology and information transfer based on superconductors. This is closely related to the transport of charge, spin, and heat.

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 problems we are attempting to solve are related to the functional properties of materials and how they can be controlled or altered by combining several materials. For instance, is it possible to use antiferromagnetic materials to control when superconductivity appears and even enhances its properties? Can one use superconductors to create spin-dependent thermoelectric effects which exceed in performance even the best bulk materials? Finally, we are interested in understanding how superconductivity is manifested in unusual solid-state systems, such as atomically thin materials.

Activity in 2021

One of our research highlights from 2021 is the prediction that a supercurrent can induce a magnon spin current. This enables a new type of quantum crosstalk between different types of information carriers, namely Cooper pairs and magnons. Moreover, we have predicted that the exchange interaction between magnetic materials is fundamentally altered by the presence of topologically protected zero-energy states in high-Tc cuprate superconductors. In collaboration with experimental groups, we have published work on how ripples in graphene affect the dissipationless flow of charge, and also demonstrated superconductivity-induced change in the perpendicular magnetic anisotropy of Fe/MgO/V layers. Our research activity includes the prediction of an electrical equivalent of spin-pumping which we call spin-orbit pumping, and the controllable enhancement of unconventional superconductivity by magnetic coupling to a conventional superconductor. Our publications in 2021 include two papers in PRL, two papers in PRB Letters, and several papers in PRB.

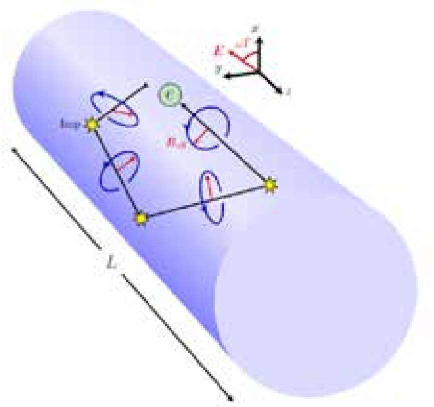


Illustration of spin-orbit pumping where a rotating electric field creates a spin signal.

JUSTIN WELLS

Electronic Structure

Theme and goal

The electronic band structure of a material contains information about all the electrons which are relevant for physical and electronic properties in a solid. It also contains information about the electron spin, about interactions of electrons with each other, impurities, vibrations, spin waves, and more. It is therefore of great benefit to be able to directly measure the electronic band structure, and hence gain access to this information. Over the past decade, the instrumentation available has improved dramatically. Recently, we have been part of this revolution in instrumentation: We have been involved in the development and installation of a new type of photoelectron spectromicroscope which boasts ultra-high efficiency spin-resolved, momentum-resolved, spatially-resolved and energy-resolved band structure imaging. During 2021 we have been extensively using this new instrument on a wide range of physical systems, including bulk ferromagnets, topological surface states, 2D materials, and more.

Key questions

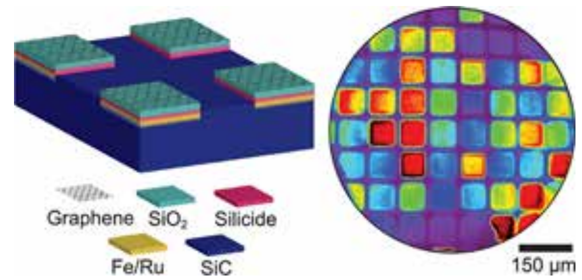
We have been studying many-body interactions in magnetic bulk materials and non-magnetic surfaces in order to disentangle electron-magnon and electron-phonon contributions to the electron lifetime. From this, a complete picture of quasiparticle formation can be formed. This will help to address questions about the role of these many-body interactions in driving transitions into quantum phases, such as a superconducting state.

Activity in 2021

Highlights from the first half of 2021 include collecting data from our new instrument, as well as resuming synchrotron activities abroad (after a pause during the pandemic). Our focus has been on the growth, manipulation, and band structure mapping of 2D materials, such as graphene, to facilitate the electron-phonon coupling to be extracted under a range of realistic degrees of doping.

In the summer of 2021, Justin Wells moved from NTNU to the University of Oslo (UiO), and his role as PI in the SFF was terminated by QuSpin. He continues at QuSpin as an associated member in an adjunct (Professor II) position.

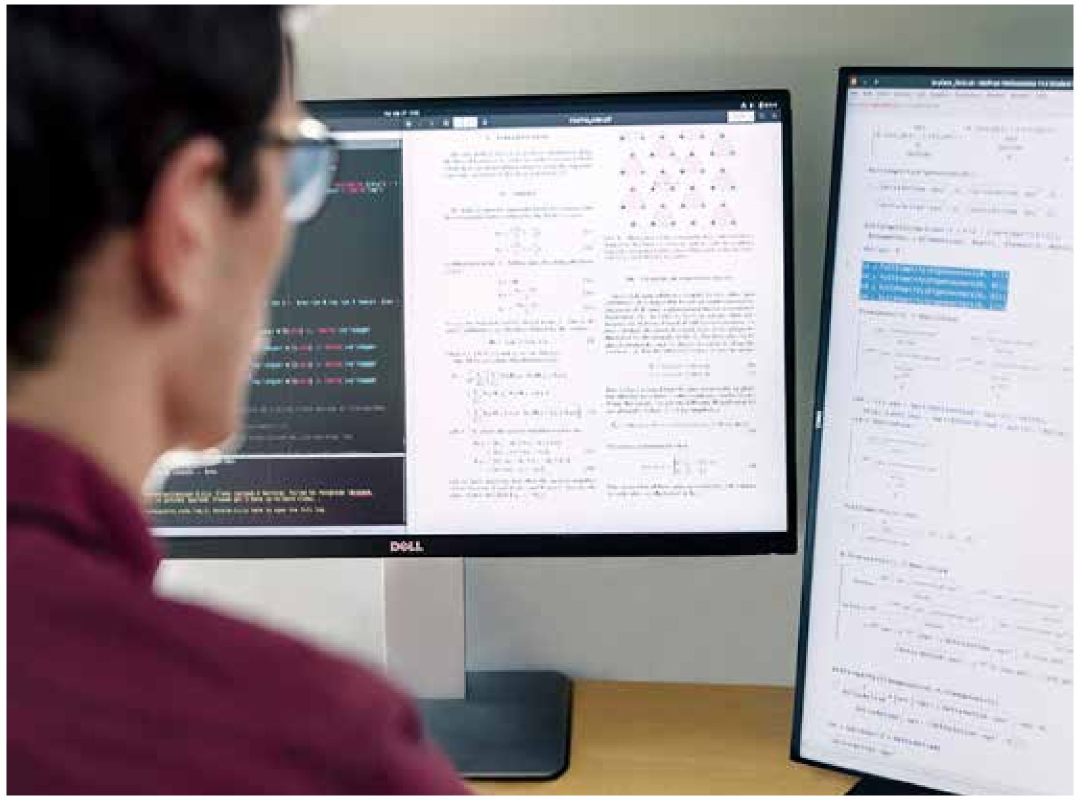
During the second half of 2021, the group participated in measurements of topological metal surfaces, in collaboration with Prof. Sudbø. We also participated in photoelectron diffraction measurements of dopant structures for quantum devices. Work carried out in the second half of 2021 was in collaboration with Justin's new group at UiO.



The surface of a semiconductor sample on which square regions of graphene have been formed. The colour scale in the image shows variations in the work function, and is imaged using a nanoESCA PEEM spectromicroscope [see: ACS Appl. Mater. Interfaces 2021, 13:37510 for further details].

THEORETICIANS AT WORK

The research performed with different means of tools and interactions.



CHRISTOPH BRÜNE

Molecular Beam Epitaxy of Antiferromagnets

Theme and goal

The QuSpin Molecular Beam Epitaxy (MBE) group's goal is to develop the synthesis of high-quality materials with potential for spintronics research and application. We have recently started up our new lab and are now synthesizing the first materials.

To do this, we rely on so-called "molecular beam epitaxy". This technique uses an ultra-high vacuum environment to guide atomic or molecular beams onto a target, where a crystalline layer will grow. Using this method, we can create very high-quality crystals with thicknesses down to a single atomic layer. It is also possible to combine different materials to create new physical properties and control them in detail or to create nano-objects like nano-wires and quantum dots. Using MBE growth for magnetic materials will enable us to create, control and investigate materials that can be used in spintronics research and applications. Furthermore, the control down to single atomic layers will allow us to tailor the material properties so that we can enhance desired characteristics or even create new ones.

Key questions

Our first 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. This work is done in close collaboration with Arne Brataas' and Mathias Kläuis' groups.

Helimagnetic systems are the group's second research area. These materials are very interesting for their complex magnetic structures, based on a spiralling (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 nano-objects for future low-energy memory devices. We will develop the growth of materials that host helimagnetic or skyrmionic structures at room temperature for future applications.

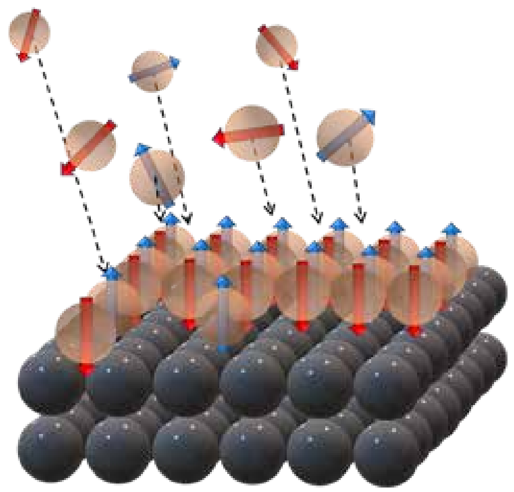


Illustration of molecular beam epitaxy growth of an antiferromagnetic layer on a non-magnetic substrate.

These investigations are conducted in close collaboration with Dennis Meiers' group, with two Ph.D. candidates shared between the two groups.

We have recently also started activities towards the synthesis and investigation of hybrid systems that combine antiferromagnets and superconductors. This work will initially focus on the antiferromagnetic semiconductor MnTe and is a collaborative effort with the theory groups at QuSpin and partners at the IF PAS in Warsaw, Poland.

Activity in 2021

The year 2021 saw the crossing of major milestones in the growth of the antiferromagnetic semiconductor CuFeS2. We were able to demonstrate the growth in different crystal structures and -orientations. Growth of the helimagnetic FeSn and MnSn material systems saw the change of substrates in order to improve crystal growth. The focus of all growth activity was put on reproducibly growing one single crystal phase and improving the surface quality of thin films.

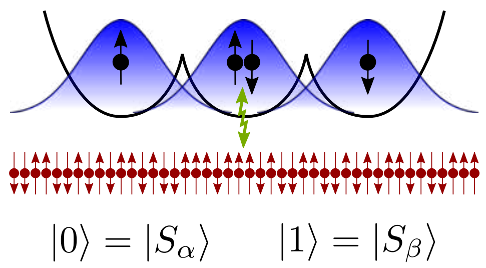
The planned installation of an additional growth chamber was further delayed by legal technicalities, but we are still optimistic about getting it up and running in 2022.

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. Although my research is theoretical, it 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. Such qubits have the attractive features of being 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 2021

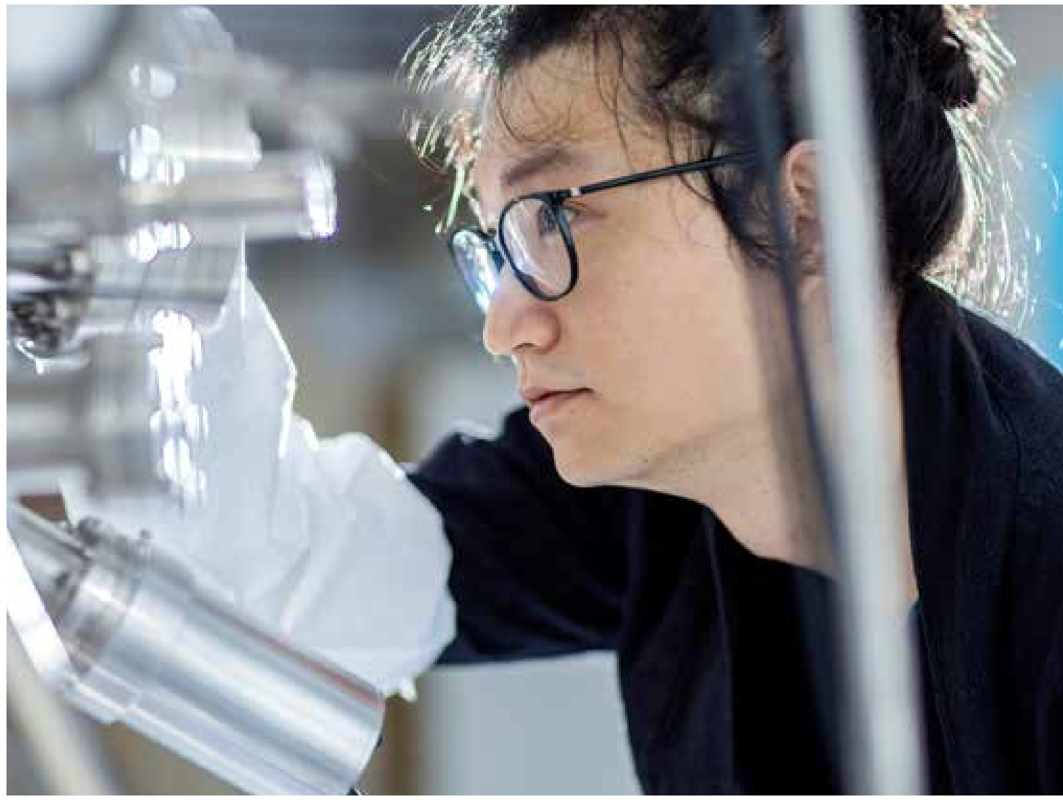
Currently, one of the core activities of my group is developing a detailed understanding of the properties of the valence-band holes in materials such as Si and Ge. Due to the underlying *p*-type nature of their wave function, the spin and orbital degrees of freedom of confined holes can become strongly mixed, resulting in complex spin dynamics that depend intricately on the interplay between the applied magnetic field, electric field, and the band structure itself.

Another direction of research in my group is to try to solve the problem of the nuclear spins in GaAs in some other way, which includes investigating protocols for actively suppressing the effect of the nuclear spins and developing qubit implementations that have an intrinsic protection to the nuclear fields, such as the singlet-only qubit we proposed a few years ago.

A few highlights of the works we published last year are (1) a detailed experimental and theoretical study of the properties of a two-dimensional hole gas coupled to two superconducting contacts, resulting from a collaboration with IST Austria, (2) a first proposal for coupling spin-qubit systems to anisotropic ferromagnets, which allows for coherently controlling multiple qubits simultaneously, and (3) a short review article giving an overview of different approaches to create qubits that are intrinsically protected against decoherence, which resulted from a collaboration with the University of Copenhagen and the University of Colorado, Boulder.

EXPERIMENTALISTS AT WORK

The Ph.D. students at work in the ARPES lab setting up for measurements of thin-film samples, and the MBE lab monitoring sample growth processes.



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.

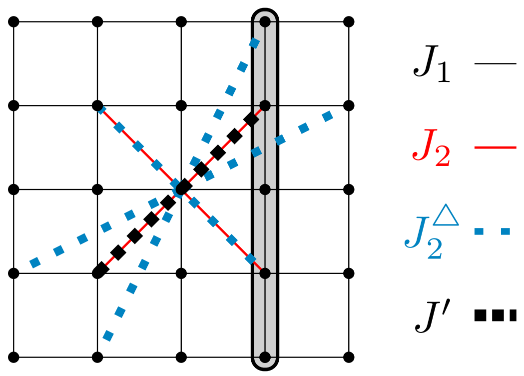
Of particular interest are phases known as quantum spin liquids, whose order is not described by broken symmetries but may instead be of a topological nature. In recent years, new materials have been discovered which exhibit evidence of unconventional behavior pointing towards spin-liquid physics.

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 magneto-electronics and magnonics of oxide ferromagnets and antiferromagnets. 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 longer-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

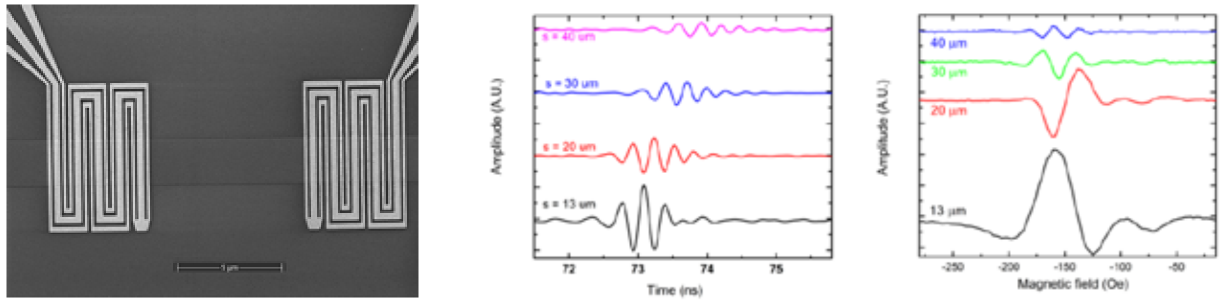
Our primary aim is to understand and probe the excitations and coupling between magnons, phonons and charge carriers at an energy scale that ranges from sub-thermal energies to electron volts. In the spin domain, the prime motive is to understand magnons, and the expression in the form of interacting and 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 collaborating and seeking collaboration with groups on the material synthesis side to address our key questions.

Activity in 2021

In 2020 we finalized our work on developing a continuous wave version of pulsed wave spectroscopy, assessing propagating properties of magnetodynamic waves between antennas through a field sweep protocol. This has been used for test samples employing both NiFe and Co2FeAl. A small collaborative work comparing a series of 1D magnonic lattices with a magnetodynamic simulations and a simple analytic model was also brought to finalization. Funding was secured for a project through the FRIPRO program supporting the main goals of the group, where we in the course of the next four years will explore and control magnon-phonon interactions in oxide systems with the aim to thermally pump the magnon system. This is an internationally collaborative effort where THz imaging (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.



Left: Gold antenna structures for sending and receiving magnetodynamic waves in magnetic striplines; (middle) time-domain pulses used for pulse-based characterization for thick films (150 nm NiFe); (right) field domain data for continuous wave characterization of superior quality for thin films (15 nm NiFe).

DENNIS MEIER

Topological Spin Textures

Theme and goal

The discovery of magnetic skyrmions and their emergent physical properties has propelled the research on topological spin states in solid state systems and motivated the design of new devices where skyrmions act as mobile information carriers. Recently, the scope has widened, and a zoo of topologically non-trivial spin textures has been discovered, including magnetic dislocations, disclinations, and helimagnetic domain walls.

We study the fundamental physics that gives rise to the formation and unique behaviors of such topological spin textures. Using advanced microscopy techniques and nano-structuring tools, we learn how these magnetic nano-objects can be controlled and explore their unusual local responses.

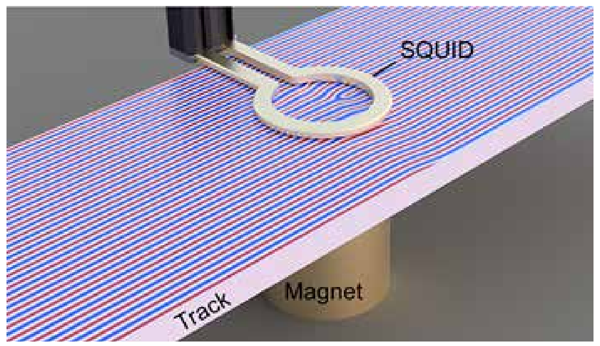
The goal of our research is to understand and utilize the emergent functional phenomena associated with topological spin textures, demonstrating novel application opportunities and innovative device concepts for next-generation spintronics.

Key questions

We aim to create fundamental knowledge about the nanoscale physics of topological spin textures. For this purpose, we apply different microscopy techniques and nano-structuring methods, such as magnetic force microscopy, electron microscopy, and focused ion beam (FIB). In addition, we perform complementary micromagnetic simulations to understand the formation process of topologically non-trivial spin structures in confined media and emergent topology-driven interactions that distinguish them from the surrounding material. We are particularly interested in novel perspectives that arise for future low-energy electronics.

Activity in 2021

In 2021, we achieved several breakthroughs concerning the control of topological spin textures and proposed different concepts for future device applications. Working together with Alireza Qaiumzadeh, Arne Brataas, and our international partners, we published an innovative read-out scheme for topological spin textures in device-relevant racetrack geometries using superconducting microcoils. In collaboration with Christoph Brüne's team, we began to investigate new magnetic thin film materials. A special highlight in 2021 was our first patent application for a new type of circular racetrack memory based on skyrmions, which was presented at the Nordic Innovation Fair. In the next step, we will design a proof-of-concept device and further improve our new technology, utilizing the unique infrastructure available within QuSpin and at NTNU Nano-Lab.



Read-out scheme for topological spin textures using superconducting quantum interference device (SQUID) technology.

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 a range of systems using theoretical and numerical techniques.

The goal of this research is to show that superconducting triplets are useful low-dissipation information carriers in emerging spintronic systems.

Key questions

Our research considers atypical geometries and model setups for examining the conversion mechanisms and manipulation of superconducting singlets and triplets, and aims to identify their experimentally accessible signatures. By challenging the geometrical constraints of conventional spintronics, we hope to enable new superconducting spintronic device design and control.

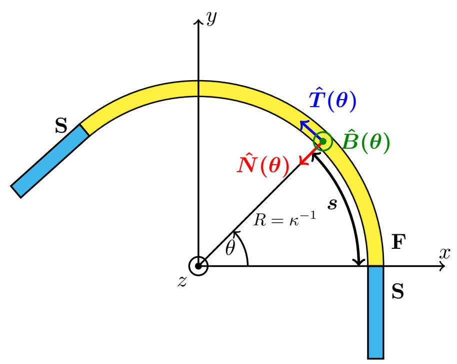
One of our key research directions is to exploit recent experimental advances in creating spintronic devices with curvature, which provides new freedoms for the design of future devices. We also aim to look beyond the conventional paradigm of direct proximity between superconducting and magnetic elements in spintronic devices, and will examine photon-mediated effects.

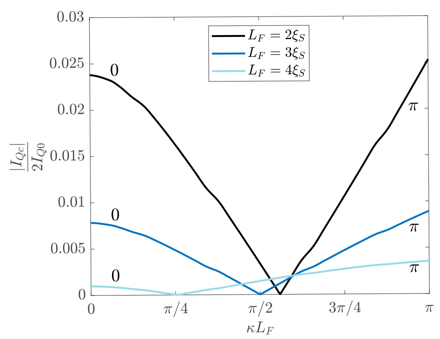
Activity in 2021

A highlight of the year for us was deriving the equations of motion for diffusive spin transport in curvilinear coordinates, which showed that bending a ferromagnetic wire can reverse the current direction in an SFS junction (see figure). Since then, we have also shown that the geometric curvature can control the superconducting transition, resulting in a superconducting spin valve (arXiv: 2112.12797). This was a collaboration between our group and Morten Amundsen, who we were fortunate to have as a frequent visitor throughout this pandemic year. We also bid farewell to Mathias Svendsen, who has gone on to study for a PhD degree in Tübingen, Germany.

This year we have also enjoyed working with Jacob Linder and Lina Johnsen on showing magnetic control of superconductor-antiferromagnet systems. Andreas Janssønn and Henning Hugdal have been working on the difficult problem of deriving the quantum details of the cavity-photon coupling between superconductors and ferromagnets, which we showed semi-classically last year, and are now near completion.

In a brief respite between the Delta and Omicron related restrictions, I attended in person as invited speaker at the Quantum Matter Academy retreat, in Erfurt, Germany. Presentations at the Technoport International conference, and the Würzburg/Dresden-cluster's event for the International Day of Women and Girls in Science, had to be moved online.





Bending ferromagnetic nanowires in SFS Josephson junctions can reverse the charge current direction. Figure from Phys. Rev. B 104, L060505 (2021).

ALIREZA QAIUMZADEH

Novel Quantum Materials

Theme and goal

Recent discovery of two-dimensional (2D) ferro- and antiferromagnetic (AFM) materials in metallic, semiconducting, and insulating phases is a paradigm shift in spintronics. In low dimensions, quantum fluctuations and interactions are usually strong and cannot be neglected anymore. The primary focus of our current research is on exotic magnetic and topological phases, nonequilibrium phenomena, and emergent phenomena in novel 2D quantum systems. In general, we are interested in phenomena such as ultrafast manipulations of spin interactions, quantum magnonics, topological magnetic solitons, topological orders and topological phases, and unconventional quantum transport.

Developing theories to understand and uncover exotic equilibrium and nonequilibrium states of novel quantum materials with an ultimate application in beyond the state-of-the-art quantum devices is our main goal.

Key questions

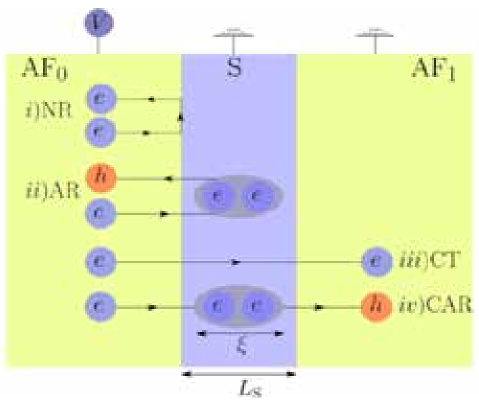
Interplay between spin, charge, and lattice degrees of freedom, interactions and hybridization between different quasiparticle and collective excitations such as magnons, phonons and plasmons, in equilibrium and nonequilibrium, lead to emerging phenomena in both real and momentum spaces.

Microscopic understanding of these phenomena are challenging problems 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 in stabilizing different topologically nontrivial magnetic phases and exotic spin transport in novel 2D spin systems. Developing theoretical and computational frameworks beyond conventional approaches for describing these phenomena on a microscopic level is an important topic in our group.

Activity in 2021

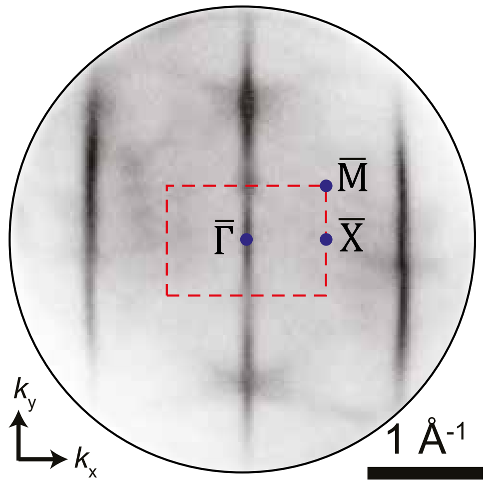
In 2021, we continued our collaboration with Arne Brataas as our main internal collaborator and several other world-leading experimental and theoretical groups. We collaborated with the experimental group of Prof. Mathias Kläu at the Johannes Gutenberg University of Mainz, Germany on magnon transport in AFM systems and Dennis Meier in QuSpin on topological spin textures. We will expand this collaboration to other mutual research interests in the future.

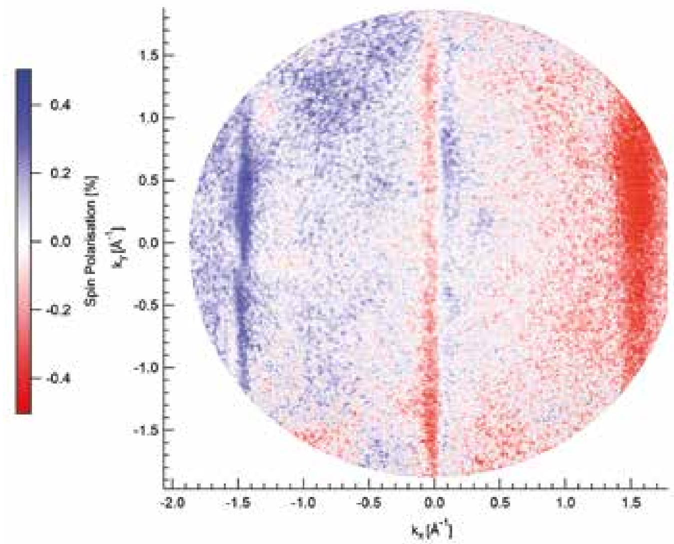
Under the *2Dtronics* project, PhD student Verena Brehm has started to work on magnon transport in biaxial AFM layers and novel 2D spin systems in collaboration with our project partners in Poland and our new collaborators Richard Evans and Elton Santos in the UK. In another project, postdoc Marion Barbeau has, in collaboration with the group of Mikhail Katsnelson and Mikhail Titov in the Netherlands, developed a quantum kinetic formalism for magnons excited by hot electrons in an AFM metal under strong laser irradiation. In collaboration with Arne Brataas and PhD student Martin Jakobsen, we found a tunable crossed Andreev reflection in hybrid superconductor-AFM junctions which can be used as a Cooper pair splitter in quantum entanglement technology (Fig). With our master student Sander Hanslin, we found light can induce nonequilibrium Dzyaloshinskii-Moriya interaction (DMI) in AFM metals. In collaboration with another master student, Herman Ottesen, we studied optical response of Dirac fermions in an AFM semimetal, and we found a transverse Hall-type conductivity with non-topological nature. Finally, thanks to NTNU Nano, the first version of our open-source software for AFM simulation, developed by master students Viroshaan Uthayamoorthy and Even Aksnes, is ready for release in early 2022.

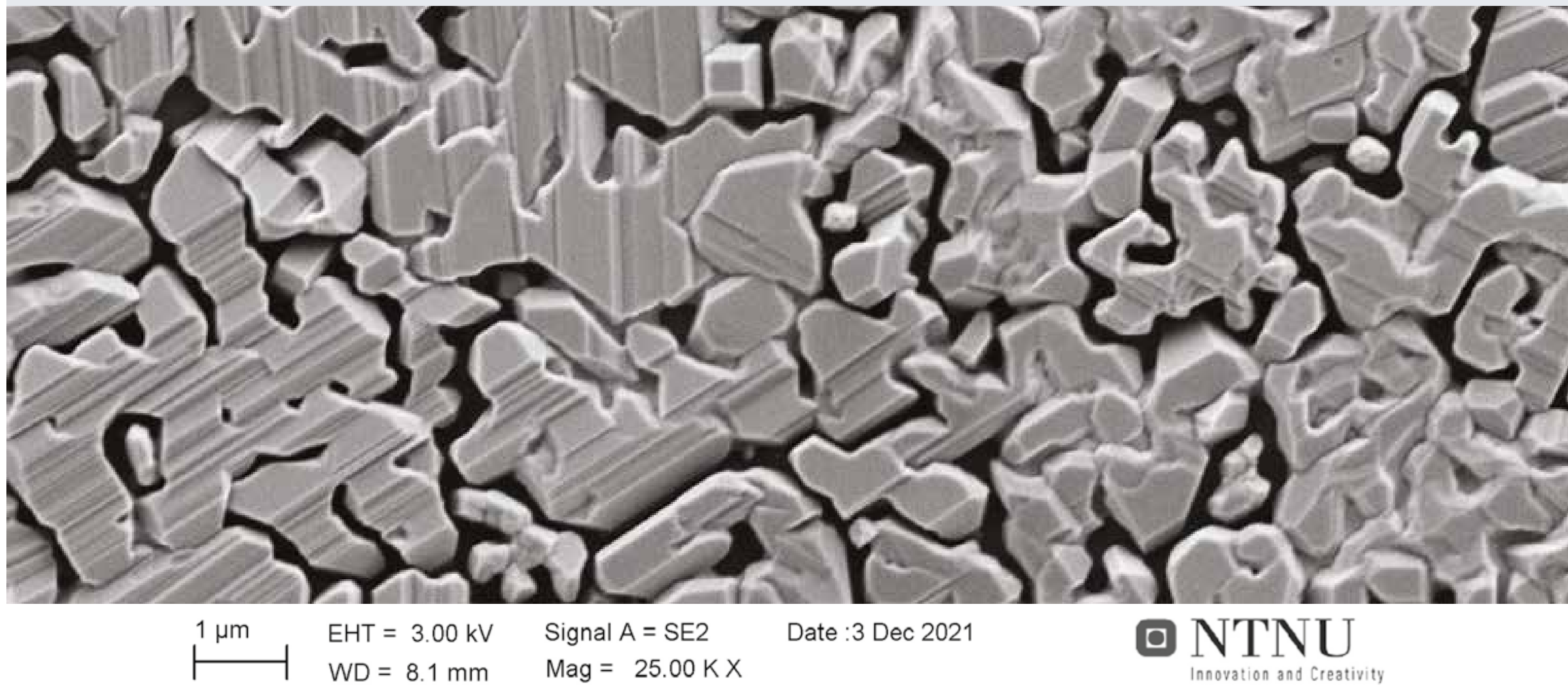


Schematic of a 2D AFM-SC-AFM heterostructure used as a Cooper pair splitter based on crossed Andreev reflection mechanism. [M. F. Jakobsen, A. Brataas, and A. Qaiumzadeh, Phys. Rev. Lett. 127, 017701 (2021)]

Images from the ARPES lab and the MBE lab

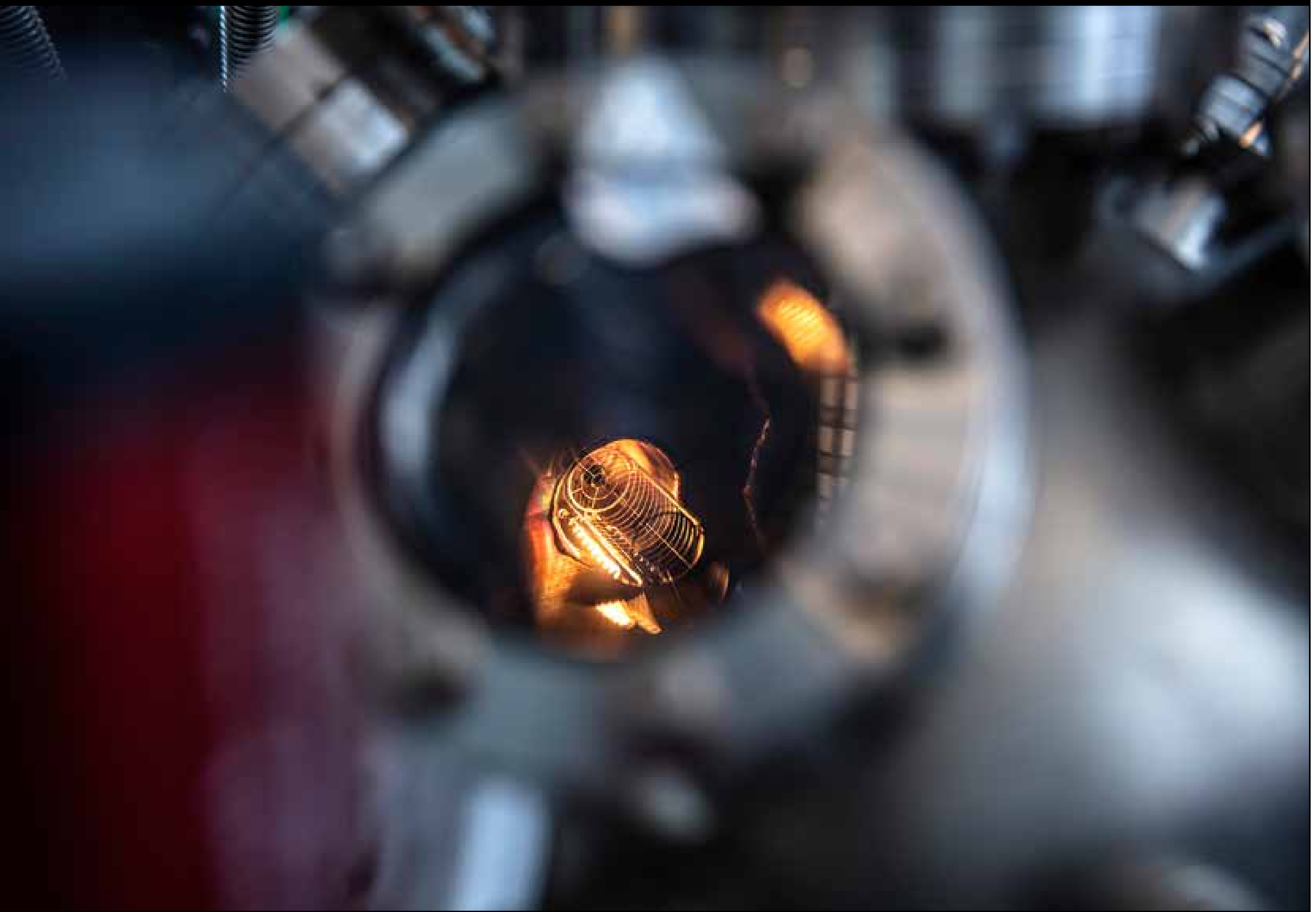






Upper image left: Spin integrated constant energy surface (kx vs. ky) of Bi(112) at the Fermi level. Upper image right: The same energy surface resolved for spin. Red and blue indicate the two orthogonal in-plane spin components.

Lower image: Scanning electron microscope (SEM) image of magnetic thin film grown by Molecular Beam Epitaxy (MBE).



International Partners and Research Network

Research is a collaborative effort that often carries across disciplines and strengthens scientific curiosity. We are privileged to have working relationships across the world that elevate our collective intelligence and add to the work in our field.

Professor Rembert Duine

Professor Mathias Kläui

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

QuSpin has the leading experimental scientist Professor Mathias Kläui as Professor II. Combined with the work of young and dynamic experimentalists in Trondheim, and supported by our excellent theory activity, QuSpin is taking its experimental activity to the next level.

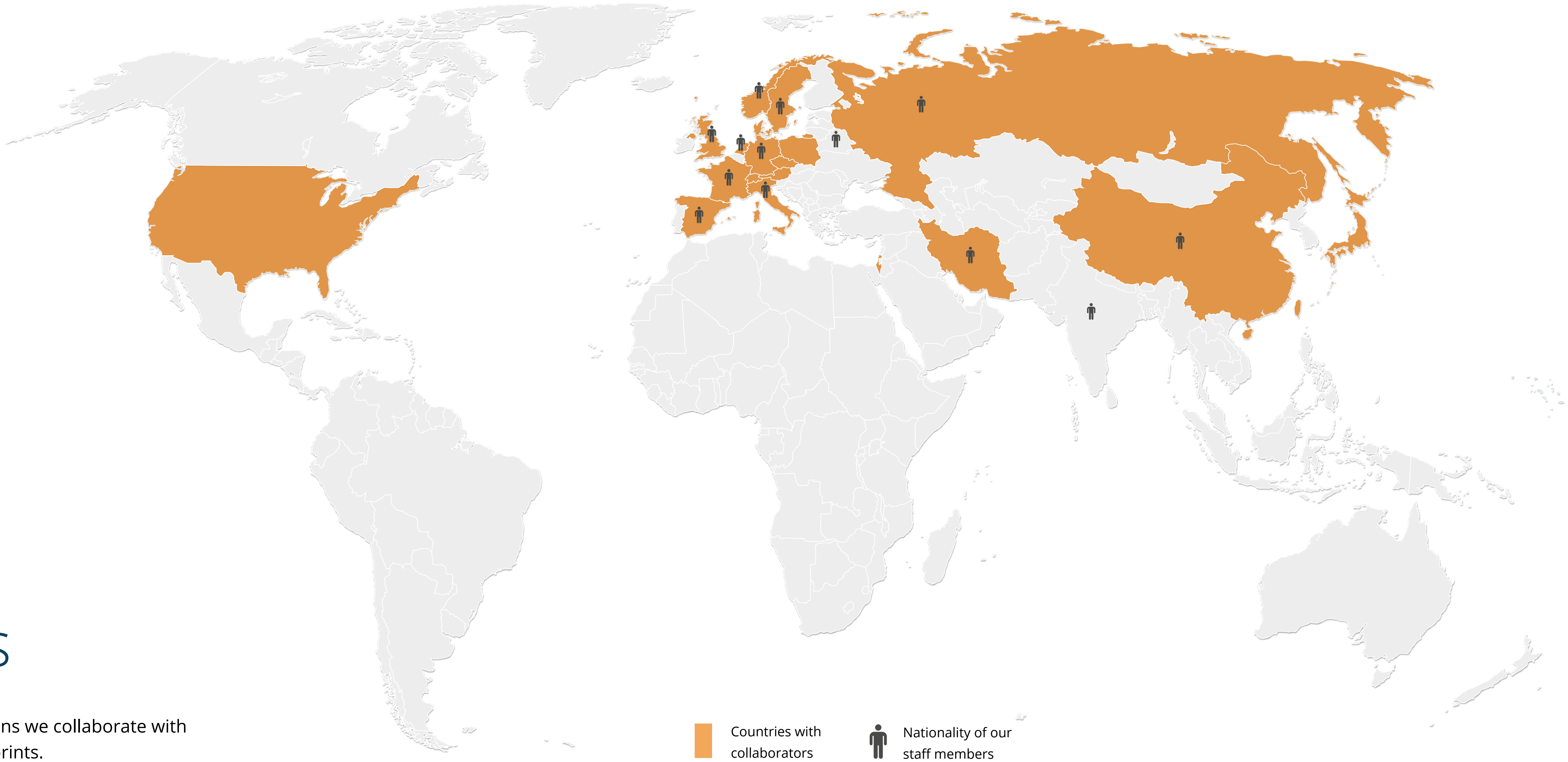
The collaboration with JGU Mainz gives QuSpin access to material growth, characterization, and transport measurements. A central theme of the collaboration has been spin transport in antiferromagnetic insulators, where we have established fruitful synergies between experimental and theoretical developments.

Professor Rembert Duine is a leading theoretician 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 sub-fields 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. Professor Duine´s past year's activities extend QuSpin´s research in the direction of the new field of spin angular momentum transferred by phonons.

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.

Due to last year's – and ongoing - international travel restrictions, the visits have been significantly reduced. Instead, we invited guests to hold scientific talks online on the Zoom platform. The talks were given by speakers from collaborating universities in the Germany, Russia, and the USA. These online talks have helped us keep up our interaction with the international research community during the pandemic and have added valuable input, knowledge, and inspiration to our ongoing research. However, we look forward to physical meetings and interactions as soon as the situation allows it.

In addition, we collaborate with internationally leading theoretical and experimental groups in many places around the world (See map next page).



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

CZECH REPUBLIC
Czech Academy of Sciences, Prague

CHINA
Central South University, Changsha
China Academy of Engineering Physics, Beijing
University of Chinese Academy Sciences, Beijing

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 of 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

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

JAPAN
RIKEN Center for Emergent Matter Science, Saitama

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

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

SWITSERLAND
ETH Zürich, Zürich

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

UK
Cambridge Graphene Centre, Cambridge
Hitatchi Cambridge Laboratory, Cambridge
Loughborough University, Loughborough
University of Cambridge, Cambridge
University of York, York
Swansea University, Swansea

US
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

QuSpin Balance Project 2021-2022

Over the period of 2021-2022, our Center has received a MNOK 1 grant from the Research Council Norway in the context of their program on gender balance in senior positions and research management in Norway. New knowledge, learning and innovative measures will lead to greater gender equality and gender balance.

In 2022, the EU Commission introduced new requirements for Horizon Europe grants. Applicants must now provide a writen Gender Equality Plan (GEP). The document must be published on the organization's website and show dedicated resources to the plan. The organization must collect and report gender data for all positions on an annual basis, and the scheme must contain competence development plans within the organization. From 2022 onwards, the Norwegian Research Council will apply the same requirements, adjusted to Norwegian legislation.

Gender Balance at our Research Center
Female researchers are totally absent from permanent positions as professors and associate professors at our Center. We want to change this. Our goal in participating in this program is to contribute with experience and new knowledge, and to benefit from ideas, knowledge, and experience from others.

We hold a diverse Center of permanent and temporary research positions with people from thirteen different countries. However, the Center is strongly male dominant, which sets the premises for our leadership, strategy, research, culture, and recruitment. The permanent top positions are few, the qualification requirements are high, and the competition is tough.

Our goal is for 1/3 of all new recruitments to be females. We need to understand what hinders this today and how to reach this goal in the future.

We also have very few female candidates and applicants. We need to understand how we can make an academic career more attractive, for both males and females. We have several female researchers with the necessary competence and personal skills. To further develop their careers towards top positions, competence as well as individual skills and mentoring are important tools. We want to help them achieve this, and actively communicate and share experience from our project.

Main project activities on different levels to increase the gender balance
This is an action-based project where we will do a survey on the status at our Center, and analyze the situation. We want to raise everyone's awareness, clarify requirements and expectations, and implement relevant.

We will draw on internal and external expertise as well as establish a mentor group with female professors from our own national and international networks.

Internal survey 2021
In the autumn of 2021 we performed an internal survey. It addressed issues such as leadership eadership, majority and minority groups, organizational culture, competencies, career development as well as recruitment. The report will be the basis for workshops and measures to be taken in 2022.

We also conducted a couple of dialogue groups with the females at the center to increase the understanding of each other's journeys and diversity, ideas, values, and interests.

Project group
The members are Center Director/Professor Arne Brataas (project owner, QuSpin), center coordinator Karen-Elisabeth Sødahl (project manager, QuSpin), PI/Professor Asle Sudbø, PI/Professor Jacob Linder, Professor Vivian Anette Lagesen (Department of Interdisciplinary Studies of Culture/NTNU) and senior researcher Dr. Sol H. Jacobsen (QuSpin)

Female researchers at QuSpin. From left: Atousa Ghanbari (Ph.D. student), Payel Chatterjee (Ph.D. student), Lina Grøvan Johnsen (Ph.D. student), Verena Brehm (Ph.D. student), Marion Barbeau (Postdoc), Anna Cecilie Åsland (Ph.D. student) and Dr. Sol H. Jacobsen (senior researcher).

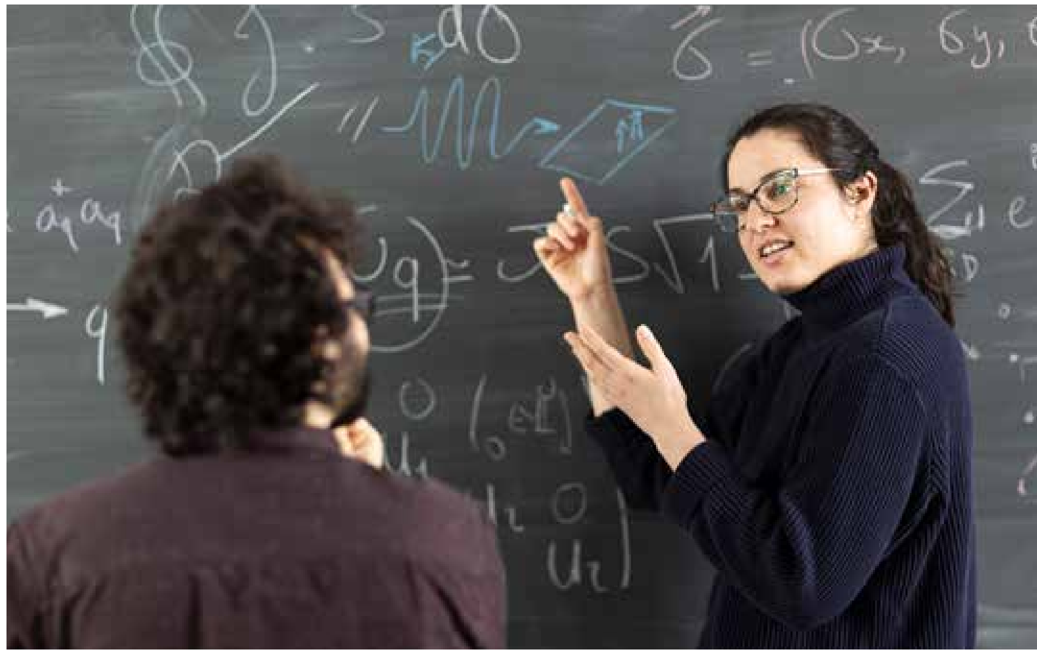
The French 2 television channel released a documentary «La science a mauvais genre» in October, 2021. NTNU was one of the institutions which presented their work towards increased gender balance in Academia. Our French Postdoc Marion Barbeau was one of the researchers being presented in this film sharing her experiences.

Research Training of our Ph.D. Students 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, as well as gain experience by co-supervising our Ph.D. students and Master's students.

Discussing scientific challenges.

Group dialogue often takes place in a relaxed environment in our lunchroom.



The blackboard is often used to explore scientific ideas and solutions to a problem.

We normally give a range of workshops and seminars at the Center. Due to the ongoing corona pandemic, our collaboration workshops have been cancelled. They were replaced by an online international seminar series on the Zoom platform where invited speakers gave their talks. This was successful, and also allowed us to reduce costs and travel time. However, this whole range of digital alternatives can never fully replace the benefits of physical meetings, where sharing ideas and knowledge takes place in a more open and spontaneous manner.

Our regular seminars and journal clubs have partly taken place online. The benefit of this solution was a larger audience. The speakers presented their work, shared ideas and discussed 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.

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 Ph.D. students, postdocs and researchers.

There were some very good talks that gave me some ideas I hadn't thought about.
- Chris Palmström

Socializing before the art tour and the workshop dinner.

QUANTUM SPINTRONICS 2021

Our Annual International Workshop

Our researchers must gather with leading international professionals outside QuSpin. Targeted workshops spark inspiring dialogues around current challenges and findings and are the ideal breeding ground for a creative environment for focused peer discussions.

After canceling the annual workshop in 2020 we were looking forward to welcoming ten international speakers to Trondheim in December, 2021. Unfortunately, at the last minute, the new corona variant, Omicron, forced us to change the program into a hybrid workshop. Only Professor Chris Palmström from Santa Barbara, California, could make it to Norway for the occasion. The other speakers joined online. We were very grateful for everybody's flexibility in adapting to the circumstances.

The ten speakers, representing both the theoretical and experimental areas, shared their perspectives and work with around sixty participants physically present at the conference center.

The various talks on state-of-the-art research were very inspiring to us all. In addition, the poster sessions gave an overview of the work performed at the Center and created a basis for many fruitful and enjoyable discussions among fellow researchers.

Our workshops are not all work and no play. We invited everyone to a guided tour at the newly opened K.U.K. art center with an international exhibition of young artists, then dinner at the restaurant Gubalari, named after Norway´s most famous female T.V. chef.

We look forward to extending our annual scientific workshop into a three-day conference in June 2022, where we will open up for a larger audience.

Our master students at the poster session.

Colleagues in close dialogue around a poster theme.

Plenum discussions.

There are different topics to discuss in the various posters.

Experiementalists in dialogue.

Outreach

One of the key goals of QuSpin is to make physics in general, and our Center in particular, attractive for young students. Moreover, we want to reach the general public by sharing our work through accessible language and tangible examples, illustrating why our research is crucial and worth funding.

In 2021 we used several opportunities to share our knowledge and the research activity at our Center with a broader audience.

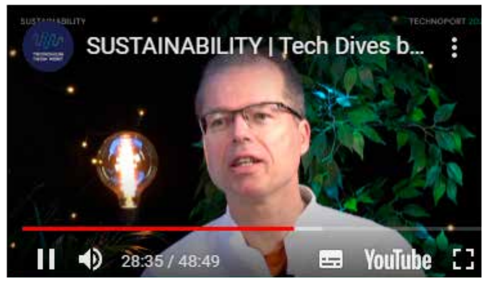
Video interviews at Technoport 2021 International Conference
Our three researchers Arne Brataas, Justin Wells and Sol H. Jacobsen were invited to talk under the theme *Tech Dives and Sustainability*. In a 15-minute interview, they presented our work, direction, and goals, and shared their experience on what is attractive about working as a researcher, and what impact our research can have on the development of a more sustainable future. The video is available on https://www.youtube.com/watch?v=t3w8d0yBQ1g

Student visits from high schools
Students from the Vestby school, Viken visited NTNU and QuSpin. Our PhD student Niels Henrik Aase gave a talk "*From High School to researcher at NTNU*", on Zoom since he was diagnosed with corona that very morning. The students also visited our ARPES lab where PhD students Frode Sneve Strand and Håkon Ivarssøn Røst demonstrated our activities. We were told that this visit was very motivating for their ongoing research projects in class, and for possibly taking their next educational step within physics at the university.

The Researcher on the Screen Project
Our PhD student Eirik Fyhn was invited to give a series of online talks on physics to a number of high-school students in Norway. The goal of this project is to motivate students for an education within natural sciences.

Motivational talks
PhD student Eirik Fyhn held motivational talks to the first-year students at our Faculty of Natural Sciences.

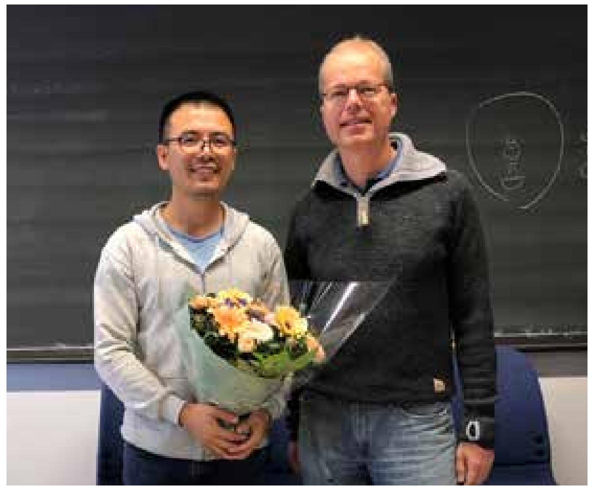
Senior researcher Dr. Sol H. Jacobsen held a motivational talk online to recruit master students at NTNU. She was also invited to speak at the "Fireplace Chat", Quantum Matter Academy retreat in Erfurt, Germany, hosted by the Wuerzburg-Dresden Cluster of Excellence. She also spoke about female recruitment at the Grete Hermann Network's online event in connection with the International Day of Women and Girls in Science.



Center director Professor Arne Brataas, Professor Justin Wells and senior researcher Sol H. Jacobsen gave online interviews at the "Technoport 2021- Deep Tech Conference" under the theme "Sustainability".

Senior Researcher Sol. H. Jacobsen gave a NTNU motivation talk online to master students on studying physics and sustainability.

The visit from Viken school after the talk by Niels Henrik Aase on Zoom, and the demonstration in the ARPES lab by the Ph.D.'s Frode Sneve Strand and Håkon Ivarssøn Røst (both in front).



Glimpses from Our Center

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

Diversity and different perspectives are essential factors in our approach of challenging questions in our Research Center. Each researcher and student who comes to the Center brings their unique personality and experience to the group dynamics, and we notice how this adds value to our research.

Our Center's researchers come from thirteen different countries. They come from different walks of life, cultures, and ethnicities. They speak a variety of language and are of diverse genders.

We normally spend time and resources on developing a prosocial and robust culture. We build arenas where people can meet, create, and interact. But physical meetings have been scarce last year, since we had to comply with pandemic restrictions and form smaller cohorts.

Our newcomers have shown impressive flexibility when boarding our Center. The use of home offices and digital meeting places have been the rule rather than the exception in 2021, but little by little we were allowed to open up again.

We used every available opportunity for social gatherings, celebrating successful publications in the Physical Review Letter (PRL), birthdays, Christmas and Easter holidays, as well as wishing good colleagues and friends all the best on their journey to the next phase in their careers. We also explored our close surroundings walking an art trail through our NTNU campus.

All in all, we are impressed with everyone for keeping up the spirit and for persisting in work and social interaction with their peers!

Ph.D. Defenses and Completed Master Theses

We congratulate our Ph.D. 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

Hugdal, Henning Goa. Ph.D. Defense Feb 8th, 2021. Title: *A study of Proximity-induced and magnon-mediated superconductivity on the surface of topological insulators.* Supervisor: professor Asle Sudbø. Co-supervisor: Professor Jacob Linder.

Jakobsen, Martin Fonnum. Ph.D. Defense Nov 19th, 2021. Title: *Transport in Magnetic and Superconducting Heterostructures.* Supervisor: Professor Arne Brataas. Co-supervisor: Associate Professor John Ove Fjærestad.

Krohg, Fredrik Nicolai. Ph.D. Defense September 10th, 2021. Title: *Studies of Ginzburg-Landau theories for two-component chiral superconductors.* Supervisor: Professor Asle Sudbø. Co-supervisor: Professor Jacob Linder.

Lysne, Erik Nikolai. Ph.D. Defense June 6th, 2021. Title: *Novel Topological Spin Solitons for Spintronics Applications.* Supervisor: Professor Dennis Meier. Co-supervisor: Professor Arne Brataas.

Simensen, Haakon Thømt. Ph.D. Defense June 6th, 2021. Title: *Magnetization dynamics and interactions in ferromagnetic, antiferromagnetic and superconducting systems.* Supervisor: Professor Arne Brataas. Co-supervisor: Professor Jacob Linder.

Thingstad, Even. Ph.D. Defense September 3rd, 2021. Title: *Collective effects in low-dimensional systems with coupled quasiparticles.* Supervisor: Professor Asle Sudbø. Co-supervisor: Professor Jacob Linder.

COMPLETED MASTER THESES

Bergan, Snorre. Title: *Topological field theories of superconductor heterostructures.* Supervisor: Professor Asle Sudbø.

Brattegard, Sindre Helling. Title: *Explorations of Coherent State Path Integral Formulations for Spin Systems Using a Projection Operator Implementation of Occupation Number Constraints.* Supervisor: Associate Professor John Ove Fjærestad.

Dyring Hansen, Martine. Title: *Spin-Orbit Enhanced Josephson Effect.* Supervisor: Professor Jacob Linder.

Falch, Vemund. Title: G*iant Anisotropy in the Josephson Effect and Magnetization Dynamics in Spin-Orbit Coupled Antiferromagnetic Josephson Junctions.* Supervisor: Professor Jacob Linder.

Johnsen, Christian Svingen. Title: *Phase-frustrated three-band superconductors.* Supervisor: Professor Asle Sudbø.

Lockert, Karl Kristian Ladegård. Title: *Phonon coupled Luttinger Liquids in Haldane armchair ribbons.* Supervisor: Professor Asle Sudbø.

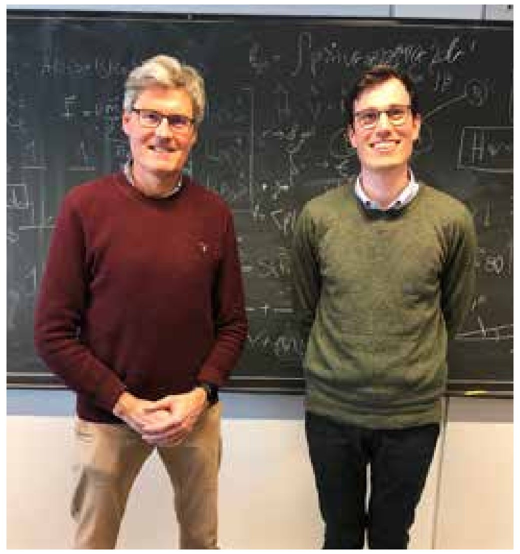
Ottesen, Herman Lileng. Title: *Optical Conductivity of Dirac Fermions in Antiferromagnetic Semimetals.* Supervisor: Senior Researcher Alireza Qaiumzadeh.

Svendsen, Mathias Bo Mjøen. Title: *Curvature in Superconductor-Ferromagnet Structures.* Supervisor: Senior Researcher Sol H. Jacobsen.

Taraldsen, Øyvind. Title: *Quantum Quenches in Noncentrosymmetric Superconductors.* Supervisor: Professor Jacob Linder.

Aase, Niels Henrik. Title: *Many-body effects in topologically non-trivial quantum systems.* Supervisor: Professor Asle Sudbø.

Even Thingstad and Asle Sudbø.



Asle Sudbø and Henning Goa Hugdal.

Arne Brataas and Martin Fonnum Jakobsen.

Asle Sudbø and Fredrik Nicolai Krohg.

Dennis Meier and Erik Nikolai Lysne.

Haakon Thømt Simensen and Arne Brataas.

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.

NORWEGIAN RESEARCH COUNCIL RESEARCHER PROJECT

Professor Asle Sudbø and Professor Jacob Linder (NTNU) received a Researcher Project Grant for their proposal on *Equilibrium and out of equilibrium quantum phenomena in superconducting hybrids with antiferromagnetic and topological insulators.*

NETHERLANDS SCIENCE FOUNDATION (NWO)

Professor Rembert Duine (UU & TU/e) and Assistant Professor Reinoud Lavrijsen (TU/e) received a grant from the Netherlands Science Foundation (NWO) of € 700,000 for the proposal 'Black Holes on a Chip'. The goal of the proposed research is to use state-of-the-art materials science and nano-fabrication techniques to experimentally realise a magnetic analogue of astronomical black holes. The underlying theory was developed by Rembert Duine and published in 2017.

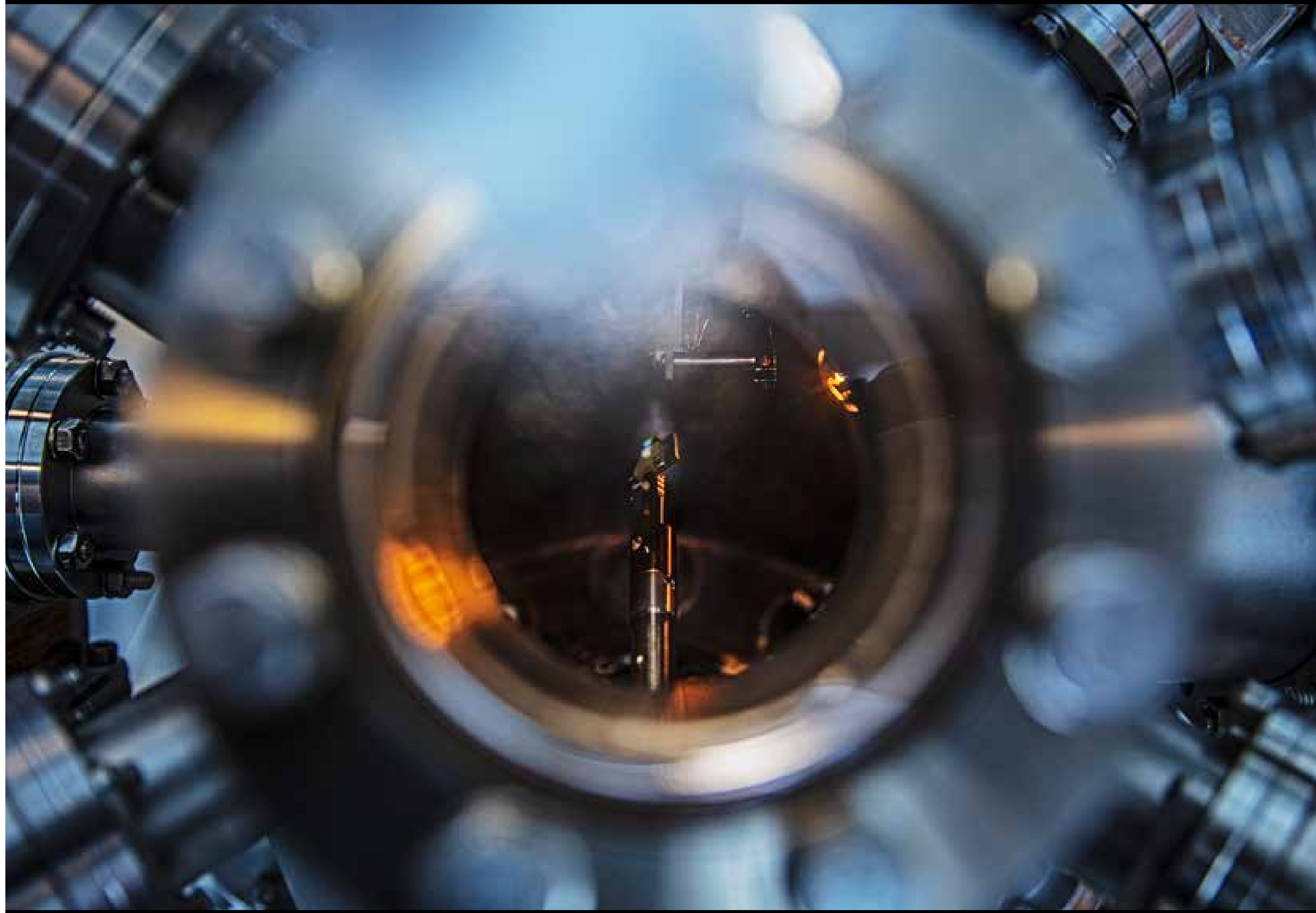
YARA'S BIRKELAND PRIZE

Knowledge grows

The NOK 100,000 Birkeland Prize in physics was awarded to Dr. Jabir Ali Ouassou for his contributions to a broad range of topics in the theory of superconducting hybrid structures. The Birkeland Prize is awarded by Yara to a PhD project at a Norwegian university, alternating between chemistry and physics. The jury wrote of Ouassou's work that it is basic research at its best, with a clear prospect for the knowledge gained to contribute to the development of practical products, possibly of great technological utility.

NORWEGIAN RESEARCH COUNCIL BALANCE PROJECT

Our center received the RCN grant of NOK 1 million over the period 2021-2022. This is part of the RCN Balance Program 2017-2022, a program to promote gender balance in senior positions and research management. New knowledge, learning and innovative measures will lead to greater gender equality and gender balance.



Highlights

FEBRUARY

PhD Defense
Henning Goa Hugdal

APRIL

Netherlands Science Foundation (NWO) Grant
Professor Rembert Duine (UU & TU/e) and Assistant Professor Reinoud Lavrijsen (TU/e)

JUNI

Norwegian Research Council Researcher Project Grant
Professor Asle Sudbø and Professor Jacob Linder

PhD Defense
Erik Nikolai Lysne

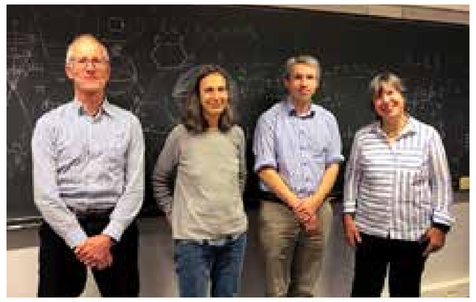
PhD Defense
Haakon Thømt Simensen

SEPTEMBER

Yara's Birkeland Prize
Dr. Jabir Ali Ouassou

PhD Defense
Fredrik Nicolai Krohg

PhD Defense
Even Thingstad



Internal center evaluation
By the Advisory Board

NOVEMBER

PhD Defense
Martin Fonnum Jakobsen

DECEMBER

Quantum Spintronics 2021
International workshop

Scientific Publications

We are privileged to have the work of our researchers published in journals such as Science, Physical Review Letters and Physical Review B. Our center has had fifty-five publications over the last year, and we look forward to continuing to add to our library of published research.

1. Boventer, I.; Simensen, H. T. ; Anane, A. ; Kläui, M. ; Brataas, A. and Lebrun, R..
Room-Temperature Antiferromagnetic Resonance and Inverse Spin-Hall Voltage in Canted Antiferromagnets.
Physical Review Letters 126, 187201

2. Jakobsen, Martin Fonnum; Brataas, Arne; Qaiumzadeh, Alireza.
Electrically Controlled Crossed Andreev Reflection in Two-Dimensional Antiferromagnets. ***Physical Review Letters*** 2021 ;Volum 127.(1)

3. Johnsen, Lina G.; Simensen, Haakon Thømt; Brataas, Arne; Linder, Jacob.
Magnon Spin Current Induced by Triplet Cooper Pair Supercurrents. ***Physical Review Letters*** 2021 ;Volum 127.(20)

4. Mueller, Manuel; Liensberger, Lukas; Flacke, Luis; Huebl, Hans; Kamra, Akashdeep; Belzig, Wolfgang; Gross, Rudolf; Weiler, Mathias; Althammer, Matthias.
Temperature-Dependent Spin Transport and Current-Induced Torques in Superconductor-Ferromagnet Heterostructures. ***Physical Review Letters*** 2021 ;Volum 126.(8)

5. Schlitz, Richard; Saül Vélez, Richard; Kamra, Akashdeep; Lambert, Charles-Henri; Lammel, Michaela; Goennenwein, Sebastian T. B. and Gambardella, Pietro.
Control of Nonlocal Magnon Spin Transport via Magnon Drift Currents. ***Physical Review Letters*** 126, 257201

6. Olthof, Linde A. B. Olde; Johnsen, Lina G.; Robinson, Jason W.A.; Linder, Jacob.
Controllable Enhancement of p-Wave Superconductivity via Magnetic Coupling to a Conventional Superconductor.
Physical Review Letters 2021 ;Volum 127. (26)

7. Bobkov, G. A. ; Bobkova, I. V. ; Bobkov, A. M. and Kamra, Akashdeep.
Thermally induced spin torque and domain-wall motion in superconductor/antiferromagnetic-insulator bilayers.
Physical Review B 103, 094506

8. Dvir, Tom; Zalic, Ayelet; Fyhn, Eirik Holm; Amundsen, Morten; Taniguchi, Takashi; Watanabe, Kenji; Linder, Jacob; Steinberg, Hadar.
Planar graphene-NbSe2 Josephson junctions in a parallel magnetic field. ***Physical Review B*** (PRB) 2021 ;Volum 103.(11)

9. Fyhn, Eirik Holm; Linder, Jacob.
Spin pumping in superconductor-antiferromagnetic insulator bilayers. ***Physical Review B*** (PRB) 2021 ;Volum 103.(13)

10. Fyhn, Eirik Holm; Linder, Jacob.
Temporarily enhanced superconductivity from magnetic fields. ***Physical Review B*** (PRB) 2021 ;Volum 103.(10)

11. Ghanbari, Atousa and Linder, Jacob.
RKKY interaction in a spin-split superconductor. ***Physical Review B*** 104, 094527

12. Ghanbari Birgani, Atousa; Erlandsen, Eirik; Linder, Jacob.
Effect of midgap states on the magnetic exchange interaction mediated by a d-wave superconductor.
Physical review B (PRB) 2021 ;Volum 104.(5)

13. Hanslin, Sander Ø. and Qaiumzadeh, Alireza.
Light-induced Dzyaloshinskii-Moriya interactions in antiferromagnetic metals. ***Physical Review B*** 103, 134428

14. Hartmann, Dion M. F. ; Wouters, Jurriaan J. ; Schuricht, Dirk ; Duine, Rembert A. and Kamra, Akashdeep.
Intersublattice entanglement entropy as an extensive property in antiferromagnets. ***Physical Review B*** 104, 064436

15. Haugen, Håvard Homleid ; Babaev, Egor; Krohg, Fredrik Nicolai and Sudbø, Asle.
First-order superconducting phase transition in a chiral p+ip system. ***Physical Review B*** 104

16. Irsigler, Bernhard ; Grass, Tobias ; Zheng, Jun-Hui ; Barbier, Mathieu and Hofstetter, Walter.
Topological Mott transition in a Weyl-Hubbard model: Dynamical mean-field theory study. ***Physical Review B*** 103, 125132

17. Johnsen, Lina G.; Linder, Jacob.
Spin injection and spin relaxation in odd-frequency superconductors. ***Physical Review B*** (PRB) 2021 ;Volum 104.(14)

18. Johnsen, Lina G.; Jacobsen, Sol; Linder, Jacob.
Magnetic control of superconducting heterostructures using compensated antiferromagnets.
Physical Review B (PRB) 2021 ;Volum 103.(6)

19. Krohg, Fredrik Nicolai; Babaev, Egor; Garaud, Julien; Homleid Haugen, Håvard; Sudbø, Asle.
Thermal fluctuations and vortex lattice structures in chiral p-wave superconductors: Robustness of double-quanta vortices. ***Physical Review B*** (PRB) 2021 ;Volum 103.(21)

20. Mæland, Kristian; Røst, Håkon Ivarssønn; Wells, Justin William; Sudbø, Asle.
Electron-magnon coupling and quasiparticle lifetimes on the surface of a topological insulator. ***Physical Review B*** (PRB) 2021 ;Volum 104.(12)

21. Sala, Arnau; Danon, Jeroen.
Line shapes of electric dipole spin resonance in Pauli spin blockade. ***Physical Review B*** (PRB) 2021 ;Volum 104.(8)

22. Salamone, Tancredi; Svendsen, Mathias Bo Mjøen; Amundsen, Morten; Jacobsen, Sol.
Curvature-induced long-range supercurrents in diffusive superconductor-ferromagnet-superconductor Josephson junctions with a dynamic 0−π transition. ***Physical Review B*** (PRB) 2021 ;Volum 104.(6)

23. Simensen, Haakon Thømt; Johnsen, Lina G.; Linder, Jacob; Brataas, Arne.
Spin pumping between noncollinear ferromagnetic insulators through thin superconductors. ***Physical Review B*** (PRB) 2021 ;Volum 103.(2)

24. Thingstad, Even; Erlandsen, Eirik; Sudbø, Asle.
Eliashberg study of superconductivity induced by interfacial coupling to antiferromagnets. ***Physical Review B*** (PRB) 2021 ;Volum 104.(1)

25. Troncoso, Roberto E. ; Lund, Mike A. ; Brataas, Arne and Kamra, Akashdeep.
Cross-sublattice spin pumping and magnon level attraction in van der Waals antiferromagnets.
Physical Review B 103, 144422

26. Zheng, Jun-Hui; Brataas, Arne.
Controlling the RKKY interaction and heat transport in a Kitaev spin liquid via Z2 flux walls. ***Physical Review B*** (PRB) 2021 ;Volum 104.(6)

27. Yuan, H. Y.; Zheng, Shasha ; He, Q. Y. ; Xiao, Jiang; Duine, Rembert A.
Unconventional magnon excitation by off-resonant microwaves. ***Physical Review B*** 103.

28. Yuan, H. Y.; Duine, Rembert A..
Universal field dependence of magnetic resonance near zero frequency. ***Physical Review B*** 103, 134440.

29. Ding, Shilei; Liang, Zhongyu; Yun, Chao; Wu, Rui ; Xue, Mingzhu ; Lin, Zhongchong ; Ross, Andrew; Becker, Sven; Yang, Wenyun; Ma, Xiaobai ; Chen, Dongfeng ; Sun, Kai ; Jakob, Gerhard ; Kläui, Mathias and Yang, Jinbo.
Anomalous Hall effect in magnetic insulator heterostructures: Contributions from spin-Hall and magnetic-proximity effects. ***Physical Review B*** 104.

30. Ross, Andrew ; Lebrun, Romain ; Evers, Martin ; Deák, András ; Szunyogh, László ; Nowak, Ulrich Ulrich and Kläui, Mathias. Exceptional sign changes of the nonlocal spin Seebeck effect in antiferromagnetic hematite.
Physical Review B 103, 224433.

31. Becker, S.; Ross, A.; Lebrun, R.; Baldrati, L.; Ding, S.; Schreiber, F.; Maccherozzi, F.; Backes, D.; Kläui, M. and Jakob, G..
Electrical detection of the spin reorientation transition in antiferromagnetic TmFeO3 thin films by spin Hall magnetoresistance. ***Physical Review B*** 103, 024423.

32. Krohg, Fredrik Nicolai ; Babaev, Egor ; Garaud, Julien ; Haugen, Håvard Homleid and Sudbø, Asle.
Thermal fluctuations and vortex lattice structures in chiral p-wave superconductors: Robustness of double-quanta vortices. ***Physical Review B*** 103, 214517.

33. Zheng, Jun-Hui; Jiang, Lijia.
Nonuniform-temperature effects on the phase transition in an Ising-like model. ***Physical Review D*** 2021 ;Volum 104.

34. Skogvoll, Ida Cathrine; Lidal, Jonas; Danon, Jeroen; Kamra, Akashdeep.
Tunable anisotropic quantum Rabi model via magnon-spin-qubit ensemble. ***Physical Review Applied*** 2021 ;Volum 16.(6)

35. Schreiber,F.; Meer,H.; Schmitt,C.; Ramos, R.; Saitoh, E; Baldrati, L. and Kläui, M..
Magnetic Sensitivity Distribution of Hall Devices in Antiferromagnetic Switching Experiments.
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Dislocation-Driven Relaxation Processes at the Conical to Helical Phase Transition in FeGe.
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43. Schneider, J. D.; Shirazi, P.; Wang, Q.; Sinova, J.; Carman, G. P. and Kläui, M..
Effective strain manipulation of the antiferromagnetic state of polycrystalline NiO. ***Applied Phys. Lett.*** 118, 172408.

44. A. Barra, A.M; Ross, A.; Gomonay, O.; Baldrati, L.; Chavez, A.; R. Lebrun, R.; Schneider, J. D.; Shirazi, P.; Wang, Q.; Sinova, J.; Carman, G.P. and Kläui, M.
Effective strain manipulation of the antiferromagnetic state of polycrystalline NiO. ***Appl. Phys. Lett.*** 118, 172408 (2021)

45. Håkonsen, Verner; Singh, Gurvinder; De Toro, Jose A.; Normile, Peter; Wahlström, Erik; He, Jianying and Zhang, Zhiliang.
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48. Antonija; Wan, Gary; Cattelan, Mattia; Prieto, Mauricio J.; Gottlob, Daniel M.; T□nase, Liviu C.; De Souza Caldas, Lucas; Schmidt, Thomas; Tadich, Anton; Cowie, Bruce C. C.; Chellappan, Rajesh Kumar; Wells, Justin William; Cooil, Simon P..
A Simplified Method for Patterning Graphene on Dielectric Layers. ***ACS Applied Materials & Interfaces*** 2021 ;Volum 13.(31) p. 37510-37516

49. Singh, Suraj Kumar; Wang, Xiansi; Kumar, Ankit; Qaiumzadeh, Alireza; Svedlindh, Peter; Tybell, Per Thomas Martin; Wahlström, Erik.
Magnetodynamic properties of dipole-coupled 1D magnonic crystals. ***Journal of Magnetism and Magnetic Materials*** 2021 ;Volum 539

50. Abdelsalam, H.; Saroka, Vasil; Atta, M. M.; Osman, W; Zhang, Q..
Tunable electro-optical properties of doped chiral graphene nanoribbons. ***Chemical Physics*** 2021 ;Volum 544.

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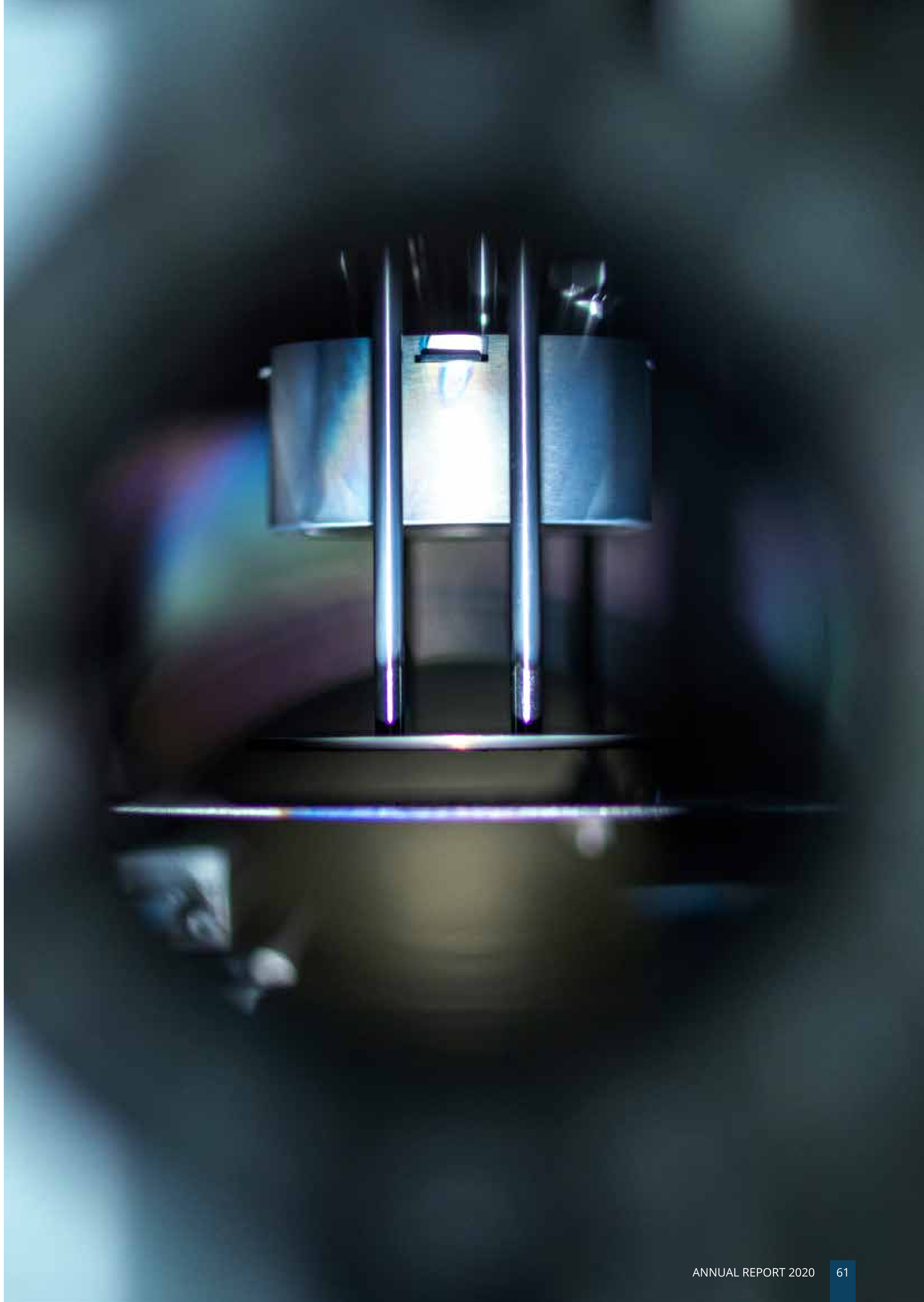

Facts

As of 2021.12.31.

8
PROF/ASSOC.PROF

2
RESEARCHERS

4
POSTDOCS

25
PHD STUDENTS

18
MASTER STUDENTS

1
ADMINISTRATOR

13
DIFFERENT NATIONALITES

2
VISITING RESEARCHERS

55
PUBLICATIONS

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

Funding

FUNDING 2021 (NOK)

The Research Council of Norway, Center of Excellence	11 000 000
Norwegian University of Science and Technology	11 056 000
SUM	**22 056 000**
The Research Council of Norway (Center of Excellence)	10 253 000
International Funding	2 478 000
Other Public	0
SUM	**12 731 000**
TOTAL FUNDING	**34 787 000**

People Overview

Colleagues who left QuSpin before 2021.12.31 are marked with an *

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Professor/Principal Investigator
Asle Sudbø

Professor/Principal Investigator
Jacob Linder

Professor/Principal Investigator
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PI until 2021.07.31
Prof II from 2022.01.01

Center Coordinator
Karen-Elisabeth Sødahl

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Associate Professor
Jeroen Danon

Associate Professor
John Ove Fjærestad

Professor (Onsager Fellow)
Dennis Gerhard Meier

Professor/Head of Department of Physics
Erik Wahlström

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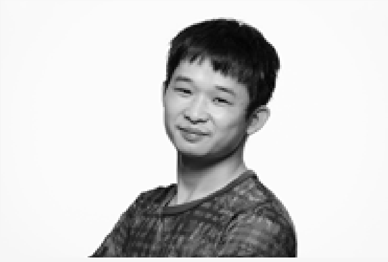

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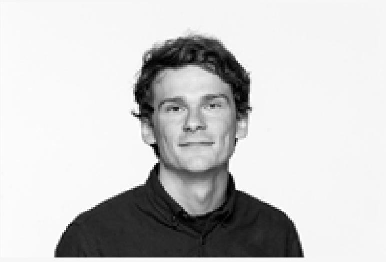
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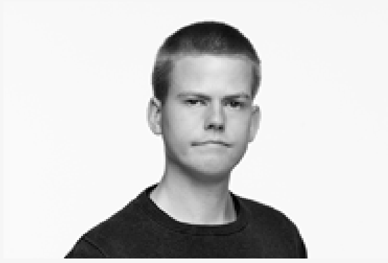
Erik Nikolai Lysne*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Niels Henrik Aase

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Hegstad, Torstein
Hodt, Erik Wegner
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Skarpeid, Alv Johan

Taraldsen, Øyvind
Uthayamoorthy, Viroshaan *
Haas, Max *
Øyvind Finnseth

*In collaboration with other NTNU department or industry.

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The Netherlands

Professor
Mathias Kläui, University of Mainz
Germany

HEAD ENGINEER

Senior Engineer
Rajesh Kumar Chellappan
Department of Physics, NTNU

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University of Cambridge, United Kingdom

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. Niklas Rohling
Researcher 2017-2019
Next position: PostDoc at Universität Konstanz, Konstanz, Germany.

Dr. Simon Phillip Cooil
Associate Professor II 2018-2020
Next position; Postdoc at Department of Physics, University of Oslo, Norway.

Dr. Roberto Troncoso.
PostDoc 2019-2020
Next position: Researcher at Department of Mechanical and Industrial Engineering, NTNU, Trondheim, Norway.

Dr. Rui Wu
PostDoc 2019-2020
Next position: Associate professor in colleague of physics at University of Electronic Science and Technology of China (UESTC).

Dr. Rajesh Kumar Chellappan
PostDoc 2019
Next position: Chief engineer, Department of Physics, NTNU, Trondheim, Norway.

Dr. Maximillian Kessel
PostDoc 2018-2019
Next position: Scientist at Fraunhofer-Institute for Applied Solid State Physics in Freiburg, Germany.

Dr. Alex Schenk
PostDoc 2018-2019
Next position: La Trobe University, Melbourne, Australia.

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

Dr. Sverre Aamodt Gulbrandsen
PhD 2017-2020
Next position: Researcher, Optonor AS, Trondheim, Norway.

Dr. Morten Amundsen
PhD 2017-2020
Next position: Postdoctoral Fellow at NORDITA, Stockholm, Sweden.

Dr. Arnau Sala
PhD 2017-2020
Next position: PostDoc at Interuniversity Microelectronics Centre (IMEC), Leuven, Belgium.

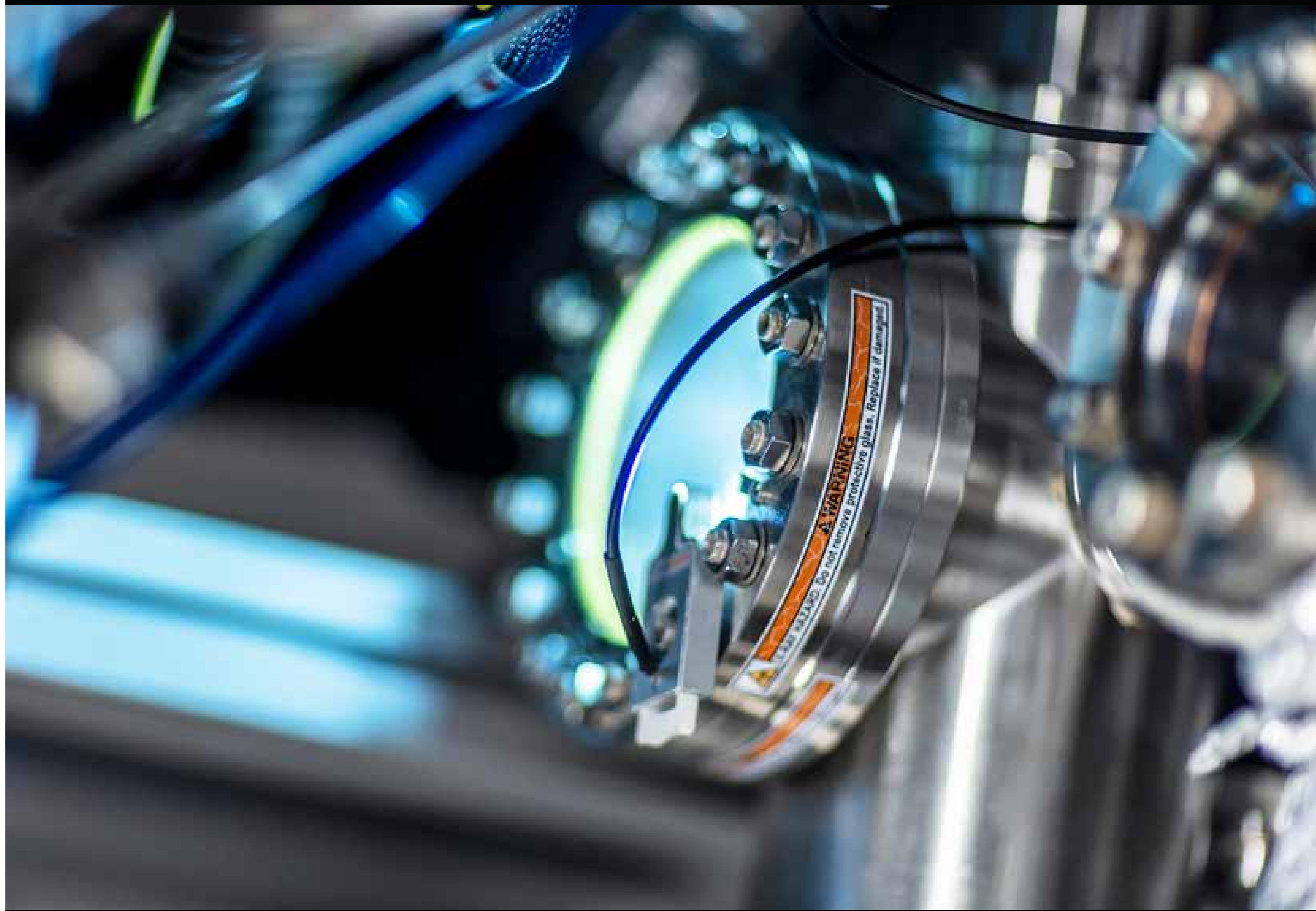
Dr. Suraj Kumar Singh
PhD 2017-2020
Next position: Postdoc at the University of Liège, Belgium.

Dr. Øyvind Johansen
PhD 2016-2020
Next position: Service Consultant at Matrix Technology AG, Munich, Germany.

Dr. Vetle Kjære Risinggård
PhD 2015-2019
Next position: Researcher at Norwegian Research Centre (NORCE), Kr.sand, Norway.

Dr. Eirik Løhaugen Fjærbu
PhD 2014-2018
Next position: Researcher at Norwegian Defense Research Establishment (FFI), Kjeller, Norway.

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



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