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Periodic review of research 2012-2020	2021-03-01	Stockholm
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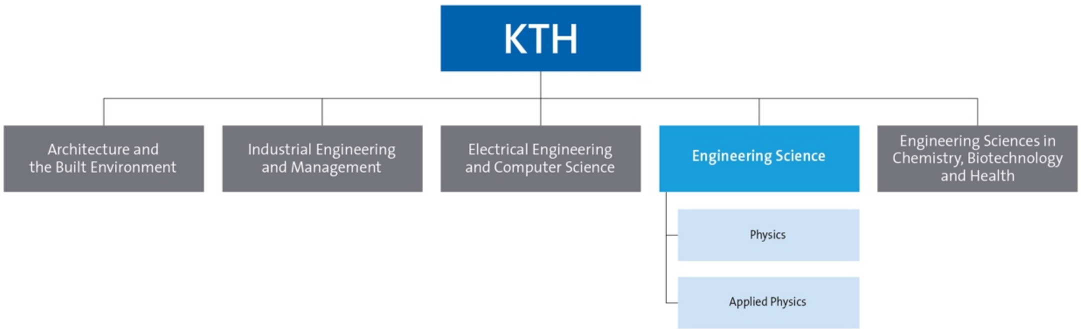
Panel 9		

Panel 9

Physics and Applied Physics



Summary

This self-evaluation report covers the research panel for Physics and Applied Physics. The two departments together correspond to about half of the School of Engineering Science (SCI), where Applied Physics is the larger of the two with 41 faculty and in total > 200 employees, while the Physics department has 31 faculty and ~ 130 employees. The two departments are the result of merger processes in 2017 where Physics and Theoretical Physics combined into the present Physics Department and where the Material and Nano-physics and Photonics divisions from the ICT school merged into the Applied Physics Department. Both departments, with the exception of the Biophysics division of Applied Physics, are located at AlbaNova.

Description of the research field of the departments included in the research panel

The Department of Physics comprises six divisions: Particle- and Astroparticle Physics; Nuclear Physics; Nuclear Engineering; Nuclear Power Safety; Physics of Medical Imaging and Condensed Matter Theory. The research covers a wide range from basic science to applied engineering, with experiment, theory, modelling and simulation in almost all of the fields. The experimental research, depending on the field, is performed at a range of locally developed laboratories, small, medium and very-large scale international facilities.

The Department of Applied Physics is organized in seven divisions: Biomedical and X-ray Physics; Biophysics; Nanostructure Physics; Laser Physics; Photonics, Materials and Nano-Physics and Quantum and Biophotonics. A focus is interdisciplinary research in three core fields Bio, Opto and Nano. Significant areas include confocal microscopy, cell-biology, fluorescence correlation spectroscopy, single molecules, x-rays (sources, optics, and microscopes), ultrasonic trapping, microfluidics, solid-state laser sources, quantum optics, nanomaterials, bio-imaging, nanophysics, spintronics, surface physics, device physics and quantum materials.

Description of the self-evaluation process for the research panel

It was at an early stage discovered that the centrally supplied RAE indicators were not properly reflecting the changes from the department mergers in 2017. This was strongly affecting the bibliometrics which in several cases suffered from not being allocated to the current unit of the authors, and that many publications and patents were missing in the data, even if they existed in DiVA.

Within each department the division heads were tasked with collecting input to the self-evaluation from their respective group. Both departments had set deadlines for the text input to early March with local meetings with divisions heads at 9th and 10th of March respectively. At this time, when the work was progressing properly, the COVID-19 crisis changed the situation drastically and all effort went into organizing work from home, arranging crisis contingencies and developing remote teaching. This forced the self-evaluation process to grind to a halt. Towards the end of March, the panel coordinator fell ill with the virus for 3 weeks. The completely new situation with remote exams took a major effort over the period until the last weeks of April, after which the writing work restarted.

For the Applied Physics department this was far from timely, since the physical move of the Materials and Nano-physics and Photonics divisions from Kista into a new building at Albanova from the beginning of May has hampered the RAE process.

From early May to mid-May the actual writing recommenced, with work mainly from department and division heads. With the short time available, the self-evaluations were briefly circulated among faculty of the departments but it has not been feasible with general meetings and discussions. The process, mainly affected by the large effort required to keep up education standard during the COVID-19 period and the moving of the Kista divisions, has resulted in self-evaluations which are not at the level required for the final self-evaluations, but will nevertheless serve as good starting-points for the RAE 2021.

Identified research panel synergies

Several timely developments will lead to exciting improved synergy effects between the departments of Physics and Applied Physics. The main development is the significantly improved academic environment resulting from the recent merger of the three physics departments and two divisions from the ICT school into two departments, and in particular with the ongoing move of the Material Physics and Photonics division to the AlbaNova campus.

The establishment of the divisions in the new campus building, called House 3, in 2020 is enabling a significantly enhanced scientific environment and strengthened synergy effects between and within the physics and applied physics departments.

This physical and structural unification will enable and inspire extended collaboration between different groups working in the materials, nanoscience, condensed matter

and nuclear physics, and various applications such as imaging for medical and related purposes. Furthermore, the ongoing establishment of a Quantum Technology Hub

(QTH) involving both departments and other relevant research at KTH is driven by synergy gains and developing mutual scientific interests in basic quantum physics and its timely applications. Fruitful collaborations between several research groups have already started and more is planned.

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Department of Physics

Self-evaluation
Head of Department: Professor Pär Olsson

Included divisions:

Division of Condensed Matter Theory, with Head of Division: Prof Jens Bardarson

Division of Nuclear Engineering, with Head of Division: Prof Pavel Kudinov

Division of Nuclear Physics, with Head of Division: Prof Bo Cedervall

Division of Nuclear Power Safety, with Head of Division: Prof Sevostian Bechta

Division of Particle and Astroparticle Physics, with Head of Division: Prof Bengt Lund-Jensen

Division of Physics of Medical Imaging, with Head of Division: Prof Mats Danielsson

Physics Department

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

	Strengths	Weaknesses
Research	1. High impact research in a broad range of fields at state of the art across the entire department with very strong publication record in top-ranked journals. 2. Mix of applied and basic research, with clear synergies; and healthy mix of experimental, modelling, simulation and theory. 3. Strong international presence and reputation in multiple fields with leadership roles in international projects. 4. Strong research centres (SKC, OKC, Space Centre) 5. Very good record of attracting external funding	1. Low level of internal funding resulting in strong dependence on external funding, potentially reducing research independence and causing difficulties for long term planning and commitments. 2. PhDs and postdocs entirely financed by external sources. 3. Essential local infrastructure and technical staff almost exclusively funded by external sources ⇒ difficulties in maintaining staff and expertise between time limited projects. 4. High level of administrative load on faculty and researchers. 5. Inhomogeneous department composition makes common agenda and practices challemging 6. Some disconnect between basic and applied research and between research divisions.
Organisation	Bulleted list, in order of magnitude. 1. Since the reorganisation, the research divisions have better critical mass. 2. Excellent education programs 3. AlbaNova environment (KTH, SU, Nordita) – collaborations and synergies with other departments at KTH, as well as with SU and Nordita. 4. Efficient local administration, shared with Department of Applied Physics	1. Poor gender balance in faculty and management. 2. Dominating line organisation. 3. Lack of formal faculty influence 4. Top-heavy faculty (intrinsic KTH issue) 5. Lack of career development path for non-faculty staff. 6. Lack of department-centralized technical support 7. Lack of financial incentives for excellence in common doctoral education programmes

b. Summary statement on contributions of department on impact, infrastructure and sustainable development.

Text?

2. Research profile

a. General information of the department

In its present form, the Department of Physics was formed in 2018 in a merger between the old Department of Physics and the old Department of Theoretical Physics. Some researchers from the former Theoretical Physics Department joined the Particle and Astroparticle Physics division, some moved to the Applied Physics Department and the rest formed the division for Condensed Matter Theory.

The department has at present about 130 employees, out of which 17 (2 female) professors, 11 (1 female) associate professors, 1 assistant professor, 2 (1 female) affiliated faculty, 21 (1 female) researchers, engineers and technicians, about 28 postdocs and temporary researchers, and about 50 (17 female) PhD students. The department also has 19 active emeriti professors and researchers. Gender balance is an issue, as across most of KTH, with the same balance as the rest of the School of Engineering Sciences for the PhD students and postdocs, but with below-average female representation among the faculty and permanent research staff.

The department consists of six research divisions:

- Particle and Astroparticle Physics (PAP),
- Nuclear Physics (NP),
- Condensed Matter Theory (CMT),
- Physics of Medical Imaging (PMI),
- Nuclear Power Safety (NPS)
- Nuclear Engineering (NE).

The research within the department spans from basic science to applied engineering, with experiments, theory, modelling and simulation in basically all the fields of research. There is significant experimental activity at very large, medium and small international facilities as well as in locally developed laboratories.

The department is co-located with the Applied Physics department and with the Physics and Astronomy departments of Stockholm University, as well as with Nordic Institute for Theoretical Physics (Nordita) in the AlbaNova University Centre. Several laboratories are located on the main campus. A common technical workshop supports the research activities. The department is hosting the Swedish Nuclear Technology Centre (SKC) as well as the KTH Space Center, and has recently, together with Applied Physics, started a quantum technology hub (QTH). The department is actively engaged in the Oskar Klein Centre (OKC) for cosmology, astrophysics and particle physics.

b. Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)

The department is active in a wide array of research fields and the central issues in these fields are addressed below, presented per research division:

Particle and Astroparticle Physics (PAP)

The division conducts research in particle physics, high-energy astrophysics and astroparticle physics, with both experimental and theoretical activities. Research is centered around the ATLAS experiment at the CERN Large Hadron Collider (LHC), underground neutrino experiments, and ground- and space-based instruments for astrophysical observations.

The research with the ATLAS experiment is concentrated around studies of the Higgs boson and searches for physics beyond the Standard Model of particle physics (SM), e.g. signs of supersymmetry. In theoretical particle physics the research focuses mainly on neutrino and dark matter physics and is done both independently and as part of international experimental collaborations, including ESSnuSB, DUNE, and T2HK. In astrophysics and astroparticle physics the group studies explosive and transient events, such as supernovae and gamma-ray bursts, compact sources such as neutron stars and black holes, and particle acceleration, using both multi-wavelength and multi-messenger techniques.

The overarching strategy of the division is to combine design and development of instrumentation with data analysis and theory. This approach has been shown to be very successful over the years, and allows the group to play defining roles in prominent international projects. A recent and welcomed development in the research division is the merger with the Theoretical Particle Physics group in 2018. This has led to fruitful interdisciplinary discussions where common interests are starting to be exploited.

On the instrumentation side, the division contributed to the design and construction of the ATLAS presampler detector, the calorimeter of the Fermi gamma-ray telescope and the anti-coincidence shield of the PAMELA satellite mission, which studied cosmic antimatter. These activities have been followed by the development of the PoGOLite, PoGO+ and X-Calibur missions for balloon-borne X-ray polarimetry, as well as the development for the High-Granularity Timing Detector upgrade of ATLAS.

The ATLAS group at KTH has been active in the ATLAS experiment since 1990. It is making significant contributions to the experiment in various physics analyses and through its involvement in the operation of the current detector and developments targeting an upgraded ATLAS detector. The detector upgrades will be installed in 2026-2027, after which the High-Luminosity phase of the LHC (HL-LHC) will commence, where the luminosity of the accelerator will be increased by an order of magnitude compared to the current operation. The HL-LHC will remain the flagship facility for collider-based particle physics for the coming decades.

- *Scientific focus:* The data analysis activities aim at finding evidence for physics which is not described by the Standard Model. This can be achieved either through precision measurements of already known particles, or through direct discoveries of new particles which are not part of the SM. Precision measurements of the Higgs boson are especially sensitive to the effects of new physics, and the group has a long-standing involvement in measurements of Higgs bosons which decay to two W bosons. Recently the group also started an analysis effort searching for the simultaneous production of two Higgs bosons, so called di-Higgs searches. This process will be the first time we can directly probe the Higgs boson self-interaction, which is a free parameter of the SM and has huge implications for the electroweak symmetry breaking, the shape of the Higgs potential, and the vacuum state of the universe. Di-Higgs processes are extremely rare however, and a discovery will only be possible with the dataset from the HL-LHC. The group is also involved in direct searches for new particles and processes beyond the SM that could explain what the dark matter (DM) dominating our universe consists of. With a suite of searches targeting experimentally challenging signatures with long-lived particles, powerful searches have excluded several interesting theoretical scenarios and signatures that often arise in beyond-SM models with good DM properties. These searches targeting unconventional event topologies can enjoy substantial gains in sensitivity also in the intermediate Run 3 during 2022-2024, and at the HL-LHC where the upgraded detector provides additional experimental handles.

- *Instrumentation:* The group plays a key role in the development the High-Granularity Timing Detector (HGTD). The HGTD is a silicon-based timing detector, using novel Low Gain Avalanche Detectors (LGAD) which are still under development, aimed at accomplishing a time resolution of 30 picoseconds per charged-particle track. By installing the HGTD in addition to a completely new central silicon tracker, ATLAS will be able to separate particles from different simultaneous proton-proton collisions happening in the centre of the experiment in both the space (by the central tracker) and time (by the HGTD) dimensions. This ensures that good performance of the experiment can be obtained even at the high luminosities of the HL-LHC. The low occupancy of the HGTD, and its excellent time resolution, also makes it an ideal detector for measuring the luminosity of the LHC accelerator. This functionality of HGTD was proposed by the KTH group, and KTH is the leading institute behind the luminosity measurement developments.

In **Astrophysics and Astroparticle physics** the focus is on high-energy phenomena in the universe using X-rays, gamma-rays, ultra-high-energy cosmic rays. The research areas addressed are:

- *X-ray polarimetry:* Since the advent of X-ray astronomy, our understanding of celestial compact objects such as black hole and neutron star systems stems primarily from spectral and timing measurements. In order to provide new and independent observational data to advance our understanding of such sources, the group develops instrumentation which can discern the linear polarisation of emitted X-rays. Our instruments have been flown on stratospheric balloons launched from the Esrange Space Centre in northern Sweden (PoGOLite in 2013 and PoGO+ in 2016). We have made the first polarimetric observations of two sources in the hard X-ray band (~20-200 keV), the Crab nebular/pulsar, and Cygnus X-1, a black-hole binary. A new mission, XL-Calibur, with order-of-magnitude improved signal-to-background is currently under development. The first flight is planned for summer 2022 from

Esrange, and observations with the NASA IXPE satellite (few keV range) are planned. Preparations are also being made for future satellite-borne X-ray polarimetry missions to allow a wide range of celestial sources to be studied.

- *Supernovae and pulsars:* Supernovae are the violent deaths of massive stars and in many cases a central rotating neutron star and a nebula are left as remains. The group studies these phenomena through highly resolved observations of, e.g. SN1987a and with X-ray polarimetric observations of the Crab nebular and pulsar system.
- *Gamma-ray bursts:* GRBs have been one of the foci within the group over the last 10 years. GRBs themselves were discovered nearly 50 years ago and still remain one of the exciting enigmas in contemporary astrophysics. During a GRB, short flashes of gamma-rays reach us from very large distances, mainly from when the Universe was young, and constitute the brightest explosions in the Universe. The gamma-ray phase is the most important phase energetically, but, there is still no consensus on how to interpret and understand it. It is of great importance to understand this phase, due to the connection with general stellar explosions, such as supernovae and neutron star mergers, and the connection to sources of gravitational waves.
- *Ultra-High-Energy Cosmic Rays (UHECR):* The group is involved in the development of space-based observations of ultra-high-energy cosmic rays through the JEM-EUSO mission, proposed for the International Space Station (ISS). Currently the effort is on determining the background in form of UV light from the night side of Earth, which will lead to new insights by itself. Theoretical investigations on the origins of these particles are also conducted, in particular on GRBs as possible sources.
- *Active Galactic Nuclei:* With a supermassive black hole at the center, an AGNs is among the brightest and most violent persistent sources in the sky. As matter accretes onto the black hole, gravitational energy is released in form of radiation across the electromagnetic spectrum and, in many cases, in the form of a relativistic plasma jet. The research in the group focusses on the long-term light curve variability and on the connection between the accretion and the formation of the jet.

Research within theoretical and phenomenological particle and astroparticle physics focuses on physics beyond the standard model. The research benefits from interdisciplinary discussions with the experimental part of the Division, and with the IceCube group at Stockholm University. The central research activities are:

- Predictions of the sensitivity of neutrino oscillation experiments (in particular ESSnuSB, DUNE, and T2HK) including different scenarios beyond the Standard Model.
- Different extensions to the Standard Model to incorporate neutrino masses and the observable effects of those models.
- The behaviour and the resulting detection signals of dark matter in astrophysical systems, and the interplay with other dark matter signals

Nuclear Physics (NP)

The Nuclear Physics Division carries out research in a broad range of experimental and theoretical nuclear physics together with applications in nuclear safeguards and security, environmental radiation measurements, hadron therapy, radiation dosimetry as well as environmental radon research. The experimental research is performed in international collaborations at large-scale research facilities in Europe and around the world, as well as in specialised laboratories at KTH, the Swedish Radiation Safety Authority (SSM) and the Skandion Proton Therapy Clinic in Uppsala. Our experimental activities combine the designing, running and analysis of experiments for fundamental physics and applications with development of instrumentation and methods. Theory activities include model development in basic nuclear physics and applications for nuclear astrophysics and proton therapy as well as code development. One of the strengths of the Nuclear Physics Division is the longstanding and strong synergy between experiment and theory.

The experimental nuclear physics team performs spectroscopic studies of nuclei near the limits of existence with respect to isospin (i.e. neutron/proton ratios), angular momentum and deformation with a special emphasis on effects of nucleon-nucleon pair correlations in the nucleus. Experiments at the international frontline at large-scale accelerator facilities like GANIL, France, GSI-FAIR, Germany, RIKEN, Japan and MSU-FRIB, USA is combined with instrumental developments preparing for the enhanced experimental access to exotic nuclear species to be available from the mid 2020s the Facility for Antiproton and Ion Research (FAIR), a European Strategy Forum for Research Infrastructures (ESFRI) flagship project. We focus on precision spectroscopy and lifetime measurements in exotic nuclei far from stability, using, in particular, the “Advanced GAmma-ray Tracking Array” (AGATA), which is operated in conjunction with various auxiliary selective devices.

In the future, our main experimental research topics will include:

- Nuclear pairing modes and their isospin properties
- Emergent phenomena like deformation and collective excitations
- Evolution of nuclear shapes
- Measurements relevant for nuclear astrophysics, i.e. of r-p and r-process nuclei
- Structure of hypernuclei, i.e. nuclei containing one or more strange hadrons

We target experimental cases where predictions of nucleonic correlations and the decomposition of the nucleon-nucleon interaction into its key components can be used to maximally constrain state-of-the-art nuclear models. The instrumentation advances driven by this work and the knowledge gained by those involved is relevant for a wide range of medical, industrial and environmental applications (see below).

The nuclear theory team focuses on the development of advanced nuclear many body models that are important not only from a theoretical point of view but also for the development of the physics programmes for the next-generation large-scale radioactive beam facilities. We will focus on:

- Novel large-scale universal Configuration Interaction (CI) approach for studying the structure and decay properties of exotic nuclei
- Shell model in the complex energy plane, role of the continuum in nuclear spectra
- High accuracy mass and level density calculations for nuclear structure in exotic nuclei
- Radioactive decays of exotic nuclei, and (v) r-process and neutron star merger calculations.

Applied nuclear physics research at KTH is aimed at nuclear safeguards and security, radiation dosimetry, hadron therapy and environmental studies. The nuclear safeguards and security team which was started by the Nuclear Physics Division in 2017, develops instrumentation and methodologies to aid in the global efforts against the proliferation of nuclear weapons and to counteract nuclear terrorism. Applications for environmental radiation detection imaging and nuclear accident emergency response are also included in the research programme. The foundation for this research is laid by the cutting-edge expertise in advanced radiation detection coming from the research activities in fundamental nuclear physics within the Division of Nuclear Physics. This applies in particular to detection systems for gamma radiation and fast neutrons developed for studies of exotic atomic nuclei far from the beta-stability line, providing interesting synergies and also opportunities for spin-off from the basic research to its applications. An example of the latter is our project in nuclear security for development of radiation portal monitors (RPMs) with enhanced sensitivity for detecting and imaging special nuclear materials, e.g. plutonium. It is currently receiving support from the technology transfer centre KTH Innovation and from Vinnova. Adapting techniques used in experimental nuclear physics, the team has developed the use of fast time and energy correlations between neutrons and prompt □-rays emitted in fission to detect, characterise and image special nuclear materials, a critical task for nuclear safeguards and security applications.

The current main research topics include:

- Development of instrumentation and techniques methods for Nuclear Security - RPM applications.
- Method development in Nuclear Safeguards - Spent Fuel Verification. Both PWR and BWR spent fuel assemblies inside their transport casks as well as in the copper canister designed for encapsulation in the Swedish final spent fuel repository are studied.
- Method development in Nuclear Material Accountability and Control for Gen-IV fuel cycle applications (D.M. Trombetta, VR Starting grant project). The project focuses on development of an NDA technique that is able to quantify minor actinide and plutonium mass that is adapted for the Gen-IV fuel cycle conditions
- Development of instrumentation and methods for Environmental Radiation Monitoring and Nuclear Emergency response.

The experimental micro- and nanodosimetry team (which started in 2015) performs measurements of radiation-induced ionization in small volumes. Such measurements can provide information on how radiation of different types and energies affect biological tissue at the scale of cells- or even the DNA molecule. The research project is a collaboration between KTH and SSM and is based on measurements using the proton therapy beam at the Skandion clinic in Uppsala, Sweden and at SSM. The main direction for the next few years is to perform nanodosimetry measurements in both gamma- and proton radiation fields.

Another activity of Nuclear Physics at KTH aims at studying radon as earthquake precursor. The aim is to develop a reliable and effective earthquake warning system using a dense sensor network combined with real time data collection, supported by analysis using artificial intelligence, and networking methods to provide daily risk assessment and analysis. Testing and development of gamma-ray based measurement techniques for radon and thoron gases are carried out, preferably in water. For the first measurements, we have assigned a pilot region which is on the faults along the Apennine Mountains in Italy.

The Nuclear Physics Division currently consists of two full professors (one female), two senior lecturers, two researchers, four postdoc (another in recruitment), seven PhD students, several Master's students and three active emeritus professors.The atmosphere in the Division is highly international with more than 50% of the staff having non-Swedish origin. We endeavour to reach a higher level of gender balance among the senior staff. However, for PhD students active in the period 2012-2019, 6 out of 10 are female. For postdocs, 9 out of 14 have been female in the same period.

Condensed Matter Theory (CMT)

Faculty members of the CMT division lead their independent research groups, as is the norm internationally, generally consisting of the PI together with postdocs and PhD students. Collaborations between groups, especially at the level of postdocs and PhD students is encouraged and common, though the major collaborations are with other groups both nationally and internationally. The major research focus of the division is broadly on quantum matter, covering the full range from fundamental theory to application in material science and device design in quantum technology, with further smaller activity in biophysics and complex matter. The division has expertise in quantum many-body numerical techniques (Monte Carlo, exact diagonalization, DMRG, etc.) in addition to a strong history in mathematical physics including in integrable quantum systems. Ultimately the research aims at developing theoretical tools for understanding and finding new physical phenomena and materials, and thus contributing to future applications of such findings. The division is a frequent user of large-scale computer facilities and also runs a medium size local computer cluster network. The Condensed matter theory division is active in research in, among others, the following fields:

Superconductivity and Magnetism:

- Superstates of matter. Superconductivity. Ultracold atoms. Phase transition and topological excitations in multicomponent gauge theories.
- Effects of frustration. Structure formation in soft matter. Spin ice and related frustrated magnetic systems.
- Modelling of quantum devices and qubits. Transport and fluctuation effects in superconducting electric circuits, with application to superconducting nanowire single photon detectors (SNSPD).

Strongly correlated materials:

- Phase transitions, classical and quantum critical phenomena.
- Disordered systems and glasses.
- Monte Carlo and molecular dynamics simulations. Development of new effective simulation methods optimized for complicated energy landscapes.
- Modelling and simulation of matter under extreme pressure.

Topological quantum matter:

- Weyl and Dirac semimetals; anomalies and their experimental realizations.
- Topological qubits in superconducting topological nanowires.

Mathematical physics, thermalization and integrability:

- Many-body quantum dynamics, localization and thermalization.
- Mathematical Physics: Quantum many-body system; exactly solvable systems; analytical and topological methods.

Future research directions have a strong focus on quantum physics. In addition to furthering the research in the above fields new activities include:

- Generalizing the recent breakthrough in computational condensed matter physics: Diagrammatic Monte-Carlo, to nuclear physics and multimessenger astrophysics.
- Open quantum systems, both many-body and interplay with topology.
- Strengthening collaborations with KTH math department with joint projects on foundations of quantum thermalization and integrability.
- Strengthening collaboration with SU condensed matter on topics such as topological quantum matter.

There are great opportunities for strong collaborations on quantum physics in Stockholm including with Nordita, Stockholm University and both the applied physics and math departments at KTH. This includes establishing common research environments and centers in addition to potential for collaborations in education.

Physics of Medical Imaging (PMI)

The overarching research goal for the Physics of Medical Imaging division is to devise new medical x-ray imaging techniques based on novel detectors and optics and bring these into routine clinical use, leading to improved diagnostic image quality, novel imaging techniques and ultimately saved human lives. This research is highly multidisciplinary and involves semiconductor device physics, integrated circuit development, image reconstruction and clinical applications.

The main focus is on photon-counting spectral computed tomography (CT) based on a silicon-strip detector invented within the division. Having developed this detector to the point where it is installed in a clinical CT scanner and is ready for clinical trials, this research project is entering a phase in which the new technology will be evaluated for a wide range of imaging scenarios, meaning that there is potential for a number of publications with high impact for healthcare. To accomplish this, the plan is to deepen the current collaboration with the Karolinska Institute and Karolinska University Hospital within the MedTechLabs center. To fully understand the benefits and applicability of the new technology, there is also a need for developing detailed simulation models, so that virtual clinical trials can be carried out, and novel image reconstruction methods, to make the best possible use of the new image information. In particular, the division is currently doing research into image reconstruction methods based on deep learning, which shows very promising results for improving image quality. An additional focus is developing metrics and measurement techniques for photon-counting CT to compare different scanner models and protocols and optimize future hardware versions.

Since the spin-off company Prismatic Sensors AB has been very successful in raising funding, many alumni from the group are currently employed by the company, now part of GE Healthcare. The division currently consists of two faculty, one embedded postdoc (employed by KTH Mathematics) two PhD students (one full-time employed by the company) and a part-time MSc student research assistant. Professor M. Danielsson's group focuses on development of novel hardware and on clinical evaluation of the novel photon-counting CT prototype. Assistant professor M. Persson's group focuses on development of novel image reconstruction methods for photon counting CT as well as on developing metrics for photon-counting CT performance.

For the future, the plan is to focus on understanding the possibilities and limitations of deep-learning-based image reconstruction, in order to use the new, image-resolved data in the best possible way. The combination of highly energy-resolved data with novel deep-learning image reconstruction methods will be applied to a variety of clinical tasks, such as determining diseased brain tissue in acute stroke, enabling ultra-low dose pediatric imaging and visualizing bone fractures in trauma imaging. The ability of photon-counting CT to generate more reliable, quantitatively accurate images is particularly promising for the ability to characterize tumors, opening possibilities for personalized medicine. Another topic of interest is how the energy-resolved information can be combined with advanced motion compensation to allow improved imaging of the heart and blood vessels, which can allow better treatment or risk prediction for myocardial infarction. The division also works on automated analysis of covid-19 lung patients, and the follow-up examination of long-term covid patients is an application where the high spatial resolution of the novel CT technology is expected to be beneficial.

On the hardware development side, a new Compton-tracking detector with micrometer resolution is being developed, promising greatly improved image quality. This high spatial resolution can also allow dose-efficient phase-contrast imaging without an analyzer grating, with a promising future potential to take phase-contrast imaging to the level where it can be routinely used in the clinic. This line of research is a highly promising future research direction for the division. Another foreseen research project is the application of an x-ray lens developed within the division for developing imaging systems with improved quality, both in medical imaging and x-ray astronomy.

Nuclear Power Safety (NPS)

The central research questions at the NPS division are driven by the remaining emerging issues important for risk of operating nuclear power plants, with the goal to ensure that nuclear power plants have the highest achievable safety level, and that the public/environment has an adequate protection against nuclear accidents.

The knowledge gaps addressed are as follows:
(i) governing physics of reactor accident phenomena in light water reactors, including thermal-hydraulics, neutron-kinetics coupled with thermal-hydraulics, design basis accidents, severe accidents and related phenomena, such as reactor core degradation and relocation, fuel coolant interactions, debris formation, steam explosion, debris re-melting, melt pool convection and heat transfer, reactor vessel failure, and melt spreading;
(ii) uncertainties in quantification of accident consequences;
(iii) validity of severe accident management and efficiency of safety systems;
(iv) standalone and coupled deterministic/probabilistic methodologies and codes for reactor safety analysis;

(v) safety of future nuclear power including Generation IV or small modular reactor (SMR) technologies.

The NPS division has three research teams for experimental investigation, analytical study and reactor safety analysis. There is a strong synergy among the three teams each led by highly competent researchers. Experimental investigation on reactor accident phenomena and associated heat and mass transfer (https://www.physics.kth.se/nps/research/facilities) brings knowledge for development of models used in analytical study, and for validation of codes for reactor safety analysis. The analytical study ranges from model development to CFD simulation. The reactor safety analysis is informed from calculations with system codes of various reference scenarios of design basis and severe accidents.

Future research perspectives are currently visible in development of accident-tolerant fuels and clads for light water reactors, SMR and reactor systems of the next generations including fast reactors with various alternative coolants, systems for minor actinide transmutation and research reactors.

NPS research activities are in the multidisciplinary field that combines scientific disciplines and approaches of reactor physics and nuclear chemistry, engineering subjects of reactor technology but also social sciences of risk management in the society and public safety. The scope of research includes perception, assessment and management of risk of rare but high-consequence events, which ranges from design-basic accidents to beyond design-basis accidents and severe accidents. Consequently, the multi-disciplinarity plays an important role in nuclear power safety and strongly motivates internal and external collaborations.

Nuclear Engineering (NE)

The main research activities in nuclear engineering at the department of physics are in the fields of

- Reactor physics – including neutronics, reactor design, transient analysis and advanced Monte Carlo method development
- Nuclear materials science – including radiation damage studies, development of novel structural steels as well as nuclear fuel development, modelling, testing and characterization
- Thermal hydraulics – including experimental and computational fluid dynamics, multiphase phenomena, supercritical water experiments and modelling, coupled neutronics – thermal hydraulics and thermo-mechanics
- Nuclear safety – including deterministic and probabilistic safety analysis, multiscale and multiphysics accident phenomena

Central research questions and themes in nuclear engineering are:

- Development of sustainable nuclear energy, with particular focus on Generation IV reactor systems, such as Lead Fast Reactors (LFR) and Supercritical Water Reactors (SCWR). Central research questions and respective tracks of activities are directed towards the development of the key technological breakthroughs needed for deployment of Generation IV systems and specifically LFRs. Many reactor projects have been proposed, a dedicated reactor physics transient analysis code has been developed. Nitride fuel development, testing and modelling for LFR has been ongoing since 2009. Radiation damage of components in LFR systems will be significant and a large part of the nuclear materials science research is focused on this aspect. In collaboration with Surface and Corrosion Science at KTH and Sandvik/Kanthal, we are the global leaders in development of novel structural Pb-corrosion resisting steels. For SCWR we are currently upgrading the HWAT (High-pressure WAter Test) loop for supercritical conditions and are expected to start the first experiments. Heat transfer properties in the supercritical state is the key application-critical issue to investigate.

- Sustainable Nuclear Energy Research in Sweden (SUNRISE) is a large scale (50 MSEK) center supported by Swedish Foundation for Strategic research (SSF). Ten senior researchers at three universities (Uppsalal Univesity, Luleå University and KTH (coordinator)) will lead a group of ten PhD students and two postdocs. SUNRISE aims to prepare for the construction and operation of a Swedish lead-cooled research reactor in Oskarshamn. The reactor should provide commercial services to customers as well as opportunities for research. The reactor will also function as a demonstration unit for an advanced nuclear power technology that can be commercialized on a large scale. Design and safety analysis of the research reactor will be conducted within WP1, WP2 will focus on development of advanced steels and radiation damage studies, WP3 will address materials development and characterization, WP4 will work on nuclear fuels and safety, and WP5 will develop experimental and modeling approaches for testing of reactor component performance in prototypic conditions. It is expected that SUNRISE will provide a platform for further strengthening of Sweden role in the European research on development of Generation IV reactor technology.
- Development of Monte Carlo methods for linear and non-linear neutron transport for support of realistic modelling of nuclear reactors. Particular emphasis is given to the development of optimisation methods for Monte Carlo criticality, kinetic and burnup problems that are needed in design and safety related R&D of current and Gen-IV reactors.
- Development of comprehensive Risk Oriented Accident Analysis Method (ROAAM+) for complex systems with significant uncertainties in physical phenomena. Main application area is severe accidents in light water reactors (LWRs). A number of detailed (full) and fast running (surrogate) models were developed for analysis of in-vessel and ex-vessel accident progression including core degradation and melt release from the vessel, steam explosion, debris bed formation and coolability. Results of this development is actively monitored by regulators in Sweden and Japan and used in their inquiries to the nuclear industry. Further extension of ROAAM+ application to Generation IV reactors is foreseen in the ongoing projects.
- Development of methods for addressing Boiling Water Reactor (BWR) containment thermo-hydraulics with emphasis on the performance of the pressure suppression pool. This topic became of wide international interest after the Fukushima accident in Japan where thermal stratification in the pool significantly increased containment pressure. Upon request from the Swedish regulator we provide analytical support to OECD/NEA projects such as HYMERES (Hydrogen Mitigation Experiments for Reactor Safety) and HYMERES-2 where large scale facility PANDA at PSI (Paul Scherrer Institute) is used to investigate relevant phenomena and provide data for code validation.

- Development of systematic approaches to code validation with uncertainty quantification and application of the validation process to the codes used in analysis of thermal-hydraulics of Gen-IV metal cooled reactors. Together with NPS, we designed the TALL-3D facility (lead–bismuth eutectic loop) in EU THINS and SESAME projects in order to demonstrate application of the validation process to standalone and coupled system and computational fluid dynamic (CFD) codes. Several benchmarks were arranged based on the TALL-3D data in the EU projects.
- Development of nuclear energy solutions for addressing the climate catastrophe. This is a new research direction at NE that aims to develop and demonstrate coupling of nuclear power installations (including lead cooled Generation IV reactors) with CO2 negative technologies such as production of bio fuel and direct air capture of CO2. The ultimate aim of the research is to make Sweden the first net-negative greenhouse gas emission society in the world by 2040.

There are strong links between different research areas and respective teams. Development of new reactor concepts and designs poses new challenges and helps to formulate new tasks for individual research directions. Expertise in building large scale and separate effect experiments for code development and validation is central for all of thermal-hydraulic, fuel and material related research. Development of risk assessment frameworks can help in devising and verifying robust design solutions.

While team “boundaries” are already quite fuzzy with key researchers contributing to different projects lead by “other” teams, further integration and leverage on the present and external (from other schools at KTH and from EU partners) expertise is expected in the new large scale projects such as SUNRISE and nuclear energy solutions for climate.

c. *Contributions to the advancement of the state of the art within the research fields of the department*

Particle and Astroparticle Physics

The ATLAS group is a strong contributor to the experimental activities at CERN:

- Group members had a leading role in the breakthrough discovery of the Higgs boson. The work has transitioned to measuring the properties of this new particle - for example interactions with other elementary particles. Any deviations from the predictions would be an indication of new physics. A very important measurement is also the Higgs boson interaction with itself, something that can only be directly accessed in di-Higgs boson production at the LHC.
- The work of the group in direct searches for physics beyond the Standard Model has led to new, stricter, limits for new particles from e.g. supersymmetry and long-lived new particles.
- The group is deeply involved in measuring the luminosity at the LHC, i.e. measuring the total number of proton-proton interactions at the centre of the ATLAS detector. Knowledge of the luminosity is required for almost all analyses in ATLAS, and the

KTH group has important leadership roles in this effort. The KTH team is a driving force in the use of the High-Granularity Timing Detector as a luminometer after the High-Luminosity LHC upgrade, and the associated detector development.

The contributions to the advancement in astrophysics and astroparticle physics cover several topics:

X-ray polarimetry: Black holes, neutron stars, and other celestial compact objects are too small and distant to be directly imaged. Information on source geometry and high-energy emission mechanisms is instead derived from spectral and timing measurements. Results are often model dependent with interpretation subject to degeneracies which are difficult to resolve. X-ray polarimetry provides a new and independent source diagnostic with two additional observables describing the high-energy emission - the linear polarisation fraction (PF) for a corresponding polarisation angle (PA). We have developed new instrumentation (spanning laboratory prototypes to flight hardware) which allows the linear polarization of X-ray emission to be determined. Our measurements have led to new insights on compact objects, e.g. constraints on the geometry of the coronal-region of Cygnus X-1 - a result which was recently published in Nature Astronomy. Observations have also probed the nature of the emission region in the magnetosphere close to the Crab pulsar. A series of international stratospheric ballooning missions (PoGOLite/PoGo+), which conducted the observations was lead from the Division. In order to maintain a leading position in this burgeoning field of high-energy astrophysics, the Division is also heavily involved in the proposal and preparation of new missions – the XL-Calibur mission will continue and expand the PoGO- science programme through observations with an order-of-magnitude improvement in signal-to-background. Studies (performance simulations and hardware developments) are also being conducted for a transition to a future satellite-based platform. Both small satellites, and more traditional observatory-class missions are being studied. MP was recently elected into the Physics Class of the Royal Swedish Academy of Sciences, with the citation referring to the development of X-ray polarimetry.

Active Galactic Nuclei, Supernovae and supernova remnants: Through studies of accretion and jets in supermassive black holes, we have obtained important new results regarding the emission processes and conditions required for jet formation. New unique observational constraints have been obtained on the explosion mechanism in core-collapse supernovae and the interaction with the surrounding medium. This includes a mapping of the 3D structure of ejecta in a nearby supernova as well as the first calculation and observational comparison of the early X-ray signal from 3D explosion models. The group has been successful in obtaining observing time at the X-ray telescope XMM-Newton and have been leading projects on variability within the Fermi Gamma-ray Space Telescope Collaboration. Time has successfully been obtained at major international facilities, e.g. the Very Large Telescope, the Hubble Space Telescope and the NuSTAR X-ray satellite. The work was also recognised with the prize "Strömer-Ferrnerska belöningen" awarded by the Royal Swedish Academy of Sciences (KVA) in 2017.

Gamma-ray bursts: The group was one of the first to advocate the photospheric model to describe the prompt gamma-ray emission in GRBs, and has been leading the development of this model enabling its use for interpreting observations. The work has received wide recognition culminating in the 2016 Göran Gustafsson Prize in Physics, which is awarded by KVA. Recent developments include establishing the importance of radiation-dominated flows and energy dissipation below the photosphere during the prompt phases in GRBs. A GRB polarimeter concept has been proposed as a national satellite mission, and was selected for Phase A study, but, ultimately, was not selected for flight.

Ultra-high-energy cosmic rays: As part of the JEM-EUSO project, we have contributed to the development of a new method for studying weak and ultrafast phenomena which produce UV-light in the atmosphere, from the ground as well as from space. A proof-of-concept experiment currently demonstrating the technique on ISS is showing excellent results. Detailed studies of the UV-background light from Earth for future experiments are by themselves giving new scientific results about high-atmosphere phenomena, meteors, anthropomorphic UV-sources and limits on Strange Quark Matter from space.

In addition, we have shown that gamma-ray bursts, which have been one of the main candidates for producing ultra-high-energy cosmic rays, cannot be the main source of the highest energy cosmic rays.

Members of the group have been strong contributors to the theory and analysis of three-flavour neutrino oscillations, as well as non-standard physics effects in oscillations. The group has produced open software for the purpose of analysing neutrino oscillation data and scanning the neutrino oscillation parameter space. The group has also been active in dark matter research, notably in terms of analysing indirect signals from dark matter in the form of neutrinos coming from the Sun and astrophysical properties.

Nuclear Physics

The KTH Nuclear Physics group plays a leading international role in the study of nuclear structure with a focus on collective phenomena and on nucleon-nucleon pair correlations. We have been at the international forefront in the exploration of nuclear superfluidity in its more exotic isospin degrees of freedom in the last decade. Following the discovery of excited states in the rare, self-conjugate, nucleus 92Pd which was published in Nature1, and which indicated a new, isoscalar, spin-aligned pairing scheme in the ground states and low-lying states of the heaviest atomic nuclei with equal numbers of protons and neutrons we have continued our studies of extremely neutron deficient nuclei with a focus on nuclear pairing modes and their interplay with the collective degrees of freedom. The isoscalar spin-aligned pairing scheme suggests a new, beyond textbook physics, phenomenon in such exotic nuclei, originally proposed by Prof. Jan Blomqvist, KTH. The theory behind was described in more detail in a subsequent article in Physical Review C by the KTH group2. The discovery was also featured in popular science media, e.g. in the quarterly journal of the Swedish Physical Society3. It remains a topic of large scientific interest in the community with around 10 and 5 citations per year for the Nature and Physical Review article, respectively (Web of Science).

In 2018, we discovered (B. Cederwall et al., Physical Review Letters 121 (2018) 022502) a pattern of transition strengths (related to state lifetimes) in the ground state bands of extremely neutron deficient isotopes of the transitional W-Os-Pt elements that indicates an unexpected phase transition between seniority symmetry (which is closely related to strong nucleon-nucleon pair correlations) and a collective vibrational regime.

This was followed by the recent discovery of evidence for isoscalar pairing in the self-conjugate nucleus 88Ru (B. Cederwall et al., Physical Review Letters 124 (2020) 062501) which for the first time provides evidence for effects of isoscalar neutron-proton pair correlations in a deformed rotating nucleus.

In the recently started work on nuclear safeguards, security and related applications we are setting a new standard for sensitive detection and imaging of special nuclear materials. A new method, originating from our experimental approach to studies of exotic neutron deficient atomic nuclei was described in a recent publication (Trombetta, Klintefjord, Axell, and Cederwall, Fast neutron and gamma-ray coincidence counting for nuclear security and safeguards applications, Nuclear Instruments and Methods in Physics Research A, 927, 119 – 124 (2019) and in a patent application which has recently passed successful evaluation in the international PCT stage (B. Cederwall, application No PCT/SE2019/050609).

The theory team has developed open-source codes and databases:

- PairDiag: Exact pairing solver based on diagonalization (fortran)
- Richardson equation solver (python and mathematica)
- Variational pairing solver (python)
- Large-scale shell model with seniority truncation (fortran)
- Neutron star merger simulator
- Nuclear mass table from TRS and HFB calculations with improved pairing.

Condensed Matter Theory

The following list exemplifies advances from the condensed matter theory division:

Superconductivity and magnetism: A new kind of mixed collective mode in three-band superconductors with broken time reversal symmetry; prediction of anomalous metallic state breaking time reversal symmetry; the notion of metallic and superconducting superfluids and their realisation in hydrogen and deuterium at ultrahigh pressure; introduction of new vortex viscosity mechanism; demonstration of glass formation and Non-Meissner electrodynamics in multiband superconductors; hopfions in superconductors and superfluids; Generalization of FFLO states to the case of unconventional pairing; new non-topological states leading to surface superconductivity in metals and new superface superconducting states; Microscopic theory of magnetic response of non-centrosymmetric superconductors; new kind of magnetic order in antichiral ferromagnetism; finding chiral magnetic skyrmions with arbitrary topological charge.

Strongly correlated materials: new approaches for analyzing quantum phase transitions and disordered systems; the Accelerated Weight Histogram (AWH) method for enhanced sampling and free energy calculations in Monte Carlo and molecular dynamics simulations; modelling of thermal and quantum phase slips in superconducting nanostructures; first numerical method that allows to obtain with controlled accuracy sphaleron solutions in gauge theories.

Topological quantum matter: coupling of domain-wall motion in Weyl semimetals with axial anomaly with applications in spintronics; entanglement spectrum and bulk-boundary correspondence in non-hermitan quantum system; fermi-arc mediated transport in Weyl semimetal nanowires; established a lattice interpretation of consistent and covariant anomalies in presence of fermi-arc states.

Mathematical physics, thermalization and integrability: discovery of new integrable systems; development of solutions methods; applications of known mathematical results to physics; physics of many-body localisation transition and quantum thermalisation; entanglement structures;

Physics of Medical Imaging

The main current research focus of the physics of medical imaging division is photon counting (CT) based on a “deep silicon” technology, invented in the division. The long-term goal of this research project is to develop photon-counting computed tomography based on this technology to the point where it can be adopted in routine clinical use at a large number of medical centers around the world. This is expected to lead to improved diagnostic performance through the better spatial resolution, better contrast-to-noise and improved energy resolution of this new technology compared to the current state of the art, and in the long run to saved human lives. Consequently, the research focus during the reporting period has been a focused effort to develop a prototype photon-counting detector and evaluate its imaging performance. At this point, the detector has been integrated into a clinical CT gantry which is being installed at Karolinska University Hospital for clinical evaluations. There are currently only a handful of photon-counting CT prototype scanners in the world, and the one is unique in being based on a silicon detector with important advantages in terms of energy information and capability to deal with high x-ray fluence rates. These studies have demonstrated the ability of the detector to separate contrast agent from calcium in an excised anatomic specimen end superior visualization of the fine structures of the temporal bone in human volunteers.

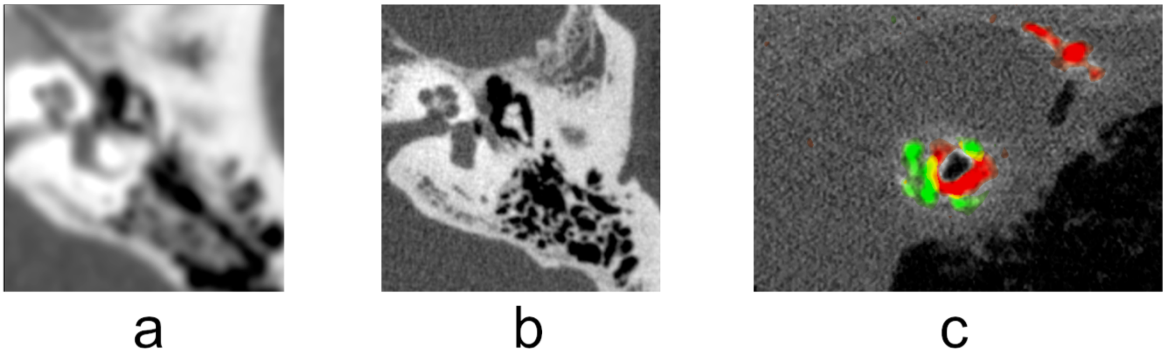


***Figure 1** : (a) Inner ear of a human volunteer imaged with a current state-of-the-art CT scanner. (b) The same inner ear imaged with the photon-counting CT prototype. Showing much improved spatial resolution. (c) Detail of excised heart specimen from a deceased patient imaged with the photon-counting CT prototype. With the energy information available in the new detector, it is possible to separate calcium (green) can iodinated contrast agent (red).*

The development of the new x-ray CT equipment has been carried out in close collaboration with a startup company, Prismatic Sensors AB, formed as a spin-off from the physics of medical imaging division. The close collaboration between the research division and the start-up company has allowed pursuing the dual goals of publishing important scientific results while at the same time developing the new technology towards the goal of a commercial product that can be widely adopted in the clinic. An important step towards this goal has been taken with the acquisition of Prismatic Sensors by GE Healthcare in December 2020 impact case X).

In addition to the research into photon-counting computed tomography, the division has also developed a refractive lens for hard x-rays with an innovative manufacturing method based on UV lithography with a custom-made UV lens. Such a lens has been shown in simulations to be able to improve resolution drastically for single-photon emission computed tomography and enable a novel concept for phase-contrast mammography. In addition, a concept for an x-ray telescope based on this lens was published in Nature Astronomy.

Other research topics pursued within the group during the reporting period include the evaluation of a photon-counting spectral tomosynthesis system in collaboration with Philips Healthcare, a feasibility study of an x-ray fluorescence computed tomography system and investigation of CT dosimetry techniques.

Nuclear Power Safety

The NPS research results generated during the last years helped to elucidate several risk-significant phenomena in reactor safety, including

1. Melt interaction with porous debris during in-vessel and ex-vessel debris re-melting
2. Turbulent natural convection and heat transfer in molten corium pools affecting thermal loading of reactor pressure vessel
3. Reactor vessel behavior under melt attack setting initial conditions for ex-vessel accident progression
4. Core melt underwater spreading and risk of stratified steam explosion
5. Debris formation during fuel-coolant interactions affecting debris bed properties instrumental for coolability
6. Steam explosion energetics setting a risk of reactor containment failure
7. Oxidation of Zr and Zr-Fe droplets in water and associated heat and hydrogen generation
8. Debris bed coolability and risk of debris re-melting
9. Spray cooling as an advanced safety option for several reactor designs, including ex-vessel cooling system for in-vessel melt retention

The impact of the research results (1) through (3) is instrumental to the assessment of in-vessel melt retention (IVR) strategy of light water reactors (e.g. AP1000 and HPR1000); while the items (4) through (8) are paramount to the safety assessment of Nordic BWRs whose severe accident management strategy (SAMS) employs cavity-flooding action (ex-vessel cooling) to arrest the corium; and the item (9) is crucial to apply the in-vessel melt retention strategy to high power reactors. Experimental results generated at NPS are used for model development and validation of several computer codes used in reactor safety analyses. Results of modelling and related safety analyses enforced safety of operating and new BWRs, PWRs and VVERs, but also of new reactor designs, such as sodium cooled fast reactor ASTRID developed at CEA, reactor part of Accelerator Driven System (ADS) - lead/bismuth cooled reactor MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) developed at SCK, and several other designs. NPS research also contributed to combined deterministic/probabilistic analysis of reactor safety.

Nuclear Engineering

- New advanced steels (FeCrAl-based) that can withstand Pb-corrosion up to 800°C for extended periods of time have been developed in collaboration with Surface and corrosion science. This is a critical development in materials for GenIV lead fast reactors (#2).
- A range of small modular reactor designs based on LFR technology (ELECTRA, SEALER, SEALER-UK, SEALER-E, SUNRISE research reactor) which have been enabled after the above materials development (#1) and fuel development (#4).
- Method development for dynamic studies of radiation damage phenomena have been extended to the explicit quantum scale for maximal physical relevance. A paradigm shift has been introduced by going beyond the previously canonical approach of using static quantum mechanics (density functional theory level) to predict some key parameters, and then build semi-empirical classical models. We developed state of the art direct dynamic quantum mechanics simulation methods. This direction is crucial for addressing performance of new materials (#1) in new reactor designs (#2)
- Advanced nuclear fuels developed to a global state of the art, with focus on nitrides and silicides. Best oxidation resisting UN pellets (better than e.g. LANL by wide margin), microstructure and grain size control through spark plasma sintering. This development is another crucial element for deployment of Generation IV designs (#2)
- Development of ROAAM+ framework and coupling with commercial software RiskSpectrum for probabilistic safety analysis of power plants. This development is important step forward in safety analysis of light water reactors and is planned to be applied in the design and licensing certification process for Generation IV reactors (#2).
- Development of effective heat and momentum source models that enabled simulation of steam injection into large scale water pools for analysis of containment thermal-hydraulics. This development is important for realistic assessment of containment performance in light water reactors and is expected to contribute more to (#5)
- Development of corium debris bed formation and coolability code DECOSIM was a significant part of phenomenological model development and validation for severe accident analysis in (#5) and relied on an extensive experimental program.
- Development of a comprehensive steam explosion risk analysis model was another critical element in (#5) and first-of-a-kind approach for adequate risk quantification using deterministic models for chaotically behaving systems.

d. Quality and quantity of contributions to the body of scientific knowledge

The department is one of the most prolific at KTH in terms of number of associated publications. It is very difficult to make a selection of about ten papers, as instructed, to exemplify the impact and wide reach of the research performed at the department. Nevertheless, we here list a small selection of papers. They are chosen in an attempt to represent the broad range of topics and to exemplify the high quality of publications emanating from the research performed at the department.

- ATLAS collaboration, "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC", Physics Letters B **716** (2012) 1.
- W. Villanueva, C.T. Tran, and P. Kudinov, Coupled thermo-mechanical creep analysis for boiling water reactor pressure vessel lower head, Nuclear Engineering and Design **249** (2012) 146.
- T. Ohlsson, "Status of non-standard neutrino interactions", Rep. Prog. Phys. **76** (2013) 044201.
- H.M. Revell, L.R. Yaraskavitch, J.D. Mason, K.A. Ross, H.M.L. Noad, H.A. Dabkowska, B.D. Gaulin, P. Henelius, J.B. Kycia, "Evidence of impurity and boundary effects on magnetic monopole dynamics in spin ice", Nature Physics **9** (2013) 34.
- M. Persson, B. Huber, S. Karlsson, X. Liu, H. Chen, C. Xu, M. Yveborg, H. Bornefalk, M. Danielsson, "Energy-resolved CT imaging with a photon-counting silicon-strip detector", Physics in medicine and biology **59** (2014) 6709.
- B.V. Svistunov, E.S. Babaev, N.V. Prokof'ev, "Superfluid states of matter", (2015 Crc Press).
- P. Olsson, C.S. Becquart, C. Domain, "Ab initio threshold displacement energies in iron", Materials Research Letters **4** (2016) 219.
- A.B. Belonoshko, T. Lukinov, J. Fu, J. Zhao, S. Davis, S. Simak, "Stabilization of body-centred-cubic iron under inner core conditions", Nature Geoscience **10** (2017) 312.
- B. Cederwall, et al., "Lifetime Measurements of Excited States in Pt-172 and the Variation of Quadrupole Transition Strength with Angular Momentum", Physical Review Letters **121** (2018) 022502.
- M. Chauvin et al. (PoGO+ Collaboration), "Accretion geometry of the black-hole binary Cygnus X-1 from X-ray polarimetry", Nature Astronomy **2** (2018) 652.
- C. Qi, R. Liotta, R. Wyss, "Recent developments in radioactive charged-particle emissions and related phenomena", Progress in Particle and Nuclear Physics 105 (2019) 214.

Reflection on the department's bibliometric performance

The full count of publications from the department over the period of assessment is show in table 1, as obtained from the KTH library.

DiVA publication type	2012	2013	2014	2015	2016	2017	2018	2019	Tot.	WoS cov.	Scopus cov.
Article, peer review	249	215	219	287	354	317	337	288	2266	97,4%	98,4%
Article, other	9	8	5	3			5	2	29	100,0%	47,8%

Conf paper, peer review	36	41	37	63	34	35	26	38	260	39,2%	39,2%
Conf paper, other	2	6	6	2	5	1	3	2	27	0,0%	4,0%
Book		3	1	1		1		1	7	0,0%	28,6%
Chapter in book	2	1	1	1	2	1	1		9	0,0%	85,7%
Report	3	1		1					5	0,0%	0,0%
Doctorate thesis	14	6	8	7	10	5	12	7	69	0,0%	0,0%
Licentiate thesis	6	3	3	3	6	4		3	8	0,0%	0,0%
Patent, approved							2		2	0,0%	0,0%

Table 1 – Publications in DIVA, total count (need update including PMI patents)

The number of peer reviewed articles lie stably at around 250-300 per year. The average number of doctoral theses are about 8-10 per year. The numbers for 2012 to 2017 do not include publications by the groups from the former Theoretical Physics department. The publishing tradition varies significantly between the different research fields of the department. In large international collaborations, like the ATLAS experiment, publications are signed by the full collaboration, resulting in a large number of authors based on that all have to contribute their share to the work and that it is not possible to single out a subset of people that are responsible for achieving the published results. The outcome of KTH library author normalized fractions is that some of the most important publications within the field like the discovery of the Higgs boson, with at present close to 16000 citations, hardly count in the library statistics although KTH faculty have made essential contributions.

The author-fraction normalized number of peer reviewed publications per year during the evaluation period is shown in **Error! Reference source not found.**. The fractionalized number peer reviewed publications is roughly stable around 60 articles and 20 conference papers per year. The highly international character of the department is reflected in the co-publishing as visible in Figure 3. 85-90% is internationally co-published, while only between 5-10% are co-authored with Swedish non-universities.

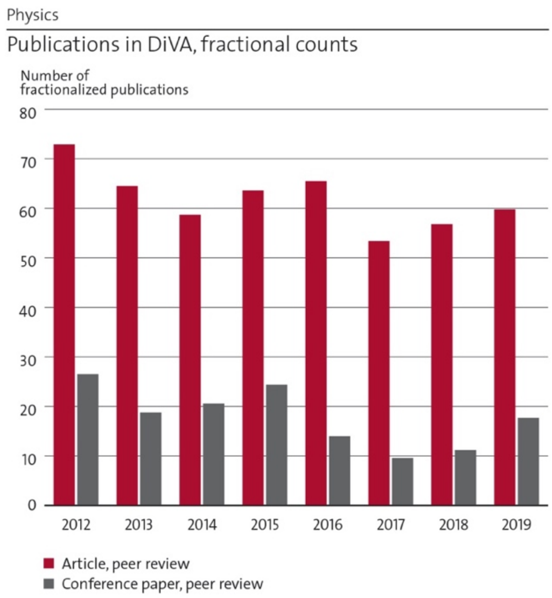


Figure 2 Peer reviewed publications in DiVA, fractional count, for the period of evaluation

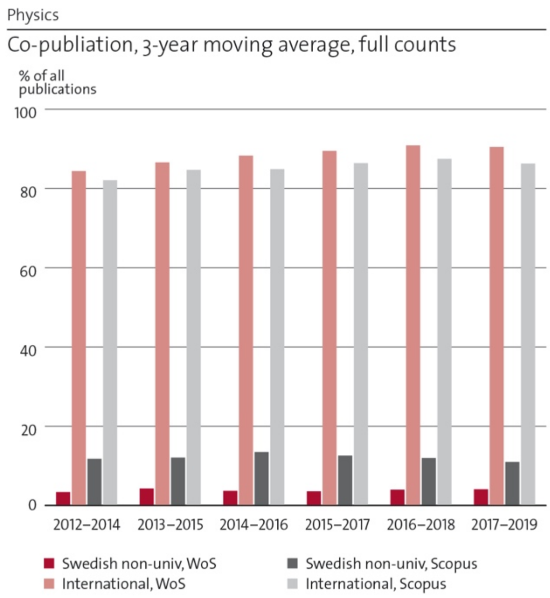


Figure 3 International and Swedish non-university co-publications, full count (3-year moving window).

The publishing strategy varies between divisions. While some divisions publish predominantly by peer reviewed article, peer reviewed proceedings have important roles others. Proceedings are better covered by Scopus than WoS. The average publication impact factor obtained using Scopus is 1.33 as seen in Figure 4.

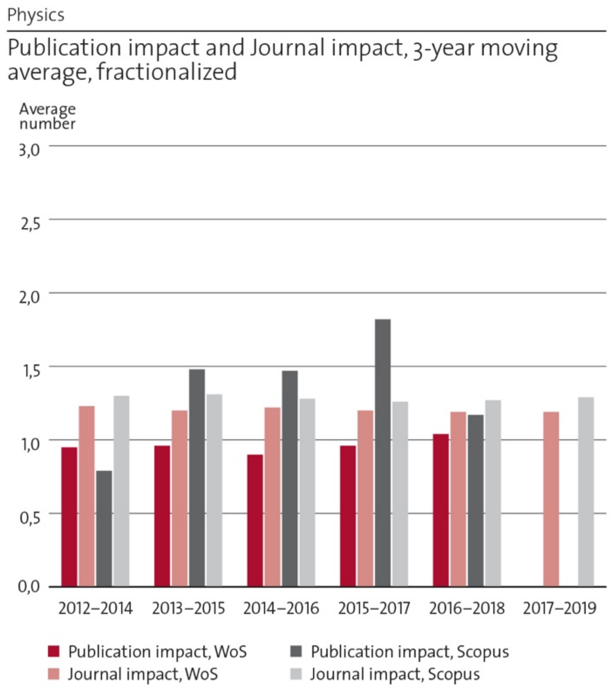


Figure 4 ***Fractional publication and journal impact in 3-year moving windos.***

e. Engagement in national and international research collaboration within academia and its outcomes.

The researchers and research groups at the department are all engaged in national and international collaborations. For certain divisions, the local environment at AlbaNova – with KTH Physics, KTH Applied Physics, Stockholm University Physics and Astronomy, and Nordita – is a major source of collaboration. For other divisions, most collaborations are found outside of KTH.

Members of the **Particle and Astroparticle Physics** Division, play a leading role in scientific collaborations, both internationally and on the national and local environment level:

- The ATLAS project at CERN:

  - Physics studies are focused on Higgs decay studies and the search for beyond standard model particles.

  - The HGTD upgrade where KTH is the lead group for the development as luminometer.
- The di-Higgs network between KTH, Lund, Uppsala and Stockholm universities to promote collaboration between experimentalists and theorists.
- The Oskar Klein Centre (OKC) – recently named as one the top three Linnaeus Centres of Excellence in Natural Sciences after an international review commissioned by the Swedish Research Council. A member of the Division was co-founder
- The KTH Space Center, which provides an interdisciplinary platform at KTH for space-related activities, including the creation of a space technology laboratory infrastructure.
- The International Space Station and the JEM-EUSO misison.
- The X-ray polarimetry group collaborates internationally, e.g:

  - PoGOLite/PoGO+ Collaboration. (~2004-2019). KTH (MP) is PI since 2009 for a Collaboration which has included members from Sweden, Japan, USA, and Russia.

  - XL-Calibur collaboration. (2019-) KTH (MP) is Co-I. Involves groups from KTH, USA, and Japan.

  - The SPHiNX mission (2016-2019) was a collaboration within the KTH Space Centre, which proposed a national satellite for GRB polarimetry. KTH (MP) was PI.

  - The XIPE mission for X-ray polarimetry. Proposed to the European Space Agency as a medium-class (M4) mission. KTH (MP) lead the working group which studied measurement backgrounds, and was a member of the mission core team.
- The Fermi Gamma-ray Space Telescope Collaboration. FR is the Swedish PI of the international collaboration of the Large Area Telescope, lead from Stanford University and he is member of the Senior Scientist Advisory Board. The Swedish effort includes Stockholm University and KTH. We are also active as members of the Gamma-ray Bursts Monitor science group, lead from Hunstville university, Alabama, USA.
- On the theory side, the group is involved in the long baseline neutrino collaborations: ESSnuSB design study, DUNE, T2HK and INO; and the European Networks:

Invisibles, Elusives and Invisibles+, as well as regular collaborations with the international high-energy physics theory community.

For **Nuclear Physics**, the experimental group is mainly conducting research at large-scale international research infrastructures. The necessary detector instrumentation is due to its complexity typically also developed within the framework of large international collaborations where each university or research institute each contributes a different expertise. Experiments are proposed in strong competition to the international programme advisory committee (PAC) at the research infrastructure by teams of scientists led be a PI/spokesperson. Approved experiments are then carried out by teams (consisting of typically 10-50 participants from one to ten international research groups). It is normally the group of the PI that takes the main responsibility for running the experiment and takes the lead in the subsequent data analysis, dissemination of results etc. KTH has been active mainly at the following research infrastructures the last eight years:

- GANIL – The French national heavy ion accelerator complex (Caen)
- RIKEN Radioactive Ion Beam Factory (RIBF), Japan
- University of Jyväskylä cyclotron accelerator laboratory, Finland
- National Superconducting Cyclotron Laboratory, Michigan Sate University, USA

We are also heavily involved in developing detector instrumentation for:

- FAIR – Facility for Antiproton and Ion Research, Darmstadt, Germany.

for which we are mainly involved in the DESPEC germanium detector array DEGAS and AGATA. While DEGAS is designed for decay spectroscopy of exotic nuclei AGATA is designed to carry out in-flight gamma-ray spectroscopy of relativistic nuclei. AGATA is constructed in phases and deployed for physics campaigns at different European accelerator facilities like GANIL and LNL Legnaro before FAIR is ready for experiments in 2026.

The main external experimental collaborations are with:

- University of Liverpool, UK; University of Padova, Italy,;Legnaro National laboratory, Italy, University of Jyväskylä, Finland; GSI, Darmstadt, Germany; Darmstadt University, Germany; Argonne National Laboratory, USA; Lawrence Berkeley Laboratory, USA; University of Paris Sud, Orsay, France; CEA Saclay, France; Uppsala University; University of Warsaw; Osaka University, Japan; University of Tokyo, Japan.

The nuclear safeguards and security team carries out most of the research in-house but also has important external collaborations with:

- SSM
- JRC, Ispra, Italy
- UC Berkeley, USA
- JRC Geel, Belgium

as well as many other groups within the framework of the European Safeguards Research and Development Association. The microdosimetry team collaborates with SSM.

The nuclear theory team has a strong collaboration with international experts in the field. We would in particular like to mention the collaboration with the University of Tokyo code from 2017 which became possible thanks to a funding from KTH through its strategic partnership with University of Tokyo. We work together on large-scale shell model calculations on intermediate nuclei and on the development of new shell model algorithms. A large-scale shell model code with a novel seniority truncation has been developed. We have also extended our study to two-neutrino/neutrioless double-beta decay studies together with the Tokyo group. It is also to be pointed out here that one of the senior researchers (Liotta) is a Divisional Associate Editor and member of the Editorial board of Physical Review Letters.

For **Condensed Matter Theory**, one main collaboration that is becoming more formalized is within quantum technology and the QTH (Quantum Technology Hub), which is an initiative to coordinate all quantum technology research at KTH. The plan is to launch the center in 2021. The mission is to bring together academia and industry to share and generate innovations in the expansive area of emerging quantum technology. The research is organized into four focus areas: 1. Sensing, nanofabrication, and communication. 2. Quantum computation. 3. Quantum phenomena in biomedical research. 4. Quantum Materials.

The Division is involved in bigger Wallenberg projects on the topics of dynamic quantum matter (together with Nordita, Stockholm University and Uppsala), quantum sensors (together with KTH applied physics) and functional quasicrystals (together with Stockholm University, ESS, and Uppsala University), in addition to an industrial collaboration with Microsoft station Q on the topic of topological quantum computing. Further joint activities with the KTH math department include hosting a guest professor from Japan funded by the Wallenberg foundation. These activities demonstrate the broad activities of quantum technology, covering the range from fundamental theory to direct applications.

We further have long standing collaborations on various projects with individual researchers in universities around the world, including, but not limited to, Leeds University, Russian Academy of Science Novosibirsk, South Florida, Livermore National Lab, University of Massachusetts Amherst, MIT, Tokyo University, Oslo university, Copenhagen university, NTNU Trondheim, Tel Aviv University, and University of Grenoble.

The **Physics of medical imaging** division has a long-standing collaboration with the Karolinska Institute and Karolinska University hospital. This has resulted in a jointly supervised PhD thesis in clinical medical physics and several joint publications with medical researchers who contribute with their expertise in the evaluation of new medical imaging technologies developed ad KTH. This collaboration has recently been deepened through the formation of MedTechLabs, a joint research center that brings together engineering researchers from KTH and medical researchers and practitioners from Karolinska in order to develop new technologies to address relevant clinical needs. This collaboration is expected to be intensified in the near future as a prototype photon-counting scanner resulting from the research in the division is currently being installed at the Karolinska premises, giving ample opportunity to joint studies of the clinical applications of the new technology. In another long-standing collaboration, the division is working together with the Department of Electrical Engineering (ISY) at Linköping University in in order to develop readout electronics for novel x-ray detectors, resulting in a cutting-edge application-specific integrated circuit for detector readout used in the photon-counting prototype CT as well as publications exploring design options for a future readout circuit currently under development.

A particularly close collaboration has been developed with the startup company Prismatic Sensors AB, founded by members of the division. By developing a closely-knit team encompassing both the research group and the startup company, it has been possible to combine the best of the academic and industrial worlds, leveraging the research competence and networks available at KTH and the development experience and funding available to a company to achieve both important science and a potentially commercializable product. An informal collaboration is still active after the acquisition of Prismatic Sensors AB by GE healthcare in 2020 and this is expected to become formalized in the near future. Other industrial collaborations include a past collaboration with Philips Healthcare around an industrial PhD project in the field of photon-counting mammography, and examination of MSc theses localized at medical technology companies in the Stockholm region.

With regards to international collaboration, the division has close connections with the department of radiology at Stanford University, CA, USA, with a fruitful exchange of expertise in x-ray detector simulation and performance modeling. The connections to Stanford University and General Electric have also been strengthened by the recruitment of Mats Persson as assistant professor after his postdoctoral tenure at Stanford University and GE Research Center in Niskayuna, NY. Other international collaborations during the reporting period are a clinical evaluation of novel mammography equipment with Cambridge Biomedical Research Centre, UK, and Radboud University Medical Centre, NL; detector modeling together with the US Food and Drug Administration and comparison of x-ray readout circuit designs with the department of radiological sciences at UCLA, CA, USA.

For **Nuclear Power Safety**, the national collaboration with Chalmers University of Technology has been established in the SSM project TSO-DSA for design-basis-accident safety analysis of Swedish NPPs, the VR project GENIUS dedicated to research for lead-cooled reactors and the series of VR projects supporting Swedish-French collaboration on the development of ASTRID SFR and Jules Horowitz research reactor (MTR). NPS also has a close collaboration with Chalmers University of Technology within the APRI program.

NPS has strong international collaborations with many organizations from different countries, such as CEA, IRSN and EDF in France; KIT and GRS in Germany; PSI and ENSI in Switzerland; ANL, SNL, NCSU and NRC in USA; NRA, JAEA, CLADS and University of Tokyo in Japan; KAIST, POSTECH and KAERI in Korea; SCK-CEN in Belgium; UJV in Czech Republic; Fortum and VTT in Finland; EK in Hungary; NRG in Netherlands; OECL in Canada; KI, NITI and LETI in Russia; CNPE and CIAE in China. These collaborations were created under coordination of EU/OECD/IAEA projects, SARNET network of excellence and NUGENIA association in EU for reactor safety research. Recently NPS together with other six large EU nuclear research centers became a part of Pan-European Laboratory of Severe Accident Research created in the EU project SAFEST. Some examples of specific collaboration areas and research outcomes are given in the following table.

Partner	Area of collaboration	Main outcomes
Karlsruhe Institute of Technology (KIT), Germany	Melt natural convection experiments	Concept of SIMECO-2 facility developed at KTH

	Experiments on melt interaction with concrete Degradation of overheated reactor core and its quenching	MOCKA experiments carried out at KIT with Swedish types of reactor concretes QUENCH-SSM tests carried out at KIT with BWR bundle mock-up
Le Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France	SA research for Gen IV systems Sodium fast reactor ASTRID FCI and steam explosion	PIRT and research roadmap Several research projects at KTH complimenting ASTRID reactor safety MISTEE experiments at KTH with single molten drops to study steam explosion and Zr oxidation during FCI
Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France	Thermodynamic modelling of corium Modelling of steam explosion	NUCLEA TD database used at KTH in safety analyses and further developed Several MC3D code developments at IRSN and applications at KTH
EU Join Research Centre (JRC), Karlsruhe	Phase diagrams and physical chemistry of corium	Laser flash melting/crystallization experiments with BWR specific compositions carried out at JRC for SSM, Sweden
Nuclear Regulatory Authority (NRA), Japan	Ex-vessel corium coolability	DEFOR, PULIMS and REMCOD tests carried out at KTH for model development at NRA
Swiss Federal Nuclear Safety Inspectorate (ENSI), Switzerland	APRI national program in Sweden	Research results of the program
Collaborative Laboratories for Advanced Decommissioning Science (CLADS), Japan	Severe accident research roadmap between Japan and EU Fukushima-related OECD projects	Roadmap published Best estimate accident analyses of unit 1 and various contributions in plant decommissioning
Korea Atomic Energy Research Institute (KAERI), Korea	Behaviour of RPV bottom penetration during late phase of severe accident	Experiments carried out at KAERI on penetration failure with chemically prototypic corium melt
Pohang University of Science and Technology (POSTECH), Korea	Two phase flows	Educational course developed at KTH

Argonne National Laboratory (ANL), US	Melt spreading under the water	Experiments with simulant melts to be carried out at KTH to support ROSAU OECD tests with prototypic corium at ANL

For **Nuclear Engineering**, the main collaborations are external to KTH, but there are many active and intense local collaborations as well, mostly with the Department of Chemistry and with Engineering Mechanics.

National collaboration is also important for Nuclear Engineering. There has been intense collaboration with different departments at Chalmers university of Technology, EDF R&D in France, Uppsala University, Linköping University, CEA Saclay, CEA Cadarache, PSI Switzerland, Luleå Technical University, VTT Technical Research Centre of Finland and Lappenranta University of Technology, to mention a few. There is also a growing role for national collaboration with safety authority (SSM) and industry.

Nuclear Engineering collaborations are extensive and multifaceted (see some example below) and not easily definable in a unified manner. Nationally most important links are with safety authority and industry. Typical strategy for engagement is to use internal (KTH) and national (SSM, industry, other universities) collaboration in order to develop unique abilities and establish strong research profile that helps to engage into international cooperation activities. Quite often Nuclear Engineering provides analytical support (model and code development) to large scale international experimental programs (e.g. under OECD). In the future we expect that Nuclear Engineering will also utilize existing and develop new experimental infrastructure to provides experimental data to national and international partners.

On the international level, the division has been leading and participating in numerous international projects, especially on the European scene. During the EC Framework program 7 (FP7), we were involved in the projects:

- GETMAT, led by KIT, Germany, from 2008-2013. PI at KTH was Pär Olsson. The project was focused on research on FeCr- and similar alloys for GenIV reactors. The main outcome from KTH was a range of seminal papers describing FeCr alloys stability and defect properties from first principles through multiscale modeling, establishing KTH as a leader in the nuclear materials modeling community. Has since been followed by MATISSE and M4F projects, see below.
- PELGRIMM, led by CEA, France, from 2012-2016. PI at KTH was Janne Wallenius. The project was focused on development of minor actinide bearing fuels for Gen-IV reactors. A central project outcome was a reference fuel design for minor actinide burning.
- MAXSIMA, led by SCK-CEN, Belgium, from 2012-2018. PI at KTH was Janne Wallenius. The project was focused on safety aspects of the MYRRHA reactor concept. From KTH, the main project outcome was an LFR safety simulator for mobile platforms.

- MARISA, led by SCK-CEN, Belgium, from 2013-2016. PI at KTH was Janne Wallenius. The project was focused on the preparation of a consortium for the MYRRHA reactor. From KTH, the main outcome of the project was establishing a legal organisation of MYRRHA.
- ARCADIA, led by ICN, Romania, from 2013-2016. PI at KTH was Janne Wallenius. The project was focused on supporting reactor development in Eastern Europe. For KTH, the main outcome of the project was a training program for Lead Fast Reactors.
- ESNII+, led by CEA, France, from 2013-2017. PI at KTH was Janne Wallenius. The project was focused on research on Generation IV reactors in Europe. From KTH, the main outcome of the project was a training program for ELECTRA.
- MATISSE, led by KIT, Germany, from 2013-2017. PIs at KTH were Janne Wallenius and Pär Olsson. The project was focused on materials development for Generation IV reactors. For KTH, the main outcome of the project was development and qualification of steels for lead-cooled reactors.
- EFDA (European Fusion Development Agreement), was a pan-European consortium over 1999-2013 in which KTH participated in modeling radiation damage in materials. This organisation was later transformed into EUROfusion, from 2014 onwards, and NE at KTH has been ramping up its participation and contribution significantly over the last 6 years. The focus is still radiation damage in materials but in recent years we have been focusing more on developing first principles methods to the stage that they can be directly used to study radiation damage phenomena, instead of relying on classical approximation models.

Since 2014, the research and development instrument in Europe has changed to the 8th framework program (Horizon 2020). In this program we have been involved in the following projects:

- SOTERIA, led by EDF R&D, France, from 2015-2019. PI at KTH was Pär Olsson. The project was focused on safe long term operation of current generation reactors and the main outcome from KTH was establishing modeling tools and paradigms for RPV steels and discovering how kinetics drive the formation of particular solute clusters that can cause embrittlement over long operation times.
- McSAFE: “High-Performance Monte Carlo Methods for SAFEty Demonstration - From Proof of Concept to realistic Safety Analysis and Industry-like Applications”, led by KIT, Germany, from 2017-2020. PI at KTH is Jan Dufek (WP leader). The McSAFE project develops and promotes Monte Carlo based stand-alone and coupled solution methodologies (advanced depletion, optimal coupling of MC-codes to thermal-hydraulic solvers, time-dependent Monte Carlo and methods and algorithms for massively parallel simulations) and implements them into widespread numerical tools for realistic core simulations.
- M4F, led by CIEMAT, Spain, from 2017-2021. PI and Domain leader from KTH is Pär Olsson. The aim of the project is to develop models for radiation induced embrittlement in materials of common interest for both fusion and fission communities.
- GEMMA, led by ENEA, Italy, from 2017-2021. PIs at KTH are PEter Szakalos and Pär Olsson. The aim of the project is to develop materials for GenIV reactor systems to maturity, ranging from advanced cladding to main structural steels.

- IL TROVATORE, led by SCK-CEN, Belgium, from 2017-2021. PI at KTH is Pär Olsson. The aim of the project is to fast track development and qualification of cladding materials for accident tolerant fuels in light water reactors. The project notably includes extensive neutron irradiation campaigns.
- INSPYRE, led by CEA, France, from 2017-2021. PI at KTH is Pär Olsson. The aim of the project is to develop mixed oxide fuels and associated materials (fuel-cladding interaction) for deployment in GenIV reactors.

Most recent EU projects include PATRICIA, PASCAL and McSAFER that address safety aspects of heavy metal cooled and small modular reactors respectively.

f. Follow up from previous evaluations

In the last RAE, of 2012, the different divisions that make up the Department were evaluated in three different panels instead of a common one, as it will be in the RAE of 2021. Therefore, we list the follow up of the previous evaluation per division:

Particle and Astroparticle Physics

The previous RAE pointed out that although the teams and the environment are good enough to enable world-leading work, the situation is fragile due to the teams being quite small relative to peer institutions. In the merger between the Physics and the Theoretical Physics departments, the theoretical particle physics group joined the division giving a stronger environment which now spans both experiment and theory which has already resulted in common funding requests. To further strengthen the environment, two faculty and two permanent researchers have been recruited.

Nuclear Physics

The previous RAE pointed out that the team was rather small and the impact on technology is rather long term. The Nuclear Physics Division has grown by approximately 50% since 2012 and has now more than 20 members. The major contributions of this increase are due to two additional senior staff members in the nuclear safeguards and security team and a larger number of PhD students and postdocs. We have made significant progress in applied nuclear physics studies and technology development in particular in nuclear safeguards.

Condensed Matter Theory

The main development since last RAE is the merger of the Physics and Theoretical physics departments. The merger was mainly motivated by the too large number of physics departments and divisions where three departments and one division were merged into two departments. The gain of merging the Physics and Theoretical physics departments is building a bigger and stronger unit, which can lead to closer collaboration between the department divisions. The condensed matter theory division has strengthened its work on quantum matter broadening the work on strongly correlated matter to include various topological phases of matter.

Physics of Medical Imaging

In RAE 2012, the Physics of medical imaging division was evaluated as part of the Applied Physics and Medical Imaging UoA and received a very positive evaluation. Therefore, the focus of this division has been to further develop the strengths identified in the previous assessment. The combination of scientific excellence with entrepreneurial spirit highlighted in RAE 2012 has been further developed by a close collaboration with the startup company Prismatic Sensors AB founded as a spin-off from the group and resulted in the development of a prototype photon-counting CT scanner and 69 granted patents in different countries during the evaluation period. As the importance of providing opportunities to young researchers was stressed in the previous evaluation, the division has been able to secure the external funding that enabled the recruitment of Mats Persson as assistant professor in 2020.

Nuclear Power Safety

Addressing the comment of RAE-2012: “The UoA seems to be in some way isolated at KTH and a closer integration is recommended into the overall energy community for example through the KTH Energy Platform initiative”, NPS division enforced internal collaborations at KTH coordinated by various platforms. Some recent examples are:

- Collaborative project with the Division of Wood Chemistry and Pulp Technology (WCPT) entitled “High temperature carbonization of wood-derived polymers for sustainable energy applications” in frames of the Call ”Energy Pairs 2020”;
- Collaboration with the Division of Laser Optics on development of Fiber Bragg Grating optical sensors for nuclear industry, safety related systems and potentially other industrial applications;
- Measurements of contact angles between Sn/Bi eutectic melt and different substrate materials in the Department of Materials Science and Engineering planned for the nearest future with NPS participation
- Collaboration on mechanical analyses of reactor pressure vessels with the Department of Mechanics and on high performance computing of turbulent convection with PDC at KTH.

The internal collaborations are economically limited by very small fraction of internal budget directed to the division from KTH. More than 80% of the division budget comes from the external customers; consequently, NPS has more external collaborations than internal ones.

Nuclear Engineering

NE is a new division since last RAE in 2012, formed by merging Reactor Physics and Reactor Technology during the department merger in 2017-2018. This was in part a suggestion from the last RAE and has led to improved synergy between the researchers in the division.

RAE 2012 suggested that “closer integration is recommended into the overall energy community”. NE is an active member of the KTH Energy Platform initiative and is establishing new links with KTH groups that are addressing issues of sustainable transformation of the energy industry.

A limited mobility of research staff between academia and industry was indicated by RAE 2012. Currently NE has two affiliated faculty members from nuclear industry.

Generation IV research was deemed essential in RAE 2012, while acknowledging that it will require “substantial focusing of resources as well as partnering across KTH, nationally and internationally”. NE is very active in development of lead cooled fast reactor technology and is collaborating with main EU partners in several Euratom projects.

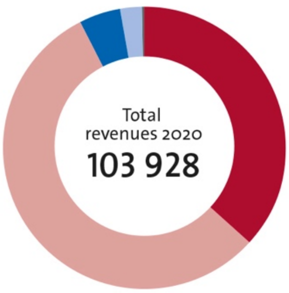
3. Viability

a. Funding; internal and external

The department has a turnover of about 105 MSEK and some 130 staff. We have a very good track record in attracting external funding, which is what allows for financing PhD students, postdocs and researchers, as well as co-financing the faculty. The balance of internal vs external funding has been fairly stable with a ration of roughly 1 to 2 over the last years. The main external contributors are currently VR, EU, SSF, SKC, SSM, Göran Gustsfsson foundation, KAW and Rymdstyrelsen. Since the last RAE in 2012, SKB has dropped out from the list of main external grant providers, due to their change in operational mode.

Physics

Sources of research income (2012, 2016, 2020)



Research income, kSEK	2012	2016	2020
Government grants for research and doctoral studies	22 655	24 576	38 317
Collaborative research funding	61 208	55 502	57 665
Contract research funding	10 626	11 723	4 986
Other revenues	2 367	2 307	2 914
Financial income	396	15	47
Total revenues	97 251	94 125	103 928

Figure 6.. Sources of income 2012, 2016 and 2020. The numbers from 2012 and 2016 do not include the groups from the former Theoretical Physics Department.

The internal funding of near 35% average is split roughly as 2/5 on teaching and 3/5 faculty support. The ratio of internal to external support is strongly varying between the research divisions. From 80/20 external/internal to 40/60 at the extremes. Handling this large variation within the Department is a challenge.

Clear issues with the current funding model is that not even faculty salaries are covered by internal faculty funds plus teaching, and all faculty have to actively work to find external sources of funding. All other staff is funded almost exclusively by external sources. The strong dependence on external funding prevents long-term strategic planning. It is particularly difficult to find sustainable funding for instrumentation, laboratories and technical staff.

Over the last years, the growth of the department (aside from the growth due to the merger in 2018) has almost exclusively come through external funding. Notable exceptions are three called professors (Ayse Atac, Christer Fuglesang and Sandhya Choubey) whose inclusions in the faculty have been partially supported centrally by increased levels of faculty funding.

b. Academic culture

It is important to stress that the department has many academic cultures; not necessarily partitioned the same way as the research divisions. This is first and foremost a strength, but unavoidably leads to some difficulties in quantifying certain parameters, such as impact, bibliometry, publication strategies, et cetera. The spread in academic culture is a consequence of the width of subject fields that make up the department. An example is experimental particle physics, which has a very different academic culture, especially as regards publication tradition, compared to most others in the department.

Generally, the working culture in the department is very international. All groups have regular seminars and meetings, either at division level or smaller research group level. The department is part of the organisation In the AlbaNova environment of high-profile colloquia in physics, that often boast truly world-leading experts, including the occasional Nobel laureate.

PhD students have journal clubs that they follow outside of their curriculum, there are good facilities at division level for spontaneous meetings and discussions in the corridors, fika- and lunch rooms. For the department as a whole this is less well organized since the different divisions are located in different parts of the main AlbaNova building.

All staff regularly participate in international workshops and conferences, and the department organises a few major conference or workshops per year. Videolink participation has skyrocketed during the Corona crisis and we assume it will be used more in the future as well, to avoid unnecessary travel to progress meetings and similar. Physical participation in conferences and workshops is such an important part of the academic culture and creative process that we do not envisage a decrease in such participation in the coming years.

c. Current faculty situation

The staff at the department in 2012, 2016 and 202 divided into cathegories is shown in

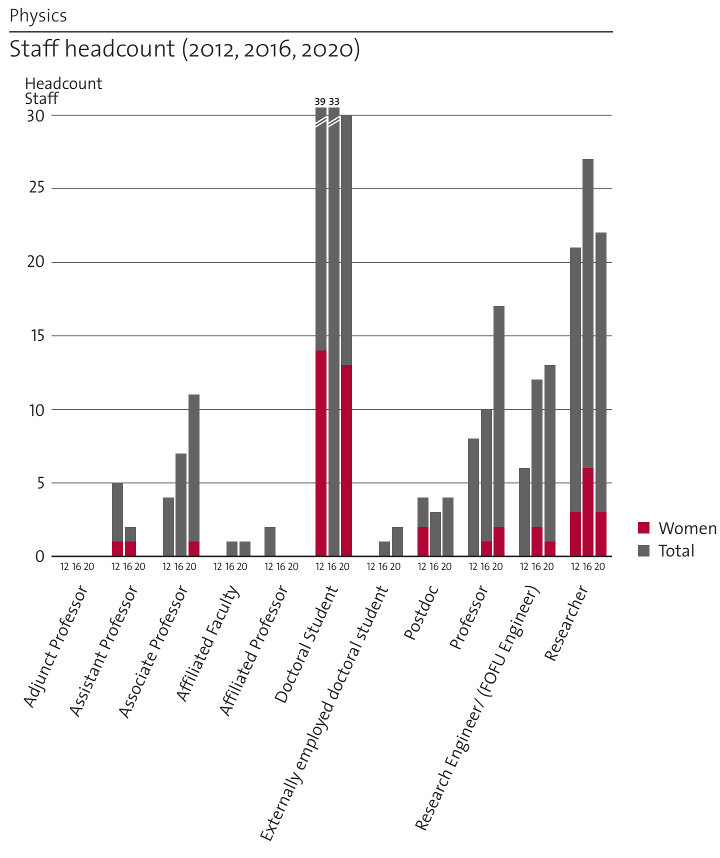


Figure 5 Number of staff in different cathegories in 2012, 2016 and 2020. The PhD student statistics for 2016 has failed to split into gender. The true numberdwould be around 13 women.

The current numer of faculty, divided in the research divisions as detailed in the table below:

Total (female)	**PAP**	**CMT**	**NP**	**NPS**	**NE**	**PMI**
Professor	6 (1)	4	2 (1)	1	3	1
Associate professor	3 (1)	3	2	1	2	0
Assistant professor	0	0	0	0	0	1
Affiliated faculty	0	0	0	0	2 (1)	0
Emeriti	5 (1)	7	3	3	1	0

The most striking issue is the strong gender imbalance, with only 10% females in the faculty (at the PhD and postdoc level the fraction is above 20%). This is clearly problematic for the department. In the management group, there has not been any females in the last years, except for the head of the physics administration. This was changed in 2020 with the appointment of associate professor Josefin Larsson as acting deputy head.

The larger fraction of professors over associate- and assistant professors is a natural consequence of the KTH promotion regulations and procedures. The major part of an normal faculty career will be spent as *professor*, as long as the faculty is sufficiently active in all areas needed to fulfil the promotion criteria. A central strategy at the department is to ensure that all faculty are clearly aware of the criteria and what is expected of them before they can apply for a promotion. Lastly, one can note that the number of faculty positions in the different research groups has stronger variation than the sizes of the groups.

There is also an important number of permanent researchers, engineers and technicians in the department (28), whereof 1 female, that contribute with extremely important specialist competences. Some of the research staff also contribute significantly to teaching. One concern regarding the non-faculty research staff is the lack of clear career paths at KTH. Such possibilities would be welcome changes of KTH policy.

d. Recruitment strategies

The department recently recruited an assistant professor in physics of medical imaging, and has over the period 2012-2020 recruited 5 faculty members at the assistant professor level, as well as three professors that have been *called* to their positions by the president of KTH.

One main issue of concern regarding recruitment is the government imposed rule of a 5-year seniority limitation for recruitment of assistant professors. In many fields it is normal to do 5 years of postdoc before starting to look for faculty positions, and for KTH it is then too late. A potential solution for KTH, to circumvent the central problem with this rule, would be to allow open rank recruitment, as is often done internationally in leading institutes. Then, recruitment focused on *potential* rather than *achievement* would remove the most troublesome issue.

There is an ongoing faculty renewal process that has been initiated during 2019 in order to set a department wide strategy for recruitment, enabled by three upcoming retirements (1 in PAP, 1 in CMT, 1 in NE) during 2022. The faculty renewal process has as a central goal to attract the best possible candidates with truly international advertisements and profiles – and with active search committees tasked with attempting to ensure a gender balance-improved pool of applicants. The department has good hope that at least two out of three new appointments will be female, thus potentially improving the gender balance in the faculty by another 7-10%. All future retirements have been mapped out and informs the recruitment strategy.

Apart from retirements, it is very difficult to have an efficient recruitment strategy at KTH given the low level of internal faculty funding. However, inviting excellent faculty from other universities into guest professorships has proven to be an effective means to attract excellent female faculty directly into the professor level.

Apart from faculty recruitment, it is proving more and more difficult to recruit PhD students and postdocs. Not because of poor candidate availability, but because of the rapidly increasing salary cost of PhD students notably. Even with a successful grant from e.g. VR, it is far from certain that a PI is able to recruit a student, since part of the grant is often needed (and expected) to cover part of the PI salary.

The department would welcome central initiatives to bring forth internal funding for PhD students; possibly in a similar vein as the excellence programme that existed many years ago. It would be important for successful competition on the international arena where PhD students often come to supervisors with their own grants.

e. Infrastructure and facilities

Infrastructures used by the Particle, Astrophysics and Astroparticle division are:

- CERN with the Large Hadron Collider and the ATLAS experiment.
- The Fermi and Swift Space Telescopes
- The group has been successful at obtaining observation time at several telescopes: Hubble and Very Large Telescope (visible) and Chandra, NuSTAR and XMM-Newton (X-ray)
- ESSnuSB, DUNE, and T2HK for neutrino oscillation research

Nuclear physics is a partner in FAIR – Facility for Antiproton and Ion Research is an ESFRI international flagship project under construction in Darmstadt, Germany with Sweden as shareholder (together with Finland) via the Swedish Research Council (VR). The construction budget is around 3 billion € with commissioning planned for 2025. The KTH Nuclear Physics group is partner of the Swedish FAIR consortium with a dedicated funding from VR for detector systems in the nuclear structure, astrophysics and reactions (NUSTAR) pillar for FAIR of around 11 MSEK.

AGATA – the Advanced GAmma Tracking Array2 is a joint European project to build the next generation gamma-ray spectrometer for experiments at the leading European nuclear physics facilities, with an aim towards deployment at FAIR starting around 2026. It is designated a research infrastructure of national interest by the Swedish Research Council.

At Physics of Medical Imaging, we have access to experimental CT scanners and electronic labs and also use the KTH Applied Physics nanolab at Albanova and the lab in Kista.

The CMT division runs a medium size computer cluster with about 500 CPU cores locally which gives valuable quick and easy access to computer resources. To stay competitive, we plan to keep this cluster useful by required additions and updates.

The infrastructure and research facilities at NPS are generally composed of the SWECOR platform with severe accident research facilities, the TALL loop for thermal-hydraulic investigation of heavy liquid metal (HLM) coolant, and facilities for basic research on multi-phase flow as well as a machining workshop. The examples of specific facilities are:

- CONMT infrastructure: A reinforced concrete containment (4×4×4 m^3) designed to accommodate high-temperature high-pressure energetic experiments in severe accident study.
- INDUC infrastructure: High- and middle-frequency induction furnaces employed for melt generations of various simulants of corium in melt-coolant interaction and coolability experiments (e.g., DEFOR and PULiMS).
- MISTEE facility: A X-ray radiation-shielding room (3×6×3 m^3) and high-speed (up to 100 000 fps) visualization system with simultaneous X-ray radiography and photography used to investigate opaque multi-phase flows (e.g. liquid metals), and energetic micro-interactions in steam explosion.
- TALL facility: A seven-meter tall heavy liquid metal (HLM) loop to study the thermal-hydraulics in HLM- cooled systems (e.g. accelerator-driven system for transmutation and lead-cooled fast reactors).
- SIMECO-2 facility: A scaled down lower head of reactor vessel in the dimensions of internal diameter × height × width = 1×0.5×0.12 m^3 to study turbulent heat transfer of stratified melt pools.
- MrsPOD facility: A vertical tube furnace with a 1300 mm x 120 mm cylindrical quartz tube and 3 heating zones to investigate melt penetration, solidification and remelting, and relocation in a multi-component and multiphase porous debris bed.
- SPAYCOR facility: An electrically heated downward-facing specimen of 120mm x 80mm area cooled by the spraying of a 3x2 array nozzle assembly.
- MICBO facility: A well-instrumented platform designed to study thermal-hydraulics of boiling phenomenon at micro scales.

Nuclear Engineering has two main laboratories, detailed below, and rely otherwise mostly on high-performance computations with support from large national and international facilities (PRACE, SNIC, CINECA, etc). The division has yearly allocations of about 70 million core-hours used for modelling and simulation.

The experimental facilities are:

- HWAT loop: high-pressure water test loop for PWR, BWR and SCWR thermal-hydraulic investigations with pressure range up to 25 MPa, total flow 1 kg/s and total power 1 MW.
- LOFAT: low-pressure fuel-assembly test facility for detailed laser-doppler measurements of turbulent flow structure in nuclear fuel assemblies with spacer grids.

- Advanced nuclear fuel laboratory: built from scratch and continuously developed since 2009. Furnaces for synthesis and for sintering, glove boxes, gas analysis, element analyzer, particle size analyser. Capacity for manufacture of low-activity actinide compound powders and pellets. Characterization using optical and electron microscopy, TGA, XRD, etc in collaboration with Materials science and with Surface and corrosion science.

4. Strategies and organization

a. Goals for development 5–10 years ahead

We aim to be one of the most internationally interesting leading centres for physics research and to attract excellent researchers and teachers in our upcoming recruitments.

Department wide strategies are focussed on central issues such as teaching, faculty funding and working conditions, gender balance, equal treatment, working environment, infrastructure and outreach actions. The goal is to work steadily at improving all areas. The immediate focus is gender balance, since there is an opportunity in the immediate future to improve this aspect through recruitment.

Our core activities are to provide excellent teaching at all levels; to perform world-leading research in physics, and to communicate with the public and with society. Our most important goal for the coming 5-10 years is to keep developing our strengths and to work to eliminate any troublesome issues in these three pillars.

A goal for the department and for KTH, would be to fully cover faculty salaries with internal funding.

Infrastructure is an important aspect which merits attention at department level, and to bring this aspect to the attention of KTH centrally. Even though the department experimental activities in basic research are mostly carried out at large international facilities, a fair share of the experimental research is conducted in the specialist laboratories in the department and they need constant support to stay active and develop the state of the art. We aim to work extensively at creating synergies in technical work between laboratories to capitalize on the local expertise.

All research groups aim to extend and improve collaborations with strategic partners. We aim to continue our good work and continue pushing boundaries. We aim to work more on improving the quality of education and to enhance the digitalisation aspects. In our applied research fields, we aim to start more spin-off companies and bring these to market to enhance our societal impact and public outreach. We aim to work at the department to affect the establishment of simple guidelines to avoid bias and conflicts of interest that may arise.

We hope KTH can work centrally to simplify legal procedures and contract formulations, because this is an aspect of our daily life that is consuming too much time and detracting from our core activities. It is, however, difficult to directly affect at department level, and thus needs lobbying towards school and central level.

b. Congruence with university-level goals for research as set out in “A leading KTH - Development Plan 2018-23” and with the school(s) development plan(s) respectively

There is general good agreement between the department's development and the university-level goals.

- The department works in both applied and basic research – and has many synergies and ongoing cross-pollinations.
- The department actively works in an international context, has been leading digitalization in both learning and research, and a majority of the research is directed towards the development of a sustainable future society. We are actively promoting equal opportunity and has been developing routines together with HR experts to ascertain that the recruitment process is fair and unbiased.
- The research is carried out using state of the art infrastructure facilities, internationally as well as locally, and staff in or near management positions are given opportunity to be trained in professional leadership through a number of courses.
- The department has great teaching staff and continues to strive for excellence. Experimental teaching has been further developed since 2012 with a clear strategy in mind to prepare students for practical work. Research projects in the educational programs (at Bachelor, Master and PhD levels) are all using and developing research infrastructure, experimental as well as computational.
- Teachers and staff from KTH should be visible in the social discourse according the the Development Plan. The department is very visible in media, both in Sweden and internationally. Research is in significant parts funded by other Swedish government agencies, such as SSM and Rymdstyrelsen, exemplifying that the research we conduct has high relevance to society.
- The department has a fair share of cross-pollination with industry, through affiliation of industrial researchers, hiring staff directly from industry, and starting spin-off companies.
- The department has a large share of its external funding from the EU, exemplifying the large degree of internationalization. We collaborate in many large international organisations, such as CERN, IAEA, OECD, etc.

c. Leadership structure and collegial structure

The department is led by a management group consisting of the Head and Deputy Head, each division head, the director of the doctoral program, the director of undergraduate education, the head of the physics administration and a PhD student representative. The management group meets monthly under normal circumstances. The responsibility includes general strategy at department level, including faculty renewal and department economy, discussion and dissemination, as well as discussing and supporting the decisions by the Head. A subsection of the management group, consisting of the head, vice head, director of doctoral program and director of undergraduate education handles more pragmatic management issues which may not merit the attention of the full management group.

Each research division is led by a division head and typically contains a number of research leaders, either as faculty or senior researchers. The division heads have division economy and personnel responsibility. The research leaders (mostly faculty) manage research teams consisting of researchers, postdocs, PhD students and research engineers, including technicians. Each division has some own variation of collegial structure.

d. Strategies for high quality

The most important aspect of quality strategy is to focus intensely on recruitment. With excellent staff comes high quality. Routines and guidelines for improved quality are second or third order compared to that. We work therefore vigorously with the recruitment process, to make sure we hire the best possible people for our positions at all levels.

One critical issue with recruitment that has been growing is the rising difficulty in financing and hiring PhD students due to difficulties in securing sustainable resources for the entire PhD project period. This has recently led to an increased fraction of postdocs than previously. This is troublesome but beyond the control of the department to influence. The main issue is the lack of internal support, the relatively rapidly rising salary cost of PhDs and the slower increase of average grant allocations.

For publication and dissemination, we have a number of different traditions in the department that are subject specific and we have no ambition and see no need to change that. The only benefit would be for easier measurements and consistent metrics, but the subject field traditions are so entrenched that there is no real possibility to affects this, even if we would have wanted to. With recent central support from the KTH library, we can now publish essentially all papers in open access form, which improves the quality of dissemination. This is and will be encouraged across the department, and is about to become necessary anyway due to changing rules from many funding agencies. Bibliometry in its current form cannot be usefully applied to the department because the field normalization simply does not work for certain fields, such as experimental- nuclear and particle physics. One glaring example is that the groundbreaking discovery of the Higgs boson counts for essentially nothing in the bibliometric counters.

The department houses a number of Editors of prestigious journals, as well as a former board member of ArXiv. There are courses given for Master ad PhD students that discuss publication traditions, pitfalls and trends – and how to spot and avoid predatory publishers and conference organisers.

For our collaboration structures, we promote formation of executive committees instead of relying on single individuals, so as to improve dialogue and diminish dependence on particular persons. An example is the Doctoral program which has a program council with one member from each research division, and a PhD student representative, led by the director of the doctoral program. There is a doctoral student council under construction, representing the different divisions, that will advice the main student representative.

For the basic education there is an executive education committee, including the Head, the Deputy Head, the Director of study and the Bachelor thesis coordinator. Periodically, there are education colloquia or workshops where all staff can participate to discuss educational developments and strategies.

5. Interaction between research and teaching

At the Physics department we have a strong tradition in promoting the connection between research and education. It is a clear strategy at the department that all faculty are active in research and teaching. Most PhD students are also enlisted as teaching assistants in different courses at the BSc and MSc level, increasing the exposure of students at that level to personnel active in research. In this way, there is a natural contact between the (BSc and MSc) students and (both senior and young) scientists at the department.

At the Bachelor level, the courses coordinated by the physics department (around 20) are typically not so specialized, but we do have a number of activities at this level designed to encourage contact with research. A few examples are given here. Since a number of years we have invited some of our staff to hold "popular science" evening lectures for the students in a Bachelor level course (Modern Physics, bachelor year 2). This is a way to connect the course content (e.g. quantum physics or special relativity) to current research activities. In another course (Applied Modern Physics, bachelor year 3) we arrange summer research projects at Zhejiang University in Hangzhou, China. Other student research projects in the same course are arranged in the local research divisions at the Physics Department at KTH. The bachelor diploma projects (15 ECTS), performed by the third year students, is another great opportunity to introduce the student to our research environments. The bachelor diploma projects are typically related to one of the ongoing research projects, and consists of a well defined research task. Although not the norm, there are examples of the results from bachelor projects directly leading to publications in scientific journals. There is an experimental teaching facility under construction, in collaboration between Physics and Applied Physics, where students will be able to develop their projects and manufacture complex experimental tools and structures - the AlbaNova Makerspace.

The courses at Master (MSc) level (around 45) are often by design connected with the research performed at the Department; the examples of research connections in the education at this level are too numerous to list here. We teach mainly in two KTH master programmes, Engineering Physics and Nuclear Energy Engineering. The Master Diploma project is usually performed in one of the research divisions at the department, but can also be performed at a research lab abroad, or at an external company. Although not a requirement, it is not uncommon that the results from master diploma projects lead to published scientific results. The master programs listed above have two compulsory courses in research methodology. One of these courses is tailor made by our department to establish a better understanding of important aspects in practical research work. In this course the students analyse scientific articles, and make oral presentations in a conference-like environment. We also invite active PhD students who meet the MSc students and talk with them about their daily life as research students.

Once per year we arrange an Open House day for Bachelor and Master students, in collaboration with the Applied Physics Department. This activity is especially designed to put BSc and MSc students in contact with the research faculty, PhD students, and other research staff. Here we present our research, hold demonstrations, and arrange lab visits.

At the PhD level, the interaction between research and teaching is always present. PhD students work with their supervisors on front-line research projects in their fields and are expected to produce a number of publications over the course of the PhD studies. Overall, the PhD students contribute with a large portion of the department’s research output through research done together with their supervisors and other collaborators.

Within the PhD programs in Physics and in Applied Physics, PhD students are also actively engaged in the education of students in other fields through the common compulsory program course where students present their work to students of other specializations during a course conference. The course also includes an ethics workshop and engages the students in popular scientific presentations, connecting their own front-line research to dissemination activities. The doctoral program also offers 32 other courses at research level. The composition of the course part of the doctoral studies is generally discussed between the supervisor and the student with the intention of constructing a study plan that is as beneficial as possible for the student's research. There is also flexibility in accrediting summer schools or other learning activities to the program and such activities are typically directly applicable to the student's own research.

The lifelong learning is rapidly getting a stronger focus at KTH and in the society at large. At Physics Department we see a growing potential in collaboration with the industry (e.g. the nuclear industry) to design tailor-made online teaching in specialist research areas. In basic physics, we also see our role as educators for the general public. One example of this is our online course in *special relativity* that already has generated a large interest.

6. Impact and engagement in society

a. Relevance of research to society at large

The department core activities are teaching, research and outreach. These contribute intrinsically to society at large. From education we have our largest societal impact with all the graduated engineers and PhDs. From basic curiosity-driven research we push the boundaries of knowledge; and from our applied research we always have a societal application and receiver. On the basic research side, our involvement in international facilities, such as CERN, FAIR, ESS and ISS, which are well-known in society, is an important part of the identity of KTH. We work with many types of outreach activities, some of which as directly related to gender imbalance in our research fields, such as "Girls do Physics".

We have an entire spin-off division from basic science in Physics of Medical Imaging, with its roots in high-energy physics and detector development, as an example of where basic science can lead to drastic societal impact. We are developing state of the art medical technology that will have immense benefit to society and human health.

Our research into quantum technology will most certainly have implications for the future. Many companies are involved in this push and thus the basic research is mixed with applications. We have staff that work as consultants for internationally leading high-tech companies, such as Microsoft.

Our research in nuclear physics and its applications have direct impact on important areas for the society at large. The research in nuclear safeguards and nuclear security is conducted in collaboration with SSM and in the European network ESARDA. In the efforts to counteract nuclear terrorism and to prevent the diversion of nuclear materials from the nuclear fuel cycle and proliferation of nuclear weapons it directly serves to make the world safer for the current and future generations. Nuclear Physics applied to nanodosimetry is important for enhancing the outcome of clinical medical radiation therapy and reducing its side effects on the patients. The research into radon as a possible indicator of earth quakes also has a potential societal impact.

A large fraction of our research portfolio is directed to sustainable energy production, with Nuclear Power Safety and Nuclear Engineering producing not only world-class relevant research, but also importantly experts that are available for the nuclear industry and regulatory bodies to hire. We have direct connections to both industry and regulator and have built up great experience in balancing these aspects, both at the national and international arena. The division of Nuclear Power Safety is fulfilling in Sweden a large part of the role that a Technical Support Organisation (TSO) would do in another country, such as SNL in the US, IRSN in France, VTT in Finland.

b. Research dissemination beyond academia

The department is generally very active in outreach and dissemination beyond academia. We are producing a number of patents every year and have started a few spin-off companies since the last RAE in 2012. We are visible in mass media several times per year, with children's books, on milk cartons, in newspapers, television, radio, podcasts and social media and with press releases at the KTH website. We give popular lectures and seminars and are often invited by society at large to talk about our research. As part of our outreach strategy the PhD students have to present their research in a popularized fashion during their studies as part of a mandatory course.

Some examples from the research divisions follow.

From Particle and Astroparticle Physics, we give and participate in Masterclasses, high school classes and Master projects at CERN. The KTH Space Center activities are very often publicized. It also organizes a well-attended termly Space Meeting which attracts particiants from the entire country. A member of the division operates the "cosmic radiation" project for high school students in collaboration with Vetenskapens Hus. Furthermore, different members of the division write popular science articles and books, give several popular science talks each year and often appear in media. Other examples are outreach activities in connection with the discovery of the Higgs boson (described later) and activities organised in connection with the 2018 PoGO+ flight, e.g. blog and Twitter campaigns, school visits and media interviews.

Members of the Nuclear Physics group are engaged in several outreach projects. We are frequently engaged in supervision of high school student projects. We have a collaboration with UC Berkeley and Lawrence Berkeley National laboratory in the Dosenet project where a worldwide network of silicon-based radiation sensors continuously measuring the ambient radiation background placed at high schools (including for example Asaka high school in the Fukushima region Fukushima and Norra Real in Stockholm) and other academic institutions are connected to the internet. The nuclear physics group also maintains the frequently visited Radioactive Orchestra popular science web site which provides an innovative connection between fundamental nuclear science and music. The group also contributes with articles in popular science media like the quarterly journal from the Swedish Physical Society, Fysikaktuellt.

Condensed Matter Theory has example contributions with:

- Invited lecture on NASDAQ on quantum technology.
- Article on Quantum computing in one of the main Swedish newspapers, SvD.
- Focus stories in Physical Review Focus, Science Magazine's ScienceNOW, PhysicsWorld and PhysicsWeb.
- Popular science article "Kvantmätningar och termalisering" in Kosmos, the yearbook of Svenska Fysikersamfundet.

Physics of Medical Imaging has had many publications at KTH facebook and web with many views. A new x-ray telescope idea featured 3.5 min on prime time national TV in the summer of 2019.

Nuclear power Safety maintains an informative website for research dissemination. For the severe accident research at NPS, regular semi-yearly seminars aka “MSWI project meetings” are organized in June and December of every year, and meeting proceedings and minutes are distributed to end-users. The audience of the seminars are all from nuclear industry, including the members of the project reference group. Therefore, effective reflection/feedback and knowledge flow between the end-users and NPS research are secured. NPS also actively participates in Nationella Strålsäkerhetsdagarna with 2-3 presentations showcasing main research results, which is a 2-day conference every two years called by SSM, and open to the public with the purpose of highlighting current issues in radiation safety and current research in the subject area.

At Nuclear Engineering, the small lead-cooled reactor designs of LeadCold, a spin-off company from the department, have been evaluated for commercial power production by the province of Ontario (2016), as well as by the UK government (2019). The company has attracted media attention all over the world, including articles and interviews in Forbes Magazine.

The research on Generation IV nuclear reactors made by the department has been the topic of several science television programs on Swedish national television, in particular Vetenskapens Värld. In addition, the research of the nuclear engineering division has been covered by more than 80 radio interviews and newspaper interviews since 2012.

c. Sustainability and the United Nations’ Sustainable Development Goals (SDG)

A substantial fraction of the research activities at the department are related to the UN SDG’s. For the basic research, it is non-trivial to assign a percentage, but overall we estimate that 60-80% can be related to sustainable development. Main factors are education (SDG4) and strong institutions (SDG16).

We work with energy (SDG7, SDG9, SDG11) and climate (SDG13), novel materials and biological physics (SDG9, SDG11). We work with development of medical technology (SDG3, SDG9) and nuclear non-proliferation (SDG14, SDG15, SDG16). We aim to improve gender balance (SDG5) in both research and education.

Sustainable development aspects have been introduced in the education system in a programmatical way across the School.

d. Impact cases

Impact case: The discovery of the Higgs boson

The Higgs boson discovery in 2012 was the first of the major breakthroughs in fundamental science in the past decade. It made the headlines in media all over the world, and created a surge of interest from young people in basic science. In the years following the discovery, we saw a doubling of the number of students selecting courses in particle physics at the master level. KTH was the only university in Sweden that was directly involved in the analyses that led to the discovery, and in the years that followed we were involved in numerous activities aimed at disseminating our understanding of the subatomic world to the general public. Examples of such activities are:

A particle physics tour in 2014, going from Stockholm to Sundsvall, Umeå, Luleå and back south to Uppsala with a van loaded with exhibition material. At each stop, there were open lectures for the students at the university, exhibitions, and open lectures in the evenings open to the general public. This was especially appreciated at the universities where there are no particle physics groups, and generated a noticeable increase in Swedish applications to student programs at CERN.

A recurring yearly charity auction for a private full-day visit to CERN, organized since 2016. Connected to a yearly fund-raising event by Swedish public service radio and TV. This has reached a very wide audience and generated lots of interest for particle physics research. As organizer of this we had a chance to talk about our research on live broadcasts to tens of thousands of viewers several of the years. It has also up to now generated a total of over 23 kEUR to charity.

Numerous other outreach activities, for example: A full-hour interview in Sweden's biggest morning radio show, with ~600k listeners, and a popular podcast version published by the Swedish public service radio channel. Serving as guides for 10s of groups of students from Swedish schools and universities, politicians, and other parties to the facilities at CERN.

Disregarding spin-off effects generated from detector and computing developments related to particle physics, such as medical imaging and the World Wide Web, it is generally true that breakthroughs in basic science need longer time scales to be commercially relevant. History clearly shows however that our advances in the understanding of the world around us are pivotal to progress in society. The theories of quantum mechanics and relativity were considered to be of purely theoretical interest when they were developed a hundred years ago, but today they are critical to technological advances in e.g. micro-electronics, medicine, and high-precision positioning devices. The future will tell when and where, but not "if", the Higgs boson discovery transitions from something that mainly satisfies the human desire to understand the universe into a theory which underpins technological advances in society.

Higgs boson discovery announcement on 4 July 2012. CERN auditorium.
Photographer: Maximilien Brice

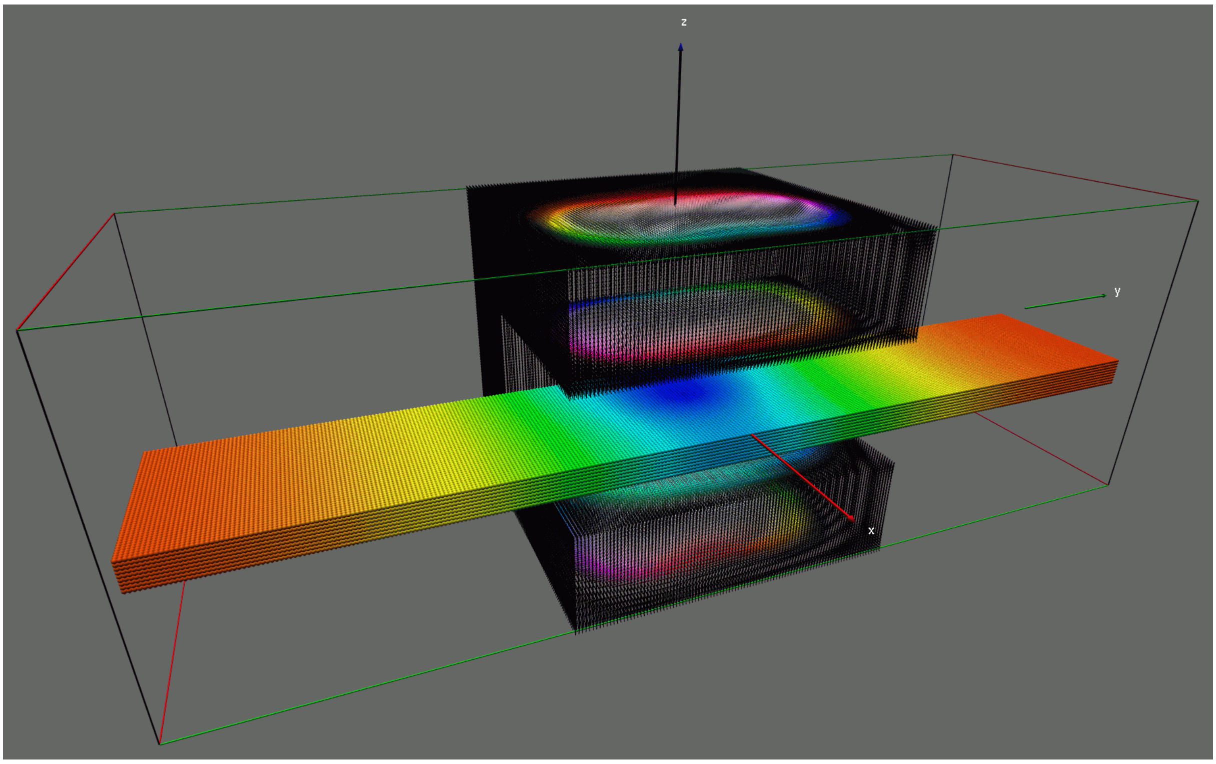
"A full day at CERN" generated 85.100 SEK for charity in 2017.

Impact case: Quantum computing and quantum sensing with superconductors

Quantum technology promises revolutionary advances in many aspects of society, such as in secure communication, ultraprecise sensing, quantum computing with near term applications to climate modelling, materials development and quantum chemistry. The importance and far-reaching promise of quantum technology is reflected in the EU quantum flagship.

The condensed-matter-theory division's research on quantum matter ranges from fundamental theory with long-term impact---including the theory of topological quantum matter---to direct development of near-term and promising quantum technology, including quantum sensing with superconducting single photon detectors and quantum computing on platforms based on unconventional topological superconductivity. Detailed modeling and computer simulations of the properties of the relevant quantum materials play an essential role in realizing the promise of quantum technology, as devices cannot be reliably developed without such input. World-leading detailed microscopic simulations of unconventional superconductivity resulted in the Babaev group taking up consulting to Microsoft Station Q in their quantum computing pursuits.

The Babev group developed unprecedented capabilities to model superconducting quantum devices using a hierarchy of macroscopic (e.g., Ginzburg-Landau) and microscopic (e.g., fully self-consistent Bogoliubov-de Gennes) models. This allows efficient simulation of superconducting correlations and current patterns in superconducting devices, which is essential for reliable design of quantum circuits for quantum computing and had remained a challenging bottleneck for simulations. This development allows for advantageously applying these methods to other problems in quantum technology utilizing superconducting devices. This includes superconducting nanowire single photon detectors, developed in the Applied physics department, with further theoretical understanding provided by the Wallin and Lidmar groups.



The impact is corroborated through:

- Spin-Orbit Protection of Induced Superconductivity in Majorana Nanowires, Editor's Suggestion in Phys. Rev. Lett. **122**, 187702 (2019).
- VR Research Environment on optical quantum sensing together with applied physics.
- Wallenberg Project Grant on Quantum Sensors together with applied physics.
- Spin-off company founded: Quantum and Classical Solutions International AB **http://quantumandclassical.com**

Impact case: Photon-Counting X-ray imaging

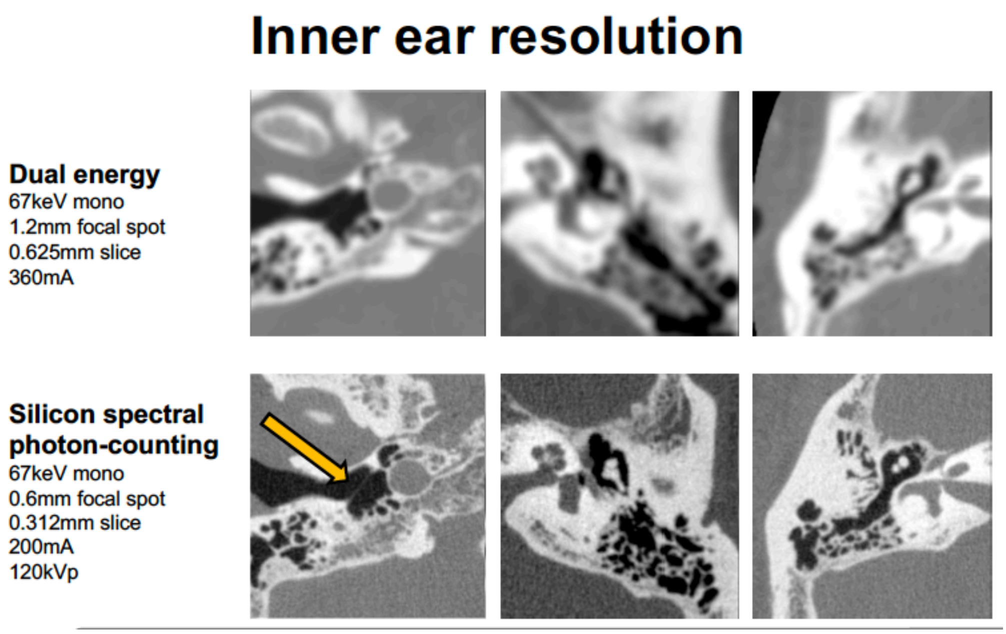
The research into medical x-ray imaging with photon-counting detectors at the department originally grew out of fundamental particle physics research. Silicon-strip detectors have been used since the 1980's for tracking particles generated in high-energy particle collision experiments. Since the late 1990's these detectors have been adapted for use in medical x-ray imaging by Mats Danielsson, now professor and head of the physics of medical imaging division. Silicon-strip detectors measure x-ray interacting directly in the semiconductor material, thereby achieving detection speed fast enough to count individual photons and measure their energy. This gives photon-counting silicon strip detectors significant advantages over conventional detectors in terms of noise performance and spatial resolution and allows measuring tissue composition based on the x-ray energy distribution.

The physics of medical imaging division pioneered the research field of photon counting x-ray imaging, authoring the first scientific papers in this area both explaining the theory and performing the first experiments. Over the years the group has generated more than 100 granted patents in different countries, covering electronics, detectors and methods for data processing and image reconstruction and published a large number of scientific articles. The first spin-off company emerging from this research was Sectra Mamea AB. The company adopted the photon counting technology to early breast cancer detection and diagnosis providing lower radiation dose for the patients, which is an important feature since the female breast is sensitive to radiation and a significant fraction of the population is being screened in national mammography programs. The system branded as “MicroDose Mammography” was the first product for medical photon counting x-ray imaging that was approved by the US Food and Drug administration (FDA). It achieved 40% lower radiation dose than conventional digital mammography at equal or better diagnostic image quality and was installed in at around 1000 hospitals in 40 countries.

From 2008 on, the division has been adapting this technology to x-ray computed tomography (CT). CT is one of the most common medical examinations with around 100 million scans being done every year only in the US and a very important tool in emergency rooms for trauma patients and for diagnosing stroke, cancer, cardiovascular disease and lung diseases such as covid-19. The group at KTH built one the first full-field prototypes in the world and demonstrated significantly higher spatial resolution as well as improved contrast and/or reduced radiation dose compared to today’s state-of-the art CT scanners. When presenting the technology 2018 at European Congress of Radiology, the largest conference in Europe in this field, we received the award as best scientific presentation in medical physics. To commercialize the technology in CT, Prismatic Sensors AB was started in 2012, and after expanding to 25 employees in 2020, the company was acquired by GE Healthcare in December 2020. One important reason for this success is the close integration between the company and the Physics of Medical Imaging research division at KTH, with several persons holding dual appointments with both the company and KTH, allowing rapid implementation of innovations generated within the research division and continuous feedback on the real-world relevance of the research.

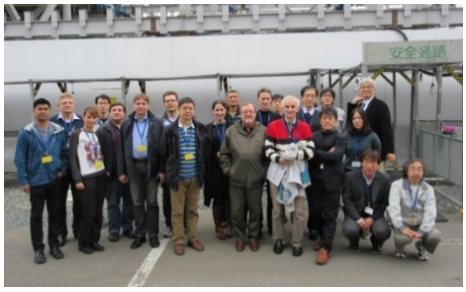
The photon-counting technology and the acquisition by GE healthcare has generated attention in Swedish and international media outlets such as Dagens Industri, Bloomberg and CNBC. After the acquisition the development of the new technology is as intense as ever, and including subcontractors at least 50 full time employees is currently working on this development and manufacturing only in the neighborhood of Stockholm. The next prototype is currently being prepared for installation in the Karolinska Hospital at MedTechLabs for clinical evaluations.

Below is an image of the inner ear for the first patient compared to state-of-the-art “dual energy” CT. The higher spatial resolution for the new spectral photon counting technology is evident, as shown for example by the visibility of the ear drum (yellow arrow).



Impact case: Containing the Fukushima accident

After the notorious accidents which occurred in Fukushima Daiichi Nuclear Power Station (FDNPS) in Japan, Nuclear Power Safety at KTH (NPS) immediately participated in the international efforts to assess the accidents and to learn its lessons. Taking advantages of NPS in-house expertise built during the previous projects supported by SSM, NPS performed quick analyses of the Fukushima accidents [Chen & Ma (2012): MELCOR simulation of SBO scenario of Fukushima Daiichi-3 BWR, Proc. of NUTHOS-9, 2012; Chen & Ma (2014): Simulation of station blackout accident in Fukushima Daiichi-2 BWR, Proc. of ICAPP 2014]. Later on, the newly established Collaborative Laboratories for Advanced Decommissioning Science (CLADS) in Japan came to NPS for collaboration and had invited NPS experts to give technical talks at CLADS workshops. In close collaboration with CLADS, NPS researchers has developed Post Fukushima EU/Japan research roadmap [Bechta, S., Ma, W., Miassoedov, A., et al. On the EU-Japan roadmap for experimental research on corium behavior (2019) Annals of Nuclear Energy, 124, pp. 541-547.] Meanwhile, under the auspices of Nuclear Regulation Authority in Japan (NRA), NPS have been carrying out experimental investigations on severe accident phenomena important to build-up of predictive capabilities at NRA for stringent regulatory needs in Japan [Hotta, A., et all. Experimental and Analytical Investigation of Formation and Cooling Phenomena in High Temperature Debris Bed (2019) Journal of Nuclear Science and Technology, Article in Press.] Moreover, NPS is the partner of a series of OECD/NEA projects dedicated to Fukushima accidents: TCOFF, PreADES and ARC-F, standing shoulder-to-shoulder with large national laboratories and TSO such as CEA and IRSN from France, SNL and NRC from USA, and VTT from Finland. In the TCOFF project, a thermodynamic analysis for corium compositions in the lower head in the FDNPS Unit 1 [Komlev et al (2019): Thermodynamic characterization of fuel debris and fission products based on scenario analysis of severe accident progression at Fukushima Daiichi NPP, Technical Report] indicated the possible improvement of the MELCOR code which is one of the workhorses for severe accident simulation, calling for an ongoing efforts at SNL in collaboration with NPS. The PreADES project supplied results of preparatory studies on fuel debris retrieval in FDNPS. Based on the on the competence of NPS on debris bed coolability, NPS is responsible for building an analytical table for maintaining cooling function during corium debris cutting, removal and decommissioning of FDNPS, and report [Ma et al (2019): On cooling function during removal, transport and storage of debris from FDNPS, Technical Report] was well received by the community. NPS research in the ongoing ARC-F project has a focus on best estimate modelling of severe accident progression in specific reactors of FDNPP plant using code inputs developed by the project partners. The results will be used in Fukushima decommissioning activities but also for safety improvements of the existing and future reactors.



Fukushima Daiichi site today (left) and OECD/NEA TCOFF experts visiting the site (right)

An example of our recent developments and practical applications, which can have strong impact on reactor safety and will influence NPS future research agenda, is new safety system invented for light water reactor by NPS division members [S. Bechta, W. Ma, A. Komlev, L. Manickam, A. Konovalenko, W. Villanueva, S. Roshan, A. Karbojian. A safety system of a nuclear reactor for stabilization of ex-vessel core melt during a severe accident. International PCT Application No. PCT/SE2018/050333. Publication number WO 2019/190367. Published: 03.10.2019].

e. Structure for increased impact

- To continue to develop teaching and our education system for the most important Impact aspect: graduated engineers and PhDs available for society.
- Capitalize on recent events to develop excellent online courses.
- To promote Physics into undergraduate teaching programmes at KTH.
- To continue to do excellent research and push boundaries; and to publish in Open Access form as much as possible.

- Develop synergies in the growing AlbaNova environment.
- To reach out to the public and society at education and research levels: Open house events, high-school student fairs, etc; writing debate articles in mass media; appearing in news and giving public seminars.
- The department has a number of spin-off companies started since 2012 that generate impact together with the department and divisions. We encourage this development and aim to simplify related routines.
- Increase fraction of innovations and patents.

7. Other

a. Specifics that the department wishes to mention and describe

If the department wishes to mention anything that has not been covered above, it can be added in this section.

Department of Applied Physics

Self-evaluation
Head of Department: Professor Oscar Tjernberg

Included divisions:

Division of Biomedical and X-Ray Physics, with Head of Division: Assoc. Prof Peter Unsbo
Division of Biophysics, with Head of Division: Prof Hjalmar Brismar
Division of Laserphysics, with Head of Division: Prof. Fredrik Laurell
Division of Materials and Nano- Physics, with Head of Division: Prof. Mats Götelid
Division of Nanostructure physics, with Head of Division: Prof. David Haviland
Division of Photonics, with Head of Division: Prof. Saulius Marcinkevicius
Division of Quantum and Biophotonics, with Head of Division: Prof. Jerker Widengren

Department of Applied Physics

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

	Strengths	Weaknesses
Research	6. Successful in attracting external funding 7. International network 8. Sustainability and impact 9. True interdisciplinarity 10. Entrepreneurial spirit	7. Falling citation rates 8. Limited and inefficient use of infrastructure 9. Text
Organisation	5. Localization 6. The bio-opto-nano concept 7. Young faculty 8. Innovative and collaborative atmosphere 9. Sustainability and impact	8. Recruitment and Gender balance 9. Text 10. Text

In this section the strengths and weaknesses identified at the department of Physics in research and organisation are presented and discussed in summary form.

Strengths

Successful in attracting external funding. Our research groups are often at the international forefront in their core fields and are typically given high grades in project evaluations by the Swedish Research Council (VR) well as in other evaluations. Groups within the department are also generally successful in attracting external funding as shown by a high ratio of external funding (~60%)

International network. We have strong and active international networks. This allows our students to gain research experience in top groups around the globe (cf. B3.6.1).

The bio-opto-nano concept. We have made a strategic and long-term decision to focus our Applied Physics on the Bio, Opto, Nano field with quantum aspects playing a major role. The Bio-Opto-Nano theme has been a guiding principle for the department for more than a decade but it continues to be a strength and a successful concept. This is slightly different from other Applied Physics environments in that that the biological and medical aspects are strongly represented and closely integrated. We are therefore pleased to see that all three of the core fields (bio, opto, and nano) are becoming increasingly interconnected and with quantum aspects coming to play a more and more important role. As regards to the interdisciplinary Bio-Opto-Nano research we believe we are excellently positioned. In short, the department research areas are coherent and complementary. We feel confident that we continue to be strategically well positioned scientifically, academically and, in the long term, also industrially. These are internationally very active fields. Optics, Bio and Nano have been important fields for a considerable time and with obvious impact on the information technology and life sciences areas. The quantum component has been obviously present in both the optics and materials physics areas but not coherently tied together until now. At present there is a strong international push for quantum technologies with the aim of realizing future information technologies such as quantum computation and communication. The department is uniquely well suited to address these areas and is already part of the KAW initiative WAQT. Recently, Applied Physics together with the Physics department has also formed the Quantum Technology Hub (QTH).

Localization. Our localization between the medical university KI and the Stockholm University SU and inside the new and rapidly expanding Albano area is optimal for the interdisciplinary profile of the Applied Physics department. With the currently ongoing move of the two Kista divisions to Albano campus the department activities can be further integrated, and the interexchange enhanced. The localization also allows us to recruit excellent graduate students via our active teaching program at the undergraduate level which keeps attracting top students to our upper-level courses. The node at Sci Life Lab further enhances interdisciplinarity and creates a direct connection to the medical side.

True interdisciplinarity. High-quality interdisciplinary work requires more than having people from different disciplines working side by side. You have to integrate closely: the researcher with different core fields should get an in-depth understanding of the tough process of the other field - without losing his/her excellence in his/her core field. We believe we are successfully promoting this integration with, e.g., joint labs, joint projects and seminars.

Young faculty. We have (so far) the advantage of growth, allowing us to hire approximately one to two young tenured faculty per year. This allows us to make long-term strategic plans as regards also collaborative infrastructure commitments.

Innovative and collaborative atmosphere. Our faculty is well aligned on core values such as scientific quality, innovation, openness to new ideas, scientific scope, and commercialization. These are the foundations for building an innovative research environment. For such an environment it is of major importance to create forums for stimulating (interdisciplinary) ideas and to lower the threshold to test these ideas. Our means for the process are joint labs, internal seed money, seminars, and social events.

Entrepreneurial spirit. We have a strong track record in successful industrial spin-offs, patenting, and students going to industry. This reflects a positive entrepreneurial spirit among the faculty which certainly will continue to influence future students to start their own businesses.

Sustainability and impact. The departments large focus on sustainability and environment has resulted in a large fraction of the research being focused in this area. Prominent examples are in the areas of energy conversion and environmental chemistry where our research has impacted photovoltaics, catalytic processes, degradation of plastics and water purification. Several of these projects have resulted in spin-off companies. Another example where our research has had a large impact is x-ray generation and detection. One example is new high-brilliance x-ray sources that have been developed and resulted in a very successful spin-off company (Excillum). The potential impact of research in the Bio and Life sciences areas is obvious and is expected to be considerable in the long term.

Weaknesses

Falling citation rates. Even though the department does well in terms of external evaluations, research funding etc. there are indications that the field normalized citation rates of publications are falling. There are at present quality issues with the bibliometric monitoring at KTH so the data is not fully trustworthy. Also, data is not available at the division level which makes it difficult to find mechanisms behind the decline.

Limited and inefficient use of infrastructure. The department has a vast range of experimental infrastructure that is not always optimally used. The cost of maintaining and running state of the art experimental infrastructure is very high and increasing as the complexity of instruments increase. The efficient use and complimentary of the research infrastructure are key issues that need to be addressed. Currently, a large portion of infrastructure is viewed as personal or group related. While maintaining personal motivation tied to perceived ownership and responsibility, it is important to develop a culture and organization where infrastructure is easily accessible and efficiently used. By this, it is in no way implied that one should move towards only standard tool facilities but rather a focus on efficient and increased use of unique spearhead infrastructure where the research can stand out in an international comparison.

Lack of technical support. Although we have increased the number of advanced technical staff the numbers are still too low. Low faculty funding prohibits more aggressive hiring. The consequence is that our faculty still does a lot of tasks that would be better done by others. Improved technical support would allow us to better utilize the true capacity of our top researchers.

Recruitment and Gender balance. Recruitment is a known Achilles' heel at KTH in general with some exceptions. The Applied physics department is, unfortunately, not such an exception and our faculty recruitments can often take several years from start to finish. The result is naturally that the most promising candidates are lost in the process. This has a strong impact in our ability to recruit the best talent and is likely to impact external candidates in favor for internal candidates. It can possibly also have a negative impact on our ability to improve the gender balance. The long-term detrimental impact should not be underestimated and can be considerable. Considering that our gender balance on the tenured faculty is still far from acceptable, it is even more important to be an attractive employer with a rapid, transparent, and efficient recruitment process and to offer an attractive employment package. A genuine effort to streamline the recruitment process, remove possible gender road blocks and to provide the best possible starting package must be one of the focus areas for the future.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

The impact of the department can be categorized in three main areas: Publications, training of persons and spin-offs. Applied physics publishes > 300 peer reviewed journal articles per year in relevant research journals. Over 30% of these are in journals that belong to the top 20% in terms of impact (KTH bibliometric statistics). The department has approximately 80 PhD students and 25 postdocs employed and thus graduates some 20 new Doctors per year and contribute to the training of 10-15 new junior scientists per year. A large fraction of publication and students are in areas with clear focus on sustainability such as materials and devices for energy conversion (solarvoltaics and heat exchange, battery materials, thermoelectric materials), processes and devices for energy efficient information processing, transfer and storage (spintronics, magnetism, quantum technologies) and nanostructures for sustainability (catalysis, water cleaning, anti-fouling and degradation of plastics). The publication and training impact of the department is on par with what is expected from a research department of this size. The department stands out more in innovation and entrepreneurial activities with a large number of patents and spin-off companies. During the last two decades, some 60 patents have been granted and 15 companies started by staff from the department. The spin-off companies have at present a turnover of more than 150 MSEK and a few select are rapidly growing. The departments activities in the Biophysics division has a special standing in terms of impact in view of the focus on research related to the diagnostics and treatment of various diseases. The impact from this research is expected to considerable in the mid to long term.

In terms of contributions to infrastructure, the department has a rather unique standing. With the responsibility for 600 m^2 of central KTH facilities such as the Nanofabrication facility, the KTH laser lab and the Advanced light microscopy facility, the department shoulders a considerable part of KTH's central research infrastructure. On top of that, the department has 2000 m^2 of specialized laboratories were unique and many times in-house developed research infrastructure is run. The department also carries a very important role in KTH's presence and involvement in national and international infrastructure. Research groups from the department have for a long time been deeply involved in the development of Max IV and ESS with our faculty being part of various beam line groups and taking responsibility for developing instruments. Our faculty also occupies various positions on boards and committees at the national facilities as well as international synchrotron, free electron laser and neutron facilities.

2. Research profile

a. General information of the department

The Applied Physics Department belongs to the School of Engineering Sciences (SCI) at KTH. It consist of >200 people, and represents 30% of the turn-over of the SCI school.

The department is divided into 7 units:

- Biomedical and X-Ray Physics (34 people, Albanova)
- Biophysics (38 people, SciLife Lab)
- Nanostructure physics (12 people, Albanova)
- Laserphysics (26 people, Albanova)
- Photonics (25 people, Kista)
- Materials and Nano- Physics (29 people, Kista)
- Quantum and Biophotonics (29 people, Albanova)

As of May 2020, the divisions from Kista are relocated to the Albano campus.

The department has more than 2600 m^2 of experimental facilities: 2000 m^2 are specialized labs, and 600 m^2 consists of National- and KTH- infrastructure.

The Department Head is Prof. Oscar Tjernberg and the deputy heads are Prof. Carlota Canalias and Prof. Martin Viklund.

The departments division and their faculty (excluding researchers) are listed below:

Division name, Location, Total number of staff	Head of unit	Faculty
Biomedical & X-Ray Physics (BioX) Albanova People:35	*Prof. Hans M Hertz*	*Prof. Martin Viklund,* *Prof Muhammet Toprak,* *Prof.Ulrich Vogt,* *Assoc Prof Anna Burvall,* *Assoc Prof Linda Lundström,* *Assoc Prof Göran Manneberg* (emeritus?) *Assoc Prof Jonas Sellberg,* *Assoc Prof Peter Unsbo*
Biophysics SciLifeLab People: 43	*Prof Hjalmar Brismar*	*Prof. Berk Hess* *Prof. Erik Lindahl* *Prof Björn Önfelt* *Assoc Prof Lucie Delemotte* *Assoc Prof Ilaria Testa*
Laser Physics Albanova People:25	*Prof Fredrik Laurell*	*Prof.Carlota Canalias* *Prof. Valdas Pasiskevicius, ,* *Assoc Prof Michael Fokine*
Material and Nanophysics Albanova People:28	*Prof. Mats Ahmadi Götelid*	*Prof. Anna Delin* *Prof Joydeep Dutta* *Prof. Oscar Tjernberg* *Prof Jonas Weissenrieder* *Prof Johan Åkerman* *Assoc Prof Magnus Andersson* *Assoc Prof Martin Månsson*
Nanostructure Physics Albanova People: 11	*Prof David Haviland*	*Prof. Vladislav Korenivski*
Quantum and biophotonics Albanova People: 35	*Prof. Jerker Widengren*	*Prof Gunnar Björk* *Prof Katia Gallo,* *Prof Val Zwiller, ,* *Ass. Prof Klaus Jöns,* *Dr. Marcin Swillo*
Photonics Albanova People: 27	*Prof Jan Linnros*	Porf. Srinivasan Anand Prof Sebastian Lourdudoss Prof. Saulius Marcinkevicius, Prof Sergei Popov Prof. Urban Westergren, Assoc Prof. Ilja Sytjugov Dr. Yantin Sun, Dr Max Yan.

b. Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)

The research of the department is primarily experimental and multidisciplinary, and spans the full range from biological and medical physics over optical physics to materials physics with quantum physics as a major part in many of the areas ("**bio-opto-nano**"). Significant areas include confocal microscopy, cell-biology, fluorescence correlation spectroscopy, single molecules, x-rays (sources, optics, and microscopes), ultrasonic trapping, microfluidics, solid-state laser sources, quantum optics, nanophysics, spintronics, surface physics, device physics and quantum materials. The broad range of activities include synthesis and processing of novel materials, nanostructures, and devices to advanced characterization with synchrotron radiation, free electron lasers, neutron and muon sources, short pulse lasers, electron and scanning probe microscopy. Development of new experimental techniques and methods is at the core of the department and has been a central theme for a long time.

Below we specify some of the central questions addressed in each of the areas

BIO

The BIO area at dept of Applied Physics cover a broad field of biomedical and biophysical research. Research is performed in 11 highly active and internationally well recognized research groups located at the Albanova and the SciLifeLab campuses. Topics include development of biophysical measurement technology in particular within spectroscopy, microscopy and imaging, development of computational methods for biomolecular analysis, protein structure determination, cellular biophysics, and applications in cell biology, immunology, neuroscience and visual optics.

The research groups are cross-disciplinary with several non-physicists in the teams (biologists, MDs, chemists), there are frequent collaborations and interactions between the teams, in particular via the shared laboratory resources, where competence is also shared in a natural and synergistic fashion. The teams are international with representation from >12 different nationalities and there is also an almost equal gender balance.

Central research questions:

X-ray science and technology: Several research groups within the department work on x-ray science and technology (development of sources, optics and image analysis) with focus on biological applications. We develop and utilize compact liquid-jet x-ray sources and apply x-ray microscopy, phase-contrast imaging and x-ray fluorescence imaging methods. This has resulted in multiplexed bioimaging in vivo with minimum radiation dose. We also use coherent x-rays produced by 4^{th} generation synchrotrons and free-electron lasers to study mesoscale structures (nominally 10 nm to 1 μm) and ultrafast dynamics (nominally 100 fs to 1 μs) in soft matter, which has led to several stepping stones toward imaging single proteins using x-rays. (Hans Hertz and Jonas Sellberg)

Visual Optics: The competence in optics and image quality analysis of the department is also applied to the area of visual optics, in which close collaborations with optometrists and ophthalmologists enable studies of how peripheral optical errors of the eye affect our vision and ocular health. A direct application of this work is the development of optical designs of spectacles, contact lenses, and intraocular lenses that can improve peripheral vision. Such designs can be used, for example, to compensate for loss of the central visual field, or to halt the increasing prevalence of nearsightedness in the world. (Linda Lundström and Peter Unsbo)

Acoustofluidics: At the department we develop microscale acoustofluidic, miniaturized fluidic systems where ultra-sonic radiation forces are used for manipulation of cells and particles, with the aim of tissue engineering. Here, ultrasound has found an important use for high-throughput production of in-vivo-like models of solid tumors. (Martin Viklund)

The Biophysics unit is located at Science for Life Laboratory. The unit is responsible for operation of the microscopy infrastructure. This infrastructure is a national infrastructure with funding from the Science Council (VR), Science for Life Laboratory as well as KTH, the microscopy laboratory is also a node in the European Infrastructure EuroBioImaging-ERIC.

Research in the Biophysics unit is performed in six research groups. The groups have a good gender balance (39% female) and broad international composition (63% international). Research questions span from the sub-molecular to the organ level and from theoretical studies of proteins to practical developments of new microscopy. The unit has extensive national and international collaborations. Several of the faculty have also dual affiliations with Karolinska Institutet and Stockholm University.

The Biophysics unit secured funding from the strategic research area Molecular Biosciences (SciLifeLab) for recruitment of two junior group leaders in 2015 (microscope development) and 2016 (computational biology). Both were internationally recruited in a highly competitive process. They have been outstandingly successful within their tenure tracks (both are now on assoc prof level, active in teaching, faculty activities and research) and by attracting external funding (ERC, VR, SSF, etc) and significant international recognition.

Method development is a common theme for the groups in Biophysics. New methods are developed driven by needs identified in applied studies. All groups are strongly multidisciplinary in between biology, medicine, chemistry and physics. The applied studies are identified and defined by the individual PIs research interests in medicine and biology that include e.g. immune therapy, renal physiology, neuroscience and neuropharmacology. The groups are also actively involved in larger research community projects coordinated by SciLifeLab and the research facilities that are supported by the Biophysics unit (the ALM microscopy facility and the Cryo-EM facilitiy).

Important development during later years includes a massively parallel analysis method for single cell functional analysis based on a microchip platform and automated confocal imaging, developments of super-resolution RESOLFT microscopy and also multifocus SIM microscopy. The unit has developed some of the world’s most used tools for modelling biological systems (GROMACS) with applications to membrane proteins and techniques for drug design. The groups has also made important contributions to the RELION code which has led to the rapidly increasing resolution and dynamics obtained with cryo-EM (through affiliation with SU and the Cryo-EM facility at Science for Life Laboratory).

The research within the QBP unit encompasses development of advanced fluorescence spectroscopy/imaging techniques and their applications for fundamental biophysical studies and towards biomedical and diagnostic applications, nonlinear and quantum photonics research with development of ferroelectric and photonic technologies for switching, communication and sensing, as well as nanoparticle research with applications in biosensing and for solar cell development. Within the unit, but also within several joint projects involving external partners on both a national and international level, synergies between these research fields are successfully exploited.

The experimental biomolecular physics (EBP) group belongs to the pioneers of fluorescence-based single-molecule detection (SMD) and fluorescence correlation spectroscopy (FCS), and the research group is still in the forefront in this field. The group was among the very first to establish fluorescence-based super-resolution microscopy (SRM), with so-called stimulated emission depletion (STED) imaging, and its use for sub-cellular characterization and diagnostics. By the so-called transient state (TRAST) imaging technique developed by the group, highly environment-sensitive fluorescence blinking events of fluorescent molecules can be visualized in biological samples, and it is now used to open new areas for cellular and molecular characterization and screening. With development of fluorescence-based ultrasensitive and ultrahigh resolution spectroscopy/microscopy techniques as a starting point, the group is active in several interdisciplinary collaborations, where the SMD, FCS, STED and TRAST techniques and further developments thereof are applied for biomolecular and cellular studies.

The research within the nonlinear and quantum photonics (NQP) group brings together the fields of ferroelectric and photonic sciences. Using lithium niobate as a model system, the group leverages the tools of nanotechnology and integrated optics to study the fundamental physics of interactions involving spontaneous polarisation and light in classical and quantum regimes, and explore their implications for information processing, optical sensing and actuation. The research activities of the group cover the entire spectrum from modelling over fabrication to experiments, and also include applications in the biomedical field, merging concepts for optical resonators, waveguides and plasmonic enhancement, with molecular spectroscopic techniques based on fluorescence and Raman scattering.

During last year, the unit has strengthened its research in nanophotonics, with a senior researcher with expertise in the field of so-called upconversion nanoparticles (UCNPs) recruited to the unit. UCNPs lend themselves to be well studied by the fluorescence techniques developed and used by the EBP group, and this is taken as a starting point for the development of UCNPs as probes in bioimaging and for solar cell applications.

Overall, the research of the unit benefits strongly from bringing together research from different disciplines. This takes place both within the unit, by interactions with groups in theoretical physics and mathematics, and not the least by collaborations with research groups in the biomedical field.

OPTO AREA

A large part of our activities is oriented towards semiconductor materials and nanostructures, and their application for photonic devices. The main driving force in this area is increase of the energy efficiency of light emitting devices, such as semiconductor lasers and LEDs, and photovoltaic devices, e.g., solar cells. In many cases, the energy efficiency of these devices is directly related to material properties; thus, gaining a detailed understanding of the material properties contributes to the increased efficiency of the devices.

Devices that we focus on are based on a variety of semiconductor materials, starting from the ones with the band gap in the near infrared (Si, InP) to wide band gap materials, e.g. GaN and Ga2O3. In the area of phosphides (InP, GaP) the main activities are: 1) Buried heterostructure mid-infrared quantum cascade lasers (QCL) for high power, high beam quality, high speed modulation and free space communication, 2) orientation-patterned GaP (OP-GaP) nonlinear optical crystal for quantum photonics and 3) III-V/Si heterojunctions for phonic integration and multijunction solar cells. Studying of these devices are enabled by exploiting hydride vapour phase epitaxy (HVPE) as other epitaxial techniques are less suitable and thereby address the knowledge gaps in semiconductor processing technology for optical communication and renewable energy.

Research on the phosphide-based semiconductor nanostructures is conducted with focus is on utilization of photonic semiconductor nanostructures for light manipulation and enhanced light matter interaction for applications in optics, optoelectronics and sensing.

The work on infrared and quantum cascade lasers is closely related to their application in telecommunications. In this area, we aim to enhance the data transmission rate of fiber-optical and wireless-optical links to meet the increased demands in capacity, considering the constraints regarding energy consumption and cost. This is done by optimizing the components, the modulation formats and coding/decoding algorithms.

In the IR spectral region, we also perform research on integrated photonics, where we work on the design of nanostructured materials and develop fabrication technologies for mid-IR generation and wave manipulation towards ubiquitous gas sensing and information transfer. These devices are mainly built on the silicon platform. The same technology set is also exploited for integrated photonics at telecom wavelengths.

Silicon-based nanostructures and nanoparticles are being studied with several applications in mind. The fabrication of these structures utilizes the Electrum and the Nanolab clean-rooms for ordinary Si processes combined with electron beam lithography, respectively. Silicon quantum dots are explored with the goal to use them in sensors, light emitters and for photovoltaics. Fundamental studies using single-dot spectroscopy and quantum yield measurements have contributed largely to the understanding of the light emission mechanism from Si quantum dots, but has also been used for characterization of novel perovskite quantum dots. A new direction is the fabrication of single or arrays of nanopores in a Si membrane. These are used for studies of translocation of single bio molecules, detected optically by fluorophores or electrically. The Si platform is also exploited to develop silicon-chip based biomolecule sensing technology and devices. The latter applications unite all three core areas of Applied Physics, namely Opto, Nano and Bio. The sensing technology is applied towards detection of exosomes which are small extra cellular vesicles secreted by all cells. The aim is to profile specific surface proteins which can be used as markers for particular cancer forms. This project involves cross-disciplinary collaboration with Karolinska Institutet as well as with KTH biotechnology groups.

In the area of wide band materials and photonic devices, we focus on fundamental material properties GaN and related quantum well (QW) structures (GaN/InGaN, GaN/AlGaN) that find applications in UV and visible LEDs and laser diodes. We are studying properties like carrier transport, recombination and localization, all critical for an efficient LED and laser diode performance. Recently, our attention gas been focused on green-emitting LEDs, which are a missing link for RGB lamps and displays. In our research, we are using advanced time-resolved and near-field spectroscopy techniques providing information on the materials and device properties on the 100 nm and 100 fs scale. Our recent studies allowed revealing critical issues for an efficient interwell carrier transport in LEDs, the role of extended defects on recombination, and determining several basic material parameters for GaN and Ga_2O_3.

We are Europe's leading group in domain-engineered ferroelectrics and our periodically poled samples, primarily made in $LiNbO_3$ and KTP, are integrated as nonlinear devices in lasers and quantum devices to provide tailored wavelength, pulse or spectral response. With KTP we have demonstrated the largest apertures, for use in high energy lasers, and bulk nanodomain gratings to be able to study backward nonlinear processes. This has not been possible in any other lab world-wide. By spatially tailoring the $\chi2$-nonlinearity we demonstrated efficient fs-pulse compression and octave-spanning continuum generation in single-pass devices. The crystals can also be engineered for THz generation and our samples will be used in the high-profile ACHIP project, where a laser-driven, chip-based particle accelerator will be built. Other addressed applications include environmental gas spectroscopy (LIDAR) for ground-based, air- and space-borne missions, as well as entangled sources for quantum communication.

We have constructed a complete laser-based laboratory for additive and subtractive manufacturing of glass. Here we custom fabricate preforms in silica to make special optical fibers and develop semiconductor-core optical fibers (Si, Si/Ge) with combined opto-electric functionality, and for use as mid-IR and THz transmission lines. We can form both gratings and graded-index structures in these fibers, obtained record-low IR transmission loss and very recently we demonstrated THz transmission in these fibers, for the first time. This has potential applications in medicine, sensing and the next generation telecommunication (6G). Furthermore, our laser-assisted glass fabrication allows printing of complex 3D structures from powder and from fiber.

In our multifunctional fibers we integrate fluid, gas and electric fields with light guidance, and apply them in life-sciences and optoelectronics. Recent focus work has been in biopsy and therapy of pancreatic cancer and the development a compact virus detector for COVID-19.

Photonics is identified as a key-enabling technology by the European union, which addresses major societal challenges (https://www.photonics21.org/). In the Laser physics group, we work with one foot in pure photonics and one in material science, with a focus on functionalizing optical materials. Our novel structures are used in lasers, nonlinear optics, and other photonic applications addressing contemporary quests. Emphasis is on ferroelectrics, diode-pumped solid-state and fiber lasers, special optical fibers and in additive and subtractive processing of glass. For this we develop new material engineering and characterization techniques.

NANO

Our research activities within the Nano area are broad and covers growth, synthesis patterning, devices and characterization as well as basic science related to surface physics, interfaces and quantum materials. A common theme is the relationship between properties such as optical, electrical and magnetic on one hand and size, structure, shape and composition on the other. The research is often interdisciplinary and connect areas such as condensed matter physics, chemistry, optics and biology. A majority of the conducted research is connected to and driven by sustainability topics such as energy conversion, storage and efficient use or decreased environmental impact and pollution reduction.

X-ray nano imaging with synchrotron radiation: The department has a close connection to the NanoMAX beamline at the Swedish synchrotron radiation facility MAX IV. Together with partners from Lund University we proposed and built the NanoMAX beamline and currently we are involved in the development of a new zone-plate-based x-ray microscope end station at NanoMAX. We also design and manufacture diffractive zone plate optics with diffraction -limited resolution in the 10 – 100 nm range. The long-term goal is 3D x-ray nano imaging experiments on the 10 nm resolution level with synchrotron radiation. (Ulrich Vogt)

Nanochemistry for nanomaterials: At the department there is a group with strong Nanochemistry profile focusing on development of fabrication strategies for nanomaterials.

The applications are in bio-medicine, as contrast agents, and harvesting waste heat via thermoelectric materials, besides materials designed for heat-transfer surfaces/fluids as well as water-remediation. One of the main focuses of the group is green chemical process development for energy and resource effective synthesis as well as scale-up of various nanomaterials. Currently collaborates with the Hertz group on the development and implementation of nano-contrast agents for x-ray fluorescene bio-imaging; with Vogt's group on the fabrication of x-ray zone plates using top-down solution chemical process; with Popov's group on the synthesis and implementation of optically active organic and inorganic materials in plasmonic and optofluidic devices. (Muhammet Toprak)

Research activities carried out in the section for Nanostructure Physics address a variety of areas, mostly related to electronic device physics. Work on nanomagnetism and spintronics focuses on small devices formed from magnetic multilayers, where electric current can induce magnetic torque to manipulate the magnetic ordering in the device. Spin vortices and thermal switching based on RKKY exchange interactions are studied. Work in the section also uses superconductivity to study quantum effects of microwave circuits and electro-mechanical devices. Nonlinear dynamics is a unifying theme of research on both electrical and magnetic circuits, as well as in the development of new modes of Atomic Force Microscopy. Simulation is a key part of the research effort, used in nearly all projects to compare physical models with data from measurements. The group also develops measurement instrumentation and techniques that exploit state-of-the-art digital signal processing, extending to microwave frequencies. This latter effort has led to spin-off commercial activity.

Recent research advancements in the section for Nanostructure Physics includes: The understanding of spin current relaxation in Antiferromagnetic spin-valves. The development of several modes of Intermodulation AFM, an information-rich technique where nonlinear cantilever dynamics is measured via frequency mixing to reveal tip-surface forces. Presently the group is adapting these AFM measurement methods to study quantum entanglement in microwave frequency combs, generated by nonlinear superconducting circuits that are driven by multiple frequencies.

The research at Material and Nano physics (MNF) is on a basic understanding of electronic, magnetic, optical, and chemical properties of quantum materials, surfaces, thin films, and nano structured materials combining experimental and theoretical methods for development of new materials within electronics, catalysis, spintronics, batteries, environment, energy, communication technology.

A large and successful activity is development of new functional nanomaterials. This includes material fabrication, development of new methods, sample analysis, testing and verification. Technological areas of interest are medical applications, energy production and environmental remediation; water cleaning, photocatalytic degradation of microplastics. anticorrosion-self healing coatings water splitting for hydrogen production and blue energy generation.

The area of material physics includes studies on quantum materials where quantum effects play a dominating role at the macroscopic level as in the case of superconductors, topological insulators, metal-insulator systems, and magnetic systems. One of the main experimental tools in this area is photoelectron spectroscopy and in particular Angle-Resolved PhotoElectron Spectroscopy (ARPES). An ongoing activity is the development of a new laser based high-harmonic source for time-resolved ARPES with high energy resolution (<15 meV). This source will be exploited to study the effects of lattice distortions on the electronic structure of quantum materials in general and in topological and superconducting materials in particular. Some of the more impactful results achieved since the last RAE are related to topological insulators. The discovery and characterization of the first topological crystalline insulator (TCI) and the demonstration of the first order nature of the topological phase transition in this system are examples of high impact results achieved within this area.

A special focus is on multifunctional materials, where one example is the $A_2TM_2TeO_6$ honeycomb series of compounds that are both novel sustainable battery cathode materials at room-temperature, as well as display potential Kitaev quantum spin liquid behavior at low temperatures.

Further, studies on surface structures and reactions of relevance for catalysis and corrosion with atom resolving microscopy and synchrotron radiation-based spectroscopy. Our ultra-fast electron microscope (UEM) is one of very few such set-ups worldwide and can resolve atomic motion on the femtosecond time scale.

Development of computational methods for spin dynamics and spin-lattice dynamics, angular momentum transfer between spin system and lattice. In addition, physics of spintronics and development of components are done in collaboration with Göteborg University.

A very important part of our experimental research involves using large scale facilities; synchrotron radiation and free-electron laser-based spectroscopy as well as material analysis using neutrons and muons. But also includes important development of methods and experimental facilities. The division has been involved in construction and development at MAX-I, MAX-II, MAX-III and MAX-IV. MNF plays a key role on the development at ESS beamlines and is a prominent developer of methods for advanced materials analysis at large-scale facilities, using neutron, muon and synchrotron techniques. A multidisciplinary approach concerning materials, collaborators and techniques is a central aspect of our research.

Gender and ethnic diversity do not play a direct role in the research, but the composition of the groups is very diverse. Students originate in China, India, Iran, Sweden, Italy, Chile. Post-docs and researchers are from Europe, China, India, USA, Iran, Sweden. The gender balance on these levels is good, with a slight male dominance. On the faculty level Swedish origin and male dominates. The scientific background is mainly from physics, but chemistry, material science and microelectronics are also represented.

c. Contributions to the advancement of the state of the art within the research fields of the department

X-ray science and technology: The department pioneered the soft x-ray liquid-jet laser-plasma source (1992) and were the first to demonstrate the tin liquid-jet source (2004), which is now the source in EUV lithography (>900 people work on this today). We have reached early-bending magnet brightness in the water-window (2012) and the source is the cornerstone for our laboratory soft x-ray microscopy. We demonstrated the first sub-visible-resolution laboratory water-window x-ray microscope (2000), the first “real” applications (soil science, 2009) and the first lab 3D cryo-tomography of intact cells (2011). Recent work is on autophagy, NK-cell interaction (2018) and virus progression (2021). (Hertz group)

The department pioneered the liquid-metal-jet-anode hard x-ray source (2003). This electron-impact source allows for up to 1000x higher brightness than any existing laboratory microfocus x-ray tube. The technology is now successfully commercialized by our start-up company (www.excillum.com). We demonstrated the first high-resolution phase-contrast imaging with liquid-metal-jet sources 2006. To our knowledge this is the only laboratory arrangement that has potential for high-resolution (cellular!) phase imaging in whole-body small-animal objects with short exposure times at an acceptable dose. Present emphasis is on whole-body mouse CT (2012), micro-angiography, and tumor imaging. The method has potential for cellular and sub-cellular-resolution imaging in thick tissue, a long-standing goal of bio-imaging, as recently demonstrated on zebrafish (2015) and coronary arteries in human heart (2018). The same research group were the first to identify a viable path for x-ray fluorescence imaging imaging to produce molecular and functional 3D imaging in mice with 10x better resolution than present methods (PET and SPECT). We rely on liquid-metal-jet sources in combination with target-seeking specially designed nanoparticles and photon-counting detectors. (Hertz group)

The coherent x-ray scattering group brings x-ray free-electron laser science to KTH in general and BIO in particular, where we extend the wide range of imaging techniques to coherent diffractive imaging. Although this is still a young technique that requires expert knowledge and continuous development, it has the potential to reach sub-nanometer resolution on micron-sized living cells without staining or sectioning and could eventually make macromolecular movies of biomolecules a reality. We also study fluctuations and crystallization in liquids and solutions using coherent x-ray scattering, where we recently participated in determining water's isothermal compressibility (2018) and specific heat capacity (2021) upon deep supercooling. (Sellberg group)

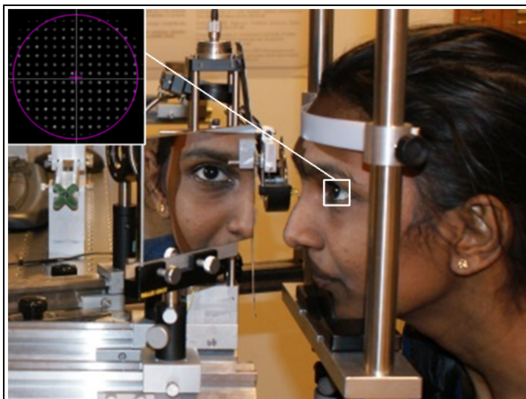


Fig 1. Peripheral vision analysis system

Visual Optics: The visual optics group at Applied Physics has established methods to quantify and analyze peripheral optical errors (aberrations) and given proof of that peripheral vision can be improved by optical correction, which has inspired industry to develop optical aids with improved peripheral image quality. We have performed one of the two first population studies of peripheral image quality. We have collected data and filed a patent on manipulating peripheral image quality to reduce the progression of myopia, which has inspired a company in Russia to develop a new type of spectacles for children becoming myopic. (Lundström & Unsbo)

Acoustofluidics: The acoustofluidics group at the department has recently made progress in transferring the technology for acoustofluidics cell manipulation from bulky and expensive equipment, to simple, compact and extremely inexpensive (Fig. 2). We collaborate with theoretical experts at DTU-Copenhagen, and with oncologists at Karolinska Institute and Hospital. Most important, we collaborate internally with Önfelt's group who use the acoustofluidic technology in combination with advanced light microscopy for immuno-therapy research. The combination of acoustofluidics and advanced light microscopy methods have resulted in a novel platform for producing and characterizing tumor models in 3D with high spatial and temporal resolution. (Viklund group)

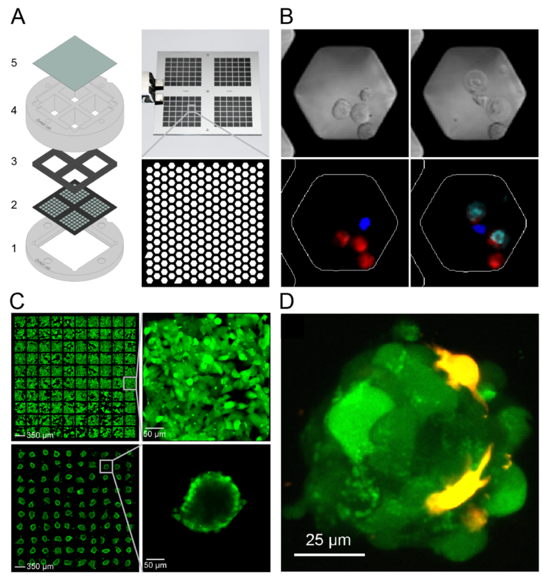


Fig 2. Microchip platform. Screening of NK and T cells reactivity at the single cell level. Microwells (60 µm) are etched in a microchip made of silicon and glass, which is fitted in a custom-made holder enabling exchange of media and CO_2 for long-term live cell imaging.

X-ray nano imaging with synchrotron radiation: The MAX IV synchrotron radiation facility is the first so-called diffraction limited storage ring. It offers a much higher brightness than traditional facilities, which is of special benefit for x-ray nano imaging experiments. The NanoMAX beamline is the first beamline that fully exploits this fact and offers superior imaging performance for users from many different research fields. The beamline was proposed and developed in close collaboration with researchers from our department (Vogt group).

Sustainable chemistry for functional nanomaterials: The work on the synthesis and processing of nanoengineered thermoelectric materials at the department has been pioneering in the field of energy harvesting materials, attracting significant attention. The nanochemistry group has demonstrated the capacity to develop scalable green chemical synthesis techniques, based on microwave-assisted heating, and high thermoelectric figure of merit in state-of-the-art thermoelectric materials based on chalcogenides ($Cu_{2-x}Se$, $Bi_{2-x}Sb_xTe_3$). Currently hybrid films are developed to offer thermal energy harvesting capacity in the presence of even few degrees temperature gradients. (Toprak group)

The same research group also developed a library of x-ray fluorescent nanoparticle-based contrast agents for in vivo biomedical imaging, designed to match the energy of the pencil beam x-ray source developed at the department. These nanoparticles have been tuned for their size and surface chemistry, and have been demonstrated as promising materials for pre-clinical research for *in-vivo* x-ray fluorescence computed tomography (XFCT) bio-imaging. Current work is focusing on targeting strategies of these nanoparticles with affibodies. This is one of the pioneering interdisciplinary works joining many disciplines together. (Toprak group)

The group for immune cell biophysics develops microchip platforms and methods to assess migration and immune cell cytotoxicity on the single cell level (Figure 2). The chip platform can be combined with ultrasound actuation to generate 3D tumor spheroids that are used as model systems for immunotherapy of solid tumors. Light sheet microscopy methods have been developed to study the evolution of tumor spheroids and the dynamics of T-cells attacking the cancer cells. We have a wide international network in the immunotherapy field and collaborate other leading groups through performing experiments with our unique assays or by sharing the microchip platform with other research groups. In several cases we have educated students and postdoc in our lab about how to use the platform before exporting the technology to other labs.

The Biophysics unit has during the past 20 years contributed to the development of advanced microscopy methods for studies of membrane proteins, in particular of Na,K-ATPase. Imaging methods have been developed to identify feedback mechanisms that regulate Na,K-ATPase and also to unravel how Na,K-ATPase is a signal transducer acting via slow calcium oscillations that activate Nf-kB and alter the signal balances in apoptosis (Fig. 3). We have demonstrated the medical impact of those findings for diseases associated with massive apoptosis. We have developed methods based on STED, STORM and PALM to identify and quantify Na,K-ATPase membrane densities and the colocalization-clustering with regulating proteins in neurons. We have also developed methods for single particle tracking to analyze local dynamics of membrane proteins and the functional consequences in neurons. Lately, methods based on light sheet and pioneering work on lattice light sheet microscopy has been important for dyanimc analysis of living systems at different scales (from subcellular junction formation to development of embryos)

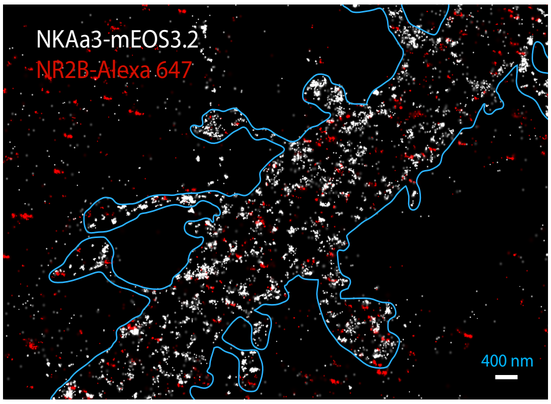


Fig. 3. Combined PALM/STORM of Na,K-ATPase and NR2B in a hippocampal neuron.

The super-resolution microscopy development in the group is on the absolute international fore front and attracts significant funding and produce high-impact publications. We have worked to create new imaging approaches that enable recording of a completely new set of super resolution data based on time lapse imaging not possible before. The new microscopes enable observations in previously impossible samples, such as highly scattering brain tissues, with a spatial-temporal precision never achieved before. No other methods can acquire whole volumetric movies in living brain slice with < 60 nm in 3D. Our microscopy innovation enables new observations, which trigger novel and better questions with the ultimate goal of creating new science.

The computation biophysics groups develop new methods and apply them in various configurations. The biomolecular simulation program GROMACS, developed in the unit, has become the most used open source code on supercomputers in the world, enabling hundreds of high-impact advances by other teams. The group is also engaged in cryo-EM computational method development, in particular for the RELION code, which has contributed greatly to the rapidly increasing resolution and dynamics obtained with cryo-EM (Fig. 4).

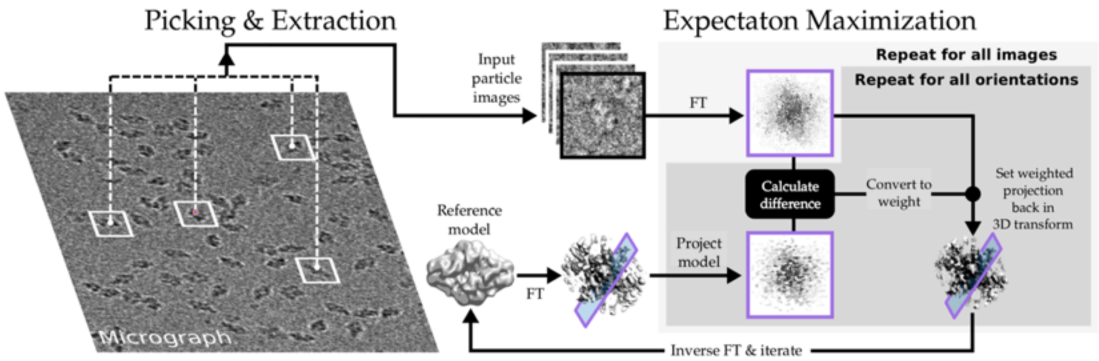


Figure 4. The resolution revolution in cryo-electron microscopy would not have been possible without large efforts to create new methods that are able to both reconstruct 3D densities from noisy micrographs. Our work has also made it possible to use the diverse raw data to predict the flexibility of molecules, and fit molecular models into 3D densities. Illustration by Björn Forsberg.

The group were the first to propose and identify the dual binding sites in ligand-gated ion channels and have determined a number of new ion channel structures. We have explained the molecular mechanisms of allosteric modulation, how poly-unsaturated fatty acids influence the gating of voltage-gated ion channels (with direct treatment impact) and used both cryo-EM and simulations to determine structure, formation and barrier properties of human skin (see Fig. 5).

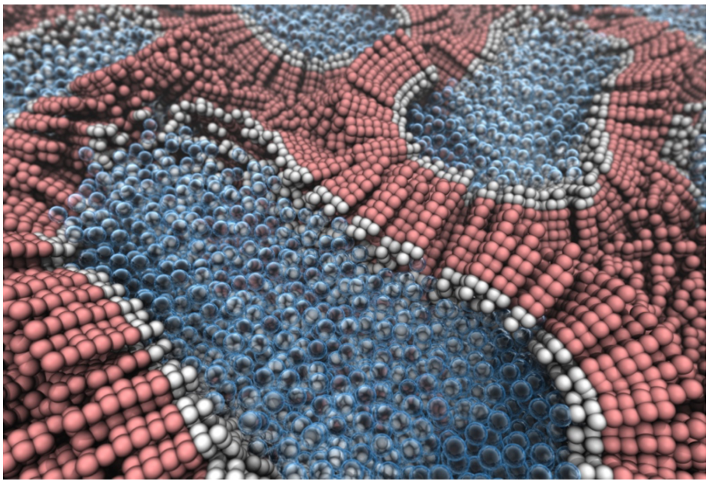


Figure 5. By involving teams both from KTH, KI, SU and the KS hospital, it has been possible to capture cryo-EM data of the formation of the horny layer of skin, the stratum corneum, and use molecular dynamics simulations to explain the process on molecular level. Illustration by Christian Wennberg.

We have also provided a host of new algorithms for MD simulations. This development has been stimulated by and made possible studies of the activation mechanism of HCN channels, the electromechanical coupling in Kv channels and in KCNQ1, into the transport cycle of the malarial parasite hexose transporter and the activation mechanism of the beta2 adrenergic receptor (Fig. 6).

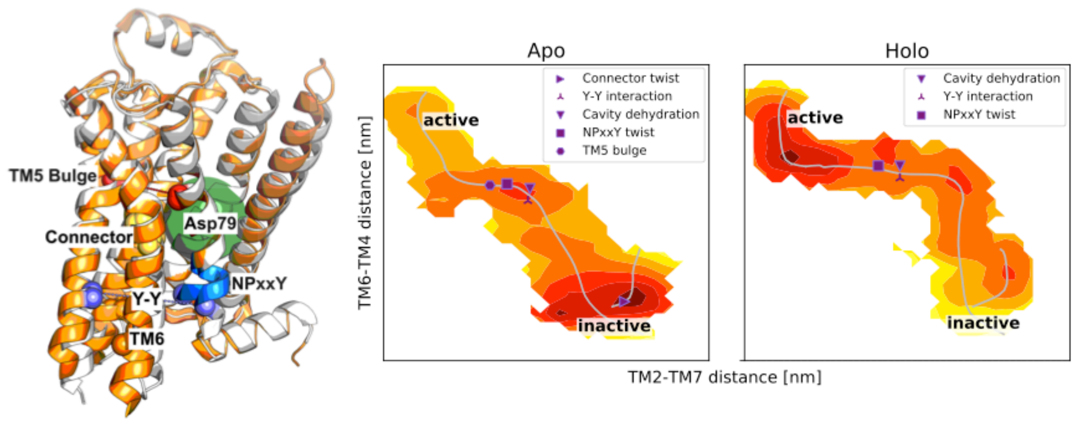


Figure 6: Activation path of the beta adrenergic receptor highlighting the sequential flip of microswitches along the path, in a manner that depends on ligand binding.

Single molecule spectroscopy: We have a strong cluster of research groups active in fluorescence spectroscopy and imaging at the department. Based on a long and strong track record in single-molecule and fluorescence correlation spectroscopy (FCS), Widengren's group contributes with important critical mass to the cluster. Current research has a focus on exploiting photophysical and photochemical information for cellular and biomolecular studies, as well as to drive the development and use of the fluorescence methods towards clinical applications and to understand origin of diseases on a molecular level.

Immune cell biophysics: Önfelt's group have developed a microchip platform and methods to assess migration and immune cell cytotoxicity on the single cell level. The chip can also be combined with ultrasound actuation (Wiklund group) to generate 3D tumor spheroids that we use as model systems for immunotherapy of solid tumors. Our group also have wide network and collaboration with world leading groups in immunotherapy. We have collaborated through performing experiments with our unique assays or shared the microchip platform with other research groups. In several cases we have educated students and postdoc in our lab about how to use the platform before exporting the technology to other labs.

Scanning near-field microscopy: The multi-mode scanning near-field optical microscopy system in Marcinkevicius Lab, is a unique facility allowing spatially- time- and polarization resolved characterisation of structural, optical and electronic material properties. Among the highlights, one can mention studies of carrier transport InGaN quantum wells, refined band structure parameters of GaN, revealed novel ultrafast effects in Ga_2O_3, etc.

Engineered ferroelectric nonlinear optical materials: The work on engineering ferroelectric nonlinear optical materials is world leading as Canalias' group is the only one that can make bulk domain structures with sub-micrometer features. Besides the domain writing capacity several unique characterization techniques have been developed. These structures are used for quasi-phase matching (QPM) nonlinear interaction devices novel frequency conversion schemes to be realized, both in bulk and waveguide format. The hybrid nano-waveguides under development holds promise for compact entangled sources for quantum communication and quantum information processing.

Large aperture, high-energy narrowband optical parametric sources employing domain-structured nonlinear ferroelectric materials have been space flight qualified for use in global CO_2 monitoring. Similar crystals have been used for high energy infrared supercontinuum generation and self-compression and functional ferroelectric meta-surfaces for THz beam handling. Nanoengineered ferroelectrics is developed for high-energy backward-wave optical parametric oscillators.

Nanoengineered thermoelectric materials: The work on the synthesis and processing of nanoengineered thermoelectric materials in Toprak's group has been pioneering in the field of energy harvesting materials, attracting significant attention. The group has demonstrated the capacity to develop scalable green chemical synthesis techniques, based on microwave-assisted heating, and high thermoelectric figure of merit in state-of-the-art thermoelectric materials based on chalcogenides ($Cu_{2-x}Se$, $Bi_{2-x}Sb_xTe_3$). Currently hybrid films are developed to offer thermal energy harvesting capacity in the presence of even few degrees temperature gradients.

X-ray fluorescent contrast agents for in vivo biomedical imaging: Toprak's group developed a library of x-ray fluorescent nanoparticle-based contrast agents designed to match the energy of the pencil beam x-ray source developed by Hertz' group. These nanoparticles have been tuned for their size and surface chemistry, and have been demonstrated as promising materials for pre-clinical research for *in-vivo* x-ray fluorescence computed tomography (XFCT) bio-imaging. Current work is focusing on targeting strategies of these nanoparticles with affibodies. This is one of the pioneering interdisciplinary works joining many disciplines together.

The division has for many years played a very active role in synchrotron radiation-based science and is at present involved in the development of three beamlines at MAX-IV; ambient pressure XPS at HIPPIE, angle resolved photoelectron spectroscopy at Bloch and RIXS at Veritas. In addition, the division has been involved in the construction of the hard X-ray "Swedish beamline" at DESY in Hamburg.

MNF has a leading position in Sweden for work using neutrons and muons, of central relevance in connection to the construction of ESS. The Swedness program finances 40 doctoral students. Important collaborations include large car and battery manufacturers in Japan.

MNF is currently the only Swedish research team that utilizes the unique μ^+SR (Muon Spin Rotation/Relaxation) technique for studying both quantum and energy materials. Further, Månsson has developed and pioneered a novel and world-leading μ^+SR method for studying ion dynamics in energy related materials (batteries, photovoltaics and hydrogen storage materials). This method has gained a lot of international attention (e.g. Gordon Research Conference) and has opened a new completely unique path for studying ion diffusion in energy materials both in bulk as well as at surfaces and across buried interfaces (Figure 7). The use of this method has generated a large number of research articles and press releases/highlights during the last 5 years.

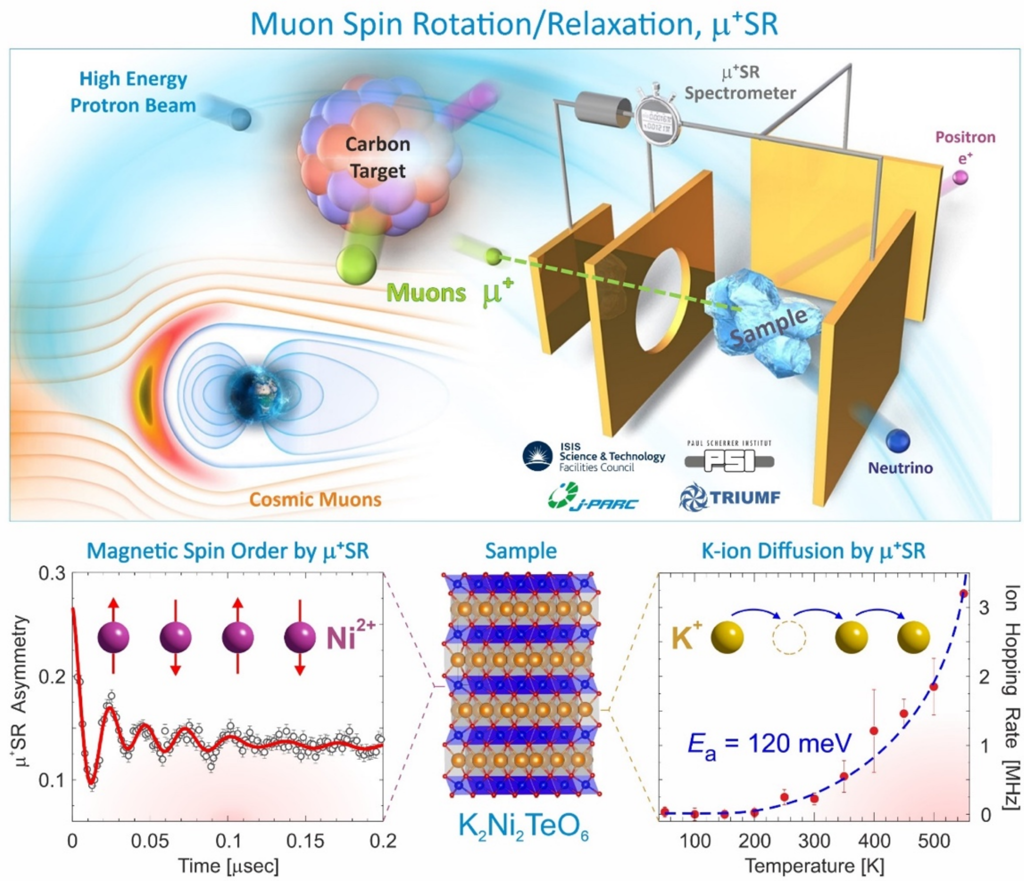


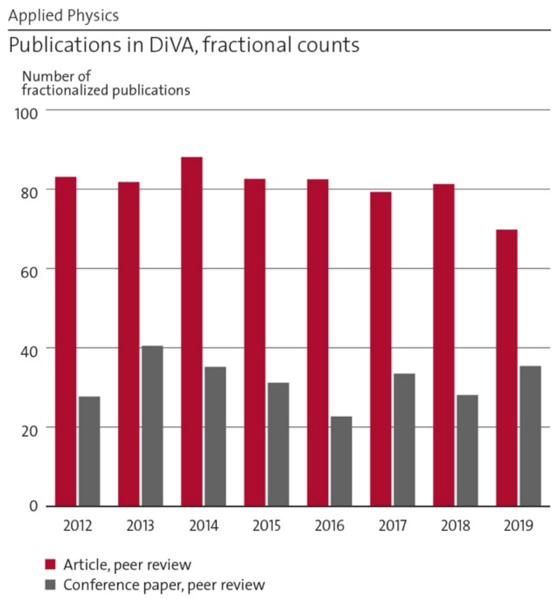
Figure 7: The unique muon spin rotation/relaxation (μ^+SR) technique allow us to study both low-temperature spin order in quantum materials as well as room-temperature ion diffusion in energy materials. See for instance: N. Matsubara, *et al.*, Scientific Reports **10**, 18305 (2020).

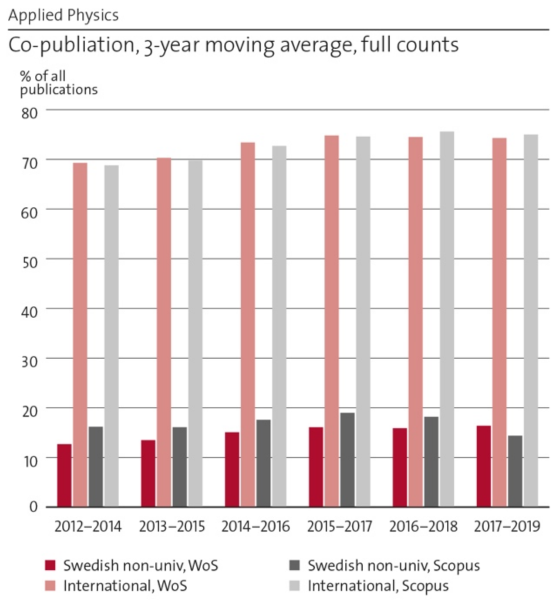
Developments at the lab at KTH includes ARPES using laser based HHG (higher harmonic generation) and ultrafast electron microscopy (UEM). These systems are unique for Sweden and among very few worldwide.

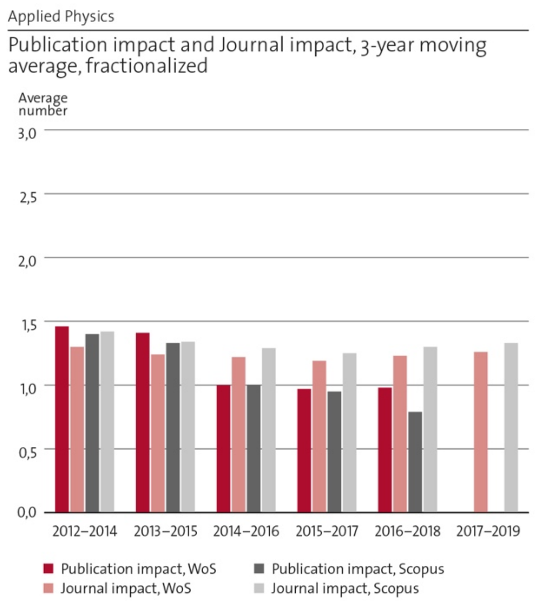
The division is leading in the development of functional nano structured materials both detection and removal impurities in water, drug delivery and catalytic degradation of plastics.

d. Quality and quantity of contributions to the body of scientific knowledge

The department publishes more than 300 peer reviewed research articles per year. This is a substantial volume and amounts to approximately one and a half published article per person and year. Approximately 30% of these articles are in high impact (top 20%) journals according to KTH bibliometric numbers. These numbers are known to be wrong, but the general trends are most likely correct. The corresponding field normalized journal citation number is 1.24 but the corresponding field normalized citation rate is 0.98 for the 2016-2018 period. These numbers could indicate that the research results of the department do not get cited to the extent that they deserve or that we are very successful in getting our results published in leading journals. Without accurate data available on the division level it is difficult to understand and evaluate the variation among disciplines and divisions, the result of different practices and trends.







Below are a few examples of particularly noteworthy publications since the last RAE in 2012.

Laser restructuring and photoluminescence of glass-clad GaSb/Si-core optical fibres
S. Song, K. Lønsethagen, F. Laurell, T. Hawkins, J. Ballato, M. Fokine, and U. J. Gibson, Nature Communications, 10, 1790 (2019), /doi.org/10.1038/s41467-019-09835.

Atomically dispersed iron hydroxide anchored on Pt for preferential oxidation of CO in H_2
L Cao, W Liu, Q Luo, R Yin, B Wang, J Weissenrieder, M Soldemo, H Yan, Y Lin, Z Sun, C Ma, W Zhang, S Chen, H Wang, Q Guan, T Yao, S Wei, J Yang, J Lu, Nature **565** (2019), 7741

Topological crystalline insulator states in Pb1−xSnxSe
P. Dziawa, B. J. Kowalski, K. Dybko, R. Buczko, A. Szczerbakow, M. Szot, E. Łusakowska, T. Balasubramanian, B. M. Wojek, M. H. Berntsen, O. Tjernberg, and T. Story

Nature Materials **11** (2012) 1023–1027

Direct Measurement of Nanoscale Lateral Carrier Diffusion: Toward Scanning Diffusion Microscopy
M. Mensi, R. Ivanov, T. K. Uždavinys, K. M. Kelchner, S. Nakamura, S. P. DenBaars, J. S. Speck, S. Marcinkevičius, ACS Photonics 2018, 5, 2, 528-534, 2018.

High performance micro-flow cytometer based on optical fibre
S. Etcheverry, A. Faridi, H. Ramachandraiah, T. Kumar, W. Margulis, F. Laurell, and A. Russom, Scientific Reports 7, 5628 (2017).

All-dielectric $KTiOPO_4$ metasurfaces based on multipolar resonances in the terahertz region
J. Tian, Y. Yang, M. Qiu, F. Laurell, V. Pasiskevicius, and H. Jang, Opt. Express 25, 24068-24080 (2017).

Supercontinuum generation and soliton self-compression in $\chi(2)$-modulated $KTiOPO_4$
A-L. Viotti, R. Lindberg, A. Zukauskas, R. Budriunas, D. Kucinskas, T. Stanislauskas, F. Laurell, V. Pasiskevicius, , Optica, 5, 711, (2018).

A 1.57 µm Fiber Source For Atmospheric CO_2 Continuous-Wave Differential Absorption Lidar
X. Yang, R. Lindberg, J. Larsson, J. Bood, M. Brydegaard, and F. Laurell,. Opt Express, 27, 10304 -10310, 2019.

Narrowband, tunable infrared radiation by parametric amplification of a chirped backward-wave OPO signal
A.-L. Viotti, A. Zukauskas, C. Canalias, F. Laurell and V. Pasiskevicius, , Opt Express, 27, 10602-10610, (2019).

Optically Transparent Wood: Recent Progress, Opportunities, and Challenges
Li, Y., Vasileva, E., Sychugov, I., Popov, S. & Berglund, L.. Advanced Optical Materials. 10.1002/adom.201800059. (2018).

Carbohydrates on the Size and Shape of Gold and Silver Nanostructures.
Yazgan, I.; Gümüş, A.; Gökkuş, K.; Demir, M. A.; Evecen, S.; Sönmez, H. A.; Miller, R. M.; Bakar, F.; Oral, A.; Popov, S.; Toprak, M. S. On the Effect of Modified *Nanomaterials* 2020, *10* (7), 1–17. https://doi.org/10.3390/nano10071417.

Nitric Oxide-Dependent Biodegradation of Graphene Oxide Reduces Inflammation in the Gastrointestinal Tract.
Peng, G.; Montenegro, M. F.; Ntola, C. N. M.; Vranic, S.; Kostarelos, K.; Vogt, C.; Toprak, M. S.; Duan, T.; Leifer, K.; Bräutigam, L.; Lundberg, J. O.; Fadeel, B. *Nanoscale* 2020, *12* (32), 16730–16737. https://doi.org/10.1039/d0nr03675g.

Modeling, Design, and Synthesis of Gram-Scale Monodispersed Silver Nanoparticles Using Microwave-Assisted Polyol Process for Metamaterial Applications. Lalegani, Z.; Ebrahimi, S. A. S.; Hamawandi, B.; La Spada, L.; Toprak, M. S. *Opt. Mater. (Amst).* 2020, *108*. https://doi.org/10.1016/j.optmat.2020.110381.

Composition Tuning of Nanostructured Binary Copper Selenides through Rapid Chemical Synthesis and Their Thermoelectric Property Evaluation.
Hamawandi, B.; Ballikaya, S.; Råsander, M.; Halim, J.; Vinciguerra, L.; Rosen, J.; Johnsson, M.; Toprak, M. *Nanomaterials* 2020, *10* (5). https://doi.org/10.3390/nano10050854.

Optical and X-Ray Fluorescent Nanoparticles for Dual Mode Bioimaging.
M. Saladino, G.; Vogt, C.; Li, Y.; Shaker, K.; Brodin, B.; Svenda, M.; M. Hertz, H.; S. Toprak, M. *ACS Nano* **2021**, *0* (0). https://doi.org/10.1021/acsnano.0c10127.

e. Engagement in national and international research collaboration within academia and its outcomes

BIO

Karolinska institutet

KTH and Karolinska institutet (KI) are long-term strategic partners in research and university education in the Stockholm area. The department of Applied Physics have many collaborative research projects together with KI on biomedical applications. These collaborations cover a wide range of bioimaging, analysis and measurement techniques.

In x-ray phase-contrast methods for 3D resection margin assessment, department of Applied physics provides the technology, KI/KS provide human samples, we do the imaging, they do the classical histology, and we compare. In the x-ray fluorescence molecular imaging project on cell-biological foundations KI provides expert biomedical advice and are responsible for ethical permits. KI also provides lung radiology expertise in the computational phase-contrast lung-imaging project at the department. KTH and KI collaborate in virtual x-ray histology of human coronary arteries with our department providing technology and performing the imaging of samples provided by KI and then the results are analyzed jointly.
(KTH: Hans Hertz. KI: Dept. of clinical pathology and cytology, Dept. of laboratory medicine, Dept. of surgery, Dept. of microbiology, tumor and cancer, Dept. of molecular medicine and surgery and Dept. of clinical sciences.)

The nanochemistry group at the department also has long term interaction in the characterization of some aspects of nanomaterials studied at KI.
(KTH: Muhammet Toprak. KI: Dept. of environmental medicine.)

In optometry and ophthalmology we are collaborating with KI on several research projects related to the development of nearsightedness in children. Here KTH provides technical competence on how to measure and analyze the image quality of the eye in different angles as well as on how to evaluate peripheral vision and KI () provides clinical experience on working with children and using different types of contact lenses to affect the accommodative state of the eye. We also perform joint studies on the remaining peripheral vision for people with age-related macular degeneration and possible improvements through optical correction.
(KTH: Linda Lundström and Peter Unsbo. KI: Dept. of clinical neuroscience.)

In acoustofluidics, KTH and KI collaborate in projects where ultrasound, microscopy and microchip technology are used for immuno-therapy research, in particular for investigating and optimizing the cytotoxic effect of natural killer cells and T cells on solid tumors. Here, KI provides patient materials and relevant cell cultures, as well as know-how and methods in

immunology and oncology.
(KTH: Martin Viklund and Björn Önfelt. KI: Dept. of oncology-pathology, Dept. of clinical science, intervention and technology, Dept. of medicine.)

Max IV

The Swedish national synchrotron radiation source MAX IV laboratory is a national infrastructure of strategic importance for the department of Applied Physics. The x-ray optics and nano-imaging group at Applied physics is a long-term collaborator of the NanoMAX beamline at the MAX IV. Ulrich Vogt and a colleague from Lund University wrote the successful proposal to fund this flagship beamline as one of the first seven beamlines at MAX IV. The beamline opened its first experimental station for both Swedish and international users in 2018. Currently, we are involved in the design and construction of the second endstation at NanoMAX for 3D nano-imaging with highest resolution, down to the single-digit nanometer regime. This endstation will use diffractive zone plate optics developed and fabricated by us in the AlbaNova nanofabrication laboratory. (KTH: Ulrich Vogt)

The coherent x-ray scattering group is also collaborating closely with MAX IV. The group leader Jonas Sellberg is a board member of the synchrotron radiation users association at MAX IV since 2018 and co-responsible for two work packages in the conceptual design report (CDR) of a soft x-ray laser (SXL) beamline at MAX IV. The CDR was recently submitted to the KAW foundation, which has co-funded the SXL project since 2018. This is big stepping stone toward a Swedish free-electron laser, a large-scale x-ray infrastructure integral to the research of the coherent x-ray scattering group at which a majority of the group's publications have been performed. Currently, the SXL working group will organize workshops to gather research interest and update the science case for an SXL beamline based on the results of the CDR. This will serve as a basis for future funding toward a technical design report (TDR) and an eventual construction of a unique x-ray infrastructure at MAX IV in Sweden. (KTH: Jonas Sellberg)

The QBP unit benefits from extensive interdisciplinary collaborations, both on a national and international level. The collaborations cover the coordination of an interdisciplinary research environment (VR, Optical Quantum Sensing) and of the national Quantum Communication pillar in the Wallenberg centre for Quantum technlogyy (WACQT), a newly started H2020 project (described separately), and participations in several interdisciplinary research projects, research environments and exchange programs (financed by SSF, Vinnova, STINT, EU H2020, and KAW).

For example, the EBP group has successfully collaborated with groups at Karolinska institutet, applying super-resolution STED imaging to identify and understand mechanisms behind early cancer development and bacterial infections (see [1]). Together with the group of Gert Auer, KI, the role of platelets in early cancer development have been studied and new features of the interplay between platelets and tumor cells on a nanoscale level have been revealed, which possibly also can form the basis for new diagnostic and therapeutic approaches (see e.g. [3]). With the group of Birgitta Henriques-Normark, KI, using a combination of advanced fluorescence techniques, the EBF group has also studied how virulence and invasiveness of bacteria (pneumococci) depend on the distribution patterns of specific bacterial proteins on the surface of the bacteria (see e.g. [2] and [4]). The latter collaboration has recently led into a H2020 project, coordinated by the QBP unit (described further below).

1. Blom H, Widengren J, *Chemical Reviews*, 117(11), 7377-7427, 2017

2. Pathak A *et al, Nature Comm.* 9, 3398, 2018
3. Bergstrand J *et al*, *Nanoscale*, 11(20), 10023-10033, 2019

Sender V *et al*, *Proc. Natl. Acad. Sci.* 117(49), 31386-31397, 2020
The Biophysics Unit has constructed and operates the cellular and molecular imaging platform at Science for Life Laboratory since 2013. In this platform we operate the Advanced Light Microscopy facility (ALM) which is a node in the national microscopy infrastructure as well as a node in the European infrastructure EuroBioimaging-ERIC. KTH (via the Biophysics unit) is the main site for the for the national infrastructure and is Swedish coordinator for the international infrastructure.

The mission of the ALM facility is to give access and expert support in state-of-the-art fluorescence microscopy techniques to Swedish researchers. A strong focus is on super-resolution microscopy. In 2017, two new staff scientists were recruited and the repertoire of techniques was broadened by the introduction of light sheet microscopy and advanced FCS analysis in the facility.

Support in Lightsheet microscopy at ALM has attracted several new research groups with a need to image larger samples, model organisms, and also for studies of cleared tissue samples. In parallel to the introduction of new imaging techniques the facility has developed sample preparation protocols and gives now advanced support that includes clearing and expansion techniques. Single molecule dynamics studies in correlation spectroscopy have been established as a core technology in the facility and there is a continuously increased use and broadened interest for those techniques.

The focus on advanced light microscopy, in particular super-resolution, is nationally unique and highly competitive internationally. Important is the combination of state-of-the-art instruments and expert support that our staff scientist give users. ALM has been selected as one of the first sites world-wide for the Lattice Light Sheet built by Carl Zeiss (AIC Janelia Farm and Betzigs lab is the first). Our in-house development of MFM-SIM further broaden our support for live-cell super-resolution microscopy projects. The nanoscale dynamical STED-FCS platform and its connected in-house competence is nationally unique and internationally competitive.

The ALM facility is associated with and supported by the Biophysics unit at the dept of Applied Physics, KTH. The Biophysics unit is located at SciLifeLab and has 57 active researchers working in development of biophysical measurement and analysis techniques, including the development of new super-resolution imaging. The research environment includes two SciLifeLab research fellows, Ilaria Testa, KTH developing super-resolution RESOLFT and related techniques, and Erdinc Sezgin, KI, developing methods in STED-FCS.

OPTO

We are running KTH Laserlab which is part of Laserlab Sweden (http://laserlab-sweden.se/) a network including KTH, Chalmers, and the universities in Uppsala, Lund, Gothenburg and Umeå. We do joint experimental and educational work, co-use equipment and organize a yearly PhD course in experimental laser physics.

We have projects with the European Space Agency, the European Defence Agency, the French aerospace lab, ONERA, and US Naval Research Labs on ground and airborne LIDAR for airborne environmental gas monitoring and the development a space mission roadmap.

Additionally – national and international collaboration

RISE-(Research Institute of Sweden), Science for Life Laboratory -Swedish Defence Agency (FOI), Linköping – joint work on development of highly sensitive mid infrared imaging using frequency upconversion correlated photon counting.

DESY Hamburg (Germany) and Nation Tsinghua University Taiwan. Light sources for particle acceleration. NTNU (Norway) and Clemson University. Semiconductor Core fibers, THz physics.

Within the area of wide band gap semiconductors and light emitting devices, we have a long-standing (~10 years) collaboration with University of California, Santa Barbara (UCSB). The group headed by Profs. James. S. Speck and Shuji Nakamura (Nobel Prize in Physics 2014) are among the world leaders in GaN-based LED and laser diode technology. The core of our collaboration, documented in many research papers, is complementary competences of KTH and UCSB researchers. The UCSB excels in the growth technology and structural characterization. At KTH, we have unique experimental techniques for time- and spatially-resolved optical measurements, which allow studying fundamental physical properties of the materials and nanostructures and identify critical issues for the improvement of device performance.

In the area of telecommunication research, we have a long-term collaboration with Chalmers University of Technology, RISE Acreo, II-VI Incorporated (former Finisar Sweden), Infinera Sweden and FOI. The international collaboration is currently within the EU projects TWILIGHT and cFLOW together with many European universities and companies. Concerning the laser modeling and design, we have collaboration and support from a dozen companies and universities around the world.

NANO

Several groups in the department are involved in WACQT (Wallenberg Center for Quantum Technology). Digital microwave electronics developed at KTH is deployed at Chalmers and KTH measures samples fabricated at Chalmers, collaborating closely with both experimental and theory groups working on superconducting quantum circuits.

Maybe some other WACQT examples from other groups would fit best here….

Our developments in AFM methodology have resulted to several fruitful academic collaborations and dissemination of our research also occurs via a spin-off company selling instrumentation and software. Presently we are leading an EU project focused on the development of the next generation of resonant mechanical force sensors for scanning probe microscopy.

Other collaborations are with (very few most significant listed) KTH groups in biomolecular and condensed matter physics via the Optical Quantum Sensing VR research environment; EU ITN Marie Curie MICROCOMB (integrated optical frequency combs); Oak Ridge National Labs (Centre for Nano Material Science) on nano-ferroelectrics; IBM-Research in Yorktown Heights, NY; NTNU-Trondheim, Norway; Anton Zellinger's group in Vienna, Austria; European Quantum Technology Flagship Consortium S2QUIP (coordinated by Klaus Jöns).

- Prof. Weissenrieder is the chairman of the user organisation at MAX-IV.

- Martin Månsson is Director of Studies for the Swedish national graduate school in neutron scattering financed by SSF. He is the leading persons in building a stronger Swedish neutron community. This task is directly initiated by the Swedish Government in relation to the investments at ESS.
- Linneaus center “Advanced optics and photonics”, 2008-18. Was central to establish new collaborations in the area of photonics between KTH groups. Besides several high impact scientific results from the center, out-reach activities included public exhibitions, Opto-pubs, Industry-academia interactions. The collaborations have also resulted in other large scale national research projects beyond the center’s funding period. (Anand).
- EU Network of excellence - Nanophotonics for Energy efficiency (2010-2015).

New collaborations in the area of solid state lighting and photovoltaics were established.

Outcome: Industry-Academia workshops conducted in Sweden resulted in new links with Swedish industry engaged in these sectors. Example is a cooperation agreement with Midsummer AB who is also a partner in a solar cell project recently funded by the Swedish energy Agency. Specific collaboration between KTH and LETI-Grenoble resulted in a 2 year sabbatical of a senior researcher from LETI to KTH and subsequent collaborative projects funded by the Swedish Energy Agency (Energimyndigheten) on LEDs. In a joint work, the teams developed a simple method to add-on surface structures by direct printing on pre-fabricated LEDs and demonstrated state-of-the-art results on light extraction enhancement. (Anand)

- Functional Materials collaborates with a wide network of institutes and research groups within Sweden as well as in the EU (Greece, Italy, France), Europe (Switzerland), USA, Latin America (Chile, Argentina), China, India, south-east Asia (Thailand, Indonesia, Philippines, Singapore, Malaysia) and the middle-east (Oman, Qatar, Saudi Arabia). This has resulted in research projects including CLAIM (Horizon 2020), HESAC (EU-ERANET), GOPELC (EU Erasmus+ CBHE action), STINT (China) and TERRACLEAN (MISTRA). (Dutta)
- International collaboration with III-V Labs, Paris and ETH, Zurich within EU project (FP7) **Mirsense** and with Harvard University, Boston, USA on QCLs resulted in high power QCLs and buried photonic crystals QCL’s. This paved the way for the benchmarking the technology for buried heterostructure QCLs.on via EU project. Recently we have an ongoing EU project (Horizon 2020) **cFlow** with III-V Labs, Paris, France and FOI (Swedish Defence Research Agency) where we develop QCLs for free space optical communication (Sun-Doss)
- Have led a five-year national collaborative project between 5 universities (KTH, UU, LiU, Lund and CTH) focusing on thermoelectric materials and devices funded by the Swedish Foundation for Strategic Research (SSF). This led to participation in EU Project Agrisensact, where the developed thermoelectric materials and devices were demonstrated to harvest low grade heat for powering sensors -aimed for precision farming. Link to SPS facility at SU via collaboration is also of significance for progressing the field of nanostructured thermoelectrics. This has led to several publications (collaborators from USA, Denmark, Italy, Poland, and Turkey) and provided us with the competence for attracting EU funding. Currently, the group is engaged in a H2020-FET Project (starting Jan 2020), coordinated by collaborating

group in Spain (partners from Spain, UK, France) focusing on novel interfacial phenomena for improving power factor of thermoelectric materials and devices. (Toprak)

- Academic research collaboration with Karolinska Institute is of utmost importance in order to establish safety protocols and safe use of nanomaterials for biomedicine. This led to several publications -and book chapters, on nanomaterials, characterization, bio-degradation mechanism, and cytotoxicity. With the interdisciplinary projects we are making stronger ties to KTH-Biotechnology, where some active targeting molecules are developed that will be used for targeting of nano-particles for in-vivo bio-imaging. (Toprak)
- Large collaboration with China (joint research grants and publications with several groups, exchange PhD students, full time CSC PhD students). Longstanding collaboration with Charles University in Prague (visiting researchers, postdocs, joint publications). Collaboration with University of Alberta in Canada (joint publications). Domestic collaboration with Wood Science Center, KTH, for wood property enhancement by integration with nanoparticles (joint postdocs, PhD students, publications). (Sytjugov)
- In the field of biosensing, we have long-standing collaboration with Protein- and Gene Technology departments at KTH, with Karolinska Institutet, with Uppsala University and with RISE ACREO research institute. (Linnros)
- Uppsala University magnetism research groups. (Delin)
- Neutron Scattering & SwedNess – Swedish Neutron Education for Science & Society

SwedNess is the national graduate school in neutron scattering. It is a strategic investment for strengthening the Swedish neutron scattering community in connection with the development of the world-leading neutron facility, the European Spallation Source (ESS) that is currently being constructed in Sweden (Lund). SwedNess is a strong collaboration between six of Sweden's strongest Universities, including KTH and Chalmers, along with Uppsala Stockholm, Linköping, and Lund Universities. It is fully funded by the Swedish Foundation for Strategic Research (SSF) where 220 MSEK is allocated (2016-2026) to fund 40 PhD students as well as running/development costs for the school and curriculum. The school is administratively managed from Uppsala University with the operative lead as well as Director of Studies (Martin Månsson) located at KTH, Applied Physics. In total KTH receives approximately 37 MSEK in funding from SwedNess, which includes 7 fully funded PhD students. The graduate school supplies an extensive course catalogue (10 different courses) that is fully open and free of charge for Swedish academia and industry. Here KTH is responsible for 4 of the courses, namely: Introduction to Neutron Scattering, Neutrons for Energy, Neutrons for Engineering Materials, and Neutrons for Magnetism. During the first 4 years, SwedNess has had over 500 registered course participants.

The 40 PhD projects spans a very comprehensive range of science, including life-science, functional materials and engineering as well as fundamental physics/chemistry and magnetism. At Aphys the PhD projects are focused within the areas of sustainable energy materials (Månsson) and quantum magnetism (Weissenrieder). The scientific output from SwedNess is both extensive and high impact (see also www.SwedNess.se), but also, having the operative lead of such a large project centered at KTH/Aphys creates numerous synergy effects and added values for the department as a whole. SwedNess has received a huge attention both within Sweden as well as internationally, and the positive impact from increased visibility and PR cannot be neglected. The PhD students, course program and inherently also the Director of Studies, are frequently refer to by University managements, funding agencies as well as the Swedish Government for national strategies linked to not only ESS but also to large-scale research infrastructures in general. As mentioned, SwedNess includes the 6 main partner universities, but through collaborations the graduate school has additional links to a large number of other national and international partners. This includes both highly respected academic institutions (e.g., ETHZ, EPFL, Stanford, Univ. of Tokyo), industry (e.g., Toyota CRDL, Sandvik, AstraZeneca, RiSE) and of course the world-leading neutron sources (e.g., PSI/Switzerland, J-PARC/Japan, ORNL-SNS/USA, ISIS/UK, ILL/France, ANSTO/Australia, ESS/Sweden). Consequently, the SwedNess ecosystem constitutes a platform for a very comprehensive range of scientific projects and related extensive network within both academia and industry. In addition, this has clearly also become an optimal breeding ground for completely new and extensive collaboration projects in the future.

Altogether, the SwedNess program has had, and will have, a significant and positive impact for KTH/Aphys within several important aspects for a long time to come.

Swedish Neutron Week 2019 organized by KTH and SwedNess (www.neutronweek.se/2019) hosting 120 participants from 32 different organizations (academia, industry, funding agencies, large-scale infrastructures & institutes).

- **KTH/NORDITA/Chalmers/Paul Scherrer Institute/University of Zürich/ESS/DESY:** This collaboration covers technical developments related to both the European Spallation Source (ESS) in Lund as well as PETRA III at DESY in Hamburg. The scientific area is novel quantum materials and involves the development of in-situ uni-axial pressure devices along with the organic materials database (OMDB). The project is financed from several sources including SSF, KAW, VR, Carl-Tryggers as well as by the partner institutions themselves. (Månsson)
- **KTH/AIST/J-PARC/Toyota CRDL/University of Tokyo:** A Sweden/Japan collaboration on sustainable energy materials with partners from both academia and industry (AIST, National Institute of Advanced Industrial Science and Technology + Toyota CRDL). The main focus of this project is sustainable batteries including lithium/potassium/sodium-based materials and devices. (Månsson)
- **KTH/ETH Zürich - Materials and Device Engineering Group/Paul Scherrer Institute:** A Sweden/Switzerland collaboration concerning neutron and muon characterization of nano-structured (particles as well as thin films) energy materials. (Månsson)
- ARTEMI - Atomic Resolution TEM Infrastructure network of Sweden (Weissenrieder)

- Cem4Mat – Centre for Microscopy for Materials Science, Stockholm-Uppsala (Weissenrieder)
- Photoemission consortium at the european XFEL and beamtimes at FLASH (DESY)
- SAXS and WAXS at DESY, Martin Månsson-Stephan Roth
- Joint China-Sweden Mobility. Financed by STINT. KTH- Hefei
- SFC (Svenska Förgasningscentrum). A collaboration between KTH, Luleå TH, Lund Univ for recycling biomass into new chemicals, from biomass to syngas. (Göthelid)

f. Follow up from previous evaluations

The previous RAE2012 resulted in a very positive feedback concerning the UoA as a whole. The societal impact in general and the spin-off part was particularly highlighted. The integration of activities across the UoA was seen as very positive as was the strengthening of core research areas. Much of the work since the last RAE has therefore focused on continuing the already started developments and in particular to join the activities within the UoA into a factual department. This has been a core focus during recent years and has resulted in two divisions (Photonics, Materials and Nano Physics) from the EECS school in Kista being integrated into the Applied Pysics department in 2017. As of May 2020 these two divisions have moved to a new building at the Albano campus and the process of integration and collaboration across the Bio-Opto-Nano domains has thus continued and will continue.

The main weaknesses identified during the last RAE concerned low internal funding, lack of technical and administrative support and an unsatisfactory gender balance. The low fraction of internal funding remains but in the same way as was pointed out in 2012, the department has increased substantially in volume (now >200 people and 275 MSEK) and at least managed to maintained the ratio of 40% internal funding. The administrative support has been solidified and streamlined thus providing rapid and qualified support without generating excessive economic overhead. The technical support has been somewhat improved by the hiring of a dedicated and highly qualified support technician. Technical support is however still an area of concern. The unsatisfactory gender balance remains even though it is improved among younger faculty. Continued work on improving the gender balance remains a focus area going forward together with improved recruitment processes.

3. Viability

a. Funding; internal and external

Growth and join from 2017 of MNF and Photonics units

Growth in terms of people and in terms of faculty

Dependent on external funding. Keeping high quality

The Applied Physics activities are heavily focused on research with 90% of its activities related to research and postgraduate education, and 10% in undergraduate education. Sixty percent of the department’s revenue comes from external grants.

Since 2012 our funding has been increasing roughly 5-10%/year. There is an apparent large increase in 2016 when the groups from Kista (MNF and Photonics) joined the department. The growth is primarily driven by a significant increase in external funding, nearly all coming from sources directed towards basic science and obtained in competition, such as VR, EU, and Wallenberg foundation. The institution is mainly externally funded (MSEK 140 externally and 80 internally) and is heavily dependent on funding from VR, KAW, SSF, EU, STEM, etc. private foundations. The SciLife-related parts of the department also have a relatively large proportion of targeted basic funds, so-called. SFO funds. The institution's large turnover (a total of SEK 273 million budgeted in 2019) and its large dependence on external financing constitute a substantial financial risk. Our worry with the low fraction of the faculty funding remains, the external-to-faculty funding ratio is approximately the same as 2012. However, given the growth of external funding, we acknowledge with some relief that the faculty funding has followed the growth rate of the external funding.

A striking example is KAW's financing of infrastructure. Previously, KAW was responsible for the majority of infrastructure investments at the department but decided a few years ago to completely stop supporting infrastructure investments. VR has also stopped supporting infrastructure and left the responsibility to the universities. At KTH, there is so far only support for a few key infrastructures, which means that most of the research infrastructure currently lacks financial support. The strategic significance and consequences in the next few years will be very large. This example clearly shows the great risks that exist in current financing and how changes in external players can have a very big impact on our activities. Internal control such as SFO funds that are locked to certain people or environments

The department has developed very positively in recent years. External funding has increased substantially and the department has grown by 10% per year over the last 10-year period. After the merge with the Department of Materials and Nanophysics from Kista in 2017, Applied Physics is now KTH's second largest department with over 200 employees and a turn-over of SEK 273 M (2019).

b. Academic culture

Academic culture implies an open exchange of ideas and teaching one-another, as well as open discussions on policies and ethical issues related to research and research practices.

The academic culture is fostered by daily discussions, project meetings and seminars.

Seminars

Each research group/unit has its own specialized seminar series that runs weekly.

Two representative examples of those are:

At SciLifeLab the Biophysics groups have monthly minisymposia, where PhD students and postdocs present “work in progress”. Those are 4-6 15-minute presentations each time, given with an aim to foster cross-group discussions and stimulate spontaneous interaction between students and faculty from the Biophysics groups (7 PIs from Applied Physics are at SciLifeLab). The group is also extended with our affiliated research groups at SU and KI.

The Albanova Nanolab (ANL) is an open access facility that we manage. Our highly successful model fosters new ideas and open engagement. Our Nanolab-seminars that we run every Friday contribute to and take part in fostering scientific exchange and nurturing students.

We also have high quality scientific presentations at seminar series with more general scope such as the Albanova colloquium and the APHYS Thursday seminars, which are important to follow science more broadly. For the latter I am happy that so many of the senior KTH researchers realize the seminars' importance and set an example for the Ph.D. students who often, at least initially, have a rather narrow focus on their own research and research field.

Participation in international conferences and workshops.

Highly fruitful meeting places for presenting and discussing research results and to initiate and germinate science are international conferences and workshops. Often one encounters new ideas and trends there and has the opportunity to discuss about these ideas with the originator, or someone deeply involved with the issue. Virtually all the PIs in the department are involved in technical committees, and chairs at the most important international conferences in their fields. Sometimes, we even host some of these conferences in Stockholm. As a recent example, the group of Prof Linnros organized the IEEE-NMDC conference in October 2019. Prof Toprak is in the organizing committee for the International Congress on advanced ceramics and composites -ICACC series held annually in the USA.

As part of their training, PhD students are always encouraged not only to attend, but to present at international conferences and workshops. There they get to meet prominent researchers in the field as well as create their own network.

Informal meetings

We have a very friendly atmosphere is our department where virtually all of us have open-door policy. Thus, scientific ideas and questions that arise when grabbing coffee are always welcome and enthusiastically followed up.

Videolink and teleconferences are used frequently to collaborate with external partners and to be able to have long discussions with people that is travelling or simply belongs to another university.

c. Current faculty situation

The faculty of Applied Physics consists of 28 professors (3 female +25 male), 3 guest or affiliated professors (1 female+ 2 male), 10 Assoc Prof (4 females +7 males), 1 Ass Prof (male), 42 researchers (12 female + 30 male), and 23 Post-docs (8 female + 15 male), and 83 PhD students (female + male).

Faculty vs Researchers

Since the activities related to undergraduate education are relatively limited, the number of tenure-track teacher positions is relatively low in relation to the turnover at the department. However, the strong external funding for research means that the need for both permanent and temporary researcher positions is relatively large. Researchers with a permanent position are large portion of the department's personnel. (42 faculty, 25 researchers (5 women + 20 men). Of those roughly 10 have duties that resemble those of an Assoc Prof.

The large proportion of permanent researchers is dictated by the need to ensure excellence and know-how on the experimental activities.

We identify a clear need of career development plan for our researchers. For all permanent researchers, KTH should offer a clear career and development plan should be developed. The researcher position should be prestigious and attractive as well as offer possibilities to salary development. In parallel, the department should develop internal strategies for how to benefit researchers' expertise as assets for the whole department.

Faculty balance

The department has relatively few assistant and associate professors and younger faculty, compared with the large number of professors. This can be partly explained due to the fact that almost all the faculty are research active and qualify for promotion to professor after a certain period of time. On the other hand, the department is lagging behind with the recruitment of new faculty and needs to pro-actively work to advertise attractive faculty positions at the Ass Prof or Assoc Prof level in strong research areas.

Given the current promotion system and retirement age, around 10-15% of the faculty should consist of assistant lecturers (if all recruitment is done at this level and the faculty has a sustainable age distribution). The department is lagging behind with recruiting new faculty and currently has only one associate professor in preparation.

Given the current retirement age of 68 years and other known conditions, a total of 8 permanent staff are retiring over the next five years. The coming 15-year period is retired on average 1.2 faculty per year.

Gender Balance

The number of female faculty (tenure-track) has been increasing during the last 10 years and it is now 22%. (At the professor-level is 11%, at the Assoc Prof is 40% and at the Ass Prof is right now 0%.)

For post-docs and researchers, the percentage of female personnel is 35% and 29%, respectively. Of the PhD students, 30 % are female.
Although there has been a gender balance improvement over the last 10 years, the gender balance is far from acceptable. Furthermore, there is a risk of keeping it still unless pro-active measures are taken during recruitment. (see next section).

d. Recruitment strategies

Faculty recruitment

The department shall develop a strategy for recruitment at the Assis. Porf. or Assoc Prof level. At this moment, the process is too slow from start to end (both at the department level and at the KTH-central level), and there is a large risk that the best candidates choose another university simply because they do not get a response from KTH.

In order to make the positions attractive, a good starting package should be offered. The department, together with the school, should work on strategies to recruit excellent female researchers for faculty positions. Otherwise, there is a large risk that the gender balance that we have right now at the assoc prof level becomes an anecdote.

Applied physics should review how the internal institution process for developing subject areas for new faculty services is implemented. At present, the responsibility rests heavily with the research departments who both propose areas and are fully responsible for the new faculty as well as carry out the administrative work with the actual establishment of the service and recruitment. In some cases, there is a need for clearer institutional joint financial responsibility for the first four-year period and support from both the school and the institution in the administrative parts. We are currently working on a strategy at the institution level.

In order to further promote equality and diversity one needs to ensure the applicants cover as broad a spectrum as possible and that requires active and long-term work outside the call opening, addressing also minorities and diversity. A good strategy is to keep that in mind and actively encourage, advise and support good candidates whenever one comes across them (through teaching, our network of collaborators, meetings, even LinkedIn). Even if this does not necessarily mean that you shall succeed in recruiting them to your own group, this is likely to make them apply to available jobs in our department. There is also a cascade-effect, if we manage to get diverse representation in our groups and make people thrive in them, it will be our own PhDs, postdocs & researchers who will "advertise" us and encourage people to apply.

Given the strong development for the research area, Applied Physics intends to recruit on average one to two assistant lecturers (or lecturers) per year over the next few years. Adjusted for retirement, this would mean that the faculty will increase from today's 42 people to about 43 people in 2025. The main focus is to recruit at the assistant professor level, as it has proven from experience to provide very strong candidates who can in a good way adapt their activities to the conditions in the experimental research infrastructure. at KTH, while supplementing and renewing the research. Recruiting younger researchers also leads to better age distribution within the department.

Recruitment of researchers

In order to conduct experimental research at an internationally leading level, laboratories with the most modern equipment and cutting-edge personnel are required in order to make the best use of the equipment. The strong local research infrastructure within the department with its specialist laboratories is a direct prerequisite for successful research. A constant renewal and development of the infrastructure is necessary in order to continue to attract large research grants of the kind mentioned above. Further development of equipment, continuity and implementation of experience made requires permanent staff in the form of researchers or advanced research engineers working in the laboratories, not just doctoral students. In order to meet the growing need for such "intellectual research infrastructure" and to compensate for retirement retirements and other foreseen changes, the department intends to recruit, on average, a new permanent researcher / research engineer every other year.

Recruitment of PhD students and Post-Docs

Recruitment is done with guidance from the HR group who has acquired experience from

many more recruitments than each of us have. They help in writing adds and often take part in interviews.

All positions are advertised on the KTH home page and candidates are selected among applicants. A preferred recruitment channel for PhD students has been courses given on a master level and Master projects. A quick evaluation and providing of the offer is very important. For postdocs/researchers: provide longer contract from the start, at least 2 years, and provide a dynamic, supportive and collaborative environment.

To support gender balance, equal number of women and men are invited for interview, since research has shown that, statistically in the written CV/application men are more likely to "slightly overstate their abilities" while women instead "are more modest". Furthermore, a female contact person will attract more female applicants.

All positions are announced openly and we advertise on European wide sides for example Quantum Flagship. Special consideration is given to female candidates, as there is are unfortunately relatively few women in our field, and women who apply.

e. Infrastructure and facilities

Below we detail the largest infrastructures and facilities that the department houses as well as some national infrastructures to which we contribute. Research infrastructure is at the core of the departments activities and is sometimes even the raison d'être. Considerable resources are necessary to develop, maintain and run the infrastructure. Within the current financing situation where dedicated infrastructure financing from external sources such as VR and KAW has been terminated it has become increasingly difficult to maintain and develop research infrastructure. This is particularly the case with our spear head laboratories. The central KTH facilities now receive some funding for investment in new infrastructure but there are no such funding available for the spear head laboratories that constitute the vast majority of our infrastructure. A measure of the necessary investments to maintain the infrastructure is given by the yearly write offs. During 2019 the write offs at the department amounted to 18 MSEK. In view of the current difficult funding situation which has resulted in lagging upgrades and limited development this figure is certainly lower than what is needed to keep the infrastructure at the international forefront. A more realistic number is probably closer to 25 MSEK but a thorough evaluation and cost estimate would have to be done on the laboratory level to give a proper estimate of the investments needed.

Spearhead labs

BALTAZAR.

BALTAZAR is a world unique facility for tr-ARPES (time resolved angel resolved photoelectron spectroscopy). The laboratory is currently being moved to the new Albano location and in connection to that being upgraded with a completely new light source and extended with new thin film growth capabilities. The goal is to approach the transform limit in the versatile combination 50-300 fs time resolution with an energy resolution of 35-5 meV. The targeted photon energy is 6 - 40 eV and the pump wavelength 0.6 - 9 micron. The pulse repetition rate will be ≥ 250 kHz for the complete energy range in order to allow for sufficient count rates. The XUV pulses are generated through High Harmonic Generation (HHG) in a high-pressure gas jet.

UEM. Ultrafast electron microscopy.

Jonas Weissenrieder contributed to the construction of the first generation UEM and published the very first results using time resolved UEM. UEM combine ultrafast lasers and TEM to facilitate atomic-scale spatial and femtosecond temporal resolutions. The KTH UEM is the only such microscope in Sweden. Since, information may be gathered by real-space imaging, Fourier-space diffraction, and energy loss spectroscopy, UEM offers abundant information for the study of transient processes. With imaging electron energy loss analyzers in the UEM, it provides information of changes in the electronic structure, directly correlated with changes in atomic structure.

Matslab. Two scanning tunneling microscopes (STM) with sample preparation in UHV and Raman spectroscopy.

The **FNM** group runs a complete lab for synthesis, characterisation and testing of nano materials. The lab also includes one SEM with EDX.

Bio-sensing and advanced optical characterisation. Electron beam lithography, chemistry lab facilities are combined with advanced optical characterization tools. A “biosensing lab” has been set up for handling biological samples, microfluidics and electrical instruments for multiplexed sensing.

KTH central infrastructure

During recent years, KTH has established centrally supported research infrastructures. The applied physics department has three of these infrastructures which are described below.

The Albanova Nanolab

The Nanostructure Physics group, with a very active participation by the Quantum-Bio-Photonics, Biomedical Physics, Laser Physics, and a number of other groups at KTH, SU, and elsewhere in the Stockholm region, run the Albanova Nanolab (director prof. Korenivski). ANL’s mission is open and fair access to frontline research infrastructure and technical support for fabrication and characterization, with nanometer scale precision. The Lab is regionally unique, benefiting the high-tech environment in and around Stockholm and thereby the economic and societal development of the region. We are planning a substantial expansion of the lab to support emerging quantum technologies. Such expansion would lay a foundation for future high-tech growth in the Stockholm region. ANL is a member of the National Swedish Network for micro- and nano-fabrication MYFAB. (see below)

Nano electronics and photonics, quantum optics, quantum computing, nanomaterials, and many other activities currently advanced using the Albanova Nanolab, are important for the Stockholm region to stay competitive in the global knowledge society of today and tomorrow. Academic research at the cutting edge of science and technology moves very fast, with new directions emerging every year. It is important that the relevant infrastructure provides enough flexibility to accommodate to these rapid changes and adapt to conditions that change as new grants are secured and new research directions emerge. The scientific agenda of the Nanolab is user-driven; our vision is to act as a conduit for collaboration on expensive infrastructure that can be shared by many users and to provide an atmosphere that fosters such collaboration.

The KTH laserlab

KTH Laser Lab is a KTH Research Infrastructure established at the Department Applied Physics, comprising well-equipped labs with a broad variety of lasers, coherent sources and necessary instrumentation. It is an open facility available for users from KTH, external partners and the industry. As partners in Laser-Lab Sweden we maintain an extensive national collaboration network, and we get access to any necessary additional equipment and qualified support to meet existing needs and challenges. https://www.kth.se/sci/2.14290/aphys/kth-laser-lab

The advanced light microscopy infrastructure

The Advanced Light Microscopy (ALM) Laboratory is a KTH research infrastructure at Science for Life Laboratory. ALM provide access and user support in light microscopy. The laboratory is one of the nodes in the national microscopy infrastructure and also a member of the european infrastructure EuroBioimaging.

At ALM the following techniques are available:

- STED microscopy
- STORM/PALM microscopy
- SIM microscopy
- Light sheet microscopy
- FCS

National labs

µFab network - The Electrum lab and Nanolab at Albanova.

Electrum Laboratory and Albanova Nanofabrication Facility are the two laboratories operated within the KTH node of Myfab. In Kista, the Electrum Laboratory is outstanding for fabrication and characterization of devices based on Si, SiGe, GaAs, InP, GaN and SiC for electronics/photonics/micro-mechanics in the nano and micro scale. Electrum Laboratory supports also the whole chain from education, research and development, to prototyping and production. The Electrum Laboratory is certified according to the international ISO 9001:2015 Quality Standard. It is also certified according to the international ISO 14001:2004 Environmental Standard.

HVPE is the key infrastructure for development of high performance optoelectronic device structures. The HVPE reactor itself is unique in the world and can produce III-V epitaxial materials at high growth rate with high selectivity. Swedish, EU and international projects collaborating with industrial partners (Intel, III-V Lab, Thales, MIRSENSE) were implemented by this HVPE. The reactor was installed in 2017. In order to extend the lifetime and keep KTH's leading position in this field, reactor upgrading is required, which needs 3-4 MSEK in 2020.

Infrastructure for Spark-Plasma-Sintering at SU. This is a national infrastructure.

Large-scale Research Infrastructures

Sweden is currently making unprecedented investments in large-scale research facilities for advanced materials characterizations with the development and construction of the European Spallation Source (ESS) and the MAX IV synchrotron. Here Aphys and especially MNF are undoubtedly the strongest KTH user group of both X-rays (ESRF, SPring-8, SLS, PETRA III/XFEL, SOLEIL) and neutron/muon sources (ILL, ISIS, J-PARC, SNS, PSI, TRIUMF) around the world. Here our department is running a very wide and high-impact scientific program, covering quantum materials, energy, catalysis, biomaterials, superconductivity, magnetism, surface science and topological states. Finally, the department is also highly involved in technical developments at several of the facilities including ESS, MAX IV, PSI and DESY. This makes Applied physics one of the most active large-scale research departments in Sweden, and in specific areas, in the world.

Computing infrastructure: we depend on the SNIC facilities. Smooth functioning of the computing resources, and access to application experts and research engineers is vital.

Additionally, we have several specialized laboratories, A World-unique multi-mode scanning near-field optical microscopy set-up that combines a near-field microscope and ultrafast laser that allows simultaneously scanning crystalline, optical and electronic material properties with high spatial and temporal resolution. The PolingLab is a specialized laboratory for periodic poling of ferroelectric crystals and in the Glass laboratory 3D printing of glass and UV inscription of gratings and waveguides take place, as well as femtosecond laser surface micro-structuring. In the Fiber lab multifunctional fiber components are put together from various micro-structured fibers.

4. Strategies and organization

a. Goals for development 5–10 years ahead

Applied physics is a department with great drive and momentum, which benefits greatly from the interdisciplinary environment. The department conducts experimentally oriented, multidisciplinary research within the "Bio-Opto-Nano-Quantum" area and the combination of basic research and entrepreneurship has been very successful. We have internationally leading research groups collaborating on multidisciplinary projects, taking the results all the way from basic science to applications and spin-off companies. We have 120 PhD students engaged in a broad, active and productive research education. We also have a strong engagement in undergraduate education, with many specialized master courses connected to our research areas and 20 basic physics courses with labs for nearly all engineering programs at KTH.

Our vision is that Applied Physics continues to be an internationally renowned research institution within our core research areas and that the department continues to play an important role for developing and providing high quality physics education at all levels at KTH.

For the next 5-10 years the department will continue to focus on current core research areas, keep and strengthen its internationally leading position within the special areas of the respective research groups and integrate to exploit the department's unique combination of multidisciplinary competences and collective resources to address even more complex research questions.

Focus: The "Bio-Opto-Nano" area is still only at the beginning of its development potential. Scientifically as well as industrially we foresee a significant growth both nationally and internationally. The EU Quantum Flagship (1 bn EUR, 10+ years) and the national Wallenberg Centre for Quantum Technology (1 bn SEK, 10+ years), both funding programs started in 2018, are illustrations of this growth and examples of areas where Applied Physics is playing an active role. The department is therefore well positioned from this standpoint and we will continue to focus on our core research areas.

Keep and strengthen: The research within the divisions' special areas is generally on a very high international standard and attract substantial external research funding. To further strengthen the research within our core areas, strategic faculty renewal and recruitment, with gender balance and diversity in mind, is crucial. To be able to attract and recruit top faculty members of the future we need to be able to offer attractive conditions. We see that relevant starting packages as well as stable long term funding for new positions is important. Possibly this is even extra important to recruit excellent female researchers with competing offers from other international universities.

Experimental research at an internationally leading level also requires laboratories with the most modern equipment and highly qualified staff to make the best use of the equipment. The strong local research infrastructure within the department with its specialist laboratories as well as our KTH research infrastructures is a direct prerequisite for successful research. The lack of funding agencies for local infrastructure is the major threat to the department. Substantial KTH-support for not only the currently established KTH research infrastructures, but also for specialized labs and equipment, is essential. The KTH leadership must take the responsibility to redistribute more of the internal research funding to specifically support experimental research. Otherwise, much of the excellent research and teaching based on local laboratories at KTH will (slowly) vanish.

Integrate: Maintaining a world-leading activity in experimentally oriented, cross-disciplinary research and education, requires a constant pursuit of improving and integrating the scientific environment. This applies to both the intellectual and laboratory environment. Central to the environment are the department's three KTH infrastructures: *NanoLab* located in AlbaNova, *Advanced Light Microscopy* at SciLifeLab (both established) and *KTH Laser Lab* at AlbaNova (interim).These are already well-functioning central facilities that serve not only KTH but the entire Stockholm area. Furthermore, our specialist labs attract many external users, both national and international. In addition to access to first-class equipment, these various laboratories are natural meeting places where new interdisciplinary ideas are born.

We want to further develop and strengthen our open laboratory environment. As far as possible, we will continue our efforts to organize the department's equipment and laboratories as joint research infrastructures open to all at KTH and to external users. In addition, Applied Physics has the opportunity to take the integration process one step further, now that the research divisions in Kista finally moved to the new AlbaNova building in May 2020. The new building also helps to relieve the acute office and lab space shortage experienced by some divisions located in the original AlbaNova building.

b. Congruence with university-level goals for research as set out in "A leading KTH - Development Plan 2018-23" and with the school(s) development plan(s) respectively.

The department's goal of conducting world leading, cross-disciplinary, applied research within an field with almost unlimited applications to many of today's societal challenges, is perfectly aligned with KTH:s goal of a leading, international university as well as the development plan for research for the School of Engineering Sciences. Our intention of taking our research results all the way from basic science to applications and collaboration with industry partners, as well as our open research infrastructures, contributes to a visible, integrated and open KTH. Applied Physics is very much a diverse environment, with more than 60 % of the employees having an international background, and the objective of the department is always to give equal opportunities to all.

c. Leadership structure and collegial structure

The department is formally divided into seven divisions. The department has a head of department and two vice heads. The work load of leading the department on a daily basis is shared between the “Prefektteam” members where each person has an area of responsibility but important questions and decisions are handled by the group. Each of the divisions have a division head and a vice head. The division heads together with the department heads form the management group of the department. All major and long-term decisions made at the department are brought up at the monthly department management meetings. The management group also contains representation from the PhD students and the young faculty group as well as the director of graduate education, the director of undergraduate education and the head of the local administration.

A guiding principal of the department organisation is to delegate the authority and responsibility to take decisions at the level that they concern i.e. the divisions have substantial autonomy to manage their economy and personnel. This means that all internal funding is distributed to the divisions and the use of the funds are entirely decided at the division level. All non-permanent staff decisions are also taken at the division level and only permanent staff recruitment is handled at the department level. The formal management structure goes hand in hand with the leadership structure for research. The choice of research topics and research direction is to a very large extent done at the division and group level even though the heavy reliance on external funding in practice means that the external funding agencies are setting the research agenda. The very strong focus on experimental research and method development at the department requires large amounts of infrastructure which in turn is costly and requires large external grants. This has at least to some extent both driven collaborations around available infrastructure but also been an incentive for cross division and cross disciplinary research thus created a collegial structure of interchange, sharing and cross fertilization. This collegial structure is also manifested in and enhanced by common activities such as the Aphys day and the Aphys seminar series. A testimony to the effectiveness of this collegial structure (more than the formal structure) is the large number of KAW project grants that the department has received.

d. Strategies for high quality

The applied physics department’s activities are to 90% research. The department’s faculty live and breathe research and have high quality research as the leading star. For most, the daily focus is on research success. The breakthrough result is what everyone is working for. In an applied project this can be a goal stated from the beginning but in many areas it is not even obvious what it will look like and part of the skill of high quality research is to learn how to recognize an important result when it shows up. Many measures of high quality research can be put up in terms of publications in leading journals, obtained research time at large scale facilities, external grants, invited talks a top conferences, appreciation from colleagues, interest from colleagues, spin-offs, patents etc. Using these measures with caution can give an indication as to the quality of the research and the department monitors these indicators to pick up positive as well as negative change. The derivative being more important than the current value as in most circumstances. The use of these indicators in the department quality strategy comes in both at the management group where they are discussed as well as at the division level during the regular division meetings. The topic is also reoccurring in the yearly development conversations.

The formal verification of research result published is through peer review as has been the tradition for a long time. The department has no formal internal review process of results before publication nor is there a plan to implement such a process. Accidental mistakes in research is best spotted by experts within the field and deliberate fraud is in general also difficult to spot. It would be highly burdensome and also detrimental to the internal culture to try to implement internal quality and fraud checking protocols. Instead, the department focuses on fostering a high quality culture including research ethical behaviour. Considering the high and ever increasing internal as well as external publish or perish pressure, the department leadership intends to increase the awareness around these issues.

It is on the other hand important to realize that high quality research is mostly something connected to training, talent and an almost unstoppable personal drive. Most highly successful researchers have a very strong focus and self-motivation for their work. As a result, the key to high quality research lies in recruitment and training much more than in internal documents, plans, procedures and checks. The main strategy for high quality is therefore to recruit the best possible researchers and have them train the most talented and best motivated PhD students and postdocs that we can find.

5. Interaction between research and teaching

a. Interaction between research and teaching at all three levels (BSc, MSc, PhD) of education

The department has courses at the three levels of education.

BSc level:

The Department of Applied Physics teaches a large number of basics classical physics courses for different programs at KTH. A common content for all courses is electromagnetism and optics, and much of the department's research is in these areas. Many of these courses include also labs, since we want to introduce the students to experimental and applied physics. About 800 students per year attend these labs. A majority of the teachers in our basic courses are active researchers, moreover, many PhD students are involved in the teaching as lab supervisors or calculation excise leaders.

MSc level:

Our department is involved in two Master programs: Engineering Physics and Nanotechnology. We are responsible for three tracks (i.e., study specialization) in the Engineering Physics Master program, and one track in the Nanotechnology Master program. Here we teach about 60 different courses, which are often very specialized and reflect the research interest and activities of different research units. Teachers are active researchers in the field and develop their courses continuously in order to include the newest research trends. An example for this is the development of a track previously called "Nanotechnology" into a new track with the name "Applied Quantum Physics" in order to reflect a new strategic research area on Quantum Technology in our department. Courses have normally about 10 – 20 students and often include some lab work within our research labs. We also offer "project courses", which are very popular. In this course, the students can work individually on a real research question with an individual supervisor in one of our research groups. Finally, about 20 – 40 students each year choose a group in our department for their Master thesis. Here the students become active members of a research group and work on relevant projects, which often result in a publication.

PhD level:

Teaching at research level is made for the students within projects at the department and courses are designed especially for them. There is a very close connection between doctoral education and research.

The Department of Applied Physics hosts one doctoral program ”Applied Physics” with two education subjects; Physics and Biological Physics. At present there are ca 120 students active within the program. The average study time is just a little over the stipulated 4 years. The connection between research and education on PhD level is very close. The doctoral education consists of two parts: research training and courses. The research training is, without any exception, done within a research project, normally funded by external grants earned in tough national competition. Here we really feel that the research interests of the faculty is a perfect ground for teaching the graduate student the tricks of the trade. In addition to the individual and daily/weekly advisor/student contacts the graduate studies are guided by the study plan. This plan is revised annually in a formal advisor/student meeting and then accepted by the dean of graduate studies. The student carries a large part of the responsibility for the progress of the project resulting in publications, patents and new discoveries. A minimum of four publications is required to earn a PhD, but the average is between 6 and 7. The quality of the work is of high international standard set by the research journals. The course package contains more than 50 courses delivered by the research groups. There is a continuous renewal of the course list to ensure quality and relevance for students within the program.

It is worth mentioning that we have a mandatory course for all our students on “Width and Ethics in Physics” 7.5 credits, that covers among other things, research methodology and ethics, the peer-review system, and gender-equality mainstreaming. Futhermore, the doctoral students are organized have a PhD council that serves as a network and gives feedback to the program regarding course content, program structure, etc.

It is worth mentioning that our department is also highly involved in the Swedish national graduate school for neutron scattering (SwedNess). This is a wide Swedish collaboration between KTH, Uppsala University, Stockholm University, Linköping University, Chalmers and Lund University. The school holds 20 (and soon 40) fully financed (SSF, 220 MSEK) PhD student projects within a broad scientific scope covering life-science, functional materials and engineering as well as fundamental physics/chemistry.

6. Impact and engagement in society

a. Relevance of research to society at large

The most important impact on society is the people we educate. We pride ourselves in educating independent and self-reliant PhDs with a broad knowledge base. They have the basis for to setting the agenda based on facts and visions. To date 75-80% of our PhDs have continued their careers in industry. We expect that our PhDs will be equally attractive for industry also in the future and that the fraction will remain equally high, thereby helping to renew industry and to keep its technological edge.

We do mainly engineering science, with a 10-20 year time perspective. That means that if the projects are successful, we hope to see them fly outside our department in 10-20 years.

Our research within the BIO area has as ultimate goal to generate knowledge that support, stimulate and drive development of new treatment strategies for human diseases. The ultimate goal is thus to improve health and to generate benefit to mankind both by wellbeing and by well understanding life. A simple example of this can be the research conducted by **Lundström** and **Unsbo**, which is important to optometric and ophthalmic industry manufacturing spectacles, contact lenses and intraocular lenses. Optimum design of these products is beneficial for the young generation to reduce the progression of myopia and for the older to improve their remaining vision. Another example is the technology developed by **Widengren** which Strategically, ultrasensitive and ultrahigh resolution fluorescence spectroscopy/microscopy is a key technology for fundamental biomolecular and cellular studies, and also for clinical diagnostics, biotechnology and drug development. As an expert group in the field, we can strongly promote neighbouring biological and biomedical research areas by interdisciplinary collaborations, stay updated, and actively contribute to the technique development. From a national point of view, with respect to both basic science and commercial interests, it is very important that leading competence in this field is maintained within Sweden, is independently supported, and further developed. By developing new imaging systems, The Testa group constantly enable new science by allowing better observation. The new images can foster biomedical studies from basic to more clinical studies. Our systems are constantly used in collaboration with biologists and medical doctors to achieve a molecular understanding of sub cellular processes such as memory formation and metabolic dysfunction in the brain.

Delemotte's research is at the basis of structure-based drug design, understanding molecular basis for function and modulation of membrane proteins is key to successful structure-based drug design.

Energy/environment/sustainability/health are the most important scientific/societal problems of our time. Almost all our research has its origin in those societal needs and technological developments; smarter materials and more efficient processes. Even though some of our work is not directly useful in an industrial setting, the potential applicability is always clear in our research.

Research on renewable energy (solar cells, hydrogen, blue energy, thermoelectrics), energy storage and fuel cells are of direct relevance to modern society and has implications on both photovoltaic industry as well as in smart integration in the built-environment where aesthetics has to be combined with energy efficiency. (**Dutta, Anand, Månsson, Sun, Doss, Göthelid, Weissenrieder, Sytjugov, Toprak**)

We have developed key water technologies including removal of ions, microplastics, arsenic, microorganisms and/or prevention of these contaminating the resources is key to our societal relevance. (**Dutta**)

Another area where impact on new technologies is expected to be high in coming years is quantum technologies (**Gallo, Zwiller, Haviland**). Right now, we are in a transition time when the technology for manipulating and measuring a single atom, ion, molecule, or photon has reached the stage to transit from research labs to industrial applications. This has certainly been noticed on the international level, with related large investments in Europe, USA, China and Japan. In Sweden the WACQT-program is a national manifestation of this fact. This program, with its important node at KTH, will serve as a vehicle to train quantum engineers and transfer know-how and technology to (mainly Swedish) industry.

We perform research, which will be crucial to develop secure communication, based on the laws of quantum mechanics. Quantum communication will protect our society of eavesdropping, enable secure digital authentication. We are currently working together with Eriksson AB to build a test-bed quantum link between Albanova and Ericsson lab in Kista (**Zwiller**).

In the last decade, the impact of optics and photonics has been extraordinary in most fields of science and technology, https://www.photonics21.org/ . Several of our national funding agencies are specifically focusing on the usefulness of science and the possibilities for exploitation. Our department has a strong tradition in work along these lines through collaboration with leading industries and we have successfully spun out several ideas in start-up companies, mostly with help from KTH Innovation and Stockholm Innovation and Growth (STING). We work extensively with RISE, (Research institute of Sweden) who almost exclusively work in projects related to Swedish industry and government institutions. Financed through SSF we have had **Michael Fokine** working 50% of his time at Northlab Photonics AB implementing one of his inventions in their products. The group has key contributions to the establishment of laser technology in Sweden. Almost all (>85%) of former students are working in industry at leading positions, mostly in the fields of optics and photonics, close to 30 % are women.

For instrument-oriented research, it does not matter how much you talk – true impact comes when the many use our tools to improve their processes. That means that the tools need to be made available to the world – which requires an industrial engagement. This also provide the real test on the value of your ideas – do people out there want to pay for it?

Therefore, commercialization is a prime tool for impact and several of the developments made at the department have been commercialized. Examples are Excillum (X-ray sources), Cobolt (Lasers), Intermodulation Products (AFM) and Single Quantum (Photon detectors).

We work on new pharmaceutics to treat (colorectal) cancer (Vinnova project, with a company – Oblique therapeutics – SLU and Karolinska). From the longer term perspective, we expand into Optical Quantum Sensing for advanced biomolecular and environmental studies (VR Res Envir); applications of nonlinear and quantum LN nanotechnology for better (faster), lower-energy-consumption communications and sensing

b. Research dissemination beyond academia

Impact on dissemination

We support and encourage contacts with journalists in traditional media – newspapers, TV, and radio. Good opportunities to reach out were given at the Nobel Price 2014 (super-resolution microscopy) and 2017 (cryo-EM) when radio and TV made interviews at SciLifeLab.

Several groups are also active in social media (Twitter and Instagram), as a mean to easy reach out beyond the traditional audience, this is particularly attractive for imaging based research where the images can convey appaling messages (or just be beautiful).

We also actively encourage science teachers (via personal contacts) to bring their students and visit the laboratories. (The microscopy infrastructure at SciLifeLab has recently applied for a VR grant to give access for schools to the infrastructure).

Lundström: Joint white-paper publication to the stakeholders in myopia-prevention (e.g. clinicians and politicians). Popular science presentations to ophthalmologists, optometrists and patient organizations on the importance of proper optical correction also with age-related macular degeneration (generally thought to be of less importance).

Prof. Viklund: Contributions to the public debate about safety in using ultrasound technology in medical engineering and biotechnology. He is continuously using his expertise for teaching purposes, such as radiology nursing and sonography clinical programs; workshops for medical doctors and for ultrasound technology companies (including engagements in ultrasound technology companies in Sweden and USA).

Prof. Dutta have been very active in contacts with high schools having arranged full-day visits of in total 180 students from a local high school. 7 of those did their high school degree projects at the Functional Materials group. More than 65% of those students were girls. This is the way to improve gender balance in technical sciences.

Prof. Björk appears frequently in the Swedish media. He contributes quite often to newspapers, Swedish Radio and Swedish television, about research and technology pertaining to quantum optics and related fields. Through Vetenskapens hus he engages with students aged 13-18, in the hope that they will become attracted to science and technology.

Prof. Gallo reaches out to high school students in Sweden and, in particular, to girls via e.g. Lise Meitner's lectures, mentoring every year two RAYS high school students, and doing other activities. We are planning to do more press releases, highlights for industry, and other dissemination activities, in partnership with Chalmers (for WACQT) and EU consortia (MICROCOMB).

Prof. Korenivski teaches two large, net-based, nation-wide courses on Modern Physics and Environmental Physics, running in both Fall and Spring, which is another way to disseminate and promote science as well as sustainable development. The student audience is as diverse as the society itself – students of all backgrounds, schoolteachers, engineers, retirees, managers, artists, diplomats, and even inmates.

Prof. Laurell is a co-founders, and **Prof. Canalias** a board member, of PhotonicSweden, the national platform in Photonics, that includes all leading universities and more than 50 companies in the field. Together with them we arrange evening lectures once a month, open to the general public. We were the local organizers of the International year of Light events (http://www.light2015.org/Home.html) and the celebration of Lasers 50 years (http://www.laserfest.org/). We have participated in several national radio and TV programs and debates, related to our research, the Nobel prizes and others (see for example https://www.iva.se/en/tidigare-event/the-future-is-light/). **Prof. Laurell** is heading the division for Basic and Interdisciplinary Engineering Sciences at the Royal Swedish Academy of Engineering Sciences.

Prof. Pasiskevicius has written a Popular science article on pioneers in Raman lasers for World of Physics. We have been involved in writing whitepapers for policymakers at EU agencies (ESA, EDA and EU commission) on the status of European non-reliance in key mid-infrared technologies.

c. Sustainability and the United Nations' Sustainable Development Goals (SDG)

Ca 80% of our research is related to sustainable development. Research on materials for solar cells, batteries, hydrogen production and storage, waste heat harvesting, LEDs and fuels cells directly relates to SDG7 (Affordable and clean energy) and SDG13 (Climate). The research leads to more efficient energy harvesting, storage and use. New materials are non-toxic and earth-abundant. Spintronics and spincaloritronics are technologies that use much less power than conventional electronics. Integration of photo voltaics in buildings targets SDG 9 and 11. Research on bio-medicine addresses SDG3.

Access to clean water is a key to peace and development. One of our objectives is to devise tools to decentralize water treatment and water re-use, and demonstrate how it can be done safely and sustainably, considering the social, environmental and economic dimensions. This works addresses SDG1 (ending poverty), SDG17 (international partnerships). Without water, food would be scarce (SDG2). Without clean water, maintaining health is doubtful (SDG3). Gender aspects (SDG 5) are intertwined with water across cultures and SDG6 deals with drinking water and sanitation. The list also includes SDG7, SDG9 (industry and innovation), SDG11 (cities), SDG12 (consumption), SDG13, SDG14 and 15 (ecosystems in the ocean and on land) and SDG16 (peace).

Sustainability and green chemistry aspects are integrated not only to our research but also to the educational programme (several courses taught in Nanomaterials and Chemistry) addressing SDG4.

Some examples of recent projects with clear SDG focus:

- 2 projects on III-V solar cells and 1 on LEDs from the Swedish energy agency.
- 2 projects from the Swedish energy agency to develop Si based multi-junction solar cell.
- Project on development of hybrid thermoelectric materials and devices (FET-OPEN, H2020)
- Project on the development of quantum-limited resonant mechanical force sensor for AFM (FET-OPEN, H2020)
- Project on project on building-integrated photovoltaics (Swedish Energy Agency). It is run together with a commercial company (Mercene Labs AB).
- Advanced nano-therapy and diagnostics (biomolecular sensing)
- Project on compact and low cost LIDAR system applied to CO_2 monitoring (with Lund University) as well as OPO system for global CO_2 monitoring (in EU project)
- Optical powering and communication system for grid control of wind mills

d. Impact cases

Case 1) Excillum and Exciscope: *X-ray start-ups from Biomedical and X-Ray Physics*

Summary of impact:

Excillum started 2008 and is now a profitable 65+ person company with a turnover of >130 MSEK/y and 30+% annual growth. It builds and sells liquid-metal-jet and other high-end microfocus x-ray sources, inventions coming from BIOX (cf below). More than 130 sources are in operation world wide (still not Africa and Antarctica). It is presently primarily an OEM

product for x-ray scattering, diffraction and imaging. Customers range from research institutions to the semi industry. Excillum aspires to be the global leader in high-end x-ray sources.
Exciscope started 2020 and received its first round of financing in September 2020. Exciscope will build and sell high-resolution phase-contrast x-ray imaging systems, in particular for low-Z (soft) materials, building on our extensive research experience with such imaging. The system offers a unique combination of speed, resolution and contrast and aims to put x-ray imaging into the hands of new industrial settings (food, packaging, histology). It is presently building its first in-house system and hopes to have its first orders within the next 12 months.

Both companies were started by Hans Hertz and teams of PhD students that did the underpinning research. For Excillum they were Oscar Hemberg, Mikael Otendal and Tomi Tuohimaa and for Exciscope William Twengström, Jakob Larsson and Jenny Romell.

Underpinning research

Excillum: Not much had happened to x-ray sources since 1929 (rotating anode) when we came up with the liquid-metal-jet-anode concept year 2000 [1,2]. The invention was stimulated by our previous research in soft x-ray liquid-jet laser-plasma sources, the transition of our community toward higher energies, and the insight that the source was the limiting factor in much of x-ray imaging. The following years three PhD students (first Oscar Hemberg and then Mikael Otendal and Tomi Tuohimaa) investigated the source and also did the first phase-contrast imaging [3,4]. Excillum started 2008.

Exciscope: When Excillum was out the door, we returned to our original interest and the original motivation for the liquid-metal-jet invention: biomedical imaging. Here we soon tried phase-contrast imaging using the new source on a wide range of samples (kidney, mice, zebrafish, biopsies, mummies [5-8]), starting 2011. The key observation was that we could achieve cellular- and sub-cellular-resolution imaging with reasonable contrast, first proved by W. Vågberg, now Twengström. Jenny Romell refined the system for different applications and Jakob Larsson joined the team with his background in x-ray fluorescence imaging systems. Exciscope started 2020.

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Sources to corroborate the impact:

Excillum: See www.excillum.com. See user's stories, world-wide sales etc etc.

Exciscope: See www.exciscope.com. Significant funding raised but still too early to judge commercial success. Please come back in a year!

Case 2) Supercapacitors clean water

Summary of the impact

Access to safe water is a fundamental human right but our world is fast running out of fresh water supplies. The world is facing a growing shortage of fresh water sources due to climate change and resource depletion. The policies and strategies adopted by governments across the globe to conserve water resources and to improve clean water availability has made water treatment a multi-billion-dollar industry. There is a constant push to improve the currently used treatment technologies to enable water re-use and make the water treatment processes more energy, cost and water resource efficient. Reverse Osmosis technology is by far the most predominant one in the market but has significant drawbacks in terms of water recovery and energy requirements. The core contribution has been in developing flexible electrode based devices using three electrodes instead of the classical two electrode systems in standard electrochemical cells leading to enhanced charge efficiency of ion removal. This membrane free and modular concept developed by Dutta can potentially lower application specific costs and real estate requirements offering lower CAPEX that will make it possible to assist the needs of even impoverished people across the globe. The concept of this water cleaning device is to provide single technology to provide safe and controlled salinity drinking water to recycling industrial and municipal waste water- somewhat like the office 365 of water treatment.

Underpinning research

The focus of the research was to build cost-effective membrane free water treatment solution using the super-capacitor concept. This research has led to a device to efficiently clean water through sustainable, chemical-free, reliable and cost effective systems to care about the well-being and health of millions. The solution is a unique membrane-less capacitive deionization (CDI) system that is efficient in removing dissolved ions from water using a novel three-electrode configuration to reduce power consumption and improve operational flexibility. Capacitive Deionization (CDI) is an electrochemical technology for removing charged species like ions of salt from water. Fundamentally it works on "capacitive ion storage", a phenomenon where in response to energy applied as voltage or current across CDI electrodes, ions of salt are accumulated and stored capacitively as electrical double layers (EDL) at the surfaces of CDI electrodes (similar to a capacitor or battery). Since the accumulation of ions is dominated by physical phenomena (no chemical reaction), it is a reversible process with systems based on CDI technology being characterized by low energy requirements, reduced maintenance and a long service life. Furthermore, Dutta's research on membrane-free process of deionization leads to lower fouling of electrodes and the simple design of the device (rolled up supercaps using flexible carbon electrodes) allow low-pressure operation and the technology is scalable and solar power driven process to treat required quantities of water simply by adding multiple devices like a "LEGO" for sustainable water treatment in circular economies. Furthermore, the electrodes when modified with "redox-couples" can lead to advanced oxidation processes- leading to new applications in the energy-water nexus. The research addresses United Nations (UN) development coals namely, SDG 6.1-6.4 for sustainable drinking water provision to populations, reduction in production costs, water consumption and treatment costs (SDG Targets 8.2 and 8.4), eventually contributing to poverty reduction (Goal 1 and 8) and improving health (Goal 3). Appropriate technology for future clean water provision can address vulnerable societies (SDG 11) while safe and clean drinking water will reduce preventable deaths among children (SDG Target 3.2).

Currently three PhD students are working in related projects, one focusing on electrode modification for enhanced operation (Esteban Alejandro Toledo Carrillo), another of water oxidation (María Isabel Alvarado Ávila) while the third student is focusing on modeling of these devices (Johan Nordstrand). A post-doc is dedicated to develop metal-organic-framework structures for enhancing ion exchange during charging and discharging of the capacitor (Xingyan Zhang).

Some illustrative publications from the group in this area of research over the last two years are:

10. Desalination 500: 114842 (2021), https://doi.org/10.1016/j.desal.2020.114842; Journal of The Electrochemical Society 168: 013502 (2021), https://doi.org/10.1149/1945-7111/abd82f;
11. Cleaner Engineering and Technology 1: 100016 (2020), https://doi.org/10.1016/j.clet.2020.100016;
12. Joydeep Dutta & Karthik Laxman Kunjali, Patent US20200180982A1, June 11, 2020, https://patents.google.com/patent/US20200180982A1/en
13. Frontiers in Chemistry 8: 774 (2020), https://doi.org/10.3389/fchem.2020.00774;
14. Electrochimica Acta 358: 136939 (2020), https://doi.org/10.1016/j.electacta.2020.136939;
15. Journal of Physical Chemistry A 123(30): 6628-6634 (2019), https://doi.org/10.1021/acs.jpca.9b05503.
16. Desalination 449, 111-117 (2019), https://doi.org/10.1016/j.desal.2018.10.021
17. Joydeep Dutta & Karthik Laxman Kunjali, Patent SE 540976, Feb 1, 2019, https://tc.prv.se/spd/pdf/AKEGQhRp2qfWS3oljenFlQ/SE540976.C2.pdf

Sources to corroborate the impact

Johan was nominated by KTH and selected for the 9th edition of the Global Young Scientists Summit (GYSS) which was held virtually on 12 – 15 January 2021. Dutta was selected amongst 50 other research projects for IVA project Research2Business, R 2B, by the The Royal Academy of Engineering Sciences (IVA).
https://intra.kth.se/sci/skolinformation/interview-with-johan-nordstrand-1.1044299

https://www.iva.se/projekt/research2business/ivas-100-lista-2020/nanowater/
https://www.kth.se/water/about/news/kth-water-research-in-the-iva-100-list-1.963511
Two Patents have been granted (SE Patent 540 976 C2; WO/2018/234386). The PCT patent has been extended to country specific applications in the EU, USA, India, China and GCC for further exploitation by Stockholmwater Technology AB (SWT), which is a spin off from this research. SWT where Dutta is the chief scientific advisor, has started commercial production and has customers in Sweden, Austria, France, India and Saudi-Arabia.

https://www.kth.se/en/om/innovation/om/nyheter/kth-bakom-17-av-sveriges-100-mest-innovativa-forskningsprojekt-1.963128
https://stockholmwater.com/about/
https://eit.europa.eu/sites/default/files/press_release-eit_awards_2020_winners.pdf

Case 3) Development and application of fluorescence-based super-resolution microscopy for cellular diagnostics and to understand the origin of cellular diseases.

Summary of impact:

We have developed and pioneered fluorescence-based super-resolution microscopy (nanoscopy) for cellular diagnostics (see [1] for a review). Differences in spatial distribution patterns of specific proteins within individual cells can be uniquely resolved, as a basis for early cancer diagnosis, and to reveal central mechanisms for bacterial virulence and invasiveness. Early cancer diagnosis is key to a successful treatment. We have shown that nanoscopy analyses from a few sampled cells, from e.g. a small early tumor, can be used to identify cancer cells, and that nanoscale protein distribution patterns in platelets can reveal early-stage tumor-platelet interplay, which can form the basis for new diagnostic and therapeutic procedures. For pneumococci bacteria, a major global killer, we have shown by nanoscopy that the distribution patterns of their specific surface proteins provide important explanations to their virulence and invasiveness, which also opens new paths for diagnostics and treatments.

Underpinning research:

From a strong research background in fluorescence-based single-molecule and fluctuation spectroscopy, we entered into this research via two EU projects, the first one developing super-resolution concepts (2006-2008, SW Hell coordinator), the second one developing subcellular cancer diagnostics based on the techniques (2008-2012, J Widengren coordinator). Following the two EU projects (2011-), supported by KTH-SLL, SSF and Cancerfonden, and together with collaborators at Karolinska Institutet, we have further adapted and used nanoscopy for platelet and bacterial studies, as outlined above (see e.g. [2-8]).

With our KI collaboration partner, and world-leading companies and institutes in Germany and Switzerland, we have now recently been granted a H2020 project (2021-2024). In a lead application, further pushing the characterization bacteria-host cell interactions, we will at the same time strongly promote photonics and microscopy research in Europe (see project summary below).

The H2020 project NanoVIB:

A new H2020 project coordinated by QBP, called "NANO-scale VIsualization to understand Bacterial virulence and invasiveness - based on fluorescence NANOscopy and VIBrational microscopy", or NanoVIB (www.biomolphysics.kth.se/NanoVIB), has recently been granted by the European Commission.

This highly multidisciplinary four-year project is an exciting extension of the collaboration with the Henriques-Normark group from KI (partner in the project), as referred to above, and with world-leading researchers in Germany. The project takes as a starting point the recent remarkable development of fluorescence-based super-resolution microscopy, and the prospects this development gives to better understand the origins and mechanisms of cellular diseases. More specifically, the six partners in this project will:

- construct prototypes of a next-generation fluorescence super-resolution microscopy platform for biomedical research and development, offering one order of magnitude higher spatial resolution than current state-of-the-art super-resolution microscopes.
- develop new single-photon detector arrays with enhanced sensitivity.
- develop a pulsed, narrow-linewidth, multi-line laser for cellular imaging based on label-free coherent Raman scattering.
- integrate the developed lasers and detector arrays into the prototypes of the super-resolution microscopy platform, offering a broadened wavelength range for imaging, faster image acquisition, lower background, and allowing correlative super-resolution fluorescence and label-free imaging of cells.
- as a lead demonstration for this platform, resolve nanometer scale localization patterns of specific proteins in bacteria and host cells, providing overlaid morphological and chemical images of the bacteria, representing key information on the mechanisms underlying virulence and invasiveness of the bacteria.

With the developed microscope platform and by this lead application, the partners expect to take a decisive step towards better diagnostics, effective treatments and prevention of severe bacterial infections causing significant morbidity and mortality world-wide. The expectation is also that the ability to resolve nano-scale localization patterns in cells, correlated to their morphology and sub-cellular environments, will open new means to understand, diagnose and prevent many other diseases. The development of laser, single-photon detector and super-resolution imaging technologies in this project, as required to reach these expectations, will strengthen Europe's position on the market for microscopes, lasers and detectors, and Europe's photonics community as a whole.

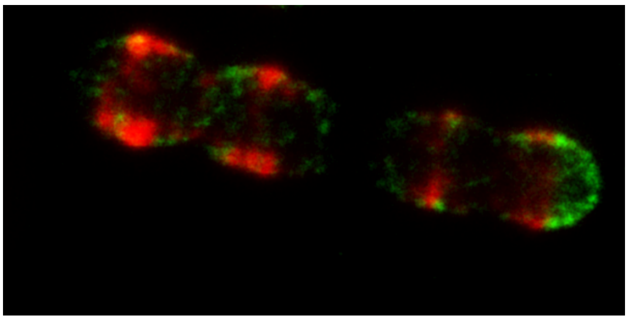

Figure: Image of pneumococcal bacteria, taken by Stimulated Emission Depletion (STED) super-resolution microscopy, showing the spatial distribution patterns of two pneumococcal surface proteins (PSPC1 and PSPC2). In a recent study by two of the partners (KI and KTH) it was found that the spatial distribution patterns of these proteins, as resolved by STED, play an important role for how the bacteria can withstand the immunological response of the host. (For further details, see Pathak et al, *Nature Comm*, 2018). With the microscope system to be developed in the NanoVIB project, the resolution can be increased by another order of magnitude, further increasing the understanding of how these proteins determine the virulence and invasiveness of the bacteria, i.e. how harmful they are to infected humans.

References:

1. Blom H, Widengren J, *Chemical Reviews*, 117(11), 7377-7427, 2017.(WoS: #cit 98, IF 60,4)
2. Mellroth P *et al*, *J Biol Chem*, 287(14), 11018-11029, 2012. (WoS: #cit 77, IF 4,2)
3. Rönnlund D et al, *Adv Healthcare Mat*, 1(6), 707-713, 2012. (WoS: #cit 19, IF 7,0)
4. Rönnlund D *et al*, *ACS Nano,* 5, 4358-4365, 2014. (WoS: #cit 17, IF 15,2)
5. Iovino F et al, *J Exp Mede,* 214(6), 1619-1630, 2017. (WoS: #cit 30, IF 12,0)
6. Pathak A *et al, Nature Comm.* 9, 3398, 2018. (WoS: #cit 11, IF 12,1)
7. Bergstrand J *et al*, *Nanoscale*, 11(20), 10023-10033, 2019. (WoS: #cit 5, IF 7,3)
8. Sender V *et al*, *Proc. Natl. Acad. Sci.* 117(49), 31386-31397, 2020. (WoS: #cit 0, IF 10,6)

Case 4) GROMACS: Moving Molecular Life Sciences from the Lab to Supercomputers

Summary of the impact

The development of GROMACS has contributed to the establishment of a new generation of **computational microscopes** used by researchers all over the world. A key reason for the success was the decision to make the **source code available as open access**, which has enabled thousands of researchers to build on the work and form a worldwide community. As indicators of the academic impact, the first paper describing the new parallel algorithms (1) has been cited over 13,000 times, the work introducing GPU accelerated simulations (2) was the most cited Swedish scientific publication in 2014, and the 23rd most cited in the world. Together with a later publication (3), there is on average a **new scientific publication citing this work roughly once every 70 minutes**.

Underpinning research

Computational Biophysics is an area that involves extensive research both in physics, computer science and biological applications. The Swedish e-Science Research Center has established a cross-disciplinary research environment led by Prof. Erik Lindahl (KTH, Stockholm University) and Prof. Berk Hess (KTH), with additional contributions by Prof. David van der Spoel (Uppsala University), which over the last 10 years has developed the GROMACS molecular simulation code into the **most widely used open source supercomputer application in the world**.

Life Science has transformed into a molecular field of research. Large efforts in structural biology mean we have access to atomic-detail structures for many of the protein molecules in our cells, and with the success of high-throughput genomics we have access to the building-block sequences for virtually all of them. To understand biology on the molecular level it is frequently not sufficient with static snapshots of structures – proteins in cells achieve their function by moving between different conformations and also interact with other molecules, such as the lipids forming the cellular membranes, which is typically not possible to investigate with methods in traditional structural biology. Over the last few decades, this has led to another approach where we start from fundamental laws of physics and use computers to calculate the interactions between atoms and simulate how molecules move. It has been a tremendous challenge to write algorithms and software that is accurate and fast enough to span from femtosecond motions in water molecules to millisecond dynamics of proteins comprising a million atoms.

The single greatest challenge was how to make simulations fast enough, requiring algorithms that can spread the work over thousands of closely connected processors in supercomputers. However, even traditional supercomputers do not provide sufficient performance to simulate systems such as membrane proteins. To break those barriers the Stockholm team was among the first in the world to invent new methods that could use graphics processor unit (GPU) accelerators to speed up simulations by an order-of-magnitude. This work requires state-of-the-art expertise also in computer architectures that was achieved by close collaboration with Prof. Erwin Laure at the PDC Center for High Performance Computing, which led to the establishment of a new joint Center-of-Excellence for accelerator software development in Sweden and Europe. This also led to another high impact development of three-dimensional image reconstruction algorithms for cryo-electron microscopy (4).

References to the research

1. Hess, B., Kutzner, C., van der Spoel, D., and Lindahl, E. (2008) GROMACS 4: algorithms for highly efficient, load-balanced, and scalable molecular simulation. J. Chem. Theory. Comput. 4, 435-447 **citations: 13231**
2. Pronk, S., Pall, S., Schulz, R., Larsson, P., Bjelkmar, P., Apostolov, R., Shirts, MR., Smith, JC, Kasson, P, van der Spoel, D., Hess, B., and Lindahl, E. (2013) GROMACS 4.5: A high-throughput and highly parallel open source molecular simulation toolkit, Bioinformatics 29, 845-854. **Citations: 5182**
3. Abraham, M.J., Murtola, T., Schulz R., Pall, S., Smith, J.C, Hess, B., Lindahl, E. (2015) GROMACS: High performance molecular simulations through multi-level parallelism from laptops to supercomputers. SoftwareX 1, 19-25 **Citations: 6269**
4. Zivanov, J., Nakane, T., Forsberg, B., Kimanius, D., Hagen, W.J.H., Lindahl, E., Scheres, S.H.W. (2018) RELION-3: New tools for automated high-resolution cryo-EM structure determination. eLife 7, e42166 **Citations: 1227**

Sources to corroborate the impact

The large user base has led to significant impact in the field of high-performance computing. According to the Intersect 360 market update at the Stanford 2018 HPC Conference, **GROMACS is the single most used of all generally available HPC applications in the world**. This has had additional major impact for the vendors developing the CPU and GPU hardware that form the core of supercomputers, since improved molecular simulation performance can correspond to hundreds of millions of dollars of savings in hardware and power worldwide.

*"Several of our users perform great research using molecular dynamics. GROMACS is critically important to them, because it scales and runs efficiently on our GPU-accelerated system Piz Daint, which is current the largest supercomputer in Europe". **Maria Grazia Giuffreda, Associate Director, CSCS Swiss National Supercomputing Center***

In particular NVIDIA and Intel, but also other vendors, have long collaborated closely with us to improve the impact both for academic and industrial customers. Several vendors now both provide full-time staff and contribute funding to further improve the code base.

"GROMACS was one of the very first GPU-accelerated codes, it remains one of our most important HPC applications, and we are delighted to continue our close collaborations with

*the Biophysics team in Stockholm." **Ian Buck, General Manager and vice President of Accelerated Computing, NVIDIA.***

However, by far the most important impact of the GROMACS research is that the work has enabled both us and thousands of other researchers worldwide to increasingly use simulations for data-driven life science.

*"Lindahl's work on GROMACS has had tremendous impact on our biomedical research at IRB Barcelona, and enabled us to perform simulations explaining a number of important diseases mechanisms that would otherwise not have been possible". **Modesto Orozco, Professor of Biochemistry & Molecular Biology, Institute for Research in Biomedicine, Barcelona***

There is a very large number of industrial applications using GROMACS to calculate binding affinities, a recent good open access publication (independent of us) reporting on significant success at Janssen Pharmaceutica and Boehringer Ingelheim is:

Gapsys V, Pérez-Benito L, Aldeghi M, Seeliger D, van Vlijmen H, Tresadern G, de Groot B. (2020) Large scale relative protein ligand binding affinities using non-equilibrium alchemy. Chem Sci. 11, 1140-52

Case 5) Optical 3D microscopy can enable more effective diagnosis of kidney diseases.

Summary of the impact

By exploring the strong entanglement between tissue-clearing and optical imaging technologies, we have established a new method for kidney diagnostics. The method is based on our recent development sample preparation techniques and fluorescence microscopy from the nanometer to the millimeter scale in kidney tissue. The new method makes clinical diagnostics of kidney disease faster, cheaper and more accurate.

Kidney disorders have a large health care cost in the modern society. Patients that get sick at young age (even at birth) suffer from a life-long condition of deterring kidney function (i.e. the possibility to filter/purify the blood). High blood pressure and diabetes are diseases that negatively impact the kidney. Until 2030 it is projected that several hundreds of millions humans will get diabetes. In diabetes the kidney filtration function slowly deteriorates over time. Better methods for kidney diagnostics, including improved knowledge to prevent and possibly also treat different filtration disorders is thus asked for. This is the aim in our research and development.

Today, kidney diagnostics of human biopsies is done using a combination of electron microscopy analysis (for the nanoscale) and light microscopy (for the macroscale). Morphological diagnostics of kidney pathology with electron microscopy and conventional light microscopy suffers a 'mismatch' in scales, and imaging of ultrathin and sliced tissue can potentially skew disease classification.

We have developed an all-optical diagnostic method by combining advanced 3D tissue-clearing preparation with high-resolution fluorescence microscopy. Our diagnostic development complements and even exceed the possibilities of today's investigations, especially regarding amount of 3D sample volume visualized, and the possibility to investigate a plethora of essential (fluorescently labelled) functional kidney proteins (see image below for a comparison).

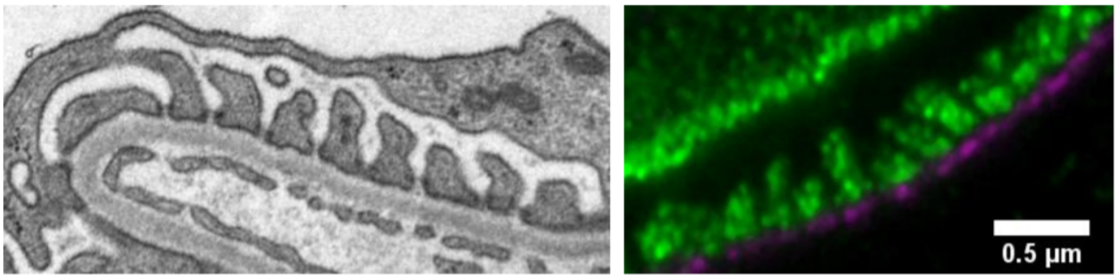

Image (Left) Electron microscopy image of the glomerular filtration unit, with podocyte foot-processes on top of the glomerular basal membrane and opposite a fenestrated blood capillary. (Right) high-resolution fluorescence microscopy image of the same structures (green = podocyte foot-processes; magenta = glomerular basement membrane). Scale bar 0.5 µm.

Underpinning research and sources to corroborate the impact

The research project started out as a KTH Master Thesis project in 2014 and was then continued as a PhD research project (presented and defended in the spring 2019). From 2020 the project has been supported by a Region Stockholm-KTH collaboration grant to validate the method with kidney researchers and pathologists at Karolinska University hospital in Huddinge.

Below are listed research publications (with number of citations from Google Scholars) as well as documents and web pages that corroborate the impact of the case.

Kidney International (2016) **89**:243-247; Unnersjö-Jess et al. Super-resolution stimulated emission depletion imaging of slit diaphragm proteins in optically cleared kidney tissue. Cited 47 times.

Kidney International (2018) **93**:1008-1013; Unnersjö-Jess et al. Confocal super-resolution imaging of the glomerular filtration barrier enabled by tissue expansion. Cited 27 times.

Kidney International (2020) https://doi.org/10.1016/j.kint.2020.10.039; Unnersjö-Jess et al. A fast and simple clearing and swelling protocol for 3D in-situ imaging of the kidney across scales. Cited 1 time.

Towards all-optical kidney pathology? David Unnersjö Jess. https://analyticalscience.wiley.com/do/10.1002/was.000400088

KTH news. https://www.kth.se/en/aktuellt/nyheter/optisk-3d-mikroskopi-kan-effektivisera-diagnos-av-njursjukdomar-1.1039573

KTH case. https://www.kth.se/en/om/stod-kth/cases-for-support/diagnos-av-njursjukdomar-blir-enklare-och-sakrare-med-ny-3d-teknik-fran-kth-1.995776

Case 6) *Using nanotechnology for probing exosomes – a liquid biopsy tool for monitoring cancer*

Summary of the impact

Despite major progress in tumor detection and in targeted therapy approaches, cancer continues to be a major cause of death. This is largely due to the metastatic spread, often occurring already at the time of the initial diagnosis, resulting in a poor prognosis for the patient. Reliable and sensitive methods to analyze cancer markers in an easily accessible patient sample, e.g. a blood sample, are highly needed. Given that the methods would be inexpensive and fast they could also serve to monitor therapy on a frequent basis during tumor progression. The "liquid biopsy concept", i.e. a direct measure of tumor in blood/plasma has therefore attracted a large interest as a way for non-invasive diagnostics but also for treatment monitoring. Methods to detect and monitor cancer have therefore shifted to blood-borne entities such as circulating DNA and small Extracellular Vesicles (EVs) or exosomes. In particular exosomes, being 30 – 150 nm in size, are released both by ordinary and cancer cells in large numbers and are used for communication and transporting cargo between cells. They carry surface proteins that uniquely identify them with their parent cells. Thus, by detecting and monitoring exosomes with a specific protein surface expression, one may monitor tumor progression and the response to targeted therapies.

Micro- and nanotechnology enables miniaturization of fluidics and sensors on a silicon chip to establish a micro laboratory. This would enable multiple parallel sensing of several markers in a fast and cheap way. The detection principle could be electrical or optical and specificity would be accomplished by functionalizing sensor surfaces by affinity probes (antibodies).

At the Department of Applied Physics, the group of Prof Linnros and Dr Apurba Dev has developed an electrical sensor technology using capillaries, functionalized with antibodies for specific proteins, to detect exosomes related to cancer tumors. The sensing is multiplexed to analyze a palette of different proteins to accurately attribute the origin of the exosomes to a specific cancer form. The microchips are fabricated using an Si platform and are capable of detecting multiple biomarkers from a small amount of body fluid. A development of a prototype is also planned for the operation of the device in clinics. Once validated in larger clinical studies, the technology has the potential to be commercialized and also applied for liquid biopsies of different cancer types once a set of relevant surface protein markers have been established. The method has been applied to a small cohort of lung cancer patients, that have been subjected to different treatment courses. A larger clinical study involving more than 80 patients is planned for in the coming years.

The research is presently supported by the Family Erling Perssons Foundation and involves 6 partners: KTH – Applied Physics, KTH – Protein Technology, KTH – Gene Technology, Uppsala University – Ångström Laboratory, Karolinska Institute – Department of Oncology and RISE/ACREO Research institute.

Underpinning research

The research group of Prof Linnros originated from the Solid State Electronics department in Kista, a heavy user of the Electrum cleanroom laboratory. The focus was on silicon nanotechnology in general where one activity was devoted to electrical sensing of biomolecules using nanowires. These work like field-effect-transistors (FET) where the functionalized nanowire acted as a base electrode open to the liquid sample volume. For protein sensing, contacts were made to Prof Eriksson-Karlström at Protein Technology of KTH. Together with ACREO research institute a 3-year large grant was received from Vinnova. By the time K A Wallenberg's foundation launched new calls for projects, the team including new partners at KTH and with Prof Lewensohn and Dr Viktorsson at Karolinska

Institute, submitted a proposal for detection of circulating tumor cells in cancer patients. Thus, a 5-year grant was received (2012 – 2016), the first project granted from KAW at KTH. Circulating tumor cells are however very rare and extremely difficult to catch in a normal blood sample. At the same time the FET sensing principle was plagued by large inherent difficulties. Taking an entirely new approach, a novel method for bio-detection was then developed by Apurba Dev. The method utilizes electrokinetic phenomena in a micro-channel and allows sensing of multiple biomarkers from a small amount of body fluids. During the course of the project, a new direction for monitoring cancer in body fluids was proposed based on exosomes and a new proposal based on exosome detection was submitted to the Family Erling Persson Foundation. The 5 year project was granted and the project is now in a phase where real samples from patients are analyzed to prove the sensing technology. Interestingly, ~20 years have now passed from the first initial steps towards using micro/nano-technology for sensing of biomolecules until todays application of monitoring the progression of cancer on patients. This has been possible only by cross-disciplinary collaboration, a difficult but rewarding endeavour that involves surmounting a high language barrier.

1. N. Elfström, A. E. Karlström and J. Linnros, **Nano Letters** 8, 945-949 (2008). (229 citations)
2. A. Dev, J. Horak, A. Kaiser, X. Yuan, A. Perols, P. Björk, A. Eriksson Kralström, P. Kleimann and J. Linnros, **Biosensors and Bioelectronics, 82**, 55-63 (2016). (9 citations)
3. S Cavallaro, J Horak, P Hååg, D Gupta, C Stiller, SS Sahu, A Gorgens, H K Gatty, K Viktorsson, S El Andaloussi, R Lewensohn, A E Karlström, J Linnros, A Dev, **ACS sensors** 4 (5), 1399-1408, 2019 (13 citations)
4. SS Sahu, C Stiller, S Cavallaro, AE Karlström, J Linnros, A Dev, **Biosensors and Bioelectronics**, 112005, 2020 (2 citations)
5. S. Cavallaro, F. Pevere, F. Stridfeldt, A. Görgens, C. Paba, S. S. Sahu, D. R. Mamand, D. Gupta, S. El Andaloussi, J. Linnros, A. Dev, **Small,** (2021) DOI: 10.1002/smll.202008155

Sources to corroborate the impact

The technology is presently at test on samples from patients at the Karolinska Hospital. A larger clinical study involving more than 80 patients are planned in the coming years. Depending on the outcome of such studies, the technology could be refined and sensor chips could be further developed for fast and parallel sensing of several markers. Finally, commercial aspects of the technique should be investigated.

Case 7) *Bispecific antibodies for treatment of leukemia and preconditioning before allogeneic hematopoietic stem cell transplantation*

Summary of impact

We have developed a concept based on bispecific T or NK cell engagers (BiTEs or BiKEs) that can reduce the need for cytostatic drugs prior to allogeneic hematopoietic stem cell transplantation (HSCT). This could reduce human suffering from side effects caused by currently used harsh treatment which would reduce treatment costs and increase the number of patients eligible for HSCT. For this we have been granted an European patent and have an ongoing patent process in the US. We have also started the company ImmuneCond Therapeutics AB to commercialize the concept.

Background

Hematological malignancies are currently often treated by high doses of cytostatic drugs, that eliminate both the patient's tumor cells and hematological stem cells (HSCs), followed by allogeneic HSCT. However, posttransplant complications such as graft versus host disease (GVHD) increases with tissue damage caused by cytostatic drugs, and, particularly in children, the use of cytostatic drugs has severe long-term side effects e.g., mental retardation, hormonal misbalance and infertility. Thus, effective pre-treatment with decreased risks of side effects may have long-term beneficial effects and also open up the field of HSCT to include diseases not eligible for HSCT today, e.g. autoimmune and chronic diseases. The cell surface protein CD34 is shared between HSC and several hematological malignancies, e.g. myelodysplastic syndromes (MDS) and acute myeloid leukemia (AML). Around 50% of all patients with MDS or AML have CD34-expressing tumor cells. Together these two malignancies make up approximately 50% of all patients undergoing allogeneic HSCT worldwide today. According to public statistics that corresponds to approximately 12000 HSCTs yearly. Thus, development of new treatment strategies for these patients can have a large impact on human life.

Antibody based immunotherapy is today a clinical reality in the form of e.g. Mabthera (rituximab) which is a monoclonal antibody directed against CD20 expressed on a variety of B cell malignancies. Recently new waves of antibodies have been engineered with dual specificity, so called bispecific antibodies or bispecific T cell engagers (BiTes) or natural killer (NK) cell engagers BiKEs. One such drug, Blinatumomab (Amgen), belonging to a novel class of BiTEs, which redirect T cells to attack cancer cells. It comprises two single chain variable fragments (scFvs) that bind CD3 and CD19, respectively. Upon simultaneous binding of both targets, Blinatumomab brings a T cell and a target cell in close proximity, which leads to T cell activation and subsequent killing of the target cell. Other targets except CD20 such as epidermal growth factor (EGFR) and CD19 have been tried in animal models and in vitro experiments but none have reached as far as Blinatumomab.

A novel strategy is to combine the powers of immunotherapy and HSCT. There have been previous attempts to target HSCs by BiTes directed against CD45 and myosin light chain but these molecules are expressed broadly across several cell types. Since CD34 is expressed on both HSCs and many tumor cells it is a way to directly target leukemic cells, cancer stem cells and healthy HSCs. Thus, in step one the bispecific antibody trigger T cells to kill the patient's HSCs and leukemic cells, preparing for step two where a new donor-derived immune and hematopoietic system repopulate the patient.

Research and commercialization efforts

We have developed bispecific antibodies targeting the cell surface protein CD34 at one end and the immune cell activating receptors CD3 or CD16 at the other end. In projects financed by both the Swedish foundation for strategic research (SFF) (1) and Vinnova (2) , these antibodies have been tested for immunological function in *in vitro* experiments with human tumor cells as targets and human T cells or NK cells as effectors. These experiments have shown that the bispecific antibodies are potent mediators of redirected immune response against both tumor cells and stems cells. This has been further corroborated by experiments performed in mouse models indicating that the BiTEs may have a clinical effect without severe side effects. Thus, the concept is viable. The results are currently summarized in a manuscript targeting a high impact journal (3).

Based on these positive results a broad patent for the concept of targeting CD34 has been granted in Europe (4). In the US a more specific patent is granted (5), and current efforts are focused on widening this to a more conceptual coverage. The company, ImmuneCond Therapeutics AB has been formed for commercialization of the concept and is currently raising capital.

In parallel, the project is pursued in labs in the inventors and co-founders' labs at Applied Physics, KTH, the Karolinska Institute and University of Totonto, Canada. At Applied Physics we are using microchip-based techniques to investige how BiTEs and BiKEs affect the ability of individual immune cells to recognize and kill tumor cells.

References

1. *Single cell assays for immunotherapy.* Önfelt, B et al. 2013-2020, Bioenginnering Grant, Swedish Foundation for Strategic Research .

2. Development of CD34/CD3 bispecific antibodies for treatment of leukemia and preconditioning before allogeneic hematopoietic stem cell transplantation. Uhlin, M et al. 2017-2019, Vinnova.

3. Bispecific antibodies for treatment of leukemia and preconditioning before allogeneic hematopoietic stem cell transplantation. Arruda, L et al: Manuscript in preparation.

4. Uhlin, M et al. Bispecific antibodies for use in stem cell transplantation . EP3105252B1 Europe, 2019.

5. Uhlin, M et al. Bispecific antibodies for use in stem cell transplantation. US10106623B2 United States of America, 2018.

e. Structure for increased impact

The department is working along several avenues to increase its impact:

- In the research that we perform, we are actively pursuing topics that align with our core competences as well as with the goal of being either of fundamental scientific importance, of high application value or of direct importance for a societal topic such as health or sustainability. This selection of research topics is a guiding principal for achieving research results that are of strong interest to the surrounding society and thus has great impact.
- The research that is performed in the department is published in journals that have the highest possible impact. Well known, well reputed, international and peer reviewed.
- The department leadership is dedicated to supporting patents and spin-offs by direct encouragement, mentorship through the large number of staff with experience in spin-

offs and by constantly working to increase KTH support for spin-off companies as well as to remove unnecessary bureaucratic hurdles.

- The department fosters a culture of exchange and engagement with society in general by encouraging participation in radio and TV broadcasts as well as other popular media such as popular science journals and social media. The department also actively outreach activities and in particular towards students. We involve students in outreach activities, for example at school visits and open house. We accept summer students from junior high school and up who are interested in research. Particularly popular has been for the younger ones to "play" in the 3 D printing laboratory. Rays for excellence is a national program for scientific training for last year high school students. We have one or two of those each year.
- Another avenue for outreach is opinion building and broad public education. An example is our exhibition and lectures in the Dome of Vision, during the year of light 2015.
- We are increasing our impact by running open facilities that are heavily used by researchers in other departments, other universities, and companies. These labs are presently increasing in size an usage. For example, our department hosts the Albanova Nanolab where our unique AFM modes instruments are available, including training courses. (something can be said here about the SCI-life imaging lab) In this way our specialized instrumentation and practical user-knowledge has impact far beyond our own research groups.

7. Other

a. Specifics that the department wishes to mention and describe

If the department wishes to mention anything that has not been covered above, it can be added in this section.

A) ATTACHMENTS

Relevant material/URL-links formulated succinctly that support the self-evaluation. No limitation in length, but do not expect panel members to read extensive added material.