SELF EVALUATION REPORT, RAE 2020 @ KTH

PHYSICS AND APPLIED PHYSICS (PANEL 9)

Introduction

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 6 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 Applies Physics is organized in 7 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 3 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, nanophysics, spintronics, surface physics, device physics and quantum materials.

Description of the self-evaluation process for the research panel

At the start of the self-evaluation process both departments had seen a change in head of department, where the head of the Applied physics department was replaced by the deputy between December 2019 until the end of March due to parental leave. In the Physics department the deputy head took over as acting head from the beginning of February due that the previous head of department became one of the deputy heads of the SCI school.
The panel coordinator and the heads of department met for discussions at the end of January to plan the work.
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 Material 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 where 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 continue for KTH to keep up education standard during the COVID19 period and the moving of the Kista divisions, has resulted 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 physics and applied physics departments. The main development is the significantly improved academic environment achieved by 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 ongoing establishment of the divisions in the new campus building, called House 3, 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.

Department of Physics

1. Overall analysis and conclusion; strengths and development areas

a. *Limited SWOT-analysis*

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

Research

Strengths	*Weaknesses*
• High impact research across entire department with very strong publication record in top-ranked journals • Broad range of research fields at state of the art level • Mix of applied and basic research, with clear synergies; and healthy mix of experimental, modelling, simulation and theory • Strong international presence and reputation in multiple fields • Strong research centres (SKC, OKC, Space Centre) • Leadership roles in international projects • Very good record of attracting external funding	• Low level of internal funding • Strong dependence on external funding ◦ potentially reduces research independence ◦ PhDs and postdocs entirely financed by external sources ◦ difficulties for long term planning and commitments • Essential local infrastructure and technical staff almost exclusively funded by external sources ◦ difficulties in maintaining staff and expertise between time limited projects • High level of administrative load by faculty and researchers • Some disconnect between basic and applied research and between research divisions • Inhomogeneous department composition makes it challenging with common agenda and practises

Organisation

Strengths	Weaknesses
• Efficient local administration, shared with Department of Applied Physics • Since reorganisation, research divisions have better critical mass • Excellent education programs • AlbaNova environment (KTH, SU, Nordita) – collaborations and synergies with other departments at KTH, as well as with SU and Nordita.	• Poor gender balance in faculty and management • Dominating line organisation • Lack of formal faculty influence • Top-heavy faculty (intrinsic KTH issue) • Lack of career development path for non-faculty staff • Lack of department-centralized technical support • Lack of financial incentives for excellence in common doctoral education programme

To summarize, we stress that we have excellent staff in a wide range of research topics in physics. The main weakness is the low level of internal funding, which leads to a range of consequences: large reliance on external funding, which can potentially affect researcher independence, can lead to uncertainties in working conditions, and may be seen as less attractive in an internation context for attracting the best future colleagues. This weakness also introduces clear difficulties for long-term planning and commitments.

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

The impact of the department will be further detailed below, but can be briefly itemized here as:

- Impact cases, further described in section 6.
- Faculty members regularly appear in media
- Several faculty members have been elected to influential academies (KVA, IVA, SUA, etc)
- In basic research, the department has very strong impact in many areas.
- In applied research, the department is a key international player in nuclear engineering, nuclear power safety and medical imaging.
- Faculty take leading roles in international collaborations.
- Synergy of basic and applied science promotes generation of impact.

The infrastructure that the department relies upon can be grouped in terms of:

- External international state-of-the-art infrastructure – a significant fraction of the basic research performed in the department is carried out in large international experimental facilities (e.g. CERN/ATLAS, FAIR, ESS, ISS, NASA/ESA, Fermi satellite).
- Involvement and use of national and regional infrastructures, such as Esrange and the Uppsala Tandem Laboratory and Skandion Clinic.
- Specialist laboratories – another significant fraction of research is performed in our in-house specialist laboratories; in both basic and applied science but with a dominance of the latter.
- The computational research relies on both international and national high-performance computation centres, as well as in-house computational resources.
- The department develops and maintains a number of internationally recognized computer codes and software packages.

Sustainable development lies at the core of a large fraction of the activities pursued at the department, in short:

- A large fraction of the research conducted in the department is linked to sustainable development.
- About one third of the research conducted at the department deals with sustainable nuclear energy production – which is of utmost importance to a carbon free future society.
- Improved health is the focus on one research division, working on development of world-leading medical imaging technology.
- Condensed matter theory research has wide range of potential applications and implications relevant to sustainable development.
- Strong fundamental research is necessary for developing a sustainable society.
- High quality education is a fundamental tenet for a sustainable society.

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. The department is now one of four departments that make up the School of Engineering Sciences: Physics, Applied Physics, Mathematics and Engineering Mechanics. The department has 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 now 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) and Nuclear Engineering (NE). In the merger in 2018, some researchers from former Theoretical Physics joined Particle and Astroparticle Physics, some moved to the Applied Physics Department and the rest formed the division for Condensed Matter Theory. 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 Applied Physics and the Physics and Astronomy departments of Stockholm University, as well as with 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).

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 Particle and Astroparticle division performs research in a broad area of experimental and theoretical Particle Physics, Astrophysics and Astro-particle Physics. The research is based around both large and small scale top of the line international facilities covering the range from the ATLAS experiment at the CERN Large Hadron Collider in experimental particle physics, underground neutrino experiments in theoretical particle physics to both ground and space-based instruments focusing on X-ray, gamma-ray, and cosmic ray physics. In Astrophysics and Astro-particle 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 multiwavelength and multimessenger techniques. The research with the ATLAS experiment is concentrated around studies of the Higgs boson and searches for physics beyond the standard model, e.g. signs of supersymmetry.

In theoretical particle physics the research is focused mainly on neutrino and dark matter physics and is done both independently and as part of international experimental collaborations, including ESSnuSB, DUNE, and T2HK. The merger of the theoretical particle physics group into the division in 2018 has led to fruitful interdisciplinary discussions where common interests start being exploited.

The long-term strategy of the division, which has been very successful, is to combine instrumentation design and development, with data analysis and theory. In the 2000's the division contributed to the design and construction of the ATLAS presampler detector, the calorimeter of the Fermi gamma ray telescope and the anticoincidence shield of the PAMELA satellite for antiparticle measurements. This has been followed by the PoGO and X-Calibur missions for balloon-borne polarimetry and development for the High Granularity Timing Detector upgrade of ATLAS.

The experimental particle physics group at KTH is active at the frontline of hadron collider physics and has contributed to the ATLAS experiment at the CERN Large Hadron Collider since 1990. The aim is to test the limits of the standard model and thus search for physics beyond it.

- The scientific focus of the data analysis activities is on measuring the properties of the Higgs boson and searches for physics beyond the standard model. Direct searches for beyond standard model physics with ATLAS data may reveal new particles which specifically could explain the dark matter.
- The group contributes actively to detector instrumentation with a strong effort in the development the High-Granualrity Timing Detector which will provide picosecond timing measurements for the High-Luminosity LHC upgrade.

Central topics in Astrophysics and Astro-particle physics are related to the study of high-energy phenomena in the universe using X-rays, gamma-rays, ultra high-energy cosmic rays. The questions concern:

- 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. We have made the first polarimetric observations of two sources in the hard X-ray band (~20-200 keV), e.g. elucidating the nature of the emission region in the magnetosphere close to the Crab pulsar, and the geometry of the corona in the vicinity of the event horizon of the accreting black hole, Cyg X-1. New missions with significantly improved sensitivity are currently under development.
- Supernovae and pulsars. Supernovae are the violent death 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 polarimetry observations of the Crab nebular and pulsar system.
- Gamma-ray bursts. GRBs have been one of the focuses 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 current Astrophysics. They are short flashes of gamma-rays reaching us from very large distances, mainly from when the Universe was young, and constitute the brightest explosions in the Universe. The γ-ray phase is the energetically most important phase, however, there is still no consensus on how to interpret and understand it. It is of great importance to understand this phase, since they are connected with general stellar explosions, such as supernovae and with neutron star mergers, and are connected to sources of gravitational waves.
- Ultra high-energy cosmic rays. The group is involved in the development of space-based observations of ultra high-energy cosmic rays, as well as theoretical investigations of their origins, in particular if GRBs could be their source.
- Active Galactic Nuclei. Containing supermassive black holes in their centers, AGNs are among the brightest and 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 is centred around the long-term light curve variability and on the connection between the accretion and the formation of the jet.

Research within the general area of theoretical and phenomenological particle and astroparticle physics focuses on physics beyond the standard model. The research benefits through interdisciplinary discussions with experimental part of the group within the division and with the IceCube group at Stockholm University. The central questions concern:

- Predictions of sensitivities in 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 signals of dark matter in astrophysical systems and the interplay with other dark matter signals

The division is a mixture of faculty, researchers, postdocs and PhD students. Recruitment is international. Most postdocs and PhD students are non-Swedish nationals. The postdoc and PhD student positions are fully gender balanced, while not yet the case for faculty although recent strategic recruitments have improved the balance.

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 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.

Some of the main experimental research topics are:

- 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 may 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. Current activities include:

- 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 γ-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, one postdoc (another in recruitment), six 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 (which is traditionally poor for the Department of Physics and KTH as a whole). 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)

All faculty members of the CMT division lead their own research projects. Projects are often performed in collaborations and together with PhD students, postdocs or master thesis students. The research covers a very wide range of topics from basic properties of quantum many-body systems to applications in materials science and quantum technology. Typical research problems consider exploring new phases and phase transitions and new properties of interacting many body systems. The research is in the front line and the papers from the division are published in the main journals in the field. Ultimately the research aims at finding new physical phenomena, materials, and approaches for applications. Also, the division is involved in several collaborations with experimentalists to explore and understand new physics, phenomena or device design principles. The research often involves development of new models and theoretical or numerical methods. 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 the following fields:

- Phase transitions, classical and quantum critical phenomena: search for new kinds of phases and phase transitions. For example, the unknown origin of the metallic phase at the superconductor-insulator transition.
- Topological quantum matter including Weyl semimetals and anomalies, and topological insulator nanowires and Majorana fermions.
- Many-body quantum dynamics, localization and thermalization. When and how do closed quantum systems thermalize?
- Monte Carlo and molecular dynamics simulations: Development and application of new effective simulation methods, in particular development of methods for enhanced sampling of systems with complicated energy landscapes, such as spin glasses and biopolymers, and methods for computing kinetics and thermodynamics of phase transitions.
- Unconventional superconductivity.
- New states of matter in systems with long-range, frustrated and strong interactions.
- Topological qubits.
- New superconducting and superfluid states.
- Ultracold atoms.
- Structure formation in soft matter.
- Phase transition and topological excitations in multicomponent gauge theories.
- Frustrated magnetism: Theory and experiments of spin ice and related systems.
- Disordered systems and localization: Role of disorder for ordering and phase transitions, spin glasses, porous media. In particular the little understood problem of spatially correlated disorder is investigated.
- Transport and fluctuation effects in superconducting electric circuits, with application to superconducting nanowire single photon detectors (SNSPD).
- Mathematical Physics: quantum many-body systems, analytical methods.
- Matter under extreme pressure.

Physics of Medical Imaging (PMI)

A central research question is to understand the fundamental limits of information in medical images and through new instruments and methods, match this know-how with clinical challenges in detection and diagnosis. Today there is a worldwide search for the next generation of medical imaging instruments, but it is to a large extent unknown what information is most important and how the most important images can be generated. Our main current research activity is photon counting Computed Tomography based on deep silicon, which was invented in our group. It is of importance that there is a gender mix at the department for social reasons and currently we are 4 males and 2 females in the division. We are highly multi-disciplinary and our research involves semiconductor devices, integrated circuits, image reconstruction and data processing.

Nuclear Power Safety (NPS)

The central research questions are (i) governing physics of reactor accident phenomena in light water reactors: including thermal-hydraulics, structural mechanics, direct numerical simulation, coupling between neutron-kinetics and thermal-hydraulics, reactor core degradation and relocation, fuel coolant interactions and debris formation, steam explosion, debris remelting, melt convection and heat transfer, reactor vessel failure, melt spreading etc.; (ii) reduction of uncertainties in quantification of severe accident risk; (iii) validation and improvement of severe accident management guidelines (SAMG); (iv) development coupled deterministic/probabilistic methodologies for reactor safety analysis; (v) safety of future nuclear power including Generation IV reactor technologies.

NPS research activities are focused on the knowledge gaps in these questions. Although NPS belongs to the discipline of Nuclear Science and Technology, nuclear power safety is a 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 hazards, 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. NPS has three research teams (experimental study, computational study and plant assessment) of highly competent researchers in all areas of reactor safety. The strong experimental programme in synergy with theoretical research, modelling and simulation benefits all developments.

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 characterisation
- 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). Several research tracks are directed towards LFR development. 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 loop for supercritical conditions and are expected to start the first experiments within a year. Heat transfer properties in the supercritical state is the key application-critical issue to investigate.

- 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.

- 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 and HYMERES-2 where large scale facility PANDA at PSI 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 developed validation process 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 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.

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

Particle and Astroparticle Physics

The experimental particle physics group is a strong contributor to the ATLAS experiment at CERN:

- Following the discovery of the Higgs boson, in which KTH members had a leading role, the work has transitioned to measuring the properties of this new particle. These properties are for example the interactions with other elementary particles. The interactions are exactly predicted by theory. Any deviations from the predictions would be indications of new and unexpected 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. SUSY 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 use of the High-Granularity Timing Detector as luminometer after the High-Luminosity LHC upgrade and the development of the measurement system for this is driven by the KTH team.

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

- X-ray polarimetry: We have developed instrumentation (spanning laboratory prototypes to flight hardware) which allows completely new measurements to be conducted on the high-energy universe. These have led to new insights on compact objects, best exemplified through the constraints on the geometry of the coronal-region of Cygnus X-1, a result which was recently published in Nature Astronomy.
- 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 has 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 collaboration for the Fermi gamma-ray space telescope. Time has successfully been obtained at the major international facilities, e.g including the Very Large Telescope, the Hubble Space Telescope and NuSTAR. 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 in combination with its use for interpreting observations. The work has received wide recognition culminating in the 2016 Göran Gustafsson Prize in Physics, which is awarded by the 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 by the group as a national satellite mission.
- 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. In addition, we have shown that gamma-ray bursts, which have been one of the main candidates for producing ultrahigh 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 that is freely available for download. 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

Development of new enhanced simulation methods for problems with complex potential landscapes with applications in a wide variety of fields: physics, statistics, biophysics, etc. The following list exemplifies advances in condensed matter theory:

- New approaches for analyzing quantum phase transitions and disordered systems, mostly for application to basic physics problems in superconductivity.
- Introduction of the notion of metallic and superconducting superfluids and the prediction of the possibility to realize such new states of matter in hydrogen and deuterium at ultrahigh pressure.
- Prediction of type-1.5 superconductivity in multicomponent superconductors.
- First discussion of hopfions in superconductors and superfluids.
- Demonstration of Non-Meissner electrodynamics in multicomponent superconductors arising as a consequence of generation of Skyrme terms by fluctuating gauge field as origin of spontaneous magnetic fields in s+is and s+id superconductors.
- Prediction of violation of the Onsager-Feynman superflow quantization in superconducting superfluid.
- First discussion of the pseudogap concept in high-energy physics context.
- Findings of new kind of stable topological solitons “chiral CP2 solitons” in three-component superconductors with broken time reversal symmetry.
- Findings of a new kind of mixed collective mode in three-band superconductors with broken time reversal symmetry, different from the Leggett modes, Anderson modes and Carlson-Goldman modes.
- Prediction of anomalous metallic state which breaks time Reversal Symmetry due to superconducting fluctuations.
- Prediction of a new vortex viscosity mechanism different from the Tinkham and Bardeen-Stephen mechanisms.
- Prediction of new thermoelectric effects in superconductors that break time reversal symmetry, different from Ginzburg effects.
- Demonstration of glass formation in a monodisperse system without disorder with application to vortex matter clean multiband superconductors.
- Generalization of FFLO states to the case of unconventional pairing.

- Finding new non-topological states leading to surface superconductivity in metals.
- Understanding of axial anomalies in the presence of pseudo fields and detection methods.
- Obtained and understood entanglement structure of many-body eigenstates at the many-body localisation transitions.
- Entanglement spectrum and bulk-boundary correspondence in topological non-hermitian models.
- Discovery of a new mechanism of the stabilization of the mechanically unstable phases.

Physics of Medical Imaging

The clinical advantages with spectral photon counting medical imaging have been clearly demonstrated. This resulted in instrumentation in labs and in hospitals and also proposed a new technology for x-ray telescopes (with data from the Diamond synchrotron).

Nuclear Power Safety

The NPS research activities helped to elucidate several risk-significant phenomena, including

1. melt interaction with porous debris
2. turbulent natural convection heat transfer in molten corium pools
3. reactor vessel behavior under melt attack
4. core melt underwater spreading
5. debris formation from fuel coolant interactions
6. steam explosion energetics
7. oxidation of Zr and Zr-Fe droplets falling in water
8. debris coolability
9. spray cooling

The prediction of the items (2) 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 (8) is crucial to apply the in-vessel melt retention strategy to reactors with high power capacity. 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. Critical materials development for GenIV lead fast reactors.
- A range of small modular reactor designs based on LFR technology (ELECTRA, SEALER, SEALER-UK, SEALER-E) which have been enabled after the above materials development.
- 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.
- 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.
- Development of ROAAM+ framework and coupling with commercial software RiskSpectrum for probabilistic safety analysis of power plants.
- 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.
- Development of corium debris bed formation and coolability code DECOSIM.
- Development of a comprehensive steam explosion risk analysis model.

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.
- W. Mi, P. Nillius, M. Pearce, M. Danielsson, "A stacked prism lens concept for next-generation hard X-ray telescopes", Nature Astronomy **3** (2019) 867.

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	Tot.	WoS c
Article, peer review	249	216	216	257	272	231	255	1696	95,8%
Article, other	9	8	5	2			5	29	100,0%
Conf. paper, peer review	36	40	34	62	34	32	22	260	39,2%
Conference paper, other	2	6	6	2	5	1	5	27	0,0%
Book		3	1	1		1		6	0,0%
Anthology (editor)	2							2	0,0%
Chapter in book	2	1	1	1	2	1		8	0,0%
Report	3	1		1				5	0,0%
Doctorate thesis	14	6	8	7	10	5	12	62	0,0%
Licentiate thesis	6	3	3	3	6	4		25	0,0%
Patent, approved							2	2	0,0%

Table 1 – Publications in DIVA

In our scrutiny of the bibliometric data, it has been discovered that a number of articles and patents have not been allocated to the department although the articles exist in DIVA with the correct author list. This reduces the validity of the bibliometric study.

The number of peer reviewed articles lie stably at around 250 per year. The average number of doctoral theses are about 10 per year. 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.

Table 2 shows citations in a 3 year window from the year of publication based on fractional count.

Publ. year	Publications	Tot. Citatiions	Aver. Citations
2012	85,3	309,7	3,6
2013	69,1	267,7	3,9
2014	60,0	213,4	3,6
2015	62,9	200,9	3,2
2016	60,7	214,9	3,5
Total	337,9	1206,6	3,6

Table 2 – Citation 3 year window, fractional count

On average each publication has 3.5 citations in the three years following publication. The highly international character of the department is visible in table 3 showing that 86% of the publications within the department is with international co-publication. Only between 4-5% are co-authored with Swedish non-universities.

Publ. years	Publications	Swed. non-univ.	Share	Internat.	Share
2012-2014	637	25	3,9%	539	84,6%
2013-2015	643	33	5,1%	554	86,2%
2014-2016	692	31	4,5%	600	86,7%
2015-2017	705	30	4,3%	613	87,0%
2016-2018	708	30	4,2%	622	87,9%
Total	1584	69	4,4%	1364	86,1%

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

Further data provided by the library show that the average citation factor (3 years rolling) is 1.22 and that 1/3 of the publications appear in journals with top 20% impact factor.

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.

For Particle and Astroparticle Physics, there is a high level of engagement in collaborations, both internationally and on the national and local environment level:

- the long-standing involvement in the ATLAS project at CERN is one of the cornerstone collaboration frameworks.
- The di-Higgs network between KTH, Lund, Uppsala and Stockholm universities to promote collaboration between experimentalists and theorists.
- The Oskar Klein Centre (OKC) – recently nominated among the top-three VR Linnaeus Centres of Excellence. A member of the division was co-founder
- The KTH Space Center collaboration, which spans all schools at KTH.
- The International Space Station and the JEM-EUSO.
- The X-ray polarimetry group collaborates internationally, e.g:
  - PoGOLite/PoGO+ Collaboration. (~2004-2019). KTH (MP) is PI since 2009.
  - XL-Calibur collaboration. (2019-) KTH is Co-I. Involves KTH+USA+Japan.
  - The SPHiNX mission (2016-2019) was (with KTH Space Centre) aimed to realise a national satellite for GRB polarimetry.
- The Fermi space telescope project collaboration.
- 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 2020. 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 main external collaborations are with:

- Microsoft Station Q, University of California Santa Barbara, TU Delft.
- Joint grants with Leeds University Math department.
- Wallenberg collaboration with Nordita, SU, and UU on dynamic quantum matter.
- Russian Academy of Science, Novosibirsk: mineral physics.
- Ukrainian Academy of Science, L'viv: computer simulation.
- Linköping University: ab initio molecular dynamics.
- University of South Florida and Livermore National Lab: synthesis of new multimegabar carbon phases quenchable to room conditions, 'new diamonds'.
- University of Massachusetts Amherst.
- Stony Brook University.
- Collaboration on axion detection with Stockholm University (joint grant with Frank Wilczek pending).
- Collaboration on multimessenger astrophysics with Stockholm University.

For Physics of Medical Imaging, the main collaborations are within the MedTechLabs center, and externally with Linköping University, which has resulted in a new circuit for photon counting and with Stanford University with many joint high-impact publications.

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 programme.
NPS has strong international collaborations with many organisations 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 centres became a part of Pan-European Laboratory of Severe Accident Research created in the EU project SAFEST.

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.

Externally, Nuclear Engineering has been collaborating intensely with different departments at Chalmers university of Technology, EDF R&D in France, Uppsala University, Linköping University, CEA Saclay, CEA Cadarache, PSI, Luleå Technical University, VTT Technical Research Centre of Finland and Lappenranta University of Technology, to mention a few.

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.

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 Nuclear Physics Division has grown by approximately 50% since the previous RAE in 2012 and has now more than 20 members. The major contributions of this increase are due to a larger number of PhD students (currently 7) and two additional senior staff members in the nuclear safeguards and security team.

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 were building a bigger and stronger unit, which can lead to closer collaboration between the department divisions. The main unsolved issue is that there are now two departments: Physics and Applied physics and they are not fully divided based on activity. It is a concern that condensed matter is divided between two departments.

Physics of Medical Imaging

We have maintained a high level of research in terms of innovations and publications and a high level of teaching activities (very good course evaluations)

Nuclear Power Safety

As commented in RAE-2012 report, the NPS division, together with Nuclear Engineering, “seems to be in some way isolated at KTH”. This situation is improving by more active involvement in teaching activities, but the issue is still difficult to be resolved by NPS alone, since its activities are project oriented, with limited support from KTH internal resources.

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.

3. Viability

a. *Funding; internal and external*

The department has a turnover of about 130 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 roughly 50% over the last years with a slight increase over time in the fraction of external funding. 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.
The internal funding of near 50% average is split roughly as 20/30 on teaching and faculty support. The ratio of internal to external support is also very 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*

Currently, there are 17 professors, 11 associate professors and 1 assistant professor, 2 affiliated faculty and 19 emeriti- professors and researchers, 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 has very recently changed with the appointment as acting deputy head of associate professor Josefin Larsson.
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 our 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 programme, 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 programme 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 ans 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 programme which has a programme council with one member from each research division, and a PhD student representative, led by the director of the doctoral programme. 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 programmes 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.

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*

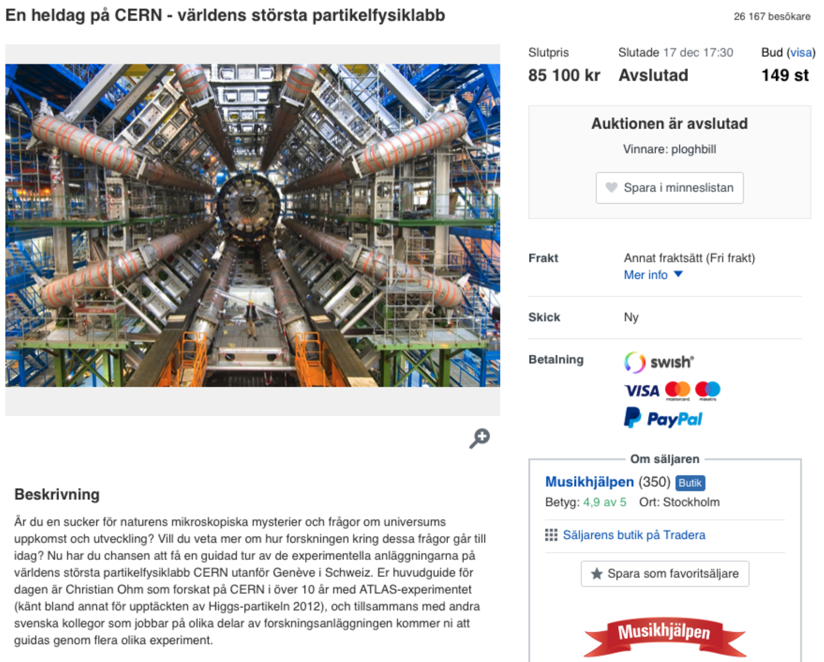
The discovery of the Higgs boson

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. 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



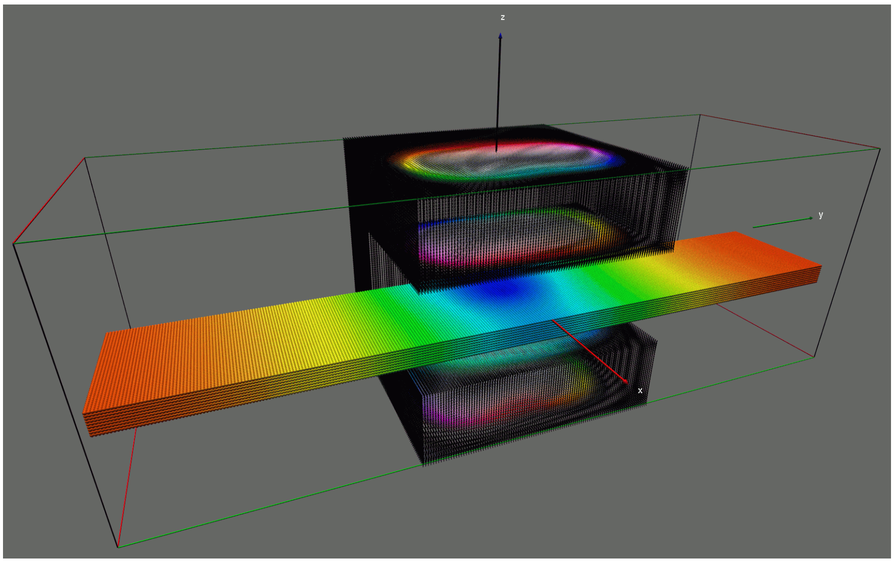
“A full day at CERN” generated 85.100 SEK for charity in 2017.

Superconductivity and quantum computing

A recent case where a long academic research track record was found of great relevance to a major international company is the example of Babaev’s research on superconductivity. The Microsoft corporation has now made strategic investment in developing quantum computer and quantum devices. Microsoft runs the project in collaboration with several Universities world-wide in order to solve a number of extremely difficult challenges that quantum computing entails.

One of the bottlenecks in the process is the necessity to know superconducting correlations and current pattern in superconducting devices. This is a highly nontrivial problem that requires expertise that is absent in industry today. Microsoft performed a worldwide search and identified Babaev's group as the one having the internationally leading expertise that could allow to confront the problem. The expertise in Babaev's group was acquired from decades of research on basic questions in the field of unconventional superconductors.

Since 2016 Babaev and part of his group have collaborated and provided consulting services to Microsoft. The group developed unprecedented capabilities to model superconducting quantum devices using a hierarchy of macroscopic and microscopic models. The acquired leadership allows to advantageously apply these methods to other problems in the emerging quantum technology because the field often utilizes superconducting devices. An example that is exploited locally is superconducting nanowire single photon detectors that are developed in the Applied physics department. A few years ago a joint research environment grant was awarded that funds collaboration of Babaev's group with the applied physics department and Wallin and Lidmar groups joined recently supported by a joint grant with the Zwiller group at Applied Physics via the Wallenberg Foundation. That created the basis for the formation of a new Quantum Technology Center that aims at combining the quantum technology expertise at AlbaNova in the light of the forthcoming EU quantum Technology Flagship. The projected center received a strong support letter from Microsoft and will utilize this collaboration to build up the quantum technology field in Sweden. One of the aims is the internationally strongest center for numerics for quantum computing and technology.



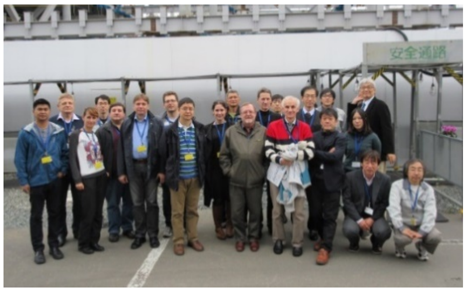
Numerical modelling of hybrid quantum device made of superconducting and magnetic parts

To that end our program includes developing internationally leading numerical capabilities at all relevant length scales. At the micro-scale level, one of the most impactful breakthroughs in recent years was the invention of the Diagrammatic Monte-Carlo (DiagMC) method that was shown to be capable of circumventing the notorious "sign problem", which otherwise usually prevents solving femionic problems. This new method has so far been successfully applied to only a few problems, but with an outstanding track record and promise. We have already acquired a good background in DiagMC. This method will enable us to determine with controllable precision the phase diagrams of whole classes of matter. That can connect with modelling at the level of Bogoliubov-de Gennes (BdG) equations consistent with the phase diagrams. The self-consistent BdG formalism is computationally extremely difficult but is the only viable method to accurately capture quantum effects in superconductors from the microscopic degrees of freedom. Currently we have the best in the world capabilities in fully self-consistent BdG computations. Understanding of these is important not only for basic physics but also for applications in quantum computers and quantum devices. The crucial shortcoming of the BdG method is that solving it at larger length scales is computationally nearly impossible. For example, studying superconducting devices or even a single superconducting qubit for quantum information applications, cannot be done today using the BdG formalism without resorting to approximations. However, in order to interpret many of the experiments, it is necessary to also have accurate solutions at large scales. Obtaining information at larger length scales is currently possible using so-called Ginzburg-Landau (GL) models, but that theory does not capture information on microscopic degrees of freedom and has parameters that are not uniquely determined. The new hierarchical method that we are currently creating will on one hand allow us to constrain the currently undeterminable parameters of the GL models, and on the other hand give boundary conditions dictated by macroscopic physics for the BdG solver that "zooms in" at the physics of microscales. Besides Ginzburg-Landau and BdG equations, we are also developing so-called quasi-classical solvers to additionally bridge into intermediate-scale solutions.

Besides the interest from companies like Microsoft the research program resulted in the creation of a new startup company Quantum and Classical Solutions International AB.

Impact on 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].

Bachelor thesis on neutron star merger

The Bachelor thesis (KEX) of Jonathan Alvelid, performed in 2014 under the supervision of Chong Qi, with title "r-Process Simulation and Heavy-Element Nucleosynthesis", has since been downloaded over 430.000 times from DiVA: Download link

A fundamental question for nuclear astrophysics is the origin of the neutron-rich elements heavier than iron, half of which may be produced by the rapid neutron-capture process (r-process). It is expected that the r-process occurs via a sequence of rapid neutron captures and photo-neutron emission reactions which produces unstable nuclei far on the neutron-rich side of stability. The relative abundance of r-process elements is then determined by the beta-decay rates along the r-process path through which heavier elements (with larger proton number) are produced.

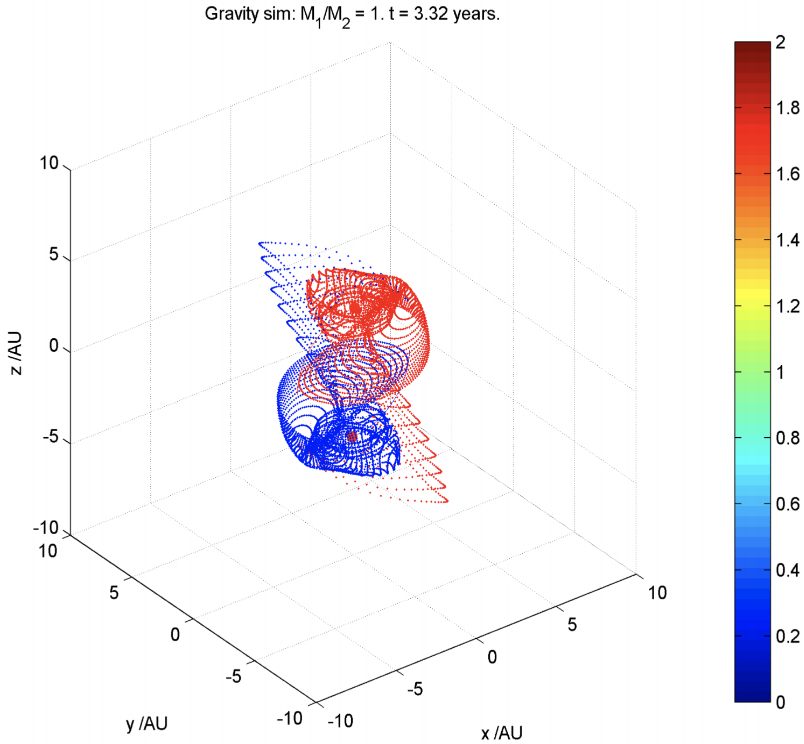
The astrophysical site for the r-process is still mostly a mystery. It is generally expected that the r-process can occur under explosive conditions with high neutron density and temperature. Recent gravitational wave (GW170817 by advanced LIGO and VIRGO) and electromagnetic signal observations indicate that neutron star merger can indeed be a possible site for the r-process. These breakthrough observations may provide fundamental new insights into the r-process and on the nature of dense matter and the nuclear equation of state. In addition to neutron star mergers, core-collapse supernovae and neutrino-driven wind (from the neutron star) can also be possible sites for the r-process. One may even expect that more than one astrophysical site have contributed to the observed solar r-process nuclei abundance.

One difficulty in constraining the r-process property is the lack of experimental data for relevant nuclei. Direct measurements of properties of selected neutron rich nuclei important to the r-process have become possible only recently. Extensive nuclear astrophysical network calculations have been carried out for the r-process. They have so far been relying on predictions from phenomenological nuclear models. The essential nuclear properties that determine the r-process include nuclear masses, beta-decay rates, neutron capture rates fission as well as beta-delayed neutron emission probabilities. Different models must be used for different kinds of quantities, which induce significant uncertainties. In this Bachelor (KEX) project, we did a pioneering study on the theoretical uncertainty in nuclear model predictions of the r-process. The thesis has generated strong interest in the community and to the general public, in particular in relation to the recent gravitational wave observation by LIGO/VIRGO.

We have developed a method based on machine learning and neural network for sensitivity analysis and uncertainty estimation of nuclear mass models. We have also found an evolution algorithm for efficient optimization of nuclear models and for making large-scale nuclear fission simulations.

The equation of state that is used to describe the properties of the neutron star is put as a test. We found that the values of the simulated data fit well the ones obtained from the LIGO and VIRGO observations. In particular we found that the stable mass for the core of the Neutron Star is 1.31 Solar Masses, which is almost the same as the 1.308 Solar

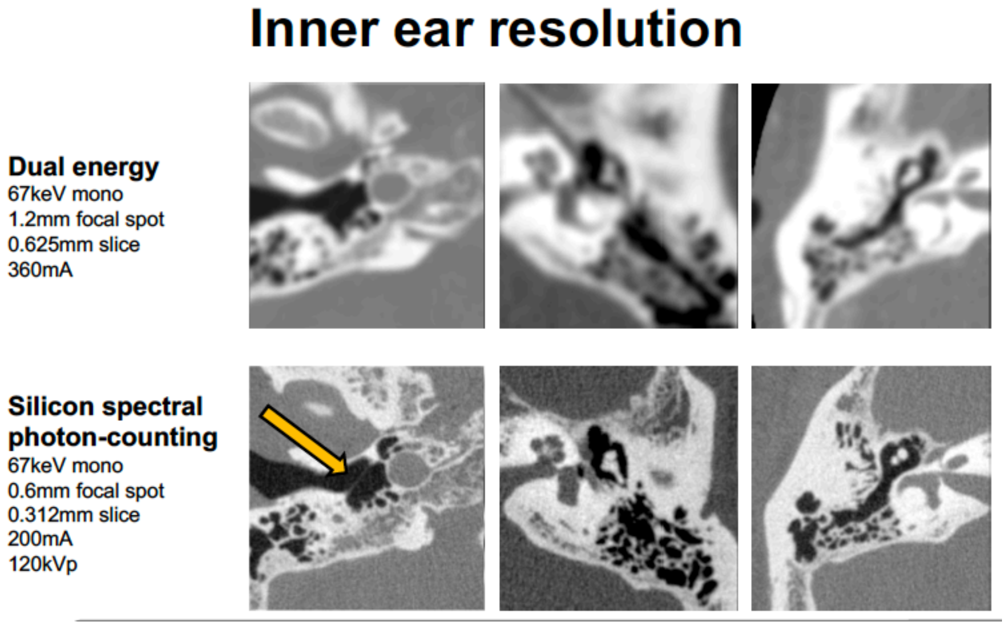
Masses observed from the LIGO observatory. Applying this model to the Relativistic Hartree-Fock set of equations, one can also get values for the Redshifts, Kepler Frequency for the nuclear as well as central energy densities which are within a 5% margin of standard deviation from the observed data. This is a great improvement as compared to values reported in the literature so far.



Simulation of gravitational waves from the merger of two neutron stars.

Photon-Counting X-ray imaging

The physics of medical imaging group 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 have filed over 100 patents covering electronics, detectors and methods for data processing and image reconstruction together with a large number of published scientific articles. The first spin-off company emerging from the 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. Since the female breast is sensitive to radiation and a significant fraction of the population is being screened in national mammography programs this is an important feature. The system branded as "MicroDose Mammography" was installed in at around 1000 hospitals in 40 countries. It was the first FDA approved product for photon counting x-ray imaging. The technology was further developed into Computed Tomography (CT). CT is one of the most common medical examinations and a very important tool for example for stroke, cancer, in emergency rooms for trauma patients and in investigations of the heart. 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. 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 2009, currently with 25 employees. Including subcontractors at least 50 full time employees is currently working on this development and manufacturing, only in the Stockholm region. The plan is to install the next prototype in the Karolinska Hospital at MedTechLabs. 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, the yellow arrow is pointing at the ear drum.



Clear improvement in fine detail resolution using photon counting CT.

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.

A) POSSIBLE 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.

Applied Physics Department

1. Overall analysis and conclusion; strengths and development areas

a. *Limited SWOT-analysis*

1. 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 though 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.

2. 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), 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 m2 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 m2 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 Engineering Science School(SCI) at KTH. It consist of >200 people, and represents 30% of the turn-over of the SCI school.

The department is divided in 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 m2 of experimental facilities: 2000 m2 are specialized labs, and 600 m2 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 Muhammed Toprak,* *Prof.Ulrich Vogt,* *Assoc Prof Anna Burvall,* *Assoc Prof Linda Lundström,* *Assoc Prof Göran Manneberg* *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 also competence is 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:

Prof. Hertz group works in X-ray science and technology (development of sources, optics and applications), with focus on biological applications of x-ray microscopy, phase-contrast imaging and x-ray fluorescence imaging.

Asoc. Prof. Sellberg group 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.

Asoc. Profs. Lundström & Unsbo are active in the field of Visual Optics and work closely with optometrists and ophthalmologists in studies of how peripheral optical errors of the eye affect our vision and with development of optics that can improve the peripheral vision to compensate for loss of the central visual field.

Prof. Widengren group works in fluorescence correlation spectroscopy **(**the current research focus on development of new techniques for fluorescence-based ultrasensitive and ultrahigh resolution fluorescence spectroscopy and imaging with applications in diagnostics, screening methodologies, and for fundamental dynamic and conformational studies of biomolecules.

Prof. Viklund group develops 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.

Prof. Önfelt group (also affiliated with the Department of Microbiology, Tumor and Cell Biology, Karolinska Institutet) studies immune cell heterogeneity using a unique in-house developed microchip platform for parallelized single cell functional analysis. The research aims towards development of new and improved strategies for immunotherapy.

Prof. Brismar group (also affiliated with the Department of Women's and Children's Health, Karolinska Institutet) works on the development and application of advanced light microscopy for studies in developmental biology, nephrology and neurology, primarily based on a clinical motivation and relevance (pediatric). The group's present studies concern disease mutations of Na,K-ATPase, the sodium pump.

Asoc. Prof. Testa group develops and applies new concepts of parallelized and smart target-switching in super-resolution microscopy (based on STED and RESOLFT). The aim is to push forward the quantitative aspects of live cell imaging, currently applied to the precise identification of selected neuronal proteins and organelles in their native environment.

Prof. Lindahl group (also affiliated with the Department of Biochemistry & Biophysics, Stockholm University), seeks to understand the properties of membranes and membrane proteins in general, and ion channels in particular. Method development includes computational chemistry, molecular dynamics simulations, bioinformatics, molecular biology, cryo-electron microscopy, neutron scattering, and electrophysiology.

Asoc. Prof. Delemotte group aims to understand the molecular basis for ion channel function and modulation. Research includes development of computational methods that go beyond the static picture afforded by classical structural techniques and also push the boundaries of what these computational methods allow to do.

Prof. Hess group aim to understand how interactions at the molecular scale affect events at larger scale, both in macromolecules and in wetting. The group develop methods for molecular dynamics and accelerated sampling of conformational transitions (all implemented in GROMACS, of which Berk Hess is a main developer)

OPTO AREA

The research is primarily on optical materials, fibers, lasers and coherent light sources including THz and materials for X-rays optics. Research areas include optical material characterization, 3d-printing/additive manufacturing of glass, fabrication of semiconductor-core glass-clad optical fibers, nano- and microstructure technology for nonlinear materials, domain-engineered ferroelectrics, light source design, parametric light sources for the mid-IR and THz, and functional fiber components.

The core of research is built around spatially and compositionally functionalized materials for advanced photonics research and applications. This allows extending existing possibilities to novel wavelength areas and creates some unique devices with designed temporal or spatial formats. Novel glass composites, ferroelectrics, semiconductors and polymer materials are presently under investigation. Global challenges related to energy, climate, sustainability and health is motivating and driving the overall research direction, but part of it is also purely curiosity driven.

Prof. Marcinkevicius group focus on studying fundamental material properties for wide band gap semiconductors (GaN, InGaN, AlGaN, G_2O_3) that find applications in UV and visible LEDs and laser diodes, and power electronics. The goal of this research is novel concepts and improved efficiency of mentioned photonic and electronic devices. This is done with a unique ANSOM technology.

Dr. Yan group develops Mid-infrared integrated photonics, looking for suitable Materials and technologies for especially MIR generation and wave manipulation, towards ubiquitous gas sensing and information transfer.

Prof. Popov research deals with high-capacity low-energy optical communication and advanced materials for photonics. The first part includes implementation of advanced and complex modulation formats in high-capacity optical communication to improve the efficiency of systems via decreasing the overall cost, energy consumption, and optimized use of available spectral band. The latter deals with the study of polymer-based optical materials targeted for applications ranging from communication to decoration and smart construction elements, with the aim of developing the truly sustainable optical materials suitable for industrial manufacturing in bulk scales.

Prof. Canalias research is devoted to engineering the linear and nonlinear properties of ferroelectric nonlinear optical materials. She develops both material engineering techniques, and material characterization techniques. Her group is also devoted to develop novel frequency conversion schemes, as well as integration of the engineered ferroelectric with other dielectric materials for increasing the functionality of the photonic devices.

Prof. Pasiskevicius research addresses questions related to development of nonlinear optical technologies for societal applications. This includes development of engineered dielectric and semiconductor nonlinear materials, their applications in novel coherent light sources, manipulation of light fields employing functional metasurfaces, development of methods for high-field mid infrared and THz fields, development of high-energy narrowband wavelength agile sources. Addressed applications include laser spectroscopy, environmental gas LIDARs for ground based, air-borne and space-borne missions, laser surgery, sources for high-capacity future generation wireless communications and sensing.

Assoc. Prof. Fokine together with **Guest professor Gibsson** group works on semiconductor-core optical fibers (Si, Si/Ge), which are developed for mid-IR and THz transmission lines and for combined opto-electric functionality. With our advanced CO_2 processing technique, we have obtained world-record low loss in the infra-red for these fibers and been able to form both gratings and graded index structures. Recently we demonstrated THz transmission for such fibers for the first time. This has potential applications in medicine, sensing and the next generation telecommunication. In the glass processing laboratory, Fokine group works laser assisted fabrication of 3D structures in glass. It includes preforms with complex shape, printing from powder and from fiber.

Prof. Laurell group focuses on functionalizing materials and apply these in laser, nonlinear optics and other photonic applications. Emphasis is on ferroelectrics, diode-pumped solid-state and fiber lasers, special optical fibers and in additive and subtractive processing of glass. Our multifunctional fibers are optical fibers capable of integrating fluid, gas and electric field handling with light guidance and apply them in life-sciences and optoelectronics, with recent focus on their use in biotechnology and medicine, particularly for biopsy and therapy of pancreatic cancer.

Prof. Vogt group designs and manufacture diffractive zone plate optics with diffraction-limited resolution in the 10 – 100 nm range for nanobeam imaging in the soft and hard x-ray range. Together with partners from Lund University we built the NanoMAX beamline at the Swedish synchrotron radiation facility MAX IV and currently we design a new zone-plate-based x-ray microscope end station. The long term goal is 3D x-ray imaging experiments on the 10 nm resolution level.

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.

Prof. Haviland leads research towards measurements at the quantum limit of action and reaction; Quantum limited force transduction with application to Atomic Force Microscopy (AFM); classical digital interface to control quantum computers; application of Field Programmable Gate Array (FPGA) technology to scientific measurements; noise squeezing and back-action evasion in measurements limited by thermal noise, with applications to AFM.

Prof. Korenivski conducts research in the field of nanomagnetism and spin-dependent transport, with the latest focus on spin dynamics and relaxation in spin-vortex and antiferromagnetic-multilayer systems, as well as spin-thermionics based on RKKY-exchange. The nanostructures produced and investigated are relevant for applications in vortex-type memory and demagnetization-type nano-calorimetric devices.

Prof. Björk and dr. Swillo lead research on quantum information technology, investigating in which areas, and to what extent, quantum technology can be utilized to improve communication, confidentiality, and measurement resolution and accuracy. Additionally, optical nonlinearities in semiconductor nanostructures are studied, with main applications in highly integrated quantum optics experiments as well as in nonlinear waveguide optics, nano-sources of entangled photons for novel applications in bio-imaging, SNOM, two-photon microscopy, sensing, quantum information and quantum imaging.

Prof. Zwiller and Dr. Jöns research a broad range of hybrid quantum photonic devices to generate and manipulate the quantum state of light for on-chip and long-range quantum communication and sensing applications.

Prof. Gallo's research is on coherent processes and nonlinear interactions in classical and quantum regimes, developing ferroelectric and photonic technologies for switching, communication and sensing, leveraging the tools of nanotechnology and integrated optics.

Prof. Sun and Prof. Lourdudoss focus on 1) Buried heterostructure quantum cascade lasers (QCL) for high speed modulation and free space communication, 2) orientation-patterned GaP (OP-GaP) nonlinear optical crystal for quantum photonics and 3) III-V/Si heterojuctions for phonic integration and multijunction solar cells.

Prof. Anand's research focus is on utilization of photonic semiconductor nanostructures for light manipulation functions and enhanced light matter interaction for applications in optics, optoelectronics and sensing.

Dr. Linnarsson studies precise accelerator based doping and analysis of SiC for power electronics.
Prof. Linnros has developed silicon-chip based biomolecule sensing technology and devices.

Prof. Sytjugov studies basic properties of nanoparticles, in particular optical properties of Si, and their use as sensors or light emitters.

Prof. Toprak group focuses on development of nanomaterials fabrication strategies for application 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.
Prof. Dutta group on Functional Nanomaterials develops functional nano materials for 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 is studied.
Prof. Tjernberg group studies 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. This group is particularly active in developing methods for time, angle and spin resolving electron spectroscopy, both using lasers and synchrotron radiation (MAX-IV)

Profs. Weissenrieder and Prof. Göthelid studies surface structures and reactions of relevance for catalysis with atom resolving microscopy and synchrotron radiation based spectroscopy. Prof Weissenrieder is also running an ultrafast electron microscope. He is also active in development of beamlines at MAX-IV.
Prof. Delin develops computational methods for spin dynamics and spin-lattice dynamics, angular momentum transfer between spin system and lattice.

Ass. Prof. Månsson develops and uses methods for materials analysis at large-scale facilities in particular neutrons and muons, with particular emphasis on energy materials.

The department has for many years played a very active role in synchrotron radiation based science, and are at present involved in the development of three beamlines at MAX-IV; HIPPIE, Bloch and Veritas. MNF also has a leading position in Sweden for work using neutrons and muons, of central relevance in connection to the construction of ESS

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

Soft x-ray liquid-jet laser-plasma sources. The Hertz group pioneered the 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 x-ray microscopy.

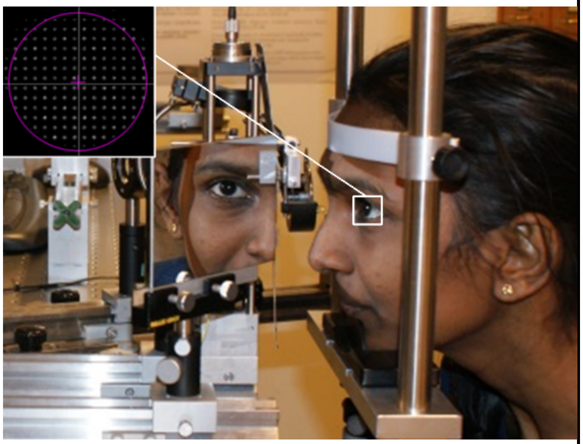
Soft x-ray laboratory microscopy. The Hertz group demonstrated the first sub-visible-resolution laboratory water-window x-ray microscope (2000), the first "real" applications (soil science, 2009) and the first lab 3D cryo-tomography of intact cells (2011). Recent work is on autophagy, NK-cell interaction (2018) and virus dynamics (2020).

Hard x-ray liquid-metal-jet sources. The Hertz group pioneered the liquid-metal-jet-anode x-ray source (2003). This electron-impact source allows for up to 1000× higher brightness than any existing laboratory microfocus x-ray tube. The technology is now successfully commercialized by our start-up company (www.excillum.com).

Hard x-ray phase-contrast bio imaging. The Hertz group 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).

X-ray fluorescence (XRF) imaging: The Hertz group were the first to identify a viable path for XRF 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 nanoparticles and photon-counting detectors.

X-ray free-electron laser science: Research in Sellberg 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.



Visual Optics: Lundström & Unsbo have 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

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.

Microscale acoustofluidics: Viklunds group have recently made progress in transferring the technology for acoustofluidics cell manipulation from bulky and expensive equipment, to simple, compact and extremely inexpensive. We collaborate with theoretical experts at DTU-Copenhagen, and with oncologists at Karolinska Institute and Hospital. Most important, we collaborate internally with Önfelts 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.

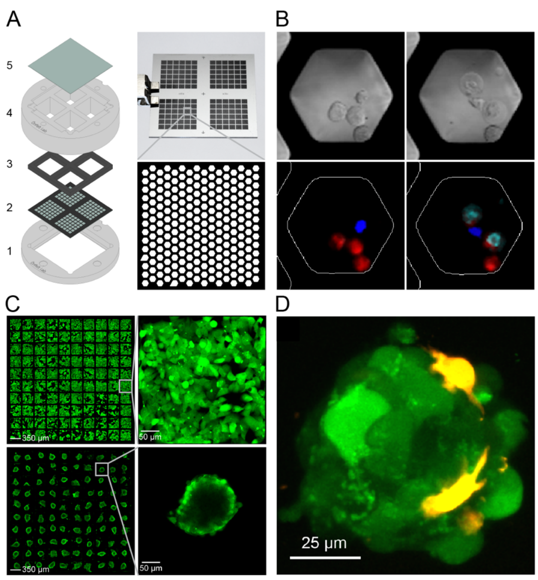


Fig. Microchip platform. Screening of NK and T cells reactivity at the single cell level. Microwells (60 µm) are etched in a microchip made of silicon and glass, which is fitted in a custom-made holder enabling exchange of media and CO_2 for long-term live cell imaging.

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.

Cellular Biophysics: Brismar's group have during the past 20 years contributed to the development of advanced microscopy methods by the needs raised in their studies of membrane proteins, in particular of Na,K-ATPase. We have developed and applied imaging methods to identify feedback mechanisms that regulate Na,K-ATPase and also found that Na,K-ATPase is a signal transducer acting via slow calcium oscillations that activate Nf-kB and alter the signal balances in apoptosis. We have demonstrated the medical

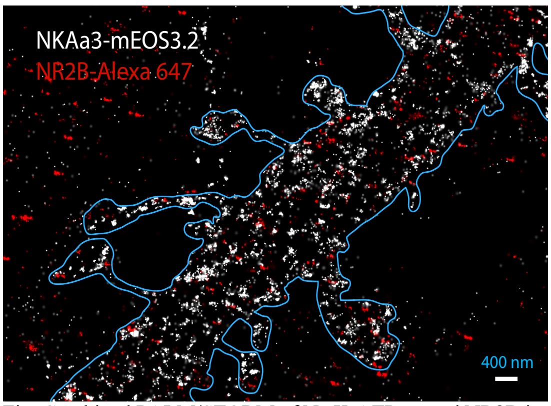


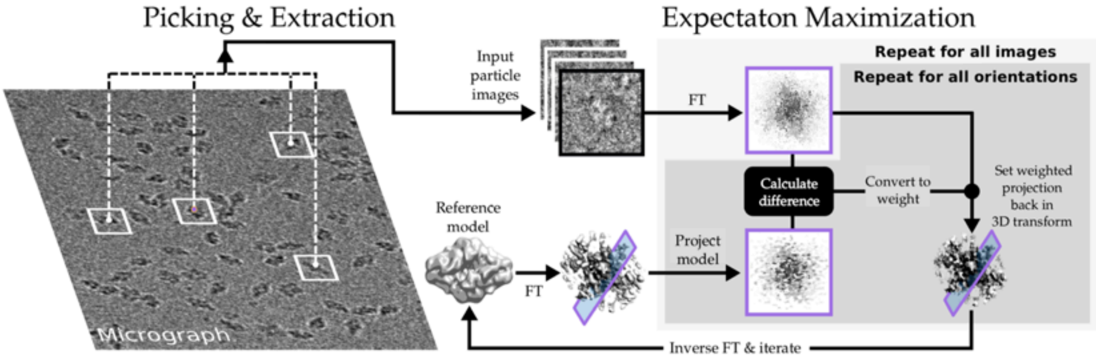
Fig. Combined PALM/STORM of Na,K-ATPase and NR2B in a hippocampal neuron.

impact of this finding 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.

Super-resolution microscopy: Testa's group have in the last five years 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.

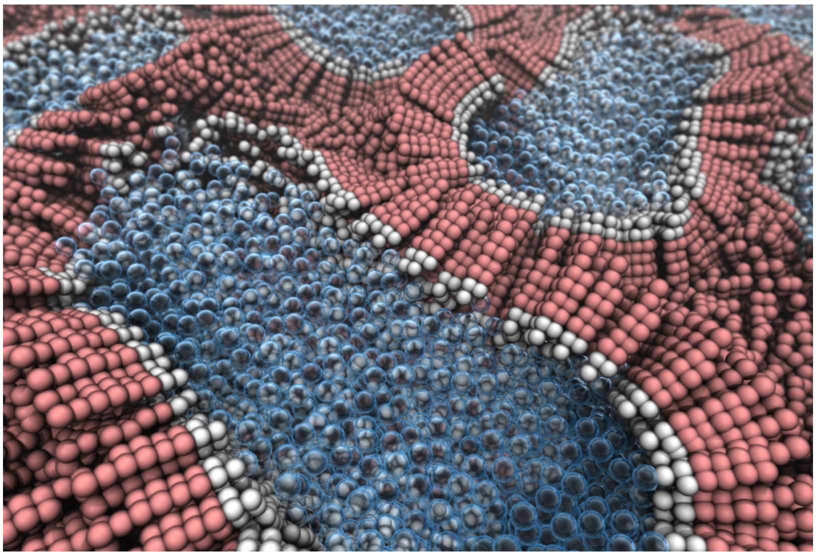
GROMACS: The biomolecular simulation program GROMACS, developed in the Lindahl & Hess groups, has become the most used open source code on supercomputers in the world, enabling hundreds of high-impact advances by other teams.

RELION: Lindahl's group is 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.



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.

Molecular Biophysics: Lindahl's 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.



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.

Computational Biophysics: Delemotte's group have 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.

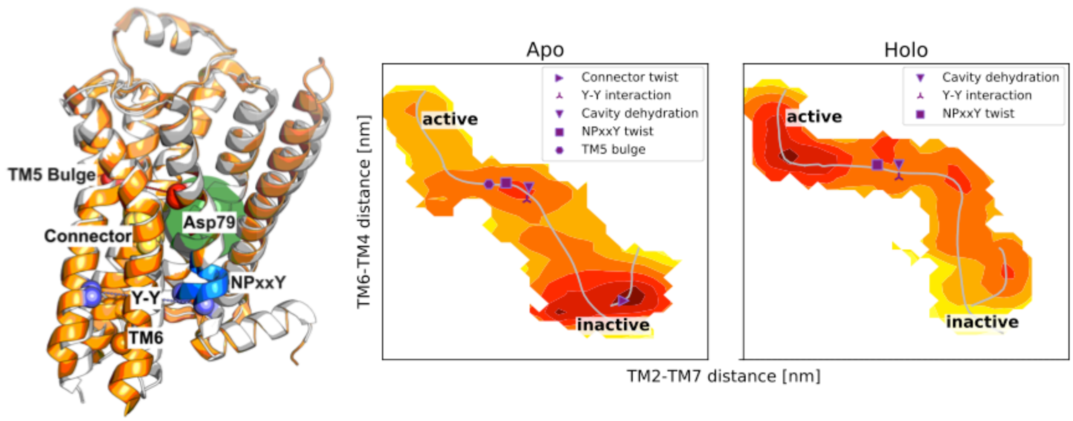


Fig: Activation path of the beta adrenergic receptor highlighting the sequential flip of microswitches along the path, in a manner that depends on ligand binding.

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-phasematching (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.

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 χ(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).

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

BIO

Hertz:
Internal: Nanolab, confocal microscopy @ Sci Life.
National: Karolinska Inst (molecular markers, zebra fish, pathology); Karolinska Hospital (pathology); Uppsala U (virus); Lund (MAX IV).
Internat'l: TU Munich (imaging) , ETH Zurich (imaging), Stanford (visiting prof, zone plates).

Sellberg:
My most important research collaboration to further develop coherent diffractive imaging of biomolecules is led by Dr. Filipe Maia at BMC, Uppsala University. It is an international collaboration that involve community proposals at MHz repetition rate sources, technique development through the single-particle imaging initative at SLAC National Accelerator Laboratory and numerous beamtimes at x-ray free-electron lasers around the world.

Lundström:
National collaboration with the optometry education at KI as well as the ophthalmic section of Astrid Lindgrens child hospital and the optometry education at Linnaeus University in Kalmar. International collaboration within Marie-Curie Research Training Networks from 2007 until now (MyEuropia, OpAL, MyFUN) involving 5-6 academic and 2-3 industrial partners in Europe. Individual research collaborations with 1 lab in USA + 1 in Australia. Visits, knowledge exchange and joint review publications with many more. Most outcome related to myopia prevention.

Widengren:
The group has many research collaborations, often interdisciplinary, on a national and international level, e.g. National: B Henriques-Normark, KI; G Auer, KI; E Norberg, KI; P Brzezinski, SU, P Ädelroth, SU. International: CAM Seidel, Univ Düsseldorf; SW Hell, MPIBPC Göttingen; J Lee, DGIST, South Korea; JC Ren, SJTU, China; M Kinjo, Hokkaido Univ, Japan; M Rabasovic, Univ Belgrade.

Viklund:
National: Prof. Björn Önfelt (in-Department collab. during the last 10 years); Assoc. Prof. Andreas Lundqvist (Oncol.-Pathol., KI); Prof. Aman Russom (KTH Biotechnology); Assoc. Prof. Dmitry Grishenkov (KTH Medical Technol.). International: Prof. Henrik Bruus (DTU-Copenhagen); Prof. Madoka Takai and Prof. Shu Takagi (Univ. of Tokyo), EU-networks (CellPROM and RAPPID projects). Outcomes: Several published papers, invited talks and sabbatical periods.

Önfelt:
The group has several important collaborations, national and international collaborators. During the last decade we have built up a strong national network of researcher, mainly through collaborative grants where I have been the coordinator on most of them. Most international collaborations has been through technology transfer from our lab to other Biological Labs. On fruitful collaboration is with Prof Jeffrey Miller, one of the pioneer in cellular immunotherapy with natural killer (NK) cells. In a first step we performed experiments in our lab investigating efficacy of immuno-oncology drugs developed by them. In a second step we have transferred our technological platform to their lab at the University of Minnesota.

Brismar:

Collaborator	Affiliation	Type of collaboration
Stefan W Hell	MPIBPC, Göttingen	Super resolution, Postdoc exchange
Sara Abrahamsson	UCSC, Santa Cruz	Microscopy development, PhD cosupervision
Antoine Triller	ENS-INSERM, Paris	Lateral diffusion, Postdoc exchange
Christophoro Scavone	Univ. Sao Paolo	Na,K-ATPase, PhD student exchange, joint grants
Edouard Pesquet	Stocholms Univ	Cytoskeleton research, PhD cosupervision
Poul Nissen	Aarhus Univ.	Na,K-ATPase structure and regulation
Per Svenningsson	Clin. Neuroscience, KI	Publications, PhD cosupervision, joint grants
Christian Broberger	Neuroscience, KI	Publications, PhD cosupervision

Testa:

Vladislav V. Verkhusha, Protein Engineering, Albert Einstein College of Medicine, NY, USA (2 publications + 1 ongoing project)

Konstantin A. Lukyanov & Alexander Mishin, Protein Engineering, Russian Academy of Sciences, Moscow, Russia (1 publication)

Andrew York, Optic element design, Calico-Google-, SF, USA (1 publication)

Johanna Rorbach, Mitochondria Biology, Karolinska, Stockholm, Sweden (2 ongoing collaboration)

Giuseppe Vicidomini, Fast detector technology, IIT, Italy (1 publication)

Silvio Rizzoli, Synaptic tagging strategies, University of Göttingen, Germany (1 publication + 1 ongoing project)

Delemotte:

University of Madison Wisconsin	USA	Baron Chanda
Uppsala University	Sweden	Jens Carlsson
Linköping University	Sweden	Fredrik Elinder
University of Madison Wisconsin	USA	Gail Robertson
Columbia University	USA	Ann McDermott
Simon Fraser University	Canada	Peter Rueben
Stockholm University	Sweden	David Drew
University Sidi Mohamed Ben Abdellah, Fez	Morocco	Yassine Amarouche
IPBS	France	Matthieu Chavent
IBPC	France	Jerome Henin

Lindahl:

We have a large international network for molecular simulation, including e.g. MPI Göttingen, UIUC, UVirginia, UColorado, Utrecht University, IRB Barcelona, University of Manchester, and Jyväskylä University, and the EU BioExcel Center-of-Excellence we lead at KTH. Our ion channel work includes collaborators at the Pasteur institute for X-ray structures, UT Southwestern for cryo-EM, and Copenhagen University for neutrons, which has resulted in a number of high-impact cross-disciplinary studies.

Institut Pasteur
UT SOUTHWESTERN MEDICAL CENTER
Max Planck Institute for Biophysical Chemistry
University of Colorado Boulder
University of Virginia 1819
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
UNIVERSITY OF JYVÄSKYLÄ
MANCHESTER 1824 The University of Manchester
IRB BARCELONA INSTITUTE FOR RESEARCH IN BIOMEDICINE
MRC Laboratory of Molecular Biology
UNIVERSITY OF CAMBRIDGE
Utrecht University
東京大学 THE UNIVERSITY OF TOKYO
RIKEN
KAROLINSKA UNIVERSITETSSJUKHUSET
SIGILLVM UNIVERSITATIS HAFNIENSIS
UMEÅ UNIVERSITET
Stockholm University
TEL AVIV UNIVERSITY אוניברסיטת תל אביב
JÜLICH Forschungszentrum
LINKÖPINGS UNIVERSITET

Hess:

OPTO

U. Vogt proposed, designed and build the NanoMAX beamline at MAX IV, a flagship beamline for x-ray nano imaging and diffraction, together with researchers from MAX IV and Lund University.

Laserlab Sweden (http://laserlab-sweden.se/) network including KTH, Uppsala University, Lund University, Chalmers TH, Göteborg University, Umeå University. Joint experimental and educational work resulted in several scientific papers and organization of a yearly PhD course in experimental laser physics where all universities contribute with facilities and students.

RISE-(Research Institute of Sweden) and Science for Life Laboratory -Extensive work in the project Multi-functional Optical Fibers.

Marcinkevicius group has an extensive collaboration on fundamental material properties of wide band gap semiconductors with prof. S. Nakamura (Nobel Prize in Physics 2014) at University of California, Santa Barbara (UCSB).

Swedish Defence Agency (FOI), Linköping – joint work on development of highly sensitive mid infrared imaging using frequency upconversion correlated photon counting. Result: published journal article 2020

Optical communication projects are run within Kista High Speed Transmisison Lab, jointly operated by KTH and RISE AB, they also include participation of our Semiconductor research group (Prof. Lourdudoss), several EU projects, and companies (Finisar AB, Infinera AB). Research on advances optical materials brings synergy collaboration with Nano-material group (Prof. Linnros), and the Wallenberg Wood Science Center (Prof. L. Berglund), and uses technologies and processes from semiconductor, polymer, and wood industry.

Some example of larger international projects 2010-2020:

European Space agency: GENUIN demonstration of frequency agile nonlinear optical sources. European Defence Agency: MICLID – development of high-energy mid-infrared lidar in 7-11 µm region. EU H2020: LEMON – development and demonstration of airborne LIDAR for environmental gas monitoring. Development space mission roadmap. US Naval Research Lab: collaboration with Boston University on power scaling of high-order mode optical fiber sources in the visible. EU COST Action MP1401: Advanced fibre laser and coherent source as tools for society, manufacturing and lifescience. Allowed, establishing and maintained collaborations with research groups throughout EU.

Other international collaborations:

DESY Hamburg (Germany). Output: conference presentations.

Max-Born Institute (Germany). Output: research articles and conference presentations.
Institute Neel (France). Output: research articles and conference presentations.
ONERA – French aerospace lab. Output: research articles and conference presentations.
Vilnius University (Lithuania). Output: research articles and conference presentations.
Institute d'Optique (France). Joint ongoing experiments.
Zhejiang University (China). Output: research articles and conference presentations.
Wroclaw University of Technology. Output: research articles and conference presentations.
BAE Systems (USA). Output: research articles and conference presentations.
KAIST (S. Korea). Output: research articles and conference presentations.
University of Pavia (Italy). Output: research articles and conference presentations.
Institute St.Louis (France). Output: research articles and conference presentations.
NTNU (Norway) and Clemson University. Semiconductor Core fibers, THz physics

NANO

We are heavily involved with Per Delsing's group at CTH on Quantum Computation within WACQT (Wallenberg Centre for Quantum Technology, sponsored by KAW), supplying them with electronics, getting and studying samples from them. Within WACQT we have numerous other collaborations in quantum electronics and quantum photonics. We have numerous international collaborators with our work on AFM. From big companies (Exon-Mobile) to small universities (U. Mons, Belgium). Many groups have purchased our technology.

We have a longstanding collaboration on quantum optics with Universidad Complutense, Madrid, Spain, and with the Max Planck Institute for the Science of Light, Erlangen, Germany. These collaborations have resulted in many tens of research papers and have led to other collaborations in Canada, and Mexico.
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 chair man 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)

- Internatioal 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.] (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 a book chapter, 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-probes for in-vivo bio-imaging. 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 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. (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
  KTH/Aphys is highly involved in (Assoc. Prof. Martin Månsson is the Director of Studies for) 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 contains 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. The influence of SwedNess spans over a very wide range covering education, scientific results as well as societal impact, which has been featured in several articles:
  - Neutron scattering course for Swedish students, Norwegian Center for Neutron Research (NcNeutron), February 2018,
  - Sverige kan förändra världen, Analys Sverige, 28 February 2018,
  - Regional Graduate Schools on Neutron Scattering Build Foundation for Early Science at ESS, European Spallation Source (ESS), 9 October 2017,
  - Forskarskola i neutronspridning – strategisk satsning som inger respekt, Framtidens Forskning, 28 June 2017,
  - Forskarskola ska sätta Sverige på kartan, NyTeknik, 25 January 2017 2016
  - 120 MSEK to the Swedish Graduate School in Neutron Scattering, KTH News, 29 June 2016

- **KTH/NORDITA/Chalmers/Paul Scherrer Institute/University of Zürich/ESS**:
  This collaboration covers technical developments related to mainly the European Spallation Source (ESS) in Lund, as well as the organic materials database (OMDB). The project is financed from several sources including SSF, 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). The main focus of this project is sustainable batteries including lithium/potassium/sodium based materials and devices. (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 over head. 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 Photnics 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 to 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.
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 level̊, 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 aquired 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 we 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 elecron 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 synthetisation, 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 infrstructures. 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, thestudents 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), energy storage and fuel cells is 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 (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. I am continuously using my 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.

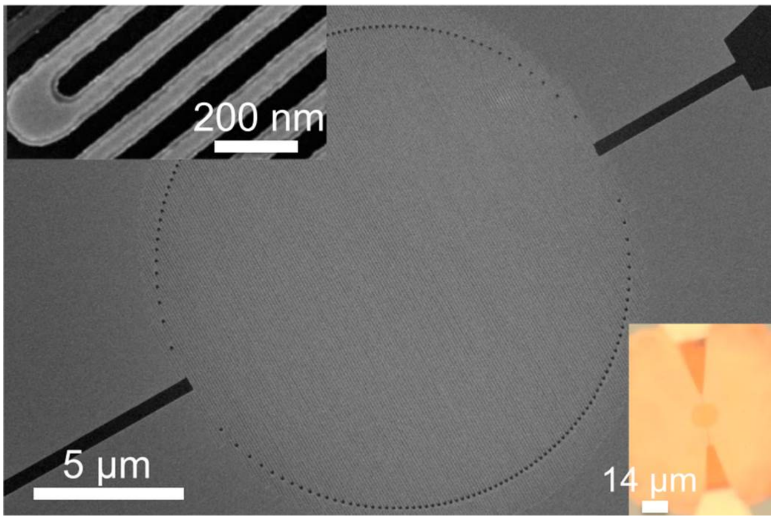
Some examples of recent projects with clear SDG focus:

- 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 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

1) Single quantum

Single Quantum, a spinoff from the Zwiller group (KTH-APhys), commercializes high-performance single-photon detectors based on superconducting nanostructures. The outstanding supercondcuting film deposition and nano-patterning processes available at KTH-ANL enable joint R&D of KTH and Single Quantum on developing a new generation of single-photon detectors with the time resolution, noise level, and detection efficiencies setting new standards in quantum optics [1]. The application space is the booming quantum communications, where SQ is one of the fastest growing start-ups internationally.

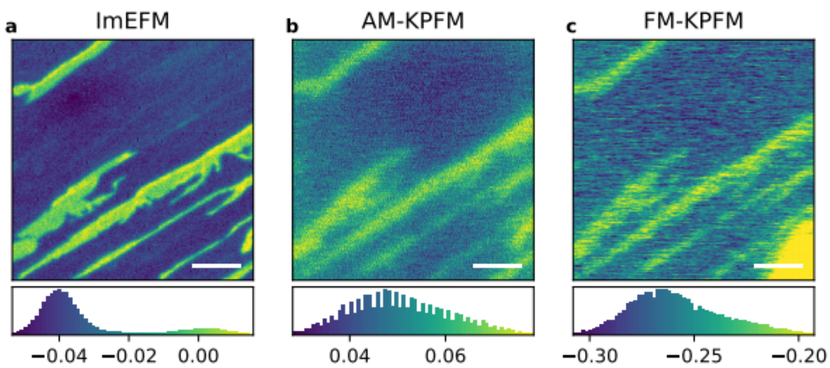


[1] J. Zichi, J. Chang, S. Steinhauer, K. von Fieandt, J. W. N. Los, G. Visser, N. Kalhor, T. Lettner, A. W. Elshaari, I. E. Zadeh, and V. Zwiller, "Optimizing the stoichiometry of ultrathin NbTiN films for high-performance superconducting nanowire single-photon detectors", Opt. Express 27, 26579-26587 (2019).

Figure main panel: top view of superconducting NbTiN meander-patterned single-photon detector; top-left: meander-nanowire close-up; bottom-right: detector integrated with optics.

2) Intermodulation Products

KTH-ANL hosts the biggest and most versatile atomic force microscopy (AFM) lab in Sweden. Thanks to this rich and flexible environment, Intermodulation Products AB was founded as a spinoff of the Haviland group (KTH-APhys). Intermodulation Products AB commercializes add-on equipment to labs and users who want to extend the measurement capabilities of their AFM with mechanical, electrical and magnetic characterization, for applications ranging from energy materials to life sciences. All the special modes developed by Intermodulation Products are available to users of the KTH-ANL AFMs. The start-up is actively expanding its products space, e.g. to high-speed multi-frequency lock-in systems.



Comparison of Intermodulation EFM and KPFM by first-time users of AFM in the KTH-ANL. Maps and histograms of work function in volts measured on a graphene monolayer (blue) with flakes of bilayer graphene (yellow). The graphene is thermally grown on a silicon carbide (SiC) substrate. The white scale bars are 3 µm. From R. Borgani, PhD Thesis, KTH 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.

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.

B) POSSIBLE 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.