KVANTUM INSTITUTE
UNIVERSITY OF OULU

Public descriptions of the Kvantum Institute projects in period 2021-2024

(in alphabetical order by Principal Investigator)

Arctic Ionospheric Response to Space Weather Events (ACROSS)

PI: Aikio, Anita

The ionosphere in the Arctic region, where aurora (Northern lights) can be seen, is the most sensitive region on the globe to Space Weather. In the ACROSS project, we will quantify the changes produced in the Arctic ionosphere-atmosphere system by the two most common Space Weather events: coronal mass ejections from the Sun and solar wind high-speed streams. We will study how the Arctic electron densities are affected, how the ionosphere is heated, and how the heated atmosphere is upwelling. We will use the world-leading EISCAT_3D radar, the EISCAT Svalbard radar, Fabry-Perot spectrometers, auroral cameras, magnetometers as well as a large number of other instruments. We will develop advanced data analysis tools using Bayesian approach and utilize computer simulations. The results of the project are important for making better space weather predictions e.g. for ionospheric storms and related increased satellite drag, HF radio communication and GNSS navigation disturbances.

Exploring geographical mismatch between supply and demand of ecosystem services using big and open source data across high latitudes (AccESS)

PI: Alahuhta, Janne

Human welfare relies on the availability of ecosystem services. Mapping can be used to illustrate and quantify the geographical mismatch between places where ecosystems' produce services and the location where people use them. This project carried out in the Geography Research Unit of the University of Oulu will utilize novel Geographic Information System-based accessibility methods to evaluate availability of ecosystem services at multiple spatial and temporal scales in terrestrial and aquatic systems at high latitudes. We will develop new multidisciplinary approaches to quantify how well people can utilize ecosystem services but also how species movement influences on ecosystems' capacity to produce services by using existing and open source data. The main goal is to increase our knowledge on the sustainable use of ecosystem services and provide easy-to-read maps of ecosystem services, which can improve policy actions to achieve fair and prosperous future for people and planet.

Energy- and cost-efficient production of solar energy under arctic environmental conditions

Responsible PI: Fabritius, Tapio
Co-PIs: Antonio Caló, Jean-Nicolas Louis, Christian Schuss

This project focuses on opportunities to enable a sustainable energy production under Arctic environmental conditions and an energy-autonomous individual transportation of human society. We concentrate on the improvement, optimization, and maximization of the degree of efficiency of photovoltaic (PV) installations and materials in Arctic conditions. The project considers both stationary PV installations on top of buildings and moving PV installations embedded in passenger vehicles to extend the electric driving range (EDR). The research uses both high frequency measurements from the University of Oulu research infrastructure and mathematical model development to integrate the impact of climate change variation on the future solar production. As a result, we make solar energy production more efficient and, at the same time, more cost- efficient.

CLEAN^{2}STEEL - Towards carbon-neutral steelmaking through hydrogen- reduction and application of clean steels

Responsible PI: Fabritius, Timo
Co-PIs: Qifeng Shu, Eetu-Pekka Heikkinen

Global climate change caused by greenhouse gas emissions is one of the biggest challenges in contemporary society. To tackle these challenges, the Process Metallurgy Research Unit is developing new concepts to reduce emissions of the steel production (which is responsible for 7% of anthropogenic CO_2 emissions) as well as new material solutions to reduce emissions during steel usage in the Kvantum project "Towards carbon-neutral steelmaking through hydrogen-reduction and application of clean steels (Clean^{2}Steel)". The primary aim of this project is to study different concepts to replace fossil-based carbon with hydrogen as a reducing agent in ironmaking which has the largest cause of GHG emissions in steel production. The secondary aim is to enable high steel cleanliness to produce advanced high-strength steels which can be used to design lightweight structures and thereby decrease the fuel consumption and lifecycle CO_2 emissions. The project will provide fundamental and applied knowledge on hydrogen reduction and advance high strength production and thereby contribute to the reduction of CO_2 emission from steel industry and transportation.

Hybrid modelling for improved permafrost risk assessments (HYPERISK)

PI: Hjort, Jan

The Arctic is undergoing unprecedented changes, with permafrost thaw as one of the most striking examples. Permafrost is critical because it controls landscape processes and human activities in the north. The HYPERISK project addresses research challenges highlighted in the recent IPCC reports. Using geospatial data-based statistical analysis, we produce high-resolution permafrost projections, identify critical permafrost hazards, and quantify infrastructure risks across the circumpolar permafrost area. The site of research is Geography Research Unit. Our ground-breaking approach is to apply multidisciplinary methods to assess the impacts of near-future climate change on permafrost, environment and human activities. The results have theoretical and applied implications and considerable societal significance. The project has the potential to provide benchmark results for the effects of global warming on the permafrost systems, natural hazards and infrastructure risks.

Electronic level understanding of transition metal based heterojunction catalysis (NANOCAT)

Responsible PI: Huttula, Marko
Co-PIs: Wei Cao, Matti Alatalo, Samuli Urpelainen, Satu Ojala

NANOCAT project uses modern experimental and modeling methods to resolve the fundamental phenomena related to solar light driven photocatalytic processes for clean energy production and water purification. The information resolved is used in the development of more efficient functional materials leading to more sustainable energy production, cleaner environment and wellbeing of humankind. The work is based on earlier developed functional materials that have shown great promise in terms of efficiency in preliminary experiments. NANOCAT is realized in collaboration with NANOMO and ECE research units combining the experts in fundamental physics with applied research.

Carbon-capturing magnesium cement (CARBO-CEM)

PI: Illikainen, Mirja
Co-PIs: Päivö Kinnunen, Minna Patanen

Modern civilizations are dependent on concrete for housing, infrastructure and defense. However, currently 5-8% of global greenhouse gases are emitted during production of cement, the binder used in concrete. Magnesium carbonate cements are an emerging class of cements, which can capture carbon dioxide during hardening, opening prospects for long-term carbon capture and utilization (CCU). Such cements are early in development, and reaction mechanisms are poorly understood. CARBO-CEM will concentrate on studying innovative methods to improve magnesium carbonate cement reactions, from pre-treatments to reaction modifications and final product properties. To aid in the experimental investigation, we will use modelling tools as well as state-of-the-art characterization methods, and develop new ones. This research will aid in bringing carbon-capturing cement closer to commercial applications. The research will be conducted at the University of Oulu (link).

Global change impacts on northern animal communities: from mechanisms to ecosystem-level implications

PI: Kivelä, Sami

Declining animal abundance has been repeatedly reported in recent times. This project, conducted at the Research Unit of Ecology and Genetics, University of Oulu, examines if such declines occur also in northern environments by using moths and birds as the study system. Moths are important herbivores, pollinators and food for insectivorous birds, so their abundance affects ecosystem functioning and ecosystem services. This project uses extensive long-term data, experimentation and advanced statistical analyses for elucidating how moths respond to climate and land use changes, and how these responses affect interactions among moth species, abundance of birds and interactions among bird species. Moreover, the project uses mathematical modelling for predicting future changes in moth and bird communities. The information on global change effects on animal communities produced here is scientifically significant and can also be applied in nature conservation and environmental management.

Robust 2D materials for sensors, photo and electrocatalysis (ROAR)

PI: Kordas, Krisztian
Co-PIs: Heli Jantunen, Riitta Keiski, Raija Oilunkaniemi, Daniela I. Bezuidenhout

Have you ever thought that a material can detect analytes well below ppm concentrations even at room temperature outperforming any semiconducting metal oxide based sensors, it has excellent photosensitivity to harvest sunlight for photochemical processes, and it is a promising catalyst in electrochemical reactions? Transition metal dichalcogenide (TMDs) based hybrid materials combine all such properties, and can do probably even more by smart materials engineering supported by computational chemistry. To make it happen, multidisciplinary research teams of the University of Oulu will explore new chemistries and structures to demonstrate environmental and energy applications that support our global efforts in sustainability.

Fall and rise of endangered species: Detection of genomic and population ecological signals of decreasing and increasing populations

PI: Kvist, Laura
Co-PIs: Jouni Aspi, Mikko Sillanpää

The project combines analyses of historical and modern genomes of wolves, wolverines and golden eagles and with various ecological variables in modelling the interplay of genomic erosion, inbreeding, population structure and gene flow with anthropogenic, environmental and stochastic effects and demographic vital rates. The aim is to understand roles of these processes in survival of populations. The study species, declined due to persecution during the last centuries in Finland (and elsewhere). Especially the wolf and wolverine were almost extirpated from Finland. These species still face threats from poaching and are reduced in numbers by legal culling. We believe that genetic and demographic processes are interwoven and that they have a large effect on each other. Our study provides new empirical evidence for the long-lasting debate of the importance of genetic, demographic and stochastic effects in conservation biology and the results will be of importance in conservation management.

Continuously observed quantum matter with superconducting circuits

PI: Silveri, Matti

Superconducting circuit based quantum technology sprints towards larger and less noisy quantum hardware. Despite the progress, near-future midsize noisy quantum devices will not be capable for textbook quantum information protocols. The challenge is: What useful problems can we solve with quantum hardware before it is large and clean enough for running typical quantum algorithms? This project proposes that they could be used to simulate continuously observed quantum matter to provide more understanding on quantum entanglement and quantum measurements in many-body settings. The project paves a way for quantum memory and quantum computation applications currently challenged by many-body effects of disorder, dissipation and measurement backaction. This project belongs to the research fields of fundamental material physics and quantum physics and it is conducted in the research unit of nano and molecular systems at the University of Oulu led by Academy Research Fellow Matti Silveri.

Advanced NMR for sustainability

Responsible PI: Telkki, Ville-Veikko
Co-PIs: Juha Vaara, Anu Kantola, Perttu Lantto, Vladimir Zhivonitko

Nuclear Magnetic Resonance (NMR) spectroscopy is one of the most powerful methods in chemical analysis. This project aims at **development and application of advanced experimental, computational and theoretical NMR methods for sustainable materials research**. We will exploit the high sensitivity and efficiency of so-called ultrafast Laplace NMR (UF-LNMR) in the characterization of various materials such as **sustainable cements** with low CO_2 emissions and **recyclable superabsorbents** used for recovering oil and chemical spills. We will develop **hypersensitive, non-toxic NMR sensors** for **sustainable materials, catalysis and biomolecules**. We will create entirely **new branch of spectroscopy relying on optical detection** of nuclear magnetization and making it use for **chemical analysis**. Furthermore, we aim at **multiscale modeling of entire experimental processes**. The simulations provide microscopic, **molecular-level interpretation** for all experimental work in the project.

Ionospheric Situational Awareness (ISaw)

PI: Ulich, Thomas

Regular measurements of the ionospheric structure by ionosondes are essential tools for radio communication by defence forces as well as civil emergency services. Ionosonde observations, so-called ionograms, are thus an important tool for Ionospheric and Space Situational Awareness, especially in high-latitude Northern Finland. Ionogram traces can be rather complicated. Several attempts have been made to interpret ionograms automatically, but these do not work well in high latitudes, where space weather severely effects the ionosphere. Consequently, high-quality ionograms of Sodankylä are manually interpreted by a well- trained specialist. In this project, we propose to use new techniques employing image recognition and modern methods of searching for similar images to make the analysis more efficient. We want to create a database for research and real-time analysis, which allows to match similar ionograms to one another and suggest an analysis solution.

Production and Development of Novel Natural Nano and Micro Biomaterials and Diagnostic Technologies for Catalytic, and Bio- and Circular Economics (BioEVEngine)

Responsible PI: Vainio, Seppo
Co-PIs: Hely Häggman, Henrikki Liimatainen, Caglar Elbuken

The field of extracellular vesicle (EV) biomaterial research has expanded tremendously in recent years with great interest in medical applications. EVs are tiny membrane-enclosed droplets that carry cellular material. We will focus on production of new biomaterials using EVs obtained from plant cells and milk. We hypothesize that EVs from these natural sources can be exploited as widely applicable medical therapeutics. Current EV isolation and purification are tedious small-scale processes, necessitating development of new high-throughput protocols for larger scale production. We will use cells from pine, spruce, wild Finnish berries, and milk for EV extraction with nanocellulose-based microfluidic devices that we will design in this project. The research will be completed at the VTT and University of Oulu with collaboration between scientists from Ecology and Genetics, Biochemistry and Molecular Medicine, and Technology Research Units. Further information on current plant biotechnology research can be found on the Oulu University PlantBIO site at http://cc.oulu.fi/~hhaggman/index.html

Interacting processes in Arctic reindeer systems experiencing rapid climate change

PI: Welker, Jeffrey
Co-PI: Maria Väisänen

Today the north is becoming a very different place than what we have come to know just a decade or two ago. The weather and climate are becoming much more erratic, inconsistent, extreme in summer and in winter; especially the form of precipitation is rain when it should be snow, across Fennoscandia and Lapland in Finland. This New North is creating a challenging place for rural communities and for those whom raise reindeer, such as the Sami and the reindeer herders of the districts throughout Finland, Sweden, and Norway seeking to maintain a culture and lifestyle they greatly value and strive to pass on their values and lifestyles to future generations. We will **create a revolutionary, holistic framework** for understanding ungulate (reindeer and caribou) systems of the north that considers the most critical facets of environment-social interactions and feedbacks. We will use a systems approach where experts from different disciplines and members of the stakeholder community (i.e. Sami, reindeer herders, LUKE) are woven into quilt of collaboration, sharing, discovery, and the co-production of new knowledge, education and management options.