



JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

ANNUAL REPORT 2017
DEPARTMENT OF PHYSICS

For **JYU**. Since 1863.

DEPARTMENT OF PHYSICS.

At the Department of Physics in the University of Jyväskylä, we research the basic phenomena of the physical nature and educate future physicists and physics teachers.

Our department is the most eminent research unit in Finland in the field of subatomic physics, i.e. particle and nuclear physics. Our Accelerator Laboratory is an exceptionally large whole of research infrastructure. The three particle accelerators in the laboratory are used to study nuclei and the structure of matter.

Our department also specializes in studying matter on the scale of a nanometre. The modern research devices for this sort of research can be found from the Nanoscience Center, located next to the Department. Internationality characterizes our department, and we collaborate with numerous universities and research institutes abroad, such as CERN.



JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

HEAD OF DEPARTMENT FOREWORD.

20 17

ANNUAL REPORT
Department of physics

CONCEPT AND DESIGN

Nitroid

PRINTED IN

Jyväskylä University
Printing House



JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

The Department of Physics has produced an annual report every year since 1976. This annual report provides a survey of our activities in research and education in 2017.

Research. The scientific activity and productivity of the Department has remained at a high level. Our research covers two main areas, subatomic physics and nanophysics, where our scientists conduct both experimental and theoretical research. Both subatomic physics and nanophysics belong to the research areas selected for profiling actions by our University.

The scientific output of the Department has seen steady but still relatively steep growth for many years, starting from around one hundred peer reviewed publications per year in 2005 and extending to the present three hundred publications. Apart from the excellent individuals carrying out their daily work in our offices and laboratories, the factors behind this progress certainly include the highly successful Center of Excellence in Nuclear and Accelerator-Based Physics and the FiDiPro program in theoretical nuclear physics, whose funding periods came to an end in 2017. A significant contribution to the total also comes from our researchers working in the various programs of the Helsinki Institute of Physics.

The great news of the year was the announcement of an ERC Consolidator Grant awarded to Anu Kankainen for stellar nucleosynthesis studies. Tuomas Lappi, the other current ERC Grant holder at the Department, was appointed Professor in theoretical physics. Keijo Hämäläinen was appointed as Professor in physics. He currently holds the position of Rector of the University.

Education. A marked drop of the number of applicants and new students enrolled for studies, which many other physics departments already witnessed earlier, hit our Department in 2017. The reason behind this unfortunate development is unknown, but it may be partly a consequence of the changes to the regulations governing the application process at the national level. It is obvious that we must strengthen our recruitment efforts, increase our outreach activities and increase our visibility.



The new syllabus was completed in spring 2017, following several years of effort from our teaching personnel and the Education Coordinator. The syllabus was brought into operation at the beginning of the autumn semester. We have continued to develop new teaching methods and practices in order to improve the learning outcomes and to make studies more enjoyable and rewarding to our students.

Events. In September, the outreach event European Researchers' Night was organized in tandem with the annual Jyväskylä City of Light event. National and local co-ordination of the event was the responsibility of Janne Pakarinen and Philippos Papadakis. Our Department, with its facade illuminated by the spectacular "Glowing University" light installation, attracted thousands of visitors to its laboratories and exhibition points during the event.

A remarkable milestone was reached in the end of 2017 when Professor Rauno Julin retired from his position. Rauno has worked at the Department for a whole 45 years and has been a central and influential figure in our experimental nuclear physics research throughout all those years.

My own term as the Head of Department came to an end in 2017. I wish to warmly thank the personnel and students of the Department for collaboration and constant support during my 12 years in the position. I wish all success to my successor Professor Markku Kataja.

Jukka Maalampi

HEAD OF DEPARTMENT 2005-2017

STATISTICAL DATA FROM 2017

160
PERSONNEL

Professors **18**
University lecturers and researchers **37**
Postdoctoral researchers **25**
Doctoral students ~ **50**
Laboratory engineers and technicians **27**
+ Several research assistants (MSc students)

400

UNDERGRADUATE
STUDENTS

of which new students ~**45**
Doctoral students ~**50**

35 BSC DEGREES

30 MSC DEGREES

0 PHLIC DEGREES

11 PHD DEGREES

Median time to complete MSc (years) **5,4**



277
NUMBER OF
FOREIGN VISITORS

377 IN VISITS

349 VISITS ABROAD



CONFERENCE AND WORKSHOP CONTRIBUTIONS
Invited talks ~**100** | Other talks ~**120** | Posters ~**50**



~**270**
Peer reviewed
publications

~**60**
Conference
proceedings

~**15**
Other (articles
in books etc.)

14.5
FUNDING (million €)

Basic financing **8.4**
External funding **6.0**

→ Academy of Finland **4.0**
→ European Union **0.7**
→ Contract research **0.8**
→ Other **0.5**

In addition, the
Department received
0.8 M€ for research
infrastructures.

CONTENT

4 Preface - Head of department foreword

MATERIALS PHYSICS

6 The year 2017 at the NSC

EXPERIMENTAL NANOPHYSICS

8 Thermal Nanophysics

9 Molecular Technology

11 Molecular Electronics and Plasmonics

12 Complex Materials

THEORETICAL NANOPHYSICS AND COMPUTATIONAL NANOSCIENCE

14 Computational nanoscience

16 Condensed matter theory

17 Quantum many-body theory

18 Low-dimensional nanomaterials modeling

19 Open quantum systems dynamics

20 Superconducting spintronics

NUCLEAR AND ACCELERATOR BASED PHYSICS

22 Communicating Science on Tutkijoiden yö

24 Accelerator laboratory

26 Nuclear spectroscopy

30 The exotic nuclei and beams

34 Instruments and Methods in Nuclear,
Particle, and Astroparticle Physics

36 Nuclear structure and nuclear processes

38 FIDIPRO - Global properties of nucle

40 Radiation effects

42 Ion sources

44 Accelerator based materials physics

PARTICLE PHYSICS

46 Cosmology

48 Neutrino physics

50 QCD theory

53 ALICE experiment at the CERN LHC

56 Industrial collaboration

57 Education

THE YEAR 2017 AT THE NSC

Year 2017 marked an important year for the Nanoscience Center, in terms of creating new global contacts to other nanoscience institutes in Europe, Israel and USA, and receiving feedback from NSC's International Advisory Board (IAB) in the biennial evaluation meeting.

The evaluation meeting with the NSC IAB took place April 25-27. The target of the evaluation was NSC's scientific and educational output during 2015-16. In their feedback report, the IAB concluded that the NSC

".. has now developed into a mature and internationally recognized center within the field of interdisciplinary nanoscience. The global influence of the research performed at the Center has continued to excel during the current evaluation period. The publication record continues to be exceptional and corroborates the success and impact of the collaborative environment and continuously growing infrastructure established at the Center, which has implemented many of the previous recommendations suggested by the IAB. Finland and University of Jyväskylä can be proud of this achievement".

NSC stressed the importance of continued efforts to keep the nano-fabrication facilities (cleanroom) up-to-date and recommended major new investments to enhanced optical imaging (e.g. "super-resolution" microscopy).

In June, a joint scientific seminar between NSC researchers and scientists from CaSTL Center in US (Chemistry at the Space-Time Limit, a NSF center of excellence) took place in Tervakoski, Finland, with 45 participants (figure A). This event started

a formal co-operation that will facilitate extended exchange visits by students and post docs between CaSTL and NSC. The next NSC-CaSTL scientific symposium is planned for June 2018 in California.

September 29 marked the second Europe's "Researchers' Night" event where NSC's doors were open to general public until midnight, drawing close to 1500 visitors in the premises.

NSC has organized a two-day high-level scientific conference "Nanoscience Days" since 2004, to mark the annual "birthday" of the Center after its inauguration in the fall of 2004. In 2017 the conference was organized October 3-4, with about 200 participants and 10 plenary speakers from Japan, USA, France, Israel, Germany, Finland, and UK. The program included also a lively poster session (figure B) and a small-scale industrial exhibition.

In the fall, NSC was contacted by the leadership of the Bar Ilan Institute for Nanotechnology and Advanced Materials (BINA, Israel) in order to establish a bilateral staff and student exchange program. NSC took an initiative to organize the first joint NSC-BINA research workshop in 2018 in Finland.

At the end of 2017, the leadership of NSC was passed on to a new steering committee with Prof. Tero Heikkilä from JYFL starting as the new NSC Scientific Director. For me, it has been a privilege and great pleasure to serve in this position the past six years, and I want to thank all the NSC researchers for creating such a wonderful working environment, as well as all the Department Heads for their crucial support. Without Departments' support, NSC would not, obviously, even exist.

Hannu Häkkinen
NSC SCIENTIFIC DIRECTOR 2012-2017

↓ Figure A



↑ Figure B

THERMAL NANOPHYSICS

Professor Ilari Maasilta

The group has currently three main research directions:

- Nanoscale thermal transport, especially focusing on phononic crystals and near-field transport
- Development of superconducting materials and devices, especially ultrasensitive superconducting radiation detectors and their applications from sub-mm to X-ray energies
- Utilizing novel nanofabrication and imaging techniques for interdisciplinary projects, such as nanoscale biological imaging with helium ion microscope (HIM)

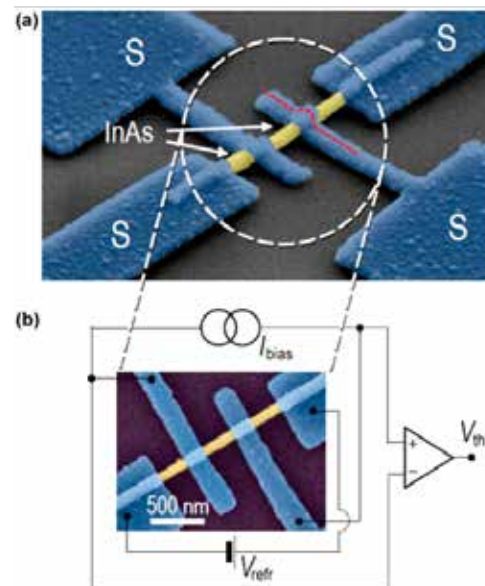
www.jyu.fi/physics/materials/thermal-nanophysics

NANOSCALE THERMAL TRANSPORT

In 2017, we continued our strong focus on the theory and experiments of nanoscale thermal transport. Some of that effort has gone into fabricating three-dimensional periodic nanoscale structures using colloidal crystallization of polymeric nanospheres, for use as phononic structures to control heat transport at low temperatures. Thick and large crystals have been successfully deposited in a single-step vertical dipping process in the past. This year we also succeeded in depositing micron-scale metal wires on top of the polymer structures using e-beam lithography and direct 3D laser writing [Tian2017], paving the way for real device applications. The success was made possible by electron-beam induced cross-linking of the deposited colloidal crystal before exposing it to the harsh chemicals used in the following lithography steps.

DEVELOPMENT OF SUPERCONDUCTING DEVICES AND MATERIALS

The basic research on thermal properties links naturally to the applications in superconducting devices. We have a strong history in superconducting radiation detector development, particularly for transition edge sensors (TES), where the focus in the past has been in X-ray detectors. Another focus area is normal metal-superconductor (NIS) tunnel junction physics and applications, including the use of novel materials. As an example of progress in 2017, we started a collaboration with NEST Pisa in Italy, within which we developed a novel NIS tunnel junction thermometer and cooler device (Fig. 1), where a semiconducting InAs nanowire was cooled directly [Mastomäki2017]



↑ Figure 1: Scanning electron micrographs of a typical InAs NIS junction device: Four tunnel junctions were created between the superconductive Al electrodes (S) and an n-doped InAs nanowire. The two larger contacts were used to refrigerate its electron system below the bath temperature [Mastomäki2017].

MOLECULAR TECHNOLOGY

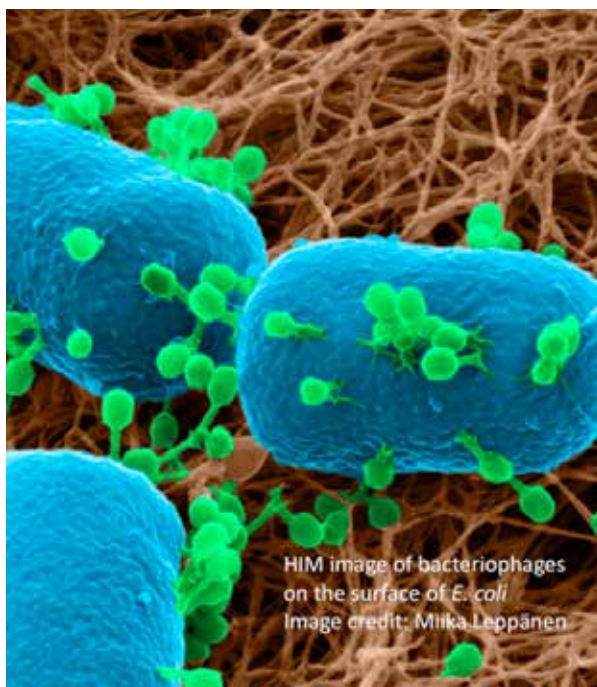
NOVEL NANOFABRICATION AND IMAGING TECHNIQUES FOR INTERDISCIPLINARY PROJECTS

A recent example of an advanced method used is the latest nanofab tool at the NSC clean room, the Zeiss Orion helium ion microscope (HIM), with both helium and neon ion beams available. With the instrument, in the best cases sub-nanometer scale imaging or ion beam milling of material is possible. We are developing both nanofabrication and imaging applications. The best example so far of results in our group, in collaboration with the group of Dr. Sundberg from biology department, is the first imaging of bacteriophage (virus)-bacteria interactions in real bacterial colonies on the agar plates [Leppänen2017]. Exquisite detail of the viruses in nm length scales was demonstrated, see Fig. 2.

[Tian2017] Y. Tian, T. J. Isotalo, M. P. Konttinen, J. Li, S. Heiskanen, Z. Geng and I. J. Maasilta, *Integrating metallic wiring with three-dimensional polystyrene colloidal crystals using electron-beam lithography and three-dimensional laser lithography*, J. Phys. D: Appl. Phys. 50, 055302 (2017)

[Mastomäki2017] J. Mastomäki, S. Roddaro, M. Rocci, V. Zannier, D. Ercolani, L. Sorba, I. J. Maasilta, N. Ligato, A. Fornieri E. Strambini, and F. Giazotto, *InAs nanowire superconducting tunnel junctions: quasi-particle spectroscopy, thermometry and nanorefrigeration*, Nano Research 10, 3468 (2017)

[Leppänen2017] M. Leppänen, L.-R. Sundberg, E. Laanto, J. Almeida, P. Papponen and I. J. Maasilta, *Imaging Bacterial Colonies and Phage-Bacterium Interaction at Sub-Nanometer Resolution Using Helium-Ion Microscopy*, Adv. Biosystems 1, 1700070 (2017)



↑ Figure 2. Helium ion micrograph of E.coli bacterial cells being attacked by bacteriophage viruses [Leppänen2017]. Smallest details seen are in nm length scale.

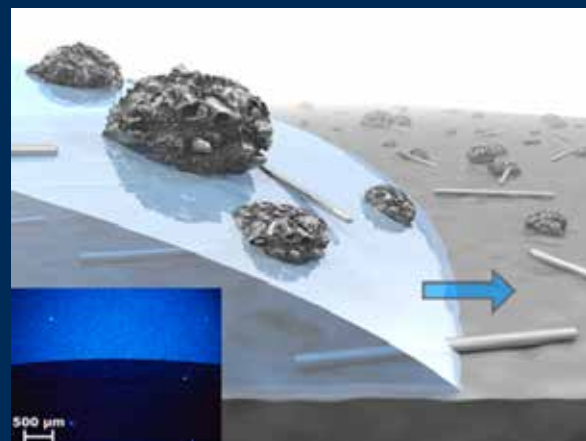
Professor Markus Ahlskog

The Molecular Technology group studies primarily the experimental electronic and mechanical properties of carbon nanotubes (CNTs) and devices that are based on them. The interests include both fundamental and applied aspects of CNT science and technology. The research in the group has extensively explored the basic electronic transport properties of high quality multiwalled carbon nanotubes (MWNT). Other topics within the group include the interaction between CNTs and liquid interfaces and the functionalization of CNTs with molecular species. The group utilizes for its research effort the modern microscopy instrumentation and the good fabrication and measurement facilities of the Nanoscience Center.

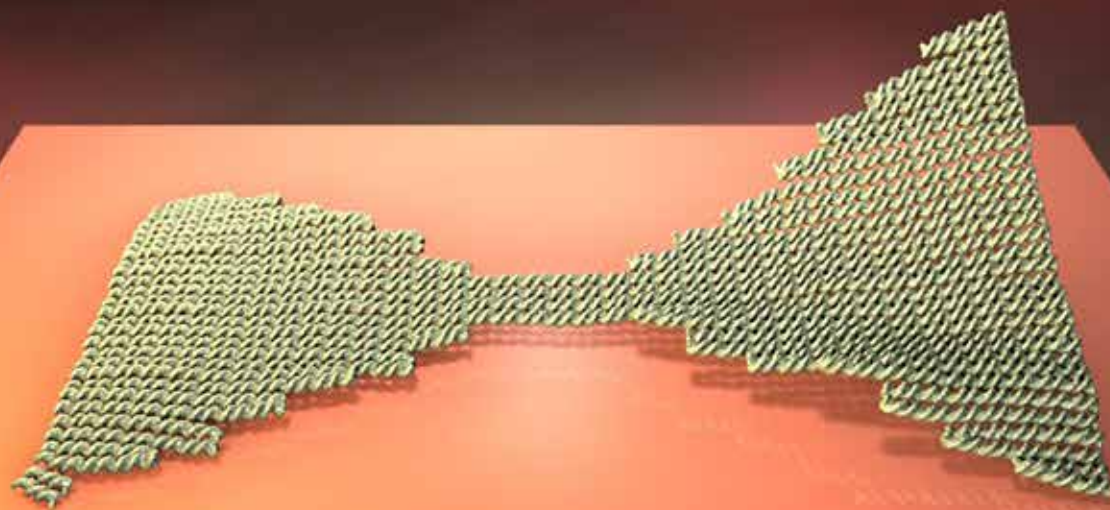
www.jyu.fi/physics/materials/molecular-technology

In January 2017 Matti Hokkanen defended his PhD Thesis. The latest of his publications [1] contained the most elaborate description of his experimental investigations, namely on the phenomena associated with the interaction between a liquid (water) wetting line and MWNTs deposited on a surface. The phenomena are visually described in Figure 1.

[1] Matti J. Hokkanen, Saara Lautala, Emmanuel Flahaut, and Markus Ahlskog *Experimental studies on the detachment of multiwalled carbon nanotubes by a mobile liquid interface* Colloids and Surfaces A, 533, 109 (2017)

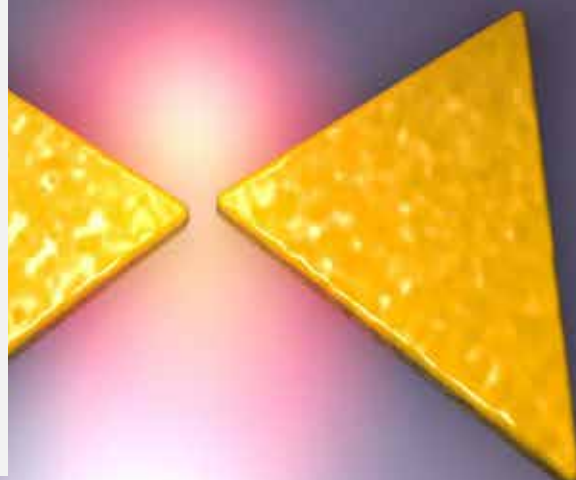
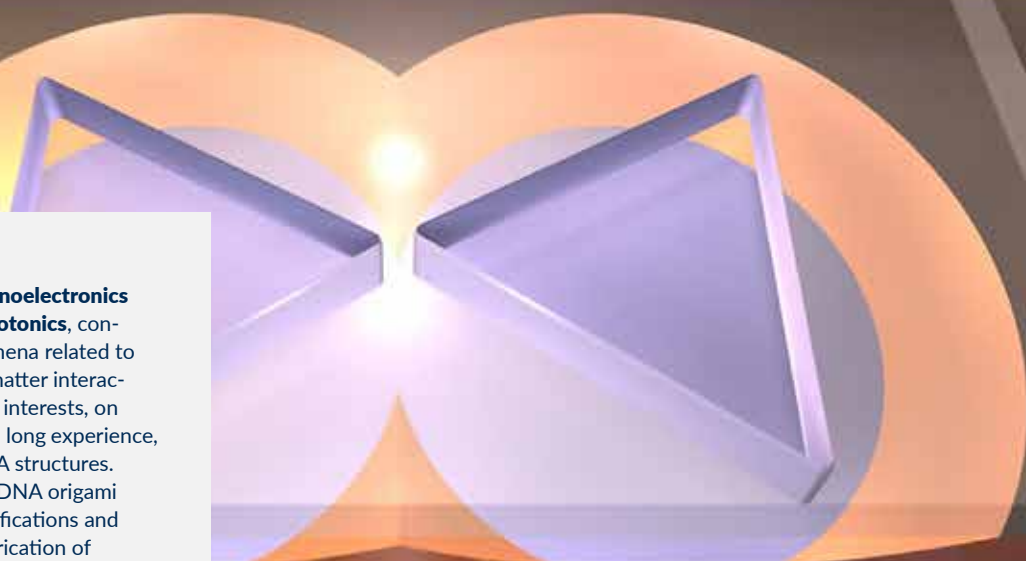


↑ Figure 1. Schematic illustration of a water interfacial contact line moving over a deposition consisting of clean MWNTs and ACPs (amorphous carbon particles) as well as MWNTs with ACPs solidly attached. The debris particles are captured by the surface tension and are suspended at the liquid surface, while some clean MWNTs are retained on the surface. Inset: dark-field optical micrograph demonstrating the effect on a MWNT deposition; The lower dark region corresponds to depopulation of coarse debris particles up to the dark/bright boundary where the contact line motion halted. The upper region is untouched and thus has debris particles that effectively scatter light and so appears bright.



The group studies nanoelectronics and -plasmonics/-photonics, concentrating on phenomena related to molecules and light-matter interaction. One of the main interests, on which the group has a long experience, is self-assembled DNA structures. The main focus is on DNA origami structures; their modifications and utilization in nanofabrication of electrical and plasmonic nanodevices. Another main interest is the coupling between surface plasmons or cavity photons and molecules, especially in a strong coupling limit. This limit brings about hybrid light-molecule -states possessing new fundamental properties. For example, it enables totally new ways for controlling chemistry or enhance light harvesting. Other topics studied are utilization of plasmonics in biotechnologies and plasmonic/optical properties of graphene.

www.jyu.fi/physics/materials/molecular-electronics-and-plasmonics



MOLECULAR ELECTRONICS AND PLASMONICS

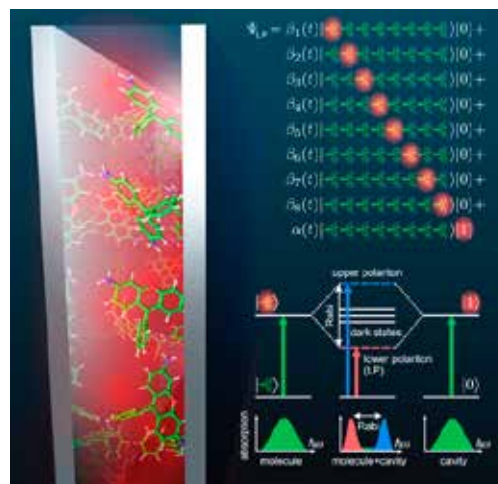
Senior Lecturer Jussi Toppari

BUILDING MINIATURE OPTICAL ANTENNAS USING DNA AS A GUIDE

In 2017 we continued our strong work on DNA-origami based fabrication methods for both electronics [Tapio2017] and plasmonics [Shen2018]. For plasmonics, we developed a new highly parallel technique to fabricate precise metallic nanostructures with designed plasmonic properties by means of self-assembled DNA origami shapes - a method called DALI (DNA-assisted lithography) [Shen2018]. Nowadays, virtually any nanoscale shape can be build using a DNA origami technique, and via DALI it is possible to use them to create millions of fully metallic nanostructures with as small as 10 nm feature sizes in one go. The trick in the DALI method is that silicon oxide can be selectively grown only on the bare areas of the substrate covered with origami (see figure 1, <https://m.youtube.com/watch?v=QO5Jcqi-SYI&feature=youtu.be>). We have demonstrated the method by covering full chips with smallest ever metallic bowtie-shaped antennas and chiral structures at one cycle of DALI. As a highly parallel method DALI enables cheap wafer-scale production of surfaces and studies to provide bioinspired surfaces and metamaterials. The work was carried out partially in collaboration with the Biohybrid Materials Group at Aalto University (Finland) and with researchers from California Institute of Technology (Caltech, USA) and Aarhus University (iNANO Center, Denmark).

EFFECT OF A STOKES SHIFT ON STRONGLY COUPLED MODES BETWEEN SURFACE PLASMON AND MOLECULES

The strong coupling between surface plasmon polaritons (SPP) and molecules manifests itself by formation of new hybrid SPP-molecule polariton states as shown on figure 2. We have studied the dynamics of these polaritons by analyzing their scattered emission [Baieva2017]. While the emission of SPP is purely transverse magnetic (TM), the strong coupling with molecules induces transverse electric (TE) component to the emission of the polariton via the partial molecular nature. We show that the TM/TE ratio of the polariton emission clearly follows the molecular contribution, and that it also depends on Stokes shift



↑ Figure 2. Artistic view of an optical cavity with organic molecules inside, and schematic illustrations of the formed hybrid polariton state and its spectroscopical properties.

of the molecule - the larger the shift the lower the TE emission. Thus, the properties of the molecule cannot be neglected, as the most existing theories do.

These experimental findings fit well with the new phenomenological theory and quantum mechanical molecular dynamic simulations realized by our collaborators in Nanoscience Center, Prof. Tero Heikkilä (Dept. of Physics) and Prof. Gerrit Groenhof (Dept. of Chemistry) [Luk2017]. These show that the TE emission raises due to a symmetry breaking as a result of the unique micro-environments of the molecules in combination with thermal motion and many molecular properties.

Selected publications

[Tapio2017] K. Tapio and J.J. Toppari, *Characterization of Emergence of the Coulomb Blockade in a Pearl-Like DNA-AuNP Assembly*, *Journal of Self-Assembly and Molecular Electronics (SAME)* 5, 31 (2017).

[Shen2018] B. Shen, V. Linko, K. Tapio, S. Pikker, T. Lemma, A. Gopinath, K.V. Gothelf, M.A. Kostianen, J.J. Toppari, *Plasmonic nanostructures through DNA-assisted lithography*, *Science Adv.* 4, eaap8978 (2018).

[Baieva2017] S. Baieva, O. Hakamaa, G. Groenhof, T.T. Heikkilä, J.J. Toppari, *Dynamics of strongly coupled modes between surface plasmon polaritons and photoactive molecules: the effect of the Stokes shift*, *ACS Phot.*, 4, 28 (2017).

[Luk2017] H.L. Luk, J. Feist, J.J. Toppari, G. Groenhof, *Multi-scale Molecular Dynamics Simulations of Polaritonic Chemistry*, *J. Chem. Theory*

← Figure 1: The DALI combines programmable DNA origami shapes and conventional lithography to create metallic nanoshapes for diverse applications. From top to bottom: DNA-origami (green) on top of a transparent substrate (blue) coated with silicon (orange); CVD-grown Silica (transparent) with origami shaped openings. Silicon is etched through the openings to form an undercut; Ready golden nanoantenna evaporated through openings. [Shen2018]

COMPLEX MATERIALS

Professor Markku Kataja

The research scope of the group includes heterogeneous materials, theoretical and numerical modelling, complex fluid mechanics and rheology, X-ray tomography and 3D image analysis, as well as their applications in various industrial problems. The group runs an extensive X-ray Tomography Laboratory that includes three X-ray scanners used in non-invasive three-dimensional imaging and analysis of the internal microstructure a wide range of heterogeneous materials. The research topics of the group include also statistical characteristics of random packings of elongated particles, structural analysis related to development of new biocomposites, complex flow dynamics and transport in heterogeneous materials.

www.jyu.fi/physics/materials/complex-materials

X-RAY TOMOGRAPHY LABORATORY

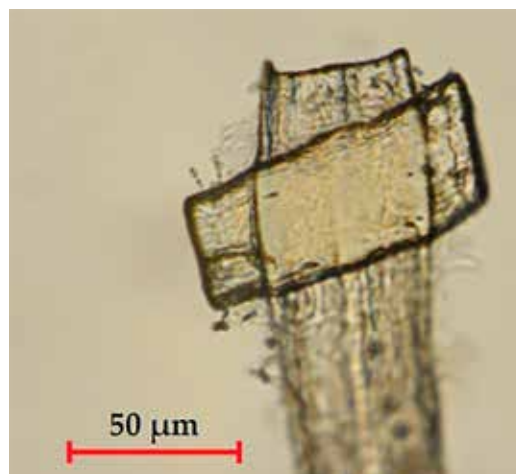
The primary research facility within the X-ray Tomography Laboratory includes three tomographic scanners including two microtomographs and a nanotomograph. Together, these devices are capable of non-intrusive three-dimensional imaging of the internal structure of heterogeneous materials with resolution ranging from 40 μm up to 50 nm. The laboratory is equipped with comprehensive set of instruments for sample preparation and manipulation. The laboratory is also equipped with specific devices for measuring various mechanical and transport properties of materials. The entire facility has high utilization rate in basic and applied research related e.g. to development of novel organic materials, and to analysis of structural and transport properties of complex materials such as composites and bentonite clay.

CONTACT AREA MEASUREMENTS OF CELLULOSE FIBRE BONDS USING X-RAY NANO-CT IMAGING

Cellulose fibres are the main constituents of paper which consists of a network of interconnected fibres that bond to each other. The bond strength and bond area have an important effect both on the mechanical and the optical properties of paper. Bond area, in contrast to bond strength, is a difficult research topic, since fibre bonding happens in molecular distances that cannot be resolved with conventional optical methods. The advancements in X-ray optics have enabled imaging devices to reach resolutions in the nanometre scale, allowing access to more accurate fibre bond research.

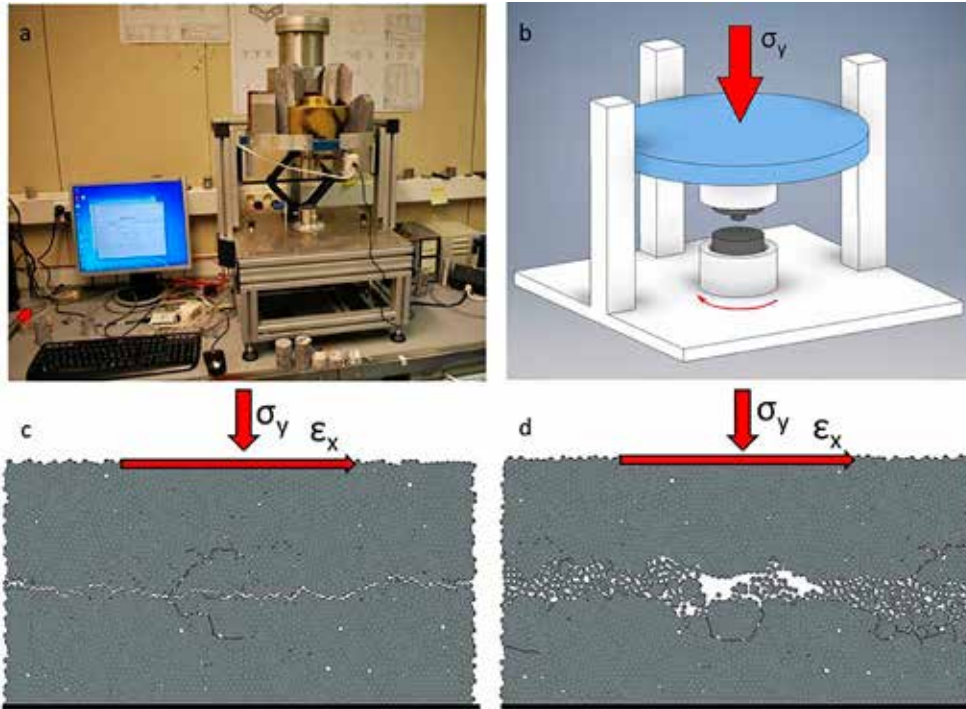
X-ray nanotomography has been used successfully to image 26 bleached kraft softwood fibre bond samples. Three different bond types were studied: spring-to-summerwood, summer-to-summerwood and spring-to-springwood fibre bonds. The obtained results showed that there was no significant difference between the relative contact area (ratio of contact area to total fibre intersection area) of the different bond types. The average was found to be 58 %.

As such, it seems that the well-established strength differences between bond types are not due to differences between relative or absolute contact areas, as can be resolved with the imaging system.



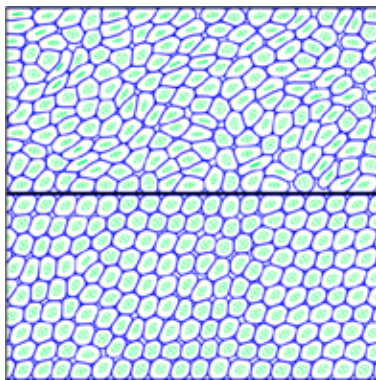
↑ Figure 1. Microscopic image of a fibre bond.

→ Figure 2. The experimental equipment is shown in (a) together with a schematic presentation of the machine (b). In (c) the simulation setup is shown with the initial crack and in (d) after shearing.



FRICION OF SHEAR-FRACTURE ZONES

Friction behavior between shearing brittle surfaces was studied using discrete element method simulations and an experimental device manufactured for this specific purpose. It was demonstrated that there is self-lubrication by fragmentation within shear-fracture zones if there is a mechanism for stress relaxation at the microscopic scale. In the numerical model used here, this mechanism is either low-friction sliding or rotation. If neither of these mechanisms are present, no self-lubrication is observed in the investigated model. In the generic case, there are many possible additional relaxation mechanisms such as partial melting, plastic deformations, creep, vibrations, etc.



↑ Figure 3. Simulated two-dimensional foam sheared at high (top) and at low (bottom) shear rates. The ellipses (green) used to characterize bubble deformation are embedded in the bubbles (blue).

SHEAR RHEOLOGY OF TWO-DIMENSIONAL WET FOAM

Shear rheology of two-dimensional wet foam was investigated with the DySMaL simulation model which features dynamically deformable bubbles in a wet foam context. It was found that the rheological behavior of the model at low shear rates is subject to a scaling law involving the bubble size, surface tension and the viscosity of the carrier fluid. This is consistent with experimental data and soft glassy rheological models for such systems. At high shear rates the model predicts a dynamic phase transition to a turbulent flow pattern in which the effective viscosity of the foam changes rapidly. This phase transition can be linked to changes in the average bubble deformation and nematic order of the system.

Selected publications

- Riikilä, T., Pylväinen, J. I., & Åström, J. (2017). *Friction of Shear-Fracture Zones*. *Physical Review Letters*, 119 (25), 255501. doi:10.1103/PhysRevLett.119.255501
- Kähärä, T. (2017). *Numerical study of two-dimensional wet foam over a range of shear rates*. *Physical Review Fluids*, 2 (9), 093303. doi:10.1103/PhysRevFluids.2.093303
- Koponen, A., Ekman, A., Mattila, K., Al-Qarah, A. M., & Timonen, J. (2017). *The Effect of Void Structure on the Permeability of Fibrous Networks*. *Transport in Porous Media*, 117 (2), 247-259. doi:10.1007/s11242-017-0831-2
- Kataja, M., Haavisto, S., Salmela, J., Lehto, R., & Koponen, A. (2017). *Characterization of micro-fibrillated cellulose fiber suspension flow using multi scale velocity profile measurements*. *Nordic Pulp and Paper Research Journal*, 32 (3), 473-482. doi:10.3183/NPPRJ-2017-32-03-p473-482
- Haavisto, S., Cardona, M. J., Salmela, J., Powell, R. L., McCarthy, M. J., Kataja, M., & Koponen, A. I. (2017). *Experimental investigation of the flow dynamics and rheology of complex fluids in pipe flow by hybrid multi-scale velocimetry*. *Experiments in Fluids*, 58, 158. doi:10.1007/s00348-017-2440-9

COMPUTATIONAL NANOSCIENCE

Academy Professor Hannu Häkkinen

ELECTRONIC STRUCTURE AND STM SIMULATIONS OF ATOMICALLY PRECISE METAL NANOCCLUSERS

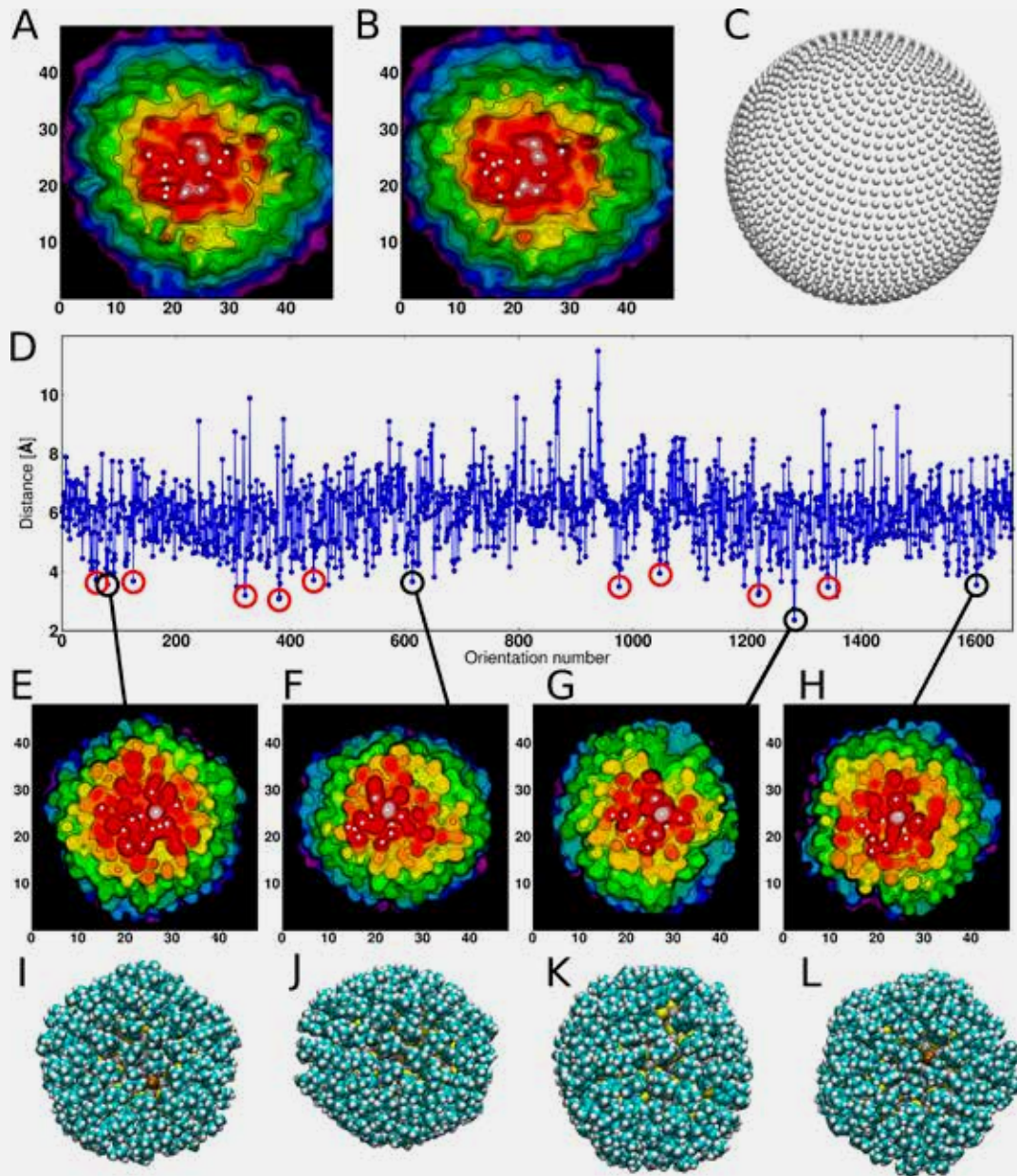
Monolayer-protected clusters (MPC) are molecularly precise metal nanoparticles with definite masses, atomic structure, and chemical composition. [1] They have a hybrid structure consisting of a metallic core of 1-3 nm in diameter (from a few tens to a few hundred metal atoms) that is stabilized by a covalently bound molecular layer (consisting of ligand molecules such as thiols, phosphines or alkenes). MPCs have an advantageous, stable, well-defined molecular structure and size compared to larger, colloidal metal nanoparticles, in which variations in diameter are typically of the order of 10% and neither the metal-ligand interface, nor the structure of the ligand surface are known in the molecular scale. Up to now, close to 100 different MPCs have been synthesized and characterized to the molecular precision. Many studies have confirmed the unique structural, optical, magnetic, and catalytic properties of these nanoclusters. These nanomaterials are expected to have applications in several areas such as in biolabeling, catalysis, medicine, and solar energy.

In the past 10 years, our group has developed concepts to understand the stability and quantized electronic structure of various MPCs consisting of gold, silver, copper, and their intermetallic compounds. Our main approach is to use density functional theory (DFT) both in the ground state and linear-response form, with numerical implementations (GPAW code [2]) that are suitable for massively parallel computations in order to deal with typical systems of several thousand valence electrons per cluster.

The largest currently known MPCs have metal cores up to 3 nm and overall diameters of 5 nm. [3] These particles are large enough so that surface probe

methods can in principle be used for studies of the organic monolayer. High-resolution real-space imaging of nanoparticle surfaces is desirable for better understanding of surface composition and morphology, molecular interactions at the surface, and nanoparticle chemical functionality in its environment. However, achieving molecular or sub-molecular resolution has proven to be very challenging, due to highly curved nanoparticle surfaces and often insufficient knowledge of the monolayer composition. By imaging crystallographically determined silver nanoclusters Ag_{374} protected by a monolayer of tert-butyl-benzene thiol (TBBT), our collaborators in Xiamen University recently demonstrated sub-molecular resolution in topography of the thiol monolayer of a 5 nm nanoparticle in scanning tunneling microscopy (STM). A resolution of a single methyl group of TBBT was achieved both at liquid helium and nitrogen temperatures. We confirmed the experimental data by a "facial recognition" method with comparisons to DFT-simulated topography images using the known atomic structure of the Ag_{374} nanocluster (see Figure). [4] Our work demonstrates a working methodology for investigations of structure and composition of organic monolayers on curved nanoparticle surfaces, which helps designing functionalities for nanoparticle-based applications.

1. T. Tsukuda and H. Häkkinen, "Protected Metal Clusters: From Fundamentals to Applications" (Elsevier, Amsterdam, 2015).
2. <https://wiki.fysik.dtu.dk/gpaw/>
3. H. Yang, Y. Wang, X. Chen, X. Zhao, L. Gu, H. Huang, J. Yan, C. Xu, G. Li, J. Wu, A.J. Edwards, B. Dittrich, Z. Tang, D. Wang, L. Lehtovaara, H. Häkkinen and N.F. Zheng, "Plasmonic twinned silver nanoparticles with molecular precision", Nature Comm. 7, 12809 (2016).
4. Q. Zhou, S. Kaappa, S. Malola, H. Lu, D. Guan, Y. Li, H. Wang, Z. Xie, Z. Ma, H. Häkkinen, N. Zheng, X. Yang and L. Zheng, "Real-Space Imaging of a Ligand-Protected Ag_{374} Nanocluster at Sub-Molecular Resolution", submitted.



↑ Figure: "Facial recognition" of experimental STM topography by an automated matching of simulated images. (A,B) Two consecutive scans of the same Ag_{374} cluster at LHe temperature (bias voltage: -1.2 V, current: 10 pA). The white dots represent the extrema of the data. (C) Visualization of the set of perspectives used to prepare the simulated STM image from the computational data. Each dot corresponds to a perspective when the cluster lies at the center of the sphere. (D) Minimum correlation distances for each perspective, resulting from comparison to the extremum points of (A). The data points in black circles denote distinct minima that had small correlation distance in comparisons to both (A) and (B). These data points are connected with lines to the respective calculated STM images (E-H) with white dots showing the extrema. The red circles contain selected data points that correspond to a perspective very close to one of the orientations E-H and that consequently give relatively small correlation distances. (I-L) The atomistic models of the cluster in similar orientations to E-H, respectively. X-Y scales are the same in experimental and simulated images, and are shown in Å. The STM simulations were done for the voltage and current values used in the experiment.

CONDENSED MATTER THEORY

Professor Tero Heikkilä

We study the quantum and classical phenomena in small electronic systems, with a focus on superconductivity, magnetism, topological media and optomechanics. Our approach is based on phenomenological low-energy theory of quantum systems. In each project we work in close collaboration with world-leading experimental groups.

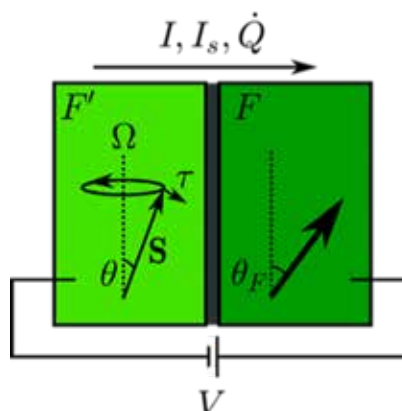
www.jyu.fi/physics/materials/condensed-matter-theory

SPIN TRANSFER TORQUE AND STOCHASTIC MAGNETIZATION DYNAMICS IN THE QUANTUM LIMIT

The state of small magnets containing a single magnetic domain can be described via their magnetization vector. Typically the size of the magnetization is fixed to some particular value, but its direction may vary. One way of changing the magnetization is via the spin transfer torque that is exerted on the magnet by a spin-polarized current injected into the magnet from a nearby ferromagnetic electrode. Under proper conditions, this spin transfer torque may drive the small magnet into a stable precession. As a result, the precession drives a reciprocal effect to the spin transfer torque: spin pumping, i.e., a spin current is injected from the magnet, and converted into a real current in the ferromagnetic electrode. These phenomena have been intensively studied in the past two decades, and they form a basis in the search of new types of methods to create magnetic memories. However, the stochasticity of the spin transfer torque or spin pumping have not been thoroughly studied in the past. We have devised a means to calculate the full probability distribution of magnetization dynamics and spin pumping, valid in the quantum limit where the precession rate (times the Planck's constant) exceeds the temperature (times Boltzmann constant). Our approach allows for example calcula-

tion of transition probabilities, current noise, and other stochastic phenomena in the magnet.

P. Virtanen and T.T. Heikkilä, *Phys. Rev. Lett.* 118, 237701 (2017)



AMPLIFICATION CLOSE TO A QUANTUM LIMIT IN OPTOMECHANICAL SYSTEMS

The quality of amplifiers can be characterised by the amount of noise they add to the amplified signal. Quantum mechanics poses a lower limit to this added noise: for large gain (amplification), the added noise to the input signal is always more than half a quantum, corresponding an added energy of $hf/2$, where h is Planck's constant and f is the signal frequency. The question is how to reach this limit. For optical frequencies (visible light) systems with noise performance very close to the quantum limit have been constructed since the 1990's, but the task has been much harder for setups involving signals in the microwave (GHz) regime. We have shown, both theoretically and experimentally (M. Sillanpää's group in Aalto University performing the experiments) that a system comprising a microwave resonator (antenna) coupled to a high-quality micro mechanical resonator can be tuned so that amplification very close to the quantum limit can be obtained. In our recent work a system consisting of two microwave resonators coupled to the same mechanical resonator allows for reaching close to quantum limited performance, and simultaneously allowing for a frequency conversion of microwave signals. This type of setup could also be

QUANTUM MANY-BODY THEORY

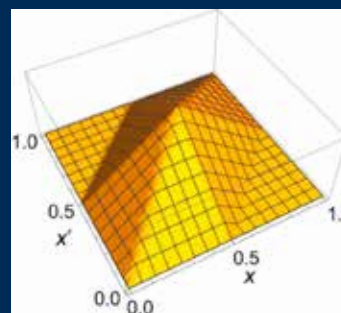
Professor Robert van Leeuwen

The main focus of this group is to study quantum non-equilibrium systems and to develop the underlying theoretical tools and methods. The main approaches to non-equilibrium physics are Time-Dependent Density Functional Theory (TDDFT) and Nonequilibrium Green's Function theory (NEGF). As an application the Green's function method is applied to describe quantum transport through molecular devices.

TIME-DEPENDENT DENSITY-FUNCTIONAL THEORY FOR STRONGLY INTERACTING ELECTRONS

We consider an analytically solvable model of two interacting electrons that allows for the calculation of the exact exchange-correlation kernel of time-dependent density functional theory. This kernel, as well as the corresponding density response function, is studied in the limit of large repulsive interactions between the electrons and we give analytical results for these quantities as an asymptotic expansion in powers of the square root of the interaction strength. We find that in the strong interaction limit the three leading terms in the expansion of the kernel act instantaneously while memory terms only appear in the next orders. We further derive an alternative expansion for the kernel in the strong interaction limit on the basis of the theory developed previously [Phys. Chem. Chem. Phys. 18, 21092 (2016)] using the formalism of strictly correlated electrons in the adiabatic approximation. We find that the first two leading terms in this series, corresponding to the strictly correlated limit and its zero-point vibration correction, coincide with the two leading terms of the exact expansion. We finally analyze the spatial nonlocality of these terms and show when the adiabatic approximation breaks down. The ability to reproduce the exact kernel in the strong interaction limit indicates that the adiabatic strictly correlated electron formalism is useful for studying the density response and excitation properties of other systems with strong electronic interactions.

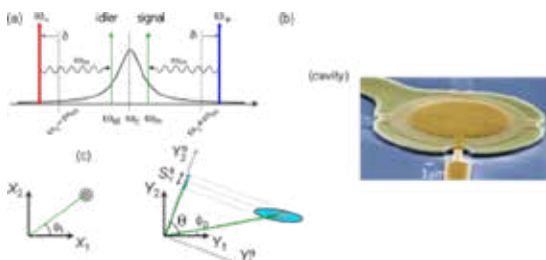
Luis Cort, Daniel Karlsson, Giovanna Lani, and Robert van Leeuwen, Physical Review A95, 042505 (2017)



used to convert quantum information between microwave and optical regimes.

C. F. Ockeloen-Korppi, T. T. Heikkilä, M. A. Sillanpää, F. Massel: *Theory of noiseless phase-mixing amplification in a cavity optomechanical system*, Quantum Sci. Technol. 2, 035002 (2017) [arXiv:1610.07579].

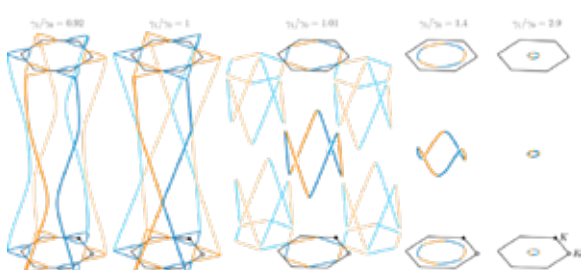
C. F. Ockeloen-Korppi, E. Damskägg, J.-M. Pirkkalainen, T. T. Heikkilä, F. Massel, M. A. Sillanpää, *Noiseless quantum measurement and squeezing of microwave fields utilizing mechanical vibrations*, Phys. Rev. Lett. 118, 103601 (2017).



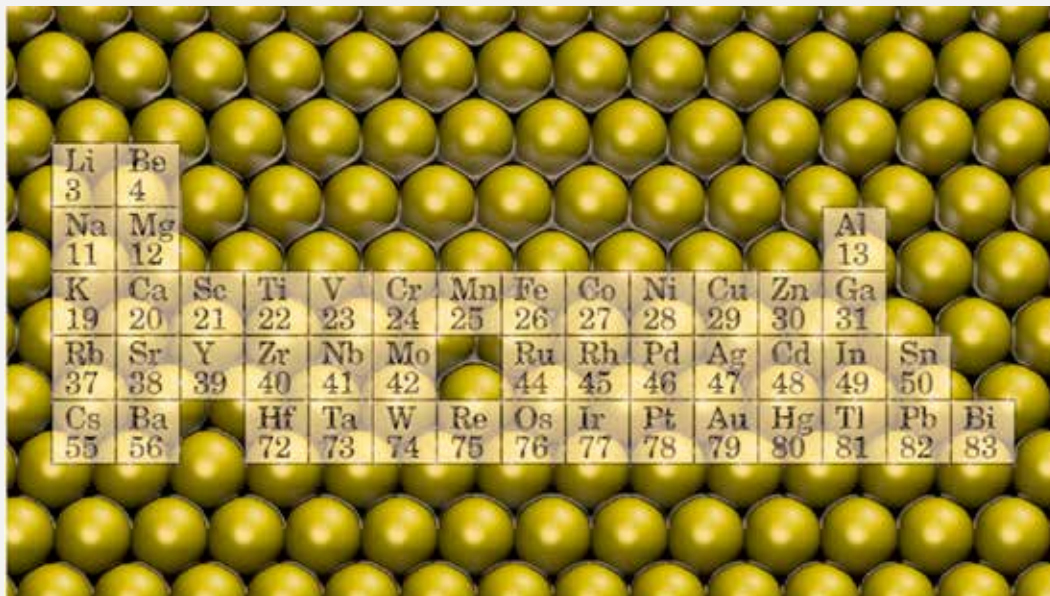
GRAPHITE AND ITS ELECTRONIC STRUCTURE

Regular graphite that can be found for example in pencils has an intriguing electronic structure. We have shown in our recent work that graphite in its pristine form is neither a regular metal, nor an insulator, but forms a semimetal structure where electronic bands cross each other. In physics such crossings are typically forbidden due to the coupling between such bands, and only allowed in the presence of some symmetry forbidding the coupling. We have shown that the crossing of the bands in graphite happens within a line of momenta, so that graphite is an example of a nodal line semimetals. There are two major types of graphite, related to how the graphene layers are stacked. In the more common Bernal (AB) graphite, the nodal line "protected" by the mirror symmetries of the graphite structure, whereas in rhombohedral (or ABC) stacked graphite the protection arises from inversion symmetry, along with the more usual spin rotation and time-reversal symmetries. One way to distinguish different types of nodal lines is to count how many times they go around the first Brillouin zone. Typical A-type nodal line materials host nodal lines within the Brillouin zone, whereas type B nodal lines go at least once around the Brillouin zone. These are topologically distinct possibilities, as type A-lines can exist and be annihilated alone, whereas the B-type nodal lines have a monopole-type topological charge, which means that they have to appear and disappear in pairs of opposite topological charge. We have shown that AB graphite hosts type A lines, whereas ABC graphite hosts type B lines. Moreover, we showed (see figure) how the type B lines (first part) can be destroyed in a process where the pairs of lines meet (second part), cut each other to form type A lines (third and fourth), and finally vanish (after fifth).

T. Hyart, R. Ojajarvi and T.T. Heikkilä, J. Low Temp. Phys. (2018)



LOW-DIMENSIONAL NANOMATERIALS MODELING



← [Nevalaita 2018] Atlas for the properties of elemental two-dimensional metals, Janne Nevalaita, Pekka Koskinen, Phys. Rev. B 97, 035411 (2018) Editor's suggestion, Physics synopsis

University lecturer Pekka Koskinen

We investigate low-dimensional nanomaterials, especially carbon nanomaterials, for their structural, mechanical, vibrational, electronic, and electromechanical properties using computational methods ranging from continuum to first-principles electronic structure methods.

www.jyu.fi/physics/materials/low-dimensional-nanomaterials-modeling

ATLAS FOR 2D METALS

In a computational study, we found simple connections between the properties of three-dimensional (3D) bulk metals familiar from the periodic table and the properties of atomically thin two-dimensional (2D) metal films [Nevalaita 2018]. Although 2D metal films were known to grow on substrates, unsupported films were not discovered experimentally until recently. Previous studies focused on a few elemental metals, but this study presented an entire periodic table for two-dimensional metals. The computationally constructed, new periodic table revealed that cohesive energies, bond lengths, and elastic moduli of 45 elemental 2D metals correlate linearly with the corresponding properties of the familiar 3D bulk metals. Most of the correlations could be understood by simple models and theoretical arguments. The presentation of these correlations and their origins makes a significant contribution to fundamental material research and helps to design novel 2D nano-heterostructures with optical, catalytic, and nanoelectronic applications.

OPEN QUANTUM SYSTEMS DYNAMICS

Academy research fellow Francesco Massel

Our research focuses on the theoretical investigation of open quantum systems, with particular emphasis of the properties of optomechanical systems in the quantum regime.

www.jyu.fi/physics/materials/open-quantum-systems-dynamics-1

WHAT IS AN OPTOMECHANICAL SYSTEM?

Broadly speaking, optomechanics studies the coupling between light and (usually macroscopic) mechanical objects. More specifically, we are interested in systems in which mechanical oscillators are coupled to one or more modes of an electromagnetic field (light, microwave) through a radiation-pressure-type interaction.

WHAT IS THE GOAL OF OUR RESEARCH?

In our activity, we try to achieve a regime in which quantum properties of these systems become relevant. To this end, we investigate the so-called strong coupling regime, in which electromagnetic and mechanical modes are strongly coupled to each other. Another line of research consists in the exploration of the consequences of being in a strongly coupled quantum regime. Does the physics of these systems correspond to anything known in other context, such as condensed matter physics? Can we exploit their properties for quantum information and communication purposes?

One of the most striking consequences of quantum theory is represented by the concept of entanglement: the dynamics of two quantum particles can be prepared such that their motion is inextricably

correlated, in ways that would be impossible for objects described by classical physics. In recent years, researchers have been exploring how entanglement can be generated in macroscopic objects.



↑ Petja Hyttinen & Olli Hanhiova
ARKH Architects Ltd

In this work [1], resulting from an international collaboration between the University of Jyväskylä, with Aalto University, UNSW (Australia) and University of Chicago (US), we demonstrated that we can generate an entangled state for the dynamics of two nearly-macroscopic mechanical objects each constituted by 10^{12} atoms. These mechanical are constituted by two vibrating membranes coupled to a microwave resonator. We showed that, by appropriately driving the microwave circuit, the two vibrating membranes enter a quantum-correlated state of motion, impossible for classical objects.

Our findings, on the one hand, provide new understanding of the quantum behavior of systems at the macroscopic scale, but has the potential to generate technological applications in the field of ultra-sensitive measurements and secure communications.

[1] Entangled massive mechanical oscillators C. F. Ockeloen-Korppi, E. Damskägg, J. M. Pirkkalainen, A. A. Clerk, F. Massel, M. J. Woolley, and M. A. Sillanpää, arXiv:1711.01640 (2017).

SUPERCONDUCTING SPINTRONICS

Academy research fellow Mihail Silaev

Our theory group works on various topics in superconductivity, including the vortex physics, non-equilibrium and spin-transport phenomena usual and topological superconductors. Our research is supported by the Academy of Finland research fellow program (Project No. 297439).

Highlights 2017: During the year 2017 we were working on several research projects:

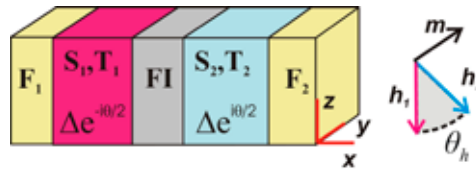
- Nonequilibrium spin states in superconductors and related effects: spin currents, spin-temperature and spin-charge coupling
- Dynamical coupling between magnetization and superconducting currents
- Multiband superconductivity

NONEQUILIBRIUM SPIN STATES IN SUPERCONDUCTORS: 0-THERMAL JOSEPHSON JUNCTION

M.A. Silaev, Phys. Rev. B 96, 064519 (2017).

We predict the thermal counterpart of the anomalous Josephson effect in superconductor/ferromagnet/superconductor junctions with noncoplanar

magnetic texture. The heat current through the junction is shown to have the phase-sensitive interference component proportional to $\cos(\theta - \theta_0)$, where θ is the Josephson phase difference and θ_0 is the texture-dependent phase shift. In the generic trilayer magnetic structure (shown schematically in the Fig.1) θ_0 is determined by the spin chirality of magnetic configuration and can be considered as the direct manifestation of the energy transport with participation of spin-triplet Cooper pairs. For typical parameters θ_0 is much larger than the phase shift of the equilibrium Josephson current.



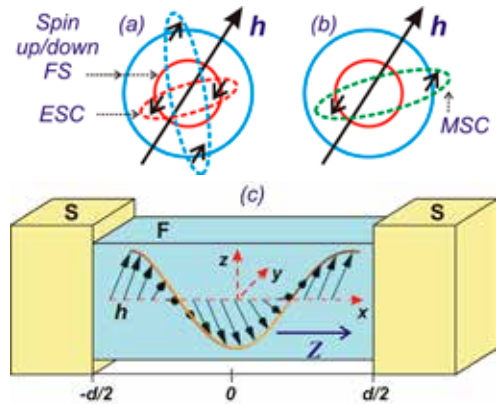
↑ Figure 1.

DYNAMICAL COUPLING BETWEEN MAGNETIZATION AND SUPERCONDUCTING CURRENTS

I. V. Bobkova, A. M Bobkov, M. A. Silaev, PRB 96, 094506 (2017);
M.A. Silaev, I.V. Tokatly, F.S. Bergeret, Phys. Rev. B 95, 184508 (2017)

Motivated by the possibilities of dissipationless switching the magnetic memory elements we have studied the coupling of magnetization and supercurrent in superconductor / magnetic hybrids (Fig.2). We have considered the basic question of whether one can induce the current by bringing the superconductor to interact with the magnetic texture. The reciprocal effect will allow tuning the magnetization with the superconducting current. These effects have been difficult to study since the supercurrent as we have shown can be coupled to the magnetization only beyond the widely-used

quasiclassical theory. Going beyond this limitation we demonstrate that F/S systems with spin-filtering elements can feature spontaneous charge currents and phase-shifted thermal interference currents which can be controlled by the magnetic configuration.

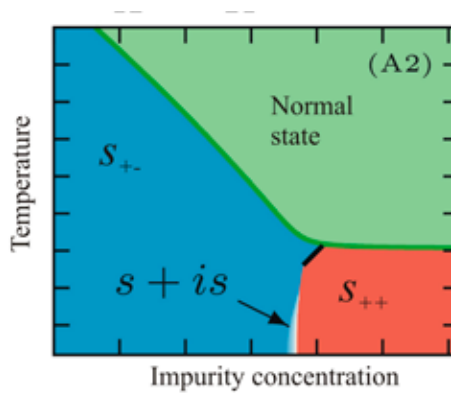


↑ Figure 2.

Phase diagram of dirty two-band superconductors and observability of impurity-induced $s+i s$ state M. Silaev, J. Garaud, and E. Babaev, Phys. Rev. B 95, 024517 (2017).

We have investigated the phase diagram (fig.3) of dirty two-band superconductors primarily focusing on the properties and observability of the time-

reversal symmetry-breaking $s+i s$ superconducting states, which can be generated in two-band superconductors by interband impurity scattering. First, we show that the $s+i s$ state can form as an intermediate phase at the impurity-driven crossover between s_{\pm} and s_{++} states. We show that there is a second scenario where domains of the $s+i s$ state exists in the form of an isolated dome inside the s_{\pm} domain, completely detached from the transition between s_{\pm} and s_{++} states. We demonstrate that in both cases the $s+i s$ state, generated by impurity scattering exists in an extremely small interval of impurity concentrations. Although this likely precludes direct experimental observation of the $s+i s$ state formation due to this mechanism, this physics leads to the appearance of a region inside both the s_{\pm} and s_{++} domains with unusual properties due to softening of normal modes.



↑ Figure 3.

COMMUNICATING SCIENCE ON TUTKIJOIDEN YÖ

Demonstrations ranging from the size of the atomic nucleus to astronomical dimensions, visitors covering the distribution of the demographic curve, stimulating discussions... Tutkijoiden yö offered plenty for all parties involved.

A constant flow of citizens streamed towards the illuminated Ylistö buildings. Inside the premises, doorways and laboratories were presented with ambient light and music. The public mingled amongst researchers presenting their forefront science, one could feel the enthusiasm. Research groups had spiced up their shows helping to provide a fresh new experience for the visitors. Nevertheless, it was person-to-person discussions that made the best impact. And yes, those were numerous, more than 2400 visitors entered the Department of Physics, while Nanoscience Centre recorded 1500 guests.

Tutkijoiden yö gave face to scientists and emphasized the importance of fundamental research. Spanning many facets of physics topics and scientists with diverse backgrounds, it delivered a message of cutting edge research conducted at the Department of Physics. The specific aim was to pro-

mote research careers especially to high school and university students, and young people in general who are about to make their first real career choice.

Tutkijoiden yö was organised as a part of the European Researchers' Night on the last Friday of September, 29.09.2017. University of Jyväskylä was the coordinating body of the Finnish consortium that included more than 10 universities and other stakeholders. With more than 24 000 visitors, Tutkijoiden yö can be considered as the largest science communication event ever organised in Finland. In particular the event in Jyväskylä, organised in close collaboration to the Jyväskylä City of Light project, was a huge success with 12 000 visitors.

Excited researchers did very well in transferring the spark of research to the visitors. We believe that a research career is now seen as a more attractive option for many visitors of the event.

Janne Pakarinen
TUTKIJOIDEN YÖ COORDINATOR

"All presenters of the Researchers' Night were real experts, easy to approach and introduced their subject with interest." – A Visitor

"Kaikki tapaamani Tutkijoiden yössä 'esiintyneet' asiantuntijat ja tutkijat olivat asiantuntevia, helpposti lähestyttäviä ja osasivat kertoa aiheestaan kiinnostavasti." – A Visitor



↑ Photo by Ari Lehtiö.



↑ Photo by Ari Lehtiö.



↑ Photo by Petteri Kivimäki



↑ Photo by Petteri Kivimäki

ACCELERATOR LABORATORY

**Professor Ari Jokinen,
Head of the Accelerator Laboratory**

The Accelerator Laboratory is an integral part of the Department of Physics. Presently it includes four accelerators with a variety of ion sources and innovative instrumentation for basic research, ion-beam based material physics and applications.

Research highlights are communicated in group reports later in this Annual Report. Demand for beam time remains high. Altogether 39 new proposals were submitted to the Program Advisory Committee (PAC) in 2017. In addition to the PAC proposals, a significant fraction of the beam time is given directly for commercial use. The request for the latter exceeded the allocated beam time. The K130 accelerator provided 6608 hours of beam time for basic research and industrial applications in 2017. The Users community of the Accelerator Laboratory is supported by the transnational access framework in the Horizon 2020 proposal ENSAR2. Such support is available for the four-year period 1.3.2016-28.2.2020.

Commercial services continued with 46 campaigns for 25 different companies, institutes or universities by using 1394 hours (22%) of K-130 beam time in

2017 – all numbers showing an increase compared to the previous year. As a result, the total revenue of RADEF (commercial and R&D projects) has continued its annual increase year after year.

At the end of the year 2017 major changes occurred in the laboratory staff. The former long-time head of the Accelerator Laboratory and the leader of the Centre of Excellence, Professor Rauno Julin, retired. Head of the Accelerator Laboratory (2014-2017), prof. Ari Jokinen, was nominated as a vice dean (Research and Innovations) of the Faculty of Mathematics and Science. He was replaced by prof. Paul Greenlees as the new Head of the Accelerator Laboratory starting in the beginning of 2018.

The year 2017 was the last year of the Centre of Excellence (CoE) in Nuclear and Accelerator-Based Physics granted by the Academy of Finland. Three-year exit-funding provided by the Rector and success in individual grants compensated the financial loss. The Accelerator Laboratory has two Academy Research Fellows (Anu Kankainen and Tommi Eronen). In 2017 Anu Kankainen received the prestigious ERC Consolidator Grant for her project MAIDEN: "Masses, Isomers and Decay studies for Elemental Nucleosynthesis".

In 2017 three new projects received funding, two by the Academy of Finland and one from the Region Normandie, France. The NANOIS project, led by prof. Timo Sajavaara, aims to develop a new way to make plasmonically-active complex 3D nanostructure shapes inside very stable insulating materials. The role of the Accelerator Laboratory is to provide a new technique of ion-beam shaping of nanostructures. SISIN led by Janne Pakarinen explores the structure of intruder states associated with different

shapes in heavy nuclei. MORA (Matter's Origin from the RadioActivity of trapped and polarized isotopes) aims to use nuclear beta decay as a probe for physics beyond the Standard Model. The first phase of the experiment will be performed over the coming years in the Accelerator Laboratory.

A significant new international training co-operation project was launched in 2017, namely the RAD-SAGA Innovative Training Network under the Marie Skłodowska-Curie Actions of Horizon 2020. In addition, in November 2017 the Pelletron group hosted a Training school on ion beam techniques to study ALD films (co-organized together with COST Action MP1402 – HERALD). This outreach and networking event brought 15 participants and 4 lecturers from 10 different countries to Jyväskylä to learn about the possibilities of ion beam analysis in thin film research.

JYFL-ACCLAB is the only national infrastructure on the roadmap of the Ministry of Education and Culture (OKM) for 2017-2020 in the category "Natural Sciences and Technology". A position on the roadmap shows the importance of the facility nationally and supports national infrastructure funding (FIRI) proposals. In 2017, the Accelerator Laboratory received infrastructure funding to the level of 1.3 M€ for a project covering various topics in the Accelerator Laboratory. The funding granted allowed procurement of an AGATA module, representing the Finnish contribution to the next generation gamma-ray tracking spectrometer.

On 1st-2nd February, a dedicated workshop for physics carried out using MARA coupled to the JUROGAM3 array of germanium detectors, was held. The workshop was attended by over 40 participants.

The European Researchers' Night took place across Europe on the 29th of September 2017. The event was a success in the Accelerator Laboratory, with more than 1000 people participating in a number of tours around the experimental facilities, lectures and interactive demonstrations. The organizers of the 2016 and 2017 event, Janne Pakarinen and Philippos Papadakis, were awarded the Science Communication Award of the academic year 2016–2017 for their merits in organizing the event.



ADMINISTRATION AND CONTACT PERSONS:

Ari Jokinen, Head of the Accelerator Laboratory

Rauno Julin, leader of the Center of the Excellence

Mikael Sandzelius, beam time coordinator

MEMBERS OF THE PROGRAMME ADVISORY COMMITTEE OF THE JYFL ACCELERATOR LABORATORY:

Michael Bender, Université de Bordeaux, France

Jon Billowes, University of Manchester, UK

Bertram Blank, CEN Bordeaux-Gradignan, France (chair)

Bo Cederwall, KTH Stockholm, Sweden

Fadi Ibrahim, IPN Orsay, France

Silvia Lenzi, University of Padova, Italy

SCIENTIFIC ADVISORY BOARD OF THE CENTRE OF EXCELLENCE IN NUCLEAR AND ACCELERATOR BASED PHYSICS:

Witold Nazarewicz, professor, NSCL,
Michigan State University, USA

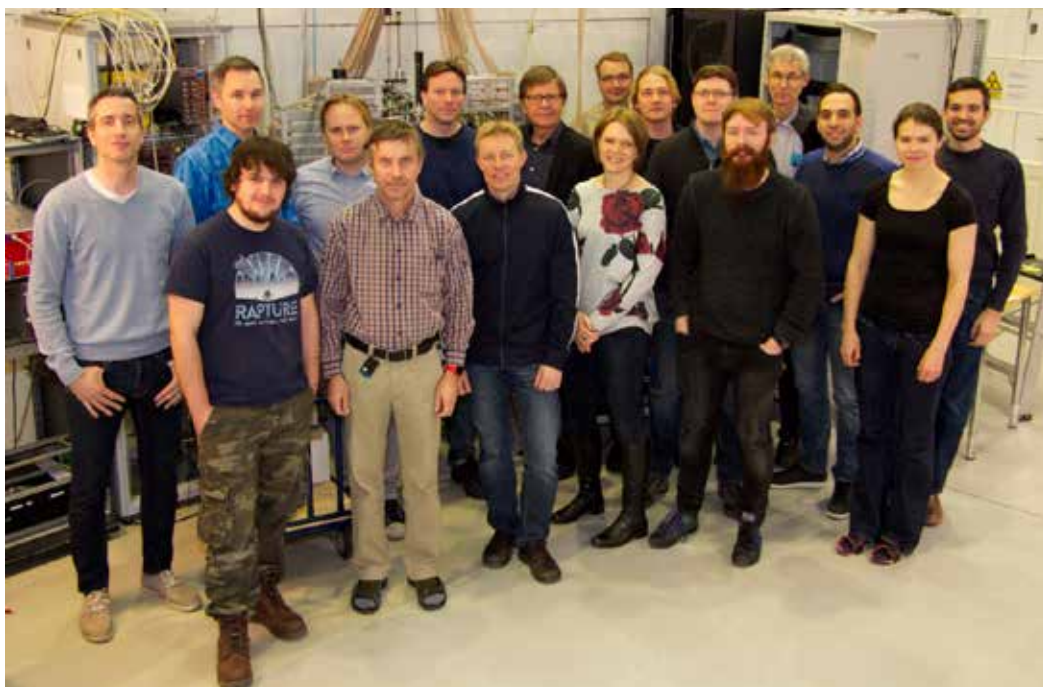
Reiner Krücken, professor, Deputy Director,
TRIUMF, Canada

Pekka Koskela, professor, University of Jyväskylä

Jukka Pekola, professor, Academy of Finland

Anna Kalliomäki, science adviser, Academy of Finland

NUCLEAR SPECTROSCOPY



MARA DEVELOPMENT AND EXPERIMENTAL PROGRAM CONTINUES

Following on from the highly successful commissioning and first production experiments in 2016 using the MARA (Mass Analysing Recoil Apparatus) separator, 2017 saw the successes at MARA continue. The group focused on further development of the instrumentation at MARA, including completion and testing of the upgraded UoYTube charged particle detector built by the University of York. The detector upgrade includes the use of new plastic scintillator detectors coupled to avalanche silicon photomultipliers and an improved target system.

Example alpha-particle energy spectra from the decay of fusion-evaporation residues implanted into the MARA focal plane double-sided silicon detector are shown in figure 1. The spectra were obtained in a test experiment using the reaction of a ^{78}Kr beam with a ^{96}Mo target, with UoYTube installed at the target position. From the spectra it can be deduced that the efficiency for detection of one proton in UoYTube is approximately 70% and that the channels corresponding to evaporation of neutrons only can be selected effectively when events involving emission of protons are rejected.

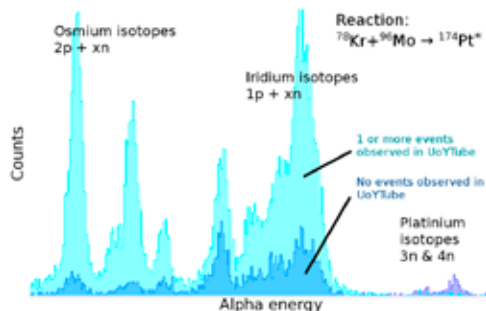
Two production experiments were also carried out using MARA, first led by the University of Liverpool and focused on the proton-emitting isotope ^{176}Tl and the second led by the local group aiming at the production of neutron-deficient Hg isotopes. The second experiment employed the reaction $^{78}\text{Kr} + ^{96}\text{Ru}$ and was indeed successful, resulting in the observation of a candidate decay chain for the new isotope ^{170}Hg . This represents the third new isotope discovered using MARA to date.

Following the successful campaign of commissioning experiments carried out in 2016, the local group organized a workshop focused on the possible physics questions to be addressed using MARA coupled to ancillary detectors and arrays of germanium detectors at the target position. The workshop was held in the Department on 1st – 2nd February with over 40 participants. Following the discussions at the workshop, a total of thirteen related scientific proposals have been accepted at the March and September meetings of the Program Advisory Committee (PAC). An active community and exciting campaign of experiments thus awaits the coupling of MARA to JUROGAM3, which will be realized in late 2018.

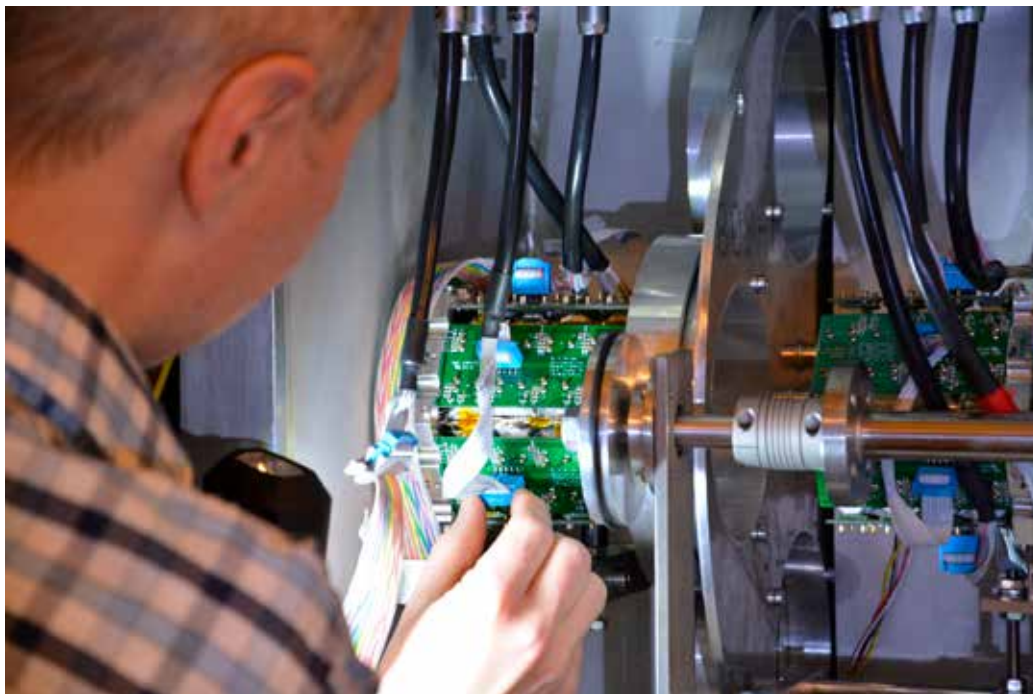
The group is one of the largest in the Accelerator Laboratory

whose work is focused on fundamental studies of the structure of the nucleus. The main focus of the research is on experimental investigations into heavy and neutron-deficient nuclei, using in-beam and decay spectroscopic techniques. In 2017, the group used a smaller than usual proportion of the K130 cyclotron beam time, using a total of 91 days for 9 different experiments. This was quite an achievement, considering that in addition to running experimental campaigns, the group also began reconstruction of the experimental caves to make way for JUROGAM3 and also performed a significant amount of development work. The group members were co-authors on 18 peer-reviewed journal articles and 5 conference proceedings. Some highlights from the year are presented in the following.

www.jyu.fi/physics/accelerator/nuclear-spectroscopy



↑ Figure 1. Example alpha-particle energy spectra from the decay of fusion-evaporation products in the MARA focal plane double-sided silicon strip detector. The reaction used was $^{78}\text{Kr} + ^{96}\text{Mo}$ and charged particles evaporated from the compound nucleus were detected using UoYTube.



↑ Figure 2: The UoYTube detector installed at the target position of MARA.

PLUNGER CAMPAIGN

Three experiments for a total of 30 days of beam time were dedicated to the study of lifetimes of nuclear states using the Recoil-Distance Doppler Shift (RDDS) technique with the DPUNS plunger device. DPUNS was mainly built by the University of Manchester and based on an existing design from the University of Cologne. As reported in the Annual Report 2016, previous experiments to measure transition probabilities in ^{168}Os (and ^{166}W) resulted in the observation of “anomalous” ratios of the reduced transition probabilities for the 4^+ to 2^+ and 2^+ to 0^+ transitions i.e. $B(E2: 4^+ \text{ to } 2^+)/ B(E2: 2^+ \text{ to } 0^+)$. Such ratios cannot be simply explained with current theoretical predictions. Two of the experiments were dedicated to follow-up measurements of this phenomenon, focused on ^{172}Pt and ^{164}W . Both experiments were successful and detailed analysis of the data is in progress.

QUADRUPOLE MOMENT OF FIRST EXCITED 2^+ STATE IN ^{12}C

In recent years, significant advances have been made in so-called “ab-initio” approaches to theoretical nuclear structure calculations, using nuclear interactions derived from chiral effective field theory. The predictions of such theories for properties such as electric quadrupole moments are sensitive to the underlying interaction employed, and can be tested by precision determinations of such moments in experiment. One case, accessible via both theory and experiment is the electric quadrupole moment of the 2^+ state in ^{12}C . A measurement of the quadrupole moment of this state is possible via the re-orientation effect in a low-energy Coulomb excitation experiment. The experiments are rather challenging, which is reflected in the fact that currently the error bar on the adopted experimental value is very large. In order to try to better determine the experimental value and to reduce the error bar to a level of better



→
Figure 3: A schematic view of the JUROGAM3 array of germanium detectors installed at the target position of the MARA separator.

than 20%, the final experiment using the JUROGAMII array of germanium detectors was dedicated to such study. The experiment was led by the University of York and TU Darmstadt, and required the installation of an additional silicon “CD” detector in order to detect the charged particles scattered in the Coulomb excitation reaction process. The experiment used a total of ten days of beam time with a low-energy ^{12}C incident on a ^{208}Pb target. During the experiment, it was possible to use a typical beam intensity of 70pA and the smooth run ensured that the requirements of the proposal were met. Analysis of the data obtained is in progress.

TRANSITION TO JUROGAM3 BEGINS

After close to ten years of hosting the JUROGAMII array of germanium detectors from 2008 to 2017, the array was dismantled in May after completion of the final experiment to study ^{12}C via Coulomb excitation. Over that period, a total of 19800 hours of beam time were devoted to a total of 103 measurements. The experiments carried out with JUROGAM and JUROGAMII since 2004 have resulted in a total of 140 refereed publications and over 70 doctoral theses in JYFL and in the institutes of our international user community.

Immediately after the ^{12}C experiment was completed on 5th May, the process of dismantling the array began, work which was completed by 22nd May. On 28th June, the detectors had been annealed, tested, and shipped to IPN Orsay where they will be employed in the NuB-ALL array for an experimental campaign lasting until August 2018. Upon return to JYFL, the detectors will be installed in a new support infrastructure known as JUROGAM3. The design of the new support infrastructure can be seen in the figure below. It is intended that it will be possible to move the array of germanium detectors from the target position of MARA to that of RITU and vice versa without the need to remove the high-voltage bias from the detectors. In this way, the appearance of neutron damage and subsequent need for time-consuming annealing and repair of the detectors is avoided. Funding for the structure was awarded by the Academy of Finland through the FIRI funding instrument.

Selected Publications

The first new isotopes of 2017 to be published, as a side product of an experiment to study the phenomenon of electron-capture delayed fission:

Konki, J., Khuyagbaatar, J., Uusitalo, J., Greenlees, P., Auranen, K., Badran, H., . . . Yakusheva, V. (2017). *Towards saturation of the electron-capture delayed fission probability: The new isotopes ^{240}Es and ^{236}Bk* . *Physics Letters B*, 764, 265-270. doi:10.1016/j.physletb.2016.11.038 Open access

THE EXOTIC NUCLEI AND BEAMS

Professors Ari Jokinen and Iain Moore

Academy research fellows Tommi Eronen and Anu Kankainen

Senior researchers Heikki Penttilä and Sami Rinta-Antila

The exotic nuclei and beams group exploits the universal ion guide production method at the IGISOL facility to explore short-lived exotic nuclei on both sides of the valley of beta stability. We use a novel combination of ion manipulation techniques, optical spectroscopy and a variety of nuclear decay spectroscopic tools to further our understanding of ground and isomeric state nuclear structure.

<https://www.jyu.fi/igisol>

Our group benefits from Horizon 2020 programs within ENSAR2, CHANDA and FET-OPEN projects as well as via the ChETEC Cost Action. The research at IGISOL is strongly supported by the Academy of Finland with two Academy Research Fellows and an Academy postdoctoral researcher working on nuclear astrophysics, neutrino physics, and laser ionization related projects, respectively. FIRI funding from the Academy of Finland has been essential for renewing our research infrastructure. We have also

actively participated in international collaborations in research and development work at other facilities, including GANIL, ISOLDE (CERN) and GSI, the site of the future RIB facility FAIR. Many of our international activities were carried out in close collaboration with the Helsinki Institute of Physics.

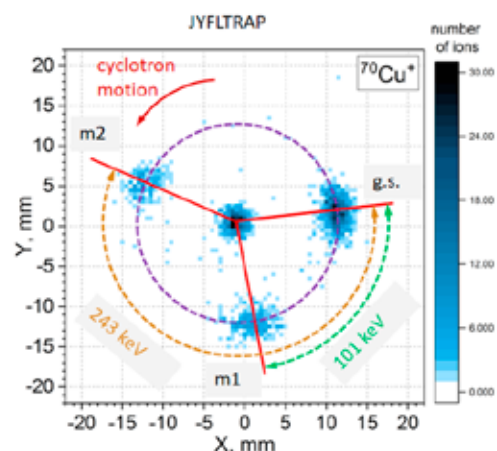
Academy Research Fellow Anu Kankainen has been awarded the prestigious ERC Consolidator Grant in 2017 for her project MAIDEN “Masses, Isomers and Decay studies for Elemental Nucleosynthesis”. This significant research funding worth of 2 MEUR, will substantially strengthen the research at IGISOL. The five-year project will start in June 2018.

A new project, Matter’s Origin from the RadioActivity of trapped and polarized isotopes (MORA), has been initiated at IGISOL. MORA aims to use nuclear beta decay as a probe for physics beyond the Standard Model. The project will exploit state-of-the-art techniques in laser polarization and ion trapping, combined with nuclear beta detection. In 2017, MORA was awarded 600 kEUR of funding from the Region Normandie to develop the required infrastructure. The first phase of the experiment will begin at IGISOL in 2019 and in a second phase, after 2022, will move to the DESIR facility, SPIRAL-2, in France.

TECHNICAL DEVELOPMENTS

Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique. In 2017, the PI-ICR technique was introduced at JYFLTRAP. This new phase-dependent technique has now been employed for atomic mass measurements of exotic nuclei and to separate isomeric states of nuclei. Mass measurement accuracy in the 10^{-10} -level was demonstrated using stable (and well known) ^{85}Rb and ^{87}Rb isotopes. This is

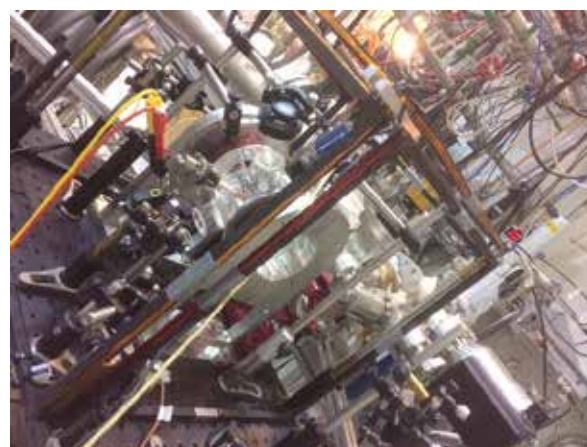
about a factor of 10 improvement over the previous TOF-ICR (time-of-flight ion-cyclotron-resonance) technique. The first mass measurements of short-lived exotic nuclei were conducted in the Fall 2017. The PI-ICR technique was also employed in a novel way to provide clean samples of isomeric states. For example, ^{127m}Cd (280 keV energy difference between states) was delivered to the TASISpec post-trap decay spectroscopy setup. To our knowledge, this is the first time PI-ICR was used to physically separate the low-lying isomeric state from the ground state for spectroscopy. Later, even better mass resolving power was demonstrated. The figure below shows the separation of the three states in ^{70}Cu with 100 ms cleaning excitation. The mass resolving power ($M/\Delta M$, full width at half maximum) in this case is more than 10^6 . By extending the cleaning time the mass resolving power can be increased up to 10^7 , allowing separation of states at the 10-keV level.



↑ Figure 1: The ground state (g.s), first isomeric state (m1) at 101 keV and second isomeric state (m2) at 243 keV in ^{70}Cu resolved using the PI-ICR technique at JYFLTRAP.

Magneto-optical trapping of Cs atoms. The cold atom team from University College London (UCL) has made excellent progress in trapping of Cs atoms at IGISOL. In 2017 a new beam line was constructed to connect the electrostatic switchyard to a new atom trap chamber (Fig. 2) which arrived after the summer. The new pyrex chamber was coated with a special organic film to reduce the loss of Cs atoms

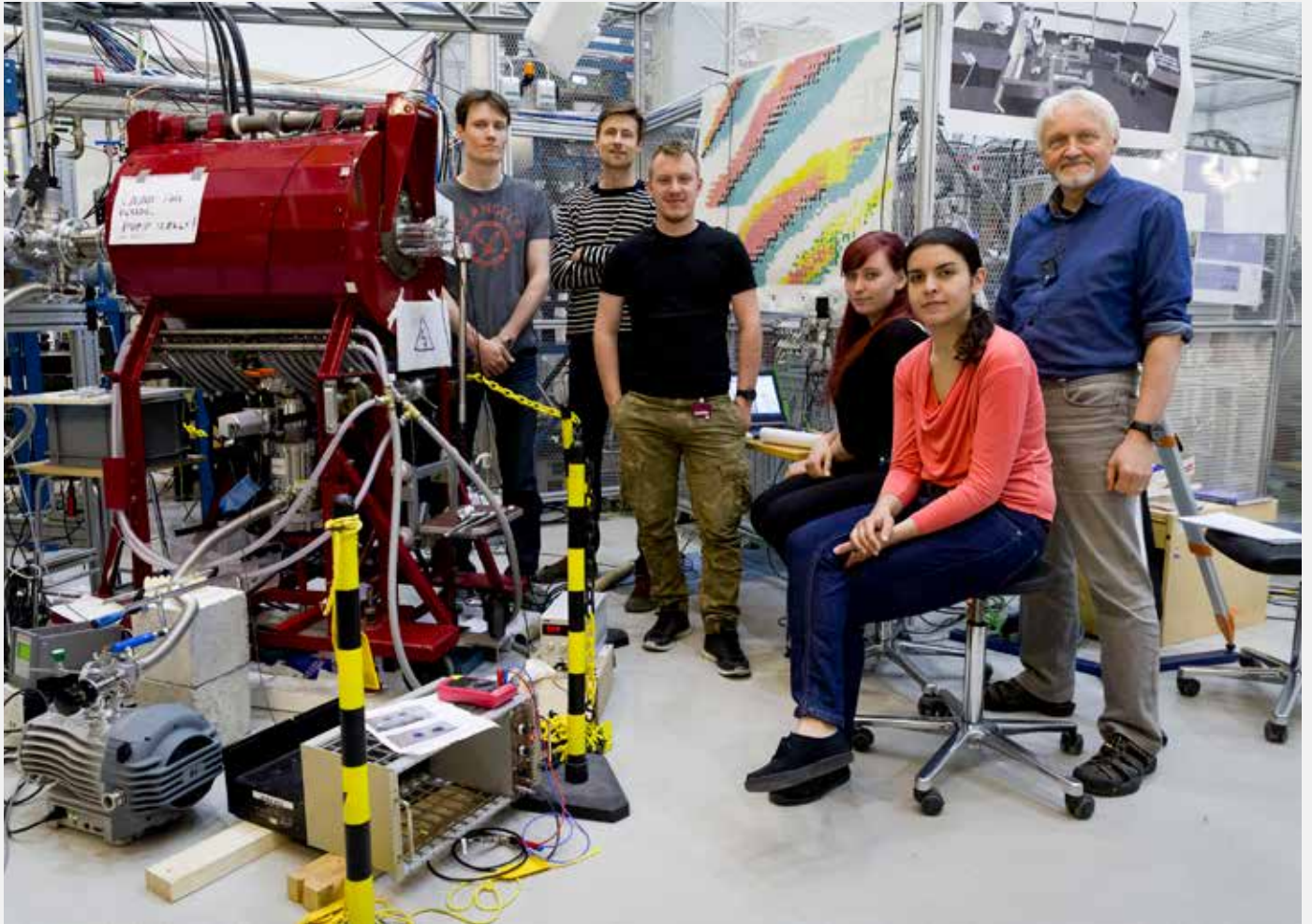
when they collide with the walls. The coating also increases the thermalization rate of atoms, which are released from a heated (up to 1000 K) yttrium neutralizer foil following implantation of the ion beam delivered from IGISOL. In December, a series of successful implantation, release, laser cooling and trapping tests were done using a stable beam of $^{133}\text{Cs}^+$ ions at 30 keV, produced from the off-line surface ion source located on the second floor of the facility. Analysis of the dynamics of evaporation, laser cooling and trapping following implantation is underway.



↑ Figure 2: The new pyrex chamber for Cs atom trapping connected to the beam line at IGISOL.

RESEARCH HIGHLIGHTS

Mass measurements of neutron-rich isotopes for nuclear structure and astrophysics. In 2017, mass measurements at the JYFLTRAP Penning trap were extended toward heavier and lighter fission fragments. Nuclei in the $A=160$ region were studied for the formation of the rare-earth peak in the astrophysical r-process. Several previously unknown nuclear masses were measured. In the lower fission-fragment region, the experimental program focused on nuclei close to ^{78}Ni . The production rates both in proton- and deuteron-induced fission on Th and U targets were explored prior to the experiment, which was ultimately run with a 35 MeV proton beam on natural uranium. Three isotopes were measured for the first time and the PI-ICR technique



←
Figure 3: The newly commissioned refurbished intermediate focus spectrometer at IGISOL in May 2017 following a successful test for the beta decay of ^{20}F .

was used for identification of ground and isomeric states. The studied nuclei are relevant for the evolution of nuclear structure around $N=40$ and $N=50$. Nuclei close to ^{78}Ni also play a central role during the core collapse phase of supernovae since electron captures on these neutron-rich nuclei cool the core via neutrino emission and affect the electron degeneracy pressure which resists the gravitational collapse.

Commissioning of HIGISOL – masses close to the $N=Z$ line. An improved and optimized HIGISOL platform for heavy-ion fusion-evaporation reactions was commissioned in 2017. A successful set of mass measurements of interest to both nuclear astrophysics and nuclear structure were performed, including measurements of $T_z=+1$ nuclei ^{82}Zr , ^{84}Nb , ^{86}Mo and ^{88}Tc , as well as ^{89}Ru ($T_z=+1/2$). The PI-ICR technique was used for a mass measurement for the first time to precisely determine the ground and isomeric state masses of ^{88}Tc .

Trap-assisted spectroscopy. In 2017 two gamma-ray spectroscopy studies of neutron-rich nuclei around $A=88$ and $A=110$ were performed in collaboration with Warsaw University, as well as spectroscopy of neutron-rich cadmium isotopes with TASISpec (a collaboration with GSI and Lund University).

Collinear laser spectroscopy of doubly-charged fission fragments. An important atomic calibration to an extensive chain of nuclear charge radii in yttrium isotopes has now been made by performing the first collinear laser spectroscopy of doubly-charged ions, produced from the IGISOL at around 10% of the singly-charged yield. Critical to this work was the availability of stable beams from a new off-line source located on the second floor of the facility. A re-measurement of the fission products of only ^{96}Y and ^{98}Y was sufficient to re-calibrate all previous data, with a vital frequency reference from simultaneously available beams of stable ^{89}Y .

Recommissioning of an electron spectrometer for the beta decay of ^{20}F . Knowledge of the electron-capture rate on ^{20}Ne is critical for understanding the final evolution of stars in the mass range between 8 and 10 solar masses. Of crucial input to stellar models would

be an experimental measurement of the second-forbidden, non-unique, $0^+ \rightarrow 2^+$ transition between the ground states of ^{20}Ne and ^{20}F . The transition strength may be determined from the branching ratio of the inverse transition in the β decay of ^{20}F , for which the experimental upper limit is $\sim 10^{-5}$. In collaboration with Wlodek Trzaska and Oliver Kirsebom (spokesperson of the experiment) we have installed and tested a refurbished intermediate-focus spectrometer capable of focusing electrons up to 8 MeV. In addition to a yield test for the production of ^{20}F via the $^{19}\text{F}(d,p)$ reaction, the complete setup was successfully tested at IGISOL in May 2017. Figure 3 shows the spectrometer after commissioning on the spectroscopy beam line at IGISOL and some of the team involved. Additional detector tests were performed (see report of W. Trzaska) and the spectrometer is now ready for the full experiment to be performed in 2018.

SELECTED PUBLICATIONS

D. A. Nesterenko, A. Kankainen, L. Canete, M. Block, D. Cox, T. Eronen, C. Fahlander, U. Forsberg, J. Gerl, P. Golubev, J. Hakala, A. Jokinen, V. S. Kolhinen, J. Koponen, N. Lalović, Ch. Lorenz, I. D. Moore, P. Papadakis, J. Reinikainen, S. Rinta-Antila, D. Rudolph, L. G. Sarmiento, A. Voss and J. Äystö. *High-precision mass measurements for the isobaric multiplet mass equation at $A=52$* . J. Phys. G: Nucl. Part. Phys. 44 (2017) 065103. <https://doi.org/10.1088/1361-6471/aa67ae>

T. Eronen, J. C. Hardy, L. Canete, A. Jokinen, J. Hakala, A. Kankainen, V. S. Kolhinen, J. Koponen, I. D. Moore, I. M. Murray, H. Penttilä, I. Pohjalainen, O. Poleshchuk, J. Reinikainen, S. Rinta-Antila, N. Soukouti, A. Voss, and J. Äystö. *QEC value of the superallowed β emitter ^{42}Sc* . Phys. Rev. C 95 (2017) 025501. <https://doi.org/10.1103/PhysRevC.95.025501>

M. Czerwinski, K. Sieja, T. Rzaca-Urban, W. Urban, A. Plochocki, J. Kurpeta, J. Wisniewski, H. Penttilä, A. Jokinen, S. Rinta-Antila, L. Canete, T. Eronen, J. Hakala, A. Kankainen, V. S. Kolhinen, J. Koponen, I. D. Moore, I. Pohjalainen, J. Reinikainen, V. Simutkin, A. Voss, I. Murray, and C. Nobs. *Penning-trap-assisted study of excitations in ^{88}Br populated in β decay of ^{88}Se* . Phys. Rev. C 95 (2017) 024321. <https://doi.org/10.1103/PhysRevC.95.024321>

V. Guadilla, A. Algora, J. L. Tain, J. Agramunt, D. Jordan, A. Montaner-Pizá, S. E. A. Orrigo, B. Rubio, E. Valencia, J. Suhonen, O. Civitarese, J. Äystö, J. A. Briz, A. Cucoanes, T. Eronen, M. Estienne, M. Fallot, L. M. Fraille, E. Ganioglu, W. Gelletly, D. Gorelov, J. Hakala, A. Jokinen, A. Kankainen, V. Kolhinen, J. Koponen, M. Lebois, T. Martinez, M. Monserrate, I. Moore, E. Nacher, H. Penttilä, I. Pohjalainen, A. Porta, J. Reinikainen, M. Reponen, S. Rinta-Antila, K. Rytönen, T. Shiba, V. Sonnenschein, A. A. Sonzogni, V. Vedia, A. Voss, J. N. Wilson, and A.-A. Zakari-Issoufou. *Experimental study of ^{100}Tc β decay with total absorption γ -ray spectroscopy*. Phys. Rev. C 96 (2017) 014319. <https://doi.org/10.1103/PhysRevC.96.014319>

A. Voss, V. Sonnenschein, P. Campbell, B. Cheal, T. Kron, I.D. Moore, I. Pohjalainen, S. Raeder, N. Trautmann and K. Wendt. *High-resolution laser spectroscopy of long-lived plutonium isotopes*. Phys. Rev. A 95 (2017) 032506. <https://doi.org/10.1103/PhysRevA.95.032506>

INSTRUMENTS AND METHODS IN NUCLEAR, PARTICLE, AND ASTROPARTICLE PHYSICS

Senior Researcher Wladyslaw Trzaska

One of the most exciting aspects of experimental physics is doing what nobody has done before. Development of new instruments and methods is an integral part of that process. Over the past decades the activities of our group expanded from low-energy nuclear physics to relativistic heavy ion collisions, neutrino physics, and ultra-relativistic cosmic rays. In addition to various spectrometers and devices for the use with cyclotron beams our group has contributed to the design and construction of the ALICE experiment at CERN, designed and build a cosmic ray experiment EMMA, and made a noticeable contribution to the LAGUNA Design Study. More on our R&D work on neutrino studies is presented in the Neutrino Physics section. Currently the main activity of our group is the design and construction of the Fast Interaction Trigger for the upgrade of the ALICE detector.

www.jyu.fi/physics/accelerator/instruments-and-methods-in-nuclear-particle-and-astroparticle-physics

ALICE FIT DETECTOR



Fast Interaction Trigger (FIT) is being designed and constructed to replace the current T0, V0, and FMD detectors during the upgrade of ALICE in 2019-2020. The work on FIT involves about 50 scientists, engineers, and students from 14 institutes in 6 countries. Our group was awarded the leadership of this project. FIT will be a key element in the operation of the upgraded ALICE. The main online functionalities of FIT will be luminosity monitoring with a direct link to the LHC and generation of fast trigger signals for the ALICE subsystems. The trigger generated by FIT will allow for online vertex determination, minimum bias and centrality-based event selection, suppression of beam-gas events, and a veto for ultra-peripheral collisions. The trigger will be generated with the latency of less than 425 ns including a 222 ns delay along the connecting cables. For the offline analysis FIT will provide the precise collision time for the Time-of-Flight (TOF) based particle identification and unbiased multiplicity distribution in the forward direction. The latter is

needed for the determination of the centrality and of the event plane in heavy-ion collisions.

In 2017 FIT successfully completed three Engineering Design Reviews and two rounds of in-beam tests. We have also finalized the modification of the MCP-PMT based photo-sensors. The mockup of the Cherenkov array was produced and integrated with other upgrade elements. The first concept of the mechanical support for the large scintillator ring was recently completed and approved by the technical coordination of the ALICE experiment.

NUCLEAR REACTIONS

During the summer of 2017 we have conducted three major experiments at the Large Scattering Chamber: (i) ^5He Cluster Transfer by Scattering of ^2H from a Be target, (ii) Study of ^{11}B (^3He , d) ^{12}C reaction, and (iii) Study of the ternary decay channel induced by shell effects via the reactions $^{34}\text{S} + ^{208}\text{Pb}$ and $^{37}\text{Cl} + ^{205}\text{Tl}$. In addition, we had test measurements in preparation for experiments scheduled for 2018. One of the important topics for us is testing the strength of the shell closure at $N=82$ via multi-nucleon transfer reactions at energies around the Coulomb barrier. Shell quenching in neutron-rich nuclei is of particular interest for the astrophysical nucleogenesis of the heavy elements as it affects the relative capture and decay rates in the vicinity of the waiting points of the r-process. The structures of the $N=82$ isotones with Z below the doubly magic nucleus ^{132}Sn are of crucial importance because of their connection with the peak at $A \approx 130$ in the solar r-process abundance distribution.



Another important astrophysical problem we are investigating is determination of the strength of the second-forbidden transition between the ground states of ^{20}F and ^{20}Ne . The result is of critical importance to understand the final evolution stages of stars in the mass range between 8 and 10 solar masses. Especially for this experiment we have refurbished our old intermediate-focus spectrometer capable of focusing electrons up to 8 MeV. A new

scintillator telescope with a muon veto was designed and constructed. The background tests were made in the Pyhäsalmi mine at the depth of 1.4 km. The final measurement was carried out in January 2018 using ^{20}F beam produced by the IGISOL facility.

EMMA EXPERIMENT



EMMA experiment makes the first attempt in the world to conduct underground a dedicated study of cosmic ray composition. The construction started back in 2006 utilizing unused access tunnels in the Pyhäsalmi mine at the depth of about 75 meters below the ground. Working together with our colleagues from the University of Oulu we have constructed 11 measuring stations spread over the area of about 3600 m². Measuring stations are equipped with drift chambers from the decommissioned DELPHI experiment at CERN and plastic scintillation detectors that were designed and built in collaboration with the physicists from the Russian Academy of Sciences. The total active area of the drift chambers is approximately 240 m². The coverage of the scintillators is about 24 m². Preparations are on the way to extend the instrumented area with 180 m² of Limited Streamer Tubes previously used by the Cascade Grande experiment in Karlsruhe.

EMMA results are expected to be unique and relevant. Muon groups containing large number of muons were observed by several underground detectors at CERN (L3+Cosmics, DELPHI, CMS), as well as HiRes (USA) and Gran Sasso (MACRO). However, their origin is still the subject of a debate. During the last decade the situation with the muon groups became even more confusing. Two experiments: Pierre Auger Observatory and Yaku-SHAL indicate that there is an excess of muons in the extensive air showers (EAS) compared with their number expected from the most realistic theoretical models. On the other hand, such experiments as Ice-Top and EAS-MSU did not find such excess. EMMA has the potential to clarify this discrepancy by yielding new data for the energies about the knee region.

NUCLEAR STRUCTURE AND NUCLEAR PROCESSES

Professor Jouni Suhonen

The nuclear-theory group of JYFL develops nuclear-structure models and applies them to topics of interest in nuclear, neutrino and dark-matter physics. The topics include neutrino-nuclear interactions at solar and supernova energies, rare weak decays like forbidden beta decays and double beta decays, WIMP-nucleus cross sections for direct dark-matter detection, nuclear muon capture, isovector spin-multipole resonances, neutrino-nucleus coherent scattering, etc. The group has a number of individual and institutional collaborators, and has connections to many large experimental collaborations doing nuclear-structure research and research related to rare nuclear decays, charge-exchange reaction, nuclear muon capture, etc.

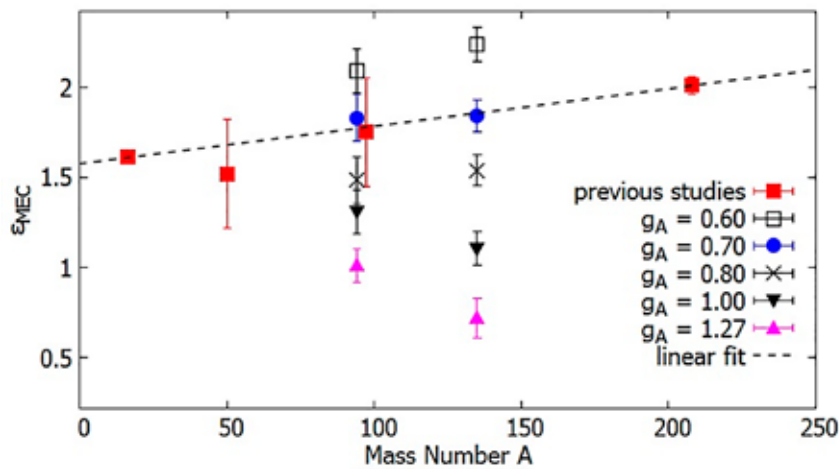
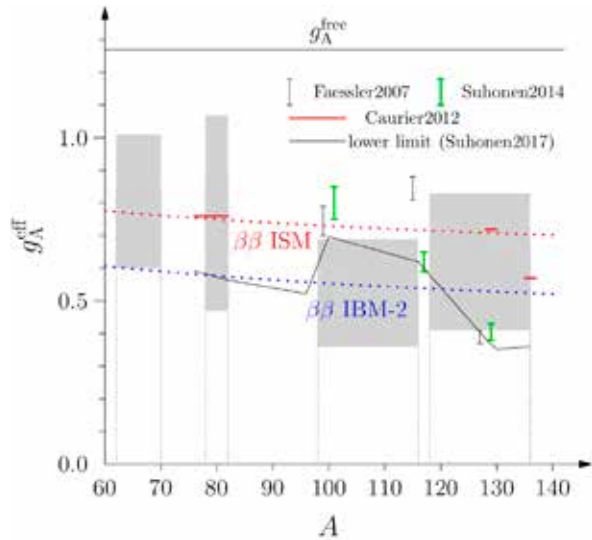
www.jyu.fi/physics/accelerator/nuclear-structure-and-nuclear-processes

QUENCHING OF THE AXIAL-VECTOR COUPLING STRENGTH IN BETA AND DOUBLE BETA DECAYS

Since long it is known that in the interacting shell-model (ISM) the description of Gamow-Teller beta decays in light nuclei requires a quenched effective value of the weak axial-vector coupling g_A . This has been indicated in the figure below by the red horizontal lines (Caurier 2012 [1]) indicating stronger quenching for larger nuclear masses A . The free-nucleon value of $g_A(\text{free})=1.27$ is indicated by the black horizontal line in the figure. The four hatched regions of the figure show the result of an extensive analysis of Gamow-Teller beta decays in the framework of the proton-neutron quasiparticle random-phase approximation (pnQRPA) [2]. The red and blue dotted lines show the results of an analysis performed in [3] for two-neutrino double beta decays in the frameworks of the ISM and the microscopic interacting boson model (IBM-2). The combined beta-decay and double-beta-decay analyses of the effective value of g_A in the framework of the pnQRPA are shown as black (Faessler2007 [4]) and green (Suhonen2014 [5]) vertical lines. The black zig-zag line is a result of the analysis performed in [6]. The results are analyzed in detail in the recent extensive review article [2].

ENHANCEMENT OF THE WEAK AXIAL CHARGE IN NUCLEI

The quenched g_A is the space part of the axial current but there is also the time part of the axial current: the weak axial charge g_5 which was found



to be enhanced instead of quenched in several early studies performed in the framework of the ISM (see details in the review [2]). The enhancement can be quantified by an enhancement factor $\epsilon(\text{MEC})$ (see the figure below) such that $g_5 = (1 + \epsilon(\text{MEC}))g_A$. A recent analysis of the enhancement has been carried out in [7] and also elaborated in the review [8].

References:

[1] E. Caurier, F. Nowacki, A. Poves, Shell model description of the double beta decay of Xe-136, Phys. Lett. B 711 (2012) 62.
 [2] J. Suhonen, Value of the axial-vector coupling strength in beta and double beta decays: A review, Frontiers in Physics 5 (2017) 55.

[3] J. Barea, J. Kotila, F. Iachello, Nuclear matrix elements for double-beta decay, Phys. Rev. C 87 (2013) 014315.

[4] A. Faessler et al., Overconstrained estimates of neutrinoless double beta decay within the QRPA, J. Phys. G: Nucl. Part. Phys. 35 (2008) 075104.

[5] J. Suhonen, O. Civitarese, Single and double beta decays in the $A=100$, $A=116$ and $A=128$ triplets of isobars, Nucl. Phys. A 924 (2014) 1.

[6] J. Suhonen, Impact of the quenching of g_A on the sensitivity of $0\nu\beta\beta$ experiments, Phys. Rev. C 96 (2017) 055501.

[7] J. Kostensalo, J. Suhonen, Mesonic enhancement of the weak axial charge and its effect on the half-lives and spectral shapes of first-forbidden $J^+ \leftrightarrow J^-$ decays, to be published.

[8] H. Ejiri, J. Suhonen, K. Zuber, Neutrino-nuclear responses for astrophysical neutrinos, beta and double beta decays, Phys. Lett. B (2018), in press.

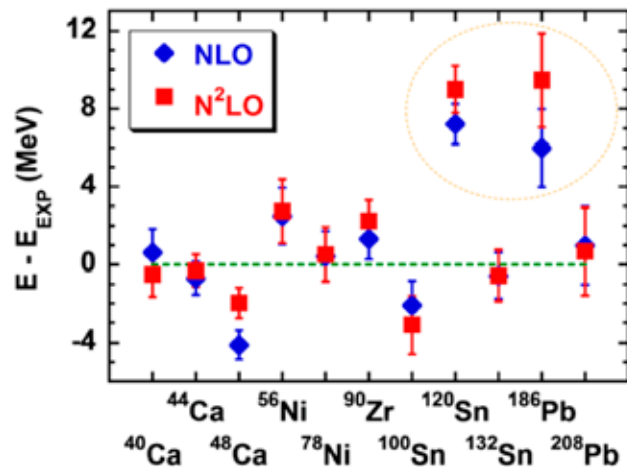
FIDIPRO – GLOBAL PROPERTIES OF NUCLEI

Senior researcher Markus Kortelainen

By the end of 2017, the FIDIPRO project has ended. The volume and significance of the scientific output was truly substantial: 154 journal and conference publications and numerous invited lectures were co-authored by 25 long- and medium-term visitors, students, and postdoctoral and senior researchers. For Jacek Dobaczewski, the project leader, the 11-year assignment to the University of Jyväskylä was a fascinating and unforgettable experience. The FIDIPRO project has brought to Finland a seed activity to spearhead the theoretical research in nuclear structure. And most importantly, it provided for future collaboration of Finnish theorists with numerous international research centres. As we decided, this future activity will continue under the FIDIPRO name – the trademark of excellence in science and scientific collaboration.

www.jyu.fi/physics/accelerator/fidipro-project

We proposed to use two-body regularized finite-range pseudopotential to generate a nuclear energy density functional (EDF) in both particle-hole and particle-particle channels, making it free from self-interaction, self-pairing, and also free from singularities when used in beyond mean field calculations. We derived a sequence of pseudopotentials regularized up to next-to-leading order (NLO) and next-to-next-to-leading order (N²LO), which fairly well describe infinite-nuclear matter properties and finite open-shell paired and/or deformed nuclei [1]. Within Landau theory of Fermi liquids, we assessed the particle-hole interaction near the



↑ Binding energies together with theoretical uncertainties for NLO and N²LO pseudopotentials.



→ The present and former members of the FIDIPRO team have gathered to attend the FiDiPro Winter Symposium on Nuclear Structure Physics, organized in Jyväskylä on December 11-15, 2017.

Fermi energy in different spin-isospin channels for generated NLO and N2LO pseudopotential EDFs. This provided a useful and efficient way to constrain properties of EDFs in symmetric nuclear matter and finite nuclei [2].

The parameters of the nuclear EDFs must be adjusted to experimental data. As a result, they carry uncertainty which then propagates to calculated observables. In our recent work [3], we quantified statistical uncertainties of binding energies, and other bulk properties for all three UNEDF Skyrme EDFs. Theoretical uncertainties were found to

increase rapidly towards neutron rich nuclei, due to less well constrained isovector properties. Information about the EDF parameter uncertainties is crucial when evaluating predictive power of the current EDFs and it allows to improve development process of the novel EDFs.

[1] K. Bennaceur, A. Idini, J. Dobaczewski, et.al., J. Phys. G: Nucl. Part. Phys. 44, 045106 (2017).

[2] A. Idini, K. Bennaceur, and J. Dobaczewski, J. Phys. G: Nucl. Part. Phys. 44, 064004 (2017).

[3] T. Haverinen and M. Kortelainen, J. Phys. G: Nucl. Part. Phys. 44, 044008 (2017).

RADIATION EFFECTS

Professor Ari Virtanen

The group specializes in applied research around nuclear- and accelerator-based technology and operates the Radiation Effects Facility, RADEF, for the studies of radiation effects in electronics and related materials. RADEF officially became an ESA-supported European Component Irradiation Facility (ECIF) in 2005. Since then the group has carried out irradiation tests not only for ESA and the European space industry, but also for other world leading space organizations (e.g. NASA, JAXA, CNES), companies and universities. Group photo with the list of team members is given in Fig. 1. Four members at the bottom of the list are not present in the photo.

<https://www.jyu.fi/accelerator/radef>



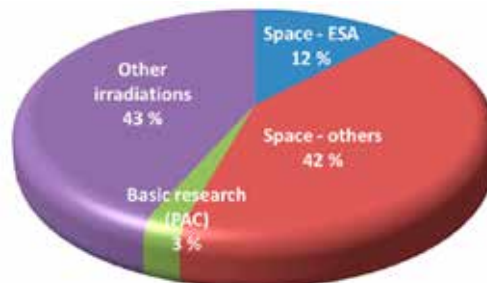
Ari Virtanen
 Heikki Kettunen
 Mikko Rossi
 Arto Javanainen
 Taneli Kalvas
 Alexandre Bosser
 Daniel Söderström
 Mikko Niskanen
 Sascha Luedeke
 Jaakko Tuominen
 Juhani Lepistö
 Andrea Coronetti (CERN)
 Davide Giurisato (ERASMUS)
 Corinna Martinella (CERN)
 Maris Tali (ESA/CERN)

↑ Figure 1. Photo of the RADEF group. The four team members listed at the bottom are not present in the picture.

RADEF's specialty is to provide high penetration heavy ion cocktail beams, protons in wide energy range and energetic electrons. For these the RADEF group utilizes combination of JYFL's ECR ion sources and K-130 cyclotron, and the LINAC electron accelerator. Because the emerging technologies make integrated circuits more susceptible to radiation, the group is expanding its research activities toward the radiation effects in avionics and ground level systems (see the RADSAGA project).

Commercial services continued with 46 campaigns for 25 different companies, institutes or universities by using 1394 hours of K-130 beam time in 2017. This corresponds to approximately 22 % of the K-130 beam hours. The distribution of beam hours between different users is shown in Fig. 2. Electron LINAC used 160 hours by five companies or univer-

sities. The total revenue of RADEF (commercial and EU- and ESA projects) in 2017 was close to 1.3 M€.



↑ Figure 2. Distribution of RADEF-beam hours for different activities (Space-ESA = ESA beam hours, Space-others = beam hours for space companies).

RADSAGA



The project RADSAGA (RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators) will, for the first time, bring together the European industry, universities, laboratories and test facilities to educate 15 PhD's on the subject of electronics exposure to radiation. Three students will graduate from JYFL, two hosted by RADEF and one by CERN. The project spans the years 2017-2021, and the kick-off meeting was held in April 2017. This EU MSCA-Horizon-2020 ITN project (GA#721624) was granted total of 3.9 M€ and is coordinated by CERN. The RADEF group is one of the seven beneficiaries. Fourteen other partners, mainly companies and research laboratories, takes part in the RADSAGA.

ESA-NPI PHD PROJECT



The aim of this thesis project is to study Single Event Effects (SEE) in hardened and state-of-the-art components for space and high-energy radiation environments. The project is funded by ESA from its NPI programme (50%) and done in a collaboration between CERN, ESA (TEC- EES and TEC-QEC) and University of Jyväskylä (RADEF). Airbus is also participating in its technical committee.

Aim of the thesis:

- Understanding and quantifying the shortcomings of the SEE prediction tools
- Contribute to establishing guidelines including the currently neglected effects
- Establish the link between proton/hadron experimental and space SEE failure rates (both proton and heavy ions)
- Performing a first screening of components in proton or mixed-field facilities (e.g. PSI, CHARM)

- Evaluate the performance of the chosen COTS devices in the relevant environments (CHARM, CERN and JUICE mission, ESA) and their compliance with radiation hardness standards

Relevant paper:

M. Tali, R. García Alía, M. Brugger, V. Ferlet-Cavrois, R. Corsini, W. Farabolini, A. Mohammadzadeh, G. Santin, and A. Virtanen, *High-Energy Electron-Induced SEUs and Jovian Environment Impact*, IEEE Transactions on Nuclear Science, vol. 64, no. 8, (2017), pp. 2016-2022

SINGLE-EVENT EFFECTS IN MEMORY COMPONENTS

When electronic memories are submitted to ionizing radiation, charge carriers are generated along the impinging particle tracks. When collected, these charge carriers give rise to parasitic current spikes, which in turn can lead to component error (data corruption) and/or failure. Using ion beams to emulate naturally-occurring radiation environments, our group has been investigating the failure modes of various types of computer memories (e.g. SRAMs, FRAMs, MRAMs, flash memories), offering insights on their failure mechanisms and helping to define the strengths and weaknesses of current memory technologies.

Relevant papers:

A. Bosser, V. Gupta, G. Tsiligiannis, C. Frost, A. Zadeh, A. Javanainen, H. Puchner, F. Saigné, A. Virtanen, F. Wrobel and L. Diillo, *Methodologies for the Statistical Analysis of Memory Response to Radiation*, IEEE Transactions on Nuclear Science, vol. 63, no. 4 (2016), pp. 2122-2128

A. Bosser, V. Gupta, G. Tsiligiannis, A. Javanainen, H. Kettunen, H. Puchner, F. Saigné, A. Virtanen, F. Wrobel and L. Diillo, *Investigation on MCU Clustering Methodologies for Cross-Section Estimation of RAMs*, IEEE Transactions on Nuclear Science, vol. 62, no. 6, pp 2620 - 2626 (2015)

RADIATION EFFECTS IN SILICON CARBIDE POWER DEVICES

Silicon carbide (SiC) devices are of great interest for their possible use in power applications in space. Higher breakdown field and thermal conductivity makes SiC a very attractive material compared to silicon for power electronics. However, like their silicon counterparts, SiC power devices (MOSFETs and diodes) are surprisingly sensitive to particle radiation. The basic mechanisms governing this SEE sensitivity has been studied recently.

Relevant papers:

A. Javanainen, K. F. Galloway, C. Nicklaw, V. Ferlet-Cavrois, A. Bosser, J.-M. Lauenstein, F. Pintacuda, R. A. Reed, R. D. Schrimpf, R. A. Weller and A. Virtanen, *Heavy Ion Induced Degradation in SiC Schottky Diodes: Bias and Energy Deposition Dependence*, IEEE Transactions on Nuclear Science, vol. 64, no. 1, (2017), pp. 415-420

A. Javanainen, K.F. Galloway, V. Ferlet-Cavrois, J.-M. Lauenstein, F. Pintacuda, R.D. Schrimpf, R.A. Reed and A. Virtanen, *Charge Transport Mechanisms in Heavy-Ion Driven Leakage Current in Silicon Carbide Schottky Power Diodes*, IEEE Transactions on Device and Materials Reliability, vol. 16, no. 2 (2016), pp. 208-212

ION SOURCES

Senior Lecturer Hannu Koivisto

The work of the ion source group can be divided into three separate domains: 1) development of ECR ion sources and positive and negative light ion sources, 2) development of ion beams in terms of ion beam variety and quality, 3) development of plasma and ion beam diagnostics. Computational physics plays a significant role in the afore-mentioned R&D work. The ion source group is also coordinating networking activity, ENSAR2/MIDAS, in Horizon 2020 program.

www.jyu.fi/physics/accelerator/ion-sources

The work of the ion source group can be divided into three separate domains: 1) development of ECR ion sources and positive and negative light ion sources, 2) development of ion beams in terms of ion beam variety and quality, 3) development of plasma and ion beam diagnostics. Computational physics plays a significant role in the afore-mentioned R&D work. The ion source group is also coordinating networking activity, ENSAR2/MIDAS, in Horizon 2020 program. Website of the ion source group: <https://www.jyu.fi/science/en/physics/research/nuclear-and-accelerator-based-physics/ion-sources>

HIGHLIGHTS IN 2017

Status of the new heavy ion source (HIISI): The construction of HIISI and its beam line was completed in spring 2017. The first beam from HIISI was extracted in May 2017 and the first mass analyzed beams of O, Ar and Xe in October 2017. The results of the first two weeks of commissioning are shown in Table 1. The intensities are compared to those extracted from the JYFL 14 GHz ECRIS demonstrating the superiority of HIISI.

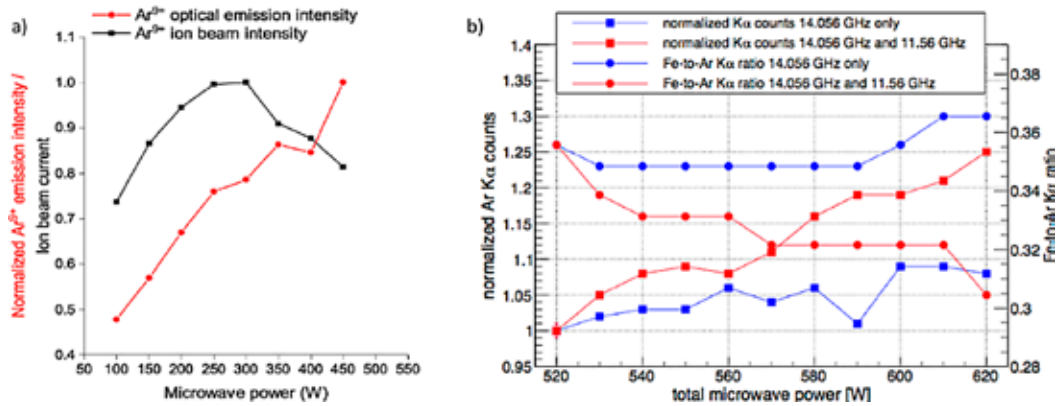
An important objective of HIISI is to increase the energy of high-energy beam cocktails from 9.3 MeV/u to above 15 MeV/u for radiation effects testing of electronics with the K130 cyclotron. In the present 9.3 MeV/u cocktail the highest energy is obtained with the Xe³⁵⁺ ion beam. In order to meet the requirement (≥ 15 MeV/u) the charge state of at least 43+ has to be produced in the case of xenon. In addition, the intensity on the radiation target has to reach the value of 10⁶ ions/s. These requirements are far beyond the performance of the JYFL 14 GHz ECRIS and have been met so far only by the superconducting ECR ion sources. The ultimate goal (Xe⁴³⁺) will be pursued via an intermediate step (12.5 MeV/u) requiring the Xe⁴⁰⁺ ion beam. The performance testing of HIISI for electronic-radiation-testing program was conducted during the last quarter of 2017. The first test was performed by producing highly charged xenon plasma and by measuring the intensity of ¹³¹Xe³⁵⁺ ion beam (9.3 MeV/u) on the RADEF station. After a short tuning procedure of HIISI the ion beam intensity of 50 nA was measured before the RADEF station corresponding to >10⁸ ions/s on the radiation target. This greatly exceeds the maximum intensity needed for radiation testing. The HIISI beam cocktail testing was continued in December 2017 by accelerating the ¹³¹Xe⁴⁰⁺ ion beam. This ion is included in the 12.5 MeV/u beam cocktail. After a short tuning of HIISI the intensity of 2 nA was measured indicating that approximately

Ion source/ion	O ⁷⁺	Ar ¹²⁺	Ar ¹³⁺	Ar ¹⁴⁺
JYFL 14 GHz ECRIS	222 μ A	103 μ A	51 μ A	49 μ A
HIISI 18 GHz	560 μ A	462 μ A	312 μ A	182 μ A

← Table 1: Comparison of ion beam intensities of the JYFL 14 GHz ECRIS and HIISI.

→

Figure 1a: Normalized Ar^{9+} optical emission intensity and extracted beam current as a function of the 14 GHz microwave power. Figure 1b: Normalised Ar K α counts and Fe-to-Ar K α ratio when ECRIS optimized for Ar^{13+} ion beam.



4×10^6 ions/s is available for the radiation effect testing. Consequently, the intermediate milestone has successfully been met.

Visible light plasma spectroscopy: The JYFL ion source group has developed a high-resolution (≈ 30 pm) spectrometer setup (POSSU) to measure visible light emission of highly charged ECRIS plasmas. As an example, the relative changes in both the optical emission and the m/q analyzed ion beam current of Ar^{9+} ion were measured (Fig. 1 a). The results indicate a discrepancy between the parametric dependence of high charge state ion densities in the core plasma and their extracted beam currents. The observation implies that the ion currents could be limited by diffusion transport and electrostatic confinement of the ions rather than beam formation in the extraction region and subsequent transport. The POSSU setup has been used also to get new information about the Electron Energy Distribution Function (EEDF) for measuring the cold electron and ion temperatures of ECRIS plasmas.

Volumetric Ka emission: Measurement of the Ka emission can be used for probing the volumetric inner shell ionization rate in ECRIS plasmas, which provides information on the physical principles of techniques, such as double frequency heating, improving ECRIS performances. Combined with optical spectroscopy the Ka diagnostics of argon plasmas have revealed that in this particular case the improvement is due to enhanced plasma density and reduced electron losses (see Fig. 1b). Furthermore, comparison of the Ka emission from the plasma volume (Ar) to the Ka emission from the surface of the biased disc (Fe) can be used for studying the role of microwave induced pitch angle scattering on warm electron losses (ongoing research).

Plasma instabilities: Plasma instabilities of 14.5 GHz PHOENIX charge breeder ECRIS (CB-ECRIS) at LPSC has been studied by measuring the character-

istic features of electron cyclotron instability. The appearance of the instabilities was detected with three diagnostics methods: (i) the plasma microwave emission (ii) bursts of bremsstrahlung indicating abrupt losses of high-energy electrons and (iii) the temporal fluctuations of the m/q -analyzed beam currents. It was found that the injection of $^{133}\text{Cs}^+$ or $^{85}\text{Rb}^+$ into oxygen discharge of the CB-ECRIS can trigger electron cyclotron instabilities, which results to an order of magnitude increase of impurity currents in the extracted $n+$ charge state distribution. This finding is very important because the beam impurities are the main drawback of ECRIS-CB compared to Electron Beam Ion Source (EBIS) type charge breeders. The transition from stable to unstable plasma regime is caused by gradual accumulation and ionization of Cs/Rb altering the discharge parameters in 10 - 100 ms time scale, not by a prompt interaction between the incident ion beam and the ECRIS plasma. This time scale is similar to the reported breeding times of the high charge state Cs and Rb ions. Since the commonly applied method of measuring the breeding time, i.e. pulsing the $1+$ injection, clearly affects the buffer gas discharge, it is argued that the actual breeding times in continuous operation can differ from those obtained by studying the injection transient. This experiment, which is supported by the sputtering experiments at JYFL, indicates that the actual breeding times can be up to 50 % shorter than values obtained by pulsing $1+$ injection.

Selected publications:

O. Tarvainen, J. Angot, I. Izotov, V. Skalyga, H. Koivisto, T. Thuillier, T. Kalvas and T. Lamy, *Plasma instabilities of a charge breeder*, Plasma Sources Sci. Technol., **26** (2017), p. 105002.

J. Laulainen, S. Aleiferis, T. Kalvas, H. Koivisto, R. Kronholm, O. Tarvainen, *Hydrogen plasma induced photoelectron emission from low work function cesium covered metal surfaces*, Physics of Plasmas, **24** (2017), p. 103502.

A. Megia-Macias, O.D. Cortazar, O. Tarvainen and H. Koivisto, *Time resolved measurements of hydrogen ion energy distributions in a pulsed 2.45 GHz microwave plasma*, Physics of Plasmas, **24** (2017), p. 113501.

ACCELERATOR BASED MATERIALS PHYSICS

Professor Timo Sajavaara

The research activities of the group can be divided into three main areas:

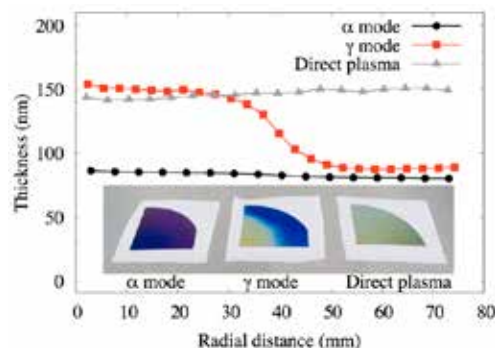
- fundamental studies of ion-matter interactions,
- detector, data acquisition and analysis software development
- application of ion beam techniques for materials and thin film studies.

The key infrastructure of the group is the 1.7 MV Pelletron accelerator and all the research equipment in its beamlines. In Nanoscience Center (NSC) clean room the group is a very active user of a helium ion microscope (HIM) and a versatile atomic layer deposition (ALD) tool. The group is an active link between the two research infrastructures Accelerator Laboratory and Nanoscience Center. In addition, the group focuses strongly in detector development related to the ion beam techniques and is tightly linked to the other thin film research groups and industry in Finland.

www.jyu.fi/physics/accelerator/abasedmat

LOW-TEMPERATURE THERMAL AND PLASMA-ASSISTED ATOMIC LAYER DEPOSITION

A special focus in the thin film studies has been in plasma-enhanced atomic layer deposition (PEALD) and especially on the plasma mode transitions, which are fundamental characteristics of plasmas but have so far rarely been taken into account in PEALD processing. It was observed that the transition from the so-called alpha to the gamma-mode in the capacitively coupled plasma used in the remote PEALD sets an upper limit for the applied RF power via formation of a parasitic discharge component [1]. This leads to thickness and composition non-uniformity at wafer scale (Fig 1).

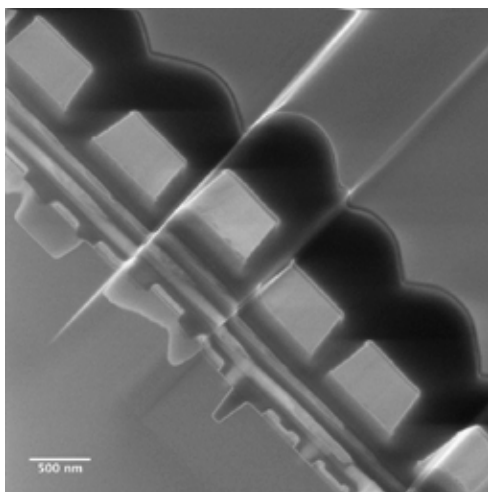


↑ Figure 1. Thicknesses of the PEALD ZnO films deposited with remote a and g mode plasma, and with direct plasma. Measured as a function of the distance from the reactor center. Inset: a photograph of the corresponding films [1].

HELIUM ION MICROSCOPY DEVELOPMENT, ION BEAM ANALYSIS OF THIN FILMS AND NEW BEAMLINE FOR PIXE AND RBS

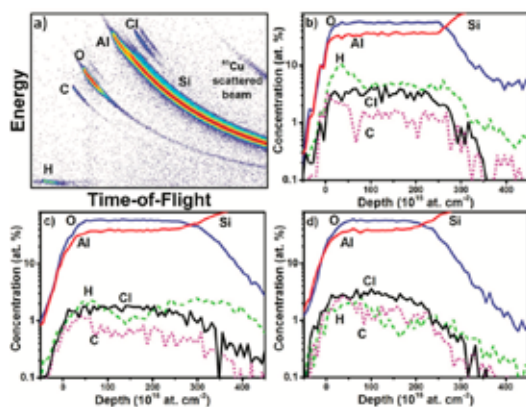
The helium ion microscope (HIM) was actively used for imaging of large variety of internal and external

samples. It has proven to be a reliable and highly useful tool for materials and biological research. One special focus in 2017 was to study the milling possibilities using HIM (Fig. 2) and it was used to prepare nanometer scale pores in Si₃N₄ membranes [2].



↑ Figure 2 Cross-section of an USB memory chip imaged using helium ion microscopy (HIM). The large area cross-sectioning was done using broad ion beam milling, and the area in the middle was milled using Ne beam from HIM.

→ Figure 3. In ToF-ERDA measurements, different masses can be separated by measuring time-of-flight and energy for each recoil atom in coincidence. Elemental depth profiles of Al₂O₃ films: b) as-deposited with 7 s ozone pulse time, c) after heat treatments with 20 s ozone pulse, and d) after treatments with 7 s ozone pulse. a) The histogram corresponding to depth profiles in (c). The film was deposited at 200 °C with 400 ALD cycles. Note: because of the sectional overlap of Al and Si at the Si/Al₂O₃ interface in the histograms, the depth profiles for Al and Si were plotted as one. From [3].



The ion beam analysis collaboration with other institutes was again very active and results of one of these studies, passivation properties of ALD thin films grown using dimethylaluminum chloride and ozone [3], are shown in Fig. 3.

The installation of a new beamline for RBS and both external and vacuum PIXE at the Pelletron was completed in 2017. The beamline has a large multi-purpose chamber for RBS and PIXE measurements, and it can also be used for ion beam irradiations from 0.2 MeV up to 20 MeV for heavy ions. After the chamber, there is a unique setup for performing high resolution PIXE measurements (TES-PIXE) with external beams. The TES-PIXE setup has polycapillary xray optics between the sample and the detector. The new beamline enables better possibilities for both scientific and industrial collaborations.

NANOIS ACADEMY PROJECT STARTED IN SEPTEMBER

September 2017 marked the beginning of a new four-year project supported by the Academy of Finland, NANOIS - Novel nanostructure morphologies by ion beam shaping. The consortium is between the Departments of Physics in Jyväskylä and Helsinki. In the project, new types of photonically active structures will be created by means of high-energy heavy-ion irradiations of carefully fabricated nanostructures. In Jyväskylä, both Accelerator Laboratory and NanoScience Center researchers are involved.



↑ Figure 4. The research group building a new beam line in summer 2017.

Selected publications

- [1] M. Napari, O. Tarvainen, S. Kinnunen, K. Arstila, J. Julin, Ø.S. Fjellvåg, K. Weibye, O. Nilsen, T. Sajavaara, *The α and γ plasma modes in plasma-enhanced atomic layer deposition with O₂-N₂ capacitive discharges*, Journal of Physics D: Applied Physics 50 (2017) 095201.
- [2] Chenyu Wen, Shuangshuang Zeng, Kai Arstila, Timo Sajavaara, Yu Zhu, Zhen Zhang, Shi-Li Zhang, *Generalized Noise Study of Solid-State Nanopores at Low Frequencies*, ACS Sensors 2 (2017) 300.
- [3] Y. Bao, M. Laitinen, T. Sajavaara, H. Savin, *Ozone-Based Atomic Layer Deposition of Al₂O₃ from Dimethylaluminum Chloride and Its Impact on Silicon Surface Passivation*, Advanced Electronic Materials 3 (2017) 1600491.

COSMOLOGY

**Professor Kimmo Kainulainen
and Senior Lecturer Sami Nurmi**

We work mainly in the interphase between particle physics and cosmology. Our research topics include dark matter, dark energy, baryogenesis, cosmic inflation and inhomogeneous cosmologies. Our group currently consists of two permanent staff members, one postdoctoral researcher and six PhD-students.

www.jyu.fi/physics/particles/cosmology

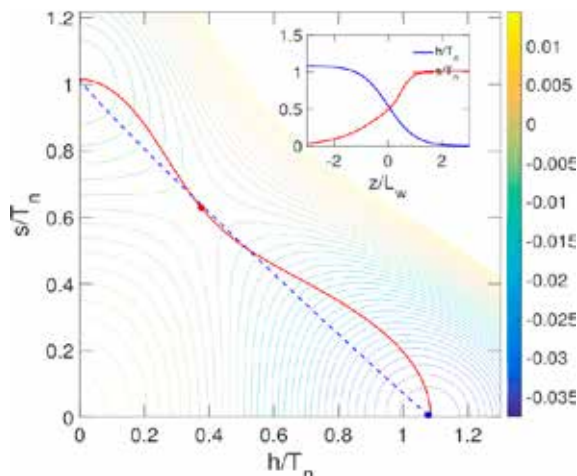
ELECTROWEAK BARYOGENESIS AND DARK MATTER

About 27% of the total energy budget of the universe consists of a pressureless fluid, Dark Matter, whose precise nature is yet unknown. Also, current standard model of particle physics offers no explanation for the origin of the matter antimatter asymmetry in the Universe.

We present [1] a simple UV-complete model that realises a successful electroweak baryogenesis from dark sector. Model contains a singlet scalar S , which enhances the transition strength, and a fermionic dark matter χ , which acquires a CP asymmetry that is transferred to the standard model through a CP portal interaction coupling it to tau-leptons and an inert Higgs doublet. The model has promising discovery potential at the LHC and robustly provides a large enough baryon asymmetry and correct dark matter

density with reasonable values of the couplings.

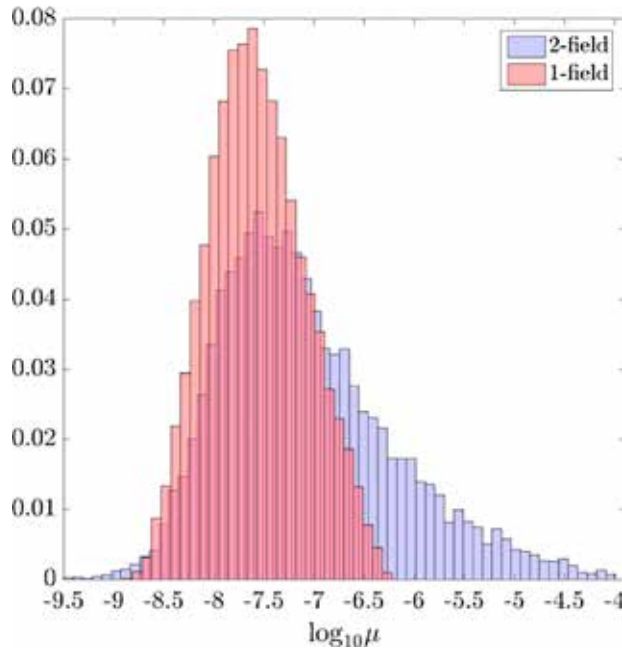
In another work [2] we connect DM with inflation: a curvature induced particle production at reheating can generate adiabatic dark matter from non-minimally coupled spectator scalars weakly coupled to visible matter. Assuming quadratic inflation, instant reheating and a single spectator with only gravitational couplings, the observed dark matter abundance is obtained for spectator mass $m \sim 0.1$ GeV and a non-minimal coupling $\xi \sim 1$.



↑ Figure 1: Potential minimizing (red) and actual tunnelling (red dashed) path in the field space along with the z -evolution (inset) of Higgs field (blue) and the singlet scalar (red) over a phase transition wall. T_n is the nucleation temperature and L_w the wall width.

INFLATION, HIGGS FIELD DYNAMICS AND VACUUM STABILITY AND LARGE SCALE STRUCTURE

Inflation is deeply rooted in the standard model of cosmology, the main reason being its succes-



←
Figure 1: Normalized histograms of the μ distortion in full general two-field case (blue) and the single field limit (red) for models compatible with Planck constraints and the COBE/FIRAS bound $|\mu| < 9 \times 10^{-5}$.

ful prediction of the primordial density fluctuation spectrum. But it may have other effects as well. For example, we have shown [3] that it is possible that large scale ($\sim 0.1\text{-}10^4\text{Mpc}$) magnetic fields were formed during inflation via a conformal symmetry breaking interaction $\sim f(\phi)F_{\mu\nu}F^{\mu\nu}$.

We also showed [3] that a coupling of Higgs field to inflaton can lead to large resonant fluctuations of the higgs field, and destabilize the electroweak vacuum. We performed a careful numerical analysis of the phenomenon and derive upper bounds on quartic and trilinear interactions between the Higgs and the inflaton and concluded that there exists a favorable range of the couplings within which the Higgs field is stabilized during both inflation and preheating epochs.

In another work [4] we verify explicitly that metric fluctuations have a negligible effect on vacuum stability during inflation if the Higgs is energetically subdominant. For Standard Model parameters we find that couplings between the Higgs and metric fluctuations are suppressed at least by a factor 10^{-7} . This confirms the validity of previous stability conditions derived by treating the Higgs as a test field in a fixed gravitational background.

Finally, we investigate [5] the CMB μ distortion in models with two uncorrelated sources for primordial perturbations. We perform a detailed analysis of the distortion signal highlighting the differences compared to single-source models. We show that in the case of a mixed inflaton-curvaton model, the μ distortion can efficiently break degeneracies of curvaton parameters especially when combined with bounds on the tensor-to-scalar ratio r . For example, assuming bounds $\mu < 0.5 \times 10^{-8}$ and $r < 0.01$, the curvaton contribution should either vanish or dominate primordial perturbations.

[1] James M. Cline, Kimmo Kainulainen and David Tucker-Smith, *Electroweak baryogenesis from a dark sector*, Phys.Rev. D95 (2017) no.11, 115006.

[2] Tommi Markkanen, Sami Nurmi and Arttu Rajantie, *Do metric fluctuations affect the Higgs dynamics during inflation?*, JCAP 1712 (2017) 026.

[3] Tommi Markkanen, Sami Nurmi, Syksy Rasanen and Vincent Vennin, *Narrowing the window of inflationary magnetogenesis*, JCAP 1706 (2017) no.06, 035.

[4] Tommi Markkanen, Sami Nurmi and Arttu Rajantie, *Do metric fluctuations affect the Higgs dynamics during inflation?*, JCAP 1712 (2017) 026.

[5] Yohei Ema, Mindaugas Karciauskas, Oleg Lebedev and Marco Zatta, *Early Universe Higgs dynamics in the presence of the Higgs-inflaton and non-minimal Higgs-gravity couplings*, JCAP 1706 (2017) no.06, 054

[6] Kimmo Kainulainen, Juuso Leskinen, Sami Nurmi and Tomo Takahashi, *CMB spectral distortions in generic two-field models*, JCAP 1711 (2017) no.11, 002

NEUTRINO PHYSICS

**Professor Jukka Maalampi and
Senior Researcher Wladyslaw Trzaska**

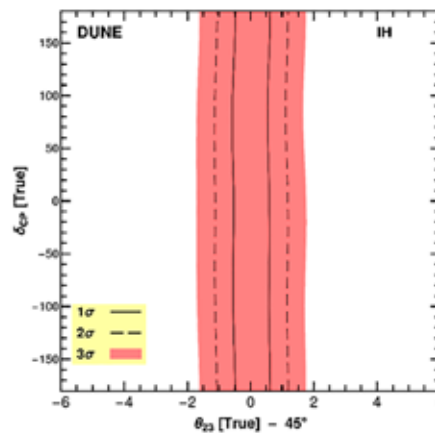
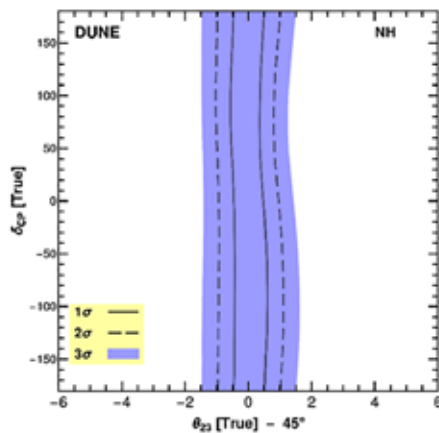
Our neutrino physics group focuses on phenomenological and experimental research of neutrino oscillations. At present, the main scientific goals of neutrino oscillation physics are the still open questions of neutrino mass hierarchy and leptonic CP violation. We are involved in studies that aim at building and operating the next generation oscillation experiments to resolve these questions and to determine the values of other relevant parameters and thereby shed light to the origin of the mass spectrum of neutrinos and other elementary particles. Our group participates in two major neutrino experiments, the accelerator experiment DUNE (Fermilab/Homestake, USA) and the reactor experiment JUNO (Jiangmen, China).

NEUTRINO PHYSICS PHENOMENOLOGY

The long-term goal of our group is to contribute both experimentally and theoretically to the solution of the remaining neutrino puzzles such as the still unknown mass hierarchy, determination of the phase of CP violation in the leptonic sector, and the existence and properties of the sterile neutrinos. Our phenomenological studies have focused on the question of the so-called θ_{23} octant degeneracy and nonstandard neutrino interactions in the framework of long baseline experiments. With simulation studies we have investigated the sensitivity of the planned long baseline experiments for resolving whether $\theta_{23} > 45^\circ$ or $\theta_{23} < 45^\circ$ and determining various parameters describing the strength of possible nonstandard neutrino interactions.

DUNE AND JUNO EXPERIMENTS

Two massive cryogenics tanks have been constructed in the new Hall (EHN1) dedicated to the project supported by CERN Neutrino Platform. The cryostats will house prototypes of large-scale Time Projection Chambers based on liquid argon. The first one will be instrumented with the charge collection and readout technology similar to the well-known ICARUS detector. As both of the collecting electrodes will be immersed in liquid argon, this prototype is called ProtoDUNE SP (Single Phase). If



← Sensitivity of DUNE for the determination of the octant of the neutrino mixing angle θ_{23} for normal and inverted neutrino mass hierarchy with allowing non-unitarity of the three-neutrino mixing.



all goes as expected, SP will be tested in 2018 with charged particle beams from CERN SPS. The data will provide the necessary calibration of the detector and benchmark new reconstruction algorithms. This is a crucial milestone for DUNE. The second prototype will attempt to achieve multiplication of the drift electrons by extracting them to the vapour layer just above the liquid and passing them through LEMs (Large Electron Multipliers); hence the name is ProtoDUNE DP (Dual Phase). As the novel technology needed an intermediate step before scaling up to the $6 \times 6 \times 6$ m³ fiducial volume, the DP concept was verified on a $3 \times 1 \times 1$ m³ prototype. Our team has participated in the measurements with the $3 \times 1 \times 1$ setup and later in the commissioning work on the DP cryostat and in the software development.

R&D on giant, liquid scintillator-based detectors has been our main experimental activity over the past decade when the Pyhäsalmi mine was the prime location for the 50-kton LENA detector. As LENA did not receive the expected funds to move to the construction phase, all of the European groups involved in R&D for LENA have joined the

JUNO collaboration. Our group continued R&D on scintillation technology by working alongside of the team from the Kerttu Saalasti Institute. In particular, we have been developing radiopurity measurement setup at the 1430 m level in the Pyhäsalmi (CallioLAB2). This work is relevant not only for JUNO but also for other large scintillation detectors.

Selected publications

Loo, K., Novikov, Y. N., Smirnov, M. V., Trzaska, W., & Wurm, M. (2017).

Omnibus experiment: CPT and CP violation with sterile neutrinos. In Neutrino 2016: XXVII International Conference on Neutrino Physics and Astrophysics (pp. 012183). Journal of Physics: Conference Series, 888. Institute of Physics Publishing.

Das, C. R., Maalampi, J., Pulido, J., & Vihonen, S. (2017). *Optimizing the θ_{23} octant search in long baseline neutrino experiments. In Neutrino 2016: XXVII International Conference on Neutrino Physics and Astrophysics (pp. 012219). Journal of Physics: Conference Series, 888. Institute of Physics Publishing.*

Huitu, K., Kärkkäinen, T. J., Maalampi, J., & Vihonen, S. (2016). *Constraining the nonstandard interaction parameters in long baseline neutrino experiments. Physical Review D, 93 (5), 053016.*

An, F., An, G., An, Q., Antonelli, V., Baussan, E., Beacom, J., . . . Zou, J. (2016). *Neutrino physics with JUNO. Journal of Physics G: Nuclear and Particle Physics, 43 (3), 030401.*

QCD THEORY

Professors Kari J. Eskola and Tuomas Lappi

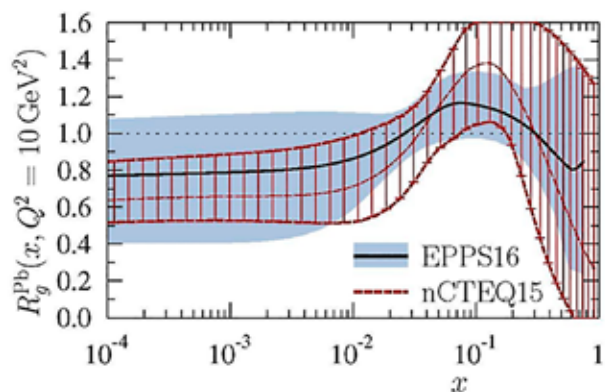
Our work revolves around different aspects of QCD at high energy and density. In addition to the phenomenology of high energy nuclear collisions at the LHC and RHIC, we are involved with physics studies for planned next generation DIS experiments. We use weak coupling QCD renormalization group equations to understand the partonic structure of hadrons and nuclei. Important specialties of our group are using this information to understand the formation of a thermalized quark-gluon plasma, and modeling its subsequent evolution with relativistic hydrodynamics. The year 2017 was the first full year of Lappi's ERC CoG project and a year of significant growth for our group. Paukkunen started as an Academy Research Fellow, Guzey as a new University Researcher in Lappi's QCD theory project at HIP, and Beuf and Mäntysaari as new postdocs. Postdocs Ducloué, Paatelainen and Zhu moved to new positions in Saclay, Helsinki and TU München, respectively.

www.jyu.fi/physics/particles/urhic

EPPS16 NUCLEAR PDFS

Nuclear parton distribution functions (nPDFs) are needed for the computation of all collinearly factorizable hard-process cross sections in nuclear

collisions. The nPDFs are determined in a global analysis involving QCD perturbation theory, DGLAP evolution equations and experimental data. Our earlier set of nPDFs, EPS09, which defined the standard for the nPDFs and their uncertainties for several years, exceeded 800 citations in 2017. As a significant step forward, in our latest set, EPPS16 published in 2017, the nPDFs are constrained for the very first time with LHC data (dijets, Z, W) from proton-nucleus collisions [1]. Also data from neutrino-nucleus deep inelastic scattering and dilepton production in pion-nucleus collisions are used as new input. The novel data constraints reduced the theoretical bias in the error analysis significantly. Consequently, EPPS16 (Fig. 1) now represents the state of the art in this field.

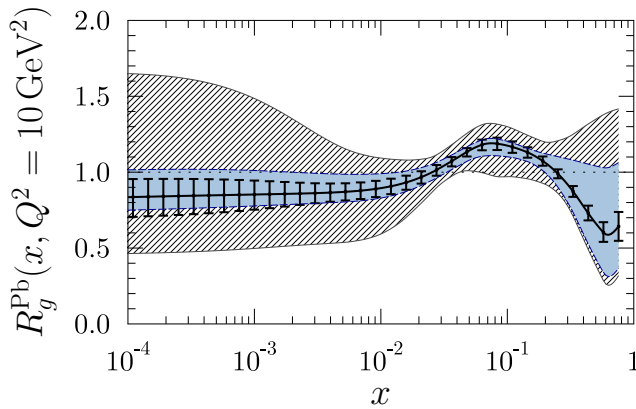


↑ Figure 1. Comparison of the EPPS16 and nCTEQ15 nuclear effects of gluon distributions in a lead nucleus [1], shown as a function of the momentum fraction x .

NUCLEAR STRUCTURE FUNCTIONS AT A FUTURE ELECTRON-ION COLLIDER

An Electron-Ion Collider (EIC) will be built in the USA in the near future. We have actively participated in the physics planning of the EIC also in

2017. Concerning the nuclear parton distributions, the measurements in this high-luminosity machine will be able to constrain in particular the small-momentum nuclear gluon distributions much more stringently than what we can do currently – see the large uncertainties still there in EPPS16 in Fig. 1. In addition to the high luminosity, the EIC will be able to vary the ion species and collision energy, which is important also for our global nPDF analysis. To quantify the expected gluon-constraining power, we studied the inclusive and charm (heavy-meson) cross-sections in deep inelastic electron-nucleus scatterings to be measured at the EIC [2]. For this, we first generated EIC pseudodata sets on these observables for lead and carbon nuclei using the EPS09 nPDFs, and then incorporated these into an EPPS16-based global analysis where we added also some more freedom to the nPDF parametrizations at small momentum fractions. The result, a significant reduction of the gluonic uncertainties, is shown in Fig. 2.

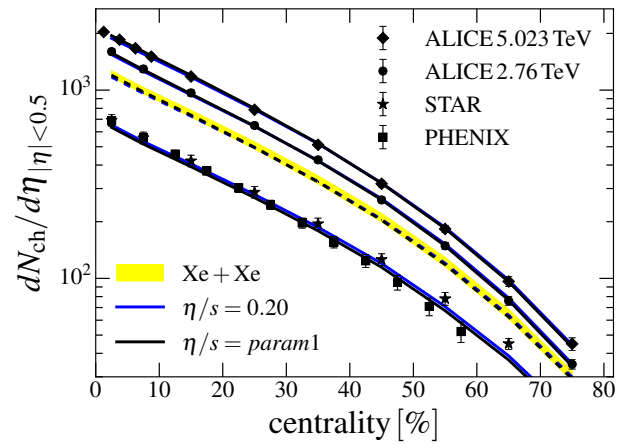


↑ Figure 2. Uncertainties in the nuclear effects of gluons in a lead nucleus, as a function of the momentum fraction x [2]. The EIC cases without (with) charm data are shown with blue error band (error bars), and the grey error band is from the baseline fit without EIC pseudodata.

PREDICTIONS FROM THE EKRT MODEL FOR LHC XE+XE COLLISIONS

Relativistic hydrodynamical studies of QCD matter spacetime evolution – our group’s longtime specialty – are now a cornerstone of URHIC physics. Our EKRT model successfully predicts the produced fluctuating

QCD-matter initial densities from next-to-leading order perturbative QCD and gluon saturation, and evolves the system in space and time event by event with dissipative fluid dynamics. Comparing a multitude of computed global and flow-related observables with RHIC and LHC data we have earlier set constraints on the temperature dependence of the QCD matter shear viscosity. Our multiplicity and flow predictions compared very well with the LHC-ALICE data measured at the highest lead-lead collision energy so far (Fig. 3). In 2017, using our best estimates for the QCD matter viscosity, we made predictions for the centrality dependence of charged particle multiplicity (Fig. 3) and flow coefficients in xenon-xenon collisions for which ALICE collected data in 10/2017.



↑ Figure 3. Predicted and measured centrality dependence of charged particle multiplicity in lead-lead (two upper sets of curves and data) and xenon-xenon (yellow band and the curves within) collisions at the LHC and gold-gold collisions at RHIC (lower set of curves and data) [3].

DEEP INELASTIC SCATTERING IN THE DIPOLE PICTURE AT NEXT-TO-LEADING ORDER

In the high energy limit, deep inelastic scattering can be understood in the dipole picture. Here the cross section is factorized into a virtual photon to quark-antiquark dipole light cone wave function, and the scattering amplitude of the dipole. In order to increase the accuracy of the theory, this formalism is currently being developed to next-to-leading order (NLO) accuracy in perturbation theory. In 2017 we developed [4] the first practical implementation of the recently

derived NLO dipole formalism. We showed that the NLO corrections can be significant. They also depend on the factorization scheme used to resum large logarithms of energy into renormalization group evolution given by the Balitsky-Kovchegov equation. We developed a factorization scheme that makes it possible to obtain meaningful results for the deep inelastic scattering cross sections.

LIGHT CONE WAVE FUNCTIONS AT ONE LOOP LEVEL

We developed methods needed to perform loop calculations in light cone perturbation theory using a helicity basis. A loop calculation in quantum field theory involves tensorial integrals that are evaluated in d spacetime dimensions, which must then be contracted with polarization vectors of gauge particles. We developed [5] a new helicity basis method to perform these calculations in a way that can be fully automatized. We demonstrated this explicitly by calculating the one-loop correction to the virtual photon to quark-antiquark dipole light cone wave function. This allows one to rederive the deep inelastic scattering cross section in the dipole

formalism to next-to-leading order accuracy, earlier obtained in a different regularization scheme.

AMPLIFICATION OF GLUON SATURATION EFFECTS IN EXCLUSIVE NUCLEAR DEEP INELASTIC SCATTERING

Gluon saturation is a change in the behavior of the gluons in a high energy hadron from a linear to a nonlinear regime due to an increase in the gluon phase space density. The effect is stronger in nuclei than in protons and is more clearly visible in exclusive processes than inclusive ones, since exclusive cross sections are proportional to the square of the gluon density. In 2017 we studied [6] the systematics of gluon saturation effects in vector meson production in exclusive deep-inelastic scattering off nuclei. We showed that gluon saturation gives rise to a strong modification of the scaling in both the nuclear mass number and the virtuality. We presented qualitative analytic expressions for how the scaling exponents are modified as well as quantitative predictions that can be tested at an Electron-Ion Collider.

[1] K.J. Eskola, P. Paakkinen, H. Paukkunen, C.A. Salgado, EPPS16: Nuclear parton distributions with LHC data, *Eur. Phys. J. C* 77 (2017) no.3, 163

[2] E.C. Aschenauer, S. Fazio, M.A.C. Lamont, H. Paukkunen, Pia Zurita, Nuclear structure functions at a future Electron-Ion Collider, *Phys. Rev. D* 96 (2017) no.11, 114005

[3] K.J. Eskola, H. Niemi, R. Paatelainen, K. Tuominen, Predictions for multiplicities and flow harmonics in 5.44 TeV Xe+Xe collisions at the CERN Large Hadron Collider, arXiv:1711.09803 [hep-ph], accepted in *Phys. Rev. D*

[4] B. Ducloué, H. Hänninen, T. Lappi, Y. Zhu, Deep inelastic scattering in the dipole picture at next-to-leading order, *Phys.Rev. D* 96 (2017) no.9, 094017

[5] H. Hänninen, T. Lappi, R. Paatelainen, One-loop corrections to light cone wave functions: the dipole picture DIS cross section, arXiv:1711.08207 [hep-ph]

[6] H. Mäntysäari, R. Venugopalan, Systematics of strong nuclear amplification of gluon saturation from exclusive vector meson production in high energy electron-nucleus collisions, arXiv:1712.02508 [nucl-th]

ALICE EXPERIMENT AT THE CERN LHC

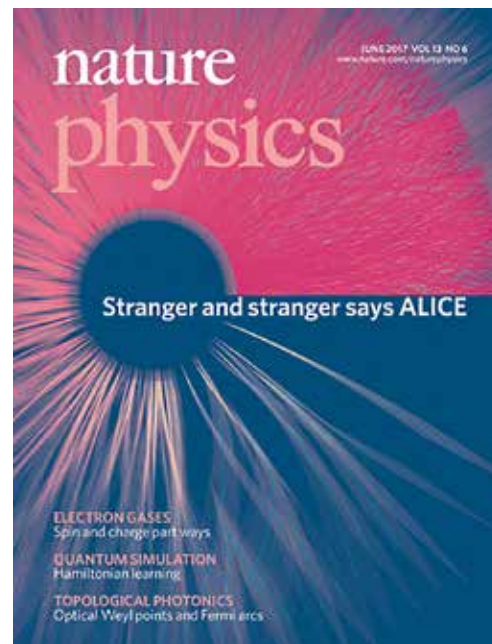
Professor Jan Rak, Senior Researcher Wladyslaw Trzaska

ALICE stands for A Large Ion Collider Experiment. ALICE apparatus registers hadrons, electrons, muons and photons produced in proton-proton, proton-nucleus, and in the collisions of heavy nuclei accelerated and circulated in the Large Hadron Collider (LHC) at CERN. The ALICE collaboration consists now of 1800 researchers representing 176 institutes from 41 countries. Jyväskylä is a member since 1998. The experiment was designed and constructed to exploit the unique physics potential of nucleus-nucleus collisions at LHC energies generating conditions reminiscent of a primordial state of the universe during the first few milliseconds after the Big Bang with temperatures corresponding to 2000 billion K. Interestingly, this extreme phase of matter, called the quark-gluon plasma (QGP), has properties of a perfect liquid.

www.jyu.fi/physics/particles/nuclear-reactions

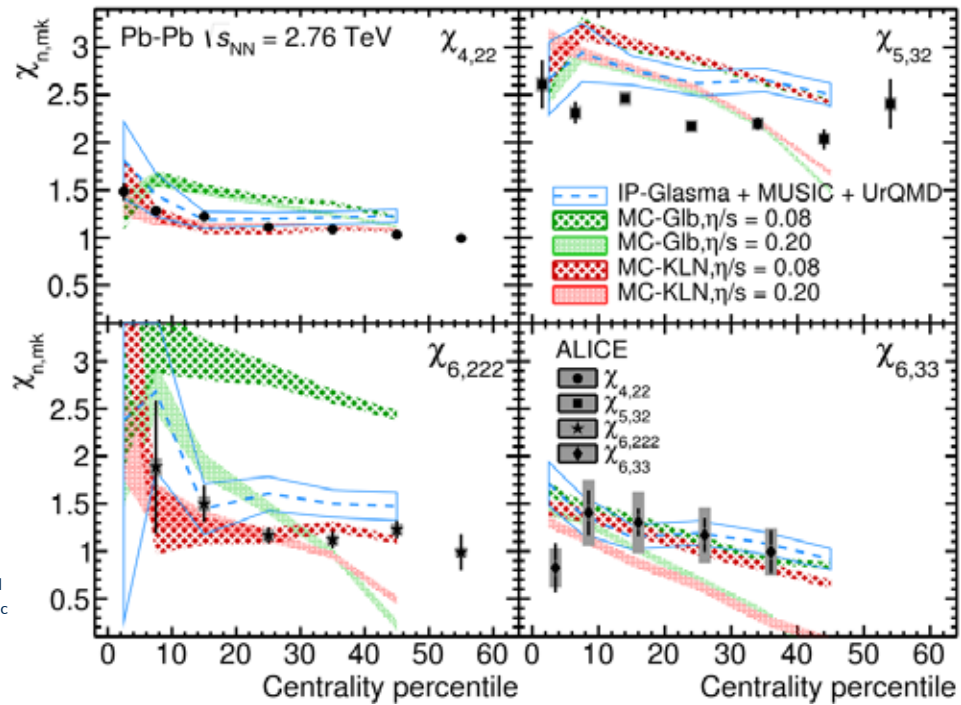
2017 was a very busy and productive year for ALICE and for our team. Throughout most of the running period LHC delivered pp collisions at the centre-of-mass energy of 13 TeV. In the autumn an

important test of the stability of the ALICE detectors was performed with LHC producing a particle load equivalent to PbPb collisions at the rate of 50 kHz. This target value corresponds to the conditions approximating LHC performance after the Long Shutdown 2. EMCal, T0 and a prototype of the Fast Interaction Trigger (FIT), that is, the detectors where we contribute the most, took part in the test as well. In October ALICE had a unique chance to register XeXe collisions at $\sqrt{s} = 5.44$ TeV giving us the opportunity to test the predictive power of hydrodynamics for smaller volumes of quark gluon plasma (QGP). The year ended with a pp reference run at $\sqrt{s} = 5$ TeV.





→ Figure 1: Non-linear flow mode coefficients measured in Pb-Pb collisions are compared to various hydrodynamic calculations.



The current main directions of the physics analysis performed by our group involve high-pT triggered correlations and studies of the jet transverse structure. The detailed analysis of pp, pPb and PbPb collisions data provides a deep insight into the QCD radiation processes and their modifications in cold nuclear matter and in QGP. We also study flow patterns via correlations among Fourier coefficients by detailing the azimuthal anisotropies of the final hadron momentum distributions in PbPb collisions.

Jussi Viinikainen finished his studies on the transverse structure on jets via two-particle correlations in pp and pPb collisions and successfully defended his PhD thesis. D. J. Kim presented studies on flow correlations at two large and highly valued conferences in our field: QM 2017 and Initial Stages 2017. M. Slupecki gave a talk on ALICE Forward Rapidity Upgrades at the 2017 EPS Conference on High Energy Physics. Proceedings papers are now in print.

The work on quality assurance of about 128 m² of Gas Electron Multiplier (GEM) foils for the new TPC readout chambers for ALICE is now nearing its completion. The last GEMs should leave the HIP Detector Laboratory during the summer of 2018. At the same time R&D on FIT is gaining full momentum. The FIT detector, replacing the current T0, V0, and FMD, will be a key element for the entire operation of the upgraded ALICE experiment. It will serve

as the interaction trigger and luminosity monitor. It will provide the precise event timing, forward multiplicity, centrality, and the interaction plane that are essential for flow measurements. In the preparation for the production stage FIT passed all the required Engineering Design Reviews.

The highlights of the scientific program of ALICE are the detailed study of higher order flow correlations [ALICE Collaboration, Phys. Rev. C 97, 024906] and quantifying the non-linear hydrodynamic response of their correlations [ALICE Collaboration, Phys. Lett. B 773 (2017) 60].

The different order non-linear mode coefficients show different sensitivities to η/s and the initial conditions. Comparisons to hydrodynamic calculations shown in Fig. 1 suggest that the data are described better by hydrodynamic calculations with smaller η/s providing further constraints on the initial conditions and η/s of the system produced in heavy-ion collisions.

New Fast Interaction Trigger for ALICE, Wladyslaw Trzaska for the ALICE Collaboration, Nuclear Instruments and Methods A, 845, 463-466.

Enhanced production of multi-strange hadrons in high-multiplicity proton-proton collisions, ALICE Collaboration, Nature Physics, 13 (6), 535-539.

INDUSTRIAL COLLABORATION

Professors Ari Virtanen, Timo Sajavaara, Ilari Maasilta, Markus Ahlskog and Markku Kataja

In addition to strong focus on fundamental research, Physics Department continues the active applied research and collaboration with a large number of Finnish and international companies. The goal is to offer our unique facilities and services for the benefit of the companies and enable our students to work with potential future working life problems.

The Industrial Applications group of the Accelerator Laboratory continued the utilization of RADEF facility under ESA's Technical Research Programme (TRP). This is done by offering heavy ion K-130 cyclotron and electron LINAC beam time for European space industry. The use of RADEF's K-130 beam time in 2017 was 1394 hours corresponding to about 22 % of the total running hours of the K-130 cyclotron. In total, 46 test campaigns for 25 companies or institutes were performed at RADEF. Also, electron LINAC was utilized commercially for 160 hours by five companies or universities. The commercial revenue in 2017 was 747 k€. Also, Horizon 2020 Marie-Curie (MSCA) RADSAGA training network provides an intersectoral structure based on a unique mixture of private companies, universities and national laboratories. The host companies of the students' secondment periods will be: 3D-Plus (FR), Airbus D&S (FR), MAGICS Instruments (BE), Yogitech (IT, part of Intel's Internet of Things Group) and Zodiac Aerospace (FR).

The Accelerator Based Materials Physics group within the Accelerator Laboratory has continued its active industrial collaboration both with international and domestic companies in 2017. Dr. Mikko Laitinen worked the whole year in the JyU spin-off company Recenart Oy gaining valuable experience in the analysis of cultural heritage objects by means of scientific techniques. New analysis beam line for Rutherford Backscattering Spectrometry (RBS) and external beam particle induced xray emission

(PIXE) was taken into use in 2017. The helium ion microscope has been used in several industrial projects.

The Thermal nanophysics group has well established collaboration with a few companies in Finland and abroad. The superconducting radiation detector work has involved collaboration with global, industry leading small and medium scale high tech companies, including one from the USA. In addition, national laboratories such as VTT Micronova and NIST Boulder have been involved. Collaboration with the NASA Goddard Space Flight Center in the US has also started, and contacts to the Jyväskylä start-up company Recenart are also close. 2017 also saw the beginning of collaboration with the Danish biotech company Novozymes in HIM microscopy.

The Molecular electronics and plasmonics group continued collaboration with lamit.fi, a company from Jyväskylä concentrating on re-newable energy. This Academy funded project on building integrable solar energy collection involves research groups also from Germany, India and Norway. In addition, the Molecular Technology group has collaborated with Morphona Oy, a local start-up company, in investigating the electronic properties of thin films of water soluble carbon nanotubes/hemicellulose complex. A publication on the work has recently been accepted to the journal Nanotechnology (IOP).

The Complex materials group utilizes the X-ray tomographic facility in applied research with industrial partners, e.g. for the analysis of structural and transport properties of fibre based materials, minerals and porous materials. Experimental work was complemented with material modelling taking basic research results of the group in immediate practical use. Individual projects were related e.g. to safety analysis of repositories of spent nuclear fuel, structural properties of fibrous materials and the analysis of contact properties of wood fibres in paper.

The collaborators included several Finnish companies as well as domestic and European and applied research institutes related to nuclear safety, geology, building materials and to other industrial research and development. Especially, the close collaboration with VTT Technical Research Centre of Finland was continued, involving e.g. 3D structural analysis of various types of materials of industrial relevance, and development of novel methods for materials analysis. In addition to industry, funding to applied research was received from Academy of Finland, Ministry of Employment and the Economy and European Union.



↑ Photo: Petteri Kivimäki

EDUCATION

Professor Jukka Maalampi, University teacher Jussi Maunuksela, Senior Lecturer Pekka Koskinen

PHYSICS CURRICULUM REFORMS

During 2017, the Department further strengthened its efforts to develop teaching methods and curricula. The developments included peer learning in small groups and self-directed studies, establishing numerical problem-solving as students' routine activities, diversifying assessment and lessening the role of final exams, and integrating communication and language teaching into physics courses. The integration saw its final phase in spring 2017 when a

course on research communication was embedded into the Bachelor's Thesis course.

However, the developments have been limited to specific courses. There has been a need to put them into more systematic, wide-spread use.

To this end, as a part of a university-wide reform process, we began planning a curriculum reform in 2016. The reform provided the freshmen an opportunity to complete basic physics studies within the first academic year. Studies included integrated communication courses, now also within the Bachelor's thesis process, and physics

content was supported by mathematics courses – not any longer taught by us, but by the Department of Mathematics. In addition to the reformation of curriculum, the basic level courses were introduced with teaching methods emphasizing peer learning in small groups, systematic integration of numerical problem-solving, and formative assessment without an end-of-course exam [1,2]. The new curriculum, along with the first courses, was put into action in August 2017.

[1] P. Koskinen, J. Maunuksela, H. Lehtivuori, J. Lämsä, T. Löytäinen, *Laatuikaoppiminen - vuorovaikutteista ja yhteistoiminnallista fysiikan opiskelua*, Yliopistopedagogiikka 1/2017

[2] P. Koskinen, J. Lämsä, J. Maunuksela, R. Hämäläinen, J. Viiri, *Primetime learning: Collaborative and Technology-Enhanced Studying with Genuine Teacher Presence* (submitted for publication)



JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Department of Physics

FACULTY OF MATHEMATICS AND SCIENCE

P.O. Box 35, FI-40014 University of Jyväskylä,
Finland

-  [jyuscience.fi](https://www.facebook.com/jyuscience.fi)
-  [jyscience](https://twitter.com/jyscience)
-  [jyscience](https://www.instagram.com/jyscience)
-  [JyvaskylaUniversity](https://www.youtube.com/JyvaskylaUniversity)

[JYU.FI/PHYSICS](https://www.jyu.fi/physics)