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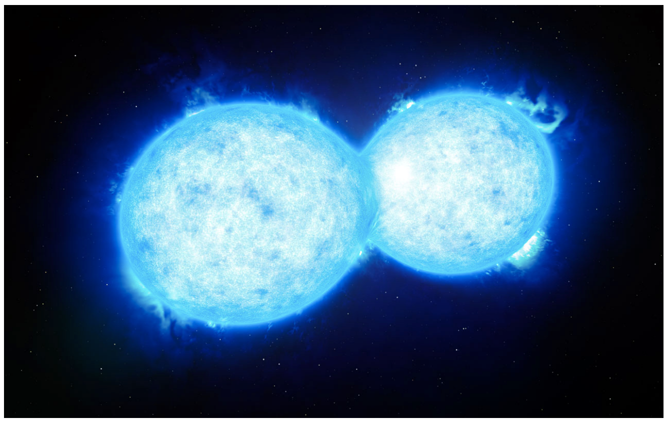
Plenary session I

The Turbulent Lives of Massive Stars: From Young Twins to Gravitational Waves Sources

Selma E. de Mink (University of Amsterdam)

Massive stars are nearly always found in close pairs when they are young. A very small fraction of these pairs stay together throughout their turbulent lives. They end their lives as a double black hole system. Their orbit slowly decays until, eventually, they coalesce. These mergers giving rise to such strong bursts of gravitational wave emission that they can be detected directly at earth by ground-based gravitational wave detectors. In this talk I will focus on the lives of the extreme progenitors of LIGO and Virgo's merging black holes and discuss what we are learning about the lives and deaths of the most massive stars.



Artist Impression of a Young Massive Contact Binary. Image Credit ESO

CURRENT TOPICS IN PROTON THERAPY

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Cancer therapy using swift protons may deliver a more favourable dose distribution than conventional radiation therapy with photons or electrons. Proton therapy may reduce the risk of complications, but also enables dose escalation for improved tumour control. Today, several commercial vendors offer cyclotron or synchrotron turn-key proton therapy facilities, which resulted in a near exponential growth in number of facilities in operation, and with it the total number of patients treated. Today, almost 70 proton therapy facilities are in operation worldwide, and another 40 are under construction.

This talk will briefly outline the merits of proton therapy from a physicist point of view, and then subsequently also address some of the controversial issues which are currently discussed in the proton therapy community. Mote noteworthy, some evidence is appearing that the relative biological effectiveness of proton beams is currently underestimated in those areas where the protons stop, due to their increased stopping power at low energies. This area may thus be associated with an unexpected increase of toxicity. In this talk I will also present some of our efforts to quantify the increased toxicity, which requires close collaboration between physicists and radiation biologists. Also I will present several mitigation strategies for overcoming this issue which have been suggested - but none of which have entered clinical routine yet.

The talk will conclude with an outlook on future ion therapy innovations, which further could improve the therapeutic outcome of radiation therapy.

Plenary session II

CLINICAL BORON NEUTRON CAPTURE THERAPY UNTIL NOW AND IN THE FUTURE

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Boron neutron capture therapy (BNCT) is biologically targeted high-LET radiation therapy modality, which requires intense external slow neutron radiation source and tumor seeking boron-10 carrier compound.

Most frequently BNCT has been used to treat patients with either primary or recurrent high-grade glioma or head-and-neck cancer. In addition, patients with some other malignancies such as melanoma and malignant meningioma have been treated.

Previously, nuclear reactor-based neutron facilities were the only available neutron sources for BNCT. Recently accelerator-based high intensity neutron sources have been developed for hospital installation.

In this presentation, past BNCT clinical trials will be reviewed concentrating on the treatments carried out in Finland by Helsinki University Central Hospital (HUCH). In addition, a new accelerator-based BNCT facility will be introduced, which will be installed at HUCH during year 2018.

The device-independent framework: a quantum information theory with black boxes

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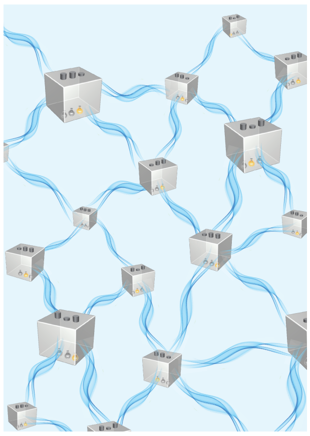
Device-independent quantum information processing represents a new framework for quantum information applications in which devices are just seen as quantum black boxes processing classical information. This level of abstraction makes device-independent protocols especially relevant for cryptographic applications, as existing quantum hacking attacks become impossible. After introducing the key ideas and concepts needed for the dedefinition of the device-independent scenario, we review the main results and open questions, and discuss how these techniques apply to other areas in physics.

In the device-independent scenario, devices are seen as quantum black boxes receiving a classical input and producing a classical output.



[1] A. Acín *et al.*, Phys. Rev. Lett. 98 (2007) 230501.
[2] S. Pironio *et al.*, Nature 464 (2010) 1021.
[3] M. Navascués, Y. Guryanova, M. J. Hoban and A. Acín, Nature Communications 6 (2015) 6288.
[4] J. Tura *et al.*, Science 344 (2014) 1256.
[5] A. Acín and L. Masanes, Nature 540 (2016) 213.

Plenary session III

Correlated Electrons – a Molecular Approach

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Strong electron-electron interactions are the source of intriguing phenomena. Prominent examples include novel types of superconductivity, multiferroicity or spin-liquid behavior. In recent years, molecular solids, made up of molecular building blocks have emerged as suitable model systems for exploring these fascinating states of matter under well-controlled conditions.

In this talk we will discuss various examples where molecular-based materials help address fundamental aspects of correlated electrons. This includes the Mott metal-insulator transition, a paradigm of strong electron-electron interactions, and the question to what extent the lattice degrees of freedom are involved in this transition [1]. Furthermore, we will discuss quantum phase transitions, $T = 0$ transitions driven by quantum fluctuations. We demonstrate that this transition, although inaccessible by experiment, can be used for realizing a highly efficient magnetic cooling [2,3].

[1] E. Gati et al., Science Advances **2**, e1601646 (2016).
[2] B. Wolf et al., PNAS **108**, 6862 (2011).
[3] B. Wolf et al., Int. J. Mod Phys B **28**, 1430017 (2014).

NEW WAYS OF LEARNING UNIVERSITY LEVEL PHYSICS

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Research of teaching and learning of physics at university level as a scientific endeavour is a relatively recent development. Since the late 1970s we have learnt much about where introductory university level students have difficulties with learning and understanding physics, and several teaching approaches have been developed and validated to help students gain deeper understanding than they would in traditional approaches.

One of the frontiers of Physics Education Research is the teaching and learning of physics beyond the introductory level. This often involves a bringing together of complex mathematical and physical concepts and techniques, and arguably the goals of teaching are often different from those at the introductory level.

This talk will focus on practical examples of research-based state-of-the-art teaching and learning in university level physics beyond the introductory level.

IOP Finland Chapter session

COLLIDER SEARCHES FOR DARK MATTER

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The quest for Dark Matter at colliders is an increasingly popular theme in High Energy Physics. Collider searches work in complementary ways to direct searches and aim to maximise the parameter space covered. New theoretical developments and experimental techniques are currently being put to test at the Large Hadron Collider. We will review the latest experimental results, and discuss prospects for future searches at yet-to-be-built colliders.

Plenary session IV

Band Offsets between Semiconductors, Insulators, Transparent Conductors, 2D semiconductors and the design of Semiconducting Devices

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The band off-set across a heterojunction between two semiconductors has been a critical parameter in many semiconductor devices, with large technical and economic implications. Likewise, the choice of HfO2 as the replacement for SiO2 as the CMOS gate oxide depended very much on its favourable band offset to Si. A number of examples are described for CMOS systems. Despite this, there is still debate as to whether to use the electron affinity (EA) model or the matching of charge neutrality levels (CNL) (branch points). This is partly because both experiment and modelling prefers lattice matching of the two lattices. We show that in practice the two extreme models often give similar answers, because (1) lattice constants vary monotonically with average atomic orbital energy and (2) the CNL actually only varies weakly with electronegativity. The description also extends to lower dimensions and van der Waals solids, where the EA rule holds for interlayer bonding, and the CNL rule holds for lateral (in-plane) junctions. Metal induced gap states (MIGS) do exist at TMD contacts, because the metals usually form full bonds to chalcogenides.

Parallel sessions I

P1

Faint and fast, bright and long-lived transients: what are they telling us?

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One of the main challenges of current supernova research is to identify the nature of stars that explode, and to link this knowledge to observed supernova properties. Nowhere is this problem more urgent than for the most massive stars in the local and distant Universe. Recent exciting results have challenged currently accepted paradigms of stellar evolution, and for these supernovae, ever more exotic scenarios are being proposed. I will discuss a few special cases within the currently-accepted framework that highlight gaps in our knowledge.

THE PROGENITORS AND ENVIRONMENTS OF STRIPPED-ENVELOPE SUPERNOVAE

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At the end of their lives, massive stars produce brilliant explosions known as supernovae (SNe). Among these, stripped-envelope (SE) SNe are characterized by the lack or weak presence of hydrogen in the spectrum. The stellar progenitors of these SNe are thus thought to have lost significant parts of their hydrogen envelope through mass loss, prior to the terminal explosion. A massive star may rid of its envelope through strong stellar winds, resulting in a stripped Wolf–Rayet star progenitor for the impending SE SN. Alternatively, interactions with a close binary companion star can also produce a stripped-envelope SN progenitor. Various observational studies including the estimates of ejecta mass through the light curves, and progenitor core mass through nebular spectroscopy, suggest that binary progenitors constitute a significant fraction of SE SN progenitors. This result is independently supported by the studies of the SN environments and surrounding stellar populations, which suggest that some SE SN progenitors must have been born from a relatively old stellar populations inconsistent with highly massive stars. Most recently, a SN lacking the signs of hydrogen and helium layers in the progenitor (SN type Ic) was found to be interacting with a hydrogen-rich circumstellar medium. Being the first to be discovered, such case is thought to be caused by a progenitor star experiencing mass loss through eruptions or binary interactions, as opposed to relatively steady stellar winds.

HIGH-MASS X-RAY BINARIES AS PROGENITORS TO CORE-COLLAPSE SUPERNOVAE

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When a massive star (M>∼8 $M_\odot$) exhausts the nuclear fuel in its core, the core will collapse, resulting in a cataclysmic explosion known as a core-collapse supernova (SN). While most of these core-collapse SNe exhibit strong hydrogen-features in their spectrum, a minority possess little to no signs of hydrogen. The progenitors of these hydrogen-poor core-collapse supernovae (also known as SN types Ib, Ic and IIb) are believed to have shed their outer hydrogen-rich envelope prior to the SN explosion. The primary mechanisms driving this loss are believed to be either extremely strong stellar winds, characteristic of massive Wolf-Rayet stars, or interaction with a close binary companion star. The precise nature of the progenitors and the relative importance of these two mechanisms remains an open question however, highlighting the importance of obtaining pre-explosion observations of these systems. We have considered a scenario where the progenitor of the hydrogen-poor SN was a massive star in a high-mass X-ray binary (HMXB), a class of interacting close binary systems where one of the stars has previously undergone a core-collapse SN producing a compact remnant (a neutron star or a black hole), and where accretion from the surviving star to the compact remnant can produce extremely bright X-ray emission. This accretion-process could lead to the stripping of the hydrogen-envelope of the surviving massive star, potentially resulting in a hydrogen-poor core-collapse SN at the end of its lifespan. I will discuss the results of our initial search for these X-ray bright progenitor systems, as well as our ongoing monitoring program to find potential candidates by searching for X-ray counterparts to newly discovered optical transients in pre-discovery X-ray observations.

SN2016gsd: an intriguing hydrogen rich core-collapse supernova

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ABSTRACT:

It is expected that stars more massive than 8 solar masses will end their existence in core-collapse supernovae (CCSNe). Through study of the evolution of the brightness and spectral features of these explosions they are broadly categorised into various groups and inferences can be made about their progenitor systems. The most common hydrogen rich CCSNe are called type II "plateau" or type II-P SNe, as after an initial decline their light curve remains steady, or "plateaus" for ≈100 days. This is physically attributed to hydrogen recombination in the SN envelope. Type II-P SN progenitor stars have been recovered from pre-SN imaging and are found to be 8-16 solar mass red super giants, which have extended hydrogen envelopes, corroborating this analysis. These SNe contrast with type II-L SNe, whose light curves decline linearly throughout, exhibiting little or no plateau phase. This naturally implies that the progenitor systems of these SN could have a smaller hydrogen envelope at the time of explosion. However direct progenitor detections are still few. Here I present a dataset on SN2016gsd predominantly obtained from the European Southern Observatory (ESO) and the Nordic Optical Telescope (NOT). This SN is a bright type II-L which is remarkably similar to the well known type II-L SN1979C photometrically, but which exhibits different and interesting spectral features. I discuss the physical interpretation of these features and what this object can reveal about type II-L progenitor stars.

OBSERVING THE EFFECTS OF GRAVITATIONAL WAVE EMISSION BEYOND THE QUADRUPOLAR ORDER IN OJ287

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Observations of eccentric compact binaries like PSR 1913 +16 are consistent with the dominant (quadrupole) order emission of Gravitational Waves. We show that observations of the binary black hole central engine of the blazar OJ287 demand the inclusion of gravitational radiation reaction effects beyond the quadrupolar order. It turns out that even the hereditary terms which depend on the history of the source are required in order to predict the impact flare timings of OJ287. We develop an approach to incorporate them into the binary black hole model for OJ287 and find an excellent agreement between the theoretical predictions and the best fit to the data that span over 10 orbital cycles. Additionally, we show that the orbit averaged gravitational wave flux deviates 10% from the flux calculated from the standard quadrupole formula.

P2

RECENT TOTEM MEASUREMENTS – PROBING THE EXISTENCE OF A COLOURLESS THREE GLUON BOUND STATE

M. Berretti, F. Garcia, J. Heino, P. Helander, R. Lauhakangas, T. Naaranoja, F. Oljemark, K. Österberg, H. Saarikko and J. Welti for the TOTEM collaboration

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High energy elastic proton proton (pp) scattering has traditionally been described by t-channel exchange of a pair (or even number) of gluons, the so-called "Pomeron", or at very low |t| by t-channel photon-exchange. The TOTEM [1] experiment at CERN's Large Hadron Collider (LHC) has recently measured the total pp scattering cross-section (σ_{tot}) at 13 TeV center-of-mass energy to be 110.6 ± 3.4 mb using the luminosity independent method [2]. In addition, TOTEM has made at the same energy the most precise ever determination of the ρ parameter, the real to imaginary ratio of the hadronic elastic scattering amplitude at t = 0, of 0.09 ± 0.01 and 0.10 ± 0.01, depending on the physics assumptions and the mathematical modelling using the Coulomb-hadronic interference [3]. The conventional Pomeron-exchange based models [4] used up to now at LHC are not able to simultaneously describe the TOTEM σ_{tot} and ρ measurements.

However, adding the t-channel exchange of a colourless three (or odd number of) gluon bound state, the so-called "Odderon", leads to a better description of the TOTEM measurements in both axiomatic field theories [5] and QCD [6] based models. The existence of such an exchange of three gluons is predicted by QCD but has so far not convincingly been proven using experimental data. The current evidence will still have to be confirmed by similar measurements at other energies and complemented by measurements of other manifestations of the three gluon exchange in elastic scattering to prove that a quantitative description of high energy elastic scattering requires this additional exchange. If not proven, the TOTEM ρ measurement may instead represent a first indication of a slowing down of the total cross-section growth at energies beyond the LHC.

[1] G. Anelli *et al.* (TOTEM Collaboration), JINST 3 (2008) S08007.
[2] G. Antchev *et al.* (TOTEM Collaboration), CERN-EP-2017-321 (2017), submitted to Phys. Rev. D.
[3] G. Antchev *et al.* (TOTEM Collaboration), CERN-EP-2017-335 (2017), submitted to Phys. Rev. D.
[4] J.R. Cudell et al. (COMPETE Collaboration), Phys. Rev. Lett. 89 (2002) 201801.
[5] E. Martynov and B. Nicolescu, Phys. Lett. B 778 (2018) 414.
[6] V.A. Khoze, A.D. Martin and M.G. Ryskin, Phys. Rev. D97 (2018) 034019.

Imaging Spent Nuclear Fuel via Passive Gamma Emission Tomography for Final Disposal in Deep Underground Repositories

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Long term management of spent nuclear fuel is an important societal challenge. Many countries have decided to dispose of their high level nuclear waste in deep geological repositories. Finland has chosen the Olkiluoto site as the location of its deep geological repository. Preparations for final disposal of spent nuclear fuel in Finland began already in the 1980s and storage operations at the Olkiluoto site are set to begin in the mid-2020s [1]. Finland will be the first country in the world to operate a deep geological repository and as such will have a leading role in developing the technology, ideas and standards for such sites worldwide.

Safeguards are a set of technical and inspection measures enacted by the International Atomic Energy Agency (IAEA) to independently ensure that nuclear facilities are not misused and nuclear material is not diverted from peaceful civilian uses [2]. Finland's deep geological repository will be under an IAEA safeguards protocol but, as the first facility of its kind to be built, new technological developments are needed to meet the IAEA's safeguards requirements.

Passive Gamma Emission Tomography (PGET) can be used to reconstruct images of spent nuclear fuel assemblies where individual fuel pins can be resolved, meeting a critical requirement of IAEA safeguards to allow detection of the diversion of small amounts of spent nuclear fuel [3]. The Finnish integrated measurement station for safeguards will include a PGET-capable instrument.

In 2017, data was collected with the PGET instrument prototype at the Loviisa and Olkiluoto power plants in Finland. In this presentation, we will describe the dataset collection process and the data pre-processing methods necessary to obtain good quality fuel images. We will discuss image reconstruction techniques for PGET data and how the images can be used as part of an integrated safeguards system at the Finnish deep geological repository.

[1] Posiva Oy, webpage, General Time Schedule for Final Disposal (2018).
[2] IAEA, webpage, Safeguards and Verification (2018).
[3] T. Honkamaa, *et al.*, A prototype for passive gamma emission tomography, IAEA Safeguards Symposium (2014).

Passive Neutron Albedo Reactivity Instrument for Spent Nuclear Fuel Assembly Characterization

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The deep geological repository for the final disposal of spent nuclear fuel to be build in Finland requires reliable instrumentation for spent nuclear fuel assembly characterization. This instrumentation is used to establish compliance between declared and measured fuel assembly fissile material content. To meet the recommendations given to the International Atomic Energy Agency (IAEA) for spent nuclear fuel assembly interrogation [1], an integrated non-destructive assay (NDA) instrument is under development. It incorporates two main parts: a Passive Gamma Emission Tomography (PGET) instrument and a Passive Neutron Albedo Reactivity (PNAR) instrument. Pin-level gamma emission signatures of fuel assemblies would be verified by the PGET instrument [2], while the role of the PNAR detector is to verify the presence of fissile material in the assembly by measuring the neutron multiplication.

This contribution focuses on a comprehensive simulation study of the PNAR instrument. We will describe the design and anticipated performance of fuel-type-specific PNAR instruments for both BWR and VVER-440 fuel. MCNP simulations of the PNAR instrument were performed to evaluate the expected performance and quantify its dependence on the uncertainties caused by: fuel cooling time, anisotropy of the assembly burnup, fuel assembly displacement inside the detector opening, water gap around the fuel assembly, variation in the boron content of the water (for VVER fuel only) and counting statistics. The proposed Finnish integrated NDA system complies to the recommendations stated by the IAEA and creates a very difficult challenge for would-be proliferators.

[1] ASTOR Group Report 2011-2016, "Technologies Potentially Useful for Safeguarding Geological Repositories," IAEA, STR-384, Vienna, Austria (2017).

[2] T. Honkamaa, *et al.*, A prototype for passive gamma emission tomography, IAEA Safeguards Symposium (2014).

P5

HOW THE CELL MEMBRANE RECEPTORS ARE MODULATED – AND WHY DOES IT MATTER?

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Cell membranes are tough systems to explore. They are not only extremely complex in terms of their composition but they are also subject to enzymatic modifications that constantly change their structure. Yet aims to understand cell membrane function are of exceptional importance given the fact that they regulate all cellular communication through receptors embedded in membranes. Importantly, any impairment in receptor function has a severe consequence, typically a disease.

Here we show through multi-scale computer simulations [1-3] how the activation of membrane receptors is modulated by nature. This knowledge is the basis of health: to understand how diseases emerge from molecular-scale malfunctions, one first has to understand how biological functions take place in the absence of disorder.

We first discuss how specific lipids in cell membranes modulate membrane receptor conformation and dynamics. The importance of this topic stems from recent findings that in many diseases the lipid content of cell membranes is altered, which suggests the function of membrane receptors and thereby cellular signaling to also be impaired. We further discuss how glycosylation of membrane receptors also modulates receptor properties, and how these sugar units and their interactions with lipids interfere receptor function. Generally, the studies discussed in this contribution demonstrate how the toolbox of physics can contribute to life sciences, and therefore to promoting better health.

[1] M. Manna et al., eLife 5, 18432 (2016).
[2] J. P. Steringer et al., eLife 6, 28985 (2017).
[3] W. Kulig et al., manuscript under preparation (2018).

REAL-TIME DIFFUSION MONTE CARLO METHOD

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Direct sampling of multi-dimensional systems with Quantum Monte Carlo (QMC) methods allows exact account of many-body effects in expectation values. Therefore, Diffusion Monte Carlo (DMC), has provided several benchmark cases for other methods to pursue. Its robustness is based on direct sampling of a positive and normalisable probability density $G(x_b, \tau_b; x_a, \tau_a)$ for driving diffusion in imaginary time τ, and thus, solving the stationary Schrödinger equation for the ground state. Let us call this method τDMC.

It has been argued that the corresponding real time diffusion can not be realised, because the corresponding "oscillating complex valued distribution" $K(x_b, t_b; x_a, t_a)$ can not be used to drive diffusion. Here, we demonstrate that this can be done with a couple of tricks turning the distribution piecewise positive and normalisable. This study is a proof of concept demonstration using the well-known and transparent case: one-dimensional harmonic oscillator. Thus, we introduce a novel real-time DMC, which we call tDMC.

Furthermore, we show that our novel method can be used to find not only the ground state but also excited states and even time evolution of a given wave function. Considering fermionic systems or excited states, this method may turn out to be feasible also for finding the wave function nodes for ground state approaches, like τDMC, see Fig. 1.

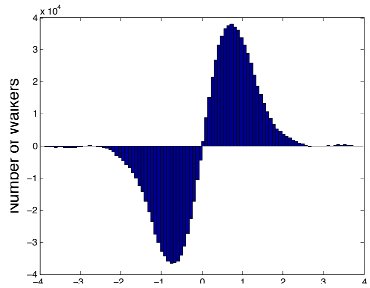

Figure 1 *The first excited state of the one-dimensional harmonic oscillator. Converged distribution of positive ($N \approx 0.57 \times 10^6$) and negative ($N \approx 0.56 \times 10^6$) real walkers.*

We illustrate, how the path integral kernel $K(\Delta x, \Delta t)$ [1] drives fully delocalised diffusion in the whole available space. Thus, the time evolution immediately responds to any distant changes in the external potential and allows tunneling into a region, where the wave function is initially zero, *i.e.,* which contains no initial walkers.

Furthermore, we compare this novel approach with our earlier Real Time Path Integral approach (RTPI) [2, 3], which is based on the same propagator K. With this, we finally demonstrate both the coherent and incoherent evolution of the wavefunction with tDMC.

[1] R. P. Feynman and A.R. Hibbs; Quantum Mechanics and Path Integrals (McGraw-Hill, New York, 1965); and R. P. Feynman, Rev. Mod. Phys. **20**, 367 (1948).

[2] Ilkka Ruokosenmäki and Tapio T. Rantala; Comm. in Comput. Phys., **18**, 91 (2015).

[3] Ilkka Ruokosenmäki, Hossein Gholizade, Ilkka Kylänpää and Tapio T. Rantala; Comput. Phys. Comm., **210**, 45-53 (2017).

PEEKING INTO THE BLACK BOX: A LOOK AT THE HIDDEN NODES OF NEURAL NETWORKS

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Kinetic Monte Carlo (KMC) is an efficient method for modelling long time scale processes such as diffusion. Computationally the most demanding part of KMC is the calculation of energy barriers related to each event that can happen during the simulation. Depending on the desired accuracy to distinguish between different events, calculating the required barriers may be unfeasibly expensive. A solution to this problem may be offered by neural networks (NN), a method that can be taught to predict barriers based on a small subset of the possible events.

A criticism NNs are sometimes subjected to is that they resemble a black box in how they learn to map input to output. The training process optimises the weight parameters in what are termed "hidden nodes" or "hidden neurons", suggesting that they need not or even should not be seen by the user. The values of these parameters may have no inherent meaning on their own, making it difficult to visualise or otherwise make sense of the trained network. The only straightforward metric of quality is the performance of the network in the desired data set. In the case of predicting barriers for KMC, the ultimate test for network accuracy is the ability to produce correct physics in simulations.

This presentation will describe a physicist's journey into the darkness of neural networks, and hopefully shed some light on whether, when and how the black box should be examined more carefully. Even established NN libraries may produce networks that are unable to improve for no apparent reason, until one takes a look at what's hidden.

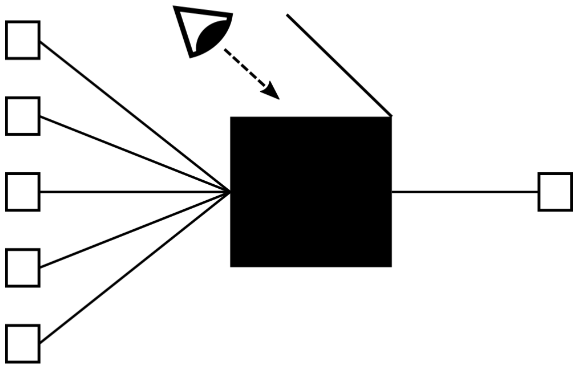

Figure 1: Neural networks map input to output without too much transparency. Can this cause unexpected problems? Should you open the black box and see what's inside?

T-MATRIX METHOD FOR FINITE AND INFINITE NANOPARTICLE ARRAYS

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The multiple-scattering T-matrix method [1] is a direct generalisation of the coupled dipole (CD) approach for computing the electromagnetic response of ensembles of compact scatterers (nanoparticles), which takes into account also the electromagnetic multipole polarisations of the individual particles to an arbitrary order. It applies to much broader set of problems than the CD approximation (which is too rough and fails where higher multipole response plays a role), while still retaining relatively low demands on computational resources.

The method is unmatched for linear response problems involving finite lattices, where periodic boundary conditions cannot be used and some lower-level methods (such as the more popular FDTD method) would not be computationally feasible. We performed such finite-lattice simulations e.g. to explain experimentally observed far-field radiation from lasing in assumed dark and bright modes of a finite-sized plasmonic lattice [2] at the visible wavelength.

However, until recently, T-matrix method could not be reliably used for infinite lattices due to the presence of diverging lattice sums. I show that this problem can be solved by an approach inspired by Ewald summation [30] (although Ewald's original work studied *electrostatics* in crystals). This brings the possibility to use the T-matrix method to calculate the dispersion relations and mode structure for different configurations (much faster and more reliably than with FDTD), and the underlying theory provides some semi-analytical means which can be exploited to design nanoparticle arrays with interesting optical properties.

[1] Yu-lin Xu, Phys. Rev. E 67, 046620 (2003).

[2] T. K. Hakala, H. T. Rekola, A. I. Väkeväinen, J.-P. Martikainen, M. Nečada, A. J. Moilanen and P. Törmä, Nature Communications 13687 (2017).

[3] P. P. Ewald, Die Berechnung optischer und elektrostatischen Gitterpotentiale, Ann. Physics, 64 (1921), pp. 253–268.

DETERMINING OXIDATION STATES OF BINARY OXIDES BY BADER CHARGES WITH BIG DATA ANALYSIS TECHNIQUES

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A connection between the oxidation state (OS) and Bader charge has been missing so far. Several studies have tried to establish the connection, and it has proven to be a non-trivial task. According to Reeves and Kanai, the charge difference between two consecutive OS (between Ru(II) and Ru(III)) [1] is rather marginal and it is much smaller than unity, but it was shown that OS and partial charges should not agree with each other due to negative-feedback charge regulation mechanism [2]. It is natural to look for a method which gives an integer number for OS, but is it true in nature? Can we say that all 8 valence electrons of osmium in OsO_4 go entirely to oxygen atoms? It is well known that all ionic bonds have some features of a covalent bond. Jansen and Wedig [3] are confident that a connection between OS and Bader charge exists and they highlight *"the need for factors other than calculated charges to be taken into consideration in order to obtain a meaningful connection with oxidation states"*. To our knowledge, all previous work tried to connect OS with Bader charges only in few compounds, and the main topic in those articles was different.

Nowadays the popularity of open and big data gives rise to continuously growing open material databases with DFT results for millions of compounds. Examples of such databases are: AFLOW [4], NOMAD [5] and others. Our aim is to find a dependency between OS and Bader charge, using a large number of compounds from an open database, and to provide a possibility to determine the oxidation state from ordinary DFT calculations. Our focus is on binary oxides, i.e. compounds of two elements, one of which is oxygen. They were chosen for simplicity as they contain only two species. They are also abundant on Earth and they are among the most calculated compound types in material databases. We show that a correlation indeed exists between OSs and Bader charges and discuss the applicability of determining OS by Bader charges in mixed-valence compounds.

[1] K. G. Reeves and Y. Kanai, The Journal Of Chemical Physics 141, 024305 (2014)
[2] H. Raebiger, S. Lany and A. Zunger, Nature 453, 763–766 (05 June 2008)
[3] M. Jansen and U. Wedig, Angewandte Chemie 47, 2008
[4] S. Curtarolo et al., Computational Materials Science 58, 2012, 227-235
[5] M. Scheffler, C. Draxl The NoMaD Repository, (2014).

P7

HIGH INTENSITY FOCUSED ULTRASOUND (HIFU) THERAPY FOR TREATING TUMORS – HOW MRI COULD HELP TO ASSESS SUITABILITY OF TUMORS FOR THERAPY?

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Magnetic resonance-guided high intensity focused ultrasound therapy (MR-HIFU treatment) is a non-surgical treatment method, in which tumor is destroyed by heating the cells with ultrasound energy. Heating tumor tissue to more than 55 Celsius degrees causes i.e. coagulation necrosis and irreversible tissue damage [1]. Due to the focusing, heating takes place only in the carefully defined area. Magnetic resonance imaging allows excellent anatomical resolution for treatment planning and real-time temperature monitoring during the treatment.

MR-HIFU can be used to treat both benign and malignant tumors, including liver, breast and prostate cancer, benign soft tissue tumors of uterus (uterine fibroids) and bone metastases which has been treated with MR-HIFU [2,3]. Non-surgical treatments like MR-HIFU have usually shorter recovery period and lower morbidity and mortality than surgery [4].

One of the greatest challenges of HIFU therapy is that the suitability of tumors for the HIFU therapy cannot be identified reliably beforehand and the successfully treated tissue cannot be identified during the treatment. This may increase the risk of not achieving optimal treatment result. Because the treatment result depends on the tumor properties the suitability of the tumor could potentially be evaluated beforehand from quantitative MR images.

The goal of quantitative MRI is not only to acquire anatomical images but also to quantitatively characterize parameters from the tissues using parameters like T1- and T2-relaxation times, apparent diffusion coefficient (ADC) and perfusion values. Results of this study indicate that ADC values are a promising biomarker for monitoring the success of HIFU therapy of uterine fibroids during the treatment and for evaluating the suitability of uterine fibroids for HIFU therapy.

[1] S.-W. Yoon, C. Lee, K. A. Kim and S. H. Kim, Obstetrics and gynecology international 2010 (2010).
[2] F. A. Jolesz, Annual Review of Medicine 60 (2009) 9.
[3] W. H. She, T. T. Cheung, C. R. Jenkins and M. G. Irwin, Hong Kong Medical Journal 22 (2016) 4.
[4] M. E. Ikink, M. J. Voogt, M. A. A. J. Van Den Bosch, R. J. Nijenhuis, B. Keserci, Y. S. Kim, K. L. Vincken and L. W. Bartels, European Radiology 24 (2014) 9.

VERIFICATION OF HYPERARC™ RADIOTHERAPY DOSE CALCULATION ACCURACY USING A ROBUST FILM DOSIMETRY METHOD

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In this study, HyperArc™ (Varian Medical Systems), a radiotherapy technique, which enables treatment of multiple small targets using a single isocentre, has been dosimetrically validated. HyperArc™ plans are potentially challenging, as many mechanical uncertainties in dose delivery, like table rotation and MLC collimation, might cause non acceptable dose delivery errors. Correspondingly, uncertainties in dose calculation, e.g. source and MLC modelling, might cause clinically unacceptable errors.

Five sphere targets (diameter 1.0 cm) are located on the central frontal plane of the plastic water phantom (30 cm x 30 cm x 10 cm). Individual spheres are set on the longitudinal axis with 4 cm offsets while the central target ball is placed to the isocentre. Plan is optimized with FFF 6 MV beam to prescription dose 10 Gy (PTV(V98%)) for TrueBeam accelerator equipped with 120 leaf MLC. Two other plans are prepared for the target sphere diameter 0.5 cm and 2.0 cm, respectively. On each plan a static MLC field, with two small openings (“the beacons”), is added to enable digitized film image registration to collimator coordinates during image processing. Dose calculation is made using the AAA algorithm with 1 mm grid size.

Two-dimensional dose distribution on the central frontal plane is detected using Gafchromic EBT3 -film and Vidar Dosimetry Pro Advantage(red) -densitometer. To minimize random errors measurements are repeated three times and films are digitized three times using different lateral positions on the densitometer. Images are registered to collimator coordinates with “the beacons” before calculation of the average result. The registration accuracy is equivalent to the theoretical resolution of the film: 0.1 mm. Densitometers lateral and longitudinal response deviations are defined and corrected. Optical density is calibrated to dose. Measured and calculated plan doses are compared on a region of interest (width = 6.0 cm) x (height = 18.0 cm) using gamma and absolute difference analyses.

For evaluated HyperArc™ plans gamma (2 mm / 2 %) pass rates are: 98.5 % (diameter 2 cm), 99.8 % (diameter 1 cm) and 99.9 % (diameter 0.5 cm) and average absolute differences are: 0.19 Gy (Ø 2 cm), 0.16 Gy (Ø 1 cm) and 0.13 Gy (Ø 0.5 cm).

The agreement between calculated and delivered dose has been found clinically acceptable on mechanically and dosimetrically difficult test cases. The size of target spheres diameter seems not to impact the level of agreement.

SYNTHETIC SCHLIEREN TOMOGRAPHY OF FOCUSED ULTRASOUND TRANSDUCERS

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Ultrasound has uses for both imaging and therapeutic purposes within the field of medicine. Both uses require accurate calibration, *i.e.* measurement, of ultrasound transducers' output. In this work, an approach called synthetic schlieren tomography (SST) [1], based on background-oriented schlieren [2, 3], is used to measure an ultrasound pressure field of a focused ultrasound transducer operating with parameters similar to diagnostic transducers.

In SST, a printed pattern (an imaged target) is placed behind the ultrasound field with respect to a camera. The imaged target is then illuminated with a pulsed light source synchronized with the ultrasound transducer. The camera is used to take an image both with and without the ultrasound field. Due to the acousto-optic effect, light rays that pass through the ultrasound field experience deflection which manifests as distortions in the pictures of the imaged target. By performing the imaging at multiple rotation angles of the ultrasound transducer a tomographic dataset is created, from which the ultrasound pressure field can be estimated.

In this work, principal physics involved, measurement setup, and an approach for estimation of the ultrasound pressure field are described. Results are shown demonstrating the feasibility of the technique for measuring the ultrasound field of a focused ultrasound transducer. The results are compared to hydrophone measurements. Strengths and weaknesses of the technique are discussed.

[1] A. Pulkkinen, J. J. Leskinen, and A. Tiihonen, "Ultrasound field characterization using synthetic schlieren tomography," *J. Acoust. Soc. Am.* **141** (6): 4600–4609 (2017).

[2] B. R. Sutherland, S. B. Dalziel, G. O. Hughes, and P. F. Linden, "Visualization and measurement of internal waves by 'synthetic schlieren.' Part 1. Vertically oscillating cylinder," *J. Fluid Mech.* **390** (4): 93–126 (1999).

[3] M. Raffel, "Background-oriented schlieren (BOS) techniques," *Exp. Fluids* **56** (3): 60 (2015).

[4] B. K. P. Horn, and B. G. Schunck, "Determining optical flow," *Artif. Intell.* **17** (1-3): 185–203 (1981).

[5] S. R. Deans, The Transforms and Applications Handbook: Second Edition (CRC Press, Boca Raton, FL, 2000)

QUALITY ASSURANCE MEASUREMENTS OF GEOMETRIC FIDELITY ON COMMERCIALLY AVAILABLE SYSTEMS FOR MRI-BASED RADIATION THERAPY PLANNING

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Using magnetic resonance imaging (MRI) as the only imaging method for radiation therapy planning (RTP) has become increasingly common as availability of commercial MR-RT platforms and the development of MRI-based dose calculation techniques have increased. Geometric distortions are often considered as limitations for MR-only simulation in RT. The number of MR-RT capable platforms is constantly growing, thus increasing the need for clinically sufficient geometric fidelity quality assurance (QA) method.

We evaluated the geometric fidelity of three 1.5 T and three 3 T Philips Ingenia MRI scanners using a true 3D geometric fidelity QA method. In one year, we also evaluated the sufficiency of 2D (in-plane) geometric fidelity QA method compared to 3D method using a 1.5 T Philips Ingenia MR-RT platform. The 3D geometric fidelity was evaluated on all six scanners using a proprietary 3D QA phantom with manufacturer's T_1-weighted gradient echo sequence-based QA protocols. The 3D QA images were analysed using manufacturer's prototype analysis software. The 2D QA measurements were performed on 1.5 T MR-RT platform and compared to 3D QA results. A long term follow-up of 2D QA results was performed on 1.5 T MR-RT platform.

Our results show that tested 1.5 T and 3 T scanners achieved similar geometric fidelity, with maximum total distortions of <2 mm at <200 mm distance from device isocentre. The geometric fidelity of 1.5 T MR-RT platform remained stable within 1 mm from initial measurements throughout the monitoring period. Both 2D and 3D QA results provided sufficient information about in-plane geometric distortions across the field-of-view when considering clinical use. Furthermore, modern scanners that can be combined with commercial MR-only analysis software and precise laser positioning system achieve sufficient geometric fidelity by default based on our 3D QA evaluation. In addition, long term stability of geometric accuracy does not seem to be an issue. This is valuable information when QA programmes for MRI scanners are planned.

Parallel sessions II

P1

TRANSIENT X-RAY PULSARS AS A TOOL FOR THE STUDIES OF MAGNETIC FIELDS IN NEUTRON STARS

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I will present a review of the observational appearances of the ultra-strong magnetic fields in the accreting neutron stars (NSs). Special attention will be given to the transient X-ray pulsars accreting in a broad range of rates, focusing on their behaviour in the very end of the outbursts. Interaction of the accreting plasma with the NSs magnetic field at low mass accretion rates results in the centrifugal inhibition of the accretion (aka “propeller effect”, one of the most direct evidence of the strong magnetic field presented in the vicinity of the neutron stars). I will review observational manifestations of the propeller effect in X-ray pulsars with broad range of the magnetic fields from 10^8 to 10^{14} G with the main focus on our recent discoveries. Observations of this effect allow to independently estimate the strength of the NSs magnetic field as well as it's structure.

APERIODIC VARIABILITY IN PULSARS AND THE DYNAMO FREQUENCY

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Highly magnetized neutron stars accreting matter via an accretion disk offer a unique way to examine the interaction of plasma with the ultra-strong magnetic field. The magnetic field will truncate the disk at the so-called magnetospheric radius, inside which the disk matter is guided onto the neutron star surface where its energy is released in X-rays (so-called X-ray pulsars). The properties of the fast flux variability carry an imprint of the geometrical and physical conditions of the system.

In the current work, we conducted comparative timing analysis of several X-ray pulsars whose magnetic fields are known through cyclotron line measurements. We examined the evolution of their power density spectra with respect to luminosity during outbursts. Our focus was on the break frequency which in the perturbation propagation model [1] is related to the inner radius of the accretion disk [2]. Magnetic dynamo action occurs in all modern accretion disk simulations and its timescale can be linked to the growth of perturbations in the disk [3]. Following the latest extension of the model (e.g. [4], the break frequency is expected to occur at the dynamo frequency of the inner disk radius. We now present limiting values for the ratio of the dynamo frequency to the Keplerian frequency of the inner radius.

[1] Y. E. Lyubarskii, MNRAS 292 (1997) 679.
[2] M. Revnivtsev et al., A&A 507 (2009) 1211.
[3] J. Hogg and C. Reynolds, ApJ 826 (2016) 40.
[4] Mushtukov, A. et al., MNRAS 474 (2018) 2259.

Photometric redshift galaxies as tracers of the filamentary network

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The Javalambre Physics of the Accelerating Universe Astrophysical Survey will observe the photometrical redshifts for galaxies up to redshift 1. The development of observational technology has boosted the importance of using the photometrical redshift galaxy data (these galaxies have rather uncertain distance estimations in redshift space). The use of photometrical galaxies would increase the number density of galaxies per volume of space, which would allow more detailed analysis of the intrinsic cosmic web, and vastly broaden the space in which cosmic web structure elements could be detected.

The mathematical framework of the Bisous model [1], developed to estimate the filamentary pattern from observed spectroscopic galaxy data (these galaxies have precise distances in redshift space), reveals a complex network of spines. The aim of our analysis is to see whether the SDSS photometric redshift galaxies dataset [2] carries any information about the filamentary spine pattern detected by the Bisous model. We have applied summary statistics to analyse the eventual correlation between the photometrical galaxies point pattern and the filamentary spine pattern. We have also analysed whether these galaxies locate inside or close to the filamentary spines physically.

Our preliminary results show that the photometrical redshift galaxies are vital building blocks in constructing the complex filamentary pattern of the cosmic web from observational data. In addition to the filamentary web analysed in our paper the results give a basis for using the information embed in the photometrical redshift galaxies in any structure element detection model.

[1] E. Tempel, R. S. Stoica, E. Saar, V. J. Martinez, L. J. Liivamägi and G. Castellan, Detecting filamentary pattern in the cosmic web: a catalogue of filaments for the SDSS, Monthly Notices of the Royal Astronomical Society (2014), volume 438, number 4, pages 3465-3482.

[2] R. Beck, L. Dobos, T. Budavári, A. S. Szalay and I. Csabai, Photometric redshifts for the SDSS Data Release 12, Monthly Notices of the Royal Astronomical Society (2016), volume 460, number 2, pages 1371–1381, Oxford University Press

MULTICHANNEL AMPLIFIER FOR ACOUSTIC LEVITATOR

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Acoustic levitation is a versatile tool for non-contacting study of samples. It increasingly gains popularity and has found many applications [1]. Traditionally ultrasonic levitators are based on a single-axis solution where a standing wave is created between a transducer and a reflector. In recent years multichannel solutions have emerged [2,3]. When constructing an ultrasonic device featuring many transducers it is unfeasible to have multiple components to operate each of the channels. This study describes an approach to minimize the number of components needed per transducer.

Our system employs FPGAs to generate square wave signals to drive each channel. The phase and amplitude of each channel is controlled individually. The amplitude is controlled by pulse width modulation. The signals are amplified by level shifter ICs. The design makes it possible to use each transducer also as a receiver. This way the performance of the system can be monitored and adjusted during operation.

[1] G. Maconi, A. Penttilä, I. Kassamakov, M. Gritsevich, P. Helander, T. Puranen, A. Salmi, E. Hæggström, and K. Muinonen, Journal of Quantitative Spectroscopy and Radiative Transfer 204 (2018): 159-164.
[2] Y. Ochiai, T. Hoshi, and J. Rekimoto, PloS one 9, no. 5 (2014): e97590.
[3] A. Marzo, S.A. Seah, B.W. Drinkwater, D.R. Sahoo, B. Long, and S. Subramanian, Nature communications 6 (2015): 8661.

COULOMB DRAG FOR SPACECRAFT PROPULSION: ELECTRIC SAIL AND PLASMA BRAKE

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Coulomb drag is electrostatic friction arising from an interaction between an electrically charged object and charged particles of a streaming plasma. It has resently been identified as an inexhaustible source of momentum for spacecraft propulsion. There are two applications, electric solar wind sail and plasma brake that both apply long lightweight tethers that are charged to high positive or negative voltages. The E-sail has potential to unprecedented speeds and travel times in interplanetary transportation. The plasma brake is a lightweight device for propellantless deorbiting of low Earth orbit spacecraft and space debris. An overview of the status and near-future prospects of these applications is given including the following: Coulomb drag science and nano satellite test missions of FORESAIL (Finnish Center of Excellence in Research of Sustainable Space) and ESTCube (Estonian student satellite program); E-sail dynamics; technology development and mission analysis; and plasma brake space debris projects.

P2

HIGHER ORDER FLOW CORRELATIONS AND THEIR NON-LINEAR MODES IN Pb–Pb COLLISIONS AT $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV WITH ALICE

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Several observables, like the symmetric cumulants and the event-plane correlations, have been constructed to study details of collective flow in heavy ion collisions. One of the primary goals in these studies has been a better understanding of the transport properties of the quark-gluon plasma (QGP), like temperature dependence of shear viscosity to entropy ratio, η/s. The higher order anisotropic flow coefficients (n > 3) can be understood to be superpositions of linear and non-linear responses to the initial anisotropies. Thus the non-linear response makes the higher order coefficients correlated with lower order harmonics [1, 2]. The different sensitivities to the initial conditions and to the temperature dependence of η/s of the medium make these observables better constraints for the hydrodynamical models [3, 4].

The symmetric cumulants, the flow modes of the response and a number of non-linear flow mode coefficients have already been measured in Pb–Pb at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$ by ALICE collaboration [3, 4, 5]. However, only harmonics up to the fifth order have been measured with a good precision, leaving the highly η/s sensitive higher orders predicted in [2] uninvestigated.

In this talk, we present the measurement of the symmetric cumulants, event-plane correlations and the non-linear coefficients in Pb–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$. Following the acquisition of significantly improved statistics, we extend the measurements up to the eight harmonic order, while also improving the precision for the observables already measured. The results will be compared to the low energy measurements and calculations from hydrodynamic models.

[1] D.Teaney, L Yan Phys.Rev. **C86** 044908 (2012)
[2] Li Yan, J.-Y. Ollitrault, *Phys.Lett.B* **744** 82-87 (2015) arXiv:1502.025021
[3] [ALICE Collaboration], *Phys.Rev.Lett.* **117** 182301 (2016)
[4] [ALICE Collaboration], arXiv:1709.01127
[5] [ALICE Collaboration], *Phys.Lett.B* **773** 68 (2017) arXiv:1705.04377

DISCOVERY OF THE NEW ISOTOPES ^{169}AU, ^{170}HG AND ^{165}PT AND A NEW ISOMER OF ^{165}IR USING THE MARA MASS SEPARATOR IN ITS FIRST TRAILBLAZING EXPERIMENT

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Measurements of proton decay from nuclei near or beyond the proton dripline have been widely used in recent works to shed light on otherwise inaccessible nuclear structure information, such as mother and daughter state spin assignments. There is a high sensitivity relationship between the proton decay energy (Q_P) and the partial proton decay half-life, and measurements of these quantities in potentially observable candidates can be used to determine spectroscopic factors, which allow testing of theoretical models. As such, many exotic proton emitters need to be measured. Using the new vacuum mode mass separator MARA in its maiden experiment, a 378 MeV ^{78}Kr beam was incident on ^{92}Mo and 96Ru targets. This produced compound nuclei ^{170}Pt* and ^{174}Hg* and MARA was tuned to collect mass 165 and 169 (as well as neighbours) respectively. Using the BB17 DSSD as part of the MARA-FP system, recoil decay tagging and a new novel trace readout analysis technique were used to identify fusion evaporated recoils and subsequent decays. Proton emission was observed from the new isotope ^{169}Au and from the ground state of ^{165}Ir, as well as alpha emission from the new isotopes ^{165}Pt and ^{170}Hg. Decay particle energies and half-lives were measured, and spectroscopic factor and hindrance factor calculations allowed assignment of spin among other interesting quantities.

EXPERIMENTAL STUDIES IN THE VICINITY OF ^{78}NI AT JYFLTRAP

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Recent sensitivity studies have shown the predominant role of neutron-rich nuclei situated near the N=50 closed neutron shell in core-collapse supernovae [1]. An important part of the dynamics of the collapse is driven by electron-captures on neutron-rich nuclei [2]. In order to improve the description of the electron-capture rates, and consequently, to reliably calculate the composition of the matter in the collapsing core, precise values of nuclear binding energies in the vicinity of ^{78}Ni are needed. These nuclei are close to the N=50 shell closure for which the present theoretical models are not in accordance with each other when approaching the magic proton number Z=28. Precise mass values allow to constrain theoretical models and to understand the nuclear structure in the ^{78}Ni region [3].

The double Penning trap mass-spectrometer JYFLTRAP [4] has been successfully used to measure atomic masses of neutron-rich Fe, Co, Ni, Cu, and Zn isotopes with a typical precision of a few keV/c². The ions of interest were produced by proton-induced fission on a natural uranium target at IGISOL [5]. The time-of-flight ion cyclotron resonance technique [6] has been utilized to measure masses for a total of 11 nuclides among which five masses have been experimentally determined for the first time. In addition, the novel phase-imaging ion cyclotron resonance technique [7] was used to identify the first isomeric state of ^{76}Cu. In this contribution, the experimental method and the preliminary results from JYFLTRAP will be discussed.

[1] C. Sullivan *et al*., Astrophys. J. 816 (2016) 44.
[2] K. Langanke *et al*., Nucl. Phys. A 928 (2014) 305–312.
[3] M.-G. Porquet and O.Sorlin, Phys. Rev C 85 (2012) 014307.
[4] T. Eronen *et al*., Eur. Phys. J. A 48 (2012) 46.
[5] I.D. Moore *et al*., Nucl. Instrum. and Methods Phys. Res. B 317 (2013) 208.
[6] M. König *et al*., Int. J. Mass Spectrom. Ion Process. 142 (1995) 95.
[7] S. Eliseev *et al*., Appl. Phys. B 114 (2014) 107.

P7

MODULATION TRANSFER FUNCTION OF CLINICAL BRAIN 3D-FLAIR SEQUENCE

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Purpose

Typically, image quality in magnetic resonance imaging is evaluated either quantitatively from quality control (QC) phantom images or subjective observer based evaluation of clinical images. However, the phantom-based quality measurements may not fully represent the quality of actual clinical images.

An important image quality metrics among image noise and contrast is spatial resolution. In medical imaging, spatial resolution is often characterized by the modulation transfer function (MTF) at a known boundary. It describes the image contrast content at different spatial frequencies. We have developed a method to characterize image resolution by measuring MTF directly from clinical brain volumes obtained with 3D-FLAIR sequence.

Materials and Methods

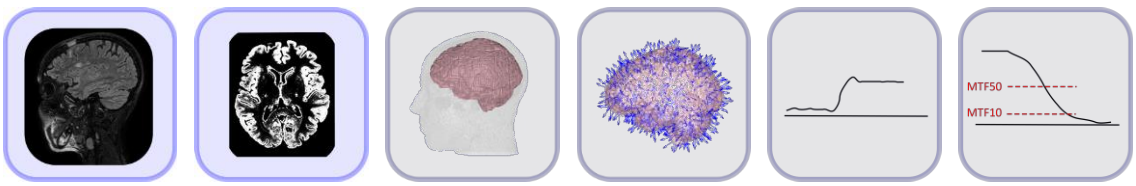
Edge profiles are extracted from a brain surface and used to calculate direction-dependent MTFs. First, the original 3D-FLAIR volume is segmented using Statistical Parameter Mapping (SPM) application. A mesh grid is fitted onto the mask volume using MATLAB-based open source toolbox iso2mesh. A typical brain surface grid includes from 60 000 to 90 000 triangular polygons. Voxel gray values and distances from the grid are recorded within cylindrical volumes perpendicular to each polygon face and intersecting the polygon center. Each resulting edge spread function (ESF) is filtered according to predetermined acceptance criteria and the accepted ESFs are centered on the detected edge. Resulting ESFs are averaged, differentiated and Fourier transformed to obtain direction-dependent MTFs.

Results

The developed method was able to determine brain surface direction-dependent MTFs from clinical 3D-FLAIR volumes. Resolution trend curves were calculated over a period of nine months.

Conclusion

The developed method provides a quantitative tool for measuring MTF directly from clinical 3D brain images. This measure could be applied in QC, protocol optimization or evaluating and comparing scanners or sequences. The method can also be applied on-line for continuous QC to detect technical or patient related issues.



ON THE DOSE-AREA PRODUCT FOR SMALL-FIELD RADIOTHERAPY DOSIMETRY

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The use of traditional beam quality identifier such as tissue-phantom-ratio $TPR_{20,10}$ in external small-field radiotherapy (RT) has many challenges. Beam diameters of less than 20 mm exhibit a loss of lateral electron equilibrium consequently increasing the detector induced perturbations [1]. The positioning accuracy of a point-like detector also reduces with decreasing field size. To overcome these challenges, a new beam quality identifier i.e. dose-area product ratio $DAPR_{20,10}$ was studied. It consists of a ratio of the dose-area products (DAP) at 20 and 10 cm depths in water. Thus, this is a transition from a point-dose measurement to a dose-area measurement, where the ionization chamber diameter is larger than the beam diameter.

The $DAPR_{20,10}$ values of cone, MLC and jaw collimated 6 MV photon beams from 4 to 40 mm in diameter were determined with measurements and calculations by Monte Carlo (MC) method. Two large-area plane parallel chambers (LAC) with measuring radii of 19.8 and 40.8 mm were used to measure the $DAPR_{20,10}$. Varian iX and Truebeam linear accelerators were modelled with the *BEAMnrc* MC user code from *EGSnrc* MC software package and the absorbed dose in water slabs and in two LACs in water phantom was calculated with the user code *egs_chamber* [2]. In addition, DAPR properties of a pencil beam were studied with MC calculations.

Measurements revealed increase in $DAPR_{20,10}$ with increasing size of LAC. Contrary to previous data, the $DAPR_{20,10}$ values were found to be field size dependent for 4-20 mm circular cone beams with a relative increase of 7.0% [3, 4]. Dissimilar results are due to different collimation and scatter. This is verified by MC pencil beam model without collimator scatter. MLC shaped fields of similar beam area showed larger $DAPR_{20,10}$ values compared to cone-beams. The $DAPR_{20,10}$ measurement was found to be straightforward, thus encouraging further investigations in transition from $TPR_{20,10}$ point-dose to $DAPR_{20,10}$ dose-area measurements to overcome the detector and beam positioning uncertainties in small-field RT.

[1] I. Das, G. Ding, A. Ahnesjö, Med. Phys. 35 (2008) 206–215.
[2] J. Ojala, Doctoral dissertation, Tampere University of Technology (2014).
[3] S. Dufreneix et al, Phys. Med. Biol. 61 (2016) 650–662.
[4] M. Pimpinella et al, Physica Medica 45 (2018) 106-116.

FINNISH COMPACT LIGHT SOURCE FOR MATERIALS SCIENCE, BIOLOGY AND MEDICINE: PLANS AND OPPORTUNITIES

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Compact light sources (CLS), also colloquially called table-top synchrotrons, are a new technological development that promises the production of highly brilliant X-rays from a device that fits into a typical laboratory. The X-ray brilliance is several orders of magnitude higher than with X-ray tubes, and has even promise of reaching that of a modest bending magnet at a synchrotron radiation source [1]. Currently a few CLSs are operational around the world, and developments are ongoing to utilize them in various fields, including materials science and X-ray imaging. For materials science the CLS promises to allow experiments that are not feasible with the present lab sources (due to low intensity) nor practical with the synchrotrons (due to difficult access), for example when measuring small signals from samples that have to be kept in a custom sample environment (such as diffraction from a thin film during its growth). For medical imaging advanced modalities such as X-ray phase contrast imaging and K-edge subtraction become possible giving access to lower dose and more quantitative imaging. Industrial applications are also possible for example in high resolution 3D imaging of materials under realistic in situ conditions, or applications in extreme ultraviolet and x-ray lithography.

We are proceeding to organize all interested parties in Finland to support such a project in order to make a CLS available to Finnish researchers, educators, and the industry. A joint meeting of the divisions of accelerator physics, synchrotron radiation, and medical physics, during in this conference, will also discuss the project. We invite you discuss the project and to become part of the network of interested scientist who want to see CLS as part of the Finnish research infrastructure.

[1] E. Eggl, et al. J Synchrotron Radiat. 2016 (**23**), 1137-42

STROBOSCOPIC TIME RESOLVED SCHLIEREN VISUALIZATION OF 220 KHZ ULTRAROUND IN AIR

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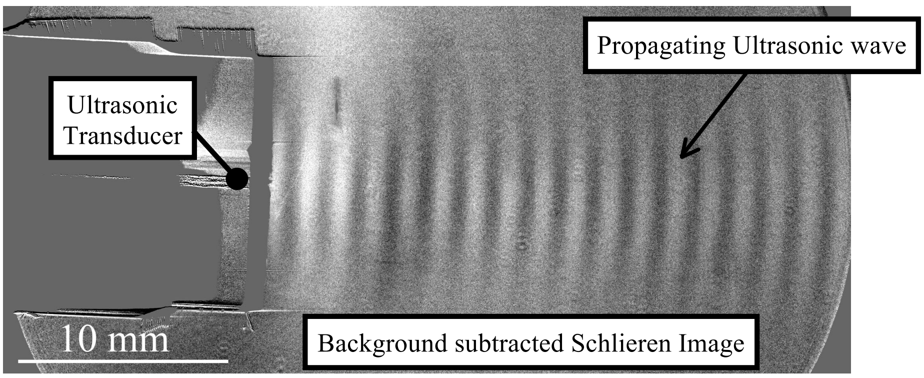
There are only a few reported attempts to visualize non-shockwave ultrasound in air [1], since it is challenging to couple ultrasound into air. High-speed methods are required to visualize ultrasound, except for standing wave situations such as those in ultrasonic levitators. Combining high-speed photography with Schlieren methods is not new [2], but enabling photography of high speed phenomena with conventional cameras to produce video material of airborne ultrasound has not been done before.

A straight Schlieren setup adjusted for extreme deflection sensitivity with two lenses (*f* = 200 mm) and a pulsed [3] LED (LZ1-00G102), combined with a commercial digital single-lens reflex (DSLR) camera (EOS 5D, Canon) and objective (EF 135 mm f/2L USM, Canon) was used to stroboscopically acquire a series of images of 220 kHz ultrasound propagating in air. The ultrasonic signal was created using a two-channel signal generator (AFG 3252, Tektronix). A LM3886TF (Texas Instruments) based amplifier module was used to in combination with a ferrite core transformer to drive an ultrasonic transducer. The signal generator also provided the stroboscopic pulses (FWHM < 100 ns) used for imaging. A video is created by taking several consecutive photographs of the ultrasound, while incrementing the relative delay between the stroboscopic and ultrasonic signals. Background subtraction and linear contrast stretching is used to make even weak ultrasonic waves visible.

We present a stroboscopic method for photographing ultrasound in air with conventional equipment. This allows us to synthetize high-speed videos of both ultrasonic bursts and continuous wave situations from stroboscopic photographs of such phenomena.



[1] J. A. Bucaro and H. D. Dardy, "Visualization of ultrasonic waves in air," *J. Acoust. Soc. Am.*, vol. 62, no. 6, p. 1506, Aug. 1977.
[2] G. S. Settles, *Schlieren and Shadowgraph Techniques*. Springer-Verlag, 2001.
[3] T. Paulin, V. Heikkinen, I. Kassamakov, and E. Hæggström, "LED driver for stroboscopic interferometry," in *SPIE Photonics Europe*, 2012, vol. 358, no. 1, p. 84301A–84301A–7.

P8

AUTOMATIC FOCUSING OF LASER BEAM ONTO SPHERICAL SURFACE

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Ability to focus is important in an instrument featuring laser optics. Algorithms solve focusing issues in e.g. CD-players [1]. These algorithms are usually optimized for flat reflectors [1]. We introduce a system that focuses a beam reflected from a spherical surface. Our algorithm determines the direction of the offset along each axis (Fig. 1a) by comparing the signals from a multi-part detector. The required beam movements are executed with a lens controlled by two coils (z- and y-axes) and a stepper motor (x-axis) (Fig. 1a). To define focus, threshold values were set for the magnitude of the difference along each axis and the total amount of light received. The system was tested with different values for these thresholds while comparing the speed of the algorithm to manual operation. The strictest thresholds were such that the accuracy of the stepper motor and the coils were the limiting factors. With these thresholds our method reached focus in 10,4 ± 0,3 seconds. In contrast, focus was reached in 34,0 ± 5,5 seconds by an expert operator. A typical focusing exercise is shown on Fig. 1b. Our approach works reliably with stationary targets and shows potential to be applicable to moving targets.

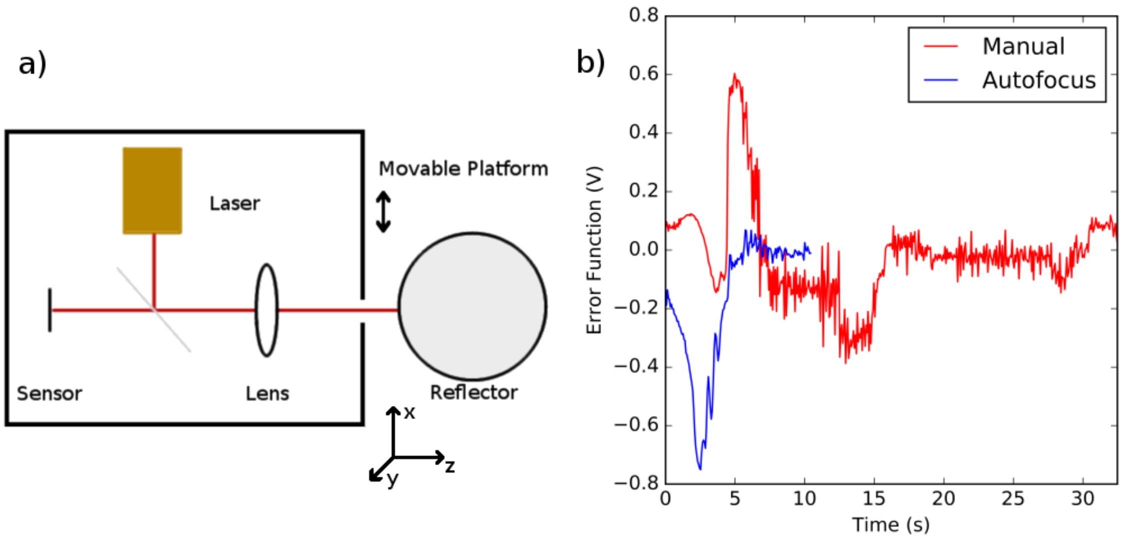

Figure 1: *a) Simplified schematic of the system. b) Comparison between two focusing runs.*

[1] D. Ulloth, Communication Technology: A Survey, University Press of America (1992).

NON-CONTACTING DAMAGE DETECTION IN STEEL HEMISPHERES BY DIRECTED LAMB WAVES.

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Laser-generated and laser-detected Lamb waves permit non-destructive evaluation in a non-contacting manner in industrial settings. Most relevant research has focused on simple geometries: plates and cylinders/pipes [1]. Curved geometries with multiple geodesic paths have not been studied as extensively. In traditional laser ultrasonics, a point source excites waves equally into all directions from the excitation point. On spheres this results in “infinitely many paths” between RX and TX along the great circles. Directed waves in hemispherical samples can improve the imaging fidelity in laser-ultrasonic measurements. The propagation paths are perpendicular to the source, which minimizes interference with waves from other paths.
We employed a line source to generate a gaussian power profile with maximum power emitted perpendicular to the line. This creates a favored path that makes detection of the position of possible defects easier. We performed tomographic experiments on a 25mm diameter steel hemisphere. The device comprised an Nd:YAG laser for excitation (λ=1064 nm, E=28 mJ), and an LDV for pickup. Our results show easier detection of a defect on the sample with a directed source compared to a point source. This is seen as a narrower diffraction pattern at 180 degrees caused by a 4 mm circular defect on the sample. (Fig.1)

[1] Victor V. Kozhushko, Peter Hess, Laser-Ultrasonics: From the Laboratory to Industry, 2008

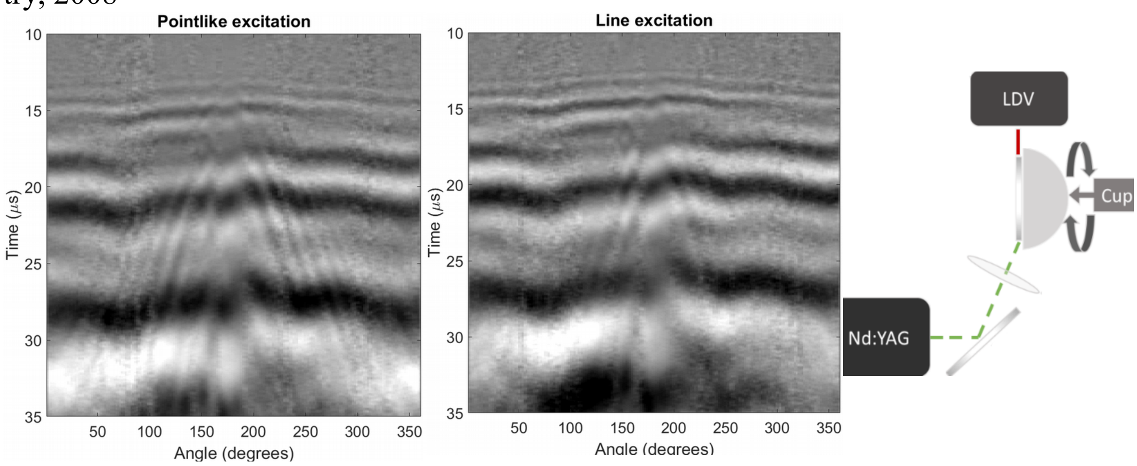

Figure 1. Comparison of point and line excitation with RX/TX from brim to brim on a hemisphere, and a schematic of the experiment.

QUANTIFYING ACOUSTIC POWER TRANSMITTED IN A CYLINDRICAL LAYERED STRUCTURE

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High-power low-frequency (20-50 kHz) ultrasound has a number of applications on various fields of the industry, such as cleaning, processing and degassing. A novel approach under development feature clamping of ultrasonic transducers and delivery of ultrasound directly in the process industry devices, such as fluid-filled steel vessels. In this work we focus on understanding how acoustic power is delivered from the transducer to the solid wall and fluid. The impact of the transducer head diameter is investigated.

An industrial vessel is mimicked by a water-filled 300 mm steel pipe with a 5 mm thick wall (Fig. 1) . A high power 20 kHz ultrasonic stack transducer, dry-coupled, was used to actuate the vessel by using a tone pulse. A Laser Doppler Vibrometer (LDV) was used to record the displacement on the vessel wall and a hydrophone was used to record the acoustic pressure in the fluid. Moreover, two-dimensional time-dependent finite element simulations (FEM) were used to predict the experiments.

In a FEM simulation (Fig. 2), a 80 mm transducer head resulted a direct acoustic pressure wave (1500 m/s) which interfered with an A0 Lamb mode (900 m/s) that leaks from the wall. The results show that one can adjust the power ratio between the direct wave packet and leaky wave packets by adjusting the diameter of the transducer head: a larger head improved power transmission to the fluid. The experiments were in agreement with simulated predictions showing that the directivity of the acoustic field into the fluid is increased with increasing the transducer head diameter.

These results are valuable for understanding one of the major challenges with the proposed ultrasonic approach and permit development of new related technologies to meet the increasing call of the process industry.

Fig 1. Experimental setup

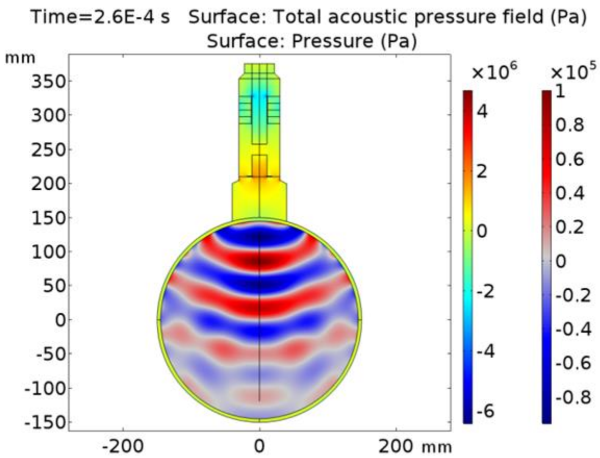

Fig 2. . FEM simulation

POSITRON ANNIHILATION SPERCTROSCOPY MEASUREMENTS ON Ge(Sn):P, AND UNDOPED Ge(Sn) SAMPLES

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The positron annihilation spectroscopy (PAS) technique is based on detecting the radiation created by annihilating positron-electron pairs. The main advantages of this technique are: the identification of vacancy type defects is straightforward, the technique is strongly supported by theory and it can be applied to bulk crystals and thin layers of any electrical conduction type. Positrons are able to get trapped in neutral or negative vacancy type defects. PAS gives microscopic information about vacancy defects such as size, concentration, charge state, and chemical surroundings of vacancies. [1, 2]

The main idea is to use Doppler Broadening Spectroscopy with a positron beam. Doppler Broadening is often monitored as a function of the positron implantation energy. The high momentum part of the Doppler broadening spectrum arises from annihilations with the core electrons which can reveal the nature of the atoms in the region where the positron annihilates. The fraction of positron annihilating with high momentum electrons is described by the high-electron momentum parameter *W*. The low-momentum parameter *S* is the valence electron contribution to the positron annihilation. [1, 2]

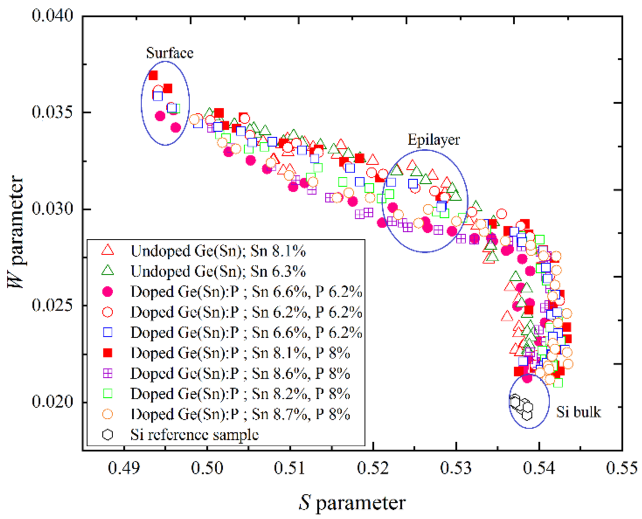

Figure 1: *W* vs *S* plots for different undoped and doped samples.

Epilayers with thicknesses of 75-90 nm were prepared using CVD with precursor gases GeH_4, $SnCl_4$, and PH_3. Both undoped Ge(Sn) samples and doped Ge(Sn):P samples with various Sn concentration, and P concentration were studied. The PAS technique has previously been used to understand the defect structure in similar epitaxial Si:P layers. Phosphorus-vacancy complexes were found to be the dominating vacancy defect responsible for the charge carrier compensation. [3] Figure 1 shows the *W* vs *S* plots for different doped and undoped samples. Clear differences in *S*-*W* behavior is seen in the epilayers. Differences in the slopes of *W* vs *S* plots between the surface and the epilayer indicate that the epilayer composition plays an important role in the defect structure. Further experiments will be performed in order to identify the defect structures.

[1] K. Saarinen, P. Hautojärvi, and C. Corbel, Identification of Defects in Semiconductors (Academic Press, San Diego, 1998), Vol. 51A, p. 209, ISBN: 978-0-12-752159-6, pp. 1-2; 17-20.

[2] F. Tuomisto and I. Makkonen, Rev. Mod. Phys. 85.1583 (2013).

[3] S. K. Dhayalan, J. Kujala, J. Slotte, G. Pourtois, E. Simonen, E. Rosseel, A. Hikavyy, Y. Shimura, S. lacavo, A. Stesmans, R. Loo, and W. Vandervorst, Appl. Phys. Lett. 108, 082106 (2016).

DISCOVERING THE INVISIBLE - ANALYSING WORKS OF ART BY SCIENTIFIC METHODS

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"*Seeing the invisible*" is something that is not only needed but also searched for, when valuable works of arts are to be authenticated or studied for additional information.

Recenart company, a recent spin-off from the University of Jyväskylä has gained recognition in the art market because of its interdisciplinary research methods [1]. In this non-conventional field, arts, for the physicists and other natural scientists, many different complementary scientific methods are needed to discover fakes and forgeries from the 51 Billion Eur annual art market [2].

Interdisciplinary research is profoundly required in this field to cover not only art and cultural sciences but also physics, chemistry and information technology when detailed information is required to authenticate works of art. Natural scientists very often cannot differ Rembrandt from Da Vinci by bare eye, but materials studied by elemental analysis, chemical analysis and imaging in different conditions can often tell the difference instantly (see Fig. 1).

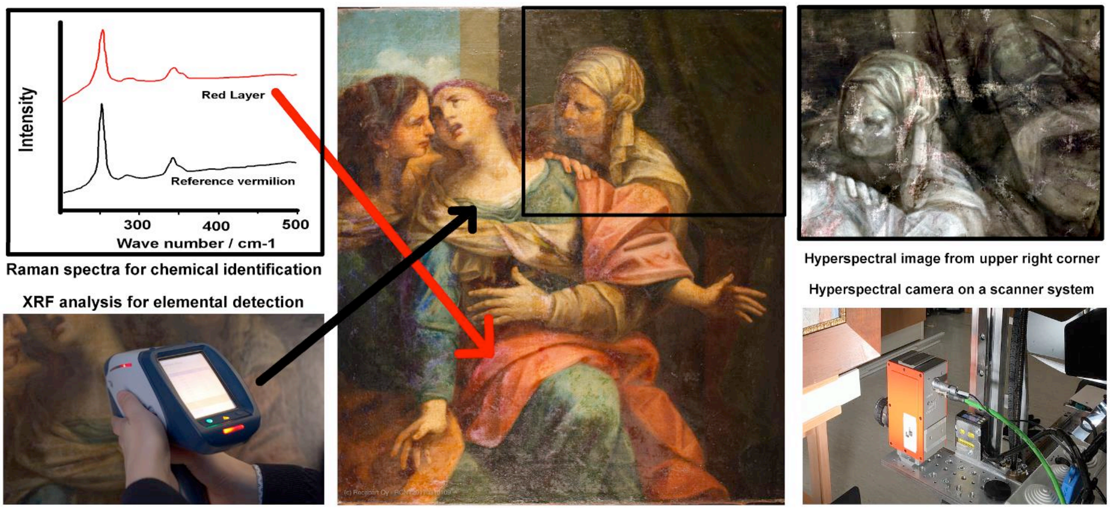

Figure 1. Example methods to obtain complementary information from the artwork.

In this talk example cases of "*how to see the invisible*" are discussed by means of elemental analysis done by XRF and PIXE, Raman spectroscopy and UV, IR and hyperspectral imaging. Examples of authentic and forged art discoveries are also presented.

[1] Few reference links:
http://yle.fi/uutiset/3-9208171 ;
http://yle.fi/aihe/artikkeli/2016/03/27/prisma-studiotaidevaarennos-karaytetaan-hiukkaskiihdyttimella ;
http://www.bbc.com/news/entertainment-arts-32048290 ;
https://news.artnet.com/art-world/biggest-art-discoveries-of-2015-392231#.VoqjX4c82s9
[2] TEFAF art market report 2015 (www.tefaf.com).

THE ORIGIN AND EFFECTS OF VACUUM BREAKDOWNS ON COPPER ELECTRODES

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Breakdowns – or vacuum arc discharges – are the main limiting factor for the high-gradient performance of future particle accelerator designs, especially the Compact Linear Collider (CLIC) which is being designed in CERN. They are also studied because of their relevance in the fields such as vacuum insulation and vacuum circuit breakers [1].

Understanding the microscopical phenomena behind the breakdown generation is crucial in being able to decrease the breakdown rate thus improving the efficiency of the applications.

Statistical properties of the breakdowns are studied using a Large Electrode DC Spark System, where copper electrodes, separated by a 60 μm gap, are placed in vacuum. Electric field up to 80 MV/m is pulsed across the gap, resulting in breakdowns. Statistics of the breakdown events are collected, analyzed and compared to the breakdown-induced features on the electrode surface.

The results show the dependence of the breakdowns on multiple variables, such as electric field, pulse length and pulsing frequency. There is also remarkable deviation in breakdown currents. In addition, various surface imaging and analysis techniques show the physical and chemical features on the electrode surfaces that affect the breakdown generation.

[1] W. Wuench, et al, Statistics of vacuum breakdown in the high-gradient and low-rate regime (2017).

Parallel sessions III

P1

MEASUREMENTS OF ENERGETIC ELECTRONS AND PROTONS ABOARD A CUBESAT ON LOW EARTH ORBIT: AALTO-1 / RADMON

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Aalto-1 [1], a three-unit CubeSat launched to Sun-synchronous Low Earth Orbit on 23 June 2017, is Finland's first satellite in orbit. It carries a payload consisting of three state of the art instruments: a hyper-spectral camera, a Plasma Brake for deorbiting demonstration, and a radiation monitor (RADMON) [2] measuring the charged particle radiation in orbit. RADMON is sensitive to >10 MeV protons and >2 MeV electrons. As Aalto-1 spacecraft is still in a tumbling mode, RADMON is rapidly scanning directions in the sky allowing one to generate an omnidirectional (direction-averaged) flux measurement from the counting rates of the detector.

We will present an overview of the first months of RADMON measurements in space. In addition to stably trapped electrons and protons in the Earth's radiation belts, RADMON observes quasi-trapped electron populations, which have been scattered to the drift loss cone and are en route to be precipitated in the atmosphere. In the first half of September, RADMON also observed a solar proton event, which was among the strongest ones in the present solar activity cycle and led to several space weather effects in orbit, including spontaneous reboots of the on-board computer of Aalto-1. During the late phase of the solar event, RADMON also observed a relativistic electron precipitation event, where the disturbed magnetospheric conditions led to loss of trapped electrons to the atmosphere.

Acknowledgements. Aalto-1 and RADMON are an effort of a large number of students in Aalto University, University of Turku and University of Helsinki. The work of Aalto-1 and RADMON teams is gratefully acknowledged.

[1] A. Kestilä, T. Tikka, P. Peitso, J. Rantanen, A. Näsilä, K. Nordling, H. Saari, R. Vainio, P. Janhunen, J. Praks, and M. Hallikainen, Geoscientific Instrumentation, Methods and Data Systems, 2 (2013) 121.
[2] J. Peltonen, H-P. Hedman, A. Ilmanen, M. Lindroos, M. Määttänen, J. Pesonen, R. Punkkinen, A. Punkkinen, R. Vainio, E. Valtonen, T. Säntti, J. Pentikäinen, and E. Hæggström, Proc. 10th European Workshop on Microelectronics Education (EWME), Tallinn, Estonia, 2014, p. 161. doi:10.1109/EWME.2014.6877418.

SEEING THE INVISIBLE - MEASUREMENTS OF THE BASIC PROPERTIES OF THE IONOSPHERE

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Sodankylä Geophysical Observatory (SGO) has been conducting geophysical measurements over a century [1]. Early measurements were focused on earths magnetic field but towards the present day, observations of the near space and upper atmosphere have grown to be increasingly important tasks. From the currently running experiments ionosonde [2] and meteor radar [3] are good examples how properties hidden from the naked eye can be measured. In both cases the main field of study is the ionosphere, the region of atmosphere above 80 km.

The main information retrieved from ionosonde measurements is the free electron density, a detail deeded for models describing ion chemistry of upper atmosphere [4]. System is basically a vertically oriented radar, a radio frequency pulse is send directly upward and the properties of the upper atmosphere are deduced from the mirrored signal.

Meteor radar relies on the same basic principle but is used to detect the radar signature of the meteor trails. Properties like altitude, Doppler velocity and trail decay time can be deduced from the meteor radar data and can be used, for example, to define the temperature of the ionosphere immediately around the meteor trail.

These devices have formed a technological base for developing the EISCAT-radar system (EUROPEAN INCOHERENT SCATTER ASSOCIATION) which started operations at the early 80's [5]. EISCAT association operates a transceiver in Tromsø (Norway) and receivers in Kiruna (Sweden), Longyearbyen (Svalbard) and Sodankylä (Finland). Furthermore, based on the experience gathered with EISCAT radar network, a new radar network called EISCAT_3D is being constructed [6]. In the presentation an introduction to the basic principles behind ionospheric measurements is given along with an outlook of the current projects and description how modern radar networks can be used for near earth space studies.

[1] H. Nevalinna, Sodankylän geofysiikan observatorio 1913-2013 - sata vuotta havaintoja ja tutkimusta (2017) .
[2] W.R. Piggott and K. Rawer, URSI Handbook of Ionogram Interpretation and Reduction, second Edition, November 1972 WDC A, Report UAG-23. April 1993.
[3] Manufacturer's description, Genesis Software Pty Ltd, 2009.
[4] Turunen, E. et al, Mesospheric ozone destruction by high-energy electron precipitation associated with pulsating aurora, J. Geophys. Res. Atmos., 121, 11852-11861.
[5] EISCAT Scientific Association, EISCAT web-page.
[6] EISCAT Scientific Association, EISCAT_3D web-page.

CASE STUDY OF EUHFORIA EMPLOYING IN-SITU OBSERVATIONS OF CORONAL MASS EJECTION ENCOUNTERED BY MULTIPLE SPACECRAFT

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Being one of the main contributors to space weather, Coronal Mass Ejections (CMEs) have been the focal point of many studies aiming to understand every aspect of them, from their origin to their effects on modern technological systems on space and on ground. Particular interest is given to Earth directed CMEs, and especially in determining whether they will affect Earth. These CMEs, also known as geo-effective, carry a strong and persistent southward oriented north-south interplanetary magnetic field (IMF) component, that can reconnect to the northward terrestrial magnetic field and penetrate deeper in the Earth's atmosphere. It is thus important, for predicting their geo-effectiveness to be able to predict the evolution of their internal magnetic field configuration as they propagate through the interplanetary space. With the ever-growing space exploration and the interest in studying the solar influence on other planets, it became important to model the interplanetary evolution and propagation of CMEs inside the 3-D heliosphere.

EUHFORIA is a data-driven physics-based model tracing the evolution of CMEs and CME-driven shocks through realistic background solar wind conditions. Recently, the capability of the model has been improved through the incorporation of a magnetic flux rope concept (spheromak) to model Interplanetary CMEs (ICMEs). To assess the efficacy of this new aspect of EUHFORIA we perform a case study and compare the EUHFORIA output to in-situ observations. We consider two well observed CMEs, having been encountered in the interplanetary space by at least two spacecraft widely separated in heliospheric longitude. We focus in particular on comparing the in-situ observations of the interplanetary magnetic field as well as solar wind plasma conditions with the model results. The analysis allows us to comprehensively evaluate the accuracy and utility of the employed flux rope modelling approach. One of the selected CME candidates is of particular interest as two of the three spacecraft that it encountered were aligned, thus providing the opportunity to assess EUHFORIA output in different helio-longitudes and helio-distances.

As a data-driven model, EUHFORIA strongly depends to the input parameters which are estimated from observations. However, different methods of determining those parameters can have a significant effect to the modelled results and thus the success of EUHFORIA. From this study we also investigate the impact of the input parameters to the model using the multi-spacecraft observations.

Imaging Shock Signatures of Coronal Mass Ejections at Radio Wavelengths

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The Sun is an active star that produces the most powerful explosions in the solar system in the form of solar flares, often accompanied by coronal mass ejections (CMEs) that drive colisionless shocks in the corona. CME shocks are efficient particle accelerators and shock signatures associated with CMEs are often observed as solar radio bursts. However, the relationship between radio shock signatures on the Sun and the expansion of a CME is still not well understood due to previous limitations of low radio frequency imaging (<150 MHz) where the most dramatic acceleration is believed to occur. Here, we exploit a unique set of observations from the Low Frequency Array (LOFAR) of a strong X8.2-class solar flare and its associated very fast CME (3000 km/s). In particular, we image for the first time a multitude of radio shock signatures called herringbones. Using multi-wavelength analysis, we provide convincing evidence for shock accelerated electrons at multiple locations on the expanding CME flank.

DATA-DRIVEN TIME-DEPENDENT MODELLING OF THE SOLAR CORONAL MAGNETIC FIELD

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Accurate modelling of the solar coronal magnetic field is of key importance for advancing our understanding of the processes governing the initiation of coronal mass ejections (CMEs) and their potential for causing severe space weather events. Currently, the most popular models employed in a data-driven event-based context are time-independent, such as the nonlinear force-free field extrapolation model. However, such modelling is limited in that inherently time-dependent effects, such as rotation, kinking or deflection of the erupting structure are not captured. Yet, these processes can significantly alter the characteristics of the ejected plasma in the interplanetary space.

Time-dependent magnetofrictional modelling offers a promising path to model the data-driven evolution of the coronal magnetic field structure and thereby advance beyond static extrapolations. The success of the method depends heavily on the realism of the boundary condition driving the model, i.e. the photospheric electric field. For this purpose we have created a toolkit for routine inversion of the electric field from time series of photospheric vector magnetic field measurements. In this work, we present an ensemble of magnetofrictional coronal simulations, driven by the electric fields computed using a collection of different inversion techniques. We illustrate the feasibility of our data-driven approach in determining the magnetic structure of an erupting CME and discuss the sensitivity of the simulation output to the properties of the data-driven boundary condition, such as the Poynting and magnetic helicity fluxes from the photosphere to the corona.

P4

BOSE–EINSTEIN CONDENSATION IN A PLASMONIC LATTICE

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We demonstrate a Bose-Einstein condensate (BEC) of surface plasmon polaritons in a lattice of gold nanoparticles [1]. Interaction of the surface plasmons with organic fluorescent molecules induces absorption, re-emission, thermalization and ultimately condensation in picosecond timescale. The dynamics are studied in an experiment that utilizes the propagation of the modes and the open cavity character of the system (Figure 1). Linewidth narrowing and increase of the spatial coherence of the mode is observed in response to onset of condensation. Transition from BEC to usual lasing [2] is observed when the periodicity of the lattice is varied. The experimental observations are supported by rate-equation simulations based on microscopic quantum model. This new form of condensate has also technological potential due to its ultrafast, room-temperature and on-chip nature.

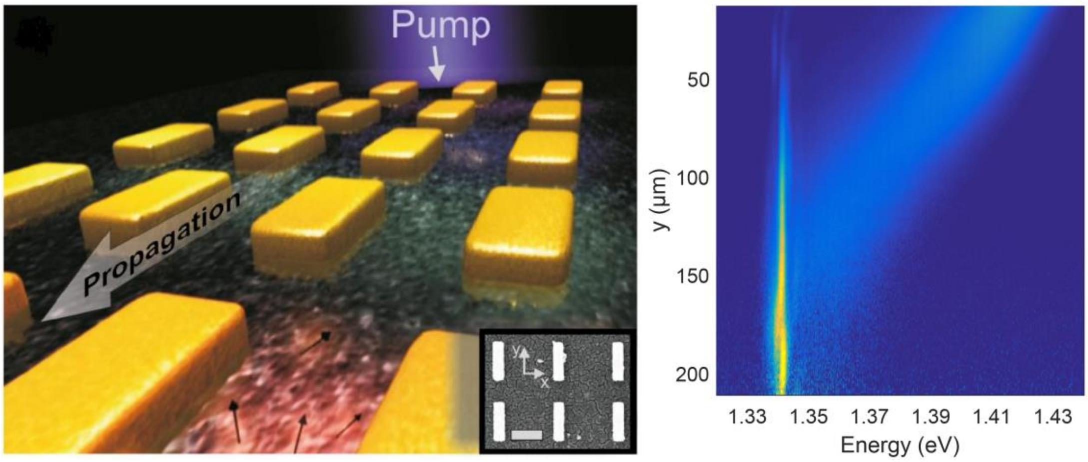

Figure 1. A schematic of the plasmonic lattice. Propagating plasmonic modes undergo a redshift and condense to the bottom of the energy band of the lattice. The inset on the left shows scanning electron micrograph of a typical sample (scale bar = 300 nm).

[1] T. Hakala, A. Moilanen, A. I. Vakevainen, R. Guo, J.-P. Martikainen, K. Daskalakis, H. Rekola, A. Julku and Päivi Törmä, arXiv:1706.01528 (submitted)

[2] T. Hakala, H. Rekola, A. I. Väkeväinen, J.-P. Martikainen, M. Necada, A. Moilanen and P. Törmä, Lasing in dark and bright modes of a finite-sized plasmonic lattice, Nature Communications 8, 13687 (2017)

Thermometry towards single-photon detection

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We are developing fast and sensitive calorimetry on low temperature nanostructures [1] with the ultimate goal of observing single microwave photons [2]. A critical element in this device is a sensitive thermometer. Here we present non-invasive electron thermometry based on charge transport through a contact between a proximitized normal metal and a superconductor via a tunnel barrier. We demonstrate experimentally the advantages of such a zero bias anomaly (ZBA) based thermometer as compared to commonly used quasi-particle (QP) one. For the sake of understanding the energy resolution of the device, we estimate theoretically temperature fluctuations of a small metallic island in the same structure [3]. By biasing an extra tunnel contact, we observe highly non-monotonous behavior of heat current and the associated fluctuations.

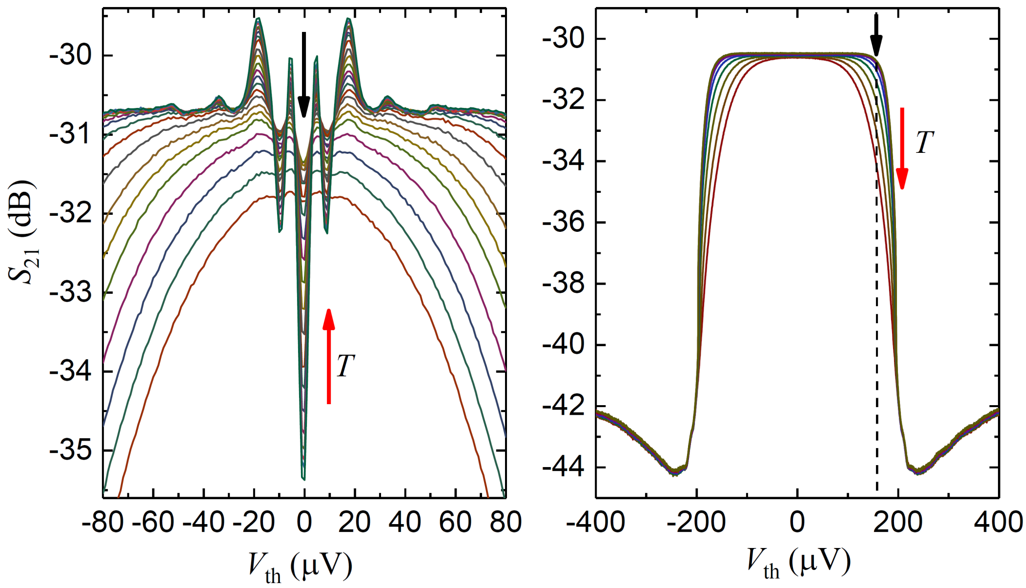

Figure 1: Radio-frequency transmission signal proportional to the negative of the differential conductance of the thermometer junction. left) ZBA that exhibits high sensitivity at low temperatures with low dissipation. right) Conventional finite bias QP thermometry that demonstrates saturation of signal towards low temperatures.

[1] S. Gasparinetti, K. L. Viisanen, O.-P. Saira, T. Faivre, M. Arzeo, M. Meschke, J. P. Pekola, Physical Review Applied **3**, 014007 (2015).
[2] J. P. Pekola, P. Solinas, A. Shnirman, and D. V. Averin, New Journal of Physics **15**, 115006 (2013).
[3] F. Brange, P. Samuelsson, B. Karimi, and J. P. Pekola, in preparation.

Scartronics: Towards controllable quantum transport through chaos

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A *quantum scar* is a striking visualization of quantum mechanical suppression of classical chaos. A scar is a track of an enhanced probability density in a quantum eigenstate. This track corresponds to a short unstable periodic orbit (PO) of the corresponding chaotic classical system [1].

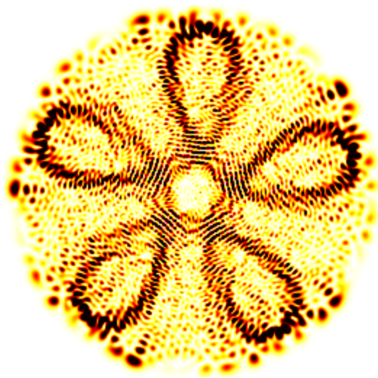

Figure 1: *Example of a skipping-like scar in a system with a perpendicular magnetic field and a harmonic confinement perturbed by local potential bumps.*

In addition to conventional quantum scars, a new type of quantum scarring [2] was recently discovered in two-dimensional (2D), radially-symmetric quantum wells perturbed by local "bumps" in the potential. In the system, some of the high-energy eigenstates are strongly scarred by short POs of the corresponding unperturbed system. These scars stem from the classical resonances in the unperturbed system and from the local nature of the perturbations.

Here, we consider these perturbation-induced (PI) scars in a 2D quantum harmonic oscillator exposed to a perpendicular, homogeneous magnetic field. This system has direct experimental relevance, since it is a prototype model for semiconductor quantum dots in the 2D electron gas. In Ref. [3], we report strong quantum scars (see Fig. 1) at specific magnetic fields. We demonstrate that the geometry and the orientation of the scars are highly controllable with a magnetic field and a focused perturbative potential, respectively [3]. Previously, it has been shown that PI scars can be employed to propagate quantum wave packets with very high fidelity [2]. Combined, these properties can be exploited in quantum transport to open up a path into "scartronics", where scars are utilized to coherently control conductance in nanoscale quantum systems. Here, we discuss our initial attempts in this direction.

[1] E. J. Heller, Phys. Rev. Lett. **53**, 1515 (1984); L. Kaplan, Nonlinearity **12**, R1 (1999).
[2] P. J. J. Luukko, B. Drury, A. Klales, L. Kaplan, E. J. Heller, and E. Räsänen, Scientific Reports **6**, 37656 (2016).
[3] J. Keski-Rahkonen, P. J. J. Luukko, L. Kaplan, E. J. Heller, E. Räsänen, Phys. Rev. B **96**, 094204 (2017).

THEORY OF ENVIRONMENT ENGINEERING FOR SUPERCONDUCTING CIRCUITS BY PHOTON-ASSISTED ELECTRON TUNNELING

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We consider a tunable broadband environment for superconducting quantum circuits. Tunable environments have applications in fast and accurate initialization of quantum devices [1] as well as in stabilizing interesting quantum states [2]. The environment here is formed by a voltage-biased superconductor–insulator–normal-metal–insulator–superconductor (SINIS) junction capacitively coupled to a superconducting resonator or qubit. When the voltage bias of the junction is below the energy gap of the superconductor, the normal-metal electron needs to receive an additional energy from the coupled electric circuit to overcome the gap, see Fig. 1. By considering these kind of photon-assisted tunneling processes, we provide a first-principles derivation of the coupling strength and temperature of the environment formed by the electron tunneling [3].

The developed model accurately describes the physics of the quantum-circuit refrigerator and the microwave absorption and emission demonstrated in Refs. [4, 5]. We are also able to capture fine details, such as tunable Lamb shift as well as multi-photon processes. Comparison with the experiments [4, 5] is excellent which verifies that our approach is valid and encourages further extension of the theory to the full spectrum of quantum devices.

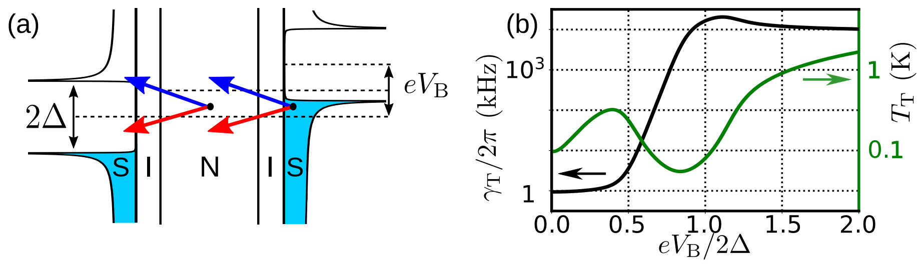

Figure 1: (a) Energy diagram of the photon-assisted tunneling in a SINIS tunnel junction. (b) Coupling strength γ_T and temperature T_T of the environment formed by the photon-assisted tunneling as a function of the two-junction voltage bias V_B.

[1] J. Tuorila *et al.*, npj Quantum Inf. 3 (2017) 27.
[2] Z. Leghtas *et al.*,Science 347 (2015) 853.
[3] M. Silveri *et al.*, Phys. Rev. B 96 (2017) 094524.
[4] K. Y. Tan *et al.*, Nat. Commun. 8 (2017) 15189.
[5] S. Masuda *et al.*, Sci. Rep. (2018) in press.

DYNAMIC POLARIZABILITIES FROM IMAGINARY-TIME QUANTUM MONTE CARLO CALCULATIONS

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Dynamic polarizability is an important quantum mechanical property with diverse physical implications, such as refractive index, long-range dispersion forces, and different kinds of nonlinear optical response. While this enables a variety of experiments, the polarizability is often studied by computer simulation. Regardless of the simulation method, it is a challenging problem in terms of numerical concerns, such as the accounts of truncated bases, dynamic correlations, and time-dependence. On the other hand, the computational approach also provides auxiliary quantities, such as tensorial or localized polarizabilities, that can be used, for example, to improve effective force-field models for molecular interactions.

In this presentation, we focus on dynamic polarizability estimation with two methods based on imaginary-time propagation: diffusion Monte Carlo (DMC) and path-integral Monte Carlo (PIMC). Using time-dependent perturbation theory, we can show the emergence of the electric field response from the multipole–multipole autocorrelation in imaginary time [1]. In particular, the dynamic polarizabilities with imaginary or real arguments can be obtained from the autocorrelation functions using Fourier or inverse Laplace transforms, respectively. The latter process is numerically unstable, hence we also demonstrate a few practical tricks to reduce statistical noise. The static polarizabilities are given in the limit of zero frequency. This transforms neatly into the case of static estimators for PIMC that have been introduced earlier [2, 3].

Finally, we look into a few small atoms and molecules, whose multipole–multipole correlation functions have been computed at finite temperatures with PIMC. The method is especially suited for obtaining novel insight to non-adiabatic effects and thermal coupling. The frequency-dependent polarizability is presented with both imaginary and real arguments: The former yields accurate van der Waals coefficients between pairs of systems. The latter is given by numerical means of analytic continuation and it yields, in principle, measurable optical properties.

[1] M. Caffarel, M. Rérat, and C. Pouchan. *Phys. Rev. A*, 47, 3704, May 1993
[2] J. Tiihonen, I. Kylänpää, and T. T. Rantala. *Phys. Rev. A*, 94, 032515, Sep 2016
[3] J. Tiihonen, I. Kylänpää, and T. T. Rantala. *J. Chem. Phys.*, 147, 204101, Nov 2017

P6

DEVELOPMENT OF (OPTO)-ACOUSTICS BASED MICROSCOPY FOR *IN VIVO* AND *IN VITRO* STUDIES OF BIOLOGICAL SYSTEMS

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The choice of a microscopy method is always a compromise between resolution and working distance. With optical super-resolution techniques it is possible to achieve resolution down-to few nanometers, but only with thin, transparent samples, such as petri dish cultured cells, fixed on a microscope cover slide. Photo-acoustic microscopy on the other hand, enables label free optical contrast imaging up to depths of several millimeters in complex biological samples, such as tissue section or animal, with sub-cellular (μm-scale) resolution.

Photo-Acoustic Microscopy (PAM) is based on "listening" the broadband ultrasonic signal that is generated by absorption of pulsed excitation light in the sample – in structures that naturally absorb light at the excitation wavelength, or that have been specifically labeled. In essence, PAM is a label-free. To control PAM image sessions there is a need for the overview image of the sample, that is difficult to obtain, due to very low optical contrast in non-labeled quasi-transparent biological samples. We propose a novel method that allows to create the overview image in PAM when working with such samples. A regular PAM microscope is used together with microscope cover glasses covered with dye with high optical absorption on the wavelength of the laser. Light absorption at the absorptive layer generates a transient ultrasound wave, that can be used for ultrasound contrast imaging, instead of optical absorption contrast, typically used in PAM. We have demonstrated the functionality our method by imaging *Drosophila* larva and zebrafish embryos – two common model organisms in biological studies, that provide very little intrinsic contrast for photo-acoustic microscopy.

In the Laboratory of Biophysics at the University of Turku photo-acoustic microscope has been build to implement both PA and photo-induced imaging. Currently, we are working on a new setup that will allow us to improve on the spatial resolution developing super-resolution approach in PAM.

METAL-IMPLANTED POROUS SILICON FOR RADIATION THERANOSTICS

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The study of targeted porous nanoparticles as drug carriers is a growing field in cancer-therapy research. The porosity of the particle enables anticancer drugs to be loaded inside the particle and its surface can be modified to include tumour targeting properties. The nanoparticles are then injected into the blood stream and through the properties of the carrier nanoparticles the anticancer drugs can be targeted to the tumour cells. Alongside anticancer drugs, the particles can also be loaded with radionuclides for diagnostics and radiotherapy. The implanted nuclides can, moreover, be chosen so that the specific radiative properties allow for both imaging and therapy at the same time. The resulting carrier particle is a theranostic (therapeutic and diagnostic) system that provides local radiotherapy, which can be observed on-line throughout the treatment by PET or SPECT imaging.

We use porous silicon (PSi) particles as carrier nanoparticles which are biocompatible, can be made biodegradable and are thus suitable for use in a living body [1-7]. To load the radioactivity into the PSi, we implant stable copper or holmium into a PSi foil through diffusion and atomic-layer deposition, respectively. The nuclei are then activated by a neutron flux in a nuclear reactor. Alternatively, we implant radioactive lanthanoids as a radioactive ion beam produced through the ISOL techniques at the ISOLDE facility in CERN.

To characterise the implantation processes, the implantation depth in the PSi structure is studied through IBA techniques. The foils are then post-processed into particles by milling. The resulting particles are incubated *in vitro* in biocompatible fluids to assess the stability of the radioactive PSi system**.** The particles can also be coated to enhance the stability. Recently we performed an initial study [8] using a model radiolanthanoid together with PSi in vivo in a mouse model of prostate carcinoma. Ours results show that the radioactive PSi system stayed intact inside the tumour over seven days after which only a slight decrease in the stability was observed.

Our recent results will be presented with our activities in studying radiometals and radiolanthanoids in a PSi carrier system for radiation theranostics.

[1] S. P. Low *et al.*, *Biomaterials*, **2009**, 30, 2873-2880
[2] T. Tanaka *et al.*, *Int. J. Pharm.*, **2010**, 402, 190-197
[3] S. Näkki *et al.*, *Acta Biomater,* **2015**, 13(Supplement C), 207-215
[4] M. A. Tölli *et al.*, *Biomaterials,* **2014**, 35, 8394-8405
[5] J.-H. Park *et al.*, *Nat. Mater.,* **2009**, 8, 331-336
[6] L. M. Bimbo *et al.*, *ACS Nano,* **2010**, 4, 3023-3032
[7] S. C. Bayliss *et al.*, *Adv. Mater.,* **1999**, 11, 318-321
[8] U. Jakobsson *et al.,* submitted

2D TO 3D MAGIC: TAKING 3D PICTURES WITH 2D MICROSCOPES

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To understand nature, we need 3D images. Still traditional 2D microscopes are common in academia and the industry. We introduce a device where one focuses onto different focus planes without using a piezo translator. Our device, fabricated using a method developed at the University of Helsinki [1], employs five steps with different heights. The steps are marked individually, and they are optically compatible with bio-samples. An image stack is taken with the focus plane placed on each step at a turn. The stack is then combined with an algorithm [2]. This enables us to reproduce 3D height maps of the imaged sample. An image of a salt crystal is shown as obtained using the 2D to 3D Magic method. The fidelity of our method is evaluated by comparing the image to one obtained with a calibrated Scanning White Light interferometer. Results show that our 2D to 3D Magic method provides images with sub 1 µm accuracy in three minutes.

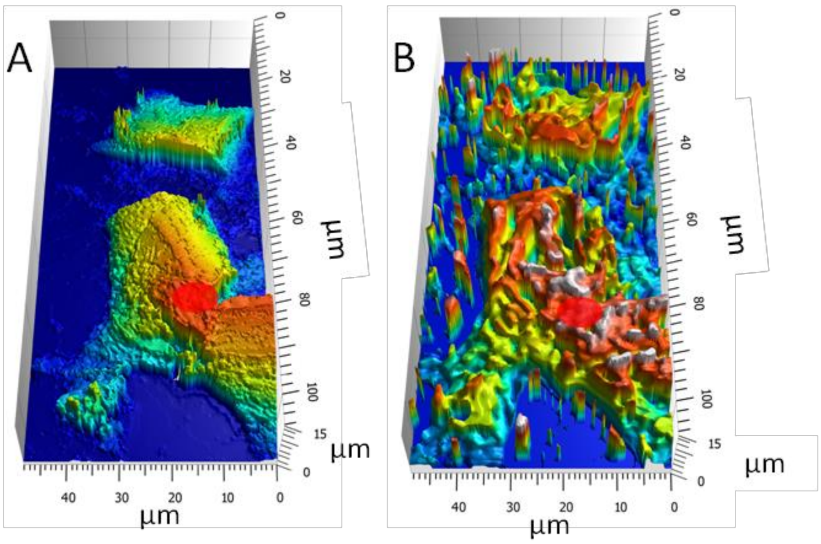

Figure 1. Comparison between the height maps of a salt crystal obtained with A) SWLI and B) the 2D to 3D magic method. The red circles represent the same area in each picture. The average height of the marked area is 10.55 µm and 11.14 µm for SWLI and 2D to 3D method, respectively.

[1] Järvinen, M., Scotti, G., Vainikka, T., Hæggström, E., & Kassamakov, I. (2017). Photomask Technology, 10451, 104511Q.
[2] Nayar, S. K., & Nakagawa, Y. (1994). IEEE Transactions on Pattern analysis and machine intelligence, 16(8), 824-831.

TESTING THE SUITABILITY OF QUANTITATIVE COHERENT ANTI-STOKES RAMAN SCATTERING (CARS) SPECTRAL IMAGING IN STUDYING PROTEIN DROPLETS

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Protein-protein interactions underlie nearly all biological functions. Many proteins that mediate DNA transcription in so-called RNA granules appear to have unique characteristics that lead to protein aggregation under certain conditions. Many of these proteins are ‘intrinsically disordered’ and undergo a liquid-liquid phase separation (forming droplets) within cells [1] and *in vitro* [2]. The presence of plaques containing these proteins is linked with many neurodegenerative disorders, including Parkinson’s, Alzheimer’s and Huntington’s disease [3]. The physico-chemical nature in these droplets is the subject of much debate as they are speculated to be precursors to proteinaceous plaques and possibly amyloid fibrils. To that end, we tested the suitability of the broadband coherent anti-Stokes Raman scattering (CARS) spectral imaging to study protein droplets for obtaining quantitative and chemically specific information. The protein structure was examined in different states of the RNA-binding protein fused in sarcoma low complexity domain (FUS LC) *in vitro*. The preliminary results show that the quantitative CARS imaging is indeed a powerful and unique tool for these studies (Fig. 1).

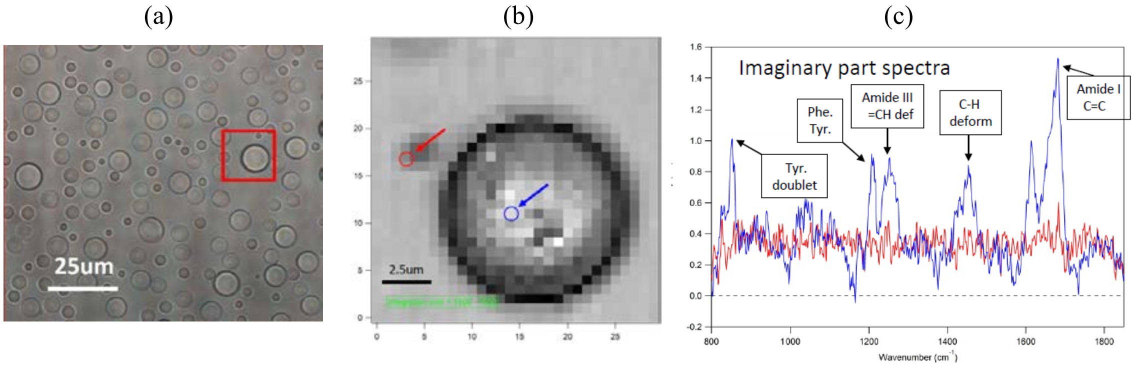

Fig 1. (a) A bright-field image of liquid-liquid phase separated protein droplets, (b) integrated CARS image, (c) the retrieved (computed) imaginary part spectra (i.e. the Raman line-shapes) inside (blue line) and outside (red line) the protein droplet.

[1] A. A. Hyman, C. A. Weber, F. Jülicher, Annu. Rev. Cell Dev. Biol. 30 (2014) 39.
[2] K. A. Burke, A. M. Janke, C. L. Rhine, N. L. Fawzi, Mol. Cell 60 (2015) 231.
[3] E. H. Koo, P. T. Lansbury and J. W. Kelly, Proc. Natl. Acad. Sci. 96 (1999) 9989.

CAN GAS-PHASE EXPERIMENTS EXPLAIN THE CHEMISTRY OF RADIOSENSITIZATION?

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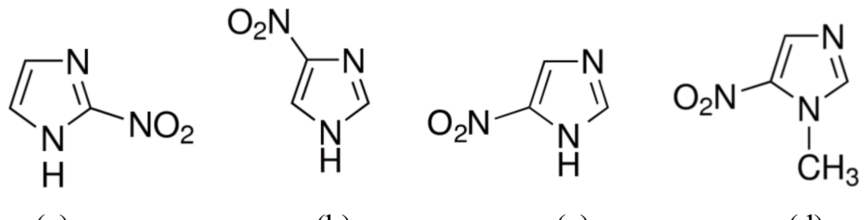
Molecular radiation damage in nitroimidazoles have recently attracted keen attention[1-4], mainly due to the clinical success in using nitroimidazoles to improve the effects of radiation therapy[5-7]. According to the oxygen fixation hypothesis,[8,9] the major contribution of the damage inflicted by ionizing radiation is caused indirectly by reactive oxygen species formed via the radiolysis of water molecules. These species form radicals when reacting with DNA. In an environment where free oxygen is present (aerobic environment), the oxygen falsely repairs the damaged DNA, making the repaired DNA function improperly. Under hypoxia, this radical formation is suppressed and DNA crosslink-repair is possible - thus the survival rate of the tumor cells is increased.

To increase the oxygenation using pure oxygen has proven to be very problematic. This has led to the development of "oxygen mimetics", compounds that match the chemical characteristics of molecular. Nitroimidazoles are one of the most common and extensively studied group of oxygen mimetics. However, despite the promising results on nitroimidazolic compounds in radiosensitization, the exact chemistry of how nitroimidazoles act as radiosensitizers is not fully understood. To study these mechanisms, we performed spectroscopic studies on several nitroimidazoles (see **Fig. 1**) in the gas phase with very interesting results.



(a) (b) (c) (d)

Figure 1. The skeletal formulas of the studied samples, 2-nitroimidazole (2-NIZ) (a), 4-nitroimidazole (4-NIZ), (b), 5-nitroimidazole (5-NIZ) (c) and 1-methyl-5-nitroimidazole (d).

[1] K. Tanzer, *et. al*, Angew. Chem. Int. Ed., 2014, 53, 12240.
[2] L. Feketeová, *et. al,* Phys. Chem. Chem. Phys., 2015, 17, 12598.
[3] L. Feketeová, *et. al,* .J. Phys. Chem. A 2015, 119, 9986-9995.
[4] P. Bolognesi, *et. al,* J. Chem. Phys. 2016, 145, 191102
[5] R. Murata, *et. al*, Radiother. Oncol. 2008, 87, 331-338.
[6] J. Overgaard, *et. al,* Int, J, Radiat, Oncol, Biol, Phys. 1989, 16, 1065-1068.
[7] J. Overgaard, *et. al,* Radiother. Oncol. 1998, 46, 135-146.
[8] P. Howard-Flanders, *et. al,* Radiat. Res. 1957, 7, 518–540.
[9] Radiobiology For The Radiologist 6th edn (E. Hall and A. Giaccia) Lippincott William and Wilkins: Philadelphia, 2006.

P8

PROPERTIES AND APPLICATIONS OF $SrTiO_3$-BASED FIELD EFFECT TRANSISTORS

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As the miniaturization of the semiconductor transistor rapidly approaches its theoretical limits, the semiconductor industry is facing a major challenge to extend information processing beyond what can be attainable by the conventional methods. A whole novel innovative combination of new devices and new processing platforms is needed. One of the main candidates as new devices is to use an insulator to 2D metal transition (IMT) at oxide surfaces.
Two-dimensional electron gas (2DEG) on the surface of $SrTiO_3$ is an excellent playground for investigating both basic physics and possible electronic applications. By modulating the carrier density, a variety of features are exhibited such as insulator-to-2DEG transition (IMT), superconductivity, ferromagnetism, and so on. Among these features, we focus on two main issues. One is the physics of IMT, and the other is its possible applications. We fabricated Field effect transistors using the surface of $SrTiO_3$ as the channel and will show that the channel conductance evolution is well explained by a percolation model with an IMT boundary of Mott-Ioffe-Regel limit h/e^2 [1]. We will also show that our devices are suitable to be basic building blocks in neuromorphic systems [2]. We will discuss which properties of the devices can be implemented, and its advantages against other similar systems.

[1] A. Schulman *et al.*, Applied Physics Letters 110, (2017) 1013502.
[2] P. Stoliar *et al.*, Technical Digest of the 2017 IEEE International Electron Devices Meeting (IEDM), (2017) 808.

Study of the GaAs-electrolyte interface in photoelectrochemical cells for solar water-splitting.

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The phenomenon of photoelectrochemical water splitting is under extensive study, due to its applications in the production and storage of solar energy in fuel form, via hydrogen production and carbon dioxide reduction. Solar water splitting, thanks to its scalability and thanks to the energy density of hydrogen fuel, has become an attractive potential solution to the global energy problem, especially in the effort of constructing tandem systems for unassisted water splitting.

To increase the efficiency of solar-to-hydrogen conversion and to improve the knowledge of the underlying phenomena, a deep understanding of the charge transfer mechanism from the electrode to the electrolyte is necessary: we present a numerical simulation based on affirmed physical models, taking however into account the interface between the semiconductor and the electrolyte, the p-n junction within the semiconductor, and the photogeneration of charge carriers. We then pair the simulation results with impedence spectroscopy and photoelectrochemical measurements to investigate the formation of charged layers at the interface, and the phenomena that hamper and prevent water-splitting from taking place.

Nanoripples production on a-Si surface under Ar irradiation

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Ion beams are frequently used in industry for composition control of different materials as well as thin film deposition. It was noticed that low- and medium- energy ions at high fluencies may produce nanoripples and quantum dots on the irradiated surfaces. The effect of displacement, erosion [1,2] and stress [3,4] induced by irradiation have been considered to be suitable explanations for the pattern formation.

In the present work we focus our attention on the study of simulated irradiation of amorphous silicon (a-Si) sample with Ar ions under different angles and different energies, taking into special consideration angles close to the grazing incidence. In this work we use two different kinds of simulations: single-ion and sequential ion simulations. The use of the former allows us to predict the ripple wavelength, and the latter, in a focused-mode, gives us the reasons of such formations, i.e. the observation of ripples when the sputtering is negligible (low-energy irradiation).

This study has been carried out with Molecular Dynamics (MD), which provides tools to measure the stress generated in the simulation cell as well as the total displacement of the particles which compound the cell. The results are subsequently analyzed in order to obtain a prediction of the ripple wavelength in the case of individual ion simulation, which can be directly compared with the experimental observations. The results extracted from the sequential impacts irradiation provide useful information about the pattern formation, especially at low-energy ion.

[1] Scott Norris, Juha Samela, Laura Bukonte, Marie Backman, Flyura Djurabekova, Kai Nordlund, Charbel S. Madi, Michael P. Brenner & Michael Aziz, Nature Communications 2, 276 (2011)

[2] A. Lopez-Cazalilla, A. Ilinov, L. Bukonte, F. Djurabekova, K. Nordlund, S. Norris & J. Perkinson, Nucl. Instr. Meth. Phys. Res. B 414, 133-140 (2018)

[3] S.A. Norris, Phys. Rev. B 85, 155325 (2012)

[4] S.A. Norris, J.C. Perkinson, M. Mokhtarzadeh, E. Anzenberg, M.J. Aziz & K.F. Ludwig, Scientific Reports 7, article no: 2016 (2017)

Sr_2FeMoO_6 based spin valves

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Semiconductor based technology struggles with physical limitations while trying to provide faster and more energy sufficient solutions. By harnessing the use of electron spin, spintronics has risen to meet this challenge. Magnetoresistance, linked to 100% spin polarization, combined with high Curie temperature of 420 K, have drawn lots of attention to Sr_2FeMoO_6 as a useful candidate for spintronic applications [1]. Research work has and continues to clear the vision and understanding of the valuable intrinsic phenomena observed in the material. In this presentation, I wish to address the goal of fabricating Sr_2FeMoO_6 based multilayer structures operating as spin valves, which are the heart of spintronic components. Some of the recent substantive advancements providing better understanding and possibilities of producing spin valves operational at room temperature are presented [2, 3].

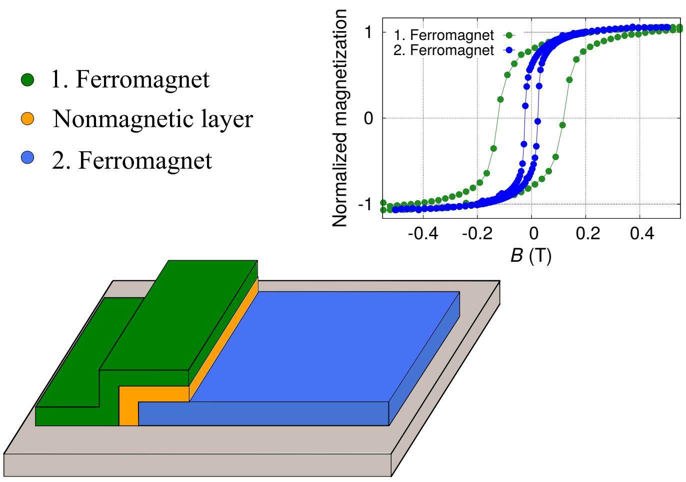

Figure 1: Schematic illustration of a possible spin valve structure, where two ferromagnets are separated by a thin layer of nonmagnetic material.

[1] K.-I. Kobayashi and T. Kimura and H. Sawada and K. Terakura and Y. Tokura, Nature **395**, 677 (1998)

[2] I. Angervo, M. Saloaro, J. Tikkanen, H. Huhtinen, P. Paturi, Appl. Surf. Sci. **396**, 754 (2017)

[3] I. Angervo, M. Saloaro, H. Huhtinen, P. Paturi, Appl. Surf. Sci. **422**, 682 (2017)

PRETREATMENT PROCEDURE OF InSb(111)B SURFACES FOR DEVICE PROCESSING

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III-V compound semiconductors are nowadays used to produce mobile-phone transistors, infrared detectors, and light-emitting diodes. Producing crystalline oxide phase at these semiconductor surface parts can decrease the structural and electrical defects between semiconductor and oxide phase.
Recently a controlled oxidation method in producing crystalline oxide phases on top of III-V(100) semiconductors has been reported [1-3] . In this method, the III-V semiconductor surfaces are oxidized in ultrahigh vacuum condition and by optimizing oxidation parameters, the crystalline oxidized phase can be produced. We used the same method to study crystalline oxide phases on InSb(111)-A and B.

Simultaneously, we investigated technologically potential methods for cleaning the InSb(111) surfaces before oxidizing. The clean surfaces were oxidized in ultrahigh vacuum condition. Optimized oxidation parameters consist of substrate temperature, oxygen pressure, and the oxidation time were found to produce crystalline oxide phases on InSb(111) surfaces.
The clean and oxidized surfaces were investigated by low energy electron diffraction (LEED), x-ray photoelectron spectroscopy (XPS), and scanning tunnelling microscopy (STM).
We concluded that pre-treatment of InSb(111) in the cleaning process, and the oxidation condition affect significantly the oxide phase formation.. At optimized condition, the crystalline oxide phase was produced while with other parameters, the amorphous oxide phase was seen or the surface was not oxidized.

[1] J.J.K. Lang et al., Phys. Rev. B 90, 045312 (2014)

[2] M. Tuominen et al., Appl. Phys. Lett. 106, 011606 (2015)

[3] M.P.J. Punkkinen et al., Phys. Rev. B 83, 195329 (2011)

CHARGE TRANSPORT IN BRANCHED CONDUCTING POLYMERS: QUANTUM GRAPHS BASED APPROACH

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Conducting polymers has attracted much attention recently in the context of organic electronics. Some types of such polymers can have supramolecular (macroscopic) branching.

Branched polymers occur when groups of units branch off from the long polymer chain [1-3]. These branches are known as side chains and can also be very long groups of repeating structures. Branching polymers can be further categorized by how they branch off from the main chain. Polymers with many branches are known as dendrimers, and these molecules can form a webbing when cooled. This can make the polymer strong in the ideal temperature range. Such branched polymer chains can be modeled in terms of so-called quantum graphs, which are the set of nanoscale bonds connected at the vertices. The connection rule is called topology of a graph [4,5]. Modeling of wave dynamics in branched conducting polymers require developing of effective methods allowing to take into account transition of the waves from one to another branches via the branching points. One of such approaches is based on the use of metric graphs as the models of the branched polymers. Within such approach, exciton dynamics can be modeled in terms of the Schrodinger equation on metric graphs.

In this work we use solve the problem of exciton dynamics and charge separation (via splitting of exciton into electron and hole) by modeling the whole system in terms of quantum graph. The main problem we studied is splitting of exciton from transmission from one branch to another one. Charge separation probability is explicitly calculated.

References

1. A. Bunde, S. Havlin, and M. Porto, Phys. Rev. Lett. **74,** 2714 (1995).
2. R. J. KLINE and M. D. McGEHEE, J. Macromol. Sci. C, **46,** 27–45, (2006).
3. Jianhua Liu, et.al, Pol. Chem. **46,** 1449 (2008) .
4. T. Kottos and U. Smilansky, Ann.Phys., **274** 76 (1999).
5. Sven Gnutzmann and Uzy Smilansky, Adv.Phys. **55** 527 (2006).

Parallel sessions IV

P3

EXERCISE ITERATION INCREASES STUDENT COMMITMENT

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The challenge in many introductory physics courses is to keep the students working. Whether due to lack of motivation or lack of skill, many more students start a course than follow through. This is a cause of frustration for students and teachers alike, as well as a waste of resources. In addition, physics instruction is generally detrimental to the development of expert-like attitudes, as measured by for example the Colorado Learning Attitudes about Science Survey (CLASS) [1, 2]. This problem concerns particularly mathematically demanding courses. We implemented changes to the exercise routine at the University of Helsinki to see whether this could be changed.

In the introductory Physics courses, students have usually had one set of conceptually and mathematically challenging exercises per week. In fall 2017, two changes were made to the exercise system. Firstly, STACK (System for Teaching and Assessment using a Computer algebra Kernel) exercises were introduced. The STACK excercises were used for introduction to the week's subject matter, with a deadline before the second lecture of the week. The purpose of the exercises was to increase calculation routine and familiarize the students with the topics.

In addition to this, the grading of the more difficult problems was changed. Students got detailed feedback on one problem weekly, and got a chance to turn in a corrected version (for full credits) the following week. The purpose was to motivate the students to go back, check their work and learn from their mistakes.

The students were more active than previously. The participation in the exercises declined only slightly during the course, and 20% more students showed up for the exam than in the previous year. The exam scores were similar to earlier years. The amount of students attending the following courses is equally higher.

However, the expert-like attitudes were not different from previous years. The overall CLASS score in the beginning of studies and the beginning of the second semester are comparatively high, but expert-like attitudes towards items addressing problem solving and learning still decline during the first months of studying. Hence, the participation and the underlying attitudes towards learning physics seem loosely if at all connected.

[1] W.K. Adams, K.K. Perkins et al., Phys Rev Spec Top Phys Edu Res 2 (2006) 010101.
[2] A. Madsen, S.B. McKagan and E.C. Sayre, Phys Rev Spec Top Phys Edu Res 11 (2015) 010115.

DRAW-A-SCIENCE-COMIC TEST (DASC): THE RESEARCH AND EVALUATION OF PRECONCEPTIONS AND VIEWS ON SCIENCE

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According to a study by Finnish Ministry of Education and Culture, 9th graders see physics and chemistry as uninteresting despite the fact that they acknowledge the importance of these subjects [1]. The career choices are strongly affected by preconceptions and views the person holds [2,3]. To address this issue we need to better understand how younger students and teachers view science [4,5] and therefore we have devised a research instrument which enables to scope these views more accurately. In Draw-A-Science-Comic -test (DASC) the participant is asked to write a set of pictures, a comic, about how they think science is made.

We conducted a study during summer 2017 for children who attended science camps organized by the University of Turku. Total of 43 drawings were evaluated from three different camps. The results showed great variety in perceptions among 10 to 13 year-olds. Some of these stereotypes give clear indication as why science might be considered off-putting or unsuitable as a career choice. By understanding these views, it is possible to offer solutions to correct these misconceptions and promote sciences as an interesting and meaningful career path.

[1] P. Kärnä, R. Hakonen, and J. Kuusela, Koulutuksen seurantaraportit 2 (2012) 1.
[2] J. DeWitt and L. Archer, International Journal of Science Education 37 (2015) 2170.
[3] X. Wang, American Education Research Journal 50 (2013) 1081.
[4] T. Campbell, C. Schwarz, and M. Windschitl, Science and Children 3 (2016) 28.
[5] D. Farland-Smith, K. Finson, W. J. Boone, and M. Yale, Journal of Science Teacher Education 25 (2012) 36.

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Contribution

WHAT TO PAY ATTENTION TO? DEVELOPING OBSERVATION SKILLS AT SENIOR HIGH SCHOOL LEVEL

Category: P3. Physics education research

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ABSTRACT

How to observe a physical phenomenon? What to pay attention to? What is important in a lightning, two magnets attraction or electricity generation from the physics point of view? Although it is the most important step when generating scientific knowledge, the observation of physical facts is one of the most omitted steps of the experimental scientific method (SC). This is a proposal, still under development, about the teaching of observation skills at senior high school level. We assume that the adequate teaching of some metrology concepts supports the development of guidelines that may help the students to identify different physical and measurable parameters involved in a natural phenomenon, in such a way that lets them to develop scientific analysis criteria for diverse physical phenomena. Main objective and specific goals of this research project are exposed, as well as its novelty and potential importance.

QUBIT AS THE FIRST EXAMPLE OF A QUANTUM SYSTEM ON INTRODUCTORY COURSES

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Quantum physics has a reputation of being notoriously difficult to learn, and many different approaches and teaching methods have been suggested to make learning more straightforward. Despite the efforts of educational researchers and instructors, difficulties seem to remain in the shifts from classical to quantum mechanics and to a more abstract mathematical framework [1]. Many instructors have tried to pave the traditional path from wave mechanics to the state space representation with visualizations and classical analogs. Nevertheless, the traditional teaching is shown to result in many student misconceptions [2]. The other approaches also have their caveats as the difficulties students encounter are numerous (e.g. [3]).

We suggest to address the problem by detaching teaching of quantum physics entirely from the classical world view. In EU project 'I SEE' (https://iseeproject.eu), we are designing a teaching module on quantum computing targeted to upper-secondary school students. In this talk, we will discuss our approach to teach quantum phenomena using basic electronics as a scaffolding and qubits as the first example of a quantum systems. We will also give examples of the quantum computing exercises designed for upper-secondary school students.

[1] C. Singh, Proceedings of the Physics Education Research Conference, Sacramento, CA, AIP Conference Proceedings, Melville New York 790, 23-26, (2005).

[2] I. D. Johnston, K. Crawford and P. R. Fletcher, International Journal of Science Education, 20:4, 427-446, (2007).

[3] C. Singh and E. Marshman, Phys. Rev. ST Phys. Educ. Res. 11, 020117, (2015).

DEMONSTRATING PARTICLE PHYSICS TO VARIOUS AUDIENCES

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Particle physics is a field of science which attracts also the general public. For demonstration purposes to various audiences of different ages we have used simple 3D-printed equipment consisting of a magnetic accelerator and a model of the Higgs potential. We have also used cloud chambers to detect tracks from background- and cosmic radiation as well as from particle sources. This we have usually accompanied with posters and displays for CMS-data, videos, and live LHC-status information and detector modules built from beverage cans. We describe the tools we have used to demonstrate particle physics research and our experiences with them.

P6

Biomechanical evaluation of the load-bearing fiber-reinforced composite plates intended for the treatment of long bone fractures

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Objectives: The state of the art treatment for long bone fractures includes the application of metallic cortical screws and/or locking head screws in a locking compression plate (LCP) through open reduction and internal fixation. Nevertheless, metallic implants have intrinsic drawbacks. Low fatigue resistance, unfavorable load distribution and interference with diagnostic imaging are among them.

Fiber-reinforced composite (FRC) technology developed at the University of Turku is based on bisphenol-A-glycidyldimethacrylate (BisGMA) and triethyleneglycoldimethacrylate (TEGDMA) polymer matrix reinforced with E-glass fibers. This FRC material combines the benefits of lower elastic modulus, high strength and adequate fatigue resistance.

The overall objective of this work was to develop novel load-bearing FRC plates which could potentially replace the metallic counterparts. In particular, this study was dedicated to the biomechanical testing of FRC plate prototypes before their implantation in a large animal model in a weight-bearing bone (femur in the minipig).

Experimental: Commercially available human stainless steel LCP plates (Synthes) with a length of 116 mm served as controls. The plates were bent to a curvature radius of ~ 290 mm. Implants mimicking the shape of the control LCP plate were manufactured from the FRC. The plates had a sandwich structure with a core made of unidirectional fibers covered on both (interior and exterior) surfaces by two layers of braiding. Biomechanical testing was performed according to ISO 9585 standard (4-point bending). Experimental groups are shown in Table 1.

Results, accomplishments significance and advancement over previous research:

Table 1. Results of the biomechanical test

Parameter	**Experimental groups**			
	FRC plates without holes (n=7)	FRC plates with 6 holes (n=6)	Control LCP plates with 6 holes (n=5)	minipig femurs (n=5)
Cross-sectional area [mm^2]	105.7	105.7	70.2	169.6
F_{max} (Proof load) [kN]	7.9	4.2	7.3	5.4
Deflection at F_{max} [mm]	5.5	5.1	3.7	4.3
Strength at F_{max} [MPa]	602	322	1431	40.7
Stiffness [Nm^2]	21.4	11.4	27.5	22.2
Bending moment [Nm]	53.6	28.6	46.5	37.3
Flexural modulus [GPa]	30.7	16.5	142	2.9

As expected, drilling of holes weakened the FRC structure; however, the strength of the plate was 8-fold higher compared to that of the minipig femur.

FRC implants based on BisGMA-TEGDMA, have gained significant interest in recent years. In craniofacial reconstructions, FRC implants have been successfully used to treat large size bone defects [1]. Various types of FRC implants were investigated for non-load bearing [2, 3] and load-bearing implant applications [4, 5].

This is the first study to address the mechanical properties of BisGMA-TEGDMA based FRC plates intended for the treatment of long bone fractures. The proposed FRC plates are suitable for implantation in a large animal model in a weight-bearing bone.

Keywords: Fiber-reinforced composite, load-bearing, implant, bone

[1] AITASALO, K.M., PIITULAINEN, J.M., REKOLA, J., VALLITTU, P.K. 2014. Craniofacial Bone Reconstruction With Bioactive Fiber-Reinforced Composite Implant. *Head Neck,*36,722-728.

[2] TUUSA, S.M., PELTOLA, M.J., TIRRI, T., LASSILA, L.V., VALLITTU, P.K. 2007. Frontal Bone Defect Repair with Experimental Glass-Fiber-Reinforced Composite with Bioactive Glass Granule Coating. *J Biomed Mater Res B Appl Biomater*, 82, 149-155.

[3] TUUSA, S.M-R., PELTOLA, M.J., TIRRI, T., PUSKA, M.A., RÖYTTÄ, M., AHO, H., SANDHOLM, J., LASSILA, L.V.J., VALLITTU, P.K. 2008. Reconstruction of Critical Size Calvarial Bone Defects in Rabbits with Glass-Fibre-Reinforced Composite with Bioactive Glass Granule Coating. *J Biomed Mater Res B Appl Biomater*, 84, 510-519.

[4] ZHAO, D.S., MORITZ, N., LAURILA, P., MATTILA, R., LASSILA, L.V.J, STRANDBERG, N., MÄNTYLÄ, T., VALLITTU, P.K., ARO, H.T. 2009. Development of a Multi-Component Fiber-Reinforced Composite Implant for Load-Sharing Conditions. *Med Eng Phys*, 31, 461-469.

[5] MORITZ, N., STRANDBERG, N., ZHAO, D.S., MATTILA, R., PARACCHINI, L., VALLITTU, P.K., ARO, H.T. 2014. Mechanical Properties and In Vivo Performance of Load-Bearing Fiber-Reinforced Composite Intramedullary Nails with Improved Torsional Strength. *J Mech Behav Biomed Mater,* 40C,127-139.

DNA ORIGAMI FOR BIOPHYSICAL DEVICES

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Customized DNA structures [1-3] can find a plethora of uses in molecular nanotechnology owing to their exceptional addressability. They can serve as templates for *e.g*. proteins [4-6], metallic nanoshapes [7-9], nanoscopic rulers [10] and electronic circuits [11] even at large scales [12]. Recently, an increasing effort has been put into applying DNA structures as smart drug-delivery vehicles [13]. Nevertheless, it is well known that their transfection rates are rather poor and they are prone to degradation [13]. To overcome these issues we have developed new strategies for shielding DNA structures (with [6,14] or without [15] a cargo) and thus improving their biocompatibility. Furthermore, we have studied their drug-loading efficiency [16] and stability in low-magnesium buffers [17]. We have demonstrated electrostatic coating of the structures with cationic polymers [14], virus capsid proteins [15] and protein-dendron conjugates [18] with enhanced properties. Importantly, our inert protein coatings can attenuate the activation of immune response and protect the structures from endonucleases [18], and therefore, these proposed systems could readily open up intriguing applications in nanobiomedicine.

[1] V. Linko and H. Dietz, Current Opinion of Biotechnology 24 (2013) 555.
[2] V. Linko and M. A. Kostiainen, Nature Biotechnology 34 (2016) 826.
[3] S. Nummelin, J. Kommeri, M. A. Kostiainen and V. Linko, Advanced Materials 30 (2018) 1703721.
[4] V. Linko, *et al*., Chemical Communications 51 (2015) 5351.
[5] V. Linko, *et al*., Nanomaterials 6 (2016) 139.
[6] A. Ora, E. Järvihaavisto, H. Zhang, H. Auvinen, H. A. Santos, M. A. Kostiainen and V. Linko, Chemical Communications 52 (2016) 14161.
[7] B. Shen, V. Linko, K. Tapio, *et al.*, Nanoscale 7 (2015) 11267.
[8] B. Shen, K. Tapio, V. Linko, *et al*., Nanomaterials 6 (2016) 146.
[9] B. Shen, V. Linko, K. Tapio, *et al*., Science Advances 4 (2018) eaap8978.
[10] E. Graugnard, W. L. Hughes, R. Jungmann, M. A. Kostiainen and V. Linko, MRS Bulletin 42 (2017) 951.
[11] B. Shen, V. Linko, H. Dietz and J. J. Toppari, Electrophoresis 36 (2015) 255.
[12] V. Linko, B. Shen, K. Tapio, *et al*., Scientific Reports 5 (2015) 15634.
[13] V. Linko, A. Ora and M. A. Kostiainen, Trends in Biotechnology 33 (2015) 586.
[14] J. K. Kiviaho, V. Linko, A. Ora, *et al*., Nanoscale 8 (2016) 11674.
[15] J. Mikkilä, *et al*., Nano Letters 14 (2014) 2196.
[16] F. Kollmann, S. Ramakrishnan, B. Shen, G. Grundmeier, M. A. Kostiainen, V. Linko and A. Keller, (2018) submitted.
[17] C, Kielar, Y. Xin, B. Shen, M. A. Kostiainen, G. Grundmeier, V. Linko and A. Keller, (2018) submitted.
[18] H. Auvinen, H. Zhang, Nonappa, A. Kopilow, E. H. Niemelä, S. Nummelin, A. Correia, H. A. Santos, V. Linko and M. A. Kostiainen, Advanced Healthcare Materials 6 (2017) 1700692.

HOLDING A SAMPLE STILL IN AN ACOUSTIC LEVITATOR

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Acoustic levitation is well known but its full potential is yet to be used. Acoustic levitation permits non-contact handling without sample preparation. Position and rotation stability is essential for making accurate measurements on a levitated sample but little research has been conducted on the quantitative stability measurement of non-ideal samples. To take a step towards reliable and stable levitation the levitated particle movement needs to be quantified. This requires position and orientation detection. Briefly, the sample needs to be held still.

We present a method to accurately determine the orientation and position of acoustically levitated samples. The method uses a structure from motion (SfM) pipeline to create a 3D model of the sample and to identify the camera angles. The SfM algorithm matches the common features in pictures taken from different angles of the sample. The method can be used for arbitrary shaped samples and requires only one fixed camera. We demonstrate the method by measuring the orientation of a levitated Styrofoam particle from video frames.

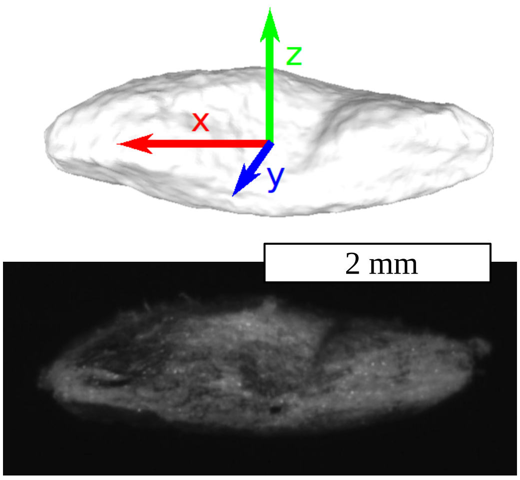

Figure 1: The obtained 3D model of the levitated sample and one of the frames used in SfM

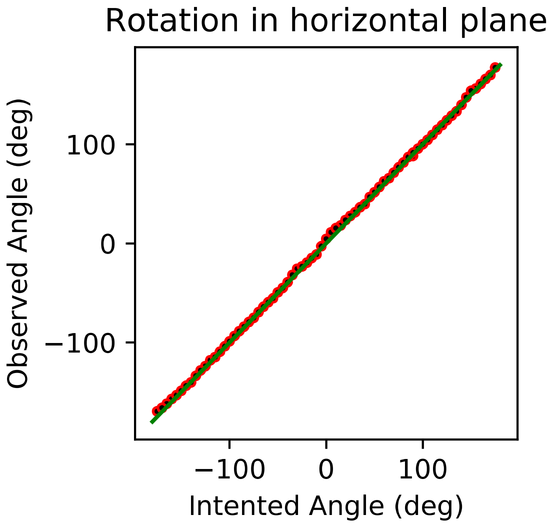

Figure 2: Results from rotation detection

PHOTOPLETHYSMOGRAHIC WAVEFORM ANALYSIS FOR OXIMETRY

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Abstracts

Photoplethysmography is a simple method for estimating arterial pulse waves (PW) in the finger. These PWs can be principally studied under the various effects of age, sex, and sauna stimulation, e.g., for testing the capability using the PPG technique for arterial elasticity analysis, oxygen saturation, and pulse wave velocity. Pulse oximeter (PO) signals are derived from the PPG waveforms on infrared and red wavelength. The determination of arterial oxygen saturation (SaO_2) in arterial blood by PO is based on the two light absorption spectra, namely, oxygenated and deoxygenated hemoglobin and the analysis of PPG signals acquired at the wavelengths. PO gives the SaO_2 value is reflecting the potential risk of the following diseases like chronic obstructive pulmonary diseases, arteriosclerosis, the peripheral circulation disorder, or cardiovascular disease. Arteriosclerosis is a vascular disease causing early arterial aging and oxygen deprivation, in addition to thickening, hardening, and loss of elasticity of the walls of arteries. This process gradually restricts the oxygenated blood to flow in the organs and tissue and can lead to severe health risks. The POs were tested with the OxSim tester. OxSim simulations were intended to produce simulated values within the specified tolerance of the PPG devices intended to be used as the POs. Typically, the POs have a tolerance of +/-3% or +/-2%. Accurate measurements and analysis of the finger, toe, or nasal SaO_2 are important for better characterization of artery diseases and the development of reliable computational models based on blood flow dynamics and oxygenation.
In the practice, the SaO_2 (%) can be measured by POs, however, the final calculations are based on the approximations and calibrations that are difficult because of the very narrow window of the SaO_2 (95-99%). The calculations for SpO2 value is based on the ratio of ratios, namely, the intensities at the wavelengths used. The ratio of red to infrared (IR) absorption is used to find the SaO_2 levels. The absorption of the hemoglobin depends on the oxygen content of the molecule. The accurate SaO_2 can be achieved by the PO device having the narrow emission spectra of the LEDs resulting in high accuracy in the determination of the absorption. However, in many commercial PO devices, there are LEDs with broadband emission spectra causing errors in SaO_2 values.

[1] M. Nitzan, S. Noach, E. Tobal, Y. Adar, Y. Miller, E. Shalom, and S. Engelberg, Calibration-Free Pulse Oximetry Based on Two Wavelengths in the Infrared — A Preliminary Study, Sensors (2014), 14, 7420-7434.

SURFACE TENSION DEPRESSION AND CLOUD DROPLET ACTIVATION OF POLLENKITT SOLUTIONS

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The formation of water droplets and ice crystals in Earth's atmosphere requires the presence of nuclei for water vapor to condense onto. Both whole grains of pollen (5–150 μm) and fragments of pollen (0.03–5 μm) have the ability to act as cloud condensation nuclei (CCN) and ice nuclei (IN) and therefore influence Earth's radiative balance and hydrological cycle [1]. Pollen grains are often coated with a sticky material called pollenkitt that may act to hold together pollen grains [2]. The chemical composition of pollenkitt is not well-studied [3], but its molecular structure and chemical composition suggest that pollenkitt may be surface active in aqueous solution and act to depress the barrier to cloud droplet formation in the same way as marine fatty acids [4, 5].

In this work, we present measurements of surface tension and supersaturated hygroscopicity of pollenkitt extracted from six different species. Surface tension of binary and ternary aqueous pollenkitt solutions were measured via axisymmetric drop shape analysis of pendant drops in air with a ramé-hart goniometer (Model 250). A Cloud Condensation Nuclei Counter (Droplet Measurement Technologies) was use to measure the ability of pollenkitt to act as CCN at several supersaturations between 0.1-1.4%. A suite of thermodynamic model frameworks were employed to predict the CCN activity and analyze the impact of droplet surface tension at the moment of activation for mixtures of pollenkitt solutions.

This work was supported by the Finnish Academy of Sciences (257411), a Georgia Power Faculty chair, a Cullen-Peck Fellowship, and funding from the European Research Council's Horizon 2020 research and innovation programme (717022).

[1] Fröhlich-Nowoisky, J., et al. (2016). *Atmos. Res.*, 182:346–376.
[2] Lin, H., Gomez, I., and Meredith, J. C. (2013). *Langmuir*, 29:3012–3023.
[3] Pacini, E. and Hesse, M., 2005. *Flora*, 200:399–415.
[4] Prisle, N., et al. (2008). *Tellus B*, 60B:416–431.
[5] Prisle, N. L., et al., (2010). *Atmos. Chem. Phys.*, 10:5663–5683.

P8

EXPERIMENTS ON PARITY AND QUASIPARTICLES IN A SUPERCONDUCTOR

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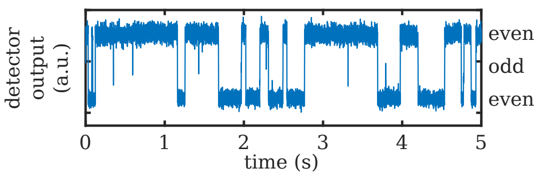
Superconductivity is based on electrons pairing to form Cooper pairs, which can then carry dissipationless supercurrent or tunnel coherently over a weak link connecting two superconductors in the Josephson effect. At temperatures low compared to the superconducting gap, there should ideally be zero unpaired electrons left, and correspondingly a measurable energy cost for having an odd number of electrons on a superconducting island. This parity effect can be observed even when the island has on the order of 10^9 electrons in total [1].

In practice, however, even at low temperatures often unpaired electrons created from unknown sources are present and the parity effect is suppressed. These quasiparticle excitations are generally detrimental to the operation of various superconducting devices. For example, they cause decoherence in superconducting qubits, and are a fundamental bound for the coherence times of topological qubits based on Majorana zero modes [2, 3].

Here, we experimentally demonstrate that it is possible to observe a clear parity effect on a superconducting aluminum island even when there is, on average, a single quasiparticle excitation left on the island. The island is coupled to normal metal leads with tunnel junctions, and we monitor its charge state in real time with a capacitively coupled charge detector. At low temperatures, the most probable charge state is even, as expected, but also the odd states have significant occupation probabilities due to the quasiparticles present. The occupation probabilities and tunneling rates between the charge states are quantitatively explained by Cooper pairs breaking on the island. In our setup, the pair breaking is caused by the backaction of the single-electron transistor used as the charge detector. [4]



Real-time charge detector output showing transitions between even and odd charge states of a superconducting island.

[1] M. T. Tuominen et al, Phys. Rev. Lett. 69, 1997 (1992)
[2] D. Rainis and D. Loss, Phys. Rev. B 85, 174533 (2012)
[3] T. Karzig et al, Phys. Rev. B 95, 235305 (2017)
[4] E. T. Mannila et al, in preparation

JOSEPHSON PARAMETRIC AMPLIFIERS UTILIZING ALUMINUM SHADOW EVAPORATION WITHOUT A SUSPENDED BRIDGE

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Low-noise amplification of microwave signals is a key requirement in numerous nano electronic experiments, including qubit readout, optomechanics and shot noise spectrometry. Lower system noise temperatures can be reached with superconductive parametric amplifiers which, however, have suffered from limited bandwidth and/or modest gain. Operating a Josephson LC resonator in an impedance-engineered environment [1], a solution that has been introduced recently, requiring Josephson junctions (JJs) having relatively large critical current. Previous work has shown in-situ fabrication of such junctions using technique without suspended bridge [2].

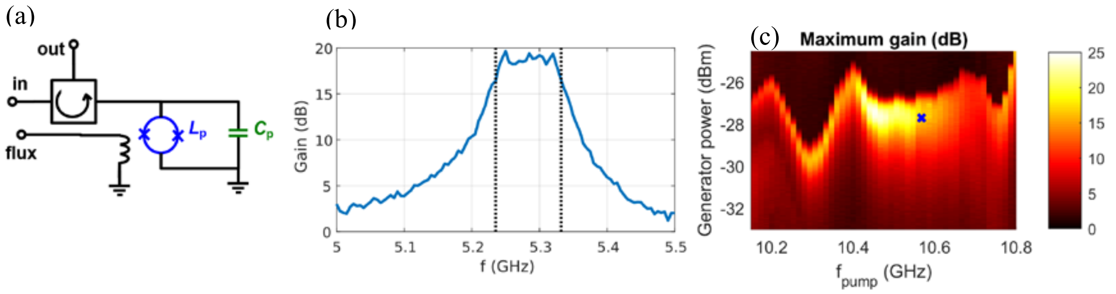

Figure 1: (a) Schematic of the flux-pumped lumped element JPA with on-chip flux line and external circulator separating the input and output signals. (b) Signal gain as function of frequency at one operation point. (c) Maximum gain as a function of pump power and frequency at single DC flux bias point. Cross denotes the operation point in (b).

In this work, we present our realization of a flux-pumped lumped element JPA containing a SQUID loop and interdigital capacitor as shown in Fig. 1 (a). All the metallization (JJs, capacitor, bonding pads etc.) is fabricated in a single lithography step utilizing double layer resist (PMMA/MAA), high/low dose 100 kV e-beam exposure and double angle evaporation of aluminum, separated by in-situ oxidation.

We present experimental results on these amplifiers, showing high gain of up to 20 dB with 100 MHz bandwidth, as shown in Fig 1 (b) with noise performance approaching the standard quantum limit. Moreover, the gain is tunable by 500 MHz by alternating the DC flux and by tuning the frequency of AC flux pump (at double the signal frequency) as shown in Fig. 1 (c).

[1] T. Roy, et al., Appl. Phys. Lett. 107 (2015) 262601.
[2] F. Lecocq, et al., Nanotechnology 22 (2011) 315302.

In-situ tunable environment for superconducting qubits

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Superconducting quantum circuits hold great potential in providing revolutionizing practical applications such as quantum sensing or computing. However, in many cases noise limits the operation and the fidelity of these circuits. Here we introduce a concept that exploits noise instead of trying to reduce it. Our concept uses photon-assisted single-electron tunneling as a controlled source for dissipation in superconducting qubits. We show how the recently developed quantum-circuit refrigerator [1], QCR, is suitable to control the dynamics of superconducting qubits. In our experiments, the QCR works as a voltage-controlled environmental bath for the qubit. The qubit-bath coupling strength can be tuned over several orders of magnitude on a nanosecond timescale. Such a tunable environment is promising for fast qubit reset and studies of dissipative open quantum circuits. Our highly integrable circuit architecture may prove useful in the initialization of qubit arrays and in dissipation-assisted quantum annealing.

[1] K. Y. Tan, et al., Nature Commun. 8, 15189 (2017)

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SINIS TUNNEL JUNCTION FABRICATION USING THREE-DIMENSIONAL LASER LITHOGRAPHY

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Pairs of symmetric NIS tunnel junctions, or SINIS junctions, have many applications in solid-state cooling and thermometry. They are often used as thermometers for example in heat transfer measurements [1], because they can be used at cryogenic temperatures and the sensing element can be made very small.[2]

SINIS junctions are most often fabricated using electron beam lithography, because of the high resolution and very accurate alignment possibilities. However, this method also has many drawbacks for more complicated sample geometries like three-dimensional (3D) structures. Firstly, it has to be possible to coat your sample with a few hundred nm thick resist layer, and then the electron beam has to be very accurately focused on all the different heights on the sample. Also non-conductive materials are problematic.

We have developed a new method for fabricating SINIS junctions especially for complicated sample geometries. The method is based on two photon polymerization (2PP) 3D laser lithography [3]. With this method thicker resist layers can be used, and the innate 3D capabilities allow for easy fabrication at different heights. Other strengths include the simplicity of the process, the possibility to use any substrate material and the ease of fabrication of large area junctions. The only drawbacks are lower resolution ($\sim$1 µm) and the limitations in alignment accuracy given by optical microscopy. In Figure 1 we show a SINIS junction fabricated on a 20 µm tall 3D structure using this method. Electrical measurements show good tunnel junction characteristics.

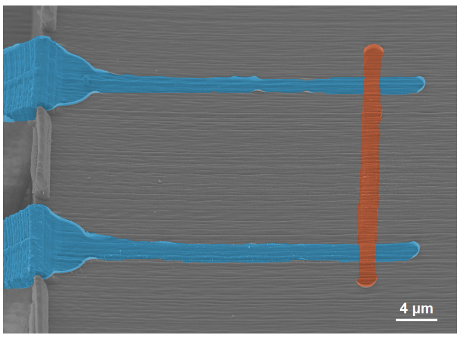

Figure 1: A SINIS junction fabricated on top of a 3D structure. The height of the structure is 20 µm. The metals used for the junction are aluminium (blue) and copper (orange).

[1] N. Zen et al. Nat. Commun. 5 (2014) 3435.
[2] F. Giazotto et al. Rev. Mod. Phys. 78 (2006) 217 - 274.
[3] T. Tanaka, H. Sun and S. Kawata, Appl. Phys. Lett. 80 (2002) 312.

NORMAL METAL - INSULATOR - SUPERCONDUCTOR THERMOMETERS AND COOLERS WITH TITANIUM-GOLD BILAYER AS THE NORMAL METAL

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Normal metal - insulator - superconductor (NIS) tunnel junctions are versatile and useful devices for thermometry, cooling, and metrological applications for the definition of ampere [1, 2, 3]. Usually, Cu has been used as the normal metal. We have observed how the Cu electrode degrades strongly with heating, and in contact with some solvents. Thus, it is desirable to find other alternatives for the normal metal.

We have fabricated superconductor - insulator - normal metal - insulator - superconductor (SINIS) tunnel junctions in which Al acts as the superconductor, Al_xO_y is the insulator, and the normal metal consists of a thin Ti layer (5 nm) covered with a much thicker Au layer (40 nm). We have characterized the junctions by measuring their current-voltage curves between 60 mK and 750 mK. In addition, we have measured dynamic conductance with respect to bias voltage and temperature above 4.2 K and calculated the thicknesses and the heights of the tunneling barriers of the junctions. For comparison, the same measurements have been performed for a SINIS junction pair whose normal metal is Cu.

The Ti-Au bilayer can reduce the tunneling resistance by an order of magnitude compared to Cu based devices, made with identical fabrication parameters. The tunneling barrier seems to be thicker but lower in Ti-Au devices than in Cu devices. Conductance-voltage curves of Ti-Au devices lose their parabola shapes when temperature is lower than room temperature. In addition, Ti-Au devices are much more robust against chemical attacks and static charge. More significantly, Ti-Au devices have one order of magnitude higher electron cooling power than Cu devices. A non-optimized Ti-Au device cools from 200 mK to 110 mK when it is biased close to the energy gap of the superconducting Al. [4]

[1] F. Giazotto, T.T. Heikkilä, A. Luukanen, A.M. Savin, and J.P. Pekola, Reviews of Modern Physics 78 (2006) 217.
[2] J.P. Pekola, O.-P. Saira, V.F. Maisi, A. Kemppinen, M. Möttönen, Yu.A. Pashkin, and D.V. Averin, Reviews of Modern Physics 85 (2013) 1421.
[3] J.T. Muhonen, M. Meschke, and J.P. Pekola, Reports on Progress in Physics 75 (2012) 4.
[4] I.M.W. Räisänen, Z. Geng, K.M. Kinnunen, and I.J. Maasilta, accepted for publication in Journal of Physics: Conference Series.

S3

SENSING AT THE PHYSICAL LIMIT WITH SOLUTION PROCESSED BIOELECTRONIC TRANSISTORS

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Label-free, fast, portable, sensitive and reliable devices capable to work in real bio-fluids are a major need to improve citizens' quality of life. The interplay among competences in the field of material science, analytical chemistry and device physics is critical to succeed in such an important aim. Particularly relevant in this interdisciplinary scenario in the field of organic and printable bio-electronics has shown high promises for healthcare and human well-being and millimetre-sized electrolyte-gated organic-field-effect-transistor (EGOFET). The realisation of a system with the elicited characteristics can play a key role for instance in point-of-care (POC) applications. Here the needed biosensors can be integrated diagnostic tools employed for the detection of clinically relevant biomarkes in biological fluids such as blood, urine and saliva. These devices must provide rapid results directly where the information is needed, thus facilitating an earlier diagnosis and a prompt patient's treatment. Various technologies have been proposed for the realization of POC biosensors including label-free techniques based on optical, mechanical and electrochemical transducers. However, reliable, quantitative and ultrasensitive devices have been not yet commercialized. Another very important area of application is the very fast growing field of liquid biopsy. Specifically, biological fluids are sampled to monitor the level of cancer biomarkers available in peripheral blood and blood-derived products such as plasma and serum. Liquid biopsy offers an easy and fast way to achieve cancer early diagnosis and to monitor cancer treatments.

In this presentation the study and the development of an unprecedented high-sensitive, label-free, printable, millimetre-sized transistor-based for single-molecule detection carried out at the University of Bari will be illustrated. This platform is foreseen to have a huge impact on fundamental research in bio-analytical chemistry pushing a label-free bioassay detecting performance towards the physical limit, being also selective and commercially highly valuable for applications in diagnosis and drug-screening.

3D conducting polymer-biopolymer scaffolds for hosting and monitoring cells

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Abstract

My research program focuses on harnessing the power of engineering for developing *in vitro* biological models in a synthetic biology approach. By developing both the biological model and the adapted monitoring methods in parallel, both may be iteratively improved resulting in enhanced systems. I define the latter combination as *in vitro* systems: an integrated system to monitor human biology *in vitro*. Specifically, I have focused on the use of polymeric electroactive materials and devices which bridge a gap between hard inflexible materials used for physical transducers and soft, compliant biological tissues. The transducer thus becomes a 'synthetic' part of the model, allowing transduction and/ or stimulation of biological systems in the least invasive and thus most biomimetic fashion possible.

In this presentation I will discuss our recent progress in adding to the repertoire of tissue engineers; alongside the well-known biochemical and mechanical cues used to recreate biologically relevant tissues, we attempt to integrate electrical cues. Electrical cues have a demonstrated role in development, not just for electrogenic tissues, but for all tissues. To enable the trifecta of stimuli necessary for recreating tissues in vitro, we have generated conducting polymer scaffolds blended with biopolymers such as collagen. I will show evidence that these structures can simultaneously host *and* monitor tissues.

CORRELATION OF GLUCOSE CONCENTRATION BETWEEN DERMAL INTERSTITIAL FLUID AND CAPILLARY BLOOD

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Diabetes is a chronic disease globally affecting 422 million people [1]. Frequent glucose monitoring is essential to prevent both acute and long-term complications. The inconvenience of standard capillary blood measurements discourages patient compliance. Emerging minimally- and non-invasive technologies pursuit harnessing of dermal interstitial fluid to measure glucose conveniently. The temporal relationship between glucose concentration in capillary blood and in interstitial fluid is unclear. We investigate the correlation between glucose concentration in capillary blood and in dermal interstitial fluid extracted by reverse iontophoresis. For four hours, the glucose concentration in blood and in interstitial fluid samples was measured every 15 min in a healthy volunteer. Capillary blood samples were obtained by standard fingertip pricking, and the glucose concentration in them was measured with a commercial device (Freestyle Lite). Dermal interstitial fluid was extracted by reverse iontophoresis using a custom-made device. The device was placed on the skin at the wrist (carpal region). The obtained samples were analysed using a commercial kit. Our results contribute to understanding the temporal relationship between glucose concentration in blood and in interstitial fluid extracted from the skin via iontophoresis. Further research on this relationship can promote the development of a non-invasive solution for glucose monitoring.

[1] World Health Organization. (2016). Global report on diabetes. World Health Organization.

TOWARDS ACTIVE CONTROL OF CELL VIABILITY USING ELECTROCHEMICAL REDUCTION OF GRAPHENE OXIDE AND THE RELEASE OF BIOACTIVE MOLECULES

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In recent years there has been a lot of interest in controlling the cell environment either by designing new biomaterials to improve the cell-surface viability or by actively controlling the interface with which cells interact with by external stimuli, such as light pulses, voltage and acidity. [1, 2] In this work we clarify if graphene oxide (GO) can be used to actively deliver bioactive molecules to a cell culture, in order to influence cell migration, proliferation and/or viability, using electrochemical reduction of a GO suspended in cell culture medium.

An extensive study of the reduction process of GO in a cell culture medium has been performed and the voltage dependent cell viability has been studied, showing that human dermal fibroblast cells can survive the voltages needed for reduction of GO in cell culture medium. [3] The release of model compounds, namely Methyl green, from the surface of a GO film suspended in cell culture medium has also been shown to work, although at quite high voltages due to strong bonds between the cyclic groups in Methyl green to GO. The devices for this work were fabricated by evaporating (physical vapour deposition) thin gold electrodes on suitable cell culture substrates (glass, plastic and paper) and a GO film was drop cast on top. Cells were left to seed for 24h on the surface before any voltages were applied.

Our current focus lies on choosing and grafting a suitable bioactive molecule to GO utilizing the carboxylic groups in GO and their well-known chemistry with amines.

[1] P. Fattahi, G. Yang, G. Kim, and M. R. Abidian, Adv. Mater. 26 (2014) 1846–1885.
[2] M. Marzocchi, I. Gualandi, M. Calienni, I. Zironi, E. Scavetta, G. Castellani, and B. Fraboni, ACS Appl. Mater. Interfaces 7 (2015) 17993−18003.
[3] M. Pesonen, J. Frisk, R. Österbacka, Organic Electronics 47 (2017) 66-71.

Parallel sessions V

P4

Molecular dynamics study of swift heavy ion induced elongation of nanoparticles

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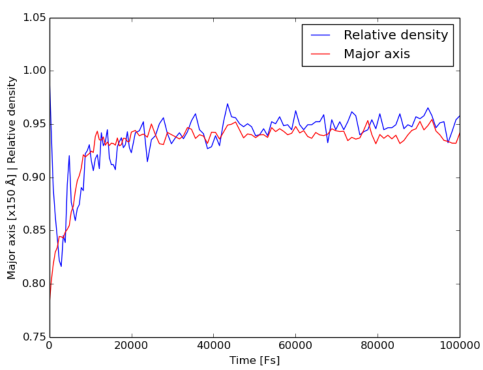
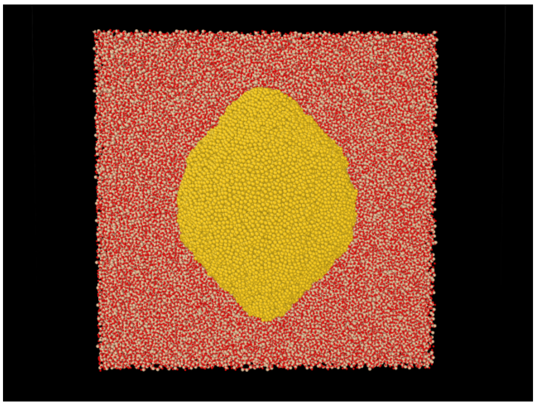
Nanoparticle shape transformation induced by swift heavy ion irradiation (SHI) has been explained by [Leino et al., 2014] by a mechanism in which molten material flows to an underdense track in matrix material and recrystallizing to conserve the new shape. In the experimental study by [Amekura et al., 2014] it was shown that this shape transformation can happen even for 50 MeV Si ions that have earlier been observed to not produce permanent tracks in silica.

We used molecular dynamics to study the shape transformation process using molecular dynamics simulations by performing multiple impacts of 50 MeV Si and 60 MeV Ti ions on Au nanoparticles.

We found out that shape transformation happens with a similar mechanism even when no permanent track is formed. This can be explained by the formation of transient underdense track. The shape transformation in this case would happen during the time where there is a track and stop when the track is closed.

In addition to the low energy impacts we studied the SHI irradiation effects on a rod shaped particle. We concluded that elongation is possibe at least for small rod like particles that fully melt on a single SHI impact.





[Amekura et al., 2014] Amekura, H., Mohapatra, S., Singh, U., Khan, S., Kulriya, P., Ishikawa, N., Okubo, N., and Avasthi, D. (2014). Shape elongation of zn nanoparticles in silica irradiated with swift heavy ions of different species and energies: scaling law and some insights on the elongation mechanism. *Nanotechnology*, 25(43):435301.

[Leino et al., 2014] Leino, A. A., Pakarinen, O. H., Djurabekova, F., Nordlund, K., Kluth, P., and Ridgway, M. C. (2014). Swift Heavy Ion Shape Transformation of

HOLOGRAPHIC PATTERNING OF FLUORESCENT MICROSTRUCTURES COMPRISING SILVER NANOCLUSTERS

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Metal nanoclusters are ultra-small particles with metal core consisting of a few to a few tens of atoms and exhibit attractive molecular properties such as ultra-small size, quantized energy levels, and strong absorption and fluorescence. Retaining these privileged properties is difficult without proper stabilization as they readily aggregate to form larger nanoparticles [1]. Stable nanoclusters have been fabricated with multiphoton direct laser writing (DLW) in glass [1], zeolites [1] and most recently in polymer [2]. The multiphoton excitation requires high laser powers and a slow point-by-point writing procedure. On contrary, single photon DLW paves a way to a cost-effective parallel fabrication by performing, e.g., holographic or shaped light exposure of larger area at once.

Here, we demonstrate the CW laser diode based parallel fabrication of fluorescent microstructures by patterning laser beam with the help of spatial light modulator (SLM). Furthermore, we utilize this technique to create photostable silver nanoclusters fluorescent micro-label as shown in Figure 1. The as-formed nanocluster microstructures absorb light of wavelength ranging from 300 nm to 700 nm with a maximum located at 435 nm and emit light at visible range upon excitation with 470 nm light [3]. Overall, the results show that SLM-based parallel writing can be used to fabricate photostable silver nanocluster microstructures in short exposure with resolution comparable to the point-by-point writing and optical properties similar to the silver nanoclusters formed by multiphoton DLW [2, 3]. Moreover, this parallel fabrication technique is flexible and overcomes the serial slow process of scanning [3].

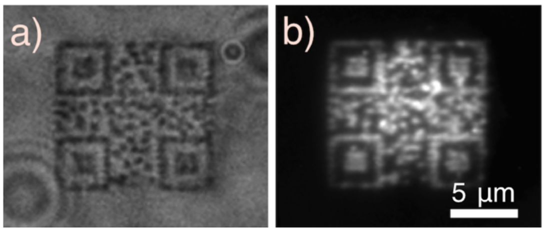

Fig. 1: (a) Bright field and (b) corresponding fluorescence microscopy image of a microlabel. Fluorescence image was recorded by exciting the structure with LED light of intensity of 2 MW/m^2 and excitation wavelength of 470 nm.

[1] I. Díez and R. H. A. Ras, Nanoscale 3 (2011) 1963-1970.
[2] P. Kunwar, J. Hassinen, G. Bautista, R. H. A. Ras and J. Toivonen, ACS Nano 8 (2014) 11165-11171.
[3] P. Kunwar, L. Turquet, J. Hassinen, R. H. A. Ras, J. Toivonen and G. Bautista, Optical Materials Express 6 (2016) 946-951.

MOLECULAR LEVEL STUDIES OF THREE OXIDIZED ORGANICS AND THEIR AQUEOUS SALTING INTERACTIONS USING SYNCHROTRON RADIATION X-RAY ABSORPTION SPECTROSCOPY ON A LIQUID FLOW CELL

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Humidified aerosol particles and cloud droplets provide the media for aqueous-phase chemistry in the atmosphere and solubility of organic-inorganic mixtures in aerosol water is a key component in atmospheric processing. Aqueous-phase molecular interactions, such as salting in and out, between different solute components impact aerosol composition via both gas-particle partitioning and precipitation processes. We have demonstrated large impacts of interactions between organic and inorganic aerosol components on their gas–particle partitioning and water uptake properties [1, 2]. In particular, the predicted Henry's law solubility of glyoxal is greatly enhanced by strong, specific complex formation with sulfate ions stabilizing the hydrates in aqueous solution, which could greatly enhance availability of glyoxal for aqueous SOA formation in regions dominated by sulfate rich aerosol. We then used COSMO-RS, a method combining quantum chemistry with statistical thermodynamics, to compute aqueous salting interactions for a large array of organic solutes and salts, including glyoxal, methylglyoxal, and glycerol [3]. COSMOTherm generally overpredicts both positive and negative Setschenow constants and in particular was unable to replicate the predicted strong salting in of glyoxal in sulfate solutions. For methylglyoxal, experimentally observed salting out was qualitatively predicted. Subsequently, we used synchrotron radiation soft X-ray absorption spectroscopy (XAS) to study aqueous interactions of binary aqueous glyoxal, methylglyoxal, and glycerol and their ternary mixtures with sulfate salts in-situ. Glyoxal was found entirely in its tetrol dihydrate form, whereas both methylglyoxal mono- and dihydrate coexist. Glycerol only shows features attributed to C-OH, as expected. For each organic, the effect of sulfate is at best modest, in apparent contrast to both previous quantum-chemical and COSMOTherm calculations, and experimental observations.

This work has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement 717022). The authors are ever grateful to the Academy of Finland for financial support.

[1] Kurten, T., et al. (2014). *J. Phys. Chem. A*, 119:4509D4514.
[2] Hansen, A. M., et al. (2015). *Atmos. Chem. Phys.*, 15:14071–14089.
[3] Toivola, M., et al. (2017). *J. Phys. Chem. A*, 121:6288–6295.

PHOTO-ELECTROCHEMICAL AND SPECTROSCOPIC INVESTIGATION OF ALD GROWN TiO_2: CHARGE TRANSFER CHARACTERIZATION AND EFFECT OF POST ANNEALING AT DIFFERENT TEMPERATURE

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Inspired by the photo-electrochemical water oxidation system reported by Fujishima and Honda [1], recent work has focused on functionalizing photoactive TiO_2 thin films on silicon (Si) semiconductor. Targeting to design an efficient photo-electrochemical device for solar fuel production, finding suitable protection layer material for semiconductors like Si, has recently gained significant attention [2].

In this work, TiO_2 thin films were deposited on highly doped Si substrate by atomic layer deposition (ALD) technique using tetrakis-dimethylamido titanium (TDMAT) and water as a precursors. In order to understand the influence of ALD parameters on TiO_2 film performance in photo-electrochemical cell, ALD growth temperature was varied from 150 °C to 225 °C and film thickness from 20 nm to 50 nm. Further efforts were made to analyze the effect of post-annealing treatment in air on ALD films and its influence on photo-electrochemical water oxidation reaction.

The highest applied bias photon-to-current efficiency for Solar Water Splitting (SWS) was obtained in 30 nm ALD TiO_2 film grown at 200 °C after post annealing at 475 °C. Annealing at higher temperatures decreased the photo-activity substantially. X-ray photoelectron spectroscopy analysis of TiO_2 (2 nm)/Si samples after annealing in air revealed the onset of interfacial SiO_2 formation at 450 °C. SiO_2 at the TiO_2/Si interface act as a charge transfer barrier with detrimental consequence on SWS on TiO_2/Si photo-anode.

[1] A. Fujishima, K. Honda, Nature 238 (1972) 37–38.
[2] Shu Hu et.al. Science Vol. 344 (2014), Issue 6187, pp. 1005-1009.

Resonance ionization spectroscopy of Nb utilizing a narrowband injection-locked Titanium:Sapphire laser

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Hyperfine structures and isotope shifts in electronic transitions contain readily available model-free information on the single-particle and bulk properties of exotic nuclei, namely the nuclear spin, magnetic dipole and electric quadrupole moments as well as changes in root-mean-square charge radii [1]. Recently, the implementation of resonance ionization spectroscopy (RIS) in a low-temperature supersonic gas jet[2] utilizing a narrowband first step excitation has gained considerable interest [3]. An optimal solution to combine high pulse powers required for efficient ionization with a narrow bandwidth is the pulsed amplification of a narrow-band continuous wave (CW) laser. While for high-gain dye lasers a single pass amplification is sufficient, the lower gain Titanium:Sapphire gain medium requires a different approach. In a regenerative amplifier, the cavity length is locked to a multiple of the seed wavelength allowing Titanium:Sapphire -based lasers to reach a final output power of several kW (during the pulse) from the few mW of CW input.

We present a pulsed injection-locked Titanium:Sapphire laser [5] for the PALIS laser laboratory [4] in the RIKEN Nishina Center. The laser has been demonstrated to perform as designed with a tuning range across the whole Master laser range, with a 30 % slope efficiency. More importantly, the laser was applied to hyperfine spectroscopy of ^{93}Nb. These measurements yielded a total FWHM of ~ 400 MHz and hyperfine A coefficient of 1866 ± 8 MHz for the ground state and 1536 ± 7 MHz for the first excited state in a good agreement with the literature values [6]. Possible future goals for niobium include the determination of the efficiency of the newly developed ionization scheme and apply it for RIS of radioactive niobium isotopes, as well as studying to possibility to separate the $^{93\mathrm{m}}$Nb isomer from the ground state for the application in integrated fast neutron dosimetry [7]. In conclusions, the injection-locked Titanium:Sapphire laser system has been demonstrated to be ready for high-resolution in-gas-jet spectroscopy at the PALIS facility in the near future.

[1] P. Campbell, I.D. Moore, and M.R. Pearson. Prog. Part. and Nucl. Phys., 86:127, 2016

[2] T. Sonoda *et al.* Nucl. Instr. and Meth. **B**, 267(17):2918, 2009.

[3] Yu. Kudryavtsev *et al.* Nucl. Instr. and Meth. **B**, 297:7, 201

[4] T. Sonoda *et al.* Nucl. Instr. and Meth. **A**, 877:118 2018.

[5] V. Sonnenschein *et al.* Las. Phys., 27(8):085701, 2017.

[6] Bouzed A. *et al.* The Euro. Phys. J. **D**, 23(1):57 2003.

[7] H. M. Lauranto *et al.* Appl. Phys. **B**, 50(4):323 1990.

P5

HIGHLY CONFIGURABLE PLASMONICALLY ENHANCED REFLECTANCE OF SEMICONDUCTOR-OXIDE MICROINCLUSIONS

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The plasmonic resonances of low-bandgap semiconductor microinclusions have excellent and tunable scattering properties. The large scattering cross-section of nano- and micro-inclusions are exploited to design devices and specialty spectrally sensitive coatings for sensors, high temperature insulators, and solar applications. Here we investigate spectrally sensitive coatings for Gradient Heat Flux Sensors (GHFS) for fire-safety applications. GHFS detect flame radiation instanteously, which is important for the fast detection of fires, and the compact mm-sized sensors unobtrusively provide more information than current sensors. The sensors are coated with semiconductor-embedded composites designed to reflect unwanted wavelengths and to distinguish the observed radiation from other sources of heat in the IR range.

Here we have developed Multiscale Modelling methods to simulate the spectral response of spherical microparticles embedded in an insulating medium at low volume fraction with controlled localized surface plasmons and broadband IR-reflectance. By adjusting the geometry, size, and dielectric environment of the particles, up to 65% of blackbody radiation between 400 and 1600 C was reflected [1]. Further, the surface resonances of core-shell and shell-core spheres can be tuned to match the flame or solar spectrum. These multilayered spheres enhance the total reflectance up to 74% of the near- and short-IR spectrum and enable specific wavelengths to be blocked.

[1] J. Tang et al. Scientific Reports 7, (2017) 5696.

MODELLING GEV ION EFFECTS IN EQUIATOMIC NICO AND NIFE

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Concentrated solid solution alloys (CSAs) are rapidly gaining attention and assessed for their radiation tolerance properties [1,2]. However, the effects of GeV ion irradiation on CSAs have been barely studied at all. While the GeV energy regime is less intriguing than the lower energy regime from an application point of view, it gives unique insights into the response of the electronic subsystem of the target to an irradiation event.

In this energy regime, almost all the energy from the deceleration of the ion transforms into electronic excitations and ionizations. Regardless, GeV ion bombardment can induce structural modifications even in metallic targets. The mechanisms by which the modifications form are still unclear.

There exists no definitive model to capture GeV ion effects in a computer simulation. As the same mechanisms are likely to be active also at lower energies, validating the models of electronic energy loss in the high energy regime is relevant for the keV to MeV regime as well. Explicit quantum mechanical simulations are difficult due to size and timescale. A prominent semiclassical model for metals is the two-temperature molecular dynamics model (2T-MD) [3], which relies on the earlier radiation damage model by I.M Lifshitz, M. I. Kaganov and L. V. Tanatarov [4]. We have studied GeV ion effects in Ni, $Ni_{50}Co_{50}$ and $Ni_{50}Fe_{50}$ using the 2T-MD model and present tentative results.

This work partially supported by Energy Dissipation to Defect Evolution (EDDE), an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences.

[1] Y. Zhang, G.M. Stocks, K. Jin, C. Lu, H. Bei et al., In, Nat. Commun. 6 (2015) 8736.
[2] F. Granberg, K. Nordlund, M.W. Ullah, K. Jin, C. Lu et al. , Phys. Rev. Lett. 116 (2016) 135504.
[3] D.M. Duffy, N. Itoh, A.M. Rutherford, A.M. Stoneham, J. Phys. Cond. Matter. 20 (2008) 82201.
[4] I.M. Lifshitz, M.I. Kaganov, L. V. Tanatarov, J. Nucl. Energy. Part A. React. Sci. 12 (1960) 69–78.

SIMULATING WAVE PROPAGATION ON A SPHERICAL MEMBRANE USING THE FINITE ELEMENT METHOD

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Wave propagation on membranes can be used to determine the tension or elasticity of a membrane from the wave propagation speed according to theory [1]. A similar approach with surface waves has been used, e.g., to determine the elasticity of tissue phantoms [2]. We propose that for a spherical, taut membrane, the propagation speed of a membrane wave can be used to determine the inflation pressure when the membrane parameters are known. We show that finite element method (FEM) modelling can predict this pressure from the wave propagation speed created by a surface excitation.

The FEM model was created with COMSOL Multiphysics (v. 5.2). The model consists of a spherical membrane modelled as a solid structure with membrane approximation. The pressure on the inner surface of the sphere was used in a stationary simulation to pre-stress the membrane. The pre-stressed state was then used in a time dependent simulation where a surface excitation was used to generate a propagating wave, Fig 1a.

The time of flight of the membrane wave at different pressures agree with experimental values, Fig 1b. The wave shape is different at some pressures. This difference is likely due to variations in the simulation's physical parameters compared to the real-world values.

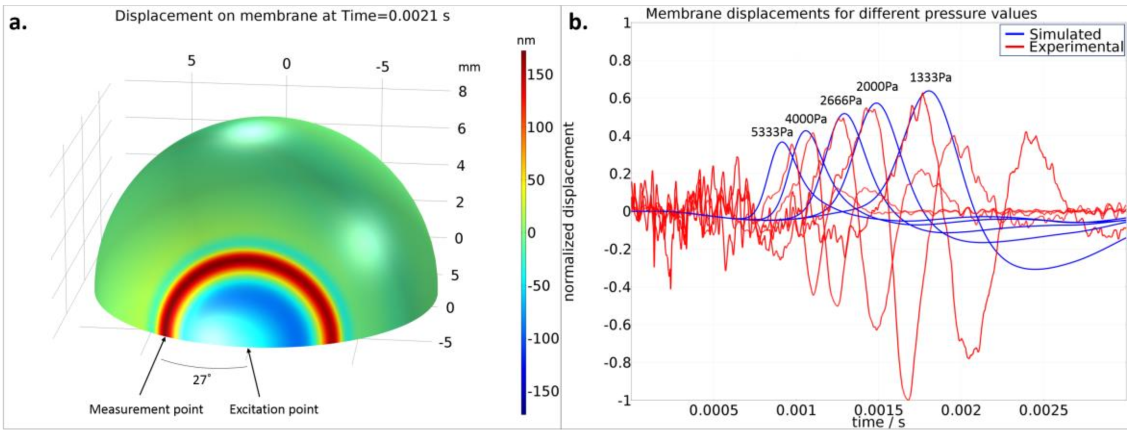

Figure 1: *a) Geometry in the FEM simulations, only half of the structure is modelled due to symmetry. b) Normalized amplitudes for simulated and measured results for different pressures at the measurement point.*

[1] P. Morse and K. Ingard, Theoretical acoustics, Princeton University Press 1968
[2] X. Zhang et al., The Journal of the Acoustical Society of America 122 (2007) 2552

CHARGE CARRIER TRANSPORT IN A PHOTOELECTROCHEMICAL CELL

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A photoelectrochemical (PEC) cell combines a power generating solar cell and a reaction driving electrochemical electrode into a single device. Although PEC cells offer an environmentally friendly way to store solar energy with good scaling potential, in order to economically compete with fossil fuels, the total efficiency of the system has to be increased. Regardless of the extensive research on the topic, the dynamics of a PEC system are not completely understood, and time consuming experimental studies are required to quantify the effects of design choices [1]. An accurate device–level model of the system would allow for the optimization of many device parameters without the need for trial–and–error experimentation.

In this work a numerical model of the semiconductor photoelectrode of a PEC cell was implemented. The carrier transport equations, the current continuity equations and the Poisson's equation are solved self–consistently within the semiconductor. The carrier transport model is combined with electrochemical boundary conditions and an analytical model of the electrolyte to simulate the response of the semiconductor electrode in working conditions. The simulation output can be directly compared to measured data from a real device, allowing educated design of the electrodes based on the results of the simulation.

This work was done as a part of a joint project of Aalto University and VTT aiming to increase the efficiency of storing the energy from sunlight in specific fuel components. The project is funded by the Academy of Finland, Aalto University, and VTT.

[1] K. Takanabe, "Photocatalytic water splitting: Quantitative approaches toward photocatalyst by design," *ACS Catalysis*, vol. 7, no. 11, pp. 8006–8022, 2017.

ELECTRONIC PROPERTIES OF ADATOMS SELF-DIFFUSING ON METAL SURFACES UNDER ELECTRIC FIELD

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Understanding the basic phenomena behind the atomic self-diffusion on metal surfaces under the electric field can potentially benefit many applications including atom probe microscopy and accelerator technology.

It has been a common understanding that atomic diffusion is biased towards the sharp features on a surface where local electric field is higher. However, the quantitative relation between the electric field gradient and a change of the migration energy barriers is not yet fully constructed. It was proposed in the 70s by Tsong et al that the reduction in the energy barrier is related to the change of the surface-induced dipole moment and polarisability of the adatom along the migration path by the electric field. [1]

In this work, we look in detail into the electronic properties of W and Cu adatoms self-diffusing on perfect metallic surfaces under electric field by the means of Density Functional Theory. We calculated dipole moments and polarisabilities of adatoms and studied how electronic properties affect the energy barriers under the electric field. We compared the obtained results for both cathode and anode cases.

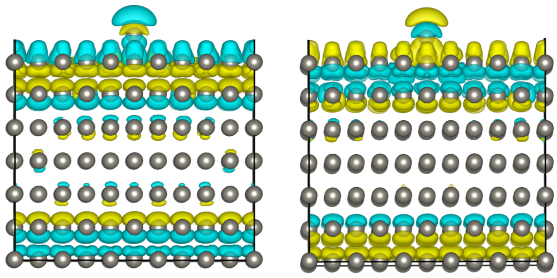

Figure 1 The change of electron density introduced by 1 GV/m electric field on an anode (right) and a cathode (left) obtained with VASP DFT code. Yellow color correspond to accumulation of electrons due to electric field, blue - to depletion. It could be seen that electrons are pushed by the electric field further to the surface on an anode side and pulled away on a cathode

[1] T. T. Tsong, and G. Kellogg, Direct observation of the directional walk of single adatoms and the adatom polarizability, Physical review B (1975), 12(4), p.1343

MICROCONTROLLER BASED FEEDBACK FOR HIGH-POWER ULTRASOUND SYSTEM

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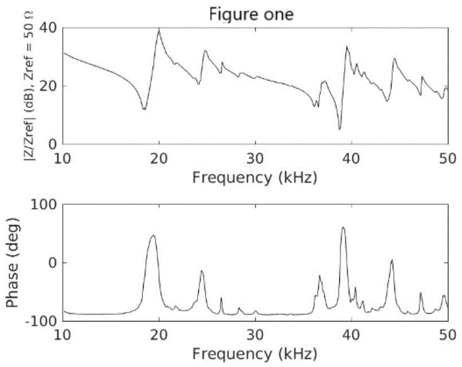
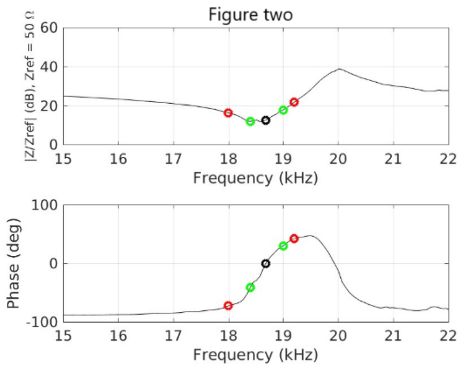
Ultrasonic transducers convert electric energy into ultrasound. To be effective, a piezoelectric transducer needs to run at its resonance frequency. It is possible to optimize systems to run on either the resonance or the antiresonance frequency. In high power ultrasound applications, the resonance frequencies creep due to temperature, loading and nonlinear effects. Narrowband systems feature a high mechanical Q-value and can deliver high power but are finely tuned to a narrow frequency range [1]. If the system creeps away from the resonance in a narrow band system, drastic changes in the impedance (from resonance to antiresonance) can quickly lead to damage or failure of the driving electronics and transducers.

The resonance frequencies can be found by minimizing the phase difference between the driving current and the voltage. We do this by monitoring and altering the driving signals by a microcontroller in a feedback loop. An Arduino Due microcontroller has an efficient processor, and an embedded analog-to-digital converter (ADC) and digital-to-analog converter (DAC). The DAC generates a 30 kHz sine wave that is amplified by a high-power amplifier (4 kW) and fed to the transducer. The ADC monitors the voltage and current and a feedback loop controls the driving frequency to minimize the phase difference. The feedback loop runs at 1Hz.

With the feedback operating, the transducers stayed much closer to the resonant frequency than what we achieved with manual tuning. Figure one shows the impedance curve of our transducer and figure two shows the zoom-in of our transducer with black mark as resonance frequency, red marks as our manual tuning limits and green marks with the microcontrolled system limits.





[1]M.Prokic, Piezoelectric Converters Modelling and Characterization, MPInterconsulting (2004).

P7

MULTI-MODALITY MEDICAL IMAGING

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Technologies in Multi-modality imaging means creating a fusion of images from a variety of sources. In addition patient information is obtained from multiple sources and the physician provides the overall picture of the correct diagnosis to achieve the best possible treatment.
Roughly speaking imaging can be separated to structure (anatomy) and metabolic activity (physiology). Radiology (native x-ray, computed tomography, magnetic resonance imaging and ultrasound) examines anatomy, although some functional descriptions, mainly related to the bloodstream, are part of the range of research. In nuclear medicine, with modest place and time resolution, more physiological questions are investigated, such as changes in metabolism (cancer, metastases), whether the tissue is still vibrant (pulmonary or cardiac perfusion) or how the brain receptors function (dopamine system). Technology development for fusion equipment started by connecting devices either sequentially (Hasegawa; Gamma camera and CT 80s) or overlapping (Townsend; rotating partial PET and CT 90s), but not for clinics. Finally a big annual radiological meeting RSNA in year 2000 finally showed convincing evidence of the strength of the PET/CT device. Today nuclear medicine devices are PET/CT, PET/MR or SPET/CT multimodality devices. Traditional isotope devices, gamma cameras, are still available without a CT option, as many basic studies, such as cardiac stress testing or the determination of renal function, are well maintained without precise anatomical information.

In my talk I will go through a bit of the history and then look at present problems, challenges and ongoing R&D work. The biggest challenge is movement, both periodic (respiratory & cardiac) and involuntary (cough, pain etc.). Several possible solutions have been presented.

In the end of my talk I will look for the future of Multi-modality both in nuclear medicine and other areas.

DEVICE FOR ULTRASONIC SPINNING OF NANOFIBERS

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Nanofibers are found in many applications, including tissue engineering and drug delivery. The manufacturing of nanofibers is commonly done by electrospinning. The traditional electrospinning systems use needle or other physical spinneret to dispense the spinning solution. The replacement of spinneret by ultrasonic fountain gives more control over the physical properties of the produced nanofibers as the acoustic parameters can be adjusted during operation [1].

In this work, we present our improved ultrasonic electrospinning device. The main upgrade is a new ultrasonic transducer which avoids the issue of standing waves forming in the system. We characterize the properties of the nanofibers produced with this system and compare them to the ones produced with the previous one. We also characterize the temporal formation of the acoustic fountain.

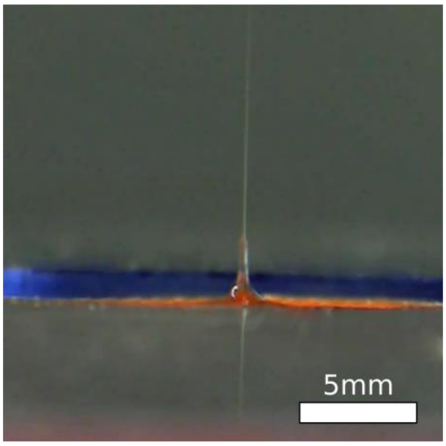

Figure 1: Nanofiber jetting from the acoustic fountain

[1] H.J. Nieminen, I. Laidmäe, A. Salmi, T. Rauhala, T. Paulin, J. Heinämäki, E. Hæggström (2018). Ultrasound-enhanced electrospinning. Scientific Reports, doi:10.1038/s41598-018-22124-z

MEASURING INFORMATION TRANSFER IN THE HEART: TOWARDS DETECTION OF VENTRICULAR ARRHYTHMIAS

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Heart dynamics is a complex phenomenon resulting from interaction between various processes. The core of this interaction is the relation between the electrical properties of the heart and the overall cardiac response in the form of muscle contraction. To this end, studies of duration of the ventricular action potential and its relation to the heart rate have particular importance.

We use advanced numerical methods from information theory to quantitatively study the mutual dynamics of the ventricular action potential duration (known as the QT interval of the electrocardiogram) and the heart rate (inverse of the RR interval) [1]. Namely, we utilize transfer entropy (TE) [2] to quantify *unidirectional* informational flows between the QT and RR coupled time series. We show that for healthy individuals there is a strong asymmetry in the information transfer: the information flow *from RR to QT* dominates over the opposite flow (from QT to RR).

Moreover, as TE assesses the degree of inter-dependence between coupled processes, the asymmetry indicates a higher degree of QT dependence on RR, rather than RR dependence on QT. The former was implicitly assumed in important clinical studies on the QT "correction", which allows for normalizing QT depending on different RR in order to compare different patients. A proper normalization of QT intervals facilitates the detection of severe ventricular arrhythmias that result from prolongation/shortening of QT, which may lead to sudden cardiac death.

Therefore, we consider how the QT "correction" affects the information flows between QT and RR. We show that the present QT correction schemes cannot provide a proper reduction in the transfer of information between RR and QT and, thus, they require further improvements. We conclude that our results obtained through a model-free information theory perspective can be directly utilized to significantly improve the present QT correction schemes in clinical studies.

[1] I. Potapov, J. Latukka, J. Kim, P. Luukko, K. Aalto-Setälä, and E. Räsänen, "Information transfer in QT-RR interval dynamics: towards quantitative model-free QT correction," *submitted* (2018).
[2] T. Schreiber, "Measuring information transfer," *Phys. Rev. Lett.* 85 (2000) 461–464.

INERTIAL CAVITATION MONITORING FOR HIGH-INTENSITY FOCUSED ULTRASOUND SYSTEM

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Inertial cavitation is a stochastic phenomenon. Therefore, utilizing it in tissue treatments requires a calibration sample (tissue phantom) to ensure repeatability of the actuation (a similar number of inertial cavitation events is produced with the same sonication parameters, at different times, with similar calibration samples). During inertial cavitation, imploding micro-bubbles in a liquid generate broad band noise in recorded pressure signals [1]. In our high-intensity focused ultrasound (HIFU) system, we used pulsed ultrasound (2.5 MHz central frequency, 80 cycles/burst, 1.6% duty cycle) on hydrogel samples and picked up echoes with the transmitting transducer (Sonic concepts, H-108). Recorded signals were transferred to a custom-made LabVIEW-program for analyses. During inertial cavitation, the shape of the received echo is distorted – the frequency content changes from the initial pulse, and momentary high pressures are recorded from shockwaves generated by the bubble collapse. Thus, we analyze the envelopes of the recorded echo signals with and without inertial cavitation using cross-correlation with a calibration signal without inertial cavitation. In the absence of inertial cavitation, the cross-correlation of the envelopes produces a single peak, whereas the broad band noise generated by inertial cavitation produces several peaks in the envelope, distinguishable from the single peak in the cross-correlogram. Hydrogel samples served as model substances for biological tissues [2].

By counting the number of inertial cavitation events we determined their relative occurrence in all transmitted signals, also as a function of focusing depth into the sample to explore the effect of tissue depth. Monitoring these events in calibration samples provides a platform for quality assurance of the HIFU system's performance before conducting future experiments with tissue samples.

[1] J. Frohly, *et al.*, "Ultrasonic cavitation monitoring by acoustic noise power measurement", *The Journal of the Acoustical Society of America,* 108(5), pp. 2012-2020, 2000.
[2] G. Menikou and C. Damianou, "Acoustic and thermal characterization of agar based phantoms used for evaluating focused ultrasound exposures", *Journal of Therapeutic Ultrasound*, 5(14) pp. 1-14, 2017.

P8

BOSE-EINSTEIN CONDENSATION OF MAGNONS AND SPIN SUPERFLUIDITY IN THE POLAR PHASE OF ^{3}HE

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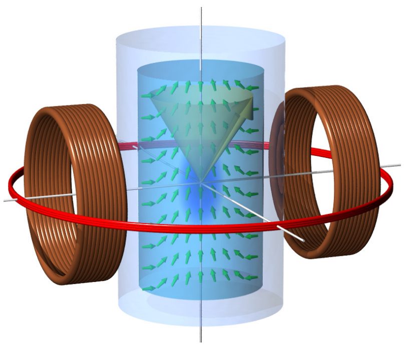
Spin superfluidity is a fascinating demonstration of macroscopic quantum coherence, others being for instance the superfluid current of atoms/mass in superfluid helium and electric charge in superconductors. Spin superfluidity manifests itself as phase-coherent precession of spins and it can be described as Bose-Einstein condensation of spin waves (magnons) [1], originally discovered in ^{3}He-B (figure). Coherent spin transport and manipulation allows for development of quantum spintronic devices, similar to how superconductivity allows implementation of quantum technology using electric supercurrents.

The polar phase of ^{3}He, which is a topological spin-triplet superfluid with a Dirac node line, has been recently stabilized in a nanoconfined geometry. We have pumped magnons into a sample of polar phase and observed how they form a Bose-Einstein condensate, revealed by the coherent precession of magnetization of the sample [2]. Spin superfluidity, which supports this coherence, is associated with the spontaneous breaking of U(1) symmetry by the phase of precession. We have observed the Nambu-Goldstone boson corresponding to this symmetry breaking, and measured its mass when the U(1) symmetry is violated explicitly by applying RF excitation.

Magnon BEC has turned out to be an excellent probe to study superfluid ^{3}He-B. The polar phase opens up new possibilities to use magnon BEC as a tool to detect various topological objects in this phase as well, such as vortices and solitons. It also allows the manipulation of the effective metric for the Nambu-Goldstone bosons, including modeling a black hole horizon, and investigation of a new type of quantum electrodynamics emerging in the vicinity of the Dirac nodal line.



Magnon BEC in ^{3}He-B.

[1] Y. M. Bunkov and G. E. Volovik, Int. Ser. Monogr. Phys. 156, 253 (2013) arXiv:1003.4889.

[2] S. Autti, V. V. Dmitriev, J. T. Mäkinen, J. Rysti, A. A. Soldatov, G. E. Volovik, A. N. Yudin, and V. B. Eltsov, arXiv:1711.02915 (2017).

SUPERFLUID WEIGHT OF SPIN-ORBIT COUPLED TOPOLOGICAL FULDE FERREL STATES IN A SQUARE LATTICE

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The Fulde-Ferrel (FF) state, an exotic superconducting state identified by finite Cooper pair momentum, has been under intense research in the context of ultracold gases. Initially proposed accessible via the mismatch of Fermi surfaces of two pairing Fermi species [1], FF phases have been recently predicted to exist also by applying spin-orbit coupling (SOC) and Zeeman fields [2, 3]. Furthermore, it has been argued that SOC-induced FF states could support topologically non-trivial phases and existence of Majorana fermions both in continuum and in lattice systems [2, 3, 4]. Such topological FF states are conceptually new superconductive phases of matter.

Despite theoretical studies supporting the existence of FF phases, the experimental realization of such exotic superfluid states has been problematic due to a need of low dimensional systems which are required to reach FF phases. In particular in 2D systems, phase transitions to superfluid states is defined by the Berezinskii-Kosterlitz-Thouless (BKT) transition temperature, T_{BKT}, which is usually extremely low. For a superconducting system the BKT temperature in turn depends on the superfluid weight D^s which is responsible for the dissipationless electric current and the Meissner effect - the fundamental properties of superconductors.

In [5] it was shown by computing the BKT temperature that SOC together with Zeeman fields can stabilize FF states in continuum. However, the stability of such phases have not been studied in lattice geometries. In our study we develop a general theory for computing D^s and T_{BKT} in any kind of lattice geometry in the presence of SOC and Zeeman fields, and apply our theory to a square lattice. We show that topologically trivial and non-trivial FF states in a square lattice indeed have finite T_{BKT} and thus could be realized in ultracold gas experiments. We further show that topological FF states are identified with the Chern numbers $C = \{\pm 1, -2\}$ and explain rich topological phase diagram by considering the symmetries of our lattice system. We also show that different topological FF phases can be distinguished from each other by investigating the momentum density profiles which are experimentally accessible quantities. Our work paves the way for stabilizing and identifying exotic topological FF phases in lattice systems.

[1] J. J. Kinnunen et al., arXiv:1706.07076 (2017).
[2] C. Qu et al., Nature Communications 4, 2710 (2013).
[3] W. Zhang and W. Yi, Nature Communications 4, 2711 (2013)
[4] Y.-W. Guo and Y. Che, arXiv:1710.07169 (2017)
[5] Y. Xu and C. Zhang, Phys. Rev. Lett. 114, 110401 (2015)

CRYSTALLIZATION OF SUPERCOOLED LIQUID ANTIMONY

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Crystallization of amorphous antimony occurs extremely rapidly, even 'explosively'[1, 2], producing heat that drive the crystallization front.The processes involved have fascinated scientists for over 100 years[3]. It is not surprising that Sb is a major component in the many commercial phase change materials (PCMs), which are based on the rapid and reversible transition between the amorphous (a) and crystalline (c) form of nanosized 'bits' in a very thin polycrystalline layer. The Sb itself is a simples possible PCM, but unfortunately too unstable for the commercial uses even its rapid crystallization is preferred. While significant progress has bee gained with the stabilizing antimony. To fully utilize the speed of the crystallization in pure antimony one should understand the mechanism of the crystallization.

Here we have present our studies of the crystallization of supercooled liquid Sb using density functional molecular dynamics (DF/MD) simulations. The crystallization is studied with six different MD simulations with up to 882 atoms in the unit cell and three different scenarios: a sample initially without crystalline atoms, four with crystalline slab template and one with a small fixed crystalline nucleus. The structural changes in bond angle, rings, cavities and near-neighbor distributions are discussed and results are viewed on the light of the bond interchange model introduced for AgInSbTe compound by Matsunaga el al.[4].

[1] H. Hendus, Z. Phys. 119, 265 (1942).
[2] F. M. Aymerich and A. Delunas, Phys. Status Solidi A 31, 165 (1975).
[3] E. Bekier, Z. Anorg. Chem. 78, 178 (1912).
[4] T. Matsunaga, J. Akola, S. Kohara, T. Honma, K. Kobayashi, E. Ikenaga, R. O. Jones, N. Yamada, M. Takata, and R. Kojima, Nat. Mater. 10, 129 (2011).

NANOMECHANICAL PROBES OF TOPOLOGICAL QUANTUM VACUUM

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Superfluid ^{3}He is a topological quantum fluid, sharing properties with the quantum vacuum of the Standard Model and other topological matter, such as topological insulators and Weyl semimetals. It allows laboratory experiments on fundamental questions in physics such as the origin of the matter-antimatter asymmetry in the Universe, and serves as a learning platform for the new classes of topological quantum materials. The topological properties of ^{3}He emerge as the gapless (massless) Majorana and Weyl fermions, which exist in the bulk, on the surface or in the cores of topological defects (such as vortices or solitons). Superfluid ^{3}He also possesses a variety of bosonic modes including analogue of the Higgs boson.

Modern micro- and nanofabrication techniques enable creation of extremely sensitive force and mass detectors. We discuss fascinating physics, which can potentially be revealed by such devices in superfluid ^{3}He in the wide frequency (energy) range from vortex-core-bound fermions, light Higgs modes and magnons below 10^5 Hz to heavy Higgs modes above 10^8 Hz and down to the smallest length scales set by the coherence length ($\sim$ 20 nm).

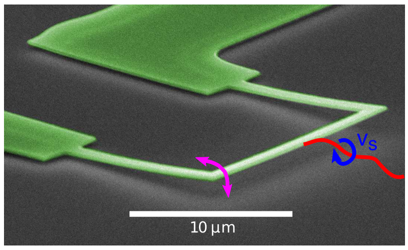

Figure 1: SEM micrograph of a studied device (green) with an illustration of attached vortex.

As the first test devices, we have fabricated suspended aluminium nanomechanical resonators with beam cross section 150 nm $\times$ 1.0 μm, dimensions $\sim$ 10 μm (Fig. 1) and resonance frequency between 300 kHz and 500 kHz. We have measured the response of these magnetomotively driven devices in vacuum and superfluid ^{4}He at temperatures down to 16 mK. The intrinsic damping depends on temperature as $Q_{\rm int}^{-1} \propto T^{0.4}$, which we attribute to tunneling two level systems present in the material. In superfluid ^{4}He, the damping increases further due to momentum transfer with ballistic phonons $Q_{\rm ph}^{-1} \propto T^4$ and rotons $Q_{\rm rot}^{-1} \propto \exp(-\Delta/T)$, whereas acoustic emission is not observed. At large oscillation amplitudes the response of the devices becomes Duffing-like nonlinear, while in superfluid ^{4}He emission of vortex rings is observed above critical velocity.

We expect that the force resolution of these devices ($\sim$ 1 fN) is sufficient for detecting a single quantized vortex attached to the device. First practical applications will be to study the cascade of Kelvin waves towards shorter wavelengths on a single vortex, the role of vortex-core-bound fermions in vortex dynamics, vortex friction due to the chiral anomaly, and the synthetic electromagnetic fields created by vortex motion.

Poster sessions

P1

Constraining supernova progenitors using integral field spectroscopy

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In our project high resolution integral field unit (IFU) spectroscopy is used to infer the properties of stellar populations that make up the host galaxy of several supernovae, NGC 2466. The location of ASASSN-14dd, a rare type Ibn supernova, is especially interesting target of study. This is achieved by fitting combinations of simple stellar populations on the spectra and capitalising on strong-line methods available for the emission lines. With simple stellar population models the age of the population and the supernova progenitor can be deduced. Age of an exploding star is directly related to the mass and type of the star. Emission lines are used to probe the quality of the surrounding interstellar medium, as properties such as metallicity can affect the prevalence of some supernovae.

Observations were done with Very Large Telescope's MUSE instrument, a state-of-the-art IFU. MUSE produces spectra for every pixel in the image instead of the narrow field in the traditional long slit spectroscopy. This allows the whole galaxy to be studied simultaneously. The high spatial resolution of the instrument, 0.2"/px, and good seeing allow recognition of regions in the scale of few hundred parsec within the large 2'x2' field of view.

The results show that the age of the ASASSN-14dd's progenitor star was several tens of millions of years with an inferred mass of less than 20 solar masses. This contradicts with the traditional view that type Ibn's progenitor is a single Wolf-Rayet type star with a minimum mass of 25 solar masses at solar metallicity. Instead the results indicates an alternative channel for these types of supernovae; an interacting binary system of lower mass stars.

LATE-TIME NEAR-INFRARED EVOLUTION OF THE EJECTA AND EQUATORIAL RING OF SN 1987A

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Supernova 1987A, located 50 kpc away in the Large Magellanic Cloud, was first observed on February 24th, 1987. It is the closest supernova observed in modern times. The circumstellar matter of SN 1987A is characterised by a system of three rings. The rings are glowing as a result of being ionized by the extreme UV and soft X-ray light from the explosion. The two outer rings are roughly three times larger than the innermost, equatorial ring (ER). The ER started brightening dramatically when the blast wave from the SN explosion reached the ER around 1995. This also gave rise to the first hotspot on the ER, where the blast wave struck a denser region of matter and subsequently slowed down. Five years later the ring was fully covered in hotspots. The near-infrared brightness of the ring reached its maximum in 2011-2013 and has since started to decline. At the same time the outer edge of the ring has started to brighten relative to the rest of the ring. We present photometry and difference images based on high-resolution near-infrared (0.8 - 2.4 μm) images from the Hubble Space Telescope (HST) and the European Southern Observatory (ESO) Very Large Telescope (VLT). The HST data span from 1997 to 2006 and the VLT data from 2006 to 2017. Similar measurements published before have been made for instance in X-rays (0.5-10 keV), optical (400-700 nm), mid and far-infrared (3.6-160 μm), and radio (3-20 cm). This is the first time such measurements have been done for the ER and ejecta for these epochs in these near-infrared wavelengths.

Characterizing the CCD cameras for astronomical purposes

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ABSTRACT

In the area of Astronomy Charge-coupled devices (CCDs) have been the most common visible and near ultraviolet imaging sensors since the 1980s. Almost all major astronomical instrumentation utilizes CCD imagers for both scientific observations and routine tasks such as telescope guiding. This work tests the instrumental characteristics of the CCD cameras part of the LISA spectrograph package to be installed on the 60cm telescope at the Tuorla observatory, University of Turku. We measured the linearity of the CCD detector, along with the associated gain and readout noise, and test these values against its manufacturer specifications.

CHARACTERISTIC ANALYSIS OF THE TYPE IV RADIO BURSTS OBSERVED DURING CORONAL MASS EJECTIONS ASSOCIATED WITH GAMMA-RAY FLARES

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In this study, we analyze several solar flares associated with Type IV radio bursts and Gamma-ray emission. Type IV radio bursts usually appeared at the part of the emission when particles have trapped in low corona by moving the magnetic structures. Therefore, triangulation measurements performed by STEREO/WIND Waves instruments can give us information on the source region. In addition, the Potential Field Source Surface (PFSS) models provide us a good approximation of the structural changes and the evolution of the magnetic field lines and gives us a better understanding of the relationship between the radio events and the CME structures. We present the study of characteristics of these events base on different images, EUV waves, radio burst dynamic spectra and also PFSS models. All these events are associated with quiet fast CMEs and long duration on Gamma-rays and it seems that it would be a correlation between the spatial evolution and propagation direction of the CMEs with the radio bursts. The detailed comparison of characteristics of CMEs and Gamma-rays for several flares will be helpful to distinguish the probabilities of the sources of acceleration particles as well.

STATISTICAL MODELING OF SOLAR ENERGETIC PARTICLE RADIATION

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Solar energetic particles (SEPs) can be considered one of the most important aspects of space weather. Particle radiation caused by SEPs is harmful for both electronic devices and biological organisms. For space missions outside the shield of the Earth's magnetic field, SEPs constitute the most severe radiation hazard. The high energy part of the SEP spectrum is capable of penetrating into the Earth's atmosphere at polar regions, and thus poses a threat to, e.g., transpolar aircraft flights. SEPs arrive in bursts, known as SEP events, during which the fluxes of particles may increase by several orders of magnitude. The occurrence of these events is random, and therefore must be modeled using statistical methods. In our research on statistical modeling of solar energetic particle fluxes and fluences (time integrals of fluxes) we have utilized data from particle instruments aboard the IMP-8, GOES and SOHO spacecraft, as well as the worldwide neutron monitor network. The measurements have been performed during over five complete solar cycles, i.e., from the beginning of cycle 19 in 1954 until the currently ongoing cycle 24. We present an overview of our modeling methods and give examples of results which can be utilized by the space weather community.

ICME impact at Earth with different plasma characteristics

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We study how the Earth's space environment responds to interplanetary coronal mass ejection (ICME) events by using the Grand Unified Magnetosphere-Ionosphere Coupling Simulation (GUMICS-4) global MHD (magnetohydrodynamic) simulation. ICMEs are large structures in the solar wind and typically drive the strongest geomagnetic disturbances.

We use solar wind data from two ICME events that occurred on 15–16 July 2012 and 29–30 April 2014. Of the two events the 2012 event was stronger in terms of solar wind plasma density, velocity and magnetic field strength. Moreover, the interplanetary magnetic field (IMF) Y component was mostly negative (positive) during the 2014 (2012) event.

In this presentation, we show an overview of the Earth's space environment dynamics during both ICME events.

THE STARVING ELLIPTICAL OF FOSSIL GROUP

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Fossil Group Galaxies are unique Objects in our Universe. Each Group contains a single giant elliptical Brightest Group Galaxy (BGG) with dominating R-band Magnitude comparing to the second brightest member (magnitude difference $\Delta m_{12} > 2\ mag$) and bright external X-ray Halo ($L_x > 10^{42}\, h_{50}^{-2}\ erg\ s^{-1}$). Because of their isolated nature, understanding the origin of Fossil Group will help us how mass assemble in elliptical galaxy. A popular theory suggests that the BGG is formed by galaxy mergers in the early epoch of the Universe. If such explanation is true, remnant of mergers such as tidal tail and cD halo, is expected to be founded in the outer region of BGG. By studying the galaxy brightness profile, we would be able to identify the formation mechanism.

18 Fossil Group BGGs were observed using Discovery Channel Telescope (DCT) for this project. The exposure time for each object is more than 3 hours to ensure the capture of faint light in the outer halo of the galaxy. The galaxies Profile is modelled by the *iraf* routine *ellipse* and extraction was extended further out from the centre than any previous studies. In type-cD galaxy, a typical product of merger, the isophote is a combination of Sersic function (n~4) and an exponential tail. The profile is analyzed by a Sersic function fits and a comparison with the type-cD galaxy.

None of our sample have Sersic index n > 4. That means our BGG samples does not have tidal feature and are unlikely to form via merger activity. The existence of colour gradient also indicates the lack of merging, since such event will redistribute the stellar population randomly across the galaxy. Hence, we believe Fossil Group are old inactive system that have not consume other Galaxy for a long time. Its formation mechanism must be something other than Galactic merger.

SHOWING THE INVISIBLE: CREATING AN EASY-TO-USE PIPELINE CODE WITH PYTHON

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While much of the inspiration of being an Astronomer is gazing at the mysteries of our wonderful Universe through telescopes, a lot of work is also being done on the computer which is rarely showcased, often getting just a line or two in the final publication. The code written for astronomical research also often is even more hidden as many processes are in the form of "black box" pipelines. In this poster I showcase the iterations, mistakes, imperfections, and the joy of finally succeeding at making a python-based routine whose purpose is to quickly process large amounts of data collected on quasar variability. Thus, through this poster, the "black box" routine that I am working on gains some visibility. Plus, it emphasizes, how the easy-to-use computer programs take time and effort to create behind the scenes.

P2

In-beam γ-ray measurement of Pb-184

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The excited states in Pb-184 were first observed at Accelerator Laboratory of the University of Jyväskylä in in-beam gamma-ray experiment using the recoil-decay tagging technique by Cocks et al. [1]. They assigned transitions belonging to a cascade of E2 transitions and forming a rotational band associated with prolate shape. In order to further probe the structure of the beyond mid-shell nucleus Pb-184, we have conducted a new in-beam study using the JUROGAMII+RITU+GREAT+TDR [2–4] instrumentation employing reaction 104Pd(83Kr,3n)184Pb with beam energy 354MeV. The improved experimental set-up allowed us to record ~130 times higher statistics compared to work by Cocks et al. In this presentation, we will show preliminary data that suggest the extension of the yrast band up to spin 14+ and provides evidence for transitions associated with non-yrast structures. Identification of the non-yrast states can provide stringent test for theoretical models in this region and probe the shape coexistence in neutron-deficient Pb isotopes beyond the N=104 mid-shell.

References

[1] Cocks, J., et al. *EPJ A*, 3(1):17–20, 1998. ISSN 1434-601X.
[2] Leino, M., et al. *Nucl Instrum Methods Phys Res B*, 99(1):653 – 656, 1995. ISSN 0168-583X.
[3] Page, R., et al. *Nucl Instrum Methods Phys Res B*, 204:634 – 637, 2003. ISSN 0168-583X.
[4] Lazarus, I., et al. *IEEE Trans. Nucl. Sci.*, 48(3):567–569, 2001. ISSN 0018-9499.

LIGHT ATTENUATION MEASUREMENTS OF LINEAR ALKYLBENZENE SAMPLES

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Use of liquid scintillator detectors has been an increasing trend in neutrino physics within the last decades. The light yield of scintillator detectors surpasses the traditional Cherenkov counters and availability of low-cost and relatively safe compounds as liquid scintillator solvent such as linear alkylbenzenes (LAB) allows the construction of larger neutrino detectors. Current experiments using liquid scintillators, for example, are SNO+ [1] (Sudbury, Ontario in Canada) and JUNO [2] (Kaiping, Jiangmen in China). A downside of liquid scintillators is their tendency to get easily contaminated and undergo changes via exposure to UV light and elevated temperatures. For these reasons, purification and optical properties of liquid scintillators must be studied to make them suitable for large neutrino detectors.

This study focuses on the linear alkylbenzene samples used in C14 experiment [3], an ongoing experiment in Callio Lab [4] (Lab 2), Pyhäsalmi mine. The linear alkylbenzene samples were purified by a standard method used in chemistry called column chromatography: the samples were passed through a fine purification material (aluminium oxide, Al_2O_3) several times. The transparency measurements for the samples were carried out via a setup using a Raspberry camera module as a light detector. The long attenuation length of linear alkylbenzene is problematic for light measurements since it means that the setup must be long enough to detect differences between the purified samples. This setup was built to examine if it is possible to detect differences with this kind of low-cost setup.

Results showed that the current setup is not precise enough to detect any differences between samples with long attenuation lengths. The setup is ideally able to distinguish samples that have at least difference of $0.4\,\%$ in their absorbance. The path length of LAB (50 mm) was not long enough to decrease the light input so that the samples would have had differences over $0.4\ \%$. However, simulations suggested that changing the image format enhances the resolution in order that a long sample container is not necessarily needed.

[1] F. Descamps, Nuclear and Particle Physics Proceedings 265–266 (2015) p.143–145
[2] F. An *et al*, Journal of Physics G: Nuclear and Particle Physics 43 (2016) 030401
[3] T. Enqvist *et al*, Journal of Physics: Conference Series 718 (2016) 062018
[4] Callio Lab, Underground center for Science and R&D

SOLUTION OF THE TIME-DEPENDENT SCHRÖDINGER EQUATION FOR DRIVEN QUBIT SYSTEMS IN TERMS OF THE CURVATURE OF PLANE CURVES

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Obtaining exact analytic solutions to the time-dependent Schrödinger equation with time-dependent Hamiltonians is a longstanding fundamental problem in quantum dynamics, and one that has gained even more importance in the recent years, because of the practical implementations in qubit systems, for example.

Following the connection between the time-dependent two-level systems and the differential geometry of plane curves introduced in Ref. [1], we discuss a method of obtaining solutions for the time evolution in this framework. In particular, since the dynamics can be understood in terms of the curvature of the plane curves alone, we discuss the dependence of the solutions on these curvature functions.

[1] J. M. S. Lehto and K.-A. Suominen, J. Phys. A: Math. Theor. **48**, 235301 (2015).

CHARACTERIZATION OF DIAMOND PARTICLE DETECTORS

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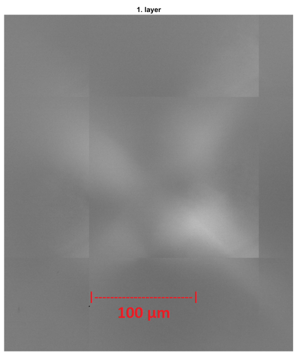
Synthetic CVD diamonds are an emerging special purpose detector technology. They are attractive due to their fast charge carrier transport, radiation hardness, resistivity to chemicals, tolerance for high temperatures and properties close to human tissue. This work is connected to the upgrades in the TOTEM and CMS experiments at the Large Hadron Collider at CERN, that utilize diamonds as time-of-flight detectors[1, 2, 3].

The crystal quality of diamonds is studied with optical characterization. Crystal defects are revealed with microscope imaging using crossed polarizers. Infrared spectroscopy is used to study the concentration of known impurities in diamonds.

The impurity levels, quality of surface processing and electrode quality are also controlled via electrical characterization. Leakage current together with signal current reveal possibly high impurity levels. The current stability over time tests in addition the electrode quality.

Diamonds are further studied using radiation sources. Signal recorded with Sr-90 radiation source gives response to minimum ionizing particles. Transient Current Technique (TCT) with a triple line alpha-source is used to probe the distribution of the electric field inside the detector. This gives information on the charge trapping, the effective doping and the electrode quality. The α-source can also be used to measure the energy resolution of the diamond.



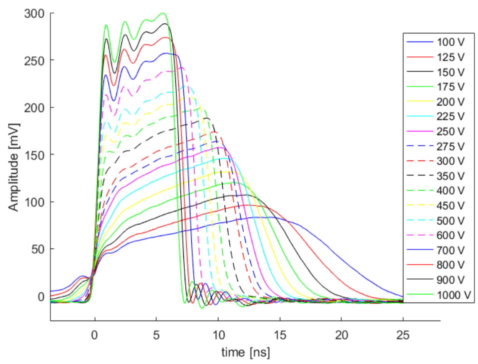


Figure 1: **Right** Example of crystal defect polarizing light **Left** Typical current transients in αTCT for diamond

[1] TOTEM collaboration, CERN-LHCC-2014-020 TOTEM-TDR-002 (2014).
[2] G. Antchev et al., (TOTEM collaboration), JINST 12 (2017) P03007
[3] CMS and TOTEM collaborations, CERN-LHCC-2014-021 TOTEM-TDR-003 CMS-TDR-13 (2014).

EXPERIMENTAL DETERMINATION OF THE TRANSITION STRENGTH OF THE SECOND-FORBIDDEN TRANSITION BETWEEN ^{20}F AND ^{20}NE

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The fate of medium-mass stars ($8 - 10$ M$_\odot$) depends sensitively on electron capture rates in the ONe core. In an important temperature-density range the electron capture rate is believed to be dominated by the second-forbidden, non-unique transition between the ground states of ^{20}F and ^{20}Ne [1]. The strength of such transition can be determined from the branching ratio of the inverse transition in the β-decay of ^{20}F. In 1970s an upper limit of < 0.001 % was obtained in the experimental study of the β-decay of ^{20}F [2].

In our project the ^{20}F activity was produced via ^{19}F$(d,p)^{20}$F reactions at the IGISOL facility [3] in the Accelerator Laboratory of University of Jyväskylä using a 9 MeV deuteron beam on a thin BaF_2 target. The $^{20}F^+$ ions were mass-separated using a dipole magnet before they were implanted into a thin carbon foil at the experimental setup. The yield of ^{20}F was around 22000-27000 ions/s at the setup, and the experiment lasted for 9 days.

The experimental setup consisted of a refurbished Siegbahn-Slatis type intermediate-image magnetic spectrometer, which was built in 1980s at the University of Jyväskylä [4], accompanied with a plastic scintillator to determine the branching ratio in the ^{20}F β-decay. The plastic scintillator was improved due to the testing done during the past year. Previously, the detector consisted of two parts: an inner part for the electron detection surrounded by an outer part for vetoing the cosmic γ-rays. However, this turned out not to be sufficient. Therefore, the inner detector was further divided into two parts, which act as a ΔE-E type of a detector. A shield to prevent positrons entering the detector and a $LaBr_3$ detector for measuring 1.6 MeV γ-rays from the ^{20}F β-decay to the first excited state in ^{20}Ne was placed inside the spectrometer. The online experiment was performed successfully in January 2018. In this contribution, the improvements of the setup and the preliminary results of the online experiment will be discussed.

[1] G. Martinez-Pinedo *et al.*, Phys. Rev. C 89 (2014) 045806.
[2] F. P. Calaprice *et al.*, Phys.Rev. C 17 (1978) 730-738.
[3] I. Moore *et al.*, Nucl. Instr. Meth. B 317 (2013) 208-213.
[4] R. Julin *et al.*, Nucl. Instr. Meth. 270 (1988) 74-77.

DETECTOR DEVELOPMENT IN HELSINKI DETECTOR LABORATORY

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The Helsinki Detector Laboratory is a national infrastructure providing premises, equipment, knowledge and technical support for research projects developing radiation detector technologies for large international experiments of particle and nuclear physics as well as applications in e.g. the security and medical fields.

Radiation hard finely segmented silicon pixel detectors are being developed for the future Phase-2 Upgrade of CERN CMS experiment. Potentially interesting approaches include the use of aluminum oxide or hafnium oxide thin films deposited by ALD (Atomic Layer Deposition) method on p-type silicon material and capacitive-coupled pixel structures. Pixel detector technology for medical imaging and x-ray beam characterization is developed with several Finnish university groups, STUK and companies. Several interesting approaches include the usage of CdTe material and thick silicon.

The Detector Laboratory is strong in GEM (Gaseous Electron Multiplier) technology. A GEM foil is a metal-coated 50-70 μm thin polyimide foil perforated with 50-70 μm diameter holes with 120-150 μm pitch. In strong electrical field, the holes act as amplifying elements to the electrons generated by incident radiation. GEM foils will be used in GEM-TPC (Time Projection Chamber) detectors, being developed for the beam monitoring of the FAIR NuSTAR Super-FRS separator. In addition, the Laboratory is in charge of optical and electrical quality assurance of about 400 GEM foils for the upgrade of the ALICE TPC detectors at CERN.

Quality assurance has been done for diamond timing detectors for the upgrade of the so-called Roman Pot stations of CERN TOTEM experiment. Diamond semiconductor detectors are a rising technology with promising properties for radiation hardness and precise timing. In Detector Laboratory, alpha-TCT (Transient Current Technique) methods, among others, are applied to characterize diamond detectors. In addition, scintillator detector concept is being developed for the replacement of TOTEM T2 experiment.

Together with STUK and Finnish industry, detector technology for nuclear safety, security and safeguards is being developed. Presently, the focus is on the characterization of spent nuclear fuel using gamma ray emission tomography and neutron measurements and on high-energy gamma ray Compton imaging.

FINLAND'S ROLE IN INTERNATIONAL RUSH/PUSH FOR FUSION ENERGY

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Fusion research is rapidly moving from academic studies to demonstration of fusion energy (ITER) and the related power plant technology (DEMO). Over the years the fusion research in Finland has diversified to cover key issues starting from the generation of fusion power in the center of the plasma all the way to handling the 'trash bins' called divertors in the reactor periphery. The four research areas where Finland has gained international reputation are, starting from the center: *heating* and *fuelling* (Aalto & VTT), plasma turbulence (Aalto), physics of *edge plasma* (Aalto), and *plasma-material interaction* (UH & VTT). In addition, Tampere (VTT & TUT) is the site for the *divertor* test platform for ITER, and has a strong role in remote handling and robotics. Robotic handling and intelligent maintenance for ITER and DEMO are developed at LUT. This contribution gives an overview of these Finnish contributors to the realization of fusion energy.

Plasma *heating* takes place via energetic particles. Impeccable confinement of these ions is required for successful operation of a fusion reactor. Today, the most comprehensive fast ion code is ASCOT, developed at Aalto. It is used to estimate the confinement and wall power loads for ITER and DEMO, as well as for the upcoming JT-60SA tokamak in Japan and world's largest stellarator W7-X. Most of the fusion power is carried out by the 14.1 MeV neutrons, the birth and transport of which are evaluated by ASCOT and Serpent (VTT).

Turbulence induced transport, a challenging problem in physics in general, can compromise the magnetic confinement and, thereby, the fusion process. To explore this chaotic transport regime a first principles computer model that solves the coupled problem of Boltzmann's kinetic equations and Maxwell's equations in a complex magnetic field is required. The gyrokinetic code ELMFIRE, developed at Aalto and VTT, has already been applied to small tokamaks to investigate transport scaling and turbulence self-organization as well as plasma *fueling* at JET. Fueling is also studied experimentally (JET in UK, DIII-D and C-Mod in US).

It is the *plasma edge* that will determine the operational conditions of future fusion reactors and the lifetime of plasma-facing components: the edge is the buffer between the 100 million degree plasma and the 'cool' vessel walls. The imperfect magnetic confinement and various 'off-normal' events, if unmitigated, can lead to excessive (tens of MW/m^2) power loads to plasma-facing components. Therefore tailoring the conditions in the so-called scrape-off-layer between the plasma and the wall is of utmost importance. Transport of heat and particles in the tokamak periphery is studied with various fluid codes at Aalto.

The power and particle load from burning plasma is challenging to any material, and *erosion, activation* and *fuel retention* can be expected. Therefore both the migration of the released impurities and changes in different materials and their effect to fuel retention have to be understood. These issues are studied experimentally at VTT and UH by analyzing tracer injection experiments and marker tiles. In addition, materials are modelled from nano to macro scales at UH, allowing not only understanding the phenomena but also developing new materials that could better survive the hostile environment of a fusion reactor.

The unavoidable particle and power load is led to the *divertors*, made of extra durable material, that will be replaced periodically. The ITER divertor test platform, where robotic change of the divertor cassettes is developed and tested, is hosted at VTT, Tampere.

OBSERVATION OF EXCLUSIVE DILEPTON PRODUCTION WITH PROTON TAG IN THE CMS-TOTEM PRECISION PROTON SPECTROMETER

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The CMS-TOTEM Precision Proton Spectrometer (CT-PPS) [1] focuses on measuring high mass Central Exclusive Production (CEP) processes, $pp \rightarrow p + X + p$, in high luminosity proton proton (*pp*) collisions at CERN's Large Hadron Collider (LHC). These processes are sensitive to beyond Standard Model physics either via loops through e.g. anomalous quartic couplings, where X could be e.g. W^+W^- *or* $\gamma\gamma$, or via direct production of new particle(s) in e.g. supersymmetric scenarios. The final state protons are measured using movable near-beam devices, so-called Roman Pots (RP), located at about ± 210 m from the interaction point. The RPs are equipped with silicon sensors for precise (~ 10 µm) position determination and diamond and silicon sensors for a precise (~ few 10's ps) proton time-of-flight measurement. The central system, X, is measured by CMS [2].

The process $pp \rightarrow p + l^+l^- + p^{(*)}$, with l^+l^- a muon or an electron pair produced at mid-rapidity with a mass $m(l^+l^-) > 110$ GeV, has been observed for the first time in *pp* collisions at $\sqrt{s} = 13$ TeV [3]. One of the two scattered protons is measured in the CT-PPS. The second proton either remains intact or dissociates into a low-mass state, p^*, which is undetected. The measurement is based on an integrated luminosity of 9.4 fb^{-1} collected during standard, high-luminosity LHC operation in 2016. A total of 12 $\mu^+\mu^-$ and 8 e^+e^- pairs, with matching forward proton kinematics, are observed, with expected backgrounds of 1.49 ± 0.53 (stat. + syst.) and 2.36 ± 0.47 (stat. + syst.), respectively, corresponding to an excess of > 5 standard deviations over the expected background. The result constitutes the first observation of proton-tagged $\gamma\gamma$ collisions at the electroweak scale. It also demonstrates that the CT-PPS performs according to design specifications.

[1] The CMS and TOTEM collaborations, "The CMS-TOTEM Precision Proton Spectrometer", CERN-LHCC-2014-021, CMS-TDR-13, TOTEM-TDR-003 (2014).
[2] S. Chatrchyan *et al.* (CMS collaboration), JINST 3 (2008) S08004.
[3] The CMS and TOTEM collaborations, "Observation of proton-tagged, central (semi)exclusive production of high-mass lepton pairs in pp collisions at 13 TeV with the CMS-TOTEM Precision Proton Spectrometer", CMS-PPS-17-001, TOTEM-2018-001 (2018), to be submitted to JHEP.

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JET ENERGY FRACTIONS IN DIJET EVENTS IN LHC RUN 2 DATA
(2016-2017)

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The LHC Run 2 has now been going on for three years (2015-2017) and it will continue until the end of 2018. After this, the apparatus will enter its second long shutdown period for 2019-2020. The second run of the LHC has been proceeding well, and during 2016 and 2017 the CMS detector has recorded 37.76 fb^{-1} and 46.02 fb^{-1}, correspondingly.

Even as the data gathering is proceeding well, no clear much-anticipated hints of new physics (e.g. supersymmetry) have been observed. This implies that alongside with the searches for new physics there is a good motivation to concentrate on precision measurements. More precise measurements provide a possible channel to observe deviations from the standard model. Alternatively, they may give a better understanding of the standard model.

One important part in precision measurements are the jet energy corrections. The term jet refers to a collimated spray of particles, observed at the detector. Typically a jet is originated from a single parton, i.e. a quark or a gluon. The jet energy corrections are used to translate the particle signals arriving to the detector into a measure of the parton from which a jet originated.

One method for studying and developing the corrections is the use of jet energy fractions. These indicate the percentages of different particle types (e.g. neutral and charged hadrons) within a jet. The fractions are typically studied as a function of jet transverse momentum and pseudorapidity.

In this poster I will present the most recent jet energy fraction results for the CMS detector at the LHC. The 2016 CMS jet energy corrections are currently reaching their final form and the first versions of the 2017 corrections are being pushed out. Thus, jet energy fractions for these years are at the moment a very timely result.

P3

UNIVERSITY OF TURKU SCIENCE CENTRE TUORLA

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University of Turku has established a science centre in the premises of Tuorla Observatory. The main activity in the centre will be organizing phenomenon based learning possibilities to school children. The philosophy behind the centre is that everyone should know how science works. We will start with natural sciences and phonetics and will continue to social sciences and humanities.

Phenomenon based learning is the new phenomenon in pedagogical thinking. It is obligatory in both ground and high school curricula, but teachers have not learned executing such projects during their studies. Science centre Tuorla aims at supporting teachers at schools by offering school trips or camps with phenomenon based projects. The centre will also be used in education of new teachers and further education of practising teachers.

The phenomenon projects will be based on the school curricula and the research done at the Faculty of Education in University of Turku. They will include planetarium shows, doing experiments, analysing results, discussing and drawing conclusions. The children will learn by their own activity how scientific conclusions are drawn. The phenomenon based projects will be modified by the age of the children, so that high school students will concentrate on the large multi-discipline societal problems listed by United Nations in Sustainable Development Goals 2016.

P4

CHSH Bell inequality test in an optomechanical device

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We propose here a scheme, based on the measurement of quadrature phase coherence, aimed at testing the Clauser-Horne-Shimony-Holt Bell inequality [1] in an optomechanical setting. Our setup is constituted by two resonant optical cavities coupled to a common mechanical resonator. We show that it is possible to generate EPR-like correlations between the quadratures of the output fields of the two cavities, and, depending on the system parameters, to observe the violation of the Clauser-Horne-Shimony-Holt inequality [2].

[1] John F. Clauser, Michael A. Horne, Abner Shimony and Richard A. Holt, Phys. Rev. Lett 23 (1969) 880.

[2] M. Asjad, J. Manninen, E. Selenius, R. Ojajärvi, P. Kuusela and F. Massel (in preparation)

Remote polarization-entanglement generation by local dephasing and frequency up-conversion

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We introduce a scheme for remote entanglement generation for the photon polarization. The technique is based on transferring the initial frequency correlations to specific polarization-frequency correlations by local dephasing and their subsequent removal by frequency up-conversion. On fundamental level, our theoretical results show how to create and transfer entanglement, to particles which never interact, by means of local operations. This possibility stems from the multipath interference and its control in frequency space. For applications, the developed techniques and results allow for the remote generation of entanglement with distant parties without Bell state measurements and open the perspective to probe frequency-frequency entanglement by measuring the polarization state of the photons.

[1] S. Hamedani Raja, et al., *PHYSICAL REVIEW A* **96**, 013844 (2017)

Dynamic nuclear polarization of doped silicon at low temperatures

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Nuclear spins coupled to electrons is interesting system for future quantum architectures. Shallow donors in Si coupled to ^{29}Si nuclei is one such system. The coherence of ^{29}Si nuclei in the "frozen core" near the nuclei is protected by the donor electron leading to very long coherence times [1]. Here, we report on dynamic nuclear polarization (DNP) experiments of ^{29}Si in As doped silicon.

The Overhauser effect hole burning DNP experiments shows preferable polarization of the spins having the weakest interaction with donor electron. This result is not expected from the usual modulation of isotropic or anisotropic hyperfine interaction. The ^{29}Si nuclei with strong anisotropic interaction can be polarized by utilizing the solid effect. The Overhauser and solid effect DNP methods provide almost full control of spin polarization of the donor and the nearby ^{29}Si nuclei [2]. In magnetic field of 4.6 T and below 1 K temperatures the donor electron spins are fully polarized. The DNP of nuclear spins is achieved by exciting electron spin resonance (ESR) transitions. Spin polarization is observed directly from the ESR spectrum and the polarization is not disturbed during the measurement.

[1] Gary Wolfowicz et al., New J. Phys. 18 (2016) 023021.
[2] J. Järvinen, et al., Phys. Rev. B, 92 (2015) 121202.

SYNTHETIC ELECTROMAGNETIC KNOT IN A THREE-DIMENSIONAL SKYRMION

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Quantum simulations of electromagnetic forces have the potential to provide information about materials and systems that do not have conveniently solvable theoretical descriptions, such as those related to quantum Hall physics [1], or that have not been physically observed, such as magnetic monopoles [2,3]. However, quantum simulations that simultaneously implement all of the principal features of classical electromagnetism have thus far proved elusive. We experimentally realize a simulation in which a charged quantum particle interacts with the knotted electromagnetic fields peculiar to a topological model of ball lightning [3]. These phenomena are induced by precise spatiotemporal control of the spin field of an atomic Bose–Einstein condensate, simultaneously creating a Shankar skyrmion—a topological excitation that was theoretically predicted four decades ago [4,5] but never before observed experimentally (see Figure 1). Our results reveal the versatile capabilities of synthetic electromagnetism and provide the first experimental images of topological three-dimensional skyrmions in a quantum system.

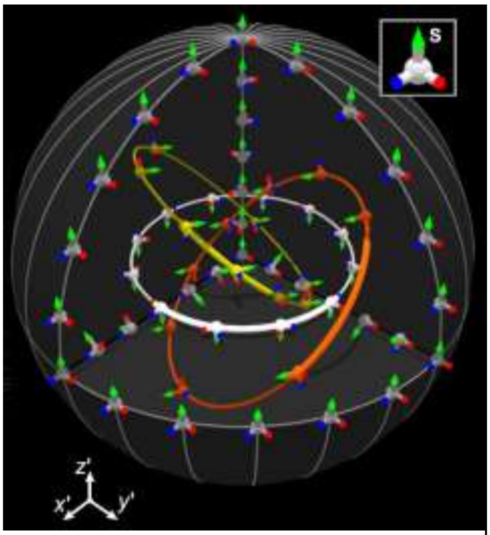

Figure 1. Structure of the created skyrmion in an octant. The quantum order parameter is described by a triad (see inset). The direction of the spin (green tip) is constant along the colored example curves.

[1] G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, and T. Esslinger, Nature 515 (2014) 237.
[2] M. W. Ray, E. Ruokokoski, S. Kandel, M. Möttönen, D. S. Hall, Nature 505 (2014) 657.
[3] M. W. Ray, E. Ruokokoski, K. Tiurev, M. Möttönen, D. S. Hall, Science 348 (2015) 544.
[4] G. E. Volovik, V. P. Mineev, Zh. Eksp. Teor. Fiz. 73 (1977) 767.
[5] R. Shankar, J. Phys. France 38 (1977) 1405.

STRONG COUPLING EFFECTS IN AN OPEN QUANTUM SYSTEM

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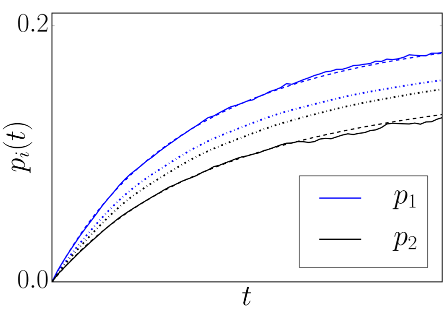
Theory of open quantum systems has a wide variety of applications in physics, ranging from quantum optics to superconducting circuits, quantum information and quantum computing. One important feature of open quantum systems is the quantum-mechanical treatment of dissipation, which is usually described by Lindblad master equations. However, due to their perturbative nature, these master equations can only model systems with weak coupling to the environment. This is a serious shortcoming for high-precision applications, such as quantum-state preparation with environmental engineering [1]. A more accurate equation of motion, the formally exact stochastic Liouville–von Neumann (SLN) equation, can be obtained for a bilinearly coupled bosonic environment using the path integral formalism [2]. We solve the SLN equation for the quantum Rabi Hamiltonian and compare the results to those obtained with two different Lindblad master equations [3]: the quantum optical master equation videly used in quantum optics, and the eigenstate master equation which describes transitions between the eigenstates of the system Hamiltonian. We find three different cases: 1) Both master equations agree with the SLN equation. 2) Only one of the master equations agrees with the SLN equation (see Figure). 3) Neither of the master equations agrees with the SLN equation. Our results highlight the validity limits of the master equation approach and demonstrate that a more accurate method should be used for solving the dynamics of open quantum systems.

Figure: Occupation probabilities of the first and second excited eigenstates of the Rabi Hamiltonian as a function of time as given by the Stochastic Liouville–von Neumann equation (solid lines), the eigenstate master equation (dashed lines) and the quantum optical master equation (dotted lines).



[1] M. Partanen, *et al.*, arXiv:1712.10256 (2017).
[2] J. Stockburger, and H. Grabert, Physical Review Letters **88**, 17 (2002).
[3] M. Scala, *et al.*, Physical Review A **75**, 013811 (2007).

SEEING THE SUPERPOSITION OF POLARIZATION VIA WEAK MEASUREMENT

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The most common way of measuring the polarization of light requires 6 different, complementary stages that can be somewhat slow, each of them collapsing the wave function ψ according to the Copenhagen interpretation. Hence, there is no straight access to ψ; One has to reconstruct it by using the 6 distinct measurement outcomes. This is called *strong measurement*. However, via *weak measurement* (first studied by Aharonov *et al.* in 1988 [1]) it is possible not to collapse ψ and determine its possible superposition structure straight away.

The idea behind weak measurement is based on using quantum probes that are extremely weakly connected to the actual state of interest. This way, measuring the probe doesn't affect ψ too much, and ψ can be calculated by using both the measurement outcome (dubbed the *weak value*) and the known connection. Kobayashi *et al.* showed in 2014 that when measuring the polarization of a Gaussian mode converted to an LG-mode, one can interpret the zero intensity point of the LG-mode as the weak value of polarization. It can then be projected to the Bloch sphere, corresponding to a unique quantum state [2].

The measurements of Kobayashi *et al.* were successfully recreated in the University of Turku in 2016. The measurement scheme was carried even further as we applied it to mixed states also. By mixing pure horizontal and vertical polarization states in different ratios we were able to travel through the Bloch sphere in a controlled fashion. This was reportedly the first time ever the Bloch sphere was pierced in such a controlled way.

Finally, applying weak measurement to determine the concurrence of a 2-qubit system was also studied (following the work of Tukiainen *et al.* [3]), leading to some very promising results, although more measurements are still needed.

[1] Y. Aharonov, D. Z. Albert and L. Vaidman, *How the Result of a Measurement of a Component of the Spin of a Spin-$\frac{1}{2}$ Particle Can Turn Out to be 100*, Physical Review Letters, **60**(14), 1351 (1988).

[2] H. Kobayashi, K. Nonaka and Y. Shikano, *Stereographical visualization of a polarization state using weak measurements with an optical-vortex beam*, Physical Review A, **89**(5), 053816 (2014).

[3] M. Tukiainen, H. Kobayashi and Y. Shikano, *Quantification of Concurrence via Weak Measurement*, Physical Review A, **95**(5), 052301 (2017).

Miniature microwave resonators for electron spin resonance

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Electron spin resonance (ESR) is a well known experimental method to detect unpaired electrons. It has numerous applications in e.g. biology, medicine, chemistry and physics. One of the main limitations of the ESR is the relatively low spectroscopic sensitivity utilizing induction detection. The detection sensitivity of ESR is $\propto \sqrt{V_c/(\omega_0 Q_u)}$ [1], where V_c is effective volume, ω_0 is frequency and Q_u is the unloaded quality factor of the cavity.

Commercial ESR spectrometers have typical sensitivity of about 10^9spins/$\sqrt{\text{Hz}}$. Scaling down the size of the resonator has been shown to improve the sensitivity by two orders of magnitude [2]. In addition to smaller size the power to B_1 field conversion ratio can be of the order of 0.1 T for only 1 W of input power [1]. This simplifies the utilization of pulse ESR methods at ultralow temperatures for e.g. electron spin qubit control.

Here we show analysis and first tests of ESR microresonator similar to ref. [1]. Resonators were fabricated on microwave substrates ($\epsilon \approx 9.8$) with standard photolithography. The resonance frequencies are from 7 to 11 GHz. The resonator is connected to x-y piezo actuators [3], which can move it on a microstrip line to adjust the coupling. The sensitivity of the spectrometer was estimated by measuring a continuous wave spectrum of a DPPH sample at room temperature.

[1] Y. Twig, E. Dikarov, and A. Blank, Mol. Phys., 111 (2014) 2674.
[2] Y. Twig, E. Suhovoy, and A. Blank, Rev. Sci. Instrum., 81 (2010) 104703.
[3] Attocube systems AG, Koeniginstrasse 11a, 80539 Muenchen, Germany (ANPx51)

A SELF-SEEDED GRATING-BASED TITANIUM:SAPPHIRE LASER

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Wide range wavelength tunability is of highest relevance for comprehensive spectroscopy in unknown atomic systems. In addition, it permits for fast switching between different elements with rather similar spectral features, e.g., different lanthanides or actinides. Indeed, for many elements, there is a lack of tabulated spectroscopic data in the region of higher-lying excited states. This becomes increasingly problematic for heavier elements which have complicated electronic structure and for which the computation of energy levels to the required precision for laser excitation of < 1 cm^{-1} is thus far not possible. Therefore, the only reliable way to obtain spectroscopic information is by direct measurement.

While the standard Ti:sapphire laser systems used at ISOL and gas cell -based facilities have a sufficiently wide tuning range, the scanning of the wavelength uses a combination of etalon and birefringent filter, often leading to mode jumps and strong output power variations which, later, must be normalized if the laser is used for spectroscopy. A more convenient way to realize the wavelength tunability is to utilize a grating [1].

Typically, the fundamental output power of a grating-based Ti:sapphire laser is much lower the standard Ti:sapphire thus resulting, for example, in low second harmonic generation efficiency. Based on recent developments elsewhere [2], we have developed a self-seeded grating laser to greatly increase the fundamental output power while preserving the GHz - range linewidth. The cavity geometry is similar to that of the standard Z-shaped design available in many radioactive beam facilities, however, instead of an end mirror, the cavity is closed with a pulse compression grating. The grating, used close to the Littrow configuration, allows for a continuous frequency tuning of the laser by changing the incident angle. The self-seeding is realized by forming another cavity within the main resonator using a partially reflecting mirror.

In this project, we present the design of such a laser along with the latest results and outlook for utilizing the laser for the search of auto-ionizing in elements such as silver.

[1] V. Sonnenschein. *Laser developments and high resolution resonance ionization spectroscopy of activide elements*. PhD thesis, University of Jyväskylä, 2014.
[2] R. Li, J. Lassen, S. Rothe, A. Teigelhofer, and M. Mostamand. Continuously tunable pulsed Ti:Sa laser self-seeded by an extended grating cavity. *Optics Express,* 25(2), 2017.

MICROWAVE BOLOMETER WITH LOW NOISE EQUIVALENT POWER

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We recently introduce a calorimeter capable of detecting packets containing 200 8.4-GHz photons, or 1.1 zJ of energy [1]. The detector consists of a series of capacitively grounded Josephson junctions strongly coupled to an absorber. The resulting LC-oscillators resonance frequency is strongly modulated by the absorbed energy due to the exponential dependence of the Josephson junctions critical current on the electron temperature.

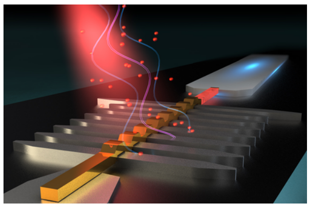
Image credit: Ella Maru Studio

In this work, we have measured a similar microwave detector in a bolometer mode. We observed a record low noise equivalent power (NEP) of 5×10^{-20} W/$\sqrt{\mathrm{Hz}}$. Furthermore, we incorporated a Josephson parametric amplifier to our readout circuitry. This improves the NEP by over a factor of two, down to 2×10^{-20} W/$\sqrt{\mathrm{Hz}}$.

Extremely sensitive bolometers can be used in astronomy, for example, to increase the accuracy of the cosmic microwave background measurement. NEP in the range of 10^{-20}–10^{-19} W/$\sqrt{\mathrm{Hz}}$ is even required for background limited THz spectroscopy in the planned SPICA mission. Bolometers also have uses in the quantum technology. For example, with a tunable bandpass filter, the bolometer could be used as a on-chip spectrum analyzer. In conjunction with on-chip signal generator, this system would form a network analyzer.

[1] J. Govenius, R.E. Lake, K.Y. Tan, and M. Möttönen Phys. Rev. Lett. 117 (2016) 030802.

SOLUBILITY AND ACTIVITY OF ATMOSPHERIC SURFACTANTS IN AQUEOUS SOLUTION CALCULATED USING COSMOtherm

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Fatty acids are important constituents of atmospheric particles and frequently found in both marine and continental environments. In the oceans, fatty acids are typically present on their ionic forms and can be emitted from the oceans to the particulate matter in the marine atmosphere. Previous studies have shown that both fatty acids and their salts can be surfactants. This, can affect the properties of their aqueous solutions, such as surface tension and water activity. The understanding of organic aerosol surfactant properties is of great importance as they pose uncertainty to climate predictions, and their effect on cloud droplet activation has been studied, both experimentally and theoretically [1], [2].

Until now, most studies consider the solutions as ideal, meaning that the interactions between the chemical species are the same. In this study, using the powerful new continuum solvent model (CSM) implementation COSMOtherm, we calculate the activity coefficient of aqueous solutions of fatty acids ($CH_3(CH_2)_nCOOH$, n=0, 4, 8) mixed with salts in order to investigate their deviation from the ideal solution. This model, combining quantum chemistry and thermodynamics can predict the properties of molecules in liquid environments. The solubility of fatty acids in neat water and in mixtures with addition of different fractions of inorganic salts has been studied in order to examine the salting in/out interactions between the organic and inorganic components. Salting in/out phenomena in aqueous solutions are considered as changes on the co-solubility of a compound due to the presence of another compound in the solution [3], [4], [5]. We present calculated activity and solubility data over a range of aqueous solution compositions, and discuss implications for aerosol and cloud properties of predicted deviations from ideality.

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[1] Facchini, M., et al., Atmos. Environ. 34 (2000) 4853–4857.
[2] Prisle, N., et al., Tellus B 60B (2008) 416–431.
[3] Gill, P. S., et al., Rev. Geophys. 21 (1983) 903–920.
[4] Lin, P. S., et al., J. Colloid Interface Sci. 291 (2005) 543–549.
[5] Kurten, T., et al., J. Phys. Chem. A 119 (2014) 4509D4514.

THE FINESTBEAMS BEAMLINE AT MAX IV LABORATORY

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The FinEstBeAMS is a materials and atmospheric science beamline located at the 1.5 GeV storage ring of the MAX IV Laboratory, Sweden. FinEstBeAMS received the first light on 24th of November 2017 and it is currently under commissioning.

The beamline covers a wide photon energy range, 4.3–1000 eV, and gives an opportunity to probe core and valence levels with a focused or defocused beam, produced by an elliptically polarizing undulator. The optical layout of the FinEstBeaMS beamline is based on the plane grating monochromator illuminated with collimated light. The beamline delivers $8x10^{13}$ ph/s – $1x10^{11}$ ph/s on sample with resolving power up to 10 000.

The FinEstBeAMS has three end stations: (i) gas-phase end station (Photoelectron-Photoion Coincidence Spectroscopy), (ii) FinEstLUMI (Photoluminescence Spectroscopy) and (iii) solid state end station (Ultraviolet and X-ray Photoelectron Spectroscopy).

FinEstBeAMS allows to investigate atoms, molecules, clusters, nanoparticles, atmospheric solid or liquid particles in gas phase or deposited on substrate, fragmentation pathways of bio- and organic molecules, atmospheric processes, scintillators, surface composition of environmental liquids, steels, and nanomolecular layers on alloy surface.

Main funding for the FinEstBeAMS beamline comes from the Academy of Finland through the Finnish Research Infrastructure funding projects [1-3] and from the European Union through the European Regional Development Fund [4].

[1] The parts of M. Huttula, E. Kukk, and J. Hölsä of the SR-MAXIV project, FIRI2010.
[2] FinEstBeaMS phase II – FIRI2013, University of Turku, University of Oulu and Tampere University of Technology.
[3] MAX IV Infrastructure – FinEstBeaMS Solid State Materials Research, FIRI2014, University of Turku, University of Oulu and Tampere University of Technology.
[4] E. Nõmmiste project "Estonian beamline to MAX-IV synchrotron", University of Tartu.

QUICKLY TUNABLE ELECTROMAGNETIC ENVIRONMENT FOR QUANTUM ELECTRIC CIRCUITS

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Quantum electric circuits enable precise control and manipulation of quantum degrees of freedom not available in the classical regime. In particular, superconducting circuits provide a scalable platform for quantum computing and simulations. We have recently demonstrated a quantum-circuit refrigerator (QCR) [1, 2] which we directly used to cool a superconducting resonator mode, and subsequently show that the QCR can be utilized as a cryogenic photon source [3]. Here, we present our new studies of in-situ control of the strength of dissipation in a superconducting resonator using a QCR, revealed through a microwave reflection experiment. Namely, we show experimental data of the effective quality factor of the superconducting resonator as a function of the QCR bias voltage. Finally, we also present preliminary experimental results on nanosecond operation of a QCR to cool a superconducting resonator.

[1] K. Y. Tan, M. Partanen, R. E. Lake, J. Govenius, S. Masuda, and M. Möttönen, Nat. Commun. 8 (2017) 15189.

[2] M. Silveri, H. Grabert, S. Masuda, K. Y. Tan, M. Möttönen, Phys. Rev. B. 96 (2017) 094524.

[3] S. Masuda, K. Y. Tan, M. Partanen, R. E. Lake, J. Govenius, M. Silveri, H. Grabert, and M. Möttönen, arXiv:1612.06822 (2016).

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FASTER ION-CASCADE SIMULATIONS WITH A SELECTIVE MOLECULAR DYNAMICS ALGORITHM

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Ion-beam induced atom mixing, followed by annealing in Si – $SiO-2$ systems, can be used to manufacture nanostructures with desirable electrical properties. When simulating the ion mixing at Si/SiO_2 interfaces, it is important to take into account all dynamic effects. Binary collision approximation (BCA) can simulate the phenomenon to some extent, but the nature of the method makes it impossible to track certain properties (e.g. viscous flow). Molecular dynamics (MD) simulations are far better at predicting the dynamics of a system, but often several orders of magnitude slower than BCA, especially with large systems comprising millions of atoms.

To reduce the required computation time of MD, a selective moving-atom algorithm is being developed. The algorithm activates and deactivates hot areas in the structure by tracking the movement of hot particles and marking the surrounding atoms as active. Once the atoms reach thermal equilibrium, they are deactivated again. Deactivated atoms are excluded from the force-calculation loop, and thus do not get their position updated until activated. They do, however, collect the force contribution from active atoms in the close vicinity, through the activated atoms' force calculations. When the total force gets above a given threshold, the atoms become mobile. The amount of calculations in a large system can greatly be reduced by simulating only the atoms that are not currently in thermal equilibrium.

The main goal of the algorithm is to provide information of the dynamics of the irradiated system, at accuracies close to regular MD, but at a faster rate. Initial tests of the algorithm indicate promising speed-ups with up to 10 times shorter simulation times. However, at room temperature notable differences in the evolution of the cascades can be observed, caused by diverging stochastic thermal motion between the algorithm and regular MD. We are currently working on solving the issues related to this observation.

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MULTI-SCALE CHARGE MIGRATION MODEL FOR HYBRID PEROVSKITES

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Hybrid organic-inorganic perovskites (HPs) are a novel materials class in photovoltaic (PV) power generation. The PV performance of HPs is impressive, although the microscopic origin of it is not well known due to the complex atomic structure of HPs. Specifically, the disordered mobile organic cations prevent the use of conventional computational models. We address this complexity by developing a multi-scale model that combines quantum mechanical (QM) calculations of small HP supercell models into large coarse-grained structures (Fig. 1). With our semi-classical hopping model, we study the effects of cation disorder on charge mobility in HPs.

Our multi-scale model parameterizes the interaction between neighboring methylammonium cations (MA^+) in methylammonium lead triiodide ($CH_3NH_3PbI_3$, or $MAPbI_3$) [1]. It is based on our previous QM study [2], in which we identified low-energy MA^+ orientations in the unit cell and observed strong coupling between MA^+ and the inorganic PbI_3^- lattice. This coupling interacts with the lattice deformation, thus altering the electronic properties of the material. To study charge migration, we first compute the nearest-neighbor electronic coupling energies for different MA^+ pair configurations using density-functional theory (DFT). We then solve the time-dependent site-to-site hopping probabilities for QM charge migration analytically, which we subsequently apply in our statistical hopping study.

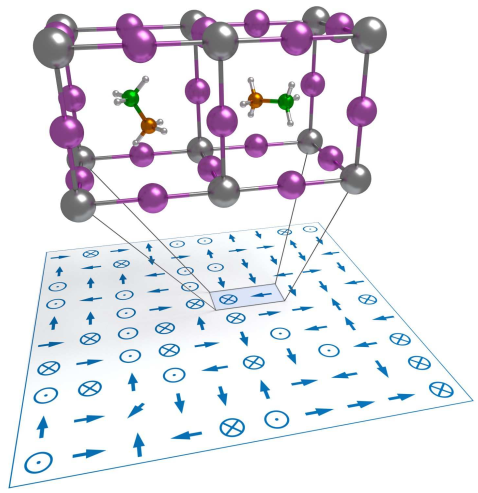

Figure 1: Coarse-grained $MAPbI_3$ structure, in which MA^+ cations are modelled as C-N dipole vectors.

With our model, we analyze charge migration velocities in $100 \times 100 \times 100$ site $MAPbI_3$ supercell models, where each site corresponds to a unit cell. We investigate a variety of ordered and disordered MA^+ structures. We also study the effect of structural defects (such as precipitates and plane defects) on charge mobility. Our results indicate different charge migration velocities in different MA^+ structures, with the fastest observed in room-temperature tetragonal crystal phase.

[1] J. Li, J. Järvi and P. Rinke, ArXiv:1703.10464 [cond-mat.mtrl-sci] (2017).
[2] J. Li and P. Rinke, Phys. Rev. B **94** 045201 (2016).

Research on InP/HfO_2 interfaces: gap states, quality interfaces and corelevel shifts

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We have done computational study on semiconductor-oxide interfaces. The target has been III-V/Hf_2 interfaces, where we have mostly focused on the InP/HfO_2 GaAs/HfO_2 system. Both III-Vs and HfO_2 are promising replacements for the Si and SiO_2 that form perhaps the most important interface in modern electronics.

Our goal has been two fold; firstly we have been searching for good quality interfaces, where the interface does not induce any gap states and the interface is stable. Secondly we have been doing corelevel shift research based on measurements done by our lab. For this we have constructed many models: both vacuum cells and double interface cells that are needed for final state approximation of the core level shifts. As a guide we have the measured binding energy shifts. We found a likely source for the shifts, which gives us information about the actual structure in the samples. Some originate from different interface structures, both steep interfaces and ones with InPO4 oxide in between the two crystals, and some from various point defects.

Regarding the quality interfaces we have also managed to construct some ideal coherent surfaces, that have no undesired gapstates induced by the interface for GaAs/Hf_2 and GaP/HfO_2 [1]. For the oxide we have used the anatase structure, because it allows us to construct coherent interfaces and also gives the best lattice constant matching and as such is easy to fit over the InP giving us small unit cells.

[1] A. Lahti and H. Levämäki and J. Mäkelä and M. Tuominen and M. Yasir and J. Dahl and M. Kuzmin and P. Laukkanen and K. Kokko and M.P.J. Punkkinen, Applied Surface Science 427 (2018) 243.

RADIATION STABILITY OF NANOCRYSTALLINE EQUIATOMIC MULTI-COMPONENT ALLOYS

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Equiatomic multicomponent (EAMC) alloys possess many desired properties that are sought after in potential building materials for future power plants, such as next-generation nuclear reactors. These materials, that are related to the High Entropy Alloy (HEA) family, exhibit traits such as promising mechanical properties, good corrosion resistance and an operational ability at both high and cryogenic temperatures. The EAMC-alloys have also shown a tendency towards a higher tolerance against radiation damage, in form of a lesser defect accumulation, during prolonged irradiation [1, 2, 3]. This tolerance has been observed both experimentally [3] and computationally [1, 2].

Previous computational endeavours have focused, as in experiments, on irradiation of single crystalline samples, which are both difficult and expensive to produce in large quantities and sizes. In this study we investigate the radiation stability of nanocrystalline EAMC-alloys, that might offer a cheaper alternative. The study is carried out computationally, by the means of Molecular Dynamics (MD) simulations. The irradiation effect is studied in different EAMC-alloys as well as single-elemental and non-equiatomic nanocrystalline materials. This is done in order to obtain any information on the effect that changing an element and/or the elemental fraction has on the stability of the alloy. The simulated materials are subjected to massively overlapping cascades in order to model a scenario of prolonged irradiation, during which any changes in the crystalline structure of the material is studied.

[1] E. Levo, F. Granberg, C. Fridlund, K.Nordlund, F. Djurabekova, Journal of Nuclear Materials 490 (2017) 323-332.

[2] F. Granberg, F. Djurabekova, E. Levo, K.Nordlund, Nuclear Instruments and Methods in Physics Research Section B 393 (2017) 114-117.

[3] F. Granberg, K.Nordlund, M. W. Ullah, K. Jin, C. Lu, H. Bei, L. M. Wang, F. Djurabekova, W. J. Weber and Y. Zhang, Physical Review Letters 116 (2016) 135504.

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DETERMINING THE SHEAR MODULUS OF GEL-LIKE SAMPLES USING AN INDENTER

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The shear modulus can be used to describe rigidity of material. We investigated the static shear moduli of hydrogel samples with a custom-made indenter that featured a cylindrical steel flat end probe (diameter = 0.4 mm). The contact between the probe end and the sample was assumed to be frictionless and the sample was assumed to be a semi-infinite elastic material [1]. The Poisson's ratio was assumed to be $\nu = 0.5$. Shear moduli of different kinds of gels were determined at 21°C followed by comparison to literature. The results suggest, that the method can quantitatively evaluate the rigidity of polymers, tissues, and gel-like materials for biomedical applications and polymer engineering.

[1] I. N. Sneddon, International Journal of Engineering Science 47 (1965) 3

MULTIDISCIPLINARY 4D IMAGING OF PLANT DEVELOPMENT, METABOLITE TRANSPORT AND ENVIRONMENTAL PROCESSES *IN-VIVO*

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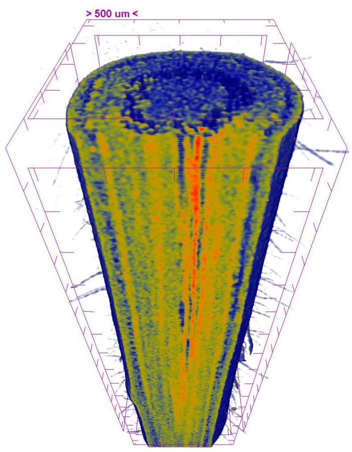
This multi-disciplinary *in-vivo* imaging project combines methods from x-ray physics, radio- and nano-chemistry, environmental & agricultural sciences, computer modelling and mathematics to visualize otherwise inseparable plants tissues to 1) determine their anatomy in 3D, 2) track tissue developmental patterning, 3) analyze transport rates of natural compounds around the plant body, and 4) study the effect of environmental conditions on plant development, compound transport and metabolism in 4D.

In order to see different anatomical features, biological samples are usually cut to thin 2D slices, stained with histological stains and imaged using light microscopy. However, only limited spatial information can be gained from 2D sections and samples represent single time points. This is problematic for developmental and temporal transport assays.

Material scientists routinely use x-ray µ-Computed Tomography (µCT) for 3D objects. Understandably, also plant researchers have found the benefits of µCT and synchrotron imaging modalities, which enable analysis of intact plant samples in 3D with high resolution. Imaging biological samples that are fixed or dried is relatively easy, but this is not the case with living subjects. Every living thing that contains water, DNA, RNA and proteins is susceptible for genotoxic radiation damage, cell death, tissue shrinkage and movement, which make *in-vivo* imaging exposure duration and radiation dose sensitive. For this reason temporal 4D x-ray microscopy analyses have not been conducted routinely.



Similarly to animal research, seemingly uniform plant tissues can be highlighted and differentiated by infusing them with contrast dyes (see image). In order to take the next big step forward, plant specific "natural-compound mimicking" custom-made radio-labelled contrast dyes will be synthetized and tested on multiple imaging modalities. To summarize, our aim to advance high resolution 4D x-ray *in-vivo* imaging by 1) generating high resolution datasets from living plants infiltrated with tissue specific contrast dyes, 2) developing new sparing imaging algorithms, and 3) enabling semi-automatic sample analysis and comparison of different 3D datasets via advanced computing.

MULTISCALE CHARACTERIZATION OF WOOD USING SCANNING X-RAY SCATTERING AND TOMOGRAPHY

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Wood forms a hierarchical structure where the macroscopic mechanical properties are derived from the interplay of structures at several length scales (Fig. 1), from the nanoscale to the year-ring scale, spanning several orders of magnitude [1].

X-ray microtomography can be used to image the sample non-destructively and reveal the three-dimensional structure of wood at the year-ring and at the cellular scale. Wide-angle X-ray scattering reveals the nanoscale structure. A unique set-up combining these modalities [2] enables these features to be connected and provides structurally relevant information that is not achievable with separate instruments [3].

Multiscale characterization of wood is vital for understanding the structure of wood and it is crucial in multiscale modeling [4]. Combining information from several length scales in plant materials yields new information on their structural and functional properties. One application for this information are woods used in electric guitars – how are the mechanical and acoustical properties of tonewoods derived from their anatomy?

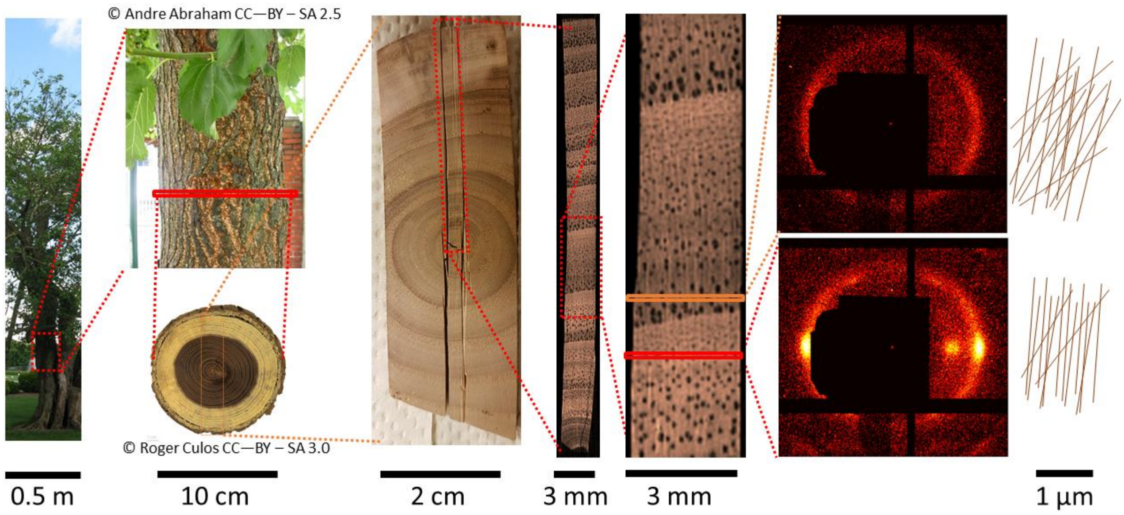

Figure 1: Hierarchical structure of *Morus alba* sketched, from left to right, top to bottom: tree, stem, stem cross-section, year rings, radially cut slice (tomographic reconstruction), close-up highlighting earlywood and latewood, X-ray scattering patterns of early- and latewood (different annual rings), schematic microfibril orientation distributions in the cell wall of early- and latewood.

[1] L. J. Gibson, Journal of the Royal Society Interface 9 (2012) 2749.
[2] J.-P. Suuronen et al., Journal of Applied Physics 47 (2014) 471.
[3] P. Ahvenainen et al., Plant Methods 13:5 (2017).
[4] H. Qing & L. Mishnaevsky, Mechanics of Materials 41 (2009) 1034.

STUDY ON SUPERIOR SURFACE ENHANCED RAMAN SCATTERING (SERS) ACTIVITY OF POPCORN SHAPED SILVER NANOPARTICLES

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Enhancement of weak Raman signal with the help of plasmonic nanoparticles enables the versatile applications of the surface enhanced Raman scattering (SERS) in the field of biophysics [1]. Silver and gold are widely used in the design of SERS active substrates due to the presence of the localized surface plasmon resonance (LSPR) on these metal particles in the visible and near infrared (NIR) range and their superior chemical and electromagnetic enhancement capability compared to other metals like aluminum or copper [2]. Depending on the sensitivity of LSPR on the particle size, the shape, the interparticle distance, and the dielectric constant of the surrounding medium, silver and gold nanoparticles are typically used at excitation wavelengths ranging from blue to green and from red to NIR, respectively, in Raman experiments. In this work, we show that popcorn shaped silver nanoparticles can be used at NIR excitation (785 nm) as much as at blue to green illumination (514 nm) in SERS applications. The SERS activity of such popcorns in terms of SERS signal intensity is superior to that of silver nanospheres at 514 nm pumping wavelength and that of gold nanospheres and pyramidal shaped gold nanoparticles in the NIR region. The idea is verified by SERS experiments with rhodamine 6G, riboflavin and adenine using both 514 nm and 785 nm excitation wavelengths and theoretically supported by finite element method (FEM) based study on LSPR of nanoparticles. The ability of silver nano-popcorn to enhance Raman signal in both blue-green and NIR region can be employed in the coherent anti-stokes Raman scattering (CARS) experiments in which multiple excitation wavelengths are used simultaneously [3].

[1] K. Kneipp *et al*, J. Phys.: Condens. Matter 14 (2002) R597.
[2] G. V. P. Kumar, J. of Nanophotonics, 6 (1), 064503 (2012).
[3] A. Volkmer, J. Phys. D: Appl. Phys. 38 (2005) R59.

MODIFYING SURFACE PROPERTIES OF POROUS SILICON FOR PRETARGET PET IMAGING AND PLASMA PROTEIN INTERACTION

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The use of organic and inorganic nanoparticles in therapeutics and diagnostics have gained considerable interest recently by providing more efficient drug delivery systems and new approaches for imaging. One such material is porous silicon (PSi), which has been shown as remarkably versatile due to its inherently large internal surface area and volume [1]. While most properties of PSi are controllable during its fabrication, few are as important as its natively hydride-terminated surface. This enables relatively easy and effective modification of the PSi surface chemistry [2]. Certain modifications of PSi also provide routes for advanced functionalization through various click chemistry reactions, without imposing limitations on the stability of the PSi under physiological conditions [3].

Recently, we have described the use of modified PSi in pretargeted PET imaging [4]. For this purpose, PSi nanoparticles were initially modified into hydrolytically stable form, and further functionalized to provide an azide group for strain-promoted azide-alkyne cycloaddition (SPAAC). For imaging, the azide termination was utilized to graft a dienophilic molecule on the nanoparticle surface. This final modification enables a bioorthogonal click reaction to take place *in vivo* with a suitable tetrazine-modified radiotracer, allowing the use of short-lived radioisotopes.

As nanoparticles are exposed to biological fluids, such as blood, they rapidly accumulate different biomolecules on their outer surface, forming a “corona”. Utilizing another click chemistry route, based on Cu-catalyzed azide-alkyne cycloaddition (CuAAC), we have studied how functionalization of PSi nanoparticles with targeting peptides and polymers affect to the composition of the protein corona, and the cellular uptake of the particles *in vitro* [5]. By modifying the PSi to present a distal alkyne group, the synthesized functionalization molecules could be conjugated to the particle surface with high efficiency and under mild conditions, thus allowing the targeting peptides to retain their activity.

Combining PSi nanoparticles engineered to high hydrolytic stability with the broad chemical toolbox provided by click reactions, we have enabled several advanced biomedical applications.

[1] H. A. Santos *et al.*, Nanomedicine **9**, 535 (2014).
[2] E. Mäkilä *et al.*, Langmuir **28**, 14045 (2012).
[3] J. Salonen and E. Mäkilä, Adv. Mater. 1703819, (2018).
[4] O. Keinänen *et al.*, ACS Omega **2**, 62 (2017).
[5] C.-F. Wang *et al.*, ACS Appl. Mater. Interfaces **7**, 2006 (2015).

ELECTROSTATIC CHARGING OF PHARMACEUTICAL POWDERS AND POWDER MIXTURES

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Insulating materials become electrostatically charged when they are brought into a frictional contact and then separated. This has a significant impact in pharmaceutical industry, where small powder particles collide with other particles and with surfaces of transportation lines. Their packing behavior and flowability, among other things, may be hampered as a result. The drug material is usually mixed with an additive powder, such as lactose, to improve dosing accuracy. If the drug powder charges strongly during the manufacturing process, it may adhere onto the surfaces of the production line. As a result, the concentration of the final product may notably differ from the planned one.

In the first part of the present study [1], lactose and salbutamol sulphate and their mixtures were charged by sliding in a grounded steel pipe in different relative humidities. The charge and the mass of the transported powder were measured and the charge-to-mass ratio was determined. Increase in relative humidity decreased the charging of lactose and the mixtures, but it did not affect the charging of salbutamol sulphate. The humidity had an unusual effect on the mixtures: the sign of the charge flipped from negative to positive as the humidity was increased and remained positive when powders were again dried. It is suggested that this was caused by the changes in the mixture: when the humidity was increased, the small salbutamol sulphate particles stuck to larger lactose particles and remained adhered even if the powder was dried.

In the second part of the study [2], the effect of surface adhesion on the charging of powders (mannitol, dicalcium phosphate, and starch) was studied. The powders were slid in a thin stream in pipes of different materials. The charge and the mass of the transferred powder were simultaneously measured, and the cumulative charge as a function of cumulative mass was observed. As particles started to adhere onto the surface, the charge of the transferred powder decreased exponentially. The charge reducing effect of adhesion could be evaluated by interpolating the cumulative charging curve to the beginning of the experiment. This value can provide an interesting insight into the physics behind the material and surface specific charge transfer process by neglecting the adhesion effects. For mannitol-dicalcium phosphate mixtures, the charge changed sign as dicalcium phosphate started to adhere onto the pipe surface. In other words, dominative charging process changed from particle-surface to particle-adhered particle contacts.

[1] J. Peltonen, O. Alanen, E. Mäkilä, M. Murtomaa & J. Salonen, Influence of relative humidity on the electrostatic charging of lactose powder mixed with salbutamol sulphate, Journal of Electrostatics 88 (2017) 201–206.
[2] J. Peltonen, M. Murtomaa & J. Salonen, Measuring electrostatic charging of powders on-line during surface adhesion, Journal of Electrostatics (2018) (under review).

RESOLVING SINGLE-PHOTON PROCESSING ACROSS THE NEURAL CIRCUIT OF THE RETINA

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Single-photon detection by the visual system is one of the most remarkable places to think about the interaction between biology and physics. It has been shown that rod photoreceptors, the light-sensitive retinal input neurons, can respond to single photons [1] [2]. However, the statistical variability in photon counts arising from Poisson distribution has made it difficult to precisely quantify how single-photon signals are processed by the retina and how neural circuits adapt to quantal signals.

Now, we use electrophysiological techniques to measure the responses of rod photoreceptors and ganglion cells (retinal output neurons that send light signals to the brain) while being stimulated with a heralded single-photon source. The resulting highly accurate estimates of photon numbers allow us to overcome the challenges arising from the inherent Poisson statistics of classical light sources with constant intensity. At the core of our light source, there is a non-linear BBO crystal that generates photon pairs in the visible wavelength range of the spectrum and a feed-forward switching triggered by the heralding detector.

We will present the setup that we have developed for measuring the responses of retinal rods and ganglion cells. We will present the measured input distributions of the numbers of photons per flash and their predicted impact on the response distributions of retinal rods and ganglion cells. We will further discuss the implications of our results on the adaptation dynamics of the retina response to single-photon signals and the absolute sensitivity limit of vision.

[1] Hecht, S., Shlaer, S., and Pirenne, M. H., ENERGY, QUANTA, AND VISION. J Gen Physiol *25* (1942) 819-840.
[2] Baylor, D. A., Lamb, T. D., and Yau, K. W., The membrane current of single rod outer segments. J Physiol *288* (1979) 589-611.

CHARACTERIZING THE PRESSURE DISTRIBUTION IN A FOCUSED ACOUSTIC FIELD

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Focused ultrasonic fields are utilized in many applications ranging from medical use to various industries. Such focused fields can be generated in various media, and it is important to be able to obtain the pressure distribution in them. Here, we built a custom-made focused ultrasonic transducer system and characterized the field generated by it with an immersion hydrophone connected to a translation stage which allowed scanning of a 2D plane. The generated ultrasonic waves were 700 kHz, 5 cycle bursts. To calibrate the system, we first measured a plane-wave field generated in a custom-made anechoic chamber, and obtained a flat response, as expected. We then applied the anechoic chamber for a focused system, and characterized the field with the hydrophone.

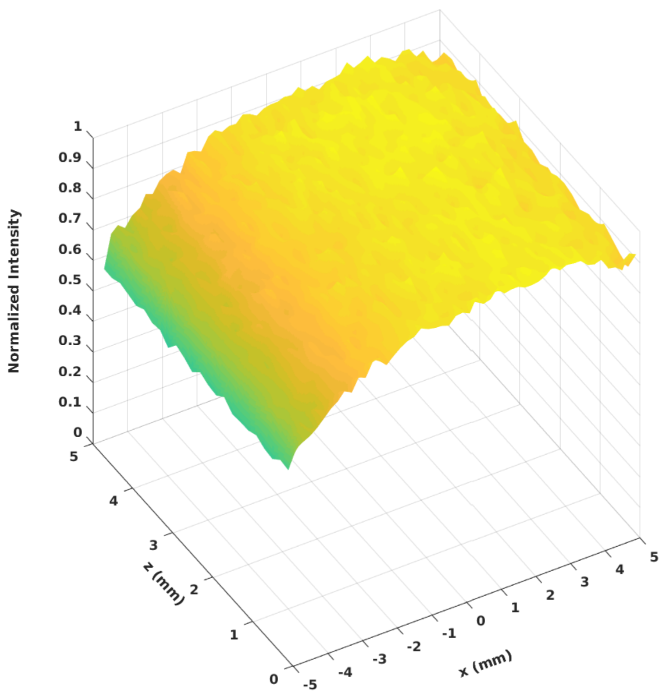

Fig 1. Mapped intensity field in ethanol confirming the incident wave prior to focusing is indeed a plane wave in a 5 mm window in the x-direction.

The results indicate that we could obtain a relative pressure map of the focused ultrasonic field in water, olive oil and ethanol. This shows applicability of our technique in various fields, both for medical systems (water) and industrial systems (oil and ethanol).

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PRELIMINARY EXPERIENCES OF THE RADIOPHOTOLUMINECENCE (RPL) DOSIMETRY

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Introduction: Radiophotoluminescent (RPL) glass rod dosimetry (GRD) is over 60 years old invention but it has been in medical use only for a few years. RPL dosimeters are small, user friendly, non-hygroscopic and non-toxic. These properties make them more suitable for many dosimetric studies if compared to e.g. TLD or ionization chamber (IC). Four different studies were conducted: 1) Dosimetric comparison of RPL dosimeter, radiochromic film and IC. 2) Verification of brachytherapy dose calculation on the surface of applicator. 3) Evaluation of absorbed dose to fetus outside an external beam in order to select the most appropriate treatment unit. 4) Evaluation of correction factors for RPL dosimetry.

Methods: The first study was done with a cell and small animal x-ray irradiation system. Measurements were performed in a water phantom at three depths. The second study was done with an Ir-192 source using two different applicators. RPL dosimeters were on the applicator's surface and Farmer IC was set at five centimeter distance from the source. The dose was calculated with Varian Eclipse 13.6 treatment planning system. The third study was carried out *in vivo*. The dose was measured with Alderson body phantom with 6 MV x-rays from two linear accelerators: Varian Clinac 600 C/D and Varian TrueBeam. The dose was measured at the surface of the patient. The fourth study was accomplished in the water phantom at 10-cm-depth using four different nominal x-ray energies from the Varian TrueBeam.

Results: 1) In the first study, the depth dose curves were similar with all dosimeters and the largest difference was noticed between filtered and unfiltered RPLs. 2) The second study shows that the dose calculation is accurate enough, while the RPL dosimetry result is ~20% smaller than that of Farmer IC. 3) In the third study, the radiation dose to the fetus was shown to be smallest with the Clinac 600 C/D due to its vertical orientation of accelerating waveguide. The evaluated maximum radiation dose to the fetus per treatment fraction appeared to be less than 2.5 mGy, while the measured dose *in vivo* at patient's surface was less than 21.0 mGy. 4) The fourth study showed that the correction factors of 1.21 can be used for the unfiltered RPLs with 6 MV, flattening-filter free (FFF) 6 MV and FFF 10 MV x-ray energies, respectively, whereas for the nominal x-ray energy of 15 MV, the correction factor is 1.15.

COMPARISON OF SPM8- AND SPM12-BASED SEGMENTATION IN MR-BASED ATTENUATION CORRECTION FOR BRAIN PET/MR STUDIES

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Introduction: We set out to investigate whether the quantitative accuracy in PET is improved when using a SPM12-based segmentation approach for performing MR-based attenuation correction (MRAC) in brain PET/MR studies. We compared the accuracy of a new SPM12-based approach to the previous SPM8-based method introduced in [1].
Materials and Methods: The data of 10 patients from consecutive PET/MR and PET/CT studies were used in the evaluation. The CTAC data was used as the reference method for attenuation correction. 3-class segmentation-based MRAC using air, soft tissue (0.096 cm-1) and bone (0.151 cm-1) was created using the method described in [1]. Tissue segmentation was performed using SPM8 and SPM12. Radioactivity uptake (kBq/mL) in PET images reconstructed with MRAC and CTAC were measured in 35 regions of interest in the gray matter. Relative differences (%) of regional radioactivity between SPM8- and SPM12-derived MRAC and CTAC were calculated and compared.
Results: The mean relative difference (%) and standard deviation to CTAC reconstructed PET for each patient over all 35 regions were: -2.93±0.66, -3.02±1.01, -0.25±1.9, -1.38±0.85, -1.04±0.67, -0.56±1.47, -4.87±0.54, -0.53±0.71, -0.69±0.97, -2.4±0.74 for the SPM12-based method and -4.32±0.93, -3.94±0.91, -0.43±1.31, -1.17±0.76, -2.32±0.7, -1.6±1.61, -5.54±0.63, -1.05±0.75, -1.72±1.01, -3.43±0.5 for the SPM8-based method. The maximum and minimum relative difference (%) over all regions and patients were: 4.16 and -5.99 for the SPM12 method, 3.82 and -8.32 for the SPM8 method. In the cerebellum, the mean relative difference (%) and standard deviation were: -2.32±1.87 and -4.21±2.05 for the SPM12- and SPM8-based method over all patients.
Discussion: Improved regional quantification in PET is achieved when using a SPM12-based segmentation approach to derive the patient skull in MRAC. The mean relative difference is reduced in the SPM12 method compared to the SPM8 method and results in smaller standard deviation in 6/10 patients. Improvements in bone delineation in the cerebellum region are evident with the SPM12-based approach, which typically contains the densest bone in the skull region and is generally considered a challenge for MRAC.
Conclusion: SPM12-based segmentation approach for MRAC offers improved quantitative accuracy in PET over SPM8-based MRAC due to improved bone delineation.
Acknowledgement: This study was financially supported by the Alfred Kordelin Foundation and the Finnish Cultural Foundation, Varsinais-Suomi Regional fund.

References

[1] J. Teuho, J. Linden, J. Johansson, J. Tuisku, T. Tuokkola, and M. Teräs, “Tissue Probability-Based Attenuation Correction for Brain PET/MR by Using SPM8,” *IEEE Transactions on Nuclear Science*, vol. 63, no. 5, pp. 2452–2463, Oct. 2016.

A PATIENT-SPECIFIC 3D BOLUS FOR IMPROVING DOSE DISTRIBUTION IN ELECTRON RADIOTHERAPY

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External radiotherapy with electrons is common way to treat tumors close to the skin surface. The optimal radiotherapy plan should deliver a uniform radiation dose to the tumor while minimizing dose to the surrounding healthy tissue. However, due to usually highly sensitive locations where tumors may be located, especially at the face area, this goal is often compromised.

An advantage of electrons in skin radiotherapy is that their absorption is highest at the surface. Penetration depth of the electron depends on the chosen electron energy, and typically the whole target is treated with single electron energy. Electron energy is chosen based on the deepest location of the target, and if the shape of the tumor is complex, healthy tissue near the tumor may get unnecessary high radiation dose. A flat gel-filled bolus with fixed thickness can be applied to the skin to alter the dose received at depth in the tissue but they may cause uneven dose distributions in the target

We have designed a patient-specific 3D-bolus that can be used to optimize the radiation dose depth in the target. Bolus is designed semi-automatically based on patient's CT images, and it compensates the thickness variation of the tumor. Bolus adjusts the distribution of radiation dose follows closely the shape of the target and prevents unnecessary high doses to the healthy tissue.

Image shows CT image of the patient, a patient specific bolus in purple, and the distribution of radiation dose in color.

We conclude that a patient-specific bolus can be used to improve the dose coverage of the radiotherapy and decrease the radiation dose to the healthy tissues. A standard 3D printer with a suitable material can be used to produce a patient-specific 3D bolus.

[1] http://www.hus.fi/hus-tietoa/uutishuone/Sivut/3D-tulostuksella-sadehoidon-tervekudosten-sateilymaarat-minimiin.aspx

THE ROLE OF T_2 AND SODIUM MRI IN THE EVALUATION OF KNEE JOINT FUNCTION DURING WALKING AND STANDING

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INTRODUCTION: The layered collagen fibril network (superficial, middle and deep zones) and the depth-dependent fixed charge density (FCD) distribution (due to proteoglycans) are responsible for the dynamic and the static properties of articular cartilage of the knee, respectively. The aim of this study was to illustrate the influence of the variation in the zone thicknesses and FCD of tibial cartilage, obtained from T_2- and sodium (^{23}Na) -mapped MRI, on knee joint function using biomechanical modelling.

METHODS: 3-D finite element models of the knee joints of asymptomatic male subjects were constructed from manually segmented MR-images. Cartilages and menisci were modelled with fibril-reinforced poroviscoelastic properties (without and with tissue swelling, FRPVE and FRPVES). Variations in the collagen network zone thicknesses were determined from T_2 mapped MRI of tibial cartilage (*Subject I,* Multi Echo Spin Echo sequence at 3T) [1]. The FCD distribution of the tibial cartilage was calculated from ^{23}Na-MRI (*Subject II,* 3-D vTE-SPGR sequence at 7T) [2]. *Subject I* (collagen) was simulated during the stance phase of gait (dynamic) and *Subject II* (FCD) during 13 minutes of standing (static). The resulted tensile stresses in the medial tibial cartilage were compared to those in the models with generic cartilage compositions (*Generic*).

RESULTS: ***Subject I vs. Generic:*** The superficial, middle and deep zone thicknesses of tibial cartilage, determined from MRI, were 9%, 19% and 72% over the tibio-femoral contact regions, respectively (*Generic:* 11%, 17% and 72%, respectively). This decreased maximum principal stresses especially in the superficial regions of the cartilage of *Subject I* during the stance phase (up to -26%). ***Subject II vs. Generic:*** The mean FCD in the tibial cartilage, determined from ^{23}Na-MRI, was 0.18 ± 0.08 mEq/ml (up to 27% increase in the superficial tissue, compared to *Generic* model). Hence, the maximum principal stresses were decreased throughout the tissue depth (up to -8% in superficial tissue) in *Subject II*, compared to *Generic* model.

DISCUSSION: The collagen architecture and the FCD distribution both were in agreement with those determined *in vitro* for healthy tibial cartilage. The thinner superficial zone at the contact regions decreased the tensile stiffness of the cartilage reducing the tensile stresses during walking. Similarly, the higher FCD in the superficial tissue increased tissue swelling and causes increase in cartilage stiffness. This reduced the axial strains and, in consequence, decreased the tensile stresses. These results indicate that the MRI devised structure and composition in the knee joint models could enable a more precise evaluation of the knee joint function and condition.

[1] LP, Räsänen, et.al. Comput Methods Biomech Biomed Engin. 19 (11), 2016. [2] LP, Räsänen, et.al. J Biomech. 49 (14), 2016.

B0-FIELD INHOMOGENEITY INDUCED LOCAL DISTORTIONS IN DIFFUSION WEIGHTED MR IMAGES: A FEASIBILITY STUDY USING SIMULATIONS AND FANTOM MEASUREMENTS

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Diffusion weighted imaging (DWI) is a widely used magnetic resonance imaging (MRI) technique to measure water diffusion in tissue. For radiotherapy treatment planning (RTP), DWI improves upon conventional imaging techniques, by better characterization of tumour tissue properties required for tumour grading, diagnosis and target delineation.

The use of DWI is hampered by geometric distortions of the imaging sequence used for obtaining diffusion weighting [1]. Especially, challenging for DWI are air cavities and presence of any metals that distort local B0 homogeneity. The geometric distortions need to be quantified and corrected to meet the requirements of high spatial accuracy of MRI for RTP.

In this work, the geometric distortions due to B0 inhomogeneities were measured in 3D geometry phantom and simulated for both turbo spin-echo (TSE) and echo-planar imaging (EPI) sequences. The differences of the two sequences were compared in terms of distortion magnitude and verified with phantom measurements in comparison to simulated distortions around air cavities and implanted gold fiducials.

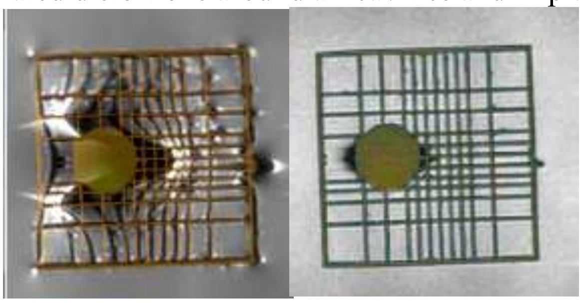

Figure 1: Left: EPI DWI image. Right: TSE DWI image. Both images are overlaid with the reference phantom grid (yellow) obtained by imaging the phantom with a high-bandwidth fast-field echo imaging.

Around an air cavity in water, the geometric distortions were significant using EPI. For TSE, the distortions due to an air cavity were less than 1 mm. Implanted gold fiducials were not causing a significant distortion with TSE. However, noticeable distortions were present with the EPI sequence. Measured distortions agreed well with simulated distortions.

The magnitude of geometric distortion around air cavities is significant and needs to be considered for applications requiring high geometric accuracy, such as RTP.

1. Schakel T, Hoogduin J., Terhaard C., Philippens M. Diffusion weighted MRI in head-and-neck cancer: Geometrical accuracy. Radiother. Oncol. 2013;109:394–7

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Multilevel Resistive Switching in Ag/$Pr_{0.6}Ca_{0.4}MnO_3$/Al Thin Film Structures

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As the field of machine learning and artificial intelligence grows, the interest for neuromorphic memory devices rises in tandem. Neuromorphic computing differs from the conventional binary logic of present day's computers. The computations are done using trained artificial neural networks, which process data in a way which resembles how the brain works. These networks consist of interconnected artificial neurons which can be modelled with devices which have access to a continuous range of states.

One possible candidate for the hardware implemention of these devices is resistive switching (RS). Resistive switching is a phenomenon where the resistance of the material can be changed reversibly by applying an external electric field. The underlying mechanisms vary between materials, but generally, the conductivity changes are caused by modification of interface properties and inside the bulk by means of phase changes or formation and rupture of conductive filamentary structures. In oxides, both cases are faciliated by oxygen transport caused by the electric field.

In our research we have manufactured working RS devices using a perovskite manganite compound $Pr_{0.6}Ca_{0.4}MnO_3$ and metal interfaces. The device exhibits homogeneous and repeatable voltage controlled bipolar resistive switching with a continuous range of possible resistance values.

The manufactured devices retain their resistive state without the need for an external field and the resistance state can be read energy-efficiently. The observed switching allows for a selection of any resistance state between the two limiting values when a suitable programming sequence is used. The characteristics of the device make it a promising candidate for a hardware implementation of neuromorphic computing.

IMPROVING THE C-AXIS FLUX PINNING WITH $BaCeO_3$ DOPING IN YBCO FILMS GROWN ON AN IBAD-MgO BASED TEMPLATE

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In order to improve the performance of high temperature superconductors in electrical power systems, IBAD-MgO based template with newly-fashioned multilayered buffer architecture is used as a reliable flexible substrate for the growth of $YBa_2Cu_3O_{6+x}$ (YBCO) doped with various concentrations of $BaCeO_3$ (BCO) [1, 2]. All the YBCO films with varying 2% to 10% of dopant content were pulsed laser deposited on metallic substrates to be studied from the flux pinning point of view. When compared to YBCO films grown on single crystalline substrates, the most critical issues that affect the suitable structural defect formation and thus the optimal vortex pinning landscape have been observed to be the nano-sized growth of BCO particles within already available naturally created and c-axis oriented defects in YBCO matrix which occur in the form of edge-type dislocations or low-angle grain boundaries due to polycrystalline substrate [2]. In this work, we find that the best critical current density (J_c) in a wide applied magnetic field and whole angular range is realized in the films doped with 2% and 4% BCO concentrations. This is explained to arise from the optimized BCO dopant concentration which helps to immobilize more vortices both in low and high field ranges. In addition, the angular dependent J_c properties show significant decrease in vortex pinning anisotropy with increasing BCO concentration up to 4% content. The optimized BCO concentration in YBCO matrix on our IBAD-MgO based template approaches the earlier observed typical behavior of $BaZrO_3$ doped films which form network of columnar pinning structure when grown on single crystalline $SrTiO_3$ substrate. Therefore, BCO growth in the form of isolated nanoparticles within structural defects of YBCO on this advanced metallic substrate is another alternative to create *c*-axis oriented pinning centers which, on the other hand, can be useful for the industrial applications.

[1] M.Q. Qing, L.L. Fei, L.Y. Jie, Chinese physical letters 32 (2015) 078102

[2] M.Z. Khan, Y. Zhao, X. Wu, M. Malmivirta, H. Huhtinen and P. Paturi, Physica C: Superconductivity and its applications 545 (2018) 50-57

METAMAGNETIC TRANSITION AND SPIN MEMORY EFFECT IN EPITAXIAL $Gd_{1-x}Ca_xMnO_3$ ($0 \leq x \leq 1$) THIN FILMS

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Epitaxial $Gd_{1-x}Ca_xMnO_3$ ($0 \leq x \leq 1$) thin films were prepared by pulsed laser deposition (PLD) on $SrTiO_3$ substrate and their magnetic properties were investigated. Similar in the bulk samples, the field cooled (FC) and zero field cooled (ZFC) curves of the films show a hump and negative value of magnetization at low temperature which could be attributed to the magnetic moments of Gd ions which order in the opposite direction of Mn ions. In contrast to the bulk samples which show OO/CO state at $x \geq 0.5$ below room temperature, the epitaxial GCMO thin films exhibit this effect at $x \geq 0.4$ above room temperature. The magnetic hysteresis loop of the films is different from that of bulk samples. In low doped concentrations, $0.1 \leq x \leq 0.3$, a metamagnetic transition occurs in low applied field at low temperature. At Ca concentration, $0.4 \leq x \leq 0.7$, the magnetization versus external magnetic field behaves like a soft ferromagnet. In high Ca concentrations, $x = 0.8$ and $x = 1$ demonstrate antiferromagnetic transition in ZFC curve and thus the magnetization shows antiferromagnetic behavior at low temperature. In contrast, $x = 0.9$ displays soft ferromagnetic hysteresis loop with evidence of training effect. It could be associated with the cluster glass peak in ZFC curve for this film.

MECHANICAL RESONANCES AND THE QUANTUM HALL EFFECT IN A SUSPENDED GRAPHENE CORBINO SYSTEM

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We study the mechanical vibrations of a suspended graphene Corbino disk whose inner and outer edges are coupled to gold resonators. The resonances are measured using a frequency mixing technique [1] where the Corbino disk down mixes the high-frequency signal sent through one of the gold resonators.

We perform a finite element simulation of the full resonator system using COMSOL Multiphysics and compare the simulated eigenmodes to the measured frequencies to identify the shapes of the detected modes. We see that our simulation agrees fairly well with the experimental results in terms of the eigenfrequencies.

Additionally, we derive the analytical expression for the displacement of the Corbino disk in the case of time-dependent boundary conditions allowing us to model how graphene experiences the coupling to the gold resonators.

We are able to detect integer and fractional quantum Hall states by measuring the conductance of the sample over a range of magnetic fields and gate voltages. The mechanical motion of the disk with respect to the back gate affects the gate capacitance and thus the charge density. However, due to the incompressibility of the quantum Hall states [2], the modulation of the charge density is suppressed, decreasing the mixing current at certain Landau level filling factors.

[1] V. Gouttenoire et al., Small 6 (2010) 1060.
[2] A. Yacoby et al., Solid State Commun. 111 (1999) 1.

CRYSTALLINE OXIDE PHASES ON InSb(111)B REVEALED WITH SCANNING TUNNELING MICROSCOPY AND SPECTROSCOPY

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Recently discovered crystalline oxides for III–V semiconductors provide an attractive platform for the control of interface chemistry on III–V/oxide interfaces due to the absence of intrinsic gap state defects on these surfaces [1]. So far, only (100) crystal planes have been under these investigations and extensive proof of viability of crystalline oxidation treatment for non-planar (III–V device) structures have been absent. We present here how oxidation treatments affect InSb(111)B surface structure and its electronic properties, probed with scanning tunneling microscopy (STM) and spectroscopy (STS) by means of continuous imaging tunneling spectroscopy (CITS).

The well-defined reconstructions after oxidation treatments correspond to the ones observed for clean InSb(111)B [2, 3], namely (2×2) or (3×3), depending on the O_2 exposure and sample temperature during oxidation. Thus, no direct evidence for an oxide phase could be observed in these conditions from low energy electron diffraction (LEED) data. However, another alternative is that the surface is oxidized, but still exhibits similar periodicities as clean InSb(111)B. This is supported by our STM and STS data (Fig. 1).

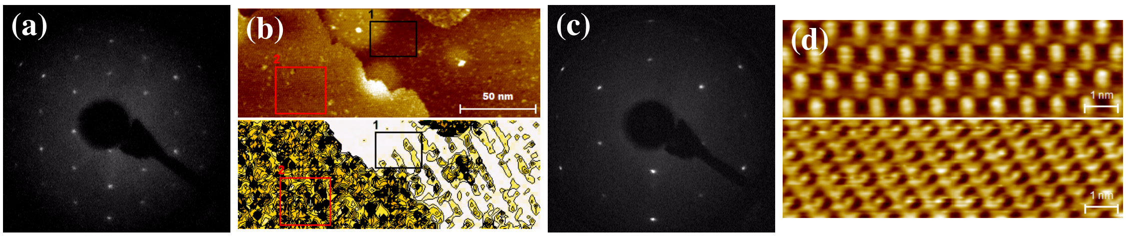

Figure 1: (a) LEED from (3×3) (49 eV), (b) STM (-1 V, 100 pA) and contour CITS $\mathrm{d}I/\mathrm{d}V$ (at -0.42 V) from the same (3×3) area showing different density of states on adjacent terraces on an oxidized sample, (c) LEED from (2×2) (47 eV), and (d) STM (0.75V, 50pA and 0.50V, 50pA) from (2×2) surface on an oxidized sample, showing different features than observed for InSb(111)B(2×2) previously.

Thus, we have found that (111)B surface can be passivated similarly with parameters close to the ones used for (100) [1]. This is of major significance for creating III–V/oxide devices with functional patterning, passivated with crystalline oxide termination.

[1] M. P. J. Punkkinen, P. Laukkanen, et al. Physical Review B 83 (2011) 195329.
[2] J. Wever, H. Meyerheim, et al. Surface Science 321(3) (1994) L225.
[3] T. Eguchi, T. Miura, et al. Surface Science 514(1) (2002) 343.

VACANCY DEFECT FORMATION IN $(In_xGa_{1-x})_2O_3$

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The seek of new and more tunable semiconductor properties has driven the research pass elementary and binary semiconductors, up to multicomponent alloys. The alloying of transparent semiconductor oxides In_2O_3, Ga_2O_3 and Al_2O_3 allows tuning the band gap from 2.9 eV of In_2O_3 to 8.8 eV of α-Al_2O_3 [1, 2, 3]. In addition to the increased control over the material properties, the increasing structural complexity also carries a burden of crystallographic phases. In order to study the vacancy formation in $(In_xGa_{1-x})_2O_3$, samples with varying In/Ga-content were grown by pulsed-laser deposition (PLD) in continuous composition spread mode. This approach provides flexibility with the determination of lattice properties.

The vacancy type defects in the undoped and Si-doped $(In_xGa_{1-x})_2O_3$ sample series were studied with positron annihilation spectroscopy. This technique allows identification of the type and concentration of the point defects as well as probing the chemical surroundings of the vacancy. Spatially-resolved X-ray diffraction (XRD) was utilised to investigate the lattice structure to complement the information of vacancy defects.

The positron results show qualitative changes in the behaviour of vacancy defects around In-fractions of 30 at% and 70 at%. The formation of cation vacancy-type defects is shown to be enhanced with the increasing In-fraction up to 70 at% whereas further increase of the In-content was found to suppress the defect formation. The observed changes in the vacancy defect formation walk hand in hand with the lattice structures observed in XRD.

[1] H. von Wenckstern Advanced Electronic Materials 3, (2017), 1600350.
[2] A. Walsh, *et al.* Physical Review Letters 100, (2008), 167402.
[3] J. Robertson Journal of Vacuum Science & Technology B 18, (2000), 1785-1791.
[4] V. Prozheeva, *et al.* Submitted to Journal of Applied Physics.

REACTIVE ION AND WET ETCHING OF THERMAL-ELECTRIC-FIELD MODIFIED GLASSES

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Formation of the relief on the surface of glassy materials is an important task for fabrication of the photonic and biophotonic devices for sensing applications. Among of techniques that allow one to modify glass surface are photo- and e-beam lithography, laser micromaching, and thermal-electric-field imprinting (TEFI). The latter can be used to form on the glass surface a nanoscale relief image of a profiled structure fabricated on the surface of a reusable glassy carbon electrode (Figure 1a). When followed by etching, TEFI, which modifies durability of the subsurface layer of the processed glass region, deserves a high interest. Etching the glass after the TEFI enables increasing the relief height up to microns (Figure 1b). Depending on the etching technique, the initial TEFI profile can be either deepen (direct profile) or reversed and then deepen. Dry reactive ion etching or wet alkaline form the direct profile [1], wet acidic etching results in the reverse profile [2, 3]. However, non-uniform modification of the glass composition results in the dependence of the etching rate on the etched depth and electrode edge effect lead to the deterioration of the surface relief (Figure 1b,c). We report on the investigation of the TEFI performance in glass profiling. By using $NH_4F{:}8H_2O$ wet acid and $12CHF_3{:}38Ar$ dry reactive ion etching we consider TEFI peculiarities caused by the influence of atmospheric species inflow in unprotected glass regions, atmospheric electric discharge near the electrode edges and glass elastic stresses.

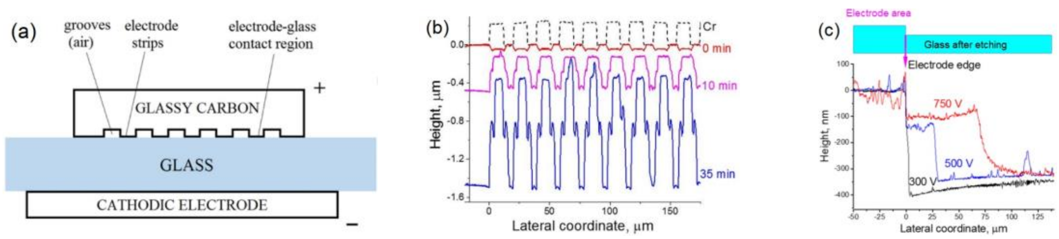

Figure 1. Relief features of glasses after thermal-electric-field imprinting (TEFI) and etching processes. Schematic of TEFI (a), etched relief of periodically poled glass (b), the near-electrode-edge relief of the glasses after acidic etching (c) [3].

[1] N. Ikutame et al, Journal of Applied Physics 114 083514 (2013).
[2] Z. Zhan et al., Materials 10 158 (2017).
[3] I. Reduto et al., Journal of the Electrochemical Society 164 13 (2017).

MODELLING OF PHASE STRUCTURE POLYMORPHS AND DISLOCATION EFFECTS OF VO_2 FILMS

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Vanadium dioxide VO_2 is a good example of so-call functional material, which possess particular native properties, and functions of its own. In thin-film structures single crystal VO_2 may occur in several phases depending on temperature and films three dimensional strain state. The change in these key parameters lead to phase transitions, including metal-insulator-transition (MIT).

The aim of this study is to show numerical model of the three dimensional strain states in single crystal VO_2 films on various different substrates, such as *a*-, *r*- and *c*-oriented Al_2O_3 and MgO single crystal substrates. Films strain relaxation due the phase transitions and dislocations are discussed in detail.

In experimental part of the study, VO_2 films were deposited using pulsed laser deposition (PLD) in *in situ* conditions at temperature of 400 °C and in various oxygen partial pressures on *a*-, *r*- and *c*-oriented Al_2O_3 and MgO single crystal substrates. Pure VO_2 films with heteroepitaxial microstructure were confirmed using x-ray diffraction (XRD), Raman spectroscopy, scanning electron microscopy (SEM), and scanning tunnelling electron microscopy (STEM) methods. Resistivity of the films was measured as a function of temperature, and MIT temperature T_{MIT} was determined.

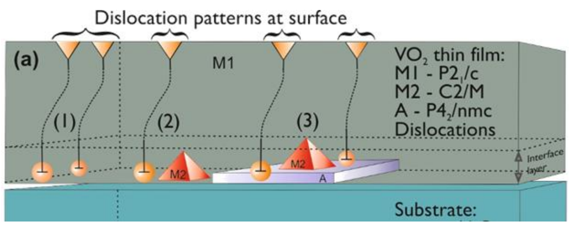

Fig. 1. Cross-section of an epitaxial VO_2 film on *c*-oriented Al_2O_3 substrate. Violet layer indicates $P4_2/nmc$ (A) phase and red pyramids C2/m (M2) phase in the film-substrate interface.

In numerical simulations, it was observed that films could not be epitaxial due to huge misfit strains leading to unrealistic values of T_{MIT} according to Clausius-Clapeyron law. However, XRD results indicated that phase-coexistence of monoclinic $P2_1/c$ (M1) and C2/m (M2) insulating phases, and dislocations in the film-substrate interface reduced the misfit strains. Including these observations to the numerical model, it leads to relaxed epitaxial structure, which strain state correlated well with both T_{MIT} predicted by Clausius-Clapeyron law and measured T_{MIT}. Results of numerical modelling, such as an epitaxial VO_2 film on *c*-oriented Al_2O_3 substrate, and alike structures, are discussed now widely in literature, leading to novel phase structure of films, as shown in Fig.1. In addition, strain energy of the film on different substrates was expressed as a function of current phase and dislocation density. The results show that proposed relaxation mechanisms minimize the films strain energy and verify the given structural models.

ELECTRICAL COMPENSATION MECHANISMS IN Ga_2O_3

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The growth of high quality Ga_2O_3 both in the form of bulk crystals and epitaxial thin films has been established over the past years [1]. The *n*-type doping is typically achieved with Sn or Si and is known to suffer from a high density of twins and stacking faults in thin films grown on the (100) cleavage plane. As a result, careful preparation of the substrates is required [2]. Compared to the (100)-plane growth, higher epitaxial growth rates can be achieved with the (010) non-cleavage plane [3]. In addition, it has been shown that electrical compensation of Si-doping can be explained by the presence of Ga vacancy-related defects [4].

The investigation of the defect formation in β-Ga_2O_3 grown by metal-organic chemical vapour deposition on native substrates was performed by means of positron annihilation spectroscopy in both conventional and coincidence Doppler broadening modes [5]. We have studied samples grown with different doping impurities (Sn, Si) and using different precursors for Ga (TMGa, TEGa), on (100) and (010) substrates. In addition, selected samples were subjected to 2 MeV proton irradiation at a fluence of 5×10^{16} cm^{-2}. We show that the choice of substrate, precursor and *n*-type dopant all have a dramatic effect on the apparent V_{Ga} concentration and on the electrical properties of thin-film Ga_2O_3. We also show that a very clear V_{Ga}-related signal emerges in the irradiated (010)-oriented films, while there is nearly no difference between the annihilation spectra of non-irradiated and irradiated (100) samples, irrespective of the presence of a V_{Ga} signal in the as-grown material. These observations suggest that the point defect distribution and the origin of electrical compensation are more complex than just a question of V_{Ga}-type defects.

[1] H. v. Wenckstern, Adv. Electron. Mater. 3 (2017) 1600350.
[2] R. Schewski *et al.*, J. Appl. Phys. 120 (2016) 225308.
[3] H. Okumura *et al.*, Appl. Phys. Express 7 (2014) 095501.
[4] E. Korhonen *et al.*, Appl. Phys. Lett. 106 (2015) 242103.
[5] F. Tuomisto and I. Makkonen, Rev. Mod. Phys. 85 (2013) 1583.

UTILIZATION OF PULSED CURRENT IN PREPARATION OF ELECTROCHEMICALLY ANODIZED POROUS SILICON FOR LI-ION BATTERY ANODES

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Utilization of silicon as an anode material for Li-ion batteries has been extensively studied during the past decade because of its ten times higher theoretical specific capacity compared to graphite. Practical implementation of the material has been challenging because of the 400% volumetric change during the lithiation/delithiation process. One way to prevent the loss of the electrical contact originating from the volumetric change, and the resulting deactivation of the anode material, is to utilize porous structure which gives the material room to expand. Common to all Li-ion batteries is that the achievable battery capacity tends to lower when the charge/discharge rate is increased because of the kinetics of the lithiation process. In the present study, electrochemically anodized porous silicon were prepared with pulsed etching current. This was done to find out if the periodical shape of the pores enhances the kinetics of the lithiation providing higher capacities at higher charge/discharge rates. Silicon anodes for battery testing were prepared by mixing the particles with polymeric binders and carbon black [1]. The comparison between the hydrogen terminated silicon particles etched with constant current (AAPSi) and pulsed current (pAAPSi) revealed that the anodes prepared with pAAPSi particles had higher specific discharge capacities of 150 – 400 mAh/g_{Si} during galvanostatic rate capability test at higher 0.2C and 0.5C charge/discharge rates. Same phenomena was also observed for the charge capacities. From these results it can be concluded that the periodical structure of the pores formed by pulsed etching enhances the kinetics of the lithiation.

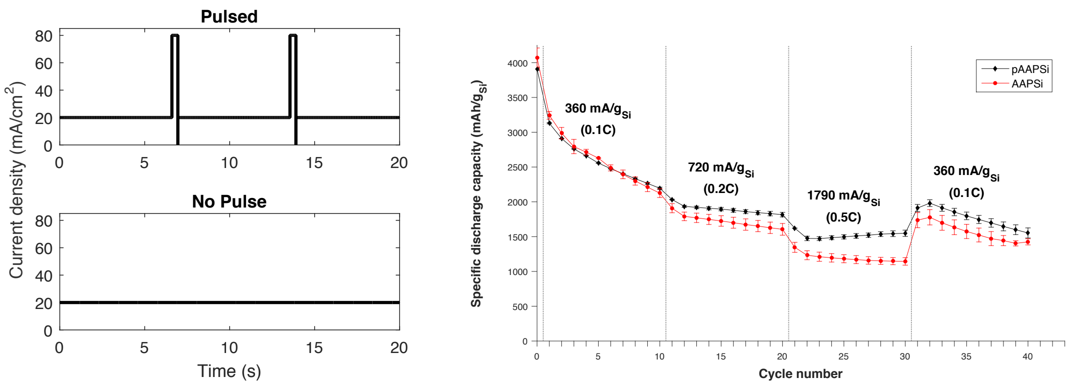

Figure 1: Left: current density sequences used for electrochemical etching of the porous silicon films. Right: galvanostatic rate capability results for Li-ion battery anodes prepared from mesoporous silicon microparticles pAAPSi and AAPSi.

[1] Koo B. et al, A Highly Cross-Linked Polymeric Binder for High-Performance Silicon Negative Electrodes in Lithium Ion Batteries, Ang. Chem. – Int. Ed. 51, 8762-8767 (2012)

TEMPERATURE DEPENDENT EFFECTS IN ORGANIC SOLAR CELLS: OPEN-CIRCUIT VOLTAGE AND CHARGE SEPARATION

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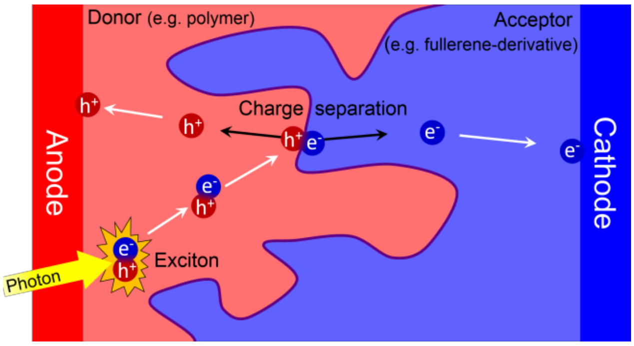

Organic bulk heterojunction solar cells consist of an interpenetrating network of phase separated donor and acceptor materials placed between electrodes for charge collection. When light is absorbed in the donor, a coulombically bound charge pair called an exciton is formed. The exciton then diffuses to a donor/acceptor interface where the electron is transferred to the acceptor, leaving the hole on the donor. The electron and hole are still coulombically bound at this point. The exact mechanism for separation is unclear, but it has been suggested that the process from this point on is driven by increased entropy at increased charge separation [1,2]. We investigate this by measuring and modelling the temperature dependence of the open circuit voltage for three samples: an undegraded and a degraded sample of P3HT:ICBA, and an undegraded sample of PTB7:$PC_{70}BM$. P3HT and PTB7 are commonly used donor polymers, and ICBA and $PC_{70}BM$ are fullerene derivatives commonly used as acceptors in organic solar cells. We compare the entropy model with a model by Braun, describing separation probability for an ion pair [3]. Both models have the initial charge separation distance as the crucial parameter, and we assume a temperature dependence in the generation of free charges.

For both P3HT:ICBA samples we observe reduced charge separation probabilities at temperatures below 220 K. For the undegraded P3HT:ICBA sample both models give very similar initial charge separation distances in the range of 1.4 – 2.2 nm. For the degraded P3HT:ICBA sample the initial separation distance cannot be extracted due to too large uncertainties in the data. The PTB7:$PC_{70}BM$ shows a charge separation efficiency close to unity down to 35 K, with too few data points below that for the models to produce meaningful results for the initial separation distance. In future work other possible models should also be considered, and possible temperature dependencies in other parameters than the generation should be investigated.

[1] B. A. Gregg, J. Phys. Chem. Lett. 2 (2011) 3013.
[2] F. Gao, W. Tress, J. Wang and O. Inganäs, Phys. Rev. Lett. 114 (2015) 128701.
[3] C. L. Braun, J. Chem. Phys. 80 (1984) 4157.

SUPGAP EXCESS NOISE OF NORMAL - SUPERCONDUCTOR JUNCTIONS

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We have observed excess noise that accompanies Andreev reflection at normal - superconductor junctions. Figure 1 shows typical results of an Al - Ag contact at 0.1 K and 1.2 K, respectively. We record the differential resistance dV/dI of the contact as function of bias voltage V and, simultaneously, the standard deviation σ of the voltage derived from its power-spectral density in the 0 - 100 kHz frequency interval. In the superconducting state the dV/dI spectrum is well described by the modified BTK theory. The excess noise $\sqrt{\sigma^2 - \sigma_0^2}$ emerges clearly from the (mainly amplifier) background noise $\sigma_0 \approx 2\,\mu V$. Inside the superconducting gap the excess noise is small. With increasing voltage σ grows rapidly, peaks near the steep rise of dV/dI, and decays exponentially at large bias. For contacts in the $1 - 100\,\Omega$ range (about 30 - 3 nm diameter) dV/dI is rather reproducible, while σ varies a lot both with respect to magnitude and width.

The enhanced σ appears to origin from two-level transitions in the $I(V)$ characteristic. These are driven by external noise that can not be resolved in the normal state of the contact. In the peak σ region, the more stable $I(V)$ branch carries more current than the other one, i.e. it has a smaller resistance. This could be caused by the superconducting proximity effect. The two $I(V)$ branches should also affect the BTK fit of the dV/dI spectrum, leading to corrections of the gap value, the Dynes' lifetime and the Z parameter.

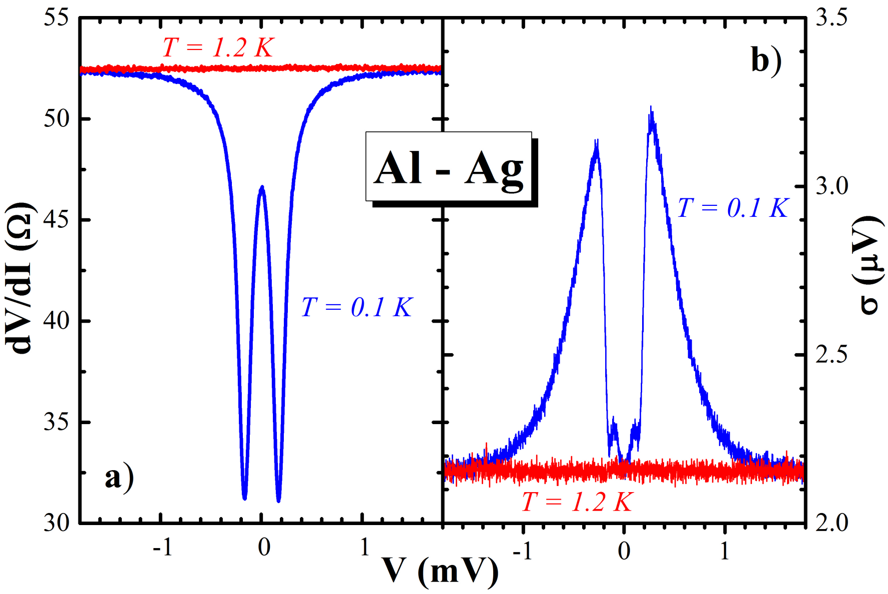

Figure 1: a) Differential resistance dV/dI versus bias voltage V and b) standard deviation σ of the voltage V of an Al - Ag contact at $T = 0.1$ K and 1.2 K, respectively.

CALIBRATING A SCANNING ACOUSTIC MICROSCOPE

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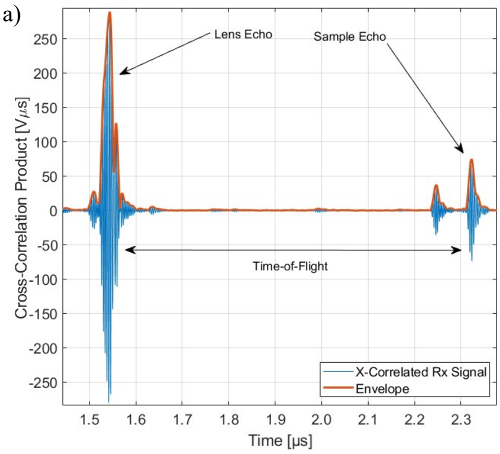
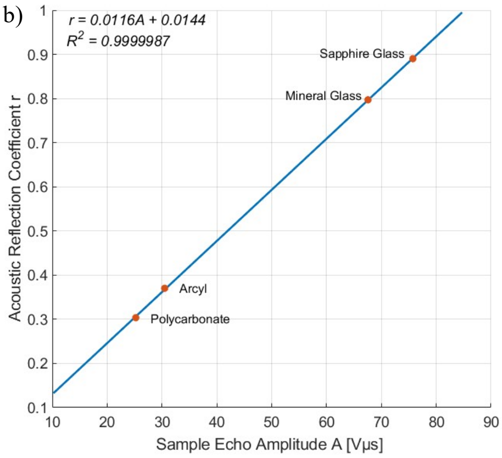
The scanning acoustic microscope (SAM) can measure a sample's surface topology and mechanical parameters with a few micron spatial resolution. With a 130-370 MHz transducer SAM reaches 3.5 µm resolution. Each single pixel contains data of both time-of-flight (TOF) and the amplitudes of different echoes (fig. 1a). The TOF information reveals the surface topology whereas the echo amplitude tells about the mechanical properties of the surface. Calibration is needed to link the measured echo amplitude to the acoustic impedance and stiffness (fig. 1c) of the sample. To determine the calibration curve (fig. 1b) four different homogenous reference materials (acryl, mineral glass, polycarbonate, sapphire glass) were measured. This calibration method is described in K. Raum *et al.* [1]. First the transducer and the sample were aligned. The transducer was moved from positive to negative defocus in 0.5 µm steps to find its focus. Altogether 100 pulse-echo (PE) measurements were performed in the focus point for all samples. Whereas a single pixel is calculated from a single PE measurement the full micro-scope image is taken by moving the sample and measuring it pixel-by-pixel.

a)



b)



c)

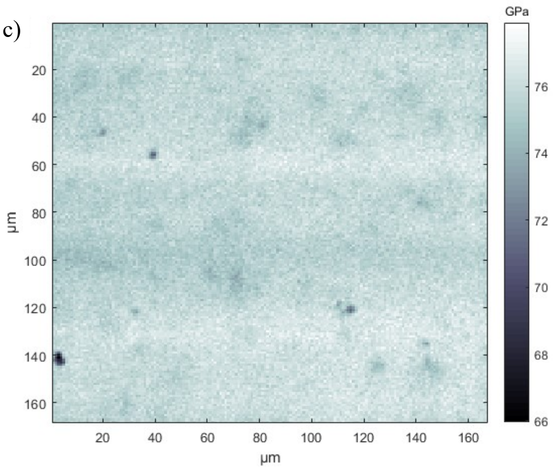


Figure 1: a) Cross-correlated Rx signal (blue) with envelope (red). b) Calibration line based on four samples. Uncertainties of measured sample points are smaller than the markers. c) The stiffness map of a mineral glass (fused silica) sample (measured 31.01.2018) with young's modulus color coding. There is ± 4% uncertainty in the color coding

[1] : K Raum[1,2], I Leguerney[1], F Chandelier[1], M Talmant[1], A Saïed[1], F Peyrin[3,4] and P Laugier[1] Published 19.1.2006 IOP Publishing Ltd, Physics in Medicine & Biology, Volume 51, Number 3: Site-matched assessment of structural and tissue properties of cortical bone using scanning acoustic microscopy and synchrotron radiation µCT

ELECTRICAL CLAMPING LOSSES IN A PIEZOELECTRIC MECHANICAL RESONATOR

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High quality factors of mechanical resonators are essential for several applications of electromechanical devises. In particular, this holds true for studies near the quantum limit of mechanical vibrations. Energy leakage through supports is a series limiting factor for high quality factors. Various approaches have been realized to mitigate this problem, for example, design of anchor points, or inclusion of phononic shields. Here we investigate how the quality factors of mm-sized quartz resonators are limited by clamping losses at deep cryogenic temperatures. We first introduce means to improve the mechanical quality factor (Q) by up to two orders of magnitude in a no-clamping scheme. We can exclude a wide coverage of aluminum metallization on the disk or bond wires as sources of dissipation. However, we find dramatic reduction of Q-factor accompanying a special metallization pattern that involves strong focusing of the vibrations in the disk center. We propose a circuit model that accounts for the reduced Q-factor. The interpretation is that the mechanical energy leaks electrically out through electrical clamping points. This presents a new mechanism for clamping losses of mechanical resonator, and highlights the importance of rigid electrical boundary conditions.

HAND-HELD MEASUREMENTS OF PRESSURE IN A MEMBRANE COVERED CAVITY

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Many biological and man-made systems, such as blood vessels, feature membranes covering pressurized cavities. Measuring the pressure in this situation is sometimes desirable, and sometimes having a suitable portable device is valuable. We report on our progress on making such a device.

We employed a water filled cylinder whose open end was covered by a membrane. A variable hydrostatic pressure could be introduced into the cylinder. The pressure was set and the resulting pressure was determined by connecting the cylinder to a manometer. We used our custom made non-contacting pressure measurement device that features a non-contact excitation and a laser-based pickup. In a hand-held device the user is faced with more degrees of freedom than is the case with a table top device. Our focus is to make the aiming of the device easier.

First, we performed measurements using a Laser Doppler Vibrometer (LDV) to pick-up a vibration propagating across the membrane whilst using the electronics of the hand-held device to indicate that it operates properly, Fig. 1, 2. We detected a predicted dependence between the arrival time of the vibration and the hydrostatic pressure in the phantom. We show results measured with the device held by hand.

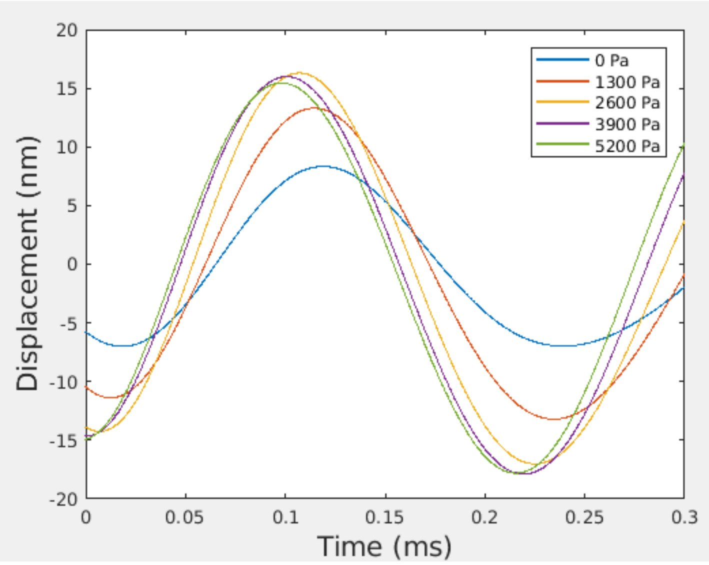

Fig 1

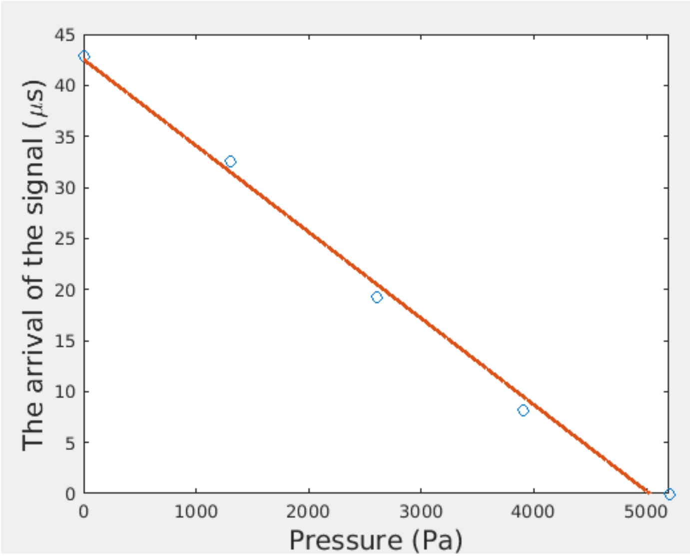

Fig 2

THERMAL PROPERTIES OF THREE-DIMENSIONAL PHONONIC CRYSTALS - FABRICATION AND SIMULATIONS

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Recent experiments on phononic crystal (PnC) membranes have shown that thin film thermal properties can be widely manipulated by periodic patterning that causes interference for the heat carrying quanta (phonons). [1,2] Three-dimensional PnC's, while being structurally robust, are predicted to have similar thermal features, such as ultralow thermal conductivity, at low temperatures. In this work we used two complementing fabrication methods for three-dimensional PnC's - nanoscale 3D-printing and colloidal crystallization of nanospheres. Using finite element simulations, we calculated how these structures modify heat capacity and thermal conductivity from the bulk reference values.

Three-dimensional PnC's were fabricated by combining many new and previously studied methods. [3] We used direct nanoscale 3D printing on IP-Dip resist to form a cubic crystal of nanospheres with a lattice constant of 3.1μm. For smaller crystal geometries (lattice constant down to 150 nm) we utilized the vertical deposition technique in a polystyrene nanosphere solution to form crystals which naturally self-assembled to a close-packed configuration. Self-assembled crystals were found to be fairly uniform (c.f. Fig. 1), bigger cracks were only rare, and the crystals adhered well to the edges of the container. For both samples we successfully fabricated metal lines of micrometer width on top of the crystals. These advances in the fabrication process pave the way for future thermal measurements on the crystals.

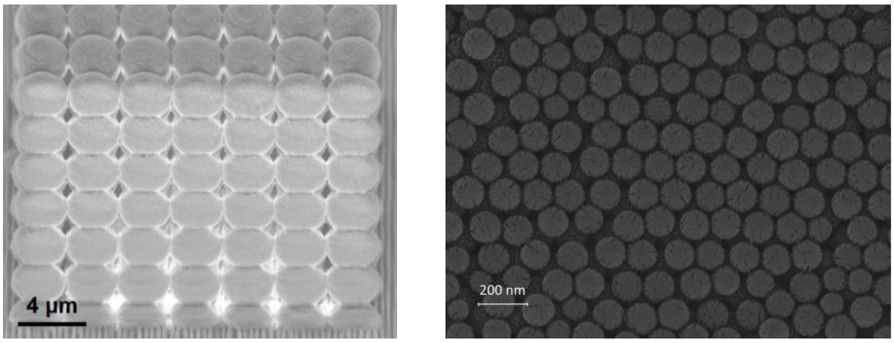

Figure 1: Scanning electron microscope images of the 3D-printed (left) and self-assembled (right) phononic crystals.

[1] N. Zen, et al. Nat. Commun. 5 (2014) 3435.
[2] T. A. Puurtinen and I. J. Maasilta, Crystals 6 (2016) 72.
[3] Y. Tian, et al. J. Phys. D: Appl. Phys. 50 (2017) 055302.

PLANAR ELECTROMAGNONIC CRYSTAL BASED ON A COPLANAR WAVEGUIDE

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Artificial magnetic materials with spatial periodic modulation of their physical properties or geometry, known as magnonic crystals, are promising for new microwave devices [1]. Recent advances related to the thin-film technology have resulted in fabrication of the multilayered multiferroic structures that combine advantages of the ferrites and ferroelectrics. Owning to the dual tunability of wave spectra by both electric and magnetic fields, such structures are widely used in microwave devices [2]. Different kinds of ferrite-ferroelectric all-thin-film structures have been suggested based on coplanar or slot transmission lines [3-5]. However, up to now the periodic multiferroic structures based only on slot transmission line were investigated. This work reports theoretical investigations of a novel thin-film periodic ferrite-ferroelectric structures based on a coplanar waveguide (CPW). We name such kind of multiferroic waveguides as electromagnonic crystals (EMC) in order to distinguish them from known ferrite magnonic crystals, as well as from photonic crystals.

Due to the symmetry of the fundamental CPW mode its dispersion relation was found through analytical solution of the full set of Maxwell`s equations utilizing the method of approximate boundary conditions described in details in Ref. [5]. The obtained dispersion relation for a regular CPW was used for a numerical calculation of the transmission characteristics of the EMC using the transfer-matrix method. Note that this method takes into account the insertion losses and is suitable for the finite-length periodic structures. As a result, the influence of EMC geometrical parameters on the transmission characteristic and band-gap positions was analyzed. It was found that high microwave signal rejection of more than 30 dB appears for the periodic structures. The optimal rejection efficiency and the required band-gap bandwidth can be obtained by adjusting the geometry of the EMC. Furthermore, the effective magnetic and electric tuning of transmission characteristics are achieved for this kind of periodic structure. All these advantages make investigated EMC perspective for development of new microwave devices. The work in SPbETU was supported in part by the Russian Science Foundation, Grant 14-12-01296P. The work in LUT was supported by the Academy of Finland.

[1] A.V. Chumak et al., J. of Phys. D: Appl. Phys. 50 (2017) 244001.
[2] M. M. Vopson, Crit. Rev. Solid State Mater. Sci. 40(4) (2015) 223-250.
[3] J. H. Leach et al., J. Appl. Phys. 108(6) (2010) 064106.
[4] A. A. Nikitin et al., Appl. Phys. Lett. 104(9) (2014) 093513.
[5] A. A. Nikitin et al., J. Appl. Phys. 118(18) (2015) 183901.

ELECTRON SPIN RESONANCE STUDY OF ATOMIC HYDROGEN STABILIZED IN SOLID NEON BELOW 1 K

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We report on an electron spin resonance study of atomic hydrogen stabilized in a solid Ne matrices carried out at a high magnetic field of 4.6 T and temperatures below 1 K [1]. The films of Ne, slowly deposited on the substrate at the temperature ∼1 K, exhibited a high degree of porosity. We found that H atoms may be trapped in two different substitutional positions in the Ne lattice as well as inside clusters of pure molecular H_2 in the pores of the Ne film. The latter type of atoms was very unstable against recombination at temperatures 0.3-0.6 K. Based on the observed nearly instant decays after rapid small increase of temperature, we evaluate the lower limit of the recombination rate constant $k_r \geq 5 \cdot 10^{-20}\,\mathrm{cm^3 s^{-1}}$ at 0.6 K, five orders of magnitude larger than that previously found in the thin films of pure H_2 at the same temperature. Such behavior assumes a very high mobility of atoms and may indicate a solid-to-liquid transition for H_2 clusters of certain sizes, similar to that observed in experiments with H_2 clusters inside helium droplets [2]. We found that the efficiency of dissociation of H_2 in neon films is enhanced by 2 orders of magnitude compared to that in pure H_2, which is instigated by a strong emission of secondary electrons.

[1] S. Sheludiakov, J. Ahokas, J. Järvinen, S. Vasiliev, Y. Dmitriev, D. Lee and V. Khmelenko, arxiv:1801.07089 (2018).
[2] K. Kuyanov-Prozument and A. F. Vilesov, Phys. Rev. Lett. 101, 205301 (2008).

ADVANCED SYNCHROTRON RADIATION TECHNIQUES TO CHARACTERIZE THE NUCLEAR FUEL

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Since decades, the nuclear fuel's physico-chemistry is at the heart of a worldwide research effort due to its high relevance for safety and economic performance of nuclear power plants and the sustainability of the nuclear waste management. From a fundamental point of view, this attractiveness is also the consequence of the actinide's complex nature involving 5f electrons. Moreover, nuclear fuel shows exciting interdependence between its properties and its electronic structures, which in most cases remain unclear. Key parameters are for instance electronic and local structures of constitutive elements, and their behaviour as a function of temperature and the defects nature and concentration. To assess these properties, synchrotron radiation based experimental techniques such as X-ray Absorption Spectroscopy (XAS) have demonstrated their strong abilities as suitable element-sensitive methods.

However, experimentally studying nuclear fuels implies to deal with complex materials containing almost all the periodic table of elements, each one contributing to the detected signal. Moreover, the structure of nuclear fuel is continuously evolving due to thermal and irradiation/radioactivity effects, as well as composition changes. Nuclear fuels usually demonstrate high radioactivity, which requests dedicated facilities. At least three synchrotron beamlines in Europe are now dedicated to radioactive materials (MARS@SOLEIL, CAT-ACT@ANKA and ROBL@ESRF), opening the possibilities of new exciting studies. In addition to their high radioactivity level authorization, they have recently developed X-ray emission spectrometer setups to perform advanced XAS. These spectrometers are mostly based on the use of silicon and germanium crystals, which, by diffracting the emitted X-rays, allows simultaneous focusing and energy discrimination with higher resolution than a conventional solid detector. Such method called High Energy Fluorescence Detected XAS (HERFD-XAS) or High energy Resolution XAS (HR-XAS), is situated at the edge of both X-ray Absorption and Emission Spectroscopies (XAS and XES), and allows the collection of spectra with a virtually reduced core-hole, which has been the main limiting factor of detailed studies in the past. This reduction is for example from 8-9 eV to 3-4 eV, and from 3-4 eV to roughly 1 eV at the actinide's L_3 and $M_{4,5}$-edges respectively, and allows for example the collection of detailed valence electronic density of states, directly comparable to theoretical calculations.

Therefore, the most recent cutting-edge achievements obtained using HERFD-XAS will be discussed.

ID20: A BEAMLINE FOR INELASTIC X-RAY SCATTERING, X-RAY SPECTROSCOPY AND IMAGING AT THE ESRF – THE EUROPEAN SYNCHROTRON

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The European Synchrotron Radiation Facility (ESRF) in Grenoble, France, is one of the world's largest synchrotron science centres, funded by 22 partner countries, including Finland. We present a new ESRF beamline ID20, which is dedicated to study the electronic structure of materials. It hosts a high-energy-resolution spectrometer for resonant inelastic x-ray scattering (RIXS) and x-ray emission spectroscopy in the 4-20 keV energy range, as well as a high-throughput large-solid-angle spectrometer for non-resonant inelastic x-ray scattering. The latter is specialized especially in x-ray Raman spectroscopy (XRS), which is inelastic x-ray scattering from core electrons and can give similar information than soft-x-ray absorption spectroscopy but with hard x-rays. The beamline is equally well equipped for x-ray absorption spectroscopy.

The RIXS spectrometer [1] is used for studies of magnetic collective excitations, crystal field excitations, and plasmons in condensed matter systems, including strongly correlated materials. RIXS is a photon-in–photon-out technique for the study of the electronic structure of materials and probes transitions involving lattice, charge, spin and/or orbital degrees of freedom and yields information complementary to other spectroscopies such as inelastic neutron scattering, X-ray resonant magnetic scattering, X-ray magnetic circular dichroism or optical Raman spectroscopy.

The XRS spectrometer [2] allows the measurements of soft-x-ray absorption edges with hard x-rays, which have the benefit of strong penetration power through complex samples. This allows for studies of chemistry of materials under in situ conditions, such as in operando batteries and fuel cells, in situ catalytic reactions, and extreme conditions, e.g., in high pressure and extreme temperatures. When combined with *direct tomography* [3] i.e., dark-field 3D imaging with x-ray spectral contrast, it can be used to study the spatial arrangement and chemistry of light-element materials in buried systems.

[1] M. Moretti Sala et al., A high-energy-resolution resonant inelastic X-ray scattering spectrometer at ID20 of the European Synchrotron Radiation Facility, J. Synchrotron Radiat. 25, 580 (2018)
[2] S. Huotari et al., A large-solid-angle X-ray Raman scattering spectrometer at ID20 of the European Synchrotron Radiation Facility, J. Synchrotron Radiat. 24, 521 (2017)
[3] S. Huotari et al., Direct tomography with chemical-bond contrast, Nature Mater. 10, 489 (2010)

A NEW X-RAY ABSORPTION SPECTROSCOPY FACILITY AT THE UNIVERSITY OF HELSINKI

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X-ray absorption spectroscopy (XAS) is a well-established technique for obtaining element-specific information on the structure and chemical environment in materials regardless of their phase or ordering. Synchrotron beamtime for XAS experiments, however, is in high demand and thus diffcult to obtain for e.g. routine characterisation and studies of slow chemical reactions. In addition, utilizing XAS for radiochemisty research is especially difficult as many synchrotrons do not allow radioactive materials on site.

To alleviate these problems, we present HelXAS [1]: a cost-efficient and easily accessible laboratory XAS instrument utilizing a conventional X-ray tube and a crystal monochromator. HelXAS is designed for XAS studies in the 5-20 keV range which covers most K edges of 3d transition metals and L edges of 5d transition metals and actinides. The typical energy resolution is around 1-2 eV. Measurements can be performed in transmission and fluorescence detection modes, the latter enabling the study of samples on thick substrate/support. Due to its simple and modular design, HelXAS can modifed to accommodate additional equipment and complex sample environments required for e.g. in situ studies such as catalysis and electrochemistry. A showcase of various applications is presented [2-5].

[1] Ari-Pekka Honkanen et al., in preparation
[2] W. Wang et al., Mass-Production of Mesoporous $MnCo_2O_4$ Spinels with Manganese(IV)- and Cobalt(II)-Rich Surfaces for Superior Bifunctional Oxygen Electrocatalysis, Angew. Chem. Int. Ed. 56, 14977 (2017)
[3] L. Kuai et al., Mesoporous $LaMnO_{3+\delta}$ perovskite from spray−pyrolysis with superior performance for oxygen reduction reaction and Zn−air battery, Nano Energy 43, 81 (2018)
[4] R. Bès et al., Laboratory-scale X-ray absorption spectroscopy approach for actinide research: experiment at the uranium L_3-edge. Submitted to Journal of Nuclear Materials
[5] J. G. Moya-Cancino et al., *In-situ* X-ray Absorption Near Edge Structure Spectroscopy of a Solid Catalyst using a Laboratory-scale Set-up, in preparation.

COMPUTATIONAL SCHEME FOR IRIDIUM 5D CRYSTAL FIELD EXCITATIONS IN Sr_3NiIrO_3

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Resonant Inelastic X-ray Scattering (RIXS) is a powerful technique for studying a wide range of low-energy excitations in solids such as magnetic collective modes (magnons) and crystal-field excitations. This versality, however, sometimes complicates spectral interpretation, which requires deconvoluting the contributions of various elementary excitations. Especially in 5d transition metals, the spin-orbit splitting and crystal field splitting of the 5d electron states are manifested strongly in the excitation spectra in the 1-5 eV energy range[1]. Using a ligand-field model Hamiltonian to describe the local atomic environment, we compute the Ir 5d excitation spectrum in Sr3NiIrO6 using Kramer's Heisenberg's relation within a dipole approximation. The results are compared to experimental ones obtained [2] using RIXS at the ID20 beamline of the European Synchrotron Radiation Facility [3, 4].

[1] L. J. P. Ament et al., Rev. Mod. Phys. 84, 705 (2011)
[2] E. Lefrancois et al., Phys. Rev. B 93, 224401 (2016)
[3] M. Moretti-Sala et al., J. Synchotron Radiat. 25, 580 (2018)
[4] S. Huotari et al., contribution in this conference

STUDY OF HELIUM BEHAVIOR IN HE ION IMPALNTATED TUNGSTEN BY POSITRON ANNIHILATION SPECTROSCOPY

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Due to the high melting point, good thermal conductivity and low tritium retention, tungsten is the promising candidate of plasma facing materials for fusion reactor system. Helium retention, diffusion and bubble formation in tungsten are important issues, which have be considered a lot in previous research works.

In present work, 100 keV helium were implanted into tungsten at room temperature and 873 K, respectively. Positron annihilation Doppler Broadening spectroscopy based on slow positron beam, including Coincidence Doppler Broadening (CDB) method, were performed to study irradiation induced microstructural evolution and helium behavior in irradiated tungsten.

The results indicate that vacancy type defects accumulated during ion implantation. Implanted helium were easily trapped by vacancies. Helium-vacancy complexes would be formed, which may suppress the increment of vacancy type defect concentration. However, He atoms and He_2 clusters in tungsten were unstable during elevated temperature irradiation. Helium diffused and being trapped by stabilized He_n clusters ($n > 2$) in tungsten, which might be the early stage of He bubbles formation. The inner pressure increment as the number of atoms increased in He_n clusters, which may displace solid atoms from lattice site. Additional dislocations and open volume defects would be formed due to the displacement process. The characteristics of larger-sized He_n clusters or He bubble effect in tungsten were detected by CDB measurement.

Computational studies on free-standing 2D metals

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Common two-dimensional (2D) materials have a layered three-dimensional (3D) structure with covalently bonded, atomically thin layers held together by weak van der Waals forces [1]. However, in a recent transmission electron microscopy experiment, atomically thin 2D patches of iron were discovered inside a graphene nanopore [2]. Further computational works predicted stable Au, Ag, and Cu membranes and even the existence of a 2D liquid [3].

Here, we present a systematic density-functional study on atomically thin elemental 2D metal films, using 45 metals in three lattice structures shown in Figure 1 [4]. Cohesive energies, equilibrium distances, and bulk moduli in 2D are found to be linearly correlated to the corresponding 3D bulk properties, enabling the quick estimation of these values for a given 2D metal and lattice structure. In-plane elastic constants show that most 2D metals are stable in hexagonal and honeycomb, but unstable in square 2D structures. Many 2D metals are surprisingly stable against bending.

Li 3	Be 4													
Na 11	Mg 12											Al 13		
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31		
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42		Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	
Cs 55	Ba 56	Ln series	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83

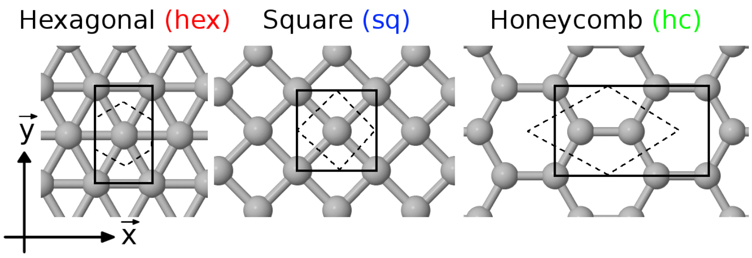

Figure 1: Part of the periodic table with the studied metals and schematic representations of the 2D lattices. Chemical symbol and proton number are given for each element. Solid line indicates the computational unit cells and dashed lines the Wigner-Seitz cells.

[1] K. S. Novoselov, A. K. Geim, S. V. Morozov, *et al.*, Science **306**, 666 (2004).
[2] J. Zhao, Q. Deng, A. Bachmatiuk, *et al.*, Science **343**, 1228 (2014).
[3] P. Koskinen, and T. Korhonen, Nanoscale **7**, 10140 (2015).
[4] J. Nevalaita, and P. Koskinen, Phys. Rev. B **97**, 035411 (2018).
(Editor's suggestion, Physics synopsis)

DETERMINATION OF A VALUE OF RESISTIVITY OF ANY SHAPE STRUCTURED MATERIAL USING FOUR POINT MEASUREMENT AND NUMERICAL SIMULATIONS

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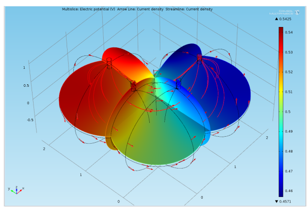
Determination of the value of resistivity using four point measurement needs information about the geometrical structure. When the shape of structure is modelled, the measurement values, voltage and current, can be estimated using the finite element analysis software, where the current density and the electric potential values are calculated inside the piece of material.

In this work the computational power of modern simulation software was used together with experimental measurements. The current density and the voltage caused by resistivity losses were computed by COMSOL Multiphysics® software. Using *Parametric Sweep* -operation the predicted voltage difference as a function of resistivity was evaluated. Experimental four point measurement measures the value of voltage difference and that value can be converted to the resistivity using simulated $V = V(\rho)$ -function. Thus, the modelling of the experimental system and the simulation of the results was used as a virtual calibration of the resistivity measurement.

The validation measurements were performed using electrically conductive plastic plates produced by Premix Oy. The voltage was measured using Keithley electrometer and the current using Fluke multimeter.

This work was done during my internship at Laboratory of Industrial Physics at the University of Turku. The Comsol simulations were evaluated at CSC Taito Supercluster using Taito-shell environment.

The electric potential and the current density calculated in the measurement system.



COMPETITION OF ELECTRON-PHONON MEDIATED SUPERCONDUCTIVITY AND STONER MAGNETISM ON A FLAT BAND

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The effective attractive interaction between electrons, mediated by electron-phonon coupling, is a well-established mechanism of conventional superconductivity. In the typical metallic systems exhibiting a Fermi surface, the resulting critical temperature of superconductivity is exponentially suppressed compared to the characteristic (Debye) phonon energy scale, and therefore such superconductors are found only at temperatures below a few Kelvin. Systems with flat energy bands have been suggested to cure the problem and even provide a route to room temperature superconductivity, but all previous studies have been limited to only Bardeen-Cooper-Schrieffer (BCS) models with an effective attractive interaction. Here we generalize Eliashberg's theory of strong-coupling superconductivity to the case with flat bands and relate the mean-field critical temperature to the microscopic parameters describing electron-phonon and direct electron-electron interaction. We also analyze the ensuing strong-coupling corrections to the BCS results, and construct the phase diagram of the model exhibiting superconductivity and magnetic phases on an equal footing. Our results are especially relevant for novel quantum materials where electronic dispersion and even the strength of interactions (via screening) are controllable.

[1] R. Ojajärvi, T. Hyart, M. Silaev, T. T. Heikkilä, arxiv:1801.01794 (2018).

Onset of novel phase behavior in sedimenting Quincke rollers

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Quincke rollers are model active particles whose propulsion mechanism originates from an electrohydrodynamic instability.[1] Collective behavior and phase diagrams of Quincke rollers have been recently established.[2,3,4] Here, we experimentally demonstrate the onset of a crystalline phase in a population of Quincke rollers under the influence of a homogenous in-plane biasing force and confinement (Fig. 1). Tuning the interplay between the biasing force and the propulsion force allows us to drive a population of rollers from an isotropic gas-like state to a solid-like crystalline state. We also explore the steady-state dynamics of the interface between these two phases. Our findings may find applications in engineering of highly dynamic crystalline materials based on colloidal particles.

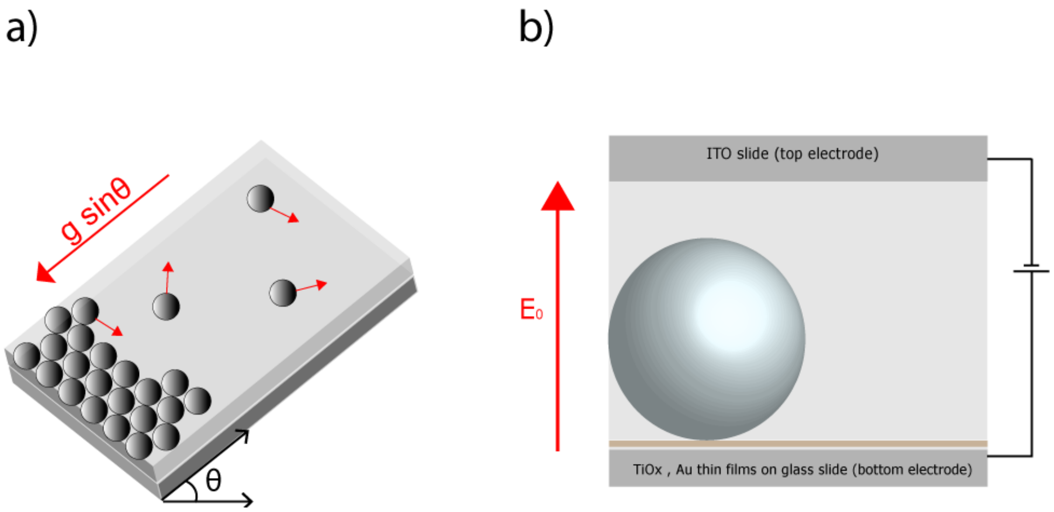

Figure 1. a) Scheme of an angled view of a sample of Quincke rollers. b) Scheme of side-view of the system showing a Quincke roller particle in leaky dielectric medium sandwiched between two electrodes.

References:

1. Quincke, Ann. Phys. Chem. **59,** 417-486 (1896)

2. Bricard et al., Nature **503**, 95–98 (2013)

3. Bricard et al., Nat. Commun. **6**, 7470 (2015)

4. Morin et al., Nat. Phys., **13**, 63–67 (2017)

Keywords: *Active particles, Quincke rotation, sedimentation-diffusion equilibrium, active matter*

MANY-BODY LOCALIZATION IN AN ARRAY OF TRANSMON DEVICES

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Superconducting circuits hold promise as good platform for quantum simulations. Up to date, the fabrication disorder of superconducting circuits has been one of the obstacles for realizing large scale quantum simulations of realistic condensed matter models. To turn disorder into an advantage, we theoretically study the prospect for quantum simulation of disordered and interacting quantum matter in long arrays of transmon devices. Specifically, we are interested in bosonic many-body localization [1]. Many-body localized states are highly-excited many-body eigenstates. Despite of high energy density, their principal properties are more similar to those of generic ground states. Additionally, they are extraordinary as they fail to quantum thermalize.

In an array configuration, transmons interact via the capacitive dipole-dipole interaction and the crucial many-excitation interaction is provided by the anharmonicity of the transmon energy spectrum. These together realize a Bose-Hubbard chain with attractive interactions [2, 3]. The decoherence rates of the state-of-the-art devices are low with respect to the typical interaction energies rendering superconducting circuits sufficiently closed quantum systems. High controllability of superconducting circuits can be used for detailed quantum measurements of individual transmons allowing experimental witnesses of many-body localization [3, 4].

Using the recently developed DMRG-like method for finding highly-excited many-body eigenstates [5], we numerically explore features of the many-body localization in arrays that comprise 10-30 transmons. Our first results show positive signs on many-body localization with experimentally relevant parameters.

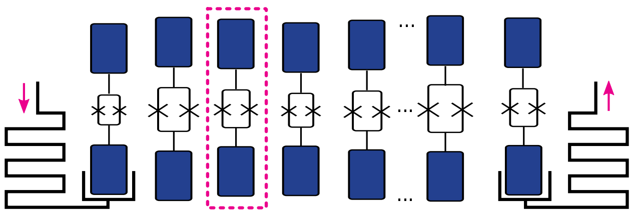

Figure 1: An array of interacting and disordered transmons (similar as recently realized in Ref. [3]). Control and read-out resonators can be coupled to any of the transmons.

[1] R. Nandkishore and D. A. Huse, Annu. Rev. of Condens. Matter Phys. 6 (2015) 15.
[2] S. Hacohen-Gourgy *et al.*, Phys. Rev. Lett. 115 (2015) 240501.
[3] P. Roushan *et al.*, Science 358 (2017) 1175.
[4] M. Goihl et al., arXiv:1601.02666 (2016).
[5] X. Yu, D. Pekker, and B. K. Clark, Phys. Rev. Lett. 118 (2017) 017201.

TUNABLE SLOT TRANSMISSION LINE BASED ON HEXAFERRITE-FERROELECTRIC BILAYER FOR SUB-TERAHERTZ FREQUENCIES

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Multiferroics in a form of waveguide structures composed of ferrite and ferroelectric layers provide a possibility of dual broadband magnetic and fast electric tuning [1]. This unique feature is based on the electrodynamic interaction between the electromagnetic and spin waves in the layered ferrite-ferroelectric structures [2]. The interaction leads to formation of hybrid spin-electromagnetic waves (SEWs). Recently advantages of the SEW spectrum were investigated in the thin-film multiferroic structures with a slot transmission line [3]. A rapidly growing interest to the terahertz technology has stimulated an elaboration of the structures operating around 0.1–1 THz. For the frequencies above 25 GHz the hexagonal ferrites having a large planar or uniaxial magnetocrystalline anisotropy field are commonly used. It is known that the M-type hexaferrite ($BaAl_xFe_{12-x}O_{19}$) allows one to increase significantly the uniaxial magnetocrystalline anisotropy field and, consequently, to achieve FMR frequencies of 0.1 THz or more for the reasonable values of bias magnetic fields [4]. Among the ferroelectrics, the thin films of barium-strontium titanate solid solutions ($Ba_xSr_{1-x}TiO_3$) are especially attractive. They exhibit weak dispersion of the relative permittivity in a vast frequency range $10^2 – 3\cdot10^{11}$ Hz [5]. The aim of this work is to investigate theoretically dispersion of the SEWs in the artificial multiferroic structure composed of the barium-strontium titanate and the M-type hexaferrite with a slot transmission line. The following parameters were used for the single crystal $BaAl_2Fe_{10}O_{19}$ in the calculations: thickness 10 μm, saturation magnetization 1850 G, and uniaxial magnetocrystalline anisotropy field 33.68 kOe. The polycrystalline $Ba_{0.5}Sr_{0.5}TiO_3$ film had thickness 2 μm and electric field tunability 2. The thickness of the sapphire substrate was 125 μm. The slot transmission line with a slot-line gap width of 10 μm was located between $BaAl_2Fe_{10}O_{19}$ and $Ba_{0.5}Sr_{0.5}TiO_3$. Results of numerical simulations for the main mode of the SEW spectrum show that a decrease of the external magnetic field from 10 kOe to 9.5 kOe and dielectric permittivity of the ferroelectric film from 1000 to 500 provided broadband magnetic and fast electric tuning, respectively. This allows to conclude that the hexaferrite-ferroelectric thin-film structures could find application at the sub-terahertz frequencies as a frequency-agile material for device applications.

[1] M. M. Vopson, Crit. Rev. Solid State Mater. Sci. **40**, 223 (2015).
[2] V. E. Demidov, B. A. Kalinikos, P. Edenhofer, J. Appl. Phys. **91**, 10007 (2002).
[3] A.A. Nikitin et. al., J. Appl. Phys. **118**, 183901 (2015).
[4] A. B. Ustinov et.al., J. Appl. Phys. **105**, 023908 (2009).
[5] G. Houzet et.al., Appl. Phys. Lett. **93**, 053507 (2008).

S3

DEVICE TO STUDY MOLECULAR TRANSPORT AND DIFFUSION THROUGH A SEMIPERMEABLE MEMBRANE

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Non-invasive transport of molecules through skin is relevant to health monitoring devices and point-of-care testing. We developed and evaluated a device to study of transport and diffusion of molecules through a semipermeable membrane (*i.e.* artificial skin). Our solution allows *in-vitro* investigation of reverse iontophoresis, a physical mechanism relevant in non-invasive sampling of dermal interstitial fluid. Our device (Figure 1) features a donor phase, a semipermeable membrane, and a receiving phase. The membrane is a Cellulose Ester (CE) membrane with molecular weight cut off (MWCO) = 500 Da. During the experiments, the donor phase chamber is filled with 100 mL of a 25 mM HEPES buffer solution containing 133 mM NaCl and 5 mM glucose. Iontophoretic treatment consisted of 60 min-long exposure to 2 mA/cm^2 current density. Samples of 1 mL where collected from each receiving chamber (anode, cathode, and control) and their glucose content was measured using a commercial kit. Our results show higher glucose concentration in the cathode chamber (n = 12; mean = 14.4 µmol/L; SD = 2.2) as compared to anode (n = 12; mean = 2.2 µmol/L; SD = 1.8 µmol/L) and control (n = 12; mean = 1.9 µmol/L; SD = 0.5 µmol/L). Our results are consistent with previous works [1]. Our device permits investigating how different parameters affect the transport and diffusion of molecules through a semipermeable membrane via iontophoresis.

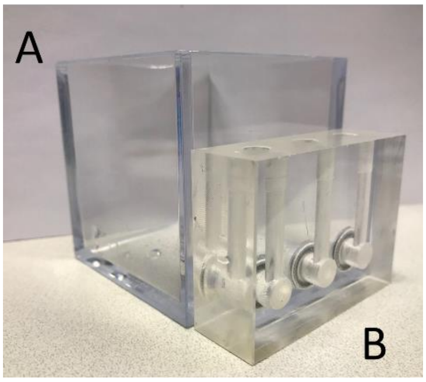

Figure 1) A is the donor chamber. Block B consists of three receiving chambers. The membrane is placed between chambers A and B.

References

[1] T. Ching ja P. Connolly, "Simultaneous transdermal extraction of glucose and lactate from human subjects by reverse iontophoresis," *International Journal of Nanomedicine,* 2008.

CHARACTERIZATION OF AN ENZYMATIC GLUCOSE BIOSENSOR

Joel Hunnakko[1], Alejandro García-Pérez[1], Zhanna Boeva[2], Teemu Nurminen[1], Risto Vänskä[1], Teemu Nurminen[1], Emily Kemp[2], Johan Bobacka[2] and Edward Hæggström[1]

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We investigate the sensitivity, range, precision, and response time of Prussian Blue-modified screen-printed electrodes drop casted with Glucose oxidase and operated by miniaturized electronics. The electrodes were operated by a 16 mm^2 low power potentiostat controlled via I^2C interface by a micro-controller ATmega328P MCU using a development board (Arduino A000066). The suitability of the investigated system in potential glucose monitoring applications is discussed.

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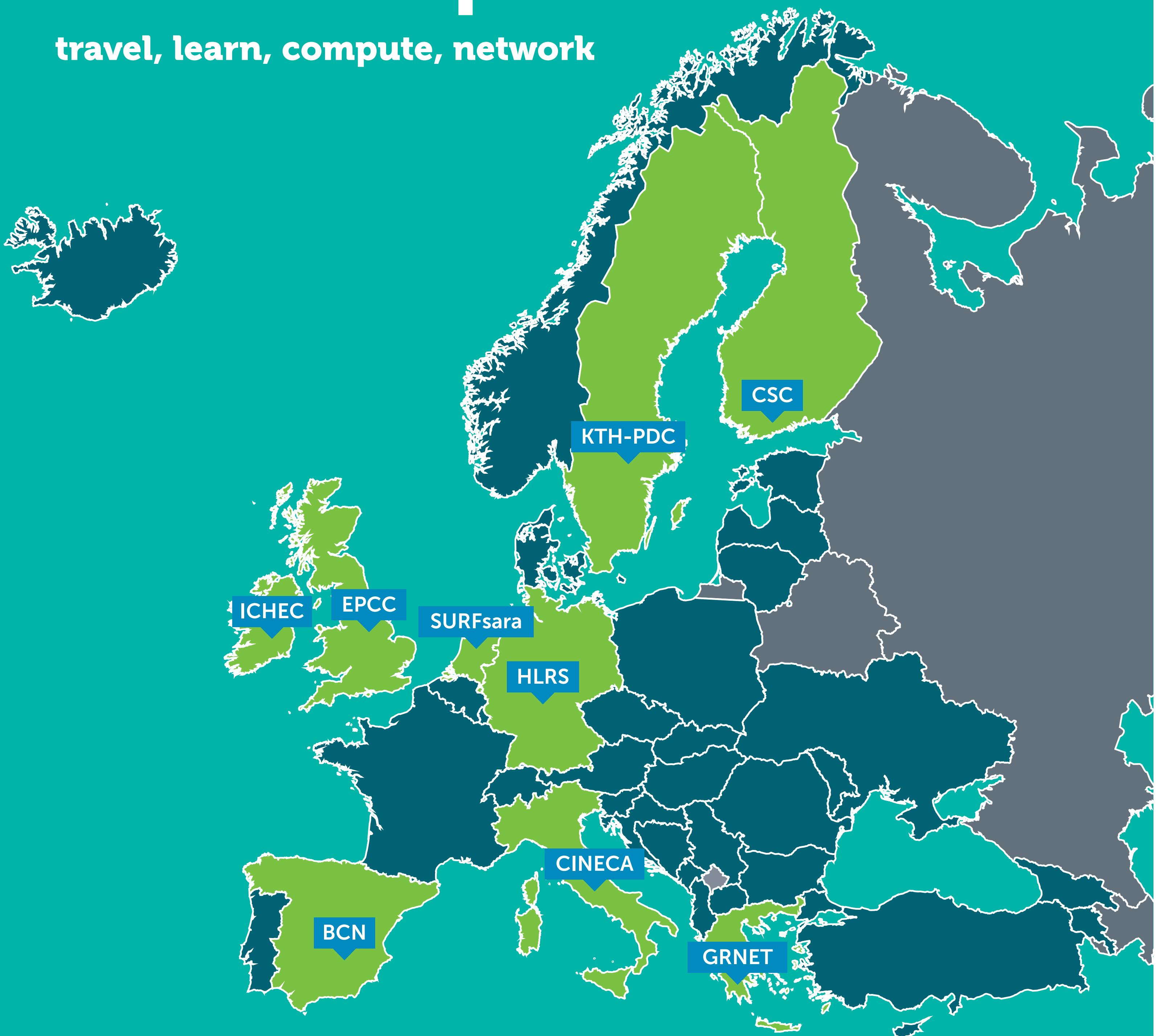

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