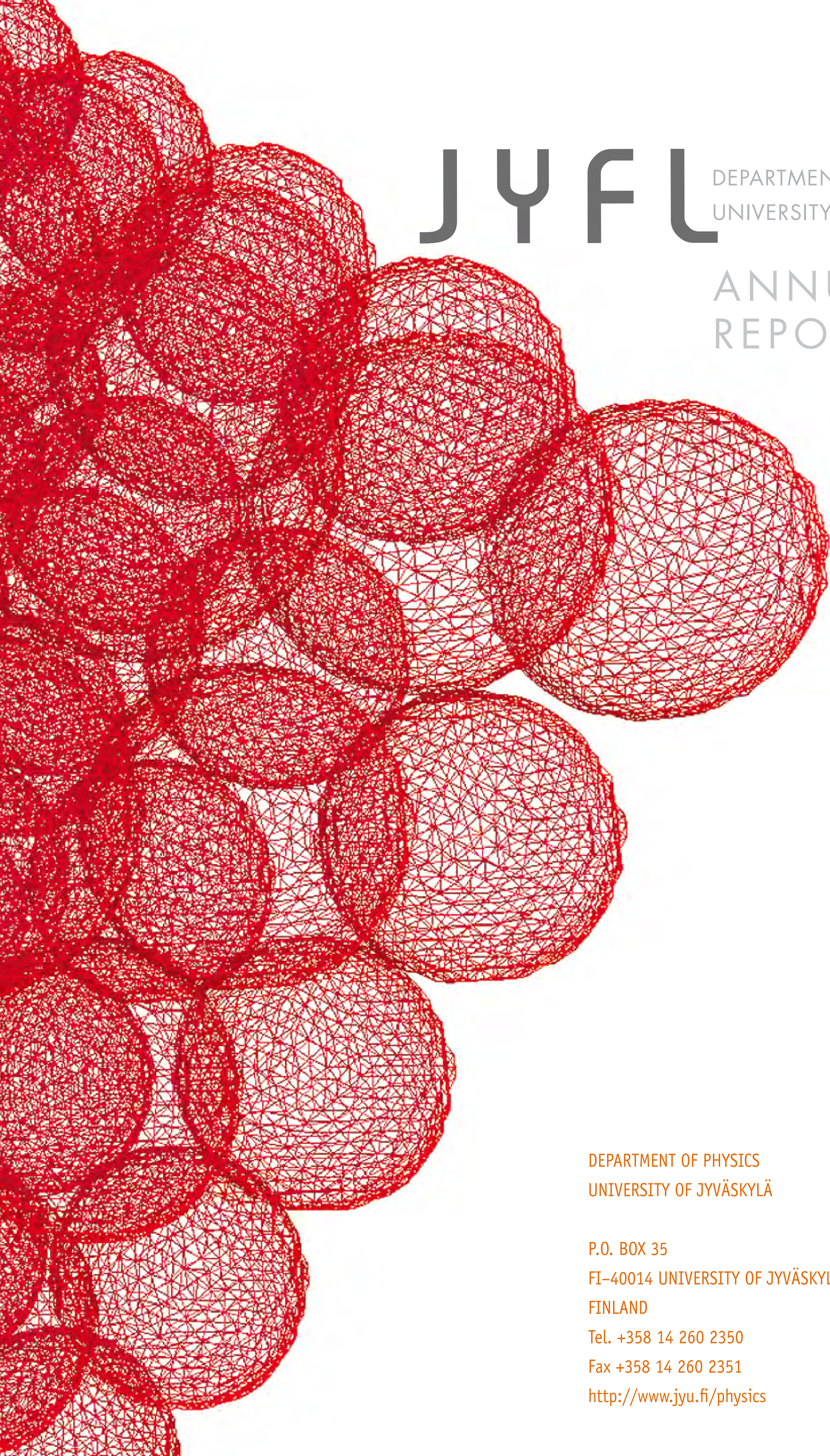

JYFL

DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ

ANNUAL REPORT 2007

DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ

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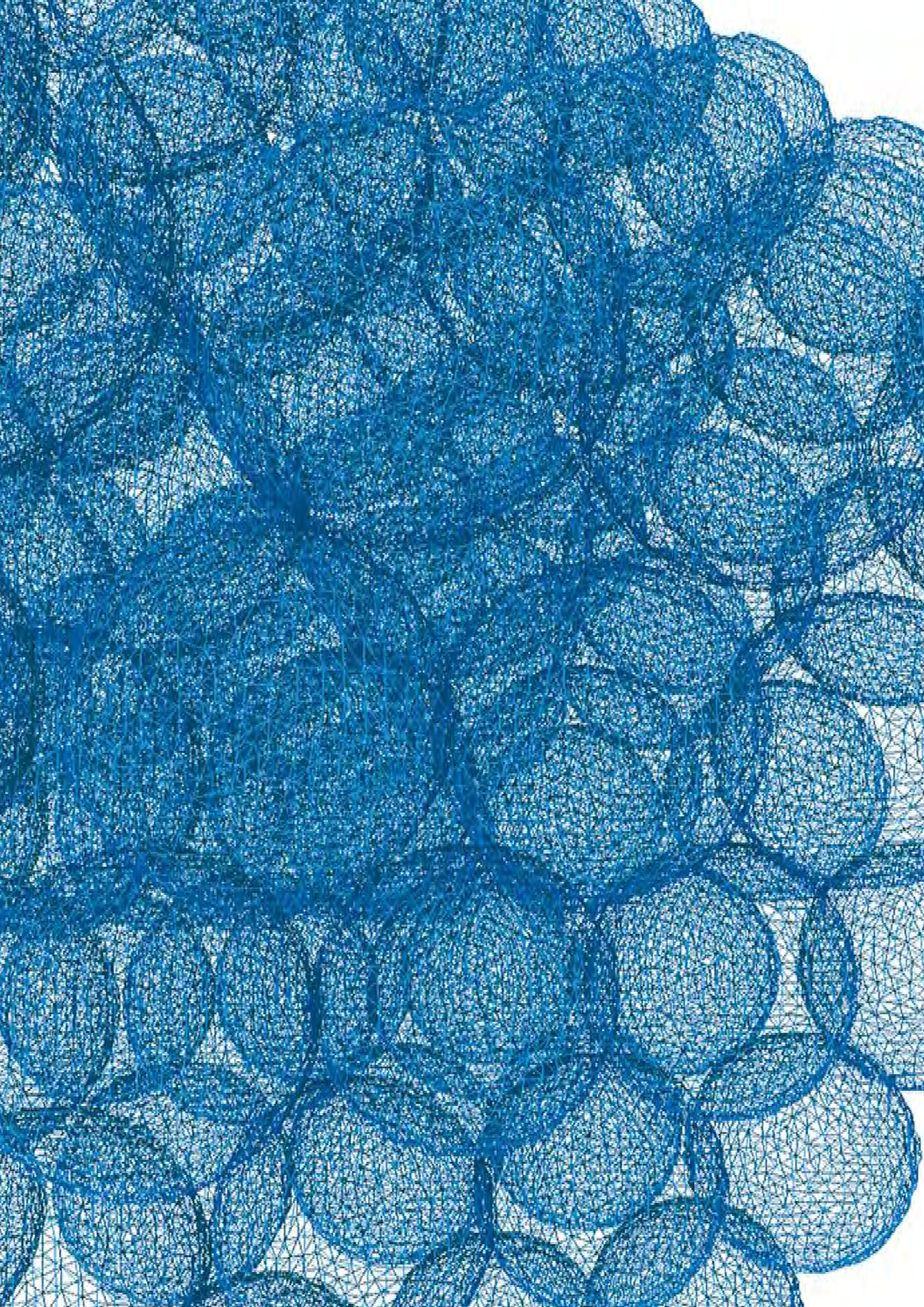


Department of Physics

Jukka Maalampi

Preface

This annual report gives an overview of the activities of the Department of Physics in 2007. The year was characterised by continued achievement of high standards both in research and education, as well as by preparing for significant future projects and facilities. The Department's performance strengthened both in scientific output and in education.

Research

The research work was active and productive in all three main research fields of the Department, which are high-energy physics, materials physics, and nuclear and accelerator based physics. The number of peer review articles was 176, to be compared with 137 in 2006, including 16 articles in Physical Review Letters. Also the number of invited talks and other conference contributions increased substantially from the previous year.

Nuclear and Accelerator Based Physics

The Finnish Centre of Excellence (CoE) in Nuclear and Accelerator Based Physics nominated by the Academy of Finland for the period of 2006-2011 continued its successful activity. The CoE covers research and development work at the Accelerator Laboratory of the Department as well as the theoretical nuclear physics research.

The contract for a delivery of a new cyclotron was signed in 2007, and our technical personnel has begun preparations for its installation which should happen by the end of 2009. Construction of the extension of the present accelerator hall for this new machine will start in 2008 and it will temporally interfere with the normal activities of the laboratory.

The confirmed participation of Finland in construction of the FAIR (Facility for Antiproton and Ion Research) next-generation accelerator facility, which started near

Darmstadt, Germany, in 2007 and will be completed by 2015, has brought new responsibilities to the Department and will cause some reorientation of activities at the Accelerator Laboratory. Once completed, FAIR will offer new and interesting research prospects for our experimental groups.

An important event in 2007 was the commissioning of the 1.7 MeV Pelletron accelerator with associated beam lines. The accelerator was donated by the Technical Research Centre of Finland (VTT) and it has strengthened significantly the resources and possibilities of experimental materials physics research in the Department. The accelerator was officially opened in November 2007 with a special one day opening seminar.

Professor Jacek Dobaczewski started in the beginning of 2007 his five-year term as a FiDiPro professor, sharing his time fifty-fifty between the Department and the Institute of Theoretical Physics of the University of Warsaw, Poland. He has quickly founded an active group of young theoreticians around him, devoted to advanced theoretical studies of the properties of exotic nuclei, in strong synergy with experimental studies performed at the Department.

Nanoresearch

The research in the multidisciplinary NanoScience Center, NSC, continued to produce significant scientific contributions in experimental, theoretical and computational nanophysics. The main activities of the experimental nanophysics group include mesoscopic superconductivity, thermal effects in mesoscopic devices, and the fundamentals of solid state quantum computing as well as research on the physical properties of single carbon nanotubes. Theoretical and computational research topics include the electronic structure of gold nanoclusters, quantum dots and modelling of semiconductive phase change materials. Professor Matti Manninen was appointed to the director's position of NSC in 2007.

The Department opened in 2007 a five-year professorship in low-temperature physics with the responsibility of conducting the experimental research in this field at the NSC. Ilari Maasilta was appointed to this position, and he will start his term in August 2008. The research group of theoretical nanophysics was significantly strengthen when Robert van Leeuwen joined the Department and started his term in a position of senior assistant. At the same time as we are delighted for these new appointments we have to accept with regret that two previous key members of the nanoscience group, professor Päivi Törmä and academy researcher fellow Sorin Paraoanu, have left the Department to take new positions in the Technical University of Helsinki.

High-energy Physics

The new LHC (Large Hadron Collider) accelerator at CERN will start operating in 2008. The Department is an active participant of the ALICE heavy ion experiment to be carried out at the LHC, keeping the local ALICE detector and physics analysis groups busy. The start of experiments is also eagerly awaited by our strong theoretical group studying ultrarelativistic heavy ion collision (URHIC) physics. The leader of the URHIC theory group Kari J. Eskola succeeded Vesa Ruuskanen as a professor of theoretical physics in 2007.

The main research topics of the group of theoretical particle physics and cosmology included neutrino mixing effects in astrophysics, quantum transport problem in connection to baryogenesis, extended gravity models and the physics of time.

The Department has continued its collaboration with the University of Oulu in the cosmic ray experiment EMMA, which is under construction in Pyhäsalmi mine. The Pyhäsalmi mine has attracted a lot of interest in the European particle and astroparticle physics community as a possible location of the very large underground neutrino experiment, the prospect studied in the European project LAGUNA .

Industrial Physics

An essential part of Department's "third task" is covered by the research activity in industrial physics and cooperation with industry and industry-related organizations. The personnel resources of the industrial physics activity was strengthened in by a new senior assistant position for which the University allocated special funding. For further developing the industrial applications of basic physics research carried on in the Department, a study was made of the possibilities and prospects for research and teaching collaboration between the University of Jyväskylä, the Jyväskylä Polytechnics and the VTT Technical Research Centre of Finland in science and technology. A new interesting initiative in industrial relations was the collaboration that started in 2007 with the German company Oxyphen GmbH in irradiating their polymer films.

HIP Collaboration

The Helsinki Institute of Physics (HIP), a research institution jointly operated by the Universities of Helsinki and Jyväskylä and theTechnical Universities of Helsinki and Lappeenranta, has played an increasing role in the research activities of the Department. The Department has a leading position at HIP in the Nuclear Matter Program, including the ALICE project and the ISOLDE project, as well as a strong involvement in the Theory Program, whose *Cosmophysics* project and *Laws of Nature and Condensed Matter Phenomenology at the LHC* –project, both led by a Jyväskylä theorist, were

Personnel (permanent posts in parentheses)	162 (60,5)
- professors	13,5 (13,5)
- lecturers	5 (5)
- senior assistants	8 (9)
- assistants	3,5 (4)
- researchers	105 (4)
- technicians	23 (21)
- administration	4 (4)
+ several research assistants (MSc students)	
Undergraduate students	525
of which new students	104
Graduate students	87
MSc degrees	49
PhLic degrees	–
PhD degrees	9
Credits (national)	5971
Median time to complete MSc (years)	5,3
Number of foreign visitors	~230
- in visits	~345
Visits abroad	~340
Peer reviewed publications	176
Conference proceedings	32
Other scientific reports (preprints etc.)	26
Newspaper articles etc.	9
Conference contributions	
- Invited talks	~115
- Other talks	~85
- Posters	~100
Seminars outside JYFL	~100
Funding (million €)	11,9
* University budget (incl. premises)	7,4
* External funding	4,5
- Academy of Finland	2,1
- Technology Development Centre	0,4
- International programmes	0,6
- HIP.	0,5
- Contract research	0,6
- Others	0,3

accepted to the HIP program starting from 2008. HIP is also the coordinator of the Finnish FAIR activity, where the Accelerator Laboratory of the Department will play a central role.

Education

In teaching the year 2007 was quite satisfactory. The number of MSc degrees was 49, which is a new record and exceeds the official goal. The number of PhD degrees was 9, a good result as well, though short of the goal of 13. At the moment more graduate students than ever are working for their doctoral thesis in the Department, promising a good yields of doctors in the years ahead.

Our Department participates in five national graduate schools and coordinates two of them, the Graduate Schools in Particle and Nuclear Physics and in Nanoscience.

Worried about the decreasing tendency in the number of applications and enrolled new students witnessed in recent years, the Department strengthened its recruiting efforts in 2007, including the printing of a leaflet advertising the study possibilities of physics and nanoscience in the Faculty, mailed to schools and also individually to a selected group of mathematically oriented students. After these efforts, it was a pleasure to realize that a full quota of well motivated new students were enrolled the Department in 2007. The new candidate's curriculum in nanoscience turned out to be a success as well.

Administration

The total funding of the Department in 2007 was 11.9 M€, about 3% more than in the previous year. The budget money increased considerably, from 6,3 M€ in 2006 to 7.4 M€ in 2007, being 65% of the total funding, but at the same time a substancial and quite worrying decrease of the outside funding, from 5,0 M€ to 4.5 M€, was witnessed. Taking into account the increase of rents, general costs and salaries, the resources available for running costs effectively decreased.

The reorganisation of the computing administration of the University meant that two support persons moved from the Department to the personnel of the Information Management Center, though remaining physically in the Department. The centralizing of the computer services has had its cons and pros, but in general the development has been clearly on the positive side, after the special needs of the Department were accepted and taken into account.

Connected to the audit of the quality assurance system of the University, scheduled to 2008, a quality manual of the Department was produced in 2007.

The Department launched in 2007 a weekly appearing bulletin in order to better inform the personnel about the matters concerning administrative plans and decisions, events, deadlines and to increase the transparency in general. The feedback from the personnel has been quite positive.

Events

The retirement of laboratory engineer Teuvo Poikolainen signaled the end of an era in our Department, and the appointment of Jaana Kumpulainen as Teuvo's successor the beginning of a new one. Another noteworth change in the technical personnel took place when Hannu Leinonen started his smooth landing to retirement, to happen officially in spring 2008. The undersigned was happy to receive two litterature prices (State Award for Public Information and Lauri Jäntti Award) for the book about Albert Einstein.

A significant change to positive direction took place in the social atmosphere of the Department when a coffee automat was opened in the lobby.

Centre of Excellence in Nuclear and Accelerator Based Physics

Rauno Julin

The Finnish Centre of Excellence in Nuclear and Accelerator Based Physics (JYFL-CoE) nominated by the Academy of Finland for the period of 2006-2011 covers research and development work as well as ion-beam applications at the Accelerator Laboratory of JYFL and theoretical nuclear physics activities carried out at JYFL.

The JYFL-CoE activities at CERN including ISOLDE and ALICE form the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP). Most of the Finnish contributions in the FAIR project are covered by the activities of the JYFL-CoE teams in the HISPEC/DESPEC, LASPEC and MATS projects at the FAIR-NUSTAR facility. The Finnish FAIR activities are coordinated via HIP.

The Accelerator Laboratory of JYFL as a part of the CoE is one of the eight major European nuclear physics infrastructures, whose action is concerted through an EU-Integrated Infrastructure Initiative project (EURONS) in the 6th Framework Programme. In addition to the Transnational Access Activity (TNA) of EURONS, the Accelerator Laboratory is a partner in 6 different Joint Research Activities (JRA) of EURONS.

In 2007, the total number of beam time hours at the K130 cyclotron used by the CoE teams in collaboration with foreign teams for basic research and applications again summed up to more than 6000 hours. Highlights and activities of the JYFL-CoE teams in 2007 are summarized in the following chapters of the present Annual Report.

Scientific Advisory Board of the Centre of Excellence in Nuclear and Accelerator Based Physics

Witold Nazarewicz, professor, University of Tennessee, USA
William Gelletly, professor, University of Surrey, UK
Timo Tiihonen, vice-rector, University of Jyväskylä
Timo Jääskeläinen, professor, Academy of Finland
Anna Kalliomäki, secretary general, Academy of Finland

Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory

Christian Beck, Dr., DRS-IPHC, Strasbourg, France
Mike Bentley, Dr., University of York, UK
Klaus Blaum, Dr., University of Mainz, Germany
Jacek Dobaczewski, professor, University of Warsaw, Poland and JYFL
Zenon Janas, Dr., University of Warsaw, Poland
Juhani Keinonen, professor, University of Helsinki, Finland (chairman)

In addition to the ^{123}I production and activities as an official ESA test facility, a new commercial application was commenced with Oxyphen GmbH (Germany) for irradiating of their polymer films using Kr beams from the K130 cyclotron.

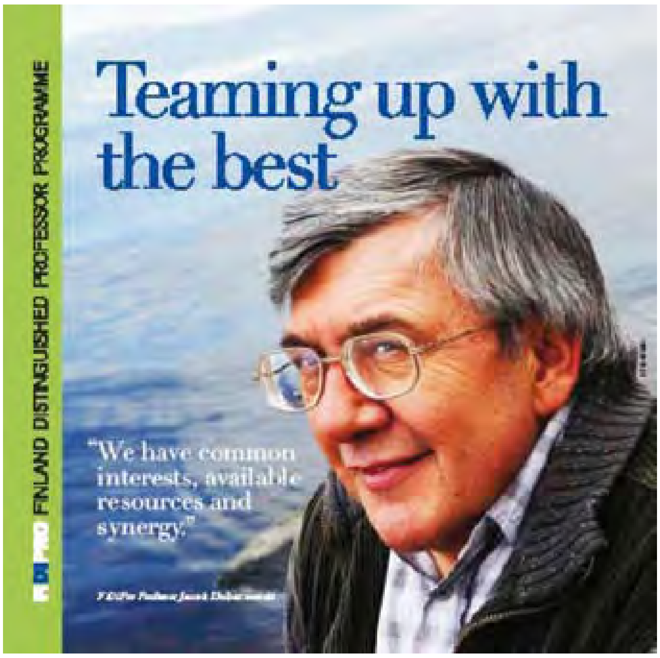
An important event for ion-beam applications was the commissioning of the 1.7 MeV Pelletron Accelerator with associated beam lines. This accelerator was donated by the Technical Research Centre of Finland (VTT) and already used, for example, in fabrication of sub-micrometer structures.

A contract was signed on February 20th, 2007, for a delivery of a 30 MeV H- cyclotron MCC30/15 from Russia as a partial compensation of the former Soviet Union dept to Finland. Construction of the extension of the present accelerator hall for this new machine will start in 2008. In addition to isotope production the beams from this new cyclotron will be used for basic research at the IGISOL facility, which will be moved to the new site.

The theory programme was expanded in 2007 when Jacek Dobaczewski from the University of Warsaw started as a FiDiPro professor at JYFL. The project is jointly funded by the Academy of Finland and University of Jyväskylä within the Finland Distinguished Professor Programme (FiDiPro). It is using and developing most advanced methods in theoretical nuclear structure research in strong synergy with experimental studies performed at JYFL.

The annual users meeting for the users of the JYFL Accelerator Laboratory was held on 22 – 23 February 2007. An international workshop on drip-line physics was organized on 19 January 2007 in collaboration with UK user groups.

In total, 37 proposals for experiments were evaluated by the Programme Advisory Committee (PAC) of the JYFL Accelerator Laboratory in the meetings on 21 April and 29 September, 2007.

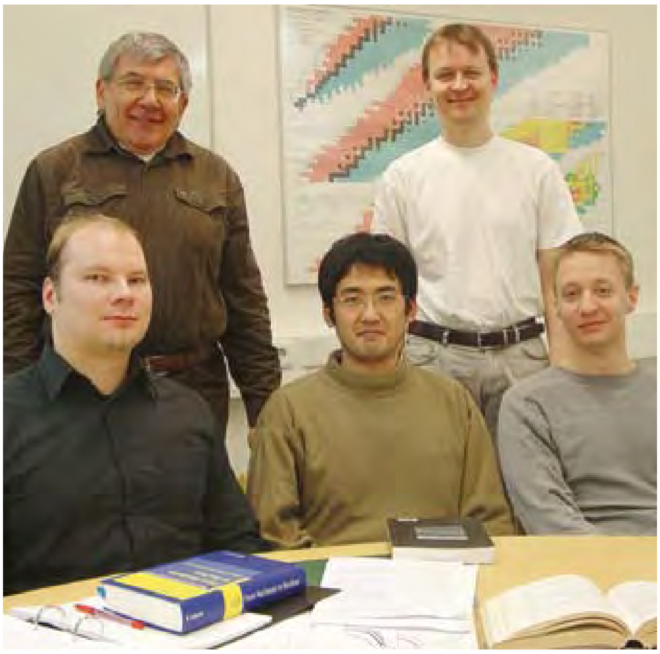


FiDiPro Professor Jacek Dobaczewski

Finland Distinguished Professor – FIDIPRO - Programme

Jacek Dobaczewski

Jacek Dobaczewski, research professor
Jussi Toivanen, assistant (also with Nuclear Structure group)
Leszek Próchniak, visiting senior researcher 5.10.-14.12.
Gillis Carlsson, postdoctoral researcher 1.1.2008-
Markus Kortelainen, postdoctoral researcher (also with Nuclear Structure group)
Kazuhito Mizuyama, postdoctoral researcher, 1.8.-



Group from the left: sitting Markus Kortelainen, Kazuhito Mizuyama, and Gillis Carlsson; standing Jacek Dobaczewski and Jussi Toivanen

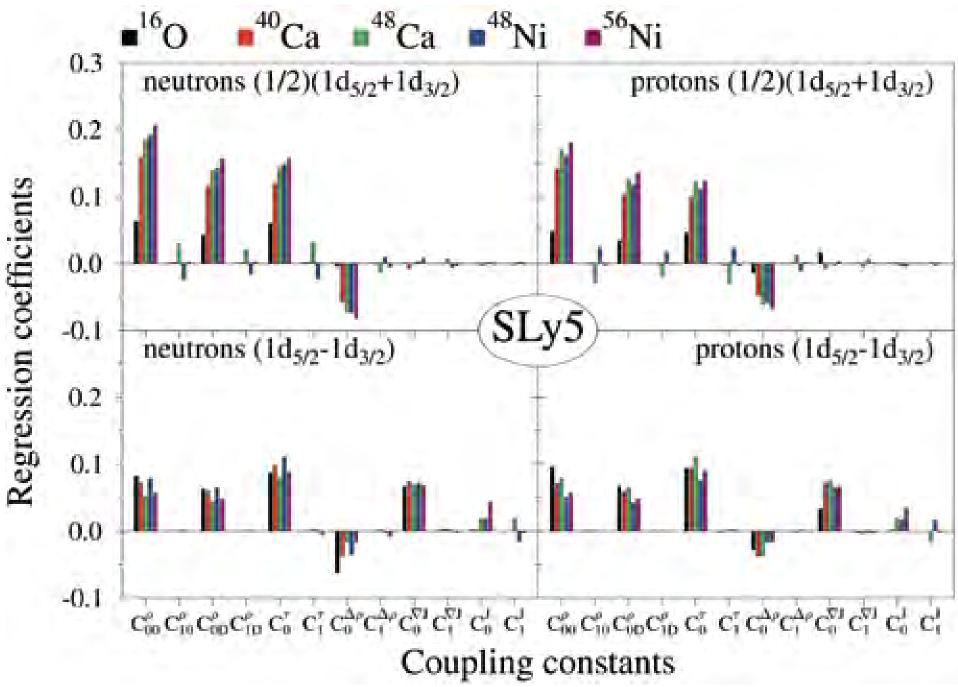
The project, which started in 2007, is jointly funded by the Academy of Finland and University of Jyväskylä within the Finland Distinguished Professor Programme (FIDIPRO). One of the 2006 grants has been attributed to Professor Jacek Dobaczewski of the Institute of Theoretical Physics of University of Warsaw, who now leads the FIDIPRO team at JYFL, and will share his time between stays in Finland and Poland. The project will last for five years (2007-2011) and has for its objectives advanced studies in theoretical nuclear structure, in strong synergy with experimental studies performed at JYFL, and with other world-wide initiatives, in order to investigate properties of exotic nuclei. The project will use and develop most advanced theoretical methods in this domain of physics as well as train young theorists within the M.Sc. and Ph.D. educational programmes at the University of Jyväskylä. At the beginning of 2007, two JYFL theorists, Markus Kortelainen and Jussi Toivanen, have joined the team. The FIDIPRO grant also allowed for hiring at JYFL two new postdoctoral researchers, Kazuhito Mizuyama (Japan), who started on August 1, 2007 and Gillis Carlson (Sweden), who arrived on January 1, 2008. The group now works as a strong team of scientists who focus on the project goals. More information is available on the project web page: http://www.jyu.fi/accelerator/fidipro/

On October 25–27, 2007, we organized at JYFL the First FIDIPRO-JSPS Workshop on Energy Density Functionals in Nuclei. The workshop was devoted to modern approaches and methods based on using energy density functionals in nuclear physics, with particular emphasis on first-principle derivations, new parameterizations, and applications including those going beyond the mean-field limit. It took place in a beautiful vacation resort hotel of Keurusselka located in Keuruu some 70 km from Jyväskylä. The workshop was partly funded by the FIDIPRO project at JYFL and Japan Society for the Promotion of Science - JSPS. We hosted over 50 participants, of whom 15 came from Japan, 5 from the United States, and 20 from all over the Europe.

Single-particle States within the Energy-density-functional Approach

We have analysed the dependence of single-particle energies (in fact, the Kohn-Sham energies as they should be correctly called) on coupling constants of the nuclear energy density functional. The aim of this work is to systematically determine the influence of the coupling constants on positions of single-particle energies. This information is essential for attempting readjustments of the functionals so as to better describe particle separation energies, which are known from experiment. The Figure below shows values of regression coefficients that characterise dependence of centroids and spin-orbit splittings of the 1d level in several doubly-magic nuclei. Twelve coupling constants of the standard functional are listed in the abscissa and the five studied nuclei are listed at top of the Figure.

The project will now be continued by introducing several other coupling constants, within the so-called density-dependent terms. As we hope, this may greatly improve the capability of the model to describe experimental data with a higher precision as compared to what has been achieved up to now. We also work on determining regions of parameter space that are safe from the point of view of density fluctuations – this information will be crucial in the process of readjusting the functionals. Moreover, in order to elucidate connections between single-particle energies and particle separation energies, we will investigate polarization effects in semi-magic nuclei. As the first example we have picked the sequence of N=50 isotones, where very precise mass measurements have recently been performed at JYFL. Apart from readjustments that are focused at the description of separation energies, we also concentrate on fitting the nuclear masses directly. Here we aim at obtaining not only the best values of the coupling constants, but also estimates of their uncertainties. This will allow us to determine theoretical error bars for masses predicted in nuclei far from stability, where measurements are not possible.



Nuclear and accelerator based physics

Accelerator Facilities

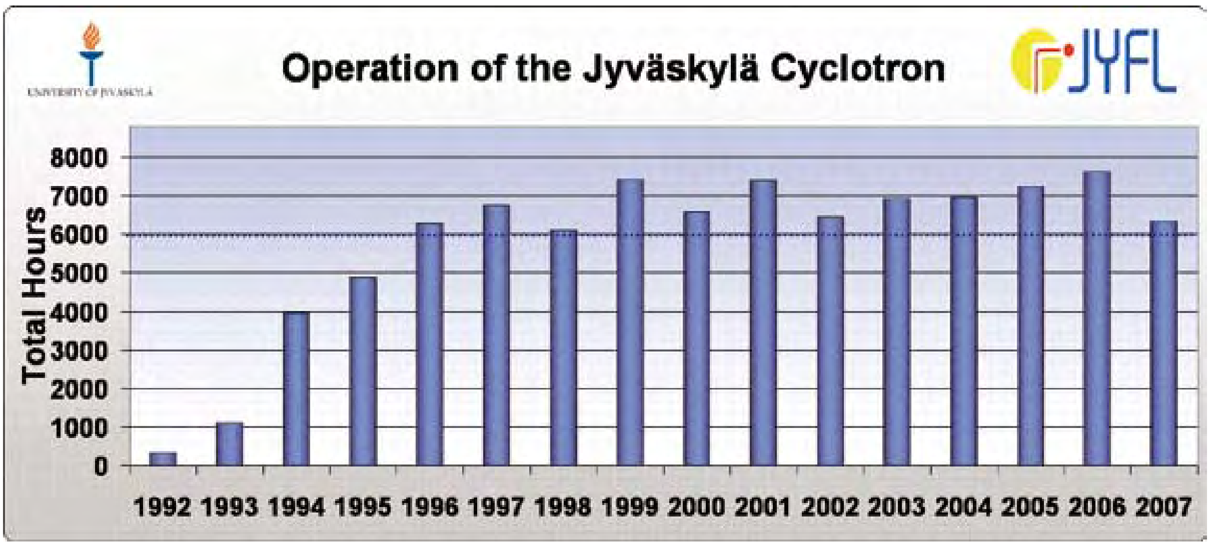
Pauli Heikkinen and Hannu Koivisto

The total operating time of the cyclotron in 2007 was 6336 hours with 4685 hours beam on target, which is a bit lower than on the record year of 2006. Rest of the time was for tuning the injection line and the cyclotron (642 h), beam developing (152 h) and stand-by time caused by the experimental groups. Due to technical problems 770 hours of allocated beam time were canceled.

Proton was still the most used ion, although its share decreased to 22 %. Protons are used mainly in ^{123}I production for MAP Medical Technologies and in IGISOL experiments. The next most used beams were ^{78}Kr (14 %) and a beam cocktail (12 %) containing seven different ions from ^{15}N to ^{131}Xe with the same mass-to-charge ratio. A beam cocktail gives a fast way of changing from one beam to another (in order to change the LET value of the beam) because only a few ion optical parameters

Pauli Heikkinen, chief engineer
Hannu Koivisto, senior assistant
Pekka Suominen, postdoctoral researcher -28.2.
Arto Lassila, laboratory engineer
Veikko Nieminen, laboratory engineer
Jaana Kumpulainen, laboratory engineer
Kimmo Ranttila, laboratory engineer
Juha Ärje, laboratory engineer (on leave)
Jani Hyvönen, operator
Anssi Ikonen, operator
Hannu Leinonen, technician
Raimo Seppälä, technician
Tommi Ropponen, graduate student
Tarmo Koponen, MSc student
Janne Ropponen, MSc student
Markus Savonen, MSc student
Ville Toivanen, MSc student

Fig. 1. Operation of the Jyväskylä cyclotron in 1992 – 2007



have to be changed. Altogether 27 different isotopes from protons to ^{131}Xe were accelerated for experiments and applications in 2007.

The Intergovernmental Agreement between Finland and Russia about compensating part of the former Soviet Union dept to Finland as services and goods was signed in August 2006. The list of the goods and services was finally approved in December 2006. This list contained a 30 MeV cyclotron for the University of Jyväskylä. The contract on the cyclotron was then signed on February 20th, 2007 by the University of Jyväskylä and Machinoimport together with the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (FSUE "NIIEFA"). After examining the contract, the corresponding Ministries of both countries approved the contract on 19th of June. According to the contract the cyclotron should arrive at Jyväskylä in 24 months from this date. Installation time of the cyclotron on the site is six months so that the cyclotron should be ready for use by the end of 2009. The cyclotron requires a new building attached to the existing laboratory so that one beam line will be connected to the 123-I production line and one to the IGISLOL beam line. Planning of the extension of the laboratory has been started. The extension will be built next to the present 51 m long hall being 13 m wide. In addition to the new cyclotron and the space for radioisotope production the IGISOL facility will move to the new hall so that it can take beams from both cyclotrons.

The development work for the production of metal ion beams was continued in 2007. The resonant circuit of inductively heated oven was successfully developed and tested. During the reliability test of 9 days the temperature of about 1850 °C was kept constant without any problems. The sputtering method was tested using a Zr sample. The Zr^{20+} intensity of about 10 μA was produced making it possible to reach the level of about 20 pnA after the cyclotron using second harmonic acceleration. Further development work is needed for new beams in order to improve the reliability of sputtered ion beams and to minimize the material consumption.

An intensive research work was started in order to determine the beam transmission related bottle necks of our accelerator facility. Several factors limiting the available beam intensity were found like 1) wrong entrance/exit angle of the analysing magnet of the 14 GHz ECRIS causing asymmetric beam envelope, 2) hollow beam structure, which probably originates from the low injection voltage needed for the cyclotron (typically about 10 kV), 3) insufficient beam line components and 4) problems in the extraction of accelerated beams. The work will be continued to solve the problems and to improve the overall beam transmission efficiency.

The simulation code for the ECRIS plasma heating was developed. According to simulations the experimentally found electron energies (up to 1 MeV) cannot be reached by stochastic heating as was already speculated by some ECRIS experts. Consequently, another heating mechanism has to occur to reach afore-mentioned energies. This important work will be continued to reveal more information about the ECR heating mechanism inside the plasma of ECR ion source.

Exotic Nuclei and Beams

Ari Jokinen, Iain Moore, Heikki Penttilä and Juha Äystö

Juha Äystö, professor
Ari Jokinen, lecturer
Anu Kankainen, assistant
Iain Moore, senior researcher
Heikki Penttilä, senior researcher
Valery Rubchenya, senior researcher (Khlopin Radium Institute, St. Petersburg)
Saidur Rahaman, postdoctoral researcher
Tetsu Sonoda, postdoctoral researcher – 30.3.
Christine Weber, postdoctoral researcher
Ulrike Hager, graduate student – 31.8.
Viki-Veikko Elomaa, graduate student
Tommi Eronen, graduate student
Jani Hakala, graduate student
Pasi Karvonen, graduate student
Thomas Kessler, graduate student
Mikael Reponen, graduate student 1.9.-
Juho Rissanen, graduate student
Janne Ronkainen, graduate student
Antti Saastamoinen, graduate student
Vesa Partanen, MSc student
Perttu Ronkanen, MSc student
Jani Turunen, MSc student
Fanny Quinquis, ERASMUS exchange student 1.5. – 31.7.

Our activity in 2007 has followed the well-established path consisting of numerous experiments and R&D instrumentation both at JYFL and at ISOLDE, CERN. The work at ISOLDE is carried out within the Nuclear Matter Program of the Helsinki Institute of Physics (HIP). In addition, our group, with support of HIP, has actively participated in the planning of the experiments within the NuSTAR collaboration for the Super Fragment Recoil Separator (S-FRS) at the future Facility for Antiproton and Ion Research (FAIR) at GSI. Our team has significantly benefited from collaborations with several groups from Europe and the US as well as from the EURONS JRA projects and the Design Study projects EURISOL and DIRAC.

A major technical effort has been taken towards the completion of the FURIOS laser ion source including a study of the first stopped and extracted heavy-ion beams at IGISOL [1]. In connection with the laser ion source programme, a hot cavity graphite ion catcher with an external electron-bombardment heating system has been tested for the future on-line extraction of *N*=*Z* ^{94}Ag [2]. Figure 2 shows a series of first step laser scans in a triple step excitation and ionization scheme on mass-separated ^{107}Ag. Metallic silver was introduced into the cavity which was heated to a variety of temperatures, the results illustrated in the figure. The collaboration with KVI and GSI to develop an ion catcher based on cryogenic helium gas continued via the design and construction of a prototype to be tested in 2008 [3]. The development and testing of the carbon cluster ion source continued successfully during a two week period in November. The most interesting development was launched in connection with the new K30 cyclotron to be delivered to JYFL in the summer of 2009. A decision was made to move the IGISOL facility from its present location to the laboratory extension that will be built primarily for the new cyclotron. The advantage of the arrangement is that it puts

IGISOL, foreseen as the heaviest user of the light-ion beams from the K30, right next to the new cyclotron. Additionally the move increases the available experimental area for the IGISOL facility thereby opening up new opportunities for future users.

Fig. 1. IGISOL group standing above the future IGISOL target position in the planned JYFL laboratory extension. The actual target will be about 7 meters below the present ground level. From left to right: Mikael Reponen, Jani Hakala, Thomas Kessler, Janne Ronkainen, Viki Elomaa, Juha Äystö, Saidur Rahaman, Pasi Karvonen, Christine Weber, Tommi Eronen, Anu Kankainen, Juho Rissanen, Ari Jokinen, Antti Saastamoinen, Heikki Penttilä and Iain Moore.

The laser-IGISOL group (Manchester and Birmingham collaboration) extensively developed, and used on-line, their new technique of optically manipulating ions in the RFQ cooler while they are being collected and bunched. The 'pumping' of population achieved during this manipulation allows the radioactive ions to be efficiently prepared in a desired metastable atomic state which is selected to have properties optimum for collinear spectroscopy. Figure 3 shows optical resonances observed in an yttrium fission fragment prepared in such a manner. In this case the metastable transition was selected to permit, for the first time, a unique assignment of the nuclear spin in the ^{100}Y system.

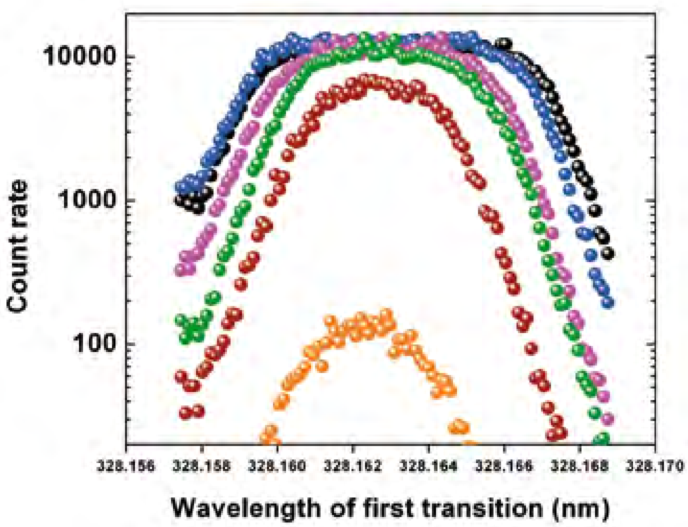


Fig. 2. Mass separated ^{107}Ag, extracted from a hot cavity ion source and laser ionized. The curves illustrate the effect of increasing oven temperature. The apparent count rate saturation at ~12 kHz matches well with the high-repetition rate of the lasers.

The main experimental achievements in 2007 include the high-accuracy Q_{EC}-value measurements of several su-

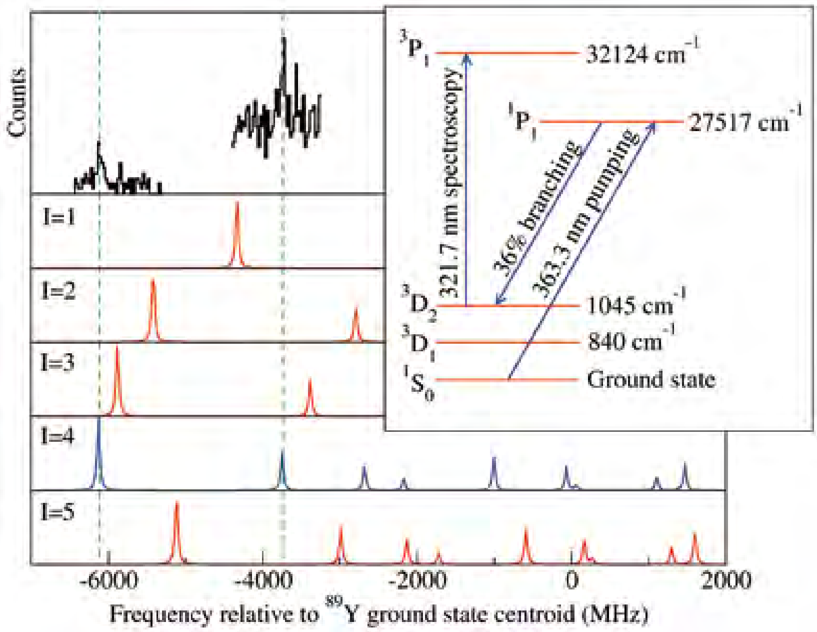


Fig. 3. Predicted hyperfine structure for a range of possible values of nuclear spin. Only two peaks needed to be measured on the 321.7 nm line for the assignment to be made.

perallowed beta decays [4, 5]. The mass measurement program at JYFLTRAP on neutron-rich nuclei followed the N=50 closed shell towards Zn [6], and measurements of neutron-deficient nuclei were made from Tc to Te. The total number of isotopes whose masses have been measured with our Penning trap setup has now reached around 200. JYFLTRAP was also used as a high-resolution mass separator to produce purified samples of fission products [7] for nuclear reactor decay heat studies using the total absorption spectrometer (TAS). With the exception of laser measurements, JYFLTRAP was employed in almost every experiment in 2007. Therefore, the quenching of the superconducting magnet on 12 June and the following three month break in trap experiments was the worst adversity of 2007.

Experimental Highlights

Superallowed beta decays [5]. Precise measurements of superallowed $0^+ \rightarrow 0^+$ nuclear transitions provide several important tests of the electroweak Standard Model, including the most stringent test currently known for the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. After the Penning trap revolution in mass measurements, the major uncertainty of these tests no longer comes from experiment but from the radiative and isospin-symmetry breaking corrections that have to be applied to the experimental results. According to the Conserved Vector Current (CVC) hypothesis, the corrected Ft values of all pure Fermi transitions should be identical. An experimental surprise arose in 2006 when the ^{46}V corrected Ft value turned out to be more than two standard deviations from the other well-known emitters. A new, more precise calculation of the theoretical corrections brought the ^{46}V superallowed beta decay rate back into agreement with the average value, yet moved ^{50}Mn and ^{54}Co away from the average. The beta-decay Q_{EC}-values of the superallowed beta-emitters ^{50}Mn and ^{54}Co were remeasured with the precision Penning trap of JYFLTRAP with a precision of 100 eV. The newly developed Ramsey cleaning technique was needed to purify the samples from isomeric contaminations only 200 keV/c^2 apart. The new values which differ significantly from the previously accepted ones increase the Ft of these isotopes such that agreement with the world average is once more realized.

Beta decay strength measurement [7]. In order to determine the beta decay strength of isotopes using the total absorption spectroscopy (TAS) technique a purified source is essential. Isobarically purified sources of ^{102,103,105,106,107}Tc, ^{103,105}Mo and ^{101}Nb isotopes were attained

List of collaborators

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ISOLTRAP and SHIPTRAP groups

using the purification Penning trap of the JYFLTRAP facility and measured with the TAS. The proton-induced fission yield before the Penning trap was recently established at a level of 10^4 atoms s^{-1} with 1.5 μA proton beam intensity. The transmission efficiency of the purification trap was on the level of 15% throughout the experiment. These isotopes are of particular interest from the point of view of reactor heat summation calculations.

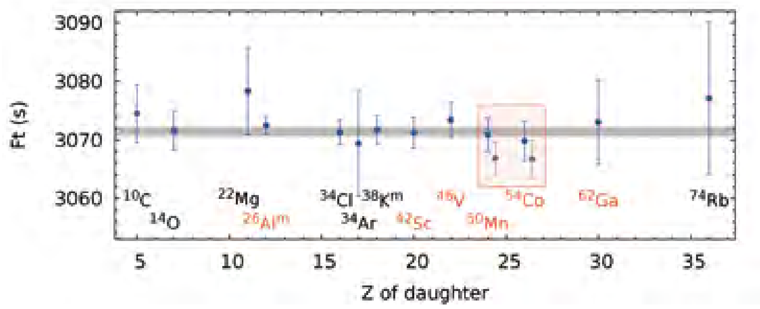

Fig. 4. Ft values for the thirteen best known superallowed decays, to which the new isospin-symmetry breaking corrections have been applied. The lower points for ^{50}Mn and ^{54}Co are obtained using the previously accepted Q_{EC}-values. The points closer to world average result from the new values measured at JYFLTRAP.

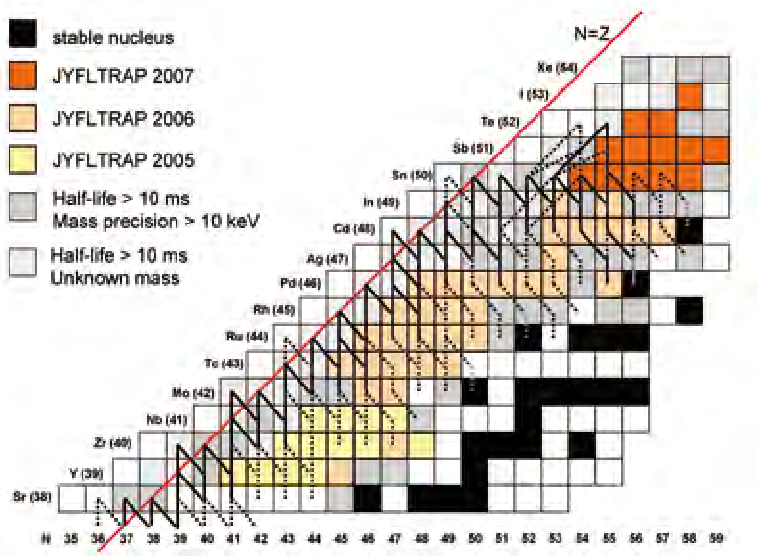

Fig. 5. The rp-process pathways according to H. Schatz et al., Phys.Rev. Lett. 86 (2001) 3471-3474, laid over the nuclide chart displaying the nuclides whose mass has been measured at JYFLTRAP.

Masses of rp and νp-process nuclides [8]. In order to model the astrophysical rp-process and the recently proposed νp-process, masses of neutron-deficient nuclides are needed as they determine the path and energy generation of these processes. About 60 masses close to the $N = Z$ line around A = 80 – 110 have been measured in 2005–2007 at JYFLTRAP. The measurements in 2007 focused on the SnSbTe-cycle considered as the end-point of the rp-process. The highlights of the year were the masses of ^{104}Sn and ^{108}Te measured for the first time.

Double-beta decay [11]. Absolute masses of neutrinos and their fundamental character (Majorana or Dirac particle) can be addressed by studying neutrinoless double-beta decay ($0\nu\beta\beta$). A precise determination of the Q-value of $0\nu\beta\beta$ is required to improve the sensitivity of experimental searches for the signature of the process as well as for the nuclear matrix element calculations. At JYFLTRAP, the Q($0\nu\beta\beta$)-value of ^{100}Mo was determined with an accuracy of 170 eV, which corresponds to a factor of 30 improvement compared to the known literature value. The obtained Q-value was also used to calculate the phase-space integrals and the experimental nuclear matrix element of double-beta decay.

Experiment spokespersons and collaborating institutes in 2007

[1] Continuation to the program of development and testing of the resonance laser ion source at IGISOL
I. D. Moore, JYFL; K. D. A. Wendt, University of Mainz, Germany

[2] Study of proton and two-proton radioactivity of proton-rich silver isotopes
I. Mukha, University of Seville, Spain; I. D. Moore, JYFL
PNPI, Gatchina, Russia; Universty of Köln, Germany; GSI, Darmstadt, Germany; Florida State University, Talahassee, USA; IKS KU Leuven, Belgium; INFN Napoli, Italy; Huelva University, Spain; University of Tennessee, Knoxville, USA

[3] Cryogenic Ion Catchers
P. Dendooven, KVI, Groningen, Netherlands
GSI, Darmstadt, Germany; Osaka Gakuin University, Japan; University of Turku, Turku, Finland

[4] Precision measurements of the half-life, the branching ratios, and the β-decay Q-value of the superallowed $0^+ \rightarrow 0^+$ β-decay of ^{26}Si and ^{42}Ti
B. Blank and G. Canchel, CEN Bordeaux-Gradignan, Gradignan, France; T. Eronen, JYFL

[5] Precision Q-value measurement of the superallowed $0^+ \rightarrow 0^+$ beta emitters of ^{50}Mn and ^{54}Co
T. Eronen, JYFL; J. Hardy, Texas A&M University, College Station, Texas, USA

[6] Precision atomic mass measurements of neutron-rich nuclei with JYFLTRAP
A. Jokinen, JYFL; S. Kopecky, IKS KU Leuven

[7] Beta decay requirements for reactor decay-heat calculations: improving the prediction power of fission products summation calculations
A. Algora and J. L. Tain, IFIC, CSIC-University of Valencia, Spain
INR, Debrecen, Hungary; GSI, Darmstadt, Germany; University of Surrey, Guildford, UK; PNPI, Gatchina, Russia; Mushashi Institute of Technology, Japan; IAEA Nuclear Data Section, Vienna, Austria; University of Washington, Seattle, USA; INFN-LNL, Padova, Italy

[8] Accurate mass measurements of nuclides at the closed SnSbTe cycle of the rp-process
Yu. Novikov, PNPI, St. Petersburg, Russia;
F. Herfurth, GSI, Darmstadt, Germany

[9] Laser spectroscopy of isotopes and isomers in Yttrium and Cerium
P. Campbell, University of Birmingham, UK
University of Manchester, UK

[10] Fission yields in fast neutron induced fission of ^{238}U
H. Penttilä, JYFL; M.V. Ricciardi, GSI, Darmstadt, Germany
Khlopin Radium Institute, St. Petersburg, Russia

[11] An off-line experiment - no proposal.
The ions of interest were produced from metal electrodes using a spark ion source.

Nuclear and accelerator based physics

Nuclear Spectroscopy

Paul Greenlees, Pete Jones, Rauno Julin, Sakari Juutinen, Matti Leino and Juha Uusitalo

In 2007, an important milestone was passed when the total number of beam time hours dedicated to in-beam spectroscopy with the JUROGAM array reached 10000. A total of fourteen experiments were carried out by the Nuclear Spectroscopy Group, including one stand-alone RITU experiment. Again, these experiments accounted for a large proportion (40%) of the total cyclotron running time (2981 hours, including time for various test runs). The main themes of recent years were continued, with studies of the structure of heavy elements in the region of ^{254}No, shape coexistence in the light lead region, recoil-beta tagging studies of N≈Z nuclei, and lifetime measurements using the Köln plunger device. The experiments were attended by more than 70 foreign researchers from 20 institutions.

In-Beam Spectroscopy Group Members
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Sakari Juutinen, senior assistant
Pete Jones, senior researcher
Paul Greenlees, academy researcher
Steffen Ketelhut, graduate student
Markus Nyman, graduate student
Pauli Peura, graduate student 1.6.-
Panu Rahkila, graduate student
Juha Sorri, graduate student (on leave)
Aki Puurunen, summer student

RITU Group Members
Matti Leino, professor
Juha Uusitalo, senior researcher
Cath Scholey, postdoctoral researcher
Ulrika Jakobsson, graduate student
Jan Sarén, graduate student
Panu Ruotsalainen, MSc student
Alexis Hugues, ERASMUS exchange student 1.5.-31.7.

The series of experimental campaigns with the current configuration of JUROGAM will come to an end in summer 2008, when JUROGAM will be superseded by the JUROGAMII and the SAGE combined conversion electron/gamma-ray spectrometer. These incarnations of the JUROGAM spectrometer will both employ the 24 clover germanium detectors from the resources of the ex-EUROBALL Gammapool, along with 10 or 15 Phase I type detectors. Important preparatory work for these projects has continued throughout the year. For the first time, all 43 detectors of JUROGAM were temporarily instrumented with digital electronics, using TNT2 units on loan from IPHC Strasbourg and CSNSM Orsay. Digital and analogue data sets were collected in parallel for several experiments, including a study of high-K states in ^{254}No, and a stand alone high-fold experiment to search for tetrahedral symmetry in ^{156}Gd. The design of the SAGE spectrometer is close to being finalised, and it is expected that the first tests should be carried out in summer 2008. A schematic of the SAGE spectrometer is shown in figure 2.

The new vacuum-mode recoil spectrometer planned for studies of lighter nuclei in the mass A≈80 region was also finally given a name: MARA (Mass Analysing Recoil

Apparatus). Construction of the spectrometer became another step closer with the delivery of the magnetic quadrupole triplet and associated stand. An order has also been placed for the magnetic dipole magnet. The limited budget available means that the construction is and will continue to be a rather protracted process.

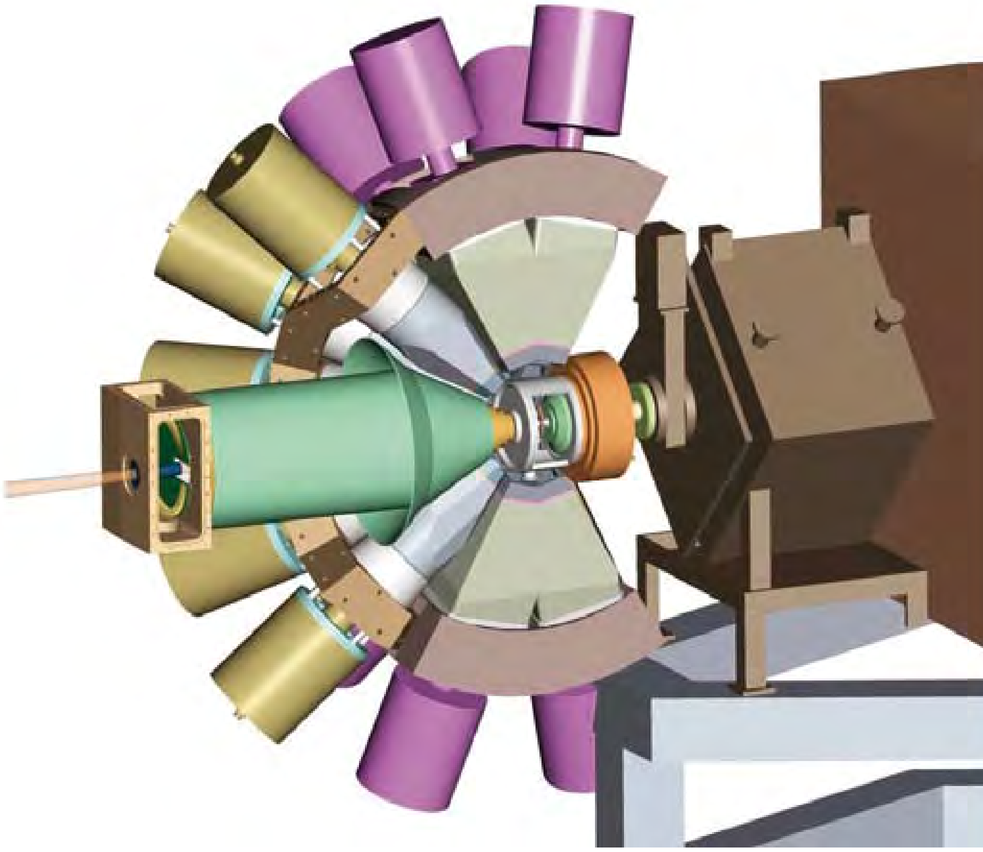

Fig. 2. Schematic drawing of the SAGE spectrometer coupled to the RITU gas-filled recoil separator. SAGE will employ the clover detectors of the former EUROBALL array in the same geometry as EUROGAMII (Courtesy of D. Seddon, University of Liverpool).

Fig. 1. The nuclear spectroscopy group with the magnets for the MARA quadrupole triplet.

Highlights from the 2007 Experimental Campaign

Structure of Heavy Elements

In a continuation of the structure studies of the heavy elements in the region of ^{254}No, an experiment was made to investigate the ground-state rotational band of the N=148 nucleus ^{248}Fm for the first time. Technical issues meant that the statistics obtained were not as high as originally hoped, though it was still possible to observe the ground-state rotational band up to a spin of 14ħ. Evidence for a new isomeric state with a half-life of around 8 ms was also found using the calorimetric technique of Jones [1,2]. A further experiment was carried out to obtain improved data in order to delineate the level scheme above the $K^{\pi}=8^{-}$ isomeric state in ^{254}No. In both of these measurements, a "digital" data set was collected in parallel to the normal TDR data stream, using the TNT2 electronics described above. A comparison of spectra obtained from the ^{254}No experiment is shown in figure 3. The upper panel shows a spectrum of the ground-state rotational band of ^{254}No obtained with the standard TDR data acquisition system, whilst the lower panel shows that obtained in parallel with the TNT2 electronics.

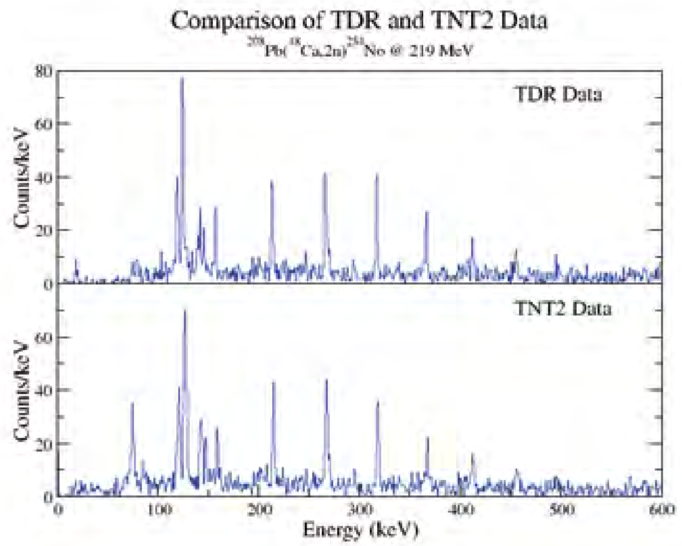

Fig. 3. Comparison of recoil-gated gamma-ray singles spectra in ^{254}No obtained with the JUROGAM, RITU and GREAT devices. The upper spectrum shows data obtained with the analogue TDR electronics, whilst the lower panel shows that obtained in parallel with TNT2 digital electronics.

Structure of Neutron-deficient Nuclei

Several experiments carried out in 2007 aimed at pushing our understanding of neutron-deficient nuclei to the extreme limit. For the first time, excited states were observed in ^{172}Hg [3] and ^{197}Rn [4], produced with cross sections of around 20 and 10 nb, respectively (for the isomeric state in ^{197}Rn). The data obtained for the light radon isotopes showed that in going towards the neutron mid-shell at N=104 a smooth transition from an an-harmonic vibrator to a moderately deformed oblate shape is observed. The transition at low spin is smoother than that predicted by theory [4].

Further Highlights

Further highlights from the 2007 campaign include the first measurement using the combination of recoil-isomer tagging with the differential plunger technique. A number of nuclei in region of ^{144}Ho which have isomeric states amenable to tagging were produced [5]. Analysis is in progress, and it is hoped that the lifetime analysis will lead to better understanding of these transitional nuclei. In the only stand-alone RITU experiment to be performed, a search was made for the new isotopes ^{182,183}Bi. Preliminary analysis suggests evidence for the new isotope ^{182}Bi, and that no clear evidence for new proton emitters was found [6].

Analysis Completed in 2007

A number of important analyses were concluded and published in 2007. Studies of the N=Z+2 nucleus ^{110}Xe established the three lowest excited states in the ground-state band. The results showed a breaking of the normal trend of increasing first excited 2^+ and 4^+ level energies as a function of the decreasing neutron number as the N=50 major shell gap is approached. This was suggested to be an effect of enhanced collectivity, possibly arising from isoscalar n-p interactions which become increasingly important close to the N=Z line [7]. A letter concerning the rotational structure of the transfermium nucleus ^{251}Md was also published, where the properties of the important [521]1/2$^-$ orbital stemming from above the possible Z=114 spherical shell gap were investigated [8]. The program of recoil-β tagging experiments also resulted in the publication of interesting results concerning anomalous Coulomb energy differences in mirror nuclei. These comparisons were made possible using new data from the various recoil-β tagging experiments and the behaviour could be accounted for in terms of small variations in the Coulomb energy due to shape changes [9].

References:

[1] G.D. Jones, Nucl. Instrum. Meth. Phys. Res. A 488 (2002) 471
[2] R.-D. Herzberg et al., To be published
[3] B. Cederwall et al., To be published
[4] K. Andgren et al., Manuscript in preparation
[5] D.M. Cullen et al., To be published
[6] A.N. Andreyev et al., To be published
[7] M. Sandzelius et al., Phys. Rev. Lett. 99 (2007) 022501
[8] A. Chatillon et al., Phys. Rev. Lett 98 (2007) 132503
[9] B.S. Nara Singh et al., Phys. Rev. C 75 (2007) 061301(R)

Experiments, Spokespersons and Collaborating Institutes for the experimental campaign in 2007

Precision study of an exotic E4/E5 gamma-decay branch from the 25/2$^+$ "alpha-decaying" isomer in ^{211}Po
T. Lönnroth, Åbo Akademi, Finland

Evolution of single-particle states near the N=82 shell gap: spectroscopy of ^{168}Pt and neighbouring isotopes
M. Belen Gomez, CCLRC Daresbury Laboratory, U.K.

Onset of deformation in the light Ra isotopes
P. Rahkila, University of Jyväskylä, Finland, S. Freeman, University of Manchester, U.K.

Search for shape transition and collective oblate rotation in ^{196,197,199}Rn
B. Cederwall, Royal Institute of Technology Stockholm, Sweden, J. Uusitalo, University of Jyväskylä, Finland

Ground-state band of ^{248}Fm
R.-D. Herzberg, University of Liverpool, U.K.

Structure of high-K states in ^{254}No
R.-D. Herzberg, University of Liverpool, U.K., P.T.Greenlees, University of Jyväskylä, Finland

Shape-changing alpha and proton decays of the lightest Bi isotopes: search for new nuclides ^{182,183}Bi
A.N. Andreyev, TRIUMF, Canada, R.D. Page, University of Liverpool, U.K., J. Uusitalo, University of Jyväskylä, Finland

In-beam spectroscopy of the N=85 isotones ^{159}W and ^{160}Re
R.D. Page, University of Liverpool, U.K.

Search for breakdown of T=1/2 mirror symmetry: recoil-β$^+$ tagging and decay spectroscopy of ^{71}Kr
D.T. Joss, University of Liverpool, U.K., R. Wadsworth, University of York, U.K., S. Fischer, De Paul University Chicago, U.S.A.

Recoil-decay tagging spectroscopy of ^{172}Hg
B. Cederwall, Royal Institute of Technology Stockholm, Sweden, C. Scholey, University of Jyväskylä, Finland

Recoil-decay tagging of ^{180}Pb
D. Jenkins, University of York, U.K., J. Pakarinen, University of Liverpool, U.K.

Search for fingerprints of tetrahedral symmetry in ^{156}Gd with high-fold germanium coincidences at JUROGAM with an α-beam
J. Robin, IPHC Strasbourg, France, D. Curien, IPHC Strasbourg, France, J. Dudek, IPHC Strasbourg, France

Lifetimes and quadrupole moments in ^{168}Os and neighbouring nuclei
T. Grahn, University of Liverpool, U.K.

First differential plunger measurements using recoil-isomer tagging on ^{144}Ho and the Köln plunger
D.M. Cullen, University of Manchester, U.K.

Nuclear and accelerator based physics

ALICE and Nuclear Reactions

Jan Rak and Wladyslaw Trzaska

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Wladyslaw Trzaska, senior scientist
Mariana Bondila, postdoctoral researcher -31.7.
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Rafael Diaz Valdes, graduate student
Tuomo Kalliokoski, graduate student 15.9.-
Tomasz Malkiewicz, graduate student
Norbert Novitzky, graduate student 1.9.-
Mikko Sillanpää, graduate student
Sergey Yamaletdinov, graduate student
Michal Oledzki, MSc student

ALICE

The main focus of ALICE group in 2007 was on the preparation for the first data taking scheduled for late summer 2008. According the Large Hadron Collider (LHC) beam use proposal, the first events to be seen by the ALICE experiment will be the proton+proton collisions at √s=14 TeV. Exploration of the p+p collision in this unprecedented energy regime provides the vast variety of physics topics to be addressed. Finnish/ALICE group concentrates on the basic pQCD phenomena related to parton properties like intrinsic parton momentum (k_T) distribution in di-jet and photon-jet events, fragmentation function and production of heavy quarks. Detailed analysis of the above-mentioned phenomena is crucial for the understanding of nonperturbative sector of QCD at this unexplored energy regime but it also serves the reference measurement for the study of the nuclear modification in heavy ion collisions.

High-p_T Particle Correlations

The data provided by Relativistic Heavy Ion Collider (RHIC) at √s=200 GeV left behind many opened questions. The strong jet quenching seen by all RHIC experiments is expected to be accompanied by k_T broadening as observed in the deep inelastic scattering. However the data reveal small broadening which questions, at least, some of the models describing the data. We explored the methods to study the average k_T magnitude in two hadron and photon-hadron correlations. Some of this studies were presented at international conferences including the major conference in the field - Quark Matter 2008 in India.

In this tremendously high center of mass energy regime, the transversal size of nucleon wave function is expected to grow far beyond the “low-energy” value of 1 fm. There are interesting suggestions to study typical heavy ion phenomena like centrality, elliptic flow and jet quenching in p+p collisions. We were exploring a possibility to measure the centrality (impact parameter) and orientation of the reaction plane using the forward multiplicity detectors in ALICE. We exploited the new computing facilities provided by CSC (Finnish IT center for science) and generated millions of full Monte Carlo data. It allowed us also to exercise the analysis code on the "real" data.

We were (and are) actively involved in the ALICE high-p_T physics working group were the results of our analysis are regularly presented and scrutinized.

Computing and Massive Data Analysis

There was a major progress in year 2007 in the availability of the computing resources for the ALICE data analysis framework. CSC institute kindly provided us by 64 CPU's resided in the "opaali" cluster at Jyväskylä and later in the year we received another 200 CPU's located at CSC. We purchased 5 TB of the disc space and another 10 TB were partially installed at CSC. This computing facility was used primarily for the ALICE full data simulation used for the correlation physics and study of the performance of the T0 detector (see next paragraph).

Electromagnetic Calorimeter and High-p_T Trigger

Since the physics interest of Finnish/ALICE group are tightly related to high-p_T photon and jet production we decided to extend our hardware involvement in the ALICE experiment. The electromagnetic calorimeter plays a crucial role for photon and π^0 identification and also serves reliable high-p_T trigger. We are developing the FPGA code for PHOS (Photon Spectrometer) and for the new EM-calorimeter (US-France-Italy-Finland collaboration) trigger boards. The code evaluates the analog sum of 2x2 towers in a sliding window and compare it to various trigger thresholds. All this relatively complicated procedure has to be performed within a 100 ns level-0 trigger window and thus it requires the usage of the high-tech FPGA processors.

T0

Construction of the trigger and fast timing detector for ALICE experiment at CERN has reached several impor-

Fig. 1. Installation of T0 detector in the central region of ALICE

tant milestones in 2007. They include installation of T0-C and T0-A arrays around the beryllium beam pipe of LHC collider and moving of the front-end electronics from the test lab to the final location at Point2. There the commissioning continued in the real environment using fast blue laser as the source of light for the photo multipliers. By the end of the year the detector and electronics were sufficiently integrated with ALICE control, trigger and acquisition be among the first detectors included in the global cosmic run of ALICE. There is still plenty of work to do before our detector and the rest of ALICE will be ready for the first collisions, but the end of the commissioning and the start of the normal operation are already in sight.

Underground Cosmic-ray Experiment EMMA

In 2006 JYFL took the scientific responsibility for a new cosmic-ray experiment that is under construction in the Pyhäsalmi mine, about 180 km North from Jyväskylä. The experiment [Nuclear Physics B 165 (2007) 349–354] aims at the study of chemical composition of cosmic rays at and above the knee region. The array, called EMMA, will cover approximately 135 m^2 of detector area at the depth of 85 metres (~240 meters of water equivalent). In 2007 the first 3 underground structures were erected to house and protect from the hostile mine environment the muon barrel detectors recuperated from DELPHI – one of the discontinued CERN experiments. After the installation the detectors are connected to the gas circulation system, powered up, and linked with the data acquisition system for tests of resolution and stability.

In addition to muon barrels EMMA will use highly fragmented plastic scintillator arrays to increase the resolution of the experiment for the detection of high density muon showers. In 2007 the agreement for the production by Russia of scintillator units worth 1 M$ has been successfully signed. The delivery of the first prototypes is expected in the Spring of 2008.

Fig. 2. Construction of underground village to house EMMA detectors

Nuclear Reactions

The absence of Academy funding in 2007 has forced us to shift the bulk of the experimental activity to other laboratories. For example we have contributed to the study of the rotation of the fissioning nucleus ^{236}U following capture of polarised neutrons in a ^{235}U target. The experiment was running at ILL over the full reactor cycle and accumulated large amount of data. Preliminary analysis confirms the existence of ROT effect [Physics Letters B 652 (2007) 13–20]. Other major experiments were carried out at Catania, Dubna and Warsaw. In December we have achieved excellent particle identification by combining fast MCP start with the rise time pulse from neutron transmutation doped silicon detector.

Accelerator-Based Materials Physics

Timo Sajavaara and Harry J. Whitlow

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Ananda Sagari A.R., graduate student
Laura Mättö, graduate student 8.10.-
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Terho Räisänen, MSc student
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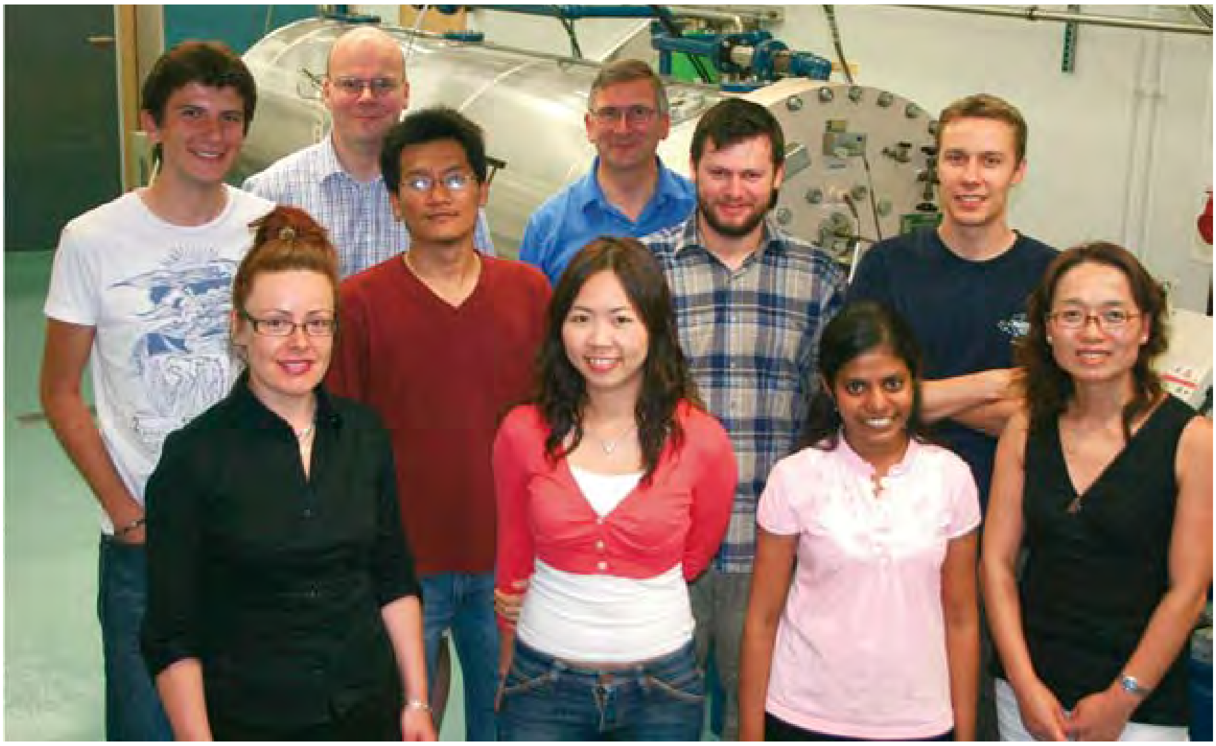
Paul Antoine, ERASMUS student, Ensicaen, Caen, France 12.4-30.8.
Felix Büttner, ERASMUS student, University of Göttingen, Germany 1.9.-31.12

The major development during 2007 has undoubtedly been the installation and commissioning of the 1.7 MV Pelletron accelerator. This accelerator was donated, together with an end-station for Rutherford Backscattering Spectrometry (RBS) / channelling. The accelerator became fully operational on 17 February 2007. Although there have been a number of technical breaks these are mainly attributed to teething problems. The accelerator was officially opened on

Fig. 1 Accelerator based materials physics group photographed in the Pelletron Laboratory.



the 16 November 2007 with a special one-day opening seminar. Since the accelerator became operational the MeV ion beam lithography system was moved from the cyclotron to the Pelletron which has allowed a more rapid development of this technique. In addition a number of industrial measurement projects have been completed. These are particularly welcome because they strengthen the ties of both the Accelerator Laboratory, and the University as a whole to industry.

The group (Fig 1.) has been very active during the year and has taken responsibility for organising some undergraduate courses. We also co-organised and ran a course where laboratory work was carried out at the Pelletron as part of the 2007 Jyväskylä Summer School on "Ion Beams and X-rays for Soft Condensed Matter Research" The lectures were given by Assoc. Prof. Thomas Osipowicz from the National University of Singapore. In the autumn a research agreement was signed with the IAEA in connection with a coordinated research project "Improvement of the reliability and accuracy of heavy ion beam nuclear analytical techniques". During the year the first PhD produced by the group was successfully defended by Minqin Ren in November.

The research activities have had a strong focus on biomedical applications of MeV ions. In collaboration with industrial partners and the BOGOTAS consortium we have developed a technique to produce biocompatible films of hydroxyapatite by Atomic Layer Deposition (ALD). It was found that annealing has a strong influence on promoting osteoblast proliferation on these films. In subsequent work, the wetting properties were investigated by measurement of the change of contact angle on annealing and ion implantation and how this correlated with osteoblast growth on the surface. This revealed that the wettability and cell attachment increased as a result of ion bombardment and annealing.

Our programmable proximity aperture MeV ion beam lithography system functions well. The technique for producing the high-quality aperture edges was refined. Experiments have been performed using both the cyclotron and Pelletron accelerators. The results demonstrate the suitability of the system for both light ion lithography with high aspect ratio (Fig. 2) and the use of high energy heavy ions for writing lithographically defined patterns of ion tracks. In parallel, fabrication techniques for nanopores with well controlled diameter and high aspect ratios were developed (Fig. 3). These structures have great potential in nanofluidics applications.

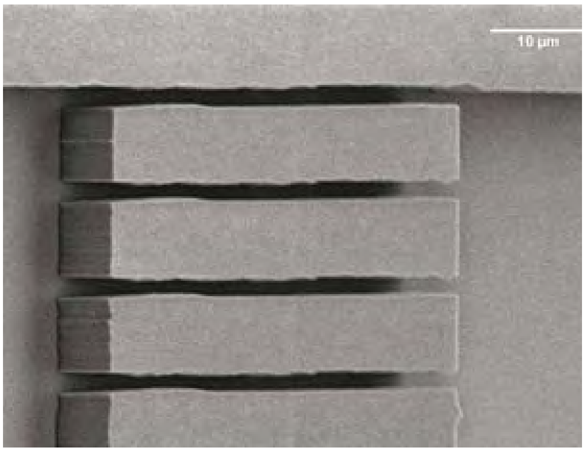


Fig. 2. Detail of a high aspect ratio microfluidics device written in 8 µm thick PMMA using 3 MeV He^{2+} ions.

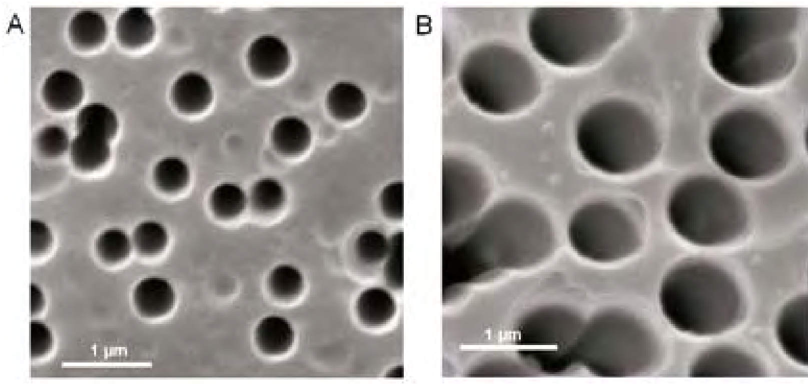


Fig. 3. Etched ion tracks in a 25 µm thick polyimide foil irradiated with 635 MeV Xe-ions. (A) Hole diameter 460±20 nm etching time 3 h. (B) Hole diameter 830±40 nm etching time 6 h.

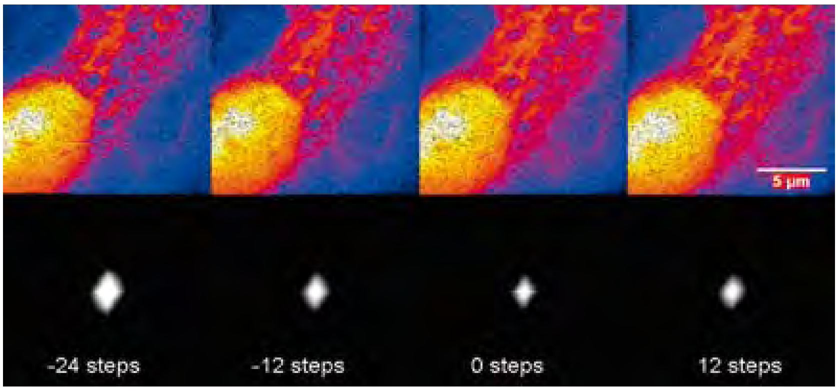


Fig. 4. Top row: Direct-STIM images of a human breast cancer cell taken through focus with 1 MeV He^{+} ions. Bottom row: 2D-Autocorrelation function expanded to emphasise the central peak.

The use of ion beams for imaging has also been developed. In a collaboration with the Centre for Ion Beam Applications at the National University of Singapore we have developed the 2D autocorrelation function as a figure of merit for focusing quadrupole multiplet lens systems where the focus must be optimized separately in the vertical and horizontal directions. This approach needs only a small fluence and can be used to directly focus on biological cells (Fig. 4).

Time-of-Flight Elastic Recoil Detection continues to be one of the groups interests. For high resolution depth profiling the close collaboration with IMEC in Belgium continues and at the Pelletron accelerator the design work of our own measurement system is almost complete. In addition, in collaboration with researchers at Pacific Northwest National Laboratory USA we have worked on extending the technique to rapidly screen new ionoluminescent materials for homeland security applications.

We have also continued to develop theoretical computer simulations as support for developing experimental techniques. The program suite GEANT4 has been used to study the edge penetration of apertures for MeV ion beam lithography and model the beam dynamics at the entrance to the accelerator. In addition, work has started on developing the Brenner code to investigate some aspects of the formation of nanohillocks on surfaces using highly charged ions.

Nuclear and accelerator based physics

Industrial Applications

Heikki Kettunen and Ari Virtanen

Ari Virtanen, director of industrial applications
Heikki Kettunen, senior researcher
Arto Javanainen, graduate student
Taneli Kalvas, graduate student
Suvi Päiviö, graduate student
Iiro Riihimäki, graduate student
Mikko Rossi, graduate student
Jukka Jaatinen, MSc student
Alexandre Pirojenko, MSc student

Fig. 1. Group members from the left: Heikki Kettunen, Arto Javanainen, Ari Virtanen, Suvi Päiviö, Iiro Riihimäki, Mikko Rossi and Taneli Kalvas.

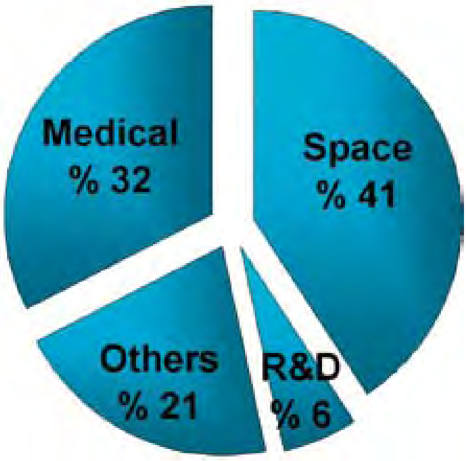


Fig. 2. Relative beam time distribution between different industrial areas. In addition to the industry, about 6 % of beam time was used for the research and development of the facility. The research means the beam time allocated via the proposal submitting procedure.

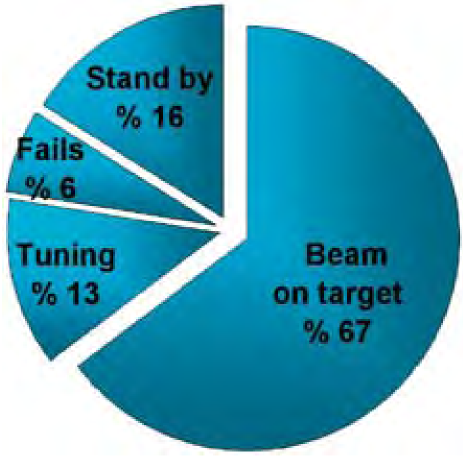


Fig. 3. Relative distribution of the beam time: "tuning" corresponds to the time needed to tune the desired beam and "fails" the time, when the cyclotron was incapable to deliver the beam to customers. "Stand by" corresponds to the time, when beam has been waiting for the customers' use.

Following users performed heavy ion and/or proton irradiations in RADEF-facility:

- Department of Physical Sciencies and Department of Astronomy, University of Helsinki
- European Space Agency, ESA/ESTEC, Noordwijk, The Netherlands
- Finnish Meteorological Institute, Helsinki
- Hirex Engineering Ltd., Toulouse, France
- Institut für Datentechnik und Kommunikationsnetze – IDA, Braunschweig, Germany
- IRoC Technologies Ltd., Grenoble, France
- Kayser-Threde GmbH, Munich, Germany
- Oxford Instruments Analytical Oy, Espoo, Finland
- OxypheN GmbH, Dresden, Germany
- Saab Ericsson Space Ltd., Gothenburg, Sweden
- ST Microelectronics Ltd., Crolles, France
- Thales Alenia Space Co., Toulouse, France
- University of Turku, Finland
- Åboa Space Research Oy, Turku, Finland

The usage of the beam time in different industrial areas is shown in figure 2. The 6% research and development time is also presented. The total beam time in 2007 was 1089 hours. Figure 3 shows the distribution of the use of the beam time.

Space Related Study

RADEF continued the operation as ESA's external European Component Irradiation Facility (ECIF). Nine separate component irradiation campaigns were performed during the year. Five of them were done by ESA. One research experiment was performed in collaboration with University of Turku. The study was a radiation hardness and performance test of the particle detector of solar intensity x-ray and particle spectrometer SIXA. It is planned to fly on board in ESA's BepiColombo mission to Mercury in the year 2013.

One of the highlights in space related study was, when the flag of the RADECS (Radiation Effects on Components and Systems) community was handed to us in the RADECS conference in Deauville, France. The flag symbolises our turn to take the responsibility to organise community's next workshop in Jyväskylä 2008.

Radio-medicine

The high-intensity proton beams from the LIISA ion source were used for the production of ^{123}I radioisotope for MAP Medical Technology Ltd. This production covers the needs of radioactive iodine for the 20 largest hospitals in Finland. The ^{123}I based radio-medicines produced by MAP are mainly used in diagnosing brain-based diseases. They are also delivered for medical research work to many other European countries. During the year 2007 over 30 production runs were performed.

Other Collaboration

The other highlight was also the start of collaboration with Oxyphen GmbH. Our cooperation aims to irradiate their polymer films, which is the first step for creating micro porous membranes made by the company. The installation of their beam line was made during the three separate beam time slots. The calibration procedures needed demanding homogeneity and current measuring properties of the beam, which partly explain the relative big tuning and stand by times shown in figure 3.

Collaboration with national companies and institutes continued on a regular basis. One MSc project was performed with Doseco Oy. The study aimed to define the critical neutron fluxes in a specific place in Loviisa nuclear power plant. The development of the gamma field detector used in cancer therapy went also forward and several tests in the local hospital were performed. The funding for our proposal to use neutrons to study properties of wood was also accepted by TEKES. The main coordinator and financer of the project is Metsäteho Oy. Metso Paper from Pori is the other cooperating industrial funding company. The study will be carried out together with VTT and the work will start at the beginning of 2008.

Major national collaborators are:

- Central Finland Health Care District, Jyväskylä
- Centre of Expertise for Nanotechnology, coordinated by Jyväskylä Innovation Oy
- Centre of Expertise for Paper Making Technology, coordinated by Jyväskylä Innovation Oy
- Doseco Oy, Jyväskylä
- Gammapro Oy, Jyväskylä
- MAP Medical Technologies Ltd., Tikkakoski
- Metsäteho Oy, Helsinki
- Metso Paper Co., Pori
- National Technology Agency of Finland, TEKES, Espoo
- Technical Research Centre of Finland, VTT, Jyväskylä

Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

Jouni Suhonen

Jouni Suhonen, professor
Jussi Toivanen, assistant (also with FidiPro group)
Johannes Hopiavuori, docent
Markus Kortelainen, postdoctoral researcher (also with FidiPro group)
Jenni Kotila, graduate student
Mika Mustonen, graduate student
Sami Peltonen, graduate student
Pekka Toivanen, MSc student

The year 2007 was a year of many successful projects in the nuclear theory team of JYFL. All in all, the following subjects were studied and reported in peer reviewed journals and/or conferences:

Nuclear Matrix Elements for Beta Decay and Double Beta Decay

The nuclear matrix elements (NME's) involved in the neutrinoless double beta decay have become a key issue in physics related to the properties of the neutrino. In particular the mass and character of it can be studied using atomic nuclei as laboratories. During 2007 our group has made evaluations of the NME's by using cutting-edge nuclear-structure tools to limit the uncertainties associated to the NME's. At the same time our group has addressed the complicated problem of highly forbidden beta transitions in nuclei. In some cases, like the 96Zr decay [1], the forbidden beta transition competes with the double beta decay.

Gamma and Beta Decays Involving Two-phonon Structures

The Microscopic Anharmonic Vibrator Approach (MAVA) has been developed earlier to study energies and gamma decays of two-phonon structures in even-even medium-heavy and heavy nuclei. Recently it has been extended to describe states and beta decays of odd-odd nuclei [2].

Detection Rates for Supersymmetric Dark Matter

The lightest supersymmetric particle, LSP, of supersymmetric theories of particle physics is considered to be the favourite candidate to constitute the bulk of cold dark matter (CDM) of the Universe. Nucleus-LSP scattering can be used for direct detection of the LSP. Our group has calculated theoretical estimates for the LSP scattering cross sections and detection rates by using nuclear wave functions obtained by large-scale shell-model calculations in the iodine, xenon and cesium regions. Both the elastic and inelastic channels have been included.

Alpha-decay Fine Structure

Alpha decay to excited final states is a complex but rewarding issue. Ratios of the decay rates to excited states and the ground state constitute the alpha-decay fine structure. The fine structure is currently of great experimental and theoretical interest. We have recently studied the fine structure corresponding to quadrupole states in a host of vibrational and transitional nuclei [3].

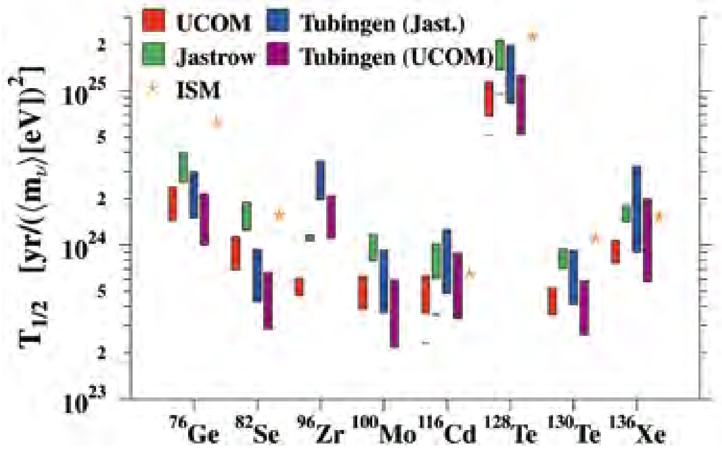


Fig. 1. Predicted half-lives of double-beta emitters on logarithmic scale.

Highlights

Short-range Correlations in Neutrinoless Double Beta Decay

In the neutrino-mass mode of the neutrinoless double beta decay the decaying two nucleons exchange a light Majorana neutrino with high average momentum. In nuclear-structure calculations the two nucleons can, in principle, overlap. This unphysical situation can be prevented by introducing an explicit short-range correlator into the calculations. Traditionally this has been accomplished by the use of the Jastrow correlator. In [4] we introduced a more complete new correlator in the form of the unitary correlation operator method (UCOM). The UCOM results deviate substantially from the old Jastrow results for the several considered double-beta decaying nuclei [5]. Later similar calculations were performed by the Tübingen group [6]. In figure 1 we show our results (red and greeen bars) together with the Tübingen (blue and violet bars) and available shell-model (stars) results [7]. In the figure the predicted ranges of half-lives of several important double beta decaying nuclei are shown on logarithmic scale in units of years scaled by the neutrino mass squared.

Fourth-forbidden Non-unique Beta Decays in the Quasiparticle-phonon Formalism

We have extended the microscopic quasiparticle-phonon model (MQPM) to proton-neutron MQPM (pnMQPM). In the pnMQPM we use proton-neutron pnQRPA phonons instead of the ordinary QRPA phonons. This formalism should describe better the beta-decay properties of odd-mass nuclei. The pnMQPM formalism was successfully applied to describe the half-lives and electron spectra of fourth-forbidden non-unique beta decays of ^{113}Cd and ^{115}In in [8]. Our results have been recently commented in the experimental work [9].

[1] H. Heiskanen, M.T. Mustonen and J. Suhonen, J. Phys. G 34 (2007) 837
[2] D.S. Delion and J. Suhonen, Nucl. Phys. A 781 (2007) 88
[3] S. Peltonen, D.S. Delion and J. Suhonen, Phys. Rev. C 75 (2007) 054301
[4] M. Kortelainen, O. Civitarese, J. Suhonen and J. Toivanen, Phys. Lett. B 647(2007) 128
[5] M. Kortelainen and J. Suhonen, Phys. Rev. C 75 (2007) 051303(R); Phys. Rev. C 76 (2007) 024315
[6] F. Simkovic et al., arXiv:0710.2055 [nucl-th]
[7] E. Caurier, F. Nowacki and A. Poves, arXiv:0709.0277 [nucl-th]
[8] M.T. Mustonen and J. Suhonen, Phys. Lett. B 657 (2007) 38
[9] P. Belli et al., Phys. Rev. C 76 (2007) 064603

Nanophysics and Nanotechnology

Markus Ahlskog, Konstantin Arutyunov, Ilari Maasilta and Sorin Paraoanu

Markus Ahlskog, professor
Konstantin Arutyunov, senior assistant
Ilari Maasilta, academy researcher
Sorin Paraoanu, academy researcher
Andreas Johansson, senior researcher (also with Nanoelectronics group)
Lasse Taskinen, postdoctoral researcher -30.6.
Vaibhav Varade, visiting scientist 1.8.-
Asaf Avnon, graduate student
Khattiya Chalapat, graduate student
Terhi Hongisto, graduate student
Tero Isotalo, graduate student 1.6.-
Jenni Karvonen, graduate student
Kimmo Kinnunen, graduate student
Panu Koppinen, graduate student
Jian Li, graduate student
Jarkko Lievonen, graduate student
Davie Mtsuko, graduate student 1.10.-
Minna Nevala, graduate student
Maciej Zgirski, graduate student
Hannu-Pekka Auraneva, MSc student
Tuuli Gröhn, MSc student
Ville Haaksluoto, MSc student
Olli Herranen, MSc student
Sampo Kulju, MSc student
Jaakko Leppäniemi, MSc student
Mikael Pajunen, MSc student
Mikko Palosaari, MSc student
Kari-Pekka Riikonen, MSc student
Kari Sarvala, MSc student
Sami Ylinen, MSc student -15.2.
Vesa Partanen, summer student

The Nanophysics group is dedicated to experimental research in some of the key issues in nanoscale or mesoscopic physics. Main activities are mesoscopic superconductivity, thermal effects in mesoscopic devices, and the fundamentals of solid state quantum computing. In addition, we do research on the physical properties of single carbon nanotubes.

Thermal Properties of Nanostructures and Radiation Detector Development

Ilari Maasilta

The main research direction of the thermal nanostructure research team led by Dr. Maasilta is to (a) understand energy flow mechanisms in low-dimensional geometries, and (b) utilize this knowledge in the development of ultrasensitive thermal and radiation sensors for space applications (bolometry). In the following, just a few highlights of the activity in 2007 are presented.

Thermal Transport in Low Dimensional Nanostructures

We have continued to utilize normal-metal-superconductor tunnel junctions (NIS) for ultrasensitive thermometry in sub-Kelvin temperature range. NIS-junctions can be used to characterize the electron-phonon (e-p) interaction in metals very accurately.

The main highlight of 2007 is the first measurement of the e-p interaction for thin enough membrane samples, so that the phonons behave as 2D[1]. The question that was answered: What happens to electronic heat loss if the sample becomes so thin that the lattice vibrations (phonons) can only move in the 2D plane? The answer is somewhat counterintuitive: Electrons can emit their energy to the lattice more effectively if the lattice is a thin 2D membrane. To see this effect, the authors studied thin copper wires (down to 15 nm) on dielectric silicon nitride membranes of varying thickness down to 30 nm at sub-Kelvin temperatures. In the thinnest samples below 0.5 K, the electrons of the Cu wires stayed much cooler when external heat was applied, showing that the heat flow between electrons and the lattice was enhanced. This improved dissipation efficiency could help delicate low-temperature circuits such as quantum bits, and may also be beneficial for the operation of solid-state coolers.

Theoretical work on phonon transport was also a focus field. We have computed the phononic thermal transport properties of thin membranes in the ballistic limit for various materials[2], see Fig. 2. The surprising result is that the materials with highest speed of sound, such as diamond, are actually the weakest thermal conductors in the ballistic limit, contrary to the diffusive transport where diamond is the best conductor. Also, by thinning the membrane, thermal conductance can actually be improved, so that per unit cross sectional area, ballistic thin membranes are much more effective conductors than bulk samples.

1. J. T. Karvonen and I. J. Maasilta, Phys. Rev. Lett. 99, 145503 (2007), Journal of Physics: Conference Series 92 012043 (2007)
2. T. Kuhn and I. J. Maasilta, Journal of Physics: Conference Series 92 012082 (2007)

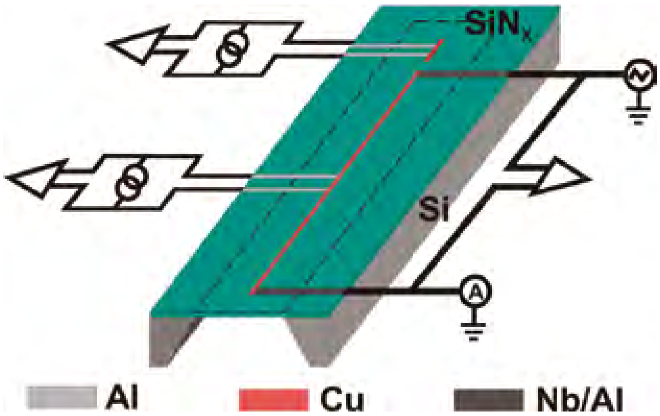


Fig. 1. Schematic of the 2D membrane sample for heat transport measurement

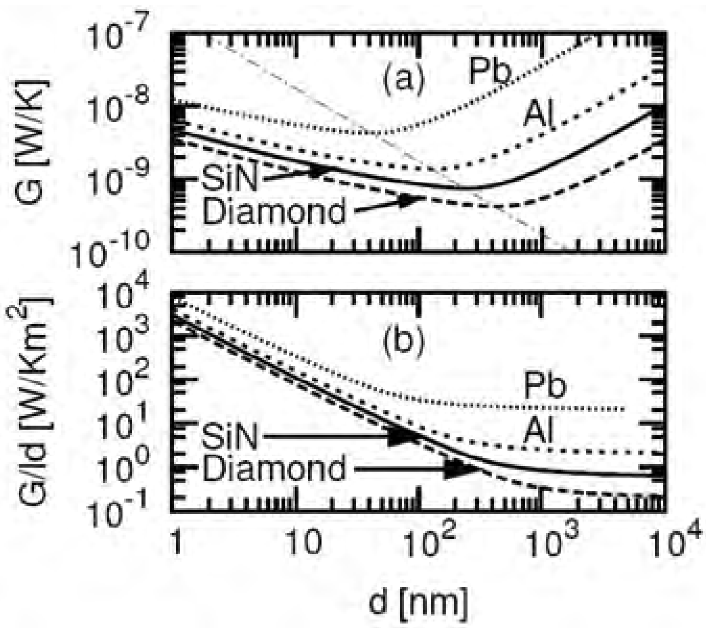


Fig 2. (a) Ballistic conductance G and (b) Ballistic conductance per unit area g/1d as a function of membrane thickness d for various materials. The dash-dotted line in (a) is proportional to 1/d.

Mesoscopic Superconductivity

Konstantin Arutyunov

Nanotechnology

We have further developed our proprietary method [patent application FIN-20060719 and K.Yu. Arutyunov, "Fabrication of quasi-one-dimensional superconducting micro- and nanostructures", Recent Patents in NanoTechnology (invited review article) 1,129-135 (2007)]for shaping and downsizing of nanostructures. Fig. 3 demonstrates applicability of the method for fabrication of Si nanowires with surface roughness < 1 nm. The method is industrially friendly being compatible with high vacuum and clean room requirements. The innovation has been awarded the TULI grant from Jyväskylä scientific park "Evaluation of commercial potential of the ion beam nanofabrication method", which gave very promising results. Implementation of the method on industrial scale is foreseen.

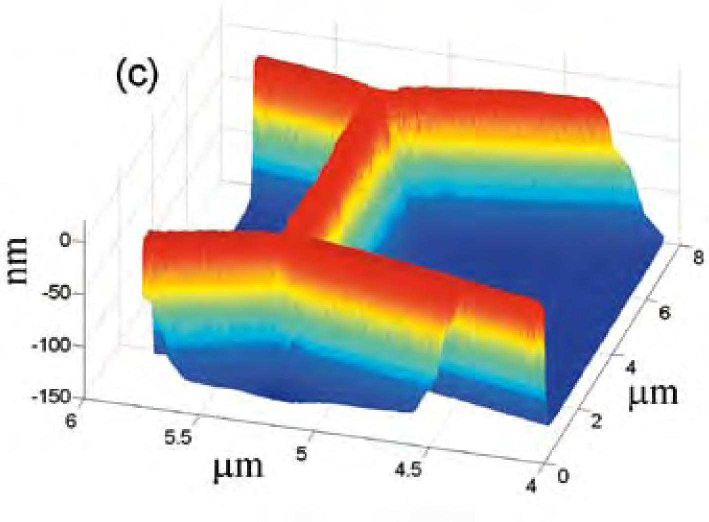
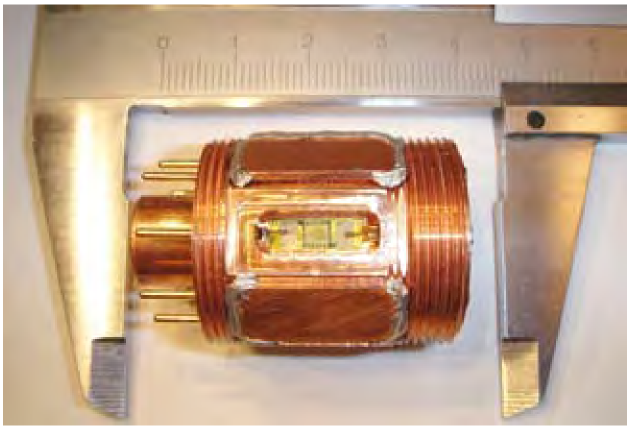


Fig. 3. SPM image of a Si nanowire obtained by the ion-beam sputtering method [M.Zgirski, K-P. Riikonen, V. Tuboltsev, P. Jalkanen, T. T. Hongisto and K. Yu. Arutyunov, "Ion beam shaping and downsizing of nanostructures", Nanotechnology **19** 055301 (2008)]

Advances in Ultra-low-temperature Instrumentation

A qualified experiment at ultra-low-T (T < 100 mK) requires very serious attention to instrumentation details. For electron transport experiments of particular importance is the ability to perform measurements without significance overheating of the conducting electrons above the lattice (phonon) temperature. Extensive rf filtering (Fig. 4a) of the environmental electromagnetic noise is one of the mandatory requirements to obtain reliable data (Fig. 4b).



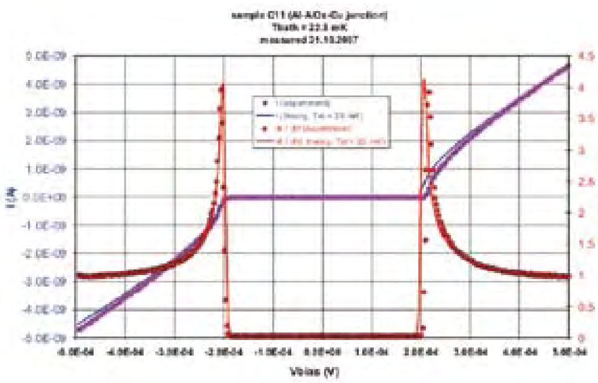


Fig. 4. (a) RC rf strip filters installed at the mixing chamber of the *Kelvinox-400* dilution refrigerator. (b) *I-V* and *dI/dV* characteristics of the Al-AlO_x-Cu tunnel junction measured at T_{bath} = 22.8 mK. Fits to theory shows that the electron temperature is T_{el} = 25 mK, which is an excellent result indicating proper thermalization of the conducting electrons [unpublished].

Relaxation of Non-equilibrium Quasiparticles Injected into a Superconductor at Ultra-low-temperatures

Though numerous devices utilize junctions between a normal metal and a superconductor, there is a very poor understanding of the process of conversion of the normal (non-paired) electron current into the equilibrium supercurrent inside a superconductor. We have developed a method of detecting the "presence" of these non-equilibrium electrons injected into a superconductor, using multi terminal tunnel nanostructures (Fig. 5). Our results indicate that the conversion (relaxation of non-paired electrons) to Cooper pairs in Al, widely used and technological friendly material, at ultra-low-temperatures happens at characteristic length of about ~ 10 μm, which is an enormously large scale for the 'nanoworld'. The discovery is of a fundamental importance for understanding the phenomenon of non-equilibrium superconductivity, and should provide an impact on development of a wide range of nanoelectronic applications.

Superconductivity in one Dimension

The group has continued the on-going research of quantum fluctuation phenomena in ultra-narrow superconducting channels [K. Arutyunov, *et.al.* , "Quantum Limitations of Electron Transport in Ultra-Narrow Nanowires", *International Review of Physics* (invited review article), 1(1), 28 (2007)]. An extensive experimental and theoretical analysis (Fig. 6) revealed the necessity of extremely cautious analysis of experimental data, where trivial inhomogeneity and finite size of a sample can easily mimic effects often assigned to "sophisticated" physics.

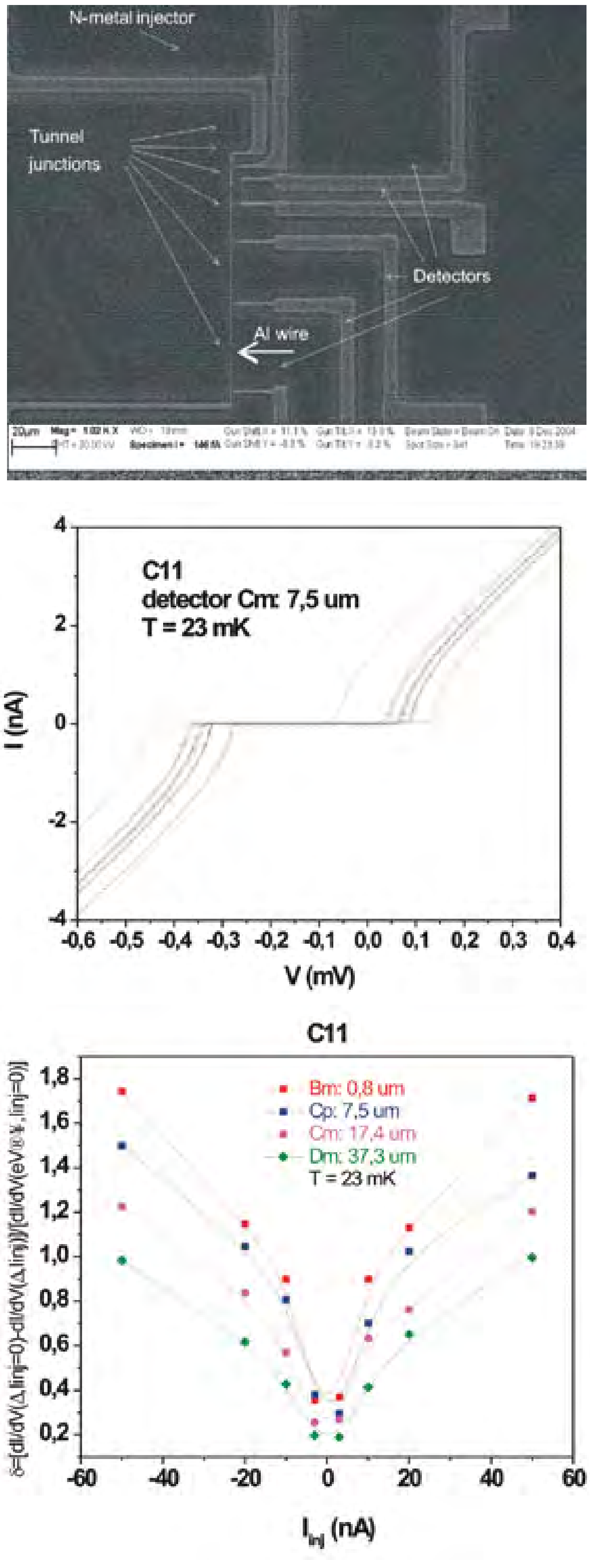


Fig. 5. (a) SEM image of the multi-terminal NIS tunnel nanostructure. (b) Effect of modification of the I-V characteristics of a detector, located at distance 7.5 μm away from the injector, as a function of the injector current (c) Effect of suppression of the differential conductance at energy $eV_{inj} = \Delta$ as function of the injector current measured by several detectors at different distances from the injector. Data (b) and (c) was obtained at temperature T_{bath}= 23 mK [unpublished].

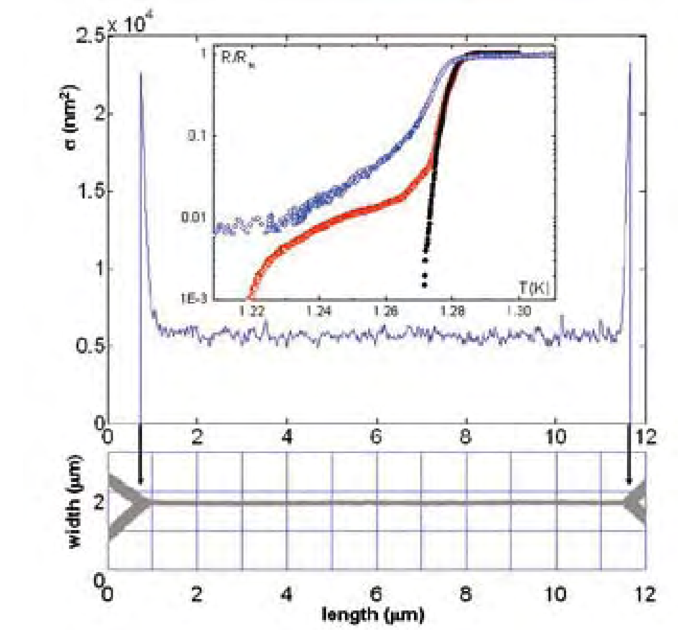


Fig. 6. Bottom panel: SPM image of a typical aluminum wire with 4 probes. Top panel: SPM measured variation of the wire cross-section σalong the sample including the node region. Inset: open circles correspond to simulated R(T) dependence without taking into consideration node regions; diamonds are results of similar calculations with contribution of the node regions within the limits indicated by two arrows; solid circles is experimentally measured R(T) dependence [M. Zgirski and K. Yu. Arutyunov, Experimental limits of the observation of thermally activated phase-slip mechanism in superconducting nanowires, Phys. Rev B 75, 172509 (2007)]

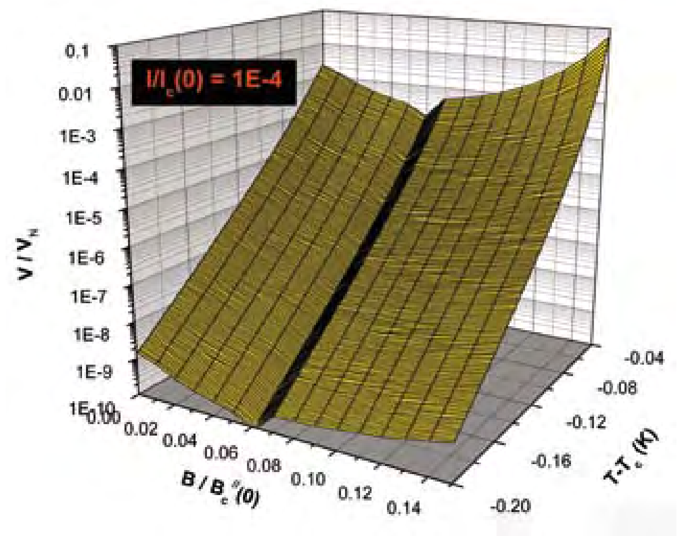


Fig. 7. Effective time-averaged voltage vs. magnetic field B and temperature T at constant DC measuring current I normalized by its zero-temperature value $I_c(0)$ for 20 nm x 20 nm 10 μm aluminum nanowire. Magnetic fields are normalized by the zero-temperature parallel critical magnetic field $B_c(0)$. One can clearly see the negative magnetoresistance developing at small fields [K.Yu Arutyunov, Negative magnetoresistance of ultra-narrow superconducting nanowires in the resistive state, Physica C (2007), doi: 10.1016/j.physc.2007.08.027].

Theoretical analysis, based on the model of charge imbalance, enabled understanding of the origin of a mysterious negative magnetoresistance observed in ultranarrow superconductors (Fig. 7).

Tunneling Spectroscopy of DYE-based Nanostructures

In collaboration with the group of Prof. J. Korppi-Tommola, Dept. of Chemistry and supported by the Finnish Academy project FUNANO, the group entered in a new field of research. Strong expertise of our team in fabrication and experiments with tunneling nanostructures lead to a new idea: use tunneling spectroscopy to study energy levels of organic DYE's. These materials are widely used as building blocks of solar cells, but not much is known about microscopic energy structure of the DYE molecule. Preliminary data are quite encouraging: we were able to fabricate tunnel structures (Fig. 8a and Fig. 8b) and the I-V dependencies clearly indicate the photo-effect (Fig. 8c). The results are of a significant importance for understanding the microscopic mechanisms of photoconductivity in molecular systems, and can lead in future to fabrication of molecular-size photoelements: cells, diodes and/or transistors.

1. P. Jalkanen, V. Tuboltsev, A. Virtanen, K. Yu. Arutyunov, J. Räisänen, O. Lebedev and G. Van Tendeloo, Sol. St. Comm.142 (2007) 407
2. M. Zgirski, K.Yu.Arutyunov, Phys. Rev. B 75 (2007) 172509
3. K.Yu.Arutyunov, Recent Patents in NanoTechnology 1 (2007) 129
4. K. Arutyunov, M. Zgirski, K.-P. Riikonen, and P. Jalkanen, International Review of Physics (IREPHY) 1 (2007) 28
5. M. Zgirski and K.Yu. Arutyunov, Physica E 40 (2007) 160
6. K.Yu. Arutyunov, T. T. Hongisto, D. Y. Vodolazov, Physica E 40 (2007) 184

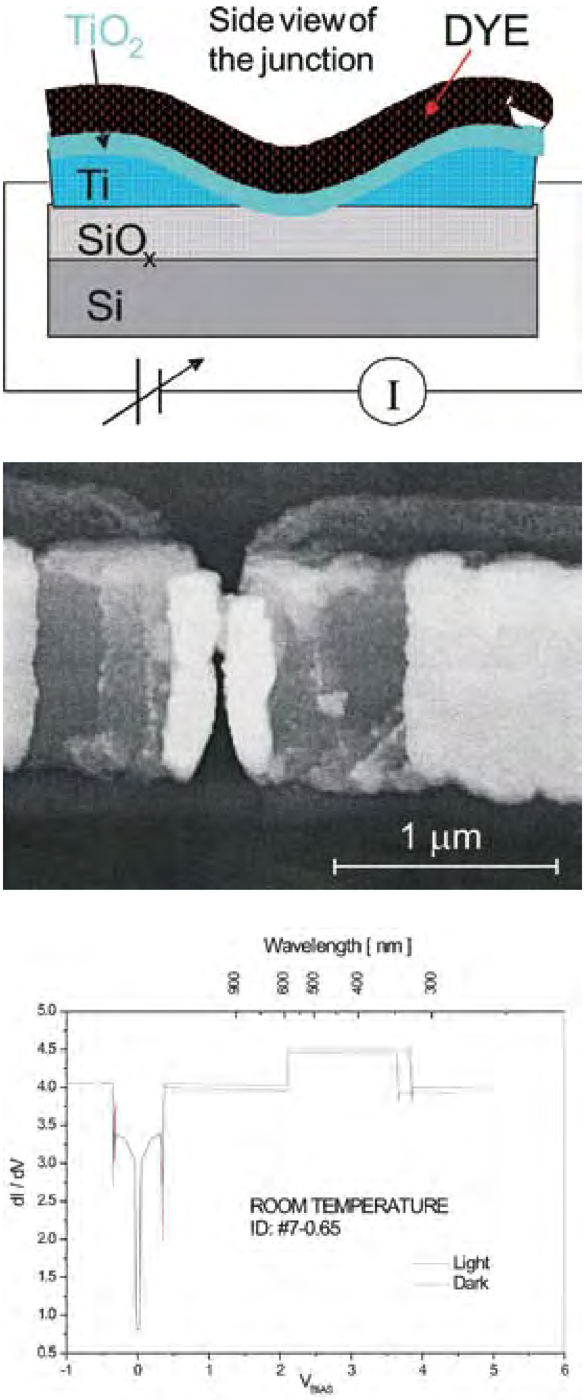


Fig. 8. (a) Schematics of the DYE-based tunnel structure. (b) SEM image of Ti/TiO_x nanocontacts. (c) dI/dV characteristic of the DYE-based nanostructure at room temperature. One can clearly see the photo-effect [unpublished].

Quantum Engineering

Sorin Paraoanu

In 2007, the Quantum Engineering (QE) unit of the NanoPhysics group has consisted of the following researchers: S. Paraoanu, K. Chalapat, J. Li, and K. Sarvala. This unit is doing research on the microwave properties of nano-structured materials and on quantum coherence effects in superconducting devices based on the Josephson effect.

Control of Superconducting Qubits

We have studied a system consisting of a superconducting coplanar waveguide resonator capacitively coupled to two charge qubits. The resonator can be read out using a single Josephson junction. Using the simulated annealing method, we show that any two-qubit gate can be implemented by a suitable combination of microwave pulses with relatively large fidelities. We propose a quantum nondemolition (conditional) method to read out the qubits: we show that an entangled state is established between the qubits when no photon leaks out of the resonator, while for a generic microwave drive we characterize the photon-qubit-qubit entanglement.

Microwave Properties of Nanocomposites

Measurements of the S-parameters and calculation of the corresponding complex electromagnetic permittivity and permeability were done by the Nicholson-Ross-Weir method using a 18GHz airline and custom-made and home-made toroidal samples. The samples measured were composites containing Co, Ni, and Au nanoparticles.

Photodevices

We have measured the IV characteristic and dI/dV at various bias voltages for a device combining the structure of a solar cell with that of a photodiode. We characterize the device under different illuminations and we point out that it can be used as a phototransistor (collaboration with the group of Prof. J. Korppi-Tommola).

Nb Single-electron Transistors

We have fabricated, measured, and modeled a Nb-island single electron transistor. We find good modulation, but relatively large intragap currents (collaboration with the ELE group).

Molecular Technology

Markus Ahlskog

The Molecular Technology group studies electronic and mechanical properties of macromolecular particles and devices that are based on them. The main focus is on carbon nanotubes (CNT), while conducting polymers and viral particles are under consideration as well.

In a project funded by Tekes (The Finnish Technology Development Center) we investigate the use of single CNTs as memory elements in digital nanoelectronic circuits. We have studied field-effect transistors made from

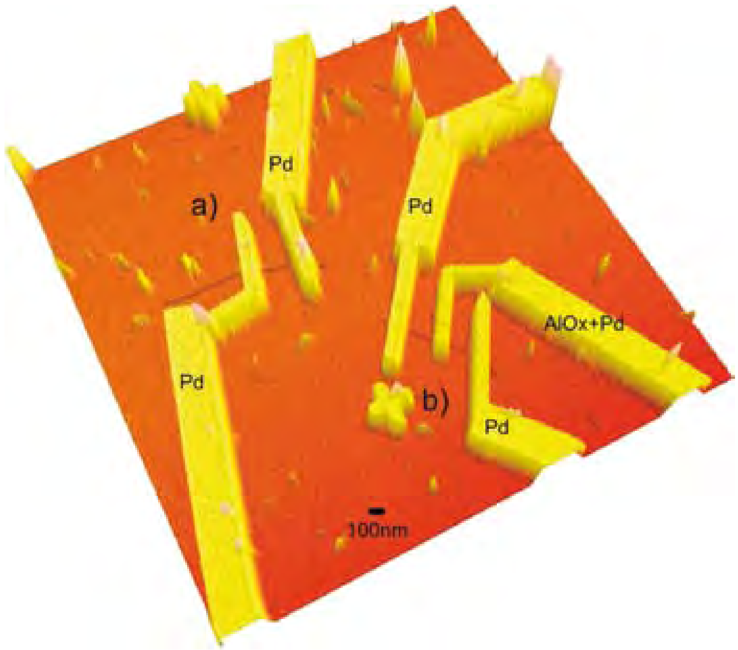


Fig. 9. Two carbon nanotube based field effect transistor. The one to the right with AlOx+Pd topgate.

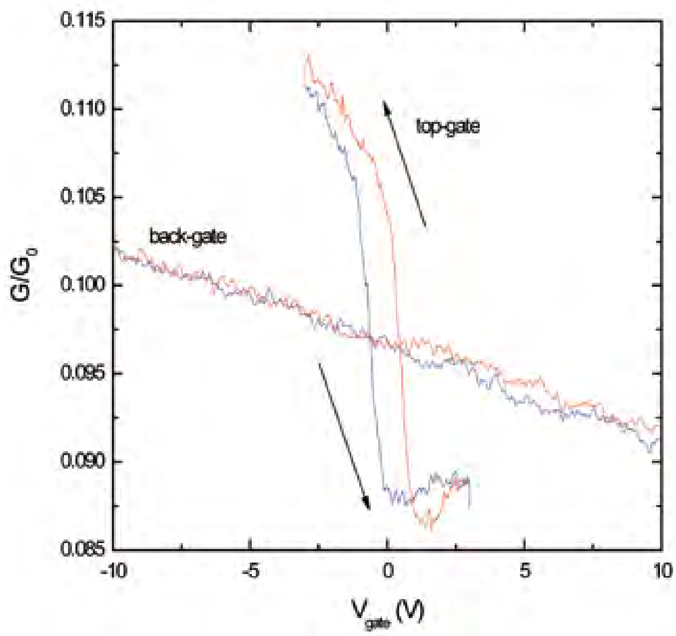
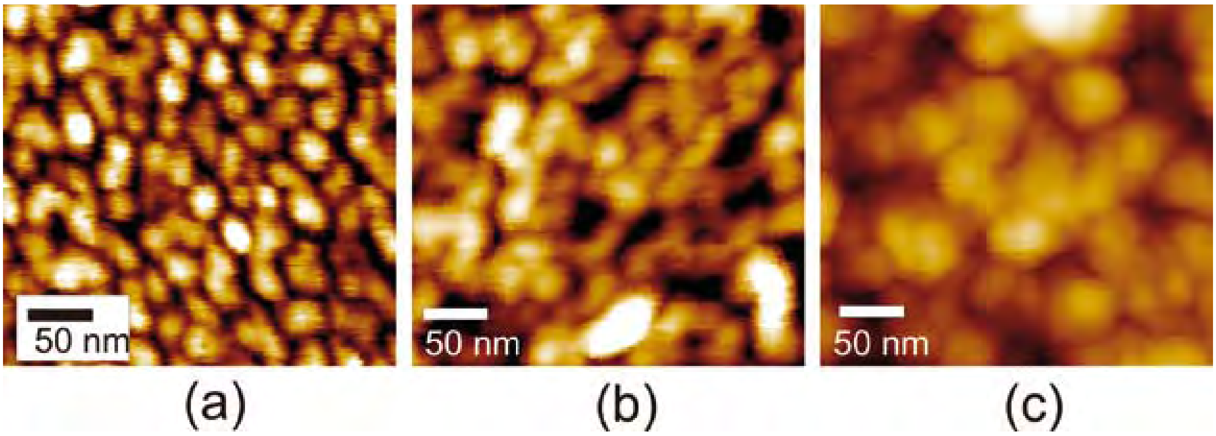


Fig. 10. Conductance vs. gate voltage for the device in Fig. 9.

carbon nanotubes with a focus on differences between using a global backgate (the underlying substrate) and a local topgate, seen in the nanotube device of Fig. 9. Local gating is necessary in order to achieve high device integration but requires nanometer accuracy in its



placement. This combined with the fact that the surface of the nanotube is very inert and difficult to coat with a thin gate insulator, makes local gating a nontrivial task. Conductance versus gate voltage is shown in the Fig. 10. for both topgate and backgate of the same device. The stronger response to the topgate is intuitively clear as it is much closer to the tube than the backgate (~20nm vs. 300nm), and therefore has a stronger capacitive coupling to the carbon nanotube.

We have fabricated a novel mesoscopic device based on a doped conducting polymer and gold dots. Ultrathin layers of polypyrrole (PPy) were electrochemically grown between microelectrodes on a Si/SiO_2 substrate. Conducting PPy was directly grown onto ultrathin discontinuous gold film between the microelectrodes, with thicknesses in the range of 10-100 nm, see Figure 11a. The system therefore forms a novel (PPy/Au) nanocomposite conductor. AFM imaging and conductivity measurements indicate that at all thicknesses a relatively uniform film is formed but with significant roughness that reflects the roughness of the metallic island layer (Figure 11b). In PPy/Au films with thickness ~ 10 nm, the small barriers around the gold islands dominate the conduction, and as the film thickness increases to 100 nm the intrinsic conductivity of highly doped PPy dominates the charge transport. The patterns can be made very small and this also provides an opportunity of studying charge transport in conducting polymers over nanoscale distances corresponding to the inter-island gaps of the metal films.

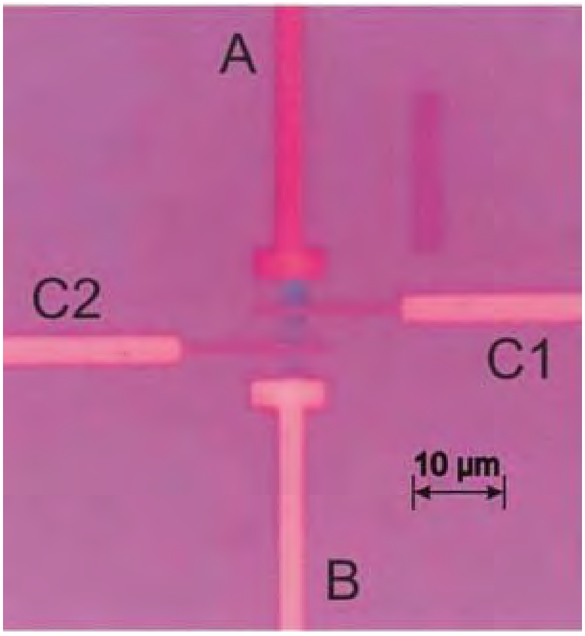


Fig. 11. (a) A gold island layer (nominal thickness 6 nm, width = 3 μm and zero bias resistance, R ~100 GΩ). (b) Surface of a sample of PPy/Au with total film thickness ($t_{Au} + t_p$) 45 nm and R = 770 kΩ. (c) Surface of PPy/Au (Sample B) with thickness ($t_{Au} + t_p$) 120 nm and R = 1.2 kΩ. d) Photograph of a structure after polymerization. The polymer covered island layer in the center has a width of 3 μm. A and B are anode and cathode, respectively and C1 and C2 are electrodes used to measure resistance of the composite film. A separate and identical non-connected island layer to the right of the A electrode displays the color change due to the polymerization. Polymer has also grown on the A electrode.b) AFM images taken of the island layer with an ultrasharp AFM tip.

Nanoelectronics and Nanotechnology

Jussi Toppari and Päivi Törmä

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Ultracold Atomic Fermi gases

Ultracold atomic gases provide remarkable tools to study quantum manybody physics, related e.g. to questions in quantum information and computing, high-Tc superconductivity, and dynamics of neutron stars. Optical lattice is a perfectly periodic potential for atoms, created by retroreflected laser beams. We have calculated phase diagrams for Fermi gases in one-, two-, and three-dimensional optical lattices as functions of temperature and population imbalance between the two species.

The phases considered in addition to the standard Bardeen-Cooper-Schrieffer (BCS) superfluid and the normal state are polarized superfluid or Sarma phase, the Fulde-Ferrel-Larkin-Ovchinnikov (FFLO) phase and phase separation into BCS and normal states (T.K. Koponen et al., Phys. Rev. Lett. 99, 120403 (2007), see Figure 1). We have taken into account the harmonic confinement present in the lattice experiments by employing the local density approximation and have found that, depending on the total amount of atoms in the system, interesting shell structures will form, such as a core of normal gas surrounded by FFLO superfluid, surrounded again by a shell of normal gas.

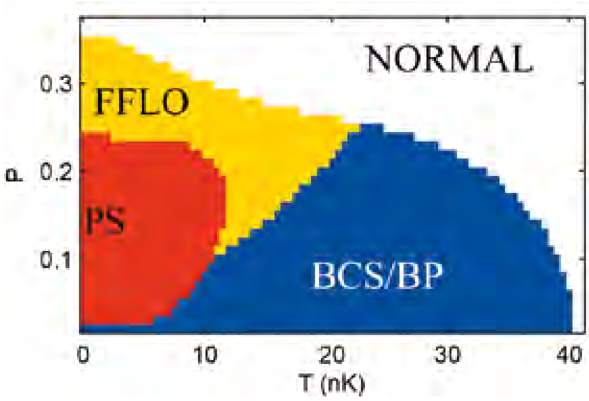


Fig. 1. Temperature - polarization phase diagram of a Fermi gas in a three-dimensional optical lattice.

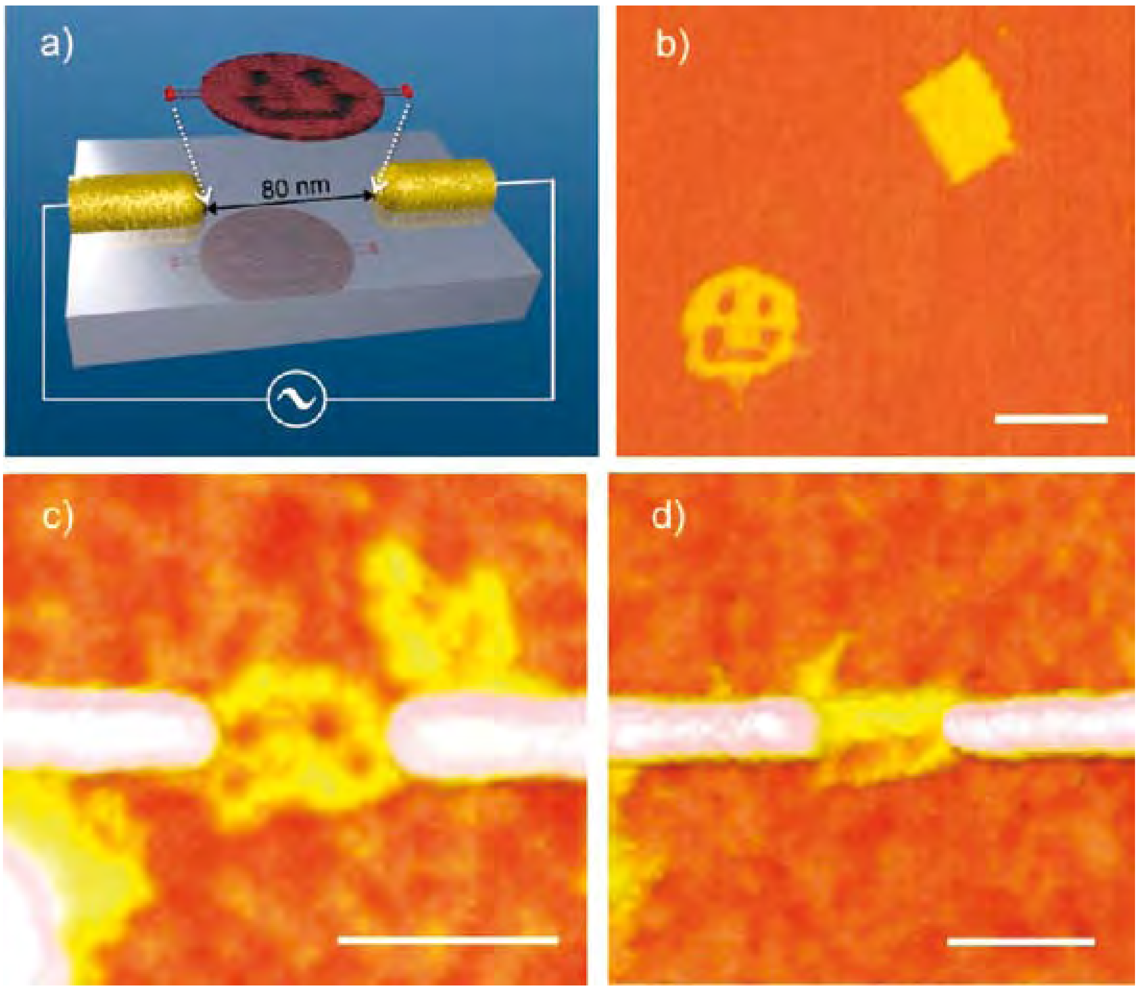
We have proposed (M.J. Leskinen et al., Phys. Rev. A 76, 021604(R) (2007)) a method for cooling fermionic atoms in a normal state by an internal tunneling contact, created by an electro-magnetic field, to a paired state. The normal state can be cooled by transferring atoms from the paired state by choosing the field detuning so that thermal holes are filled.

Trapping and Modification of a DNA-origami

Due to its exceptional self-assembly properties, DNA could become a key player in bottom-up fabrication of nanoscale systems. A striking example of a DNA self-assembly technique is "DNA origami", which involves folding a long single-stranded DNA with the help of short oligonucleotides. DNA molecules and DNA self-assembled structures can be used as a template for attachment of various materials (proteins, carbon nanotubes, metal nanoparticles) with 6 nm resolution.

Controlled positioning of origami structures on a chip is a crucial open challenge for the realization of the full potential of DNA origami as template. We have developed dielectrophoresis (DEP)-based method for trapping DNA origami structures. This is the first demonstration of DEP manipulation of complex, designed self-assembled structures. See Figure 2.

Fig. 2. Trapping DNA origami structure with dielectrophoresis. a) Schematic view of the origami trapping experiments. b) AFM image of origami structures used for DEP trapping. c), d) AFM images of a single "smiley" and a rectangular origami trapped with the optimal DEP parameters. The scale bar is 100 nm.



The work was done in collaboration with Bernard Yurke from Bell Labs (now at Boise State University) and Erik Winfree's group at Caltech.

Molecular Scale Memory Elements

Carbon nanotube field-effect transistors (CNT-FETs) have been proposed as possible building blocks for future nano-electronics, but there are several challenges: one of them is to control the influence of the surrounding environment. For example, the often natural occurrence of mobile charges or charge traps in the vicinity of a CNT-FET is known to randomly cause undesirable hysteresis in its transfer characteristics. On the other hand, if the hysteresis could be controlled, the device would have potential as a nanoscale memory element.

We are studying the possibilities to control the hysteresis and create such a memory element by utilizing a semiconducting single walled CNT in combination with a carefully chosen nanometer thin dielectric layer. The choice of gate insulator film is found to have a crucial influence on the operation of the CNT-FET. In Figure 3 below is a graph with typical transfer characteristics from a CNT-FET that exhibits a clear memory effect. Note that the measurements were made at room temperature, showing that carbon nanotubes may provide solutions to everyday electronics products.

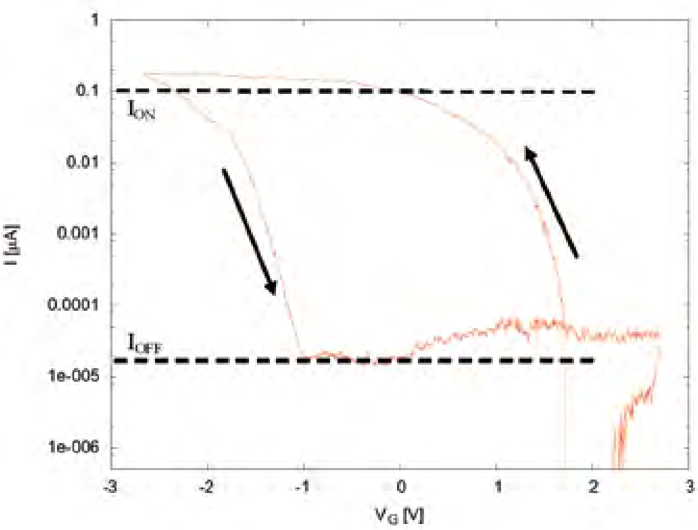


Fig. 3. Transfer characteristics of a carbon nanotube field-effect transistor exhibiting hysteresis.

The project is done in collaboration with M. Ahlskog's and K. Rissanen's groups at JYU and E. Kauppinen's group at HUT as well as Nokia Oyj, Planar Inc and Vaisala Oyj.

Molecular Coupling of Light with Plasmonic Waveguides

Surface plasmon polaritons [SPP, or briefly, surface plasmons (SP)] offer fascinating prospects for understanding and exploiting phenomena related to nanoscale confinement of light. SPs are coupled modes of electromagnetic field and free electrons in metal, bound to a metal-dielectric interface. They can be confined to dimensions much smaller than wavelength of the light in free space. Ultimately, SPs may provide the path to integrated electrical and optical circuits for information processing at the nanoscale.

We have used molecules to couple light into and out of microscale silver stripes acting as plasmonic waveguides and demonstrated energy transfer, mediated by surface plasmons, from donor molecules to acceptor molecules over ten micrometer distances (A. Kuzyk et al., Opt. Express 15, 9908 (2007)). Also surface plasmon coupled emission, from the donor molecules, has been observed at similar distances away from the excitation spot. The use of molecules as couplers between far-field and near-field light offers the advantages that no special excitation geometry is needed, i.e., any light source can be used to excite plasmons. The lithographic fabrication method we have developed for positioning the dye molecules allows scaling to nanometer dimensions, which yields another advance: the excitation area, determined only by the size of the molecule ensemble, can be localized below the diffraction limit. Moreover, the use of molecules has the potential for integration with molecular electronics and for the use of molecular self-assembly in fabrication. The utilized experimental setup is shown in Figure 4.

The project is done in collaboration with H. Tikkanen, M. Petterson and H. Kunttu at chemistry department of JYU.

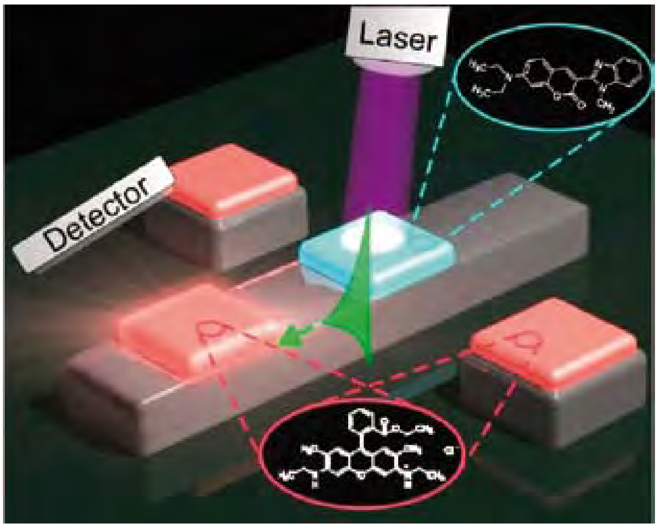


Fig. 4. A schematic presentation of the structure of the samples and the measurement setup consisting of 405 nm laser exciting the donor molecule (Coumarine, cyan) area and detection of fluorescent from the acceptor molecule (R6G, red) area by confocal microscope. The molecules are embedded in SU-8 resist. The plasmons (green) emitted by donor propagate along the silver waveguide and couple to the acceptor resulting in the energy transfer between the molecules.

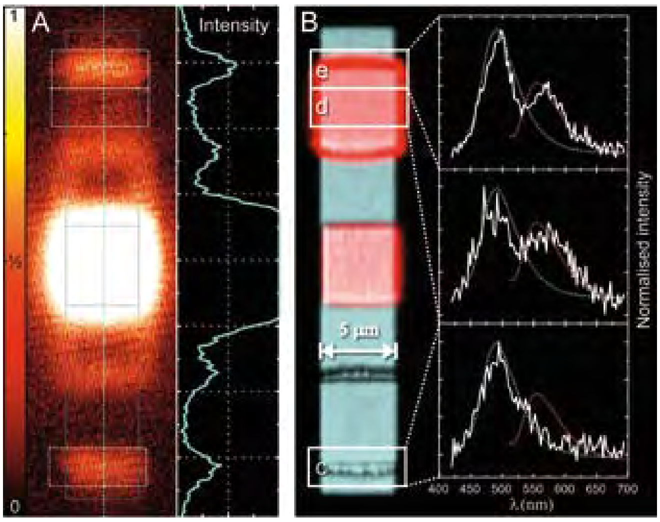


Fig. 5. Confocal microscope images. A) An image obtained by the experimental setup shown in Figure 4. B) The same plasmonic channel showing the silver structure and the dyes. The Coumarine is located in the middle red area as well as the R6G in the upper one. The lowest rectangular region is a reference with bare SU-8 without any dye. On the right (insets (c) – (e)) are shown the spectra measured at different regions under excitation of the donor with 405 nm laser. The reference spectra for Coumarine (cyan) and R6G (red) are shown also.

Computational Nanosciences

Jaakko Akola, Hannu Häkkinen and Matti Manninen

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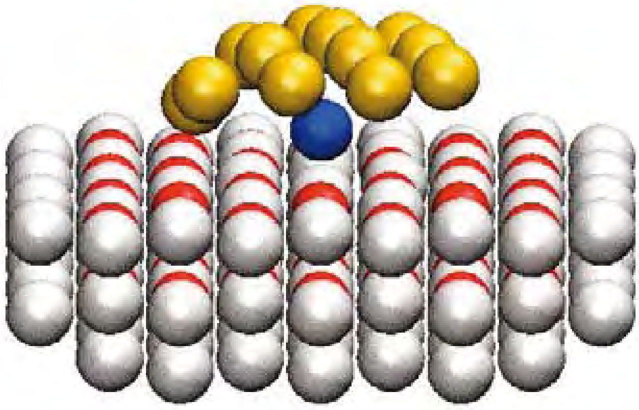
Electronic Structure of Magnesia-supported Gold Clusters: Quantum Dots Probed by STM

Recent developments in methods to control growth of ultrathin insulating (alkali-halide or metal-oxide) films over a metal surface have made it possible to fabricate well defined templates for spectroscopic studies of insulator-supported metal particles and molecule-metal junctions. While the few-monolayer-thick films are thick enough to isolate the adsorbate (metal adatom, metal cluster or a molecule) electronically from the metal support, they are however thin enough to enable tun-



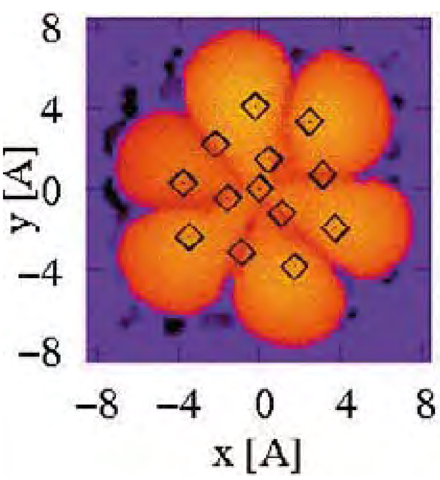


Fig. 1. Atomic structure of a 13-atom gold cluster, adsorbed at an oxygen vacancy on MgO(001) surface.

Fig. 2. The simulated STM image of the highest occupied electron state of the gold cluster, located in the band gap of MgO.

neling from/to the STM tip under imaging conditions. This facilitates investigations of nanoscale metal-insulator-metal systems, where new insights can be gained into (i) factors defining the electronic structure of the adsorbate, (ii) charge state(s) of the adsorbate and (iii) the molecule-metal bond formation.

We investigated [1] via density functional theory the appearance of MgO-supported gold clusters in a scanning tunneling microscope (STM) experiment. Comparing simulations of ultrathin films on a metal support with a bulk MgO lead to similar results for the cluster properties relevant for STM. Simulated STM pictures show the delocalized states of the cluster rather than the atomic structure (Figs. 1,2). This finding is a consequence of the presence of Au(6s)-derived delocalized states of the cluster near the Fermi energy. The properties of theses states, in particular for symmetric clusters, can be understood in a jellium model for monovalent gold.

1. M. Walter, P. Frondelius, K. Honkala, H. Häkkinen, "Electronic structure of MgO-supported Au clusters: Quantum dots probed by STM", Phys. Rev. Lett. 99, 096102 (2007)

Rotating Fermions and Bosons Traps

We have continued the study of the similarity of rotating electrons in quantum dots and weakly interacting fermionic and bosonic atoms in harmonic traps. Fast rotation forces the particles to localize in a rigid classical configuration. The quantum mechanical energy levels are then determined from the classical vibrational frequencies with proper analysis of the group theory (Nikkarila and Manninen, Solid State Commun. 141, 209 (2007), Phys. Rev. A 76, 13622 (2007)).

The similarity of the particle localization and vortex formation in boson and fermion systems suggests that the many-particle wave functions are closely related. We followed the ideas of the Jain construction (Jain, Ann. Phys. 41, 105 (1992)) and the suggestion of an exactly solvable model (Ruuska and Manninen, Phys. Rev. B 72, 153309 (2005)) for converting the boson wave function into a fermion wave function. This allowed us quantitative comparison between fermion and boson states, by computing the overlap of the wave functions. The result indeed shows that for a large range of angular momenta the wave functions of these two systems are mathematically closely related (Borgh et al, arXiv:0801.0966).

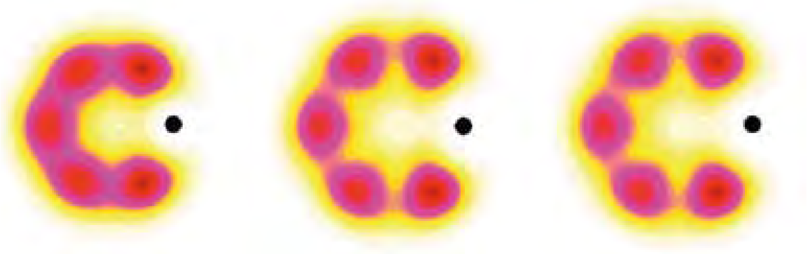


Fig. 3. Pair correlation function of six rotating particles rotating in a harmonic trap. Left shows bosons with angular momentum L=42, middle shows bosons converted to fermions, L=57, and right shows the pair correlation for fermions with 57.

Magnetism of Fermionic Atoms in Artificial Lattices

Quantum dots can be manufactured to form a regular lattice in one or two dimensions using semiconductor heterostructures. An other kind of artificial lattice is the optical lattice where neutral atoms can be trapped. The structure of artificial lattices is dictated from the outside of the system and the particles confined in the lattice can not change it, acontrary to normal lattices where the electrons play a dominating role in determin-

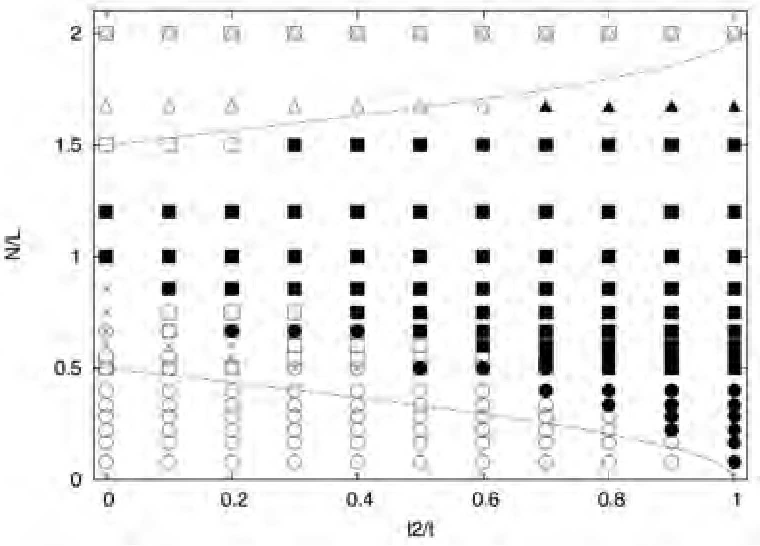


Fig. 4. Phase diagram calculated with a generalized Hubbard model for a row of quantum dots. The open symbols show antiferromagnetic regions and the solid symbols ferromagnetic results. The solid lines are analytic estimates for the phase boundaries. The horizontal axis is the ratio of the two hopping parameters of the model and the vertical axis is the number of p-electrons per site.

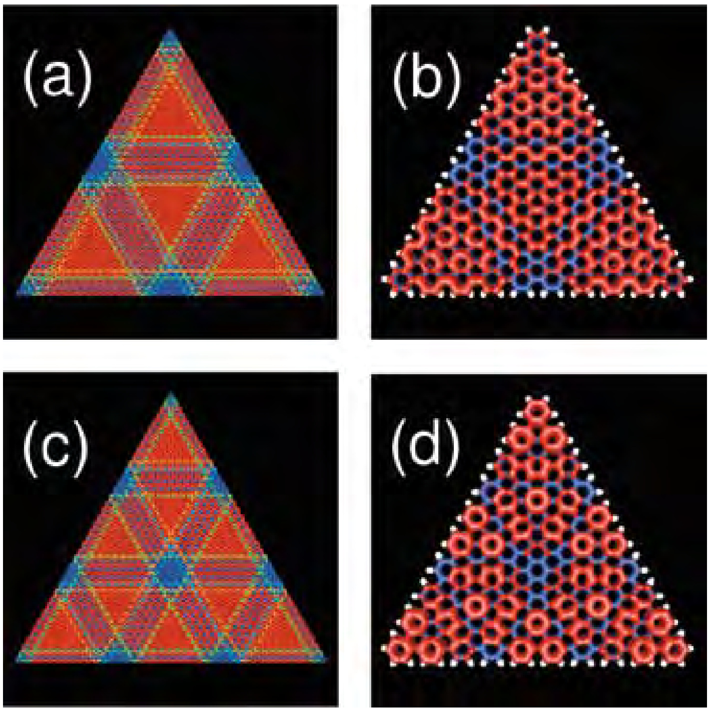


Fig. 5. Examples of electron wave functions in triangular quantum dots of graphene.

ing the lattice structure. Consequently, artificial lattices can form magnetic structures which are not easily accessed in normal materials.

We are using a generalized Hubbard model to study artificial lattices with more than two particles in each lattice site. In one-dimensional lattice with 2 to 4 particles per lattice site, the system shows an intrigue magnetic phase diagram shown in Figure 4. The boundaries between the ferromagnetic and antiferromagnetic regions can be explained with simple analytic model.

Magic Triangles of Graphene

The level structure of particles in a triangular cavity can be analytically solved. For example, electrons in a triangular confinement form clear shell and supershell structures. Graphene opens up an interesting new material to study triangular quantum dots. Graphene has hexagonal symmetry which allows perfect equilateral triangles as finite clusters. Moreover, close to the Fermi level the dispersion relation of the energy bands is linear making the electrons in effect massles.

We have used a tight binding model and ab initio electronic structure calculations for studying the shell and supershell structures close to the Fermi level in graphene triangles. The results show that the levels structure and the wave functions can be reliably derived from a simple tight binding model. The levels can be quantitatively related to those of free massles particles confined in a cavity. However, the underlying lattice makes the wave functions to have interesting symmetries as shown in Figure 5.

Modelling of Phase Change Materials Used in Rewritable Data Storage

Jaakko Akola

Computers and other electronic devices place ever-increasing demands on the density, speed, and stability of memory. Phase change (PC) materials are among the most promising candidates for the next generation of computer random access memory (RAM), and they are already familiar to us as rewritable media [CD-RW, DVD-RW, DVD-RAM, Blu-ray disk (BD)]. PC materials are alloys of certain elements of groups IV, V, and VI that can be switched reversibly between their amorphous and crystalline states with an electric current, and the electrical resistance and optical properties of these two states differ substantially. Unlike conventional RAM, the content, that is stored as nanometer-sized bits, is not lost when power is disconnected (nonvolatile memory). The most widely used recording material today is the pseudobinary compound GeTe-Sb_2Te_3 (GST), particularly its stoichiometry $Ge_2Sb_2Te_5$. As a DVD-RAM material it fulfills three essential features: records can be written very fast, rewritten at least 10^4 times, and are stable over extended periods. The basic mechanism in DVD-RAM is that a laser irradiation causes a phase change between the amorphous and crystalline phase in a "bit" in the recording layer. The two phases are used as the memorized and erased states of a recorded memory, respectively.

The amorphous structure of the GeTe-Sb_2Te_3 materials has been recently under debate, and a vast amount of experimental work has been performed on the topic. Experimental methods are very limited with amorphous materials, and the achieved data has been restricted to structure factors (X-ray diffraction) and average nearest-neighbor distances (EXAFS). On the other hand, the ternary GST alloys are difficult to model theoretically, as the required system size (simulation box) is large for electronic structure calculations, and a development of a classical force-field has proved to be extremely challenging. For the very first time, we have been able to provide insight into the amorphous structure of GST by using a method (CPMD code, DFT) that takes the electronic structure of the material explicitly into account while performing molecular dynamics at a finite temperature [J. Akola and R. O. Jones, Phys. Rev. B 76, 235201 (2007), see Fig. 1]. The large-scale density functional (DF) calculations using up to 2048 CPUs have been performed on the IBM Blue Gene/L supercomputer located at the Forschungszentrum Jülich.

Our first simulations of the $Ge_2Sb_2Te_5$ alloy have provided us valuable information about the amorphous

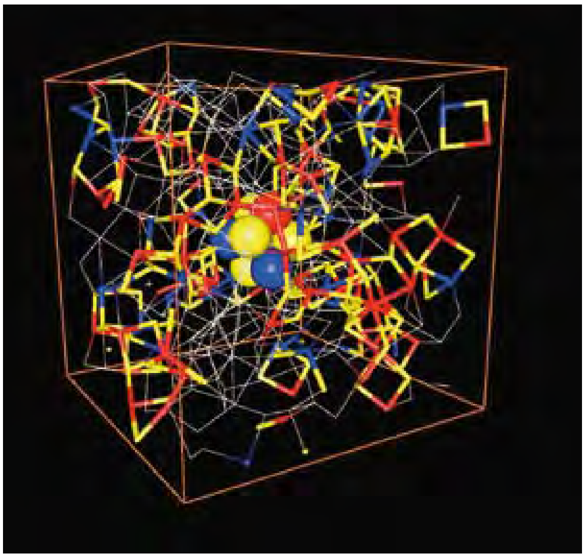


Fig. 6. Amorphous structure of the $Ge_2Sb_2Te_5$ alloy (top) and a medium-sized vacancy (bottom). The final geometry (460 atoms) was obtained after 300 ps of DFT simulations (melt-quenching technique, CPMD code). The material comprises ABAB squares and cubes, and the corresponding atoms are high-lighted (top). Color key: Ge, red (type A); Sb, blue (type A); and Te, yellow (type B).

phase. In addition to the radial correlation functions, angular distributions, torsional angles etc., i.e. properties that cannot be obtained experimentally directly,

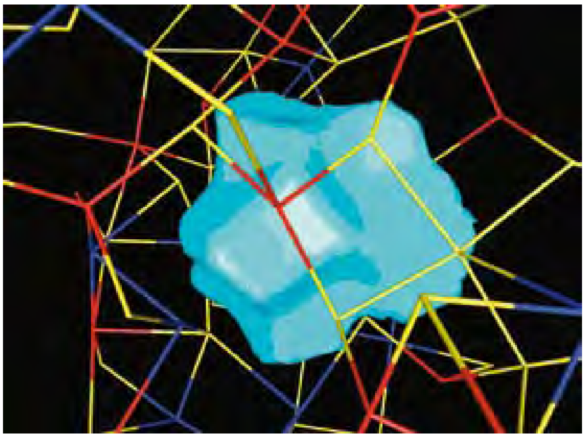


Figure 7. A medium-sized cavity that has been evaluated by a method similar to Wigner-Seitz cell or Voronoy polyhedron in crystalline and amorphous materials, respectively.

we have simulated the electronic band structure and vibrational properties of this material in comparison with the metastable crystalline NaCl structure. Our main finding is that the amorphous material comprises *ABAB* squares where the atomic types Ge/Sb (type *A*) and Te (type B) alternate. Taking into account that the crystalline structure consists of ordered *ABAB* rings, it appears plausible that this structural motif could be involved in the remarkable phase-change properties of the GST materials. Furthermore, the presence of vacancies (or cavities) is known to improve the rapid phase transition, and our analysis reveals a wealth of cavities of different sizes and shapes. The new insight provided by the density functional simulations challenges the popular hypothesis of "tetrahedrally coordinated Ge atoms" that hop between tetrahedral and octahedral sites in a Te-sublattice.

Materials physics

Soft condensed matter and statistical physics

Markku Kataja, Juha Merikoski and Jussi Timonen

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Fragmentation and Elasticity

Our discrete element model for elastic materials was developed so as to allow elastic as well elasto-plastic beam elements. Numerical simulations with this model revealed that plasticity destroys the self-similar nature of crumpling of thin elastic sheets, and that the fractal dimension of a crumpled structure is smaller for elasto-plastic sheets. The distribution of elastic energy under loading in a random network of fibres described by the above model was found to be a power law with a scaling exponent corresponding to marginal normalizability.

Microfracturing data of very high resolution on a sapphire crystal displayed scaling properties very similar to those of seismic data on earthquakes. Precursors could be observed at a relatively high rate but they could only predict a major fracture in a very weak probabilistic sense.

Fig. 1. An elastic sheet crumpled inside a sphere

Stochastic Systems

Zero-range processes of interacting particles were studied analytically. Deviations from typical extremal distributions, phase transitions on graph structures, and anomalous density profiles of tracer particles in random media were found. The finite-size scaling of the largest cluster was analyzed numerically. Current inversion in the presence of a fluctuating external field in the motion of particles with internal structure, and the width dynamics of coupled interfaces, were also studied.

Transport Properties

A method was developed to measure the heat diffusion coefficient of thin samples of solid material based on time development of an induced temperature distribution. Heat losses by controlled convection and radiative heat transfer are controlled by modelling. Accuracy of the method was further developed so as to determine the temperature dependence of the coefficient.

High-resolution tomographic reconstructions of paper, paper-making fabrics, granular materials and tumor vasculature were used to numerically analyze by the lattice-Boltzmann (LB) method their fluid transport properties, and effects there on of structural features. A numerical invasion percolation model was also developed to analyze intrusion and extrusion of nonwetting liquid into tomographic structures. The LB method was validated by comparison with experimental permeability for selected materials. Simulations of flow by the LB method over structured surfaces with bubbles revealed that bubbles can lead to increased friction and even to negative slip due to the increased roughness they induce. This phenomenon can have applications in microfluidic devices.

A two-phase flow model for the filtration process of fibre suspensions was developed and implemented numerically. The model includes realistic dynamics of large deformations, viscoelastic behaviour and the effects of shear flow on the binary mixture of liquid and fibres.

Diffusion of viral proteins in live cells was analyzed by using diffusion equation modelling in combination with photo-bleaching experiments.

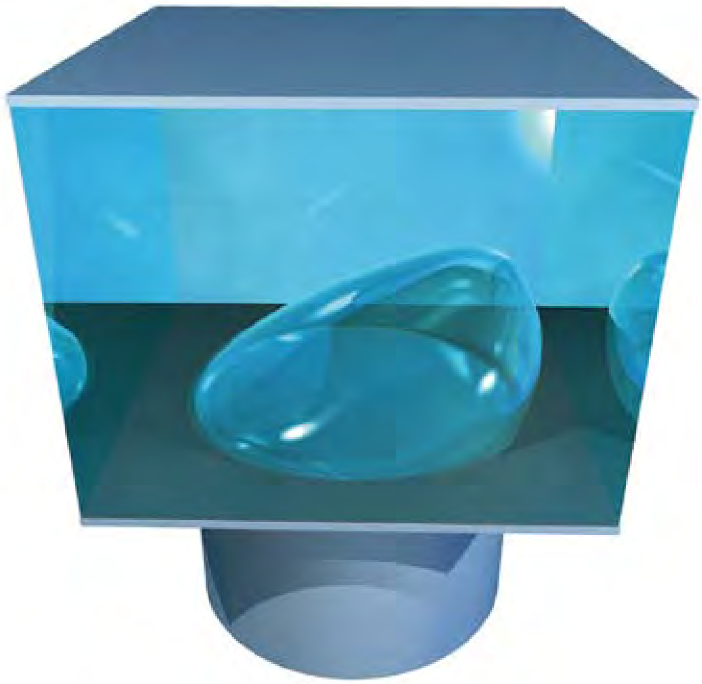

Fig. 2. Couette flow in a microchannel with a trapped bubble deformed by the shear (visual Jyrki Hokkanen, CSC).

Structural Studies Based on High-Resolution x-ray Tomography

X-ray tomographic imaging was used to analyze the three-dimensional structure of paper, coating layers on paper, paper-making fabrics, layers of mineral pigments, crystalline rock, and tumor vasculature. Both an in-house device with a resolution of a µm, and the synchrotron radiation facility at ESRF with a resolution of 0.7 µm and 0.28 µm, were used. To improve image quality, new methods for noise reduction were developed, and for improved structural analysis, new segmentation methods were constructed. In the case of coated paper the influence of coating colour on the structure of the coating layer, and structural reasons for gloss and print colour variations were analyzed. In layers of mineral pigments the effect of pigment shape and compression pressure on the pore-size distribution, the related changes in liquid absorption properties, and in altered crystalline rock the three-dimensional distribution of porosity and mineral components, were analyzed. In the case of tumor vasculature, the connectivity properties and aperture distributions of the vasculature were analyzed in view of the blood flow properties.

Assessment of Bone by Ultrasonic Guided Waves

A numerical bone model was used to simulate propagation of ultrasound by a finite-difference method. Simulated and measured (in vitro) ultrasound velocities were found to be in close agreement. Special attention was paid to determination of cortical bone thickness by guided wave ultrasonic measurements. Simulations mimicking realistic experimental conditions indicated problems in propagation mode assignment owing to effects of overlying soft tissue. Clinical studies in large subject populations were performed to estimate the ability of ultrasound methods to diagnose and monitor the quality of bone. A new measurement set-up was constructed with a customized array transducer.

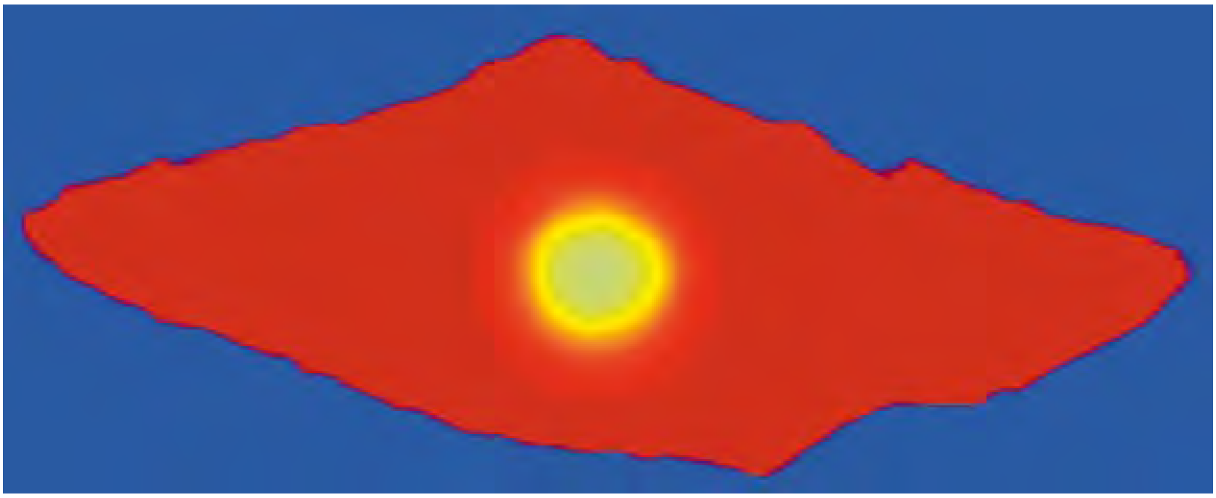

Fig.3. Simulated diffusion of viral proteins into a bleached region.

Ultrarelativistic Heavy Ion Collisions

Kari J. Eskola and Kimmo Tuominen

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Hannu Holopainen, MSc student

The primary goal of ultrarelativistic heavy ion collisions (URHIC) is to study strongly interacting elementary particle matter, Quark Gluon Plasma (QGP), and its transition to a gas of hadrons. In URHIC theory, our goals are to understand the QCD matter properties and QCD dynamics, and to produce solid predictions for various observables measurable soon in the ALICE experiment at CERN-LHC, currently in the BNL-RHIC and previously in CERN-SPS experiments. Our basic computational tools are QCD perturbation theory (pQCD), relativistic hydrodynamics and effective field theories at finite temperature and densities.

Our research is financially supported by the Academy of Finland (SA) and private foundations. Together with prof. Kajantie's group in Helsinki, we form the *URHIC* theory project lead by Eskola at HIP in 2002-7. We are also in a close contact with prof. Rummukainen in Oulu and the ALICE group at JYFL. Our collaborators abroad come from, e.g., CERN, Rome, Frankfurt, Odense, LBNL, Duke U., McGill U. and Nagoya. We participate in international conferences and workshops such as *Quark Matter* and *Hard Probes*, as well as in the activities of the Giessen-Copenhagen-Helsinki-Jyväskylä-Torino collaboration in the *European Graduate School of Complex Systems in Hadrons and Nuclei*. Together with the local ALICE group, we organized the 2nd international workshop on *High-p_T Physics at LHC* at JYFL in 3/07. We participate also in international EU and NordForsk networks and new proposals. Ruuskanen retired in 12/06, Eskola became professor in 4/07, and Tuominen senior assistant in 8/07.

Parton Distributions of Bound and Free Nucleons

Specific QGP signals in URHIC are examined against reference cross sections of inclusive hard processes, such as direct photon and high-p_T hadron production. These can be computed through the QCD factorization theorem, provided that *nuclear* parton distribution functions (nPDFs) are available. Previously, we have pioneered a global analysis, where the QCD-evolving nPDFs are extracted from nuclear hard-process data and conservation laws. Our *EKS98* parameterization is in a worldwide use and a standard reference in the field. We have now, after extensive further work, published a statistical error analysis for the obtained nPDFs. For the very first time in such global analyses, we have also been able to include constraints given by the RHIC high-p_T hadron data from d+Au collisions, and obtain much better controlled gluon distributions than before. These results are to be published soon. Further data constraints from direct photon and heavy quark production at RHIC, as well as the extension to next-to-leading order pQCD, will be considered in the future.

Hydrodynamic Modelling of Nuclear Collisions with Minijet Initial Conditions

Relativistic hydrodynamics provides an appealing method to study the evolution of a locally thermalized expanding system and phenomena like electromagnetic emission during the expansion stage. Strong features in its favour are the implementation of conservation laws and the QCD phase transition through the equation of state. In addition to the hydrodynamic modelling itself, one of our pioneering specialities is the calculation of the QGP initial densities in a (nearly) closed framework of pQCD minijet production and gluon saturation. In fact, we have been among the few groups in the position of making hydrodynamic predictions for future colliders. Based on the successful tests at RHIC, we have predicted the bulk hadron p_T-spectra, multiplicities and net-proton number in central Pb+Pb collisions at the LHC, and the amount of elliptic flow in noncentral collisions. These results were presented e.g. in the CERN workshop *Last Call for LHC Predictions* in 5/07.

The latest improvements here are a dynamical decoupling procedure, based on comparing the rates of QCD-matter expansion and pion scattering, and the study of the correlation of final flow and the yet uncertain initial energy density profile. The next step will be viscous hydrodynamics.

High-p_T Hadrons as Probes of QCD Matter

The modifications of hard processes in the medium produced in URHIC are promising QCD-matter probes, which is why they are a hot topic both theoretically and experimentally. Such modifications are seen both in hard single-hadron p_T spectra and in correlations with a hard trigger-hadron. One of the most striking QGP signals observed so far is the factor 5 suppression of single inclusive high-p_T hadron spectrum in central Au+Au collisions at RHIC relative to p+p collisions. We have studied this phenomenon extensively, by embedding the nPDF-modified high-p_T parton production into hydrodynamically evolving QCD matter, and applying the

The URHIC theory group. From the left; Standing: Tuomas, Matti, Hannu, Topi, Thorsten, Kimmo, Perttu; Sitting: Jussi, Kari, Vesa, Harri, Vesa.

energy-loss formalism developed by our collaborators. Our RHIC-tested prediction for Pb+Pb collisions at the LHC has been presented, e.g., in the CERN workshop mentioned above. Together with our collaborators, using a 3d hydro code, we have extended these studies to the angular dependence of the suppression in non-central collisions at RHIC. In addition to the radiative eikonal processes considered in the above analyses, a Monte Carlo study with finite kinematics and including also elastic energy loss mechanism, is in progress.

We have demonstrated that determination of the QCD-matter properties requires other observables to be analysed simultaneously with the single-hadron suppression. The angular correlations associated with a hard trigger-hadron can, at low p_T, be seen as a Mach-cone-like shockwave driven by the lost energy, whereas at high p_T the fragmentation of partons punching through the medium is predominantly seen. Model calculations for the shockwave at low p_T have been extended to 3-particle correlations, and the results show a peak structure which agrees well with the experimental results at RHIC. At high p_T, we have utilized parton shower simulations to study the suppression of back-to-back dihadron correlations observed at RHIC and, in particular, to make a prediction for Pb+Pb collisions at the LHC.

Electromagnetic Probes

The dimuon spectra measured by NA60 at CERN-SPS in In+In collisions as a function of both invariant mass and transverse momentum, allows an analysis of the QCD-medium flow on the basis of electromagnetic observables alone. As we originally predicted, the effective slope of the dimuon p_T spectra as a function of the invariant mass shows a sudden drop beyond the rho mass, indicating a change of the dominant emission source from late hadronic emission, characterized by sizeable flow, to early partonic emission with negligible flow. By refining our analysis we have now extracted a flow field which appears surprisingly strong as compared to what is known at the same energy in Pb+Pb collisions. Hydrodynamical studies to understand this phenomenon and a similar analysis for RHIC are in progress.

Effective Theories for QCD and Electroweak Symmetry Breaking

We have studied effective theories for QCD at finite temperature and density to obtain description of QCD thermodynamics at temperature regions relevant for URHIC. Our results, to be published soon, demonstrate how phenomenological effective theories can be constrained by lattice data, vacuum properties and analytic results from perturbation theory at asymptotically high temperatures. We are in progress to study explicit chiral symmetry breaking in these theories in order to understand the corresponding features in the lattice data.

Investigations of the dynamics of various strongly interacting theories have far reaching consequences also beyond hadron physics: The electroweak symmetry breaking may be driven by a new kind of strong interaction termed Technicolor. We have proposed a minimal walking Technicolor (MWTC) theory and shown that it is consistent with the precision data from current collider experiments. Simultaneously MWTC theory is also able to provide a candidate for dark matter particle (WIMP) with observed relic density. Various collider signatures of this model have been analysed. Currently we are in progress of studying an extended model which is, in addition to the properties of MWTC, able to provide a SUSY-like unification of electroweak and strong coupling constants with minimal particle content beyond the standard model one.

High energy physics

Theoretical Particle Physics and Cosmology

Kimmo Kainulainen, Markku Lehto and Jukka Maalampi

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Kimmo Kainulainen, lecturer
Markku Lehto, senior assistant
Maxim Dvornikov, postdoctoral researcher
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Minja Hänninen, graduate student
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Daniel Sunhede, graduate student
Jussi Virkajärvi, graduate student
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Perttu Hietanen, MSc student

Neutrino Physics

Jukka Maalampi

The recent activity in theoretical particle physics has concerned mainly with neutrinos, in particular astrophysical neutrino phenomena. We have studied the effects and observational signals of the possible sterile

Fig 1. From left to right: Jussi Virkajärvi, Maxim Dvornikov, Johanna Piilonen, Diego Meschini, Jukka Maalampi, Pyry Rahkila, Daniel Sunhede, Janne Riittinen, Matti herranen, Risto Hautala, Minja Hänninen and Kimmo Kainulainen.

neutrinos in astrophysical environments. Sterile neutrinos have no interactions with matter, except that they can mix quantum mechanically with the ordinary active neutrinos and form as a result a part of the propagating neutrinos that have a definite mass. They are predicted by many theoretical models, and they may have an important role in neutrino mass and mixing mechanism. Most recently we have investigated these issues in connection to supernova explosions, where neutrinos encounter the effects of the matter of the star envelope they traverse. This has also lead us to study a more general question of level crossing, so called multilevel Landau-Zener problem, in the case of non-linearly varying Hamiltonians.

Our group have also studied neutrino oscillation from a more formal point of view by formulating the problem using relativistic quantum mechanism, i.e. the Dirac theory. Using this formalism, we have investigated the magnetic-moment-induced spin-flavour oscillations of Dirac neutrinos and the spin-flavor oscillations in rapidly varying magnetic fields, as well as interactions of mixed fermions with classical sources. We have solved the Dirac equation for a massive neutrino with a magnetic moment propagating in background matter and interacting with the twisting magnetic field.

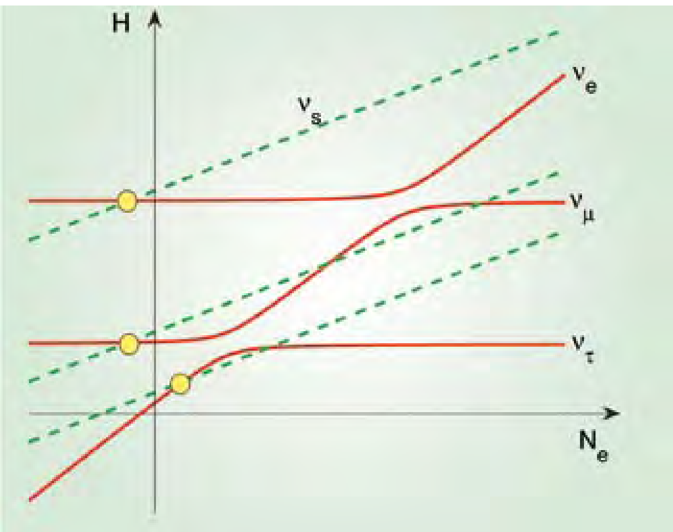

Fig. 2. Neutrino energy eigenstates as a function of electron density for three active neutrinos (solid lines) and three sterile neutrinos(dashed lines). For clarity the states are drawn with no active-sterile mixing. Circles show the crossings that would give rise to enhanced transition in the presence of active-sterile mixing.

Cosmology

Kimmo Kainulainen

Dark Energy and Dark Matter

One of the greatest mysteries of the modern cosmology concerns the apparent accelerated expansion of the universe -- the simplest explanation for which postulates that the universe is filled with a substance called "dark energy" (DE), carrying a negative pressure. An alternative solution for DE is that Einstein's theory needs to be modified at large distances. Our group has studied large dimensions motivated scalar-tensor theories as well as phenomenologically motivated f(R)-gravity extensions of the classical Einstein-Hilbert-theory. Our current activities concentrate on studying the constraints on these extensions arising from precision measurements in the Solar system and on strong gravitational fields. We are also studying the formulation of the extended gravity theories in the context of the Palatini-variational principle.

Almost equally mysterious is the observation that most of the pressureless matter in the universe cannot be in form of normal baryons. We have recently proposed that this dark matter (DM) component consists of a relic density of new weakly interacting neutrinos predicted by new type of "walking" technicolour theory, originally proposed to solve the hierarchy problem of the particle physics. Viability of the model requires either that the expansion rate of the universe was faster than normal during the freeze out, or that the DM-particle interacts more weakly than a corresponding standard model neutrino. Former can be the caused by evolution of new scalar fields and the latter can be realized, for example, by allowing the DM-particle to mix with another sterile neutrino. We are also studying a new class of technicolour-motivated models, where the DM particle is a new neutral adjoint fermion. This model has the potential to simultaneously solve the hierarchy problem, the gauge-coupling unification and the DM-problem without supersymmetery.

Quantum Transport Problem and Electroweak Baryogenesis

Another intriguing problem in modern cosmology concerns the origin of the baryon asymmetry, excess of matter over the antimatter, in the Universe (BAU). Our group has studied the creation of BAU in the electroweak phase transition (EWPT). A proper treatment of electroweak baryogenesis calls for the use and development of the quantum transport equations (QTE) in non-equilibrium plasmas and in spatially changing backgrounds. The QTE's for EWBG were first derived by us in the WKB approximation. We are studying the derivation of QTE's in the context of the Schwinger-Keldysh closed time path (CPT) formalism, where the WKB-limit is recovered in the limit of slowly varying backgrounds and weak interactions. We have recently extended the quantum transport formalism to include non-local quantum coherence effects (reflection) and we are developing a numerical code to solve for the momentum dependent diffusion of the CP-even and –odd currents in realistic situations both in the WKB- and in the thin wall limits. Among our main goals in this work is to compute the BAU in the context of the minimal supersymmetric standard model including also the CP-violating currents from the neutralino sector.

Time, Space, Gravitation, and Quantum physics

Markku Lehto

Physics of Time

The *physical core* of relativity was identified to lie in clock measurements made by an observer. Making a geometric picture in which phenomena (events) are points of a four-dimensional continuum, the observer with his clock a material point, and his history a worldline, clock measurements gave the invariant measurable extension Δs of the travelled worldline as an absolute spacetime property.

The natural raw material encoded by Δs found *mathematical expression* via the Riemannian hypothesis: $ds = \sqrt{-g_{\alpha\beta}(x)dx^{\alpha}dx^{\beta}}$. Field $g_{\alpha\beta}(x)$, known as the spacetime metric, was found to bear no direct invariant connection with gravitation; it is the Riemann tensor that carries this role. The metric field is not then the gravitational field but the chronometric field.

The signature (+,+,+,–) of physical spacetime, or its local geometry, was found to be indeterminable from physical clock measurements alone or further mathematical analysis thereof. It could only be ascertained with the help of the *human experience* of past, present, and future.

Relativity was thus built upon the three cornerstones of all physical theorizing: (i) the natural raw material of simple physical experiments and measurements; (ii) their mathematical expression with human tools of thought; and (iii) essential categories of human experience through which the world is intuitively grasped.

The classical clock correlations d*s* were deemed to play a central role in the conflation of general relativity with quantum physics and the previously unearthed meta-geometric time elements related to it.

Physics of Black Holes

There are good reasons to believe that the quantum-mechanical degrees of freedom of the black hole are due to the microscopic structure of spacetime at the event horizon. Therefore, one is led to probe the microscopic properties of the event horizon. It is possible, for example, to construct the horizon from microscopically small black holes such that the correct (statistical) entropy is produced. This is an encouraging result since it has been proposed that microscopic black holes might have something to do with the structure of spacetime at the Planck-length scale. The concept of entropy may be associated with other horizons of spacetime as well and, at least to some extent, even with any spacelike two-surface of spacetime. One believes that these entropies also stem from the microscopic structure of spacetime. An understanding of the nature of black-hole radiation may therefore give valuable insights into the microscopic theory of spacetime itself.

Industrial Collaboration

Markus Ahlskog, Jussi Timonen, Päivi Törmä and Ari Virtanen

The Department has numerous contacts with domestic and foreign industry and research laboratories.

Thirteen campaigns were performed in RADEF facility of the accelerator laboratory operated by the *Industrial applications group*. One was a research experiment and the others irradiation tests, which were performed by European companies. Six of these, covering more than 40 % of RADEF beam time, were done for European Space Agency. IRoC Technologies Ltd. from Grenoble, France, Kayser-Threde GmbH from Munich, Germany, OxypheN GmbH from Dresden, Germany, and ST Microelectronics Ltd. from Crolles, France, were performing irradiations for a first time here. The activity with OxypheN GmbH aimed at irradiating of polymer films as the first step for creating micro porous membranes. The total RADEF beam time in 2007 was 736 hours.

Another important branch of the industrial collaboration with the accelerator is related to the medical applications. The Iodine-123 production for MAP Medical Technologies continued. More than 30 production runs were performed. The total beam time for this was over 350 hours. Another medical project was continuing in collaboration with Gammapro Ltd. and Jyväskylä Radiotherapy Hospital. In this project a detector, which monitor the intense gamma field used in cancer therapy, is under development.

Co-operation with Doseco Ltd. continued in terms of one MSc project. This was done with the national Radiation and Nuclear Safety Authority including a neutron detection study for Nuclear Power Plant of Loviisa. A new project together with Metsäteho Ltd, Metso Paper Corp. of Pori, and local VTT received funding from TEKES. The idea in this project is to study properties of wood, and especially its humidity, by using neutrons. After this pre-study the aim is to apply intense neutron fluxes for these purposes by using modern and compact neutron generators originally developed for the detection of explosives and drugs. In this work the experience gained by the group members when working for years in the Plasma and Ion Source Technology group of Lawrence Berkeley National Laboratory, USA, will be exploited.

Accelerator based materials physics started a TEKES project "Development of new tailored biomimetic surfaces for implants and cell growth substrates (BOGOTAS)" together with Department of Health Sciences and industrial partners Beneq Oy and Beijing Pukang Sports & Medical. The ion beam analysis techniques available in the Pelletron facility have created active collaboration with several domestic and international companies and research institutes.

The Nanophysics and Nanoelectronics groups have well established collaboration with a few companies in Finland. For example: the nanoelectronics group in collaboration with the companies Enermet, Metso Drives, Nanoway and JSP (Jyväskylä Science Park), was earlier funded by Tekes within the Miniaturization of Electronics research. The project focused on micro- and nanosensors and a patenting process has been started as a result of this former project. Equally, for about three years ultrasensitive radiation detectors based on calorimetry and bolometric sensing for x-rays and IR-radiation have been developed by nanophysics group in collaboration with Oxford Instruments Analytical company from Espoo (formerly Metorex International). At the first stage the work has been motivated by the need of on-chip integrable ultrasensitive sensors in space research.

During the year 2007 the industry collaboration in both the Nanophysics and Nanoelectronics groups was continued under new projects and including companies interested in nanotechnology such as Nokia, Planar and Vaisala, with funding from the FinNano Nanotechnology Programme of Tekes. The development of ultrasensitive radiation detector is continuing as collaborative projects with the Space Research Center Netherlands (SRON), funded by the European Space Agency. In addition, short term collaboration with other companies, e.g. ABB Oy, exists also in the form of co-supervised master thesis.

The Nanoscience Center research infrastructure programme 2004–2006, mainly funded by EU via the regional government and partly by companies (about ten participating), is still an important platform for industry collaboration. It allowed development of research facilities and investments to equipment essential for nanoelectronics and nanotechnology.

The soft condensed matter and statistical physics group continued its established collaboration with a number of companies in several branches of industry.

X-ray microtomography was used in several applied and industrial research projects for studying e.g. the structure of paper and pigment coating layers, paper-making fabrics, minerals, mineral wool and biological samples. In this work an in-house table-top x-ray scanner was used together with the synchrotron radiation based tomography facility at ESRF. Work at ESRF involved large international collaboration with more than ten research groups in Europe and the USA. Related to these tomographic techniques, noise-reduction and segmentation algorithms were developed. Flow simulations based on the lattice-Boltzmann method were also carried out with tomographic images of industrially relevant materials in order to gain better understanding of the transport properties of these materials.

The research group continued participation in six large national research consortia funded by Tekes, industry and the Ministry of Trade and Commerce. These projects focused on developing new experimental and numerical techniques for flow in porous media, on basic and applied research on the rheological properties and dynamics of fibre suspensions, on tomographic imaging of paper-like materials and pigment layers, transport issues related to nuclear waste management and on ultrasound methods in assessment and monitoring of the quality of bone.

Several other projects involving direct collaboration with industry were carried out. These projects included experimental structure research, numerical simulation and modeling, and involved problems like transport of fluid in paper, matrix diffusion, rheological properties of pigment suspensions, and structural properties of paper, MEMS devices, paper-making fabrics and mineral wool. A device for testing properties of intraocular lenses was also designed and constructed.

Industrial collaborators included Metso Paper, Stora Enso, UPM, M-real, ABB, Sulzer Pumps Finland, Kemira, Omya Finland, Specialty Minerals Nordic, Hansaprint, Ciba Specialty Chemicals, Tamfelt, KCL, Top Analytica, Next Wave, Numerola, Paroc, Posiva, and SIFI SpA.

Education

Jukka Maalampi and Juha Merikoski

The Department of Physics offers an internationally competitive study program at all academic levels. Teaching at all stages of studies is closely connected with present-day research and the students are taken to participate in all activities of the Department, including research, teaching and student recruitment. In 2007 the number of MSc degrees taken at the Department was 49, which is an all-time high. Of them 11 included teacher qualifications. The Department produced 9 PhD degrees.

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Jussi Helaakoski, graduate student
Olavi Hakkarainen, graduate student
Asko Mäkynen, graduate student
Mika Nieminen, graduate student
Henri Hurtamo, MSc student
Katja Iivonen, MSc student
Juuso Jehkinen, MSc student
Jukka Korkea-aho, MSc student
Jonne Lakanen, MSc student
Mikko Räsänen, MSc student
Simo Räty, MSc student
Terhi Sario, MSc student

Students

In 2007 there were 496 applicants for physics studies, with 232 of them indicating physics as their first choice. As a whole, 104 undergraduate students enrolled in 2007, 9 of them directly to MSc programs. The majority, 98 % of new BSc students, were admitted based on their high school record and national maturity test result, the rest via a traditional entrance examination. The new national maturity test in physics appears to help in selecting students better motivated and qualified to physics studies.

In 2007 there were about 525 undergraduate students at the Department. Some 30 students, many of them with a polytechnic engineering background, studied in the master programs for industrial physics, nanoelectronics and renewable energy. The number of postgraduate students aiming at the degree of Doctor of Philosophy was 87.

Our Department participates in five national graduate schools and coordinates two of them, the Graduate Schools in Particle and Nuclear Physics and in Nanoscience.

Teacher Education

In 2007 eleven incoming students chose direct enrollment to teacher education, which has become a popular route to teacher qualifications. The students now commonly write their BSc theses on questions related to physics teaching and often continue that project in their MSc thesis. The trilateral co-operation between the Departments of the Faculty, the Department of teacher education and the Teacher training school Norssi is close, including thesis supervision and further education of personnel involved in teacher education.

The Department participates in the *Finnish graduate school of mathematics, physics, and chemistry education*, with five students working on a degree of doctor or licentiate of philosophy in physics education. Olavi Hakkarainen defended his PhD thesis *Pupils' mental models of a pulley in balance, and how the models are changed by successive pulley demonstrations* in 2007

Teaching Development

The first-year crash course *Flying start* was given for the seventh time and has been recognized as a trademark of the Department and found to reduce quitting of studies. The research-oriented approach was complemented with more effort to provide a good start for regular studies, in which well-performed and enthusiastic physics students used as tutors play the key role. To take into account the needs of the research groups of the Department and the more practical aims of the Bologna process, including employment, the curriculum and the teaching practices are continuously being developed. In particular, a project was initiated to develop a continuation of the *Flying start* for third-year students.

Other Education Activities

In addition to its regular teaching program, the Department has continued the co-operation with the Open University supplementary-education program for teacher qualification. The Department was active in the 16th Jyväskylä International Summer School. The Department has continued co-operation with schools in the Central Finland district. Physics students frequently visit high schools to increase interest in studies in natural sciences. The Department collaborates with schools within the CERN network by organizing training lectures prior to the CERN visits of student groups. The Accelerator laboratory and the Nanoscience center remain popular excursion destinations for school students.

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Note: ä=a, ö=o, å=a

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Invariance of the Kohn center-of-mass mode in a conserving theory
Phys. Rev. B76 (2007) 045341

N.E. Dahlen and R. van Leeuwen
Solving the Kadanoff-Baym equations for inhomogeneous systems: Applications to atoms and molecules
Phys. Rev.Lett. 98 (2007) 153004

Theses

MSC THESES
(Alphabetical order)

Jarno Alaraudanjoki, Optisen tomografian sovellusmahdollisuuksien kokeellinen tutkiminen

Jussi Auvinen, Elastiset törmäykset suurienergiaisten partonien poikittaisliikemäärän vaimenemismekanismina kvarkkigluoniplasmassa

Ville Haaksluoto, Development of a high frequency measurement system for low-temperature experiments with quantum circuits

Risto Hautala, Poincarén ryhmän unitaariset esitykset, supersymmetria ja supergravitaatio

Matti Heikinheimo, Sähköheikko symmetriarikko tekniväriteorioissa

Henri Hurtamo, Tietokoneavusteinen laboratoriotyö: Kinematiikan kuvaajat

Katja Iivonen, Vertailua Suomen ja Ruotsin modernin fysiikan lukio-oppikirjojen välillä

Tero Isotalo, Fabrication of free-standing piezoelectric nanostructures for thermal transport studies

Henri Jaakkola, Ohuiden AIM-kalvojen ominaisuuksista

Ulrika Jakobsson, Neutronirikkaiden keveiden ydinten tutkiminen käyttäen RITU separaattoria

Juuso Jehkinen, Kitkakäsityksen modernisoiminen lukio-opetuksessa

Tuomo Kalliokoski, Production of D mesons according to the parton model and their dedection in ALICE

Tuomas Karavirta, Tiheä kvarkkiaine ja Nambu-Jona-lasinio (NJL)-malli

Pasi Karinkanta, Puukuitususpension putkivirtauksen virtausprofiilin symmetrisyys ja sen turbulenttisen alueen mallintaminen

Rudolf Klemetti, Pimeä aine dynaamisen pimeän energian kosmologiassa

Petri Kiuru, Dileptonituotto ultrarelativistisissa raskaionitörmäyksissä

Jukka Korkea-aho, Tieteellisen päättelykyvyn yhteys fysiikan oppimistuloksiin ja esitysmuotojen hallinnan koherenssiin

Mikko Koskinen, Hiilinanoputkilla modifioidun epoksihartsin fysikaaliset ominaisuudet

Jarmo Kuivalainen, Nesteen imeytyminen huokoisessa materiaalissa: simulointeja hila-Bolzmann – menetelmällä

Jonne Lakanen, Mikrotason kuvailu lukion lämpöopin opetuksessa

Petteri Lappalainen, Ionivirran mittauksen kehittäminen

Tzu Chao Lin, Application of artificial neural network and genetic algorithm for wind power forecasting

Veikko Linko, Dielectrophoresis of thiol-modified DNA origami

Jarmo Lähdevaara, Atomiklustereiden tasapainomuodon Monte Carlo –simulointi

Atte Marttinen, Rainanmuodostuksen suotautumismekanismit

Eeva Metsälä, Kofeiinitablettien huokoisuuden tutkiminen röntgentomografialla

Davie Mtsuko, Electron transport in polypyrrole on ultrathin gold films

Perttu Mäkinen, Relativistisen skalaarikenttäteorian paine

Katri Mäntyniemi, Cs-137 aktiivisuuspitoisuuden määrittäminen elävistä poroista

Laura Mättö, Nanorakenteiden valmistus yksittäisten suurenergisten raskaiden ionien avulla

Jari Parantainen, Lämpökameran käyttö hiukkaskiihdyttimen kunnonvalvonnassa

Joni Pasanen, Microscopic imaging of magnetic fields with atomic condensates

Pauli Peura, Digitaalisen TNT2 signaalinkäsittelylaitteiston käyttö gammaspektroskopiassa

Mikael Reponen, Off-line ionilähde WITCH kokeen optimoimiseksi

Perttu Ronkanen, Studies of resonant laser ionization of yttrium atoms in helium

Panu Ruotsalainen, Rekyylien beetamerkkaus tuikeilmaisimella

Mikko Räsänen, Lämpöopin peruskäsitteitä arkiympäristön ilmiöiden selittämiseen soveltuvan oppikirjatekstin rekonstruktio

Simo Räty, Paino ja painottomuus

Terhi Sario, Lukiolaisten käsityksiä magnetismista sekä opettajien käsityksestä magnetismin ongelmakohdista lukiolaisille

Mikko Sillanpää, Particle identification method combining time-of.flight and pulse rise-time descrimination techniques

Aghanwi Nkwenti Tse, Preparation of polymer-nanocomposites and characterisation of their studies

Jani Turunen, ^{133m}Xe konversioelektronimittaus ja kansainvälinen kattava ydinkoekielto

Antti Tynkkynen, Lo1 primääripiirin pääkiertopumppukuopan neutronisäteily

Jussi Viinikainen, Paperinvalmistuprosessin vaikutus kaksitelapinnoitteen ajettavuuteen

Dayu Yang, Performance analysis of a grid connected hybrid photovoltaic and wind electricity generation system in cold climate

Tommi Ylimäki, Värin laikuttumisen tutkiminen tietokonetomografialla

Sami Ylinen, Toward two-qubit coupling via a superconducting resonator: fabrication and first measurements

Marina Zavodchikova, Memory effects in carbon nanotube-based transistors and ways towards their controlled fabrication

PHD THESES

(Chronological order)

Pasi Jalkanen, Properties of SiGe alloys studied by ion beams and implantation induced superconductivity suppression of Al films
JYFL Research Report 1/2007

Thomas Kühn, Phononic transport in dielectric membranes
JYFL Research Report 2/2007

Ulrike Hager, Precision mass measurements of neutron-rich nuclides around A = 100
JYFL Research Report 3/2007

Otto Pulkkinen, Zero-range processes and their applications
JYFL Research Report 4/2007

Ari Peltola, Studies on the Hawking radiation and gravitational entropy
JYFL Research Report 5/2007

Min-Qin Ren, Nuclear microscopy: development and applications in atherosclerosis, Parkinson's disease and materials physics
JYFL Research Report 6/2007

Olavi Hakkarainen, Pupils' mental models of a pulley in balance, and how the models are changed by successive pulley demonstrations
JYFL Research Report 7/2007

Ari Jäsberg, Flow behaviour of fibre suspensions in straight tubes: new experimental techniques and multiphase modeling
JYFL Research Report 8/2007

Sergey Yamaletdinov, Studies of exotic decay modes in fission of heavy elements
JYFL Research Report 9/2007

DEGREES

(Alphabetical order)

BSC DEGREES

(main subject)

Holopainen, Hannu (physics)
Laitinen, Kimmo (physics)
Leijala, Ulpu (physics)
Luukko, Perttu (physics)
Manninen, Marko (physics)
Saloviin, Minna (physics)
Vanhanen, Antti (physics)
Ylimäki, Tommi (physics)

MSC DEGREES

(main subject)
* = MSc includes teachers pedagogical studies

Alaraudanjoki, Jarno (appl. physics)
Auvinen, Jussi (theor. physics
Haaksluoto, Ville (electronics)
Hautala, Risto (theor. physics)
Heikinheimo, Matti (theor. physics)
Hurtamo, Henri (physics)*
Iivonen, Katja (physics)*
Isotalo, Tero (physics)
Jaakkola, Henri (physics)*
Jakobsson, Ulrika (physics)
Jehkinen, Juuso (physics)*
Kallinen, Timo (electronics)
Kalliokoski, Tuomo (theor. physics)
Karavirta, Tuomas (theor. physics)
Karinkanta, Pasi (appl. physics)
Kiuru, Petri (theor. physics)
Klemetti, Rudolf (theor. physics)

Korkea-aho, Jukka (physics)*
Koskinen, Mikko (electronics)
Kuivalainen, Jarmo (appl. physics)
Lakanen, Jonne (physics)*
Lappalainen, Veikko (electronics)
Lin, Tzu Chao (appl. physics)
Linko, Veikko (physics)
Lähdevaara, Jarmo (appl. physics)
Marttinen, Atte (appl. physics)
Metsälä, Eeva (physics)
Mtsuko, Davie (electronics)
Mäkinen, Perttu (physics)
Mäntyniemi, Katri (physics)
Mättö, Laura (appl. physics)
Nkwenti, Tse Aghanwi (physics)
Parantainen, Jari (physics)
Pasanen, Joni (theor. physics)
Peura, Pauli (physics)
Pirojenko, Alexandra (appl. physics)
Reponen, Mikael (physics)
Ronkanen, Perttu (physics)*
Ruotsalainen, Panu (physics)
Räsänen, Mikko (physics)*
Räty, Simo (physics)*
Sillanpää, Mikko (physics)*
Turunen, Jani (physics)
Tynkkynen, Antti (physics)
Viinikainen, Jussi (appl. physics)
Yang, Dayu (appl. physics)
Ylimäki, Tommi (appl. physics)
Ylinen, Sami (electronics)
Zavodchikova, Marina (physics)

PHD DEGREES

Hager, Ulrike (physics)
Hakkarainen, Olavi (physics, teacher education)
Jalkanen, Pasi (physics)
Jäsberg, Ari (appl. physics)
Kühn, Thomas (physics)
Peltola, Ari (theor. physics)
Pulkkinen, Otto (theor. physics)
Ren, Minqin (appl. physics)
Yamaletdinov, Sergey (physics)