HIGHLIGHTS FROM

THE 2010 SCIENTIFIC RESULTS OF

THE RESEARCH INSTITUTE

FOR PARTICLE AND NUCLEAR PHYSICS

OF THE HUNGARIAN ACADEMY OF SCIENCES

2010

MISSION of the MTA KFKI RMKI:

Experimental and theoretical basic research in nuclear and particle physics, heavy ion physics, fusion plasma physics, atom optics, cosmic physics, nuclear solid state physics, nuclear materials science and application of physics in bioscience.

Development activities in the fields of fusion technology, laser physics, nuclear analysis, space technology, fast data processing and evaluation, spectroscopy, dedicated electronics and software.

Operating of the accelerator system composed of the 5 MV Van de Graaff and the 500 keV Heavy Ion Cascade accelerators, and the Molecular Beam Epitaxy (MBE) device.

Operating and developing sophisticated GRID systems and the computer network for KFKI Campus .

MAIN STATISTICAL DATA of the MTA KFKI RMKI:

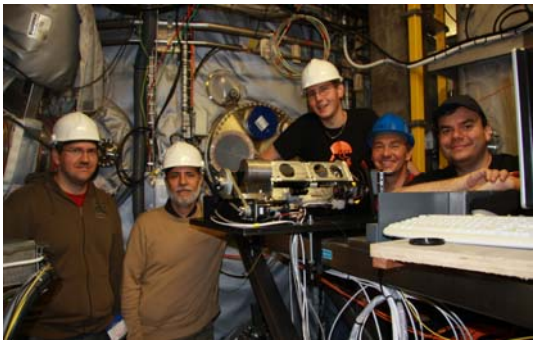
Staff:	**214 - including 125 research fellows**	
Annual budget:	**1 560 million HUF (5.7 million EUR)**	
	core funding from HAS:	**1 053 MHUF**
	EURATOM:	**151 MHUF**
	National Research Fund (OTKA):	**98 MHUF**
	ESA PECS:	**86 MHUF**
	National Office of Research Tech. (NKTH):	**86 MHUF**
	contracts (tenders):	**86 MHUF**
Number of publications in SCI journals:	**401**	
Staff members teaching in universities:	**23**	

CONTENTS:

PLASMA PHYSICS AND THE PHYSICS OF COLD ATOMS

FUSION PLASMA PHYSICS AND TECHNOLOGY

In 2010 RMKI researchers have built a two-dimensional beam emission spectroscopy (BES) diagnostic equipment at the MAST spherical tokamak (Culham, UK). This is the first BES device in Europe with microsecond time resolution which aims at measuring plasma turbulence by observing fluctuations in the visible light emitted by a heating atomic beam. Besides turbulence the diagnostic can also measure plasma flows which are considered to be a key element in the self-regulation of turbulence. This equipment is the result of a close British-Hungarian collaboration. The most important parts of the diagnostics is an in-vacuum observation system and a camera unit optimized for a low-noise light level with small spatial but high time resolution, developed by one of the spin-off companies of RMKI.



The detector and the optics of the Hungarian Beam Emission Spectroscopy diagnostics at MAST, and the international team after the installation.

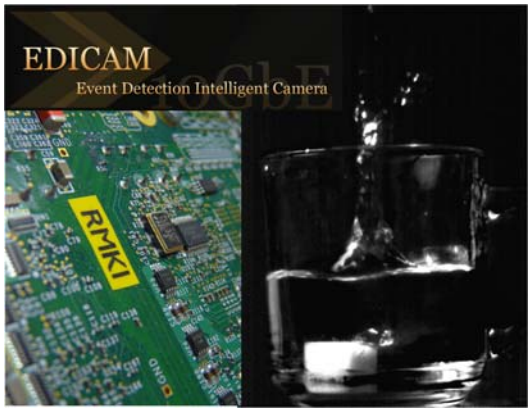
At the TEXTOR tokamak (Jülich, Germany) a lithium BES device was built in the previous years and in collaboration with a German and a Belgian group a detailed study of plasma turbulence and zonal flows was performed in 2010. By the processing of data from three different measurement methods it was found that the periodic zonal flows (Geodesic Acoustic Mode, GAM) are asymmetric in both angle directions of the tokamak, i.e. along the poloidal and toroidal directions, and along the minor radius they show a characteristic phase variation. At the edge of the plasma outgoing flow modulations can be seen. The dependence of the tilt of the turbulent eddies as a function of the magnetic field strength and direction was also studied in detail.

The video diagnostic unit has been installed successfully at ASDEX. The 16 Gbit link has also been developed at KFKI RMKI

The ten-channel video diagnostic unit of the Greifswald Wendelstein W7X stellarator is also being developed by the KFKI RMKI researchers. The thermal and mechanical tests of the prototype system were successfully completed. A special imaging optics and the prototype of the EDICAM (Event Detection Intelligent Camera) using a 10 Gbit link were also built. This camera (in addition to the COMPASS tokamak, where it was used for plasma monitoring) was successfully installed also at the ASDEX Upgrade tokamak and with the help of the fast framing capability (10-30 kframe/s), the paths and ablation characteristics of cryogenic pellets are traced routinely.

The EDICAM – beside “conventional” fast framing camera functions - is designed to be able to perform also intelligent operations. This means that real time processing of the frame stream will be possible by means of the FPGA based camera electronics and results can be used for labeling the images (real time recognition of predefined events), for triggering or warning other diagnostics, for providing information for the safety and control system of the stellarator and also for changing the camera operation itself (e.g. fast recording of a predefined region of interest). The hardware of the present camera prototype incorporates already all necessary components and presently the software elements are under development. After detailed discussion, the camera control software/firmware was structured into several components and each component was designed together with the functional interfaces. Presently the coding of these

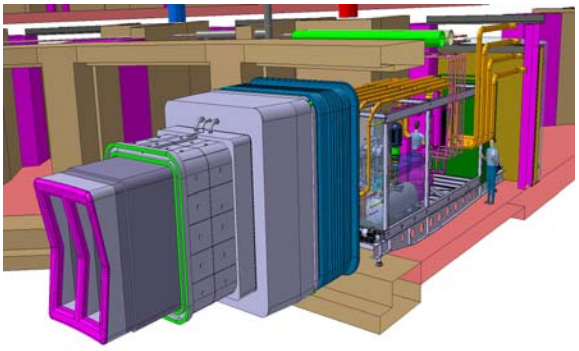
components is ongoing and the first functioning system is expected to be ready by the end of 2011.



Sugar dropped into water and imaged with the fast EDICAM camera.

The lithium beam diagnostic system – which was developed with several years work by the physicists and engineers of RMKI - for the COMPASS tokamak in Prague, was delivered at the end of the year according to the plans.

In several projects to be continued also in 2011 the tasks planned for 2010 have been fulfilled. A milestone was the development of the prototype of the camera system for the W7X stellarator, the diode covering mechanics of the AXUV camera system of the TCV tokamak in Zürich, the modification of the periscope head for the JET tokamak (Culham, UK) as well as the development of the opening-closing mechanics of the camera system for the ASDEX device in Garching. The most important of the various tasks under development for the experimental fusion reactor ITER in France is the conceptual design of the service unit of the „tritium breeding module" (TBM), which is being built in the frame of a tender by the Fusion for Energy agency (Barcelona).



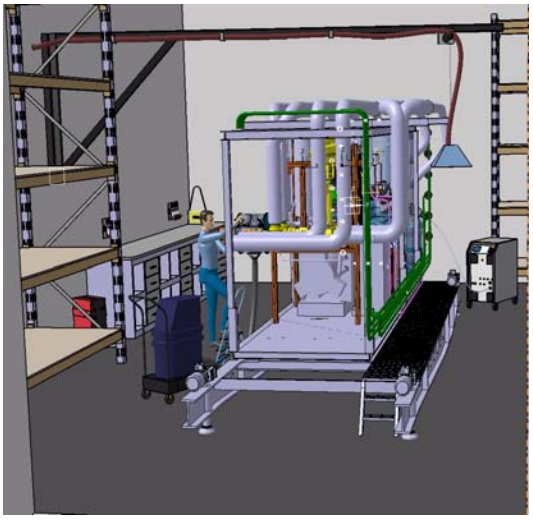
TBM and ancillary system in ITER Tokamak building

The main goal of TBM experiment is to allow testing DEMO relevant tritium breeding and heat recovering capabilities in ITER reactor. Up to six concepts for various tritium breeding blanket systems will be tested simultaneously in 3 allocated Equatorial Ports (EP) of ITER (ports No. 2, 18 and 16).

In Equatorial Port #16 that is devoted to EU, two breeding blanket concepts are selected for the experiment. One is Helium Cooled Pebble Bed (HCPB) originally developed by Karlsruhe Institute of Technology (KIT) in Germany and one is Helium Cooled Lithium Lead (HCLL) originally developed by the French Atomic Energy Agency (CEA, Commissariat à l'énergie atomique). HCPB TBM is a ceramic breeder concept that contains lithium ceramic breeder and beryllium in the box as breeder material and tritium extraction from the system is solved by low-pressure helium stream. HCLL TBM uses slow-circulated liquid lithium-lead eutectic as breeder material and tritium extraction is solved by ancillary system. TBM ancillary equipments are integrated in a common support structure, called Ancillary Equipment Unit (AEU). Configuration of AEU, as one assembly structure, facilitates installation/removal operation and allows the limitation of interfaces for TBM supply lines inside PC.

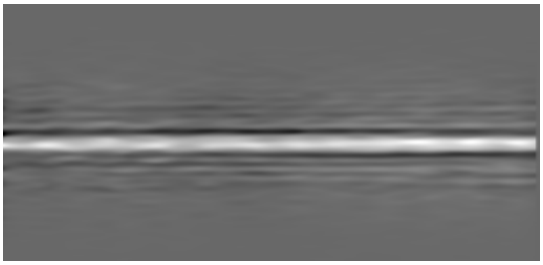
PFFO engineers have played a vital role in AEU development and integration study, carried out within the framework of two years grant under contract between consortium of six associates and Fusion for Energy (F4E, the European Domestic Agency of ITER). The work performed contains design and analysis of modular frame structure encompassing all necessary sub-components of TBM ancillary system. Design process enclosed of thorough structural and thermo-mechanical analysis of support- and high pressure piping systems. Sub-component integration studies have been completed together with clear definition of maintenance/removal/installation sequences of the PC sub-systems giving particular focus on their contamination and radiation level in comparison with ITER regulations of human working conditions for nuclear environment.

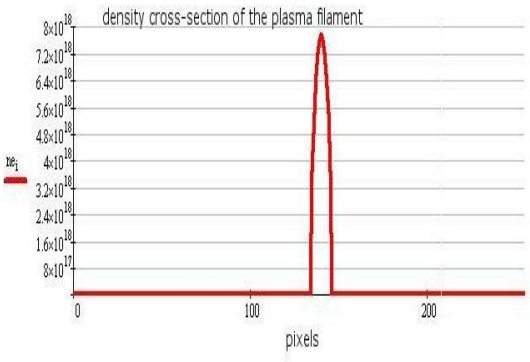
The researchers of the RMKI in collaboration with a Polish group at the High Intensity Laser Laboratory of Szeged University performed measurements in argon gas at the wavelength 83 nm for the resonant third KrF harmonic using a diamond detector insensitive to the fundamental frequency.



The TBM module and its maintenance in ITER

In addition to the 3ω also signals from 5ω and 7ω were detected. According to preliminary data the conversion factor was found to be 10^{-3}, i.e. smaller by one order of magnitude than described previously in an experiment of the LLG, Göttingen but in agreement with the previous RMKI results. In collaboration with the Technical University of Prague a complex interferometric diagnostics was developed which makes possible the measurement of plasma density from 10 ps to 6 ns delay from the main laser beam of 600 fs duration. In the first experiments laser sparks were studied in air. The expansion of the long filament and the forming of a cavernous structure in it was observed.

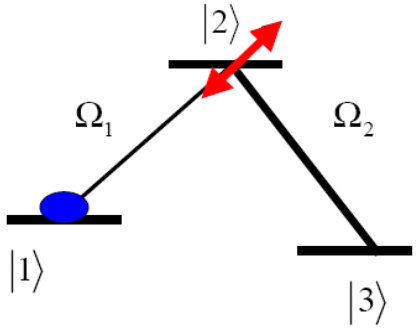




Phase-shift caused by the plasma filament and density cross-section

PHYSICS OF COLD ATOMS

The interaction of multilevel atoms cooled and trapped in a magneto-optical trap (MOT) with short laser pulses was also studied. With the methods developed previously the meta-stable states and the coherences between them can be manipulated without significant excitation of the atoms. On the basis of a model with tripod level scheme the possibility of generating deterministic coherence between the three ground states at arbitrary time was considered. Decoherence caused by spontaneous emission from excited states was minimized due to suppression of the atomic excitation. In the same time, decoherence arising from transverse relaxation has been eliminated by the use of ultra-short frequency modulated laser pulses.



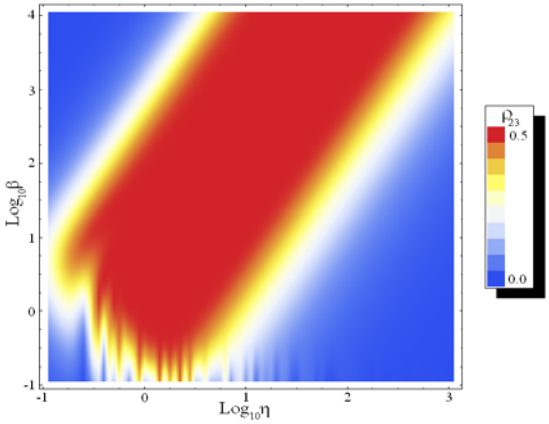
Schematic of Λ-like atom with two acting laser fields: one with chirped frequency and the other one with constant carrier frequency

New method was elaborated for producing Zeeman coherence in 83Rb atoms between the magnetic sublevels of the hyperfine magnetic levels of the D2 line. In collaboration with Polish scientists from the Jagiellonian University, Krakow an experimental procedure was proposed for the measurement of artificially produced coherence based on the nonlinear Faraday-effect describing the rotation of the plane of polarization of the light propagating in the medium. A powerful method was proposed for quantum systems with sizeable inhomogeneous widening of transitions (e.g. solid state media) for the mapping of optical information into the populations to the position of atomic levels and coherence between quantum states.

Initial preparation of atoms in coherent superposition of a ground state and the excited state may significantly (by many orders of magnitude) enhance efficiency of multi-photon ionization and generation of high-order optical

harmonics in gases. If there is a collection of atoms, to obtain a coherent enhancement of a multi-photon process, all of the atoms have to be prepared in a same coherent superposition, preferably with maximum absolute value of the coherence, and with a same (arbitrary) initial phase of the coherence. A new extremely robust scheme was developed for creation of maximum coherence of 0.5 between a ground state and the excited state in a model ?-structured atom using two short laser pulses. One of the pulses has constant carrier frequency quasi-resonant with transition between an initially empty ground and the excite state. The frequency of the second pulse is chirped through the resonance with the adjacent transition between the initially populated ground state and the common excited state of the atom.

An extremely high robustness of the scheme is demonstrated against variation of parameters of the laser radiation in relatively broad region of values (see color map below).

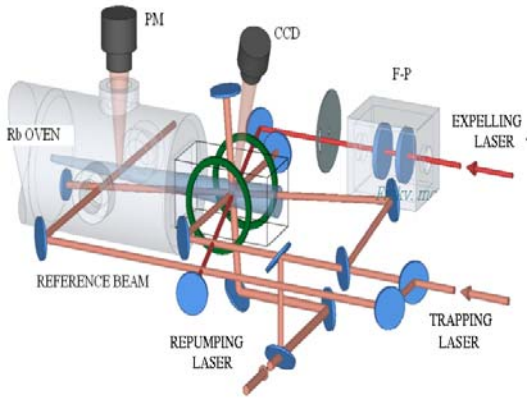


Color plot of the absolute value of the created coherence versus the speed of the chirp and ratio of the peak Rabi frequencies of the two laser fields

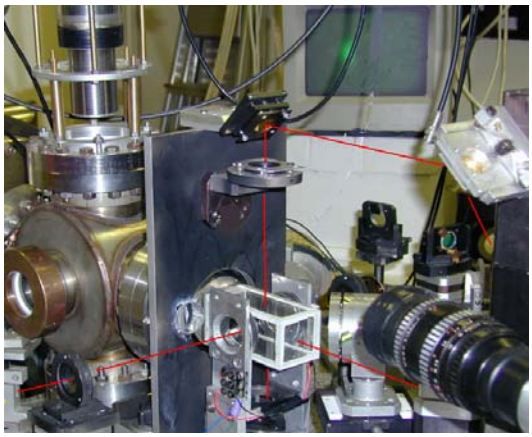
The proposed scheme will find important applications in the field of multi-photon ionization and high-order harmonics generation in gases, as well as nonlinear wave mixing in the coherently prepared media.

By studying multiphoton adiabatic transitions generated by partly overlapping laser pulses in rubidium atoms it was shown that the atomic quantum state can be efficiently controlled even if the energy levels of the atom are degenerated and the transition matrix elements between the magnetic sublevels are different. Such an entanglement of pairs of laser pulses was successfully produced between the internal magnetic states and the external translational state.

In order to experimentally verify the theoretical results a new method was elaborated to produce intense, varying frequency nanosecond laser pulses by using narrow bandwidth semiconductor lasers, integrated electro optic modulator and laser amplifier. The optimal parameters of the source of laser pulses, the applied optical device, the modulator as well as the amplifier were determined.



The schematic figure of the experimental tool…



… and the MOT

Methods have been worked out for the measurement of the properties of the chirped laser pulses and the processing of the signals of the interferometers and frequency run of pulses were determined. The laser pulses were then used to irradiate trapped rubidium atoms in the magneto-optical trap (MOT) and the movement of the atomic cloud was measured as a function of the starting frequency and frequency chirp run of the of the light pulses. It was shown that the laser pulses generated by the new method can be used to coherently generate cooled atom packets.

MATERIALS SCIENCE BY NUCLEAR METHODS

NUCLEAR METHODS IN MATERIALS SCIENCE: WHY DO WE NEED THEM?

Particles as local probes and tools of manipulation of condensed matter

Condensed matter is all around us. Solids and liquids form our planet, our buildings, food, drinks, artworks, drugs, but also the living creatures, plants, animals and even ourselves. Improving properties and understanding the structure and governing phenomena of hard and soft condensed matter to our benefit is an issue of ultimate importance. Conventional investigation and engineering methods are *macroscopic*, a serious limitation in many cases. Photons, neutrons, accelerated ions, positrons, i.e. particles from radioactive sources or from accelerator beams act as *local probes* to investigate condensed matter and they are also used to *modify material properties on an atomic scale*. Consequently, nuclear methods play an indispensable role in materials science (MS) and technology alike.

Here the term 'materials science' is used in a broader sense than usual. By this phrase we mean all disciplines related to the analysis and study of physical-chemical phenomena and deliberate modification of the properties of hard or soft condensed matter.

Applying nuclear methods in MS implies a specified knowledge and research infrastructure. These are put together at the MS division of RMKI. The division's mission is to conduct experimental basic research in this field and to develop the nuclear solid-state methods and their theories as well as the related infrastructures in home laboratories and at large international research facilities.

The 'MS division' is an informal research community in RMKI consisting of the co-workers of the Department of Nuclear Physics and the Nuclear Analysis Group of the Department of Biophysics.

Due to the complexity of the methods and infrastructures involved, the activity of the MS division is methodologically defined, the applications range from spintronics to preserving cultural heritage and from chemistry and life sciences to study new functional materials. Past experience proved that methodological coherence and thematic diversity is a real strength of research of the division. Below some activities in the year 2010 are listed.

Operating, developing and using research infrastructures

The division operates and develops major pieces of research infrastructure of RMKI.

- The EG-2R electrostatic accelerator and the NIK heavy-ion implanter coupled by a common implantation/scattering chamber is a unique accelerator complex. It enables *in situ* ion-beam analysis of ion-implanted samples as well as the proton microbeam and external millibeam PIXE studies on the EG-2R.

The EG–2R-electrostatic accelerator of 5000 kV terminal voltage

- The molecular beam epitaxy (MBE) facility, (at the time of the report, Hungary's only machine of the kind) is used to prepare metallic thin films. About 75 samples were prepared in

The MECA-2000 molecular beam epitaxy facility for preparing metallic thin-film samples under ultrahigh-vacuum conditions

2010 for research groups in Hungary and for our collaborators in Germany and Russia.
- The GINA polarised neutron reflectometer accomplished at the Budapest Neutron Center (BNC) is open to transnational access in the FP7 Integrated Activity (IA) NMI3 of the EC.

The GINA reflectometer with newly installed electromagnet and closed cycle He-cryostat at the Budapest Neutron Centre (BNC).

- The magnetic thin-film laboratory comprises Mössbauer spectrometers, radiochemistry facilities and direct access to the MBE machine.
- The X-ray spectrometry laboratory, with its fixed and mobile XRF spectrometers, including the external millibeam PIXE facility of EG-2R are open to transnational access in frames of the FP7 IA CHARISMA of the EC.
- The positron annihilation laboratory.

The accelerator and MBE complex are parts of the Hungarian Ion-beam Physics Platform (HIPP), a consortium with the Institute of Nuclear Research (ATOMKI, Debrecen). BNC is a consortium of four research institutes including RMKI. The magnetic thin-film laboratory is part of the national Network of Mössbauer Laboratories (NML). HIPP, BNC and NML are recognised as *Strategic Research Infrastructures* of NEKIFUT, the National Research Infrastructure Survey and Roadmap Programme.

NMI3:	**http://neutron.neutron-eu.net/n_nmi3**
HIPP:	**http://hipp.atomki.hu/**
BNC:	**http://www.bnc.hu/**
CHARISMA:	**http://www.charismaproject.eu/**
NEKIFUT:	**http://www.nekifut.hu**

On beam-time application and cooperation grounds alike, MS division researchers are regular users of European synchrotrons – European Synchrotron Radiation Facility (ESRF), Grenoble, France, Swiss Light Source (SLS), Villigen, Switzerland and neutron sources – FRM-II, TU München Germany, IBR-2, JINR, Dubna, Russia.

MAGNETIC HETEROSTRUCTURES

Atomic-scale diffusion in epitaxial FePd films

The researchers of RMKI MS division developed a piecewise constant diffusion coefficient model for inhomogeneous media and applied it to Fe_xPd alloys. Evaluating neutron and Mössbauer reflectometry as well as conversion electron Mössbauer spectroscopy data they revealed the degree of anisotropy of diffusion and extracted three local diffusion coefficients in epitaxial FePd films of Fe in the FePd structures upon heating and light ion irradiation.

Interaction of superconducting and ferromagnetic layers in proximity

Using polarised neutron reflectometry (PNR) combined with the resonance enhancement of the neutron intensity in a waveguide layer structure, in a joint project with JINR, Dubna, the effect of the superconducting (SC) transition was detected as formation of cryptoferromagnetic domains in the ferromagnetic (FM) layer of the Ni_xCu_{1-x}/V FM/SC bilayer in which weak ferromagnetism was screened within the SC coherence length.

Magnetic anisotropy of thin films

For promoting applications of the Fe_xPd and Fe_xPt systems, researchers of the MS division – in cooperation with colleagues from the Research Institute for Technical Physics and Materials Science of HAS – prepared laterally periodic close-packed out-of-plane magnetic nanostructures of 230 nm periodicity in FePd alloy films by ion irradiation through a self-organizing nanosphere mask. These magnetic thin films have great potential in magnetic recording and spintronics.

Participation in development of magnetic films for neutron optics

Continuing their collaboration with Mirrotron Ltd., using PNR on GINA, MOKE and XRD, researchers of the division contributed to the development of neutron optics elements. In 2010, a method based on light-ion irradiation was developed for Fe/Si polarizing neutron supermirrors to relax the residual stress, which – if untreated – may be as high as to cause the layer to peel off the substrate.

ION-SOLID INTERACTIONS

SPIRIT Round Robin to determine the implanted fluence by RBS

Thin-film depth profiling is a basic technology for materials science. Rutherford backscattering spectrometry (RBS) is one of the few tools available for accurate sub-micron depth profiling. This Round Robin is organised by SPIRIT with the aim to determine an implanted fluence of arsenic in silicon by a 1% confidence interval of the average of the individual values supplied by the laboratories with a coverage probability of 0.95. Such accuracy has become available only recently, with a protocol based on accurate knowledge of Si stopping powers.

At the MS division, 1.2% accuracy was achieved using a 1.5-MeV, double-detector, double-incident-angle $^{4}He^{+}$-RBS method. The electronic gain was calibrated on various samples. Pulse-height defect (dead layer only) and electronics stability was determined using a ^{241}Am source. Beam energy was verified by $^{16}O(\alpha,\alpha)^{16}O$ resonance at 3038 keV. The spectra were evaluated using the RBX code.

Depth distribution of hydrogen in amorphous silicon

Amorphous silicon (a-Si) layers are frequently used in thin-film solar cells. For enhancing their stability, namely reducing the speed of re-crystallization, the amorphous structure has to be stabilized, i.e., the dangling bonds have to be terminated. Having no effect on the functionality of the a-Si, the most appropriate material is hydrogen for the purpose.

In cooperation with USZ, a-Si films were grown by pulsed laser deposition at various H_2 background pressures and changes in film properties were followed by spectroscopic ellipsometry. The composition of the layers was determined by RBS and Elastic Recoil Detection Analysis. Due to oxide formation in the films, as shown by RBS, the H_2 background gas shifts the optical properties from an a-Si to SiO_2-like character. The films exhibit an in-depth graded refractive index that correlates with the gradient of the oxygen concentration.

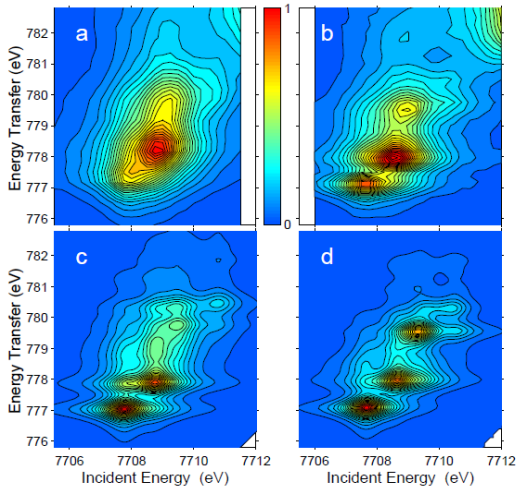
SPIRIT Project – Support of Public and Industrial Research using Ion Beam Technology, EU FP7 IA consortium: http://www.spirit-ion.eu/

USZ: University of Szeged

X-RAY SPECTROSCOPY WITH SYNCHROTRON RADIATION

Detailed electronic structure of CoO as revealed from 1s2p RIXS

X-ray absorption spectroscopy is a powerful tool to study the electronic structure; however, it faces several limitations including limited resolution due to lifetime broadening and spectral overlap, which can be overcome by resonant inelastic X-ray scattering (RIXS). In order to reveal the fine details of the electronic structure of the charge-transfer insulator CoO, 1s2p RIXS has been measured with unusually high resolution by using a 2 m diameter Rowland circle spectrometer instead of the usual 1 m one: panels a) and b) in the figure show the improvement. The spectra have been analysed with charge-transfer multiplet calculations. A local description works perfectly, no features due to non-local transitions or charge transfer are observed due to the relatively small cobalt-oxygen overlap as compared with higher-valent systems. The 1s2p RIXS calculations – through the excellent agreement of the structures in Fig. b and d – confirm the importance of interference effects between the scattering paths, which has been showed for the first time for hard x-ray RIXS. The detailed analysis of the high-resolution 1s2p RIXS plane allows a more detailed determination of the ground state as compared to 2p X-ray absorption.



Experimental and calculated 1s2p RIXS spectra of CoO. Top panels show spectra taken with an analyzer of 1m (a) and 2m (b) bending radius, which provide 1 eV and 0.3 eV overall energy resolutions, respectively. Bottom panels display the modelled RIXS without (c) and with interference (d) between the absorption and emission process.

POSITRON ANNIHILATION IN CONDENSED MATTER

Nanostructure studies

Applying the positron annihilation lifetime spectroscopy (PAL) for the study of LTA and MFI zeolites prepared by different techniques it has been shown that the long o-Ps lifetime components extractable from the PAL spectra show the occurrence of latent crystalline structure well before crystallinity becomes observable by X-ray diffraction. This finding is of high importance for application of zeolites as catalytic agents.

The high formation ratio of long-living o-Ps in porous materials is being exploited also in the anti-gravity experiments at CERN.

Free-volume studies in organic substances

A pronounced correlation has been found between the free-volume fraction and the amount of the long-living o-Ps component in cyclodextrines. However, it was shown that already in a few days the radiation damage evoked by the positron source might cause irreversible destruction, a problem to be taken into account in the investigation of biological and biomedical samples.

XRF SPECTROMETRY FOR PRESERVING CULTURAL HERITAGE

A compact, mobile XRF spectrometer based on Amptek® units and featuring a mini X-ray tube has been constructed and has been optimised by establishing the best combination of filter layers positioned before the exciting X-ray and/or the detector, resulting so in the highest element-sensitivity. The results obtained were compared to data collected with an identical spectrometer but operating with radioisotopes. It was concluded that the sensitivity of the X-ray-tube-based instrument surpasses that of the radioisotope-based one by about one order of magnitude but for elements Z > 18 Ti filters are more advantageous than Cu filters. It is now a well-founded hope that such X-ray-tube-based spectrometers can be extensively used in field applications in museums and in art collections where up to now *in situ* applications posed serious difficulties of radiation safety regulations.

The XR100CR Si X-ray detector fitted with a ^{109}Cd source doing XRF on a painting. This picture appears by permission on the home page of Amptek® (http://www.amptek.com/art.html).

THEORY, DATA EVALUATION

Evaluation in nuclear solid-state spectroscopies

An important development was achieved in FitSuite 1.5 nuclear solid state spectroscopic evaluation environment. Any parameter in a simultaneous fit may now be distributed and the histogram is fitted using the maximum entropy principle.

FitSuite:	http://www.fs.kfki.hu/

Reciprocity violation in nuclear resonant scattering of SR

The reciprocity principle requires the scattering amplitude to be symmetric for the transposition of the detector and the source. Reciprocity – a more general concept than time reversal – is not necessarily fulfilled in all experiments. Based on the concept of complex symmetric operators a representation-independent form of reciprocity theorem was expressed and a general condition for the reciprocity violation in case of 2x2 potentials was given. Reciprocity violation may be obtained in magneto-optical gyrotropy, a well-known property of the Mössbauer nuclear medium. Simulations of significant reciprocity violation in Mössbauer scattering of SR were fully verified in a recent nuclear resonant forward scattering experiment at the ID22N beam line of the European Synchrotron Radiation Facility, Grenoble.

THEORETICAL PHYSICS

MATHEMATICAL PHYSICS

Integrable field theoretical models

Recently it turned out that the finite size effects (FSE) of an integrable non-relativistic sigma model describes the planar limit of the AdS/CFT correspondence. This is why in our work we focused on the study of FSEs of integrable sigma models. Using the Bajnok-Janik conjecture which expresses the exponentially small volume corrections to the energies in terms of the S-matrix data of an integrable model, and exploiting the AdS/CFT correspondence, we calculated the 5-loop anomalous dimension of the Konishi operator in the N=4 super Yang-Mills theory. This work demonstrates that the integrability in AdS/CFT allows us to get high loop perturbative results in the gauge theory.

More recently by carefully analyzing the analytic structure of the TBA (Thermal Bethe Ansatz) for the ground state of the problem we proposed TBA equations describing (a certain class of) excited states in the model. In the limit of small coupling this exactly reproduces the anomalous dimensions obtained from the S-matrix data by the Bajnok-Janik method.

Also motivated by the AdS/CFT problem, we studied the FSEs of the O(3) non-linear sigma model. Namely, we proposed a set of non-linear integral equations and corresponding quantisation conditions for the finite size spectrum of the model. The equations were tested by high precision numerics against the Bajnok-Janik formula in the infrared limit and against perturbative results in the ultraviolet limit. The one-dimensional integrable many-body systems of Calogero-Moser-Sutherland type are intensely studied for decades due to their many physical applications and connections to central areas of mathematics.

J. Balog, Á. Hegedűs:
The Bajnok-Janik formula and wrapping corrections
JHEP 1009, 107, 2010
J. Balog, Á. Hegedűs:
5-loop Konishi from linearized TBA and the XXX magnet
JHEP 1006, 080, 2010
J. Balog, Á. Hegedűs:
The finite size spectrum of the 2-dimensional O(3) nonlinear sigma-model
NUCL. PHYS. B829, 425-446, 2010

Radiation of oscillons

Numerical works indicated that spatially well localized lumps are formed from rather generic initial data when a single massive, real scalar field is coupled to gravity. Such localized scalar lumps are not static, they are oscillating in time. In the literature of the topic such objects are called oscillatons. Their existence is rather surprising as oscillatons are coupled to the radiation field and they are not stabilized by conserved charges. Once formed, they appear to be very stable.

They are rather different from boson stars created from a charged scalar field coupled to gravitation which have a conserved charge and simple time dependence – a time-periodic phase. As it turns out their oscillations are not exactly periodic, the oscillation frequency changes slowly in time and in fact they do radiate scalar waves albeit at a very low rate. Since oscillatons do radiate they are continuously losing mass. They can be imagined of as a spherically symmetric lump of a well determined size together with a very small amplitude outgoing wave-tail.

Since current physical theories need various massive scalar fields (e.g. inflaton, axion, Higgs) such oscillatons appear as natural candidates for dark matter. Clearly it is a crucial question: what is the timescale on which such lumps radiate away most of their mass as to their physical relevance. In the limit of small (central) oscillaton amplitudes we have succeeded to compute the amplitude of the outgoing scalar wave-tail using asymptotic analysis. This made it possible to find a reliable estimate of their mass loss. We have shown that for an extremely large range of scalar field masses oscillatons lose only a small fraction of their total mass on timescales comparable to the current lifetime of the Universe. Therefore such objects merit serious studies as possible dark matter candidates.
We have also shown that in a de Sitter-type inflationary universe the effect of the expansion of Universe leads to a mass loss of both boson stars and oscillatons. This mass loss is exponentially suppressed when the expansion rate is slow.

G. Fodor, P. Forgács, M. Mezei:
Mass loss and longevity of gravitationally bound oscillating scalar lumps (oscillatons) in D-dimensions
PHYS. REV. D81, 064029, 2010
G. Fodor, P. Forgács, M. Mezei:
Boson stars and Oscillatons in an inflationary universe
PHYS. REV. D82, 044043, 2010

Improved behaviour of self-energy contributions to the S-matrix

The S-matrix is a central object in scattering theory and its calculation is of basic importance both in quantum mechanics and in quantum field theory. There are certain well known problems that one encounters in scattering calculations; one of them is that of the divergences caused by non-vanishing self-energies which often appear in quantum field theory. A general definition of the S-matrix can be given in terms of the total Hamiltonian operator H of the interacting physical system and a free Hamiltonian operator H0. In quantum mechanics this definition can usually be applied without difficulty. In quantum field theory, however, one encounters divergences in perturbation theory arising from disconnected vacuum-vacuum diagrams and from radiative corrections on the external lines, if one takes in a straightforward manner the quadratic part of H as H0. The disconnected vacuum-vacuum diagrams and the radiative corrections on the external lines are known to correspond to shifts of the vacuum energy and of the masses of the particles caused by the interaction part of H.

The mentioned divergences are distinct from the usual ultraviolet or infrared divergences and are present whenever the vacuum self-energy and the self-masses are nonzero. This problem is usually solved in the framework of renormalization theory. If H0 and H are chosen appropriately, then the disconnected vacuum-vacuum diagrams cancel out entirely and the radiative corrections on the external lines get replaced by factors called field strength renormalization constants. We propose a simple modification of the standard definition of the in and out states and thus of the S-matrix. The modification consists in certain phase factors in the definition of the in and out states. Such a modification is allowed by the fact that physical states correspond to rays rather than to vectors, i.e. the phase of a state vector is not determined by the physical state that it represents. We suggest that with our definition the complications related to self-energy corrections are considerably milder than with the usual definition and that our definition allows more general pairs of H0 and H operators than the standard definition.

G.Zs. Tóth:
Proposal to improve the behaviour of self-energy contributions to the S-matrix
CENT. EUR. J. PHYS. 8, 527-541, 2010

The weak theory of monads

Many constructions related to Hopf algebras and occurring in the Hopf Galois theory, fit the so-called formal theory of monads; that is, the abstract description of monads in a 2-category due to Lack and Street. E.g. the crossed products with bialgebras are examples of the wreath products of monads and Hopf modules can be interpreted as coalgebras of a lifted comonad on the Eilenberg-Moore category of a monad.

By diverse motivations, several years ago, jointly with Nill and Szlachanyi we generalized Hopf algebras. Weakening the axioms involving the (co)algebraic (co)unit we defined so-called weak Hopf algebras. In the past decade, several groups worldwide managed to extend most Hopf algebraic constructions to weak Hopf algebras. All these constructions work well and have several applications. However, they do not fit the formal theory of monads. This paper thus addressed the question how to extend the formal theory of monads; so that the resulting new, more general theory would be capable to describe constructions in terms of weak Hopf algebras as well: For an arbitrary 2-category K, a 2-category was introduced which contains the 2-category of monads due to Lack and Street. The 0-cells are still monads in K. The new feature is that the compatibility condition between the 1-cells and the units of the monads is replaced by an additional requirement on the 2-cells. This implies that instead of certain identity 2-cells we obtain idempotents. A monad in this new 2-category of monads does not determine a monad via the wreath product. Instead, the naive wreath product admits an idempotent. Whenever it splits, the corresponding retract becomes a monad. It was proven that weak crossed products arise as retracts precisely in this way.

In 2-categories in which the Eilenberg-Moore objects of monads exist, `weak' liftings of 1-, and 2-cells were defined, by replacing the usual equality of certain 1-cells by the existence of a split idempotent. It was proven that whenever idempotent 2-cells split, any weak lifting arises from a cell in the new 2-category of monads via an appropriate 2-functor.

The comonad playing the central role in weak Hopf Galois theory was shown to arise as a weak lifting.

G. Böhm:
The weak theory of monads
ADV. MATH. 225, 1-32, 2010

GRAVITATION AND GENERAL RELATIVITY

Space-time extensions

The Hawking-Penrose singularity theorems prove only the existence of incomplete geodesics. We expect that either some of the components of the tidal force tensor, or the energy density becomes singular as it reaches the end of these geodesics The global extendibility of smooth causal geodesically incomplete space-times was investigated. Denote by γ one of the incomplete non-extendible causal geodesics of a causal geodesically incomplete space-time (M, g_{ab}). First, we proved that it is always possible to select a synchronized family of causal geodesics Γ and an open neighborhood U of a final segment of γ in M such that U comprises members of Γ, and suitable local coordinates can be defined everywhere on U provided that γ does not terminate either on a tidal force tensor singularity or on a topological singularity.

Rácz I:
Space-time extensions II.
CLASS. QUANTUM GRAV. 27, 155007, 2010

Gravitational waves from binaries on unbound orbits

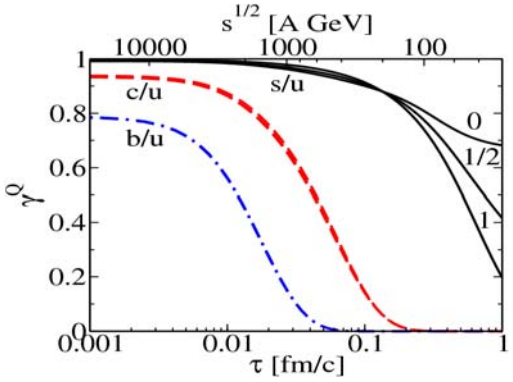
A generalized true anomaly-type parametrization which is convenient to describe both bound and open orbits of a two-body system in general relativity is introduced. A complete description of the time evolution of both the radial and the angular equations of a binary system taking into account the first order post-newtonian (1PN) is given. The gravitational radiation field emitted by the system is computed in the 1PN approximation including higher multipole moments beyond the standard quadrupole term. The gravitational waveforms in the time domain are explicitly given up to the 1PN order for unbound orbits but the results are also illustrated on binaries on elliptic orbits with special attention given to the effects of eccentricity.

J. Majár, P. Forgács, M. Vasuth:
Gravitational waves from binaries on unbound orbits
PHYS.REV. D82, 064041, 2010

HEAVY ION PHYSICS

Quark pair production in strong time-dependent non-Abelian fields

Ultrarelativistic heavy ion collisions can be described as the overlap of two Lorentz-contracted clouds of color charges. In this case the formation of a strong color field in the center of the collision is expected. During the collision the strength of this color field is increasing, and decreasing later on very quickly, $\tau << 1$ fm/c. In such a case particle-antiparticle pair production appears which is dominant in the early stage of heavy ion collisions. In a kinetic model based on a Wigner function method we have followed the above mentioned time evolution and determined numerically the particle-antiparticle production in strong non-Abelian fields. The pair-creation yield strongly depends on the gradient of the time-dependence. If the overlap is very fast and τ is very small, then this parameter becomes the most important quantity, the only scale to describe the process.



The τ characteristic time dependence of heavy quark suppression γ^Q, indicating the corresponding collision energy.

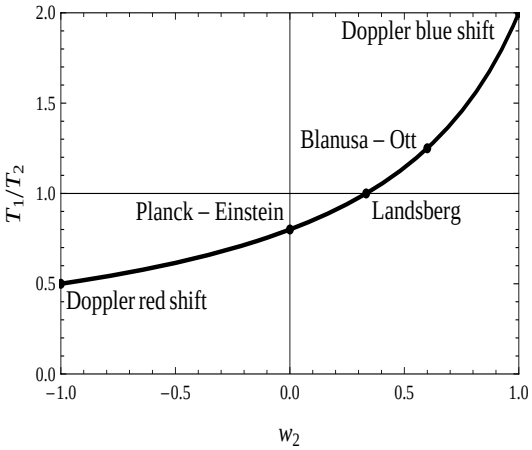
If we consider quark-antiquark pair production in ultrarelativistic heavy ion collisions, then the mass difference between the different quarks becomes negligible with increasing energy. Thus the suppression of the heavy quark production will not be valid anymore, the yield of light and heavy quark-pairs become very similar. Our numerical calculations support this expectation, contradicting the usual idea of heavy quark suppression based on Schwinger-mechanism in constant strong fields.

P. Levai, V.V. Skokov:
Nonperturbative enhancement of heavy quark-pair production in a strong SU(2) color field
PHYS. REV. D82, 074014, 2010

About the temperature of moving bodies

By confronting relativity theory with thermodynamics the question of the proper transformation of the absolute temperature is most exciting. To this several answers have been historically offered, practically including all possibilities. In 1907 Planck and Einstein concluded that moving bodies appear cooler by a Lorentz factor. Following some preceding claims Ott has challenged this opinion in 1963 by stating that such bodies are hotter. Landsberg argued for unchanged values of the temperature in 1966. Several authors observed that for a thermometer in equilibrium with black body radiation the temperature transformation is related to the Doppler formula.

Coming to the era of fast computers, a renewed interest emerged in such questions by modeling relativistic stochastic phenomena. Dissipative hydrodynamics applied to high energy heavy ion collisions also requires the proper identification of temperature and entropy.



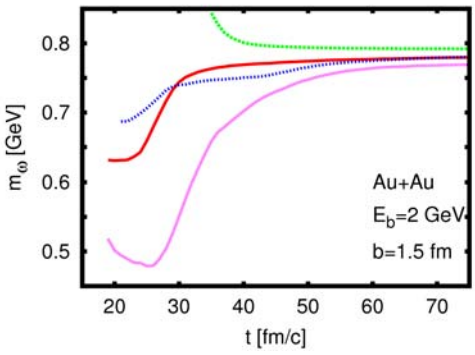
The ratio of the temperatures shown by an ideal thermometer, T1, and of the observed body, T2, as a function of the speed of the heat current in the body, w2. The relative velocity: v=-0.6 c.

The physical root of the paradox lies in the fact that the momentum exchange cannot be separated from the energy exchange at relativistic speeds. Beyond the two velocities of the interacting thermodynamic bodies the energy and momentum equilibration accentuates two additional velocities. By a Lorentz transformation only one of the four velocities can be eliminated. The remaining three reflect physical conditions on the system. The requirement of observer independent thermodynamic equilibrium leads us to a generalized Doppler formula. It depends on two physical velocities, the relative velocity of the bodies and the relative velocity of the energy flows inside the bodies. We reproduce the formulae of Einstein and Planck, Ott and Doppler according to respective physical assumptions on the energy flow.

T.S. Bíró, P. Ván:
About the temperature of moving bodies
EUROPHYSICS LETTERS 89, 30001, 2010

Particle production in heavy ion reactions with a transport model

With the help of the Budapest-Rossendorf transport model we described the dielectrom invariant mass spectrum at 1 and 2 AGeV bombarding energy measured by the HADES detector at SIS. In this model the spectral function of the particles propagate dynamically and even by drastic in-medium effects on the vector mesons spectra by the end of the collisions the particles regain their vacuum properties. We showed that even a drastic change of the vector meson spectrum in dense matter is hardly observable in the dilepton spectrum in a light system. For heavy system a detector with better resolution is required.



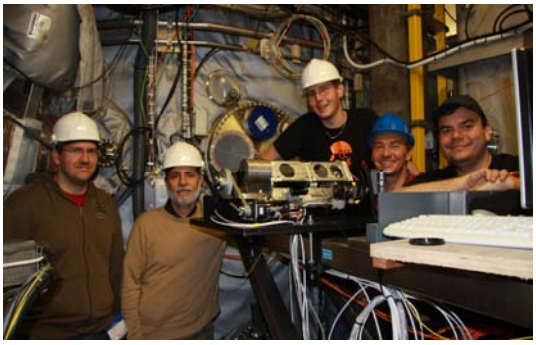
Time evolution of ω masses during a collision. While at high density their masses differ substantially from the vacuum value, at the end of the collision they regain it.

H.W. Barz, B. Kämpfer, Gy. Wolf and M. Zétényi:
Propagation of Vector-Meson Spectral-Functions in a BUU Type Transport Model: Application to Di-Electron Production
THE OPEN NUCLEAR & PARTICLE PHYSICS JOURNAL , 3, 1-15, 2010

PLASMA PHYSICS AND THE PHYSICS OF COLD ATOMS

FUSION PLASMA PHYSICS AND TECHNOLOGY

In 2010 RMKI researchers have built a two-dimensional beam emission spectroscopy (BES) diagnostic equipment at the MAST spherical tokamak (Culham, UK). This is the first BES device in Europe with microsecond time resolution which aims at measuring plasma turbulence by observing fluctuations in the visible light emitted by a heating atomic beam. Besides turbulence the diagnostic can also measure plasma flows which are considered to be a key element in the self-regulation of turbulence. This equipment is the result of a close British-Hungarian collaboration. The most important parts of the diagnostics is an in-vacuum observation system and a camera unit optimized for a low-noise light level with small spatial but high time resolution, developed by one of the spin-off companies of RMKI.



The detector and the optics of the Hungarian Beam Emission Spectroscopy diagnostics at MAST, and the international team after the installation.

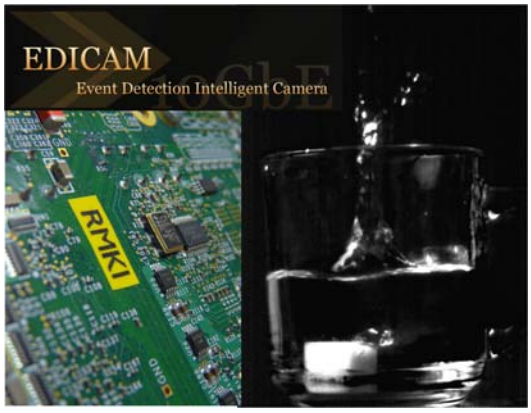
At the TEXTOR tokamak (Jülich, Germany) a lithium BES device was built in the previous years and in collaboration with a German and a Belgian group a detailed study of plasma turbulence and zonal flows was performed in 2010. By the processing of data from three different measurement methods it was found that the periodic zonal flows (Geodesic Acoustic Mode, GAM) are asymmetric in both angle directions of the tokamak, i.e. along the poloidal and toroidal directions, and along the minor radius they show a characteristic phase variation. At the edge of the plasma outgoing flow modulations can be seen. The dependence of the tilt of the turbulent eddies as a function of the magnetic field strength and direction was also studied in detail.

The video diagnostic unit has been installed successfully at ASDEX. The 16 Gbit link has also been developed at KFKI RMKI

The ten-channel video diagnostic unit of the Greifswald Wendelstein W7X stellarator is also being developed by the KFKI RMKI researchers. The thermal and mechanical tests of the prototype system were successfully completed. A special imaging optics and the prototype of the EDICAM (Event Detection Intelligent Camera) using a 10 Gbit link were also built. This camera (in addition to the COMPASS tokamak, where it was used for plasma monitoring) was successfully installed also at the ASDEX Upgrade tokamak and with the help of the fast framing capability (10-30 kframe/s), the paths and ablation characteristics of cryogenic pellets are traced routinely.

The EDICAM – beside “conventional” fast framing camera functions - is designed to be able to perform also intelligent operations. This means that real time processing of the frame stream will be possible by means of the FPGA based camera electronics and results can be used for labeling the images (real time recognition of predefined events), for triggering or warning other diagnostics, for providing information for the safety and control system of the stellarator and also for changing the camera operation itself (e.g. fast recording of a predefined region of interest). The hardware of the present camera prototype incorporates already all necessary components and presently the software elements are under development. After detailed discussion, the camera control software/firmware was structured into several components and each component was designed together with the functional interfaces. Presently the coding of these

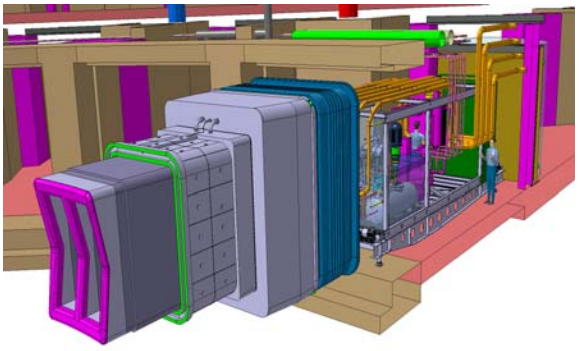
components is ongoing and the first functioning system is expected to be ready by the end of 2011.



Sugar dropped into water and imaged with the fast EDICAM camera.

The lithium beam diagnostic system – which was developed with several years work by the physicists and engineers of RMKI - for the COMPASS tokamak in Prague, was delivered at the end of the year according to the plans.

In several projects to be continued also in 2011 the tasks planned for 2010 have been fulfilled. A milestone was the development of the prototype of the camera system for the W7X stellarator, the diode covering mechanics of the AXUV camera system of the TCV tokamak in Zürich, the modification of the periscope head for the JET tokamak (Culham, UK) as well as the development of the opening-closing mechanics of the camera system for the ASDEX device in Garching. The most important of the various tasks under development for the experimental fusion reactor ITER in France is the conceptual design of the service unit of the „tritium breeding module" (TBM), which is being built in the frame of a tender by the Fusion for Energy agency (Barcelona).



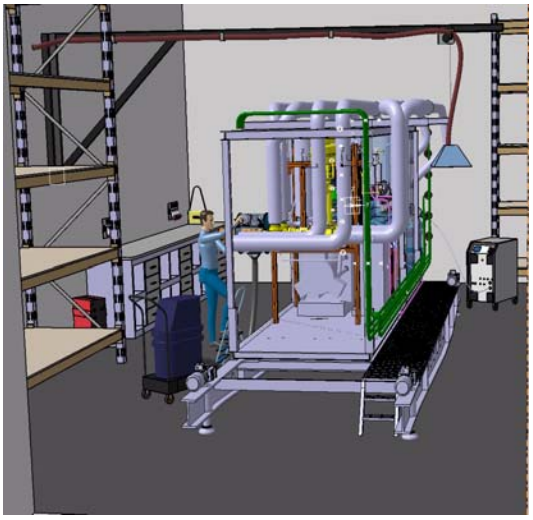
TBM and ancillary system in ITER Tokamak building

The main goal of TBM experiment is to allow testing DEMO relevant tritium breeding and heat recovering capabilities in ITER reactor. Up to six concepts for various tritium breeding blanket systems will be tested simultaneously in 3 allocated Equatorial Ports (EP) of ITER (ports No. 2, 18 and 16).

In Equatorial Port #16 that is devoted to EU, two breeding blanket concepts are selected for the experiment. One is Helium Cooled Pebble Bed (HCPB) originally developed by Karlsruhe Institute of Technology (KIT) in Germany and one is Helium Cooled Lithium Lead (HCLL) originally developed by the French Atomic Energy Agency (CEA, Commissariat à l'énergie atomique). HCPB TBM is a ceramic breeder concept that contains lithium ceramic breeder and beryllium in the box as breeder material and tritium extraction from the system is solved by low-pressure helium stream. HCLL TBM uses slow-circulated liquid lithium-lead eutectic as breeder material and tritium extraction is solved by ancillary system. TBM ancillary equipments are integrated in a common support structure, called Ancillary Equipment Unit (AEU). Configuration of AEU, as one assembly structure, facilitates installation/removal operation and allows the limitation of interfaces for TBM supply lines inside PC.

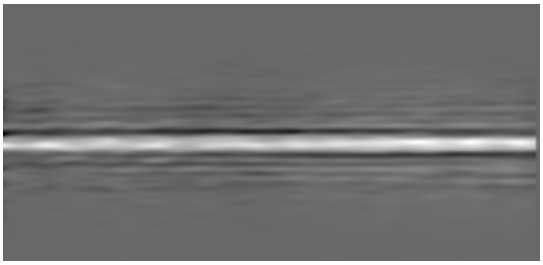
PFFO engineers have played a vital role in AEU development and integration study, carried out within the framework of two years grant under contract between consortium of six associates and Fusion for Energy (F4E, the European Domestic Agency of ITER). The work performed contains design and analysis of modular frame structure encompassing all necessary sub-components of TBM ancillary system. Design process enclosed of thorough structural and thermo-mechanical analysis of support- and high pressure piping systems. Sub-component integration studies have been completed together with clear definition of maintenance/removal/installation sequences of the PC sub-systems giving particular focus on their contamination and radiation level in comparison with ITER regulations of human working conditions for nuclear environment.

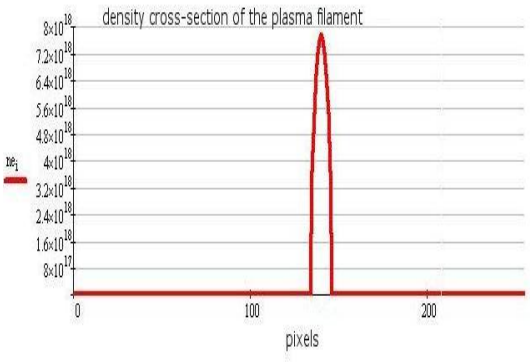
The researchers of the RMKI in collaboration with a Polish group at the High Intensity Laser Laboratory of Szeged University performed measurements in argon gas at the wavelength 83 nm for the resonant third KrF harmonic using a diamond detector insensitive to the fundamental frequency.



The TBM module and its maintenance in ITER

In addition to the 3ω also signals from 5ω and 7ω were detected. According to preliminary data the conversion factor was found to be 10^{-3}, i.e. smaller by one order of magnitude than described previously in an experiment of the LLG, Göttingen but in agreement with the previous RMKI results. In collaboration with the Technical University of Prague a complex interferometric diagnostics was developed which makes possible the measurement of plasma density from 10 ps to 6 ns delay from the main laser beam of 600 fs duration. In the first experiments laser sparks were studied in air. The expansion of the long filament and the forming of a cavernous structure in it was observed.

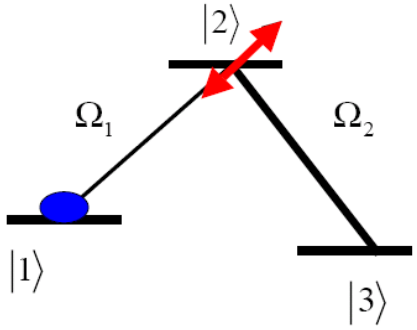




Phase-shift caused by the plasma filament and density cross-section

PHYSICS OF COLD ATOMS

The interaction of multilevel atoms cooled and trapped in a magneto-optical trap (MOT) with short laser pulses was also studied. With the methods developed previously the meta-stable states and the coherences between them can be manipulated without significant excitation of the atoms. On the basis of a model with tripod level scheme the possibility of generating deterministic coherence between the three ground states at arbitrary time was considered. Decoherence caused by spontaneous emission from excited states was minimized due to suppression of the atomic excitation. In the same time, decoherence arising from transverse relaxation has been eliminated by the use of ultra-short frequency modulated laser pulses.



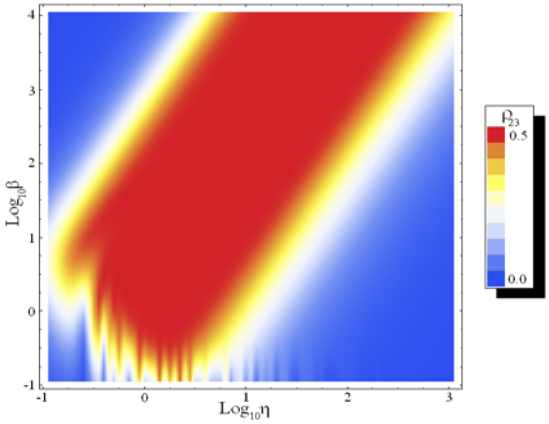
Schematic of Λ-like atom with two acting laser fields: one with chirped frequency and the other one with constant carrier frequency

New method was elaborated for producing Zeeman coherence in 83Rb atoms between the magnetic sublevels of the hyperfine magnetic levels of the D2 line. In collaboration with Polish scientists from the Jagiellonian University, Krakow an experimental procedure was proposed for the measurement of artificially produced coherence based on the nonlinear Faraday-effect describing the rotation of the plane of polarization of the light propagating in the medium. A powerful method was proposed for quantum systems with sizeable inhomogeneous widening of transitions (e.g. solid state media) for the mapping of optical information into the populations to the position of atomic levels and coherence between quantum states.

Initial preparation of atoms in coherent superposition of a ground state and the excited state may significantly (by many orders of magnitude) enhance efficiency of multi-photon ionization and generation of high-order optical

harmonics in gases. If there is a collection of atoms, to obtain a coherent enhancement of a multi-photon process, all of the atoms have to be prepared in a same coherent superposition, preferably with maximum absolute value of the coherence, and with a same (arbitrary) initial phase of the coherence. A new extremely robust scheme was developed for creation of maximum coherence of 0.5 between a ground state and the excited state in a model ?-structured atom using two short laser pulses. One of the pulses has constant carrier frequency quasi-resonant with transition between an initially empty ground and the excite state. The frequency of the second pulse is chirped through the resonance with the adjacent transition between the initially populated ground state and the common excited state of the atom.

An extremely high robustness of the scheme is demonstrated against variation of parameters of the laser radiation in relatively broad region of values (see color map below).

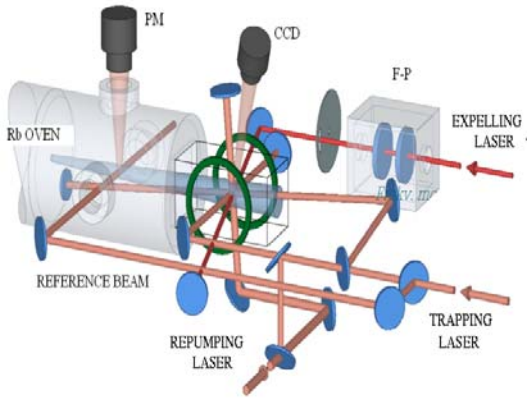


Color plot of the absolute value of the created coherence versus the speed of the chirp and ratio of the peak Rabi frequencies of the two laser fields

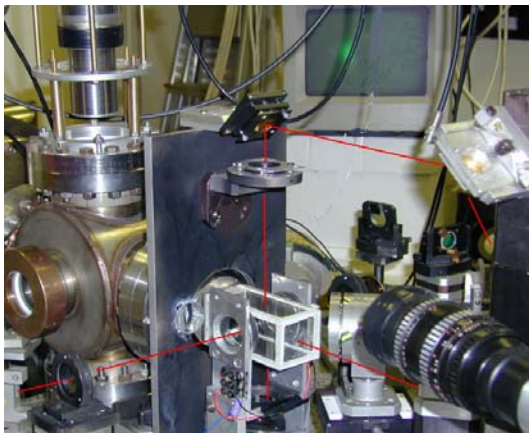
The proposed scheme will find important applications in the field of multi-photon ionization and high-order harmonics generation in gases, as well as nonlinear wave mixing in the coherently prepared media.

By studying multiphoton adiabatic transitions generated by partly overlapping laser pulses in rubidium atoms it was shown that the atomic quantum state can be efficiently controlled even if the energy levels of the atom are degenerated and the transition matrix elements between the magnetic sublevels are different. Such an entanglement of pairs of laser pulses was successfully produced between the internal magnetic states and the external translational state.

In order to experimentally verify the theoretical results a new method was elaborated to produce intense, varying frequency nanosecond laser pulses by using narrow bandwidth semiconductor lasers, integrated electro optic modulator and laser amplifier. The optimal parameters of the source of laser pulses, the applied optical device, the modulator as well as the amplifier were determined.



The schematic figure of the experimental tool…



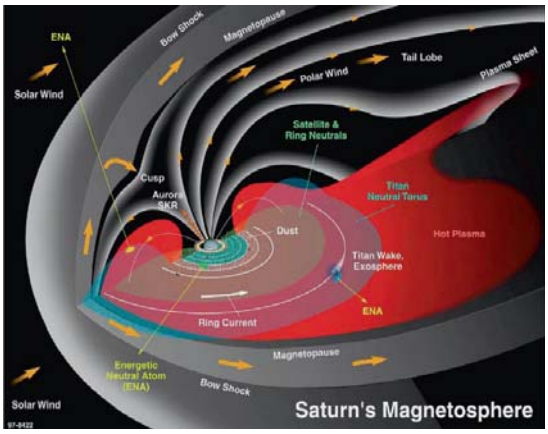
… and the MOT

Methods have been worked out for the measurement of the properties of the chirped laser pulses and the processing of the signals of the interferometers and frequency run of pulses were determined. The laser pulses were then used to irradiate trapped rubidium atoms in the magneto-optical trap (MOT) and the movement of the atomic cloud was measured as a function of the starting frequency and frequency chirp run of the of the light pulses. It was shown that the laser pulses generated by the new method can be used to coherently generate cooled atom packets.

SPACE PHYSICS AND SPACE TECHNOLOGY

INVESTIGATION OF THE PLASMA ENVIRONMENT OF SATURN AND TITAN

The aim of the Cassini mission is to study the planet Saturn, its satellites, and its very complex plasma environment. One of the main objectives is the investigation of the moon Titan which is unique among the numerous satellites in the Solar System.



Saturn's magnetosphere. Due to the dense plasma and neutral clouds originating from the rings and satellites, Saturn's magnetosphere is huge and very complex. One of the most striking features is that the magnetic field highly deviates from the simple dipole due to the strong currents flowing in Saturn's dynamic magnetodisc

Scientists of RMKI participating in the Cassini mission enriched our understanding about Saturn's magnetosphere and the moon Titan with new elements. Using the density, temperature and velocity momentum calculated from the primary mission they began a comprehensive study of the magnetodisk which forms a kind of trap for magnetospheric ions; heavier (water group) ions are concentrated within a very narrow region whereas protons are found in a larger volume. The quantitative analysis of the relationship between the magnetodisk and magnetospheric ions supported the models depicting the magnetodisk as an asymmetric rotating object. The probe approaches Titan under essentially different conditions in the course of subsequent flybys which were classified according to the ion data. It has turned out that one of the most important factors affecting the flyby circumstances is the position of spacecraft relative to the magnetodisk.

Our researchers have pointed out that many features of the T9 Titan flyby were presumably caused by the fact that Cassini entered the magnetodisk of Saturn before the encounter, a region dominated by protons. The nighttime ionosphere of Titan is exclusively due to magnetospheric electrons.

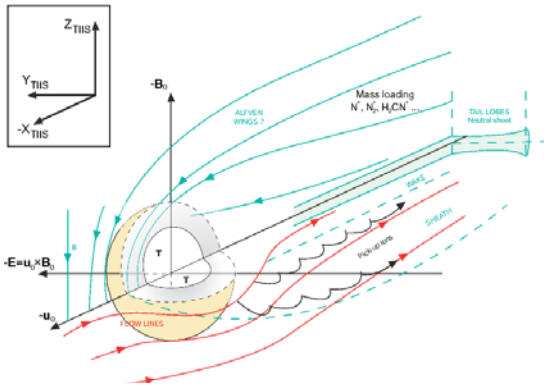
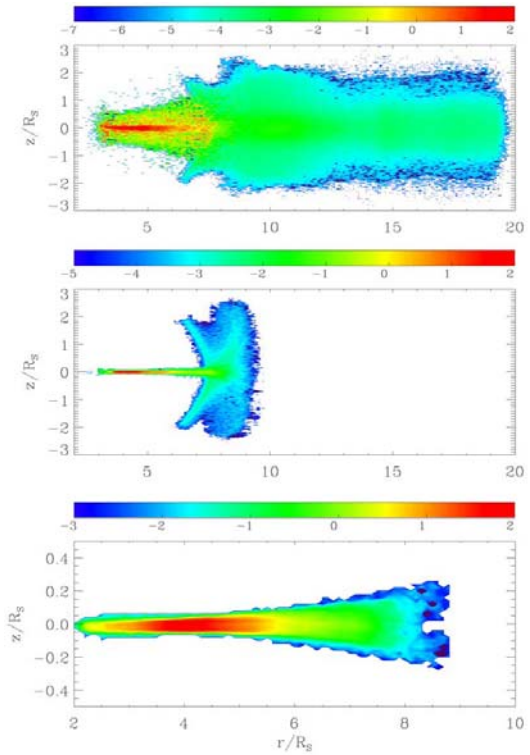


Illustration of the interaction between Saturn's magnetosphere and Titan. The satellite is traveling in a high speed magnetized plasma flow because the magnetospheric plasma co-rotates with the planet. (The inset shows the definition of Titan Interaction System (TIIS) coordinates as defined by Backes et al. (2005))

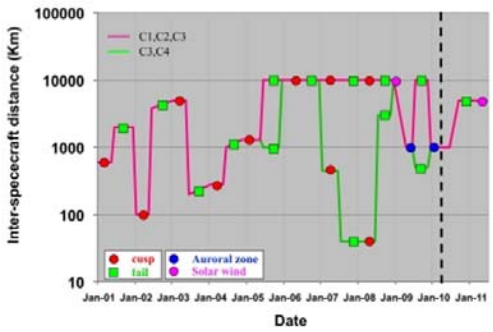


The azimuthally averaged density distribution of dust grains with r_μ radii (in microns): (top) $0.1 < r_\mu < 0.5$; (middle) $0.5 < r_\mu < 1$; and (bottom) $1 < r_\mu < 3$. The largest grains remain confined to the classical E ring while the smallest particles can reach the orbit of Titan

Recently discovered geysers on the geologically active south-polar region of the moon Enceladus are now recognized as the dominant source of material in Saturn's E ring. The ring was traditionally thought to span the region between 3 to 8 R_S, where R_S is the radius of Saturn. However, new in situ dust measurements indicated that the density of small grains might continuously extend far beyond these boundaries, and the E ring could reach even beyond the orbit of Titan (20.3 R_S). Scientists of RMKI modelled the long-term evolution of dust particles comprising the E ring and showed that grains from Enceladus could indeed reach the outskirts of Saturn's magnetosphere.

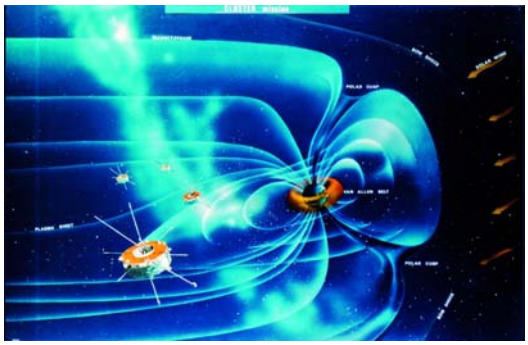
CLUSTER MISSION AND SPACE WEATHER

Scientists of RMKI have been participating in ESA's Cluster program since the mid 90's. In the framework of this project, four identically equipped satellites have been investigating the plasma environment of the Earth since 1 February 2001. Ten of the eleven experiments are still collecting data, several of them aboard all four satellites, therefore the mission was recently granted an extension up to the end of 2014. From simultaneous particle and field measurements at four locations, spatial and temporal variations can be separated providing a unique opportunity for three dimensional observations. Processes of different scales can be studied by changing the separation distances between the spacecraft depending on the region (polar cusp, magnetotail, bow shock, solar wind, etc.) to be investigated. The polar orbit is slowly evolving as the major axis is gradually turning to the south from the ecliptic plane. This way, different regions of the terrestrial plasma environment can be studied which were not sampled earlier in the mission.



Distance between the Cluster spacecraft during the mission investigating the different plasma regions

RMKI is providing the infrastructure and personnel of the Hungarian Cluster Data Centre producing the auxiliary data files for the Cluster Science Data System. The HDC also stores and makes available the data files of the scientific instruments produced by other five national data centres of the Cluster community. Our scientists, as Co-Investigators of the magnetometer and an energetic particle detector, also participate in data analysis. The evolution of low frequency MHD mirror type magnetic field fluctuations has been investigated in the magnetosheath (between the bow shock and the magnetopause) and in the interplanetary field. Also, statistical studies were performed on magnetic cavities filled with hot plasma developing at the interaction of a tangential discontinuity and the bow shock.



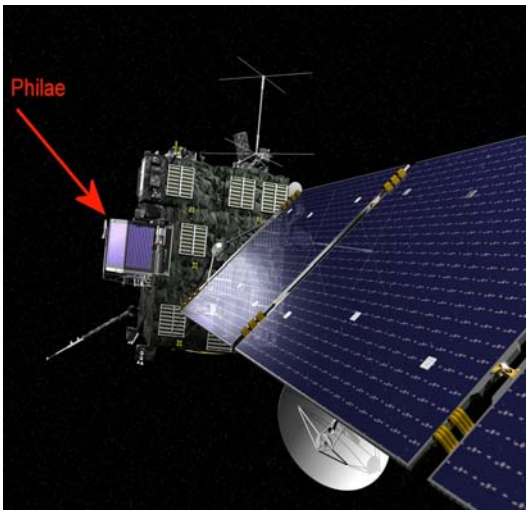
Four identical Cluster spacecraft orbiting around the Earth

The RMKI project proposal called SOlar-TERrestrial Investigations and Archives (SOTERIA) submitted together with 15 European collaborating institutes acquired support from the Seventh Framework Programme of the EC. The project is realizing a widespread collaboration in the fields of solar physics, space physics and geophysics by simultaneous ground-based and space-born observations through the analysis of a large number of solar originated geoeffective space weather events. The aim is to provide an archive of models suitable to predict large geomagnetic storms based on solar and interplanetary observations. RMKI participates in modelling the outer boundaries of the terrestrial magnetosphere (bow shock and magnetopause) when interplanetary plasma and magnetic field parameters have extreme values due to large solar events. They also investigate the temporal evolution of the fluxes of solar energetic particle events by comparing observations with model calculations. It was found that the velocity of a shock wave obtained near the Sun yields inaccurate arrival time at the Earth which is necessary for predicting space weather events.

ROSETTA-PHILAE SPACE PROBE PAIR

The first soft landing on the comet nucleus

ESA's Rosetta spacecraft will be the first to undertake the long-term exploration of a comet.



Philae lander on the Rosetta Orbiter (artist made imagination picture)

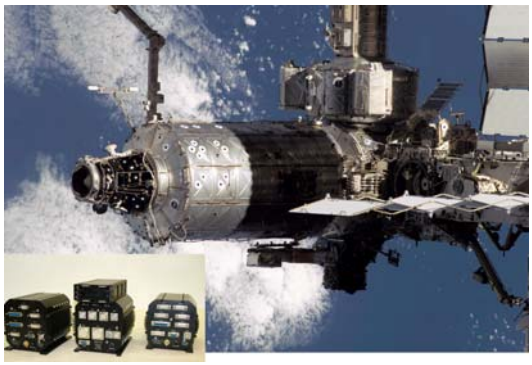
It comprises a large orbiter, which is designed to operate at large distances from the Sun, and a small lander. Each of these carries a large complement of scientific experiments designed to complete the most detailed study of a comet ever attempted. The Rosetta-Philae space probe pair of the European Space Agency was launched to comet Churyumov-Gerasimenko in 2004; Philae is scheduled to land on the surface of the cometary nucleus in 2014.

The RMKI has participated in the development of the Command and Data Management Subsystem (CDMS) for Philae lander. The in-flight corrections of the parameters referring to the instruments and to the comet require continuous fine-tuning of the software of the CDMS. Our scientists as software developers of the central computer of Philae are actively participating in this procedure. A new software version was uploaded to the Lander in 2010 before hibernation. The improved software version has been successfully tested on separation, descent and landing sequences. This software will allow executing the long term science activity and further minor modifications without uploading the entire software again.

PLASMA WAVE COMPLEX FOR INTERNATIONAL SPACE STATION

Distributed computer system

The main goal of Plasma Wave Complex (PWC) system is to study dynamic processes in the magnetosphere and ionosphere accompanied by a variety of electromagnetic phenomena by means of a permanent long-term observation site onboard the International Space Station (ISS). The PWC Team is an international consortium with contributions from Bulgaria, England, Hungary, Poland, Russia and Ukraine. The computer system of PWC which has been developed by our engineers is a distributed intelligence system working in its own local network of three processors. This network structure has the advantage of increased data acquisition capacity, reliability and fulfils special requirements of electronic isolation between experiments and onboard electronics. It provides interfaces for onboard telecommunication of the ISS. The data acquisition software of the 3-unit computer system of the Plasma Wave Complex to be flown aboard the ISS was finalized by the RMKI staff last year. The flight model was delivered to Russia in 2010. The tests were successfully completed in Moscow. One additional model is being manufactured, as the ground reference model will be used on Earth



Two computers are outside and the third one is inside of the Russian Modul of the ISS for controlling and collecting 11 sensor signals

during flight for data evaluation of experiments. The manufacturing of PWC is a complex job since it requires not only precise assembly but beyond electronic tests the mechanical and thermal parameters of equipment have to be tested in thermo vacuum chamber and on vibration table.

BEPICOLOMBO MISSION

Visit to Mercury

RMKI researchers have completed the electrical model of the power supply unit for the Plasma Ion Camera (PICAM) of ESA's BepiColombo mission to be launched to Mercury in 2014. The mission will consist of two separate spacecrafts. ESA is building the Mercury Planetary Orbiter (MPO) and the Japanese space agency ISAS/JAXA will contribute the Mercury Magnetospheric Orbiter (MMO). The MPO will study the surface and internal composition of the planet and the MMO will study Mercury's magnetosphere that is the region of space around the planet. The PICAM instrument is part of SERENA (Search for Exospheric Refilling and Emitted Natural Abundances) system on the MPO.

The electrical model of the Low Voltage DC/DC converters including the variable gate voltage of the mass spectrometer

An international consortium led by the Space Research Institute of the Austrian Academy of Sciences (IWF) provides PICAM. The PICAM Team is an international consortium with major contributions from Austria, Belgium, ESA/ESTEC, France, Germany, Hungary, Ireland, and Russia. PICAM is an ion mass spectrometer operating as an all-sky camera for charged particles to study the chain of processes by which neutrals are ejected from the soil, eventually ionized and transported through the environment of Mercury. PICAM will provide the mass composition, energy and angular distribution of low energy ions up to 3 keV in the environment of Mercury. The instrument combines high spatial resolution, simultaneous measure-ments in a hemispheric field of view with a mass range extending up to ~132 amu (Xenon) and a mass resolution better than ~100. In the cooperation inside the SERENA team, we have manufactured some mechanical parts of MIPA sensor for Swedish Institute of Space Physics (IRF). Using our new CNC machine we could manufacture small parts of the MIPA sensor which required high accuracy. This successful cooperation gives a good reference about our work and the result is that we have been invited into the preparation of the detector of Energetic Neutral Atoms for the new Chinese mission to Mars. This is important because according to the current plans of ESA there is no such mission. It is ESA's first spacecraft to visit this planet.

VENUS EXPRESS MISSION

Automated Calibration System

The ESA's Venus Express probe studies the Venusian atmosphere and clouds in unprecedented detail and accuracy. ASPERA-4 (Analyzer of Space Plasmas and Energetic Atoms) investigates the interaction between the solar wind and the Venusian atmosphere, determines the impact of plasma processes on the atmosphere, the global distribution of plasma and neutral gas, studies energetic neutral atoms, ions and electrons and analyzes other aspects of the near Venus environment. The simultaneous observations by Mars Express and Venus Express give scientists the data they need to investigate the evolution of the two planets' atmospheres. Both spacecrafts carry ASPERA. This allows scientists to make direct comparisons between the two planets.

RMKI engineers have developed an automatic computer system for the existing calibration system. The automated computer system consists of a usual PC and three embedded processors which are galvanically insulated to avoid the high voltage propagation in case of failure. Last year scientists performed the software and hardware modifications on the calibration system at Kiruna necessary for the post-calibration of the ASPERA particle detector of the Venus Express space probe.

In 2010 RMKI issued a new software version and extended the hardware configuration with more measurement points of high voltages. This new configuration will give more accurate post calibration.

BIOPHYSICS

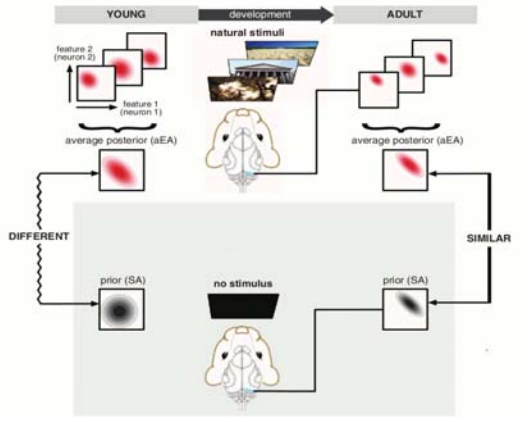
The Budapest Computational Neuro-science Group is an interdisciplinary research group the interdisciplinarity of which is reflected in the composition of the group as well: a chemist, biologists, computer scientists and physicists. The main foci of the group are:

- understanding of functional organization, performance and pharmacological modulation of certain neural structures;
- analysis, characterization and modeling of networks, especially growing networks.

COMPUTATIONAL NEUROSCIENCE

Spontaneous cortical activity reveals hallmarks of an optimal internal model of the environment

The brain maintains internal models of its environment to interpret sensory inputs and to prepare actions. Although behavioral studies have demonstrated that these internal models are optimally adapted to the statistics of the environment, the neural underpinning of this adaptation is unknown.

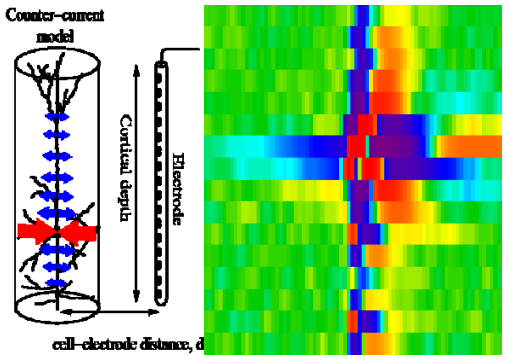


The sign of an optimal internal model in the brain: the probability density distribution (PDD) of the neurons' spontaneous activity assimilates to the average PDD of the natural stimuli during development.

Using a Bayesian model of sensory cortical processing, we related stimulus-evoked and spontaneous neural activities to inferences and prior expectations in an internal model and predicted that they should match if the model is statistically optimal. To test this prediction, we analyzed visual cortical activity of awaken ferrets during development. Similarity between spontaneous and evoked activities increased with age and was specific to responses evoked by natural scenes. This demonstrates the progressive adaptation of internal models to the statistics of natural stimuli at the neural level.

Model-based source localization of extracellular action potentials

We have developed a new micro electric imaging technique which is able to determine the membrane currents on single neural cells based on potential measurements with micro-electrode arrays. This new method is based on the inverse solution of the Poisson-equation and was applied on extracellular spatial potential patterns of neural action potentials. Using our new method many details of the spatiotemporal dynamics of spikes became uncovered. In perspective, this new method raises the possibility of identifying synaptic inputs which causes a cell fire. We have shown that it is possible to reconstruct the intracellular membrane potential based on extra-cellular potential measurements and developed a three-step model-based method to reach this aim. In the first step the micro-electric imaging method was used to reconstruct the spatiotemporal distribution of the single cell current source density from the EC potential patterns. We have shown that the CSD calculated from the EC potential does not correspond to the total membrane current.

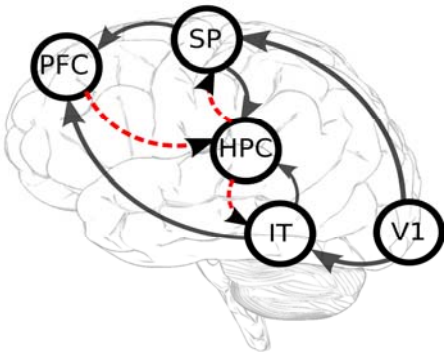


The action potentials were measured in cat primary auditory cortex with a 16 channel chronically implanted linear probe in vivo. The current-source density map of a neural action potential in space (vertical axis, cortical depth) and time (horizontal axis). The propagation of inward current waves appears as red diagonals while outward counter-currents as blue areas

Then we have introduced a second step of the analysis, a model-based spatiotemporal deconvolution to reconstruct the spatiotemporal distribution of the net membrane current from the CSD distribution. Finally, the membrane potential was reconstructed by using a current-based compartmental model.

Dynamic modeling of associative learning in schizophrenia

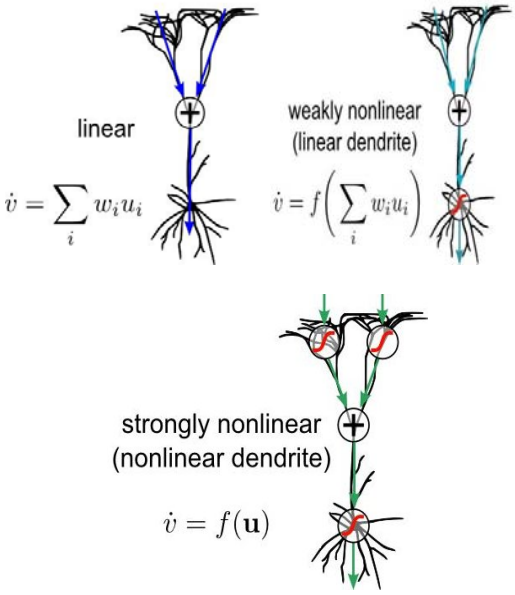
Schizophrenia is a complex disease of very diverse symptoms and mostly unknown causes. A possible underlying phenomenon is the functional disconnection of cortical macro-networks implementing the given tasks. Vaibhav Diwadkar (Wayne State University, Detroit, USA) has conducted an fMRI study of associative learning with schizophrenia patients. The data are analyzed using Dynamic Causal Models to reveal the structure of connections between brain areas in healthy and schizophrenic subjects. Results show impairment in the prefrontal control of the associative memory formation in the hippocampus.



Information processing network of brain areas

Probabilistic computation in dendritic trees

The operation of neural circuits fundamentally depends on the capacity of neurons in order to perform complex, nonlinear mappings from their inputs to their outputs. Indeed, a lot of classical theoretical works focused on how networks of nonlinear units are able to perform cognitively relevant, highly sophisticated computations. However, the variables relevant for such computations are often assumed to be represented by analogue quantities e.g., the membrane potential of neurons, ignoring that neurons communicate by spikes, and in turn spike generation loses information about the detailed dynamics of subthreshold membrane potential fluctuations. Thus, neurons need to perform nonlinear computations on their inputs and they need to do this in the face of significant uncertainties as well. We have been investigated weakly nonlinear computations in which neurons need to compute some global (somatic) nonlinear function of the linear combination of their synaptic inputs. Such weakly nonlinear transformations seem to suggest linear dendritic operations and are often assumed in descriptive models of neural coding. In contrast, we found that the optimal implementation of even purely linear dendritic computations requires the interplay of many independent nonlinear subunits within the postsynaptic dendritic tree.



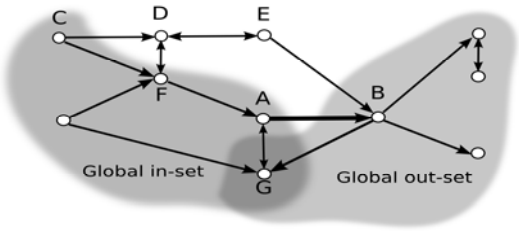
Linear, weakly nonlinear and strongly nonlinear computations. We demonstrate that the optimal implementation of even linear or weakly nonlinear computations requires strongly nonlinear dendritic tree if presynaptic neurons are correlated and neurons communicate by spikes

We demonstrate that nonlinear dendritic trees bring significant benefits to single-neuron computation across a wide range of input correlations even if the individual synapses are optimal estimators of the corresponding presynaptic membrane potentials. We have also proved hat the optimal synaptic weights reflect the statistical structure of presynaptic membrane potentials. Our results demonstrate that active

dendritic processing has an essential role in circuit-level computations in spiking networks. This approach provides unique insights into some puzzling forms of nonlinear dendritic dynamics and plasticity.

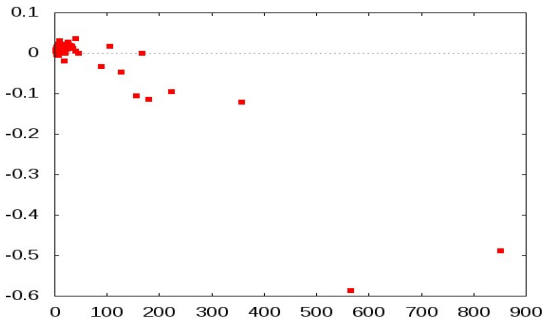
Organization of signal flow in directed networks

Complex data and systems can often be represented as directed graphs. Many of such systems implement some sort of signal processing, transmission and control. In this project the question is: how does the structure of the network influence the signal processing features or stated as a reverse engineering problem, given the structure of a network what can be deduced about node's functional properties. We have introduced novel edge-based measures to describe the convergence and circulation of the information on a given edge, both based on the notion of shortest paths passing through the given edge. These measures provide additional information to the traditional measures such as the clustering coefficient or degree distribution, so they are useful to differentiate and classify real-world networks or random graph models with different information processing properties. The measures introduced are scalable; it is possible to adjust the appropriate or desired level of resolution.



Convergence fields of an edge

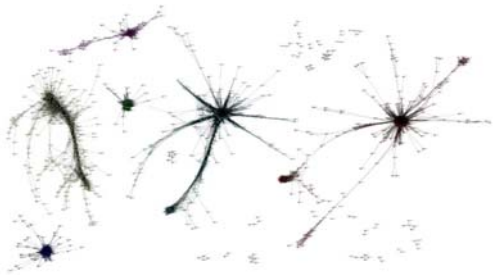
We condensed the edge-based information to network nodes and were able to define formal flows useful in determination of functional properties of network nodes. In case of real-world networks our approach allowed comparison with the existing background knowledge to relate empirically introduced classifications of network edges and nodes with our formalism. In case of large networks our methodology allows study of community-scale functional properties which relates functional properties of signal processing at the level of communities to their internal structure.



Relation between the convergence degree flow of the aggregated network and the respective community size, shown is the relation for the Linux kernel

Prediction of technological development from patent citation network

Patent citation network is an imperfect but faithful representation of technological development. A patent citing another implies that the cited patent represents a piece of previously existing knowledge that the citing patent builds upon. Consequently a directed link between patents can be interpreted as an idea-flow. The patent citation network is a complex system growing in time. It has already been proved by the RMKI group and collaborators that the development of the network shows similarities to other real world networks such as the Internet or the World Wide Web. The network is sparse and the degree distribution of nodes follows a power law. We have built a model that assigns citation probabilities at any given time to each patent which considers the patent's age, in-degree and the patent's industrial category as well.



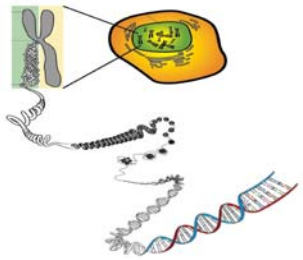
Clusters of patents based on citation similarity

We are now extending our research to explore the community structure of the patent and are developing a methodology which identifies clusters of patents: technological branches and their evolution over time. The method lets us make predictions about the near future answering questions like what are the technologies of the 21ST century.

GENOMICS

Grid application in genetics

Genetics is the science of information transfer in the biological cells and other microscopical living objects. This transfer is based on the structure of DNS and/or RNS, and genoms are the elementary units which are conducting this transfer. Thus genomics became the basic scientific field to study the nature of human genetics.



DNS spiral in the chromosomes of the cells

One chromosome contains thousands and thousands of genoms. The connection between these genoms and the transferred information is even more complex. Recent efforts to understand this connection and verify the most important genoms correspond to well-known diseases are in the forefront of scientific research. With the financial support of the National Office for Research and Technology (NKTH) and with the leadership of the Silicon Graphics (SGI) a consortium has been established by the RMKI, the Semmelweis University (SOTE), the Budapest Technical University (BME) and the Csertex Co. to start the GENAGRID project. In this common effort the bio-informatics researchers of the BME are apply their statistical analysis method on genomics databases of the SOTE and using one of the most powerful computers of the SGI to accomplish their analysis. The target topics are leuchemie, allergy and obesity but the system is open to investigate other fields of health problem, also. The SGI ICE supercomputer with 512 cores (5 Teraflops) and 16 TB storage are installed at the RMKI. The project started at the beginning of 2009. After the complete installation of the ICE the continuous computer analysis work started in 2010.

The SGI ICE machine with 512 cores

On the basis of earlier experience with GRID systems the GENAGRID team at RMKI provides the support to run the SGI ICE in 24 hours at high level of safety and manages the users from the fields of bio-informatics and genomics. In parallel a low installation cost and low running cost cooling system has been developed to maintain the SGI ICE, which consume 32 kW at peak-power. This special water and air cooling complex at RMKI serves as a reference unit in Hungary.

Water + air cooling system to support the SGI ICE

NETWORKING AND IT SERVICES

COMPUTER NETWORKING CENTER

Campus backbone and central services

The Computer Networking Center (CNC) is responsible for maintenance and development of the KFKI campus backbone network. The uplink connections to the Hungarian academic backbone (HBONE) (and the also commercial backbone) are managed by the CNC.

The department runs the central services: firewalls, VPN concentrators, mail gateways with spam and virus filtering, mailing lists, user account servers with regular backups, domain name and time servers, database (SQL, LDAP) servers, authentication servers for the international research and education communities (eduroam and eduGAIN), videoconferencing gatekeepers, web servers and provides server and web hosting services for the research groups and communities. CNC manages the server for the campus library as well.
Several open source IT projects are developed and maintained by CNC:

Postfilter – Centralized, highly configurable, redundant spam filtering system.

L2D2 – Database management tool to handle DNS and DHCP data both for IPv4 and IPv6 networks.

The head of CNC, József Kadlecsik, is a member of the Netfilter core team, which maintains and develops the firewalling part of the Linux kernel. CNC is a regional center of the Hungarian academic network (Hungarnet). There is an IT Committee on KFKI Campus coordinating networking activities of the on-campus research institutes, the chairman of the Committee is the Head of CNC.

Grid services

The Grid group of CNC is responsible for the development and operation of the high performance and high capacity computing resources of RMKI. These resources support a wide range of scientific applications and research fields, such as high energy particle and heavy ion physics, astrophysics and various topics in theoretical physics. In addition, mathematical, medical and engineering communities and applications are supported as well. The most important resources and activities of the Grid Center are:

1. The BUDAPEST Tier-2 site of the Worldwide LHC Computing Grid. These resources are a part of the global computing grid that is dedicated to the physical analysis of the CERN LHC experiments. In particular, over 500 CPU cores and 300 Terabyte of disk storage are dedicated to the CMS and ALICE experiments, providing about 1% of the whole WLCG Tier-2 installed capacity. Thanks to the excellent operational level provided by the CNC Grid Group, the BUDAPEST grid site has finished in second place of the CMS aggregate availability and reliability rankings for the year 2010, with over 98% availability. This is a marked improvement over the 2009 results (6th place with 96%).

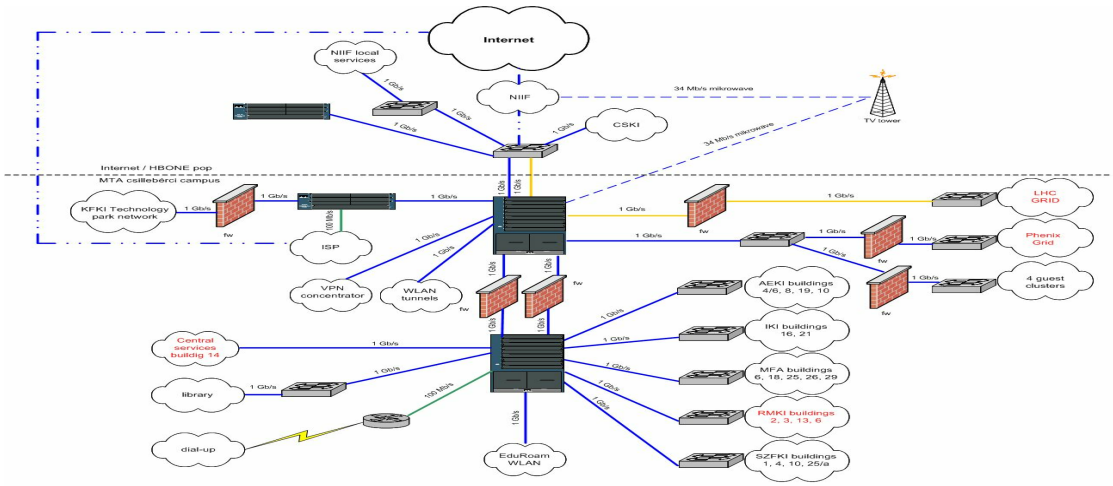


Diagram of the campus backbone

2010. 08. 08.

2. The Grid Center resources are also part of the European research grid provided by the EGI (European Grid Initiative) collaboration. The Hungarian NGI (National Grid Initiative) grid infrastructure is operated with a strong leadership of RMKI, with over 80% of national resources and all core services provided by the CNC Grid Group. The only established platform of the Hungarian NGI infrastructure, the Hungrid Virtual Organisation is developed and operated under the authority of RMKI. Hungrid provides important tools and resources to the whole national academic and research community, and supports medical, engineering, mathematical and climate research applications. Hungrid is involved in dissemination and university education as well.

3. The Grid Center operates resources dedicated to the support of the VIRGO-LIGO experiment. Over 40 Terabyte of disk storage and a GPU computing cluster are provided for the physical analysis of the VIRGO-LIGO gravitational wave detector data.

4. The Grid Center operates a cluster within the framework of the PHENIX Grid, a distributed computing resource dedicated to the support of the PHENIX experiment of the BNL RHIC facility. The cluster supports various heavy ion physics analysis and simulation applications.

Speech Technology

The sub-department of CNC, the Laboratory of Speech Technology for Rehabilitation (LSTR) does research and works on a set of integrated text to speech tools for the blind. Their project is the successful **MOST** (MObile SlateTalker) system.

Virtual Braille cell keyboard

The “MOST” device is based on hand-held computers and a special software framework developed by the GVOP project consortium. Instead of using a screen reader, it provides applications with audio interface created specifically for blind users. An intuitive navigational system provides program control and execution for the blind user. Text input is performed using a virtual Braille cell keyboard on the touch screen of the device.

The Mobile Slate Talker is powerful - it integrates many different functionalities previously only found in several specialized devices. It is simple - no special training or in-depth computer knowledge is required for using the device. Program control and text input is designed especially for blind users.

The following applications provide the core functionality of the system:

Notepad - Text editor for reading and editing documents, send text as SMS or E-mail.

Contacts - Contact manager to contact information for phone calls, short text messaging and e-mails.

Mobile phone - Program to initiate calls, sending and receiving SMS, accessing call history and settings.

E-mail client - Supports the POP3 and IMAP mail protocols.

Audio player and recorder - To record voice memos or music through the internal microphone of the device. It also works as a playback device supporting WAV and MP3 file formats.

Clock, calendar and alarm - These programs provide time and date management functions.

GPS navigation – Blind friendly no graphics GPS navigation plug-in, based on the navigation engine of the Nav-N-Go Ltd.

Device manager – To check and/or set battery and memory status, TTS settings, volume level, etc.

The MOST system has been reworked to support a new type of PDA (Airis T483). Two dozens of these types were bought by blind users and for them the MOST system was installed and the owners were trained to use it, including the new GPS module. A **Talkpad touch-pad** software was designed for facilitating the communication of autistic persons and a new woman-voice speech syntethizer has been added to the system and given for testing to an autist young girl.