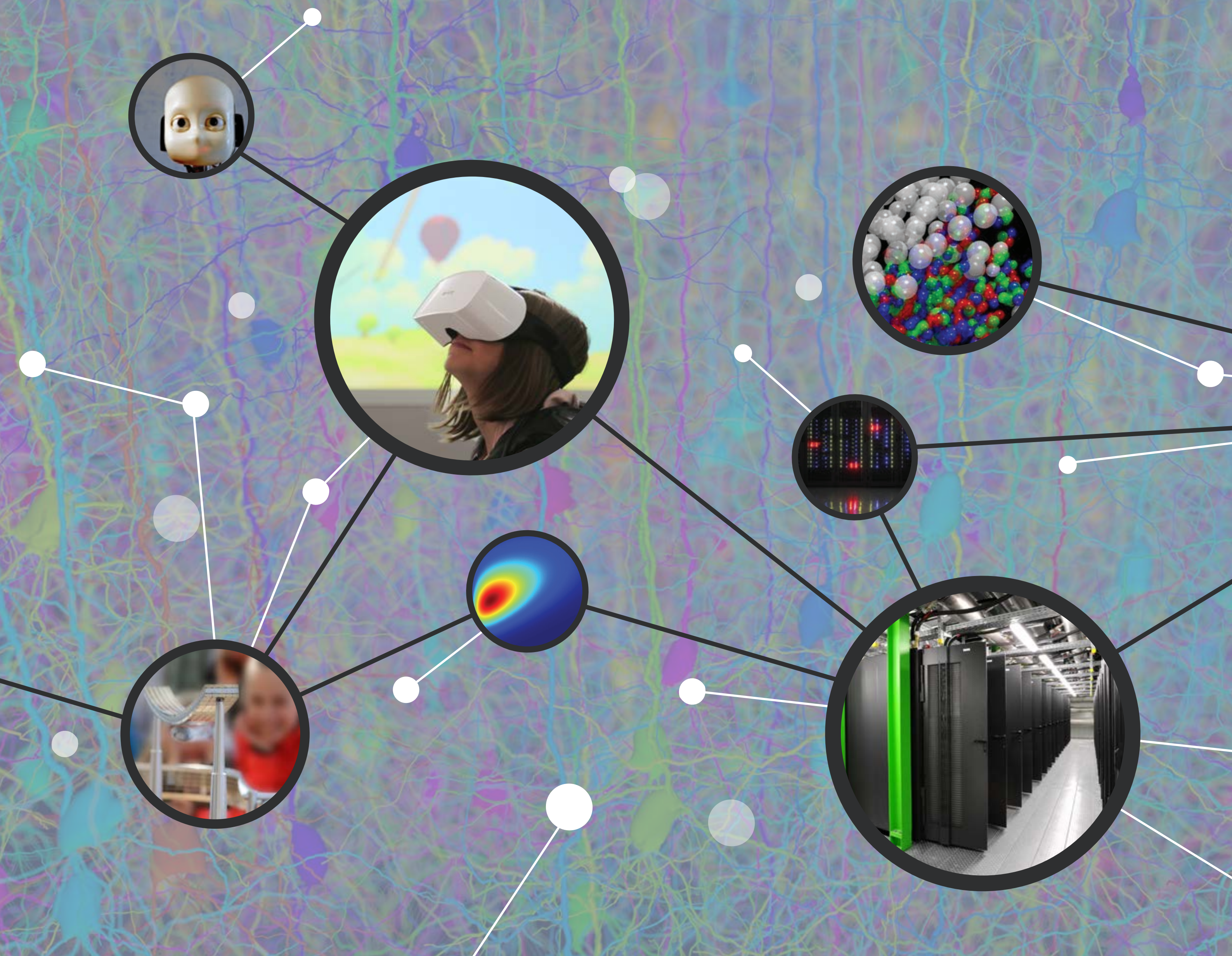
FIAS Frankfurt Institute for Advanced Studies

2016



FIAS

Science for the world of tomorrow

– rarely was the founding slogan of FIAS as relevant as in 2016. In a lot of research and various events, the FIAS scientists and its supporters looked into the future.

The Green IT Cube, which was developed at FIAS and operated at the GSI Helmholtzzentrum in Darmstadt, was inaugurated in January. During the CoNDyNet workshop it was discussed how we can achieve reliable and stable power networks. The event highlight of the year has been the first Giersch International Symposion in September, where the Nobel laureate in physics Gerard 't Hooft was named the first FIAS Senior Fellow Laureatus. The event was made possible by Stiftung Giersch, FIAS' largest private supporter in 2016. Also Franziska Matthäus, started her work as a Giersch endowed professor in the field of bioinformatics.

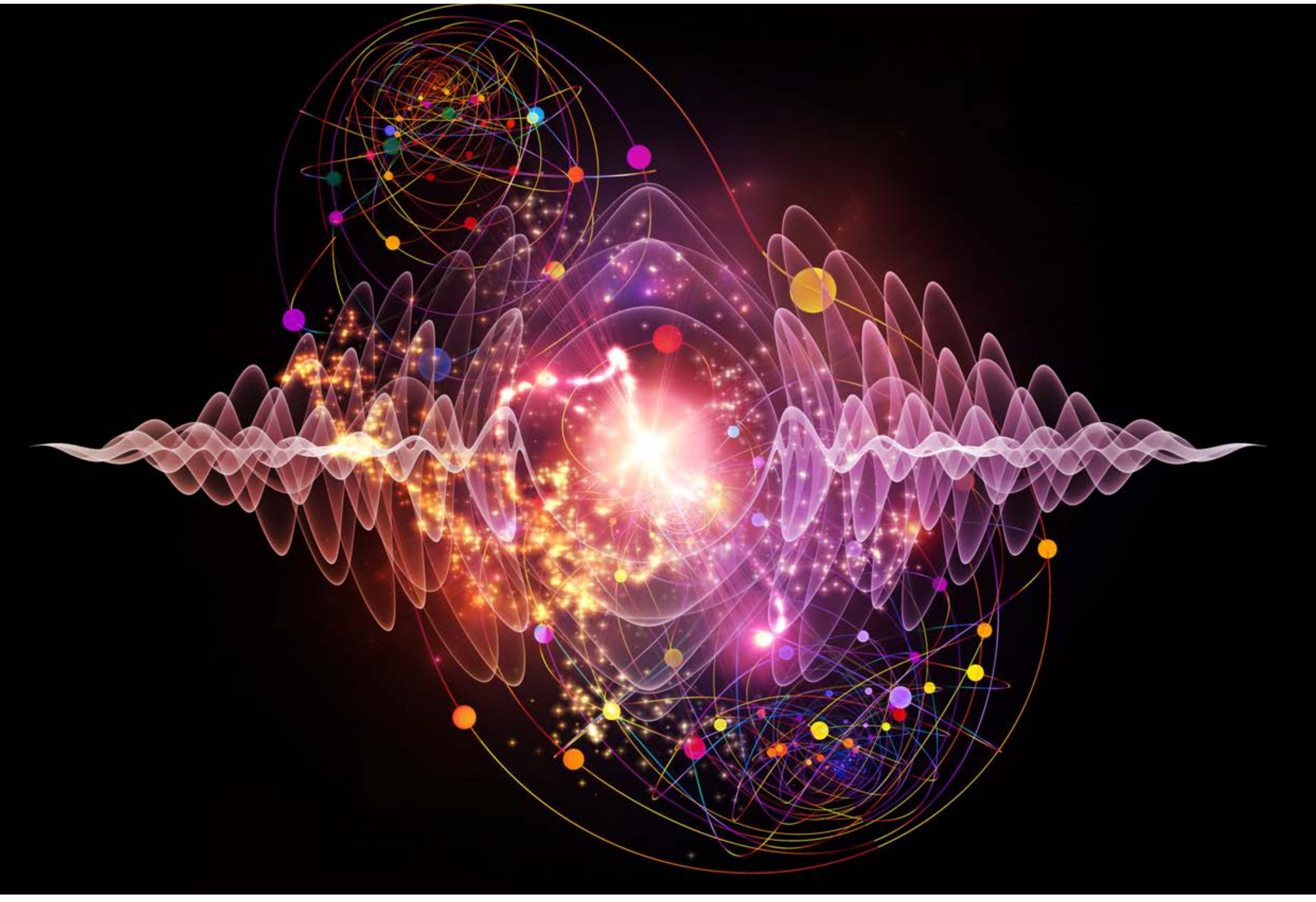
The world of tomorrow was also a huge scientific topic at FIAS. For instance is the FIAS a partner in the new EU project GOAL-Robots, where it is envisioned to develop autonomous learning robots.

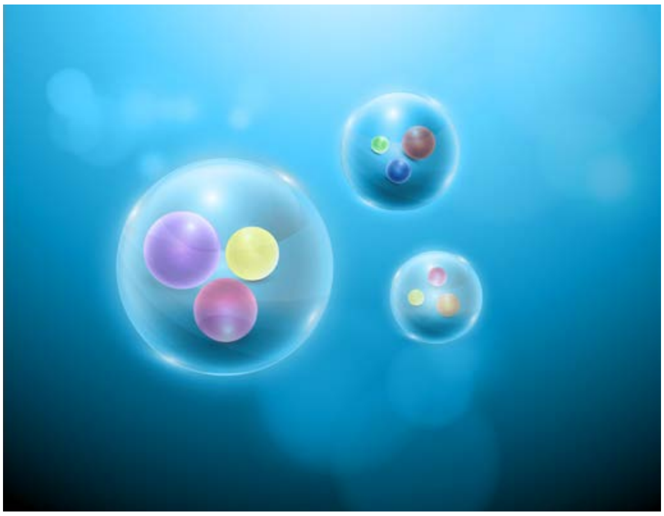
But 2016 was also the year of farewells — FIAS has lost its founding director Walter Greiner and its Scientific Secretary Joachim Reinhard, two outstanding scientists and driving forces of FIAS. We will miss them dearly.

These topics can only show a small part of the FIAS year 2016. On the following pages you will get a closer look what scientists at FIAS achieved in the previous year.

Content

Physics





Quantum gravity:

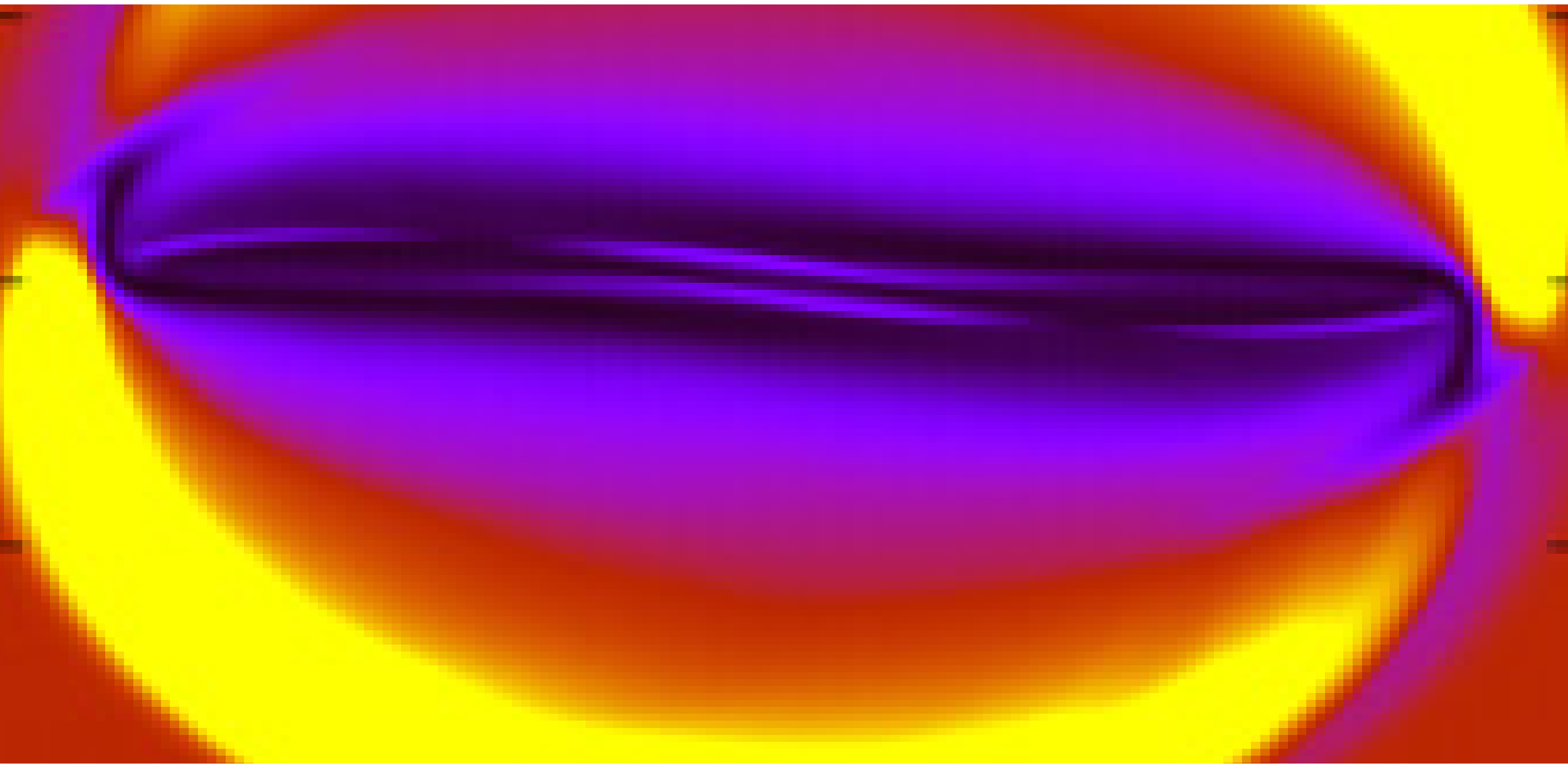
For years, experimental measurements of the gravitation force at the quantum level have seemed technically unachievable. But new observational methods and highly precise measurements could show their first successes in the foreseeable future. That is why this year, the Giersch International Symposium made the topic of "quantum gravity" its main focus. Quantum gravity is meant to unite quantum physics with the theory of relativity, and thereby form a coherent theory that takes all elemental powers into account.

Theoretical physics is the discipline that aims at describing how the world works in terms of fundamental equations. The goal is to abstract explicit phenomena by reducing them to underlying principles that are responsible for many different manifestations in nature. Physical processes are often the basis for other natural sciences, e.g. quantum mechanics is important to understand atoms and therefore chemistry. Establishing knowledge about the microscopic dynamics is crucial to understand macroscopic emergent phenomena. Theoretical physicists at FIAS are working on complex models on very different scales from the elementary particles in the universe to huge objects like neutron stars, two examples of structures governed by the theory of strongly interacting matter.

The properties of such matter under extreme conditions, governed by the theory of Quantum Chromo Dynamics (QCD), are still largely unknown. At high temperatures - accessible in heavy ion collisions - QCD predicts a phase transition from ordinary matter to the Quark-Gluon-Plasma, where the elementary constituents become unconfined. Other interesting new phases of strongly interacting matter, e.g. color superconductivity, at high densities and low temperatures might be realized in the interior of compact stars.

At FIAS, theoretical physicists focus on understanding the properties of strongly interacting matter using a broad range of methods and tools:

- Calculations of the equation of state and the phase diagram with effective models based on hadronic and partonic degrees of freedom, e.g. different versions of the relativistic mean field model, chiral models with Polyakov loop and dilaton field, resonance gas model.
- Dynamical modelling of the complex many-body dynamics of heavy-ion collisions, using methods from classical and quantum mechanics, statistical mechanics, transport theory, quantum field theory, and gravity duality. The employed models include e.g. relativistic hydrodynamics and transport theory, employed for example in UrQMD or SMASH.
- Studies on the structure of exotic nuclei away from the band of stability including hypernuclei and antinuclei by solving the corresponding many-body problems. Binding energy and excitation spectra of these nuclei help understand the syntheses of heavy atoms in stellar explosions.
- Also topics like the distribution of renewable energy can be solved using very similar techniques. Various groups at FIAS are thus involved in modelling energy scenarios. Research in physics is also highly interdisciplinary. Collaborations especially with computer scientists are essential for state-of-the-art research in theoretical physics. Theorists at FIAS closely collaborate with their experimental colleagues working at major accelerator centres like GSI (Darmstadt), CERN-LHC (Geneva), BNL-RHIC (Brookhaven) and are closely involved in the preparations for the future FAIR experiments within the program HIC for FAIR.



Group Information

At FIAS
since 2010

Research Area

Theoretical Physics
Heavy Ion Physics
Medical Physics
General Relativity

Team

Dr. Sergei Ostapchenko
Dr. Alexei Larionov
Gabriele Inghirami
MSc. Paula Hillmann
BSc. Thorben Finke
Amanda Konieczna

Collaborations

SUBATECH, Nantes, France
SUT, Nakhon Ratchasima, Thailand
LBNL, Berkeley, USA

Marcus Bleicher

Heavy-ion collisions create novel states of matter in the laboratory which otherwise only existed microseconds after the Big Bang or nowadays in neutron stars. An especially interesting new state of matter at extreme temperatures and densities is called the Quark-Gluon-Plasma (QGP). Numerical simulations of Quantum Chromodynamics (QCD) at finite temperature in thermodynamical equilibrium indicate that in a QGP the degrees of freedom are not hadrons as in ordinary matter but quarks and gluons, the elementary quanta of the strong interaction. Apart from its relevance for the understanding of the first instants of the expansion of our Universe, the characterization of such state of matter would help to understand why quarks and gluons are confined inside hadrons in normal matter. In fact QCD is responsible for 95% of the mass of matter, while only 5% of the mass is generated by the Higgs mechanism. The degrees of freedom of QCD and the generation of mass constitute key open questions in fundamental physics, with immediate implications on particle, nuclear and condensed matter physics. The present state-of-the-art, resulting from the experimental programs at the SPS and LHC experiments at CERN, and at the RHIC experiments at BNL, is summarized as follows:

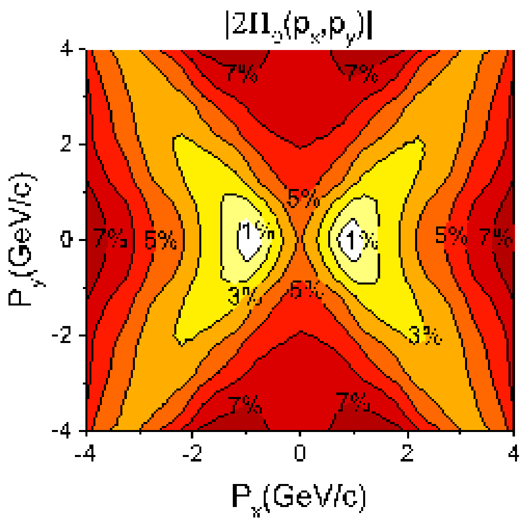
Bulk properties: At the high temperature frontier, i.e. LHC and RHIC, the study of bulk properties, i.e. low momentum modes or soft probes, of the QCD medium has revealed that the initial particle production shows a degree of thermalization that makes a nucleus-nucleus collision (even a proton-nucleus one) different from a superposition of proton-proton collisions. The produced particles seem to develop collective behavior very quickly and the dynamic is describable by relativistic (viscous) hydrodynamics. The formation of a thermalized system allows extracting specific values of the transport coefficients, the degrees of freedom and the equation of state. The created medium can be characterized I) by a very small shear viscosity, very close to an ideal fluid - thus strongly interacting, II) the temperature can be estimated to be above 400 MeV, III) the degrees of freedom are quarks and gluons. At the high density frontier, i.e. collision energies at CERN SPS, FAIR and NICA, the created system is more transient and the onset of deconfinement is expected. Understanding and modelling reactions at this lower energy demands more complicated approaches than at ultra-high energies. Here, the system is not homogenous and quick equilibration may not be assumed. Currently one observes irregular structures in fluctuation/correlation observables that may be tied to the onset of QGP formation and may indicate the existence of a critical point. From the exploration of the in-medium spectral functions of vector mesons via di-lepton experiments, one may conclude that the widths and masses of the hadrons are strongly modified in the dense hadronic medium. In addition also flow observables and particle number ratios do hint to irregular structures, compatible with the onset of QGP formation at low energies.

Rare probes: The medium can be studied by hard probes with the help of perturbative methods. Such probes include high momentum particles and jets, heavy quarks, and quarkonium bound states. These probes revealed that the medium is very opaque for high momentum particles and dissolves loosely bound quarkonium states. There is some probability of quarkonium formation via recombination of the abundant charm quarks produced in the collision. The extracted values of the corresponding transport coefficients point to sizeable interactions inside the produced medium, consistent with the soft probes discussed above. Thermalization and Collectivity: Finally, smaller systems like very high-multiplicity pp collisions, and pA collisions, show several of the collective features found in nucleus-nucleus collisions. Here we address the approach to thermalization, the onset of collective behavior and the minimal size for collective mechanisms to be applicable to describe a system.

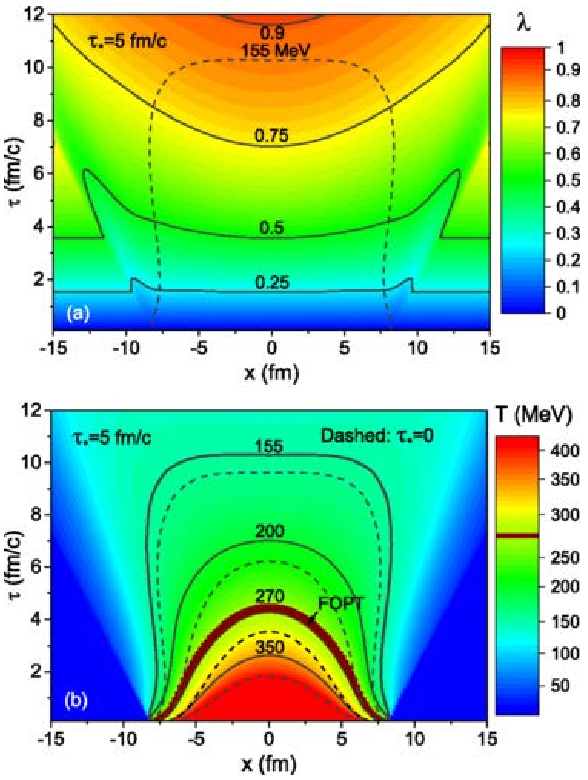
All in all, the picture of the heavy-ion collisions at RHIC and the LHC that we get is that of a dense medium made of quarks and gluons, with sizeable interactions, but still far from the ideal, high temperature limit of a plasma made of quasi-free quarks and gluons. At lower energies, a consistent picture includes the onset of deconfinement and the approach to chiral symmetry restauration.

Prof. Dr. Marcus Bleicher

Marcus Bleicher, born in 1970, received his doctoral degree from the Goethe University in 1999 and his Habilitation in 2007. Afterwards he spent his post-doctoral years in Berkeley, USA and in Nantes, France. From 2003 to 2009, he was a Junior-Professor. In 2010, he was appointed as a (tenured) Professor of Theoretical Physics at Goethe University. He was the Scientific Director of HIC for FAIR, from 2011 to 2015. Besides he has been a Senior-Fellow at FIAS since 2010 and has served as Member of the Board of Directors of FIAS, from 2014 to 2017. His main research topics are numerical transport simulations of heavy ion reactions to understand the properties of QCD-Matter at extreme densities and temperatures, e.g. the Quark Gluon Plasma.



Magnetic pressure in a relativistic magneto-hydrodynamics simulation. Taken from Ingharimi et al, Eur.Phys.J. C76 (2016) no.12, 659.



Picture 1: Contour plots of the quark fugacity λ (a) and temperature T (b) in the x−τ plane for the 0–20% most central Pb+Pb collisions at $\sqrt{s}$=2.76 TeV. The solid curves show contours of λ and T (in units of MeV). The dashed line in (a) corresponds to the isotherm T=155MeV. The dark band labeled by FOPT corresponds to the mixed-phase region of the first-order phase transition at $T=T_C$=270MeV.

Group Information

At FIAS

since 2004

Research Area

Equation of state of strongly-interacting matter under extreme conditions

Hydrodynamic modelling of relativistic heavy-ion collisions

Properties of nuclear matter in supernova explosions and compact stars

Modelling Ion-Beam Cancer therapy

Team

Dr. Shun Furusawa
Allesandro Brillante
Claudio Ebel
Daniel Yueker
Sophie Dewey

Collaborations

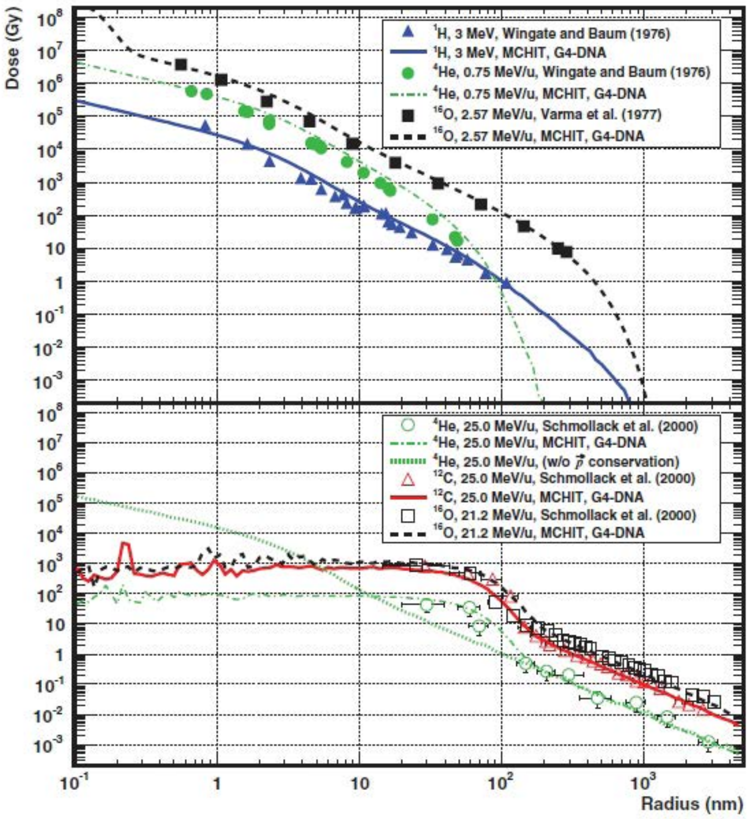
DKFZ, Heidelberg
Kurchatov Institute, Moscow
INR, Moscow
Bogolyubov Institute, Kiev

Igor Mishustin

The main question of the relativistic heavy-ion physics, is there any strong (1-st order) phase transition between the hadronic and quark-gluon phases of strongly-interacting matter, remains still unsolved. We have performed 3d-hydro simulations assuming that the initial state of the fireball is dominated by gluons, but quarks are produced at later stages of its expansion, see Picture 1. Our conclusion is that the strong first-order phase transition in the gluonic matter may produce noticeable signatures in the photon and dilepton spectra.

The properties of clusterized nuclear matter under the condition of electro-neutrality, as expected in supernova interiors, are calculated under different assumptions regarding the nuclear ensemble (multi-nucleus versus mono-nucleus). We have investigated the sensitivity of the predicted nuclear composition to the model parameters, see Picture 2. These calculations are needed for better understanding of nucleosynthesis and neutrino transport in the course of supernova explosions.

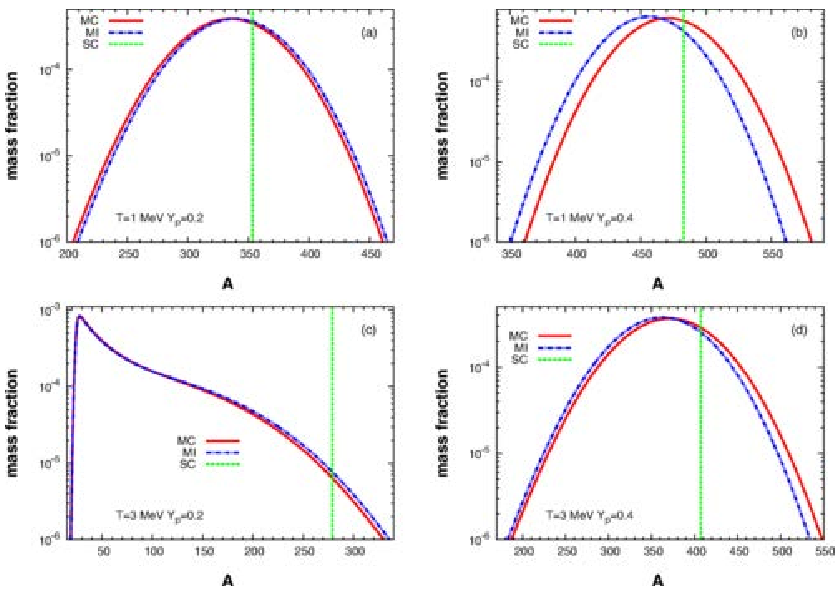
Proton and ion beams are widely used now for cancer therapy via depositing energy into the malignant tissues. The challenge is to develop theoretical models for accurate evaluation of the delivered dose and harmful effects of irradiation. The Monte Carlo Model for Heavy Ion Therapy (MCHIT) developed earlier at FIAS has been extended recently to the micrometer (cellular) scales. The predicted distributions of deposited energy around the ion tracks are in good agreement with experimental data obtained by microdosimetry method.



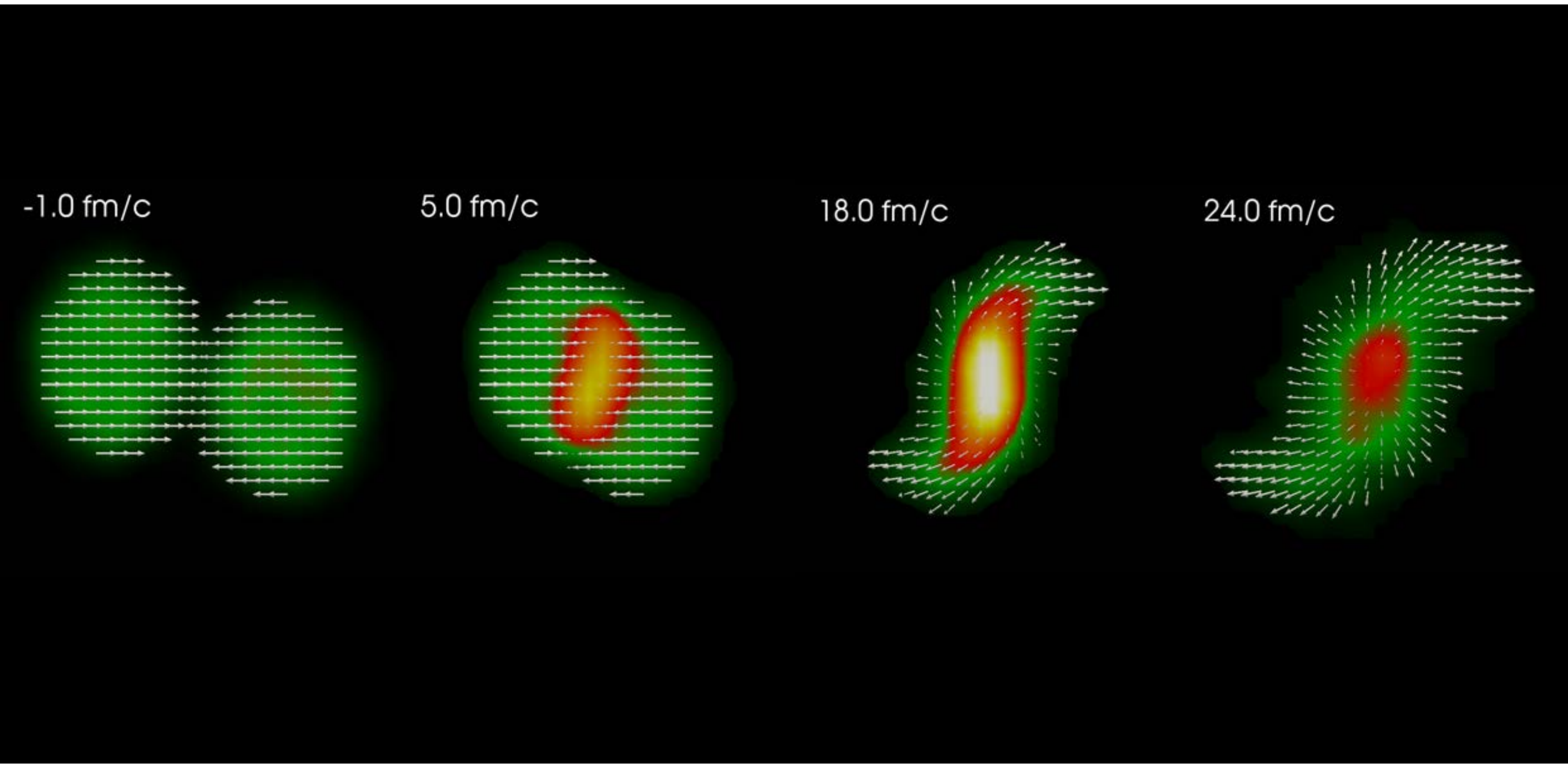
Picture 3: Radial dose profiles for 1H, 4He, 12C and 16O ions propagating in water. MCHIT-calculated results are shown as lines. 25 MeV/u 4He results, shown as green dash-dotted and dotted lines, were obtained, respectively, by simulations with and without imposing momentum conservation in ionization events. Experimental data are shown by symbols of various colors and shapes.

Prof. Dr. Igor Mishustin

Igor Mishustin studied theoretical physics and astrophysics at the Moscow State University. He obtained his PhD and then the Doctor of Sciences degree (habilitation) at the Kurchatov Institute in Moscow. After various stays at other institutes, he joined the newly-established Frankfurt Institute for Advanced Studies, in 2004. Here he leads the group of theoretical subatomic physics and astrophysics. Over the years he was lecturing graduate and post-graduate courses as well as supervising Diploma and PhD students at several Universities.



Picture 2: Mass fractions of heavy nuclei as functions of mass number A for different assumptions regarding the nuclear ensemble, as a function of nB at T=1 MeV (top row) and 3 MeV (bottom row) and Yp=0.2 (left column) and 0.4 (right column).



Hannah Petersen

Group Information

At FIAS
since 2012

Research Area
Theoretical nuclear physics
Heavy ion collisions
Transport theory and hydro-dynamics

Team
Dr. LongGang Pang
Dr. Juan Torres-Rincon
Dr. Feng Li
Dr. Sangwook Ryu
Dmytro Oliinychenko
Vinzent Steinberg
Alba Soto-Ontoso
Jean-Bernard Rose
Markus Mayer
Anna Schäfer
Jan Staudenmaier
Christian Schwarz
Jan Hammelmann
Ömür Erkiner
Niklas Ehlert
Niklas Cichutek
Justin Mohs

Collaborations
David Blaschke, Wroclaw University
Xin-Nian Wang, LBNL &CCNU
Ulrich Heinz, Ohio State University

The major goal of heavy ion research is the exploration of the phase diagram of strongly interacting nuclear matter. In highly relativistic collisions of ions at almost the speed of light, the quark-gluon plasma, the state of matter shortly after the Big Bang is formed. To learn something about the transition and the properties of the transition from the quark-gluon plasma to the hadron gas phase, theoretical models of the dynamics are essential.

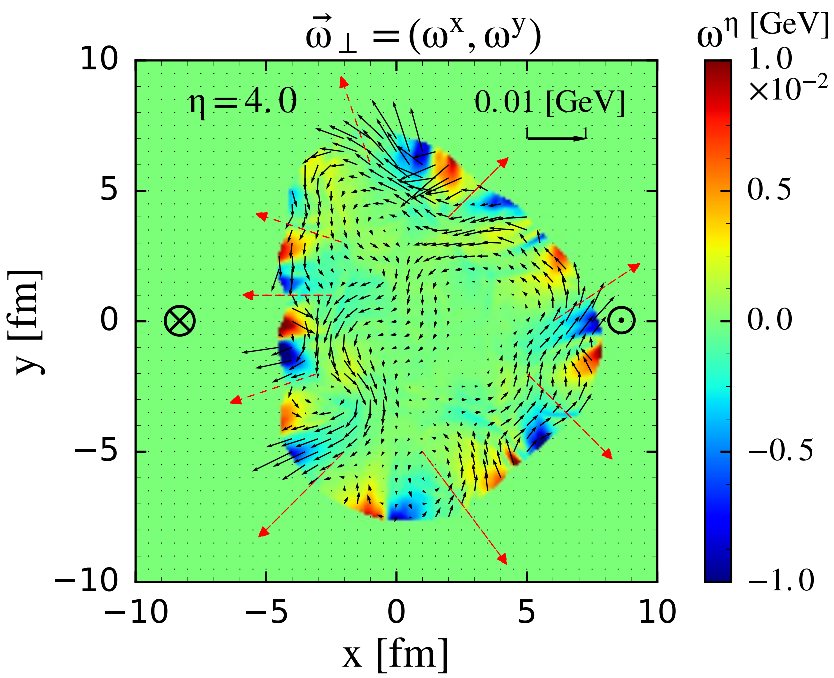
With the recent new experimental data on resonance production at low beam energies and advances in high performance computing the necessity arose to develop a new hadronic transport approach to describe heavy ion reactions at low beam energies as they are currently performed at GSI and in the future at FAIR. The new approach (SMASH –Simulating Many Accelerated Strongly-interacting Hadrons) solves the Boltzmann equation for all known hadronic states up to a mass of 2 GeV with their individual cross sections and is used for a first comparison to experimental data on particle yields and spectra. All reactions fulfill detailed balance and the equation of state of a hadron gas is reproduced. In the figure above the time evolution of a heavy ion reaction is shown within this approach. To display the energy density and collective flow velocities, the particle properties have been coarse-grained. It is visible that over time the expected profile of transverse flow develops from the original longitudinal collision.

The second aim of heavy ion research is the investigation of the properties of matter at extreme temperatures and densities. One of these properties is the shear viscosity over entropy ratio. The shear viscosity of the quark-gluon plasma affects the hydrodynamic response of the system that transforms initial state geometry and fluctuations to final state flow observables. In Fig. 2 the transverse plane is shown and there are vortices indicated that develop around the initial hot spots of the system. By spin-orbit coupling this local vorticity is transferred to correlations of polarized hyperons that can be measured by experimental collaborations at the Large Hadron Collider (LHC). The degree of the correlation provides an independent constraint on the shear viscosity of the quark-gluon plasma.

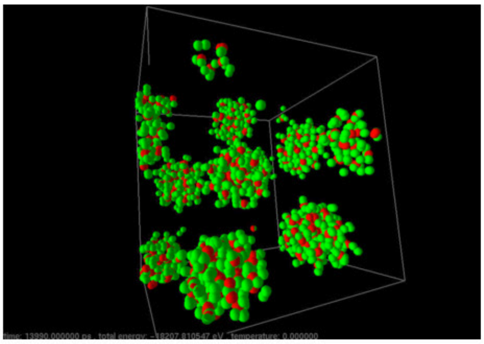
In addition, the two nuclei do not necessarily hit each other head on, but most of the time, they actually only touch each other partially. In these more peripheral collisions the fast nuclei constitute an electric current giving rise to a very high magnetic field. To investigate in a realistic dynamical approach, if the influence of the magnetic fields is large enough to produce a visible effect, we have studied different spatial and temporal structures of the magnetic field and its influence on a viscous hydrodynamic approach. At the highest LHC energies in the most optimistic magnetic field configuration the elliptic flow is reduced by 10 %, which results in a change of the effective shear viscosity of the quark-gluon plasma that would be extracted by a factor of 2.

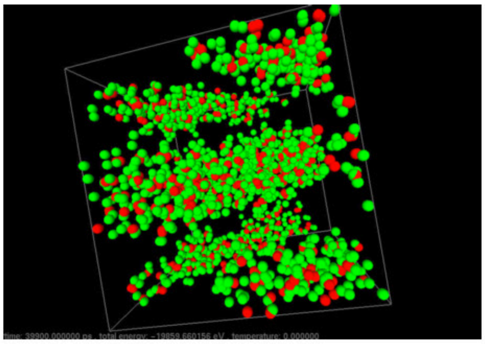
Prof. Dr. Hannah Petersen

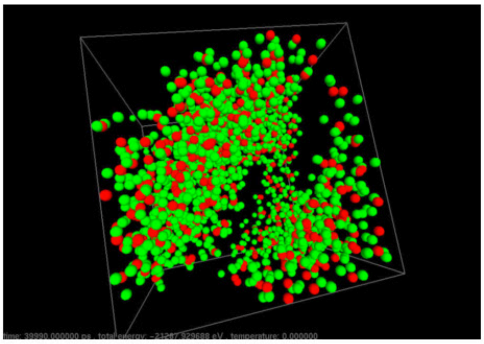
Hannah Petersen is leading a Helmholtz Young Investigator Group at FIAS, since October 2012. She obtained her PhD degree at Goethe University in 2009 sponsored by a stipend of the Deutsche Telekom Stiftung and spent 3 years as a Humboldt fellow and visiting assistant professor at Duke University. Her work concentrates on the dynamical description of heavy ion collisions with transport and hydrodynamics.
In 2016, she received the most prestigious award for young scientists in Germany, the Heinz Maier-Leibnitz prize by the DFG and BMBF.

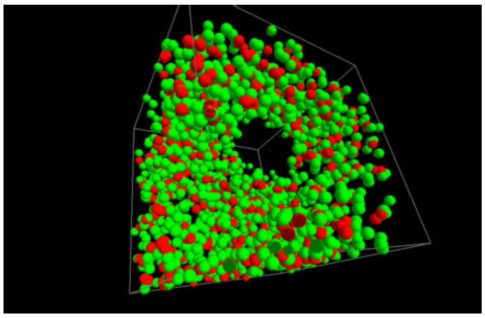


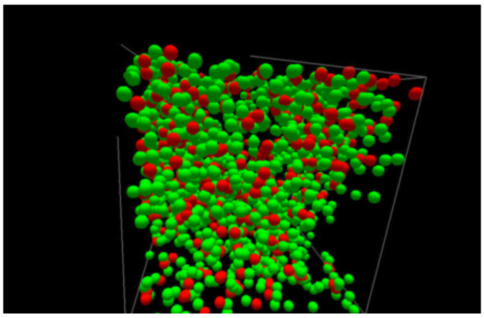
Initial state fluctuations create vortices in the transverse plane, that can be observed by measuring correlations of hyperon spins in highly energetic heavy ion collisions from PRL https://arxiv.org/pdf/1605.04024.pdf











Stefan Schramm

Group Information

At FIAS

since 2004

Research Area

Nuclear Physics
Astrophysics
Heavy-Ion Physics
Complex Networks

Team

Dr. Thomas Brown
Dr. Alexander Kies
Dr. Rosana Gomes
David Schlachtberger
Jonas Hörsch
Ayon Mukherjee
Fabian Hofmann
Markus Schlott
Clara Steinebach
Dominik Kaufhold
Omar el Sayed
Pia Jakobus

Collaborations

A. Bhatthacharya, U. of Calcutta
M. Greiner, U. of Aarhus
R. Mallick, IIT Bhopal
F. Weber, UC San Diego
R. Negreiros, Fluminense U.
V. Dexheimer, Kent State
C. Vasconcellos, UFRGS
M. Malheiros, ITA Sao Paulo
R. Nandi, TIFR Mumbai

The research of Prof. Schramm's group concentrates on two main topics - (1) strong interaction physics in dense and hot matter and (2) complex networks with emphasis on electricity grids and energy systems.

Addressing the dense matter problem: Strong interaction physics under extreme conditions of temperature, density, as well as isospin are central to a large amount of theoretical and experimental activities, including heavy-ion collision experiments, the study of neutron stars as well as the production of exotic neutron-rich nuclei and hypernuclei. While there are many theoretical calculations investigating separate aspects of this physics regime, very few attempts exist pursuing a unified modelling of the phenomena. To this end we developed a combined description of hadronic and quark degrees of freedom, investigating the phase structure of strong interactions as it relates to heavy ions as well as to neutron and neutron-quark (hybrid) compact stars. In the latter case, we also study the effect of strong magnetic fields on the properties of neutron stars and white dwarfs, predicting measurable gravitational wave signals from white dwarfs for the first time.

In the lower-density regime the properties of the neutron star crust are crucial for the understanding of the neutron star phenomenology and the dynamics of supernova explosions. In order to study the crust numerically we developed a very efficient GPU-based quantum molecular dynamics code for the motion of the nucleons in the crust.

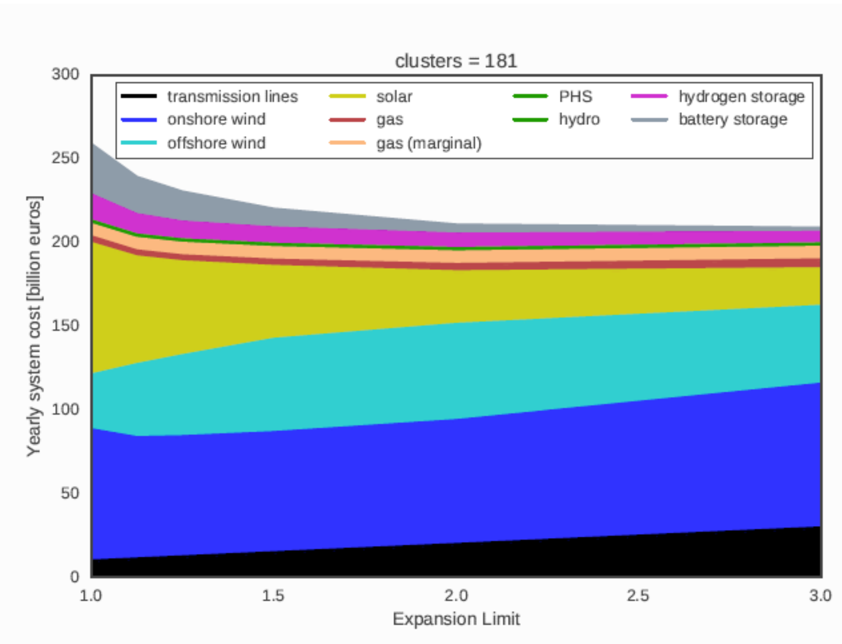
We were already successful in studying various exotic nuclear structures occurring in the inner crust, and we computed first transport coefficients, which are essential for understanding neutron star phenomenology as well as for the neutrino reheating, which is crucial for a successful supernova explosion.

In the field of complex networks, with the backdrop of the "Energiewende" in Germany and the general increased use of renewable energy sources, we investigate the properties and stability of complex network structures. The intrinsic variability of renewable energy production defines a theoretically very interesting system of a network with strongly fluctuating sources, but it generates significant challenges of ensuring a reliable (and cheap) power supply. To study these aspects we developed an open-source software for modelling and optimising electricity grids, including many types of electricity producers, like solar, wind and fossil fuel power stations as well as energy storage components. Couplings to the heating as well as transport sector, i.e. electric cars have been started to be implemented. The software is already being used by many groups working in this field.

Results of modelling the European electricity network show a price-competitive energy system, mainly based on renewable sources with a cap on CO2 emissions, if there is a sizeable, but manageable extension of the power grid. As general approximation schemes we investigated various cluster algorithms and their applicability, similar to changing the renormalization scale of a quantum system. We also developed new mathematical methods to solve the power flow equations efficiently, based on ideas from field theory.

Prof. Dr. Stefan Schramm

Prof. Schramm did his PhD at the Goethe University with Walter Greiner on strong-field Quantum Electrodynamics. He was a Postdoctoral Researcher with Steven Koonin at Caltech and Charles Horowitz at Indiana University, working on a variety of astrophysics and nuclear physics problems. As head of the Center of Scientific Computing he was in charge of setting up the first high-performance compute cluster at the Goethe University. His current work covers modelling and simulation of neutron star physics, non-equilibrium effects in heavy-ion collisions as well as the study of large-scale incorporation of renewable energy sources in the electricity grid and the energy system at large.



European electricity system costs as function of grid extension.

Group Information

At FIAS
since 2015

Research Area
Quantum Gravity
General Relativity
Quantum Foundations
Philosophy of Science
Sociology of Science

Team
Ricardo Torromé
Tobias Kleinert
Tobias Zingg

Collaborations
Nordita, Stockholm
Perimeter Institute, Canada
SISSA, Trieste

Sabine Hossenfelder

In the foundations of physics, we tackle ancient questions like "What is matter?", "What is space?", and "What is time?" Our currently best theories have left us with many open questions which we presently can't answer. The most pressing one is how to reconcile quantum theory and gravity. The two theories are inconsistent, and this tension must be resolved by a yet-to-be-found theory of quantum gravity that describes the behavior of space and time on shortest distances.

Research on quantum gravity has traditionally relied on mathematical consistency, but this approach stalled decades ago. In the phenomenology of quantum gravity, we now study the question how to find experimental evidence for quantum gravity to guide the development of the theory. This is the main focus of Sabine's research.

The phenomenology of quantum gravity brings different research areas in physics together. It draws on cosmology and astrophysics as much as on quantum information and particle physics. Moreover, in the previous decade it has been shown that the mathematical formalism of gravity is closely linked to that of condensed matter systems. This makes it possible to use Bose-Einstein-Condensates (pictured) to study analogous gravitational situations, like black holes or the rapid expansion in the early universe, in the hope of better understanding whether gravity can emerge from the interaction of microscopic constituents of space-time.

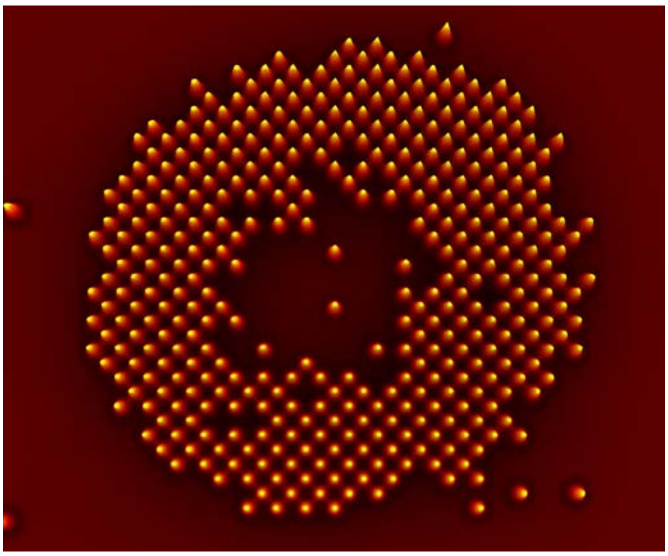
But there are other puzzles in the foundations of physics besides the quantization of gravity. We know, for example, that to adequately describe the dynamics of the universe we must assume the existence of both dark matter and dark energy. The microscopic properties of dark matter (pictured) and dark energy, however, are unknown. Most important, it is unclear whether these are indeed types of matter and energy, or if not the inference of their presence from the data instead signals that general relativity has to be modified. Studying whether modifications of gravity can account for the observations is another research area of Sabine's group.

The question of how to quantize gravity is also intimately linked to the foundations of quantum mechanics, for our failure to quantize gravity consistently might be due to our lacking understanding of quantum mechanics. In recent years, thus, Sabine has studied the prospects of a long-abandoned approach to quantum mechanics, based on non-local hidden variables.

Finally, underlying the quest in theoretical physics is the mother of all questions: What makes a good question? How scientists select research projects and what problems they consider interesting has historical, social, and psychological aspects next to the scientific ones. For this reason, Sabine also contributes to the sociology and philosophy of science, for example with her upcoming book about the role of arguments from naturalness and beauty.

Dr. Sabine Hossenfelder

Sabine graduated from Frankfurt in 2003 and was a postdoctoral fellow, among others, at UC Santa Barbara, and the Perimeter Institute in Canada. Before returning to Frankfurt, she held a position as assistant professor at Nordita, in Stockholm, Sweden. Sabine's research is presently supported by the Swedish Research Council, the German Research Foundation, and the Foundational Questions Institute. Besides her research, Sabine is also active in science communication. She has contributed to several magazines, writes a popular science blog, and will soon publish her first book.



Fluorescence image of Bose-Einstein-Condensate. Image Credits: St. Kuhr and I. Bloch, MPQ.

Scale invariance of macroscopic objects is realized in science fiction only. Scales invariance, however, might naturally emerge at extremely tiny length scales.

Group-Information

At FIAS

since 2010

Research Area

Classical and quantum gravity
Black hole thermodynamics
Quantum field theory in curved space
Particle theory
Mathematical physics

Team

Dr. Antonia M. Frassino
M.Sc. Alain Dirkes
M.Sc. Sven Köppel
M.Sc. Michael F. Wondrak
B.Sc. Marco Knipfer
B.Sc. Roman Smit
B.Sc. Athanasios Tzikas

Collaborations

Prof. Dr. Gerard 't Hooft (Utrecht)
Prof. Dr. Steve Giddings (Santa Barbara)
Prof. Dr. Carlo Rovelli (Marseille)
Asst. Prof. Dr. Matthias Kaminski (Alabama)
Prof. Dr. Jonas Mureika (Loyola Marymount Los Angeles)
Prof. Dr. Marcus Bleicher (FIAS)

Piero Nicolini

Despite the great success, both the Standard Model and General Relativity are far from being complete. Both of them fail to be predictive in the extreme high energy regime. At Planckian scales one can only invoke a quantum theory of gravity to efficiently describe the Universe. Unfortunately the situation is plagued by severe problems. First, there is no candidate theory solving all the issues of general relativity e.g. curvature singularities, a microscopic description for black hole thermodynamics, and the cosmological constant problem. Second, there is no quantum gravity data to discriminate among different theoretical proposals. Therefore, it has become more important to investigate the conditions upon which any piece of new physics can be exposed. String inspired effective theories and non-Einstein gravity theories are expected to shed light on such long standing issues. In such a framework, the group's recent activity has been devoted mostly to black hole thermodynamics and a new state of matter called un-particles.

Thermal properties of black holes are generally negligible for black holes one usually encounters in astrophysics. There might, however, exist primordially produced black holes with the size of a particle or even smaller. Interestingly such microscopic black holes are expected to radiate thermally like a black body within a process called Hawking evaporation. One of the major difficulties is that such black holes might drastically depart from a conventional General Relativity description. Due to their size, they should be described in terms of a quantum mechanical formulation. For instance, according to Dvali's black hole quantum portrait paradigm, microscopic black holes are a condensate of gravitons. The number of such gravitons is related to the pixelization of the event horizon in fundamental qubits, namely cells of Planckian area. In this picture, the Hawking radiation corresponds to the quantum depletion of the condensate that produces a thermal spectrum. Unfortunately, the conventional Schwarzschild metric is in conflict with all black hole models emerging from a quantum mechanical description.

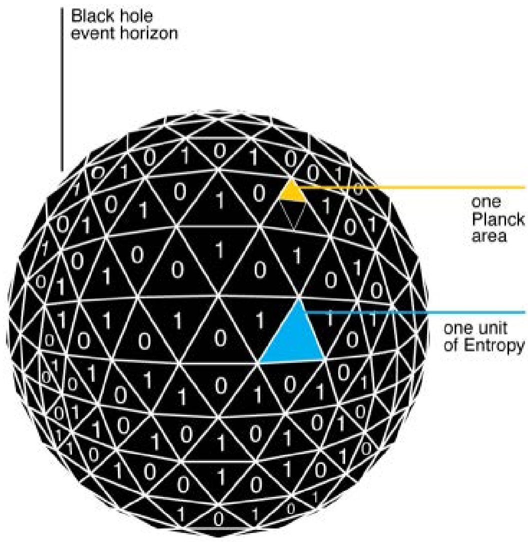
Our major contribution has been to overcome such a conflict. By employing a non-local modification of the Einstein-Hilbert action, we derived a new black hole metric that is compatible with the "pregeometry" resulting from the graviton condensate. As a special feature the black hole is endowed with a potentially observable long range quantum hair.

On the side of particle physics, we devoted our efforts on un-particles, a conjectured new state of matter that is supposed to show up at extreme high energies. As a special feature un-particles are a scale invariant massive sector with a non-integer particle number. Un-particles play a fundamental role in the fractal properties of a quantum spacetime and offer compelling corrections to standard black hole metrics. The theory is essentially governed by the energy scale and the scaling dimension, the latter replacing the conventional particle number.

In such framework, we faced the problem of the Schroedinger equation with a continuous power potential resulting from the un-photon exchange between the proton and the electron in the Hydrogen atom. By calculating energy level shifts we derived bounds on relevant un-particle physics parameters. Our results led to the conclusion that un-particle effects, though important in the high energy regime, can also successfully be tested in atomic physics experiments.

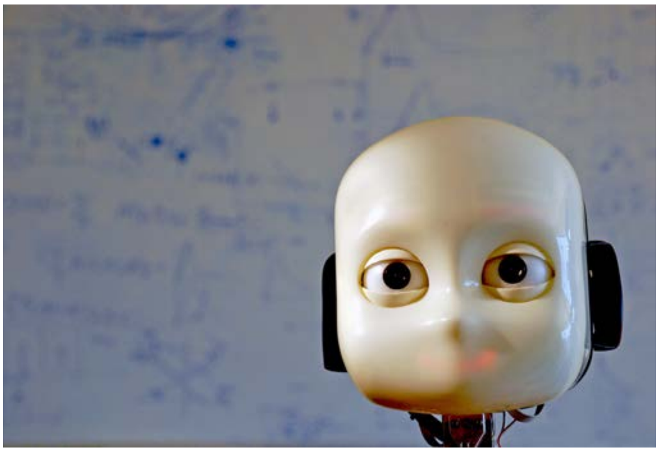
PD Dr. Piero Nicolini

Piero Nicolini received his PhD from the University of Bologna in 2002 and his Habilitation from the Goethe University in 2013. He held postdoctoral positions in Marseille and in Trieste. Currently he is Research Fellow at FIAS and Privatdozent at the Goethe University. His research interests cover quantum gravity, quantum field theory, and the physics beyond the standard model. Piero Nicolini is best known for having first proposed noncommutative geometry as a tool for studying evaporating black holes beyond the semiclassical limit.



Black hole entropy in terms of pixel (bit of information), i.e., Planck area surface elements, covering the event horizon.

Neuroscience



GOAL-Robots:

A robot as an aid in everyday life – a dream out of science fiction films to which we're getting closer and closer.

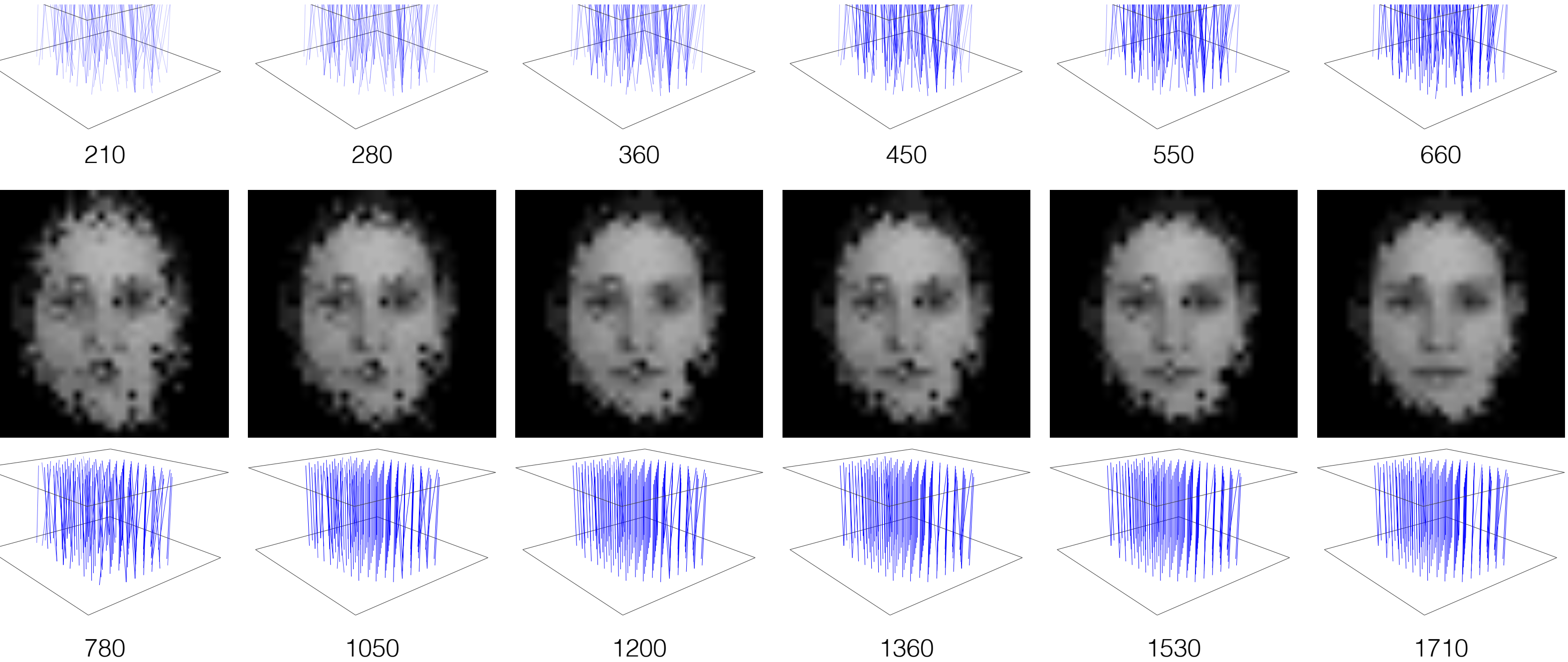
Every year, more and more modern and sophisticated robots are developed with the associated, capable algorithms. But the execution of complex tasks and solving unknown questions still requires painstaking programming of each individual detail. In comparison to biological intelligence, robots are still behind, especially in terms of autonomy and variety.

In fact, future robots should learn to master their environment independently, i.e. generate their own goals and acquire the skills they need to achieve these goals independently and efficiently. Precisely that is what FIAS scientists are striving for in the new EU project GOAL Robots, which Prof. Jochen Triesch's working team is working on with scientists from the Italian National Research Council, the Institute Paris Descartes de Neurosciences et Cognition, and the Technical University of Darmstadt. In the next few years, they will work together to create algorithms that will imitate a person's curiosity and intrinsic motivation, meant to facilitate an endless learning process independent of regular programming and further development by human experts.

The brain is considered the most complex structure on earth. It is composed of a network of billions of nerve cells. Our goal is to understand how cognitive phenomena can arise from the collective interactions of these many neural elements. We firmly believe that by studying the organizational principles of neural information processing through computational modelling, we can further our understanding of brain function and organization and also make progress towards building a new generation of intelligent artificial information processing systems with potentially profound social and economic implications.

In particular, we investigate how the brain's networks and subsystems can self-organize their information processing capacity to give rise to perception and action. Most of our research focuses on:

- the mathematical analysis of high-dimensional spatio-temporal activity patterns that emerge in defined neuronal networks of animal and human brains during cognitive and executive functions and are provided by the associated experimental institutions,
- the simulation of biologically inspired neuronal networks and
- the implementation of insights gained into mechanisms underlying visual perception, action, and learning in robotic systems.



Group Information

At FIAS

since 2004

Research Area

Modelling of
Brain Function

Collaborations

Prof. Irving Biederman,
University of Southern
California

Christoph von der Malsburg

As part of a long-term effort to create a clear picture of how the brain represents the (visual) world, I am working on a model of invariant recognition and representation of visual patterns based on a concept of homeomorphy. According to it, the mental representation of the sector of the environment that is currently fixated is homeomorphically related to the structure of that sector, homeomorphy being based on mapping between structures preserving element type and structural relations. The necessary mappings relating mental representations to sensory input must be dynamically changing objects themselves as sensory patterns are subject to perspective movements.

The model poses the problem how representations can be formed before there are dynamic mappings and how dynamic mappings can be formed before there are representations. In a series of studies, my students and I have shown that both problems can be solved simultaneously by a process of network self-organization (see the figure). Network self-organization is driven by two factors. Temporally correlated activity in two neurons strengthens their excitatory connection ("Hebbian plasticity"), and the total strength of connections converging on one neuron is limited. The first influence favors the consistency between alternative pathways between a source neuron and a target neuron, the second favors sparse networks (neurons with few inputs). Among the structures that are generated or stabilized by network self-organization are, first, two-dimensional neural fields with local connectivity and, second, neighborhood-preserving fiber projections (homeomorphic mappings).

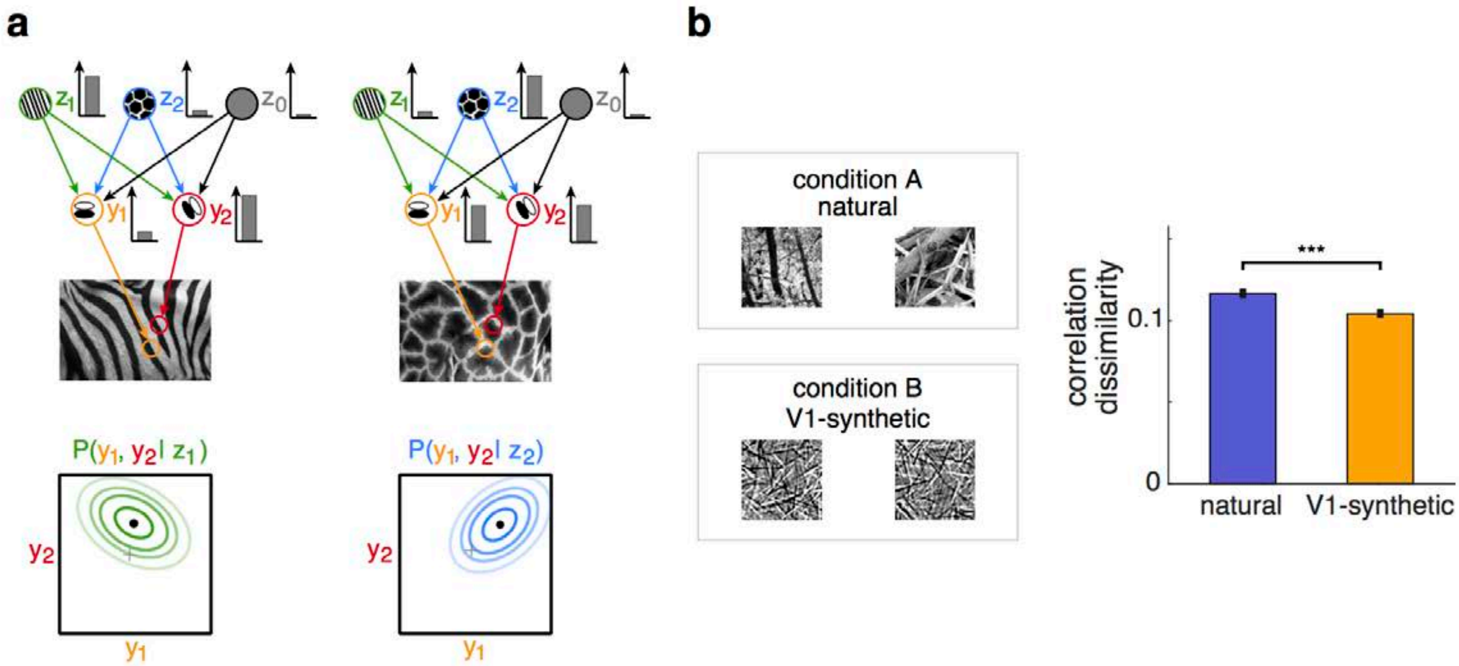
With those two types of networks -- two-dimensional fields of locally connected neurons and topological projections between such fields -- all processes and structures of vision can be realized. To represent rich content, very large numbers of networks have to co-exist in the same tissue, have to be generated during development and learning and have to be activated within the time-scale of cognitive processes. This richness is generated by the combinatorial generation of complex networks out of smaller network fragments. My ongoing activities are directed at understanding the necessary processes.

In order to cope with the visual world, the brain has to decompose the sensory input into different aspects (texture, color, reflectance, depth, motion, shape, contours, illumination, ...) and learn to model two-dimensional models of those as well as the dynamic mappings to link between representations in different coordinate frames -- retinal, object-centered and scene-centered. By decomposing concrete input in this fashion, learning is made extremely efficient, shapes being learned independent of surface markings, illumination, pose and so on, or surface markings are learned independent of shape etc. Once a structural model base for all visual aspects has been learned, the system will be able to decompose and re-compose -- that is, model and predict -- the visual input.

My activities have been and are directed at preparing a major project for realizing a model visual system along those lines.

Prof. Dr. Christoph von der Malsburg

Christoph von der Malsburg is engaged in a long-term quest for a description of the brain as a functional entity. A major focus of his work are the questions how the neural tissue of the brain generates the mental content that we experience, how this neural code is generated in development and learning, and how actual brain states are formed. He is working towards demonstrating his solution to those problems in the form of a model visual system.



Group Information

At FIAS

since 2003

Research Area

Visual cortex, non-linear dynamics, synchrony and oscillations
Plasticity and learning
Recurrent networks

Team

Dr. Andrea Lazar
Yiling Yang

Wolf Singer

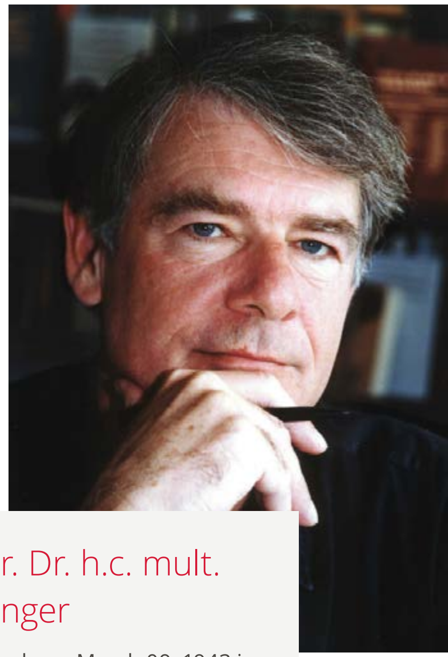
The visual cortex is believed to represent an internal model of the visual environment, where the responses of neurons have been adapted to the statistics of natural stimuli. Inferences made during visual perception, utilize this internal model to remove any ambiguity inherent in the visual stimulus. Uncertainty about the contribution of one or the other representational feature present in the stimulus can emerge at every level of the computational hierarchy and its neuronal representation has been linked to neuronal response variability and covariability. We recorded population responses simultaneously with chronically-implanted, movable electrodes from the primary visual cortex (area V1) of awake rhesus macaques and studied how (1) single unit response variability, (2) spike-count correlations between responses of neuronal pairs and (3) band-limited gamma oscillations in the local-field potential, depend on the content of the visual stimulus (e.g. natural scenes, abstract shapes, textures, synthetic stimuli).

The onset of a visual stimulus causes a reduction in neuronal variability in V1, implying mechanistically that interactions in cortical circuits become more stable when driven. Interestingly, in preliminary analysis we found that both natural scenes and phase-scrambled controls decreased mean firing variability at the level of V1 to a similar extent, however only the natural scenes generated stimulus specific evoked responses. One interesting interpretation of this result is that scrambled images contain less reducible information compared to natural scenes.

In recent work, we studied the fine structure of spike-count correlations and assessed their dependence on stimulus identity and on stimulus statistics. A natural consequence of statistical computations in a hierarchical model of natural images, reflecting the hierarchical organization of the ventral stream, is that inferences on the presence of high-level features influence inferences on the presence of low-level features. In our data, we demonstrated that, as predicted by hierarchical inference, stimulus-dependent spike-count correlations are characteristic of natural images and that this dependence can be manipulated by controlling the higher-order structure in synthetic stimuli.

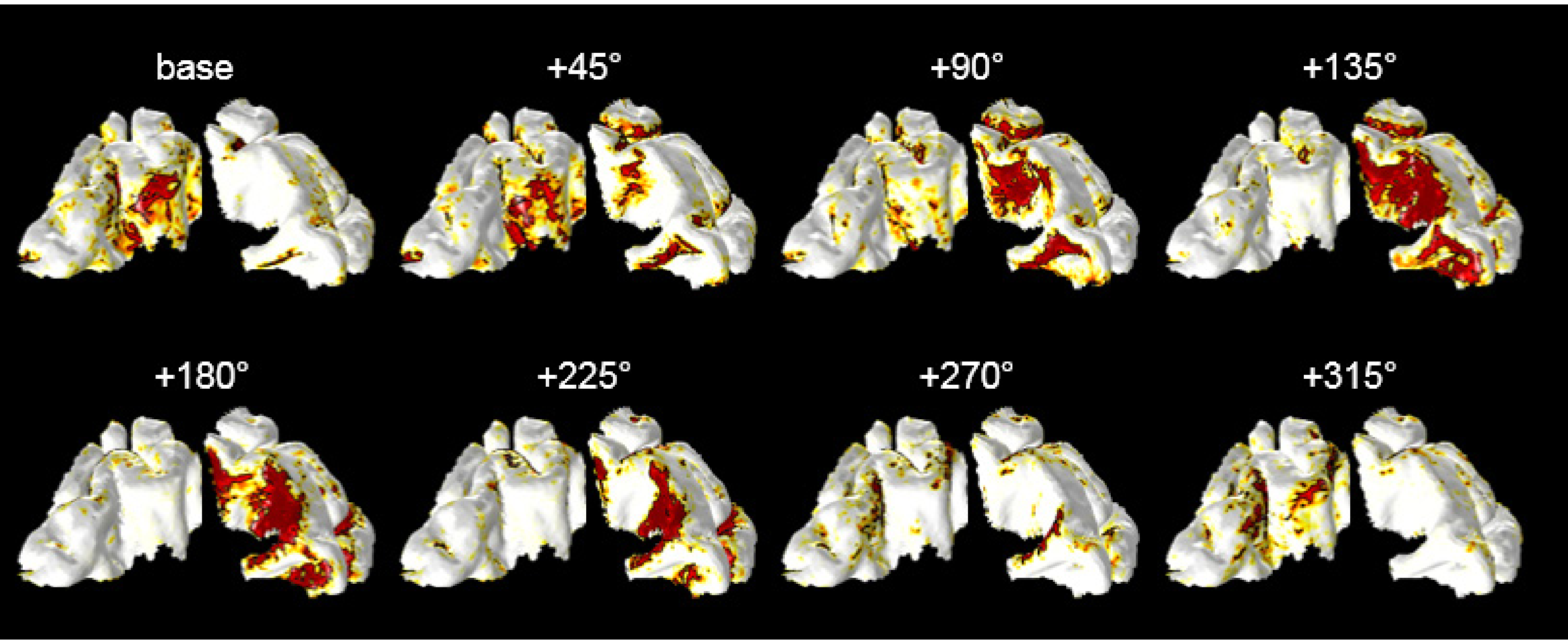
Finally, we showed that not only the spiking activity but also the band-limited gamma oscillations in the local-field potential contained information about stimulus identity and stimulus type. Shapes and natural scenes induced stronger band-limited gamma oscillations than scrambled images and noise. Interestingly, structured stimuli (natural scenes and shapes) led to a build-up in gamma power over trial time and were modulated by attention.

Taken together, these results suggest that any neuronal transformation aimed to increase the efficiency of stimulus representations at the level of the primary visual cortex, may act as a filter which disproportionately favors stimuli with natural structure.



Prof. Dr. Dr. h.c. mult. Wolf Singer

Wolf Singer, born March 09, 1943 in Munich studied Medicine in Munich and Paris, received his PhD from the LMU Munich and his habilitation at the TU Munich.
He is one of the directors of the MPI for Brain Research and FIAS, as well as founding director of FIAS and the Ernst Strüngmann Institut for Neuroscience.
He currently is the scientific director of the Enst Strüngmann Forum in Frankfurt.
His research is devoted to the exploration of neuronal foundations of cognitive functions. Central to his research is the question over how many brain areas processes are connected to allow for coherent perception.



Group Information

At FIAS

since 2005

Research Area

Plasticity and Learning in Spiking Neural Networks
Active Efficient Coding
Learning in Human Infants
Transcranial Magnetic Stimulation

Team

Samuel Eckmann
Dennis Forster
Felix Hoffmann
Florence Kleberg
Lukas Klimmasch
Alexander Lelais
Alexander Lichtenstein
Diyuan Lu
Max Murakami
Bruno Del Papa
Natalie Schaworonkow
Johann Schneider
Charles Wilmot

Collaborations

Bert E. Shi (Hong Kong)
Ulf Ziemann (Tübingen)

Jochen Triesch

Neuroscience is profiting from a range of new techniques for recording and manipulating neural activity and reconstructing neural circuits. Next to providing techniques for data analysis, Computational Neuroscience seeks to reveal the computational principles of these circuits through the construction of computational models and theoretical analyses. Advances in computing greatly facilitate these developments, but the field also needs to make fundamental progress at the conceptual level, e.g., regarding the nature of neural codes and the plasticity and learning mechanisms that establish them.

Studying Plasticity in Spiking Neural Network Models is therefore a major research theme of our group. We have pioneered the study of spiking neural networks combining different plasticity mechanisms and have achieved a number of noteworthy results regarding the structure and function of such circuits. For instance, we have proposed self-organizing models explaining the statistics and fluctuations of synaptic connection strengths and predicting the distribution of lifetimes of synapses. Our models have also offered insights into the functional role of spontaneous brain activity suggesting that the brain's coding strategy may be much more efficient than previously thought.

Going beyond the scale of local circuits to the systems level, our group, together with Prof. B. Shi in Hong Kong, has invented the Active Efficient Coding (AEC) framework, a generalization of classic efficient coding theories to active perception. We have used it to build self-calibrating models of active binocular vision and active motion vision. We have validated these models in humanoid robots and are exploring the implications of AEC for developmental disorders of binocular vision in children with clinical partners.

The study of learning processes in human infants is another focus of our group. Together with developmental psychologist Prof. M. Knopf at Goethe University we have introduced a new way of studying infant learning based on gaze-contingency. Using eye tracking technology, we put infants in control of their physical environment through their eye movements, before they are old enough to push buttons etc., and use this to study their learning abilities.

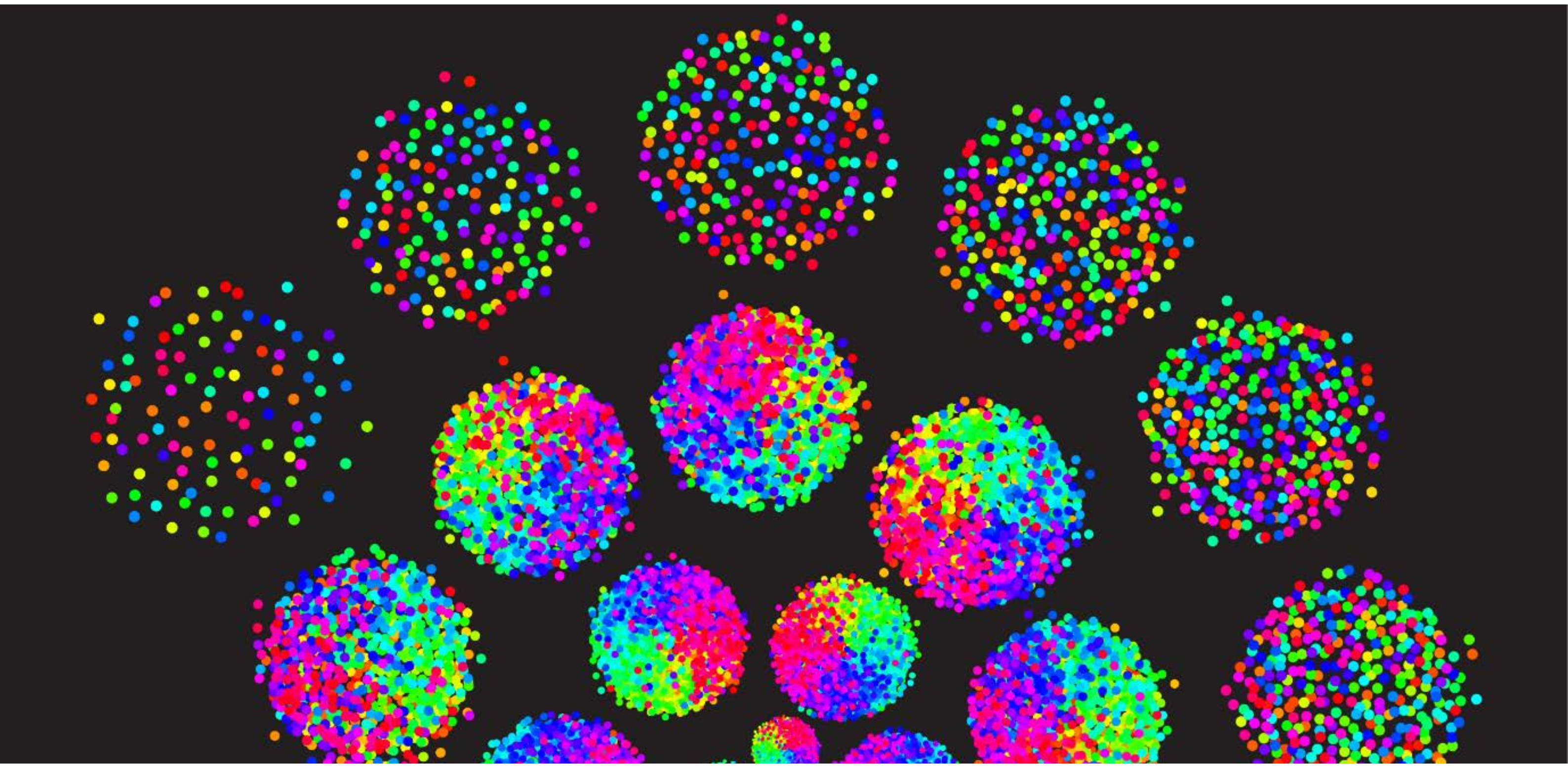
A fourth major research area is the so-called Transcranial Magnetic Stimulation (TMS) of the brain. Together with neurologist Prof. U. Ziemann and other collaborators, we have developed multi-scale computational models to better explain the mechanisms through which TMS activates neural circuits, laying a foundation for the development of improved stimulation techniques for clinical and basic research settings.

These activities are complemented by a number of recently emerging activities. These include the coordination of a German-wide priority program Computational Connectomics funded by the DFG (~6.3 Mio. Euros), a new European Future and Emerging Technologies (FET) Open project GOAL-Robots on curious robots that define their own learning goals and participation in a project on the personalized treatment of epilepsy (CePTER) funded by the LOEWE initiative of the state of Hesse.

Prof. Dr. Jochen Triesch

Prof. Dr. Jochen Triesch is the Johanna Quandt Professor for Theoretical Life Sciences at FIAS. He also holds professorships at the Dept. of Physics and the Dept. of Computer Science and Mathematics at Goethe University Frankfurt. Before joining FIAS in 2005, he was Assistant Professor at UC San Diego, USA. Originally trained as a physicist, he discovered his passion for studying the brain already during his graduate education.

The Triesch Group on the FIAS Rooftop.



Group Information

At FIAS
since 2014

Research Area
Network modelling
Biophysically realistic models of single cells
Neuroanatomy models

Team
Dr. Felix Effenberger
Dr. Alexander Bird
Dr. Marcel Beining
M.Sc. Marvin Weigand
M.Sc. André Casto
B.Sc. Alexandra Vormberg
B.Sc. Lisa Deters

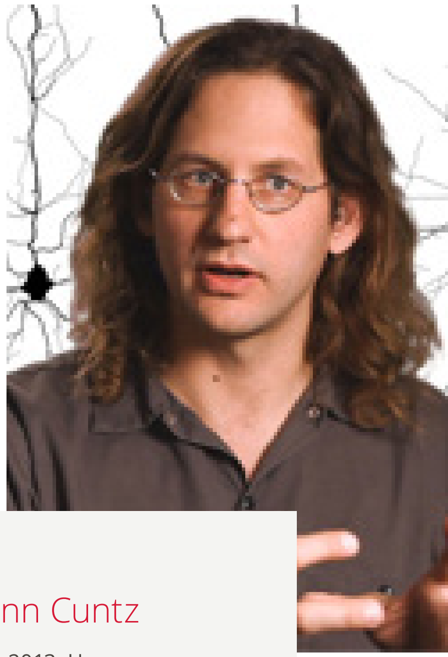
Collaborations
Peter Jedlicka
Gaia Tavosanis
Stephan Schwarzacher
Thomas Deller

Hermann Cuntz

We use generative models based on simple optimisation criteria to predict neuroanatomical structures at various scales. For example, we can predict the branching structures of neuronal dendrites and axons from wiring constraints assuming that neurons minimize conduction times and total amount of material to collect their inputs from other cells. Also, dendritic branch diameters taper toward the tips to optimise the current transfer from distal synapses to the signal summation point in the soma. In a novel complementary approach we can predict neural placement on the premise that neurons with similar connectivity structure should be located near each other to minimize wiring length.

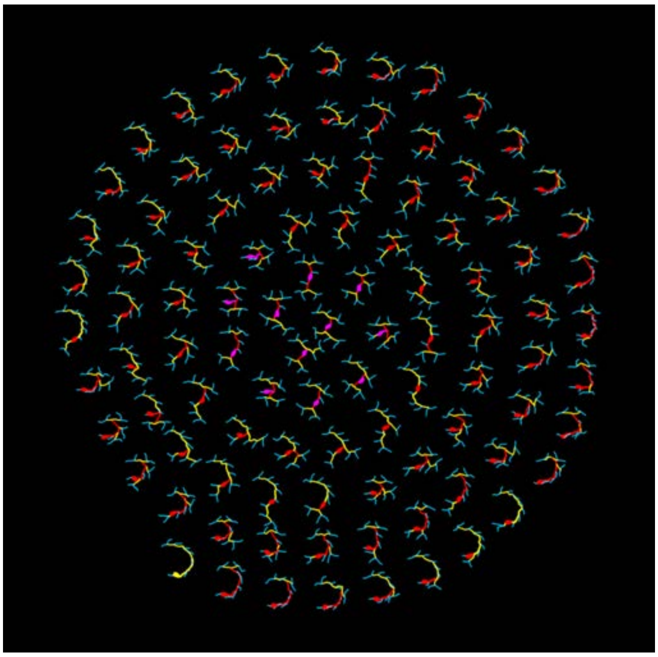
In 2016 we established a number of approaches that enable us to better understand and take advantage of these models. Alexander Bird established cable theory equations that predict current flow in dendrites of arbitrarily tapered branches to use analytical methods to show that dendritic taper optimises current transfer (1). Felix Effenberger together with Laura Anton, an exchange PhD student from the Cajal Institute, developed a new branching statistic that relates how regularly synaptic inputs are spread with features of dendritic trees (submitted). Alexandra Vormberg, who meanwhile finished her Master thesis, studied centripetal ordering of branching statistics and found some remarkable relationships that are meanwhile published (2). Marcel Beining, who obtained his PhD this year in a cooperation with Peter Jedlicka and Stephan Schwarzacher, established morphological models to study dendrite morphology alterations in adult-born dentate granule cells (3) and for the use in compartmental modelling (submitted). Marvin Weigand established the optimal neural placement rule mentioned above and found that with increasing numbers of neurons, structure appears in neural maps (4). In doing so, he found a simple explanation why orientation preference maps are "salt-and-pepper" in the small mammals such as rodents while they show interesting structural features in larger animals. We also established the first time-lapse images to study the dynamics of biological dendrite growth using models in fly neurons (André Castro in cooperation with Gaia Tavosanis) and in adult-born dentate granule cells (in Stephan Schwarzacher's group with one first article in (5)). We also used our morphological models in combination with compartmental modelling to study the effects of lesion on dendritic computation (6), meanwhile summarised in an invited chapter on the topic in (7).

To better promote our field, I have been involved in a Research Topic for Frontiers in Neuroanatomy ((8); now available as e-book) and have written an invited chapter Modelling dendrite shape (9) in the new edition of the book Dendrites (Stuart, Spruston and Häusser).



Dr. Hermann Cuntz

In the year 2013, Hermann Cuntz received the prestigious Bernstein Award with a prize money of around 1.25 million Euros to establish his group at FIAS and at Ernst Strüngmann Institute. In his proposal he plays with the idea of approaching cellular neuroanatomy in a similar comparative manner as Santiago Ramón y Cajal one of the founders of the field of Neuroscience. Instead of using pen and paper as in his beautiful drawings the group of Cuntz takes advantage of computer models to reproduce dendritic structures from simple general principles.



Many topological measures in real dendrites exhibit similar relationships with centripetal branch order as any typical set of binary trees. This image depicts all possible binary trees with 10 termination points and the respective colour-coded centripetal Horton-Strahler orders for each branch (cyan – 1; yellow – 2; red – 3; purple – 4). Tree asymmetry increases with distance to the centre of the image. For artistic reasons, the binary trees are rendered visually as dendrites with tapering branches and a somatic bulge at the root.

1. A. D. Bird, H. Cuntz, PLOS Comput. Biol. 12, e1004897 (2016).
2. A. Vormberg, F. Effenberger, J. Muellerleile, H. Cuntz, PLoS Comput. Biol. 13, e1005615 (2017).
3. M. Beining et al., Brain Struct. Funct. 222, 1427–1446 (2017).
4. M. Weigand, F. Sartori, H. Cuntz, Proc. Natl. Acad. Sci. 114, E4057–E4064 (2017).
5. T. Radic et al., Sci. Rep. 7, 43724 (2017).
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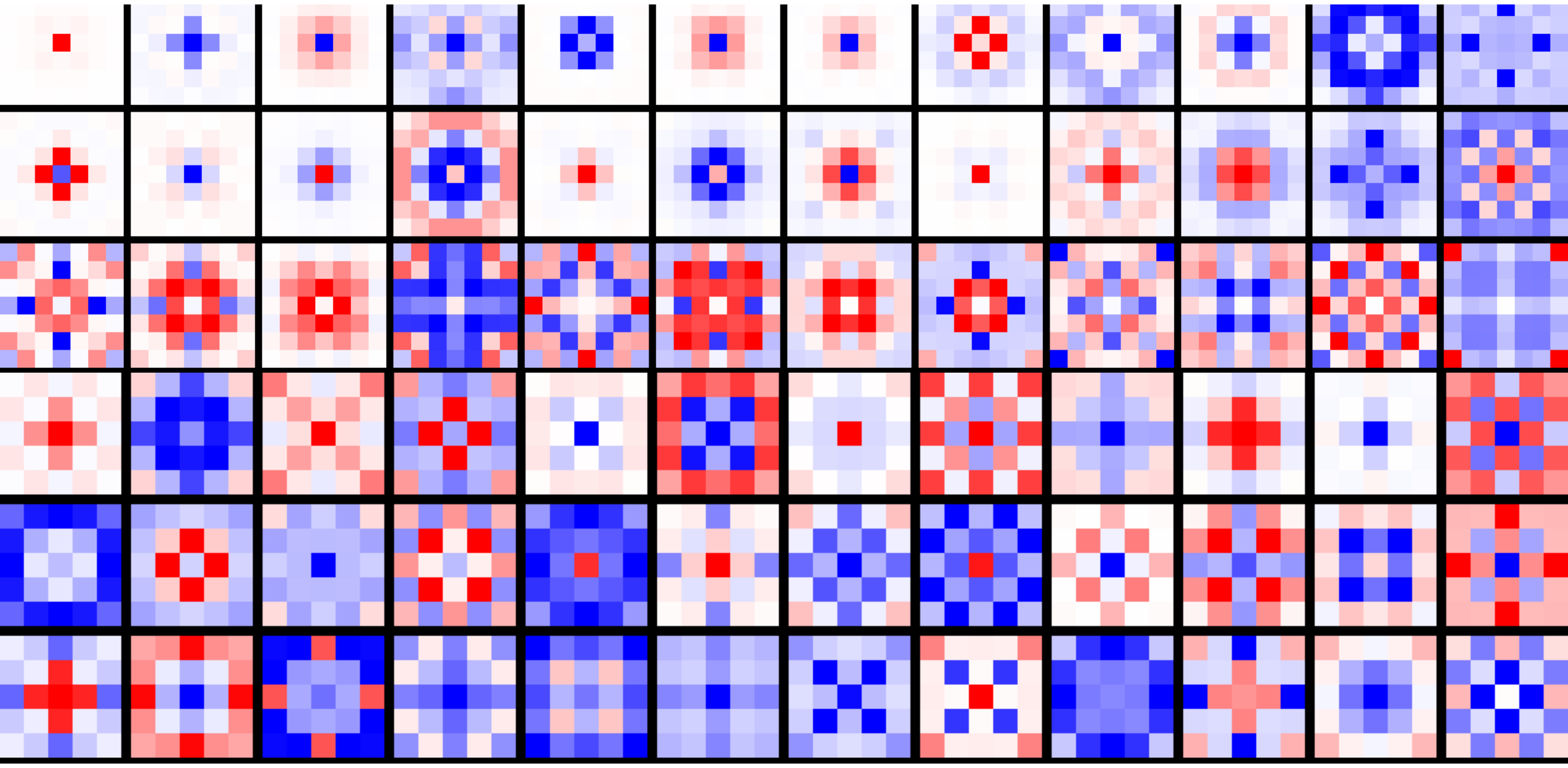
7. S. Platschek, H. Cuntz, T. Deller, P. Jedlicka, in The Rewiring Brain (Elsevier, 2017), vol. 15, pp. 203–218.
8. J. M. L. Budd, H. Cuntz, S. J. Eglen, P. Krieger, Eds., Quantitative Analysis of Neuroanatomy (Frontiers Media SA, 2016), Frontiers Research Topics.
9. H. Cuntz, in Dendrites. Oxford University Press, New York (2015), pp. 487–504.



Group Information

At FIAS
since 2010

Research Area
Computational Neuroscience

Team
Sebastian Blaes
Alexandros Bouras
Luke Ewig
Martin Mundt
Nils Neupärtl

Collaborations
Peter de Weerd, Maastricht University
Ronald Westra, Maastricht University

Thomas Burwick

Our research studies brains and machines. On one hand, we aim at understanding the information processing in brains and use this understanding to facilitate the design of intelligent machines. On the other hand, we use the challenge of creating machine intelligence to understand the tasks that brains and nervous systems have to cope with in complex environments and search for the mechanisms that are used by nervous systems to realize biological cognitive systems.

In 2016, our work concentrated on two directions of neural network modelling. We continued our work on using Oscillatory Neural Network (ONN) models to understand the functional relevance of the brain's oscillatory activity from a theoretical and computational perspective. Moreover, we considered hierarchical neural architectures and studied issues of Deep Neural Networks (DNNs).

With respect to ONNs, we studied the communication-through-coherence (CTC) hypothesis, which was proposed by Pascal Fries (2005, 2015) of the Ernst Strüngmann Institute (ESI), Frankfurt am Main, Germany. The CTC hypothesis states that a sending group of neurons will have a particularly strong effect on a receiving group if both groups oscillate in a phase-locked ("coherent") manner. We studied a situation with two visual stimuli in the receptive field and confirmed a mechanism that was proposed by Bosman et al. (2012) to explain experimental findings with regard to the CTC hypothesis. Moreover, we found frequency-based conditions for switching the information flow from bottom-up to top-down, a crucial difference for recognition processes and attentional selection.

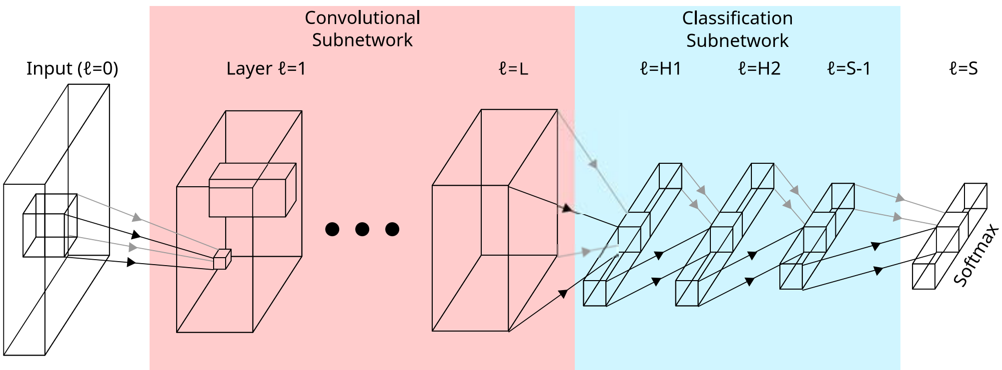
With respect to DNNs, we studied various aspects. Firstly, we extended the usual DNN architecture through giving a phase variable to each of the units of the network, thereby allowing for an oscillatory dynamics. Moreover, we included recurrent couplings so that a dynamic in the network could be built that allows for top-down modulations to enable feature binding as a kind of attentional selection. Thereby, we were able to implement a figure-ground segmentation of selected objects in a visual scenery that is based on temporal segmentation.

Secondly, we considered applications of DNNs to Computer Go, following the common habit in artificial intelligence research of using strategy games as a test bed for challenging applications of (biologically inspired) machine intelligence. Using a data base of thousands of expert games, we succeeded in designing algorithms based on recurrent information flow in the deep network that allow to identify the relevance of certain positional patterns for selecting the experts' moves. As an application one may think of automated tutoring systems that not only predict expert moves but explain the motivations behind such moves.

Thirdly, we studied a topic of utmost importance for current applications of DNNs: the learning of new categories based on only few (say, up to ten) examples, frequently referred to as "low-shot learning". This is in contrast to current ways of learning new categories with an extensive number of thousands of examples which are needed for learning the categories. Starting from a pre-learned network, we proposed a prototype-based approach ("Global Prototype Learning", GPL) to allow for few-shot learning of new categories. We found surprisingly good classification results for a large portion of the newly learned categories.

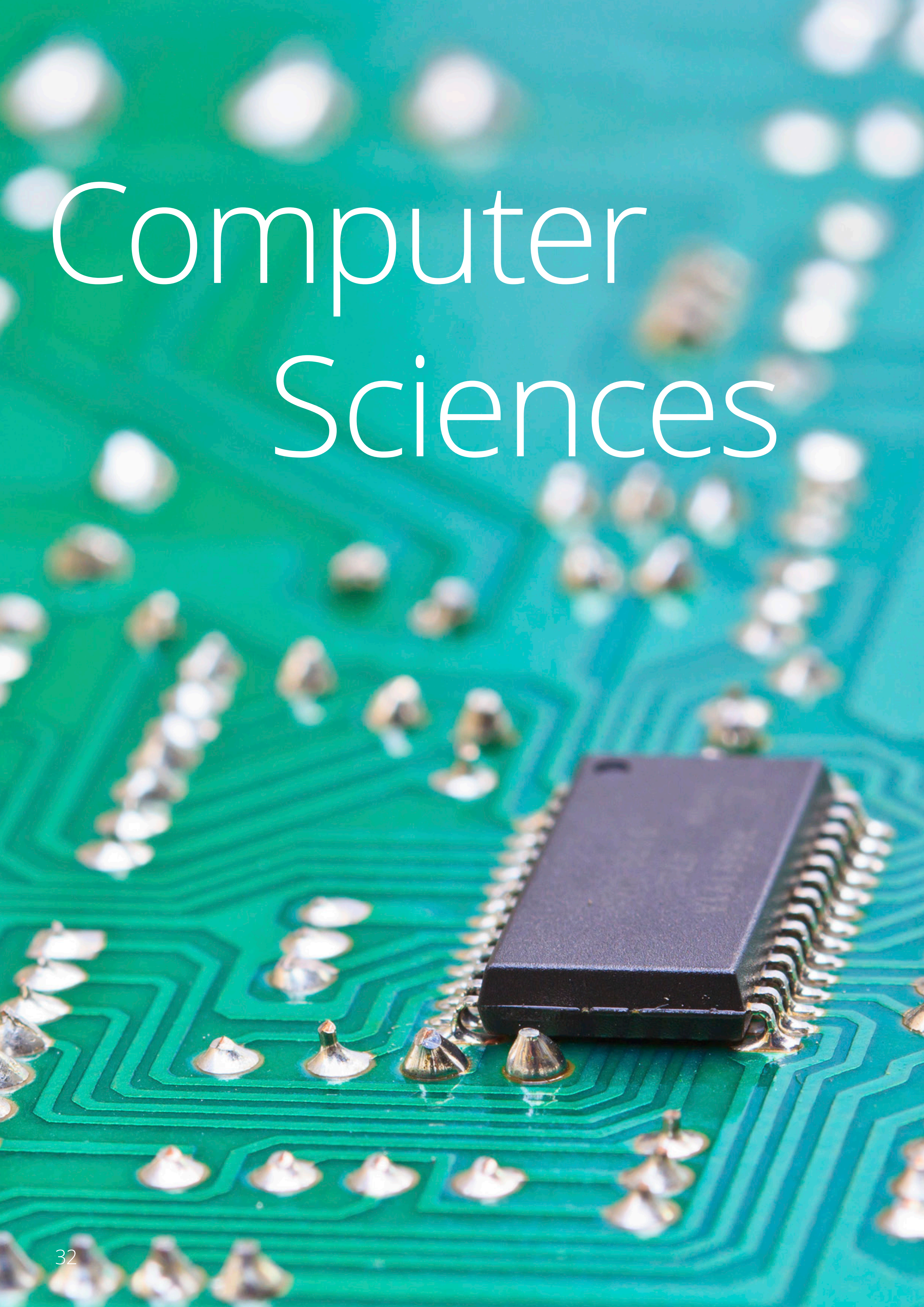
PD Dr. Thomas Burwick

Thomas Burwick studied mathematics and physics at the ETH Zurich, Switzerland, and at the Université de Paris VI, France. He received his PhD in theoretical physics from the University of Zurich, Switzerland. Subsequently, he was a postdoctoral fellow, working at Stanford University, California, USA. In 1999, he co-founded a software company. In 2012, he has been awarded the German qualification for Professorship (Habilitation) in Theoretical Physics at the Goethe University Frankfurt. He is a Research Fellow at FIAS.



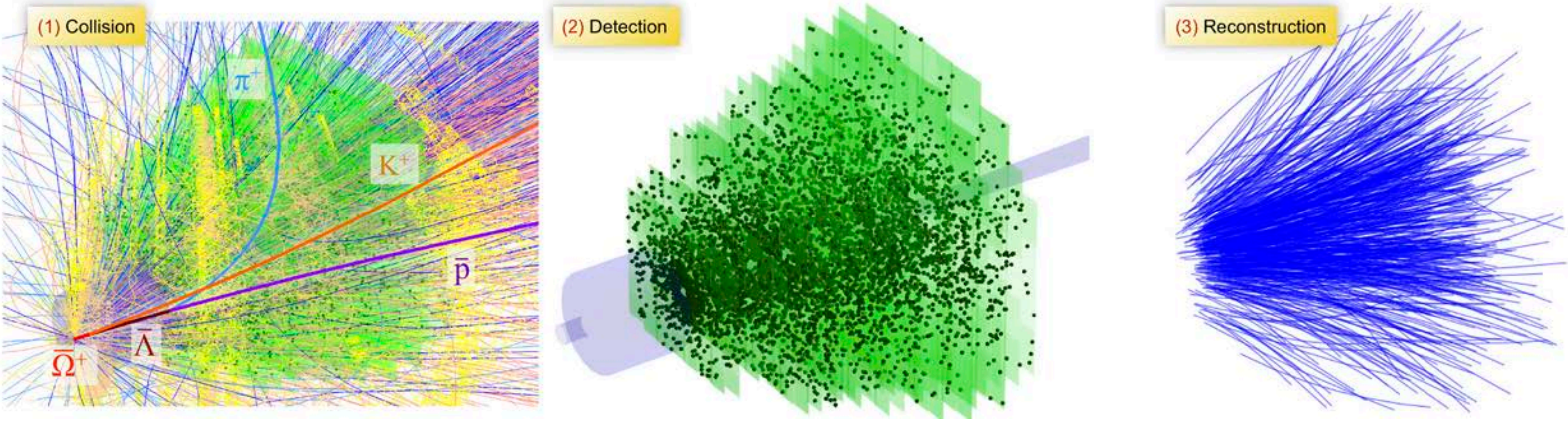
Architecture of the deep neural network that we used for few-shot learning of new categories

Computer Sciences



The Green Cube developed by FIAS scientists.

The Computer Science groups at FIAS are interested in High Performance Computing and how to further advance the architecture, the applications and the continued development of high performance computers useful to the natural and life sciences. Our focus is on the selection and analysis of experimental data generated by accelerator facilities such as the GSI Helmholtzzentrum für Schwerionenforschung (Darmstadt, Germany) and CERN (the European Center for Nuclear Research in Geneva, Switzerland). Both of these facilities employ shared, typically massive parallel systems and clusters operating under high-level, real-time and dependability standards. Our task is the research and development of new computer architectures and algorithms to achieve better energy-efficiency. Within the context of shared computing we implement both GRID and virtual technologies as well as cloud computing systems.



Ivan Kisel

Group Information

At FIAS

since 2012

Research Area

Supercomputers
Online big data processing
Parallel programming
Heavy-ion physics
CBM, PANDA, ALICE, STAR experiments

Team

Artemiy Belousov
Grigory Kozlov
Mykhailo Pugach

Collaborations

CBM
PANDA
ALICE
STAR

Rapid growth of experimental data volume is a distinctive feature of modern science. High-energy and in particular heavy-ion experiments on modern accelerator facilities such as LHC, RHIC and FAIR are characterized by extremely high collision rates and a very large number of produced particles, non-uniform magnetic fields and a complicated detector system that needs processing of experimental data in the multi-petabyte range now and in the exabyte range in 2021-2025. Processing, management and analysis of such extremely large data samples require completely new algorithmic approaches and use of modern many-core CPU/GPU computer architectures.

Data reconstruction and selection of the most interesting collisions are key elements of success of the experiments, thus being a problem of fundamental character. In addition, a full event reconstruction and selection must be done in real time (on the fly) that demands parallel processing and calibration of experimental data obtained directly from the detector setup.

Parallelisation of the computation at the level of cores, threads and vectors requires corresponding optimisation of the algorithms for reconstruction and analysis. Usually, for effective utilisation of heterogeneous computer architectures (CPU/GPU) the algorithm should be developed from scratch.

The developed by the group First Level Event Selection (FLES) package for the CBM experiment at FAIR is intended to reconstruct online the full event topology including trajectories (tracks) of charged particles and short-lived particles. The FLES package consists of several modules: Cellular Automaton (CA) based track finder, Kalman Filter (KF) based track fitter, KF particle finder and physics selection.

The FLES package is portable to different many-core CPU architectures. The package is vectorized using SIMD (Single Instruction, Multiple Data) instructions and parallelized between CPU cores. All algorithms are optimized with respect to memory usage and speed. It has a strong many-core scalability achieving the reconstruction speed of 1700 collisions per second on a server with 80 CPU cores. The FLES package in the CBM experiment will be performed on a dedicated many-core CPU/GPU farm with compute power equivalent to 60,000 modern CPU cores.

At the first stage of data processing particles registered in the detector system are reconstructed by the CA track finder. The reconstruction efficiency of majority of signal tracks (decay products of D-mesons, charmonium, light vector mesons) is equal to 97.1 %. The total efficiency for all particles is 88.5% with a large fraction of low-momentum particles. The level of incorrectly found particle trajectories is 0.7% only.

Reconstruction of heavy-ion collisions grouped in time-slices (so-called 4-dimensional reconstruction) has been developed within the CA track finder as well. The algorithm recovers the reconstruction efficiency and speed of the conventional event-by-event approach of 8.5 ms per collision.

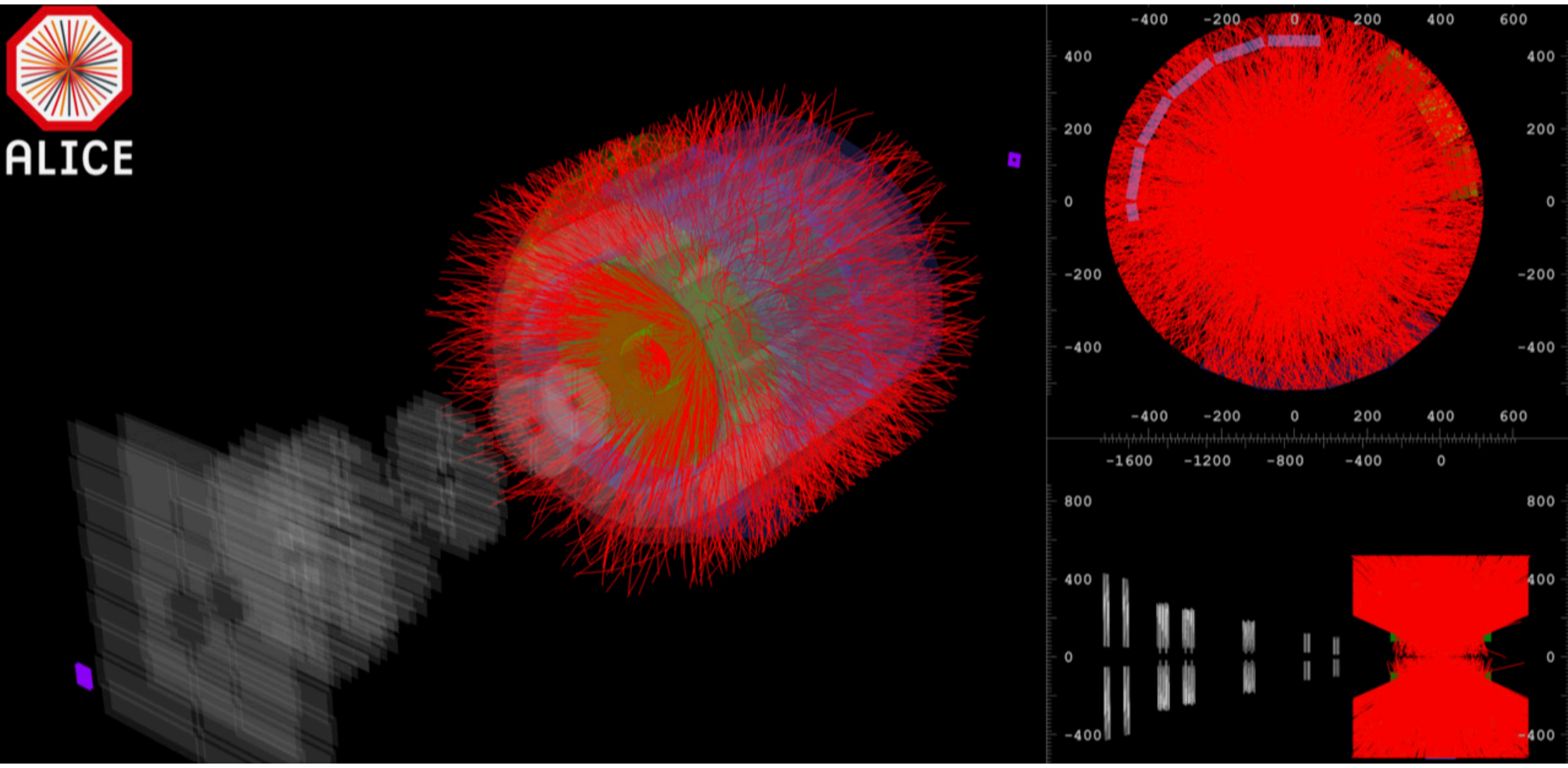
Precise estimation of the full particle trajectory in the detector system and its momentum is done by the KF track fitting algorithm, which performs up to 372 particles per microsecond on an AMD Radeon HD 7970 graphics card.

The fast and efficient KF particle finder package for reconstruction and selection of short-lived particles searches currently for more than 100 decay channels of charged and neutral particles produced in a collision of heavy ions. The package is developed in a general form and can be used as a platform for physics analysis in other high-energy and heavy-ion experiments.

Within the FAIR Phase-0 program a Cellular Automaton (CA) track finder has been developed for the TPC detector of the STAR experiment (BNL, USA) and is used since August 2016 for data production.

Prof. Dr. Ivan Kisel

Ivan Kisel works on data reconstruction in high-energy and heavy-ion experiments. His approach based on cellular automata allows to develop parallel algorithms for real-time physics analysis using HPC. He received his PhD in physics and mathematics from the Joint Institute for Nuclear Research (Dubna, 1994). He worked at the University of Heidelberg, where he gained his habilitation in physics, in 2009, and at the GSI Helmholtz Centre for Heavy Ion Research. Since 2012, he is a professor for software for HPC at the Goethe University and a fellow at FIAS.



Volker Lindenstruth

Group Information

At FIAS

since 2007

Research Area

Green-IT
Highly efficient data centers
High performance computing
Real-time event reconstruction
GPU- and FPGA- accelerated tracking
Heavy-ion physics
Algorithm engineering

Team

Jan de Cuveland
Nadine Flinner
Sergey Gorbunov
Dirk Hutter
Stefan Kirsch
Mikolaj Krzewicki
Sarah LaPointe
Johannes Lehrbach
Gvozden Neskovic
David Rohr

Collaborations

CBM
ALICE

Currently, big data and its subsequent handling is a hot topic. The LHC facility at CERN is the world leader, being the largest source of data production, with the ALICE experiment having data rates in excess of 48 GB/s. This data includes digitized particle detector signals that not only need to be processed into something tangible but also compressed to save on storage space. The ALICE High Level Trigger (HLT) system pioneered the use of FPGA and GPU based algorithms to reconstruct charged particle trajectories and reduce the data size in real-time. The techniques developed and implemented in the HLT have more than quadrupled the amount of data that can be stored offline for physics analysis.

The HLT compute farm is composed of about 200 nodes. Detectors send exact copies of the data to the HLT, where it is reconstructed on GPUs, visualized in Fig. 1. The processed event is sent to data acquisition along with a readout decision, which specifies what should be stored or discarded. The HLT compute nodes primarily use off-the-shelf components, with the exception of the Read Out Receiver Card (RORC), a custom FPGA-based card. Modern hardware, e.g. the faster PCI Express interconnect, allow the HLT to consolidate based on server type. Leading to a configuration of 188 ASUS ESC4000 G2S servers with twelve-core Intel Xeon IvyBridge E5-2697 CPUs running at 2.7 GHz, with one AMD S9000 GPU each. In this configuration the HLT can equip a total of 74 nodes with RORCs for input and output, yielding efficient resource utilization of all processors. A fast network is guaranteed via a 56 Gb/s InfiniBand computer-network communication.

The baseline for the entire HLT operation is full real-time event reconstruction. For this, elaborate cluster and track finding algorithms have been developed. The pipelined analysis begins with the local clusterization of digitized data, online calibration of the electron drift velocity in the ALICE Time Projection Chamber (TPC), continuing with charged particle track finding for individual detectors, and ending with the creation of data files, which contain all properties needed to perform a physics analysis.

Due to the sheer size of the data produced by the TPC, event reconstruction of the raw data is the most compute intensive task. Naturally, it is therefore a perfect candidate for data compression. This process starts with the compression of the TPC clusters, which runs parallel to the tracking. A series of additional compression steps are employed, ending with Huffman encoding which compresses fixed size properties. An overall, average compression factor of 5.5 was achieved in 2016 proton-proton collisions.

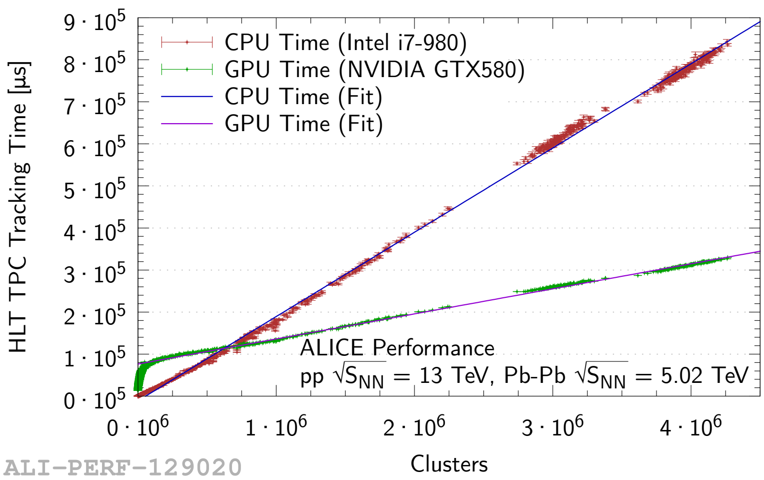
The HLT also runs various types of quality assurance frameworks that allow for real-time monitoring of the performance of ALICE. Information ranging from event, track, and collision vertex properties, along with compression parameters is processed in the HLT. The components that are considered fast (not disrupting normal operations) are run in the HLT processing chain, while other asynchronous components are handled by the ZeroMQ messaging library. The output is published online for simple access and analysis.

The HLT has been reconstructing collisions in the ALICE detector since 2009.

Concepts and technologies developed in the HLT, in parallel to being currently studied, prototyped and tested in a production environment are being adapted and further developed for the software framework of Online-Offline (O2) computing upgrade for Run 3 of the LHC.

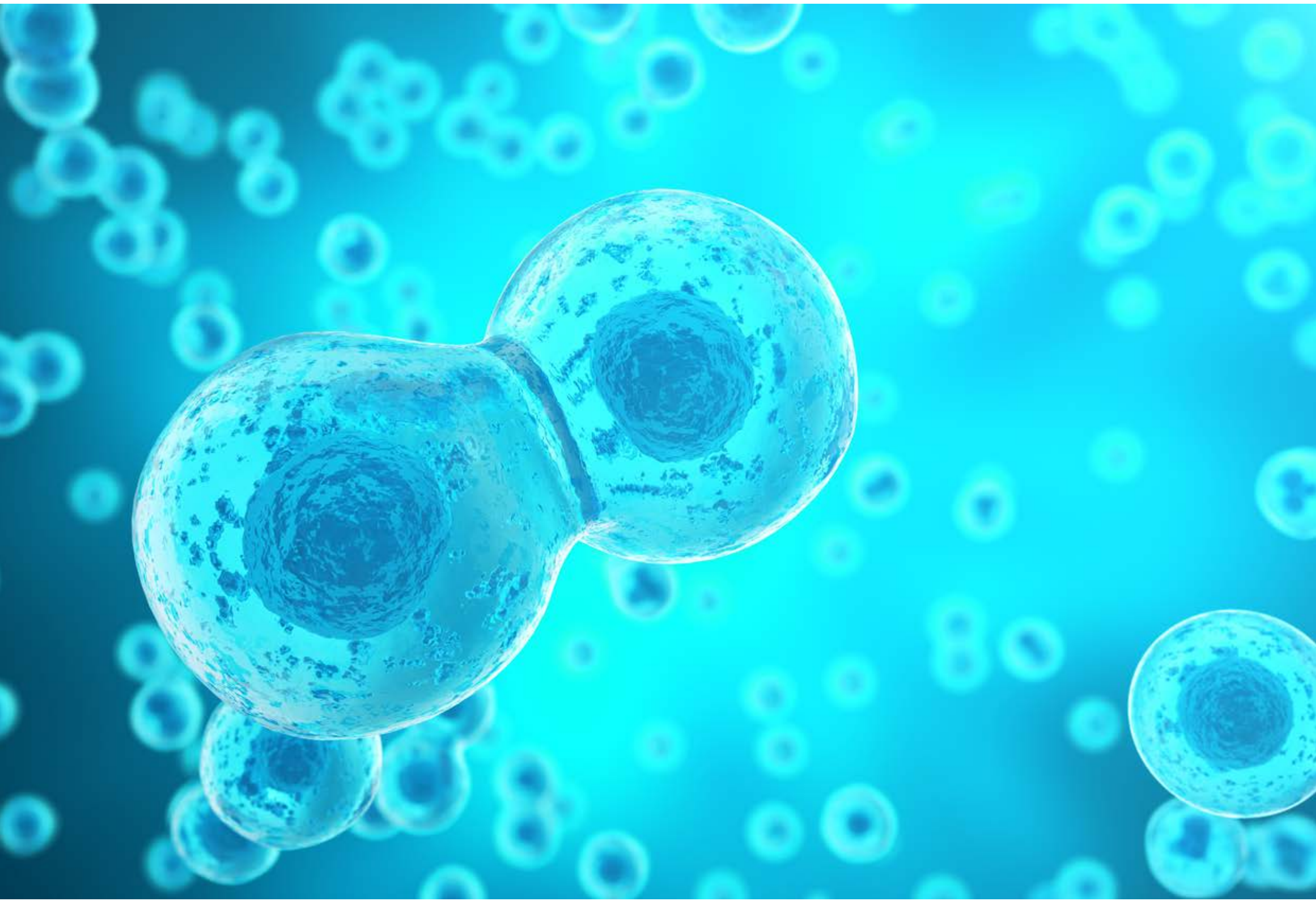
Prof. Dr. Volker Lindenstruth

Professor Volker Lindenstruth studied physics at TU Darmstadt and received his doctorate in 1993 at Goethe University. He spent his Postgraduate years as a Feodor v. Lynen Fellow at LBNL, USA at the UC Space Science Laboratory. In 1998, he returned to Germany as a Professor and department head at the University of Heidelberg. In addition, he has been the head of the ALICE HLT project at the LHC since 2000 and from 2006 to 2007 also a CERN Assosiate. At FIAS he held the position of Fellow since 2007 and became a Senior Fellow soon thereafter. Furthermore the Chair of High Performance Computer Architecture of the Goethe University has been in his care since 2009. Since 2010, Professor Lindenstruth is a part of the board of directors of FIAS, being its chairman since 2012.



Time needed for track finding on a CPU compared to a GPU as a function of the number of TPC clusters

Life Sciences



Biological processes are inherently complex as they are not only governed by the interaction of physical and chemical processes but also underlie genetical constraints and evolution. Theoretical biology aims at a quantitative understanding of biological systems, their dynamics and interaction across scales. To this end new analysis approaches are developed to extract relevant information from either tera and petabyte sized data sets, or from very scarce data.

Based on quantitative information provided by experimental data, mathematical models can be formulated in order to abstract and generalize the structure or behavior of a system, and to allow predictions. Mathematical models are a means to identify the level of complexity necessary to explain a given observation, but also represent building blocks to create understanding of the behavior of larger systems.

Model predictions provide guidance for experimental design and clinical studies, reduce the need for animal testing, and help to develop treatment strategies and ecological policies.

Current topics in theoretical biology are the interplay between chemical signaling and biomechanics (forces), decision-making on the cell and systems-level, emergent phenomena, such as collective behavior, or the formation of patterns or structures based on the (inter-)action of small-scale components.

At FIAS, the theoretical life sciences aim at developing efficient pipelines for image processing and analysis, as well as the generation of quantitative mathematical models, simulation and model validation approaches to address, amongst others, the following questions:

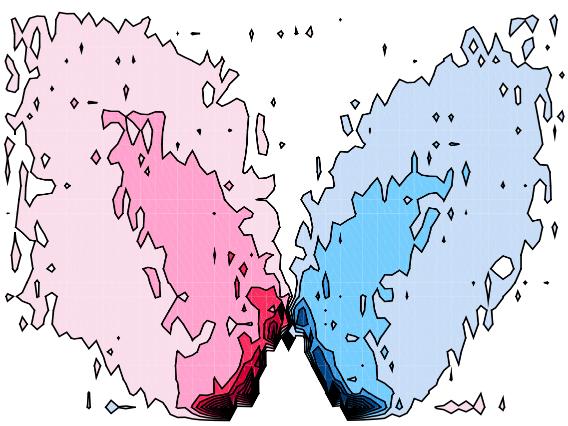
• How can chemical signaling pathways and/or mechanical forces regulate directed movement and collective behavior of small bacterial pathogens?

• Which specific nonlinear interactions between pathogens and immune system components lead to the occurrence of chronic infections? And how can chronic infections be treated?

• How important are mechanical cues and inter-cellular forces for migratory properties of cancer cells, and how are the mechanical properties of cancer cells affected by chemical inhibitors targeted against migration and metastasis?

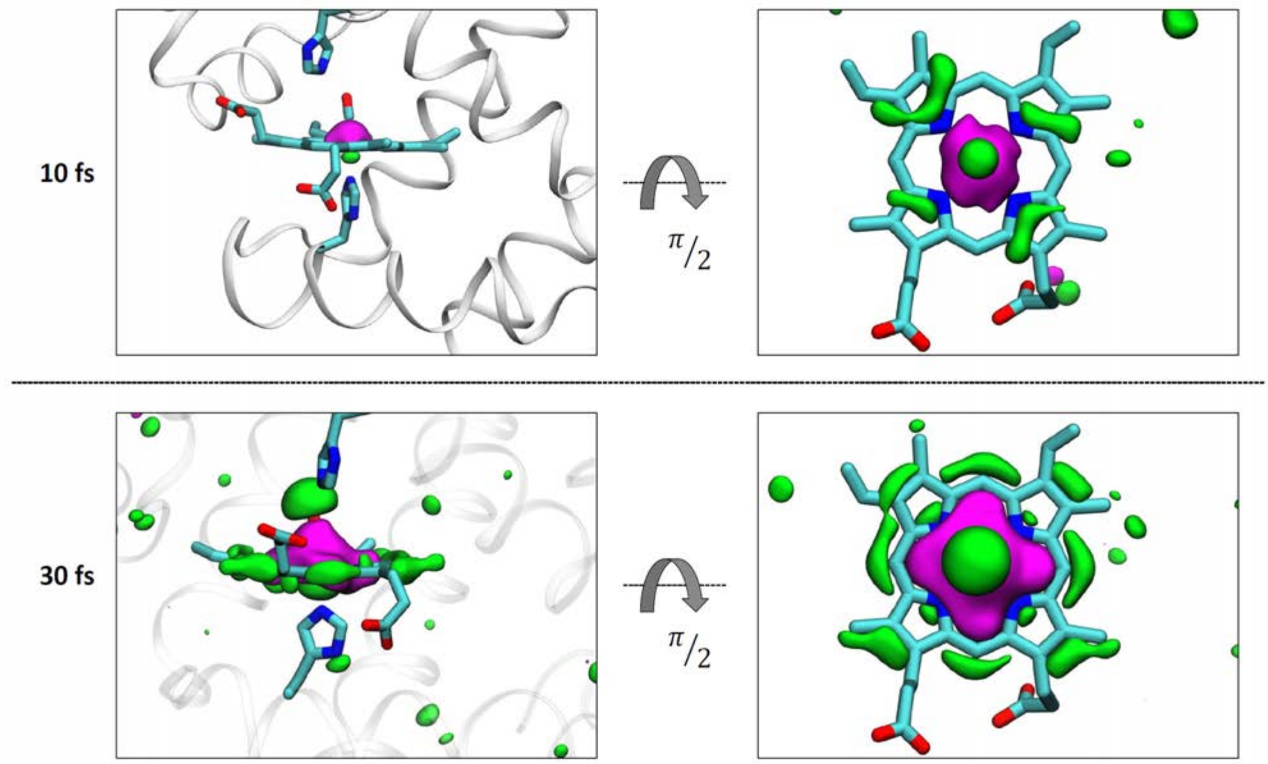
• How are cellular forces and shape changes coordinated across a tissue to achieve morphogenesis?

• How does the interplay of mechanical, chemical or neuronal cues shape and control the development and properties of spatial and spatio-temporal patterns, e.g. skin camouflage patterns in the cuttlefish or the regular pattern of hair follicles during embryonic development?



Quantitative life sciences

The biosciences have transformed into a strongly quantitative science. New technologies are constantly developed and refined to yield quantitative data on biological process across many spatial and temporal scales. One example are imaging approaches. Here two Nobel prizes were awarded in the years 2014 (fluorescence microscopy) and 2017 (cryo-electron microscopy). Another example are the various –omics and sequencing approaches, providing quantitative measurements on the composition and activity of a multitude of components simultaneously and time-resolved.



Group Information

At FIAS

since 2015

Research Area

Functional dynamics of biomolecules

Team

Dr. Pilar Cossio

Gerhard Hummer

Theoretical molecular biophysics experiences a phase of rapid advance. Dramatic improvements in model quality, algorithms, their computer implementations, and raw computational power are making it possible to study complex biomolecular systems over biologically relevant scales of time and space. Recognition of these advances is reflected in the 2013 Nobel Prize in Chemistry awarded for multiscale molecular modelling to Profs. Levitt, Karplus and Warshel (see Hummer, Nature 2013). Computational studies of large biomolecular systems with atomic resolution from picoseconds to milliseconds timescales are now in reach.

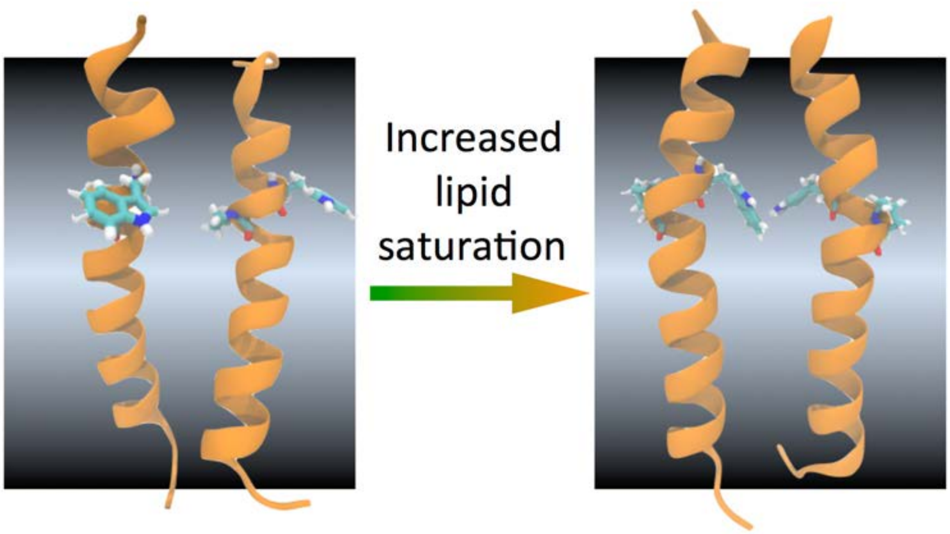
Watching proteins carry out their function is one of the main objectives of our work (title-figure). For this, we use a battery of molecular simulation methods and team up with experimentalists. To describe chemistry in solution and inside a protein, we employ hybrid descriptions that merge quantum mechanical and classical treatments. In collaboration with the group of Prof. Ilme Schlichting (MPI for Medical Research), we could compare the light-induced dynamics in a protein to experiment, taking advantage of the unprecedented temporal and spatial resolution offered by femtosecond time-resolved crystallography at an x-ray free-electron laser (Barends et al., Science 2015).

Molecular motions also affect properties at the scale of entire organelles. One of the central challenges in a cell is to control the fluidity of its membranes. This and related properties are affected by a plethora of factors, including the mixture of lipids, their level of saturation, and the content of cholesterol. The wide range of factors makes it extremely challenging to come up with a chemical test of the membrane fluidity, say, from a mass-spec lipidomics fingerprint. So how do cells deal with what is in effect a "physics problem?" In collaboration with the group of Prof. Robert Ernst at the University of Frankfurt, we have been working on a yeast system involved in lipid-saturation sensing. Mga2 is an ER-anchored transcription factor that gets activated by proteolytic release of its soluble domain (Figure 2). In molecular simulations, we observed that its single transmembrane helix readily dimerizes, and that the relative orientation of the two helices depends on the level of lipid saturation (Covino et al., Mol. Cell 2016), likely exposing different parts of the protein for ubiquitination. This surprising finding was corroborated by extensive biophysical and biochemical characterizations in vitro and in vivo. Eukaryotes thus use a mechanism for ER quality control that is remarkably different from hydrophobic-thickness sensing in bacteria.

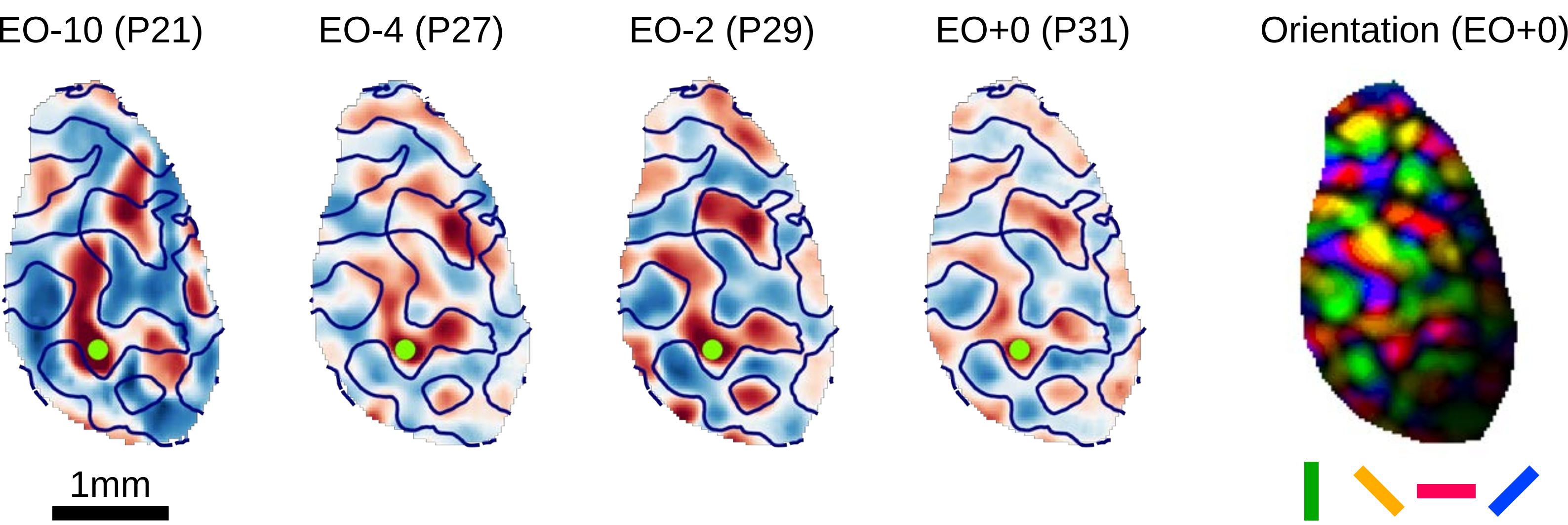
Over the last few years, cryo electron microscopy (EM) has moved to the forefront of structural biology, thanks to advances not only in microscopes and detectors, but also in the analysis software. However, despite the many improvements, extensive disorder still poses an enormous challenge to the currently favored approach of 3D reconstruction. To prepare the ground for the next phase of cryo EM and tomography, we are developing a Bayesian approach alternative and complementary to 3D reconstruction (Cossio and Hummer, J. Struct. Biol. 2013). In collaboration with Prof. Volker Lindenstruth and his group, we developed software that runs efficiently on both regular CPUs and graphics programming units (GPUs) on massively parallel computing architectures (Cossio et al., Comp. Phys. Commun. 2017). In this way, and by algorithmic improvements, we realized efficiency gains over the original software by a factor 10,000. The new BioEM software package has just been released to the public.

Prof. Dr. Gerhard Hummer

Gerhard Hummer uses theory and simulations to study biological systems at the molecular level. Following his PhD in physics (University of Vienna, 1992), he joined the Los Alamos National Laboratory, first as a postdoctoral fellow (1993-1996) and then as a group leader (1996-1999). He then moved to the National Institutes of Health, where he became Chief of the Theoretical Biophysics Section, NIDDK. Since 2013, he is Director at the Max Planck Institute of Biophysics in Frankfurt. In 2015, he became a Senior Fellow at FIAS, and in 2016, a Professor of Biophysics at the Goethe University.



Rotatory sensor of lipid saturation. In the densely packed environment of saturated lipids, the knob-like protrusions formed by two tryptophan residues are pushed into the interface of the membrane-embedded transmembrane helices of two Mga2 molecules. This rotatory motion is used as a lipid-saturation sensor (Covino et al., Mol. Cell 2016).



Group Information

At FIAS
since 2011

Research Area
Functional organization and development of visual cortex
Stability of sensory coding in auditory cortex
Input-output transform and hierarchical motor networks in cuttlefish

Team
Dr. Dmitry Bibichkov
Dr. Enrique Hansen
Bettina Hein
Bastian Eppler
Fatemeh Bagheri
Hanna Kamyshanska

Collaborations
David Fitzpatrick, MPI Florida
Simon Rumpel, University Mainz
Gilles Laurent, MPI for Brain Research
Kenichi Ohki, University of Tokyo

Matthias Kaschube

Brains are complex dynamical systems comprised of networks that operate across many different temporal and spatial scales. While for several important model systems research in neuroscience has identified many of the relevant players (e.g. proteins, neuron types), we still lack an even basic understanding of how these players act together in networks to establish its functionality. Novel theoretical concepts are necessary to analyse, predict and interpret the multi-level and multi-omics data that current neuroscience and systems biology provide.

We are approaching this issue in a variety of neural systems, focusing on the following general three questions: How is genetic and sensory information dynamically integrated to establish cortical circuits during development? How do the patterns of electrical activity generated by these circuits represent the sensory world? What maintains the functionality of cortical circuits, in light of the observed significant turnover on cellular, subcellular and molecular levels?

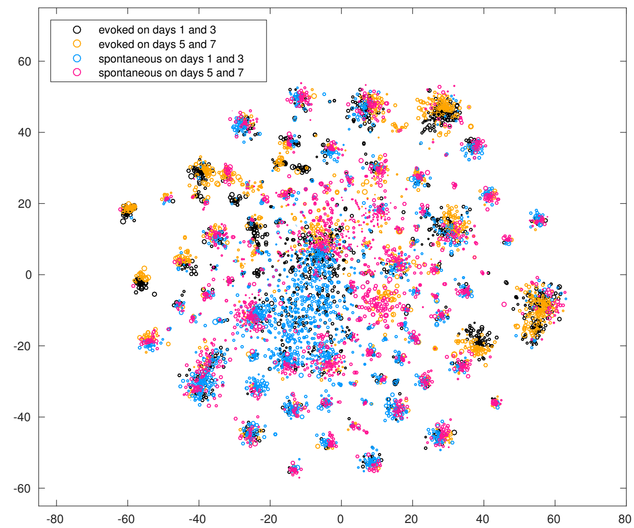
During the past year we have tackled these questions in a variety of well-suited and relevant model systems, in tight collaboration with experimental groups in Frankfurt and abroad. In one project my group has studied the stability of sensory coding in a general dynamical circuit model and compared the results to chronic recordings of stimulus-driven and spontaneous population activity in the auditory cortex of awake mice. These recordings were performed in the group of Simon Rumpel, a neurobiologist at the University Mainz. We observe that neural population activity typically falls into one out of a discrete set of states, which can be visualized - appearing as clusters - when projecting the activity into two-dimensional space using dimension reduction techniques (Fig. 1). While many clusters are stable across days, some drift and the mapping between a stimulus and a cluster may change, sometimes even affecting several stimuli simultaneously. In fact, the model suggests that even subtle and random ongoing changes in synaptic connectivity can have a significant and highly nonlinear effect on the stability of sensory representations and a consistent picture is seen in the experimental data.

In another project my group has studied the role of spontaneous activity and cortical network interactions in early cortical development, using image analysis and theoretical network models (with David Fitzpatrick, Max Planck Florida Institute, USA). Tracking the correlation structure of spontaneous activity in visual cortex back in time, we found that it is present and similar to its mature organization already at very early stages in development (Fig. 2). It is predictive of the mature organization of cortical response properties, such as orientation preference (Fig. 2), suggesting the presence of a scaffold for establishing sensory representations during cortical development. Furthermore, the question arises how such an elaborated long-range correlation structure can arise in the early cortex, at a time when anatomical connections are still immature and mostly local. To explain this we proposed a circuit model based on local, heterogeneous connections and showed that heterogeneity reduces the dimensionality of the space of spontaneous activity patterns and that this alone is sufficient for generating long-range correlations.

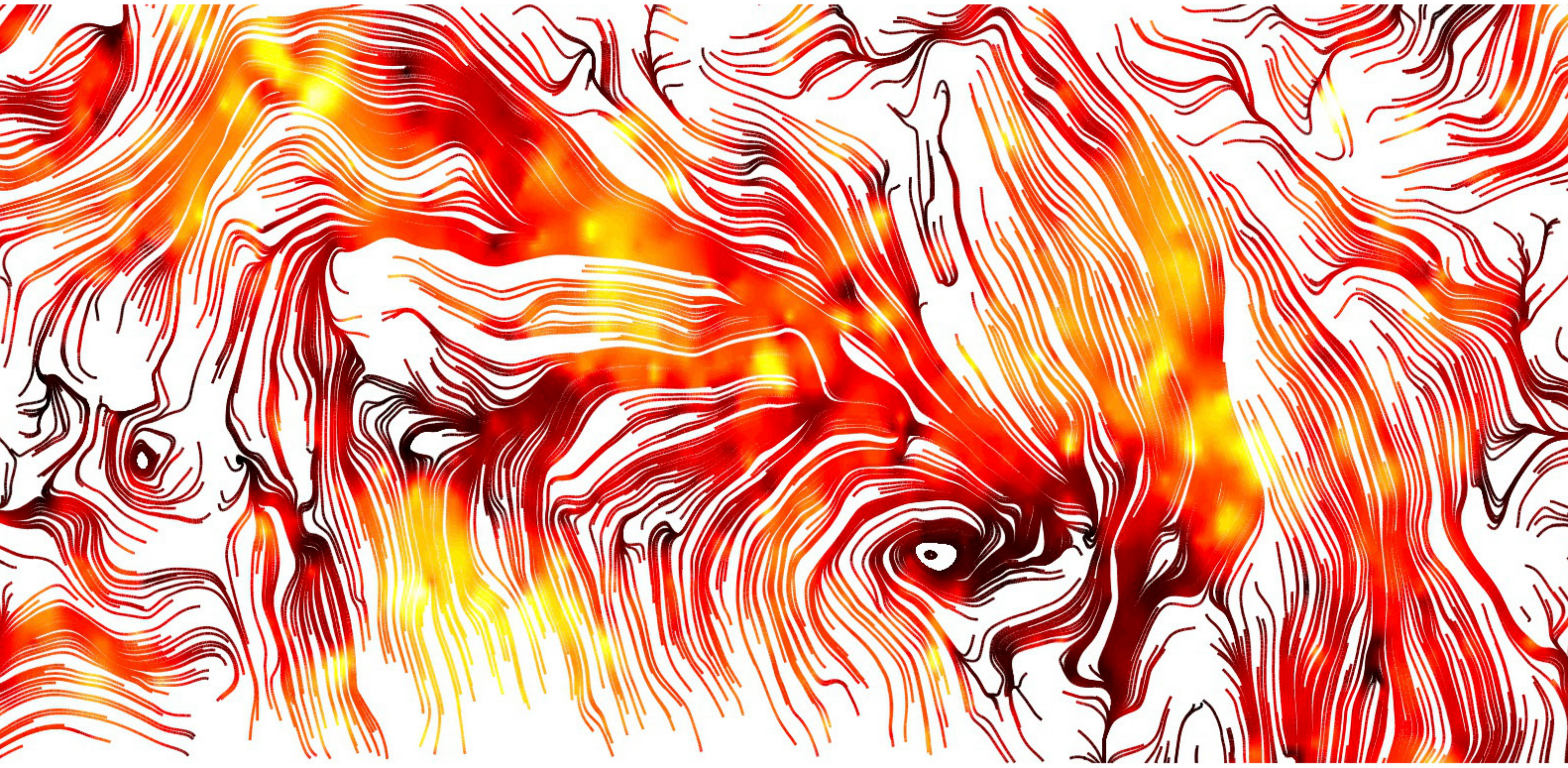
Together these two studies shed new light on the formation and stability of sensory representations in cortical circuits. They furthermore highlight the role of spontaneous cortical activity and its strong interrelation with stimulus-evoked patterns throughout lifetime.

Prof. Dr. Matthias Kaschube

Dr. Matthias Kaschube graduated in physics in 2000 with a diploma from the Georg-August-Universität Göttingen in cooperation with the Max Planck Institute for Dynamics and Self-Organization, where he obtained his doctorate, in 2005. From 2006 to 2011, he went to Princeton, where he worked as a Lewis Sigler theoretician at the Lewis Sigler Institute for Integrative Genomics and as a lecturer at the Physical Institute of Princeton University. In 2012, he became Professor of Computer Engineering and Mathematics at Goethe University and a Fellow at FIAS.



Activity vectors recorded in a population of ~300 neurons in mouse auditory cortex projected into two-dimensional space using the method t-distributed stochastic neighbor embedding (tSNE). The activity falls into a near discrete set of different patterns, some dominated by stimulus-evoked, some by spontaneous activity, others by both.



Group Information

At FIAS
since 2016

Research Area
Cell motility
Mathematical modelling
Simulation
Data analysis

Team
Kai Kopfer
Santiago Moreno

Collaborations
A. Frangakis (BMLS)
E. Stelzer (BMLS, FB 15)
D. Headon (Roslin Inst. Edinburgh)
K. Breuhahn (University Hospital Heidelberg)
U. Klingmüller (DKFZ Heidelberg)
M. Engstler (Biologie, Würzburg)

Franziska Matthäus

Cell motility is an important aspect of developmental processes, tissue regeneration, or the immune response. For all these processes, it is essential that cells respond correctly to external stimuli, given as chemical or mechanical cues. The response is regulated by complex intracellular signaling pathways, involving enzymatic reaction cascades and gene-regulatory processes. Perturbations in these complex pathways can lead to defect immune response, malformation in development, or diseases like cancer.

To better understand how intracellular processes, as well as cell-cell interaction, regulate collective cell behavior, like the formation of pattern or shapes, the group of Franziska Matthäus aims at the development of mathematical models coupling intracellular processes, cell-cell interaction mechanisms and the behavior and features of individual cells. Mathematical models are formulated in terms of agent-based approaches or systems of partial differential equations describing the dynamics of the spatially resolved cell density. All mathematical models are developed following an exhaustive analysis of data provided by experimental collaborators. Hereby, image processing tools, such as single cell tracking and particle image velocimetry (PIV) are applied, from which many quantitative spatiotemporal measures, such as velocity distributions, spatial velocity correlation, divergence, or vorticity can be derived.

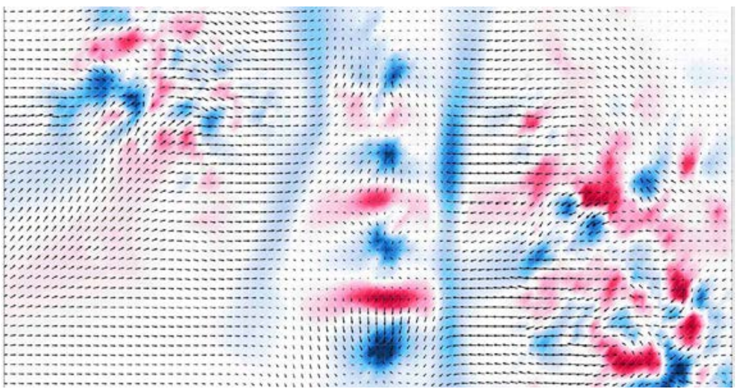
Based on these quantities, agent-based models are derived, usually given in terms of systems of stochastic differential equations. These models capture motion and migration strategies, mechanics of cell-cell interactions, interactions with and response to external cues.

In 2016 the group finalized a project on the collective migration of lung cancer cells, conducted in collaborations with the University Hospital and DKFZ, Heidelberg. Based on time-lapse video data of collectively migrating cells in a classical lateral migration assay, quantitative information on spatio-temporal velocity distributions and correlations were derived. The data served as basis for the development of a mechanical model of cell interaction, capturing cell adhesion, random migration as well as mechanotransduction. Simulations show that the included mechanical processes are sufficient to reproduce, by parameter variations, most phenomena observed in the data (about 1500 time lapse movies). In particular, we observed that the balance of involved antagonistic effects, cell-cell adhesion on one hand (impeding cell motility) and mechanotransduction on the other (stimulating motility) decide which migration phenotype is eventually observed.

In another project we investigated, in collaborations with experimental partners at the Roslin Institute, Edinburgh, UK, skin patterning in the chicken and mouse embryo. Here the motile mesenchymal cells migrate and form placodes - regularly distributed aggregates at positions where feather buds and hair follicles develop. We followed the question whether the aggregates form in response to a chemical Turing pattern provided through epidermal cells, or by chemotaxis to self-generated chemoattractands. Interestingly, we could show that both processes contribute: A chemical pattern of FGF, WNT and BMP generated by epidermal cells guides mesenchymal cells. If this pattern is knocked-out, placodes are still formed through TGF-β-mediated chemotaxis. By extensive data analysis we were able to quantify differences in the cell behavior in both cases, as well as differences in the arrangement and size of the aggregates. Presently a mathematical model for this process is under development.

Prof. Dr. Franziska Matthäus

Following her studies in biophysics at the Humboldt University of Berlin, including one year research stay at UC Berkeley (USA), Franziska Matthäus spent five years in Warsaw (Poland) on her PhD and scientific research. Between 2005 and 2016, she held two postdoc positions and a group leader position at IWR, University of Heidelberg. In 2016, she received a junior professorship at CCTB, University of Würzburg. Since October 2016, she holds a W2 position in bioinformatics, funded by the Giersch-Foundation, at FIAS Frankfurt.



Velocity field (arrows) and divergence for migrating mesenchymal cells forming feather buds in the chicken embryo. Blue color indicates sinks, e.g. cell aggregates where the placodes are formed, red color indicates sources of migration.

Systemic Risk

The latest financial crisis has painfully revealed the importance of a working financial system for the real economy. Many countries are still slowly recovering from the disruption of financial services, not least due to a lack of understanding what caused the near breakdown of financial institutions and how to best counteract the on-going economic downturn.

While practice and research on economic activity and risk management has focused on individual institutions it is only recently widening its view towards systemic interactions. At this level new mechanisms and feedback, some certainly still waiting to be identified, come into play which can threaten the stability of the financial system as a whole. To tackle this problem, our research takes an interdisciplinary approach drawing on expertise from machine learning, information theory and complex systems.


80%
70%
60%

Group Information

At FIAS
since 2015

Research Area
Information theory
Complex systems
Financial data analysis
Stochastic volatility models

Team
Dr. Oliver Pfante
Rajbir Nirwan

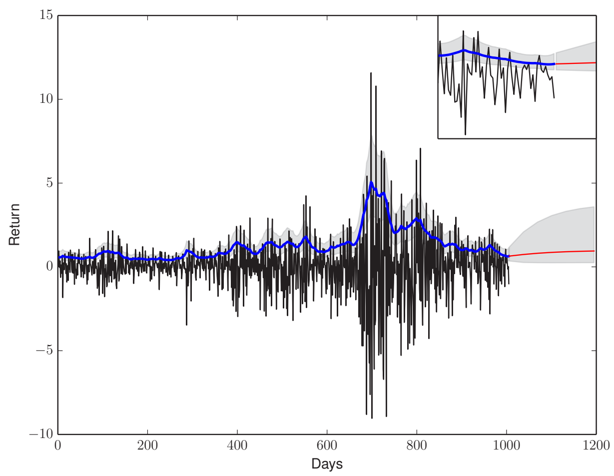
Collaborations
Juergen Jost,
Max-Planck Institute
for Mathematics in the
Sciences
David Wolpert,
Santa Fe Institute

Nils Bertschinger

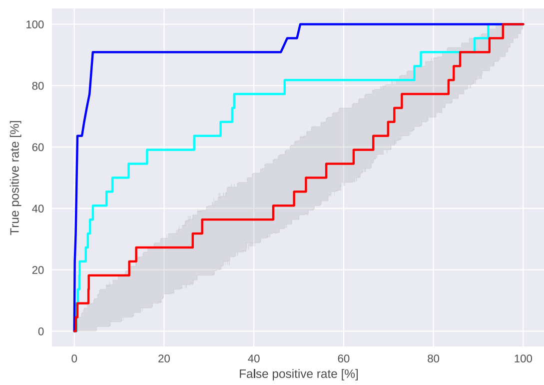
Market prices reflect and react to many investment risks. Especially rapid market downturns are often unexpected and -- as painfully revealed by the latest financial crisis -- can even unfold to system wide market distortions. Many countries are still slowly recovering from the disruption of financial services, not least due to a lack of understanding what caused the near breakdown of financial institutions and how to best counteract the on-going economic downturn. Financial theory has long studied how to measure and model market risk. Volatility which quantifies the intensity of price fluctuations is well established and many statistical models strive to capture its temporal properties. So called stochastic volatility models consider volatility as an unobserved stochastic process which then drives the observed market returns. These models capture many stylised facts such as volatility clustering, i.e. its temporal persistence exhibiting long-range memory, and the leverage effect, i.e. the tendency of volatility to rise after market downturns. Accordingly, such models are in wide-spread use not only to forecast volatility, but especially in the pricing of options and other derivatives which are highly sensitive to market volatility. Given its historical importance one should expect that volatility is not only well modelled, but can also be accurately estimated from market data. Surprisingly this is not the case. Using sophisticated methods from information theory we have studied this question in detail. We could show that across a wide class of volatility models, including state of the art approaches, stock prices provide rather little information about volatility leading to imprecise estimates. This is not due to a lack of model fit, but arises from fundamental information theoretic constraints on the temporal structure of volatility. Further, for essentially the same reasons, prediction of volatility more than a few weeks ahead is inherently impossible. Beyond this purely statistical approach, we examine possible mechanisms that can cause strong market fluctuations. Several mechanisms such as herding behaviour of traders or chartist strategies are thought to amplify market fluctuations. Especially in the area of econophysics corresponding models have been developed and each illustrates possible mechanisms and their consequences for the dynamics of volatility. Particular attention is given to the bifurcation structure, i.e. critical points where dynamic instabilities occur. Different types of bifurcations not only lead to different predictions regarding the market dynamics, but more importantly are accompanied by characteristic, statistical signatures indicating nearing market instabilities. We use this insight to derive early warning indicators and systematically investigate their performance on both simulated as well as real market data. Overall, practice and research on economic activity and risk management has largely focused on individual institutions and is only recently widening its view towards systemic interactions. At this level new mechanisms and feedback, some certainly still waiting to be identified, come into play which can threaten the stability of the financial system as a whole. We believe that our interdisciplinary approach combining statistical methods and theories of complex systems as established and pursued at FIAS is essential to achieve further progress on this highly relevant problem.

Prof. Dr. Nils Bertschinger

Nils Bertschinger is Helmut O. Maucher-Stiftungsjuniorprofessor for systemic risk. He studied computer science at RWTH Aachen and did his PhD at the Max-Planck Institute for Mathematics in the Sciences about information processing in complex systems. At FIAS he now applies methods from information theory and machine learning to investigate how systemic risks can develop and spread in financial systems.

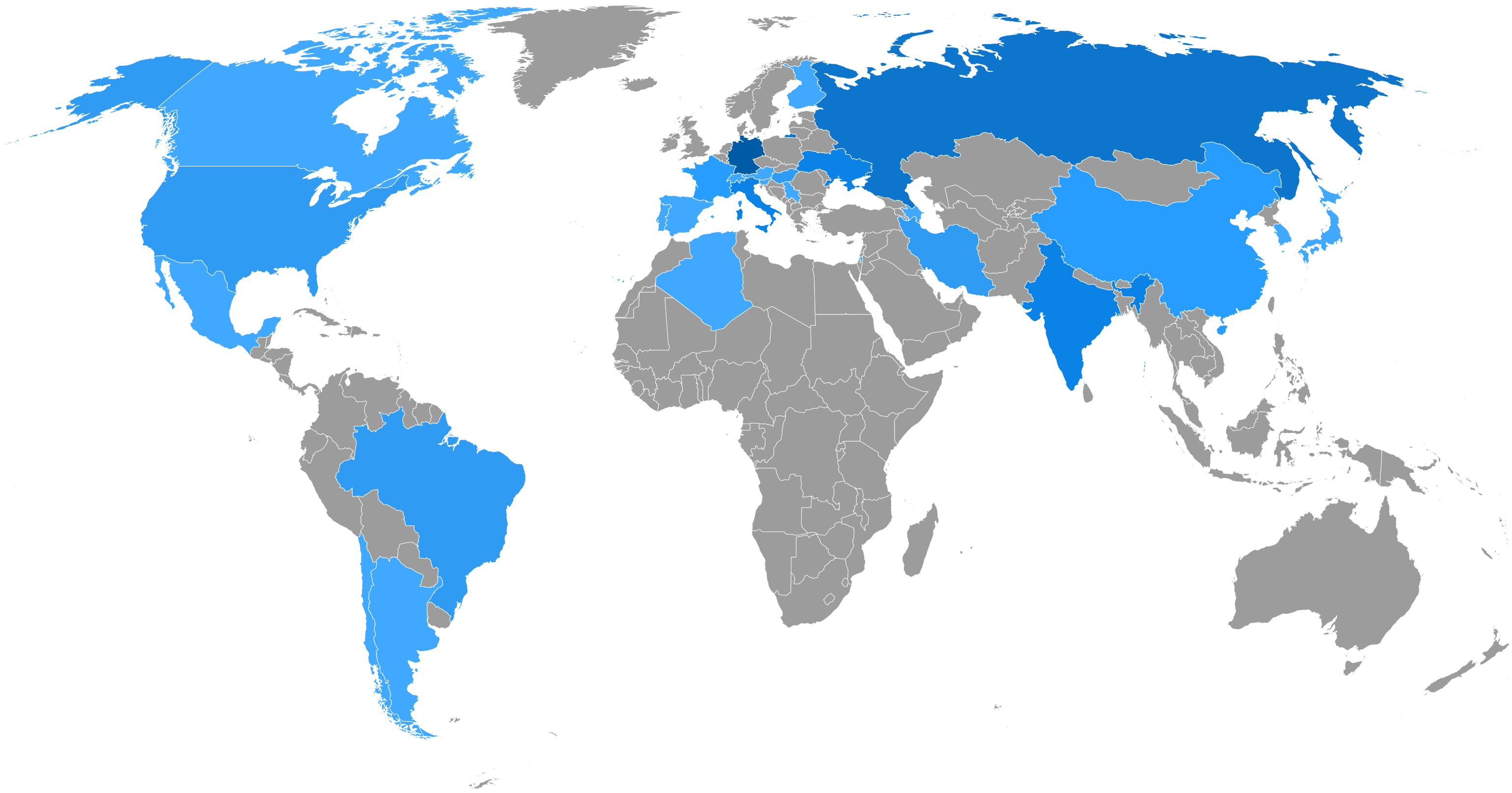


Volatility (blue) estimated from daily stock returns. Note the large and quickly growing uncertainty when forecasting (red).



Performance of several early warning signals of market instabilities in an econophysics model.

People at FIAS



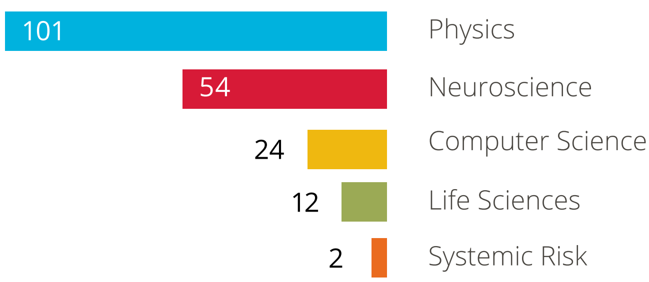
The performance of any scientific institute depends crucially on the people involved with it. This is not different at FIAS – with their enthusiasm and engagement our researchers are the foundation of our success.

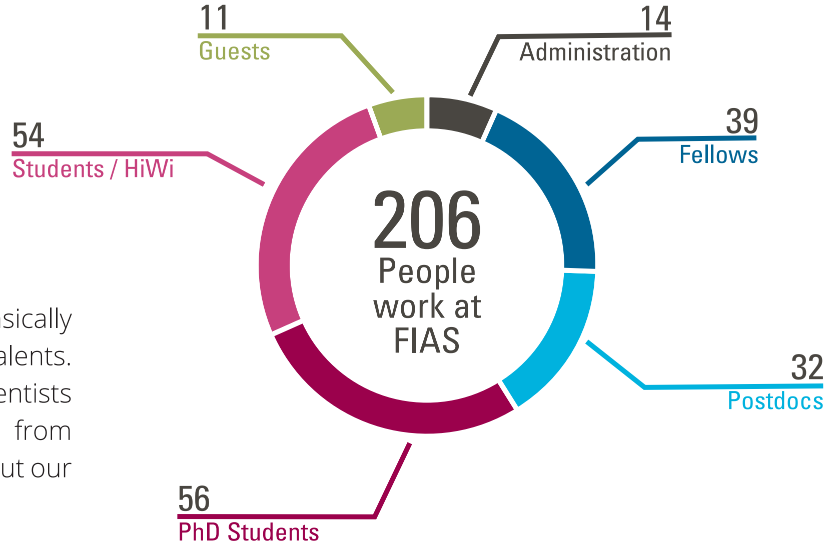
With 40% of our researchers being not from Germany, FIAS is very international. In 2016, we had scientist from 26 different nations working at our institute.

Many scientists are in Frankfurt only for a short time: PhD students stay for 3-4 years, and post-doctoral researchers mostly stay for 1-2 years. In addition we have about 10 guest researchers monthly, they visit FIAS for just a week or up to several months. This means we have new people coming to FIAS on a monthly basis and we are doing our best making them feel at home as soon as possible.

Behind all this stands a small, but strong administrative team, organizing everything in the background.

FIAS scientists by research area:





Lasting scientific success is intrinsically linked with the fostering of young talents. At FIAS we support our junior-scientists with an ideal staff-student-ratio, from whom not only our students profit, but our fellows and post-docs, as well.

New Fellows 2016

Senior Fellows

Prof. Dr. Martin-Leo Hansmann

Pathology

Fellow since: December 2016

Prof. Dr. Enrico Schleiff

Molecular Cell Biology

Fellow since: June 2016

Fellows

Prof. Dr. Franziska Matthäus

Bioinformatics

Fellow since: Oktober 2016

Prof. Dr. Jürgen Struckmeier

Physics

Fellow since: December 2016

Research Fellows

Dr. Sabine Hossenfelder

Physics

Fellow since: February 2016

Dr. Raoul-M. Memmesheimer

Neuroscience

Fellow since: December 2016

Adjunct Fellows

Prof. Dr. Jörg Aichelin

Physics

Fellow since: June 2016

Prof. Dr. Henner Büsching

Physics

Fellow since: March 2016

Prof. Dr. Eduardo Guendelman

Physics

Fellow since: September 2016

Awards


URKUNDE
DFG
DFG
erleihung der
Heinz Maier-Leibnitz-Preise
2016

Prof. Dr. Dr. h.c. mult. Horst Stöcker after the ceremony that awarded him a honorary doctorate by the JINR in Dubna.

Prof. Dr. Dr. h.c. mult. Horst Stöcker was awarded a honorary doctorate by the Joint Institute for Nuclear Research (JINR) in Dubna (Russia). The title was given to him for his "extraordinary contribution to the scientific advancements and for the training of junior scientists" .

Prof. Dr. Christoph von der Malsburg was named Fellow of the International Neural Network Society.

Prof. Dr. Mishustin and Prof. Dr. Rezzolla were chosen to be "Outstanding Referees" of the Physical Review Journals.

Once a year the Heinz Maier-Leibnitz Prize is awarded to early career researchers in recognition of their outstanding achievements, by DFG. The prize, valued at €20,000, assists researchers in furthering their scientific careers. One of this years award winners is FIAS Fellows Prof. Dr. Hannah Petersen. She got the prize for her work on new theoretical descriptions of the "Little Bang" in the area of relativistic heavy ion collisions.

PD Dr. Piero Nicolini got a Peer Review excellence recognition from Physica A and the "Physics of the Dark Universe, Physics and Astronomy Sentinel of Science Award 2016" by Publons.

In addition he was awarded the Carl-Wilhelm-Fueck-Preis by the "Frankfurter Förderverein für physikalische Grundlagenforschung", valued at €5,000.

Dr. Sabine Hossenfelder was the second person to get the Carl-Wilhelm-Fueck-Preis by the "Frankfurter Förderverein für physikalische Grundlagenforschung", valued at €5,000.

Not only the fellows, but the junior scientists as well were quite successful. Dr. Antonia Frassino for example got a prize for her outstanding dissertation: The Giersch-PostDoc-Startup.

Vincent Steinberg, Stephan Endres and Michael Wondrak were given the Giersch Excellence Award 2016 for their exceptional work as PhD students.

Gerard 't Hooft

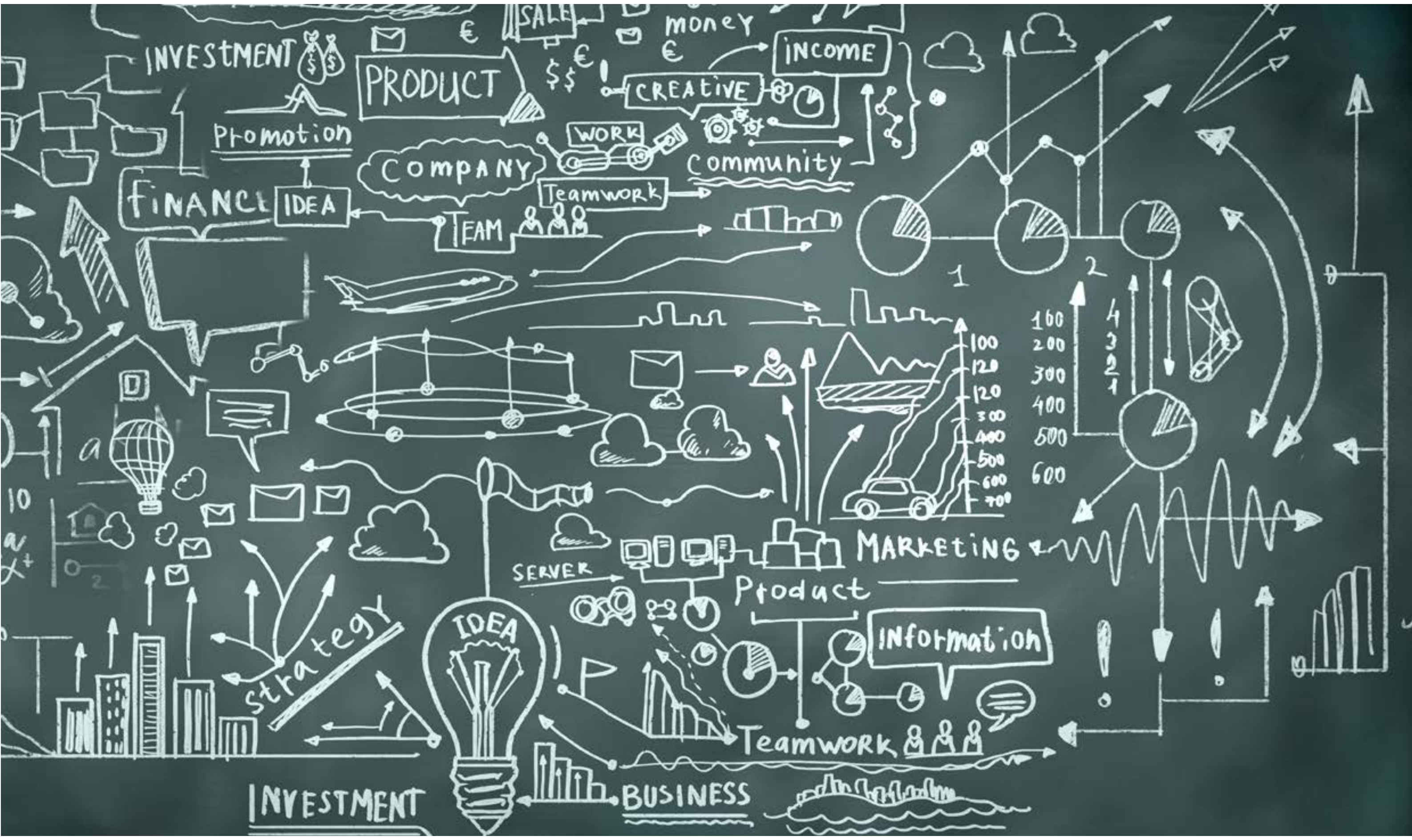
FIAS Senior Fellow Laureatus

The Nobel Prize winner distinguished himself with his extraordinary performances in the fields of quantum field theory and quantum theory, especially through his engagement for young scientists. Over the course of his scientific career he made many important contributions to modern physics, especially to renormalization, which is the determination of a suitable energy scale electroweak interaction. For this, ‘t Hooft received the Nobel Prize in Physics in 1999, together with Martinus Veltman. The ceremony in celebration of the appointment of Gerard ‘t Hooft as an Honorary Fellow of the FIAS was moderated by Prof. Dr. Dr. h.c. mult. Horst Stöcker, Board Director of the FIAS. The presentation of the document and the €10,000 prize was personally presented by donor Senator E. h. Prof. Carlo Giersch.

Prof. Dr. Gerard ‘t Hooft was appointed a FIAS Senior Fellow Laureate by FIAS and the STIFTUNG GIERSCH at a ceremony on September 28, 2016.

FIGSS

Frankfurt International Graduate School for Science



Much of the research at FIAS is performed by our PhD students. The Frankfurt International Graduate School for Science (FIGSS) is the graduate school of FIAS. It provides a framework for structured doctoral education at FIAS and guarantees the interdisciplinary nature of the program for doctoral candidates. The PhD degrees are granted by the departments of Goethe University Frankfurt. The FIGSS PhD students are typically funded by research grants to their advisors and are expected to obtain their PhD degrees within 3 years. Current enrollment is about 60 students with roughly half of them being foreign nationals.

Next to research training, the doctoral education in FIGSS comprises various courses taught by FIAS Fellows such as a base course in Methods for the Study of Complex Systems as well as many specialized courses in the different research areas of the institute. In addition, students can choose from a wide range of transferrable skill courses offered by GRADE, the Goethe Graduate Academy of Goethe University.

A core activity of FIGSS is its weekly interdisciplinary seminar, where FIGSS students and post-docs of the institute report on the status of their research. Special care is taken that the talks are accessible to an interdisciplinary audience. In 2016, presentations ranged from topics like "What is a neuron?", via the question "Why do we perceive the world in 3-D?" to "Magneto-hydrodynamical numerical simulations of heavy-ion collisions".

Events

Giersch International Symposium

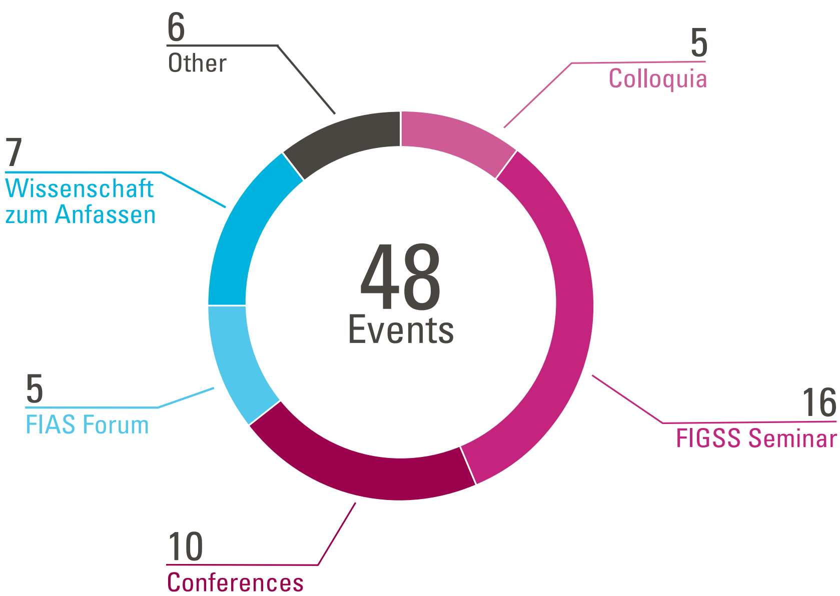
Cosmic matter and the experimental search for quantum gravity formed the focuses of the first "Giersch International Symposium," which took place at FIAS from September 19-30.

Over the span of two weeks, internationally recognized scientists from a current area of research have been brought together with young up-and-coming scientists to exchange ideas, discuss, and form networks. Nobel Prize winner Prof. Dr. Dr. h.c. mult. Gerard 't Hooft was the guest of honor. He was appointed a FIAS Senior Fellow Laureate at a ceremony on September 28.

Therefore in the first week of the symposium, scientists from all over the world came together to exchange their latest findings and jointly discuss ways for finding experimental evidence of quantum gravity. In the second week, participating students and young scientists were able to deepen their knowledge in specialist fields like quantum field theory, cosmology, or big data. Renowned scientists including the Leibniz and Lise Meitner award winner Prof. Dr. Dr. h.c. Reinhard Stock, Director of the Zuse Institute of Berlin, Prof. Alexander Reinefeld, and the new FIAS Fellow Laureate, Nobel Prize winner Prof. Dr. Dr. h.c. mult. Gerard 't Hooft lent them their support.

The "Giersch International Symposium" was the first event of this new conference series facilitated by a generous donation by the GIERSCH STIFTUNG.

Overview of all FIAS Events in 2016:



Ernst Strüngmann Forum

As in previous years, FIAS was the location for events by the Ernst Strüngmann Forum. In three workshops, international scientists from various disciplines were able to exchange ideas on current topics and work on new concepts.

The topics in 2016 were "Contextualizing Attachment: The Cultural Nature of Attachment," "Rethinking Environmentalism: Justice, Sustainability, and Diversity" and "Agrobiodiversity in the 21st Century."

Dr. Thomas Brown is speaking at the CoNDyNet Workshop.

FIAS Fellow Christoph von der Malsburg speaking at the Night of Science.

The General Manager Gisbert Jockenhöfer together with Rudolf Steinberg, chairman of the Board of Trustees at the FIAS Forum.

The Hessian Minister for Economics Tarek Al-Wazir at the Innovation Aliance Data Centers Meeting at FIAS.

Innovation Alliance Data Centers

The symposium of the innovation alliance data centers took place on January 22, 2016 at the FIAS. Minister of Economics Tarek Al-Wazir inducted the conference of the Hessian Ministry of Economics with a short welcoming speech. The event ran under the slogan, "Data centers as the linchpin of the digital transformation."

International Physicist Tournament

The German prequalifiers for the International Physicist Tournament took place at FIAS in November. Three student teams measured their physics knowledge over the span of two days in lectures and debates. The title defending group from Frankfurt emerged as the victors and will now participate at the international competition in Gothenburg, Sweden.

Night of Science

As in previous years, the FIAS once again participated in the 2016 Night of Science at the Riedberg campus. From the late afternoon of June 13, 2016 until the early morning hours of the next day, visitors got excited about science. Experiments under the slogan "Hands-on Science" and the "Bembelcup" took place in the FIAS. Robot soccer teams from all over Germany came together for the occasion.

CoNDyNet Workshop

On November 22-23, the partners of the CoNDyNet (Collective Nonlinear Dynamics of Complex Electricity Grids) project met with firms and network operators to discuss how a long-lasting stability of power grids can be achieved under ever-increasing shares of renewable energies. The amount of electricity fed into the power grid fluctuates almost every minute, especially when it comes to solar and wind energy.

Public Relations

One of the most important activities within the scientific community apart from research and teaching is the communication of scientific discoveries into the public domain.

Here FIAS established various different formats over the last few years and also in 2016 exceptional activities took place.

The FIAS Forum continued, a series where the general public is invited and presentations about current research is given. Special focus here is that all presentations are understandable not only by scientific audiences, but rather can be understood by non-scientists. In 2016, the speakers were:

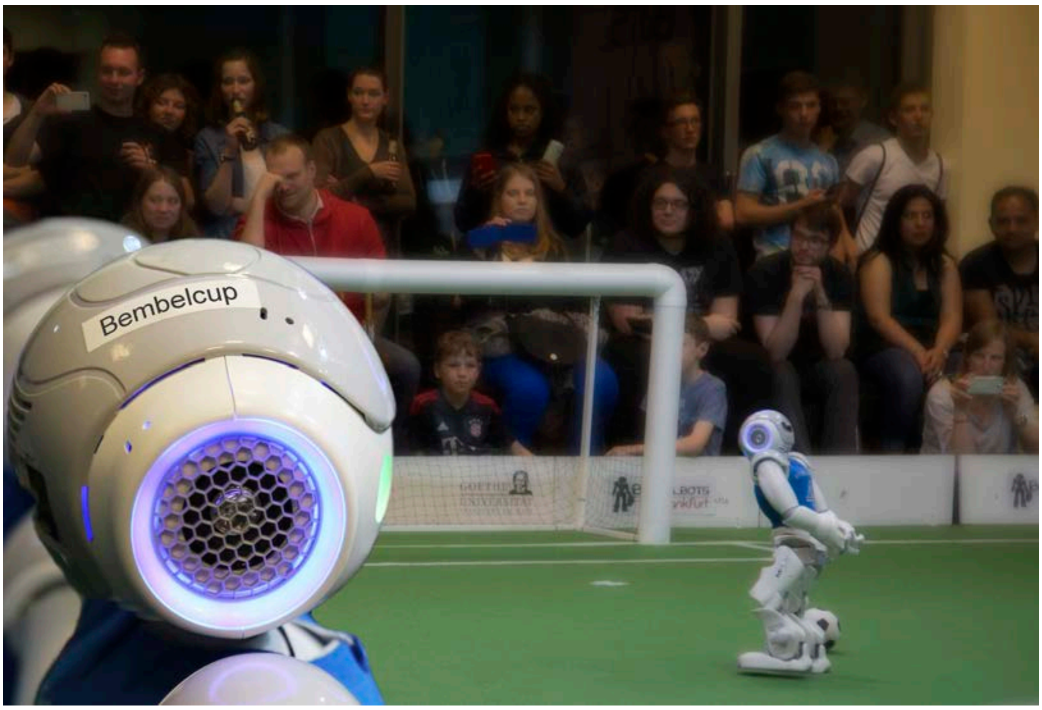
- Stefanie Dimmeler - Genom ohne Funktion? Die biologische Bedeutung des „Dark Genomes" .
- Theodor Dingermann - Das ZIKA-Virus – Eine relevante Gefahr für unsere Gesundheit?
- Harald Schwalbe - Wettkampf der Ideen – Wie entwickeln wir neue Arzneimittel?
- Werner Müller-Esterl - Exzellenz oder Dekadenz – deutsche Universitäten am Scheideweg.
- Wolfgang Bauer - Kann die Energiewende das Überhitzen der Erdatmosphäre verhindern?

October, 2016. Visitors of the Frankfurt Book Fair are asthonished by our superconductor experiments.

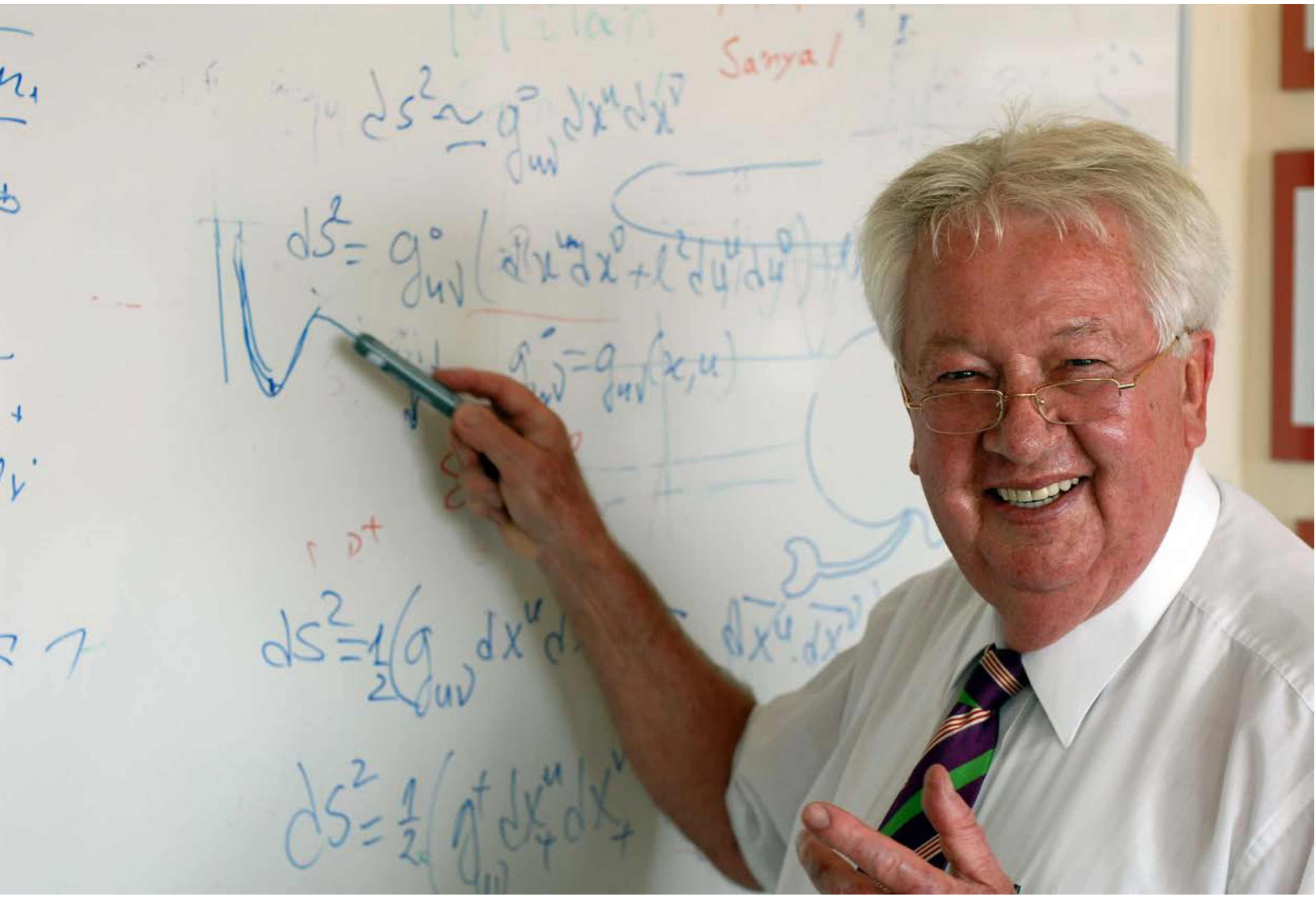
Especially noteworthy are the activities of the team of the exhibition "Hands-on research", here the team around Sascha Vogel presents science, especially research of FIAS in an hands-on exhibition, where people can operate a particle accelerator, learn how algorithms work and experience what a vacuum does to a chocolate marshmallow. In a cooperation with the initiative "Hessen schafft Wissen" the exhibition travels around Hessen and is presented in schools, at the yearly Hessentag exhibition (with up to 30000 visitors!) and at the Frankfurt Book Fair.

FIAS also takes part in the Night of Science, which takes place once per year at the Campus Riedberg of the Goethe University. Here the lecture hall is remodelled and the "FIAS Bembelcup" is played. Various robot football teams from all over Germany join us for a chance to win the trophy - the traditional FIAS Bembel.

The faculty lounge displays the newest exhibits of the hands-on research exhibition where people join and learn about our science. In addition plenty of FIAS Fellows are involved in giving talks during the nightly program.



Remembering



Joachim Reinhardt

For more than a decade, Joachim Reinhardt made significant contributions to the successful conception of the FIAS and coordinated its scientific activities as the institutes scientific secretary.
He played a part in many fields with much perspective and extraordinary commitment. In addition to the structural work, Joachim Reinhardt was always an important scientific discussion partner. Together with Walter Greiner, he wrote several textbooks and, when a text about FIAS was needed for the public, he found the right words with certainty.

We have lost a very good and loyal friend whose high scientific qualifications were only exceeded by his modesty.

Walter Greiner

He was the "grand old man" of Frankfurt's heavy ion physics. As one of the founding directors of the FIAS, he initiated and monitored a unique meeting place for scientists of various disciplines.

Whether there would even be a GSI Helmholtzzentrum in Darmstadt today without his perseverance and unconventional methods of persuasion is questionable. As the co-founder of the interdisciplinary FIAS, he's also responsible for teaching generations of junior scientists at this institute, to see the larger picture of their own fields. As has always been known, he demanded a lot from his graduate students and himself. Nevertheless, more than 160 physicists from all corners of the world wanted to do their doctorates with him. Approximately 50 of them hold professorships throughout the world now.

His scientific qualifications are documented in countless publications, his textbooks which are translated into several languages, the prizes and awards bestowed upon him, his numerous memberships and honorary memberships in renowned scientific committees, and his honorary professorships and doctorates around the world.

With his work and his passion for research, he has been a crucial influence on all of us. His life's work and commitment will remain a vital standard for us.
We will miss our academic instructor, colleague, and friend Walter Greiner very much.

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General Manager: Gisbert Jockenhöfer

presse@fias.uni-frankfurt.de
phone: 069 798-47688
www.fias.uni-frankfurt.de

Postal adress
FIAS Frankfurt Institute for Advanced Studies
Ruth-Moufang-Straße 1
60438 Frankfurt am Main

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