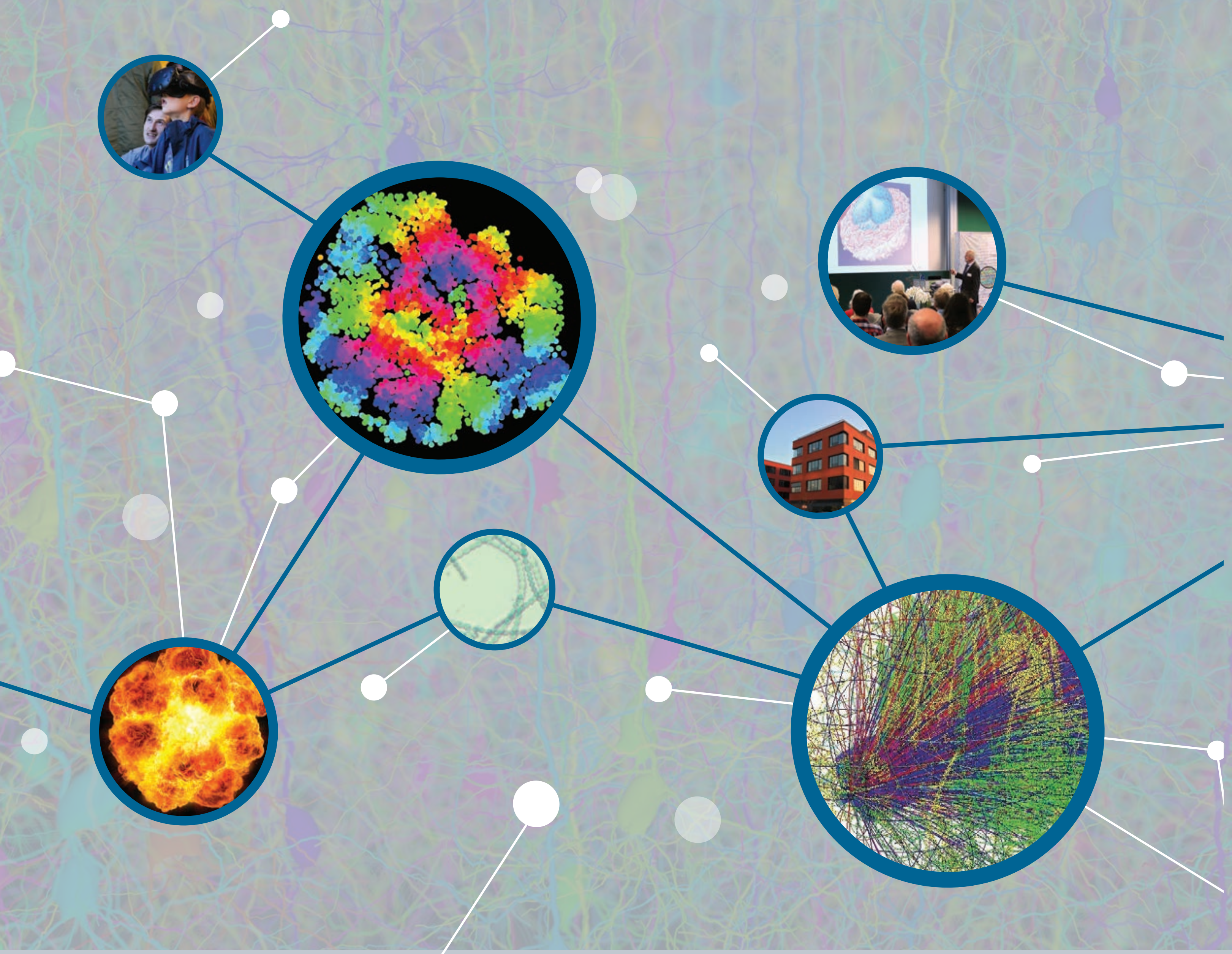
FIAS Frankfurt Institute for Advanced Studies

2018



FIAS

connecting science

– the year 2018 was marked by the advancement of interdisciplinary projects at FIAS.

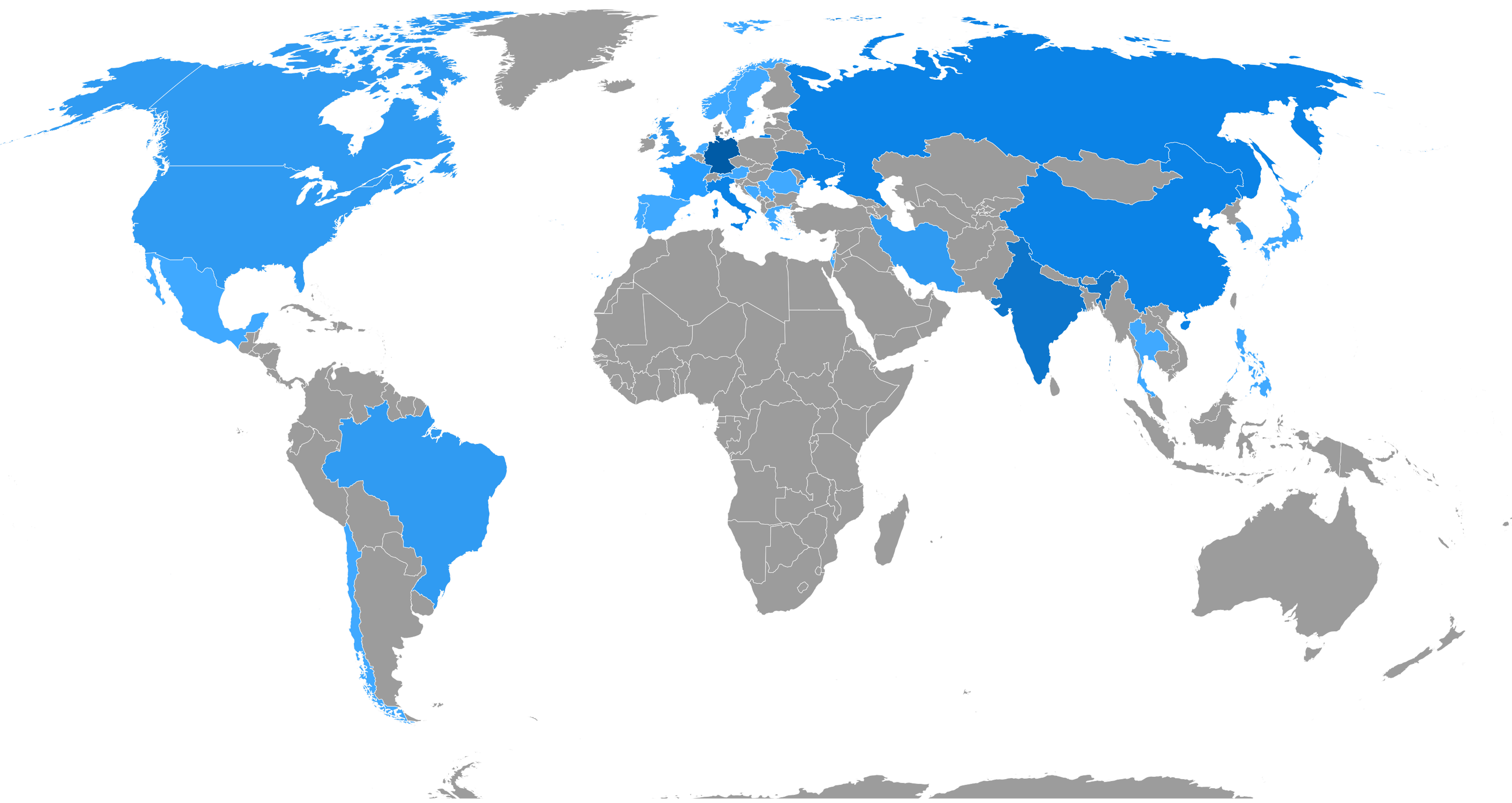
The third Giersch Symposium took place and the participants had a closer look on the logistics of neural function. The group working on deep and machine learning connected and collaborated throughout the world. Severeal conferences, workshops and meetings took place at FIAS, mostly on interdisciplinary topics.

The work of the SPP2041 started with a kick off meeting at FIAS. The Core Research Area for MultiScale Modelling was initiated and was handed in as a proposal within the Hessian Excellence Initiative LOEWE.

These topics can only show a small part of the various interdisciplinary projects at FIAS in 2018. On the following pages you will get a closer look what scientists at FIAS achieved in the previous year.

Content

People at FIAS



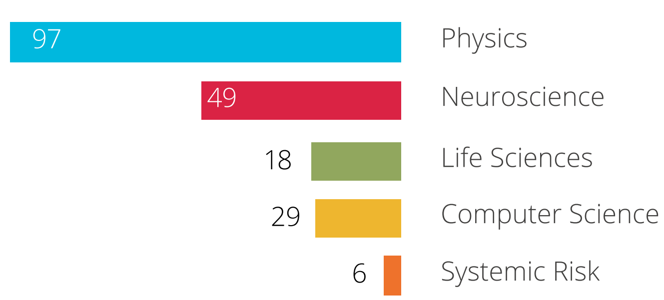
The performance of any scientific institute depends crucially on the people involved with it. This is not different at FIAS – with their enthusiasm and engagement our researchers are the foundation of our success.

With 35% of our researchers being not from Germany, FIAS is very international. In 2018, we had scientist from 31 different nations working at our institute.

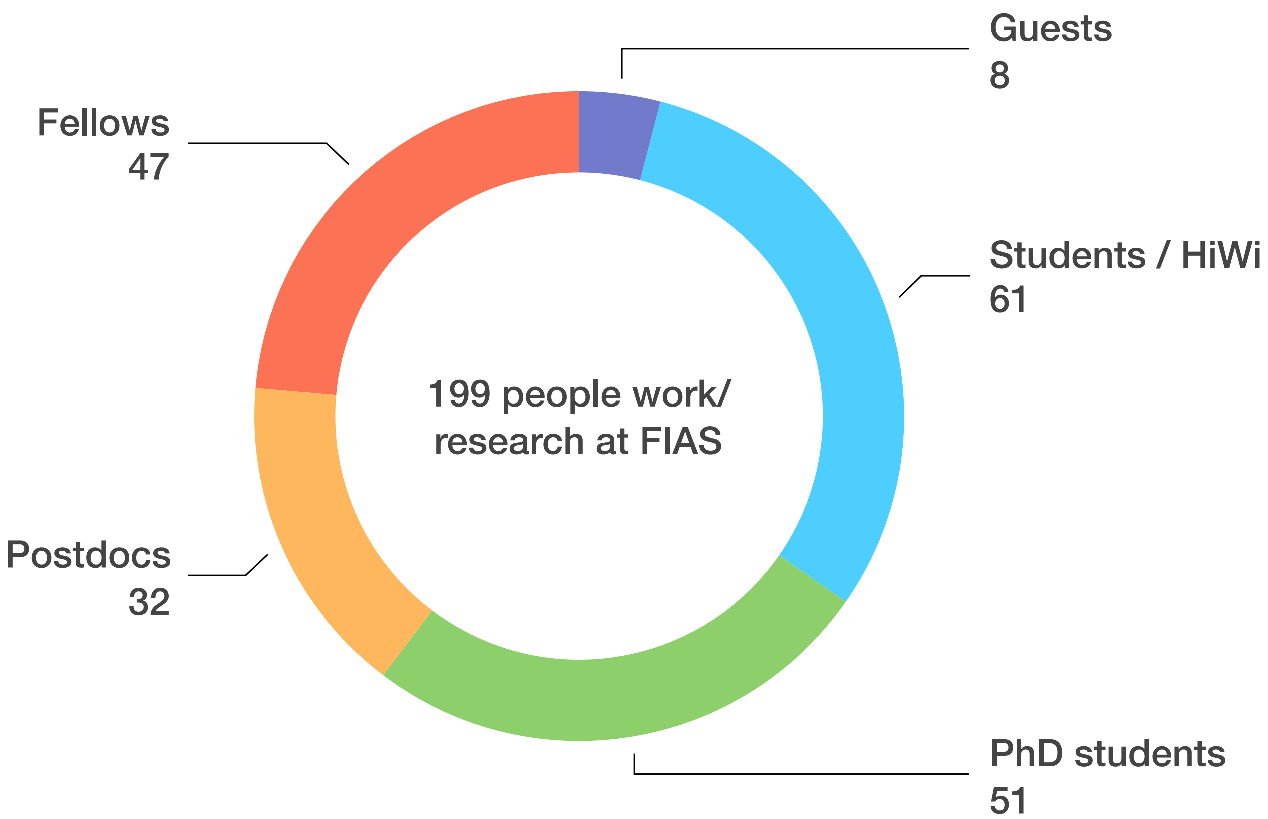
Many scientists are in Frankfurt only for a short time: PhD students stay for 3-4 years, and post-doctoral researchers mostly stay for 1-2 years. In addition we have about 10 guest researchers monthly, they visit FIAS for just a week or up to several months. This means we have new people coming to FIAS 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.



Edvard Moser

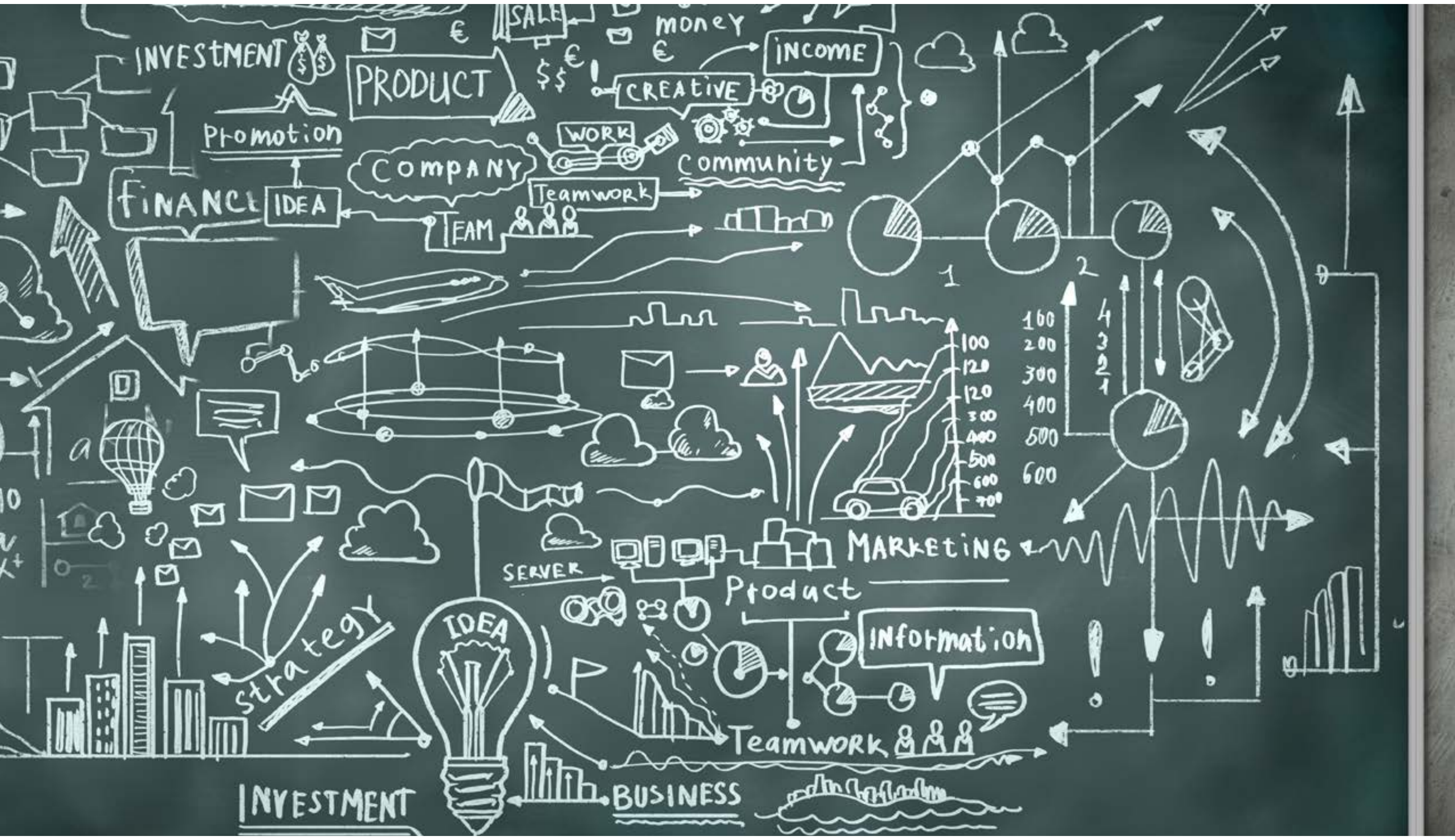
FIAS Senior Fellow Laureatus

On September 3, 2018, a ceremony was held to mark the appointment of Prof. Dr. Edvard Moser to FIAS "Senior Fellow Laureatus". This honorary award is given to outstanding international scientists who are not only distinguished by their excellent research work, but are also committed to the scientific community.
The prizewinner Prof Dr. Edvard Moser is a Professor of Psychology at the Norwegian University of Science and Technology in Trondheim.
After receiving the honorary fellowship from Senator E.h. Karin Giersch and Senator E.h. Prof. Carlo Giersch, Professor Moser gave a lecture on his current research.

Prof. Dr. Edvard Moser was appointed a FIAS Senior Fellow Laureate by FIAS and the STIFTUNG GIERSCH at a ceremony during the Giersch International Symposium.

FIGSS

Frankfurt International Graduate School for Science

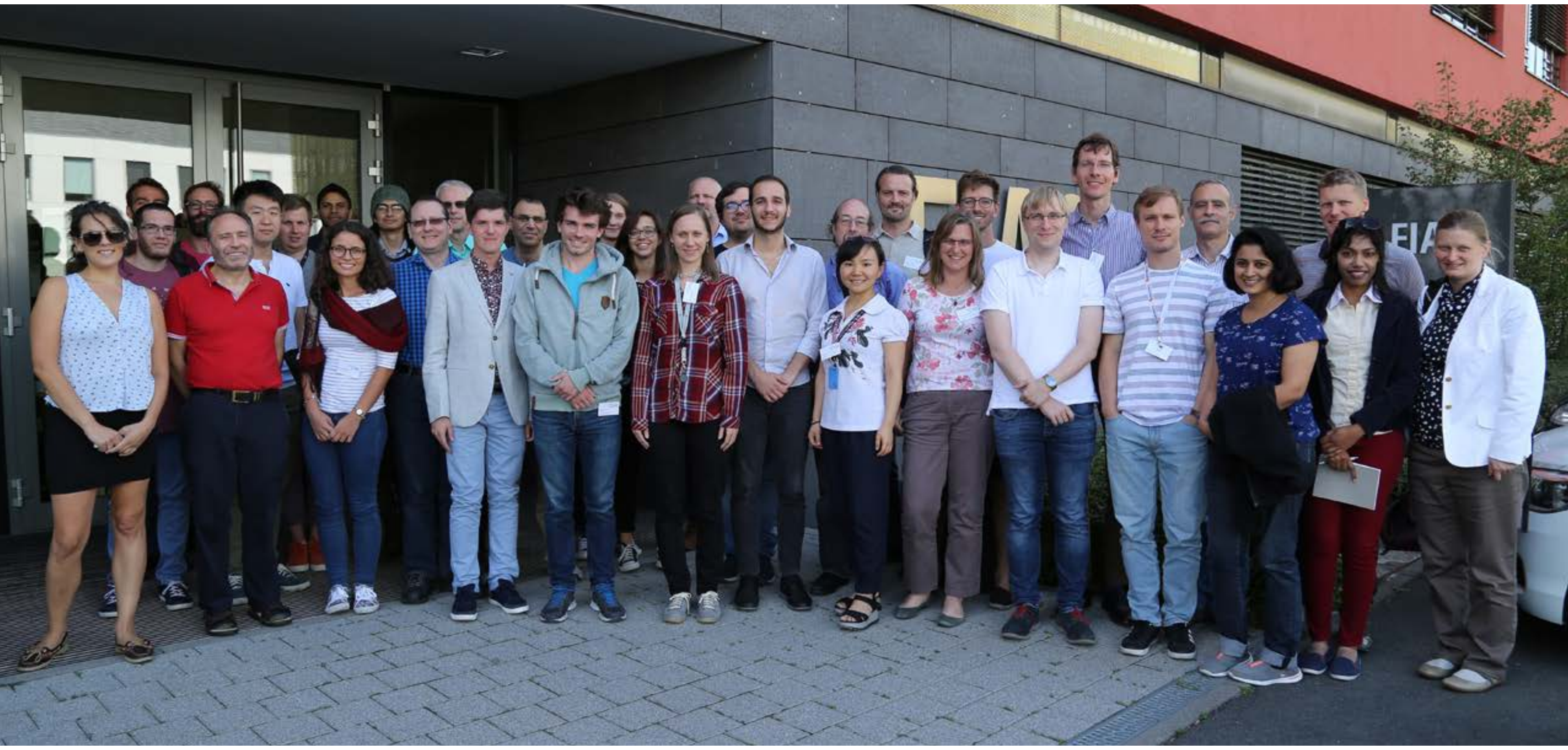


Much of the research at FIAS is performed by our PhD students. The Frankfurt International Graduate School for Science (FIGSS) is the graduate school of FIAS. It provides a framework for structured doctoral education at FIAS and guarantees the interdisciplinary nature of the program for doctoral candidates. 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. In 2018 for the first time dedicated soft skill courses have been offered, with huge success.

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.

Events



The participants of the 3rd Giersch International Symposium.

Participants of the Giersch International Symposium discussing

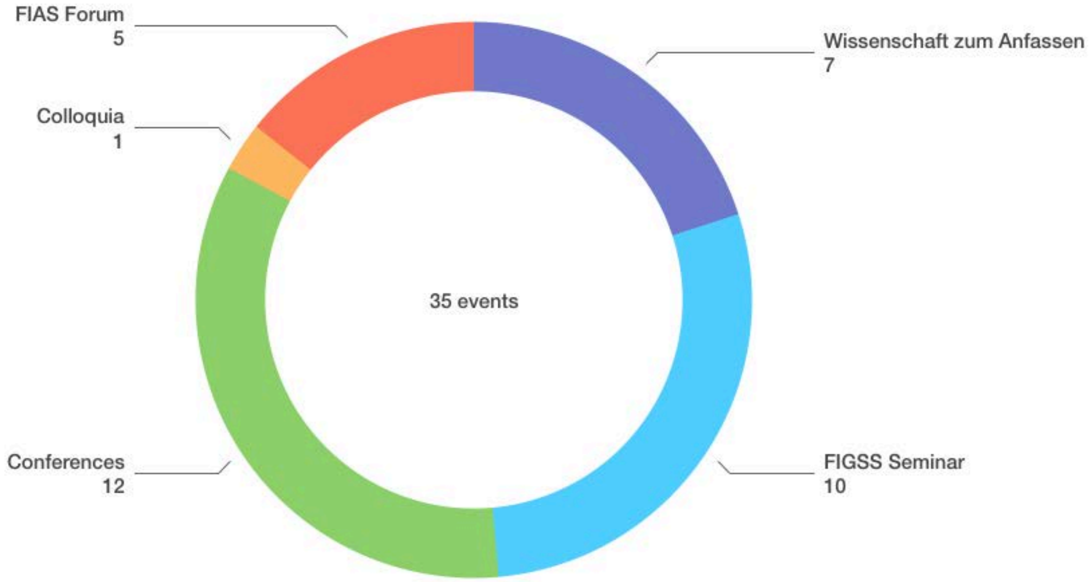
Giersch International Symposium

Neurons face a variety of logistics challenges. They need to organize the production, transport, storage, and recycling of various molecules such as neurotransmitters, mRNA, and proteins to fill their extensive dendritic and axonal arbors. This first workshop on the logistics of neuronal function brings together leading experimentalists, theoreticians, and method developers to exchange ideas on these fundamental questions.The third Giersch Symposium, was held from August 28 to September 7, at FIAS in Frankfurt with its main focus on the logistics of neuronal funciton. With the start of the first clinical facility with dual ion options (protons and carbon) in Heidelberg, Germany, in 2009, the interst in hadrontherapy has been constantly growing. The Symposium brought together leading international experts in the field of hadrontherapy to discuss the present status of the field and to identify the challenges for the future.

Coupled with the Conference, there was a Summer School for young researchers. Here leading experts taught about the fundamentals of the field.

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

Overview of all FIAS Events in 2018:



Keynote Lectutre "When physics is art" at the Workshop "Interdisciplinary Science Communication 2017" by Ágnes Mócsy, Pratt University.

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 2018 were "Cerebral Cortex 3.0," and "Youth Mental Health".

Kick-Off: SPP 2041 - Computational Connectomics

FIAS hosted the kick-off meeting of the DFG priority programme "SPP 2041 - Computational Connectomics". The goal of SPP 2041 is to better understand the interconnection and function of our brain and nervous system. Using methods of computer science and mathematics, the participating scientists try to better understand the structure of the connections between individual nerve cells or entire brain regions by using the term "computational connectomics".

The participants of the SPP Kick-Off Meeting.

Lecture of Long Cai at the GIS 208

15th SAB Conference

This interdisciplinary conference brings together researchers in computer science, artificial intelligence, artificial life, control, robotics, neurosciences, ethology, evolutionary biology and related fields in order to further our understanding of the behaviours and underlying mechanisms that allow natural and artificial animals (so-called animats) to adapt and survive in uncertain environments.

CONNECT 2.0

The Symposium "Science and Society" did create a collaborative platform and brougt together young researchers and established scientists from the balkan region. Given the historical background of the region, the group of participants and keynote speakers/lecturers was carefully selected and represented the different ethnical groups as well as the different countries and regions.

Public Relations

Enrico Schleiff, the new FIAS director giving a presentation at the FIAS Forum

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 2018 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 2018 the speakers were:

- Heidi Keller - Bindung und Kultur. Bilder von Kind und Familie im Kulturvergleich
- Marcel Verhoff - Rechtsmedizin – zwischen Krimi und Wissenschaft
- Matthias Alfeld - Die Bilder hinter den Bildern - Was bildgebende spektroskopische Verfahren in Kunstanalytik und Archäologie sichtbar machen
- Enrico Schleiff - Die Tomate und die Vereinigten Staaten von Amerika
- Jürgen Schaffner-Bielich - Reise in das Innere eines Neutronensternes

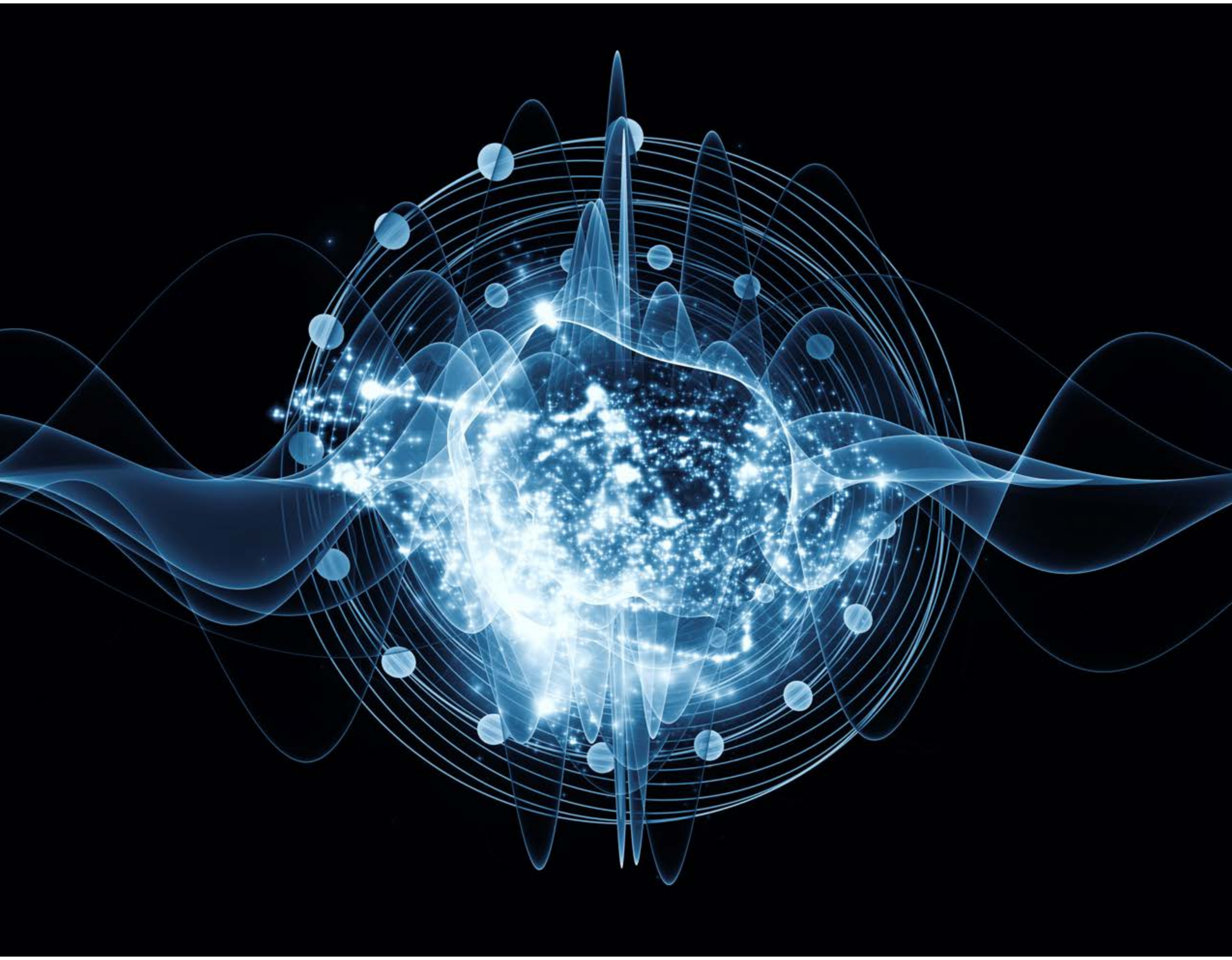
Especially noteworthy are the activities of the team

Night of Science 2018. |

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. In the faculty club the newest exhibits of the hands-on research exhibition where displayed and people joined and learned about our science. In addition plenty of FIAS Fellows are involved in giving talks during the nightly program.

Physics



Optimization of Network building costs:

Due to the increasing share of renewable energies in the electricity grid, there are always grid bottlenecks. Fortunately, there are solutions: new technologies that can quickly compensate for fluctuations, wind turbines with synthetic inertia and better system control. At the moment, network operators usually counter these fluctuations with short-term control measures. The efficient operation and expansion of the transmission grid is therefore an essential part of the integration of renewable energies.

In 2017, a project funded by BMWI was started at FIAS and partner institutions, where the scientists will develop and evaluate algorithms for the distribution of load flows and network costs and then systematically compare them. In addition, the effects of different cost distribution approaches on short-term operating and long-term investment decisions in the German electricity market are examined.

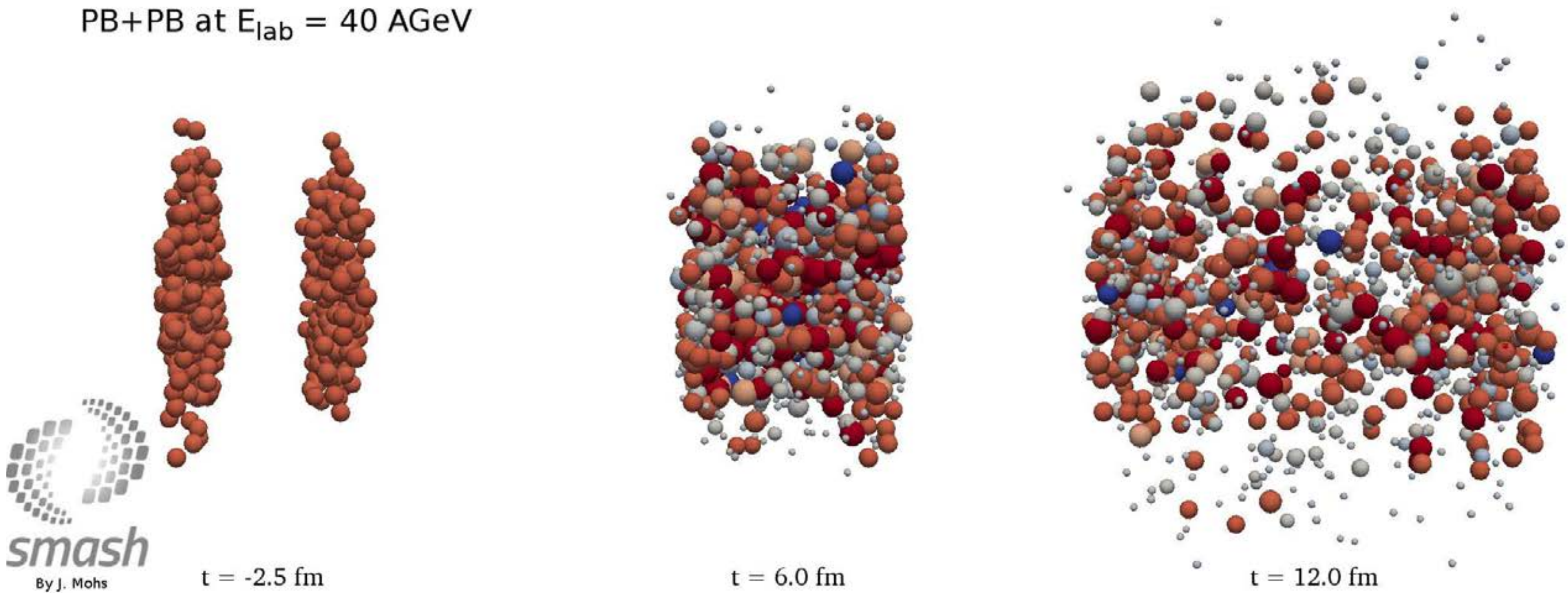
Theoretical physics is the discipline that aims at describing how the world works in terms of fundamental equations. The goal is to abstract explicit phenomena by reducing them to underlying principles that are responsible for many different manifestations in nature. Physical processes are often the 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.



Picture 1: Time evolution of a heavy ion collision at a beam energy of 40 AGeV within the new hadronic transport approach, SMASH.

Group Information

At FIAS

since 2012; Fellow

Research Area

Theoretical nuclear physics
Heavy ion collisions
Transport theory and hydrodynamics

Team

Dr. Feng Li
Dr. Sangwook Ryu
Vinzent Steinberg
Alba Soto-Ontoso
Jean-Bernard Rose
Anna Schäfer
Jan Staudenmaier
Jan Hammelmann
Justin Mohs
Jonas Rothermel
Philip Karan
Damjan Mitrovic
Yannick Paumen
Natey Kübler

Collaborations

David Blaschke, Univ. Wroclaw
Xin-Nian Wang, LBNL & CCNU
Ulrich Heinz, Ohio State Univ.
Charles Gale, McGill Univ.
Javier Albacete, Univ. of Granada

Hannah Elfner

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.

The hadronic transport approach (SMASH –Simulating Many Accelerated Strongly-interacting Hadrons) has been developed under open source license and is released to the public since November 2018 (https://smash-transport.github.io). The code is already integrated in international collaborations (JETSCAPE and BEST) and will be used by experimental collaborations at GSI and LHC. One of the ongoing activities is therefore, the participation in a transport code comparison project, where 10-20 different transport approaches are scrutinized to disentangle systematic uncertainties from interesting physics. The highlights of the new approach have been presented in a presentation at Quark Matter 2018, where Hannah Elfner received the prestigious Zimanyi medal by the Wigner Institute. This prize is awarded at each Quark Matter conference, the largest conference in the field, to an outstanding young theoretical heavy ion physicist.

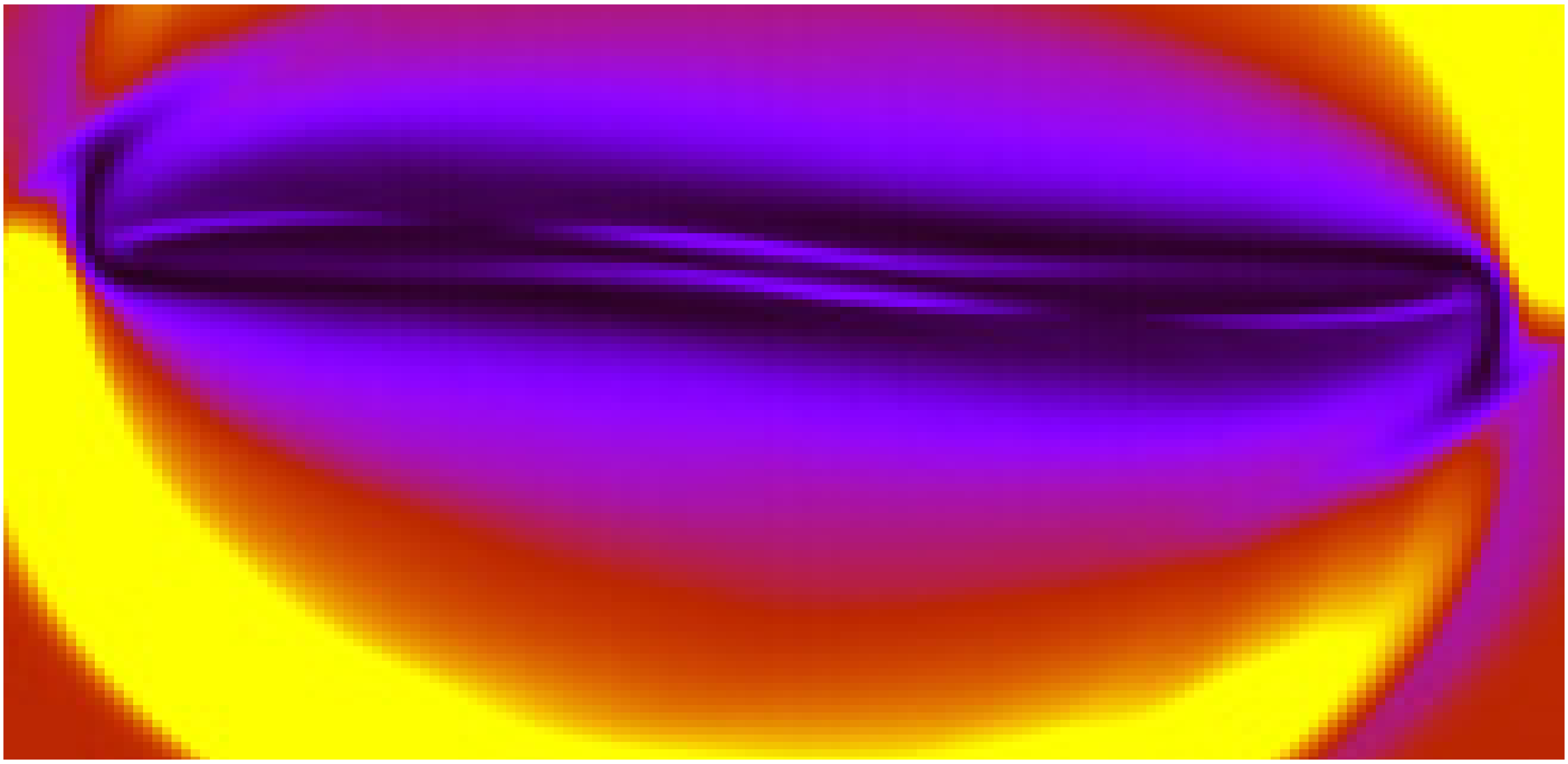
The electric conductivity is one of the fundamental properties of any material. For strongly-interacting matter transport coefficients are of great interest as well. We have calculated the electric conductivity of a simplified hadron gas as a function of temperature and match analytic expectations from kinetic theory perfectly. Surprisingly, we have found no drastic influence of the resonance lifetimes, since the charge current relaxes already in the formation process and is therefore not delayed as the momentum transport. Another topic under active investigation by the HADES collaboration at GSI is the production of strange particles below or just slightly above the kinematic threshold. Within SMASH, we have carried out a comprehensive analysis of elementary exclusive production cross-sections. On that basis, a comparison to strangeness production in heavy-ion collisions has been performed. A hadronic transport approach with vacuum properties is not sufficient to describe the strangeness production in central collisions of large systems.

In addition, the late stage of heavy-ion reactions at high beam energies is dominated by hadronic interactions. Therefore, SMASH has been employed as part of a hydrodynamics+transport hybrid approach to investigate the production of deuterons in PbPb collisions at LHC. Deuterons are composite particles out of a neutron and a proton and have a very low binding energy. The exciting finding that even these exotic particles follow the predictions of the thermal model has been explained microscopically by the high hadronic cross-sections. Therefore, the deuteron yield will be regenerated during the hadronic stage, even if there are no deuterons produced on the transition hypersurface close to the chemical freeze-out. The production of these fragile objects in a hot and dense environment has been dubbed 'snowballs in hell'.

Prof. Dr. Hannah Elfner

Hannah Elfner is the head of the group 'Transport and Experiment Simulations' at GSI, professor for Theoretical Physics at Goethe University and a fellow at FIAS since 2013. 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. In 2018, she was awarded the Zimanyi medal at the Quark matter conference, the highest recognition of young theoretical heavy ion physicists.

Picture 2: Logo for the transport approach SMASH (Simuluating Many Accelerated Strongly-interacting Hadrons).



Group Information

At FIAS

since 2010, Senior Fellow

Research Area

Astrophysics
Cancer Research
General Relativity
Heavy Ion Physics
Medical Physics
Nuclear Physics
Theoretical Physics

Team

Dr. Alexander Botvina
Vincent Gaebel, B.Sc.
Paula Hillmann, M.Sc.
Dr. Gabriele Inghirami
Amanda Konieczna, B.Sc.
Dr. Alexei Larionov
Prof. Piero Nicolini
Dr. Sergey Ostapchenko
Tom Reichert, B.Sc.
Dr. Christian Spieles
Michael F. Wondrak, M.Sc.

Collaborations

Suranaree University of Technology, Nakhon Ratchasima, Thailand
ICIMAF, Havana, Cuba
University Tuzla, Bosnia
Univerzita Mateja Bela v Banskej Bystrici, Slowakia
SUBATECH, Nantes, France
LBNL, Berkeley, USA

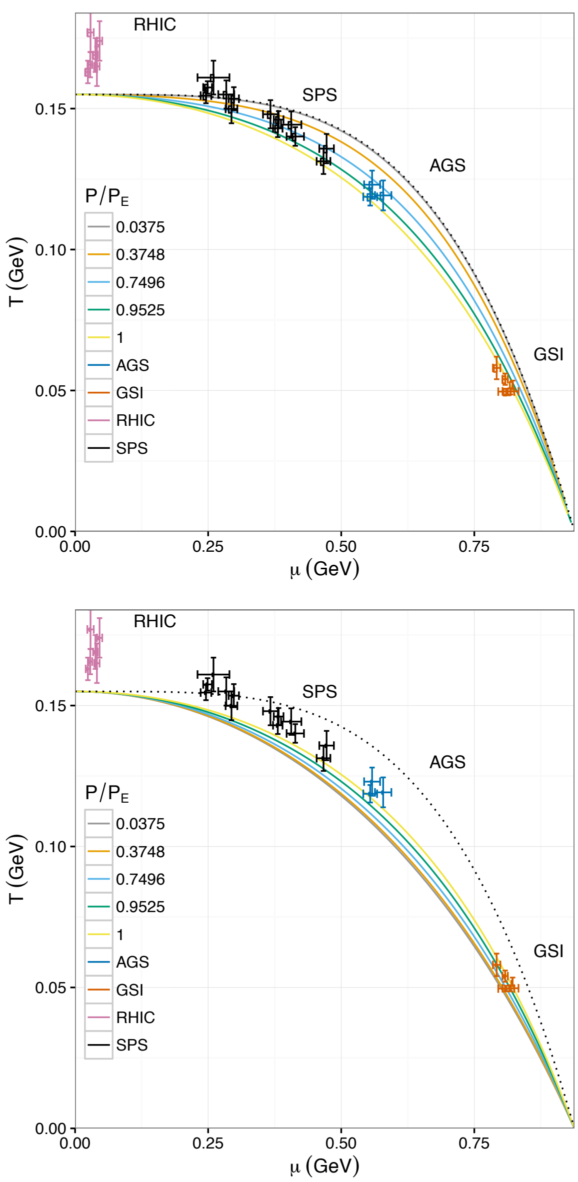
Marcus Bleicher

On the scientific side, Professor Bleicher's research is focused on heavy ion collisions and QCD. 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. Professor Bleicher and his group have made substantial contributions to the field showing his qualities as an inspirational scholar and leader in his field who creates and fosters collaborative national and international efforts.

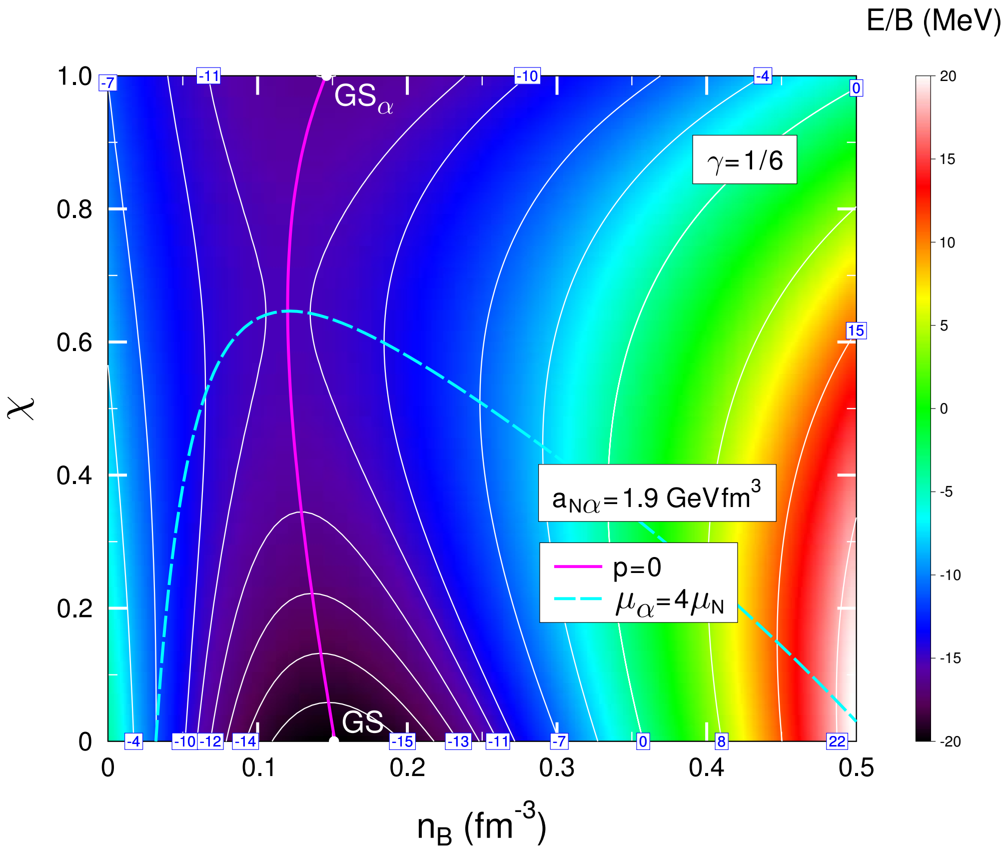
On the science management side, Professor Marcus Bleicher is the director of the LOEWE research center HIC for FAIR. He and the members of the international HIC for FAIR community look back on more than a decade of accomplishments, which include unifying the scientific HIC for FAIR community, increasing its diversity and strategic focus, providing the scientists with office space in a newly constructed building, and establishing the standing and prominent visibility of HIC for FAIR worldwide. Presently, Marcus Bleicher is in the process of guiding HIC for FAIR into a permanently financed and sustainable scientific institution. HIC for FAIR is intended to being transformed into a Helmholtz Research Academy Hesse for FAIR – an unrivaled type of scientific organizational entity within the Helmholtz Association – as from January 2020. The impact of HIC for FAIR on FIAS cannot be underestimated, as it provides stipends for doctoral students and guest scientists, supports conferences and workshops, takes over travel expenses as well as generously invests in personnel, and is the main sponsor of the high performance computing center.

Prof. Dr. Dr. h.c. Marcus Bleicher

Marcus Bleicher received his doctoral degree from Goethe University in 1999 and his Habilitation in 2007. He spent his post-doctoral years in Berkeley, USA, and in Nantes, France. In 2003 he was appointed as a Professor of Theoretical Physics at Goethe University in Frankfurt am Main. He is the Scientific Director of the LOEWE center "Helmholtz International Center for FAIR" (HIC for FAIR). HIC for FAIR substantially finances the physics and high performance computing activities at FIAS.
Professor Bleicher 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. Since 2017 he is the elected chair of the European COST Action THOR. His exceptional performance was honored by the Goethe University by naming Professor Bleicher an outstanding scientist (top 10%) of the University. His leadership in the field is exemplified by various highly cited publications and memberships in several advisory boards and organizing committees.



Freeze-out data in the statistical hadronization model compared with the criteria for the small AdS black hole solution (top panel) and for the large AdS black hole solution (bottom panel). The dashed curve is for the case P = 0. The other lines are the temperatures for different values of P (and corresponding values of (G, M)).



Picture 1: Lines of constant energy per baryon, E/B, of cold α + N matter for Nα interaction strength. The ground states of pure nucleonic matter (lower white dot) and pure α-matter (upper white dot) are separated by the potential barrier

Group Information

At FIAS

since 2004; Senior Fellow

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. Leoniid Satarov
Dr. Shun Furusawa
Allesandro Brillante

Collaborations

Prof. Dr. Mark Gorenstein,
Prof. Dr. Dmitry Anchshkin,
both B. Inst., Kiev
Prof. Laszlo Csernai,
Univ. Bergen

Igor Mishustin

Project 1: Bose condensation of alpha-particles in warm nuclear matter

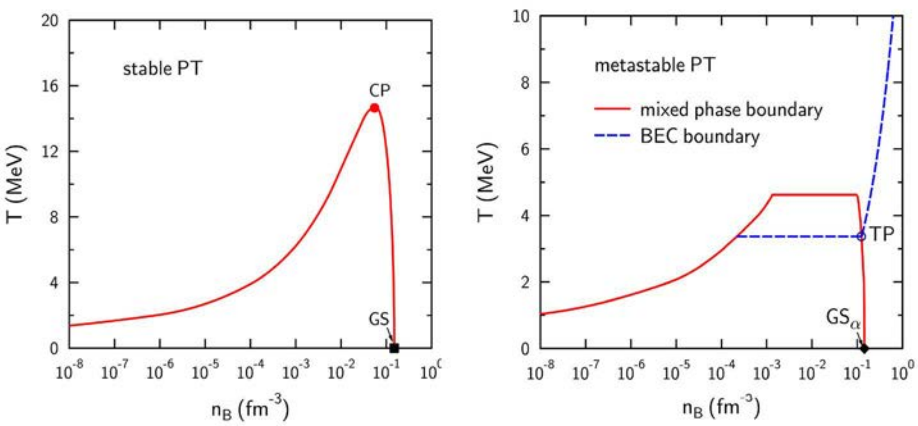
The equation of state and phase diagram of isospin-symmetric nuclear matter composed of alpha-particles and nucleons are studied in the mean-field approximation with Skyrme-like effective interactions. The effects of Fermi and Bose statistics for nucleons and alphas are taken into account. Parameters of the potentials are chosen by fitting known properties of pure nucleon- and pure alpha-matter at zero temperature, see Fig. 1. The sensitivity of results to the choice of the alpha-nucleon attraction strength is investigated. The phase diagram of the alpha-nucleon mixture is studied with a special attention paid to the liquid-gas phase transitions and the Bose-Einstein condensation of alpha particles. We have found two first-order phase transitions, stable and metastable, which differ significantly by the fractions of alpha particles, see Fig. 2. It is shown that states with alpha condensate are metastable.

Project 2: Phase Transition in Interacting Boson System at Finite Temperatures

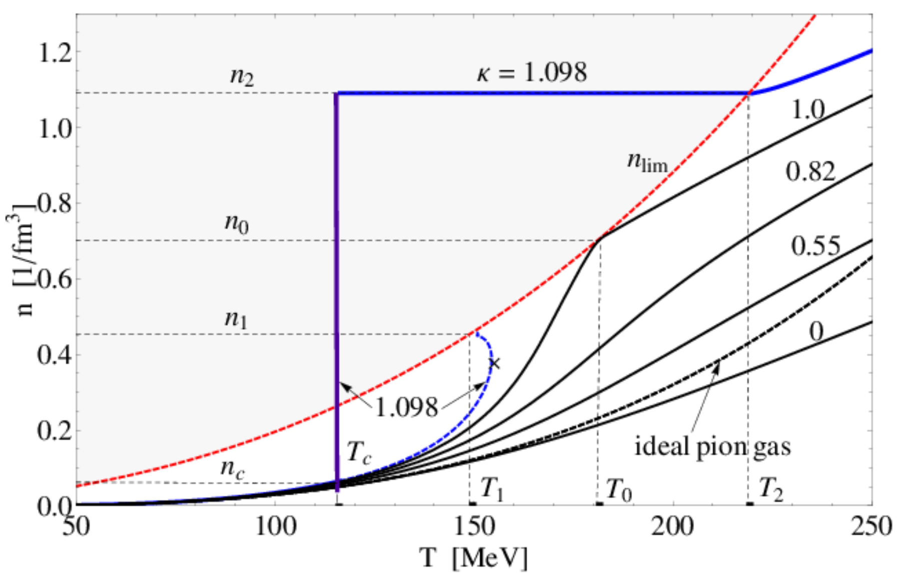
Thermodynamical properties of an interacting boson system at finite temperatures and zero chemical potential are studied within the framework of the Skyrme-like mean-field model. It is assumed that the mean field contains both attractive and repulsive terms, U(n)=-An+Bn^2. . Self-consistency relations between the mean field and thermodynamic functions are derived. It is shown that for sufficiently strong attractive interactions this system develops a first-order phase transition via the formation of Bose condensate. The energy density exhibits a jump at the critical temperature. An interesting prediction of this model is that the condensed phase is characterized by a constant total density of particles. The thermodynamical characteristics of the system are calculated for the liquid-gas and condensed phases.

Prof. Dr. Igor Mishustin

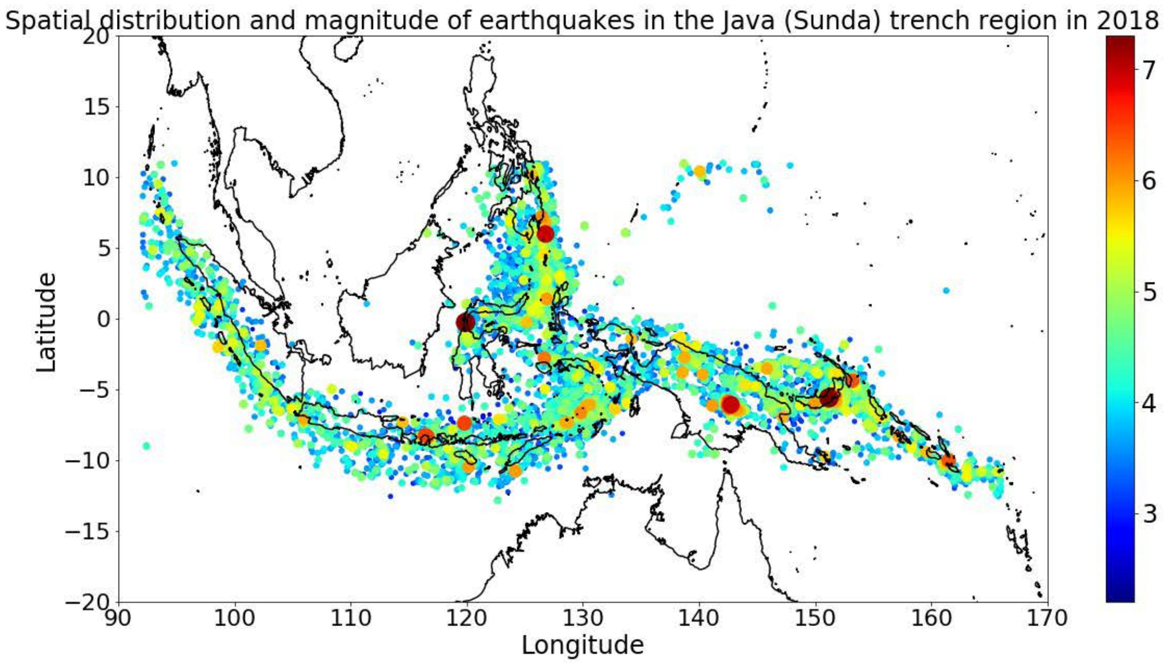
Igor Mishustin studied theoretical physics and astrophysics at the Moscow State University. He obtained his PhD and then the Doctor of Sciences degree (habilitation) at the Kurchatov Institute in Moscow. After long-term stays in the Niels Bohr Institute (Denmark) and the University of Minnesota (USA), 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: Phase boundaries for stable (left) and unstable (right) phase transitions in αN mixture. Dashed line shows the BEC boundary.



Picture 3: Bosonic particle density versus temperature for interacting system with μ = 0. The curves are labeled by the values of parameter characterising the strength of the attractive interaction.



Spatial distribution of earthquakes in the Java trench (Indonesia) region in 2018 together with their magnitude. aThis dataset corresponds to 10,000 single earthquake events.

Group Information

At FIAS

since 2004; Senior Fellow

Research Area

Nuclear Physics
Astrophysics
Heavy-Ion Physics
Complex Networks
Machine Learning

Team

Nishtha Srivastava
Kai Zhoua
Jan Steinheimer

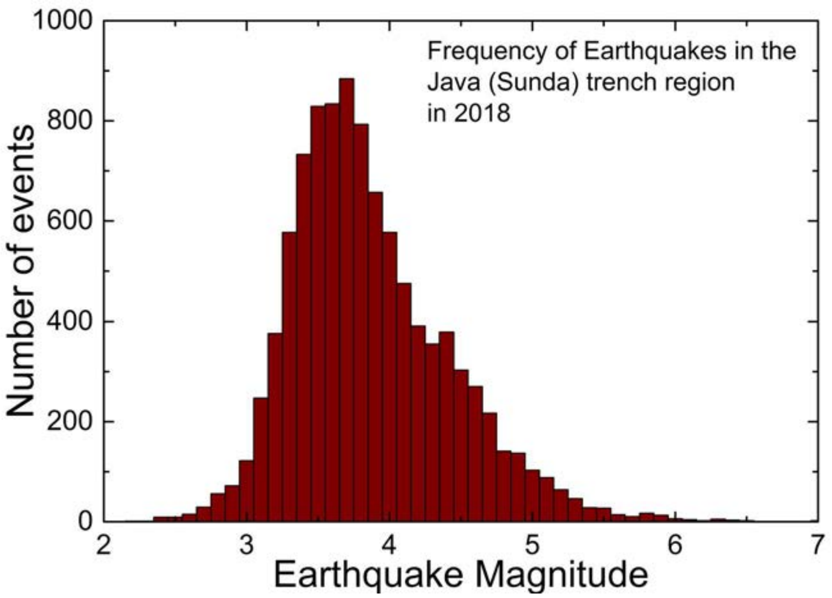
Horst Stöcker

Time and again, catastrophic earthquakes have disastrously impacted civilization, devastated urbanization, annihilated human lives and created substantial setbacks in the socio-economic development of a region. Earthquakes are considered a major menace among all the natural hazards, affecting more than 80 countries and causing over 1.6 million deaths each year. The impact due to an earthquake, interacting with a vulnerable social system continues to grow due to phenomenal rise in the global population and growth of mega cities and their exposure in the earthquake prone regions across the globe. A single earthquake may take up to several hundred thousand lives (e.g., the 2010 Haiti earthquake which took 222570 human lives) and cause huge economic loss (e.g., the 2011 Tohoku earthquake caused the direct damage worth US $211 billion). A large earthquake can trigger an ecological disaster if it occurs in close vicinity to a dam or a nuclear power plant (e.g. the Tohoku earthquake and subsequent tsunami damaged the Fukushima Dai-ichi nuclear power plant). Approximately a million earthquakes with magnitude greater than two are reported each year among which nearly a thousand are strong enough to be felt and about a hundred events destruction depending on physical vulnerability and exposure.

Earthquakes are inevitable and considered extremely difficult to predict. The analysis of past seismic stress history of an active fault can help in understanding the stress build-up and local breaking point of the fault. However, analysing and interpreting the abundant seismological dataset is a time consuming task. The implementation of Artificial Intelligence (AI) powered by deep learning algorithm has the potential to decipher the complex patterns in past stress history that is nearly impossible for conventional methods. This careful implementation of deep learning algorithm will significantly improve the early warning system and thus could help save human lives.

Our group is currently attempting to understand the intricate pattern associated with the seismic stress released by various Deep Learning/Machine Learning algorithm in the past earthquake data available for the South-East Asian country which lies on the Pacific Ring of Fire, Indonesia. The spatial and magnitude distribution of the earthquakes is shown above, while the frequency of earthquakes is shown in the figure below. Owing to the high frequency of earthquakes striking every year from different epicentres, the region provides a huge database which has been assembled during the first part of the project. This newly composed dataset is now being used to train a machine/deep learning algorithm to decipher time and spatial correlations in the stress accumulation and release pattern, consequently leading to earthquakes. We are considering both small and large magnitude earthquakes to generate a localised time series to understand the seismic history of the region. Training a machine learning algorithm by using the earthquake dataset of past 50 years allows us to study possible predictions on the stress release for the coming year/month/week.

Distribution of earthquake magnitudes in the Indonesia region in the year 2018.



Prof. Dr. Horst Stöcker

Horst Stöcker was born in Frankfurt am Main in 1952 and grew up in Oberursel im Taunus. After graduating from high school in 1971, he studied physics, mathematics, chemistry and philosophy at the Johann Wolfgang Goethe University in Frankfurt am Main.

Following his diploma in 1976, he worked on his dissertation "Shock waves in nuclear matter - proof by circumstantial evidence" with Walter Greiner and received his doctorate at the Goethe University Frankfurt in 1979. In 1979, he first became a guest researcher at the former Society for Heavy Ion Research in Darmstadt.

In 1980, Stöcker joined the Lawrence Berkeley Laboratory of the University of California, Berkeley, USA, as a DAAD-NATO Fellow. From 1982 to 1985, he was an Assistant Professor at the Department of Physics and Astronomy at Michigan State University and the National Superconducting Cyclotron Laboratory (NSCL).

In 1985 Horst Stöcker accepted a professorship in Theoretical Physics at the Johann Wolfgang Goethe University in Frankfurt am Main. He currently holds a professorship in Theoretical Physics and Astrophysics at the Goethe University and holds the Judah M. Eisenberg Chair - "Professor Laureatus of Theoretical Physics" at the Department of Physics there.

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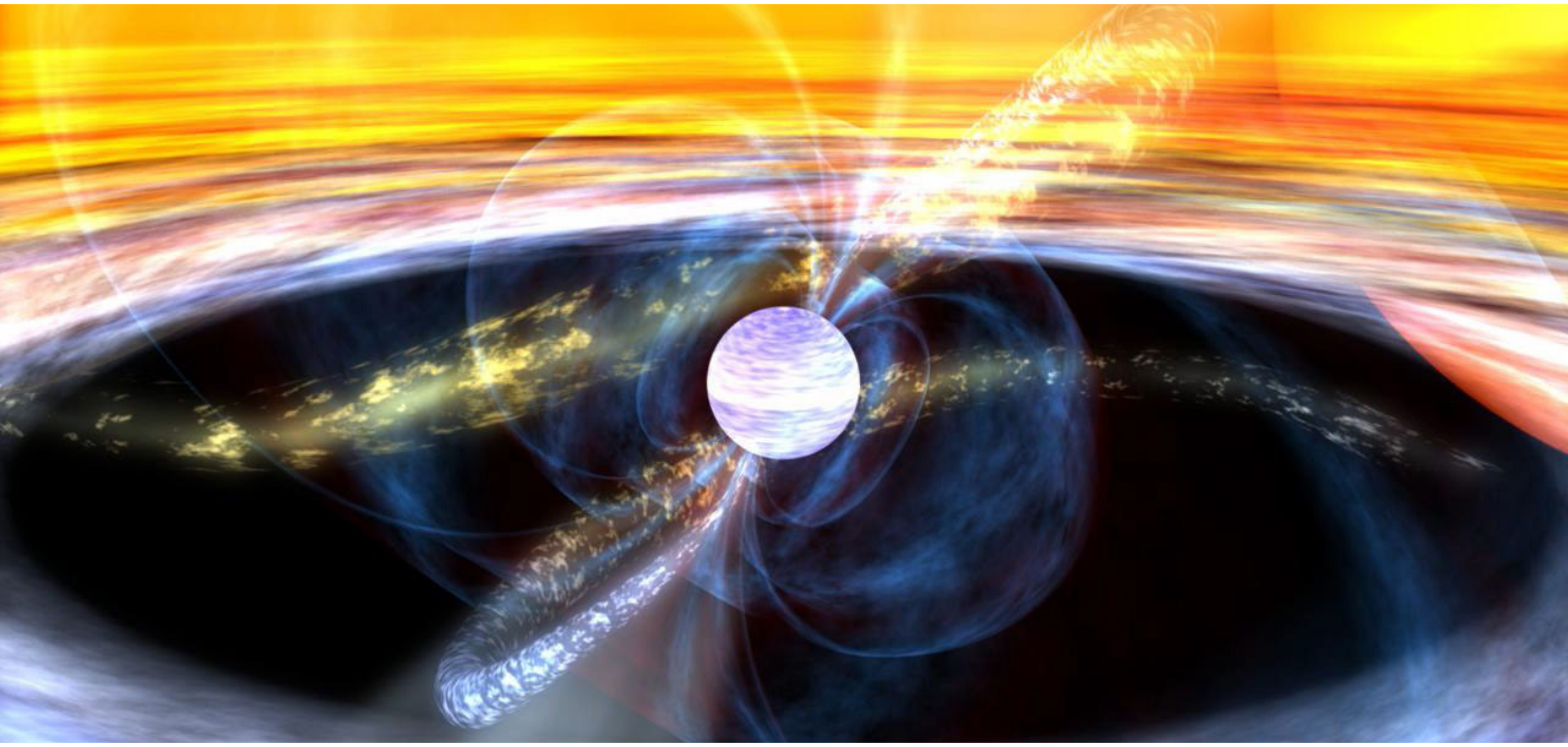


Group Information

At FIAS

since 2017; Fellow

Research Area

Astrophysics of compact stars
Effective models of QCD
Microphysics of nuclear systems

Team

Dr. Jia-Jie LI
Dr. Arus Harutyunyan
Jerson Bonilla

Collaborations

Prof. Mark Alford, Washington Univ.
Prof. David Balschke, Wroclaw Univ.
Adriana Raduta, NIPNIE, Bucharest
Prof. Fridolin Weber, San-Diego State

Armen Sedrakian

In the field of fluid dynamics and magento-hydrodynamics our group made progress in two directions. Firstly, our microscopically computed conductivity for stellar plasma was combined with the numerical simulations of magnetized neutron star binary mergers to obtain the time-scale over which the dissipative effects are important. We have found that neutron star merger time-scales are typically too small for dissipation to be relevant. At the same time we have established the significance of the non-dissipative Hall effect under such conditions. Secondly, we have developed the relativistic hydrodynamics to second order using a non-equilibrium statistical operator formalism. This provides a new alternative to the existing formulations of the relativistic hydrodynamics. This work was done by the group member Dr. A. Harutyunyan, who finished her PhD thesis at Goethe University with summa cum laude and Profs. D. Rischke and L. Rezzolla.

On the front of nuclear physics we have been working on a large review article (with Prof. John Clark) on superfluid properties of nuclear systems and neutron stars. It provides a rather complete and up-to-date description of the field and incudes a survey of many-body methods, and applications to neutron stars.

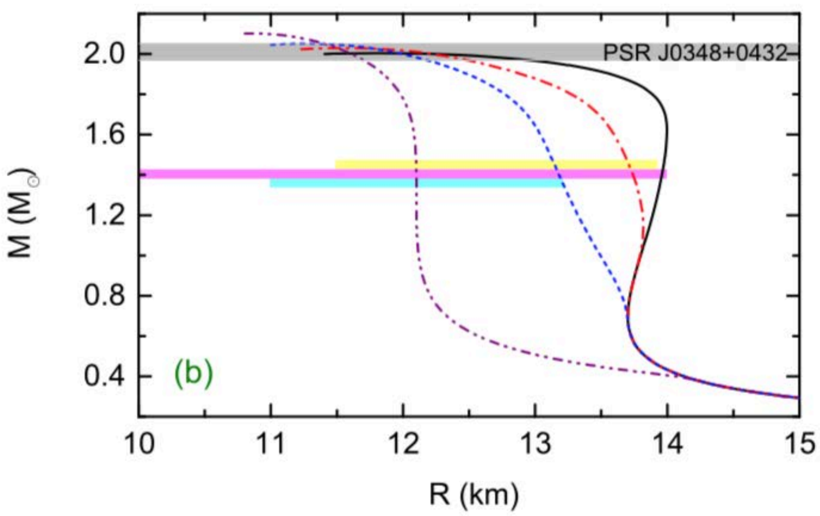
We have continued the studies of relativistic density functionals for hyperonic systems and hypernuclear stars. The equation of state of such matter was derived within the Hartree-Fock approximation including heavy baryons and delta resonances in collaboration with Dr. J. J. Li and Prof. F. Weber. We have also studied the thermal evolution of hypernuclear stars in collaboration with Dr. A. Raduta. We have covered a wide range of issues related to stars made of hypernuclear matter, including their microscopic equation of state, composition, global parameters such as radius and mass, as well as cooling behaviour. Our current models are consistent with the observational data on surface temperatures of neutron stars and gravitational waves observed from these objects.

On the front of effective models of QCD we have studied a new model of two-flavor pairing in dense and cold matter on the basis of time-retarded gap equations (this is an analogue of Eliashberg theory in QCD). Numerical results were obtained for the first time for the imaginary part of the gap assuming one-gluon exchange pairing interaction. These results were obtained with colleagues from ECT (Trento) Prof. J. Wambach and Dr. R.-A. Tripolt.

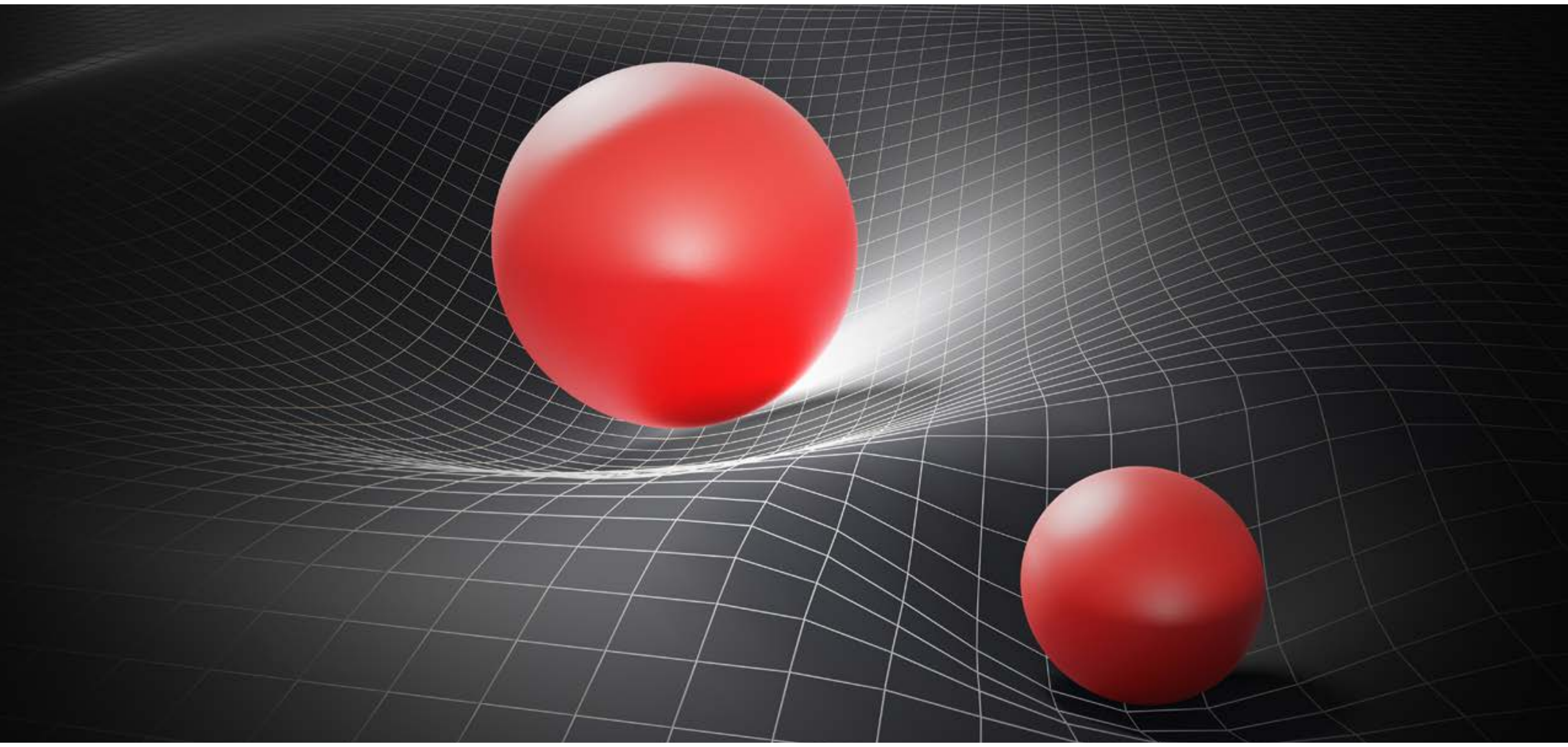
Finally, the we have contributed a chapter to the volume "The Physics and Astrophysics of Compact Stars" which was mainly concerned with the superfluid properties of these objects. The chapter is a part of a dozen of selected contributions by the experts which ideally should be used in the studies of neutron stars by undergraduate and graduate students.

Dr. Armen Sedrakian

Dr. Armen Sedrakian, born in 1965, received his physics degree from the University of Rostock in 1989 and subsequently obtained his doctorate in Theoretical Physics at the Yerevan State University in Armenia in 1992. In 2002, after several post-doc positions around the world, he returned to Germany to work as a research associate and lecturer at the University of Tübingen, where he habilitated in 2006. Since 2007, he teaches at Goethe University at the Institute for Theoretical Physics and holds a professorship at the Department of Physics at the Yerevan State University in Armenia since 2011. Since January 1st 2017, he has the position of Fellow at FIAS.



The mass vs radius relation for nucleonic black), hypernuclear (red and blue), and hypernuclear plus delta-resonance (violet) stars. The vertical lines show the lower limits on the maximum mass of a neutron star. The dramatic reduction of the radius of the star with the inclusion of delta-resonances is an effect that allows to bring the radii predicted by the models in agreement with the GW170817 discovery of gravitational waves from the binary neutron star mergers.



Group Information

At FIAS

since 2016; Fellow

Research Area

Covariant Hamiltonian Field Theory
Canonical Gauge Theory of Gravitation

Team

David Benisty
Dirk Kehm
Johannes Kirsch
Patrick Liebrich
Johannes Münch
David Vasak
Julia Lienert
Vladimir Denk
Matthias Hanauske

Collaborations

Eduardo Guendelman, Ben-Gurion Univ.
Peter Hess, Univ. Nacional Autonoma

Jürgen Struckmeier

The action principle and the general principle of relativity is the basis of our successful derivation of a Palatini-type gauge theory of gravitation. Using canonical transformation theory ensures, by construction, that the form of the action functional is maintained and thus complies with the General Principle of Relativity. The resulting Hamiltonian system is form-invariant under arbitrary spacetime transformations, and describes both, the dynamics of matter fields and the dynamics of spacetime itself. This way, it is unambiguously determined how spin-0 and spin-1 fields couple to the dynamics of spacetime. Our results imply that Einstein's theory holds only for structureless (spin-0) and massless spin-1 particles. However, massive particles with spin are shown to couple to the torsion of spacetime. The proper source term for the spacetime dynamics is then given by the \emph{canonical} energy-momentum tensor – which embraces also the energy density furnished by the microscopic internal spin.

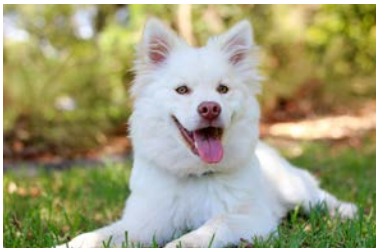
Moreover, the final, generally covariant Hamiltonian must contain a term quadratic in the conjugate momenta of the gauge fields, in order to yield a closed system of field equations --- in complete analogy to all other Hamiltonian descriptions of field theories. The canonical gauge theory of gravity derived here requires that both, quadratic curvature tensors and canonical energy momentum tensors, enter into the field equation for the spacetime dynamics. This leads to a qualitatively new framework for general relativity. The theory is published in Physical

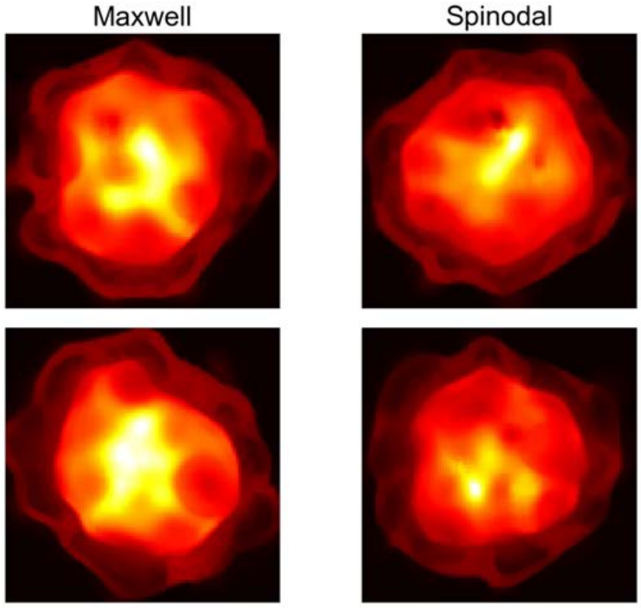
Review D, 95, 124048 (2017). A subsequent paper has been submitted and a third one is actually being prepared for submission.

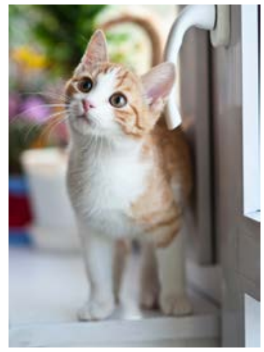
The Covariant Canonical Gauge Theory of Gravitation (CCGG) introduces an important feature into the theory of gravitation, and adds novel dynamic aspects into cosmology: Einstein's general theory of relativity contains only a linear term, the Ricci scalar, in the Lagrangian. Therefore, spacetime lacks in its description a conjugate momentum field, which is required to enable a dynamical response to deformations of the metric. This is different in the CCGG theory: spacetime itself has a conjugate momentum and thereby a proper dynamical quality of its own. The resulting "restraining force to maximum symmetry" is a reminiscent of a restoring force in analogy to that of a strained string. This changes the description of compact astrophysical objects and of relativistic collapse dynamics, with significant impact on the description of binary neutron star structure, mergers and pulsar dynamics. The CCGG theory developed here also entails important cosmological consequences. It can lead to a new understanding of Friedman cosmology and the cosmological constant problem. Modifications of the Friedman equation, for example, suggest a non-standard running cosmological constant and a new interpretation of Dark Energy, and hence change the standard evolution scenario of the universe. Presence of large curvatures may impact the theory of neutron stars and black holes, and modify the interpretation of gravitational waves. As the CCGG theory unambiguously determines the coupling of spacetime to matter fields, an inflation scenario based on a dynamic "quintessence" field can be implemented.

Prof. Dr. Jürgen Struckmeier

After having passed his physics diploma examination at the Goethe University Frankfurt in 1978, Jürgen Struckmeier got an appointment as staff scientist at the "Gesellschaft für Schwerionenforschung (GSI)" in Darmstadt, which lasted until 2017. Based on his scientific work there, he obtained his PhD in 1985. In 1995, Prof. Struckmeier received the "Particle Accelerator Conference Award" in Dallas (Texas): "For physical and mathematical description of emittance growth phenomena in intense beams". In 2002, his habilitation thesis was accepted at the Physics faculty of the Goethe University Frankfurt. Having worked as a lecturer, he was appointed there as "Extracurricular Professor", in 2010. In 2016, he joined FIAS as "Fellow".







Group Information

At FIAS

since 2017; Research Fellow

Research Area

Physics
Machine learning

Collaborations

Berkeley National Laboratory, USA
Huzhou University, China
SUBATECH, Nantes
SUT Korat, Thailand
Akita University, Japan

Jan Steinheimer-Froschauer

The main remaining question in the field of high energy nuclear physics is the possible existence of a phase transition in very hot and dense matter as it can be found in the early universe and inside neutron stars and their mergers. In order to finally verify the phase structure of QCD, several large scale heavy ion experiments are currently performed or under construction at the worlds largest accelerator facilities (RHIC, SPS-CERN, GSI, NICA, JPARC-HI).

At these experiments, heavy nuclei are brought to collision at almost the speed of light, creating a fireball with temperatures and densities that can melt the basic constituents of matter, the protons and neutrons. This process occurs incredibly fast, so fast that the system cannot maintain a phase equilibrium as it passes through the possible phase transition and becomes mechanically unstable. Such an unstable system is known to go through so-called spinodal decomposition.

Spinodal decomposition is a well understood phenomenon and we know how to calculate such instabilities numerically. The figures below show how spinodal decomposition can be described by computational fluid-dynamics. The instabilities cause characteristic density fluctuations and an increasing density correlation.

However, we have not been able yet to extract unique observables which would verify the existence of such an unstable phase during the evolution. This is mainly because of the short lifetime and tiny size of the system which makes a direct observation of the density fluctuations impossible. Recently it was suggested that a new approach, based on modern machine-learning methods can offer a new promising venue. As modern neural networks are powerful tools in extracting information from complex datasets it has been suggested to use them to circumvent the biased 'hand-crafting' of observables.

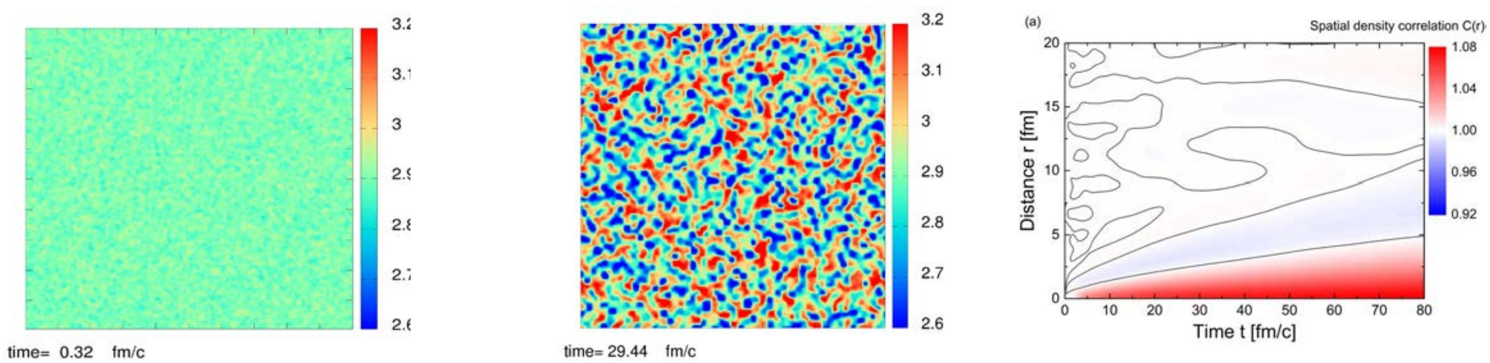
As a first step we used a convolutional neural network to distinguish single events with spinodal decomposition at the phase transition from events where a phase transition occurs, but no instabilities (Maxwell construction). Therefore we prepared a large dataset of two dimensional density contours, as shown above.

These 100x100 sized "images" of the normalized density where then used to train the neural network. After training the testing gave a >95% prediction accuracy. This means that indeed it was able to capture important features of the decomposition on an event-by-event basis. Something which has not been shown before.

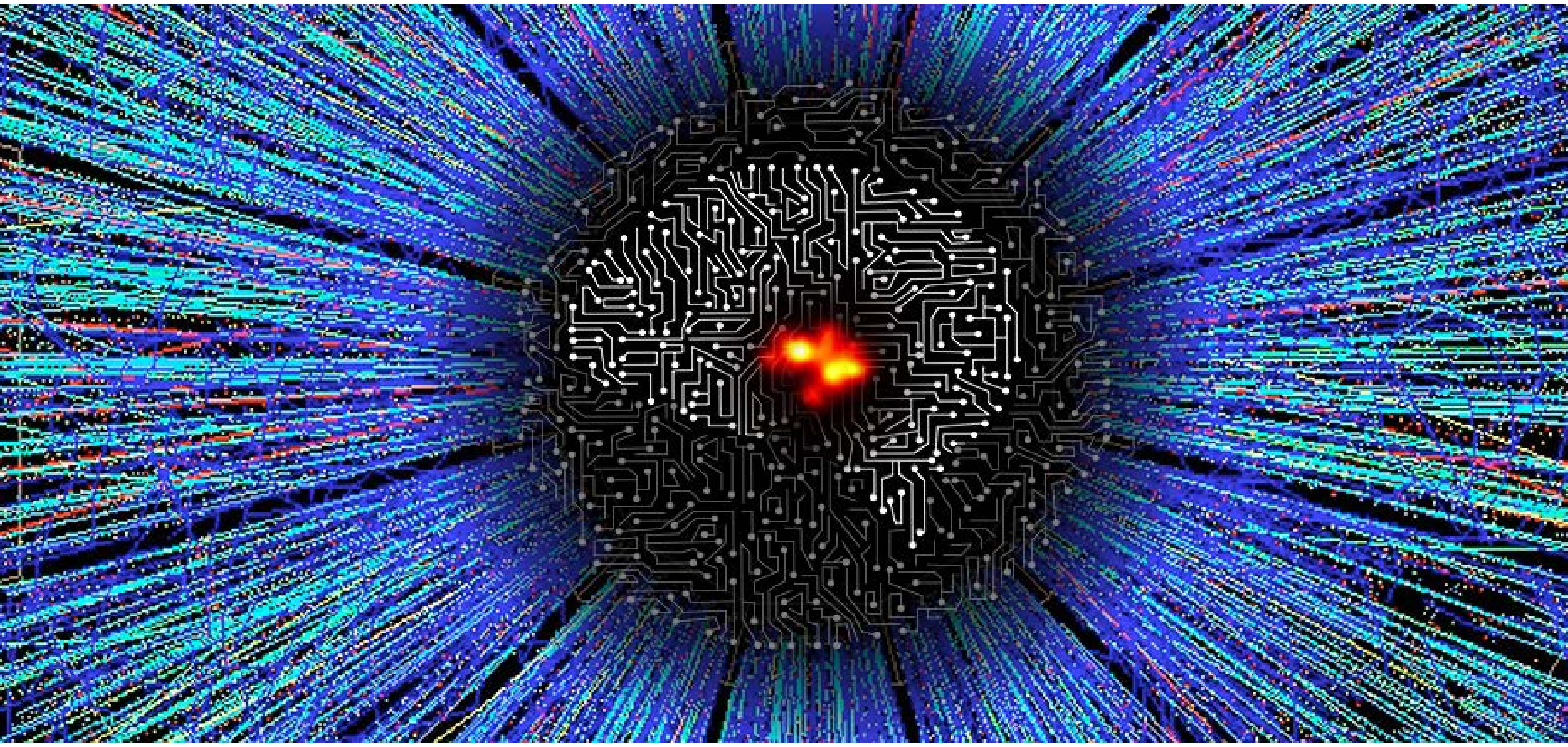
As a next step we will extend our study to distributions of the measurable densities in momentum space, rather than coordinate space. Here the relevant correlations between particles may be much harder to find which is a more challenging problem for the neural network.

Dr. Jan Steinheimer-Froschauer

Dr. Jan Steinheimer-Froschauer is a research fellow at FIAS since 2017. His main areas of research are high energy physics and machine learning. In 2008, he obtained his Diplom in Physics at the Goethe University in Frankfurt am Main. After a short time at the FIAS he was awarded a Feodor-Lynen research grant to the Lawrence-Berkeley-National-Laboratory in the US. He returned to FIAS in the year 2013 as a Postdoc where he focused his research on the physics of high energy heavy ion collisions, and since 2017 also on the applications of machine learning methods in physics and related areas.



Left: Example of spinodal density clumping as it evolves as function of time, the colors indicate different densities from low (blue) to high (red). Right hand side: The corresponding time- and distance-dependent density correlation function.



Group Information

At FIAS

since 2017; Research Fellow

Research Area

Theoretical Physics
Heavy-Ion Collisions
Machine Learning/Deep Learning

Team

Dr.Lijia Jiang
Yi-Lun Du

Collaborations

ITP, Goethe University
Tsinghua University, China
Xi'dian University, China
Berkeley National Laboratory, USA

Kai Zhou

We pushed further the idea of using Deep Learning to construct equation-of-state (EoS) meter in heavy-ion collisions (published this year : https://www.nature.com/articles/s41467-017-02726-3) into a more realistic situation, to include the afterburner hadronic cascade which is essential but missed in the previous study. We employed a hybrid simulation consisting of a 2+1D hydrodynamic and UrQMD for after-burner. A four layers Convolutional Neural Network (CNN) is devised to classify the two EoSs : cross-over and first order transition type. After training, we found, 1) with event-by-event particle spectra to be the input, the classification performance (~80%) is less than pure hydro case (99%) previously, which is in line with expectation since the cascade involves stochastic sampling in particle collisions thus hinder part of the impact from phase transition. 2) Averaging events with the same centrality-bin or hydrodynamics can enhance the performance evidently (~99% for centrality-bin averaging, ~90% for cascade averaging), which can be realized in experiments. This provides us the realistic tool to unveil the hidden knowledge from highly implicit data in heavy-ion-collisions.

The paper of this work is to be submitted out soon.

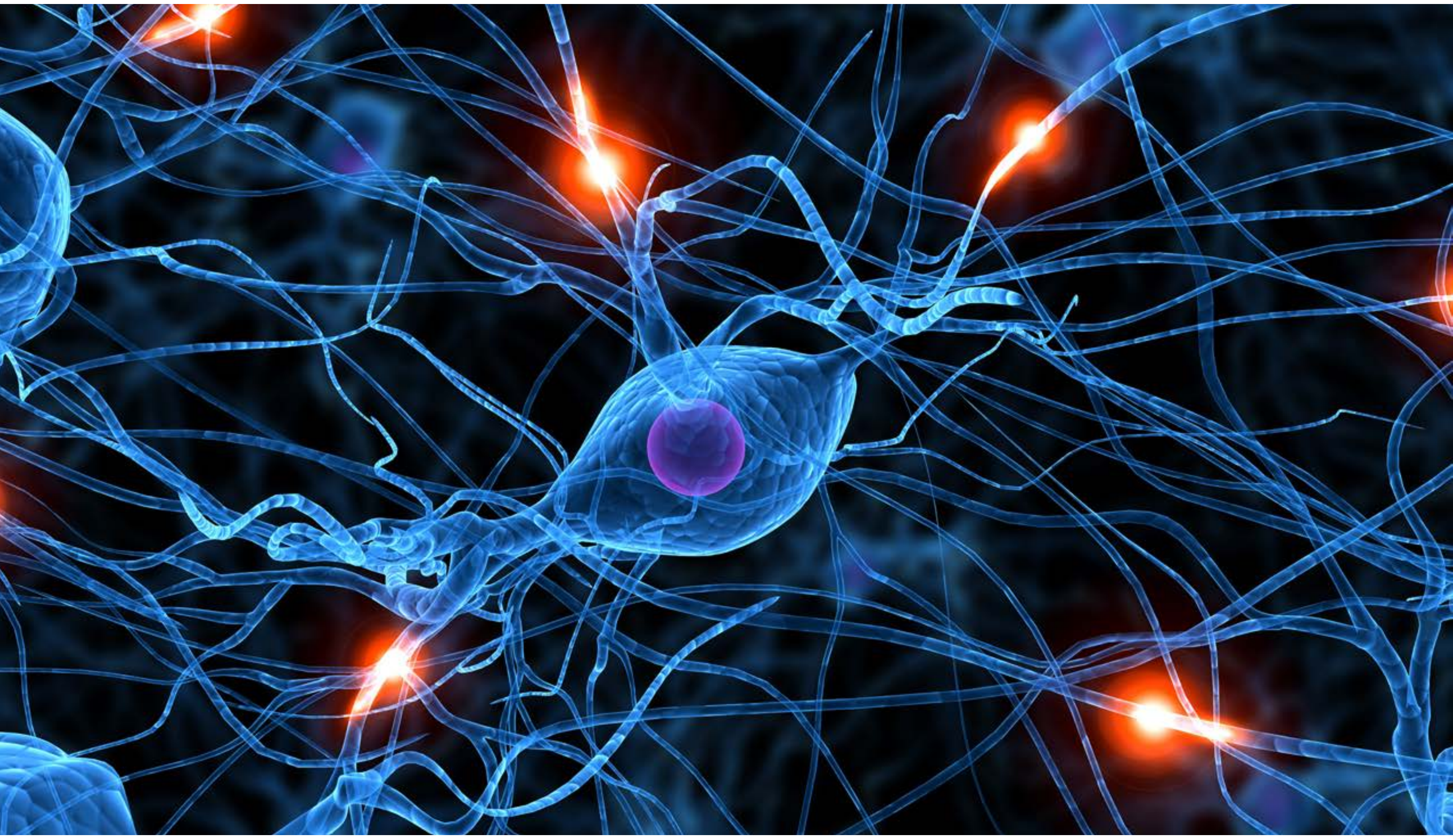
We explored the perspectives of AI / Deep Learning in the context of lattice quantum field theory taking for first step the two-dimensional complex scalar field at nonzero temperature and chemical potential with a nontrivial phase diagram. A neural network is successfully trained to recognize the different phases of this system and to predict the value of various thermodynamic observables based on the microscopic configurations. We analyze a broad range of chemical potentials and find that network is robust and able to recognize patterns far away from the point where it was trained. We found that the network is capable of recognizing correlations in the system between various observables and phase classification without the specific guidance. Very interestingly it discovered a correlation beyond the conventional analysis which enabled it to use even restricted input to recognize phase transition. The regression network also showed remarkable performance on physical observables (n and squared field) prediction when tested at chemical potential beyond the training set. This provides an effective high-dimensional non-linear regression method with limited data points. Aside from these discriminative tasks, which belong to supervised learning, we further proposed an unsupervised generative network to produce new quantum field configurations that follow a desired distribution. An implicit local constraint fulfilled by the physical configurations was found to be automatically captured by our generative model GAN. We found that the generator in GAN can represent well the distribution of prominent observables with direct sampling. This thus helps reducing large ensembles of field or system configurations into a single (highly trained) network and thereby significantly reducing storage requirements which is crucial in many areas nowadays.

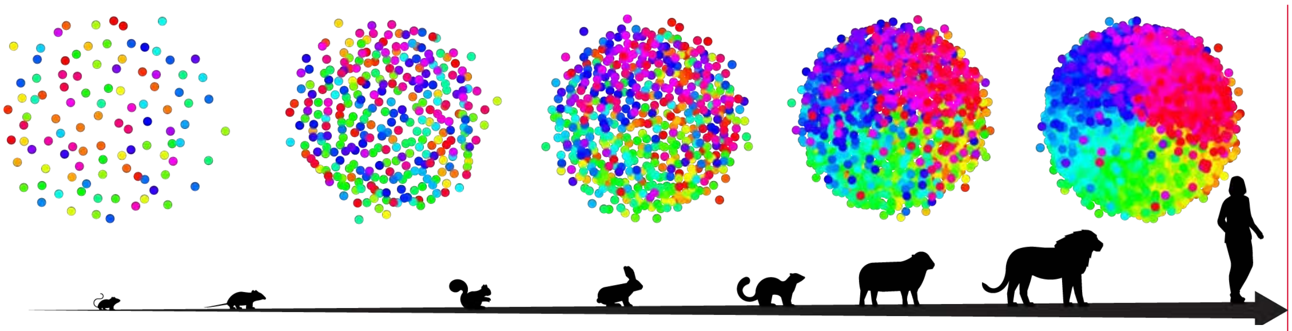
We further developed the analyze tool for 'Smart Valve' project collaborated with Samson AG. With the new experimental data generated from the innovation center, we trained deep learning to perform classification for different flow status (choked cavitation, constant cavitation, incipient cavitation, turbulent and no flow background) and flow velocity prediction based on the sensor recorded acoustic signal for the valve. A 90% average accuracy for classification and R2=0.97 for flow velocity regression performance are obtained. We further tried signal with noise to decode the same information, also got good results. We then put the trained model into mobile phone App for demonstration.

Dr. Kai Zhou

Dr. Kai Zhou was born on 1st October 1987 in China. He received the BSc degree in Physics from Xi'an Jiaotong University, in 2009, and his PhD degree in Physics with 'Wu You Xun' Honors from Tsinghua University, in 2014. Afterwards he went to Goethe University Frankfurt to do postdoctoral research work at the Institute for Theoretical Physics (ITP) . Since August 2017, he is a FIAS Research Fellow focusing on Deep Learning (DL) application research, and guides the 'Deepthinkers' group at FIAS as their group leader. Dr. Zhou has a very broad interest in physics and AI/ DL application in different fields. Recently with his collaborators he developed a deep learning based strategy to help efficiently extracting essential properties of the very involved dynamical evolution from only final observation, they applied it in Heavy Ion Collisions to construct an Equation-Of-State (EOS) meter which is an ultimate goal for the experiments efforts.

Neuroscience





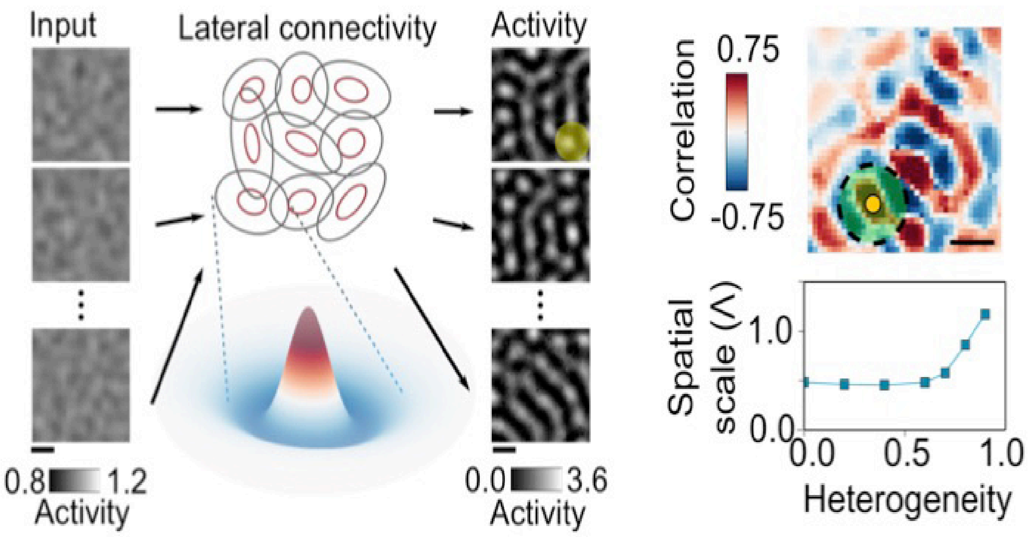
Harmony in Numbers:

The human brain consists of a highly complex network of approximately 85 billion nerve cells (neurons), which continually exchange information with each other. In order for this complex network to function efficiently, it is important that the distances between neurons encoding similar properties remain relatively short. In the human visual system and in that of many mammals, the neurons that respond to objects with similar orientation are indeed located near each other. Interestingly, such an ordered structure cannot be found in rodents. Researchers from the Frankfurt Institute for Advanced Studies, the Max-Planck-Institute for Brain Research and the Ernst-Strüngmann Institute for Neuroscience have studied why such differences between the animal species exist – using two different computer models. Unexpectedly, the researchers found that the existence of this ordered structure is not only determined by the connectivity in the circuit, but also by the total number of neurons. In 2017 the findings of Research Fellow Hermann Cuntz and his colleauges were published in the scientific journal PNAS.

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.



Left: A dynamical circuit model of spontaneous activity in the early cortex: a constant input modulated spatially by filtered noise is fed into a recurrent network with short-range, heterogeneous Mexican-hat (MH) connectivity. It produces a set of modular output patterns with typical spatial scale Λ determined by the local lateral connections (average size illustrated by the yellow circle). Right top: The model produces long-range correlations in agreement with experiment (n=100 output patterns, 16% of modelled region shown). Right bottom: The spatial scale of correlations increases with increasing heterogeneity in the lateral connections.

Group Information

At FIAS

since 2011; Fellow

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
Bettina Hein
Bastian Eppler
Fatemeh Bagheri
Sigrid Trägenap

Collaborations

David Fitzpatrick, Max Planck Florida Institute
Simon Rumpel, Univ. Mainz
Gilles Laurent, Max Planck Institute for Brain Research
Kenichi Ohki, Univ. 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 and guide behaviour? 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 collaborations with experimental groups in Frankfurt and abroad. Here, I focus on two selected projects that study the organization and functional role of neural population activity. One project focuses on a part of the mammalian cortex that is involved in the processing of incoming visual information. The second project is dealing with the last steps of neural processing, towards motor output, in a species that diverged from mammals in evolution more than half a billion years ago.

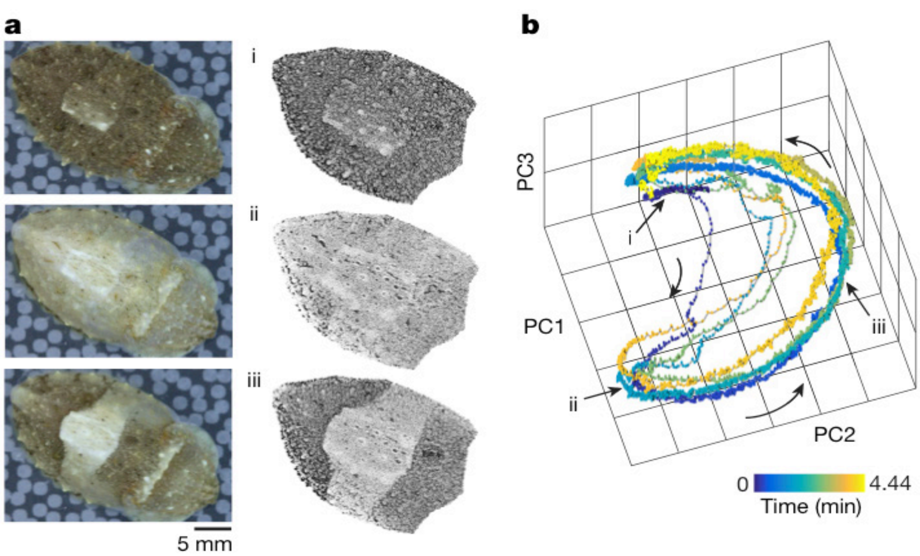
In one project my group has studied the role of spontaneous activity and cortical network interactions in the emergence of long-range order in the early developing visual cortex. Together with neurobiologist David Fitzpatrick at the Max Planck Florida Institute, USA, we found that spontaneous activity shows long-range correlations at an age when anatomical connections are still immature and mostly local in visual cortex. To explain this intriguing finding we proposed a circuit model based on local, heterogeneous connections and showed that heterogeneity reduces the dimensionality of the space of spontaneous activity patterns. This novel mechanism can explain how long-range correlations can arise from only local circuits in the early cortex (Fig. 1). These early long-range correlations may provide a scaffold for structuring long-range anatomical connections at subsequent developmental stages. This work was published in Smith et al., Nature Neuroscience, 2018.

In another project, in collaboration with Gilles Laurent at MPI BR we have studied the control and development of skin patterning in cuttlefish. Few animals provide a readout that is as objective of their perceptual state as camouflaging cuttlefish. Their skin display system includes an extensive array of pigment cells (chromatophores), each expandable by radial muscles controlled by motor neurons. If one could track the individual expansion states of the chromatophores, one would obtain a quantitative description—and potentially even a neural description by proxy—of the perceptual state of the animal in real time. We developed computational and analytical methods to achieve this in behaving animals, quantifying the states of tens of thousands of chromatophores at sixty frames per second, at single-cell resolution, and over weeks. We inferred a statistical hierarchy of motor control, revealed an underlying low-dimensional structure to pattern dynamics and uncovered rules that govern the development of skin patterns. This approach provided an objective description of complex perceptual behaviour, and a powerful means to uncover the organizational principles that underlie the function, dynamics and morphogenesis of neural systems. This work appeared in Reiter et al., 2018, Nature.

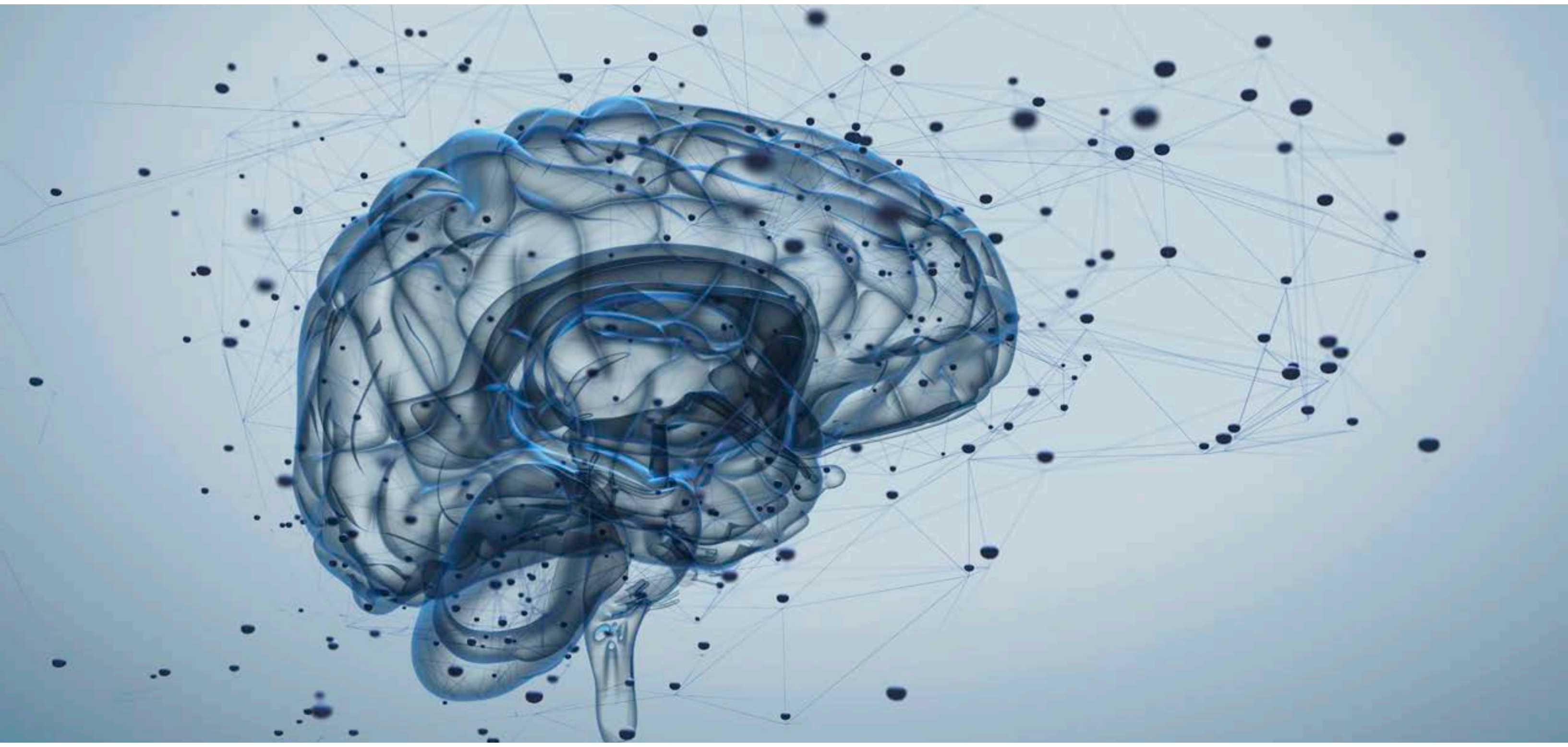
Together these two studies shed new light on the importance of combining advanced data analysis and theoretical approaches with large-scale neural recordings to shed light on different facets of neural population activity underlying perception and action.

Prof. Dr. Matthias Kaschube

Matthias Kaschube studied Physics and Philosophy in Frankfurt and Göttingen and obtained his doctoral degree in theoretical physics working with Fred Wolf and Theo Geisel at the Max Planck Institute for Dynamics and Self-Organization. From 2006-2011 he held the position of a Lewis-Sigler Theory Fellow at Princeton University, working on theoretical neuroscience and developmental biology. In 2011 he became a Fellow at FIAS and a Professor for Computational Neuroscience in Computer Science at Goethe University Frankfurt.



Tracking camouflage skin pattern changes at cellular resolution in sepia. a, Snapshots (i–iii) of an animal reacting to motion. Left, raw images. Right, corresponding segmented images: chromatophores are shown as disks proportional to actual size (n = 17,305 chromatophores, see Supplementary Video 5). b, Full sequence of skin patterns (17,305-dimensional vectors of chromatophore sizes, unfiltered) over repeats of the behaviour, projected into space of the first three principal components (PC1–PC3). Time is shown in colour.



Group Information

At FIAS

since 2003; Senior Fellow

Research Area

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

Team

Dr. Andrea Lazar
Yiling Yang
Dr. Katharine Shappcot

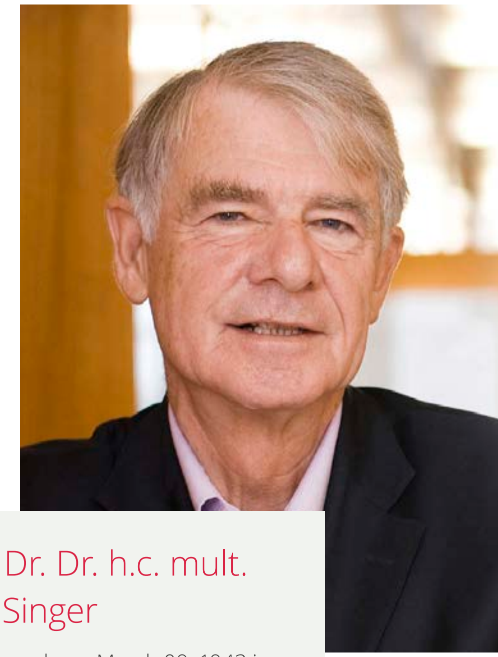
Wolf Singer

Our current understanding of primary visual cortex function comes primarily from studies of individual neurons stimulated with response-tailored visual input (sinusoidal gratings). To this day, it remains unclear how populations of cells act together to perform the computations necessary for processing complex visual scenes. Using chronically-implanted, movable electrodes, we recorded simultaneously population responses (multi-unit activity and local-field potentials) from the primary visual cortex (area V1) of awake rhesus macaques. To enhance aspects of distributed coding, we employed structured visual stimuli (natural scenes or simple visual shapes) and investigated in great detail the variability and covariability of the resulting neural responses.

In particular, we showed that 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, we found that both natural scenes and phase-scrambled controls decreased mean firing variability at the level of the primary visual cortex to a similar extent. However, only the natural scenes generated stimulus specific evoked responses. Inspired by concepts from machine learning, we used a naive Bayesian classifier to decode stimulus identity from both multi-unit population activity and band-limited gamma power. We found that both multi-unit activity and gamma oscillations contained information about the visual stimuli, were modulated by attention and by the type of visual stimulus presented.

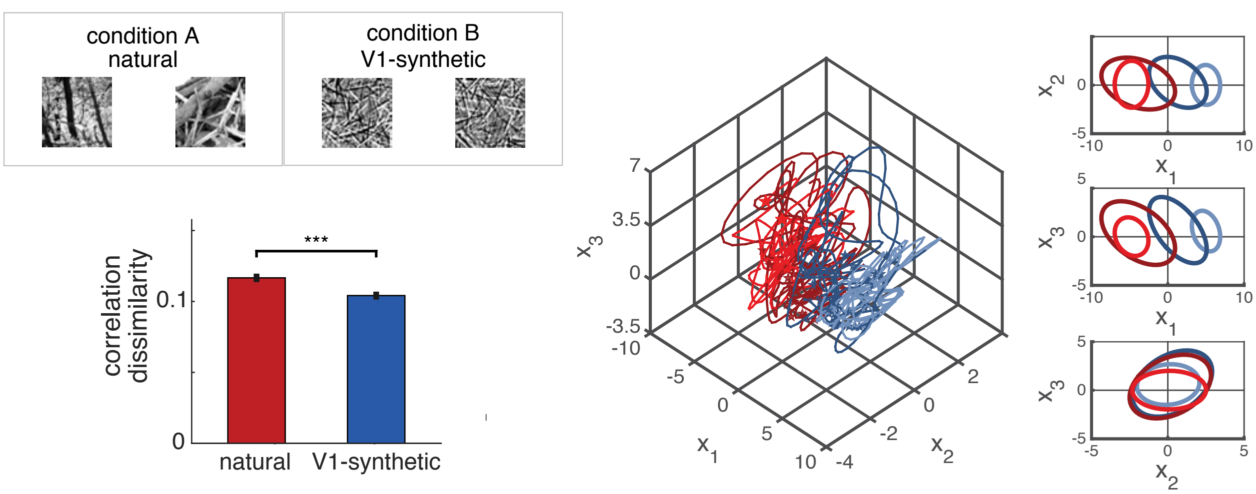
Finally, we studied the fine structure of spike-count correlations and assessed their dependence on stimulus identity and on stimulus statistics. We demonstrated that, as predicted by a hierarchical inference model for visual perception, stimulus-dependent spike-count correlations are characteristic of natural images and that this dependence can be manipulated by controlling the higher-order structure present in visual stimuli (Fig. 1A). In preliminary analysis, we used time-varying latent variable models (e.g. GPFA, Fig. 1B) to extract population dynamics on low-dimensional latent state-space manifolds and studied the time course with which state space trajectories converge and diverge as a function of stimulus structure.

Early theories of perception have suggested that the brain interprets sparse and impoverished input signals on the basis of previously acquired information about the visual environment. In our most recent research efforts, we investigated the encoding, storage, and processing of information that takes place in the high-dimensional state-space provided by the non-linear recurrent dynamics exhibited by primary visual cortex populations.



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.



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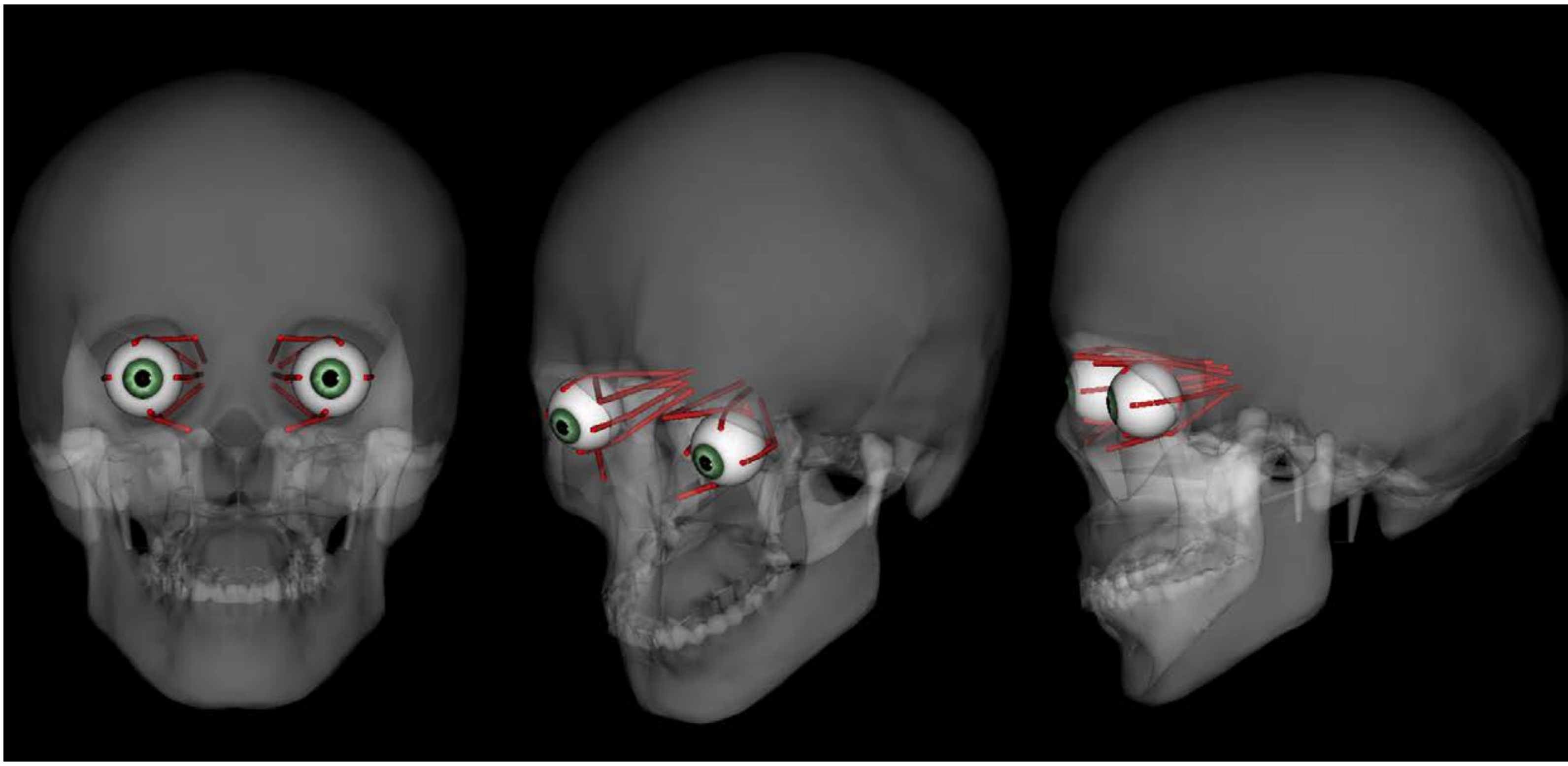


Group Information

At FIAS

since 2005; Senior Fellow

Research Area

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

Team

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

Collaborations

Gedeon Deak (San Diego)
Maria Fronius (Frankfurt)
Anne-Sophie Hafner (Frankfurt)
Hiroshi Ito (Frankfurt)
Bert E. Shi (Hong Kong)
Ulf Ziemann (Tübingen)

Jochen Triesch

The research of my group revolves around the theme of learning. On the one hand we try to better understand how learning works in the brain. On the other hand, we try to imitate the principles of the brain's learning mechanisms in computers and robots to make them more intelligent.

Studying Plasticity and Learning in Spiking Neural Network Models is a central component of our research. Our group has pioneered the study of networks of spiking neurons that combine associative and homeostatic plasticity mechanisms for learning. By simulating such networks in computers, we have improved our understanding of the structure and function of brain circuits. For instance, we have proposed neural network models to explain the statistics and fluctuations of synaptic connection strengths. These offer an explanation for why most synapses are only short-lived, but we can still remember certain things for years and years. Our models have also offered insights into the functional role of spontaneous brain activity, suggesting that the brain uses a highly (energy-)efficient coding strategy and may be much less "noisy" than previously thought. Furthermore, we have proposed a model of learning in visual cortex that makes precise predictions as to how the connections between individual neurons are changing throughout learning. Most recently, we have also started to study some of the molecular mechanisms underlying the brain's learning abilities.

Going beyond the scales of molecules, neurons, and local circuits to the systems level, our group, together with Prof. B. Shi in Hong Kong, has developed the Active Efficient Coding (AEC) framework of perception. AEC is a generalization of the classic efficient coding theory to active perception. In a nutshell, it argues that the brain not only tries to encode sensory information in a particularly (energy-)efficient manner (classic efficient coding), but that it also uses behavior, e.g., various kinds of eye movements to further improve its efficiency when encoding sensory information. We have used AEC to build self-calibrating models of active binocular vision and active motion vision and have validated these models in humanoid robots. Most recently, we have investigated how changes in rearing conditions or poor visual acuity can disrupt visual development and lead to disorders such as amblyopia. Building on this understanding, we have also been working on improved treatment methods for this disorder.

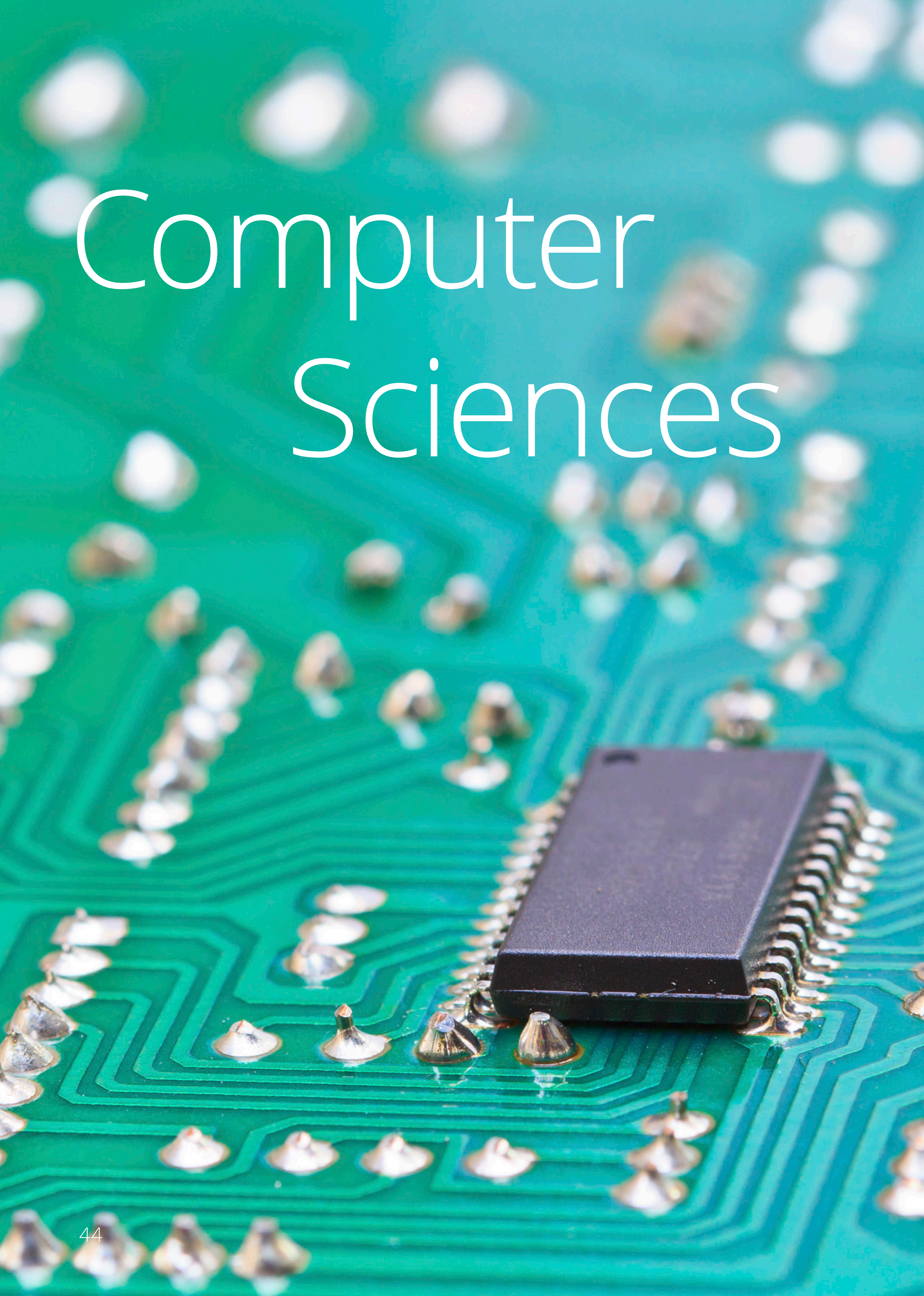
Another research focus of the last year has been the application of modern machine learning techniques for biomedical data analysis. In particular, so-called deep neural networks, while probably learning quite differently from the brain, have proved to be incredibly useful tools for the analysis of biomedical data. During the last year, we have explored the utility of deep learning approaches for the diagnosis of epilepsy and brain tumours, obtaining promising first results. Furthermore, we have applied these methods to analyse large-scale recordings of brain activity performed by colleagues from the Max-Planck-Institute for Brain Research. For example, we can predict from the electrical activity in an area of a rat's brain not only where the rat is currently located, but also where it plans to go next. Such approaches will help us better understand what information is encoded in different brain areas, bringing us one step closer to understanding how our brains create intelligent behavior.

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.

Virtual Reality computer game for the treatment of amblyopia. The contrast in the image presented to the right eye is reduced to avoid suppression of the left eye and facilitate binocular fusion.

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.

STS
Silicon Tracking System*

MVD
Micro Vertex Detector*

* magnetic field

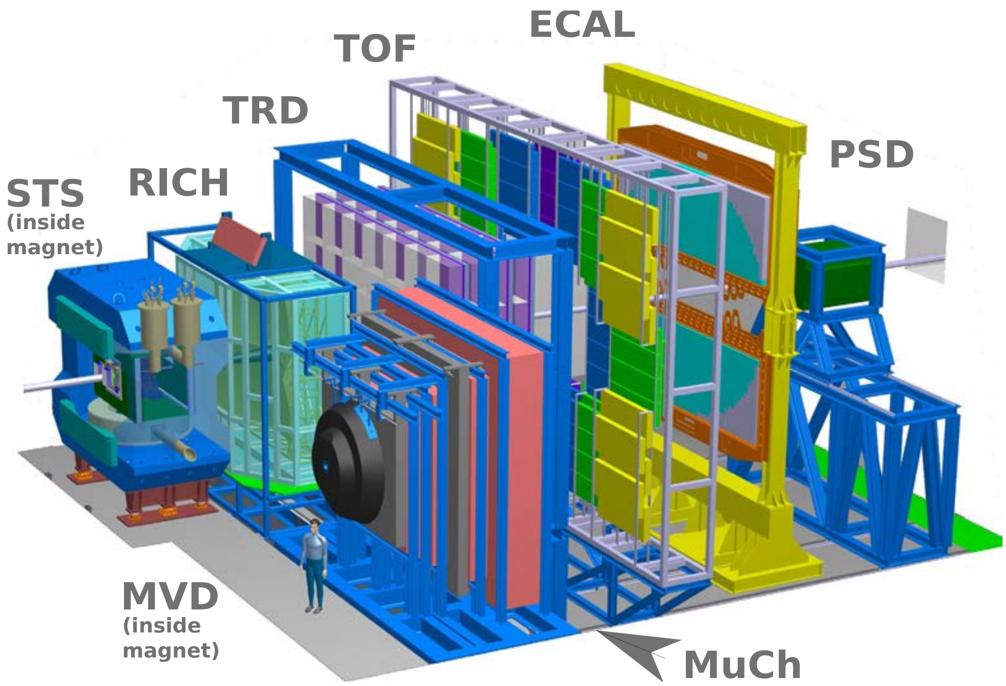
MuCh or RICH
MuonChamber System/ Ring Imaging Cherenkov Detector

TRD
Transition Radiation Detector

ToF
Time-of-Flight Detector

ECAL
Electromagnetic Calorimeter

PSD
Projectile Spectator Detector



Volker Lindenstruth

Group Information

At FIAS

since 2007; Senior Fellow

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

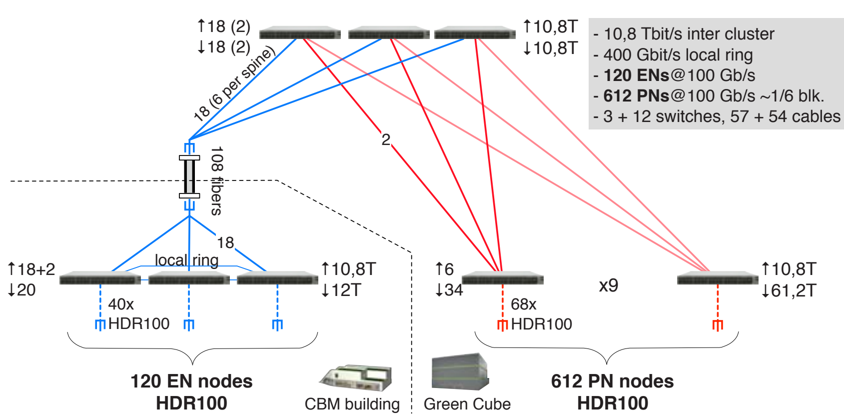
Team

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

Collaborations

CBM
ALICE

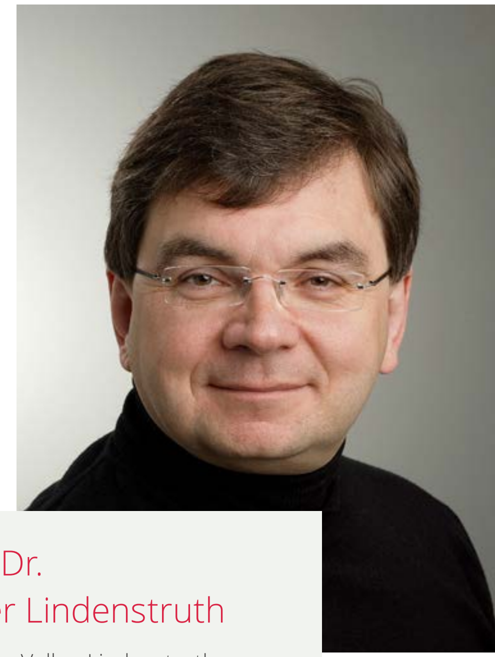
The CBM experiment will investigate heavy-ion reactions at the FAIR facility at unprecedented interaction rates requiring a novel read-out and data acquisition concept with self-triggered front-end electronics and free-streaming data. Events will be selected by a high-performance computer cluster, the First-level Event Selector (FLES) based on online analyses including complete reconstruction. The FLES network infrastructure has been refined including studies for efficient data transport for long-haul connections. First results show that future InfiniBand generation network equipment may provide sufficient reach for distances relevant for CBM. Also algorithms used for local hit reconstruction in detectors designed for CBM have been optimized reducing the corresponding runtimes significantly.



Several detectors have been integrated into the prototype experiment mini-CBM studying combined and synchronous data taking based on the demonstrator setup for the future FLES. Also a prototype for a high-level experiment control system has been implemented, containing all levels of state machines and particularly the functionality to manage the configuration needed to start a data taking run.

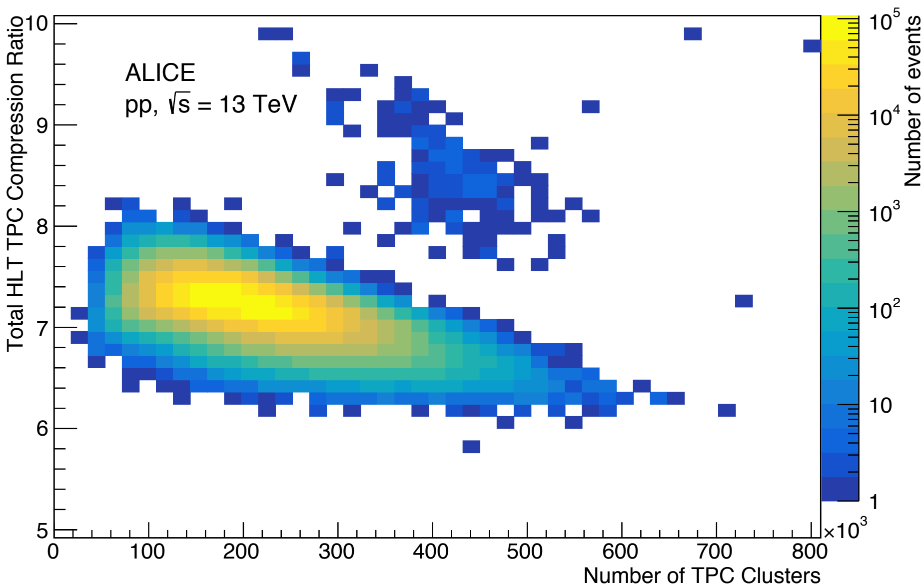
The main aim of ALICE, the dedicated heavy-ion experiment at the CERN LHC, is to characterize the properties of the medium produced in head-on collisions of heavy nucleons. The final state particles produced in these collisions stream into the various detectors of ALICE, yielding data rates in excess of 48 GB/s. The HLT system of ALICE, a compute farm composed of about 180 nodes, has been processing such collisions since 2009. It utilizes FPGA- and GPU-based algorithms to reconstruct charged-particle trajectories and compresses the data size in real time. The use of such technologies by the HLT pioneered hardware-accelerated real-time computing at the LHC. [arXiv:1812.08036]

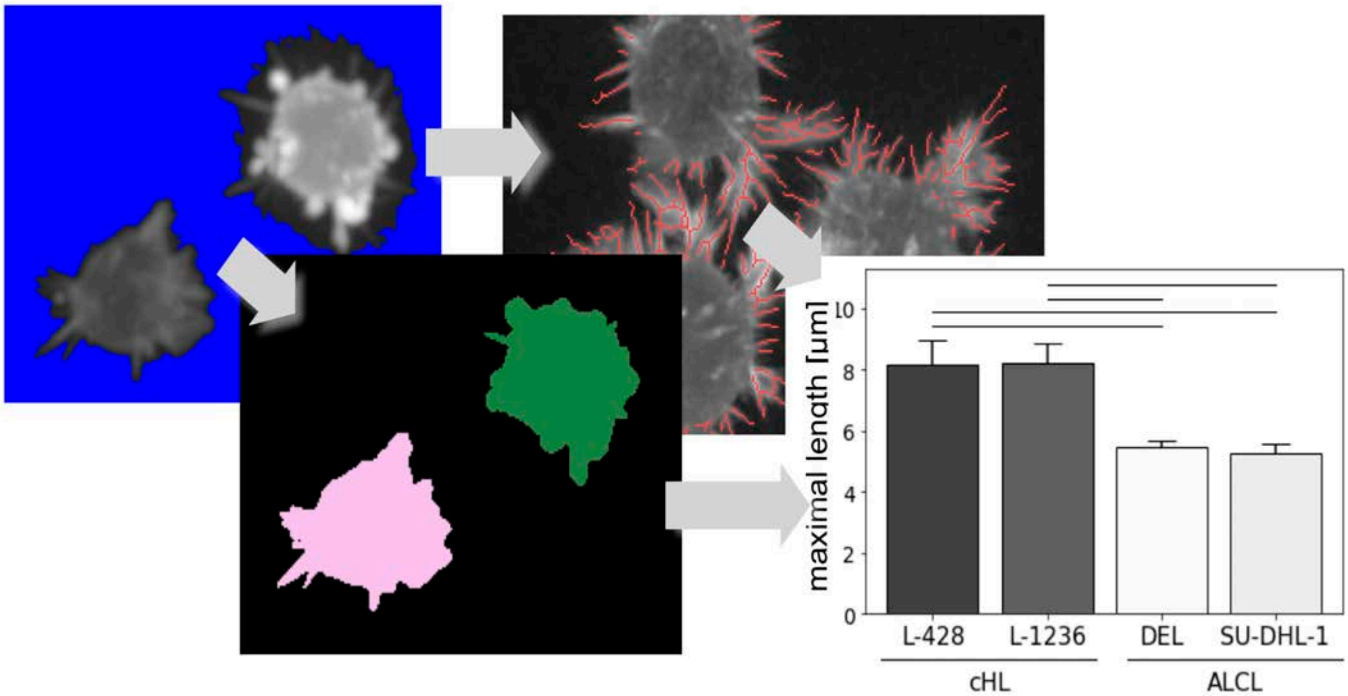
In 2021 the LHC will begin Run3, with ALICE expected to collect 100 times more data with respect to what was recorded since 2009. The new detector readout will change from triggered to continuous, yielding a lead-lead collision rate of up to 50 kHz. This increase in statistics requires that the collision events be reconstructed and calibrated synchronously. Additionally, in order to transport the data for permanent storage it is also essential that we go beyond a data-stream compression factor of 20. In order to meet these challenges, the concepts and technologies advanced by the HLT are already now being studied, prototyped, and tested for such a framework.



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.





Group Information

At FIAS

since 2007; Senior Fellow

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
Sarah LaPointe
Sergey Gorbunov
Dirk Hutter
Stefan Kirsch
Mikolaj Krzewicki
Johannes Lehrbach
Gvozden Neskovic
David Rohr

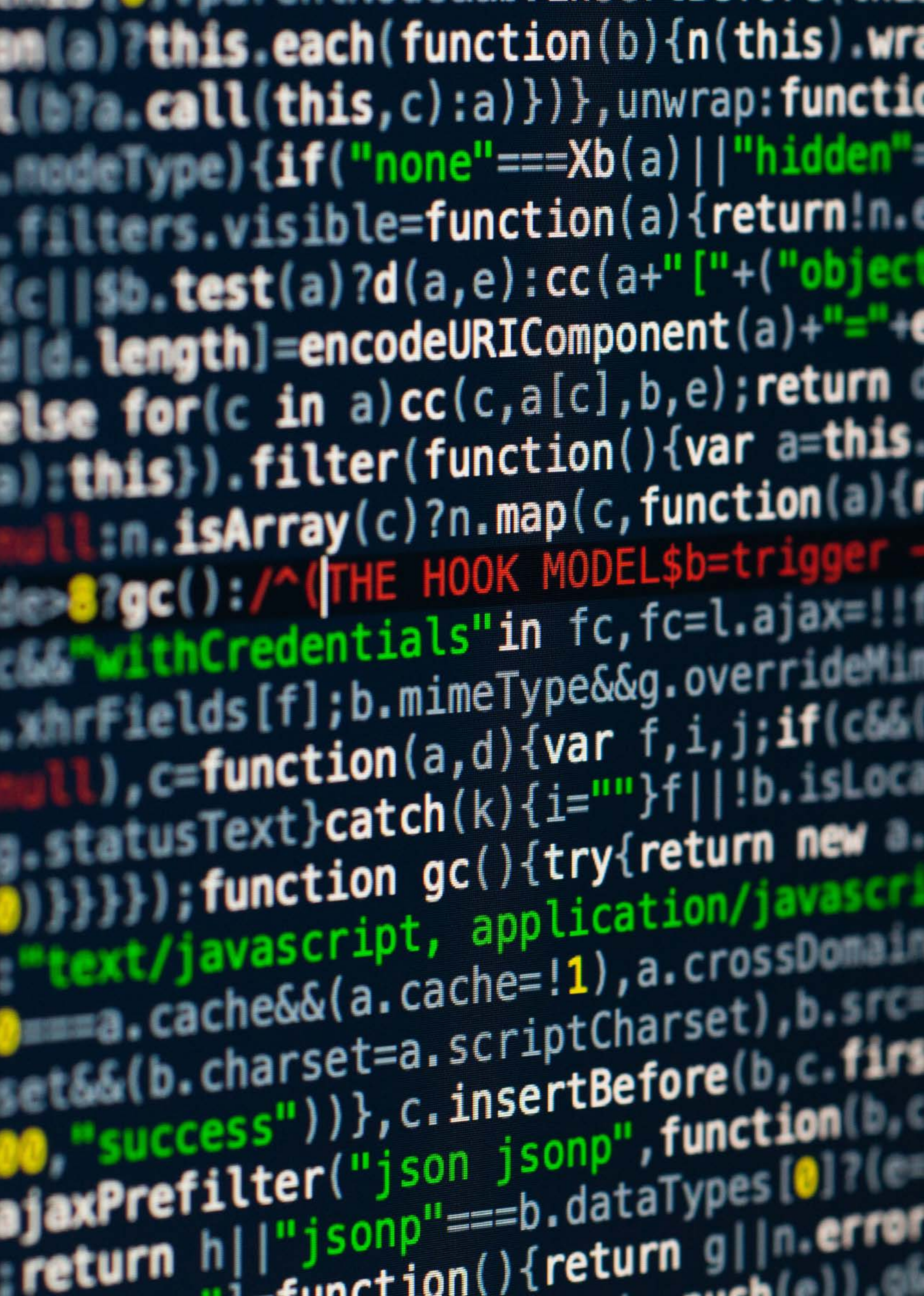
Collaborations

CBM
ALICE

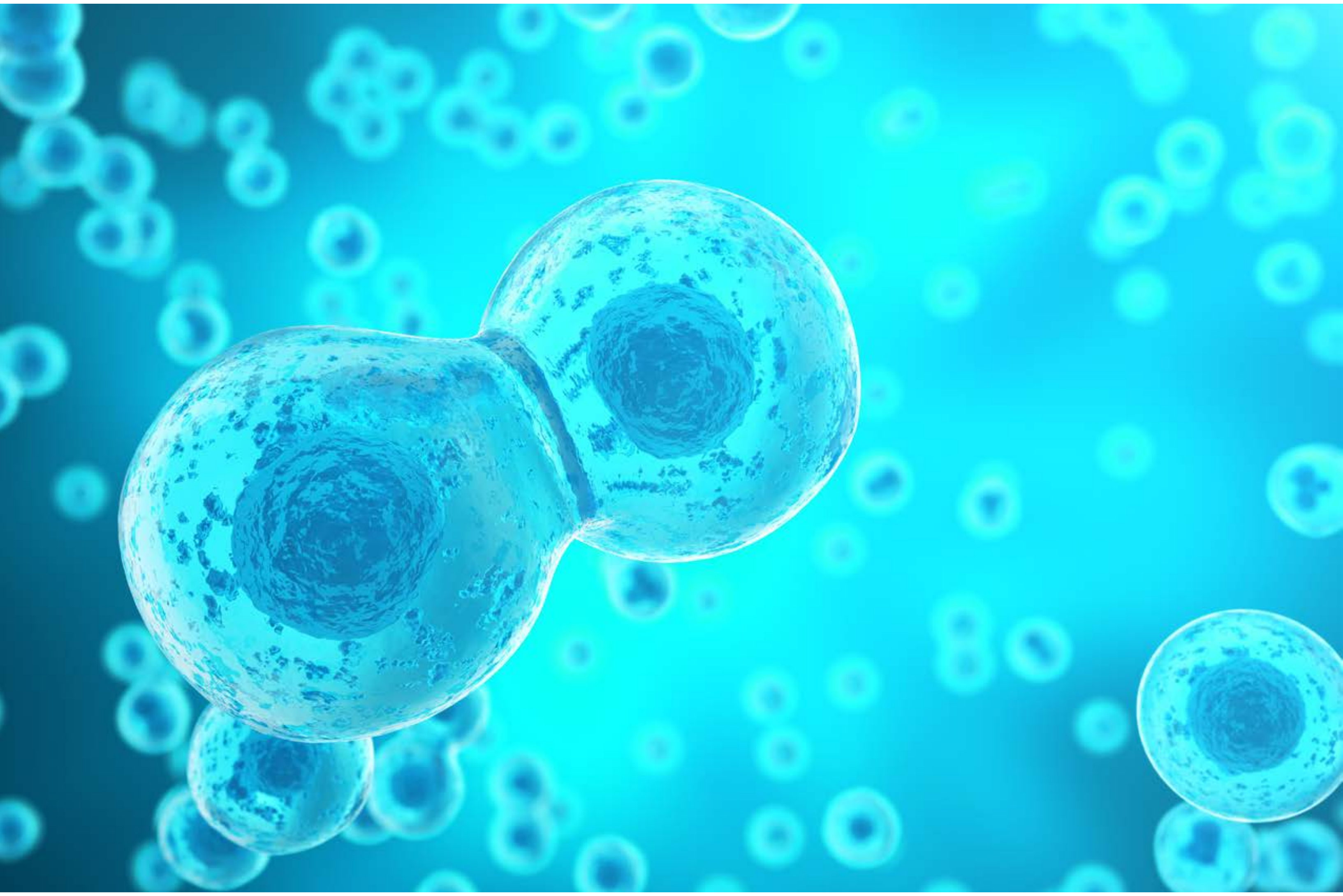
In medical research microscopic images are frequently analysed by hand, which could result in biased data. In order to standardise the analyses and make them reproducible we develop automatic segmentation pipelines.

In one example we compare the LifeAct labeled actin cytoskeleton of different cancer cell lines (Hodgkin Lymphoma (HL) and Anaplastic Large Cell Lymphoma (ALCL)). Our pipeline first segments the cells by using a global threshold to detect all cells. Next a local threshold is applied for each single cell to determine its exact shape and size. This two step approach is necessary because the fluorescent signal is expressed by each cell with a different level and additionally the signal is unevenly distributed within the cell. In a second step the actin cytoskeleton, which forms long and thin filopodia-like structures in these cells, is segmented by using DoG filters, global thresholds and skeletonization.

The analysis of this unbiased segmentation indicates that HL cells, compared to ALCL cells, have more fiolopodia-like structures and sample a bigger area around their cell body. It is well known that HL cells heavily communicate with their environment and so it is likely that the fiolopodia-like structures are used by HL cells for communication and not for cell migration - which is an other typical function of the actin cytoskeleton.


THE HOOK MODEL

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:

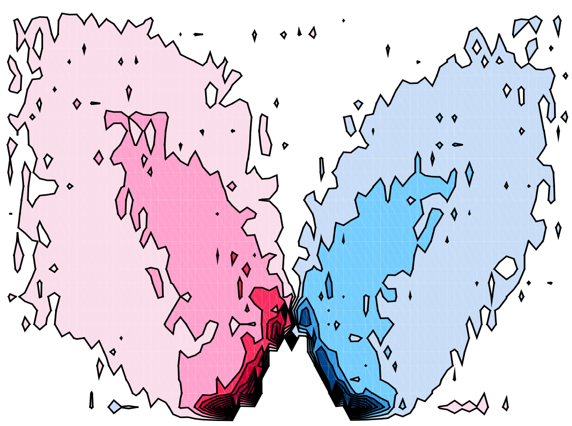
• How can chemical signaling pathways and/or mechanical forces regulate directed movement and collective behavior of small bacterial pathogens?

• 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.

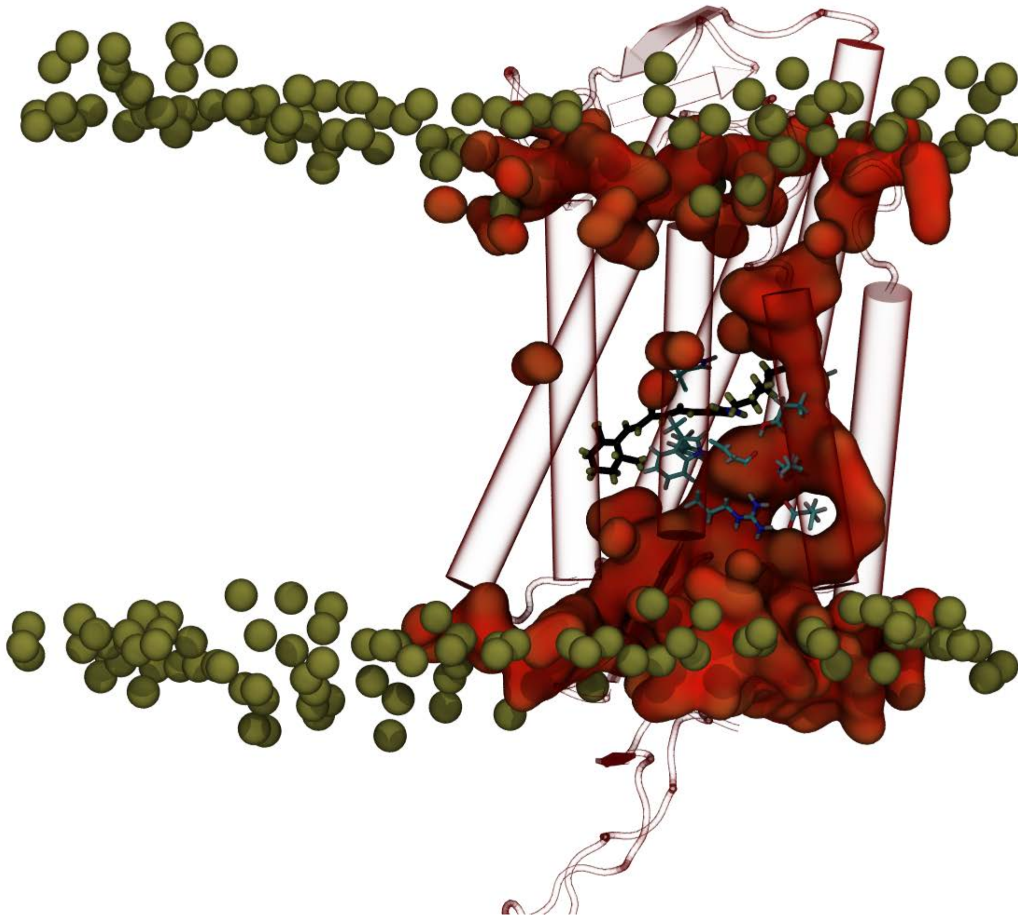


Figure 1. Water pre-pore (red) in channelrhodopsin 2 (shown schematically as transparent secondary-structure elements). Retinal and key amino acids are shown as sticks. Phosphate headgroups (gold) indicate the boundaries of the lipid membrane (Ardevol and Hummer, PNAS 2018).

Group Information

At FIAS

since 2015; Senior Fellow

Research Area

Functional dynamics of biomolecules

Team

Dr. Pilar Cossio

Gerhard Hummer

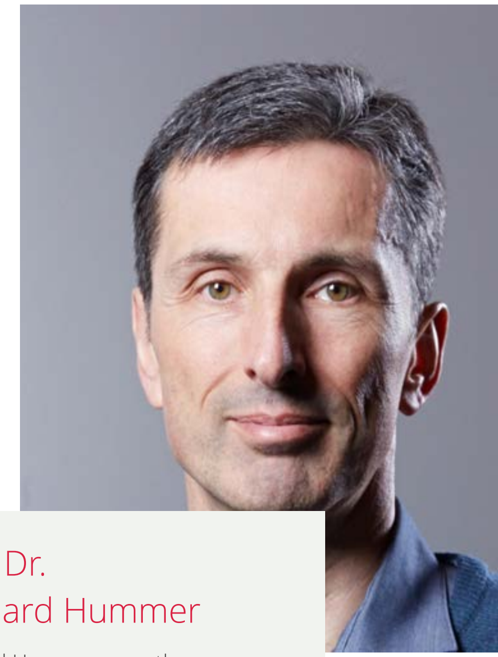
Theoretical and computational approaches play an increasingly important role in the molecular biosciences. Improvements in model quality, algorithms, computer implementations, and raw computational power make it possible to study complex biomolecular processes over biologically relevant scales of time and space, from light-driven channel activation in optogenetics over membrane sensing to large-scale membrane reorganization.

In molecular dynamics simulations of channelrhodopsin-2 (ChR2), we could observe the early events in light-triggered ion-channel opening (Ardevol and Hummer, PNAS 2018). ChR2 is a light-sensitive ion channel that has found wide applications in optogenetics. The absorption of light triggers an isomerization transition of a covalently bound retinal. The resulting strain in the protein eventually leads to the opening of a cation-selective channel. By combining classical and quantum mechanical molecular dynamics simulations, we could study how water entered into the vestibules of an initially closed channel upon light-actived retinal all-trans to 13-cis isomerization. The structural reorganization of a charge cluster forming the channel gate then triggered further influx of water and the creation of a membrane-spanning preopen pore (Fig. 1). This water influx is consistent with time-resolved infrared spectroscopy and electrophysiology experiments. Water thus emerged as a key player in light-driven ChR2 channel activation.

Molecular dynamics simulations of lipid membranes and their interactions with membrane proteins have also given us detailed insights into unusual regulatory mechanisms. In collaboration with the group of Robert Ernst (Univ. Saarland), we showed how eukaryotic cells exploit specific molecular interactions to maintain their membraneous organelles (Covino et al., Mol. Cell 2018). In the case of Opi1, a sensor for phosphatidic acid in the ER, our simulations identified the key recognition elements holding the protein attached to the membrane (Hofbauer et al., J. Cell Biol 2018). From our simulations, general principles underlying the homeostasis of subcellular membranes and their adaptation during stress are starting to emerge. Remarkably, transient interactions of proteins with specific lipid membranes also play a key role in controlling autophagy, a central housekeeping process in eukaryotes. In collaboration with the groups of Jim Hurley (UC Berkeley) and Tamotsu Yoshimori (Univ. Osaka), we could show by molecular dynamics simulations how rubicon regulates PI 3-kinase and how this regulation is subverted by HIV-1 Nef (Chang et al., Mol. Cell 2019).

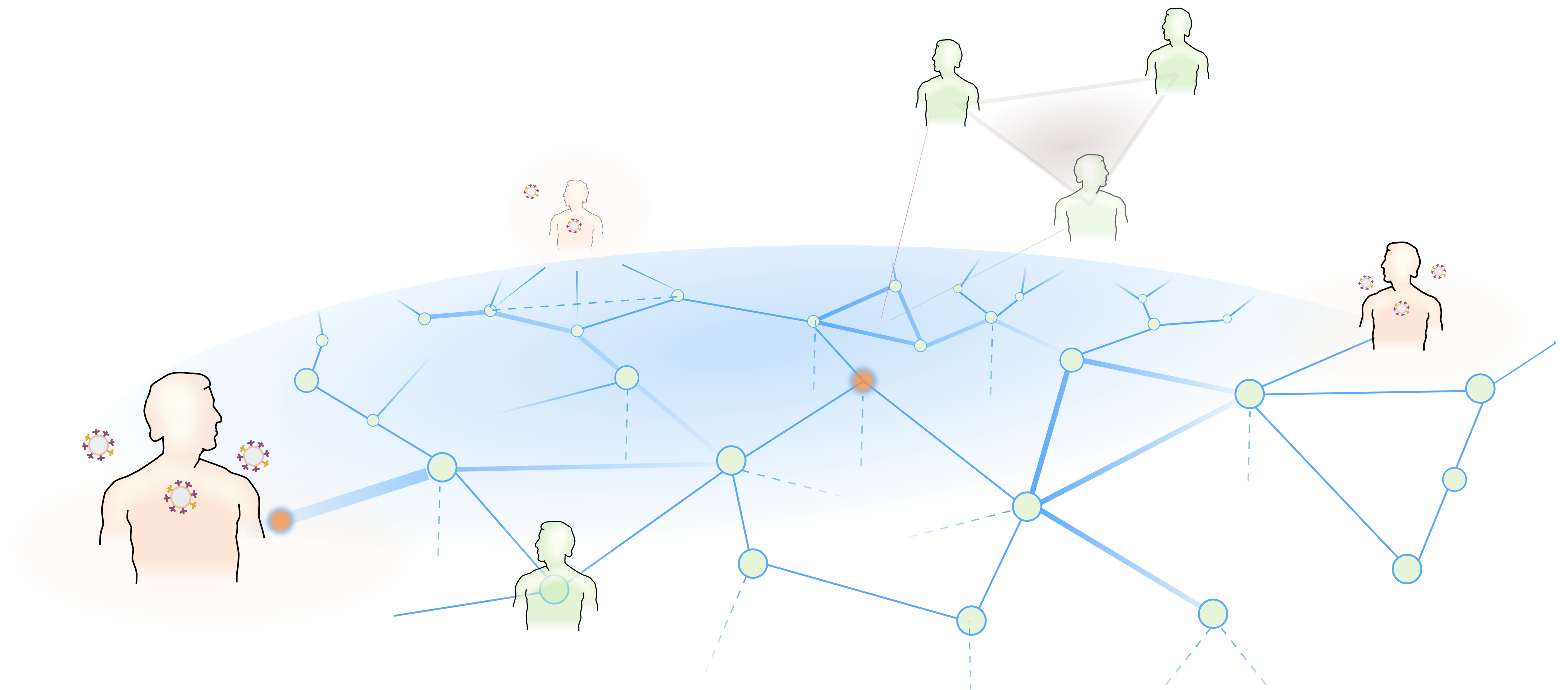
On an even larger scale, in collaboration with the Hurley and Bustamante groups at UC Berkeley, we used membrane elastic models to study how ESCRT proteins induce membrane scission. The ESCRT scission is central to cell division, the budding of HIV from infected cells, and the trafficking of cell-surface receptor proteins among other processes. In a clever setup, our collaborators succeeded in studying the unusual inside-directed membrane scission using both optically and mechanically. By modeling the membrane mechanics probed in the optical-tweezer pulling of membrane nanotubes, we gained insight into the molecular factors controlling the activity of ESCRT proteins. Remarkably, the remodeling of the membrane is associated with the generation of force and requires activation by ATP-hydrolyzing proteins (Schöneberg et al., Science 2018).

Our theoretical and computational studies have not only led to deeper insight into important biological processes, but also pushed us to advance our simulation methodology. Arguably one of the most exciting methodological contributions for us in 2018 was a combined theoretical and computational study in which we showed that lipid and membrane protein diffusion coefficients in molecular dynamics simulations are subject to logarithmically divergent finite-size dependences. We could then turn this devastating finding into a positive result by showing, in simulations with over 100 million particles, that the finite-size effects follow hydrodynamic theory. Hydrodynamics in turn allows us to extract not only meaningful diffusion coefficients but also membrane viscosities (Vögele et al., PRL 2018).



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.



Esteban A. Hernandez-Vargas

Group Information

At FIAS

since 2017; Research Fellow

Research Area

Infectious Diseases
Immune System
Mathematical modeling
Simulation
Data analysis
Control Theory

Team

Dr. Esteban A. Hernandez-Vargas
Dr. Cesar Parra Rojas
Dr. Karin Andrea Sasaki
Gustavo Hernandez-Mejia
Josephine Naa Ayeley Tetteh
Suneet S. Jhutty

Collaborations

Dunja Bruder (HZI)
Veronika von Messling (PEI)
Franklin Toapanta (Maryland University)
Yassine Taoufik (Hôpital Bicêtre)
Alma Alanis (Universidad de Guadalajara)
Frank Pessler (MHH)

Throughout history, we have witnessed alarmingly high death tolls derived from infectious diseases around the globe. One of the deadliest natural disasters in human history was caused by a viral infection, the 1918 flu pandemic, which killed approximately 50 million people. Infectious diseases are latent threats to humankind - killing annually 16 million people worldwide. The spread of pathogens between infectious and susceptible hosts can be orchestrated via close physical interactions. Understanding disease transmission remains a central vexation for science as it involves several complex and dynamic processes. The link between the infection dynamics within an infected host and the susceptible population-level transmission is widely acknowledged. However, several technical aspects of the interface of within- and between-host are still in their infancy.

Fusing interdisciplinary activities, the groundbreaking ambition of our research is to apply mathematical modeling and computational simulations to *in vivo* experiments to

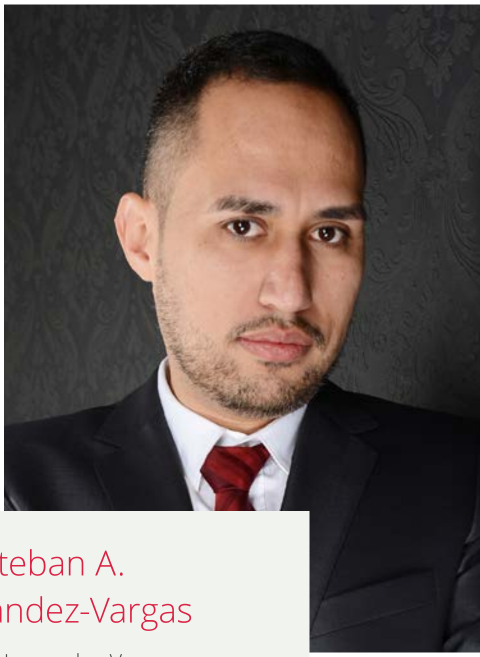
(i) dissect host immune-regulatory mechanisms during acute and chronic infections, and their respective shift in the elderly;

(ii) develop mathematical models for decision making to influence the use of vaccines and drugs; and

(iii) establish the foundations for predictively simulating disease transmission across scales - from the infected host-dynamics to the population level.

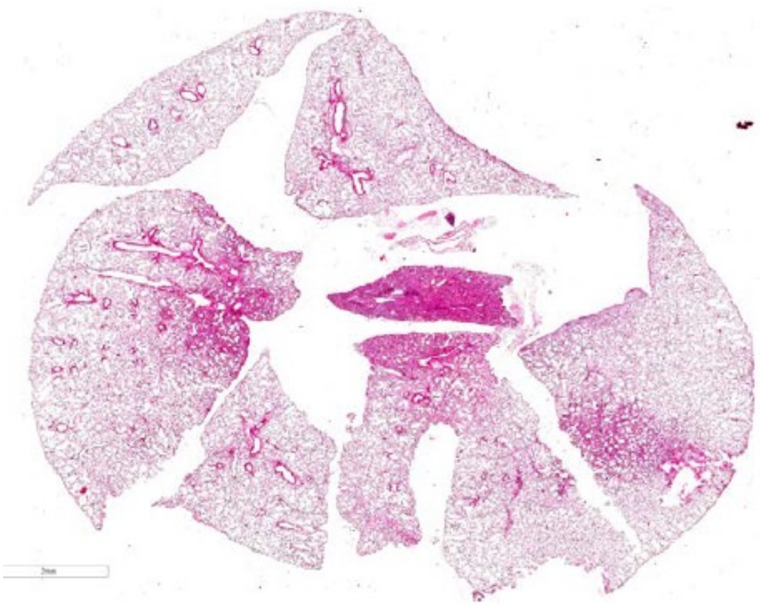
Our research group has a special interest in influenza infection. Up to 20,000 people succumb to the consequences of an influenza disease each year in Germany alone. However, in most cases, it is not the influenza virus that leads to serious complications, but a second bacterial infection acquired by the patient after the onset of influenza. In collaboration with experimental partners at the Helmholtz Centre for Infection Research, Braunschweig, we linked laboratory work with mice, which were infected concurrently with the influenza virus and *Streptococcus pneumoniae*, and computer-based modeling of the infection processes. Based on our results, we are presuming that the immune cells (macrophages) can no longer effectively eliminate the bacteria because of the inflammation response (IFN-γ) of the adaptive immune system to influenza. Our collaborators are testing the simulation predictions in laboratory experiments. With the aid of the established models, it will be possible to predict rational combinations of immune modulators and test them specifically. Thus, it is also conceivable that the insights gained from our research could result in therapeutic alternatives to antibiotics the coming years.

In another project, our group is on the quest for an HIV cure which is a central paradigm in infection research. At present, combined antiretroviral treatment (ART) potently suppresses the virus to undetectable levels in the blood. Nevertheless, virus persistence within different reservoirs and compartments presents a major barrier to eradicate the virus in patients undergoing long-term antiviral combination therapy. The journey towards curing HIV has already started, our group brings together a collaborative approach to assemble the necessary multidisciplinary expertise to advance holistic comprehension of the underlying mechanisms that establish HIV persistence.



Dr. Esteban A. Hernandez-Vargas

Esteban Hernandez-Vargas obtained a PhD in Mathematics at the National University of Ireland. Esteban held a three-year postdoc position at the Helmholtz Centre for Infection Research, Braunschweig. In the same place, he established the Systems Medicine of Infectious Diseases research group. Since March 2017, he holds a Research Fellow funded by the Alfons und Gertrud Kassel-Stiftung, at FIAS Frankfurt.



Histopathological changes in the lungs of mice infected with influenza

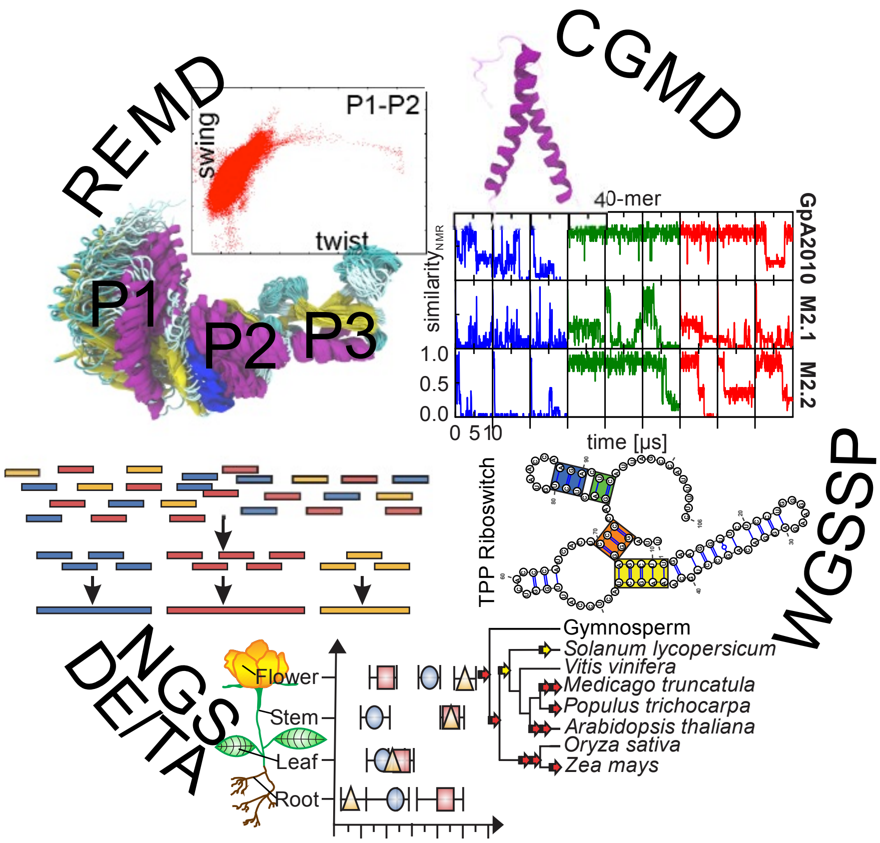


Figure 1: Overview of method repertoire. Methods to analyze protein structures and their dynamics are Replica-Exchange Molecular Dynamics (REMD) and Coarse-Grained Molecular Dynamics (GCMD). For RNAs and to create functional networks we perform Genome Wide RNA Secondary Structure Predictions (WGSSP) and Next Generation Sequencing (NGS) to Assemble Transcriptomes (TA) and analyze differential expression (DE).

Enrico Schleiff

Group Information

At FIAS

since 2017; Senior Fellow

Research Area

Cellular Homeostasis
Next generation sequencing
Big data analysis
Sequence alignments and phylogeny
Structural modelling of molecules
Structural dynamics of molecules
Network identification and modelling

Team

Stefan Simm
Henning Wehrmann
Jannik Berz
Niclas Fester

Collaborations

SPOT-ITN
DynaMem
SFB 807 / 902
Nir Keren,
Hebrew Univ. Jerusalem
Arndt von Haesler, CIBIV, Wien

Organisms are ensembles of cells, which in eukaryotic systems are highly specialized in their function. Each of the cells are further divided in different subcellular compartments ensuring dissection of molecular and biochemical processes. The differentiation and the molecular networks of cells are highly regulated. The regulation ensures programmed development and responses to alterations of the environmental conditions typically defined as manifestation of tissue dependent interactions and responses to biotic and abiotic stresses. While the individual processes of the cellular program follow defined rules and laws, the behavior of the cellular ensemble and cellular responses have in parts properties of complexity.

In our research group we focus on photoautotroph systems, namely plants and cyanobacteria. Plants are multicellular systems and by that as complex in their development and function as mammals. In addition, they are sessile organisms and thus evolved defense strategies to ensure cellular homoeostasis, cellular dynamics and cellular surveillance. We focus on the deciphering of underlying processes and general networks. The latter was exemplified for the metabolism of Arabidopsis thaliana for the hormone synthesis pathways in plants and for the heat stress reaction networks . We unify experimental and theoretical approaches to define models explaining the global behavior, function and adaptation of plant cells. (Figure 1).

We have focused on the description of processes of cellular adaptation during heat stress at global level. We discovered general modes of alternative splicing of mRNAs and described the molecular function of involved proteinaceous components. The combination of large scale analysis and description of molecular mechanisms enables us to define the responses to heat stress at different scales. We have also started to target specificities of the network in different cell types as well, however, these approaches are still to be expanded. For example we determined the processes in pollen, a highly specialized cell type, and compared the information to that of tissues generally investigated like leaves .

Beside the description of cellular adaptation and surveillance we analyze the processes underlying cellular homeostasis. We aim at understanding the general principles leading to regulation of membrane structures and described a new lipid-transporter in the chloroplast membrane important to define the lipid composition under different environmental conditions. In parallel we formulate the general principles that regulate the biogenesis of the protein synthesis machinery – the ribosome – and that define the intracellular folding and distribution of proteins , both prerequisite for cellular homeostasis.

We are further interested in cell differentiation and function of cyanobacteria that are seen as ancestor of the central eukaryotic organelle plastids. Information about the bacterial system are important to understand the organelle function in the eukaryotic cell. In addition, cyanobacteria are important components of the ecosystem. The understanding of their function is prerequisite to develop reliable models of ecosystem behavior. Our main focus is the analysis of the communication of the bacteria with its environment, and thus we aim at understanding the transport mechanism of nutrition's, chemical molecules and proteins. We target the complex network for metabolite, iron, lipid and protein transport . While we analyze the function of the molecular components of the transport systems we accumulate biochemical and biophysical data in order to obtain quantitative data for modeling (Figure 2), which is a future goal of our group.

In general, our research composed of experimental and theoretical approaches aims at a detailed description of cellular responses ranging from atomistic to organismic scale as well as in short term to long term response. For example, we have just opened a new research area where we aim at developing detection systems for ultrafast responses in plant cells to combine the description at second range with the phenotypic development of plants.

Prof. Dr. Enrico Schleiff

Prof. Dr. Enrico Schleiff, born on November 17, 1971 in Luckenwalde, studied physics at the Charles University in Prague, and later at the Gutenberg University in Mainz and at the University of Basel. In 1999, he did his PhD at McGill University Montreal, Canada. Later he worked at Christian-Albrechts-University zu Kiel, at the Ludwig-Maximilians-University, Munich, lead a junior research group set up by the Volkswagen Foundation. Since 2007, he has held a W3 professorship for Molecular Cell Biology of Plants at the Institute of Molecular Biology at JWG University Frankfurt, where he has been vice president, since 2012. Since 2017, he is also a member of the board of directors at FIAS.

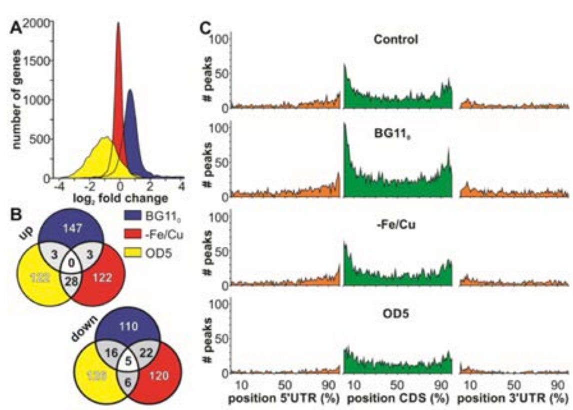


Figure 2.: NGS analysis of Anabaena sp. PCC 7120 response to iron starbation and high cell densities.

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.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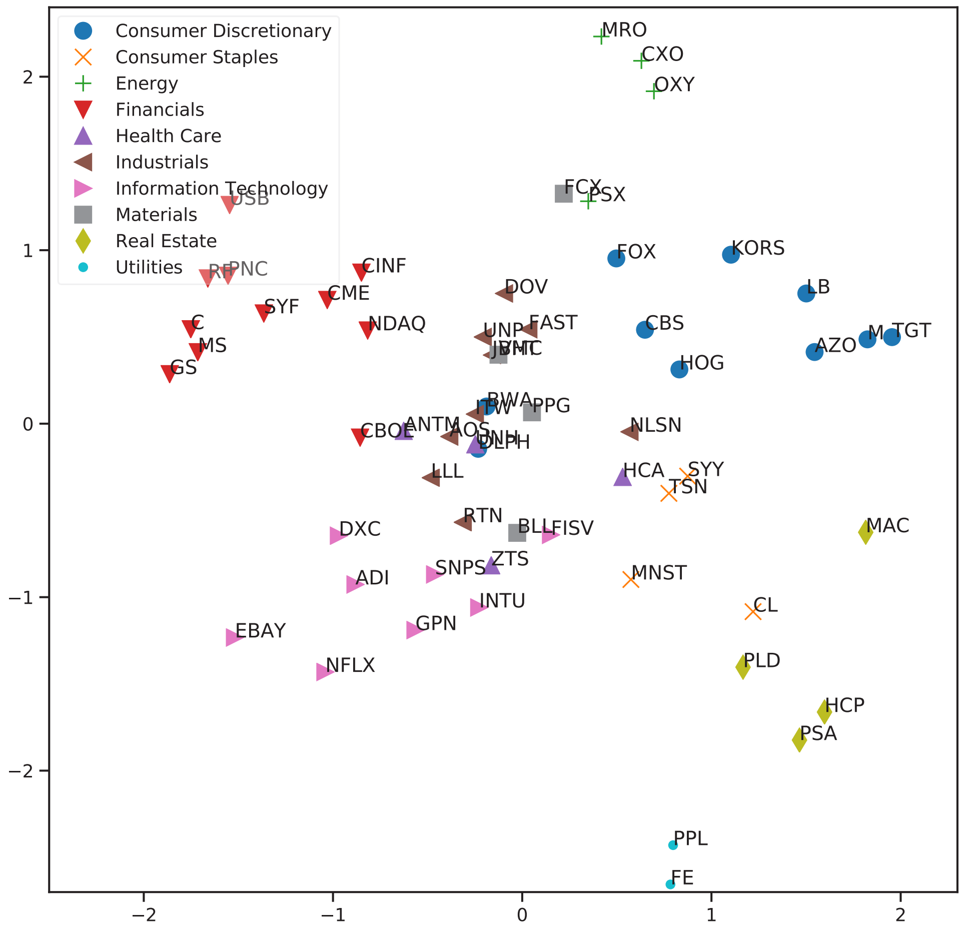

Group Information

At FIAS
since 2015; Fellow

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

Team
Rajbir Nirvan
Mirco Parschau

Collaborations
Juergen Jost,
MPI for Mathematics in the Sciences
David Wolpert,
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Financial theory has long studied how to measure and model market risk. Yet, practice and research on economic activity and risk management has traditionally focused on individual institutions and is only recently widening its view towards systemic interactions. At the same time, financial innovation is increasing the interconnectedness and complexity of the financial network. Thus, seemingly small risks can propagate through the system as painfully revealed during the latest crisis. Thereby not only wiping out the savings of millions of people, but also threatening the trust into the global financial system which required costly interventions by governments world-wide.

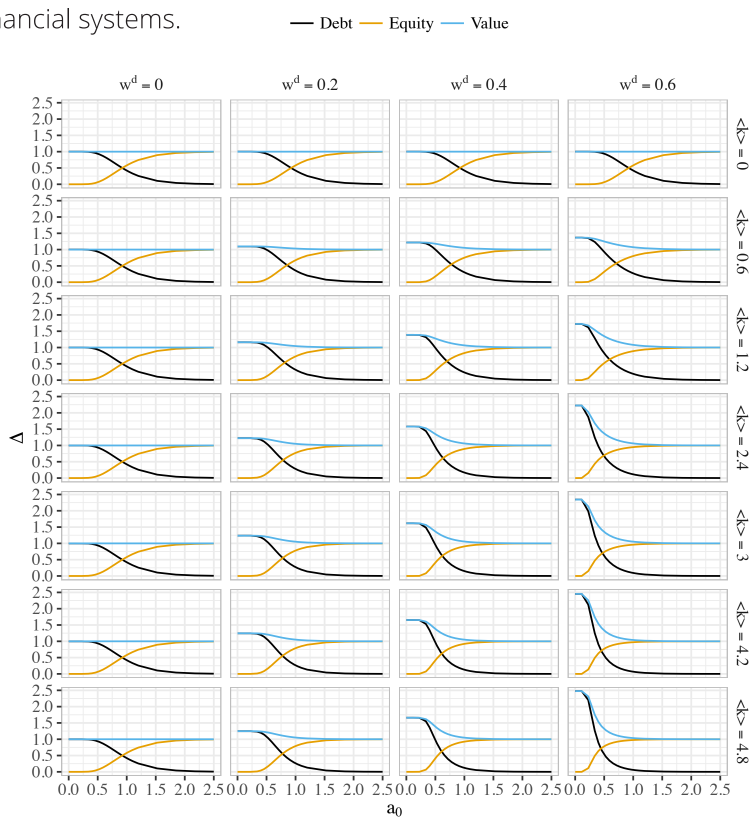
At FIAS, we have investigated financial risks from several angles. Volatility which quantifies the intensity of price fluctuations is well established as a measure of market risk and many statistical models strive to capture its temporal properties. In this context, we could show that across a wide class 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. Furthermore, we examined possible mechanisms that could drive the observed volatility dynamics. To this end, we considered models from econophysics which explain volatility as arising from the collective actions of many traders. Especially, herding behavior of traders or chartist strategies are thought to amplify market fluctuations. Formulating established models in statistical terms, we could fit different models from econophysics to actual market data and compare them on empirical grounds.

Beyond these approaches describing the prices of single firm assets, studying systemic risk requires to take into account the feedback mechanisms arising from financial interconnections. To this end, we developed sophisticated models for the correlation between stock prices of hundreds of firm. By building on Gaussian processes, a flexible tool from machine learning to express non-linear relationships, we could improve on established linear approaches by a large margin. Furthermore, our model provides a latent embedding of firms with an intuitive interpretation where stock prices of firms are strongly correlated if they are embedded close together. In addition to this purely statistical approach, we have developed a novel measure of systemic risk in financial networks. In particular, we established a close connection between valuations in financial networks with derivative contracts, e.g. options or futures. In turn, we computed the so called "Greeks", established and practical measures to quantify the sensitivities to a variety of risks, e.g. price shocks or volatility, in a network context. We could prove that cross-holdings between financial firms strongly amplify risks. Especially worrisome is our finding that this effect is most pronounced if capitalization is already low, such as during a financial crisis.

Overall, our research draws on a wide range of techniques and methods, combining sophisticated statistical approaches with elaborate modeling of risks from the perspective of single firms as well as networks of interconnected financial firms. We believe that such an interdisciplinary approach as established and pursued at FIAS is essential to eventually understand how systemic risks develop and spread in financial systems.

Prof. Dr. Nils Bertschinger

Nils Bertschinger is Helmut O. Maucher-Stiftungsjuniorprofessor for systemic risk. He studied computer science at RWTH Aachen and received his PhD from 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.



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