Report by the Managing Director

The present report is a survey over the scientific activities of the Max Planck Institute for Gravitational Physics (Albert Einstein Institute/AEI) in the years 2010-2012. In the years since its foundation in 1995, the institute has established itself as one of the world's leading centers of gravitational physics, and is unique in the breadth and depth of its approaches to the subject. Research at AEI is devoted to all aspects of Einstein's theory of General Relativity, ranging from the geometrical and analytical aspects of the theory over current attempts to bring together general relativity and quantum theory all the way to the astrophysics of gravitational waves, and covering also the experimental approaches and techniques (laser interferometry and quantum optics) required to test the predictions of general relativity and to open new windows in astronomy.

The international standing of AEI is not only visible in the growing scientific output, but also in a notable increase of the institute's rating with respect to several impact factors over the past years. I am especially pleased to report that several members of AEI have received prestigious national and international distinctions and awards in the reporting period (see chapter "appraisals and prizes" for a complete list). A similar indication of the institute's strength as a 'global player' is the fact that several recipients of the Humboldt Award have chosen AEI as their host institution, most recently Claudio Bunster, Ludwig Faddeev and Marc Henneaux.

There is no room in this short introduction to highlight or even mention all the important developments of the last three years, but there is one issue that deserves to be brought up especially in this preface. The single most important decision for the near and longer term future of AEI concerns the replacement of the directors of two of its Golm divisions, respectively, the mathematical relativity division, and the astrophysical/numerical relativity division. On 31 March 2013 Gerhard Huisken left AEI to return to a Chair at the University of Tübingen and to take up the Directorship at the Oberwolfach Mathematical Institute. Bernard Schutz will retire on 31 August 2014, after almost twenty years at AEI. While the negotiation process with a candidate chosen to succeed B. Schutz as head of the division is well under way, the discussions concerning possible successors to G. Huisken are still at an early stage.

The achievements, the scientific advances and events in all five divisions of the institute will be described in some detail in the reports of the individual sections. Among the special highlights concerning the institute as a whole, however, the following deserve to be mentioned specially in this preface:

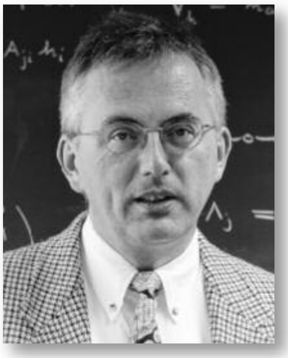
- An ERC Starting Grant was awarded to Jean-Luc Lehners who established an Independent Research Group on String Cosmology in January 2011.

- Ulrich Menne started a second Independent Research Group on Geometric Measure Theory, funded by the Max Planck Society in April 2012.

Both groups closely cooperate with the Quantum Gravity and the Geometric Analysis and Gravitation Division, respectively.

- In 2010 and 2011 four new Max Planck Partner Groups, led by former AEI postdocs, were established in Pune and in Trivandrum (India) and Santo André (Brasil).

In the year 2015 the world of physics will celebrate the Centenary of General Relativity, one of the towering intellectual achievements in human history. At the same time, we look forward to celebrating the 20th anniversary of AEI, taking pride in the fact that this will be very close to the geographical location where Einstein presented his field equations for the first time. One hundred years after its discovery, General Relativity is more vibrant than ever, and we are confident that AEI will continue to play a central role in its further development.



Hermann Nicolai

Content

Research Highlights (contd.)

Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

The Albert Einstein Institute was founded in 1995 by the Max Planck Society for the purpose of pursuing research into the fundamental laws of gravitation. The Institute was established in Brandenburg as part of the expansion of the Max Planck Society after the reunification of Germany.

The Institute moved from central Potsdam to its new building in Potsdam/Golm in 1999. In 2002 the Institute opened a branch at the University of Hannover that specializes in the development of gravitational wave detectors. The GEO600 detector is operated by the Hannover branch.

The AEI was founded in 1995 as a result of the initiative of its founding Director, Jürgen Ehlers, who passed away in 2008. The vision that Ehlers displayed in convincing the Max Planck Society to establish the institute has been amply validated by the rapid growth of the AEI over the last seventeen years, including the opening of its branch institute in Hannover, devoted to experimental gravitation. During this period it has become the largest research institute in the world devoted to gravitational physics, and it serves as a focal point for scientists working internationally in many areas. More than three hundred scientists visit each year; the institute regularly hosts workshops and conferences; we publish one of the principal scientific journals in relativity and host community-service websites; and many AEI staff occupy leading positions in big collaborations, external institutions, and in public advisory bodies. We also take satisfaction in the careers of the many former AEI scientists who now occupy leadership positions in research and science management around the world.

The years 2010-12 have been a period of rich activity across all five divisions, some of which is reviewed in this volume. Our International Max Planck Research School (IMPRS) in Gravitational Wave Astronomy was reviewed and extended by the Max Planck Society. We gained two new independent research groups, one in quantum cosmology and the other in the mathematics of measure theory; the mathematics group is a close cooperation with the University of Potsdam. Our GEO600 gravitational wave detector remained the only operating interferometer while the larger instruments in the USA and Italy continued their upgrades, and we began to assist the development of new interferometers in Japan and India. The AEI continued to coordinate data analysis for the international LIGO Scientific Collaboration through its chairmanship of the Data Analysis Council. The Einstein@Home citizen computing platform has developed into a powerful data analysis tool that is beginning to make discoveries in radio and gamma-ray astronomy as well as perform thorough searches of our first-generation gravitational wave data. The AEI began to make important theoretical contributions to a very promising way of detecting very low-frequency gravitational waves using pulsar timing, working closely with our colleagues at the Max Planck Institute for Radio Astronomy in Bonn. Our theoretical work in numerical relativity and in string theory achieved important milestones, proving results in each area that had long been suspected but had remained elusive. And LISA Pathfinder reached the last stage of its payload integration in preparation for its launch in 2015.

Science of the AEI: Relativity in Physics and Astronomy

The founding of the AEI in 1995 came at a time of enormous expansion of interest in and importance of Einstein's theory of gravitation, general relativity. During the first 50 years after Einstein proposed his theory in 1915, mathematicians and physicists struggled to develop techniques that were capable of unravelling the mysteries of the equations and making sound physical predictions. No physical theory had been as challenging mathematically as general relativity. But elegant and fundamental mathematical work in the 1950's through the 1970's put the theory on a sound footing. By the mid-1970's, theorists understood black holes, gravitational waves, gravitational lensing, and cosmology well enough to make confident physical predictions.

This was just in time, because general relativity was becoming important to astronomy. The application of advanced technology to astronomical observing from the ground and in space led to the discovery of many new and exotic phenomena that could be explained only by using relativity. Black holes, gravitational lensing, the cosmological constant – it is a rare conference on astronomy today that does not deal in an almost routine way with some or all of these concepts, which a few decades ago were regarded as exotic, if not impossible.

A remarkable feature of the current epoch is that a variety of techniques are being developed and applied to detect gravitational waves of different frequencies, and the AEI is playing a key role in most of them. Since 1990, striking technological advances have been made in the design and construction of ground-based gravitational wave detectors of enormous size, based on the technique of laser interferometry. They look for high-frequency waves, which means 100-1000 Hz. By 2010 a worldwide network of such instruments had accumulated more than two years of full first-stage sensitivity observing, including the AEI's GEO600, a collaboration with British and other European scientists. The period covered by this report has been one of intense analysis of the data, which has not revealed a detection. Although disappointing, this was not surprising, since the first stage of sensitivity of these enormously complicated instruments was set at a level where signals were not assured but the collaboration would learn enormously about how to control and operate these detectors and to analyse their data. In 2015 we expect to start observing again after a major hardware upgrade, which is largely based on techniques and components first developed for GEO600 to allow it to compete in sensitivity with the larger interferometers during the first stage of observing. First detections are confidently expected between 2016-18, as the sensitivity steadily increases. At the same time, radio astronomers are intensively searching for the signature of gravitational waves in the variations in pulse arrival times of ultra-stable pulsars, and according to the predictions of AEI scientists, they may well make their first detections of nano-Hertz gravitational waves before 2020. The AEI has also been a leader in the design and development of the LISA space-based gravitational wave mission, aimed at detecting gravitational waves at milli-Hertz frequencies. During the period covered by this report, the collaboration between Europe and the USA on this project collapsed when NASA withdrew due to funding difficulties. ESA has reformulated its program and a re-designed eLISA mission is a prime candidate for one of two launches of large missions planned for the late 2020s and early 2030s. Meanwhile, preparations for eLISA include the LISA Pathfinder mission, due for launch in 2015, a technology-proving mission in which AEI scientists in Hannover are playing a leading role. The design of eLISA itself, and the setting of its science goals, are also activities in which AEI scientists have leadership positions.

While astronomers were discovering how exotic our universe can be, physicists studying fundamental physics began turning to general relativity as well. By the mid-1970's they had achieved considerable success in understanding, at least in outline, how all the forces of nature except gravitation fit together into a single theory. They were then ready to try to include gravitation into the unified picture that was emerging. Virtual black holes, black hole entropy, the cosmological constant, inflation, wormholes, strings, eleven dimensions – fundamental physicists today work in the exciting border areas between classical gravitation and quantum field theory, searching for the "theory of everything".

Mathematical work in general relativity continues to flower. The theory still presents significant challenges that affect the way it is used in astronomy and particularly in quantum gravity. The field is ever interested in new developments in any field of mathematics that can aid understanding. And, as so often happens in physics, the theory is stimulating the creation of new mathematical concepts and constructs that themselves become interesting research topics.

Structure and Research of the Institute

The AEI brings all these threads of research together into a single institute, where scientists working in all these areas can interact with one another, learn from one another, and collaborate with one another. The Institute has five divisions: three in Golm and two in Hannover.

- The Astrophysical Relativity Division (Golm/Schutz) specializes in the applications of relativity in astronomy. It has two main groups, one concerned with the search for gravitational radiation and the other with the computer simulation of black holes and neutron stars and their dynamics, plus a smaller astrophysics group. The gravitational radiation group analyzes data from the LSC-Virgo network of gravitational wave detectors and performs theoretical studies to understand sources of gravitational waves, working closely with the two AEI-Hannover departments. It also plays an important role in European studies of data analysis for the space-based eLISA gravitational wave mission, and in preparing the science case for mission proposals. The division's numerical relativity group is one of the largest in the world, developing techniques for studying situations that may be important sources of gravitational waves but that are not amenable to analytic calculation or approximation: collisions and mergers of black holes and neutron stars. It has a particular strength in using magnetohydrodynamics in such simulations. The astrophysics group supports the other two and has developed an international reputation for its work on binary systems involving supermassive black holes.

- The Geometric Analysis and Gravitation Division (Golm/Huisken) extends the techniques that have unlocked the basic meaning of the theory. The division is a leader in understanding the local and global properties of solutions to Einstein's equations, both those that are dynamical and emit gravitational waves, and those that develop singularities, places where the predictive power of general relativity itself breaks down. The division is broadening its research into areas of geometrical mathematics that have proved powerful in studying general relativity in the past and which show great promise for further progress and for applications in numerical relativity and quantum gravity.

- The Quantum Gravity Division (Golm/Nicolai) studies methods for developing a theory of gravitation that replaces general relativity by making it compatible with quantum mechanics, and if possible unifying gravity with the other forces of nature at the same time. There are several different threads to research in this area around the world, the main ones being supergravity and string theory and canonical quantization (in particular loop and spin foam quantum gravity). The AEI is one of the few places in the world which tries to represent all the major approaches, and where scientists have significantly contributed to very different research directions in quantum gravity. It is in this research area that the most fundamental insights and the most exciting changes in our picture of how Nature is organized can be expected.

- The Laser Interferometry and Gravitational Wave Astronomy Division (Hannover/Danzmann) develops and operates the GEO600 gravitational wave detector, in cooperation with its UK partners in Glasgow and Cardiff. The department is a major contributor to the upgrade to Advanced LIGO, is implementing the GEO upgrade to GEO-HF, and does research into future detector technologies. A new 10-m prototype interferometer supports this work. The Department also plays a leading role in the development of the eLISA space-based gravitational wave detector mission proposal and its technology-proving predecessor, LISA Pathfinder. Pathfinder is due to be launched in 2015 by the European Space Agency (ESA), and it is hoped that eLISA will be selected for further development by ESA at the end of 2013. The department is currently also developing applications of its LISA Pathfinder technology in earth geodesy.

- The Observational Relativity and Cosmology Division (Hannover/Allen) was established at the beginning of 2007 with the appointment of Bruce Allen from the University of Wisconsin at Milwaukee. The Department has built the very powerful ATLAS cluster computer with an associated massive data storage facility. This is currently the principal data analysis platform in the LSC-VIRGO collaboration. It also operates, in cooperation with the University of Wisconsin at Milwaukee, the Einstein@Home citizen-computing project, which provides a huge amount of computing resource to the search for gravitational waves. The Department has a primary focus on ground-based gravitational wave data analysis and on developing the interface between data and theory. It has recently been analysing data from radio telescopes and space-based gamma-ray telescopes to look for pulsars, with considerable success. These searches use the same basic techniques as have developed for gravitational wave searches for pulsars, and besides returning important astronomical information, they also provide the opportunity to learn more about these techniques on real data.

In addition to its permanent research divisions, the AEI hosts four fixed-term independent research groups:

- In January 2009, Daniele Oriti established the group Microscopic Quantum Structure and Dynamics of Spacetime, a Sofja Kovalevskaja Independent Research Group funded by the A. von Humboldt Foundation. The aim of this research is to examine the implications of current theories of quantum gravity for the structure of space and time on the very smallest scales: is it a continuum, or is it (as is often expected) a complex and continually changing web of lower-dimensional structures? This is one of the most fundamental questions that quantum gravity tries to address.

- Canonical and Covariant Dynamics of Quantum Gravity: this group, led by Bianca Dittrich, started up in September 2009 with funding from the Max Planck Society with an initial duration of 5 years. The research of the group focuses on the construction and examination of quantum gravity models. The aim is to improve current descriptions for the dynamics of quantum gravity in canonical and covariant formulations and in particular to obtain a better connection between these two formulations. In January 2012, B. Dittrich took on a faculty position at Perimeter Institute for Theoretical Physics in Waterloo.
- In January 2011, Jean-Luc Lehners established a research group on String Cosmology, funded by an ERC Starting Grant. The aim of this group is to enhance our understanding of the very early universe and its most mysterious aspect, the big bang. There currently exists no complete theory that satisfactorily explains the initial conditions for the evolution of the universe that was set at that time, nor how quantum effects might modify the initial singularity or even allow a continuation from an earlier phase. The group studies and develops cosmological theories, like inflationary cosmology or the theory of the cyclic universe within the context of string theory.

These three research groups closely cooperate with the Quantum Gravity Division.

- In April 1012, Ulrich Menne started his Max Planck Research Group on Geometric Measure Theory which was set up jointly with the University of Potsdam. The group focuses on two-dimensional or higher-dimensional surfaces in flat or curved spaces of three or more dimensions respectively. The problem of the embedding of surfaces that satisfy variational properties, such as surfaces of extremal area, is challenging, and the existence of smooth solutions is not guaranteed. The group works to develop theorems governing the properties of such solutions.

This research group is in close contact with the Geometric Analysis and Gravitation Division.

To support this work the AEI provides in Golm an extensive library and one of the best computing environments available to any research institute of its size. The library is a leader in providing electronic access to journals for our scientists. Our computer installation includes not only high-performance workstations and servers, but three teraflop-class cluster computers dedicated to specific areas.

Even more than the physical facilities, the Institute sees the work of its support staff as a key part of its performance: caring for the needs of visitors, maintaining the computer systems and making them accessible to all, ensuring that the library responds to the needs of scientists, supporting scientists who need to administer external research grants – all of these must happen if the research environment is to be productive. Our public outreach and public relations activities are also given a high priority, because there is an especially strong interest among the general public in research associated with Einstein's theories.

The Institute collaborates closely with its 4 Max Planck Partner groups in India and Brasil. Two are led by former postdocs in the Quantum Gravity Division: one was established 2009 at the Indian Institute of Science Education and Research in Pune (leader: S. Ananth), the other in 2011 at the Indian Institute of Science Education and Research in Trivandrum (leader: S. Shankaranarayanan). The other two are led by former members of the Astrophysical Relativity Division: one was established 2010 at the Federal University of ABC in Santo André, Brasil (leader: C. Cirenti) and the other in 2011 at the Indian Institute of Science Education and Research in Trivandrum (leader: A. Pai).

The Institute also maintains an extensive guest scientist program. The lists in this report of guest scientists for 2010-2012 and of seminars given at the AEI show how rich the intellectual environment is.

The AEI and Universities

As the largest research institute of its kind in the world, the AEI occupies a key position not only in world research in relativity but especially in Germany. Despite the fact that general relativity was created in Germany, research in mathematical and astrophysical general relativity is unfortunately not strongly supported at most German universities. Apart from the contributions of a strong group at the Max Planck Institute for Physics and Astrophysics (which became the core of the AEI when it was established) and of a few individuals and small groups at German universities, the focus of the development of classical relativity in the 1960's through the 1990's was outside Germany. Today, increasing numbers of German students are going abroad to study the subject at an advanced level.

In order to help to make Germany attractive to young students, and to foster its own research, the AEI participates in at least five different cooperative initiatives.

The first is its close cooperation with the University of Potsdam. The newest aspect of this is the independent research group in Geometric Measure Theory that was set up jointly with the university in 2012 (see above). Another aspect is our long-standing annual vacation course in relativity, offered in cooperation with the University of Potsdam, in which the AEI provides students from all over Germany the opportunity to learn the foundations of general relativity here. Those who want to pursue the subject further may then be able to work at the AEI. The Institute, through its partnerships with Potsdam University, the Humboldt University of Berlin, and the Leibniz Universität Hannover, can supervise work towards advanced degrees of those universities.

A second form of cooperation with universities is the participation of the AEI in two SFBs (*Sonderforschungsbereich* = special research area), in which it collaborates with scientists at German universities in areas of mutual interest. These research grants, which run for many years and can involve hundreds of scientists, are a principal source of support for university research. The SFB TR7 "Gravitational Wave Astronomy" joins the AEI with the Universities of Jena, Hannover, and Tübingen and the Max Planck Institute for Astrophysics in Garching in a wide-ranging research program, which is helping to develop a university research community supporting the experimental activities of GEO600. Another SFB in mathematics and theoretical physics entitled “Space-Time-Matter” is a joint project between the AEI, Potsdam University, Free University and Humboldt University.

The AEI’s third and fourth initiatives are its two International Max Planck International Research Schools (IMPRS). The first one, started in 2004, is in Geometric Analysis, Gravitation, and String Theory and it was reviewed and extended in 2009. It is a cooperation with Potsdam University and the Free University of Berlin. The second, which began in 2006, is in Gravitational Wave Astronomy, and is a cooperation with Leibniz Universität Hannover. It was reviewed and extended in 2010/11. These two schools not only offer new opportunities to German students to study at the frontiers of physics, but they also bring good students to Germany from many countries. IMPRS’s are a very successful recent innovation by the Max Planck Society. They offer instruction through the medium of English and provide students with a “graduate-school” environment in which to study for a Ph.D., something which had been lacking at German universities before.

The fifth form of cooperation between universities and the AEI is our leadership role in the QUEST Center of Excellence, which is described more fully in Danzmann’s sections of this report. Danzmann is Deputy Coordinator. Originally funded by a large grant from the German Federal Government, it is now settling into a long-term vehicle for joint research cooperation between the AEI in Hannover and Leibniz Universität Hannover. This has brought a large increase in research staff, including a number of permanently funded professorships in our research area at Hannover University.

The AEI naturally also trains many young German and foreign postdoctoral scientists in its research groups. Our experience is that when these young scientists leave the AEI they generally go to excellent academic positions, mostly outside Germany. In time, and despite the current serious financial pressures on the German research and education systems, we hope that a larger fraction of our young scientists will enter academic positions at German universities, so that they can offer many more German students the opportunity to learn about and work in the rapidly developing field of research in gravitation.

Another resource that the AEI provides for the university community, both within Germany and outside it, is the internet-based review journal Living Reviews in Relativity. This has become a standard reference not only for relativists but for researchers in allied subjects. The quality of the editorial board and of the reviewers has led to very high usage figures on our website, and all of our articles have been downloaded hundreds (in some cases thousands) of times. The journal is now indexed by Thompson-ISI and currently has an Impact Factor of 17.6, which is the largest impact factor of any open access journal in the scholarly world. In recent years we have started up four sisters journals, Living Reviews in Solar Physics, Living Reviews in European Governance, Living Reviews in Landscape Research, and Living Reviews in Democracy. A new journal, Living Reviews in Computational Astrophysics, is expected to publish its first articles later in 2013. Further journals are under discussion. Further journals are expected to join the family in the next year or two. The publishing activities are in association with the newly-established Max Planck Digital Library.

The Research Vision of the AEI

In a longer view of our research, there are goals and challenges that motivate AEI scientists. We work from day to day, writing papers, holding meetings and other discussions, thinking in quiet isolation, travelling to work with collaborators; but all of this activity accumulates to move research in certain directions and to prepare for certain expected developments. Here is a partial list.

- The first direct detection of gravitational waves will place the AEI at the center of this new branch of astronomy. As a partner in the LIGO detectors, which employ GEO600 technologies, the AEI will participate in these first detections. The data analysis group, our gravitational-wave theorists, and the numerical simulations group will also play key roles in the interpretation of the first observations.
- Software and supercomputers are now powerful enough to do realistic calculations in general relativity: to perform long simulations of black holes and neutron stars merging, to perform somewhat realistic calculations of the formation of neutron stars and black holes, and to begin to explore mathematical questions, such as the development of singularities, that have not been solved analytically so far. This capability opens up tremendous new opportunities for exploring general relativity, as well as for assisting the discovery and interpretation of gravitational waves.
- The launch of new space-based astronomical observatories – not only eLISA but also new observatories for the cosmic microwave background radiation, for X-ray astronomy, for cosmological observations in the infrared, and more – and the commissioning of many new sophisticated ground-based telescopes – will not only challenge us with unexpected discoveries about black holes, their relation to the formation of galaxies, and the overall structure of the universe, but they will also provide us with a massive amount of quantitative information about the universe that will be unprecedented in its precision and detail. Gravitational theory will be much in demand for the interpretation of this data.
- Mathematics is advancing rapidly in many areas, especially in those that use computers as an aid to proving theorems, exploring geometrical concepts, and gaining insight into complex situations. Relativity provides an attractive area for the application and even the development of new techniques, offering challenging problems in singularities and in the global structure of solutions. The cross-fertilisation of relativity and other branches of mathematics can lead to fruitful research in the next decade.
- If the optimism of scientists working today in string theory and in loop quantum gravity is justified, then in only a few years we may see the emergence of a coherent but mathematically complex theory that shows how gravity is related to all the other forces of nature. Already exciting and radical ideas are emerging about how these theories might alter our notions of gravity, explain the Big Bang, and predict completely new phenomena. Work to understand the theories and

explore predictions that will be testable by experiments and by astronomical observations will require new mathematics and creative young minds. For the first time it may be possible to ask sensible questions – and expect sensible answers – to questions like: what happens inside black holes, what happened "before" the Big Bang, what is space-time like on the very smallest scales, how many dimensions does space really have, and what is time itself?

The work of the AEI in 2010-2012, as described in these pages, should be seen in the light of these challenges and opportunities. In almost every case, scientists at the AEI are addressing issues that lie at the heart of progress on these questions. A Max Planck Institute is a long-term investment in a research field, and for gravitational physics the prospects for the future are especially exciting. We look forward to many more years of research with optimism and anticipation.

Bernard F. Schutz

International Max Planck Research Schools (IMPRS)

The Max Planck Institute for Gravitational Physics hosts two graduate schools: the IMPRS on Gravitational Wave Astronomy that covers all aspects of Gravitational Wave Astronomy ranging from theoretical to experimental Gravitational Wave Physics, and the IMPRS for Geometric Analysis, Gravitation and String Theory that deals with the mathematical and theoretical foundation of Einstein's theory of general relativity and its quantum description.

The aim of the schools is to give an excellent education in an outstanding research environment at one of the world's leading institutions in this field. When they obtain their doctoral degree, the students should have grown into independent researchers with a profound scientific knowledge. During their education they are guided towards independent research by their supervisors and experienced colleagues, and on the other hand they are offered a high-level curriculum to obtain a solid background in their field. In addition the students also acquire other competences like scientific writing, presentation skills, proposal writing and project management.

Both schools experience the challenges and opportunities of interdisciplinarity: theorists and experimentalists in the IMPRS on Gravitational Wave Astronomy, and mathematicians and physicists in the IMPRS for Geometric Analysis, Gravitation and String Theory, work and learn together. The education that is offered aims to enable a fruitful communication between the fields: it bridges the gaps and provides a basic understanding of each other's daily work and challenges.

Members of the IMPRS-GW during a lecture week 2010.

The schools work closely together with several partner universities, these are the Leibniz Universität Hannover and the University of Potsdam for Gravitational Wave Physics, and the Humboldt University of Berlin, the Free University of Berlin and the University of Potsdam for Mathematics and Quantum Gravity. There is a collaboration and exchange between groups at the University and the Max Planck Institute. The universities offer a curriculum of high-level advanced courses for graduate students to which also researchers of the Max Planck Institute contribute.

The IMPRS have a very international orientation: on the one hand, about half of the students come from other countries including Armenia, Bulgaria, Canada, China, France, Greece, India, Iran, Italy, Mexico, Russia, Spain, Switzerland, UK, Ukraine, and USA. As the standard language in the research groups is English, knowledge of the German language is not a prerequisite; foreign students however have the opportunity to take German courses. On the other hand, IMPRS students come into contact with researchers from all over the world through a top-level and international visitor program, and through the possibility to travel to international conferences or schools, or to visit other research institutions for a scientific project.

Both schools have a specific scientific profile in a worldwide unique constellation:

The IMPRS on Gravitational Wave Astronomy (IMPRS-GW) comprises three divisions of the AEI (Karsten Danzmann, Bruce Allen, Bernard Schutz) with contributions from the Laser Zentrum Hannover. In the eighths year after its start, our IMPRS-GW is really flourishing. We have found an efficient and stable curriculum, a stimulating group spirit and a very productive research environment.

By 2013 there are 58 doctoral students (thereof 13 women) in the IMPRS program, 6 of them in Golm and 52 in Hannover. Students are financed from different funding sources, 10 by our IMPRS budget, the remaining ones by the cluster of excellence Quest, Halostar, SFB TR7, DAAD, DFG, BMBF, DLR, ESA and Volkswagen. Currently there are 35 German students and 23 international ones. Up to now 58 students have successfully completed their PhD degrees within this IMPRS program.

The IMPRS for Geometric Analysis, Gravitation and String Theory is a joint program of two divisions of the AEI (led by Gerhard Huisken and Hermann Nicolai) and groups at Universities in Potsdam and Berlin. The doctoral students work on research problems in mathematics and theoretical physics that are related to Einstein's theory of general relativity. This includes for example research on partial differential equations, geometry, black holes, cosmology, quantum gravity and string theory.

By 2013 there are about 25 students in the program, 12 of which are financed by MPG funds, whereas the remaining ones are paid from different sources including DFG, ERC, the Chinese Academy of Sciences, and the Erasmus Mundus program. About 25% of the students come from other European countries, and another 15% come from outside Europe. Since the inception of the school in 2004, 50 students obtained their doctoral degree.

Stefan Fredenhagen & Melanie Hase

Geometric Analysis and Gravitation

The division "Geometric Analysis and Gravitation" is concerned with the physical concepts and mathematical models that allow the description of space and time and gravitational phenomena. In this area of research Analysis, Geometry and Physics interact in fascinating and challenging ways. The methods employed range from differential geometry, nonlinear partial differential equations, calculus of variations and geometric measure theory all the way to discrete approximations and numerical analysis. Special emphasis is given to Einstein's field equations in classical General Relativity modelling phenomena such as isolated gravitating systems and black holes, gravitational waves and cosmology.

There are close scientific connections with the other divisions at the AEI and to the nearby Universities in Berlin and Potsdam. At the institutional level collaborations exist through collaborative research structures (International Max Planck Research School "Geometric Analysis, Gravitation and String Theory" ("IMPRS"), Special Research Center 647 "Space-Time-Matter" of the German Research Foundation DFG ("SFB647") and the Berlin Mathematical School in the DFG "excellence initiative" ("BMS")). The IMPRS has attracted excellent students from around the world and intensified the collaboration between this division and the "Quantum Gravity and Unified Theories" division as well as with Potsdam University and Free University Berlin. Some of the students have in addition become members of the BMS leading to new links with the wider Berlin mathematical community. Successful joint research projects between these groups have been carried out for example on subjects such as "Membrane Theory" and "Ricci-flow". In a joint appointment with Potsdam University an independent Max Planck Research Group was set up in the area of "Geometric Measure Theory". Methods from geometric measure theory turn out to be crucial in the understanding of positive mass theorems, energy inequalities and marginal outer trapped surfaces.

International collaboration has been supported by the guest program of the institute and has taken place in many directions. Funds from the AEI and from the IMPRS and the BMS allowed many students to participate in conferences and to visit partner institutions. Institutional links are in place with the research group of our external scientific member R. Bartnik at Monash University in Melbourne, Australia, frequent exchanges took place with the research group of J. Bicak and his colleagues in Prague as well as with the research group of P. Chrusciel in Vienna. In 2012 P. Bizon has joined the AEI as a longterm senior visiting professor. L. Andersson and G. Huisken were among the organisers preparing a special program in Mathematical Relativity taking place at the Mathematical Sciences Research Institute in Berkeley, that allowed several AEI researchers to link up with colleagues from around the world.

Members of the division have taught major courses at Potsdam University, Free University Berlin and Tübingen University. Specialised lecture courses were given at the IMPRS and at special events such as the annual vacation course in collaboration with Potsdam University, which is now being organised by Lars Andersson. Invited research lecture series were given by members of the division a number of other universities and institutes. Members of the division participated in the organization of several international conferences and workshops and helped in the administration and evaluation processes of their research fields.

In spring 2013 Gerhard Huisken left the institute to take up a professorship at Tübingen University as well as the directorship at the Mathematische Forschungsinstitut Oberwolfach. Lars Andersson now leads a core group of researchers in Mathematical Relativity until a new director is appointed while Gerhard Huisken will remain associated with the division as an external scientific member of the AEI. At the same time Alan Rendall let the AEI to take up a full professorship at the University of Mainz. The institute is currently in the process of finding successors for these positions.

Concerning specific research highlights, major progress was made on the structure of axially symmetric black holes and the relation between their mass, angular momentum and area of their horizon, where sharp inequalities between these quantities were proven. A precise quantitative description of the asymptotic behaviour of gravitational radiation was another important project – from a mathematical perspective this involves estimates on the dispersive behaviour of solutions to hyperbolic equations on curved backgrounds. These investigations are crucial for long-term goals such as the stability properties of axially symmetric black holes. Another important research theme was the mathematical understanding of black hole boundaries, modelled as marginally outer trapped surfaces (MOTS). The understanding of these structures requires sophisticated mathematical techniques such as geometric variational problems, geometric flows and geometric measure theory described in more detail below.

Several models of expansion in cosmology were studied and the interaction of gravitation with other matter fields in such models was investigated. Closely related is the study of the singular behaviour of a space-time near a "big bang", which requires a delicate analysis of the nonlinear partial differential equations involved and the time-dependent geometry in such regions.

In 2012 Oliver Rinne joined the division with a research program combining analytical investigations and numerical modelling of solutions to Einsteins equations. These studies are important both for the numerical simulation of black holes as well as for stable algorithms concerning the behaviour of gravitational fields near spacelike infinity. These studies also provide a close link with the research group on numerical relativity in the division "Astrophysical Relativity".

Another major direction of research concerns theoretical mathematics that underpins General Relativity and related theories of gravitation: These include geometric variational problems, nonlinear wave equations as well as the deformations of metrics and submanifolds by parabolic geometric evolution equations. Important progress was made in this regard concerning the description of isolated horizons by surfaces of specified mean curvature, where methods from minimal surface theory are combined with the properties of a space-time solution of

Einstein's equations. In another difficult subject regularity properties for systems of geometric wave equations were studied at a fundamental level, in order to understand both singularity formation and nonlinear stability in certain solutions.

Concerning parabolic evolution equations, both the evolution of hypersurfaces in an ambient manifold with curvature dependent speed and the Ricciflow of Riemannian metrics were investigated. For mean curvature flow the relation between generalised solutions involving from a surgery procedure and solutions constructed by a level-set formulation was clarified and the structure of certain ancient solutions to the flow was classified. The concept of weak solutions for inverse mean curvature flow developed by Huisken and Ilmanen was extended to surfaces moving in direction of their null inverse mean curvature, leading to a new method for the construction of marginal outer trapped surfaces.

Two specific highlights of the research in "Geometric Analysis and Gravitation" are presented further down in the report by Martin Reiris ("Developments in Axisymmetric Gravity") and Oliver Rinne ("From Here to Infinity on a Single Computer").

Gerhard Huisken

Astrophysical Relativity

Introduction

Einstein's theory of general relativity plays a central role in the understanding of the fascinating and surprising universe that astronomers have uncovered in the last thirty to forty years. Relativistic objects like black holes and neutron stars dominate much of modern astrophysics, and general relativity provides the arena – the expanding universe – in which astrophysicists are now beginning to understand deeply how our modern universe came to be. In a few years, general relativity will begin to make an important new contribution: when astronomers finally are able to detect and analyze gravitational waves, they will have an important new messenger that is able to bring information from the darkest and most remote parts of the universe.

The Astrophysical Relativity Division of the AEI focuses its work on gravitational waves: how they are generated by black holes and neutron stars, how we detect them, and how we will extract information from the waves we detect. There are five main divisions of activity: numerical relativity, data analysis for ground-based detectors, data analysis for pulsar timing arrays, preparations for LISA, and astrophysics of gravitational wave sources.

Numerical relativity

Some of our scientists in the Astrophysical Relativity Division perform large supercomputer simulations of the mergers of black holes and neutron stars. Not only are these merger events expected to be among the first gravitational wave sources to be directly detected by the LSC and Virgo detectors, but these events are also intrinsically very interesting because they have much to tell us about general relativity and physics under extreme conditions. Numerical simulations of this kind are a kind of laboratory astrophysics: since we can't experiment directly on neutron stars and black holes, and since they are too complex for us to solve the full Einstein equations for with paper and pencil, our approach is to solve the Einstein equations numerically to understand the evolution of systems we believe exist, using as much other physics as we are able to include.

The AEI group is a world leader in examining the effects of strong magnetic fields on mergers of neutron-star; we know that neutron stars have such fields, and the AEI group has shown that the magnetic fields configure themselves in a matter of milliseconds into remarkably ordered patterns capable of channelling hot plasma away from the merger and producing jets that underlie many of the gamma-ray bursts that satellites regularly detect [1].

We have also continued our work on black hole mergers, primarily with the aim of understanding the physics of the merger. One interesting aspect of mergers is that if the two black holes are not identical, then the gravitational radiation of the merger will be emitted in an asymmetrical pattern, carrying off net linear momentum in the radiation. That produces a recoil, and the final merged black hole moves off with equal but opposite momentum. We say it has received a "kick". This phenomenon has been explored in detail numerically by ex-AEI scientist Manuela Campanelli, who now leads her own numerical relativity group at the Rochester Institute of Technology. Manuela has shown that under the right conditions, the final black hole can be kicked up to a good fraction of the speed of light, enough to eject it from the galaxy in which it formed [2]. But exactly how to predict the momentum and therefore the magnitude of the kick has been a puzzle. The AEI group showed that a key component of the kick is a reverse kick (the "anti-kick") that happens in the final phase of merger, and it comes from the settling down of the distorted final black hole. This analysis required a delicate union of numerical and analytical techniques, and these are described in the article below by José-Luis Jaramillo.

Analysis of data from ground-based detectors

As members of the GEO project, scientists at AEI/Golm and AEI/Hannover work with our partners elsewhere in Europe, in the USA, and worldwide within the LIGO Scientific Collaboration (LSC). The LSC includes the three large LIGO detectors in the USA and the GEO600 detector operated by AEI/Hannover. The LSC shares its data with that from the large Italian-French Virgo detector in Pisa, performing joint analyses to extract the greatest possible science. At the beginning of this report period, in September 2010, the LIGO detectors shut down for a major sensitivity upgrade to what are called Advanced detectors, which should be completed in 2015. Virgo and GEO600 did some joint observing, and then Virgo shut down for a similar upgrade.

The smaller GEO600 meanwhile has been performing "Astrowatch" monitoring of the sky while also upgrading its sensitivity and installing new technologies, like squeezed light. This is described in the report on Karsten Danzmann's division elsewhere in this report. Over a longer timescale two further large detectors are in the planning stages: one in Japan (KAGRA) and another LIGO detector to be built in India.

The LIGO, GEO600, and Virgo detectors performed science data runs during the period 2005-10, and during the current report period the data analysis teams of the Astrophysical Relativity Division worked intensively to finish the analysis of these first runs [3]. No signals have been found in the data, but this was not a surprise: the first-stage sensitivity of these new instruments was not expected to produce regular detections. The current sensitivity upgrade has been planned from the beginning, and there are good reasons to believe that the first detections will be made soon after the Advanced detectors begin operating at or near their full sensitivity.

Although the analyses of the first data runs produced only upper limits on many sources, the exercise provided vital experience for the teams. During the current reporting period we have begun to use this experience to produce the software and analysis procedures that will enable us to identify signals quickly and reliably in the Advanced detector data, so that astronomers in other fields can train their telescopes onto regions of the sky where our sources are and look for emissions of light, X-rays, and gamma rays associated with the gravitational wave event. Our data analysis scientists work with large supercomputers at AEI/Golm and AEI/Hannover, and with the Einstein@Home volunteer computing project (described in the report of Bruce Allen's division).

A good insight into the nature of this work is given by the report below by M.-A. Papa and R. Prix. Dr Prix is in Bruce Allen's division at AEI/Hannover. Dr Papa also works at AEI/Hannover but leads the data analysis work of the Astrophysical Relativity Division. She is the LSC's co-chair of the LSC-Virgo Data Analysis Council, which oversees the entire joint data analysis of the LIGO, GEO, and Virgo detectors. Her own special interest is in searches for spinning neutron stars, or gravitational-wave pulsars, an activity she led for the collaboration until she took over the overall chair. This search is the main activity done on the Einstein@Home network.

Preparations for the LISA space-based gravitational wave mission
Scientists at AEI/Golm have worked intensively during this report period on the proposal to the European Space Agency for the LISA space-based mission to detect low-frequency gravitational waves. LISA will be the most sensitive gravitational wave detector ever operated, and it will operate in the milliHertz gravitational wave frequency band, which is rich with important sources, especially the black holes that sit at the centres of most galaxies. The analysis of LISA data presents special challenges. Unlike the ground-based instruments, where we have to search for signals buried in instrumental noise, LISA will be so sensitive that the signals will be immediately recognizable; but then the reverse problem will challenge us: separating strong, overlapping signals from one another to get the greatest information from all of them. This analysis problem has been the subject of considerable work at the AEI over many years, in a group led by Stanislav Babak.

In 2011 we entered a competition for the next launch of a large ESA mission, in which the other two candidates were a mission to the moons of Jupiter and an X-ray observatory. All three missions were expected to be joint missions with NASA. But before the competition was decided, NASA withdrew from all collaborations because of a lack of funds: cost overruns on NASA's James Webb Space Telescope project left them with no money for a new mission. So ESA instructed all three candidates to come back to a competition the following year with a descoped mission, that could be done by ESA alone.

The redesign of LISA to what became known as NGO (Next Gravitational-Wave Observatory) took an intensive effort on the part of many European scientists, and teams from AEI/Hannover and AEI/Golm were central to it. The data analysis methods played a big part, because the only way to know what science the new mission could return was to estimate its sensitivity and then run simulated signals through data analysis pipelines to see what could be measured. This is an extension of the Mock LISA Data Challenge activity that was described in our last report.

So in 2012 the ESA competition was run again, and NGO was not selected, deferring to JUICE, the Jupiter mission. But NGO received the highest scientific rating of all three candidates from the selection panels; it was not selected because we are still waiting for the launch of LISA Pathfinder, now scheduled for 2015. The next competition was to be in 2013, and the team is again intensively redefining the mission, with a new name: eLISA. The result of the competition will be reported in the AEI's next report.

Pulsar timing for gravitational wave detection

In the last few years a new and exciting method for detecting gravitational waves has been developed and is now being intensively pursued around the world: using signals from millisecond pulsars to measure gravitational waves that pass through the Earth. These pulsars are, when averaged over a period of several months, excellent clocks, as good as any that we can build. When a gravitational wave passes the Earth, it delays or advances the arrival time of pulses by a very small amount, and the pattern of delays and advances on the sky is very distinctive. By monitoring pulsars over the whole sky regularly, astronomers hope to recognize the characteristic signature of a gravitational wave.

This only works at very low frequencies, say 10-100 nHz, because the pulsar arrival times have to be averaged over several-month periods. This is far below the LISA band. At these frequencies the dominant sources are expected to be binary systems of supermassive black holes of the kind that power quasars. AEI scientist Alberto Sesana, a member of our astrophysics group (next section), is the world-leading expert on the evolution of these systems, and has shown that the most likely first signal to be detected will be stochastic, that is a random superposition of many such binary signals. His report, below, describes this new and exciting field in more detail.

Astrophysics

Our astrophysics research group, led by Pau Amaro-Seoane, has been very active, supporting the interests of the data analysis and numerical groups, but also developing its own research on the star clusters surrounding the massive black holes that astronomers have been finding at the centers of galaxies. Pau has organised a regular series of Astro-GR workshops, which bring together experts from astronomy and general relativity to discuss progress on issues primarily associated with gravitational waves that could be detected by LISA. During the reporting period, workshops have been held in Paris, Mallorca, and Beijing. Pau also operates the LISA Brownbag website [4], which gathers references to papers on LISA science in one convenient location. Associated with the Brown Bag is the GW Notes journal, which publishes occasional articles of a technical nature on gravitational wave science.

Staff

Equally important is that the work we have done has enabled many AEI scientists to advance their careers and leave the AEI for very good positions. We have established another Max Planck Partner

Group, this one led by Archana Pai at IISER Trivandrum in India. Archana was a postdoc at the AEI working on ground-based data analysis, and will play an important role in the planned LIGO-India detector. Our scientists do not always go on to academic jobs: Alexander Beck-Radzka, who very ably led our eScience group for many years, left to work in the commercial IT sector.

Bernard F. Schutz

References

[1] Rezzolla, L., et al, *Astrophys J Lett*, **732**, L1-6 (2011).

[2] Campanelli, M., et al, *Phys Rev Lett,* **98**, 231102 (2007).

[3] A bibliography of papers from the LSC and Virgo collaborations is on this URL: https://www.lsc-group.phys.uwm.edu/ppcomm/Papers.html

[4] http://brownbag.lisascience.org

Quantum Gravity and Unified Theories

Research in the Division focuses on two central challenges, namely the search for a consistent theory of quantum gravity reconciling quantum theory and general relativity, and the search for a unified theory of gravity and the elementary particle interactions. The theory of quantum gravity that will one day supersede Einstein's theory, is expected to revolutionize our understanding of space and time, such that classical space-time descriptions emerge from the complete theory only as a limiting case. The unified theory of all interactions should encompass the well-established standard models of elementary particle physics and of cosmology. The approaches that have been developed to date range from supergravity and superstring theory over canonical approaches (loop quantum gravity and spin foam models) and discrete approaches to attempts to formulate "physics without space and time" in the deep quantum gravity phase. AEI is thus one of the few institutions worldwide that represents the major lines of research in quantum gravity under one roof and that aims to pursue them at the highest level.

During the reporting period, the scientific output of the Division has been significantly enhanced by four independent junior research groups which were closely integrated into the Division's activities: "Duality and Integrable Structures" (Niklas Beisert), "Canonical and Covariant Dynamics of Quantum Gravity" (Bianca Dittrich), both of which were funded by the MPG, and "Microscopic Quantum Structure and Dynamics of Spacetime" (Daniele Oriti), funded by the A.v. Humboldt Foundation via the S. Kovalevskaja program. While the first of these two have now come to an end, the third will continue until the end of 2013. Since 2010, there is yet another independent group "String Cosmology" (J.-L. Lehners) which is supported by an ERC starting grant. The existence of these groups at AEI is testimony not only to the continued attractiveness of the institute as an international research center, but also to its stimulating and lively research atmosphere. In addition the Department has established two Max Planck Partner Groups in India (in Pune and in Thiruvanathapuram, respectively), both of which are led by former AEI postdocs.

Jointly with the Geometric Analysis and Gravitation Department, the Division runs the IMPRS "Geometric Analysis, Gravitation and String Theory" with about 25 PhD students, and participates in the SFB "Space-Time-Matter" together with Potsdam University, FU Berlin and Humboldt University Berlin (an application to extend this collaborative research project to an excellence cluster is in preparation). At the same time, it benefits from numerous third party funds (ESF projects, Humboldt Prizes and Fellowships, Einstein Foundation Berlin, etc.) and an increasing number of visitors who come with their own funds.

Because of the departure of several senior and junior members, the Division faces a continual challenge of re-orientating and 're-inventing' its research activities. With T. Thiemann's departure to a Chair at Erlangen University, research activities in canonical gravity have recently shifted from Loop Quantum Gravity to Spin Foam Gravity and Group Field Theory. Likewise, the departure of Matthias Staudacher to a Chair at Humboldt University, Berlin and the departure of N. Beisert to a Chair at ETH Zürich, have led to reduced activities in the area of integrability of N=4 Yang Mills theory and string theory on AdS_5 x S^5, where AEI has been at the forefront of research during the past years. The resulting shift of focus to new research directions will be evident from the specialized sections in this report.

Synopsis of main research areas

The following is a review of the research activities and highlights during the past three years. Special contributions by A. Kleinschmidt and D. Benedetti (see chapter "Research Highlights") describe in more detail the progress that was made in two research topics of current interest: Supergravity and Asymptotically Safe Gravity.

The approach favoured by a majority of researchers continues to be superstring theory. With the possible exception of N=8 supergravity (the maximally supersymmetric field theory extension of Einstein's theory), this is currently the only ansatz that may succeed in overcoming the inconsistencies of perturbatively quantized general relativity. The main challenge is to find a non-perturbative formulation of the theory (often referred to as "M Theory"). Current efforts in this direction concentrate on exploring aspects of the AdS/CFT correspondence amongst other approaches. From the investigation of integrability properties of N=4 Yang Mills theory and string theory in AdS_5 x S^5, attention has shifted to other aspects in the last three years. New activities center around Higher Spin Gauge Theories and the development of techniques for the computation of physical amplitudes in N=4 Yang Mills theory, N=8 supergravity and superstring theory, as well as the investigation of duality symmetries and their implications. More technical aspects of the Division's string research program concern the following subjects, amongst others: boundary conformal field theories; Calabi-Yau compactification; the classification of BPS solutions in supergravity; entanglement entropy and the AdS/CFT correspondence; the 'a-Theorem', new 'moonshine' conjectures. The research program also carries on with long-term efforts to develop a concrete proposal for M Theory based on the hyperbolic Kac-Moody algebra E10 that might lead to a formulation of quantum gravity purely on the basis of symmetry principles with 'emergent' space-time.

A very different approach that continues to be supported at AEI proceeds from canonical quantization of Einstein's theory in terms of fluxes and holonomies. While the original version of this approach, Loop Quantum Gravity, was pursued at AEI in the past (especially T. Thiemann and his group), attention has meanwhile shifted to Spin Foam Gravity, a "covariant" path integral variant of canonical loop quantum gravity and to group field theory. The chief aim of this approach is to find a background independent formulation of quantum general relativity by directly implementing the basic principles underlying Einstein's theory. Just as the absence of background structures in Einstein's classical theory of general relativity forced physicists to re-think established notions of space and time, these attempts to quantize geometry without reference to any specific space-time background have led to completely new ideas about the structure of space and time at very short distances. A dedicated special effort is currently being devoted to Group Field Theory, which itself developed out of spin foam models and generalizes the matrix model approach to quantum gravity in two space-time dimensions to higher dimensions. Finally, efforts to more strongly support research in (quantum) cosmology than has been the case in the past have borne fruits recently with the arrival in 2010 of a new Junior Research Group devoted to "String Cosmology", lead by J.-L. Lehners.

Hermann Nicolai

Laser Interferometry and Gravitational Wave Astronomy

The report period was a time of rapid growth, great achievements and great disappointments for the Division “Laser interferometry and gravitational wave astronomy”. The greatest achievements were certainly:

- the continued success of our Cluster of Excellence QUEST (Quantum Engineering and Space Time Research), which was a very welcome recognition for the work done here in Hannover, and Karsten Danzmann is the Deputy Coordinator of the cluster;
- our delivery of the 35 W lasers for Enhanced LIGO and three 200 W high-power pre-stabilized laser systems to Advanced LIGO as the core of the LIGO interferometers;
- the installation of squeezed light into GEO600 and its continuous operation as the first and only gravitational wave observatory with squeezed light in Astrowatch data taking mode, as the other large laser interferometers are down for upgrading until around 2015; and
- the recent approval in principle of the US-German GRACE Follow-On space mission for a 2017 launch with an AEI-led inter-satellite laser interferometer on board.

But there were also two very disappointing events in this period:

1. After the successful completion of the five year Mission Formulation Phase of the joint ESA-NASA LISA space mission, culminating in the Mission Consolidation Review in December 2010, it became obvious in early 2011 that NASA would not have the funds to participate in any of the large joint missions proposed for the near future and ESA directed the Science teams to rescope the three concerned missions LISA, IXO and Laplace to be realizable as ESA-only undertakings. In April of 2012, the three rescoped missions were presented to the ESA advisory structure and, even though NGO (or eLISA, i.e. the rescoped LISA) was unanimously voted as number one in scientific interest and quality, it was Juice (the rescoped Laplace), a mission to Jupiter’s moons, that was chosen as L1, the next large ESA mission to fly in 2022. While this seemed devastating at first, it may well be an advantage for LISA to fly on the more relaxed schedule for an L2 launch in 2028, because it allows international partners in the US and China to organize their participation. The final selection of L2 is expected for 2016 and with a successful LISA Pathfinder flight in 2015, it is highly unlikely that any other mission could then be chosen. It is the announced intention of ESA to follow the selection with an intense payload EQM phase 2016 – 2020, so that the industrial implementation of the full mission could start around 2020, perfectly timed for a 2028 launch.

2. Our QUEST Cluster of Excellence at Leibniz Universität Hannover, with appreciable AEI participation, completely transformed the Physics scene in Hannover by making 15 new junior and senior professorial appointments between 2008 and 2010. In 2011, scientific results were beginning to be very promising and we applied for renewal of the Cluster into the next period 2013-2017 of the Excellence Initiative. Even though we received a lot of praise by the referees for our achievements, the funding for the Cluster was not renewed. QUEST nevertheless continues as a Leibniz Forschungsschule at

Albert Einstein Institute Hannover
The AEI Hannover grew out of the gravitational wave group of the Max Planck Institute for Quantum Optics in Garching. It came into proper existence in 2002, with the appointment of Karsten Danzmann as the first director in Hannover. In 2007 we have begun building the second division by appointing Bruce Allen as the second Director.

At AEI Hannover the MPG works closely together with the Leibniz Universität Hannover. The MPG committed to provide stable research funding for both of the planned divisions and the University provided a new building with 4000 m^2 of lab and office space, equipped with basic scientific inventory.

Leibniz Universität Hannover, at first on ramp-down funding from the DFG and then partly on incremental funding from the state government, as originally promised by Niedersachsen. The AEI involvement in QUEST Science will continue and the remaining funding gap will be made up by third-party funding. A pre-proposal for the first new Sonderforschungsbereich together with colleagues from Geodesy has just been submitted and was very positively evaluated. We will follow up with a full proposal.

GRACE follow-on

In the context of QUEST, we are now closely collaborating with colleagues from the Institute for Geodesy, developing future space missions to map the gravitational field of the earth and its time variations. This is a very welcome application of the space interferometry expertise we accumulated in the preparation of the LISA and LISA Pathfinder space missions. In 2008, we were directly approached by NASA with the proposal to collaborate on a laser interferometer for a GRACE follow-on mission to determine the Earth gravity field with unprecedented spatial and temporal resolution. That mission is going ahead now as a US-German collaboration, similar to the old GRACE set-up. The main aim is to continue the valuable microwave-derived ranging data between two low-flying satellites after the imminent end of the original GRACE mission. At the same time, it will carry an experimental Laser Ranging Interferometer (LRI), intended as a technology demonstrator, but also to deliver improved ranging data including new channels for the line-of-sight alignment. The LRI is a collaboration between partners in the US (NASA/JPL) and Germany (AEI, GFZ, DLR, and industry), and will be the first inter-spacecraft laser interferometer when launched in 2017. Within the US-German GRACE Follow-on project, AEI formally plays the role of “Instrument Manager” and “Instrument Scientist” for the LRI, with corresponding counterparts in NASA. GFZ takes the project lead on the German side and AEI is leading the interferometry.

LISA Pathfinder

LISA Pathfinder flight hardware is finished with minor exceptions and the mission is, after a few delays, now on track for a launch in 2015. After intense phases of testing the interferometry payload flight hardware at the AEI, we are now preparing for the operations phase, developing the data analysis software and practicing flight operations.

In the LISA context, we are experimentally studying all aspects of the interferometry, with particular interest in fundamental physical noise sources. We are now also developing the phase readout capability including ranging and data transmission that previously was a NASA-provided item.

GEO600

GEO600 has gone through several periods of Astrowatch data taking and upgrading into GEO-HF. The most important addition was the introduction of squeezed light into the detector. GEO600 is now the first and only large laser interferometer in the world to routinely use squeezed light, making use of the large expertise at the AEI, where we are holding the world record in squeezing of light since 2008. The last joint international data taking run was the VSR4/S6e run between

Virgo and GEO600 in June to August 2011 with both observatories at roughly equal sensitivity in the kHz range. LIGO and Virgo are now down for upgrading and GEO600 will remain in Astrowatch data taking mode, only occasionally interrupted for service and upgrading, until 2015.

Advanced LIGO and ET

Our work towards future gravitational wave observatories is well on track. We have delivered and installed the 35 W lasers for Enhanced LIGO and the 200 W systems for Advanced LIGO. In a collaboration with DESY in Hamburg, our high-power lasers are also finding application in "Light shining through wall" experiments at DESY. A Design Study for the third generation gravitational wave observatory ET (the Einstein Telescope), funded by the European Community (EC), was conducted from 2008 to 2011, with the AEI playing a leading role. Non-classical interferometry and diffractive optics are being studied for next generation observatories. The non-classical light experiments have now been extended to study quantum opto-mechanical effects and applications in Einstein-Podolsky-Rosen entanglement. Our new 10m prototype interferometer is making good progress and will soon be ready for first thermal noise experiments before attempting Quantum Non-Demolition measurements.

Graduate students

The cooperation with the Leibniz Universität Hannover is going well. Currently, 43 graduate students are working in the laser interferometry division. All of them are members of our International Max Planck Research School (IMPRS) for Gravitational Wave Astronomy and all of them are registered as doctoral students at the Leibniz Universität. Most of them are or were financially supported by the Sonderforschungsbereich SFB TR7 "Gravitational Wave Astronomy", the HALOSTAR Graduate School, the European Graduate College, the QUEST Cluster, the IMPRS on Gravitational Astronomy, or other grants from ESA, DLR, BMBF and the European Community.

Karsten Danzmann

Observational Relativity and Cosmology

This AEI Hannover Division was started in 2007, and its central theme remains unchanged. Our main goal is to play a significant role in the data analysis and discovery process associated with the first direct gravitational-wave observations from ground-based detectors. The consensus view is that these first detections will take place later this decade.

Computing systems

An essential tool for large-scale data analysis is computing systems. The Division operates the Atlas computing cluster [1] for this purpose. Atlas is the largest cluster in the world primarily designed and employed for gravitational-wave data analysis, and is used to store and analyze existing data and to develop new algorithms and methods. Over the past three years, Atlas has delivered close to 200 million Central Processor Unit (CPU) core-hours of computing for the AEI and for the LIGO and VIRGO Scientific Collaborations. These have been used for many of the analyses of data from the LIGO S5 and S6 science runs: the most sensitive gravitational wave searches ever undertaken.

In 2010/11, as we expanded our storage systems past 4 Petabytes, and added more than 250 Graphics Processor Unit (GPU) cards and better networking, Atlas saturated the available space and power. We then embarked on the design and construction process to build-out the data facility to the originally envisioned 1000kW/4000 rack-units scale. The construction was completed early in 2013, and the full 1000kW of power and cooling should become available in spring 2013, when three defective chiller units from the first construction phase are replaced. We'll then begin the "leapfrog" process of first constructing a new cluster, and then gradually decommissioning the previous one. The computer systems we are now procuring might well be the ones on which we will make the first direct gravitational-wave detections.

Unfortunately the "golden age of computing", where compute performance at fixed cost doubled every 18 months, has come to an end. These days, the most cost-effective way to do scientific computing is with GPU cards. These offer an order-of-magnitude larger performance/price ratio than CPUs, but can be difficult to program. During the past two years we have done extensive work developing GPU versions of some of our existing search codes. Some of these codes are close to a factor of one hundred faster than their single-CPU-core counterparts [2]. In 2014/15, when these search codes are more mature and the technology market leaders are more clearly established, we expect to build-out the GPU side of the cluster.

LIGO data analysis

The expectations are that in 2017-20 the LIGO instruments in the USA (possibly in conjunction with the Virgo detector in Italy) will detect at least a handful of binary inspiral events, from pairs of neutron stars and/or black holes [3]. But the nature of the data analysis has evolved; the tools used to analyze data from the first-generation interferometers are no longer sufficient. On the experimental side, the main change is the increased low-frequency sensitivity of the advanced detectors. In contrast with the initial generation, where the signals remained in the detector band for only a few seconds, in the second-generation instruments the signals can last up to 30 minutes. In both analysis and theory, there have been advances in understanding the waveforms from systems with spins, low latency analyses, and improvements in methods for the most sensitive "fully coherent" analyses. These changes significantly increase the computing cost. I am optimistic that our work on coherent search techniques and improved methods to find spinning systems, together with the increase in computer power we will achieve when these codes run efficiently on GPUs, will enable AEI to play a key role in these first discoveries. This is described in detail in the accompanying report by Dr. Badri Krishnan.

Because the first gravitational-wave detections are likely to be very weak, it is important to search for corresponding signals from other types of detectors. Moreover, the methods used for such searches need to be robust enough that they can detect signals from systems where either the theory has not gotten it correct, and the model waveforms are wrong, or where numerical and approximation methods have not yet been able to provide a numerical model. AEI scientists have been assisting in the further development and characterization of the burst search pipelines, as well as leading the all-sky searches for burst sources in the LIGO S6 data set [4].

Einstein@Home

Einstein@Home is a volunteer distributed computing system with more than 350,000 contributors worldwide [1]. In January 2013, for the first time, it exceeded 1 Petaflop of compute-power, putting it among the fastest 25 computer systems worldwide. The AEI continues to be a major contributor to development and operations work of Einstein@Home, working together with US National Science Foundation funded efforts at the UW Milwaukee, UC Berkeley, and Cornell.

Einstein@Home continues to run most computationally-expensive search of the LIGO Scientific Collaboration. This search, for the continuous gravitational waves (CW) that would be emitted by the "bumps" on rapidly rotating neutron star, relies on methods developed and perfected at the AEI over the past 15 years. The results of a full search through the LIGO S5/S6 data have just been published in Physical Review [5]. While the main result is an upper-limit (no signals were found) the search is notable because it is the first time a hierarchical coherent + decoherent method has been used. An important advance is the AEI development of an automated "zoom and refine" follow-up that will enable Einstein@Home host machines to carry out a full follow-up on candidate signals found in the first stage, returning only candidates whose waveform follows the expected modulation pattern in a year or more of data [6]. By permitting weaker candidates to be followed-up, this will greatly increase the sensitivity of a search. It will also make it simpler, since we don't expect instrumental or environmental noise sources to mimic these signals over such long time baselines. These and other advances in the search for CW signals, are described in the accompanying report by Papa and Prix.

An interesting "side-product" of the work in my division is our continued success of applying gravitational-wave data analysis methods and technology to search for weak electromagnetic signals [7]. For example, during the past 2 ½ years, Einstein@Home has found close to fifty new pulsars, including 24 in archival data [8] from the Parkes Multibeam Pulsar Survey, carried out in the late 1990s. These, include exotic systems such as millisecond pulsars in binary systems, and a disrupted recycled pulsar.

Applying these new data analysis methods to data from the Large Area Telescope on board the Fermi Satellite has discovered more than ten new gamma-ray pulsars [9]. The increased sensitivity afforded by these methods has permitted the discovery of the weakest gamma-ray pulsars found in a blind search, as well as the first-ever discovery of a millisecond pulsar through its gamma-ray emissions. The latter system, a "black widow" system, is also the most compact binary system ever found, with a record-breaking orbital period of just 93 minutes [10].

While this work is a "sideline", it brings some important benefits. Obviously it is very satisfying to prove that the new methods work as promised and can discovery new astronomical systems. The gain of a 20% sensitivity-increase is not purely "academic" when it permits new and interesting electromagnetic signals to be found in archival data! It also brings us into closer working contact with experts in astronomy and astrophysics; for example we have become close collaborators with Kramer's group at the MPI for Radio Astronomy in Bonn. This work is also a useful learning tool. For example, since the electromagnetic search codes are significantly simpler, they were ported to GPUs before the gravitational-wave search codes were.

To summarize, the division consists of a world-class data analysis and computing group with outstanding computing systems, playing a central role in analysis of data from the global gravitational-wave detector network.

Bruce Allen

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Duality and Integrable Structures

This Max Planck Research Group focused on dualities between gauge and string theories and extended symmetry structures which have recently been identified in this context. The aim was to deepen our understanding of these models on which classical and modern particle physics is founded. The group was established in August 2006 under the leadership of Niklas Beisert. It ended in September 2011 with the group leader taking up an associate professorship at ETH Zurich. During the final two years the group hosted 4 postdoc researchers and 3 doctoral students. The group was mainly funded by the Max Planck Society with additional support by the DFG (SFB647) and GIF (project 962).

Main research areas

Four-dimensional gauge theories provide the theoretical foundation for the standard model of particle physics. Direct computations in these models follow simple and well-defined rules outlined by Feynman. Unfortunately, applying them represents a formidable combinatorial and calculational problem thus putting an upper limit to the precision of feasible computations. Research in this group centres on two methods to improve the situation: dualities and symmetries.

A duality implies an alternative description of some physical model giving insights into regions which are practically inaccessible in the original description. The most actively discussed duality in theoretical particle physics is the AdS/CFT conjecture: It proposes the exact equivalence of particular pairs of gauge and string theories. The duality has far-reaching implications due to the fact that a string theory always contains gravitational interactions. Consequently conventional gauge theories may provide a consistent quantisation of gravitational models, and new insights into the long-standing problem of formulating quantum gravity theories can be gained. Conversely, hard to compute strong-coupling phenomena in gauge theories can be expressed through straight-forward calculations in string theory. This duality is also one of the subjects investigated in the Quantum Gravity & Unified Theories division of the institute with which close collaborations exist.

Symmetries, on the other hand, relate and constrain the observables of the model. An extremely rich hidden symmetry has been identified in the study of the primary pair of AdS/CFT dual models: Maximally supersymmetric gauge theory and strings on the so-called $AdS_5{\times}S^5$ background. This symmetry is called integrability and it constrains the observables to an extent such that full determination becomes very efficient. For example, a specialised method developed in the context of condensed matter theory, the so-called Bethe ansatz, opens a window to the exact spectrum at finite coupling strength. A goal of the research group was to develop further and apply these integrable structures. We have also deepened these exciting connections between condensed matter and particle physics.

Activities

The subject of AdS/CFT integrability has developed rapidly and has produced many branches. Although several reviews were written, the recent ones became more and more specialised. Yet, there was an increasing need for an up-to-date global review, especially for junior scientists wishing to enter the subject. Therefore I invited around 20 colleagues to write short accounts of particular aspects which were carefully chosen towards a complete coverage of the overall subject. An introductory chapter ties the individual contributions together and puts them into a bigger context. The review appeared as a special issue of Lett. Math. Phys. (volume 99) of over 500 pages. It was received very well and perceived by many as a prototype of a novel kind of review. This success is owed to the large amount of coordination between the authors via internet.

Research Highlights

A central object for all Bethe Ansätze in the AdS/CFT context is the worldsheet S-matrix. We continued our studies of this S-matrix and its quantum-deformation: We derived a peculiar affine Lie bialgebra to describe the classical limit of the S-matrix. We then promoted it to a quantum affine algebra. This infinite algebra allowed us to explicitly derive the S-matrix for (infinitely many) bound states which is relevant to the formulation of the Thermodynamic Bethe Ansatz (TBA). Our results are not only relevant to AdS/CFT, in particular to the Pohlmeyer reduction of string theory. In a condensed matter context they equally apply to an integrable deformation of the one-dimensional Hubbard model.

Another question that we have addressed is to which extent the methods of integrability can be extended to field theories with less (super)symmetry. There are two convenient ways of breaking some symmetry while retaining integrability: deforming the superpotential or orbifolding (β- or γ-deformed theories). We have studied the effect of this symmetry breaking on the Thermodynamic Bethe Ansatz which manifests in the appearance of chemical potentials. We then applied the TBA to the spectral problem.

We also continued our work on conformal symmetries and integrability for the spacetime S-matrix of AdS/CFT. We investigated symmetry breaking effects at loop level and we proposed a curious extension of the Yangian symmetry related to integrability. Many of these results are reviewed in our contribution to a special issue of J. Phys. A on scattering amplitudes.

In collaboration with the MPI for Physics and other institutions, we investigated counterterms in N=8 supergravity. This remarkable model was previously observed to be free from divergences at four loops raising hopes that a perturbatively finite conventional quantum gravity model may exist. We applied methods of superalgebra representations, string scattering and computerised combinatorics to the enumeration of duality-invariant counterterms and found the first consistent counterterm at 7 loops. On the one hand, it confirms and extends the earlier results (also obtained by members of the Quantum Gravity and Unified Theories division). On the other hand, the finiteness is likely to break down at this order on general grounds. Whether this is indeed the case requires further study, either by elaborate explicit calculations or through novel insights.

Niklas Beisert

Canonical and Covariant Dynamics of Quantum Gravity

This Max Planck Research Group (MPRG) funded by the Max Planck Society and led by Bianca Dittrich started in 2009 and was fully funded from September 2009 to December 2011. In January 2012 the group leader took on a faculty position at Perimeter Institute for Theoretical Physics (PI) in Canada, but stayed part time associated to the Albert Einstein Institute until December 2012.

Quantum gravity aims at understanding the central objects of physics, namely space and time. It unifies Einstein's vision of space-time as a dynamical object with the realization that fundamental physics and hence space-time has to be quantum.

This research group focuses on the construction and examination of quantum gravity models as well as the extraction of predictions from these models.

Main research areas

Quantum gravity research provides models for the quantum structures underlying space-time. A number of such models have been developed in the last years, typically describing space-time, and the dynamics of quantum gravity, as arising from some microscopic constituents.

The key and most pressing issue for most of these quantum gravity approaches is to show how macroscopic space-time and the dynamics of gravity arise on larger scales. This is comparable to showing how condensed matter phases arise from microscopic constituents. However, in the case of quantum gravity there are a number of conceptual challenges as well as technical complexities to overcome.

On the conceptual side we deal with a theory without a canonical notion of energy. Similarly a notion of scale is not included from the outside but has to arise from the dynamics of the theory. This prevents the naive application of e.g. standard coarse graining and renormalization techniques to many quantum gravity models. Such techniques are however essential for the investigation of the large scale properties of a given system.

Finally, gravity is a very special interaction as its fundamental symmetry is given by diffeomorphism symmetry. This gauge symmetry is special as it interchanges space-time points and thus leads to non-local properties of the theory. Furthermore the notion of diffeomorphism symmetry in the discrete was debated for some time. Research in this group put forward a notion that reflects the action of diffeomorphism symmetry in the continuum in interchanging space-time points. This turns diffeomorphism symmetry into a very powerful symmetry in the discrete, being equivalent to discretization (i.e. regularization) independence. Generically quantum gravity models break this symmetry however and the issue is now to show that this symmetry is regained in the continuum limit.

On the technical side, for instance spin foam models, are much more intricate models than lattice gauge theories for quantum chromodynamics. This explains why so far the macroscopic phases described by these models are not known yet.

Work in this group provided a conceptual basis to investigate the continuum limit of quantum gravity models, in particular with regard to challenges posed by diffeomorphism symmetry and the notion of an dynamically emerging scale.

Furthermore techniques have been introduced and adapted from condensed matter in order to investigate the continuum limit and possible phases of spin foam models and first numerical investigations have been performed.

Research in this group involved not only spin foam models and loop quantum gravity, but also a number of different quantum gravity scenarios, like asymptotic safety, tensor models, group field theory, supersymmetric theories and loop quantum cosmology. The efforts in these approaches are to understand better the dynamics of these different scenarios, to show consistency of the given model and to extract predictions, in particular with regard to cosmological observations.

Workshops

Members of this group were involved in the organization of three workshops: "Quantum Gravity in Germany 2010" at the Max Planck Institute for Complex Systems in Dresden, "Spacetime as a statistical system" at the AEI and "Exploring Quantum Spacetime" at the Bad Honnef Physics Center. The first workshop brought researchers in quantum gravity from Germany together in order to enhance collaborations. We will report on the second workshop elsewhere (see chapter "events"). At the "Exploring Quantum Spacetime" international experts presented different quantum gravity approaches and very fruitfully exchanged viewpoints on the different pictures of spacetimes that emerge from these approaches.

Bianca Dittrich

Microscopic Quantum Structure and Dynamics of Spacetime

This Independent Research Group, led by Daniele Oriti, is funded by the A. von Humboldt Foundation, through a Sofja Kovalevskaja Prize. It has started its activities in January 2009 and has a planned duration of five years (thus until December 2013).

The research of the group focuses on Quantum Gravity, that is the construction of a theory of gravity in which space and time are described as fundamentally quantum systems, valid at all scales of distances and energies, but reducing to General Relativity in the semiclassical and large scale approximation. A theory of Quantum Gravity would also be needed to describe the universe as a whole, including its beginning and possible end, and could shed light on cosmological puzzles like the nature of dark matter and dark energy, and on the fate of Lorentz and Poincaré symmetry at higher energies.

Our group works in the context of several recent approaches to Quantum Gravity, in particular Group Field Theories, Loop Quantum Gravity, Spin Foam Models, Simplicial Quantum Gravity, all closely related to each other. These approaches do not assume a fixed background spacetime structure, but deal with how spacetime itself (in both its geometric and topological properties) is dynamically generated from some basic building blocks. In particular, Group Field Theories (GFT) are field theories on group manifolds which have similar quantum states as in Loop Quantum Gravity, and Feynman diagrams having the combinatorial structure of d-dimensional simplicial complexes (but this can be generalized), interpreted as discrete spacetimes of arbitrary topology. Each of them is weighted by a Feynman amplitude that can be written as spin foam model or equivalently as simplicial gravity path integral. So GFTs potentially represent a truly unified framework for both loop quantum gravity (of which they represent a 2nd quantized re-formulation) and simplicial approaches. The GFT formalism also allows a more direct use of quantum field theory concepts and methods, e.g. renormalization, to the study of the dynamics of quantum space. All these approaches have obtained important results but still present many aspects in need for a better understanding, and a good part of our research concerns precisely their formal development, and the clarification of the links between them.

The main question that all these approaches to quantum gravity have to answer is: how does the continuum spacetime we experience at low energies and macroscopic scales emerge from its fundamentally discrete building blocks, and end up being described by General Relativity? It is one of our main research objectives to answer this question in a rigorous way. In doing so, we also aim at producing effective descriptions of the fundamental quantum dynamics of space and matter, which could be used to predict new phenomena and quantum gravity corrections to the large scale cosmological dynamics, and shed light onto the early Universe and the true nature of the Big Bang.

The general vision is that *the very description of spacetime as a continuum fails at very short distances and very high energies*, and should be dropped together with the General Relativistic description of its dynamics. *Spacetime disappears or dissolves in the microscopic, quantum domain*. Instead, spacetime and its geometry are replaced, at the microscopic level, by discrete, pre-geometric degrees of freedom, of combinatorial and algebraic nature. *Continuum space, time and geometry would be emergent concepts* at macroscopic scales, whose emergence is the result of a *dynamical process of the fundamental degrees of freedom.*

One main hypothesis of our work is that what we call *continuum spacetime is but a phase of an underlying GFT system*. It would correspond to a *collective, emergent configuration of a large number of quantum gravity building blocks, possibly after a phase transition*. Emergence of spacetime becomes a problem akin to the emergence of large scale, collective behaviour from atoms in condensed matter theory, and it should be studied using the same language and methods. One can put forward the more specific hypothesis that *spacetime is the* *result of a condensation of its microscopic GFT building blocks turning it in a very peculiar type of quantum fluid*, like Bose-Einstein condensates. General Relativity would then correspond to (or be extracted from) the (Gross-Pitaevskii-like) hydrodynamics of the GFT condensate, in a further *classical* approximation following the *continuum* (thermodynamic) limit of the *quantum* GFT system. In the above picture, the GFT models play the same role as the microscopic quantum field theories for the atoms play in any condensed matter system in the real world: the "fundamental" theories from which macroscopic properties of the given physical system could, at least in principle, be derived.

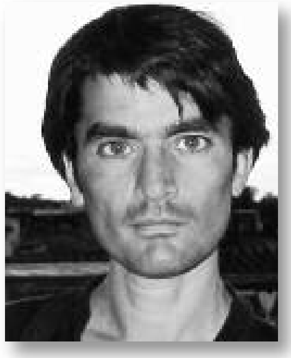
One can put forward a further hypothesis and identify the process (phase transition) of quantum spacetime condensation with a known, even if not understood, physical process: the big bang singularity. We identify the coming of the universe, i.e. of space and time, into being with the physical condensation of the spacetime atoms. Literally, there was no space and not time before this condensation happened. We call the spacetime condensation *geometrogenesis*.

The research of the group, alongside other research activities, aims at realizing the above vision and is organized along three main directions:

- The development of compelling group field theory models of the quantum dynamics of space, in particular the definition of convincing spin foam amplitudes (and thus, 2nd quantized LQG dynamics) for 4d quantum gravity (coupled to matter fields), and the realization of an explicit duality, within the GFT approach, between spin foam models and simplicial gravity path integrals. This implies understanding in detail how "seeds" of geometric structures are encoded in the GFT quantum states and amplitudes, and also analyzing the symmetries characterizing these models, in particular the discrete analogue of diffeomorphism symmetry, which is the symmetry characterizing gravitational theories.

- The application of methods from quantum field theory, statistical mechanics and condensed matter physics to the analysis of GFT models, in particular concerning their renormalizability, the control of the sum over spacetime topologies they define, and their associated critical phenomena and phase structure, identifying a phase of GFTs that can be described in terms of smooth spacetime and geometry. Here a main research activity has been the study of the scaling behaviour of interesting GFT models (i.e. understanding what type of discrete spacetimes they favor at different scales) and establishing the renormalizability of GFT models for gravity, thus ensuring that they define proper quantum field theories. Another has been the study of phase transitions in both group field theories and the related, but simpler tensor models (characterized by the same Feynman diagrams but simpler amplitudes).

- The extraction, again using condensed matter and QFT techniques, of effective dynamics of geometry and matter in a semiclassical, continuum approximation, from fundamental quantum gravity models. We have focused on two sub-directions. The first was the study of quantum field theories on non-commutative spaces, which generically exhibit quantum gravity-induced deformations of dispersion relations and scattering thresholds. The second concerned the extraction of cosmological dynamics from quantum gravity (GFT) models, which can offer a new understanding of the early Universe, and indicate which quantum gravity effects play a role close to the Big Bang. In particular, we have worked on studying GFT condensates and shown that they can be indeed interpreted as cosmological spacetimes, and then extracted an effective dynamics for such spacetime, using the same techniques that are used for real Bose condensates and quantum fluids.



Daniele Oriti

String Cosmology

This research group is led by Jean-Luc Lehners and is funded via a Starting Grant from the European Research Council (Grant 256994: "String Cosmology and Observational Signatures"). The group was created in December 2010 and consists of the principal investigator, three postdoctoral researchers, one doctoral student and a master's degree student.

The focus of the group is on the cosmology of the very early universe, and on the interrelationship of cosmology and string theory. This implies two main work methods: on the one hand to use ideas from string theory to construct cosmological models, and on the other hand to try to embed existing models in string theory. The goal of the group is to use this kind of cross-fertilization to make progress in our understanding of the basic cosmological questions: what happened at the big bang? Was the big bang the beginning of our universe? If not, to what extent are the current properties of the universe dependent on what came before the big bang? Is our universe unique? If not, where in the multiverse are we likely to live?

Main areas of scientific work

The way in which string theory provides a global framework for cosmology is via the (still hypothetical) notion of a landscape of vacua. Although a full non-perturbative understanding of string theory still remains elusive, there are numerous indications that string theory allows for a large number of solutions corresponding to possible universes with different numbers of large spatial dimensions and different effective physical laws in these large dimensions. The way in which the vacuum energy of these configurations depends on the parameters that are considered (such as the shape of the compactification manifold, or the values of generalized electromagnetic fields) can be thought of as a "landscape" where the bottoms of valleys correspond to the vacua themselves, and the mountains in between represent the energy barriers that separate such vacua. If at least one vacuum is a sufficiently long-lived de Sitter universe, then eternal inflation will take place. This metastable de Sitter universe will continue expanding forever, creating more and more space as it does so. There is then a tiny, but non-zero, probability that a region of space can perform a quantum jump to a different vacuum of string theory – by tunneling through a mountain in the landscape. Even though such processes of quantum tunneling are exceedingly rare, given that the initially considered de Sitter vacuum keeps expanding forever, all possible such quantum transitions will necessarily take place. Moreover, if the newly created universes also expand for a long time, then inside these universes other such quantum tunneling events can occur. In this way all possible universes will be created inside of each other, and all mathematically possible cosmologies become a physical reality. In this framework, it is of crucial importance to have an understanding of three things, namely

- whether the framework itself of having a landscape plus quantum tunneling makes sense.
- which types of cosmologies are allowed in string theory and what their predictions for cosmological observations are. This is of crucial importance in order to be able to confront any theoretical bias with upcoming observations. Work on this question is also relevant independently of whether or not the multiverse framework makes sense. For this reason, it is to this question that the majority of the work of the group is dedicated.
- which type of universe the theory predicts to be the most likely.

These questions form the basic themes of the research group, and over the last two years we have made progress on various aspects of these questions, as will be described next.

Research overview

Above, three key questions were identified as being the "leitmotiv" of research in the group. They will be addressed in turn.
As described above, new universes can arise inside of existing universes when a region of space performs a quantum jump to a different vacuum of the theory. Such tunneling events are described by so-called "instanton" solutions. However, in order for the interpretation of these solutions as mediating the decay of one vacuum into another to hold up, it is necessary that the fluctuations around these instanton solutions exhibit one unstable fluctuation mode. Only then does the tunneling/decay interpretation make sense. We have studied this question in detail for certain shapes of potential barriers – see the contribution by Lorenzo Battarra in this report for a description of the results of this analysis.

Regarding question 2 above, it is of paramount importance to find out which kinds of cosmologies are allowed by fundamental physics, and in particular by string theory. Since the known string theories can typically be approximated by a supergravity theory in many cases of interest, a first step is to see what kinds of cosmologies are allowed in supergravity. It is to this question that a large part of our recent work has been dedicated. Together with Michael Koehn and Burt Ovrut of the University of Pennsylvania, we have developed a method to construct N=1 supergravity extensions of higher-derivative scalar field theories [1]. The non-supersymmetric versions of these theories are used in many extensions of the simplest cosmological models – in particular, they are used in higher-derivative Dirac-Born-Infeld (DBI) inflation, in models based on Galileons and in models of non-singular cosmic bounces. The supersymmetric extensions of these theories have led to the discovery of a number of unforeseen effects: first of all, these theories split up into several inequivalent branches, with only one branch being related to the previously known supergravity theories. The relationship between these branches is a little mysterious, and we are currently investigating it. The second feature is that in the most interesting regime, where the higher derivative kinetic terms become important, the potential necessarily becomes negative. Thus, obtaining models of inflation, where the potential needs to be positive, is challenging for such models. Nevertheless, we have discovered a way to overcome this obstacle by coupling the new higher-derivative theory to a standard canonical theory, and in so doing we have constructed the first working model of DBI inflation in supergravity [2]. This is an important step, as most string-theory-inspired cosmological models involve the motion of branes whose dynamics is described precisely by such a DBI action. Third, we have recently demonstrated that the currently fashionable Galileon models, when extended to supersymmetry, are catastrophically unstable as they contain so-called "ghosts" (which can render the energy arbitrarily negative) [3]. This result indicates that, contrary to expectations, certain Galileon theories cannot be expected to have a special status in string theory, in contrast to the DBI action for example. Lastly, this program has enabled us to work out a supergravitational version of a key ingredient of all models of non-singular bounces [4]. In such models, just before the big bang the universe contracts to a finite size and then starts re-expanding in a smooth fashion without a big crunch-type singularity. This bounce is then identified with the big bang. What we have done is to model the bounce phase in supergravity, and, contrary to some expectations, we have demonstrated that no problems appear when doing so. We now plan to apply this result to the construction of a full-fledged non-singular supergravitational cosmological model in the near future.

Furthermore, it is crucial to understand to what extent cosmological models can be distinguished by data, and to what extent they can lead to degeneracies in their predictions. Rhiannon Gwyn has worked on these issues, and together with Markus Rummel and Alexander Westphal of the University of Hamburg, she has shown that some characteristic signatures of non-canonical (DBI-like) inflation can in fact be mimicked by standard canonical inflation in the presence of a specific potential containing summed modulations [5]. This work is important in that it shows a clear example of what degeneracies one has to keep in mind in interpreting forthcoming observational data from the Planck satellite.

The last question in the previous section, namely where in a multiverse we might be likely to live, is notoriously hard to tackle. This is because the quantum tunneling events described above never end, and lead to the appearance of an infinite number of universes, many of which grow indefinitely over time. The problem of dealing with these infinities is known as the "measure" problem, and its resolution is crucial for making predictions in a multiverse context. J.-L. Lehners, in collaboration with Matt Johnson of the Perimeter Institute, has recently made progress on this issue by pointing out the importance of including universes that undergo cycles of evolution [6]. In this work, two results of interest emerged: first, that cyclic universes by themselves are much more immune to the measure problem than inflation-

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ary universes because in the cyclic universe all phases of evolution proceed at a slower expansion rate than the phase where life can form. Conversely, in inflationary models the inflationary phase proceeds at a much higher expansion rate than during the habitable phase, and because of this such models are unstable to large quantum fluctuations, which are at the root of the measure problem. The second result of this work is that in a multiverse where both inflationary and cyclic universes coexist, under many circumstances cyclic universes are preferred [7]. This result suggests a new picture of a diverse multiverse, where pocket universes containing a wide variety of cosmologies all play a significant role. Thus, diversity should not be regarded as the exception, but rather as the norm – both on Earth and in the multiverse!

Jean-Luc Lehners

Geometric Measure Theory

The Max Planck research group "Geometric Measure Theory", lead by the author, started at 1 April 2012. It is based on a cooperation of the Max Planck Society with the University of Potsdam. In particular, the jointly appointed leader of the research group is Professor for Geometric Analysis at the University of Potsdam and teaches two hours per week each term. Also, the group may contain people of any level between Bachelor student and Junior Scientist (postdoc). The members of the group currently (April 2013) are Sławomir Kolasiński (Junior Scientist), Jeremias Herrmann (PhD student) and Christian Scharrer (Bachelor student).

Geometric Measure Theory is a mathematical language which allows to describe very general surfaces of arbitrary dimension and codimension in flat as well as curved spaces. (Codimension is defined to be the dimension of the space minus the dimension of the surface.) The term surface stems from the familiar notion of two-dimensional surfaces in flat three-dimensional space but it may refer to a five-dimensional object in curved seven-dimensional space just as well; here the codimension is two. The strength of Geometric Measure Theory lies in the fact that the surfaces described may be very general. That means that they do not need to be regular everywhere but possibly additionally contain all sorts of so-called singularities (edges, cusps, and many more complex local structures which are not nice and smooth). Geometric Measure Theory is applied for example in Geometric Analysis, a part of mathematics dealing with problems which involve geometric objects governed by partial differential equations. Moreover, many questions in Einstein's General Relativity necessitate the study of such geometric objects, for instance of general surfaces in curved space-time. Therefore Geometric Measure Theory, Geometric Analysis and General Relativity are connected in a natural way; the two latter topics being the focus of the division "Geometric Analysis and Gravitation" currently led by Hermann Nicolai on an interim basis. In fact, since several decades results and methods originating from Geometric Measure Theory have played an important role in Geometric Analysis and the mathematical treatment of General Relativity.

This is witnessed by the proof of the positive mass theorem by Richard Schoen and Shing Tung Yau [1], the proof of the Riemannian Penrose inequality by Gerhard Huisken and Tom Ilmanen [2] or the proof of the Willmore conjecture by Fernando Marques and André Neves [3]. In all of these cases a resolution of a fundamental question was achieved using results and methods from Geometric Measure Theory. The latter had already existed for one or two decades but had to be employed and combined with other techniques in a new and intricate way. The research group at the Albert Einstein Institute correspondingly has a twofold aim. Firstly, contributing to the supply of new results and methods from Geometric Measure Theory. Secondly, contributing to a faster incooperation of results and methods from Geometric Measure Theory into Geometric Analysis and General Relativity.

Main areas of scientific work

A common theme of the research group are studies of the regularity properties of the afore-mentioned, very general surfaces of arbitrary dimension and codimension in flat as well as curved spaces. The classical aim of such studies is to determine a set of conditions which rules out the existence or puts restrictions on the size of singularities. To illustrate the relevant conditions, consider the so-called Plateau problem of finding the surface minimising area amongst all surfaces with a given boundary. Notice that this includes for example the case of five-dimensional surfaces having a given four-dimensional boundary in curved seven-dimensional space; area then refers to five-dimensional area in seven-dimensional space. More generally, one considers surfaces which are merely stationary (the derivative of the area functional vanishes at the surface) or stable (the surface is stationary and the second derivative of the area functional is nonnegative at the surface). Clearly, the minimising condition implies the stability condition which in turn implies the stationarity condition.

In order to put the new results into perspective, the central estimates on the size of the singular set of such surfaces satisfying these conditions will be described. In the minimising case, precise dimension estimates on the singular set are available. If the surface is merely stationary extremely little is known of its structure – not even whether it needs to be regular almost everywhere, i.e. whether for example a five-dimensional surface cannot have singularities occupying a set of positive five-dimensional measure. In fact, the latter is a central open question of the field. In the special case of stable hypersurfaces (i.e. surfaces with codimension one) substantial progress in this direction has been made by Neshan Wickramasekera [4]. However, returning to the stationary case, a result of Reiner Schätzle also concerning hypersurfaces at least yields a notion of curvature (second fundamental form) almost everywhere using the concept of second order rectifiability [5]. A priori, the surfaces considered are so general that one can make barely sense of tangent planes but not of the rate of change of tangent planes as measured by curvature.

In [6, Theorem 4.8], the author then has established second order rectifiability of the surface under a condition substantially weaker than stationarity. Nevertheless, in higher codimension, the result is new even in the stationary case. This result serves as a starting point for several projects of the research group.

For instance, having a notion of curvature at hand, one can now investigate whether a classical integral formula for smooth hypersurfaces involving curvature extends to the class of singular surfaces considered. In fact, this is exactly what was obtained by the author for singular hypersurfaces of dimension at least two under a natural condition weaker than stationarity, see [7, Theorem 3]. This result is again new even in the stationary case. An immediate consequence of it is the extension of a certain sharp geometric inequality to this class of surfaces, see [7, Corollary 4]. Also, in establishing the integral formula, results have been obtained by the author which are important also in less singular settings often present in Geometric Analysis. This project gives an example of the close connection of the Geometric Measure Theory done in the group with Geometric Analysis.

Moreover, Sławomir Kolasiński has studied studied several classes of possibly singular surfaces defined mainly in terms of the finiteness of certain curvature energies. These classes are related to the study of variational problems involving curvature rather than area. In this framework it is natural to consider different – less local – concepts of curvature than the second fundamental form. In the previously considered classes the structural properties directly entailed by the definition are by now well described and the research reported above concerned the additional regularity that surfaces possess which are a solution to a variational problem. In the present case, the structural properties are significantly less understood. An important contribution in this direction has been made by Sławomir Kolasiński and his collaborators. Namely, they were able to characterise the surfaces in a considerable range of classes in terms of well understood function spaces yielding in particular a link to the concept of second order rectifiability, see [8]. This result is valid in arbitrary dimension and codimension.

Finally, also the regularity questions currently investigated by Jeremias Herrmann in his PhD thesis are likely to be connected to the concept of second order rectifiability.

Selected events

In 2012, jointly with Gerhard Huisken and Neshan Wickramasekera, the author organised a conference on Geometric Measure Theory at the Albert Einstein Institute from July 2nd to 4th (see the separate report). The conference was preceeded by IMPRS lecture days on the same topic for PhD students where Michael Eichmair (ETH Zürich), Leon Simon (Stanford University) and Neshan Wickramasekera (Cambridge University) were external speakers.

Ulrich Menne

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Developments in Axisymmetric Gravity

When a subject is too complex, it is most natural to reduce it by imposing restrictions, delimit smaller areas, and then remove them progressively until the whole is understood. The idea is to design a division in parts of similar difficulty but one that we are capable of analyzing. All at once the whole may be difficult but not when we think it in appropriate sectors. This reductionism occurs most often spontaneously when the subject is too big that there is no agreement or simply no possibility of agreement among scientists on how to make a convenient partition. Under such circumstances people from different backgrounds, different places and sometimes at different epochs, chose what they believe is more interesting and more convenient to do. The subject is then investigated a bit chaotically, what carries obvious advantages and disadvantages. Axisymmetric Gravity enjoys a bit of everything.

Celestial bodies with the simplest shapes are those spherically symmetric. Such objects look the same when we rotate them in any direction. Axisymmetric bodies instead have the next degree of complexity. They look the same when we rotate them only through a particular axis, the *symmetry axis*. A soccer ball is spherically symmetric, but pears or eggs are just axially symmetric (roughly). Axisymmetric gravitational systems are, by definition, ones having an axis of symmetry. They can be for instance stars, pulsars, galaxies, black holes or gravitational waves. These systems are obviously important in the current international context of research. Its complexity balances somewhere between that of the whole Einstein's theory and that of very reduced systems considered in the past.

Historically, mathematical studies of General Relativity were divided according to their mathematical complexity (this can be good or bad, but it is undeniably human). It turns out that the more symmetries a system has, the simpler it is to analyze. For this reason spherically symmetric systems are among the simplest ones and the more investigated. On the other hand axisymmetric systems are more complex and require also greater mathematical complexity. Let us bring some examples. Spherically symmetric (vacuum) black holes there are only of one type, the *Schwarzschild black holes* and are parametrized simply by their mass. They were discovered by K. Schwarzschild in 1915 just a few months after Einstein's explanation of Mercury's perihelion and before the definitive version of General Relativity appeared (!). For many reasons, Schwarzschild's article is a historical landmark. But it took almost fifty years until rotating axisymmetric black holes were found by R. Kerr in 1963 and are parametrized by their mass and angular momentum. Kerr's achievement is another landmark (here it does not matter how mathematically simple things look from our contemporary eyes).

The story ends with the proof that stationary-axisymmetric single black holes are known to be just of the Kerr type. This is the result of many years of research, with many highlights, but I will not enter into that here.

But what about two black holes aligned along a symmetry axis (as depicted in Figure 1)? If two aligned black holes were to spin in opposite directions, the net effect of the counter rotation would be a net repulsion. Could then two black holes remain each other apart (but in equilibrium) by the balance between spin repulsion and gravitational attraction? And, what about three or more holes in equilibrium? This is an interesting story in which many people at the AEI played a role. It is also a story that has more to say and this is why we are describing it in this short report.

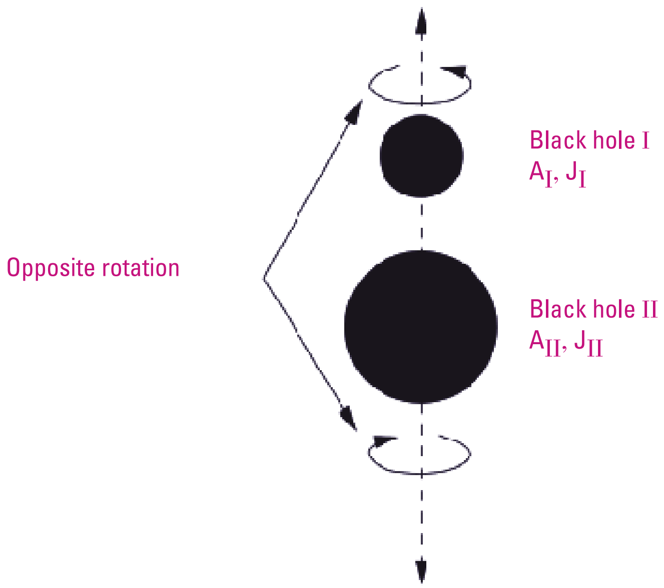

Fig.1: Representation of two aligned rotating black holes of areas A_1 and A_2 and angular momentums J_1 and J_2.

What Gernot Neugebauer (F. Schiller University - Jena) and Jörg Hennig (Otago University - New Zealand; formerly at the AEI) had found was that such configuration in fact cannot exist (see [2] and references therein). The key ingredient was the remarkable inequality $A \geq 8\pi|J|$ between the area A and the angular momentum $|J|$ of black holes. The inequality roughly says that the more black holes rotate the bigger they are. What Neugebauer and Hennig showed was that, if two aligned black-holes exist in equilibrium, then the inequality $A \geq 8\pi|J|$ cannot hold simultaneously at both holes. They concluded then, a posteriori, that the assumed configuration is impossible. The inequality $A \geq 8\pi|J|$ was first proved by Hennig, Ansorg and Cederbaum (all formerly at AEI) for stationary black-holes. What is remarkable is that it is also an inequality valid for dynamical (i.e. non-stationary) axisymmetric black holes as shown by S. Dain and the author [1]. As important, the method of proof in [1] allowed a variety of other achievements. First, it was extended to higher dimensions (by Hollands), extended to include charge (by Gabach, Jaramillo & Reiris), and to include a dilaton field (by Yazadjiev). Finally, in a joint work (to appear) between the author and Eugenia Gabach (formerly at the AEI) it allowed a complete description of the whole geometry of dynamical black holes, namely it allowed a detailed and accurate account of the shapes that black holes can enjoy.

Many avenues of research are open for the time to come. First, it is still open the question whether more than two black holes could stay in axisymmetric equilibrium. Or, what about non-aligned black holes?

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Could there exist configurations where several non-aligned black holes remain in equilibrium? In other words are the Kerr black holes the only (vacuum) ones existing in nature? These old questions entangle fascinating mathematical difficulties that are currently being investigated by the community and where the developments mentioned above could play a big role.

Martin Reiris

From Here to Infinity on a Single Computer

Numerical relativity has made great strides in recent years. Simulations of binary black hole mergers, a major unsolved problem until the breakthrough in 2005, have by now become routine. Yet several issues remain, and these can often benefit from an improved mathematical understanding of the field equations and global properties of their solutions. In the following we give one example of such a problem.

A reasonable idealisation of a common situation in astrophysics is an *isolated system*, i.e. an asymptotically flat spacetime containing a compact self-gravitating source, e.g. a neutron star, black hole binary, etc. The highly non-linear dynamics close to the source require a numerical solution of the field equations. But how do we represent the entire unbounded domain with finite computational resources?

Let us recall that there are three different types of "infinity" in general relativity: spatial infinity, future/past timelike infinity (which the worldlines of observers approach) and future/past null infinity (which light rays approach). This can be conveniently represented in a Penrose diagram (Figure 1).

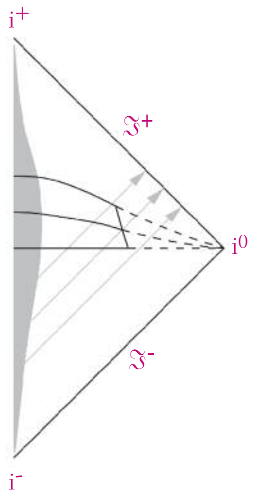

Fig.1: Penrose diagram of Minkowski space, with spatial infinity i^0, future/past timelike infinity $i^{\pm}$ and future/past null infinity $\mathscr{I}^{\pm}$. Included is a compact source (grey area) and outgoing radiation (grey arrows). The horizontal lines represent a foliation of spacetime into spacelike hypersurfaces approaching spatial infinity, truncated at a finite distance (vertical line).

Evolution with finite boundary

The standard method is to slice spacetime into spacelike hypersurfaces approaching spatial infinity (also shown in Figure 1). Each slice corresponds to one instant of time. In the 3+1 formulation of general relativity, the Einstein equations split into *constraint equations* that must hold on each slice, and *evolution equations* that take us from one slice to the next. As is apparent from Figure 1, outgoing radiation never leaves the spatial slices as time proceeds, because all the slices end at spatial infinity. Therefore, compactifying the spatial coordinates on the slices so that spatial infinity is brought to a finite coordinate location is not a good idea because the wavelength of the radiation will appear to be increasingly "blue-shifted" and ultimately will fail to be resolved on the numerical grid.

Instead, one usually truncates the spatial slices at a finite distance from the source and only solves the equations in the interior. This introduces an artificial timelike boundary, where boundary conditions must be imposed. Among other things, these should (ideally) guarantee that the solution on the truncated domain is identical with the solution on the unbounded domain. In particular, one would like gravitational radiation to pass through the boundary without causing spurious reflections.

Reaching out to future null infinity

One way of doing this is to foliate spacetime by spacelike hypersurfaces that approach future null infinity instead of spatial infinity (Figure 2). Such surfaces are called *hyperboloidal*. If we wanted to draw such a surface in the standard coordinates of flat (Minkowski) spacetime, it would look just like a standard hyperboloid, shown in Figure 3. One way of compactifying such a surface is illustrated in Figure 4. More generally in curved spacetime, a purely geometric prescription for choosing hyperboloidal surfaces is to demand that the mean curvature of the surface be constant. Looking again at outgoing radiation (Figure 2), we see that it now leaves the spatial slices as time proceeds and there is no resolution problem.

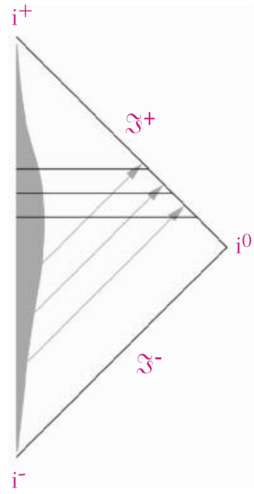

Fig.2: The same diagram as in Figure 1 but now showing a hyperboloidal foliation of spacetime.

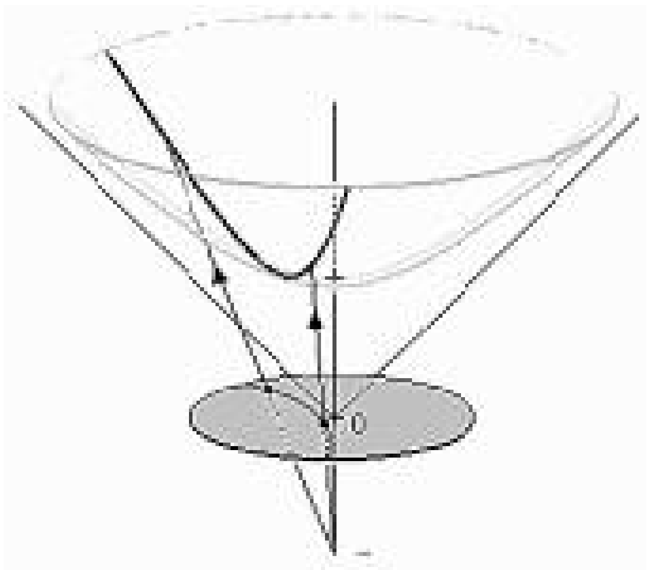

Fig.3: A hyperboloidal surface in Minkowski space. Time is the vertical axis, space is represented by the horizontal planes. Also indicated is a way of compactifying this surface by mapping it onto the *Poincaré* disk.

Major progress with the Einstein equations on such hyperboloidal spacetime foliations was made by Helmut Friedrich, who developed a reformulation of the equations that is entirely regular at future null infinity and has other appealing mathematical properties [1]. Much of the follow-up work was carried out at the AEI. Versions of Friedrich's system were used for numerical evolutions by a number of authors (Peter Hübner, Jörg Frauendiener, Sascha Husa, and collaborators), with a boost of activity in the late 1990s.

In the work reported here we take a slightly different approach and work directly with the Einstein equations in a straightforward 3+1 split on constant mean curvature surfaces. The motivation for this is that we wanted to be able to draw on the considerable experience that numerical relativists by now have with similar formulations of the Einstein equations. As in [1] we apply a conformal transformation to the spacetime metric, i.e. it is written as a conformal metric divided by a conformal factor, where the conformal factor vanishes at null infinity and the conformal metric is everywhere finite with respect to a suitably compactified coordinate system, as in the Penrose diagram. When this form of the metric is inserted directly into the Einstein equations, however, they develop terms containing inverse powers of the conformal factor, which are singular at future null infinity. Fortunately we were able to show in [2] that the formally singular terms in the evolution equations can in fact be evaluated in a regular way at future null infinity provided the constraints hold. Using these analytical results we were able to obtain stable numerical evolutions in a number of situations.

Applications to black hole spacetimes

In [3] we considered vacuum black hole spacetimes, which in order to reduce the computational effort were assumed to be axisymmetric. We obtained long-term stable evolutions of a perturbed Schwarzschild black hole and read off the gravitational radiation emitted by the system at future null infinity. Part of the initial perturbation escapes to future null infinity immediately, while another part falls into the black hole and excites it, which then essentially behaves as a damped harmonic oscillator and emits the so-called quasinormal mode radiation. Our numerical results for this are in good agreement with linear perturbation theory for the relatively weak perturbations we considered. At late times the qualitative behaviour is expected to change to a power-law decay caused by the backscattering of the radiation off the curved background spacetime, a phenomenon commonly referred to as a *tail*. With the current numerical resolution we were unable to resolve this feature, but hope to improve the code in the future.

As a first step, however, we decided to make a further simplification and impose spherical symmetry. Due to Birkhoff's theorem, any spherically symmetric vacuum spacetime must be static (in fact, it is given uniquely by the Schwarzschild black hole), so in order to have nontrivial dynamics we need to include matter. How to do this in our conformal setting is an interesting problem in its own right. In [4] we showed that our earlier regularity analysis at future null infinity is unaffected provided the energy-momentum tensor is tracefree, a condition that is satisfied for most radiative forms of matter.

As specific examples we considered in detail a massless scalar field and Yang-Mills theory, a generalisation of electromagnetism to non-abelian gauge groups. With a reduction of these systems to spherical symmetry we were able to obtain numerical evolutions both of initial data that disperse to leave flat space behind, and initial data that collapse to form a black hole. As an example, Figure 5 (overleaf) shows a collapsing scalar field evolution. The tail at late times is now clearly visible. Notice how the decay rate at future null infinity is different from the one at a finite distance (here, at the horizon) — a fact that would be impossible to see using the "old" approach to evolution with artificial timelike boundary.

For the Yang-Mills field we obtained similar results, and here we generalised the ansatz for the field used in previous numerical studies,

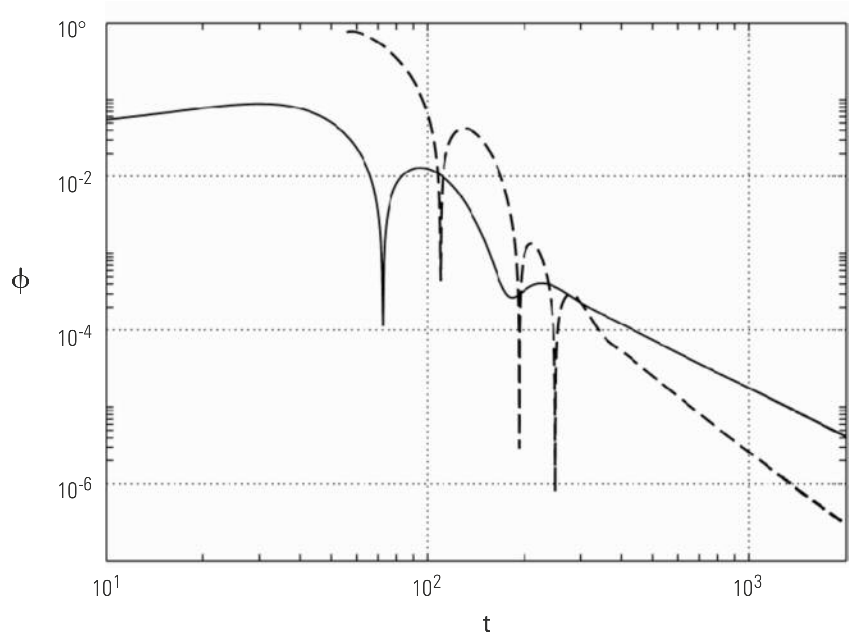

Fig.5: Evolution of a spherically symmetric massless scalar field coupled to the Einstein equations that collapses to form a black hole. Shown is the scalar field as a function of time t at future null infinity (solid line) and at the black hole horizon (dashed line) from when it first forms. Note the power-law decay at late times (straight lines on this double-logarithmic plot).

discovering some interesting new gauge dynamics in the hitherto unexplored sector. With its nontrivial static solutions (Bartnik-McKinnon instantons and coloured black holes) that play the role of intermediate attractors in gravitational collapse, the Einstein-Yang-Mills system exhibits unusually rich dynamics that we hope to explore further in future work.

Oliver Rinne

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Pulsar Timing Arrays: Listening to the Universe With a Galactic Scale Interferometer

General Relativity, together with Quantum Mechanics, represented one of the main achievements of the scientific thinking in the past century. Since the times of the ancient Greeks, space and time have been considered absolute and steady concepts; the background stage where things happen. This conception was refined in the centuries and established by (among others) Isaac Newton and Immanuel Kant as a fundamental pillar of the structure of Nature itself and of the way we understand it. General Relativity unveiled a different nature of space and time, which were promoted from being the mere background to primary actors of the physical world. Space and time are not absolute, rigid and immutable, but dynamical entities that couple together with mass and energy through Gravity.

Gravitational waves

One of the inevitable consequences of General Relativity is that accelerating masses cause modifications of the spacetime that propagate at the speed of light, better known as gravitational waves [1]. Just think about stirring your finger in a pond: its motion generates waves in the water that propagate from your finger outwards. Well, the gravitational pull of a rotating system of compact stars (i.e., two masses accelerating under the effect of their mutual gravity) has a similar outcome, with the notable difference that it is not a medium (the water) that oscillates with respect to some fixed background (the 'absolute' reference frame of the pond), but it is the background itself (the spacetime) that oscillates! The two accelerating bodies are *stirring the spacetime*, generating waves that propagate at the speed of light. This spacetime vibration is associated, in another popular analogy, to the air vibrations that carry sounds. This is why when scientists refer to gravitational wave detection, they talk about *listening to the Universe*, in contrast to conventional observations of stars and galaxies in the electromagnetic spectrum (from radio wavelengths, to optical, up to γ-rays). *Gravitational waves are the soundtrack of the Universe* - which we can usually see, but not hear. These waves are perpendicular to the direction of propagation (the same as the more familiar electromagnetic waves), quadrupolar, and have two polarizations. Their quadrupolar nature implies that perpendicular directions experience opposite squeezings. Consider a Cartesian reference frame 'x,y,z'; if the wave propagates in the z direction, the 'spacetime metric' (that defines the distances betweeen objects) shrinks in the x direction while expanding in the y direction and viceversa in a oscillatory fashion. The amplitude of the gravitational wave is denoted with h, usually referred to as strain. h represents the *relative stretch of the metric*: if two test masses are placed at a distance L, a passing wave results in a oscillatory relative change of their distance $\Delta L/L \sim h$: the measurement of this relative change is at the basis of gravitational wave detection [2]. But here come the troubles: these waves are tiny! As a matter of fact the spacetime is extraordinarily rigid. In fact, in Einstein's equations, the matter-spacetime coupling constant is of the order of G/c^4 (G is the gravitational constant and c is the speed of light), which is about 10^{-50}! This implies that, even though you produce gravitational waves also by moving your arm up and down, only massive, compact astrophysical objects can produce a sizable strain that would be observable with advanced technology. To give an example, consider a binary of stellar black holes orbiting each other in some nearby galaxy (i.e. at a distance of megaparsecs, that is, several millions of light years), such binary generates a wave at twice it's orbital frequency that reaches the Earth with a strain $h \sim 10^{-20}$ (in comparison, the strain caused by your oscillating arm at, say, 1 meter distance is $h \sim 10^{-45}$), corresponding to a relative change in distance of a femto-centimeter (10^{-15} cm) over a baseline of a kilometer. To detect such signal, one needs to built a device that is sensitive to displacements of the order of one-hundredth the size of the nucleus of an atom!

Millisecond pulsars as gravitational wave detectors

The most popular gravitational wave detectors are laser interferometers. In these devices, an ultra-stable laser beam is split in the two arms of length L, and travels forth and back in the arms before being recombined. A putative passing wave causes a $\Delta L \sim hL$ that can be observed in the interference pattern of the recombined light. Several such interferometers are (or soon will be) operational all around the world (see, e.g., the LIGO and Virgo projects [3,4]), with prospects of first detection within the next five years.

The depths of the Cosmos provide us with a variety of fascinating objects, among which, millisecond pulsars represent an extraordinary alternative tool to detect gravitational waves. Pulsars are a particular class of neutron stars; compact collapsed objects that are sustained by the neutron degeneracy pressure against their own gravity. Neutron star matter is in such extreme conditions that a mass larger than the Sun is enclosed in a diameter smaller than the Berlin Autobahn ring. A 'spoon' of neutron star weights about a billion of tons, i.e., like a portion of 60km^3 of the Earth. Neutron stars are surrounded by strong magnetic fields where particles are accelerated at relativistic speeds generating powerful radio beams. Some of these stars are rapidly spinning, rotating around themselves hundreds of times per seconds (hence with a period of few milliseconds, and that is why we call them millisecond pulsars). It turns out that the spinning axis is often offset with respect to the magnetic axis, making them *cosmic radio lighthouses*. If the beam happens to point toward the Earth, we receive radio pulses at extremely regular intervals: one for each rotation. Millisecond pulsars are the most stable natural clock in the Universe [5], and the time of arrival of their pulses can be currently predicted with a precision of the order of ~100 nanoseconds: that is why they can be used to measure gravitational waves. If we consider the pulsar and the Earth to be in 'free-fall' in a spacetime perturbed by a gravitational wave, the wave passage will leave a characteristic fingerprint in the time of arrival of the radio pulses (see, e.g., [6]). As a matter of fact, the passing wave is 'changing the distance' between the pulsar and the earth, which play now the role of the test masses in our detector, causing the pulses to arrive a bit earlier or a bit later than expected. By correlating observation from a set of ultra-stable pulsars (a 'Pulsar Timing Array') the gravitational wave signal can be extracted among the other sources of noise. The principle is not different than that of interferometers, but in this case one measures delays in time of arrival of the pulses, rather than changes in the interference pattern of laser beams.

For this reason, pulsar timing arrays are sometimes referred to as 'galactic scale interferometers', which sounds pretty cool indeed.

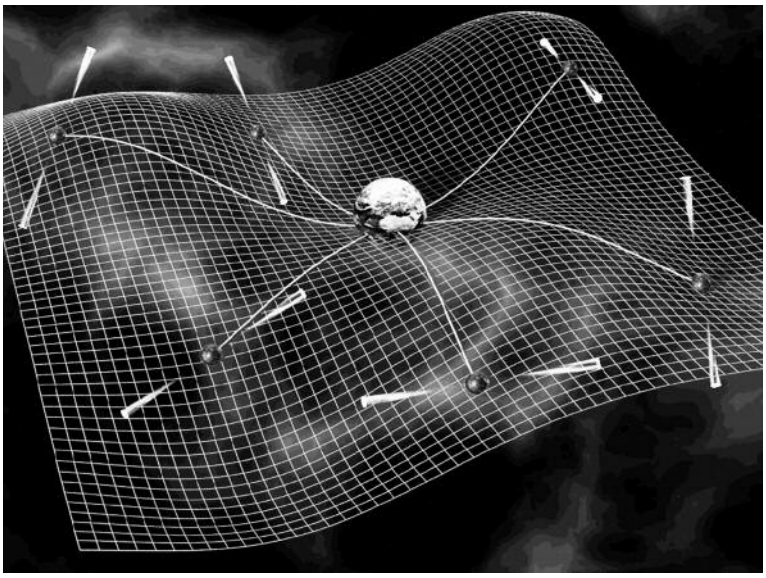

Fig.1: A "natural" gravitational wave detector: radio signals from pulsars propagate through space-time curved by low-frequency gravitational waves and are detected on Earth.

Science with pulsar timing arrays

The great thing about timing pulsars is that it opens a frequency window to which we would be deaf otherwise (the nano-Hz frequency regime), at a relatively cheap coast (many large radio telescopes are available around the globe). Given their frequency range (nano-Hz to micro-Hz) and extraordinary stability (timing precision sometimes better than 100 nanoseconds, corresponding to strains of the order of $h \sim 10^{-14}$ - 10^{-15}), pulsar timing arrays are particularly sensitive to the foreground generated by cosmic massive black hole binaries populating the low redshift Universe [7]. Massive black holes are, in fact, ubiquitous in nearby galaxies [8]. In our standard model of the Cosmos, structures (i.e. galaxies and galaxy clusters) grow in a bottom-up fashion, with small protogalaxies forming first and then merging hierarchically with each other to form the big galaxies we see today. Massive black holes harbored at their center share the same evolutionary path, experiencing several mergers with other holes following their host galaxy mergers [9]. In this evolutionary scenario, a large population of massive black hole binaries lies idle at the heart of Galactic nuclei, sending waves throughout the Universe, unheard. Such population can be estimated by exploiting a range of independent complementary techniques, yielding compatible results [7,10,11]. The prediction is the existence of a gravitational wave background (given by the superposition of the signal coming from each individual binary) with a characteristic strain in the range $3\times10^{-16} < h < 3\times10^{-15}$ [7,11] at a frequency of 31 nano-Hz (i.e., with an oscillation period of 1 year). The exciting thing is that, thanks to modern large band receivers and more efficient and improved data processing, pulsar timing arrays are almost there! The current best published limit is $h = 2.4\times10^{-15}$ [12] at the same frequency, already skimming the upper limit of the expected range. This is raising a wave of excitement in the astrophysics and gravitational wave community, with more and more scientists involved in optimizing data acquisition and processing as well as data analysis algorithms to possibly extract this low frequency gravitational wave

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signal among the timing noise. Currently the AEI is a major actor in the European and International pulsar timing array projects (EPTA [13] and IPTA [14] respectively), where new extended datasets are being analyzed. The sensitivity might realistically go down to $h \sim 10^{-15}$ or better in the next five years, implying a good chance to make a detection. This timeframe is of the same order of the expected first detection by ground based interferometers, meaning that *pulsar timing arrays have a chance to provide the first direct detection ever of gravitational waves*, the ultimate, yet directly unverified, prediction of Einstein's theory of General Relativity.

Beyond the scientific value of the detection in itself, the signal will tell us about the underlying population of massive black holes in the low redshift Universe, constraining their merger history and their intimate connection to massive galaxy evolution. Moreover, the overall signal is expected to be dominated by a handful of sparse, loud sources, that might be individually identified [10]. For such sources sky location within few tens to few deg^2 is possible [15]. Even though this is a large chunk of the sky, these systems are extremely massive and at relatively low redshift ($z<0.5$), making any putative electromagnetic signature of their presence (emission periodicity related to the binary orbital period, peculiar emission spectra, peculiar fluorescence line profiles, etc.) detectable, thus opening new avenues in the realm of multimessenger astronomy [16,17]. Our Universe is indeed not only very bright at all electromagnetic wavelengths, it is also very loud, we are just deaf to it...but maybe only for few more years; keep calm and listen.

Alberto Sesana

A Correlation Approach to Space-time Classical Dynamics

General relativity provides a magnificent conceptual framework for classical gravity, explaining it in terms of a dynamical spacetime whose curvature accounts for the gravitational field. Moreover, it provides powerful tools for the study of extremely violent events in the Universe, happening in astrophysical and cosmological scenarios. Experimental evidence has accumulated over the years confirming the validity of many crucial aspects of this picture. The strong confidence in the theory has tantalized the efforts to develop an array of gravitational antennae that are expected to detect gravitational waves in the coming years. In parallel, an extensive theoretical program is producing remarkable achievements in the systematic modeling of the corresponding sources of gravitational radiation.

However, in spite of these successes and good prospects, classical general relativity is not yet fully understood. The understanding of the dynamics of the gravitational field in the strong-field regime, as well as the detailed manner in which such dynamics eventually drives a given gravitational system to stationarity, still poses important open problems. These issues are crucial both at the foundational level of the theory and in the study of fundamental astrophysical and cosmological problems. First, the assessment of the consistency of general relativity as a model for classical gravitational dynamics lies heavily on the understanding and control of the late time behavior of (strong) gravitational fields [1]. This is essential for elucidating basic questions such as the stability of black hole spacetimes or the role of the cosmic censorship conjecture in preventing the formation of naked singularities in classical gravitational collapse. Second, understanding the strong-field regime of spacetime dynamics is crucial in those astrophysical and cosmological scenarios involving the violent interaction of black holes. Such systems stand among the most important sources of gravitational radiation and are crucial in the development of cosmological evolution pictures. Recent numerical relativity breakthroughs [5] have opened a probe into gravitational strong-field dynamics, but an analysis effort is still needed to shed light onto the qualitative mechanisms and physical effects buried in these numerical outcomes. The development of a systematic framework for such an a posteriori analysis is our main motivation here.

A natural approach to gravitational dynamics consists in extending to the relativistic realm the Newtonian description of gravitationally interacting bodies. However, such a "celestial mechanics" strategy meets fundamental obstacles when dealing with the general dynamics of the gravitational field itself. A main feature of general relativity is that all fields in the theory are determined dynamically. This defines a theory in which a priori rigid structures providing canonical references, such as the inertial frames existing in non-relativistic physics and in special relativity, are generically absent. Familiar notions such as the mass, binding energies, linear and angular momentum, associated with individual objects, are tremendously difficult to characterize. This challenges the adequacy of such a strategy in the strong-field regime of spacetime dynamics. We propose a complementary approach [2,3,4,6] in the spirit of a coarse-grained description of the dynamics, in which we emphasize the global properties of the relevant dynamical fields in an explicitly relational treatment. In particular, we aim at capturing the functional structure of the dynamical gravitational field in terms of appropriate correlation functions.

Placed in a black hole setting, we take advantage of the synergy between recent advances in mathematical and numerical relativity. A crucial input from the mathematical side has been the notion of stability for "marginally outer trapped surface" (MOTS). The latter constitute a limiting case of "trapped surfaces", occurring when "light bending" is able to force the local convergence of all emitted light rays. MOTS-worldtubes formed by piling up such surfaces in spacetime play a key role in our analysis. On the numerical side, a crucial outcome of the systematic exploration of fully dynamical vacuum spacetimes is the simplicity of the a posteriori dynamical description. This observation supports the applicability of a coarse-grained approach to the analysis of generic spacetime dynamics.

We outline the cross-correlation methodology to the gravitational field dynamics as follows:
i) Spacetime dynamics in a region R is probed through the cross-correlation of geometric quantities h_{inn} and h_{out} "measured" at spacetime hypersurfaces placed, respectively, at inner and outer positions in the causal future of R.

ii) These outer and inner hypersurfaces are taken as geometrical "test screens" responding to bulk dynamics in R without backreacting on it. The spacetime is then explored in the spirit of an "inverse scattering approach".

We dwell in the restricted context of near-horizon black hole dynamics, see Fig.1. A natural candidate for the outer hypersurface is provided by the spacetime outer "boundary" reached by all escaping future lightlike geodesics, namely "null infinity" $\mathscr{I}^+$. In practice, a worldtube B of very large spheres also provides a good model for the outer test screen. MOTS-worldtubes H^+ provide inner test screens, acting as "balloon probes" in the black hole region, with remarkable geometric properties guaranteed by the MOTS-stability condition. A natural quantity h_{out} to monitor at infinity is the "news function", encoding the information about those components of the (Weyl) curvature accounting for the emitted gravitational radiation. From the MOTS-worldtube geometry one can identify the "shear tensor" describing the deformations of H^+ as a news-like function on the inner screen providing the inner counterpart h_{inn}. The two time-series h_{inn} and h_{out} encode the relevant geometric information, so that the application of standard time-series analysis tools provides a first step in the cross-correlation study.

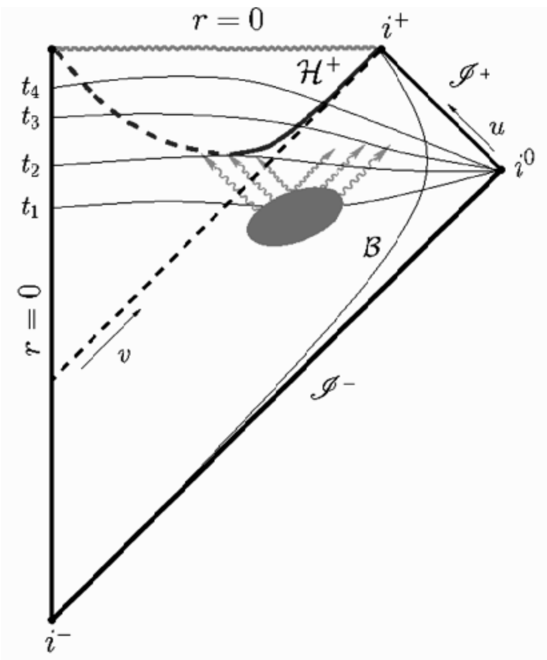

Fig.1: Illustration of the "scattering picture" in a near-horizon setting, using a Carter-Penrose spacetime diagram where lightlike rays lay at ±45°. The dashed line at ±45° line represents the event horizon, separating the black hole region to its left (containing the spacetime singularity corresponding to the horizontal oscillating line) from the rest of the spacetime. Dynamics happening in the shaded near-horizon region affects the inner screen H^+ and the outer large spheres world-tube B (or null infinity I^+), where quantities h_{inn} and h_{out} are "measured". The approximately horizontal lines represent spatial slices at times t_1, t_2, t_3,... in a so-called Cauchy evolution of the spacetime, providing the labels for the time series to be correlated.

As an illustration, we have studied the recoil dynamics of black holes resulting from asymmetric binary mergers [6,3]. This is astrophysically relevant since such recoil can play an important role in the growth of supermassive black holes via mergers of galaxies and on the number of galaxies containing black holes. In particular, we aimed at getting insight into the systematics of a late-time deceleration referred to as the "anti-kick". The relevance of this specific problem lays on the actual capability of making a priori estimates, since a relatively large anti-kick reduces the resulting recoil (kick) velocity,

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whereas large final kicks are associated with small relative anti-kicks. The anti-kick results from the interplay between the oscillation and decay dynamics of the gravitational field in the near-horizon zone. This motivates the introduction of a "slowness parameter", as the rate between the oscillation and decay characteristic timescales. The study of the head-on collision of two black holes of different masses provides a simple model to explore the relevant dynamics. The main features of the associated recoil dynamics are summarized in Fig. 2. The application of the presented cross-correlation analysis has revealed the structure of the slowness parameter in terms of the coupling of the quasi-normal mode frequencies of the resulting black hole. Such insight is extremely valuable, since final quasi-normal modes can be faithfully estimated in terms of the initial pre-merger configuration of the system, thus conferring a predictive power to the performed analysis. A more geometric understanding follows from the analysis of the equations driving the MOTS-worldtube evolution, in particular its analogy with a viscous fluid with corresponding bulk and shear viscosities, leading to a purely geometric characterization of the slowness parameter in terms of the expansion and the shear of the MOTS-worldtube generator.

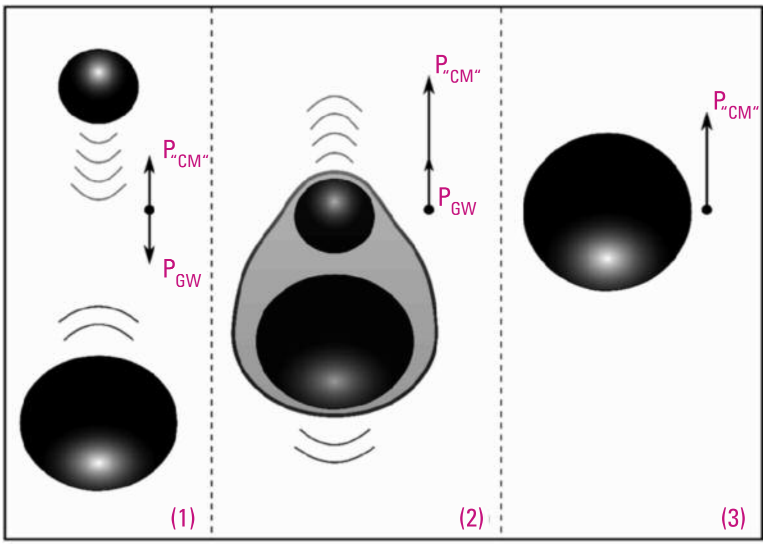

Fig.2: Illustration of the recoil of a black hole resulting from an asymmetric head-on collision of two non-rotating black holes. Initially the smaller black hole moves faster and linear momentum is radiated mostly downwards, thus leading to an upwards recoil of the system [stage (1)]. The resulting distorted black hole continues recoiling in the upward direction, but spacetime anisotropic dynamics induces an acceleration-deceleration phase (anti-kick) in the motion of the black hole [stage (2)]. Spacetime dynamics relaxes to stationarity and the black hole moves at a uniform velocity [stage (3)].

These results illustrate the kind of qualitative and quantitative insight into the underlying dynamics pursued by the presented cross-correlation approach, demonstrating its capability to pierce and illuminate the entangled dynamics of the strong gravitational field. Next steps will involve the systematic importation and adaptation of concepts and tools from statistical field theory to the analysis of spacetime dynamics, as well as extending the applications to more general settings.

José-Luis Jaramillo

Generalised Geometry and Supergravity

One of the cherished principles of Einstein's general theory of relativity is its geometrical nature. The effects of gravity are encoded in the geometry of space-time and space-time geometry is determined by the distribution of matter. The presence of massive objects like our Sun curves space-time. A curved space-time implies that the notion of a straight line as the shortest path from A to B has to be modified. The optimal path now is described by a so-called geodesic in space-time which is a curve that is 'bent' by the curvature of space-time. This effect is responsible for example for gravitational lensing by which light rays from distant stars (or other sources) can be focussed or deflected on our way to us when they pass by heavy objects.

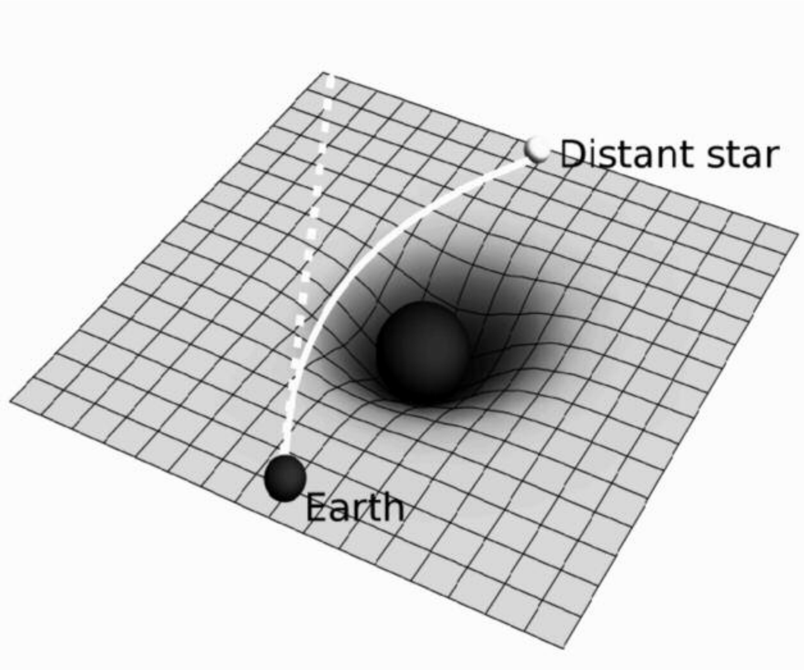

Fig.1: Heavy objects (dark central mass) curve the geometry of space-time. This influences the way a light ray (white solid line) travels from a distant star to us (earth). The perceived position along the dashed white line is different from the actual position due to the curvature of space-time.

Mathematically, the curvature of space-time is expressed in terms of a metric structure on space-time. This means that there is an object called metric that (a) can be used to measure distances in space-time and (b) encodes the curvature of our space-time. The metric is the central object of study in general relativity as everything derives from it. Space-times with a metric are called (pseudo-)Riemannian manifolds. It is a key property of general relativity that one can choose coordinates on space-time as one pleases: The physical properties do not depend on the way space-time points are labelled. This property is often called general covariance or also diffeomorphism invariance. A diffeomorphism is a way of relabelling the points on space-time and physics is invariant under it.

Supergravity as gravity-matter system

The curvature of our Universe is determined by the distribution of ordinary matter (planets, stars, galaxies, …), dark matter and dark energy. The Einstein field equations of general relativity relate the curvature of space-time to the matter and energy distribution; at the same time the matter in our Universe has to also fulfil its own dynamical equations that in turn contain the curved space-time. Solving this coupled system of equations is in general not an easy task.

There are many different matter types that can be coupled to gravity in this way and give rise to different combined gravity-matter systems. Among the standard choices are the matter fields of the standard model of particle physics (photons, electrons, ...) but also inflaton fields that are used to model inflationary cosmologies. Depending on what aspect one wants to capture one has to choose the appropriate gravity-matter system.

Fig.2: What appears to us as a point particle could actually be an extremely tiny string seen from a distance. If we had appropriate magnifying glasses (particle accelerators), this idea could be directly tested.

It is a well-known problem of modern theoretical physics that Einstein's general relativity is hard to reconcile with the principles of quantum mechanics. Constructing a quantum theory of gravity is not only an academic problem but is highly relevant for understanding the origins of our Universe and properties of black holes. One of the main contenders for solving the problem of quantum gravity is string theory. In this vast generalisation of the standard concept of a point particle, the elementary objects are tiny strings whose vibration modes give rise to the observed physics. The strings are so tiny that they are not directly observable by means of particle accelerators (e.g. at CERN in Geneva) that are the most powerful microscopes available on earth. Therefore one has to construct an effective theory that can make contact with the accessible and observable energies. This is achieved by taking a limit of string theory that yields a conventional quantum field theory.

This quantum field theory turns out to be what is known as supergravity, i.e., a theory of gravity and matter that possesses so-called local supersymmetry. The strong constraints of string theory predict these very specific gravity-matter systems where by supersymmetry each bosonic particle has a fermionic partner particle et vice versa.

Among the basic properties of supergravity systems is that the matter contained in them is also subject to gauge invariances, just like the geometry was invariant under diffeomorphisms. Gauge transformations are local symmetry transformations that act on the matter fields without changing the physics that is being described. Besides the gauge transformations supergravity also exhibits so-called global symmetry transformations that can be used to relate physically inequivalent configurations to each other.

Generalised geometry

There is a certain apparent dichotomy in the equations of supergravity in that one side of the equations contains the geometric curvature with its diffeomorphism invariance and the other side contains the matter fields with their gauge and global symmetries. Could it be possible that one can treat both the metric and the matter fields on an equal footing?

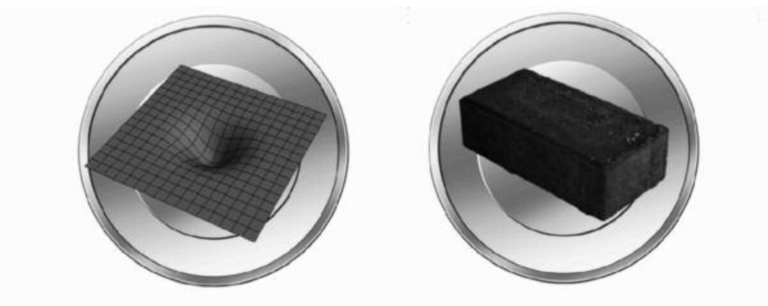

Fig.3: Could it be that space-time geometry and matter are in fact two sides of the same coin? This is the basic assumption of generalised geometry that deals only with one currency that comprises everything.

Assuming that this can be done is the basic hypothesis of a recent research field called generalised geometry. The hypothesis entails that there is a unifying object called the generalised metric that is subject to generalised diffeomorphisms and that combines the standard metric and matter fields and their invariances. This must be done in such a way that one can disentangle in principle the generalised metric and recover the standard constituent equations. The dynamical equation that the generalised metric is subjected to should be a geometric equation in the generalised geometry. In fact, there is nothing but generalised geometry: all matter and energy has been absorbed into the generalised metric.

It turns out that implementing this idea is not straightforward. The main difficulty is that 'geometrising' the invariances of the matter fields requires the introduction of additional space-time dimensions beyond the standard four-dimensional space-time. The diffeomorphisms of this extended space-time cannot be arbitrary but have to be such that they reproduce only the correct invariances of the matter. This implies that generalised geometry is not just standard geometry in an extended space-time but that there are additional constraints that make the analysis much more involved.

Work at the AEI over the last years has addressed these questions with an intensified effort in the last two years. It was known that among the additional constraints one has to implement the so-called 'section condition' which restricts the invariances in the right way. Recent progress showed how to analyse the generalised diffeomorphisms in the presence of this constraint. The invariances turn out to be part of an intricate hierarchy of symmetry transformations that mathematically reflect the so-called reducibility of the generalised diffeomorphisms. Among the surprising features of this hierarchy of symmetry transformations was that they are very closely related to other hierarchies that were known in supergravity but which were not related to any geometric properties.

Investigating generalised geometry can also help understand another problem in standard general relativity, namely that of its possible dual formulations. For electromagnetism, it is known that there is a so-called duality transformation that exchanges electric and magnetic fields. Realising similar duality transformations in gravity is a hard problem due to the non-linear aspects of the Einstein field equations. It is known that one can make a linearised approximation to the Einstein equations and then perform the dualisation of gravity but the sought-after non-linear dualisation is severely restricted by several no-go results. However, in some circumstances generalised geometry is known to necessarily require a non-linear dual and it is in these cases that a further analysis of the generalised diffeomorphisms can help.

Generalised geometry is still in its infancy and there are a number of concepts that still require a better understanding. These include the question whether all possible generalised curvature tensors can be unambiguously defined in a manner analogous to that of standard geometry. In current formulations, there are ambiguities but we have hints that these ambiguities do not affect the physically relevant dynamical equations.

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Having gravity and matter on an equal footing allows the exploration of a unified description of genuine string theory effects on physics. As supergravity is only an effective description at low energies one knows that calculations in supergravity will have to be modified at higher energies in order to be compatible with string theory as a quantum gravity theory. These modifications are not easy to deduce from direct string theory calculations and generalised geometry holds the prospect of constraining the modifications. This is achieved by demanding that all modifications are also of a geometric nature but now in generalised geometry. This approach is currently under investigation at the AEI.

In summary, generalised geometry is a way of obtaining a unified view on gravity-matter systems by interpreting both gravity and matter as components of a generalised metric. This is not only an interesting mathematical generalisation of curved space-time but also holds the promise to help constrain and evaluate otherwise difficult string theory calculations.

Axel Kleinschmidt

Asymptotically Safe Gravity

Reconciling quantum mechanics with Einstein's theory of gravity is one of the major outstanding challenges in theoretical physics. Among the several different possible routes to quantum gravity which are being explored by researchers at the AEI, one promising approach which has received some renewed attention in recent years, and on which I am working, is the one known as *asymptotic safety*.

A historical background: the crisis of quantum field theory and the discovery of asymptotic freedom

The unification of quantum mechanics and special relativity (the theory of relativity in the absence of gravity) was successfully accomplished in the last century, leading to the theoretical framework known as quantum field theory. The path to success was of course neither easy nor linear, and it faced two major crisis (for a brief recount see for example [1]). The first arrived with the appearance of infinities in practical calculations, and was eventually solved by R. Feynman, J. Schwinger, and S.-I. Tomonaga with the formulation of the *renormalization theory*. The solution appeared however as a mysterious trick, and it left open a number of problems which led to a second crisis. All known renormalizable quantum field theories seemed to have the property of screening charges at large distances, but as we measure non-zero charges at large scales this meant that at very short distances a charge had to be very large, and actually it would diverge at some finite short scale: infinities were striking back, and quantum field theories seemed to be valid only at large scales.

Theoretical physicists finally came out of such crisis with the proof by G. 't Hooft and M. Veltman of the renormalizability of a new class of theories, Yang-Mills theories (which would then become the building block of the Standard Model of particle physics), and with the discovery by D.J. Gross, H.D. Politzer and F. Wilczek of an unexpected behaviour of such theories: antiscreening. The latter is the opposite of screening, that is, charges decrease as we go to shorter and shorter distances, eventually vanishing at infinitely small distance. Since vanishing charge means that particles do not interact with each other, and hence behave as free particles, such property was named *asymptotic freedom*. Theories enjoying asymptotic freedom make sense down to the shortest possible scale, and for this reason such discovery marked a solution to the crisis of quantum field theory. At the same time K. Wilson's development of the *renormalization group theory* [2] led to a deeper understanding of the renormalization procedure, and in the technical jargon introduced by such development we talk of asymptotically free theories as having a free theory as ultraviolet fixed point of the renormalization group.

From freedom to safety: a solution to the problem of quantum gravity

Quantum field theory provides a successful formulation of a quantum theory for the electromagnetic, weak and strong interactions, all combined together into the Standard Model of particle physics. Gravity still stands out of the picture because the renormalization procedure for eliminating infinities fails in its case. Indeed a quantum field theory of gravity can be formulated, but in order to make sense of it certain parameters need to be fixed by experiments, and cannot be predicted. Unlike the case of the other interactions, for gravity the number of such parameters is not fixed once and for all, but grows with the accuracy we are aiming for, giving rise to the unacceptable consequence that we would need to make an infinite number of experiments in order to make a single prediction about infinitesimally small-distance interactions. One basic reason for such a situation is that the effective gravitational "charge" is provided by the ratio of Newton's constant and the square of the length being probed, and hence gravity presents a screening effect already at a classical level, making its quantum theory very ill behaved.

Many possible alternative solutions have been proposed, some requiring new particles and symmetries (as in supergravity and string theory), some suggesting radical changes in the quantization procedure (as in loop quantum gravity and spin foams). One alternative preserving the quantum field theory framework, without postulating new particles or symmetries, was suggested long ago by S. Weinberg and it is known as asymptotic safety [3].

Weinberg's proposal came at the end of the '70s on the stream of the successful developments of quantum field theory and the discovery of asymptotic freedom. The idea is that what we learned from the previous history is that actually all we need for a quantum field theory to make sense all the way down to infinitely short scales is that it admits an ultraviolet fixed point of the renormalization group, and the fact that such fixed point in Yang-Mills theories corresponds to a free theory is just a lucky coincidence.

The essential feature is again antiscreening, however, as we said, gravity is already characterized by a natural screening at the classical level, hence we cannot expect its quantum version to behave like

Yang-Mills theories. Instead we can hope that quantum effects will give rise to an antiscreening able to compete and eventually win over classical screening. In other words, antiscreening could make such that Newton's constant scales to zero exactly like the square of the length being probed, so that in the limit of infinitely small distances the effective gravitational charge would stay finite instead of diverging (but still be non-zero, hence the asymptotic theory being non-free). In physical jargon we say that the theory flows to a non-trivial fixed point of the renormalization group. In such a scenario there could still be other relevant parameters of the theory behaving similarly according to antiscreening, and these would all need to be fixed by experiments. In order for asymptotic safety to be a successful solution to quantum gravity we then need to show first that indeed the gravitational coupling does not diverge at small distances, and second that such behaviour can be obtained by leaving behind only a finite number of free parameters. If confirmed, such a scenario would mean that a quantum theory of gravity exists in the framework of quantum field theory, like for the other interactions of the Standard Model.

Towards a proof of asymptotic safety: past and present efforts

The asymptotic safety scenario requires a delicate balance of screening and antiscreening effects, for which the standard techniques (perturbation theory) are not fully reliable. For such reason not much progress was made for several years following Weinberg's conjecture. However, over the last decade the application of new renormalization group techniques and approximation methods has led to the accumulation of a great number of supporting evidence [4].

While a mathematical proof might be a too ambitious goal, the hope of establishing the validity of the asymptotic safety scenario over the next few years relies on the combination of such renormalization group techniques with other methods, like the "lattice" approach known as *causal dynamical triangulations*. The situation could be compared to the problem of confinement in quantum chromodynamics, for which a proof is still lacking but nevertheless it is widely accepted as a valid scenario, thanks to the combination of different continuous and lattice results.

I have been working in both approaches to asymptotic safety, in particular concentrating during my years at AEI on the continuous renormalization group methods. The main ingredient behind these methods is the use of an exact equation governing the change in the effective description of our theory with the scale at which we probe it. Such equation cannot be solved exactly in general, hence the need for approximation methods. In the standard perturbative approximation one expands the equation in a power series in the interaction strength, truncating the series to a certain order and solving the system consistently to that order. In practice the search for asymptotic safety via perturbative expansion would amount to looking for zeros of a specific function (known as *beta function*) approximated by a polynomial. In order for that to be reliable we would need a good (high order) polynomial approximation of our beta function, something that in the case of gravity is very difficult to obtain for practical reasons. Instead we can use a different approximation scheme, where we make a guess on what contributions are more important to keep in the beta function, but we do not expand the latter in a power series. The reliability of our original guess is tested by gradually including more and more contributions to the beta function, and checking that the results are not significantly affected and converge to a definite result. In this way a substantial amount of evidence has been accumulated in recent years.

While at AEI, I have contributed along these lines by developing a number of technical methods to deal with more complicated contributions to the beta function of gravity [5], and in the last year F. Caravelli and I have introduced a method for simultaneously studying the effect of an infinite number of contributions to it [6]. In technical terms, this amounts to approximating the effective action of gravity with an f(R) theory for an unspecified function of the Ricci scalar. More recently, within this approach it was possible to prove that if the theory has a non-trivial fixed point, then it admits only a finite number of free parameters [7]. The power of this methods is still largely unexploited and much more can be expected from the coming years.

Dario Benedetti

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Laser Interferometry and Gravitational Wave Astronomy Division

GEO600: A Test-bed for Next Generation Gravitational Wave Detection Technologies

GEO600 is one of a handful of gravitational wave detectors around the world which have been built to measure gravitational waves. These tiny waves of space-time have been predicted by Albert Einstein in his theory of general relativity, but have not been measured directly to this day. Besides confirming their existence, the goal of the gravitational-wave detectors is to open up the new field of gravitational-wave astronomy as a new window to the universe, possibly allowing for the solution of the enigmas that dark matter and dark energy are to today's astronomers and cosmologists.

Fig.1: Central cluster of GEO600.

Fig.2: The main control room of GEO600.

The challenge in gravitational wave detection is the multitude of noise sources that conceal the miniscule gravitational wave signal. Noise sources include seismic motion of the ground, fluctuations in the power and 'color' of the laser, fluctuations in materials of the mirrors that are used to direct the laser beam, and even the quantized nature of light itself.

Fundamentally the most sensitive gravitational wave detectors to date are based on Michelson interferometers. In these instruments, fluctuations of the relative length of two 'arms' are measured to an astonishing accuracy using a strong laser beam. The measurement happens by using a so-called beam-splitter to split the laser beam into two, at the place where the two arms meet. The two beams travel along the perpendicularly arranged arms and are reflected back towards the beam-splitter, where they are recombined. Tiny changes in the relative arm lengths are then visible as fluctuation in the recombined laser beam. GEO600's sensitivity to such changes is on the order of 10^{-19}m, or a ten-thousandths of the size of a proton. This sensitivity allows GEO600 to see gravitational waves from astrophysical events like the merging of two black holes up to a distance of more than 10 million light years.

While GEO600 is currently the only operational gravitational wave detector, there is a concerted international effort in gravitational wave detection. Strong commitments come from France, Germany, Great Britain, Italy, Japan, the Netherlands, and the USA. The USA built two detectors with 4km arm lengths called LIGO Hanford and LIGO Livingston, France and Italy have constructed a detector with 3km arm lengths called Virgo in Italy. LIGO and Virgo are currently undergoing major upgrades and are expected back in operation after 2015. The construction of a Japanese underground gravitational wave detector with 3km arm lengths called KAGRA is currently underway. The construction of an additional LIGO detector in India seems likely. The use of multiple detectors has several advantages. Firstly when a gravitational wave signal is detected nearly simultaneously in multiple detectors one knows with high certainty that the signal is not just a glitch in the measurement that is caused by other sources. This can be achieved to a lesser extent by comparing gravitational wave detection candidates with simultaneous optical and radio-frequency observations and neutrino detection events, too. Secondly, the use of multiple detectors allows for the localization of the gravitational wave source, similar to how the human ears can detect the direction of a source of sound.

GEO600 is a far smaller project than the LIGO, Virgo, and KAGRA projects. Its budget is only approximately 1/10 of the LIGO and Virgo projects' respectively. This smaller size allows and requires it to be slightly more aggressive in the employed technologies and techniques. This unique position makes GEO600 not only a gravitational wave detector but also a major test-bed for next generation gravitational wave detection technologies. Past techniques pioneered by GEO600 and picked up by LIGO and Virgo projects include, amongst others, the use of fused silica (glass) fibers for the suspension of the ~kg heavy mirrors, the use of signal-recycling to make the detector resonant to gravitational waves and the use of electrostatic actuators.

GEO600 high-tech

GEO600's mirrors are suspended as pendulums to isolate them from seismic motion of the ground. The pendulums are formed by the mirrors and fused silica fibers that are melted to the mirrors. The advantage of this quasi-monolithic design is that it makes the mirror less susceptible to the noise that is a consequence of so-called Brownian motion inside the mirrors. More traditional designs that suspend mirrors using steel wires posses a much higher thermal noise, a design that would severely impair the sensitivity of future gravitational wave detectors.

Signal-recycling is an optical technique that makes a detector resonant to gravitational waves. When signal-recycling is employed, the signals that gravitational waves generate inside a detector are not directly detected, but are sent back into the detector first. The result is not unlike a playground swing, where relatively small excitations add resonantly to cause a large effect. With signal-recycling, the sensitivity to gravitational waves is increased manifold.

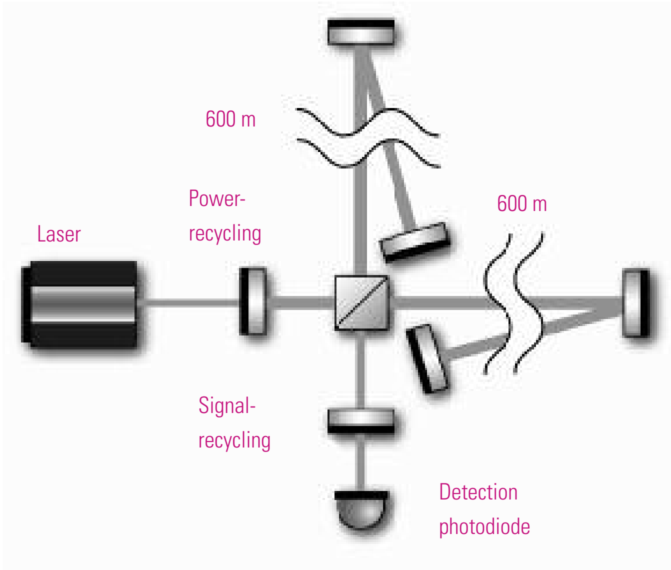

Fig.3: Simplified layout of GEO600.

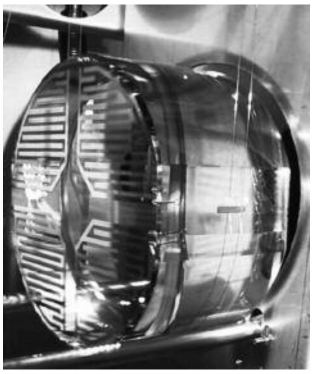

Fig.4: A mirror of GEO600 with visible electrostatic drive.

Because GEO600's mirrors are suspended as pendulums they tend to drift around, this must be prevented. To keep the mirrors at fixed positions an extremely low noise actuator is required. GEO600 pioneered the use of so-called electrostatic drives for this. In this a glass substrate similar to the mirror is located right behind the mirror that is to be acted upon. The glass substrate, the so-called reaction mass, is suspended in the same fashion as the actual mirror. A metallic grid is applied to the front of the reaction mass. When a voltage is applied to this metallic grid a small force between the mirror and the reaction mass is generated. This small force allows for extremely precise control of the mirrors' positions.

Squeezed light, output mode cleaner, high power laser, and DC readout

Since 2009 the GEO-HF upgrade program commenced at GEO600 to once more extend the technologically possible. Amongst the next generation techniques implemented in GEO600 since 2009 are the implementation of squeezed light, the inclusion of an output mode cleaner, an increase of the employed laser power, a compensation of thermal warping of optics, a changed readout of the detector, and a change in the signal-recycling. We will discuss some of these techniques in detail:

The application of squeezed light injection at GEO600 has raised particular interest in the international research community. Its use is advised since GEO600 has pushed the limits in its measurements so far that it is limited by the quantum nature of light itself. The laser beam used to measure the differential arm length in GEO600 is not truly continuous, but consists, as any beam, of a large number of light particles (photons). The very nature of light itself implies that these photons are not arranged like a string of pearls but are travelling in irregular groups, and it is this grouping that creates noise in the gravitational wave measurement. In 2010 GEO600 was the first gravitational wave detector to apply squeezed light injection to reduce this quantum noise and to this day GEO600 is the only gravitational-wave detector routinely using squeezed light injection. The squeezed light source was developed and built at the Albert Einstein Institute, and currently the optimal application of squeezed light injection is being researched at GEO600. Active fields of investigation are the control of the alignment of the squeezed light beam onto the interferometer and the control of its exact frequency. This research will allow future gravitational wave detectors to utilize squeezed light injection to its fullest.

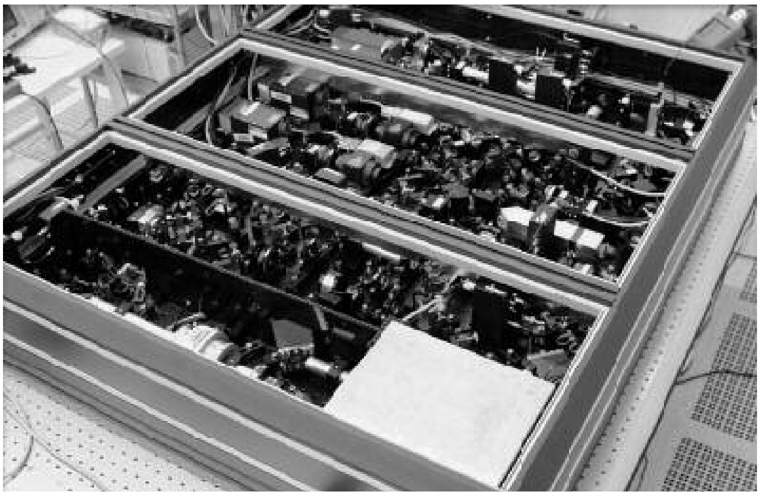

Fig.5: Squeezed light source.

The implementation of an output mode cleaner is another field of international interest. In a gravitational wave detector the gravitational wave signal is encoded in the interferometer's output beam. Due to microscopic defects in GEO600's mirrors there is also light in the output beam that does not carry a gravitational wave signal. This light conceals the signal GEO600 is looking for and therefore has to be removed. The output mode cleaner that was implemented in 2009 is an arrangement of mirrors, a so-called optical resonator, which only lets that light pass through which carries the gravitational-wave signal. The exact design choice of such a resonator and the best system to control the resonators alignment are an active field of research to which GEO600 has made important contributions.

GEO600 needs a laser for the measurement: In 2011 GEO600 switched from a 14W laser system to a more powerful 35W laser system. Both systems were developed and built at the Albert Einstein Institute. The increased laser power emphasizes another challenge in the operation of gravitational wave detectors. Modern gravitational wave detectors use a technique called power-recycling in which the laser power that travels along the two arms is increased manifold. In the case of GEO600 the circulating power is increased by about a factor of 1000 over the power that the laser system delivers. A small fraction of these several kilowatts of light power is absorbed in the mirrors that from GEO600's interferometer. This absorption heats the mirrors which warps them into an incorrect shape. Compensation of this warping is an active area of research. The existing thermal compensation system at GEO600 has recently been enhanced, evaluating a possible solution of the thermal warping problem.

A particularly challenging task in operating a gravitational wave detector is to extract the information about the relative arm length fluctuations from the interferometer's output port. This is because gravitational wave signals are encoded in the output beam as phase fluctuations on the order of 10^{-12} radians. To extract this information GEO600 implemented a new readout technique, the so-called DC readout, simultaneously with the LIGO detectors. As expected this new readout technique gave a modest increase to the detectors' sensitivities, among some other technical advantages.

GEO600 is so far the only gravitational wave detector employing signal-recycling. It provides a profound sensitivity improvement and its use is planned for both the Advanced LIGO and Advanced Virgo detectors. GEO600 researched different signal-recycling configurations in detail, which resulted in a considerable sensitivity improvement at high frequencies.

GEO600 continues to make valuable contributions to the international gravitational wave detection efforts, and with its help the gravitational wave community expects the first direct detections of gravitational waves between 2015 and 2018.

Mirko Prijatelj

Searching for Dark Matter with light-shining-through-a-wall Experiments

The dark matter puzzle is one of the most striking topics of cosmology and particle physics today. What are the constituents of this substance that makes up more than 80% of matter in our universe?

Ever since the question was asked, scientists came up with different solutions to the dark matter problem. Many answers today involve extensions to the Standard Model of particle physics. While the most prominent candidate are weakly interacting massive particles (WIMPs), which only interact through gravity and the weak force, other explanation such as weakly interacting sub-eV particles (WISPs) are getting more and more attention.

Light-shining-through-a-wall concept

The theoretical well-funded concept of a new light-weight particle that exhibits only very weak interaction with ordinary matter calls for experimental proof to get beyond speculation. However, ultimate proof can only be provided by detection. Detection, on the other hand, is eventually bound to a finite interaction cross-section. As for example, the coupling between the WISP field and an electromagnetic field. Unfortunately, the theoretical models do not predict coupling strength and mass of WISPs, and thus, these parameters are only confined by astrophysical observation. A possible approach to the detection of WISPs in the laboratory is the light-shining-through-a-wall (LSW) concept. Strong light fields are send towards a wall that is opaque to photons but transparent to WISPs due to their vanishing interaction with ordinary matter. WISPs, which exhibit coupling to a photon field, can thus be produced in front of the wall and be reconverted behind the wall and consequently be detected by a photon detector.

The ALPS collaboration was established in 2007 when the idea evolved to combine the particle physical approach to WISP searches at DESY with the experience in laser optics that was gained at the AEI during one decade of installation and operation of the gravitational wave detector GEO600. Together with collaboration partners from the Laser Zentrum Hannover and the Sternwarte Hamburg, an LSW experiment was performed. A WISP production environment was prepared by 1 kW of green laser light circulating inside an optical cavity with a length of about 6 m placed inside a HERA dipole magnet. Behind a wall and an empty regeneration region, also located inside the magnet, a CCD camera was used to search for possible reconverted photons. Although no detection could be made, the design proved to be very successful and the ALPS measurements were able to improve bounds on the photon coupling rates of different kind of WISPs for laboratory-based searches.

Exploring uncharted territory with ALPS-II

Since the collaboration had turned out to be so fruitful, it was agreed to come up with a design for a successor experiment: ALPS-II. Additional motivation was provided by new astrophysical observation that yield hints to WISPs within a certain range of masses and coupling constants not accessible by earlier LSW experiments. The ALPS-II design has improved in many points from the outline of the first ALPS experiment: Research into a new detector, the so-called transition edge sensor, is undertaken that promises very low dark rates exploiting superconducting phase transition. The optical wavelength of the primary light is changed from green to infrared to have more power available on the production side. 30 W of single-mode laser power provided by the enhanced LIGO master oscillator power amplifier (MOPA) system incident on a production cavity with a power build-up of 5000 bring about an effective production power of 150 kW. The most fundamental optical update is the implementation of a regeneration resonator located behind the wall, acting as a counterpart to the cavity on the production side. On resonance, it amplifies the flux of regenerated photons by the power build-up factor of 40000. Also, the setup is growing in size: the cavities are designed for a length of 100 m each.

Challenging requirements on the optical design

A key challenge of the ALPS-II experiment is to achieve proper overlap between the optical Eigenmodes of the production and regeneration resonator. A WISP field created in front of the wall would occupy almost the same volume in space as the electromagnetic production field. Due to the small mass of the WISPs that are to be probed in the ALPS-II experiment, the regenerated signal mode behind the wall can basically be considered as a direct continuation of the production mode in space and frequency, similar to free space propagation. The

Eigenmode of the regeneration resonator has to match this mode. This places challenging requirements on the mutual alignment and length stabilization of both cavities. With 12.4 mm, the waist diameter of the Eigenmodes is chosen to be relatively large, so that the beam stays well collimated over the full extend of the 100 m long ALPS-II cavities. The larger the waist diameter of the Gaussian beam, the smaller its divergence angle. But furthermore, larger modes become more susceptible to angular misalignment. In order to achieve 95% overlap between the Gaussian Eigenmodes of both resonators, the acceptable tilt between the optical axes has to be smaller than 5 μrad. This is the angle at which a penny appears when viewed from a distance of 4 km.

The requirements for the length stabilization of the cavities are hardly less demanding. Due to the high power build-up, the light will have to travel 40000 times on average in each direction inside the regeneration resonator. Small phase shifts caused by fluctuations of the mirror positions accumulate during that process, tuning the cavity off-resonance. To keep the power buildup within 5% of its maximum value, the acceptable frequency mismatch between the light and the cavity resonance frequency is 100 mHz, which corresponds to length fluctuations of 1 pm, the hundredth part of a Hydrogen atom radius.

Dichroic stabilization scheme

While these numbers obviously pose a big challenge on the experimental design, experience with Gravitational Wave Interferometers at the AEI has proven that precision measurement and control at these levels is feasible providing that the experiment is well designed.

But still, there is a fact that makes the stabilization of the ALPS-II cavities harder compared to other high-precision interferometric experiments: in order to sense the state of the resonator we cannot use light of the same wavelength we try to make the cavity resonant for. A common technique for the stabilization of an optical cavity to the laser frequency or vice versa is the Pound-Drever-Hall (PDH) scheme. Sidebands are modulated to a beam incident on an optical cavity and the relative phase shift of the sidebands to the carrier is used to determine the frequency offset between beam and cavity Eigenmode near resonance. High accuracy can be achieved with PDH sensing due to the interferometric readout of the cavity length. This, however, obviously requires some light to be send into that cavity. In fact a many orders of magnitude higher photon flux than the flux regenerated from WISP that we try to detect. Hence it is not possible to use light of the same wavelength that was used to generate the WISPs. The ALPS-II single photon detector, which is sensitive to very few photons per hour, would no longer be able to recognize the signal-photons and would be completely saturated by the readout beam.

This is why ALPS-II employs a slightly different approach here. It is worthwhile to recall that not only one certain wavelength can resonate inside an optical resonator but light of every wavelength that is an integer fraction of the cavity mode perimeter. Therefore, the second harmonic of a light beam, which has half the wavelength, can be used to read out the cavity length just as well as the fundamental mode. In ALPS-II the second harmonic wave of a fraction of the light emerging from the production resonator is generated using a nonlinear periodically poled potassium titanyl phosphate (PPKTP) crystal. If the read-out of the regeneration resonator Eigenmode is now performed using this green probe beam, it can be later discriminated from the infrared signal mode prior to detection. This dichroic concept can be employed in both, the sensing for the length and alignment stabilization, with the same probe beam.

New insight into the dark matter puzzle

Because ALPS-II does not only represent an update of the ALPS-I project but involves a new design with major upgrades in all parts of the experiment – dipole magnets, vacuum system, detector and optics – it will be setup in distinct steps. The first stage consists of two 10 m cavities in vacuum. Since no magnets are installed at this stage, the search is restricted to a subclass of WISPs, so-called hidden-sector photons. The second step will scale this setup without magnets to 100 m long cavities, while in the third stage the full experiment will be installed – this includes a serial configuration of HERA dipoles around the vacuum pipes of the cavities, providing a magnetic field with a strength of 5 T perpendicular to the beam axis.

Currently installation of the 10 m production cavity of the first stage of the ALPS-II experiment is underway in the HERA Hall West at DESY while the stabilization concept for the regeneration cavities is being developed at the AEI. Therefore an ALPS-II prototype experiment with two 1 m long cavities is being installed in the AEI optics labs, which will allow to verify the dichroic length and alignment stabilization scheme. According to our plans, the full ALPS-II WISP search will be performed in 2017 and will hopefully give new insight into particle physics and cosmology.

Robin Bähre

Developments in Gravitational Wave Searches for Binary Systems

Gravitational wave (GW) signals from the inspiral and coalescence of black holes and neutron stars (abbreviated as CBC (Compact Binary Coalescence) signals) are expected to be the first signals detected by the advanced ground based interferometric detectors, LIGO, Virgo, GEO and Kagra. We can, of course not be certain about how many such events will be detected by these advanced detectors by, say, the end of this decade; however, based on our current understanding of the astrophysical processes involved and assuming that the advanced detectors operate as designed, we expect to be able to detect about 40 binary neutron star mergers within a year. The goal of the research described here is to make significant contributions to these first discoveries. I will describe two topics here to which AEI scientists have made significant progress over the last 3 years: incorporating effects of spin in our searches, and low-latency analyses.

Most of the searches for binary signals thus far have assumed that the components of the binary system are not spinning. This might seem surprising at first; after all, spin angular momentum is a fundamental property of a neutron star or black hole. Neutron stars are known to be capable of spinning at rates of hundreds of cycles each second (the fastest known rate is presently 716 Hz), and astrophysical black holes are expected to be spinning even faster, in fact close to the maximum value allowed by general relativity. Nevertheless, what matters for the gravitational wave signal is the ratio J/M^2 with J being the angular momentum and M the mass of the star. This turns out to be a sufficiently small effect for neutron stars (though not necessarily for black holes). Furthermore, the first generation of interferometric detectors where not sufficiently sensitive to detect the extra modulations caused by spin. For the advanced detectors, it turns out that spin effects become visible and it thus becomes important to include the complications due to spin especially if the binary system includes a black hole. Dealing with spin leads to two complications: First, as one might expect, the GW signal becomes more complicated and must be modeled with sufficient accuracy. Second, having additional parameters in the signal makes searching for the signal more complicated and computationally intensive; this calls for an improvement in the data analysis pipeline. Here we shall first focus on the developments in addressing the second problem.

A number of scientists at AEI have developed a new software infrastructure called PyCBC [1], based on the Python programming language, capable of addressing the computational problem for filtering data from the advanced GW detectors. An important feature of PyCBC is its ability to switch seamlessly between using standard CPUs and GPGPUs (General Purpose Graphics Processing Units), which are becoming increasingly useful for scientific computing. This leads to gains in computational speeds of up to two orders in magnitude which is why it will help enormously in addressing the problem of spin described earlier. PyCBC is currently in the final testing phase with the first non-trivial application being the development of a prototype search pipeline capable of searching for binary systems consisting of a neutron-star and a black hole. We expect that PyCBC will become the key data analysis tool for binary inspiral searches in the advanced detector era.

Let us now turn to developments in low latency analyses. In a binary system involving a neutron star, the tidal disruption of the star could lead to an electromagnetic counterpart to the GW signal. The GW signal can, in principle be detected before the neutron star is disrupted. Thus, if we could make GW detections sufficiently close to real time, we could provide early warning to astronomers. Any chance of making such early warnings for a reasonable number of events requires close to zero latency which is a significant computational challenge. Scientists from the AEI have contributed to such a low latency data analysis pipeline known as LLOID (Low Latency Online Inspiral Detection), based on "gstreamer", a commonly used multimedia software for audio and video processing. A major part of the computational challenge arises because the expected signals from binary neutron star systems can be visible for up to 30 minutes in the advanced detectors (as opposed to less than 30 seconds for the initial detectors). This in turn implies that a large number of such waveforms need to be searched in order to make a detection. Fortunately, it turns out that the morphology of these waveforms is such that the different waveforms are actually highly correlated. A useful technique for removing this redundancy is known as the singular value decomposition (SVD) which is an essential part of LLOID. The SVD allows one to reduce the number of waveforms by up to an order of magnitude thereby making the low latency search computationally feasible [2].

Badri Krishnan

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Continuous Gravitational-Waves

This research is a joint project with the Astrophysical Relativity Division

Albert Einstein predicted the existence of gravitational waves from his general theory of relativity in 1916. He deemed these ripples in space-time, emitted by accelerated, massive objects too small to be ever directly detectable.

After almost 100 years, an international collaboration is on the verge of the first direct detection of gravitational waves. By using kilometer-sized interferometric detectors and mathematical filtering algorithms to detect weak signals in the detector noise, the first direct detection of gravitational waves is only a matter of years.

Continuous gravitational waves (CWs) are one of the most promising signal types for the first direct detection of gravitational waves. Their most likely sources are rapidly rotating compact stellar remnants, called neutron stars. They have a diameter of about 20 kilometers, and have masses of 1.3 to 2 times that of our Sun. They have extremly strong gravitational and magnetic fields and high rotational velocities, reaching up to 700 revolutions per second.

There has been significant progress on a diverse range of problems relating to the search for CWs. Here we report on the relevant efforts and accomplishments in the Allen (AEI Hannover) and Schutz (AEI Golm) divisions. Our divisions play a leading role in the search for CWs conducted by the international gravitational-wave science community (LIGO Scientific Community, LSC).

Our efforts fall into three main categories: blind all-sky searches, in which none of the parameters describing the signal is known, directed searches, in which the sky position is assumed known, the improvement of existing search methods, and the development of new methods.

All-sky searches for continuous gravitational waves

In blind all-sky searches for CWs from isolated neutron stars, there are at least four unknown parameters describing the CW signals: sky position (two parameters), spin frequency, and frequency spin-down. The search problem is further complicated if higher-oder spin-downs have to be taken into account, or if the neutron stars is member of a binary system. Our division leads efforts in both blind all-sky searches for isolated neutron stars and blind all-sky searches for binary neutron stars.

All-sky searches for signals from isolated systems on LIGO data

The most sensitive blind all-sky search for CWs in LIGO data is done by the Einstein@Home project. Einstein@Home is a distributed volunteer computing projects that uses computing power donated by the general public to conduct a blind search for CWs emitted by isolated, rapidly rotating neutron stars. Successive improvements the search methods have further increased the sensitivity of the Einstein@Home searches.

Members from our division led the analysis of three Einstein@Home runs on data from LIGO's fifth science run (S5). The three searches are called S5R3, S5R5 and S5R6. The search did not yield any detection but set the most constraining upper-limits on the gravitational wave amplitude over the entire sky and the broadest frequency band to date, e.g. strain $h<7\times10^{-25}$ around 150 Hz. The reach of the search is a few kilo-parsecs for signals at these frequencies and corresponds to ellipticities that could only be sustained by fairly exotic neutron star models.

The analysis comprises various stages of post processing: removal of known spectral disturbances caused, e.g., by resonances in the detector, signal-based vetoes, characterization of the hardware injections present in the data stream, hierarchical search follow-up on different data and ad-hoc follow up of a handful of surviving candidates. Each step was developed and characterized on the actual data. The search and its results were reviewed by an internal LSC-Virgo committee to ensure their scientific veracity and quality. The paper was published in early 2013 [1].

We have now also started the analysis of data from the later sixth science run (S6) of the LIGO detectors. S6 data were used in the latest all-sky E@H runs. These data could harbor our first GW detection! The S6 all-sky E@H runs implement a new improved detection statistic to deal with disturbances in the data (see below). The analysis and characterization of the performance of these runs will help us determine an effective way to adaptively tune the free parameters of this new detection statistic.

All-sky binary CW search

While most current methods and searches in the CW-subgroup of the LSC are focused exclusively on isolated sources (for example, neutron stars that are not in binaries) we have been developing, with colleagues from the University of Michigan, USA, a new method called "TwoSpect" to search for unknown binary systems over all the sky and in a wide frequency band.

The TwoSpect methodology article [2] was selected as a Classical and Quantum Gravity highlight article for 2011-2012. The method and implementation have undergone rigorous testing and have reached a mature state. The search is running on the Atlas cluster at the AEI in Hannover, using LIGO S6 and Virgo VSR2 science data, and working upwards in frequency. The search is still progressing. The astrophysical results from this analysis will set the first-ever all-sky upper-limits on CW sources in binary systems and will likely be submitted for publication later this year.

The TwoSpect methods is also used in a collaborative effort to compare the sensitivity of different binary-pulsar search pipelines to that of a directed search for CWs from the low-mass X-ray binary Sco-X1. This system is the most promising potential source of CWs from a known binary system.

Directed searches for continuous gravitational waves

In directed searches, the sky position is assumed known. This cuts down the size of the parameter space to be searches, which enables directed searches to “dig” deeper into the detector noise and to find weaker signals with the same or even less – though still enormous – computational effort. These searches typically are run on large computing clusters and do not make use of the distributed computing project Einstein@Home.

Search for signals from the galactic center on LIGO data

A very promising region of the sky is the center of our Galaxy. As shown by radio observations, it is rich in neutron stars, increasing the chances of direct gravitational-wave detections from this point of the sky.

We have completed the first search for continuous GW signals from the galactic center. This search targets a population of young objects, with spin-down age 200 years or greater. It uses the entire S5 run LIGO data set and a novel hierarchical search scheme (similar to the all-sky search described above). The search did not result in a detection; upper-limits on the GW amplitude of a population of sources at the galactic center yields values as low as strain $h<3\times10^{-25}$ around 150 Hz. These limits are a factor of two more constraining than the all-sky upper-limit. The post-processing includes an improved spectral line-cleaning procedure, a new signal-based veto which tests the persistency of candidate signals and an ad-hoc coherent follow-up of about 1000 candidates.

The follow-up probed candidates down to levels of significance very close to the minimum that could be confidently disproved as being of GW origin within the time-span of the data. At the time of writing the search and the post-processing of the results is complete, the internal review is nearing completion and a draft of the observational paper has been finished. We expect the observational paper to be submitted to Physical Review D soon.

Search method improvements

As of today, there are still open questions in the construction of mathematically optimal searches for weak CW signals in noise. Our divisions have contributed to improvements of the search methods employed in a variety of fields.

Sensitivity estimation

Correctly estimating the expected sensitivity of a semi-coherent search for CWs has proved to be surprisingly difficult. A rough scaling relation, which had been commonly used for this purpose, was recently found to be biased by up to a factor of 2.

We have developed an improved semi-analytical method to quantitatively estimate semi-coherent sensitivities, published in [3]. We have further developed an easy-to-use numerical implementation, for accurately estimating the sensitivity of so-called StackSlide and Hough-type semi-coherent searches. This method was successfully applied to estimate the expected sensitivity of the recent 'S5R5' Einstein@Home search on S5 data. Our theoretical prediction agreed with the actual obtained sensitivity of this search to better than 10%, see the red curve in Figure 1.

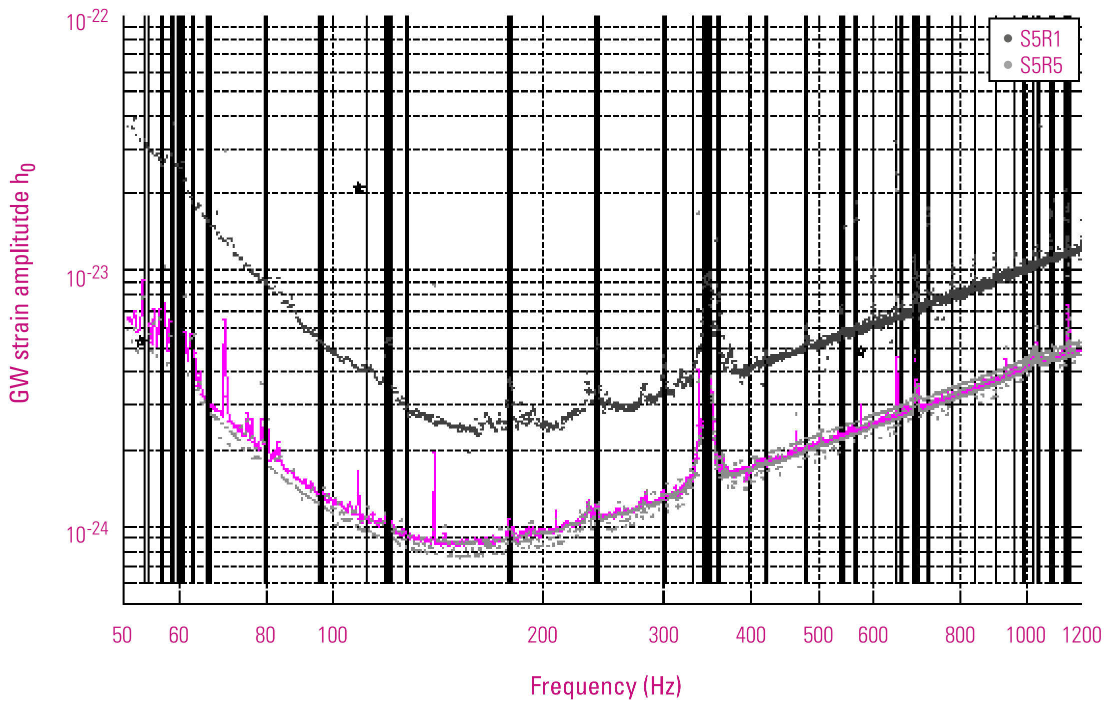


Fig.1: Upper limits on strain amplitude h_0 at which 90% of signals would be detected, from the S5R5 and S5R1 Einstein@Home all-sky searches, which used LIGO S5 data. The three stars correspond to hardware-injected simulated pulsars which were recovered in the S5R5 search. The red curve shows the theoretically predicted 90%-confidence sensitivity. The vertical bars indicate frequency bands contaminated by instrumental disturbances for which no upper limits are provided.

Improving semi-coherent search methods

For virtually any wide parameter-space searches, the currently most sensitive method known at fixed computing cost consists in using a semi-coherent statistic. This means computing a coherent statistic, e.g., the so-called F-statistic, over a number of shorter segments of data, and then combining these statistics incoherently. A number of important questions about these methods remain unanswered, and a lot of work on improving our sensitivity is therefore currently focused on this domain.

We have found a semi-analytical solution to finding the optimal search parameters at given computing cost [4], which applies to the "classical" StackSlide semi-coherent method currently used within the CW search group of the LSC. This simple method can determine optimal solutions under "ideal" conditions of stationary data without gaps. We are currently working on extending this method numerically to the more realistic case of non-stationary data with gaps. We have also found a way to improve the StackSlide sensitivity (at fixed computing cost) by up to ~20%, by using overlapping segments instead of non-overlapping segments [5]. These improvements amount to increasing by up to ~70% the sensitive volume of such a search.

Recent work in our divisions is focused on better understanding our current "workhorse" implementation of the StackSlide method, based on the particular "global correlations transform method" and the semi-coherent metric. This method and implementation was used in recent Einstein@Home and galactic-center searches, discussed above

CW metric

The CW "metric" describes the loss of signal-to-noise ratio of a detection statistic as a function of the parameter-offsets from a putative signal, and is an essential ingredient to building effective template banks. For many years, the intrinsic curvature and coordinate-dependency of the sky metric has thwarted our efforts to construct efficient and simple template banks for all-sky CW searches. This technical difficulty has also slowed-down efforts to implement efficient all-sky semi-coherent methods which work correctly for arbitrary segment lengths and data-spans.

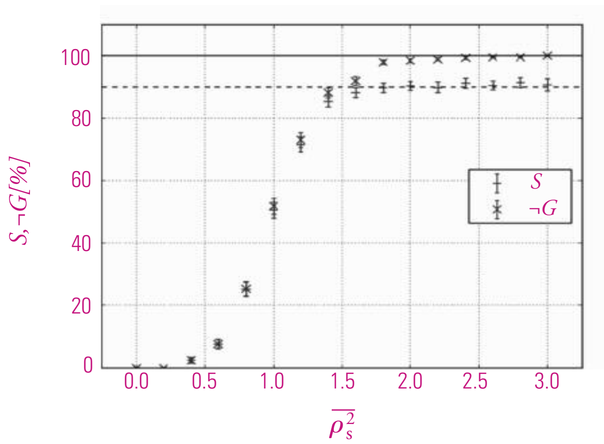
We have been working on a flat all-sky metric approximation, which is based on the observation that the so-called "supersky" CW metric is strictly flat. In this approach the physical 2D sky-sphere is viewed as an embedding in a 3-dimensional "supersky". This constant metric is very useful for measuring mismatches, but further work had been required to derive a flat approximation in the "physical" 2D sky, which is necessary for constructing efficient template banks. This project is approaching its conclusion, and a paper on the method is currently in preparation.

Coherent follow-up of semi-coherent candidates

A common problem faced in the post-processing stage of semi-coherent searches is the efficient and conclusive follow-up of interesting candidates, using a more sensitive method. This is necessary in order to be able to either rule out candidates or to confirm them as potential CW sources. Given that such searches often yield an enormous number of candidates, a computationally-efficient follow-up method is required.

We have initially studied the minimal required coherence time for fully-coherent follow-up of such candidates, depending on their strength and have subsequently developed the first automatic follow-up pipeline. This coherent follow-up uses a "mesh-adaptive direct search" (MADS) method, as implemented in the publicly available NOMAD library. This dramatically reduces the computational requirements for such a "brute force" follow-up, compared to a traditional grid-based search, which would often not be computationally feasible (especially for all-sky searches).

This pipeline has been successfully used in the follow-up of Einstein@Home candidates from the S5R5 run, and a methods paper on this fully-coherent follow-up pipeline has been submitted for publication [6]. Figure 2 shows a representative example of the MADS follow-up performance on Einstein@Home-like semi-coherent candidates.



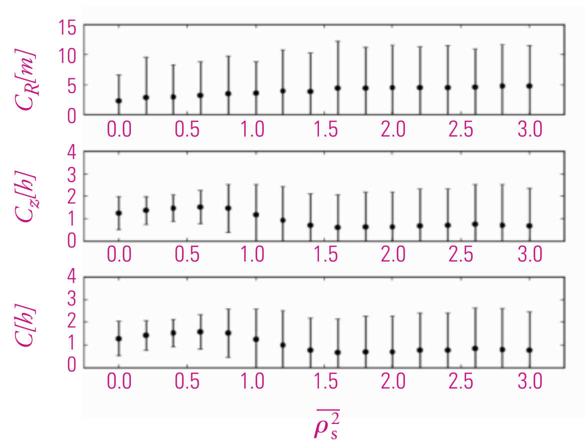


Fig.2: Monte-Carlo study of a 2-stage follow-up of candidates from an all-sky semi-coherent search with 200 segments of 1-day duration. Left: Percentage of injected signals classified as recovered (–) and of non-Gaussian origin (x) as a function of signal strength. Right: Computing cost of follow-up refinement stage (upper plot), fully-coherent zoom stage (middle plot) and total computing cost (lower plot), as a function of signal strength.

We are now working on further improvements to this pipeline, which incorporate several intermediate semi-coherent stages, which are expected to improve sensitivity and reduce computing cost. Our hope is to move this automated follow-up, or some similar type of follow-up, upstream to the Einstein@Home host machines. Then, these hosts will only return candidates that are statistically-significant when coherently integrated against the entire science data set.

Robust CW statistic versus detector artifacts

A common problem for CW searches is that our standard statistics typically test the signal hypothesis against the Gaussian-noise hypothesis only. Real detector data, however, contains many artifacts, some of them resembling the CW signals we are looking for (these artifacts are commonly referred to as "lines").

Formalizing the heuristic methods employed in analyses of real data, we have developed a new approach. This extends the Gaussian-noise hypothesis by a (simple) line hypothesis, and computes the corresponding extended Bayes factor. This new statistic can be tuned either to test for signals versus lines (i.e. to function as a "line veto"), or to test signals versus "noise" that is either Gaussian or a line (yielding a "line-robust" statistic).

A preliminary study on this idea was published [7], and a paper describing the full extension and testing of this method on real data is currently in preparation. Figure 3 shows the improvement in detection efficiency of this new statistic.

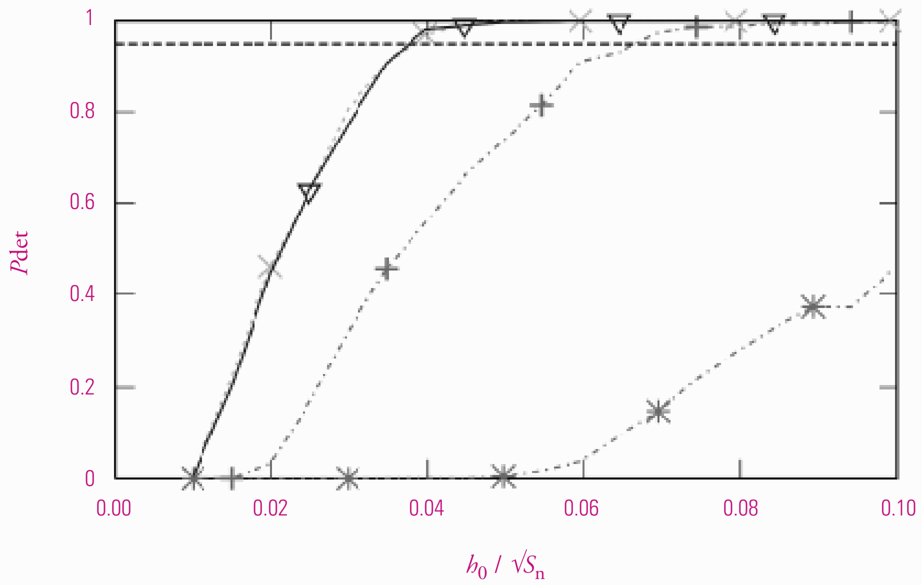


Fig.3: Detection probability as a function of scaled signal strength, comparing different statistics on a LIGO S5 first-year frequency-band (69.70-69.75 Hz) containing strong detector arti-facts. The curve with stars shows the standard F-statistic and the curve with plus-signs the same with additional F-statistic consistency veto. The curve with triangles shows the new "line-robust" detection statistic and the line with crosses a simpler "line-veto" statistic.

This new statistic is currently being deployed in the all-sky Einstein@Home search on S6 data. The performance of the technique is being benchmarked as part of the full analysis of this data.

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Canonical and Covariant Dynamics of Quantum Gravity Max Planck Research Group

Towards the Continuum and Large Scale Limit of Quantum Gravity Models

"What is the nature of space and time?" This is a question that has been central to the development of physics through the centuries. Quantum gravity research aims at unifying Einstein's vision of space-time as a dynamical object with the realization that fundamental physics and hence space-time itself has to be quantum.

Discrete models have become the leading tool for the construction of quantum gravity theories, such as loop quantum gravity, spin foams, causal sets, Regge gravity and dynamical triangulations. Not only do discrete models provide a very effective method to access non-perturbative physics. In many approaches to quantum gravity, discrete structures are also postulated to be fundamental. This offers the compelling picture of space-time emerging from some more fundamental structure.

A better grasp of this transition from some discrete microscopic structures to some continuous phase, describing space-time on larger scales is the most crucial point for non-perturbative approaches to quantum gravity. It is an imperative to realize a smooth continuum limit in order to validate any approach to quantum gravity and to make predictions of measurable physical effects.

This can be compared with deriving the hydrodynamics description of water from its atomic descriptions and interactions. There are however several additional challenges: Whereas (matter) atoms move in space, in our case the (space-time) atoms make up space-time itself. This prevents us from using standard notions, which are used in describing macroscopic states of matter, most importantly the notion of energy. Such a notion is however essential in the usual derivations of large scale behavior from a microscopic theory, as it distinguishes relevant (for large scale dynamics) and irrelevant degrees of freedom. Adopting so called tensor network techniques that have been developed in condensed matter systems Dittrich (2012) [1] proposed a scheme that circumvents these difficulties. The relevance of degrees of freedom is decided by the dynamics of the system without having to specify an energy parameter from the outset. The dynamics also decides in which way microscopic variables are summarized into parameters describing physics on larger scales.

These methods have been applied to a number of simplified spin foam models by Eckert, Martin-Benito and Dittrich (2011) [2], showing the feasibility of this framework for background independent models.

Furthermore a reformulation of spin foam models put forward by Bahr, Dittrich, Hellmann and Kaminski (2012) [3] allowed new insights into the dynamics of these models. This work put also forward a range of simplified models that are amenable to numerical treatment but still feature the key dynamical mechanisms of spin foam models.

Numerical investigations of these models is currently under way and the results will show which macroscopic phases we have to expect for spin foams.

Hellmann and Kaminski [4] used this new formulation of spin foam models in order to investigate the regime where the building blocks are large. To this end they adopted theorems and techniques from micro-local analysis to lattice gauge theories. Whereas before this kind of limit has been investigated on single building blocks, the techniques introduced by Hellmann and Kaminski allowed for the first time an understanding of this regime for arbitrary triangulations. This allowed key insights into the dynamics of spin foam models, as indeed an important part of it describes how the building blocks couple to each other.

Bianca Dittrich

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Microscopic Quantum Structure and Dynamics of Spacetime Research Group

Cosmology from Group Field Theories

One of the most pressing issues in any quantum gravity approach is the connection of the microscopic theory with the physics of large scales, a necessary step to provide quantitative predictions for observable quantities.

The early Universe is a context where this is urgently needed. Indeed, the early stages of the evolution of the Universe have a strong influence on the seeds for inhomogeneities in the distribution of matter, resulting in the evolution of structures and, ultimately, us. These primordial inhomogeneities leave a characteristic imprint on the Cosmic Microwave Background (CMB) radiation, whose properties are nowadays observed with greatest precision.

Despite the success of phenomenological effective theories in fitting the data, we still do not have a model solidly grounded in a fundamental theory of space, time and matter giving rise to testable predictions directly from the microscopic theory. However, some important steps in this direction have been made, recently, within the framework of Group Field Theories, with the identification of states associated to homogeneous cosmologies and their dynamics.

Spacetime as a condensate

From a technical point of view, Group Field Theories (GFTs) are quantum field theories over group manifolds, designed to define a sum over histories approach for gravity. With the appropriate assumptions, a perturbative expansion of the partition function generates Feynman diagrams that have a precise correspondence with discrete geometries, and their quantum amplitudes. Alternatively, they can be seen as second quantized theories for Loop Quantum Gravity (LQG) spin networks. The Feynman diagrams of GFTs, then, can be seen as quantum histories for spin networks, i.e. spinfoams.

The key feature of GFTs is that they are pre-geometric: spacetime is a derived concept, related to the collective behavior of a large number of quanta, combinatorial in nature. We will call this process, the birth of space and time, geometrogenesis. The first task, then, is to show how it occurs. Inspired by the results of matrix models and (causal) dynamical triangulations, it can be argued that it should correspond, technically, to a phase transition of the microscopic model. This is essentially an open problem, in GFT.

Pictorially, one can imagine that geometrogenesis is the transition from a phase in which the elementary GFT quanta are in a disordered state, to a phase in which they are coherently assembled in terms of a macroscopic entity effectively described by continuum geometry and matter fields living over it. Geometry would be analogous to the spontaneous magnetization in a ferromagnet or to the fluid density and velocity in a Bose-Einstein condensate of ultracold atoms, a special class of fluids for which quantum mechanics plays a major role.

This analogy has to be taken with a grain of salt, of course, but, as it turns out, it leads to important consequences and precious insights.

Inspired by these ideas, in a very recent paper [1], Gielen, Oriti and Sindoni have introduced a class of quantum states which have a natural interpretation in terms of homogeneous cosmologies, i.e universes that are homogeneous at large scales. Furthermore, following the standard methods used to describe Bose-Einstein condensates, it has been shown for the first time how to derive the effective dynamics for the corresponding cosmological spacetimes, directly from the microscopic theory. The explicit form of the equations for the effective geometry, in simple cases, is similar to the equations derived from General Relativity, i.e. the Friedmann equations.

GFT Condensates and Cosmology

The basic ingredient of the derivation is the choice of a special class of states in the complete theory. We call them GFT condensates, because this is what they are: coherent states of pairs of GFT quanta, similar to the states used to describe Bose-Einstein condensates.

In the case of four-dimensional theories, these states have the natural interpretation of an ensemble of (disconnected) quantum tetrahedra whose wave function encodes the geometric data (eg. areas, volumes, etc). Consequently, GFT condensates can be seen as quantum superpositions of samplings of a spatial slice of a four dimensional geometry by means of tetrahedra.

Being Bose condensates, these states associate to each quantum tetrahedron the same wave function and the same geometric data. Therefore, they are naturally compatible with a notion of homogeneous (but possibly anisotropic) geometry, as it can be shown explicitly with an embedding procedure.

The wave function of the tetrahedra plays the same role of the condensate wave function of real Bose-Einstein condensates. Its equation of motion, derived directly from the complete GFT quantum equations of motion, can be seen as a Gross-Pitaevski equation for the hydrodynamics of the condensate. Being nonlinear, it is a peculiar generalization of the standard Wheeler-DeWitt equation for quantum cosmology.

It can be shown very easily that, for a certain class of models, this equation contains a modified Friedmann equation for the usual cosmological variables (the scale factor and the Hubble parameter). The corrections to the standard relativistic equation are controlled directly by the microscopic dynamics of GFT. Modified Friedmann equations should arise in a similar way from the models for four dimensional gravity, like the one proposed by Baratin and Oriti or the so called EPRL model, although this is still work in progress.

A road to observations

Analogies are not identities, but they can still be useful to rephrase a problem in a different language and propose trial solutions in unconventional terms. GFT condensates represent an example of a fruitful analogy.

Summarizing the results, GFT condensates offer a first description of macroscopic cosmological spacetimes directly in terms of the fundamental quantum constituents. At the same time, the effective dynamics of the macroscopic geometry can be computed immediately from the equations of motion of the full quantum gravity model, and they have the form of modified Friedmann equations.

This achievement is extremely valuable for at least two reasons. First, it is a first example of a derivation of the effective theory for continuum geometry directly from a pre-geometric model and its equations, a necessary step to connect quantum gravity with observations.

Second, it can play a guiding role in the proof that the geometrogenesis transition really occurs. This requires the analysis of the perturbative expansion at large order, the resummation of the perturbative series, the analysis of singularities and the study of the renormalization properties. There are important recent results, especially by Carrozza, Oriti and Rivasseau [2] on renormalizability, but much more work is needed. For this purpose, hints from physical intuition can be extremely important, and GFT condensates might give important clues and suggestions.

GFT condensates represent also a turning point with respect to the current approaches to quantum cosmology originated from LQG and spinfoam models. Indeed, instead of the quantization of the restricted sector of general relativity corresponding to cosmology, GFT condensates are quantum states of the full theory, corresponding to what can be identified as the homogeneous sector. Their equations of motion, then, contain the effects of the complete dynamics of the full microscopic theory.

Furthermore, contrary to other quantum cosmological models like spinfoam cosmology, these states do not make reference on a fixed triangulation of spacetime. This fact will be of great importance for the physical predictions that these states could provide for the early universe and the origin of cosmological perturbations, since there is no obvious cutoff for the modes, given the lack of a background lattice structure.

Further developments are needed: the analysis of Lorentzian models, the coupling with various forms of matter fields and the inclusion of inhomogeneities as phonons above the condensate. With these ingredients, the ambitious goal of formulating concrete physical predictions, e.g. the spectrum of anisotropies in the CMB radiation, as measured by the satellite Planck, will be within reach. Such a direct connection with observations could be a new and unexpected way to test and constrain microscopic models for spacetime.

Lorenzo Sindoni

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Classical and Quantum False Vacua

In classical theories, vacua are solutions of the field equations which minimize locally the energy functional. In most cases the latter includes a positive–definite kinetic term and the requirement of minimal energy implies that, in a vacuum state, all generalized coordinates do not vary in time. The importance of finding the classical vacua of a given system and understanding their properties is intuitively clear but also deep–rooted. First, in many situations the interactions with external degrees of freedom can act effectively as a dissipative force, increasing entropy and draining energy out of the system: this process ends when the state of the system approaches a vacuum state and energy cannot be further lowered. Second, solving the field equations after linearizing them around a vacuum solution is usually much simpler than finding the general non–linear solution. Linearized solutions describe the evolution of small deviations from the vacuum and remain a good approximation to the full dynamics even on long time scales: an uncontrolled growth of these deviations, hence the escape from the regime of validity of the linear approximation is not compatible with energy conservation (perturbative stability). In short, energy conservation makes classical vacua the natural endstates of a dissipative evolution, also "preventing" residual small fluctuations from moving the system far away from such end–state. This also implies that, once a vacuum is "selected" by the classical evolution, the existence of other vacua is essentially irrelevant from a classical viewpoint.

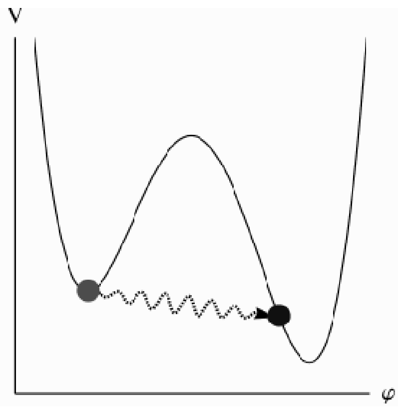

Fig.1: Quantum fluctuations enable tunneling from a meta-stable vacuum (light gray) to a lower energy vacuum (dark gray).

When quantum fluctuations are taken in account, these conclusions must be radically re–considered. According to one of the interpretations of Heisenberg's uncertainty principle, violations of energy conservation of arbitrarily amplitude can take place, provided they last for a short enough time. This implies that, if the system is initially "trapped" around a given vacuum, quantum fluctuations can always make it tunnel towards a lower energy one, if this exists, in such a way that energy conserva- tion is restored after the quantum leap (see Figure 1). In this case, the initial classical state is called meta–stable or false vacuum, and no stationary quantum states corresponds to it. The decay rate, hence the lifetime of the meta–stable vacuum, can be computed in a closed form in the semi–classical approximation, by finding a solution of the classical Euclidean field equations, called instanton or bounce, which approaches the false vacuum in the asymptotic Euclidean past and future. In this formalism, the bounce solution describes the classical state of the system after tunneling: a bubble of true vacuum appears, whose size and properties are described by the instanton. Afterwards, vacuum energy gets converted into kinetic energy of the bubble wall, in such a way that the latter starts expanding at nearly the speed of light (see Figure 2). Bubbles randomly appearing at different times and places inevitably collide, and the energy carried by their walls is turned into inhomogeneities. In the end, all space is filled with true vacuum and the phase transition is complete.

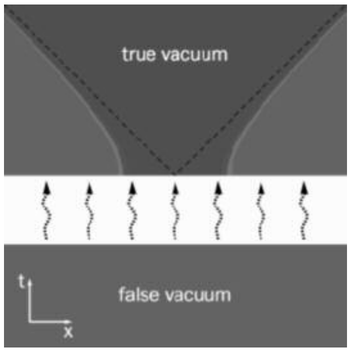

Fig.2: Space-time representation of vacuum decay in Minkowski field theory: a bubble of true vacuum materializes and starts expanding at nearly the speed of light.

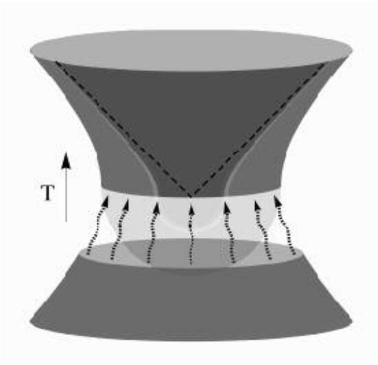

Fig.3: Space-time representation of bubble nucleation in de-Sitter space, in a three-dimensional embedding. The Euclidean CdL instanton, depicted in transparency, sets the initial conditions for the appearance and evolution of the bubble.

Decay of cosmological vacua: the Coleman–de Luccia picture

Not surprisingly, meta–stable vacuum decay is a central concept in many cosmological scenarios. The first inflationary models (old inflation) explained the early phase of accelerated expansion, required to solve the classical cosmological problems, as a consequence of the vacuum energy of a meta–stable vacuum, in which the universe was trapped while cooling down [1]. Decay via bubble nucleation was then considered as the natural mechanics to end inflation and enter the hot big bang era. Afterwards, it was realized that bubble collision was too unlikely, due to the expansion of the false vacuum separating different bubbles, to produce the amount of radiation needed for the subsequent hot big–bang era. However, meta–stable vacuum decay remains somehow inevitable as soon as the theory one considers admits multiple vacua. In String Theory this property is dramatically present: the number of false vacua, forming the so–called string landscape, is thought to be a very large number of order 10^{500}. Vacuum decay then describes how, via bubble formation, this landscape can be randomly "populated" starting from generic initial conditions: the rates governing this stochastic process can be computed by finding the appropriate instanton solutions.

The semi–classical approach to vacuum decay in curved space, relevant for cosmological applications, was first developed by Coleman and de Luccia in 1980 [2]. Since then, their analysis has become a classic of theoretical physics, and the solutions they discovered are commonly referred to as Coleman–de Luccia (CdL) instantons. These are solutions of the Euclidean field equations de- scribing matter coupled to Einstein gravity: the resulting instanton geometries are generally curved (see Figure 3), and the corresponding decay rates are different from flat space.

Beyond CdL

Even though CdL solutions have been now known for more than 30 years, important issues have been addressed only much more recently, while others are still open today. All of them can be associated to two key features which distinguish the CdL setup from the flat–space case. First, the physical interpretation of curved–space instantons as decay–mediating solutions must be revisited or even abandoned. For example, the role of thermal effects in the decay of de Sitter (dS) space has been clarified only in recent years [3]. It is now understood that decay of dS vacua requires a preliminary process of "thermal activation": the temperature associated to the de Sitter horizon allows thermal fluctuations which can displace the order parameter from the false vacuum value, before the instanton–mediated tunneling takes place. A second example is given by "strange" instanton solutions which, though they look like standard CdL instantons, should not contribute to vacuum decay. Indeed, a consistency condition in the semi–classical treatment restricts this interpretation to those solutions which possess a single negative mode, i.e. a single direction in configuration space along which the Euclidean action decreases. The correct way to implement this condition in the curved–space context, established more than a decade after CdL's work, still appears to be unadapted to some recently discovered CdL solutions. This problem, whose resolution is decisive for the consistency of instanton–mediated vacuum decay picture, is currently under investigation.

A second class of issues is related to the ambiguity of the notion of "energy" for bubble sections in curved space. The failure of existence and uniqueness properties of instanton solutions, insured by energy–related arguments in flat space, is a clear manifestation of this ambiguity: almost twenty years after Coleman and de Luccia's work, new instanton solutions were found for which the order parameter, taken to be a single scalar field, oscillates multiple times between the true and false vacuum values across the bubble wall [4]. It is still today not fully understood to which extent these solutions have to do with vacuum decay. Moreover, in apparent contradiction with the flat– space existence proof, the CdL solution describing the decay of de Sitter space disappears when the wall thickness exceeds the de Sitter radius. Finally, in a recent paper in collaboration with G. Lavrelashvili, the author and J.–L. Lehners have shown the existence of CdL instantons mediating between degenerate de Sitter vacua [5]. These solutions have no flat space analog, where no decay can take place between degenerate vacua, but have been shown to possess a single negative mode, which makes them indistinguishable from standard CdL solutions.

Instanton–mediated vacuum decay is today a standard tool in theoretical cosmology and, in particular, plays a crucial role in the cosmology of the string landscape. The beautiful answers provided by Coleman and de Luccia's work have left important issues and questions unresolved: while some of them have been addressed since then, a solid understanding of the general picture of tunneling via bubble nucleation is still not reached. Whichever new conclusions this picture will bring, they are likely to occupy a special place in our description of the very early universe.

Lorenzo Battarra

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Activities and Highlights of the IT Department in 2010-2012

During the past years we could increase the level of efficiency. Green IT was no longer a buzzword only, but efficiency in saving energy became a default requirement for the general infrastructure when purchasing and operating hardware. As good designed software can contribute to power savings as well, applications are also being examined since 2010.

While efficiency became a normal aspect for operating IT infrastructure, it was not yet adopted to the processes and procedures in the work of the IT staff. So in 2011 we started to implement methods to improve the IT service management. The organizational structure of the IT department was rebuilt regarding efficiency and transparency. Some elements of the ITIL (Information Technology Infrastructure Library) formed the basis for this renewal.

Organizational structure

The IT department serves the general IT infrastructure on both sites, AEI Hannover and AEI Potsdam. The requirements of the scientists at both branches are different in terms of daily requests as well as in general services. But nevertheless special subgroups in the IT department that have specific tasks and responsibilities can be identified.

Group "Operation"

The responsibility of this group is to maintain the IT infrastructure. The group has to operate the core services such as mail and web, has to be aware of IT-security, has to patch and update the clients (LINUX, MAC and Microsoft Systems), and has to run the various networks (WAN, LAN, WLAN (including eduroam[1])) etc.

During the past three years many projects have been set up to improve the core services. Outstanding projects were:

- Introducing Single Sign-on
- Setting up a new mail server including groupware facilities
- Integrating the storage, respectively the file system of the high performance compute cluster into the general IT infrastructure and vice versa and thus creating a private storage cloud
- Upgrading the backbone network in Potsdam
- Increasing the capacity of the network link between Ruthe and AEI Hannover.

IT service desk

The IT service desk is part of the group *Operation*. It is the single point of contact where the users can find help for and answers to all kind of problems and questions. The IT service desk is responsible to set up accounts, to help users in their daily work with IT components, including mobile devices like smartphones, tablet PCs and such. The staff gives advise for using dedicated software and installs the appropriate apps. A ticket request system helps to keep track of all the requests and wishes of the users.

The staff of the IT service desk also supports all kind of events or meetings where special equipment (videoconference or presentation technique) is required.

1 **eduroam** is an acronym for roaming in the education and research area. (See http://www.eduroam.de/what-is-eduroam/)

HPC, visualization, Labs

The staff responsible for operating the complex infrastructure for high performance computing (HPC), for visualization and for running the very special IT equipment in the labs (in Hannover only) is also part of the group *Operation*.

A highlight for the HPC group was the inauguration of the new NEC-cluster Datura, on 5th April 2011. The inauguration took place during the Cluster-Day2011@AEI meeting.

Datura was purchased as replacement of the outdated cluster Damiana.

The performance of Datura is 2-3 times higher than that of Damiana but has less power consumption. On full load the power consumption is 80 kWh with Datura and 70 kWh with Damiana.

Datura is a high performance Infiniband cluster equipped with 200 nodes, 2400 Cores, 4800 GB main memory, 2 visualization machines, 6 Lustre[2] storage servers, 12 Lustre storage targets, 2 head nodes. The main communication and storage network is based on Infiniband QDR 40Gbit/s to benefit of low latency and high bandwidth. To achieve the maximum throughput and to handle the huge amount of parallel I/O operations, Datura is using a 4-folded multi-homed global Lustre file system with 214 TB of disc space for production runs.

It is remarkable that the 200 nodes from the outdated cluster Damiana nowadays serve as virtual desktop machines. The nodes are no longer fast enough to run high performance applications but as virtual machines they do a perfect job.

User Data Office + Application & Database Services

The staff of the "User Data Office + Application & Database Services" is responsible for all user data handled by the IT department and other service departments. The data is stored in databases and is used with directory services or helpful web-based applications. The data mainly concerns user accounts, access rights, loans of IT equipment, and such. Tools written by the staff help to automatically generate member lists for web sites or other lists for all kinds of reports. Directories are synchronized with the appropriate databases, so that user accounts can better be kept under control in respect of validity and expiration dates.

Canto Cumulus is a scientifically driven application. This software is a powerful digital asset management software that organizes images, movies, videos and documents. New workflows were created to make the usage of the rather complex software as easy as possible.

This group also investigates in setting up an Identity Management System (IDM). Such a system leads to better administration of Single Sign-on. The IDM would also enable an exchange of entities, which allow access the various applications and services regarding the identity roles and rights.

The group is not only responsible for providing IT devices and software for the members of AEI but also develops and maintains databases that help with the inventory of all IT stuff at all.

Group "WEB developments"

The web developers are responsible for designing, programing and providing web sites and for developing web-based applications. This support is requested by the scientists who want to present their scientific results on the WEB as well as by the service departments that need special applications to handle bulk procedures more efficiently (e.g. support tender procedures).
The support for large conferences (more than 200 participants) is always a big challenge. Back office activities for registration and handling the various international payment methods are invisible to the participants but are very important and time saving to the financial department and the local organization team.

An important issue in 2012 was the launch of our new Intranet. It helps since then to distribute internal information in an easy and good structured manner. The well-known and well established intranet from the IT department (help.aei.mpg.de) has been integrated into the new Intranet, so that handling for the users remained unchanged.

At the time of writing (March 2013) the team together with the public relations office is working on a relaunch of the main AEI web site (www.aei.mpg.de). Special web sites like hyperspace.aei.mpg.de and einstein-online.info are linked from the main page of www.aei.mpg.de. The web developers also have developed most of the conference or event sites.

Christa Hausmann-Jamin

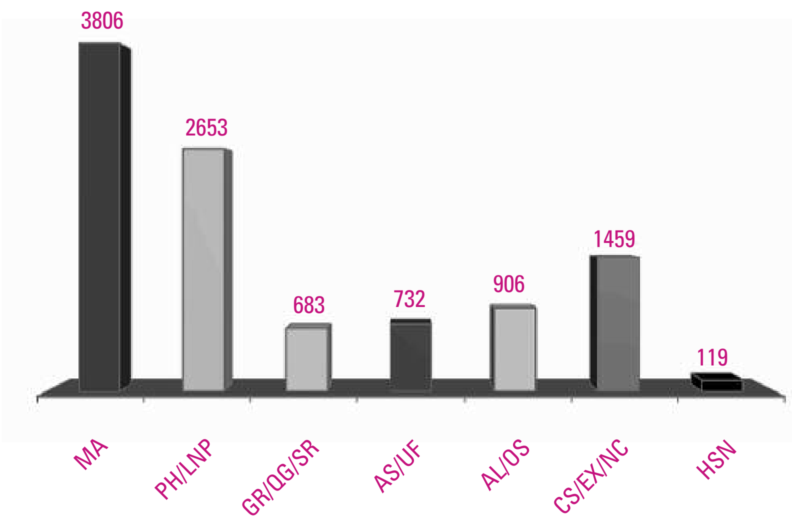
2 Lustre filesystem: „Lustre is a parallel distributed file system, generally used for large scale cluster computing." (http://en.wikipedia.org/wiki/Lustre_(file_system))

Activities and Highlights of the Library in 2010 - 2012

The library is a specialized library offering services primarily to scientists working at the institute in Golm and Hannover. Scientists from outside are welcome and usage is possible on appointment.

Two librarians manage the library: Mrs. Elisabeth Schlenk (head of the library) and Mrs. Anja Lehmann.

The collection increases continuously. By the end of 2012 our catalogue listed 11.315 monographs and conference reports, 13.190 bound journal volumes, 134 printed journal subscriptions and online access to journals covered by the Grundversorgung, i.e. the Max Planck Society (MPG) secured a permanent right to full text access for more than 32.000 journal titles.



AL: General; **AS:** Astronomy, Astrophysics, Cosmology; **CS:** Computer Subjects; **EX:** Exp. Methods Measurements; **GR:** Gravitation & Relativity ; **MA:** Mathematics; **NC:** Numerics & Computation; **OS:** Other Sciences; **PH/LNP**: Physics incl. Lecture Notes in Physics; **QG**: Quantum Gravity; **SR:** Special Relativity; **UF:** Unified Field Theory & Other Theories of Gravitation; **HSN:** Theses

Concerning the free use of e-books we also benefit from the Grundversorgung and about 100.000 e-books are searchable in the catalog of the Max Planck Virtual Library (http://vlib.mpg.de/). Information on access, content and licences is also available at this location.

In terms of an embedded library and in addition to the usual tasks of librarians, we are constantly looking for new ways to facilitate and optimize the use and the organization of the library.

After numerous discussions we have taken responsibility for the management for the institute's scientific publications. Anja Lehmann is responsible for the registration of all AEI publications into the PubMan server 'MPG.PuRe' (http://pubman.mpdl.mpg.de/). This refers to 3.950 items since 2010. For most of them this includes a link to the fulltext version. The intention of this electronic document server is to increase the visibility of the intellectual output of the MPG and to add to the world-wide virtual repository of high-quality scientific information. It was developed and is updated by the MPDL (Max Planck Digital Library) and contains bibliographic data and numerous fulltexts of the publications of MPG researchers.

Other topics we actively support are Catalogue Enrichment, e-Books, Virtual Library, Open Access, Document Ordering, Electronic Resource Management and Bibliometric Analysis. Those topics arise either from initiatives of the MPDL (Max Planck Digital Library), colleagues from other libraries or requests from scientists working at the AEI.

Regarding bibliometric analysis it becomes apparent that we have to accept the assistance of professionals, because the publication behavior of our scientists is diverse. The MPG uses methods for the interpretation and representation of the results following the 'Standards for the application of bibliometrics in the evaluation of research institutes in the field of natural sciences'. This covers only articles and reviews published in scientific journals which are analysed in the Thomson Reuters Web of Science (WoS). Other publications are not included in this quantitative analysis of scientific activities.

Lutz Bornemann (Division for Science and Innovation Studies, MPG) and Werner Marx (MPG, Information Retrieval Services, IVS-CPT) made a bibliometric analysis (January 2013) of AEI publications in the period 2002-2012.

What follows is a summary of this analysis; further information is available on the library-homepage:

- The institute produces, on the average, 143 papers per year with a clear increase over the years.
- Two-thirds of all publications appeared in only seven journals (Physical Review D, Classical and Quantum Gravity, Journal of High Energy Physics, Physical Review Letters, Nuclear Physics B, Astrophysical Journal, Physics Letters B).
- They were cited 29.372 times, including self-citations by the authors and other AEI members.
- The institute's published papers belong, on average, to the top 25% most cited papers within their subject categories.

The last but not least two points to mention are:

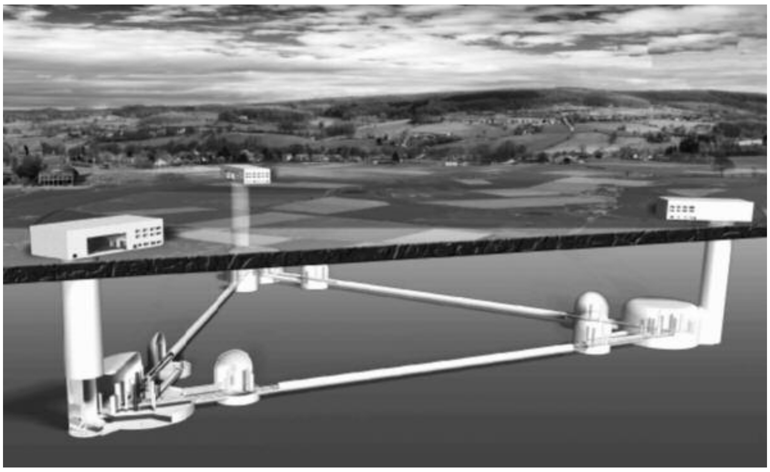
- Anja Lehmann has sucessfully finished an Open University Course in Information Sciene at the Fachhochschule Potsdam with the qualification 'Diplom in Librarianship'
- In May 2013 we are organizing, for the third time, the Annual Meeting of MPG-Librarians.

Elisabeth Schlenk

Events

4th Einstein Telescope symposium, December 4-5, 2012, AEI Hannover

The 4th Einstein Telescope symposium was organized by and held at the AEI Hannover with about 80 participants, 63 of which were visitors from outside the institute. The scope of the conference was the communication of the current status of the research done and the results achieved in the various institutions within the last year and a discussion about the future organization of the research and funding. A representative of the BMBF was also participating in the meeting. Despite very limited funds available for ET research all over Europe the cohesion of the ET community was impressive and remarkable scientific progress could be observed. The meeting showed clear synergies between the Einstein Telescope and the KAGRA project (a Japanese underground GW detector project, pioneering some of the ET technology), which are exploited in the ELiTES project to the mutual benefit of both sides of the scientific exchange.



Artist's impression of the Einstein Telescope

For further information please see: *http://et-meeting2012.aei.mpg.de/*

Harald Lück

Workshop "Reflections on Space, Time and their Quantum Nature" November 26-28, 2012, AEI Golm

The workshop has brought together theoretical physicists working on spacetime theories, cosmology and quantum gravity, and interested in foundational issues, with philosophers of science studying conceptual aspects of spacetime physics and of quantum gravity. The total number of participants, in the end, including local AEI members who attended most of the talks, was 26. The range of topics was quite broad, touching upon philosophical and physical aspects of classical and quantum gravity, foundational issues in quantum mechanics and problems in the foundations of cosmology. The list of external participants (beside members of the AEI) includes theoretical and mathematical physicists working on quantum gravity, cosmologists, philosophers working on foundations of spacetime theories, and historians of theories of space, relativity and geometry. The workshop has been co-organized by Dr. Oriti and Prof. Nicolai. A member of the administration, C. Gottschalkson, has also participated to the local organization of the logistic aspects of the workshop. The necessary funding was provided by an FQXi grant awarded to Dr. Oriti, by the Quantum Gravity and Unified Theories division of the AEI and by the Alexander von Humboldt Stiftung, via the Sofja Kovalevskaja Award to D. Oriti.

For further information please: *http://workshops.aei.mpg.de/philQG*

Daniele Oriti

EPTA consortium meeting, November 4-7, 2012, AEI Golm

Meetings of the EPTA (European Pulsar Timing Array) consortium take place twice a year: in spring and in autumn. Two members of AEI (Alberto Sesana and Stanislav Babak) have become members of EPTA yearly 2012. In this meeting we have established several working groups responsible for the observations, data reduction and quality, gravitational wave sources modelling and data analysis. Each group has reported on their progress and we have set up a plan for the end-to-end (from production to analysis and result interpretation) search of PTA data for gravitational wave signals in nano-Hertz frequency band.

The official part of the meeting has finished on November 7th but the majority of the participants have stayed until the end of the week and continued discussion and work in small groups.

For further information please see:
http://workshops.aei.mpg.de/epta-meeting2012

Stanislav Babak

Phasemeter Test Readiness Review,
September 28, 2012, AEI Hannover

This review was an important milestone in the ESA-funded activity to develop a European Phasemeter for LISA in a consortium consisting of Danish partners and the AEI Hannover. The hardware which had been designed by AEI and manufactured in Denmark was delivered to AEI for testing. It contains all functions for a LISA phasemeter including clock noise transfer via GHz sidebands, data transfer, absolute ranging and functions for initial acquisition and was designed using space-qualifiable components. The ESA representatives and contract officers declared the review "successful". Immediately after the review the test campaign at AEI started, which will conclude in the summer of 2013.

Gerhard Heinzel

Workshop "Black Holes in Supergravity and M/Superstring Theory"
September 10-12, 2012, AEI Golm

The AEI hosted the second workshop in a joint series with Cambridge University, Imperial College, Penn State and Texas A&M. The three-day event brought together about 40 scientists interested in aspects of black holes in supergravity and string theory. The 14 talks covered topics concerning the quantum microstates of black holes, the low energy supergravities in various dimensions, the black hole firewall, subtracted geometries and conformal symmetries in black hole systems. Some of the talks also addressed deep mathematical structures as the Mathieu moonshine relations between sporadic finite simple groups and elliptic genera of string compactifications and Don Zagier presented an introduction to so-called mock modular forms.

For further information please see: *http://bhsugra2012.aei.mpg.de/*

Axel Kleinschmidt

Workshop "Physics of de Sitter Spacetime" September 11-14, 2012, AEI Hannover

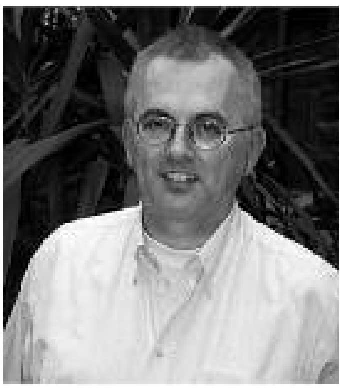
The purpose of the workshop was to provide a venue for young outstanding researchers in the field to present their work and participate in extensive discussions. There were about 30 participants from Europe, North America and Asia and about half of them were junior scientists. Besides giving their talks, the young participants interacted very well with their senior counterparts. The scientific topics presented in the workshop covered the full range of de Sitter physics: its mathematical structure, the issue of perturbative calculations, the issue of quantum gravitational back-reaction, the issue of observables, the connection with CMBR, the connection with the AdS/CFT ansatz. Although no new "breakthrough" result was announced, small progress in all these aspects was realized in a subject that is still quite controversial.

For further information please see: *http://hep.physics.uoc.gr/deSitter/*

Nicholas Tsamis (University of Crete)

Conference "Symmetries, Unification and the Search for Quantum Gravity", September 6-8, 2012, AEI Golm

A conference devoted to the long-standing research interests of Hermann Nicolai was held at the AEI on the occasion of his 60th birthday. With almost 50 external participants and 17 scientific talks, this event covered topics from supergravity, string theory and cosmology with a particular emphasis on the underlying symmetry structures and their unifying properties. A prominent theme was the current debate on the finiteness (or not) of N=8 supergravity as a quantum field theory. Other topics included string scattering amplitudes, Kac–Moody symmetries, the conformal standard model, the multiverse, properties of phi**4 theory and integrability and the AdS/CFT correspondence. The talks reflected Hermann Nicolai's lasting contribution to the subject. A special treat was an organ concert performed by Hermann Nicolai and the cordial atmosphere of the whole meeting.



The conference was devoted to the long-standing research interests of Hermann Nicolai.

For further information please see:
http://www.aei.mpg.de/~axkl/nicolai/Conference_on_the_occasion_of_Hermann_Nicolais_60th_anniversary.html

Axel Kleinschmidt

Conference on Geometric Measure Theory,
July 2-4, 2012, AEI Golm

The conference was organised by Gerhard Huisken (AEI), Ulrich Menne (AEI) and Neshan Wickramasekera (University of Cambridge). It was focused on the study of regularity properties of singular submanifolds of Riemannian manifolds and some of its applications. In this field the gap left behind by Almgren's death and the change of research topic by many of his descendants is still noticeable. Therefore a principle objective was to further stimulate this area of research again. In fact, the participation of about 3/4 of the leading experts and about 70 participants in total made the conference a success. In many talks the role of Geometric Measure Theory as powerful toolbox for problems in Geometric Analysis was visible – a striking example being the proof of the Willmore Conjecture by Fernando Marques and André Neves.

Selected speakers in chronological order: Fernando Marques (Instituto de Matemática Pura e Aplicada), Brian White (Stanford University), Yoshihiro Tonegawa (Hokkaido University), Tristan Rivière (ETH Zürich), Robert Hardt (Rice University), Leon Simon (Stanford University).

For further information please see: *http://workshops.aei.mpg.de/gmt2012*

Ulrich Menne

Workshop "Exploring New Horizons with Gravitational Waves"
June 8, 2012, AEI Hannover

The meeting was organized as a satellite workshop of the "Gravitational Waves physics and Astronomy" workshop to minimize costs and make the logistics as simple as possible.

The goal was to bring together people from different communities, in an informal atmosphere, so that everyone could grasp the status of the various research programs and feel free to ask questions. This would help recognize opportunities of interaction while at the same time highlighting the major obstacles.

The workshop was very well attended (approximately 30 people). About a half of the attendees were from the LIGO/Virgo collaboration and the other half split between numerical relativity and theory. This resulted in some very interesting and stimulating talks and discussions that spanned topics from QFT in curved spaces, Effective theory of gravity, Black hole thermodynamics, Dynamical horizons and marginally trapped surfaces in NR, simulation of collapse in tensor-scalar theories of gravity to Astrophysical population of black holes, Parameter estimation and Data analysis methods for testing GR with advanced LIGO/Virgo detectors.

For further information please see:
https://sites.google.com/site/gwnewhorizons/

Gian Mario Manca

Gravitational Wave Physics & Astronomy Workshop (GWPAW), June 4-7, 2012, AEI Hannover

A new vista on the Universe is set to open from 2015 onwards with the operation of a network of advanced gravitational-wave detectors. How this window will be opened and what we will be able to see through it formed the subject of this meeting, organized by AEI Hannover with the support of the MPG, and held in the Novotel hotel built around Hannover's historic Bahlsen biscuit factory. With 138 international participants the meeting was busy and well attended. In addition to 44 scheduled presentations over the subjects of detector technology, numerical relativity, search techniques for gravitational-wave sources, multi-messenger observations, and the future implications of GW detections for astrophysics, fundamental physics and cosmology, a session was set aside for viewing and discussing the numerous posters displayed by attendees. Social events included a tour of the GEO600 detector, and tours of the AEI's experimental and computing facilities.

For further information please see: *http://gwpaw2012.aei.mpg.de/*

Thomas Dent

Aspen Summer Workshop "A Window To The Formation Of The Milky Way", May 20 – June 9, 2012

The workshop brought together experts in stellar dynamics, astrometry, radio, optical and X-ray observations, numerical modeling of dense stellar systems and also gravitational wave science in order to promote collaborations between these groups. The three-week workshop had one week with a focus on theoretical astrophysics, more specifically astrodynamics. The main topic of one other week was observations and another week was devoted to numerical techniques to simulate galactic nuclei and globular clusters.

The workshop significantly contributed to building new collaborative relationships - as well as strengthening existing ones between the different communities of astrophysics, cosmology, general relativity, data analysis and numerical relativity.

For further information please see:
http://members.aei.mpg.de/amaro-seoane/a-window-to-the-formation-of-the-milky-way/

Pau Amaro-Seoane

3rd ASPERA Computing and Astroparticle Physics Workshop, May 3-4, 2012, AEI Hannover

ASPERA is a network of national government agencies responsible for coordinating and funding European research efforts in Astroparticle Physics (*http://www.aspera-eu.org/*). The large-scale projects and activities proposed in the ASPERA Roadmap face challenging problems of data collection, data storage and data mining. For some, these computing costs will be a significant fraction of the cost of the infrastructure. The issues of computation, data mining complexity and public access are extremely challenging.

The Hannover Workshop was the third in an annual series of ASPERA workshops that directly address these data collection, storage and analysis issues. This workshop focused on hardware and technology. In some cases the computing challenges are the bottleneck, and so using the best and most appropriate hardware and technology will enable more and better science to be done. Because computing technology is largely driven by non-science market forces, the workshop also involved three of the relevant market leaders, whose technology roadmaps are of great relevance. Representatives of NVIDIA, Intel and AMD gave talks about their upcoming product roadmaps for GPUs and multi-core CPUs.

There were also talks about the processing needs of the Large Synoptic Survey Telescope, the Cherenkov Telescope Array, and the Pierre Auger Observatory, and the use of GPUs in Fermi Satellite data analysis, gravitational wave data analysis, transient detection in LOFAR, and volunteer distributed computing.

For further information please see:
http://indico.cern.ch/conferenceDisplay.py?confId=159120

Bruce Allen

Future Gravity Field Satellite Missions Progress Meeting, February 29 – March 1, 2012, AEI Hannover

The Future Gravity Field Satellite Missions project is a collaboration of institutes in Germany funded by the BMBF to develop a roadmap for future gravimetric satellites, in particular to develop a description of feasible mission scenarios.

GRACE Follow-On will observe the critical indicators of climate change through changes in Earth's gravitational field.

The AEI is providing in-kind support and does not receive funding from the BMBF as part of this project. The meeting had approximately 15 attendees from the collaborating institutes, including attendees from the Geodätisches Institute of Universität Stuttgart, Institut für Erdmessung of Leibniz Universität Hannover, Institut für Astronomische und Physikalische Geodäsie, Technische Universität München, Deutsches GeoForschungs Zentrum, TimeTech GmbH, Kayser-Threde GmbH and MenloSystems GmbH as well as 8 attendees from the AEI Hannover working on laser interferometry for GRACE-FO and other future gravimetric satellite missions.

The meeting included presentations on the progress in the development of the metrology and system aspects of the mission concepts as well as the results of full-scale mission simulations from a geodetic perspective. After the meeting a tour of the AEI labs was given.

Benjamin Sheard

Spring Meeting of the Sonderforschungsbereich Transregio 7, February 14-15, 2012, AEI Hannover

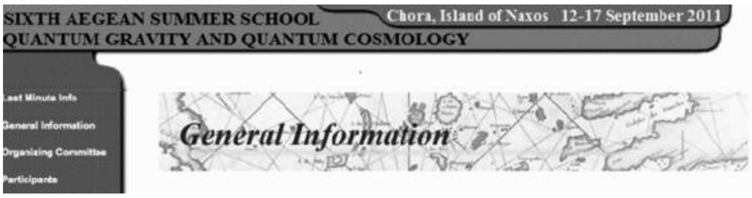
The Sonderforschungsbereich Transregio 7 (SFB TR7) „Gravitationswellenastronomie" is a Collaborative Research Centre funded by the German Research Foundation (DFG). To facilitate the collaborative work between the participating groups from Jena, Tübingen, Garching, Potsdam and Hannover semi-annual meetings are held. The spring meeting 2012 was held at the AEI Hannover on February 14-15 and hosted about 60 participants. It is customary that the talks focus on the main research areas of the host institution. Hence, over the two days of the spring meeting 15 talks were given on various aspects of the SFB, focussing on experimental topics (research area C). The second afternoon was dedicated to strategic planning regarding the continuation of collaborative research after the end of the final funding period at the end of 2014. With the second generation of interferometric gravitational wave detectors going online in 2015 the era of gravitational wave astronomy is dawning. It is therefore of the utmost importance that this successful research collaboration continues. The SFB TR7 spring meeting 2012 at the AEI Hannover consolidated this claim.

For further information please see:
http://wwwsfb.tpi.uni-jena.de/Events/Hannover12/index.shtml

Michèle Heurs

Sixth Aegean Summer School on Quantum Gravity and Quantum Cosmology, September 12-17, 2011 Naxos, Greece

The focus of the conference was quantum gravity in various approaches and formalisms, and its role in fundamental cosmology, in particular in high-energy and high-curvature regimes of the early universe. Important topics like the possible quantum gravity resolution of the initial big bang singularity, the cosmological constant problem and the physics at the Planck scale, have been discussed at length, as well as the relation of quantum gravity models with the inflationary scenario and its alternatives. Another issue what was explored was what type of signatures of current quantum gravity frameworks can be detected by experiments. The conference was also aimed at introducing postgraduate students and young researchers to these very challenging topics.



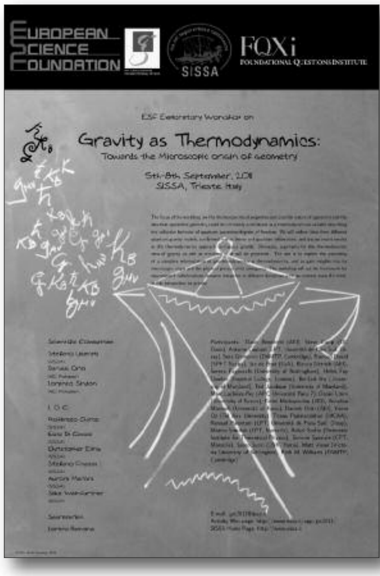
The conference was funded by the AEI in Potsdam, and by the Alexander von Humboldt Stiftung, via the Sofja Kovalevskaja Award to D. Oriti, and by the University of Crete, the University of Tennessee and the Physics Department of the National Technical University of Athens, and cosponsored by the Municipality of Naxos and the General Secretariat of Aegean and Island Policy. The conference has been co-organized by Dr. Oriti and Dr. Calcagni (AEI), by E. Kiritsis and N. Tsamis of the Univ. of Crete, G. Koutsoumbas and L. Papantonopoulos of the NTU-Athens, and by G. Siopsis of the Univ. of Tennessee, USA.

For further information please see:
http://www.physics.ntua.gr/cosmo11/Naxos2011/gen_info.html

Daniele Oriti

Workshop "Gravity as Thermodynamics", September 5-8, 2011, SISSA, Trieste, Italy

The focus of the workshop was the relationship between gravitation and thermodynamics. The basic aspects of this connection have been reviewed and extensively discussed from different points of view (both at the classical and quantum levels). The meeting brought together leading researchers pursuing different approaches, from 'bottom-up' (starting from macroscopic phenomena in classical gravity) to 'top-down' ones (i.e. starting from various Quantum Gravity models) with experts Condensed Matter Physics and Statistical Physics completing the mix. The aim of the workshop was to provide a common basis for the community of researchers working on the topic by exchange of insights and methods and to stimulate new collaborative projects, bridging the gap between Quantum Gravity models and effective and hydrodynamic theories, necessary to provide an explanation of the peculiar features of classical gravity. The conference was funded by the AEI in Potsdam-Golm, by the Alexander von Humboldt Stiftung, via the Sofja Kovalevskaja Award to D. Oriti, by SISSA in Trieste, by the INFN (the italian National Institute for Nuclear Physics), and by the European Science Foundation (ESF). The workshop has been co-organized by Dr. Oriti and Dr. Sindoni (AEI), and by Prof. Liberati, of SISSA, Trieste.



For further information please see: *http://www.sissa.it/app/gtc2011/*

Lorenzo Sidoni

7th International BOINC Workshop, August 18-19, 2011, AEI Hannover

The workshop on the Berkeley Open Infrastructure for Network Computing was hosted by the AEI Hannover directly after the IDGF event. The BOINC workshops are held annually since 2005 on changing locations and have two main objectives:

- Exchange of experience between the scientists involved in projects using BOINC for distributed computing, and feedback between the scientists, as users of BOINC, and the developers of BOINC, in order to shape the further development of the software according to the requirements of the participating projects.

As Einstein@Home is among the most popular projects using the BOINC platform, the AEI is one of the key stakeholders in the BOINC project. Conferences like this one are a most welcome opportunity to influence its future development and help ensure the quality of the development process of BOINC.

The official program of the workshop was divided into two parts: The first day was dominated by talks presented by scientists of several participating projects. The second day included a so called "Hackfest" where the approximately 50 participants split into ad-hoc working groups who focused on concrete aspects of the further development of BOINC (e.g. documentation, concepts, prototyping). The results were then presented to the plenum at the end of the second day.

For further information please see:
http://boinc.berkeley.edu/trac/wiki/WorkShop11

Heinz-Bernd Eggenstein

8th IDGF Workshop, August 17, 2011, AEI Hannover

Desktop Grids are gaining more and more attention as eScience infrastructure. They can be categorized as volunteer Desktop Grids, collecting computer capacity from tens-of-thousands of PCs at home, or as local Desktop Grids consisting of otherwise unused machines inside a university or institute. International Desktop Grid Federation brings together various Desktop Grid technologies, such as BOINC, OurGrid, XtremWeb, Condor and IDGF communities such as SZTAKI Desktop Grid, and Rechenkraft.

The workshop was organized by the International Desktop Grid Federation and by MTA SZTAKI (Hungary) for the European chapter, and it was co-located with the 7th BOINC Workshop (see above). This workshop focused around the Desktop Grids for eScience Roadmap - a new version had just been published - and a panel session on issues and opportunities in Desktop Grids.

The workshop provided a platform for scientific users, Desktop Grid operators, system administrators and application developers to exchange experiences about Desktop Grids and related technology. The workshop and the tutorial were useful for those who wanted to get an insight in the technologies provided by Desktop Grid systems and applications and in addition gather the theoretical and practical knowledge about them.

We highly recommended attending on this event for:

- Operators of Volunteer Desktop Grids or local Desktop Grids
- System administrators and IT managers who consider setting up a local or Volunteer Desktop Grid
- Scientists and application developers looking for ways to use more computing power
- NGI/EGI Grid operators who want to extend their services with more resources and are considering Desktop Grids

The goal of the presentations was to show the power of Desktop Grid computing and its potential to support the emergence of eScience. In addition a number of presentations about practical experiences with Desktop Grids completed the programme.

For further information please see:
http://desktopgridfederation.org/8th-idgf-workshop

Peter Kacsuk (MTA SZTAKI, Budapest, Hungary)

Workshop "Spacetime as a statistical system: from Quantum Discreteness to Classical Continuum", July 21-23, 2010, AEI Golm

The goal of the workshop was to bring quantum gravity researchers together with experts in statistical field theory, to discuss the issue of the transition from a description of spacetime in terms of discrete and quantum structures, characterizing several quantum gravity approaches, to the continuum description of the same provided by General Relativity. In particular, a main topic of the discussion was the renormalization group and other statistical field theory methods and their possible role in quantum gravity models, concerning the above issue.

During the entire duration of the workshop there have been several discussion sessions. Due to the variety of the scientific backgrounds of the participants, as well as the differences in the points of view, the discussions have always been interesting, animated and produced a valuable opportunity to confront different ideas on some of the basic problems of quantum gravity.

Naturally, these discussions led to new collaborations among participants, coming from different scientific backgrounds or working on different approaches to quantum gravity. In particular, a promising collaboration has started between the AEI group(s) and the group in Paris XI-Orsay, with the additional support of matrix models experts in Saclay; this collaboration focuses on group field theory renormalization and phase transitions.

Another topic on which collaborations have begun, between the AEI group(s) and researchers at Cambridge University, ENS-Paris and ENS-Lyon, is the application of coarse graining and mean field theory techniques, as developed for lattice models in condensed matter physics, to discrete gravity path integrals (and group field theory).

Benjamin Bahr

GEO-HF meeting, May 11-12, 2010, AEI Hannover

A GEO-HF progress and planning meeting was held at the AEI in Hannover in May 2010, where about 25 participants attended locally and another 10 remote participants joined via the EVO tele-conference system. During the first day of the workshop the scientists involved in the daily detector work engaged in in-detail discussions of the current status and challenges of projects within the GEO-HF upgrade program. Topics ranged from the Output Mode Cleaner performance and control, over scattered light investigations, laser power enhancement issues, integration of the squeezed light source into GEO600, to calibration procedures and calibration accuracy. The second day was devoted to discussions on the planning of the remaining GEO-HF upgrade steps, the organisation of data analysis efforts for GEO600, a discussion of the gap between the projection of known noise sources and the observed sensitivity and the science potential of the promising high frequency sensitivity improvement of GEO600. This planning activity was supported by an “over-lunch” meeting of the GEO executive committee.

Harald Lück

Jürgen Ehlers Spring Schools in 2010, 2011 and 2012, AEI Golm

Each year the AEI invites advanced undergraduate students to a course on General Relativity and related areas. The course runs for two weeks during the spring vacation period, usually in March, with around 50 participants. Since 2009 the lectures are given in English which makes it possible for non-German students to attend. The first week of the course gives a the foundations of general relativity, and including historical background, motivation and the necessary tools and concepts from differential geometry. The most important examples of spacetimes are discussed, including the Schwarzschild spacetime and the Robertson-Walker spacetimes. These lectures are given by post-docs from the Geometric Analysis division at AEI. The second week is devoted to more specialized topics and alternates, and rotates between the three divisions of AEI. In 2010, the lectures in the second week were given by Jan Metzger and Jörg Hennig of the Geometric Analysis division on Geometric Aspects of Mass and Black Holes)Metzger) and Black Holes and Neutron Stars (Hennig). The second week lectures in 2011 were given by Luziano Rezzolla and Stanislav Babak from the Astrophysics division on Formation and evolution of compact objects (Rezzolla), and Gravitational Wave Astronomy (Babak), and in 2012, the second week lectures were given by Jean-Luc Lehners (Quantum Gravity division) on String Cosmology.

For further information please see: *http://ferienkurs.aei.mpg.de/*

Lars Andersson

Astro-GR meetings 2010 – 2013

Since the last Fachbeirat meeting, Pau Amaro-Seoane has kept the Astro-GR meetings alive. There were four meetings so far with the fourth taking place in Atlanta in November 2013.

We had on average some 50 participants. As usual, the most important thing is multidisciplinarity, meaning that the goal of the meetings is to get astrophysicists, relativists, data analysts and people working on numerical relativity to talk and collaborate with each other.

It is important to note that the organization of the 2012 session took place in Beijing. During the meeting it was officially announced the commitment of China to the LISA mission, with up to a 20% of the total cost.

For further information please see:
Astro-GR@Paris (Paris, France, Sep. 2010):
www.aei.mpg.de/~pau/Astro-GR@Paris
Astro-GR@Mallorca (Mallorca, Spain, Sep. 2011):
www.aei.mpg.de/~pau/Astro-GR@Mallorca
Astro-GR@Beijing (Beijing, China, Sep. 2012):
http://astro-gr.aei.mpg.de/Astro-GR@Beijing-2012
Astro-GR@Atlanta (Atlanta, USA, Nov. 2012):
http://members.aei.mpg.de/amaro-seoane/astro-gr-atlanta/

Pau Amaro-Seoane

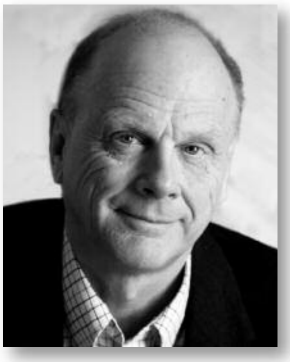
Through the eyes of a visitor

I did not come to Golm the first few years when the Institute got established there. It probably took up to the year 2000 or even 2001 that I made my first visit. I spent two weeks in the Guest House and had dinners at "Zum gemütlichen Bahnhof" (my name), one of the least good restaurants in the Berlin area. I was stuck in Golm and went only once to Potsdam to buy food and beer. Still I went back home with a very nice feeling and started to come back to Golm, the next few times staying in the Landhotel in Golm. After some time Hermann asked me if I was willing to candidate to become a foreign member (auswärtiges Mitglied) and in 2004 I was elected and I was very pleased and honoured, and since then I have tried to come to the Institute some two or three times a year. Now I stay in Potsdam for my visits which I enjoy very much. It has become (again) such a beautiful city. It is easy to get to the Institute by bus or by hitch-hiking with some of the friendly people in the Institute that live in Potsdam. Friendly is the word. I think the Institute is unique by having so friendly and competent staff with Frau Roos and Frau Gottschalkson and the others.

The Institute is probably also unique in the world since it concentrates fully on gravity. It is of course both a strength and a weakness but the leadership is fully aware of it and uses it to make the Institute a leading one in the world. It arranges a series of workshops and conferences every year and the central theme is always Einstein's gravity theory. You can always count on having world-leading speakers at these meetings and the whole atmosphere is very relaxed since the whole Institute is usually behind these events. There are really no disturbing elements like you find in ordinary universities.

During more than two years I had one of my collaborators, Sudarshan Ananth, working as a post-doc in Golm so during that time I had more frequent contacts. Otherwise I use my trips to Golm mostly to get some peace, to be able to sit for myself working on some scientific problem, to discuss with Hermann and the others regularly, to enjoy the tea and other stuff that Frau Gottschalkson spoils me with and to go to the talks and enjoy the high level of them. At home I have always had meeting to go to, people to talk to, boring reports to write etc. In Golm I forget that. During these years I have been a member of the Nobel Committee in Sweden which is one of the most secretive commission you can have. Often I have needed to read old texts. The Institute has been extremely useful for that. Through the computer one can reach any relevant journal in physics, which is not the case back home. Nobody has been checking me what I read and what I print. This I can reveal now when I am leaving the Nobel work.

Let me finish by telling the story from 2008 when we were preparing the press releases for the physics prize of that year. Since the three laureates were Japanese I wanted to have the press release properly translated to Japanese. The Nobel Foundation had access to professional translators but I did not trust them. I needed a physicist. In Golm I had a young Japanese colleague, Hidehiko Shimada. I wrote to him and said that I happened to be passing by and had a Japanese text that I wanted him to translate to English. Of course he said and we met in my hotel. This was a week before the announcement. I handed him the English text and told him that I had cheated and that I wanted him to translate it to Japanese. He got completely red and repeated many times "I am so honoured, I am so honoured….". He did a marvellous job and after the announcement he could tell his family and friends what he had done. After this I always get friendly questions if I will come to Golm that week of the year and if I need a translation to French or Hebrew or Italian or…..



Lars Brink, Chalmers University of Technology, Göteborg/Sweden

Short Notices

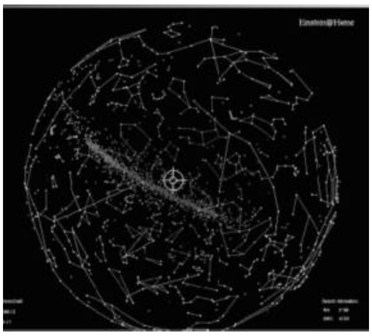
Visit of a delegation from China, July 30, 2012, AEI Hannover

In July 2012, a delegation from the Chinese Academy of Science (CAS) and the Chinese Space Agency with 12 members visited the AEI Hannover. Presentations and laboratory visits about the research at the AEI were given, and the upcoming "Exploratory Round Table Conference" between Max Planck Society and CAS in Shanghai (November 2012) was discussed.

Gerhard Heinzel

Einstein@Home public event, July 2, 2011, AEI Hannover

As Einstein@Home relies only on the time contributed by volunteers, making and keeping contact to present and potential contributors is crucial for the project. Therefore on the occasion of the anniversary of the first radio pulsar discovery made by Einstein@Home the AEI hosted a public event in 2011.



The event consisted of five talks, guided tours of the AEI labs and Atlas computing cluster and quite some time for discussion about the Einstein@Home project. It addressed present participants as well as the general public. The organizing committee included Allen, Machenschalk, Mueller, Mokler.

The talks were given by Allen, Knispel, Leong, Michael Kramer (Max Planck Institute for Radio Astronomy, Bonn) and Eggenstein (Einstein@Home volunteer at that time). These covered historical and technical aspects of the Einstein@Home project as well as the future of gravitational wave and radio astronomy.

About 50 present or potential participants enjoyed the deep insight into gravitational wave science and the opportunity to ask their questions to the Einstein@Home team and the scientists that drive the project. For further information please see:
http://gwdaw11.aei.mpg.de/eah.php

Bernd Machenschalk

ClusterDay2011@AEI, April 5, 2011, AEI Golm

Following the tradition started a few years ago, the members of the Numerical Relativity Group (led by Prof. Rezzolla) and of the IT Department (led by Hausmann-Jamin) invited physicists and computer scientists from the Brandenburg/Berlin area to the 2011 edition of the Cluster-Day@AEI. As in the past, the meeting was meant as a forum to exchange experiences mainly in the use but also in the management of High Performance Compute Clusters, as well as a way to report on new approaches and future strategies in the supercomputing world.

The main theme of the event was “German High Performance Computing in the new Decade”. The morning session was reserved for the scientific projects with reports from the groups at the AEI. The afternoon session was dedicated to presentations from external colleagues from the Berlin/Brandenburg area. The vice president HPC Europe from NEC, Mr. Sasakura, and further experts of NEC added valuable information about new technologies and future visions.

The highlight of the event was the official inauguration of the new AEI HPC-cluster, “Datura”. The event was made even more memorable by the presence of the Brandenburg Minister of Science, Research and Culture, Prof. Dr.-Ing. Dr. Sabine Kunst who gave the opening address. She emphasized the importance of the developments in high performance computing and the large impact that the Max Planck Institutes have on the scientific life of the whole Brandenburg region. Particular appreciation was made for the organization of the ClusterDay as a way to synergize the efforts of universities and research centers.

Cluster Day 2011 at the AEI

During the meeting a tour of the cluster rooms of the AEI gave the participants a nice opportunity to visit the new Datura cluster, a 200 nodes high performance cluster with a high speed network. Datura was delivered by NEC Deutschland GmbH December 2010.
For further information see: *http://supercomputers.aei.mpg.de/*

Christa Hausmann-Jamin & Luciano Rezzolla

Playfully learning mathematics

In October 2010, the Albert Einstein Institute welcomed a group of teachers and prospective teachers for a continuing education seminar in mathematics. Every teacher was accompanied by a student of age 10-12 from one of their classes. In the seminar, Carla Cederbaum and Elke Müller presented an interactive mathematical board game they have developed and tested it with the participants. There was also a session delivering background information to the teachers. The game is designed for usage in the classroom and in families. It is currently being prepared for publication.

Young students discussing mathematical problems.

The event was supported by the German Mathematical Society DMV and funded by the award "Wissenschaft interaktiv" that Carla Cederbaum and Elke Müller received from the Stifterverband für die Deutsche Wissenschaft in 2009.

Carla Cederbaum

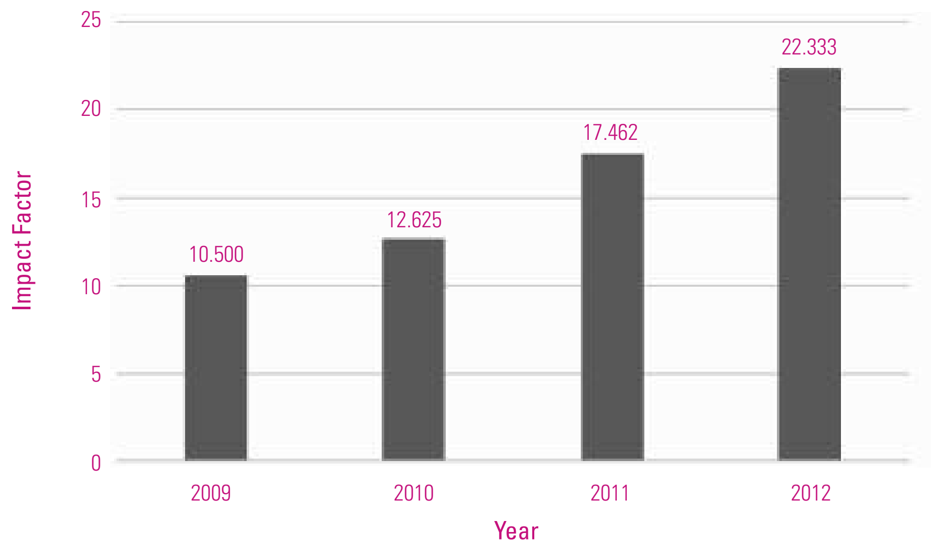
Living Reviews in Relativity

The open access journal Living Reviews in Relativity has published its 100th article in March 2011; currently we maintain 121 reviews on 72 topics. In the past 15 years, the unique concept of providing regularly updated overviews on the state of research has been acknowledged by readers and authors alike. While more than 230 scholars have accepted an invitation to contribute their expertise, 800 readers subscribed to our newsletter and 360 'fans' like us on Facebook! A user survey in 2009 returned 80 questionnaires with positive feedback and useful comments.

The journal's reputation as a high-quality scientific publication is also visible in the increase of citation numbers and the high rank in Thomson Reuters' Journal Citation Report (JCR). Overall, citations to Living Reviews in Relativity's articles increased from 7,082 (2011) to 8,322 (2013).

Although controversial, the Journal Impact Factor (JIF) is one of the most widely used tools for assessing scientific journals. It allows users to evaluate a journal's performance and its influence on research. In 2012, Living Reviews in Relativity has been leading the category Physics, Particles & Fields for the second year, rising to #54 in JCR's complete list of about 8000 indexed journals.

Journal Impact Factor
Living Reviews In Relativity



Alternative citation measures confirm the position the journal has gained in the scientific community. For example, Inspire includes 10 Living Reviews articles among its 100 most highly cited papers of all time (2011 edition) in the gr-qc archive.

Bernard Schutz, the journal's editor-in-chief, summed up the first 10 years of Living Reviews in Relativity in 2008: "The founders set out with the goal for the journal to become one of the first places a scientist looks for information about work in the field of gravitational physics. And we are delighted to have reached the goal of providing this service." He added, "the successful adaptation of the concept in other scientific fields is an additional confirmation of our idea."

The Living Reviews family is growing, after the success of Living Reviews in Solar Physics (JIF 12.500) we will launch a third physics journal in 2013, the Living Reviews in Computational Astrophysics. Thus, the editorial back office at the MPI for Gravitational Physics (AEI) will serve three Max Planck institutes who act as publishers and host the editors-in-chief. In addition, our external partners in Austria, Germany, and Switzerland maintain three further journals.

While the publishing collaboration with the MPI for Solar System Research, the MPI for Astrophysics, and the Max Planck Digital Library (MPDL) currently allows us to share the editorial costs, the long-term support for these journals is not yet secured. Developed as projects at institute level, a sustainable financial solution has to be established that looks beyond the annual budget of a department or institute.

Living Reviews' publication software ePublishing Toolkit (ePubTk), originally developed between 2002 and 2006, has been continuously improved and enhanced according to new requirements and advances in web technology. The journal web site and article presentations have been redesigned and new features were added. From 2007 to 2011, Living Reviews worked in close collaboration with the MPDL, where our main developers Robert Forkel and André Wobst constituted the Digital Editions team, managed by our former editor Christina Weyher. Server administration and technical support for all journals were thus provided by the MPDL. The experience gained at Living Reviews was successfully used for new projects (e.g., in linguistics) and the creation of the general MPDL infrastructure and tools.

One joint project, in which the Living Reviews team has been involved, was the conceptual design, development, and maintenance of the community portal hyperspace@aei. Both, the hyperspace@aei portal and Living Reviews journals have shown the great impact that electronic services developed and run by the community can have. They are frequently used by scholars as a knowledge data base and tool for research, and by interested non-professionals as a source for information.

The journal's reference database collects all citations from our articles, and thus shows the enormous range of literature we have covered in the last 15 years. For a review journal, these references are important research data that the authors present. A total number of more than 26,000 different records have been reviewed in Living Reviews in Relativity, covering about 600 journals, 800 books, and 20,000 authors.

Living Reviews has been regularly promoted at physics conferences (GR19 in Mexico 2010, ESPM13 in Rhodes, AE100 in Prague 2012) and is interestedly following (and followed by) the Open Access movement. About 20 press and scientific publications mentioned the project since 2010; recently in an online feature article at Open Access Success Stories. Since January 2013, Living Reviews is part of the Open Access Publishers Association (OASPA), which provides a forum for standards and innovation in Open Access publishing.

In July 2010, Mukund Rangamani from Durham University joined Living Reviews in Relativity as topic editor for "String Theory and Gravitation". The editorial board currently consists of the following members: Bernard F. Schutz, Robert Beig, Bernd Brügmann, Chris Isham, Bala R. Iyer, Renate Loll, Donald Marolf, Jorge Pullin, Mukund Rangamani, Jürgen Renn, Edward Seidel, Joachim Wambsganss, and Clifford M. Will.

The editorial work, technical support, and software development has involved the following team: Frank Schulz, Vera Osswald, Christina Weyher (1997-2011), Robert Forkel (2002-2011), André Wobst (2005-2011), and Miranda Dettwyler.

Frank Schulz

Cooperations and Outside Funding

The years 2010 to 2012 were characterized by successful collaborations with German and foreign institutions and foundations. This is evidenced by the amount of projects funded by third-parties both in Hannover and Potsdam-Golm.

Tremendous financial contributions came from the BMBF (Bundesministerium für Bildung und Forschung) including the DLR (Deutsches Zentrum für Luft- und Raumfahrt) as the most important funding institution for the AEI Hannover. For the AEI Potsdam-Golm the DFG (Deutsche Forschungsgemeinschaft) gave the major part of external funds during the reporting period.

The following report shows all institutions and foundations (in alphabetical order) as well as the funded projects in more detail.

Alexander von Humboldt-Stiftung - AvH (Humboldt Foundation)

In the reporting period 2010 – 2012 the AEI Potsdam-Golm hosted the Friedrich Wilhelm Bessel Research Award laureate Dr. Hans Ringström (Sweden) and the Humboldt Research Award laureate Prof. Dr. Marc Henneaux (Belgium).

Additionally, the AEI Potsdam-Golm was the host institution for eight postdocs who have been awarded an AvH Fellowship: Dr. Andres Anabalon, Dr. Oscar Varela, Dr. Jose-Luis Jaramillo, Dr. Alex B. Nielsen, Dr. Evgeny Skvortsov, Dr. Riccardo Ciolfi, Dr. Fotini Markopoulou Kalamara, Dr. Jianwei Mei as well as Prof. Kirill Krasnov who obtained an AvH Fellowship for experienced researchers.

The Sofja Kovalevskaja Award laureate Dr. Daniele Oriti and his research group are closely cooperating with the Quantum Gravity and Unified Theories Division. Oriti's prize is accompanied by 1.400.700 EUR which can be spent until 2014.

Bundesministerium für Bildung und Forschung - BMBF (German Ministry for Education and Research)/ Deutsches Zentrum für Luft- und Raumfahrt (DLR)

Within the German Israeli Project Cooperation (DIP) the project Applications of string theory to particle physics and to Gravity a binational center for the study of string theories has been established in the Quantum Gravity and Unified Theories Division.

The BMBF also supported a bilateral Cooperation in Education and Research between the University of South Africa and the Numerical Relativity Group/Astrophysical Relativity Division of the AEI for three years.

At the AEI Hannover the DLR is funding the LISA Technology Package (LTP) aboard the LISA pathfinder (LPF) mission. It is dedicated to demonstrate and verify key technologies for LISA, in particular drag free control, ultra-precise laser interferometry and gravitational sensors. The project covers the phase C/D of the German contribution to

LTP (systems engineering of the industrial architect Astrium GmbH and sub-contractors Kayser-Threde GmbH for the laser assembly and TESAT Spacecom GmbH & Co. KG for the laser reference unit).

Deutsche Forschungsgemeinschaft – DFG (German Research Foundation)

I. Sonderforschungsbereiche - SFB (Collaborative Research Centers)

- *SFB Transregio 7 Gravitationswellen-Astronomie:* The SFB/TR7 aims at the detection and analysis of gravitational waves that reach us from astrophysical sources like black holes, neutron stars, or supernovae. The 'Transregio' signifies a collaboration of groups at the Universities of Jena, Tübingen, and Hannover, and at Max Planck Institutes in Garching, Hannover and Potsdam. It will be running until December 2014.

- *SFB 647 Raum-Zeit-Materie:* In the SFB 647 entitled Space-Time-Matter the Divisions for Geometric Analysis and Gravitation and Quantum Gravity and Unified Theories at AEI are collaborating with the Humboldt Universität zu Berlin, the Freie Universität in Berlin and the University of Potsdam. In this project mathematicians and physicists explore the exciting research field where theoretical physics, geometry and analysis meet. The DFG started funding this Collaborative Research Center in January 2005 and has extended it until December 2016.

II. Gottfried Wilhelm Leibniz-Preis (Leibniz-Prize)

The Leibniz Prize – the most prestigious German research prize - was awarded to Prof. Gerhard Huisken in 2003. The award is accompanied by 1.55 Mio € which was spent for personnel and travel until the end of 2010.

III. Sachbeihilfen (Individual Research Grants)

The DFG approved funds for three Individual Research Grants "Supermassive Schwarze Löcher, Akkretionsscheiben, Stellardynamik und Gezeitenstörungen von Sternen" (Gravitational Waves Group/Astrophysical Relativity Division), "Insight into Gravitation via a Combination of Analytical and Numerical Methods" (Geometric Analysis and Gravitation Division) and "String theory, quantum field theory and gauge/gravity duality" (Quantum Gravity and Unified Theories Division). These Individual Research Grants usually include funding for staff and travel.

Europäische Kommission – EU (European Commission)

In the reporting period the European Commission provided funding for five projects: *Einstein Telescope (ET); Computing in the dark sector: a Cactus toolkit for modified-gravity cosmologies (COSMOTOOLKIT); String Cosmology and Observational Signatures (STRINGCOSMOS); Integrability, Symmetry and Quantum Space-time (ISAQS)* and *ET-LCGT Telescopes: Exchange of Scientists (ELITES):*

- ET/ Laser Interferometry and Gravitational Wave Astronomy Division (Infrastructures FP7) concerns the study and the conceptual design for a new infrastructure that will bring Europe to the forefront of the most promising new development in our quest to understand the history and future of the Universe, the emergence of the field of Gravitational Wave Astronomy.

- COSMOTOOLKIT/ Numerical Relativity Group/Astrophysical Relativity Division (Marie Curie Reintegration Grant/ FP7) intends to test cosmologically-relevant proposals using Cactus in order to extend the domain of current codes.

- STRINGCOSMOS (ERC Starting Grant for J.-L. Lehners/ FP7) aims to enhance our understanding of the very early universe and its most mysterious aspect, the big bang. In the January 2011 Dr. Jean-Luc Lehners established his independent research group on String Cosmology at AEI Potsdam-Golm. The group closely cooperates with the Quantum Gravity and Unified Theories Division.

- ISAQS/ Quantum Gravity and Unified Theories Division (Marie Curie International Research Staff Exchange Team/FP7) brings together leading researchers with broad, complementary expertise: from conformal field theory, gauge theory, supergravity, string theory, to the more mathematical aspects of integrable systems and non-commutative geometry, to form a team with the common goal of understanding the fundamental nature of quantum gravity.

- ELITES/ Laser Interferometry and Gravitational Wave Astronomy Division (Marie Curie International Research Staff Exchange Team/FP7), the Large-scale Cryogenic Gravitational wave Telescope (LCGT) in Japan and the Einstein gravitational-wave Telescope in Europe will adopt new technologies (in cryogenics, mechanics and optics) that necessitate an intense R&D activity and a fully collaborative exchange of know-how between Europe and Japan. ELITES aims to furnish the initial kick-off to this exchange programme.

Furthermore, the Quantum Gravity and Unified Theories Division is partner in the Erasmus Mundus Joint Doctorate Programme in Relativistic Astrophysics funded by the European Commission.

German-Israeli Foundation for Scientific Research & Development (GIF)

The German-Israeli Foundation supported a proposal for a joint research project of the Quantum Gravity and Unified Theories Division together with the University of Tel Aviv entitled String Theory Meets Gauge Dynamics.

Perimeter Institute – PI

The Perimeter Institute provided two fellowships to students of the Quantum Gravity and Unified Theories Division.

John Templeton Foundation

The John Templeton Foundation granted a postdoctoral fellowship for the study on Quantum Information before Spacetime in the Quantum Gravity and Unified Theories Division.

Volkswagen-Stiftung (VW Foundation)

The VW Foundation is currently funding the R&D programme Advanced LIGO. The objective of that project is the development and delivery of high-power pre-stabilized laser systems for the Advanced LIGO gravitational wave detectors. It is jointly conducted by the AEI Laser Interferometry and Gravitational Wave Astronomy Division and the Laser Zentrum Hannover.

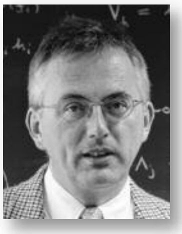
Furthermore, the VW Foundation is funding a project in which the Numerical Relativity Group and the Uzbek Academy of Sciences are working together on General-Relativistic Electrodynamics of Astrophysical Compact Objects.

Together with the Yerevan Physics Institute the Quantum Gravity and Unified Theories Division is working on the proposal Infinite-Dimensional Symmetries, Gauge/String Theories and Dualities which is funded by the VW Foundation as well.

Constance Münchow

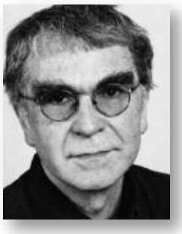
Appraisals and Prizes

Karsten Danzmann was elected a *Member of the Akademie der Wissenschaften* in Hamburg in 2010 in recognition of his leadership in gravitational wave detection.



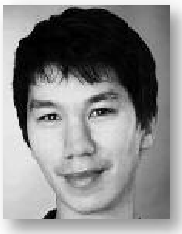
Hermann Nicolai was awarded with the *2010 Einstein Medal of the Albert Einstein Society in Bern*, in recognition of his outstanding scientific achievements in quantum gravity. In 2012 he has been awarded the highest Franco-German science prize, the *Gay-Lussac-Humboldt Prize.*

Bernard F. Schutz was elected *Member of the Learned Society of Wales* in 2011. Also in 2011 he received an *Honorary Doctor of Science from the University of Glasgow* in recognition of his vital and internationally recognised contributions to theoretical astrophysics.



Stefan Theisen was awarded with the *Hans D. Jensen Prize of Heidelberg University* in 2011. He received this award in recognition of his work in string theory.

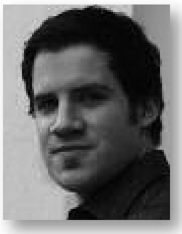
Alexander Khalaidovski was presented in 2012 with the newly established *Stefano Braccini Prize* for best doctoral thesis in the field of gravitational physics. He received the award for his PhD work on improving the sensitivity of gravitational wave detectors. In 2012 he won the *first prize* for poster presentation at the 508th Heraeus-Seminar on "Quantum Meets Gravity and Metrology" in Bad Honnef.



Patrick Kwee has won the "*Wissenschaftspreis der Universität Hannover*" in 2010 for his outstanding doctoral thesis on laser stabilization. This price is awarded to young researchers each second year.

Rutger van Haasteren received an *honourable mention in the Stefano Braccini Prize* for his doctoral research at University of Leiden on how pulsars could be used to measure gravitational waves.

David Link won the 2010 *Heraeus Prize* for his Diploma thesis work on accretion tori in binary neutron star mergers at the Humboldt University in Berlin.



Holger Pletsch won the *GWIC Thesis Prize* for his thesis on data analysis for continuous gravitational waves. Pletsch also won the *Dieter Rampacher Prize* for being the youngest scientist in the Max Planck Society to complete his PhD this year.

Henning Vahlbruch won a second award for his PhD thesis on squeezed light when in 2010 the *Deutsche Physikalische Gesellschaft awarded him its Thesis Prize*.

Barry Wardell won the *IOP Award* for his PhD Thesis on Green's functions. The prize was awarded to him in Glasgow in April 2011.

Academic Achievements

Professorships at AEI and abroad

Andres Aceña left AEI in July 2011 to take up an adjunct professorship at Universidad Nacional de Cuyo, Argentina.

In November 2010 Andrés Anabalon took on a professorship at University Vina del Mar, Chile.

Niklas Beisert, leader of the Max Planck Research Group on "Duality and Integrable Structures" was appointed associate professor for mathematical physics at ETH Zurich and moved to this position in August 2012.

In January 2012 Bianca Dittrich, leader of the Max Planck Research Group on "Canonical and Covariant Dynamics of Quantum Gravity" took on a faculty position at Perimeter Institute for Theoretical Physics in Canada. She stayed part time associated to the AEI until December 2012.

In July 2010 Michèle Heurs took up a junior professorship at the Centre for Quantum Engineering and Space-Time Research (QUEST) at Leibniz Universität Hannover. She established her research group on "Quantum Control" at AEI Hannover.

Gerhard Huisken, director of the Geometric Analysis and Gravitation division at AEI, left the institute in April 2013 to take on professorships at University of Tübingen and Mathematisches Forschungsinstitut Oberwolfach. He was appointed External Member of the AEI.

Brett Kotschwar left the institute in July 2011 to take up an assistant professorship at Arizona State University.

Badri Krishnan was appointed to a W2 professorship in Bruce Allen's division at AEI Hannover in August 2010.

Antoine Petiteau left AEI in 2011 and took up an assistant professorship at University Paris Didérot.

In April 2013 Alan Rendall left AEI to take on a professorship for Analysis at University of Mainz.

Luciano Rezzolla left AEI for a professorship at Frankfurt University in October 2013. He will stay part-time affiliated to the institute until Summer 2014.

In January 2013 Amitabh Virmani left AEI to take up an assistant professorship at Bubaneshwar University, India.

New Independent Research Group at AEI

Jean-Luc Lehners won one of the ERC starting grants in 2010. The prize enabled him to establish an independent research group on "String Cosmology" at AEI, which will be funded until November 2015.

New Max Planck Research Group at AEI

In April 2012, Ulrich Menne set up a Max Planck Research Group on "Geometric Measure Theory" at AEI. He was appointed jointly with Potsdam University where he holds a professorship for Geometric Analysis.

Doctoral Theses

Gastón Avila (Potsdam University 2011): Asymptotic staticity and tensor decompositions with fast decay decisions. Supervisor: Helmut Friedrich

Aneta Barbos (Free University Berlin 2010): Energy decay law in n-dimensional Gowdy spacetimes with torus topology. Supervisor: Alan Rendall

Till Bargheer (Humboldt University Berlin 2010): Symmetries of Tree-Level Scattering Amplitudes in Supersymmetric Gauge Theories. Supervisor: Niklas Beisert

Nicolas Behr (Humboldt University Berlin 2012): D-branes in Kazama-Suzuki models. Supervisor: Stefan Fredenhagen

Johannes Brödel (Leibniz Universität Hannover 2010): Alternative approaches to maximally supersymmetric field theories. Supervisor: Stefan Theisen

Oliver Burmeister (Leibniz Universität Hannover 2010): Optical properties of 3-port-grating coupled cavities. Supervisor: Roman Schnabel

Carla Cederbaum (Free University Berlin 2011): The Newtonian limit of geometro-statics. Supervisor: Gerhard Huisken

Marina Dehne (Leibniz Universität Hannover 2012): Construction and noise behavior of ultra-stable optical systems for space interferometers. Supervisor: Gerhard Heinzel

James diGuglielmo (Leibniz Universität Hannover 2010): On the Experimental Generation and Characterization of Entangled States of Light. Supervisor: Roman Schnabel

Irene di Palma (Leibniz Universität Hannover 2012): A First Search for coincident Gravitational Waves and High Energy Neutrinos. Supervisor: M. Alessandra Papa

David Fajman (Free University Berlin, 2012): Future non-liner stability for the 2+1-dimensional Einstein-Vlasov system. Supervisor: Alan Rendall

Roland Fleddermann (Leibniz Universität Hannover 2012): Interferometry for a space-based gravitational wave observatory – Reciprocity of an optical fiber. Supervisor: Gerhard Heinzel

Cecilia Flori (Humboldt University Berlin 2010): Approaches to quantum gravity. Supervisor: Thomas Thiemann

Boris Hage (Leibniz Universität Hannover 2010): Purification and Distillation of Continuous Variable Entanglement. Supervisor: Roman Schnabel

Muxin Han (Humboldt University Berlin 2010): The relation between canonical and covariant loop quantum gravity. Supervisor: Thomas Thiemann

Florian Hanisch (Potsdam University 2012): Variational problems on supermanifolds. Supervisor: Christian Bär

John Head (Free University Berlin 2011): The surgery and level set approaches to mean curvature flow. Supervisor: Gerhard Huisken

Michael Jasiulek (Potsdam University 2012): Novel geometric methods in numerical relativity for isometric embeddings, quasi-local spin and the wave equation. Supervisor: Badri Krishnan

Alexander Khalaidovski (Leibniz Universität Hannover 2011): Beyond the Quantum Limit – A Squeezed-Light Laser in GEO600. Supervisor: Roman Schnabel

Benjamin Knispel (Leibniz Universität Hannover 2011): Pulsar Discoveries by Volunteer Distributed Computing and the Strongest Continuous Gravitational Wave Signal. Supervisor: Bruce Allen

Michael Köhn (Humboldt University Berlin 2011): Quantum aspects and arithmetic structures of cosmological singularities in gravitational theories. Supervisor: Hermann Nicolai

Patrick Kwee (Leibniz Universität Hannover 2010): Laser Characterization and Stabilization for Precision Interferometry. Supervisor: Benno Willke

Nico Lastzka (Leibniz Universität Hannover 2010): Numerical modeling of classical and quantum effects in non-linear optical systems. Supervisor: Roman Schnabel

Florian Loebbert (Humboldt University Berlin 2010): Integrable Spin Chains in Supersymmetric Quantum Field Theories. Supervisor: Niklas Beisert

Thomas Marquardt (Free University Berlin 2012): The inverse mean curvature flow for hypersurfaces with boundary. Supervisor: Gerhard Huisken

Moritz Mehmet (Leibniz Universität Hannover 2012): Squeezed light at 1064nm with a nonclassical noise suppression beyond 10db. Supervisor: Roman Schnabel

Tobias Meier (Leibniz Universität Hannover 2011): High-Power CV Green lasers for Optical metrology and Their Joint Benefit in Particle Physics Experiments. Supervisor: Benno Willke

Carlo Meneghelli (Humboldt University Berlin 2011): Superconformal Gauge theory, Yangian symmetry and Baxter's Q-operator. Supervisor: Matthias Staudacher

Philipp Mösta (Potsdam University 2012): Dynamics of binary black holes with unequal masses. Supervisor: Luciano Rezzolla

Anneke Monsky (Leibniz Universität Hannover 2010): Understanding drag-free sensors in space using intelligent data analysis tools. Supervisor: Gerhard Heinzel

Kristen Moore (Free University Berlin 2012): On the Evolution of Hypersurfaces in Asymptotically Flat Riemannian Manifolds by their Inverse Null Mean Curvature. Supervisor: Gerhard Huisken

Thilo Notz (Free University Berlin 2010): Closed hypersurfaces driven by their mean curvature and inner pressure. Supervisor: Gerhard Huisken

Ernesto Nungesser (Free University Berlin 2012): The future of some Bianchi A spacetimes with an ensemble of free falling particles. Supervisor: Alan Rendall

Frank Ohme (Potsdam University 2012): Bridging the gap between post-Newtonian theory and numerical relativity in gravitational-wave data analysis. Supervisor: Badri Krishnan

Stefan Pfenninger (Humboldt University Berlin 2012): Three-dimensional higher—spin gravity and asymptotic symmetries. Supervisor: Stefan Fredenhagen

Mirko Prijatelj (Leibniz Universität Hannover 2012): Gravitational Wave detection with refined light – The implementation of an output mode cleaner at GEO600. Supervisor: Harald Lück

Christian Reisswig (Leibniz Universität Hannover 2010): Binary Black Hole Mergers and Novel Approaches to Gravitational Wave Extraction in Numerical Relativity. Supervisor: Luciano Rezzolla

Dennis Rätzel (Potsdam University 2012): Tensorial spacetime geometries and background independent quantum field theory. Supervisor: Frederic P. Schuller

Sergio Rivera (Potsdam University 2012): Tensorial spacetime geometries carrying predictive, interpretable and quantizable matter dynamics. Supervisor: Frederic P. Schuller

Constanze Rödig (Potsdam University 2012): Massive Black Hole Binaries in Gaseous Environments. Supervisor: Alberto Sesana

Aiko Samblowski (Leibniz Universität Hannover 2012): State Preparation for Quantum Information Science and Metrology. Supervisor: Roman Schnabel

Lucia Santamaria Lara (Potsdam University 2010): Coalescence of Black-Hole Binaries: from Theoretical Source Models to Applications in Gravitational-Wave Astronomy. Supervisor: Luciano Rezzolla

Jennifer Seiler (Leibniz Universität Hannover 2010): Numerical Simulation of Binary Black Hole Spacetimes and a Novel Approach to Outer Boundary Conditions. Supervisor: Luciano Rezzolla

Per Sundin (Humboldt University Berlin 2010): Perturbative quantization of superstring theory in Anti de-Sitter spaces. Supervisor: Jan Plefka

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Aaryn Tonita (Potsdam University 2012): MHD of mixed binaries. Supervisor: Luciano Rezzolla

Gudrun Wanner (Leibniz Universität Hannover 2010): Complex optical systems in space: numerical modeling of the heterodyne interferometry of LISA Pathfinder and LISA. Supervisor: Gerhard Heinzel

Stefan Zieme (Humboldt University Berlin 2010): Integrability in N=4 SYM. Supervisor: Matthias Staudacher

Diploma Theses

Steffen Aksteiner (Leibniz Universität Hannover 2010): Linear perturbation of vacuum type D spacetimes. Supervisor: Lars Andersson

Norbert Bodendorfer (Erlangen University 2010): Canonical Analysis of Gravity Theories without the Time Gauge. Supervisor: Thomas Thiemann

Nils Brause (Leibniz Universität Hannover 2011): Bau und Test eines Phasenmeters. Supervisor: Gerhard Heinzel

Frank Eckert (Heidelberg University 2012): Coarse graining simplified spin foam models. Supervisor: Matthias Bartelmann, Bianca Dittrich

Vitus Händchen (Leibniz Universität Hannover 2010): Verschränkte Lichtfelder bei 1550nm für faserbasierte Quantenschlüsselverteilung. Supervisor: Roman Schnabel

Gargi Maheshwari (Birla Institute of Technology and Science, Pilani 2012): Curvature Contributions in Group Field Cosmology. Supervisor: Isabeau Premont-Schwarz

David Mesterhazy (Humboldt University Berlin 2010): Polygonal Wilson loops in superspace. Supervisor: Niklas Beisert

Antonio Pittelli (University of Trieste and University of Udine 2012): Coherent states for Quantum Gravity and applications. Supervisors: Lorenzo Sindoni, Stefano Ansoldi

Hans-Christian Ruiz (University of Munich 2012): Toroidal Spin Networks: Towards a Generalization of the Decomposition Theorem. Supervisor: Aristide Baratin

Jan Rybizki (Leibniz Universität Hannover 2011): LISA back-link fibre: back reflection of a polarization maintaining single-mode optical fiber. Supervisor: Gerhard Heinzel

Marco Scalisi (University of Catania 2011): Fractal and Noncommutative Spacetimes. Supervisors: Daniele Oriti, Gianluca Calcagni

Emil Schreiber (Leibniz Universität Hannover 2010): Korrelierte Michelson-Interferometer im Megahertzbereich. Supervisor: Benno Willke

Dirk Schütte (Leibniz Universität Hannover 2010): An InGaAs camera as real-time phasemeter and star-tracker. Supervisor: Michael Tröbs

Gunnar Stede (Leibniz Universität Hannover 2011): Interferometrische Charakterisierung von Retroreflektoren für satellitengestützte Erdschwerefeldbestimmung. Supervisor: Benjamin Sheard

Sebastian Steinhaus (Potsdam University 2010): Quantum perfect actions for one-dimensional reparametrization invariant Systems. Supervisors: Bianca Dittrich, Martin Wilkens

Andreas Thurn (Erlangen University 2010): Constraint Analysis of D+1 dimensional Palatini Action. Supervisor: Thomas Thiemann

Daniel Wahlmann (Leibniz Universität Hannover 2010): Laserstabilisierung auf der Basis des optischen Kerr-Effekts. Supervisor: Roman Schnabel

Volkmar Wieland (Potsdam University 2010): Kinematic effects of a generally hyperbolic spacetime geometry. Supervisor: Frederic P. Schuller

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Herman Witzel (Potsdam University 2009): Curvature of the refined spacetime geometry probed by photons. Supervisor: Frederic Schuller

Bernhard Wurm (Bonn University 2008): Twistor String Theories. Supervisor: Stefan Theisen

Master Theses

Andreas Sawadsky (Leibniz Universität Hannover 2012): Das Michelson-Sagac-Interferometer mit SiN-Membran und Signal-Recycling. Supervisor: Roman Schnabel

Rui Sun (Chalmers University Gothenburg 2010): Limits of N=2 superconformal minimal models. Supervisor: Stefan Fredenhagen

Bachelor Theses

Brigitte Kaune (Leibniz Universität Hannover 2011): Kontrolle und Charakterisierung von piezobetriebenen Kipp- und Linearaktuatoren für die optische Bank von LISA. Supervisor: Michael Tröbs

Igor Libman (Leibniz Universität Hannover 2011): Design and characterization of a thermal shield for LISA optical bench testing. Supervisor: Michael Tröbs

Alexander Meier (Leibniz Universität Hannover 2012): Implementierung und Charakterisierung einer InGaAs Kamera zur Satellitenausrichtung bei LISA. Supervisor: Michael Tröbs

Ramon Moghadas Nia (Leibniz Universität Hannover 2010): Highly efficient frequency doubling of 1550nm laser light. Supervisor: Roman Schnabel

Clemens Schäfermeier (Leibniz Universität Hannover 2010): Wavefront analysis by CCD imaging. Supervisor: Gerhard Heinzel

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Dietlind Witzger	Cleaning Lady (AEI Potsdam)
Marvin Zindler	Freiwilliges wissenschaftliches Jahr (AEI Hannover: LUH)
Heiko zur Mühlen	Electronic Technician (AEI Hannover)
Karl-Heinz Zwick-Meinheit	Technician (AEI Hannover: LUH)

MPG: Max-Planck-Gesellschaft

LUH: Leibniz Universität Hannover

Guest Scientists in Potsdam-Golm (2010)

Abdikamalov, Ernazar - California Institute of Technology
Ahmedov, Bobomurat - Uzbekistan Academy of Sciences
Aksteiner, Steffen - University Bremen
Anabalon, Andres - University Adolfo Ibanez, Vina del Mar
Ansorg, Marcus - Helmholtz Zentrum, München
Azeyanagi, Tatsuo - Kyoto University

Baccetti, Valentina - Rome University
Bäckdahl, Thomas - Queen Mary University of London
Bahr, Benjamin - University of Cambridge
Bai, Shan - Chinese Academy of Sciences, Beijing
Banerjee, Nabamita - Utrecht University
Barausse, Enrico - University of Maryland
Barbour, Julian - University of Oxford
Barnich, Glenn - University of Brussels
Barranco, Juan - UNAM, Mexico
Bartnik, Robert - University of Canberra
Beguin, Francois - University Paris Sud
Beig, Robert - Universität Wien
Bentivegna, Eloisa - Louisiana State University
Berger, Max - Leopold-Franzens-Universität Innsbruck
Bernal, Argelia - University Michoacana, Morelia
Berti, Emanuele - University of Mississippi
Beyer, Florian - University of Otago, New Zealand
Bicak, Jiri - Charles University, Prague
Bishop, Nigel - Rhodes University, South Africa
Blaut, Arkadiusz - University of Wroclaw
Blue, Pieter - University of Edinburgh
Bochicchio, Marco - INFN, Rome
Bohara, Bidur - Louisiana State University
Bojowald, Martin - Pennsylvania State University
Bona, Carles - University of the Balearic Islands, Mallorca
Botvinnik, Boris - University of Oregon
Bouchard, Vincent - University of Alberta, Edmonton
Breiner, Christine - Massachusetts Institute of Technology
Brink, Lars - Chalmers University of Technology
Brödel, Johannes - Stanford University
Brunner, Ilka - LMU, München
Bunster, Claudio - CECS, Chile

Chen, Yanbei - California Institute of Technology
Chirco, Goffredo - SISSA, Trieste
Chirenti, Cecilia - University of Sao Paulo
Chrusciel, Piotr - Vienna University
Ciolfi, Riccardo - Universita La Sapienza Rome
Colpi, Monica - University of Milano
Conrady, Florian - Perimeter Institute, Waterloo
Corvino, Giovanni - University of Rome
Cournou, Jean Louis - Observatoire de Meudon
Cuadra, Jorge - Pontificia Universidad Catolica de Chile

Dadhich, Naresh - IUCAA, Pune
Dafermos, Mihailis - University of Cambridge, UK
Dahl, Mattias - Royal Institute of Technology, Stockholm
Damour, Thibault - Institute des Hautes Etudes Scientifiques, Paris
Das, Saurya - University of Lethbridge, Alberta
Dasgupta, Arundhati - University of Lethbridge, Canada
Dhurandhar, Sanjeev - IUCAA, Pune
Ding, YOU - CPT, Marseille
Dolan, Francis - University of Amsterdam
Dotti, Massimo - University of Milano
Dreyer, Malte - Max Planck Digital Library
Dupuis, Maite - ENS, Lyon
Dutta, Suvankar - Swansea University

Edelstein, Jose - University of Santiago de Compostela
Edmunds, Mike - Cardiff University
Eichmair, Michael - ETH Zürich

Farrell, Sean - University of Leicester
Finster, Felix - Regensburg University
Fisher, Mark - Monash University, Australia
Fleig, Philipp - Imperial College London
Font, Anamaria - UCV, Caracas
Francia, Dario - University Paris 7
Frauendiener, Jörg - University of Otago, New Zealand
Frolov, Sergey - Trinity College, Dublin
Futamase, Toshifumi - Tohoku University Sendai

Gad, Ragab Mohamed - El Minia University, Egypt
Gair, Jonathan - University of Cambridge, UK
Garcia Parrado, Alfonso - University of Gent
Garecki, Janusz - University of Szczecin
Giacomazzo, Bruno - University of Colorado
Giangreco M.Puletti, Valentina - NORDITA, Stockholm
Gibbons, Gary - DAMTP, Cambridge
Gielen, Steffen - Perimeter Institute Waterloo
Giesel, Kristina - Louisiana State University
Gogberashvili, Merab - Andronikashvili Institute of Physics, Tbilisi
Gomes, Henrique - Imperial College, London
Govindarajan, Suresh - Indian Institute of Technology, Chennai
Govindarajan, Tupil Rangachari - The Institute of Mathematical Science, Chennai
Grosse, Harald - University of Vienna
Gryb, Sean - Perimeter Institute, Waterloo
Guerlebeck, Norman - Charles University, Prague
Guffin, Joshua - University of Pennsylvania
Gundlach, Carsten - University of Southampton, UK

Hacket, Jonathan - Perimeter Institute, Waterloo
Hamber, Herbert - University of California, Irvine
Hamma, Alioscia - Perimeter Institute, Waterloo
Han, Muxin - CPT, Marseille

Guest Scientists in Potsdam-Golm (2010)

Henneaux, Marc - University of Brussels
Hillmann, Christian - Institute des Hautes Études Scientifiques, Paris
Höhn, Philipp - Utrecht University
Hu, Bei - Lok-University of Maryland

Ilmanen, Tom - ETHZ Zürich
Isidro, Jose - University of Valencia

Jaramillo, Jose-Luis - Astrophysical Institute of Andalucía
Jatkar, Dileep - Harish Chandra Institute
Jezierski, Jacek - Warsaw University
Johansson, Henrik - CEA Saclay
Joung, Euihun - SNS, Pisa

Kapitanski, Lev - University of Miami
Kempf, Achim - University of Waterloo
Khanna, Gaurav - University of Massachusetts at Dartmouth
Kiefer, Claus - Universität Köln
Kimura, Tetsuji - KEK, Japan
King, Andrew - University of Leicester
Kleinschmidt, Axel - Université Libre de Bruxelles
Kluson, Josef - Masaryk University, Brno
Ko, Yumi - Sogang University, Seoul
Kofron, David - Charles University, Prague
Kong, De-Xing - Hangzhou University
Krishnan, Chethan - SISSA, Trieste
Krolak, Andrzej - Academy of Sciences, Warsaw
Kuwert, Ernst - Universität Freiburg
Kuzenko, Sergei - University of Western Australia

Landwehr, Torsten - Generalverwaltung der MPG
Latosinski, Adam - Warsaw University
Lavrelashvili, George - A. Razmadze Mathematical Institute, Tbilisi
Le Tiec, Alexandre - Institute of Astrophysics, Paris
Lee, Kimyeong - Korean Institute for Advanced Study, Seoul
Lee, Sungjay - Korean Institute for Advanced Study, Seoul
Liebling, Steve - Long Island University
Livine, Etera - ENS, Lyon
Lorenz, Larissa - University Louvain de Neuve, Belgium
Lukowski, Tomasz - Jagellonian University, Krakow

Ma, Yongge - Beijing Normal University
Madigan, Ann-Marie - Leiden Observatory
Maeda, Hideki - Center for Scientific Studies, Valdivia
Magueijo, Joao - Imperial College London
Mahapatra, Swapna - Utkal University, Bhubaneswar
Maharana, Jnanadeva - Institute of Physics, Bhubaneswar
Maharana, Karmadeva - Utkal University, Bhubaneswar
Mandal, Ipsita - Harish-Chandra-Institute, Allahabad
Marini, Antonella - Yeshiva University, New York
Martin-Garcia, Jose Maria - Laboratory of Universe and Theories (Meudon)
McOrist, Jock - DAMTP, Cambridge
Meissner, Krzysztof - Warsaw University
Meziane, Ahmed - University of Oran, Algeria
Mimica, Petar - University of Valencia
Minasian, Ruben - CEA, Saclay
Miskovic, Olivera - Catholic University of Valparaiso, Chile
Misra, Aalok - Indian Institute of Technology, Roorkee
Mokler, Felicitas - AEI Hannover
Moncrief, Vincent - Yale University
Montero, Pedro – Max-Planck-Institut für Astrophysik
Montuori, Carmen - University of Milano
Mottola, Emil - Los Alamos National Laboratory
Müller, Juliane – MPDL

Nagar, Alessandro - Institute des Hautes Etudes Scientifiques Paris
Nardelli, Guiseppe - Catholic University, Brescia
Nicolas, Jean - Philippe-Université de Bretagne, Brest
Nutma, Teake - University of Groningen

Obukhov, Yuri - Moscow State University
Ó Colgáin, Eoin - Korea Institute for Advanced Study, Seoul
Oeckl, Robert - UNAM, Mexico
Olea, Rodrigo - Catholic University of Valparaiso, Chile
Oliynyk, Todd - Monash University, Australia
Ooguri, Hirosi - California Institute of Technology
Ortiz, Omar - University of Cordoba, Argentina
Oz, Yaron - Tel Aviv University

Page, Dany - UNAM Mexico
Palmkvist, Jakob - University of Brussels
Pang, Da-Wei – Max-Planck-Institut für Physik, München
Panosso Macedo, Rodrigo - University of Sao Paulo
Papadopoulos, George - Kings College, London
Park, Chang-Soon - California Institute of Technology
Pasquetti, Sara - CERN, Geneva
Perez, Alfredo - CECS Valdivia, Chile
Pfister, Herbert - Universität Tübingen
Plefka, Jan - Humboldt-Universität, Berlin
Pollney, Denis - Rhodes University South Africa
Porter, Edward - APC, University Paris 7
Prabhu, Siddharth - Indian Institute of Technology, Kharagpur
Pranzetti, Daniele - CPT, Marseille
Preto, Miguel - Astronomisches Recheninstitut, Heidelberg

Qin, Li - Beijing Normal University
Quinn, Eoin - Trinity College, Dublin

Rabinovici, Eliezer - The Hebrew University, Jerusalem
Rampa, Giulio - Cambridge University
Reisswig, Christian - California Institute of Technology
Reuter, Martin - Universität Mainz
Ribas, Ignasi - University of Barcelona
Ringström, Hans - Royal Institute of Technology, Stockholm
Rosquist, Kjell - Stockholm University
Rostworowski, Andrzej - Kraków University
Rummel, Markus - Universität Aachen

Guest Scientists in Potsdam-Golm (2010/2011)

Rupflin, Melanie - ETH Zürich
Russo, Jorge - University of Barcelona

Saa, Alberto - State University of Campinas
Samblowski, Aiko - AEI Hannover
Santamaria Lara, Lucia - California Institute of Technology
Schäfer, Gerhard - Universität Jena
Scheven, Christoph - Universität Erlangen
Schlotterer, Oliver - Max-Planck-Institut für Physik, München
Schmidt, Bernd - München
Schneider, Justus - Astronomisches Rechen-Institut Heidelberg
Schödel, Rainer - Astrophysical Institute of Andalucia
Schoen, Richard - Stanford University, USA
Scholtz, Martin - Charles University, Prague
Schomerus, Volker - DESY, Hamburg
Schubert, Christian - University Michoacana, Morelia
Schwimmer, Adam - Weizmann Institute, Rehovot
Siegel, Daniel - Kiepenheuer-Institut für Sonnenphysik, Freiburg
Simon, Walter - Universität Wien
Sinestrari, Carlo - University of Rome II
Sivakumar, Muthuswamy - University of Hyderabad
Smerlak, Matteo - CPT, Marseille
Smilga, Andrei - University of Nantes
Soroush, Masoud - LMU, München
Spallicci, Alessandro - University of Orléans
Speziale, Simone - CPT, Marseille
Staudt, Christian - Cambridge University
Steinacker, Harold - Universität München
Steinhaus, Sebastian - Perimeter Institute, Waterloo
Stella, Luigi - Astronomical Observatory of Rome
Stelle, Kellogg - Imperial College, London
Stieberger, Stephan - Max-Planck-Institut für Physik, München
Sulkowski, Piotr - California Institute of Technology
Sun, Rui - University of Gothenburg
Svedberg, Christopher - Royal Institute of Technology, Stockholm
Szpak, Nikodem - Universität Duisburg-Essen

Takami, Kentaro - Hiroshima University
Tchrakian, Tigran - Dublin Institute for Advanced Studies
Thiemann, Thomas - Universität Erlangen
Thornburg, Jonathan - Indiana University
Tiglio, Manuel - University of Maryland
Tinaglia, Giuseppe - Kings College London
Tlapak, Vaclav - Humboldt University
Torlina, Lisa - University of Edinburgh
Troessaert, Cedric - University of Brussels

Vacaru, Sergiu - University of Iasi, Romania
Vasiliev, Misha - Lebedev Institute, Moscow
Vasset, Nicolas - Observatoire de Paris
Vicedo, Benuit - ENS, Paris
Vidotto, Francesca - University of Padua
Virmani, Amitabh - University of Brussels
Visser, Matt - Victoria University Wellington
Volonteri, Marta - Institut d Astrophysique de Paris

Wagemann, Friedrich - University of Nantes
Waldmann, Stefan - Universität Freiburg
Wan, Yidun - Kinki University, Osaka
Weber, Joachim - Humboldt University Berlin
Weinfurtner, Silke - University of British Columbia
Weyher, Christina - Max Planck Digital Library
Wise, Derek - Universität Erlangen-Nürnberg

Zamaninasab, Mohammad - Universität Köln
Zenginoglu, Anil - Universität Wien
Zhang, Hongbao - University of Crete, Heraklion

Guest Scientists in Potsdam (2011)

Ahmedov, Bobomurat - Uzbekistan Academy of Sciences
Akhmedov, Emil - ITEP, Moscow
Aksteiner, Steffen - University Bremen
Amelino-Camelia, Giovanni - University of Rome La Sapienza
Ammann, Bernd - Universität Regensburg
Anabolon, Andrés - University Adolfo Ibanez, Vina del Mar
Andersson, Nils - Southampton University
Ansoldi, Stefano - University of Udine
Arutyunov, Gleb - Utrecht University

Bahr, Benjamin - University of Cambridge
Bai, Shan - Chinese Academy of Sciences, Beijing
Baiotti, Luca - Osaka University
Barack, Leor - University of Southampton
Baratin, Aristide - Perimeter Institute, Waterloo
Bassan, Nicola - SISSA Trieste
Bastianelli, Fiorenzo - University of Bologna
Baumgartl, Marco - LMU, München
Belinski, Vladimir - ICRANET, Pescara
Bergshoeff, Eric - University of Groningen
Beyer, Florian - University of Otago, New Zealand
Beyer, Horst - Universidad Michoacan, Mexico
Bicak, Jiri - Charles University, Prague
Bilson-Thompson, Sundance - University of Adelaide, Australia
Bishop, Nigel - Rhodes University, South Africa
Bizón, Piotr - Jagiellonian University, Krakow
Bodendorfer, Norbert - Universität Erlangen
Boels, Rutger - DESY, Hamburg
Bossard, Guillaume - University of Amsterdam
Botvinnik, Boris - University of Oregon
Brink, Lars - Chalmers University of Technology
Brizuela, David - Pennsylvania State Universtiy
Brödel, Johannes - Stanford University
Bruni, Marco - University of Portsmouth
Bulik, Tomasz - Warsaw University
Bunster, Claudio - CECS, Chile

Guest Scientists in Potsdam-Golm (2011)

Calogero, Simone - University of Granada
Chacaltana, Oscar - ICPT Trieste
Chandra, Mani - Indian Institute of Technology Kanpur
Chirenti, Cecilia - University of Sao Paulo
Clarkson, Christopher - University of Cape Town
Cordero, Isabel - University of Valencia
Coutant, Antonin - LPT, Orsay
Cuadra, Jorge - Pontificia Universidad Catolica de Chile

Dahl, Mattias - Royal Institute of Technology, Stockholm
Dain, Sergio - University of Cordoba, Argentina
de Aranjo, Mariana - Universidade de Porto
de Pietri, Roberto - Universitá di Parma
Delfino, Gianluca - University of Nottingham
Ding, Adalbert - TU Berlin
Dotti, Massimo - University of Milano
Doulis, Georgios A. - University of Otago
Drasco, Steve - California Polytechnic State University
Durrer, Ruth - Université de Genève
Dvali, Georgi - LMU München

Egido-Cuchi, Francisco-Javier - Universidad de Salamanca
Eichmair, Michael - ETH Zürich
Eisenbeiss, Thomas - Universität Jena
Elvang, Henriette - MIT, Cambridge

Fertig, Angelika - University of Cambridge, UK
Fischbacher, Thomas - University of Southampton, UK
Font, Anamaria - UCV, Caracas
Förste, Stefan - Universität Bonn
Franci, Luca - Parma University
Francia, Dario - University Paris 7
Fraß, Stephan - Max-Planck-Institut für Astronomie, Heidelberg
Frauendiener, Jörg - University of Otago, New Zealand
Frolov, Sergey - Trinity College, Dublin

Gair, Jonathan - University of Cambridge, UK
Garbarz, Alan - University of Buenos Aires
Garecki, Janusz - University of Szczecin
Ghoshal, Debashis - Jawaharlal Nehru University, New Delhi
Giacomazzo, Bruno - University of Colorado
Gielen, Steffen - Perimeter Institute Waterloo
Giesen, Gregor - Warwick Mathematics Institute
Gionti, Gabriele - Vatican Observatory, Rome
Goerlich, Andrzej - Niels-Bohr-Institute, Copenhagen
Gomez, Humberto - University of Sao Paulo
Govindarajan, Tupil Rangachari - The Institute of Mathematical Science, Chennai
Groot Nibbelink, Stefan - LMU, München
Gualtieri, Leonardo - Università di Roma
Guarino, Adolfo - University of Groningen
Guenter, Sibylle – Max-Planck-Institut für Plasmaphysik
Gurau, Razvan - Perimeter Institute
Gürlebeck, Norman - Charles University Prague
Gusev, Yuri - IRMACS, Canada
Gutperle, Michael - UCLA, Los Angeles
Gwyn, Rhiannon - Kings College London

Haardt, Francesco - Università dell'Insubria Como
Hamma, Alioscia - Perimeter Institute, Waterloo
Haslhofer, Robert - ETH Zürich
Hawke, Ian - University of Southhampton
Hellermann, Simeon - University of Tokyo
Henneaux, Marc - University of Brussels
Higuchi, Atsushi - University of York
Hoegner, Moritz - DAMTP, Cambrige
Hoffmann, Dieter - Max-Planck-Institut für Wissenschaftsgeschichte
Höhn, Philipp - Utrecht University
Hoppe, Jens - KTH Stockholm
Huet, Idrish - University of Jena

Iyer, Ashwathi - Cornell University

Jacobson, Theodore - University of Maryland
Jennen, Hendrik - Catholic University, Leuven
Jezierski, Jacek - Warsaw University

Kanning, Nils - HU Berlin
Kastaun, Wolfgang - SISSA Trieste
Katsimpouri, Despoina - Universität München
Ketov, Sergej - Tokyo Metropolitan University
Khavkine, Igor - University of Utrecht
Kiefer, Claus - Universität Köln
Kiermaier, Michael - Princeton University
Kim, Nakwoo - Kyung Hee University, Seoul
Kleinschmidt, Axel - Université Libre de Bruxelles
Klevtsov, Semyon - University of Brussels
Kofron, David - Charles University, Prague
Komissarov, Serguei - University of Leeds
Komossa, Stefanie - Max-Planck-Institut für Radioastronomie, Bonn
Konstantinidis, Simeon - University of Thessaloniki
Korzynski, Mikolaj - Vienna University
Koslowski, Tim - Universität Würzburg
Kostecki, Ryszard - University of Warsaw
Krasnov, Kirill - University of Nottingham
Kreiss, Heinz-Otto - KTH Stockholm
Kroyter, Michael - Tel Aviv University
Kuzenko, Sergei - University of Western Australia

Labus, Peter - FU Berlin
Lal, Shailesh - Harish Chandra Institute, Allahabad
Lander, Samuel - University of Southampton
Latosinski, Adam - Warsaw University
Lavrelashvilli, George - A. Razmadze Mathematical Institute, Tbilisi
Lecian, Orchidea - IHES, Paris
Lewandowski, Adrian - Warsaw University

Guest Scientists in Potsdam-Golm (2011)

Lindman Hörnlund, Josef - Chalmers University of Technology

Linshaw, Andrew - Technische Universität, Darmstadt

Livine, Etera - ENS, Lyon

Lukyanenko, Alexander - State Polytechnical University, St. Petersburg

Majumdar, Parthasarathi - Saha Institute of Nuclear Physics, Calcutta

Maliborski, Maciej - Jagiellonian University, Krakow

Mandal, Bhabani Prasad - Banaras Hindu University Varanasi, India

Mandel, Ilya - Northwestern University

Mars, Marc - University of Salamanca

Martinetti, Pierre - Università di Roma

Maselli, Andrea - Università di Roma

Meissner, Krysztof - Warsaw University

Milman, Emanuel - Israel Institute of Technology (Technion)

Minasian, Ruben - CEA, Saclay

Möller, Niels - MIT, Cambridge MA

Moncrief, Vincent - Yale University

Montuori, Carmen - University of Milano

Müller, Ingo - TU Berlin

Nölle, Christoph – Leibniz Universität Hannover

Odintsov, Sergei - Tomsk University

Oliynyk, Todd - Monash University, Australia

Olmedo Nieto, Javier - Institute for the structure of matter, Madrid

Ott, Christian David - California Institute of Technology

Palmkvist, Jakob - University of Brussels

Panosso Macedo, Rodrigo - University of Sao Paulo

Park, Chanyong - Sogang University, Seoul

Passamonti, Andrea - Tübingen University

Percacci, Roberto - SISSA, Trieste

Perez, Alfredo - CECS Valdivia, Chile

Perna, Rosalba - University of Colorado Boulder

Pfister, Herbert - Universität Tübingen

Pilch, Krzystof - University of Southern California

Porter, Edward - APC, University Paris 7

Preto da Silva, Miguel - Astronomisches Recheninstitut Heidelberg

Pugh, Tom - Imperial College, London

Qing, Jie - University of California at Sanata Cruz

Rahman, Rakibur - Normal School, Pisa

Regis, Marco - University of Turin

Reintjes, Moritz - Universität Regensburg

Rembiasz, Tomasz - Max Planck Institute for Astrophysics, Garching

Reuter, Martin - Universität Mainz

Rim, Chaiho - Sogang University, Seoul

Rinne, Oliver - University of Cambridge

Rosales, Leobardo - Rice University

Rosso, Matteo - ETH Zürich

Rostworowski, Andrzej - Kraków University

Rovelli, Carlo - Université de Marseille

Roy, Xavier - Université Lyon 1

Sahlmann, Hanno - Asia Pacific Center for Theoretical Physics, Korea

Santamaria Lara, Lucia - California Institute of Technology

Scalisi, Marco - University of Catania

Scarinci, Carlos - University of Nottingham

Schell, Christian - Universität Köln

Schlotterer, Oliver - Max-Planck-Institut für Physik

Schlue, Volker - Kongs College, Cambridge

Schmidt, Bernd - München

Schmidt-Colinet, Cornelius - IPMU, Kashiwa, Japan

Schroer, Bert - Freie Universität Berlin

Schubert, Christian - University Michoacana, Morelia

Schwimmer, Adam - Weizmann Institute, Rehovot

Seidel, Ed - National Science Foundation

Shen, Gang - Los Alamos National Laboratory

Siegel, Daniel - Institut für Sonnenphysik, Freiburg

Simon, Walter - Universität Wien

Smilga, Andrei - University of Nantes

Sonnenschein, Jacob - Tel Aviv University

Sonner, Julian - Imperial College, London

Sorkin, Rafael - Syracuse University

Speziale, Simone - CPT, Marseille

Spiridonov, Vyacheslav - Joint Institute for Nuclear Research, Dubna

Steinhoff, Jan - Universität Jena

Stephany, Jorge - University of Caracas

Svarc, Robert - Charles University Prague

Szpak, Nikodem - Universität Duisburg-Essen

Taghizadeh Firouzjaee, Javad - Sharif University of Technology Tehran

Tambornino, Johannes - ENS, Lyon

Taronna, Massimo - SNS, Pisa

Tchapnda Njabo, Sophonie Blaise - University of Yaounde

Thornburg, Jonathan - Indiana University

Tiglio, Manuel - University of Maryland

Tlapak, Vaclav Marcus - HU Berlin

Tod, Paul - St. Johns College, Oxford

Vasiliev, Misha - Lebedev Institute, Moscow

Virmani, Amitabh - University of Brussels

Waldram, Daniel - Imperial College, London

Waldron, Andrew - University of California at Davis

Wang, Yan - AEI Hannover

Wang, Yi - Princeton University

Watanabe, Yuki - University of Texas at Austin

Wecht, Brian - University of Michigan

Weinstein, Gilbert - University of Alabama at Birmingham

Wex, Norbert - Max-Planck-Institut für Radioastronomie, Bonn

Whale, Ben - University of Otago, NZ

Williams, Ruth - DAMTP, Cambridge

Guest Scientists in Potsdam-Golm (2011/2012)

Winicour, Jeffrey - University of Pittsburgh
Wise, Derec - Universität Erlangen-Nürnberg
Woolgar, Eric - University of Alberta

Xu, Peng - Chinese Academy of Science Beijing
Xu, Yingying - Chinese Academy of Sciences, Beijing
Yang, Gang - Queen Mary College, London

Zanotti, Olindo - University of Trento
Zieme, Stefan - NORDITA, Stockholm
Zipfel, Antonia - TU Berlin

Guest Scientists in Potsdam-Golm (2012)

Abdikamalov, Ernazar - California Institute of Technology
Adam, Ido - UNESP, Sao Paulo
Ahmedov, Bobomurat - Uzbekistan Academy of Sciences
Akhmedov, Emil - ITEP, Moscow
Aksteiner, Steffen - Universität Bremen
Allen, Paul - University of Washington, Tacoma
Alós-Ferrer, Carlos - Universität Konstanz
Andriot, David - Universität München
Ansoldi, Stefano - University of Udine
Aranguiz, Ligeia - Technical University Santa Maria, Valparaiso
Arnlind, Joakim - Linköping University
Astefanesei, Dumitru - University of Waterloo

Bahr, Benjamin - University of Cambridge
Bambi, Cosimo - LMU München
Banerjee, Nabamita - Utrecht University
Barbado, Luis Cortes - Instituto de Astrofisica de Andalucia (CSIC),
Bassan, Nicola - SISSA Trieste
Bastianelli, Fiorenzo - University of Bologna
Baulieu, Laurent - LPTHE, Paris
Baumgardt, Holger - University of Queensland, Australia
Beheshti, Shabnam - Rutgers University
Bellova, Katarina - Courant Institute, New York University
Bernard, Yann - Universität Freiburg
Berti, Emanuele - University of Mississippi
Bertolini, Marco - Duke University, Durham
Bicak, Jiri - Charles University, Prague
Bishop, Nigel - Rhodes University, South Africa
Blazewicz, Marek - Poznan Supercomputing and Networking Centre
Bojowald, Martin - Pennsylvania State University
Bose, Soumyajit - IIT Kanpur, India
Botvinnik, Boris - University of Oregon
Boulanger, Nicolas - University of Mons
Brem, Patrick - Universität Heidelberg
Brendle, Simon - Stanford University
Brink, Lars - Chalmers University of Technology
Brizuela, David - Pennsylvania State University
Brown, Duncan - Syracuse University
Bunster, Claudio - CECS, Chile
Buonanno, Alessandra - University of Maryland
Burda, Philipp - ITEP, Moscow
Buric, Maja - University of Belgrade

Campiglia, Miguel - Penn State University
Canto, Rodrigo - Catholic University of Chile
Cao, Huai-Dong - Lehigh University
Caravelli, Francesco - Perimeter Institute, Waterloo
Carqueville, Nils - Universität Bonn
Carrasco Ferreira, Alberto - University of the Basque Country, Mérida, Badajoz, Spain
Cederbaum, Carla - Duke University
Cederwall, Martin - Chalmers Technical University
Chankowski, Piotr - Warsaw University
Chirenti, Cecilia - University of Sao Paulo
Chrusciel, Piotr - Vienna University
Cole, Robert - University of Cambridge
Cortes Barbado, Luis - Institute of Astrophysics, CSIC, Granada
Corvino, Giovanni - University of Rome
Cozzini, Stefano - SISSA, Trieste
Cuadra, Jorge - Pontificia Universidad Catolica de Chile

Dahl, Mattias - Royal Institute of Technology, Stockholm
Dain, Sergio - University of Cordoba, Argentina
Danèk, Jiri - Charles University, Prague
de Araujo, Mariana - Universidade de Porto
De Felice, Fernando - University of Padova
de Pietri, Roberto - Parma University
Dhurandhar, Sanjeev - IUCAA, Pune
Didenko, Vyacheslav - Lebedev Institute, Moscow
Dittrich, Bianca - Perimeter Institute
Dominik, Michal - Warsaw University
Dotti, Gustavo - FAMAF, Cordoba, Argentina
Dotti, Massimo - University of Milano
Dreyer, Olaf - Pennsylvania State University
Duff, Michael - Imperial College London
Dupius, Maite - Universität Erlangen

Eichmair, Michael - ETH Zürich
Erickson, Stephanie - University of Southampton
Espin, Johnny - Ecole Federale Polytechnique, Lausanne
Evans, Charles - University of North Carolina Chapel Hill

Fewster, Chris - University of York
Finster, Felix - Universität Regensburg
Font, Anamaria - UCV, Caracas
Franci, Luca - Parma University
Frauendiener, Jörg - University of Otago, New Zealand
Freyn, Walter - Technische Universität, Darmstadt

Gair, Jonathan - University of Cambridge, UK
Gajic, Dejan - Christs College Cambridge
Giasemidis, Georgios - Oxford University
Gicquaud, Romain - Tours University

Guest Scientists in Potsdam-Golm (2012)

Gielen, Steffen - Perimeter Institute Waterloo
Glushikhina, Maria - Space Research Institute Moscow
Goldman, Dorian - Courant Institute, New York University
Gopakumar, Achamveedu - Mumbai
Gralla, Samuel - University of Maryland
Grant, James D.E. - Universität Wien
Gregoris, Daniele - Stockholm University
Groh, Kai - Universität Mainz
Guenther, Christine - Pacific University
Gulliver, Robert - University of Minnesota
Gundlach, Carsten - University of Southampton, UK
Gürlebeck, Norman - ZARM, Universität Bremen
Gusev, Yuri - IRMACS , Canada

Häfner, Dietrich - Université de Grenoble
Halácek, Jakub - Charles University, Prague
Hall, Steven - IOP Publishing, Bristol
Hamber, Herbert - University of California, Irvine
Hardt, Robert - Rice University
Hartley, David - Monash University
Hejda, Filip - Charles University, Prague
Hirsch, Jonas - Uni Karlsruhe
Hofmann, Werner - Max-Planck-Institut für Kernphysik
Hollands, Stefan - University of Cardiff
Honda, Masazumi - KEK Theory Center, Tokyo
Hoppe, Jens - KTH, Stockholm
Hughes, Spencer T. - DAMTP, Cambridge
Hynek, Mariusz - KTH, Stockholm

Iyer, Bala - Babson College, Massachusetts

Jalmuzna, Joanna - University of Krakòw
Jeon, Imtak - Sogang University
Jezierski, Jacek - Warsaw University
Joung, Euihun - SNS, Pisa

Kennedy, Gareth - Chinese Academy of Sciences
Klose, Thomas - Uppsala University
Kolasiński, Sławomir - University of Warsaw
Kolekar, Sanved - IUCAA, Pune
Komossa, Stefanie - Max-Planck-Institut für Radioastronomie, Bonn
Korzynski, Mikolaj - Vienna University
Krasnov, Kirill - University of Nottingham
Kundu, Payel - Jadavpur University, India

Laszlo, Andras - Wigner Research Center for Physics Budapest
Lau, Yun Kau - Chinese academy of sciences
Lavrelashvili, George - A. Razmadze Mathematical Institute, Tbilisi
Ledvinka, Tomas - Charles University Prague
Lee, Kanghoon - Sogang University
LeFloch, Philippe G. - Universitè Pierre et Marie Curie, Paris
Lentati, Lindley - Cambridge University
Liang, Xiangyu - Paris University
Lin, Chun-Chi - Max-Planck-Institut für Mathematik in den Naturwissenschaften
Lindblom, Lee - California Institute of Technology
Livine, Etera - ENS, Lyon
Lukyanenko, Alexander - State Polytechnical University, St. Petersburg
Lyutikov, Maxim - Purdue University West Lafayette

Mafra, Carlos - DAMTP, Cambridge
Maharana, Anshuman - Harish-Chandra Research Institute Allahabad
Maheshwari, Gargi - Birla Institute of Technology & Science, Pilani
Maldacena, Juan - Institute of Advanced Studies, Princeton
Maliborski, Maciej - Jagiellonian University, Krakow
Manvelyan, Ruben - Yerevan Physics Inst.
Marini, Antonella - Yeshiva University, New York
Marronnetti, Pedro - University of Texas, Austin
Mason, Lionel - Oxford University
Maureira Fredes, Cristían Danilo - Universidad Tècnica Valparaiso
McOrist, Jock - DAMTP, Cambridge
McWilliams, Sean T. - Princeton University
Meissner, Krysztof - Warsaw University
Mekareeya, Noppadol - Max-Planck-Institut für Physik
Merloni, Andrea - Max-Planck-Institut für extraterrestrische Physik, Garching
Michishita, Yoji - Kagoshima University
Minasian, Ruben - CEA, Saclay
Minguzzi, Ettore - Florence University
Mishra, Chandra Kant - Raman Research Institute Bangalore
Moncrief, Vincent - Yale University
Mondino, Andrea - Scuola Normale Superiore Pisa
Montuori, Carmen - University of Como
Morrison, Ian - DAMTP, Cambridge
Mösta, Philipp - California Institute of Technology
Mottola, Emil - Los Alamos National Laboratory
Mukhopadhyay, Ayan - LPTHE, Paris
Müller, Reto - Imperial College, London
Müller, Werner - Universität Bonn
Musaev, Edvard - Queen Mary University of London

Neilsen, David - Brigham Young University, Provo
Neira, Carolina - Universität Regensburg
Neuhäuser, Ralph - Universität Jena
Nicolas, Jean - Philippe-Universitè de Bretagne, Brest

Oh, Sung-Jin - Princeton University
Olea, Rodrigo - Catholic University of Valparaiso, Chile
Oliynyk, Todd - Monash University, Australia
Ortiz, Omar - University of Cordoba, Argentina
Ortiz Madrigal, Néstor - Universidad Michoacana de San Nicolas de Hidalgo
Ovrut, Burt - University of Pennsylvania
Oz, Yaron - Tel Aviv University

Pai, Archana - Indian Institute of Science Education and Research
Palmkvist, Jakob - IHES, Bures-sur-Yvette
Perez, Alfredo - CECS Valdivia, Chile
Persson, Daniel - Chalmers University of Technology

Petiteau, Antoine - Laboratoire AstroParticle et Cosmologie Paris

Pfeifer, Christian - DESY, Hamburg

Pfister, Herbert - Universität Tübingen

Pittelli, Antonio - University of Trieste

Plesser, Ronen - Duke University, Durham USA

Pollney, Denis - Rhodes University South Africa

Ponomarev, Dmitry - Mons University

Preto da Silva, Miguel - Astronomisches Recheninstitut, Heidelberg

Rácz, István - MTA Wigner Research Center for Physics, Budapest

Recknagel, Andreas - Kings College, London

Reintjes, Moritz - Universität Regensburg

Reisswig, Christian - California Institute of Technology

Reiter, Peter - ETH Zürich

Reula, Oscar - University of Cordoba, Argentina

Riello, Aldo - CPT, Marseille

Ringström, Hans - Royal Institute of Technology, Stockholm

Rivasseau, Vincent - LPT, Orsay

Robbins, Daniel - A & M University, Texas

Rödig, Constanze - Johns Hopkins University

Roenne, Peter - Niels Bohr Institute, Copenhagen

Rosquist, Kjell - Stockholm University

Rossi, Elena - Leiden Observatory

Roychowdhury, Raju - Sogang University, Seoul

Saravanan, Satish Kumar - FU Berlin

Sarbach, Olivier - Universidad Michoacana de San Nicolas de Hidalgo

Sardelli, Francesco - University of Tours

Scalisi, Marco - University of Catania

Schell, Christian - Universität Köln

Schmidt, Bernd - München

Schmidt, Brian - Australian National University

Schmidt, Josef - Technical University, Prague

Schnetter, Erik - Perimeter Institute Waterloo

Schoen, Richard - Stanford University, USA

Scholtz, Martin - Charles University, Prague

Schomerus, Volker - DESY, Hamburg

Schubert, Christian - University Michoacana, Morelia

Schulze, Felix - FU Berlin

Schwimmer, Adam - Weizmann Institute, Rehovot

Sedrakian, Armen - Universität Frankfurt am Main

Shankaranarayanan, Subramaniam - IISER, Trivandrum

Simon, Leon - Stanford University

Simon, Miles - Universität Magdeburg

Simon, Walter - Universität Wien

Sircar, Nilanjan - Tata Institute, Mumbai

Skakala, Jozef - Universidade Federal do ABC, Santo André

Smulevici, Jacques - Université Paris-Sud

Song, Wei - Harvard University

Sopuerta, Carlos - Institute of Space Sciences, Barcelona

Sorkin, Evgeny - University of British Columbia

Spadaro, Emanuele Nunzio - Max-Planck-Institut für Mathematik in den Naturwissenschaften

Stalker, John - Trinity College Dublin

Starrov, Iva - Lewis & Clark College

Steinwachs, Christian - Universität Köln

Stelle, Kellogg - Imperial College, London

Stergioulas, Nikolaos - University of Thessaloniki

Stieberger, Stephan - Max-Planck-Institut für Physik, München

Suchanek, Paulina - DESY, Hamburg

Suh, Yoonji - Sogang University

Tahvildar - Zadeh, A Shadi-University Piscataway, NY USA

Tambornino, Johannes - ENS, Lyon

Tanaka, Takamitsu - Max Planck Institute for Astrophysics, Garching

Taylor, Stephen

Tiglio, Manuel - University of Maryland

Tonegawa, Yoshihiro - Hokudai University

Tucker, Evan - University of Arizona

Tursunov, Arman - Astronomical Institute Tashkent

Valiente Kroon, Juan Antonio - Queen Mary College, London

Velazguez, Juan - Bonn University

Vercnocke, Bert - CEA, Saclay

Volonteri, Marta - Institut d Astrophysique de Paris

Vulcanov, Dumitru - Timisoara University

Wang, Mu-Tao - Columbia University

Wannerer, Thomas - ETH Zürich

Wardell, Barry - Complex & Adaptive Systems Laboratory Dublin

Weigand, Timo - Unversität Heidelberg

White, Brian - Stanford University

Wickramasekera, Neshan - DPMMS Cambridge

Wiegand, Alexander - Universität Bielefeld

Wieland, Wolfgang - CPT, Marseille

Wilson-Ewing, Edward - CPT, Marseille

Woan, Graham - University of Glasgow

Wosiek, Jacek - Jagellonian University, Krakow

Yankielowicz, Shimon - Tel Aviv University

Yin, Yihao - University of Groningen

Zanelli, Jorge - Centro de Estudios Científicos de Santiago, Chile

Guest Scientists in Hannover (2010)

Abele, Hermann - EADS Astrium GmbH

Adler, Dieter - EADS Astrium GmbH

Altenfeld, Sabine - Deutsches Zentrum für Geophysik

Anderson, Stuart - LIGO

Anjos, Denis - Versatus HPC

Artmann, Oliver - Max-Planck-Institut für Marine Mikrobiologie

Ballmer, Stefan - National Astronomical Observatory of Japan

Bandikova, Tamara - Institut für Erdmessung, Leibniz Universität Hannover

Guest Scientists in Hannover (2010)

Barlage, Bernhard - EADS Astrium GmbH

Barlage, Bernhard - EADS Astrium GmbH

Bartoszek, Marshall - Fortinet Inc.

Behnke, Berit - AEI Potsdam-Golm

Bejger, Michal - Nicolaus Copernicus Astronomical Center

Bindel, Daniel - ZARM, Bremen

Blaut, Arkadiusz - University of Wroclaw

Bond, Charlotte - University of Birmingham

Borja, Sorazu - University of Glasgow

Bork, Rolf - LIGO Lab California Institute of Technology, Pasadena

Bose, Sukanta - Washington State University

Brieden, Phillip - Institut für Erdmessung, Leibniz Universität Hannover

Brieussel, Alexandre - École normale supérieure Lettres et sciences humaines, Lyon

Brown, Duncan - Syracuse University

Brown, Daniel - University of Birmingham

Buchanan, Mark - Write about Science

Cannini, Fabricio - Versatus HPC

Carbone, Ludovico - University of Birmingham

Carvell, Ray - The Spinney Brightwell-cum-Sotwell

Cesa, Marco - ESA-ESTEC

Cheatham, Morgan - Dickinson College, Carlisle, USA

Chen, Yanbei - California Institute of Technology

Cordes, James - Cornell University

Costea, Adrian - Institut für Angewandte Mathematik, Leibniz Universität Hannover

Cutler, Curt - Jet Propulsion Laboratory

Danilishin, Stefan - Moscow State University

Degallaix, Jerome - CNRS

Diaz-Aguilo, Marc - Castelldefels Campus UPC

Dittrich, Lutz - STI

Doll, Berhard - STI

Döhle, Mathias - Max-Planck-Institut für Marine Mikrobiologie

Dübe, Marcel - Kayser-Threde GmbH

Eatough, Ralph - Max-Planck-Institut für Radioastronomie

Eggenstein, Heinz-Bernd - AOL

Ergenzinger, Klaus - EADS Astrium GmbH

Falvella, Maria Cristina - Agenzia Speziale Italiana

Fechtner, Frank - GeoForschungsZentrum Potsdam

Feili, Davar - Justus-Liebig-Universität Gießen

Fertin, Dennis - ESA

Fiurasek, Jaromir - Palacky University, Dept. of Optics

Flury, Jakob - Institut für Erdmessung, Leibniz Universität Hannover

Frede, Maik - Laser Zentrum Hannover

Freire, Paulo - Max-Planck-Institut für Radioastronomie

Freise, Andreas - University of Birmingham

Fulda, Paul - University of Birmingham

Garcia, Cesar - ESTEC

Gerardi, Domenico - EADS Astrium GmbH

Gerndt, Rüdiger - EADS Astrium GmbH

Ghosh, Shaon - Washington State University

Gleixner, Thomas - Freelancer, Uhldingen, Germany

Goetz, Evan - University of Michigan

Grothues, Hans-Georg - Deutsches Zentrum für Luft u. Raumfahrt e.V.

Grynagier, Adrien - Institut für Flugmechanik + Flugregelung

Gusev, Yuri - The Irmacs Centre, Simon Fraser University

Hannes, Alexander - Kayser-Threde GmbH

Harms, Jan - California Institute of Technology

Harper, Caroline - Overseas Development Institute

Hattner, Sabina - University of Glasgow

Hayama, Kazuhiro - National Astronomical Observatory of Japan

Hessels, Jason W. F. - Astronomical Institute Anton Pannekoek

Hild, Stefan - University of Glasgow

Hogan, Craig - Fermilab Center for Particle Astrophysics

Hough, Jim - University of Glasgow

Huntington, Elanor - University of New South Wales

Huttner, Sabina - University of Glasgow

Ivanov, Alex - LIGO Lab California Institute of Technology

Izumi, Kiwamu - National Astronomical Observatory of Japan

Jackson, Mark - Lorentz Institute

Jeannin, Olivier - AstroParticule et Cosmologie (APC) CNRS

Jin, Gang - Institute of Mechanics, Chinese academy of sciences

Johlander, Bengt - ESA-ESTEC

John, Carsten - Max-Planck-Institut für Marine Mikrobiologie

Jolander, Bengt - ESA-ESTEC

Kalmus, Peter - California Institute of Technology

Kampfer, Georg - Kayser-Threde GmbH

Kelesoglu, Murat - Fortinet

Kemmerle, Kurt - Kayser-Threde GmbH

Keppel, Drew - LIGO Lab, California Institute of Technology

Khalili, Farid - Moscow State University

Khanna, Gaurav - University of Massachusetts Dartmouth

Kim, Chunglee - Lund Observatory

King, Peter - California Institute of Technology

Klimenko, Sergey - University of Florida

Kokeyama, Keiko - University of Birmingham

Kolbe, Dieter - EADS Astrium GmbH

Kolbe, Dieter - EADS Astrium GmbH

Köhler, Michael - EADS Astrium GmbH

Krauss, Lawrence - Arizona State University

Krolak, Andrzej - Institute of Mathematics, Polish Academy of Sciences

Kusch, Bernhard - Kayser-Threde GmbH

Lau, Yun-Kan - Institute of Appl. Maths, Academy of Maths and System Science

Lämmerzahl, Claus - ZARM, Bremen

Leininger, Michael - Kayser-Threde GmbH

Liang, Jingyuan - Wuhan, China

Livas, Jeffrey - Goddard Space Flight Center

Lloro, Ivan - Institut de Ciències de l'Espai Campus UAB

Guest Scientists in Hannover (2010/2011)

Lombardi, Alexander - University of Florida
Luo, Ziren - Institute of Mechanics, Chinese Academy of Sciences
Lützow-Wentzky, Peter - EADS Astrium GmbH

MacDonald, Erin - Institute for Gravitational Research
Manca, Gian Mario - AEI Potsdam-Golm
Marec, Petr - Dept. of Optics, Palacky University
McLaughlin, Maura - West Virginia University
Meyer, Renate - The University of Auckland
Mul, Frans - Nikhef, Amsterdam
Mullins, Justin - Write about Science
Muslem, Leila
Müller, Jürgen - Institut für Erdmessung, Leibniz Universität Hannover

Naeimi, Majid - Institut für Erdmessung, Leibniz Universität Hannover
Nielsen, Bo Merholt - Universität Kopenhagen, Kopenhagen, Dänemark
Ng, Cherry - Max-Planck-Institut für Radioastronomie
Nicklaus, Kolja – STI

Ohme, Frank - AEI Potsdam-Golm

Parameswaran, Ajith - California Institute of Technology, LIGO Lab and Theoretical Astrophysics
Peterson, Philip - University of Leicester
Piermaria, Mauro - ESTEC European Space Research and Technology Centre
Pikovski, Alexander - Institut für Theoretische Physik
Pranz, Christine - Max-Planck-Institut für Marine Mikrobio-logie
Prat, Pierre - AstroParticule et Cosmologie (APC) CNRS
Preston, Alix - NASA Goddard Space Flight Center
Puncken, Oliver - Laser Zentrum Hannover

Rabeling, David S. - Nikhef, Amsterdam
Racca, Giuseppe - ESTEC European Space Research and Technology Centre
Rasel, Ernst-Maria - Institut für Quantenoptik, Leibniz Universität Hannover
Rogalla, Kurt - EADS Astrium GmbH
Rowan, Sheila - University of Glasgow

Sammut, Letizia - University of Melbourne
Sand, Rolf - STI
Schink, Dietmar - EADS Astrium GmbH
Schroeven, Hilde - ESTEC European Space Research and Technology Centre
Schulz, Bastian - Laser Zentrum Hannover
Schütze, Daniel - Universität Bonn
Searle, Antony - LIGO Laboratory
Shoda, Ayaka - University of Tokyo
Siddiqi, Maham - Harvard University
Sievers, Kay - Freelancer, Hamburg
Skorupka, Sascha - Institut für Quantenoptik, Leibniz Universität Hannover
Slutsky, Jacob - Louisiana State University
Smit, Martijn - Space Research Organization Netherlands (SRON)
Sorazu, Borja - University of Glasgow
Stephan, Ernst
Strain, Kenneth - University of Glasgow, Glasgow, United Kingdom
Sutton, Patrick - University of Cardiff

van der Putten, Sipho - Nikhef
Vasilyev, Denis - St. Petersburg State University
Veltkamp, Christian - Laser Zentrum Hannover
Vitale, Stefano - Universität Trento
Vitale, Salvatore - Embry-Riddle Aeromatical University
Vockerodt, Tobias - Institut für Quantenoptik, Leibniz Universität Hannover
Vollmer, Günter - EADS Astrium GmbH

Walz, Sebastian - RUAG Space
Wand, Vinzenz - EADS Astrium GmbH
Wang, Mengyao - University of Birmingham
Weßels, Peter - Laser Zentrum Hannover
Winkelmann, Lutz - Laser Zentrum Hannover
Wuchenich, Danielle - The Australian National University
Wübbena, Jannes - PTB Braunschweig
Wübbena, Temmo - Institut für Quantenoptik, Leibniz Universität Hannover

Xuereb, André - University of Southampton

Yamamoto, Kazuhiro - INFN, Sezione di Padova
Yeh, Hsien-Chi - Huazhong University of Science and Technology

Zaglauer, Albert - EADS Astrium GmbH
Zweifel, Peter - ETH Zürich

Guest Scientists in Hannover (2011)

Abd el Bsset, Djemai - Einstein@Home Volunteer, France
Adams, Thomas - Cardiff University
Aliotta, Marialuisa - University of Edinburgh
Anderson, David - University of California, Berkeley Space Sciences Laboratory
Anderson, Nils - University of Southampton
Aurelien, Dantan - University of Aarhus

Babak, Stanislav - AEI Potsdam-Golm
Bai, Yan-Zheng - Huazhong University of Science and Technology
Barrett, Sean - Imperial College London
Beckert, Uwe - Rechenkraft.net.e.V.
Beer, Christian - Rechenkraft.net.e.V.
Berghöfer, Thomas - DESY
Bergmann, Elko - Einstein@Home Volunteer, Germany
Berkau, Christoph - Einstein@Home Volunteer, Germany
Binetruy, Pierre - AstroParticule et Cosmologie (APC) CNRS
Blumberg, Matthew - GridRepublic, Carlton
Bond, Charlotte - University of Birmingham

Guest Scientists in Hannover (2011)

Bose, Sukanta - Washington State University

Boward, Andy - Oxford

Bozzi, Antonella - European Gravitational Observatory

Brasiliero, Francisco - AKA Fubica, UFCG

Brown, Duncan - Syracuse University

Brown, Daniel - University of Birmingham

Brügmann, Bernd - Friedrich-Schiller-Universität Jena

Caprini, Chiara - Institute de Physique Théoretique CEA & CNRS

Carbone, Ludovico - University of Birmingham

Cavcic, Dina - Einstein@Home Volunteer

Chand, Karam - School of Engineering and Information Technology

Chang, Yue - Institute of Theoretical Physics, Chinese Academy of Sciences

Colvin, Chris - Einstein@Home Volunteer, USA

Colvin, Helen - Einstein@Home Volunteer, USA

Coors, Heinz - Einstein@Home Volunteer, Germany

Coss, David - St. Jude Children's Research Hospital

Costa, Fernando - University of Coimbra

Couvares, Peter F. - Syracuse University

Cuoco, Elena - EGO European Gravitational Observatory

Dal Canton, Tito - New York State Psychiatric Institute

Damjanic, Marcin - Laser Zentrum Hannover

Davidovic, Aleksander - University of New South Wales

de Zutter, Willy - BOINC, Roosendaal

Debreczeni, Gergely - KFKI Research Institute for Particle and Nuclear Physics

Dent, Thomas - Cardiff University

Dergachev, Vladimir - California Institute of Technology

Diaz Barriga, Oscar - Pontificia Universitdad Católia del Perú

Dittus, Hans-Jörg - Deutsches Zentrum für Luft- und Raumfahrt

Drago, Marco - Università degli Studi di Trento, Dipartimento di Fisica

Drasco, Steve - California Polytechnic State University

Eggenstein, Heinz-Bernd - Einstein@Home Volunteer, Germany

Farkas, Zoltan - Institute for Computer Science and Control, SZTAKI

Fasko, Daniel - Einstein@Home Volunteer, Germany

Ferrer, Dario - University of Zaragoza

Ferrini, Federico - European Gravitational Observatory

Fidecaro, Francesco - European Gravitational Observatory

Filipov, Yuri - Einstein@Home Volunteer, Germany

Filipovic, Miroslav - Einstein@Home Volunteer, Serbia

Fiurasek, Jaromir - Palacky University

Fonseca, Pablo - Pontificia Universitdad Católia del Perú

Freise, Andreas - University of Birmingham

Gabriel, Christian - Department für Physik der FAU Erlangen-Nürnberg

Galloway, Duncan - Monash University

Gebhardt, Daniel - Universität Mainz

Genes, Claudiu - Institut für Theoretische Physik, Universität Innsbruck

Gianolio, Alberto - ESA

Gotthelf, Eric - Columbia University, Columbia Astrophysics Laboratory

Grishchuk, Leonid - Cardiff University

Grondin, Marie-Hélène - Max-Planck-Institut für Kernphysik

Guillemot, Lucas - Max-Planck-Institut für Radioastronomie

Hanappe, Peter - Sony Research

Haselgrove, Richard - Einstein@Home Volunteer, UK

Hayama, Kazuhiro - National Astronomical Observatory of Japan

Heinzel, Stefan - Rechenzentrum Garching der MPG

Hejc, Gerhard - Timetech GmbH Stuttgart

Hempel, Marc - DESY

Heng, Ik Siong - University of Glasgow

Henjes-Kunst, Katharina - DESY

Herzke, Uwe - Einstein@Home Volunteer

Hesping, Sandra - DESY

Hewson, Mike - Yarra Valley, Clinic

Hilbig, Thomas - University of Applied Sciences, Bielefeld

Hild, Stefan - University of Glasgow

Hofer, Sebastian - Institut für Theoretische Physik, Leibniz Universität Hannover

Hofmann, Gerd - Universität Jena

Hua, Wensheng - Freelancer, Fremont, USA

Huang, Junwu - DESY

Huntington, Elanor - University of New South Wales

Huttner, Sabina - University of Glasgow

Inta, Ra - Australian National University

Ivanov, Alex - LIGO Lab California Institute of Technology

Jenrich, Oliver - ESA

Johnne's, Emmanuel - Einstein@Home Volunteer

Joshi, Abhay – ChipSat

Kabanov, Anton - Einstein@Home Volunteer

Kacsuk, Peter - Institute for Computer Science and Control, SZTAKI

Kallapur, Abhijit - University of New South Wales

Kaukonen, Jesse - Laurea University of Applied Sciences

Kelley, Ian - University of Cardiff

Kelly, Christopher - Massachusetts Institute for Technology

Kizou, Wolfgang - Einstein@Home Volunteer

Klatt, Torbjoern - Rechenkraft.net.e.V.

Kley, Ernst-Bernhard - Friedrich-Schiller-Universität Jena

Klimenko, Sergey - University of Florida

Kokkotas, Kostas - Eberhard Karls Universität Tübingen

Komma, Julius - Universität Jena

Komossa, Stefanie - Max-Planck-Institut für extraterrestrische Physik

Kondo, Derrick - INRIA

Kosolapov, Nickita - Einstein@Home Volunteer, Russia

Kouchner, Antoine - AstroParticule et Cosmologie (APC) CNRS

Kracht, Dietmar - Laser Zentrum Hannover e.V. (LZH)

Guest Scientists in Hannover (2011)

Kramer, Michael - Max-Planck-Institut für Radioastronomie Bonn

Kroker, Stefanie - Universität Jena

Krolak, Andrzej - Institute of Mathematics, Polish Academy of Sciences

Lederer, Hermann - Rechenzentrum Garching der Max-Planck-Gesellschaft

Legrand, Arnaud - INRIA

Liang, Yu - Rong-Center for Gravitational Exp., Huazhong University of Science and Technology

Lobo, Alberto - IEEC

Lorenzini, Matteo - INFN Sezione di Firenze

Lovas, Robert - Institute for Computer Science and Control, SZTAKI

Lundgren, Andrew P. - Pennsylvania State University

Manca, Gian Mario - AEI Potsdam-Golm

Mandel, Ilya - MIT Kavli Institute

Massey, Neil - Oxford

McLeod, John - Einstein@Home Volunteer

McMahon, Malcolm - University of Edinburg

Melcher, Peter - Einstein@Home Volunteer, Germany

Mercer, Adam - University of Wisconsin, Milwaukee

Messenger, Christopher - Cardiff University

Milde, Susanne - Milde Marketing

Molnár, Gábor - IIT Budapest

Möller, Steffen - University of Lübeck

Mönch, Karsten - Einstein@Home Volunteer, Germany

Nawrodt, Ronny - Universität Jena

Nelemans, Gijs - Universität Utrecht

Neuhaus, Leonhard - EPFL Lausanne

Nguyen, Hien - University of Houston

Nicklans, Kolja - Space Tech GmbH

Nielsen, Alex - AEI Potsdam-Golm

Nikitina, Natalia - Russian Academy of Sciences

Nitz, Alex - Syracuse University

Northup, Tracy - Universität Innsbruck, Österreich

Ohme, Frank - AEI Potsdam-Golm

Özel, Feryal - University of Arizona

Patel, Siddrath - Einstein@Home Volunteer

Penschuck, Jörg - Einstein@Home Volunteer, Germany

Peters, Achim - Humboldt Universität Berlin

Petiteau, Antoine - AEI Potsdam-Golm

Philippe, Jetzer - Universität Zürich

Porter, Ed - AstroParticule et Cosmologie (APC) CNRS

Porto, Rafael - Institute for Advanced Study, School of Natural Sciences

Prodi, Giovanni Andrea - Università degli Studi di Trento

Raatz, Sascha - Einstein@Home Volunteer, Germany

Rampp, Markus - Rechenzentrum Garching der Max-Planck-Gesellschaft

Ransom, Scott - National Radio Astronomy Obervatory

Rasel, Ernst - Institut für Quantenoptik, Leibniz Universität Hannover

Rasmussen, Torben - Axcon Aps

Ray, Paul - Naval Research Laboratory

Re, Virginia - INFN Sezione di Roma Tor Vergata

Reed, Kevin - IBM

Rezzolla, Luciano - AEI Potsdam-Golm

Ries, Christian Benjamin - University of Applied Sciences

Rivero, Alejandro - Ibercivis

Roberts, Gareth - Einstein@Home Volunteer, Australia

Roberts, Pamela - Einstein@Home Volunteer, Australia

Robinson, Emma - AEI Potsdam-Golm

Sammut, Letizia - University of Melbourne

Sanz, Francisco - Ibercivis

Schäfer, Gerhard - Universität Jena

Schnell, Henrik - IIT Budapest

Schutz, Bernard - AEI Potsdam-Golm

Segal, Ben - CERN

Sher, Helen - Einstein@Home Volunteer, Russia

Shirayev, Vitaliy - Einstein@Home Volunteer, Russia

Siegel, Daniel - Universität Freiburg

Smith, Nicolas - LIGO MIT

Somiya, Kentaro - Tokyo Institute of Technology

Song, Hongbin - School of Engineering and Information Technology

Sorazu, Borja - Glasgow University

Spurzem, Rainer - Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg

Stannigel, Kai - Universität Innsbruck

Stebbins, Robin - Goddard Space Center

Sterling, Thomas - Center for Computation and Technology, Louisiana State University

Stiller, Andreas - Heise Zeitschriften Verlag

Straka-Emden, Matthias - Einstein@Home Volunteer

Subhlok, Jasper - University of Houston

Sumner, Tim - Imperial College London

Sutton, Patrick - Cardiff University

Sutton, Andrew - The Australian National University

Tarantino, Michael - University of Basel

Torres, Cristina Valeria - LIGO Livingston Observatory

Upplinger, Keith – IBM

van den Elst, Jorden - Einstein@Home Volunteer

van Haasteren, Rutger - Universiteit Leiden, Huggens Laboratory

Vendt Hansen, Torben - Axcon Aps

Verbiest, Joris - Max-Planck-Institut für Radioastronomie

Vitale, Stefano - Universität Trento, Dipartimento di Fisica

Walton, Rom - UC Berkeley

Wang, Mengyao - University of Birmingham

Was, Michal - Laboratoire de l'Accélérateur Linéaire, Université Paris-Sud 11

Weber, Bill - Trento

Wex, Norbert - Max-Planck-Institut für Radioastronomie

Guest Scientists in Hannover (2011/2012)

Wilhelm, Martin - Einstein@Home Volunteer
Willis, Joshua - Abilene Christian University
Wilson, Simon - UK Met Office
Woan, Graham - University of Glasgow
Wu, Shufen - Einstein@Home Volunteer

Xu, Peng - Academy of Maths and system science

Zanolin, Michele - Embry Riddle Aeronautical University

Guest Scientists in Hannover (2012)

Acernese, Fausto - Universität Salerno, INFN Sezione di Napoli Complesso
Adams, Thomas - Cardiff University
Agathos, Michalis - Nikhef
Agrafioti, Ino - CNRS - Centre national de la recherche scientifique
Alic, Daniela - AEI Potsdam-Golm
Anderson, David - University of California, Berkely Space Sciences Laboratory
Anninos, Dionysios - Participant: Workshop "The Physics of de Sitter space- time", Greece
Armano, Michele - ESA
Astone, Pia - Dipartimento di Fisica, Universita di Roma
Aylott, Ben - University of Birmingham

Barbado, Luis C. - Instituto de Astrofisica de Andalucia
Barcelo, Carlos – Instituto de Astrofisica de Andalucia
Barone, Fabrizio - Universität Salerno, INFN Sezione di Napoli Complesso
Barrett, Sean - Imperial College London
Barsotti, Lisa - MIT/LIGO
Bastieri, Denis - University and INFN Padova
Bell, Angus - University of Glasgow
Berghöfer, Thomas - DESY
Bertollini, Alessandro - Nikhef, Sience Park, Amsterdam, The Netherlands
Bhagwat, Swetha - IISER Pune
Bizouard, Marie Anne - Université Paris Sud,
Bond, Charlotte - University of Birmingham
Bosch, James - LSST Corporation
Boutigny, Dominique - CNRS - Centre national de la recherche scientifique
Bozzi, Antonella - European Gravitational Observatory
Brandenberger, Robert - McGill University
Braxmeier, Claus - Deutsches Zentrum für Luft- und Raumfahrt
Breton, Rene - University of Southampton
Brown, Duncan - Syracuse University
Brown, Daniel - University of Birmingham
Brückner, Frank - University of Birmingham
Buchanan, Mark - Nature Physics
Burkhardt, Armin - Max-Planck-Institut für Festkörperforschung

Caballo, Raúl - Spanish National Research Council
Cagnoli, Gianpietro - Laboratoire Materiaux Avancés, LMA
Cannon, Kipp - University of Toronto
Carbone, Ludovico - University of Birmingham
Cesarini, Elisabetta - INFN
Cesarini, Andrea - European Gravitational Observatory
Chudoba, Jiri - Institute of Physics, AS CR
Cornelius, Herbert - INTEL
Corsi, Alessandra - California Institute of Technology
Creighton, Jolien - University of Wisconsin-Milwaukee
Cutler, Curt - Jet Propulsion Laboratory

d'Arcio, Luigi - European Space Agency
Da Silva Costa, Carlos Filipe - INPE Divisao de Astrofisica
Das, Pranita - Pandu College
Daw, Edward - University of Sheffield
de Vega, Hector - LPTHE
de Vine, Glenn - JPL
Debreczeni, Gergely - KFKI Research Institute for Particle and Nuclear Physics
Degallaix, Jerome - Laboratoire Materiaux Avancés, CNRS
Del Pozzo, Walter - Nikhef
Delfino Reznicek, Manuel - Port d'Informació Científica, PIC
Demonfaucon, Hélène - FOM-Nikhef
Dent, Thomas - Cardiff University
Desai, Shantanu - Universitätssternwarte München, Ludwig-Maximilians-Universität München
DeSalvo, Riccardo - University of Sanio
Dhurandhar, Sanjeev - IUCAA, Pune University Campus, Ganeshkind
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Douchy, Laurent - ISDC, Data Centre for Astrophysics
Douglas, Rebecca - Glasgow University
Dupuis, Rejean - UK

Enggard, Anders - AXcon Aps, Lynby, Denmark
Ergenzinger, Klaus - EADS Astrium GmbH

Fafone, Viviana - Universita di Roma
Fairhurst, Stephen - Cardiff University
Fang, Qiang - Bureau of International Coorporation
Fender, Rob - University of Southampton
Ferriaoli, Luigi - AstroParticule et Cosmologie (APC) CNRS
Ferrini, Federico - EGO Cascina
Fitzsimons, Ewan - University of Glasgow
Flaminio, Rafaele - Laboratoire Materiaux Avancés, CNRS
Flechtner, Frank - GeoForschungsZentrum Potsdam
Flury, Jokob - Institut für Erdmessung, Leibniz Universität Hannover
Folkner, William - Jet Propulsion Laboratory
Freise, Andreas - University of Birmingham
Frob, Markus - University of Barcelona

Gan, Li - ETH Zürich
Gath, Peter - EADS Astrium GmbH
Gemme, Gianluca - INFN, Seziona di Genova
Genin, Eric - European Gravitational Wave Observatory
Gennai, Alberto - INFN – Sezione di Pisa
Gerling, Rainer - MPG, Generalverwaltung

Guest Scientists in Hannover (2012)

Gianolio, Alberto - European Space Agency

Gibert, Ferran - Institut d'Estudis Espacials de Catalunya (IEEC)

Gohlke, Martin - Deutsches Zentrum für Luft- und Raumfahrt

Granata, Massimo - LMA-CNRS, Laboratoire de Materiaux Avancés

Hammond, Giles - University of Glasgow

Hanna, Chad - Perimeter Institute, Waterloo

Hansen, Torben Vendt - Ascon Aps, Lynby, Denmark

Harry, Ian - Syracuse University

Hartman, Thomas - Institute for Advanced Study

Haughian, Karen - University of Glasgow

Hayama, Kazuhiro - National Astronomical Observatory of Japan

Heinzel, Stefan - Rechenzentrum Garching (RZG) der MPG

Henjes-Kunst, Katharina - DESY

Hesping, Sandra - DESY

Hild, Stefan - University of Glasgow

Hirose, Eiichi - University of Tokyo

Hofer, Sebastian - Universität Wien

Hofmann, Gerd - Universität Jena

Holz, Daniel E. - University of Chicago

Hornstrup, Allan - National Space Institute

Hough, James - University of Glasgow

Hueller, Mauro - University of Trento

Husa, Sascha - University of the Balearics Islands

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Ivanov, Alex - California Institute of Technology, LIGO Lab

Jacobi, Emanuel - DESY

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Kitamoto, Hiroyuki - KEK

Klimenko, Sergey - University of Florida

Klipstein, William - Jet Propulsion Laboratory

Korai, Yusuke - Participant: Workshop "The Physics of de Sitter space- time", Japan

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Kremer, Kurt - Max-Planck-Institut für Polymerforschung

Kroker, Stefanie - Universität Jena

Kuroda, Kazuaki - University of Tokyo

Küster, Petra - Max-Planck-Institut für biophysikalische Chemie

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Lassus, Antoine - CNRS

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Liolios, Anastasios - Aristotle University of Thessaloniki

Lobo, Alberto - Institut d'Estudis Espacials de Catalunya (IEEC)

Lorenzini, Matteo - INFN

Lyard, Etienne - ISDC, University of Geneva

Macarthur, John - University of Glasgow

Mandel, Ilya - University of Birmingham

Marozzi, Giovanni - Departement de Physique Théorique, Universitè Geneva

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Nemeth, Vilmos - National Innovation Office

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Orlotti, Edmondo - NVIDIA

Owen, Benjamin - The Pennsylvania State University

Pai, Archana - Indian Institute of Science Education and Research, Trivandrum

Pantle, Carmen - Max-Planck-Gesellschaft, Generalverwaltung

Panzer-Steindel, Bernd - CERN

Paravac, Aleksander - Universität Würzburg

Peinado, Antonio M. - Universidad de Granada

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Polzik, Eugene - Niels Bohr Institute, Copenhagen University

Porto, Rafael - Institute for Advanced Study, School of Natural Sciences

Prokopec, Tomislav - ITP & Spinoza Institute

Punturo, Michele - INFN Sezione di Perugia

Puppo, Paola - INFN, Sezione di Roma

Rabeling, David - Nikhef

Rácz, István - Wigner RCP

Reid, Stuart - University of the West of Scotland, Thinfilm Center

Renn, Jürgen - Max-Planck-Institut für Wissenschaftsgeschichte

Rezzolla, Luciano - AEI Potsdam-Golm

Ricci, Fluvio - University of Rome la Sapienza

Robertson, David - University of Glasgow

Rocchi, Alessio - INFN Roma

Rodriguez, Carl - Northwestern University, Dearborn Observatory

Romania, Maria - University of Crete

Romano, Joseph - University of Texas at Brownsville

Roura, Albert - Institut für Quantenphysik, Universität Ulm

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Shoemaker, Deirdre - Georgia Institute of Technology

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Smith, David - C.E.N. de Bordeaux-Gradignan, Le Haut Vigneau

Smith, Rory - University of Birmingham

Sodnik, Zoran - ESA / ESTEC

Somiya, Kentaro - Tokyo Institute of Technology

Spero, Robert - Jet Propulsion Laboratory

Stiller, Andreas - Heise Zeitschriften Verlag

Stitt, Mark - Max-Planck-Institut für molekulare Pflanzenphysiologie

Sturani, Riccardo - University of Urbino

Stühmer, Walter - Max-Planck-Institut für experimentelle Medizin

Suckfüll, Harald - Max-Planck-Gesellschaft, München

Sun, Weining - Shanghai Institute of Plant Physiology and Ecology

Sutton, Patrick - Cardiff University

Tagoshi, Hideyuki - Osaka University

Tella, Abiodun Olumide - Kembem Motors

Thiel, Walter - Max-Planck-Institut für Kohlenforschung

Tokmakov, Kirill - University of Strathclyde

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Urakawa, Yuko - Participant: Workshop "The Physics of de Sitter space-time", Spain

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Vaulin, Ruslan - MIT

Vecchio, Alberto - University of Birmingham

Veitch, John - Nikhef

Verbiest, Joris - Max-Planck-Institut für Radioastronomie

Vitale, Stefano - University of Trento

Vitale, Salvatore - Nikhef

Voss, Kai - Space Tech GmbH

Wade, Madeline - University of Wisconsin-Milwaukee

Walter, Roland - University of Geneva

Walton, Rom - UC Berkeley

Wang, Zhongxiang - Shanghai Astronomical Observatory

Wang, Mengyao - University of Birmingham

Ward, Harry - University of Glasgow

Ware, Brent - JPL

Wegner, Peter - DESY

Weise, Dennis - EADS Astrium GmbH

Weßels, Peter - Laser Zentrum Hannover

Whelan, John T. - Center for Computational Relativity and Gravitation, Rochester Institute of Technology

Whitehorn, Nathan - University of Wisconsin-Madison

Willis, Joshua - Abilene Christian University

Wittenburg, Peter - Max-Planck-Institut für Psycholinguistik

Woan, Graham - University of Glasgow

Woodard, Richard - University of Florida

Xue, Fang - Academy of Science, Shanghai Branch, Shanghai, China

Xue, Hongwei - Shanghai Institute for Plant Physiology and Ecology

Yahyapour, Ramin - Gesellschaft für wissenschaftliche Datenverarbeitung mbH

Yamamoto, Kazuhiro - University of Tokyo

Yang, Yifan - IIHE - ULB

Yao, Yaping - Academy of Science, Shanghai Branch, China

Youssef, Ahmed - Humboldt Universität Berlin

Zhang, Shuangnan - Institute of High Energy Physics

Zhang, Chen - National Astronomical Observatories

Zhu, Zhiuyuan - Academy of Sciences, Shanghai Branch

Publications by the Institute

Max-Planck-Institut für Gravitationsphysik (Ed.), Living Reviews in Relativity, Living Reviews in Relativity 13 (2010), 14 (2011), 15 (2012). *http://www.livingreviews.org*

Publications by AEI Members and Guest Scientists

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Ajith, P., Hannam, M., Husa, S., Chen, Y., Bruegmann, B., Dorband, N., Mueller, D., Ohme, F., Pollney, D., Reisswig, C., Santamaria, L., & Seiler, J. (2011). Inspiral-Merger-Ringdown Waveforms for Black-Hole Binaries with Nonprecessing Spins. Pysical Review Letters, 106: 241101. doi:10.1103/PhysRevLett.106.241101.

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D. Page (Instituto de Astronomia, Universidad Nacional Autonoma de Mexico)
Thermal Evolution of Neutron Stars / 17 February 2010

Sean Farrell (University of Leicester, UK)
Exploring the Nature of the Intermediate Mass Black Hole Candidate HLX-1
in the Galaxy ESO 243-49 / 17 March 2010

Ignasi Ribas (Institut de Ciencies de l'Espai (CSIC-IEEC), Spain)
Exoplanets and life / 22 March 2010

Tilmann Spohn (DLR-Institut für Planetenforschung, Berlin, Germany)
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Peter Kalmus (California Institute of Technology - LIGO Laboratory, Pasadena, USA)
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Elanor Huntington (Univ. of New South Wales at the Australian Defence Force Academy, Canberra)
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Jason W.T. Hessels (Netherlands Institute for Radio Astronomy (ASTRON) and University of Amsterdam, The Netherlands)
Bursters, Burpers, and Repeaters: Charting the Transient Radio Sky on Sub-Second Time-Scales with LOFAR / 28 October 2010

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Yu-rong Liang (School of Physics, Huazhong University of Science and Technology, Wuhan, People's Republic of China)
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Steve Drasco (California Polytechnic State University, Physics Dept., San Luis Obispo, USA)
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Andrew Sutton (The Australian National University, Canberra, Australia)
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David Smith (C.E.N. de Bordeaux-Gradignan, France)
Gamma ray pulsars: towards a high energy census of the Milky Way / 19 January 2012

Sergey Klimenko (University of Florida, Gainesville, USA)
Coherent Network Analysis / 09 February 2012

Shantanu Desai (Universitätssternwarte der Ludwig-Maximilians-Universität München, Germany)
Probing Dark Energy and fundamental physics with galaxy cluster surveys / 12 April 2012

Rene Breton (University of Southampton, UK)
Neutron star masses from the flushed face of irradiated pulsar companions / 10 May 2012

Maria Alessandra Papa (AEI Potsdam, Germany)
Gender differences in science? / 20 December 2012

Invited Conference Talks given by AEI members

Aldana C.

22 June 2012 – **The determinant of the Laplace operator on the moduli space of punctured Riemann surfaces**
Workshop on analytical torsion and its applications, Paris

23 October 2012 – **Conformal surgery and compactness of relatively isospectral sets of surfaces**
Workshop "Recent Developments in Conformal Geometry", Nantes, France

Allen B.

07 October 2010 – **Hardware and Software for Gravitational Wave Data Analysis**
Aspera Workshop, Lyon

08 December 2010 – **The Einstein@Home Search for New Neutron Stars**
AIP/ACOFT 2010 Congress, Melbourne

26 January 2011 – **Studying the galactic pulsar population using gravitational waves**
GWPAW Workshop, Milwaukee

05 April 2011 – **Direction detection of gravitational waves: status and prospects**
NPPD Conference, Glasgow

30 April 2011 – **The Einstein@Home search for new neutron stars**
April Meeting 2011 of the American Physical Society, Garden Grove, USA

30 May 2011 – **Overview of Models for Gravitational Wave Experiments**
Computing and Astroparticle Physics-2nd ASPERA Workshop, Barcelona

01 July 2011 – **Supercomputing for everyone (and by everyone!)**
OKCon 2011, Berlin

08 September 2011 – **Gravitational wave tricks for multi-messenger astronomy**
TAUP Munich

06 January 2012 – **The Einstein@Home search for gravitational waves and neutron stars**
The State of the Universe/Stephen Hawking Birthday Symposium, Univ. of Cambridge, UK

28 August 2012 – **Science Highlight talk (MSP Blind Searches)**
FERMI Collaboration Meeting Fall 2012, Washington

Amaro-Seoane P.

08 June 2010 – **Capturing compact objects in dense stellar systems**
460. Wilhelm and Else Heraeus Workshop: "Black Holes"

01 July 2010 – **The connection between missing cusps and GR**
LISA 8th International Symposium, Stanford

07 October 2010 – **Capturing compact objects in dense stellar systems**
"Contemporary astrophysics: traditions and perspectives" dedicated to the 60th anniversary of the Fessenkov Astrophysical Institute". Fessenkov Astrophysical Institute, Kazakstan

02 August 2011 – **The connection between missing cusps and GR**
Gravitational Wave Astrophysics, Binary Supermassive Black Holes, and Galaxy Mergers Lijiang, Yunnan, China

23 February 2012 – **The connection between missing cusps and GR**
2nd Iberian Gravitational Wave meeting

26 June 2012 – **Fake EMRIs in galactic nuclei**
"Tidal Disruption events and AGN outbursts workshop", Madrid

Andersson L.

26 January 2010 – **Hidden symmetries and linear fields on Kerr**
General relativity and geometric analysis, Monash

Invited Conference Talks given by AEI members

23 February 2010 – **The Black Hole Stability Problem**
Symposium on Geometric Analysis and Mathematical Relativity, Miami

06 March 2010 – **The Black Hole Stability Problem**
Equations hyperboliques en metrique de Kerr, CIRM, Marseilles

19 March 2010 – **Self-gravitating elastic bodies**
DPG Spring meeting

15 June 2010 – **Hidden symmetries and linear fields on Kerr**
Workshop on geometric analysis, ICMR, Peking University

21 March 2011 – **Linear fields on the Kerr spacetime**
Analysis of PDEs, JHU, Baltimore

08 May 2011 – **The black hole stability problem**
PNGS, Seattle

24 May 2011 – **The Black Hole Stability Problem**
Conference "Complex Analysis & Dynamical systems V", Akko, Israel

05 April 2012 – **Hidden symmetries and conserved charges**
Einstein spacetimes with symmetry, Paris VI

Arnlind J.
22 April 2010 – **Nambu-Poisson algebraic formulation of classical geometry, non-commutative curvature and the Gauss-Bonnet theorem**
Seminar Sphus Lie, Mulhouse

Babak S.
05 July 2010 – **Cosmology and fundamental physics with LISA**
GR19, Mexico

Bahr B.
03 March 2010 – **LQG coherent states**
Workshop "Open problems in Loop Quantum Gravity", Zakopane, Poland

Baratin A.
28 February 2010 – **Group Field Theory with Non-Commutative Metric Variables**
Workshop "Open problems in Loop Quantum Gravity", Zakopane, Poland

08 October 2010 – **Spin foams and group fields in a nutshell**
Quantum Gravity Colloquium 5, APC, Universite Paris 7

13 February 2011 – **2-Group Representations for State Sums**
Conference "Higher Gauge Theory, TQFT and Quantum Gravity", Lisbon

25 March 2011 – **Aspects of Group field theories**
Quantum Gravity Conference, LPT Orsay

10 May 2011 – **State sum invariant from a 2-category**
Conference "Higher Gauge Theory, TQFTs, and Categorification ", Cardiff University, Wales

22 November 2011 – **Spin foams and group field theory: the dynamics of quantum geometry**
Workshop "Renormalization, algebraic, analytic and geometric aspects", Institut Henri Poincaré, Paris

25 November 2011 – **A 2-categorical state sum model**
Conference "Categories and physics 2011", APC, Université Paris 7

26 March 2012 – **State sum model from a 2-category**
Conference "Quantum Gravity in Paris", LPT Orsa

Invited Conference Talks given by AEI members

Beisert N.

24 March 2010 – **Conformal Symmetry and Integrability in Perturbative N=4 Scattering Amplitudes**
Simons Center Workshop "Superstrings in Ramond-Ramond backgrounds", Stony Brook

07 May 2010 – **Conformal Symmetry and Integrability in Perturbative N=4 Scattering Amplitudes**
Workshop Amplitudes 2010, Queen Mary, University of London

26 May 2010 – **Integrability in Planar N=4 Gauge Theory**
Gribov-80 Memorial Workshop on Quantum Chromodynamics and Beyond, ICTP Trieste

30 June 2010 – **Quantum Deformations of Worldsheet Scattering**
Integrability in Gauge and String Theory 2010, NORDITA Stockholm

20 July 2010 – **Integrability for Scattering Amplitudes in Planar N=4 super Yang-Mills**
LMS Durham Symposium "Non-Pertubative Techniques in Field Theory", University of Durham

22 September 2010 – **Integrability for Scattering Amplitudes in Planar N=4 super Yang-Mills**
DESY Theory Workshop, DESY Hamburg

02 December 2010 – **Quantum Deformations of Worldsheet Scattering**
From Sigma Models to Four-Dimensional QFT, DESY Hamburg

26 April 2011 – **Review of Yangian and exact superconformal symmetries**
Workshop "The Harmony of Scattering Amplitudes", KITP

16 June 2011 – **Conformal Symmetry and Integrability for Scattering Amplitudes in N=4 Super Yang-Mills**
Conference "Quantum Theory and Gravitation", ETH Zürich

17 June 2011 – **Integrability in Planar N=4 Gauge Theory**
Gemeinsame Jahrestagung 2011 der Schweizerischen und der Österreichischen Physikalischen Gesellschaften, EPFL Lausanne

27 June 2011 – **Counterterms and E7(7) Symmetry in N=8 Supergravity**
Strings 2011 Conference, Uppsala

26 July 2011 – **AdS/CFT and applications**
EPS "2011 International Europhysics Conference on High Energy Physics", Grenoble

08 August 2011 – **Counterterms and E7(7) Symmetry in N=8 Supergravity**
7th International Symposium on Quantum Theory and Symmetries, Prague

12 August 2011 – **On Wilson Loops in Superspace**
Exact Results in Gauge/Gravity Dualities Workshop, Perimeter Institute, Waterloo

Benedetti D.

24 March 2011 – **On phase transitions and continuum limit in gravity**
"Mathematical, Physical and Conceptual aspects of Quantum Gravity" workshop, APC, Paris, France

06 September 2011 – **Quantum gravity and critical phenomena**
"Gravity as Thermodynamics" ESF workshop, SISSA, Trieste, Italy

05 March 2012 – **Testing the asymptotic safety conjecture**
"Exploring Quantum Space-Time" workshop, 499th WE-Heraeus-Seminar, Bad Honnef, Germany

26 March 2012 – **The local potential approximation in quantum gravity**
"Quantum gravity in Paris" workshop, LPT Orsay, France

21 November 2012 – **A lattice approach to quantum gravity**
"Non-perturbative Aspects in Field Theory" workshop, King's College London, UK

14 December 2012 – **The mixed blessing of a foliation**
"CDT & Friends" workshop, Radboud University Nijmegen, The Netherlands

Invited Conference Talks given by AEI members

Budewitz N.
10 June 2011 – **Datura - The new HPC-Plant at Albert Einstein Institute**
NEC-User-Group-Meeting in Prague, Czech Republic

12 June 2012 – **Technology at the Max Planck Institute for Gravitational Physics**
NEC-User-Group-Meeting, Potsdam-Golm

Calcagni G.
09 April 2010 – **Fractal universe**
Max Planck Institute for the Physics of Complex Systems, Dresden

09 April 2010 – **Challenges in quantum gravity and cosmology**
Max Planck Institute for the Physics of Complex Systems, Dresden

Campoleoni A.
05 July 2010 – **Asymptotically AdS solutions of higher-spin gauge theories in D=2+1**
QFTG 2010, Tomsk, Russia

26 August 2010 – **Asymptotic symmetries of three-dimensional gravity coupled to higher-spin fields**
40th Ahrenshoop Symposium, Berlin

08 July 2011 – **Asymptotic W-symmetries in 3D higher-spin gauge theories**
3rd Joburg Workshop on String Theory and Higher Spins, Wits Rural Facility, South Africa

15 September 2011 – **Asymptotic W-symmetries in 3D higher-spin gauge symmetries**
Workshop on Fields and Strings, Corfu Summer Institute, Corfu, Greece

16 April 2012 – **Towards a metric-like formulation of three-dimensional higher-spin gauge theories**
ESI Workshop on Higher Spin Gravity, Vienna, Austria

Danzmann K.
16 March 2010 – **Gravitational Wave Observatories in Space**
DPG Spring meeting, Bonn

16 September 2010 – **Multi Wavelength Gravitational Wave Astronomy**
Astronomische Gesellschaft, AG 2010, Bonn

05 July 2011 – **Gravitational Waves in Germany**
BMBF Gravitationswellensymposium, AEI Hannover

01 August 2011 – **Gravitational Waves**
JDPG Tagung, Hannover

30 September 2011 – **Listening to the Universe with Einsteins Gravitational Waves**
DESY Workshop, Hamburg

11 October 2011 – **LISA in ESA Cosmic Vision**
SFB TR7 Tagung, Universität Tübingen

27 March 2012 – **Measuring the Universe with Einsteins Gravitational Waves**
125 Jahre PTB, Braunschweig

19 April 2012 – **Gravitational Waves and the Early Universe**
Akademie der Wissenschaften, Hamburg

25 April 2012 – **Laserinterferometry and Einsteins Gravitational Waves**
EFTF Conference, Göteborg

08 May 2012 – **Laserinterferometry in Space for Gravitational Wave Detection and Geodesy**
CLEO Conference, San Jose

Invited Conference Talks given by AEI members

21 May 2012 – **The Status of LISA**
LISA 12, Paris

16 October 2012 – **LISA after the Cosmic Vision Selection**
SFB TR7 by Annual Meeting, MPA Garching

07 November 2012 – **Gravitational Wave Detection from Space**
Space Part 12 Conference, CERN, Genf,

Devchand C.
06 September 2012 – **Oxidation of self-duality through heat flow and remixing**
Alekseevsky-Fest, Luxembourg

Di Palma I.
21 September 2011 – **Results from the first joint search between Gravitational Waves and High Energy Neutrinos**
ANTARES Collaboration Meeting, Bamberg, Germany

Dittrich B.
02 March 2010 – **Diffeomorphism symmetry in discrete gravity**
Workshop "Open problems in Loop Quantum Gravity", Zakopane, Poland

06 July 2010 – **Diffeomorphism symmetry in discrete gravity**
GR 19, LQG and Spin Foam Session

09 February 2012 – **Coarse graining spin nets with tensor networks**
Computational methods at Perimeter, Perimeter Institute, Waterloo, Canada

27 March 2012 – **Why spin foams are lattice gauge theories and why they are not**
Quantum Gravity in Paris, LPT Orsay, France

23 August 2012 – **Canonical dynamics from holonomy spin foams**
29th International Colloquium on Group-Theoretical Methods in Physics, Tianjin, China

25 October 2012 – **Modelling continuum dynamics on discrete space times**
Experimental Search for Quantum Gravity, Perimeter Institute, Waterloo, Canada

13 December 2012 – **Coarse graining spin nets and spin foams: first results**
The search for quantum gravity: CDT and friends, Nijmegen, The Netherlands

Enders J.
03 October 2010 – **On Type I Singularities in Ricci Flow**
AMS Meeting Syracuse, New York

Forini V.
27 March 2010 – **Exact semiclassical strings and QCD-like properties in AdS/CFT**
Conference "Problemi attuali di Fisica Teorica", Vietri sul mare, Italy

Fredenhagen S.
26 September 2012 – **Towards a metric-like higher-spin gauge theory in 2+1 dimensions**
DESY Theory Workshop, Hamburg

Friedrich H.
05 April 2010 – **On the conformal structure of static vacuum data**; Granada

10 June 2010 – **On the asymptotic structure of gravitational fields**
Université de Strasbourg

08 July 2010 – **On radiative and static vacuum space-times**
GR 19, Mexico City

11 April 2011 – **On conformal structures of asymptotically flat, static vacuum data**
Grav11, La Cumbre

24 May 2011 – **On conformal structures of asymptotically flat, static vacuum data**
Conference "Complex Analysis & Dynamical systems V", Akko, Israel

27 June 2012 – **The large scale Einstein evolution problem**
Relativity and Gravitation: 100 years of Einstein In Prague, Prague, Czechia

Goßler S.
24 February 2010 – **The AEI 10m Prototype Interferometer**
AIGO conference, Perth

Grigorian S.
19 March 2010 – **Betti numbers of barely G2 manifold**s
Mini-Conference in Geometry, IMS, Hong Kong

Grote H.
01 March 2010 – **GEO600 status**
LSC meeting Arcadia

20 March 2010 – **GEO600 status**
LSC meeting Crakow

17 May 2010 – **Lessons Learned?**
GWADW conference Kyoto

11 March 2011 – **First Generation Gravitational Wave detectors**
Moriond conference

12 March 2011 – **GEO600 status**
LSC meeting Arcadia

22 September 2011 – **Status of GEO600**
LSC meeting Gainsville

23 March 2012 – **Status of GEO600**
LSC meeting Boston

Head J.
16 March 2010 – **Mean Curvature Flow with Surgery**
Workshop on mean curvature flows and related topics, Johns Hopkins University, Baltimore

23 July 2010 – **The Surgery and Level-Set Approaches to Mean Curvature Flow**
Calculus of variations workshop, Oberwolfach

Heinzel G.
9 June 2010 – **Ranging, clock comparison and data transfer - auxiliary functions of the laser link**
LISA Symposium, Stanford

28 June 2012 – **LISA in 2012 and beyond!**
Relativity and Gravitation: 100 years of Einstein In Prague, Prague, Czechia

17 September 2012 – **The GRACE follow-on Laser Ranging Interferometer**
GRACE Science team meeting, Potsdam

01 November 2012 – **Gravitational Physics from Space - Gravitational Waves and Earth gravity**
The Third Exploratory Round Table Conference (MPG-CAS), Shanghai Inst. of Advanced Studies

Hennig J.
08 April 2010 – **Non-existence of stationary two-black-hole configurations**
Conference "PDEs, Relativity and Nonlinear Waves", Granada, Spain

Huisken G.
29 September 2010 – **Curvature estimates and singular behavior in mean curvature flow**
The Abel Symposium 2010, Norwegian Academy of Sciences

Invited Conference Talks given by AEI members

22 October 2010 – **Rigidity properties of geometric evolution equations**
Konferenz anlässlich des 70. Geburtstages von Willi Jäger, Universität Heidelberg

08 January 2011 – **Regidity results for curvature flows**
IHÈS, Paris

03 March 2011 – **Curvature estimates for mean curvature flows**
CIRM, Marseille

25 May 2011 – **Mean curvature flow with surgeries**
Conference "Complex Analysis & Dynamical systems V", Akko, Israel

23 September 2011 – **Evolution of hypersurfaces and isoperimetric inequalities on manifolds with nonnegative Ricci curvature**
Conference on Geometric Evolution equations, Konstanz

19 October 2011 – **Rigidity estimates for mean curvature flow**
Chern Meeting, Academia Sinica, Taipei

15 January 2012 – **Inverse mean curvature flow**
60th Birthday of Peter Li, University of California

28 March 2012 – **Isoperimetric inequality and quasilocal mass**
Workshop on Geometric Analysis, Joh.-W.-Goethe-Universität Frankfurt/Main

17 July 2012 – **New estimates for mean curvature flow**
Australian National University

09 October 2012 – **Analytical and geometrical properties of inverse mean curvature flow**
Symposium on H. Yserentants 60. birthday, TU Berlin

Joudioux J.
08 November 2010 – **Conformal scattering for a nonlinear wave equation**
Conference "Black hole, General Relativity, Waves", Roscoff, France

19 January 2011 – **Conformal scattering for a nonlinear wave equation**
Journees Nanceiennes de Geometrie

09 March 2011 – **Conformal scattering for a nonlinear wave equation**
Meeting "Resonances and Scattering in General Relativity", Dijon, France

09 February 2012 – **Decay of linear fields using spin lowering and spin raising processes**
4th meeting of the CNRS research group in Quantum dynamics, Toulouse, France

14 December 2012 – **Hertz potentials, peeling and the Cauchy problem**
Workshop "Dynamics in general relativity", Erwin Schrödinger Institute, Vienna

Keppel D.
12 October 2011 – **Use of Singular-Value Decomposition in Gravitational Wave Data Analysis**
Third Galileo – Xu Guangqi Conference

03 May 2012 – **GPUs in Gravitational-Wave Data Analysis**
3rd ASPERA Computing and Astroparticle Physics Workshop, AEI Hannover

Kleinschmidt A.
11 July 2012 – **Perturbative Terms of Kac Moody Eisenstein Series**
Algebra, Geometry and Mathematical Physics Conference, Tallinn

Krishnan B.
25 January 2010 – **Prospects for detecting continuous gravitational waves from accreting neutron stars**
14th Gravitational Wave Data Analysis Workshop, Rome, Italy

8 January 2010 – **The interface between numerical relativity and gravitational wave data analysis**
14th Gravitational Wave Data Analysis Workshop, Rome, Italy

Invited Conference Talks given by AEI members

26 September 2012 – **Searching for gravitational waves from pulsars - How LOFT can help**
Second LOFT Meeting, Toulouse, France

Lee H.
04 July 2012 – **Global existence and nonrelativistic limit for the Vlasov-Maxwell-Chern-Simons system**
AIMS Conference, Orlando, Florida, USA

Lim W.
09 July 2010 – **Spike crossings in spacetimes with one Killing vector field**
GR19, Mexico City

Lück H.
25 February 2010 – **Gravitationswellen GEO600 / ET / LISA**
Astroteilchenphysik in Deutschland: Status und Perspektiven, Zeuthen

13 April 2010 – **The Einstein Telescope**
QUEST Symposium: Precision Matter Wave Optics

28 September 2010 – **Third Generation Gravitational Wave Observatories**
QUEST Klausurtagung, Bad Pyrmont

14 October 2010 – **ET - the Einstein Telescope; instrumental aspects**
GW conference, Minneapolis

08 September 2011 – **The Einstein Telescope: A third generation gravitational wave observatory**
TAUP, München

28 March 2012 – **GW detection across frequencies: Current status, challenges, and future opportunities**
National Meeting of the Royal Astronomical Society, Manchester

Marquardt T.
16 March 2010 – **Inverse Mean Curvature Flow for Hypersurfaces with Boundary**
Workshop on Mean Curvature Flows, Johns Hopkins Univ., Baltimore, USA

Menne U.
26 July 2012 – **A sharp lower bound on the mean curvature integral with critical power**
"Calculus of Variations" (ID 1230), Oberwolfach conference, Germany

17 September 2012 – **Rectifiability of higher order**
2nd workshop "Geometric curvature energies", Kloster Steinfeld, Kall (Eifel), Germany

Metzger J.
20 January 2010 – **Surfaces minimizing the Willmore functional under an area constraint**
Workshop Geometric Analysis and General Relativity, Monash University, Melbourne

Nicolai H.
13 February 2010 – **E10, Cosmobilliards, and Quantum Gravity**
KazamaFest, Komaba, Tokyo, Japan

08 June 2010 – **Symmetry and quantum gravity**
RacahFest, Jerusalem

15 July 2010 – **Symmetries and Singularities**
2nd Galileo Xu-Guangqi Meeting, Ventimiglia

26 July 2010 – **Arithmetic quantum gravity**
International Conference on Strings, M Theory and Quantum Gravity, Ascona

05 October 2010 – **N=8 Supergravity: an Update**
TAM 2010, Budva, Montenegro

Invited Conference Talks given by AEI members

24 June 2011 – **Infinite dimensional symmetries and the Wheeler-DeWitt equation**
Quantum Theory and Gravitation, ETH Zürich

06 January 2012 – **Consistent Kaluza Klein Universes from Maximal Supergravity**
"The State of the Universe", celebrating S. Hawkings 70th birthday, University of Cambridge, UK

28 March 2012 – **Infinite dimensional Kac-Moody symmetries and higher spin gauge theories**
CQUeST Workshop on Higher Spin Gauge Theories, Seoul, Korea,

26 April 2012 – **Dualities vs. Counterterms**
WetterichFest, IWH Heidelberg

27 June 2012 – **Quantum gravity: the view from particle physics**
Relativity and Gravitation: 100 years of Einstein In Prague, Prague, Czechia

02 July 2012 – **Hidden Symmetries: from BKL to Kac-Moody**
XIII Marcel Grossmann Meeting, Stockholm, Sweden

26 July 2012 – **Alternative approaches to quantum gravity: a brief survey**
STRINGS 2012, LMU München

22 November 2012 – **Universal BPS structure of stationary supergravity solutions**
"Geometry and Physics", LMU München

Nutma T.
30 August 2012 – **Polycritical Gravity**
41st International Symposium Ahrenshoop

Ohme F.
10 July 2011 – **Modeling waveforms of compact binary coalescences - where analytical and numerical relativity meet**
NRDA 2011/Amaldi 9

Oriti D.
10 April 2010 – **An overview of the group field theory approach to quantum gravity**
Focus Workshop on Quantum Gravity 2010, Max Planck Institute for the Physics of Complex Systems, Dresden

16 May 2010 – **The microscopic dynamics of quantum space as a group field theory**
Workshop on Non-commutative Geometry and Physics, Bayrischzell, Germany

28 September 2010 – **The microscopic dynamics of quantum space as a group field theory**
Conference "Quantum field theory and gravity", Regensburg, Germany

24 May 2011 – **Group field theory: recent, current and future developments**
Loops 11, CSIC, Madrid, Spain

16 June 2011 – **The group field theory approach to quantum gravity: brief review of recent developments**
Conference "Quantum Field Theory and Gravitation", ETH, Zürich

29 June 2011 – **Aether and the theory of relativity: Einsteins Leiden lecture in 1920 (as a source of inspiration for current research in quantum gravity)**
Workshop "Roots of Quantum Gravity", Max Planck Institute for the History of Science, Berlin

01 February 2012 – **The group field theory description of quantum spacetime**
499th WE-Heraeus Seminar: "Exploring quantum spacetime", Bad Honnef

20 March 2012 – **The quantum geometry of group field theories**
Conference "Quantum Gravity in Paris", Univ. Paris XI-Orsay and Univ. Paris VII Diderot

21 August 2012 – **The quantum geometry of tensorial group field theories**
XXIX Conference on Group Theoretical Methods in Physics, Chern Institute for Mathematics, Tian Jin, China

Invited Conference Talks given by AEI members

13 September 2012 – **Tensorial Group Field Theories: a new type of quantum field theory for quantum gravity**
Conference “New Trends in Algebraic Quantum Field Theory”, INFN Laboratories, Frascati, Italy

20 September 2012 – **Non-commutative spaces: questions from the bottom-up**
Incontri di Geometria Non-commutativa, Dept. Physics, University of Naples, Italy

24 October 2012 – **Is spacetime fundamentally discrete?**
Conference “Experimental search for Quantum Gravity: the hard facts”, Perimeter Institute, Waterloo, Canada

Prix R.
24 October 2012 – **Searching for Periodic Gravitational Waves from Spinning Neutron Stars**
CoCoNuT meeting, Mallorca

Puetzfeld D.
18 March 2010 – **Motion of extended bodies in General Relativity**
DPG spring meeting, Bonn

Rendall A.
28 January 2010 – **Relations between Gowdy and Bianchi spacetime**s
Programme Quantitative studies of nonlinear wave equations, ESI, Vienna

09 April 2010 – **Some wave maps related to the Einstein eqations**
Conference, PDEs, relativity and nonlinear waves, Granada, Spain

21 June 2010 – **Higher dimensional cosmological models**
Banff International Research Station, Canada

04 December 2010 – **Self-similar collapse of collisionless matter**
Swedish GR Meeting, Karlstad

22 June 2011 – **Late-time behaviour of homogeneous solutions of the Einstein-Vlasov system**
Conference, Kinetic Theory and Related Fields, Pohang

21 September 2011 – **A self-similar solution of the Einstein-Vlasov system**
Conference, Vlasov models in kinetic theory, Brown University

04 September 2012 – **Construction of oscillatory singularities**
Spanish Relativity Meeting, Guimaraes, Portugal

Rezzolla L.
25 January 2010 – **GW emission from binary neutron stars**
GWDAW14 Conference, Rome

16 February 2010 – **Modelling the inspiral and merger of binary neutron stars**
CompStar Workshop on Computational Astrophysics Caen

13 April 2010 – **Binary black-holes in general (numerical) relativity**
60. Wilhelm and Else Heraeus Seminar: "Black Holes", Bad Honnef

31 May 2010 – **On the ubiquity of polish doughnuts**
A relativistic Whirlwind, ICTP-Trieste

15 June 2010 – **Towards a self-consistent modelling of SGRBs**
Italian Conference on GRBs, Cefalu

02 September 2010 – **Synergy between observations and Numerical Relativity in the ET era**
Meeting of the ET WG-4, Nice

13 September 2010 – **Learning from merging binary black holes: waveforms, EM counterparts**
LISA Astro-GR Meeting, Paris

30 September 2010 – **Using NR to explore fundamental physics and astrophysics**
SIGRAV International Conference, Pisa

Invited Conference Talks given by AEI members

10 November 2010 – **Modelling sources of gravitational waves**
10th Anniversary of the Hasso-Plattner Institute, Hasso-Plattner Institute, Potsdam, Germany

15 November 2010 – **Simulating BH mergers and their EM emission**
ColloquiumST Action Meeting, Valencia

24 November 2010 – **Understanding Neutron Stars with ET**
3rd ET Annual Workshop, Budapest

29 November 2010 – **Using NR to explore fundamental physics and astrophysics**
MESGW2010, Maresias

20 March 2011 – **Dynamics of compact-star binaries**
Rencontres de Moriond, La Thuile

23 March 2011 – **Using NR to explore fundamental physics and astrophysics**
Spring Meeting of the DPG, Karlsruhe

28 March 2011 – **GW and EM emission from compact-object binaries in GR**
Electromagnetic Astrophysics and Cosmology With Gravitational Waves, Milan

03 May 2011 – **Modelling binary neutron stars**
STARS2011, Havana

10 May 2011 – **Dynamics of magnetized binaries**
CompStar Spring meeting, Catania

03 June 2011 – **Compact objects and gravitational waves**
Rencontres de Blois, Blois

13 June 2011 – **The missing link: from binary neutron stars to magnetic jets**
Astronum-2011 Valencia

13 June 2011 – **The missing link: from binary neutron stars to magnetic jets**
Advances in Computational Astrophysics: methods, tools and outcomes, Cefalu

06 July 2011 – **On the Riemann problem in relativistic HD and MHD**
Toro 65, Santiago de Compostela (Spain)

07 September 2011 – **Jets from merging binaries of compact objects**
Workshop on Numerical Relativity and Gravitational Waves 2011, Parma

04 June 2012 – **Colliding the largest "nuclei" in the universe**
CompStar Meeting 2012, Tahiti

28 June 2012 – **Using NR to explore fundamental physics and astrophysics**
Conference „Einstein in Prague“, Prague

03 July 2012 – **EM counterparts from the coalescence of binary black holes**
MG13 Stockholm

04 July 2012 – **Using NR to explore fundamental physics and astrophysics**
MG13 Stockholm

05 July 2012 – **Instability-driven evolution of magnetic fields in relativistic stars**
MG13 Stockholm

07 August 2012 – **Modelling the inspiral and merger of binary neutron stars**
Cairns

12 October 2012 – **Binary neutron stars to explore nuclear physics and astrophysics**
EMMI meeting, Tübingen

Invited Conference Talks given by AEI members

18 October 2012 – **Using numerical relativity to explore fundamental physics and astrophysics**
CCP2012, Kobe

21 November 2012 – **Binary neutron stars to explore nuclear physics and astrophysics**
Recent developments in astronuclear and astroparlicle physics, Trieste

Rinne O.
28 November 2011 – **Evolution of the Einstein equations on constant mean curvature surfaces**
Workshop "Geometric Partial Differential Equations: Theory, Numerics and Applications",
Mathematisches Forschungsinstitut Oberwolfach

13 October 2012 – **Hyperboloidal Einstein-matter evolution and tails for scalar and Yang-Mills fields**
Workshop on Numerical and Mathematical Relativity, Oppurg

Roura A.
09 April 2010 – **Quantum effects and the stability of de Sitter spacetime**
Quantum Gravity Focus Workshop, Dresden

24 June 2010 – **Quantum back-reaction in non-equilibrium AdS black holes**
Peyresq Cosmology Meeting, France

14 July 2010 – **Quantum light-cone fluctuations: probing quantum metric fluctuations with massless fields**
Experimental Search for Quantum Gravity, NORDITA, Sweden

28 October 2010 – **One-loop Riemann correlators and de Sitter invariance**
IR issues and loops in de Sitter space, Perimeter Institute, Waterloo, Canada

02 December 2010 – **Atom vs. laser interferometers for gravitational-wave detection**
QUEST Symposium, Leibniz Universität Hannover

21 December 2010 – **One-loop Riemann correlators and de Sitter invariance**
Theoretical Physics Christmas Meeting, University of Barcelona, Spain

20 June 2011 – **One-loop gravitational wave spectrum in de Sitter spacetime**
Peyresq Cosmology Meeting, France

Rupflin M.
13 May 2012 – **Flowing to minimal surfaces**
Workshop on Nonlinear Evolution Equations, Oberwolfach, Germany

06 June 2012 – **Uniqueness for the polyharmonic map flow**
Workshop on higher order problems in geometric analysis, University of Bath

10 September 2012 – **Flowing to minimal surfaces**
International Conference on Nonlinear PDE, University of Oxford

Ryan J.
01 March 2010 – **The phase space of BF theory and LQG**
Zakopane, Poland

Salemi F.
15 March 2011 – **S6-VSR2/3 offline all-sky burst analysis**
LSC-Virgo Meeting, Arcadia

24 September 2011 – **All-sky search for gravitational-wave bursts in the second joint LIGO-Virgo run**
Presentation of the all-sky burst paper at LVC Meeting, Gainesville

Schlotterer O.
24 July 2012 – **Hidden Simplicity in Superstring Amplitudes**
Conference „Strings 2012“, Munich

04 December 2012 – **Motivic Multiple Zeta Values and Superstring Amplitudes**
Conference „Amplitudes and Periods“, IHES Bures-sur-Yvettes

Invited Conference Talks given by AEI members

Schnabel R.

22 May 2010 – **Squeezed Light for Gravitational Wave Detection**
CLEO/QELS, San Jose

20 March 2011 – **GEO600: The First Application of Squeezed Light**
Rencontres de Moriond, LaThuile

02 May 2011 – **The first application of squeezed light in a gravitational wave detector**
ICSSUR 2011, Foz do Iguacu

20 May 2011 – **GEO600: The first Application of Squeezed Light**
GWADW 2011, Elba

24 July 2011 – **Michelson-Sagnac Interferometer with a Translucent Micro-Mirror**
Quantum Optics of Micro- and Nanomechanical Systems, Monte Verita

15 January 2012 – **A Gravitational Wave Observatory Operating Beyond the Quantum Shot-Noise Limit: Squeezed Light in Application**
1st NASA Quantum Future Technology Conference, San Francisco

04 March 2012 – **Optomechanics in a Michelson-Sagnac Interferometer**
2012 Mechanical Systems in the Quantum Regime, Gordon Research Conf., Galveston, Texas

27 April 2012 – **A GW Observatory Operating Beyond the Quantum Shot-Noise Limit: Squeezed Light in Application**
CVQIP, Copenhagen

14 May 2012 – **Why Squeezing is Remarkable**
GWADW 2012, Hawaii

22 July 2012 – **A Gravitational Wave Detector Operating Beyond the Quantum Shot-Noise Limit: Squeezed Light in Application**
ICAP 2012, Paris

Schutz B.

20 January 2010 – **Exploring the dark universe with gravitational waves**
Annual FOM Review Meeting, Eindhoven, The Netherlands

21 January 2010 – **What do we need to know in gravitational physics?**
Fundamental Physics in Space, ESTEC

10 February 2010 – **Measuring the Evolution of the Universe with LISA**
LISA Massive Black Hole Binaries in the Cosmic Landscape, Zürich

14 May 2010 – **Gravitational Physics in the Coming 15 Years**
Institute of Physics, London

10 June 2010 – **Expectations of LISA Studies of Black Holes**
460 WE Heraeus Seminar, Bad Honnef

13 September 2010 – **Hearing is Believing: LISA as a Black Hole Monitor**
Astro-GR Conference, Paris

23 September 2010 – **Gravitational Astronomy with LIGO, VIRGO, and LGCT**
JGRG-20 Conference
14 June 2011 – **Probing Cosmology with Gravitational Waves**
Conference on Cosmological Frontiers in Theoretical Physics, APC, Paris

08 September 2011 – **Enabling Open Access**
Leibniz Publik, Munich

30 September 2011 – **Gravitational Wave Explorations of Cosmology**
Theory Workshop, DESY, Hamburg

Invited Conference Talks given by AEI members

09 November 2011 – **Welcome from the Max Planck Society**
Berlin 9 Open Access Conference

17 December 2011 – **Gravitational Waves: Astronomy for the 21st Century**
ICGC Conference, Goa, India

02 April 2012 – **NGO: Revealing a Hidden Universe**
Ninth LISA Symposium, Paris

12 April 2012 – **Open access policy & business models for the literature: Four Questions**
Open Infrastructures for Open Science meeting, org by EU Commission, Rome

17 May 2012 – **Testing GR with LISA Pathfinder, BBO, and Other Future Projects**
Seventh Sackler Conference, Harvard

31 May 2012 – **Gravitational Wave Astronomy: A Completely New Way of Perceiving the Universe**
Conference on Gravitational Wave Astronomy in Africa, Pretoria, South Africa

05 June 2012 – **Gravitational Wave Astronomy**
50 years after the Jablonna Meeting, Warsaw

27 June 2012 – **Gravity talks: Observing the Universe with gravitational waves**
Relativity and Gravitation: 100 years of Einstein In Prague, Prague, Czechia

11 July 2012 – **Sources of Gravitational Waves for Space Detectors**
Fifth ASTROD Meeting, Bangalore

29 September 2012 – **Gravitationswellen: dem Universum zuhören!**
Physical Society of Switzerland annual meeting, Zürich

23 October 2012 – **Data sharing and research excellence in astronomy and beyond: synergies and tensions**
First EUDAT Meeting, Barcelona

07 November 2012 – **Welcome from the Max Planck Society**
Berlin 10 Open Access Meeting, Stellenbosch, South Africa

Sesana A.
11 February 2010 – **Massive Black Hole Binaries: formation, dynamics and gravitational waves**
Workshop on LISA massive black hole binaries, University of Zürich

Sheard B.
17 March 2011 – **Inter-satellite laser ranging system for GRACE follow-on**
DPG spring meeting, Dresden

Sindoni L.
03 March 2010 – **Continuum approximation of microscopic quantum dynamics: lessons from condensed matter systems**
Workshop "Open problems in Loop Quantum Gravity", Zakopane, Poland

09 April 2010 – **Condensed matter and gravity: an overview**
Focus Workshop on Quantum Gravity, Max Planck Institute for the Physics of Complex Systems, Dresden

Smulevici J.
13 January 2010 – **Global geometry of T2 symmetric spacetimes with weak regularity**
AMS Special Session on the Mathematical Challenges of Relativity, San Francisco
09 April 2010 – **The global geometry of T2 symmetric spacetimes with weak regularity**
PDEs, relativity & nonlinear waves, Granada

Tambornino J.
01 March 2010 – **A non-commutative flux representation for Loop Quantum Gravity**
Workshop "Open problems in Loop Quantum Gravity", Zakopane, Poland

Invited Conference Talks given by AEI members

Tröbs M.
23 May 2011 – **Laser systems for LISA and its precursor mission LISA Pathfinder**
GWADW, Elba

Vahlbruch H.
11 March 2010 – **The GEO600 squeezed light laser**
DPG spring meeting, Hannover

Vartanov G.
27 August 2010 – **Supersymmetric dualities beyond the conformal window**
40th International Symposium Ahrenshoop on the Theory of Elementary Particles, Berlin

29 November 2010 – **Recent results on superconformal indices**
Conference "From Sigma Models to Four-dimensional QFT", DESY

22 June 2011 – **From 4d superconformal indices to 3d partition functions**
UNIFY Workshop on Frontiers in Theoretical Physics, Porto

29 October 2011 – **4d Superconformal index and its reductions to partition functions in 3d and 2d**
Geometric Correspondences of Gauge Theories, SISSA, Trieste

Virmani A.
31 May 2012 – **Subtracted Geometry from Harrison Transformations**
Isaac Newton Institute for Mathematical Sciences: Branes and Black, Holes (a London Satellite Meeting), London, UK

10 September 2012 – **Subtractet Geometry from Harrison Transformations**
Workshop on Black Holes in Supergravity and M/Superstring Theory, AEI Golm

16 December 2012 – **Inverse Scattering and the Geroch Group**
Indian Strings meeting, Puri, India

Volpato R.
25 October 2011 – **The Mathieu group M24 and K3 sigma models**
Conference on Algebraic Geometry and Mathematical Physics, Mulhouse

07 November 2011 – **Mathieu Moonshine and symmetries of K3 sigma models**
Workshop on Automorphic forms and string theory, Karlstad

11 July 2012 – **A generalized Mathieu Moonshine?**
Conference 3Quantum: Algebra, Geometry, Information, Tallin

12 November 2012 – **Mathieu Moonshine and sigma models on K3**
Workshop on Algebra, Geometry and Physics of BPS states, Bonn

30 November 2012 – **Generalised Mathieu Moonshine**
Conference on Algebraic geometry, modular forms and applications to physics, Edinburgh

Was M.
07 June 2012 – **Searches for gravitational waves associated with gamma-ray bursts**
Gravitational Wave Physics & Astronomy Workshop, Hannover

20 June 2012 – **Searches for gravitational waves associated with gamma-ray bursts**
Gamma Ray Bursts in the Era of Rapid Follow-up, Liverpool

Willke B.
24 April 2012 – **Optical Design for Resonant Photon Regeneration**
Vistas in Axion Physics: A Roadmap for Theoretical and Experimental Axion Physics through 2025, Seattle

Lectures and Lecture Series given by AEI members

Adam I.
19 February 2010 – **An introduction to path integrals and perturbative quantum field theory**
IMPRS day, AEI

Allen B.
08 December 2010 – **Einstein's legacy, and the search for gravitational waves**
AIP/ACOFT 2010 Congress, Melbourne

Andersson L.
12 October 2011 – **Introduction to the black hole stability problem**
MSC, Tsinghua University

Arnlind J.
04 February 2010 – **Poisson algebraic formulation of classical geometry, non-commutative curvature and the Gauss-Bonnet theorem**
IHES Paris

Beisert N.
20 September 2011 – **Introduction to String Theory**
ETH Zürich

Bentivegna E.
24 January 2012 – **Black-hole lattices and inhomogeneous dust: modelling the three-dimensional universe with numerical relativity**
Institut für Physik, Mainz

Budewitz N.
16 January 2012 – **LaTeX Training #1of2**
Tutorial, MPI for Demographic Research, Rostock

20 February 2012 – **LaTeX Training #2of2**
Tutorial, MPI for Demographic Research, Rostock

Calcagni G.
19 April 2010 – **Course on Quantum Cosmology**
AEI, Potsdam U

Cederbaum C.
16 February 2010 – **What is curvature?**
Berlin Mathematical School

Danzmann K.
28 February 2010 – **IMPRS Lecture Week**
Erkner, Bildungszentrum

01 April 2010 – **Physik II, 4+2 SWS**
Leibniz Universität Hannover, Summer Term 2010

30 May 2010 – **IMPRS Lecture Week**
Mardorf

07 June 2010 – **Multi Wavelength Gravitational Wave Astronomy**
Bonn, Heraeus Seminar

01 October 2010 – **Physik I, 4+2 SWS**
Leibniz Universität Hannover, Winter Term 2010/2011

13 February 2011 – **IMPRS Lecture Week**
Motzen

03 March 2011 – **IMPRS Lecture Week**
Köpenik

Lectures and Lecture Series given by AEI members

01 April 2011 – **Physik II, 4+2 SWS**
Leibniz Universität Hannover, Summer Term 2011

19 June 2011 – **IMPRS Lecture Week**
Mardorf

01 October 2011 – **Physik I, 4+2 SWS**
Leibniz Universität Hannover, Winter Term 2011/2012

30 October 2011 – **IMPRS Lecture Week**
Mallorca

04 March 2012 – **IMPRS Lecture Week**
Motzen

01 April 2012 – **Gravitationsphysik, 4 SWS**
Leibniz Universität Hannover, Summer Term 2012

17 June 2012 – **IMPRS Lecture Week**
Mardorf

01 October 2012 – **Gravitationsphysik II, 4 SWS**
Leibniz Universität Hannover, Winter Term 2012/2013

28 October 2012 – **IMPRS Lecture Week**
Mallorca

Degeratu A.
20 January 2010 – **Harmonic functions on complete manifolds**
AEI

Devchand C.
24 February 2012 – **An Introduction to Solitons**
IMPRS Lecture Day

03 May 2012 – **Solitons and Integrable Systems**
Universität Bonn

26 September 2012 – **Instantons**
Schneverdingen / GRK463

07 December 2012 – **Markow-Prozesse: eine Einführung**
Bonn

Dittrich B.
20 April 2010 – **Introduction to Quantum Gravity**
Lecture course, University of Potsdam

Goßler S.
01 March 2010 – **The British-German interferometric gravitational-wave detector GEO 600**
Summerschool, Perth

Grote H.
05 March 2010 – **Interferometer Noise Sources**
IMPRS lecture week, Erkner

Heinzel G.
23 August 2011 – **LISA Laser Interferometer Space Antenna**
Xiangshan Science Conference, Beijing, China

25 August 2011 – **Inter-satellite laser ranging instrument for GRACE follow-on**
Xiangshan Science Conference, Beijing

Lectures and Lecture Series given by AEI members

Hennig J.
08 March 2010 – **Black holes and neutron stars**
Jürgen Ehlers Spring School "Gravitational Physics", AEI Golm

Huisken G.
01 April 2010 – **Aspekte des Ricciflusses**
Universität Tübingen

05 October 2010 – **Analytic and geometric promerties of mean curvature flow**
Britton Lectures, McMaster University, Canada

06 October 2010 – **Mean curvature flow with surgeries**
Britton Lectures, McMaster University, Canada

07 October 2010 – **Rigidity results and isoperimetric inequalities**
Britton Lectures, McMaster University, Canada

08 October 2010 – **Geometric evolution equations and the mass of isolated gravitating systems**
Britton Lectures, McMaster University, Canada

15 October 2010 – **Fluss entlang der mittleren Krümmung**
Universität Tübingen

15 April 2011 – **Fluss entlang der mittleren Krümmung II**
Universität Tübingen

15 September 2011 – **A priori estimates and surgery**
Summer School on Partial Differential Equations, Caputh

10 October 2011 – **Mathematische Aspekte der Allgemeinen Relativitätstheorie**
Universität Tübingen

17 October 2011 – **Applications to Isoperimetric Inequalties and General Relativity**
National Tsing Hua University, Taiwan

17 October 2011 – **Differentialgeometrie III: Mathematical aspects of General Relativity**
Freie Universität Berlin

21 October 2011 – **Mathematische Aspekte der Allgemeinen Relativitätstheorie**
Universität Tübingen

24 October 2011 – **Mean Curvature Flow in Geometry and Physics**
National Tsing Hua University, Taiwan

25 October 2011 – **Regularity Properties and Estimates for Mean Curvature Flow**
National Tsing Hua University, Taiwan

26 October 2011 – **Structure of Singularities and Surgery for Mean Curvature Flow**
National Tsing Hua University, Taiwan

24 April 2012 – **Mean curvature flow and asymptotically flat 3-manifolds**
Tsinghua University, Beijing

25 April 2012 – **Inverse mean curvature flow and its applications to General Relativity**
Tsinghua University, Beijing

27 April 2012 – **Isoperimetric concepts for the mass and geometric flows**
Tsinghua University, Beijing

16 July 2012 – **Geometry and Gravity**
Australian National University

Lectures and Lecture Series given by AEI members

26 September 2012 – **Singularities of mean curvature flow**
Chebyshev Laboratory, St. Petersburg

28 September 2012 – **Surgery for mean curvature flow of 2-convex surfaces**
Chebyshev Laboratory, St. Petersburg

29 September 2012 – **Application of mean curvature flow to General Relativity**
Chebyshev Laboratory, St. Petersburg

Khalaidovski A.
24 February 2010 – **Generation of strong low-frequency squeezing for the GW detector GEO 600**
Institute of Quantum Optics, Hannover

Kleinschmidt A.
20 October 2012 – **Einführung in die allgemeine Relativitätstheorie**
HU Berlin, Vorlesung (2+1 Wochenstunden mit Übungen), mit H. Nicolai

Knispel B.
12 September 2011 – **Astronomie für Neugierige**
Volkshochschulkurs der VHS Hannover zur modernen Astronomie

Lück H.
13 April 2010 – **ET - the Einstein Telescope**
QUEST Vorlesung, Hannover

08 March 2011 – **Interferometers and readout**
IMPRS lecture week, Köpenik

02 November 2011 – **Squeezed light in GW Detectors**
QUEST Ringvorlesung, Hannover

07 March 2012 – **Interferometer and readout**
IMPRS Lecture week

09 March 2012 – **Interferometer noise sources**
IMPRS Lecture week

Menne U.
07 April 2010 – **Federers curvature measures**
Freie Universität Berlin
15 April 2011 – **Some aspects of Allards regularity theorem**
Mini course, Massachusetts Institute of Technology

03 May 2012 – **Almgrens optimal isoperimetric inequalities**
University of Potsdam

28 June 2012 – **Hausdorff measure and rectifiability**
IMPRS Lecture Days "Geometric Measure Theory"

Nicolai H.
11 October 2010 – **Introduction to Supergravity (5 lectures)**
GK "Masse, Spektrum, Symmetrie", Humboldt Universität zu Berlin

20 December 2010 – **Einführung in die Supergravitation (vier Vorlesungen), GK1463 Analysis, Geometrie und Stringtheorie**
Universität Hannover

24 January 2011 – **Quantum Gravity (4 introductory lectures)**
CERN Winter School, CERN, Geneva

12 September 2011 – **Lectures on Canonical Gravity**
Erasmus PhD Pogram, Universite de Nice, France

Lectures and Lecture Series given by AEI members

28 October 2011 – **Einführung in die Allgemeine Relativitätstheorie**
HU Berlin, Vorlesung (2+1 Wochenstunden mit Übungen), mit A. Kleinschmidt

27 February 2012 – **Ways to Quantum Gravity (3 lectures)**
Schladming Winter School

19 March 2012 – **Einführung in die Theorie der Kac-Moody Algebren (mit Anwendungen)**
Blockvorlesung an der Universität Hannover

05 June 2012 – **Symmetries and the Unification of Physics**
Asim O. Barut Lecture, Bogazici University, Istanbul, Turkey

20 October 2012 – **Einführung in die Allgemeine Relativitätstheorie**
Vorlesung Wintersemester 2012/13 Humboldt Universität zu Berlin, mit A. Kleinschmidt

Nungesser E.
14 September 2010 – **Isotropization of non-diagonal Bianchi I-symmetric spacetimes with collisionless matter at late times assuming small data**
Salamanca

Oriti D.
19 September 2011 – **From loop quantum gravity to group field theory, via spin foams**
CERN Theory Institute Program "Quantum Gravity from UV to IR", CERN, Geneva, Switzerland

Pletsch H.
10 February 2012 – **Gamma-ray pulsar discoveries using ¬gravitational-wave search methods and ongoing Einstein@Home searches for neutron stars**
Institute of Mathematics, Polish Academy of Sciences, Warsaw, Poland

Pöld J.
09 August 2012 – **Lasers and Optics**
LLO Surf Lecture

Prix R.
22 June 2012 – **Lectures on Probability & Statistics**
IMPRS lecture week, Mardorf

Rendall A.
13 April 2010 – **General relativity**
Freie Universität Berlin

16 November 2011 – **A guided tour of partial differential equations**
Two 90 minute lectures for IMPRS lecture day, AEI

10 April 2012 – **Nonlinear hyperbolic equations**
Freie Universität Berlin

Rinne O.
19 September 2012 – **Numerical relativity beyond astrophysics**
IMPRS Excursion, Lindow

Salemi F.
19 June 2011 – **Data Analysis**
IMPRS Lecture Week, Mardorf

08 November 2011 – **Gravitational wave data analysis**
IMPRS winter semester courses on gravitational wave data analysis

24 February 2010 – **Gravitation: An Overview**
Porto University, Portugal

Lectures and Lecture Series given by AEI members

12 April 2010 – **Scientific Opportunities in Astronomy and Astrophysics Involving Gravitational Waves**
California Institute of Technology, Pasadena, CA

25 May 2010 – **Sources of Gravitational Waves**
Hannover University

31 May 2010 – **General Relativity, Part 2**
IMPRS Gravitational Waves Lecture Series

28 February 2011 – **Opening the Gravitational Wave Window on the Universe**
Arnold Rosenblum Lecture, Jerusalem University

23 May 2011 – **Astrophysics of sources of gravitational waves**
Cargese School on Gravitational Waves, Corsica

31 August 2011 – **Gravitational Waves**
School on Observational Cosmology, Azores

24 January 2012 – **Enabling the Transition of Existing Journals to Open Access**
Association of Publishing in Europe 2012 Meeting, Berlin

08 February 2012 – **The Enabling Environment: Wie Forschungsorganisationen den Wechsel zu Open Access fördern können**
Treffen der Arbeitsgemeinschaft wissenschaftlicher Verleger, Stuttgart

Willke B.
03 March 2010 – **Interferometer readout and DC detection**
IMPRS Lecture week, Erkner

16 October 2012 – **Laserstabilisierung und Kontrolle optischer Experimente**
Vorlesung Wintersemester 2012/2013, Leibniz Universität Hannover

Popular Talks given by AEI members

Allen B.
18 February 2011 – **Einstein@Home und die Suche nach Neutronenstenen mit Gravitations- und Radiowellen**
Urania Berlin e.V.

Beisert N.
19 March 2010 – **Was ist Stringtheorie?**
Bruno-H.-Bürgel-Sternwarte, Berlin

Budewitz N.
30 April 2011 – **High performance computing @ AEI**
Internal presentation for the service departments, Potsdam-Golm

Cederbaum C.
01 February 2010 – **Von Newton zu Einstein: ein Kurztrip durch Raum und Zeit**
Science Slam Berlin

03 March 2010 – **Prüfziffern als Detektive**
Day of mathematics, University of Heidelberg

Danzmann K.
23 January 2010 – **Schwarze Löcher, Monster im Universum**
Saturday Morning Physics, Leibniz Universität Hannover

12 February 2010 – **Cosmische Begegnungen**
Universität Tübingen

25 February 2010 – **Listening to the Universe in Einsteins Gravitational Waves**
Universität Perth

17 June 2010 – **Willkommen im Max-Planck-Institut für Gravitationsphysik**
MPG Jahrestagung, Hannover

12 July 2010 – **Schwarze Löcher, Monster im Universum**
Rotary Club, Hannover,

29 October 2010 – **Das Universum hören mit Einsteins Gravitationswellen**
Max-von-Laue Kolloquium, Berlin

02 November 2010 – **Einstein und die Gravitation**
Krupp-Vorlesung, Greifswald

11 April 2011 – **Willkommen im Institut für Gravitationsphysik**
Presidents Club, Uni Hannover

13 February 2012 – **Willkommen im Albert-Einstein-Institut Hannover**
Kuratoriumssitzung, AEI Hannover

Degeratu A.
27 April 2010 – **Geometry from Physics: Calabi-Yau spaces**
Universidad Autónoma de Madrid, Spain

Khalaidovski A.
03 November 2010 – **Wissenschaft sichtbar machen - Die Wellenjäger**
November der Wissenschaft, AEI Hannover

Kleinschmidt A.
19 January 2012 – **Das Higgs Teilchen als Ursprung der Masse**
Science Caffè - Café 11-line, Potsdam

Knispel B.
08 April 2010 – Celestia - **Das virtuelle Universum**
Monatsvortrag Volkssternwarte Hannover

Popular Talks given by AEI members

12 August 2010 – **Vom Urknall bis heute: die Geschichte des Universums**
Monatsvortrag Volkssternwarte Hannover

07 October 2010 – **Vom Urknall bis heute: die Geschichte des Universums**
Lister Turm, DARC Hannover

18 November 2010 – **Gravitationswellen - Ein neues Fenster zum All**
Monatsvortrag Volkssternwarte Hannover

16 December 2010 – **Vom Urknall bis heute – die Geschichte des Universums**
Vortrag für die gymnasiale Oberstufe am Gymnasium Langenhagen

10 February 2011 – **Gravitationswellen - Kann man das Universum hören?**
Monatsvortrag Volkssternwarte Hannover

05 May 2011 – **Gravitationswellen - Kann man das Universum hören?**
Lister Turm, DARC Hannover

11 August 2011 – **Pulsare - Leuchttürme des Weltalls**
Monatsvortrag Volkssternwarte Hannover

10 September 2011 – **Einsteins exotisches Universum: Von Schwarzen Löchern, Wurmlöchern und gekrümmter Raum-Zeit**
Tag der Offenen Türen 2011, AEI Golm

11 November 2011 – **Pulsare - Leuchttürme des Universums**
Max-Planck-Tag 2011, AEI Hannover

09 February 2012 – **Sterne, Nebel und Schwarze Löcher in der Milchstraße**
Monatsvortrag Volkssternwarte Hannover

Koehn M.
08 November 2012 – **"Breaking the wall of..." the Big Bang Theory**
Falling Walls Conference, Berlin

Lück H.
17 November 2012 – **Gravitationswellen- Die Suche nach dem Zittern der Raumzeit**
Saturday morning lectures, Hannover

Nicolai H.
08 January 2010 – **Den Urknall verstehen**
URANIA, Berlin

26 February 2011 – **N=8 Supergravity, and beyond**
IISER, Pune, India

11 July 2011 – **Quantengravitation: Physik ohne Raum und Zeit?**
"Naturwissenschaft aktuell", Carl-Friedrich von Siemens Stiftung, München

23 May 2012 – **Eine kurze Geschichte des Universums**
Kolloquium Universität Potsdam

Oriti D.
29 October 2012 – **Quantum Gravity, or the quest for the nature of space and time**
9th Japanese-German Frontiers of Science Symposium, Potsdam

Otto M.
28 October 2010 – **Das Orchester des Universums - Gravitationswellenastronomie heute**
Pavillon Hannover

04 March 2011 – **Das Orchester des Universums - Gravitationswellenastronomie heute**
Haus der Wissenschaften, Braunschweig

Popular Talks given by AEI members

24 May 2011 – **Mathematik ohne Grenzen - Forschung ohne Grenzen!**
Mathematik ohne Grenzen Preisverleihung, Schillerschule Hannover

27 May 2011 – **Das Orchester des Universums - Gravitationswellenastronomie heute**
Magdeburg

28 May 2011 – **Das Orchester des Universums - Gravitationswellenastronomie heute**
Lange Nacht der Wissenschaften, Magdeburg

06 July 2011 – **The Orchestra of the Universe - Gravitational Wave Astronomy today**
International Office der Leibniz Universität Hannover

Rezzolla L.
10 July 2010 – **Modelling sources of gravitational waves**
Computer Science Students, University of Potsdam

29 July 2010 – **Alla scoperta delluniverso di Einstein con buchi neri, stelle di neutroni e supercomputers**
Sesto, Italy

Schutz B.
25 February 2010 – **Gravitational Waves: True Music of the Spheres**
Porto University, Portugal

10 March 2010 – **Schwerkraftwellen: Sphärenmusik tatsächlich hören!**
German Physical Society Evening Lecture, Hannover University

07 April 2010 – **Gravitational Waves: True Music of the Spheres**
McDonnell Invited Lecture, Washington University, St Louis

08 May 2010 – **Gravitational Waves: Listening to the True Music of the Spheres**
Beijing Planetarium, Beijing

20 October 2010 – **Schwerkraftwellen: Sphärenmusik tatsächlich hören!**
Karl Schwarzschild Vortrag, Frankfurt

05 July 2011 – **Gravitational Waves: Listening to the True Music of the Spheres**
Invited popular talk during Capra Conference, Southampton, England

13 July 2011 – **Gravitational Waves: Listening to the True Music of the Spheres**
Invited popular talk during Amaldi Conference, Cardiff, Wales

03 September 2011 – **Gravitational Waves: Listening to the True Music of the Spheres**
Popular lecture during cosmology school, Azores

09 September 2012 – **Listening to the universe with gravitational waves**
British Science Festival, Aberdeen

Thienert M.
10 September 2011 – **Wie bringt man einem Raumschiff das Fliegen bei**?
Tag der Offenen Türen, Wissenschaftspark Potsdam-Golm

Guided Tours at GEO600

Aufmuth, P., Grote, H., Lück, H.

"GEO600: The German-British Gravitational-Wave Detector"
Introductory talk and guided tour

Appr. 662 visitors

11 February 2010 (8) / 9 March 2010 (32) / 11 March 2010 (17) / 22 April 2010 (16) / 9 June 2010 (12) / 17 June 2010 (10) / 24 August 2010 (15) / 13 January 2011 (3) / 14 April 2011 (45) / 1 July 2011 (3) / 6 September 2011 (12) / 24 September 2011 (400) / 25 October 2011 (7) / 1 November 2011 (5) / 17 February 2012 (4) / 23 February 2012 (2) / 16 March 2012 (14) / 10 April 2012 (11) / 22 June 2012 (1) /10 July 2012 (3) / 18 July 2012 (11) / 30 July 2012 (11) / 10 November 2012 (20)

The Max Planck Society: Profile and Organisation

The Max Planck Society for the Advancement of Science is an independent, non-profit research organization. It was founded on February 26, 1948, and is the successor organization to the Kaiser Wilhelm Society, which was established in 1911. The primary goal of the Max Planck Society is to promote research at its own institutes.

The currently 82 Max Planck Institutes conduct basic research in the service of the general public in the natural sciences, life sciences, social sciences, and the humanities. Max Planck Institutes focus on research fields that are particularly innovative, or that are especially demanding in terms of funding or time requirements. And their research spectrum is continually evolving: new institutes are established to find answers to seminal, forward-looking scientific questions, while others are closed when, for example, their research field has been widely established at universities. This continuous renewal preserves the scope the Max Planck Society needs to react quickly to pioneering scientific developments.

The Max Planck Society maintains 82 institutes and research facilities (as of January 1, 2013), including five institutes and one branch abroad. On January 1, 2013 the Max Planck Society employed a total of 16,918 staff, of whom 5,470 were scientists.

Additionally, as of January 1, 2013 there were 4,487 junior and visiting scientists working in the institutes of the Max Planck Society. A total of 21,405 people (16,918 staff and 4,487 junior and visiting scientists) worked at the Max Planck Society. In the course of 2012, a total of 13,149 Bachelor students, fellows of the International Max Planck Research Schools, PhD students, postdoctoral students, research fellows, and visiting scientists worked at the Max Planck Society.

The financing of the Max Planck Society is made up of 80% basic financing from the public sector the MPG is financed to approximately 1,53 billion euros in 2013. In addition, third-party funding contributed to basic financing.

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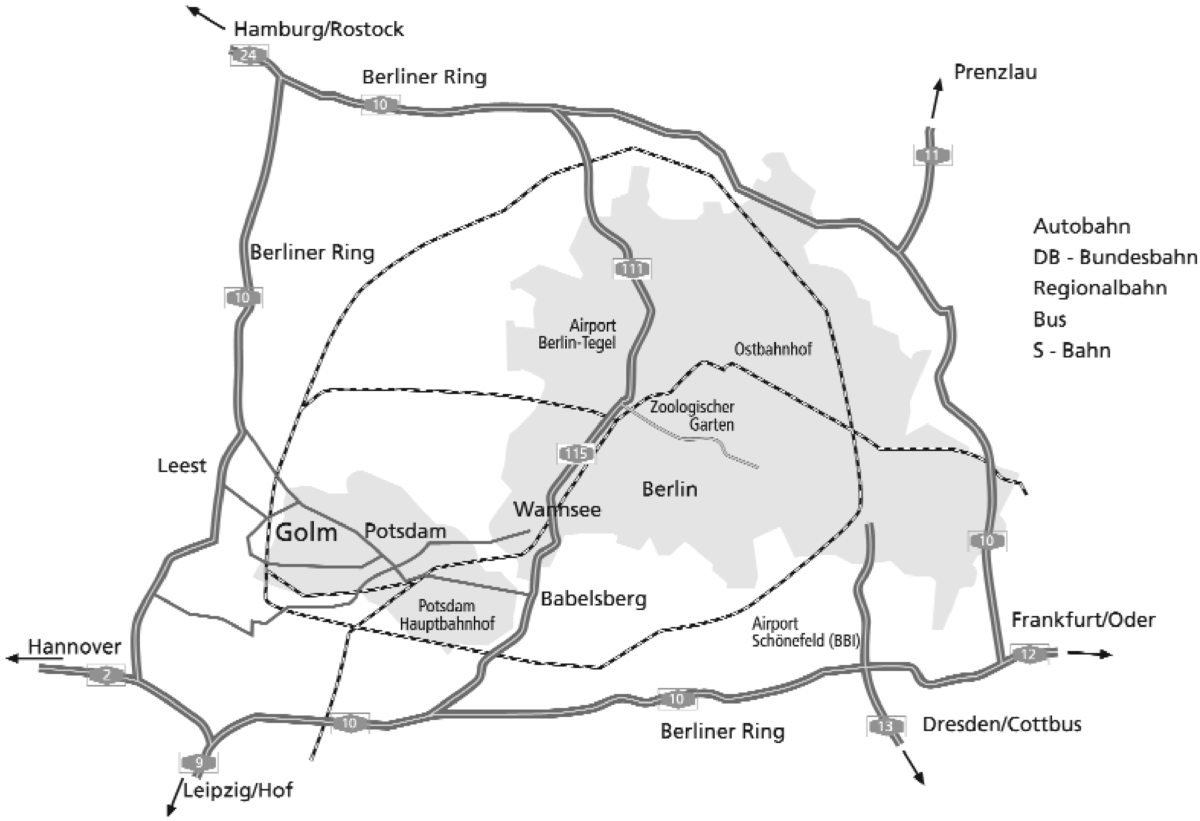
How to get to the AEI in Hannover

From the airport:
Take the S-Bahn no. 5 to the Central Station ("Hauptbahnhof"). Leave the Central Station direction "City"; walk along the Bahnhofstraße to the subway station "Kröpcke" (at the "Kröpcke" square); take subway no. 4 direction "Garbsen" or no. 5 direction "Stöcken". Leave the train at the fourth stop "Schneiderberg/Wilhelm-Busch-Museum"; cross the Nienburger Straße, walk along the Schneiderberg; after the refectory (Mensa) turn left into the Callinstraße; no. 38 at the right hand side is the AEI.

By train:
Leave the Central Station direction "City" and follow the above directions.

By car:
Take the highway A2; exit "Hannover-Herrenhausen", follow the sign "Zentrum"; drive along the B6 (Westschnellweg), exit "Herrenhausen"; take the Herrenhäuser Straße to the right; pass the Great Garden; at the fork to the right into the Nienburger Straße; the second left is the Callinstraße; no. 38 at the left hand side is the AEI.



How to get to the AEI in Potsdam-Golm

From the airports:
Tegel: Take the bus X9 to train station "Zoologischer Garten"
Schönefeld: Take the train "Airport Express" to "Zoologischer Garten"

then take S-Bahn or Regionalbahn to train station "Potsdam Hauptbahnhof" and take Bus 605 or 606 straight to the Max Planck Campus („Wissenschaftspark Golm").

By train:
Take any train going to "Potsdam Hauptbahnhof", then follow the above directions.

By car:
From Berlin: leave Autobahn A115 at exit "Potsdam-Babelsberg", go in the direction "Potsdam-Zentrum".

Follow signs "Autobahn Hamburg" until Golm is indicated.

Other routes: leave Autobahn A10 at exit "Leest", go in the direction "Potsdam", pass Leest and Grube to reach Golm.

Masthead

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Title Images (from top left): WovenSystems/FortiNet switches in the Atlas cluster at the AEI (B. Knispel/MPG) | Numerical simulation of the gravitational waves emitted during the merger of two neutron stars into a black hole (Numerical simulation: B. Giacomazzo & L. Rezzolla/AEI; Scientific visualization: M. Koppitz (AEI/Zuse Institut Berlin) | LISA Pathfinder in front of the space chamber at IABG (ESA/Astrium/IABG) | Numerical simulation of the gravitational waves from the merger of two black holes (W. Benger, Zuse-Institut Berlin and AEI) | A mirror of GEO600 with visible electrostatic drive (GEO600/AEI Hannover) | A scientist working at the laser for GEO600 (AEI Hannover) | GEO operations: The large screen shows live images of laser beams in the locked GEO600 detector (GEO600/AEI Hannover)

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Research overview: SDO/AIA (Sonne), AEI
Research Highlights: AEI Hannover, GEO600
IT & Library Highlights: M. Fiorito, N. Fluturel/MPG
Events: AEI
Through the Eyes of a Visitor: M. Fiorito, N. Fluturel/MPG
Short Notices: N. Michalke/AEI
Living Reviews: AEI
Cooperations: S. Rieger/Milde Science Communication
The Max Planck Society: E. Müller/AEI

p 50 Fig.3: Wikimedia Creative Commons
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Note: Academic Achievements: This page shows Albert Einstein's results in his final school exams. A "6" is the highest possible grade in the Swiss system!