## 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 2006 and 2007. 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 perhaps 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 institute's international standing has been recently confirmed by the AEI Fachbeirat which visited the institute in the first week of December 2007, and whose report attests that AEI is "performing outstandingly well ... judging by the standard criteria of the depth and significance of its scientific results, quality of publications, and esteem of its scientific peers".

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. However, there were several special highlights concerning the institute as a whole, which deserve to be mentioned specially in this preface. These are:

1. The appointment of Bruce Allen as the director of the division "Observational Relativity and Cosmology", which is the 5th division of AEI, and the second division of its Hannover branch. With this appointment, the institute is now complete and thus has reached a stationary state after many years of buildup. The new directorship provides a crucial link between the theoretical and experimental activities of AEI.

2. In the second round of the Exzellenzinitiative only one cluster of excellence in physics survived the competition: The QUEST cluster at AEI Hannover. QUEST (Quantum Engineering and Space Time Research) is a joint research programme of the Leibniz Universität Hannover, the Laser Zentrum, the Physikalisch-technische Bundesanstalt in Braunschweig, the Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation, and the AEI. Research will concentrate on the advancement of quantum engineering and space-time to gain a better understanding of the underlying physics and to improve or utilise resulting innovative methods in fundamental physics and applied fields.

3. Since January 2006 the AEI hosts an International Max Planck Research School (IMPRS) on Gravitational Wave Astronomy. This second IMPRS is based in Hannover, and is run jointly by the Hannover divisions and the Astrophysical Division in Golm. The first (and Golm-based) IMPRS on Geometric Analysis, Gravitation and String Theory has been running successfully for a number of years and is now preparing for evaluation later in 2008. With its two IMPRS, the institute participates very actively in the education and training of students and young researchers, providing them with a top rate research environment at the frontiers of modern research.

4. An Independent Junior Research Group "Duality and Integrable Structures" was awarded to Niklas Beisert, and has been in operation since 2006. A second Independent Research Group on Canonical Quantum Gravity is due to start in 2009, to be headed by Bianca Dittrich. Both groups are funded by the Max Planck Society. In view of the tough competition for these research funds, we are very proud to host two such groups.

I am especially pleased to report that several members of AEI have received prestigious national and international distinctions and awards, in particular:

- B. Schutz was awarded the second Amaldi Gold Medal by the Italian Society of Gravitation (SIGRAV) in 2006
- T. Thiemann shared (with M. Bojowald, a former member of AEI) the Xanthopoulos Prize 2007 of the GRG Society for his work on canonical quantum gravity
- N. Beisert was awarded the 2007 Gribov Medal of the European Physical Society for his contributions to string theory and AdS/CFT duality
- J. Ehlers was awarded the Commemorative Medal of the Faculty of Mathematics and Physics of Charles University, in acknowledgement of his outstanding achievements as one of the world's leading specialists in the general theory of relativity and cosmology.
- Several young researchers received recognitions for their PhD work: To C.D. Ott the Young Researcher's Prize of the City of Potsdam and (in 2008) the Otto Hahn Medal were awarded. B. Dittrich received another Otto Hahn Medal and K. Giesel won the Michelson Prize of Potsdam University.
- M. Pössel received the 2007 Roelin Award for science writing in recognition of the popular AEI web portal Einstein Online and his book "Das Einstein-Fenster".

In June 2008 my colleague Bernard Schutz took over as Managing Director of AEI. At the end of my two-year term I would therefore like to thank all the scientists and support staff of the AEI for their continued support and enthusiasm. I think that it is not only its science that makes AEI such a unique place for researchers from all over the world, but also such things as – to quote just one visitor – "secretary efficiency and smile", and the general friendliness and helpfulness of our administrative and computer support staff. Indeed, as that same visitor told me, I "should feel lucky to be the director of such an institute". I do!

Hermann Nicolai

PS: Sadly and unexpectedly, our founding director Jürgen Ehlers passed away on May 20, 2008. He was present and worked at AEI until the last day before his untimely death. We have therefore decided to append the AEI obituary to the historical article he contributed to this report.

## Content

### The Institute



### Research Overview



### Research Highlights

## 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. Its establishment was an initiative of its founding Director, Jürgen Ehlers, who retired at the end of 1998. The Institute moved from Potsdam to its new building in 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.

Founded in 1995, the AEI has enjoyed twelve years of very rapid growth, including the founding 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 150 scientists visit each year; the institute regularly hosts workshops and conferences; we publish one of the principal scientific journals in relativity; and many AEI staff occupy leading positions in big collaborations, external institutions, and in public advisory bodies. We also take satisfaction that former AEI scientists occupy permanent positions and in many cases leadership positions in several of the important relativity research groups around the world.

The years 2006-7 saw the completion of the AEI's expansion in Hannover as Bruce Allen joined the Institute as its fifth director, for the Observational Relativity and Cosmology Division. During this period the extension building in Golm (in Potsdam) was completed, providing much-needed office space and a wonderful covered atrium, which has become a focal point for relaxed conversation and social activity. We installed two new supercomputers at Golm to support numerical relativity and gravitational wave data analysis, and we began planning for a yet more powerful computer for Professor Allen in Hannover. A new International Max Planck Research School (IMPRS) in Gravitational Wave Astronomy started up during this period, as a collaboration between the Golm and Hannover branches. It joins the existing Golm-based IMPRS for Geometric Analysis, Gravitation, and String Theory.

### 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 1960's and 1970's put the theory on a sound footing: 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 two decades ago were regarded as exotic, if not impossible.

In recent years the most striking technological advances have been in the design and construction of gravitational wave detectors of enormous size, based on the technique of laser interferometry. A world-wide network of such instruments has now completed two years of full-time observing, including the AEI's own 600 m detector, GEO600, a collaboration with British and other European scientists. In the more distant future, the joint European-American space mission LISA will turn gravitational wave astronomy into a field rich in signals and exotic sources. Preparations for LISA include launching LISA Pathfinder in 2010, a technology-proving mission in which AEI scientists in Hannover are playing a leading role. The design of LISA 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 the dynamics of black holes and neutron stars. The gravitational radiation group is very heavily involved in the ongoing analysis of the data from the large gravitational wave detectors, and this analysis could at any time make the first direct observations of signals from distant astronomical sources that are carried by the gravitational field itself. 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.

- 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 two main threads to research in this area around the world, called string theory and canonical quantization, and the AEI is one of the few places in the world where scientists study both. 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 GEO collaboration is a world leader in detector technology. The optical and mechanical systems they designed for GEO600 are planned to be a key component in the upgrade of LIGO that will take place at the end of this decade. The Division also plays a leading role in the development of the LISA space-based gravitational wave detector, which is planned to be launched in 2018 jointly by the European Space Agency (ESA) and the US space agency NASA. Danzmann is the European Mission Scientist for LISA. In preparation for LISA, the Division has a major role in the LISA Pathfinder mission, which will be launched by ESA in 2010 to test the measurement and control systems designed for LISA.

- 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. Allen had previously been a frequent visitor to the AEI and AEI scientists already had many collaborations with him. The new division will also be active in ground-based gravitational wave data analysis and in developing the interface between data and theory (which is called phenomenology). The overlap with the activities of the Astrophysical Relativity Division is strong at the beginning, but this will change as the Golm division focuses more of its work on space-based gravitational wave detection.

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

- The Theoretical Gravitational Wave Physics research group was established by the award to its leader, Yanbei Chen, of a Sofja Kovalevskaja Award by the Humboldt Foundation in 2004. It does research into the design of interferometric gravitational wave detectors, especially with reference to their quantum properties, and into new methods of data analysis for gravitational waves. In late 2007 Chen took up a professorship at the California Institute of Technology, and the activities of the group will gradually wind down over the subsequent year.

- The Duality and Integrable Structures research group is funded by the Max Planck Society under a grant to its leader, Niklas Beisert, in 2006. Its research focuses on the integrable structures that have recently been identified in gauge and string theories. The aim is to deepen our understanding of these models on which classical and modern particle physics is founded. This group is expected to work for a term of five years.

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 two teraflop-class cluster computers dedicated to specific research areas. A third, even more powerful cluster computer is under construction at the Hannover branch. In Hannover as well the Institute hosts a very modern and highly capable machine shop that supports both ground-based and space-based experimental activities.

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 also maintains an extensive guest scientist program. The lists in this report of guest scientists for 2006/7 and of seminars given at the AEI show how rich the intellectual environment is.

**QUEST: Partnership in quantum engineering**

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. It has begun to use its special position to assist universities to strengthen their research in gravitational physics and to train new scientists in this exciting and expanding area. The most exciting such development so far is the QUEST Center of Excellence.

QUEST (Centre for Quantum Engineering and Space-Time Research) was awarded in 2007 as the outcome of a competition among many German universities for funding earmarked for strengthening research in areas where Germany had world-class leadership positions. At the core of QUEST are the AEI/Hannover, the Institute for Quantum Optics of the University Hannover, to which are added a number of partners, including Geodesy, Theoretical Physics and Mathematics Institutes of the University Hannover, the Laser Zentrum Hannover, the Physikalisch-Technische Bundesanstalt Braunschweig, the Centre for Applied Space Technology and Microgravity (ZARM) at the University of Bremen, AEI/Golm, the GEO600 detector, and industrial partners.

QUEST intends to take quantum optics out of the realm of pure research and into the new and rapidly emerging applications. Rapid research progress has opened new horizons in quantum metrology for testing fundamental physical laws, reaching unprecedented levels of precision in measurements of space and time, and applying sensors based on these novel quantum technologies in global geodesy, inertial sensing, navigation and laser ranging. The new center will focus on four interdisciplinary areas of research: Quantum Engineering, Quantum Sensors, Space-Time Physics, and Enabling Technologies. QUEST's funding will strengthen its research capabilities and sustainability through the implementation of several new professorships for renowned experts, attractive positions for excellent young researchers and leading postdoctoral positions in junior research groups.

**Other initiatives with universities**

The AEI participates in at least four further cooperative initiatives with universities in Germany. The first is its 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 University of Hannover, can supervise work towards advanced degrees of those universities.

A second form of cooperation with universities is the participation of the AEI in three 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 will help to develop a university research community supporting the experimental activities of GEO600 and LISA. For over a decade, the AEI Hannover has been a major player in the SFB 407 "Quantum Measurement", involving scientists from the University of Hannoer, the PTB Braunschweig and the Laserzentrum Hannover. Both these SFBs will benefit from joint research with members of the QUEST center in Hannover. In 2005 a new SFB in mathematics and theoretical physics entitled "Space-Time-Matter" started. This SFB 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 Research Schools (IMPRS). The first one, started in 2004, is in Geometric Analysis, Gravitation, and String Theory. It is a cooperation with Potsdam University, the Free University of Berlin and Humboldt University. The second, which began in 2006, is in Gravitational Wave Astronomy, and is a cooperation with Hannover University. This, too, will benefit from association with QUEST. 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 AEI naturally also trains many young German and foreign postdoctoral scientists in its research groups. Our recent 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 editorial staff of the journal are now supported by the Heinz-Nixdorf Center for Information Management (ZIM) of the Max Planck Society, and in recent years we have started up three sisters journals, Living Reviews in Solar Physics, Living Reviews in European Governance, and Living Reviews in Landscape Research. Further journals are expected to join the family in the next year or two.

### 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 member of the most sensitive network of detectors ever constructed, the GEO600 instrument should 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 LISA 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 2006/7, 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

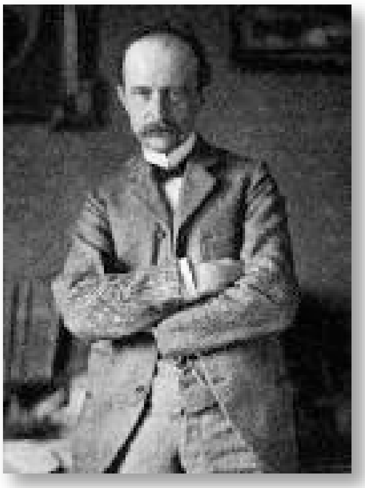
## Max Planck, Albert Einstein, and Relativity

Our institute owes not only its name, but also the subjects and aims of its research in large measure to Max Planck and Albert Einstein. Different in background, political attitude and life style, these two men were driven by the same desire: to grasp the general principles governing the physical universe.

Max Planck's 150th birthday on April 23 2008 is celebrated with talks, articles and an exhibition. This event offers a unique opportunity to honour the two great name-giving patrons of our institute by relating some episodes from their encounters and scientific exchanges.

When in 1905 the patent clerk Einstein published his revolutionary ideas, among them the relativity paper, in the Annalen der Physik, Max Planck was already (since 1892) director of the institute of theoretical physics at the university of Berlin and had become famous by his discovery and theoretical interpretation of the law of black body radiation in 1900. According to Einstein's sister Maja, her brother "imagined that his publications in the renowned and much read journal would draw immediate attention. But … it was followed by an icy silence." However, a little later Einstein received a letter from Planck who asked for some clarifications. Einstein's joy was great. At last, the silence was broken, and that by the leading theoretician of the time. About 10 months after the appearance of Einstein's relativity paper, Planck published the basic laws of relativistic mechanics, introducing the expressions for momentum and energy of a particle in the new theory, as well as giving Lagrangian and Hamiltonian formulations for its motion. Einstein later noted: The rapid attention given to special relativity was largely due to Planck's warm and decisive engagement for it.

Planck was attracted to relativity theory because it was based on general principles, esp. the relativity principle, which promised a unification of physics. In line with this hope he combined the principles of least action and of relativity in an article in 1907. Planck emphasized that the action, like the fundamental constant $h$ with the introduction of which he had initiated quantum physics, is invariant, i.e. independent of the inertial reference system, and he derived general dynamical laws encompassing mechanics, electrodynamics and his favourite subject, thermodynamics. In particular, Planck pointed out that momentum density and energy flux density are essentially the same quantities, thereby strengthening the equivalence of mass and energy. In a lecture which he gave at the same meeting at which H. Minkowski geometrized special relativity (1908), Planck even suggested to transfer these concepts to the field of gravity.



Max Planck (1958 - 1947)

Planck was apparently the first physicist to recognise the extraordinary depth of Einstein's ideas. In 1910 he recommended Einstein for a professorship in Prague. "Einstein's work on relativity probably exceeds in audacity everything that has been achieved so far in speculative science and even in epistemology." He went on to compare Einstein to Kopernikus.

In the spring of 1913, when Nernst and Planck visited Einstein in Zurich to find out whether he would be interested to come to Berlin, Planck asked Einstein what he was working on. Einstein described his recent and ongoing work on a generalization of relativity theory to incorporate gravity by using a Lorentzian metric. Planck said: “As an older friend I must advise you against it, for in the first place you will not succeed, and even if you succeed no-one will believe you.” Fortunately Einstein did not follow this advice. He continued to develop a theory of gravity in which for the first time the space time metric was treated as a dynamical entity. Ironically, one idea which encouraged Einstein in introducing a variable metric, had been Planck’s action principle mentioned above which led to geodesic hypothesis.

Planck’s drive towards “the absolute” is illustrated by his introduction of natural units, now called Planck units. Already before he found his radiation law, he noticed that the dimensional constant $c$, the speed of light; $k$, the constant of gravity; and the two constants appearing in Wien’s radiation law – Boltzmann’s and Planck’s constants – can be used “to set up units for length, mass, time and temperature which, independent of particular bodies or substances, by necessity keep their meaning for all time and for all, even non-human cultures.” In more down to earth language, this means that in contrast to Euclidian geometry, nature does have preferred scales.

Einstein expressed his admiration of and gratitude to Planck first in an article “Planck as researcher”, written in Zurich a year before he went to Berlin. Einstein begins: “For the academic year 1913/14 the rectorate of Berlin university has been put into the hands of the theoretical physicist Max Planck. We, the colleagues, are happy to use this occasion to express with gratitude the achievements which science owes to you.” In recalling Planck’s work on thermal radiation Einstein, in his characteristic style, remarks: “It would be elevating if we could put on scales the brain substance which has been sacrificed on the altar of this universal [Wien] function, and no end to this cruel sacrifice is yet visible.”

In the summer of 1914 Einstein gave his inaugural lecture at the Prussian Academy of Sciences in Berlin. He described the status of theoretical physics: On the one hand, owing mainly to Planck’s researches, splendid successes had been achieved in accounting for some properties of radiation and molecular motion. On the other hand, these same researches deprived physics from its conceptual foundation, the principles of classical physics. “We have to admit that today we are as helpless as concerns the fundamental laws of molecular motions as were astronomers before Newton regarding planetary motions.” While in this area physicists lack theoretical principles, the situation in relativity, Einstein then points out, is quite different. There, clearly formulated principles lead to predictions which may require long experimental researches to decide whether these principles correspond to reality. He was referring to his new theory of gravitation in which accelerated frames of reference were to take the privileged role of the inertial systems. In his amiable, carefully phrased reply Planck, secretary of the physics and mathematics section of the academy, “could not resist to object in one important point.” Rather than regarding the privileged role of uniform motions in special relativity as not fully satisfactory, Planck considered the opposite standpoint as equally convincing, pointing out that Einstein himself had just shown that even in his generalized relativity theory (the Einstein-Grossmann theory) not all coordinate systems are physically equivalent. But, Planck concluded, “these differences of opinion concern expectations, not scientific knowledge.” It took another five years until Einstein’s conception of general relativity won (more or less) general acceptance.

Albert Einstein in his office at Haberlandstraße in Berlin (1927)

In his Nobel lecture, delivered in 1920, when Einstein had become world famous because British astronomers had verified his prediction that light has weight and space is curved, Planck noted: “It must appear as a strange coincidence that at exactly the time when the idea of general relativity has led to spectacular successes, nature has revealed, at a place where one could not in the least expect it, an absolute, unchanging unit measure which may be used to express the amount of action contained in some spacetime element by a completely determinate, convention-free number.” In view of recent developments in quantum field theories it is interesting to note the emphasis Planck put on spacetime invariant action integrals. In a letter to C. Runge (1908) Planck head already formulated: “The elementary quantum has the dimension energy x time, hence its explanation requires not to consider a state, but a process. We are here concerned not with an atomism of space, but of time. Perhaps Minkowski’s views on spacetime could be evaluated to gain an intuition for the action-atom, which is Lorentz invariant in contrast to lengths, times, energies etc.”


Planck and Einstein received the Max Planck Medal in 1929

I end these remarks by quoting some passages from Einstein’s memorable speech given when he received the Planck medal in June 1929. He begins: “How could I put in words my emotion, standing in front of the revered master and friend with whom I have been connected for many years by the same striving.” After recalling his enthusiasm in following Planck’s work since 1900, he continues: “My ideas were centred in particular on two thoughts: nature’s working seems to be determined to such an extent that not only the time sequence of events, but also the initial state is largely bound by law. I tried to achieve that by looking for overdetermined systems of differential equations. … The postulate of general relativity and the hypothesis of the uniform structure of the

physical field were supposed to guide me. This goal stands unrivalled, and hardly a colleague could be found to share my hope. What I found in the area of quantum physics are only occasional insights, splinters which fell during my fruitless efforts towards the great problem. I feel ashamed to receive now such a high honour for that. I still feel strongly that subcausality will not prevail, but that eventually even supercausality will be achieved. Nevertheless I highly admire the results of the younger generation referred to as quantum mechanics, and I believe in the latter's deep truth contents; only I feel that the restriction to statistical laws will only be a temporary one." Einstein then closed by again expressing his devotion and gratitude to Planck.

Jürgen Ehlers

## Jürgen Ehlers (1929 – 2008)

Jürgen Ehlers, one of the most distinguished and influential German scientists of his generation, died very suddenly and unexpectedly on 20 May 2008. A specialist in the study of general relativity, and at the same time a generalist and humanist with a passion for the fundamentals of the natural world, Ehlers played a leading role in the revival of research in general relativity in modern Germany from its small beginnings in the 1950s through to the flowering of the subject during the past decade. The institute he founded in Potsdam in 1995, the Max Planck Institute for Gravitational Physics (more commonly known by its subsidiary name, the Albert Einstein Institute – AEI), has become the largest institute of its kind in the world. It is a fitting memorial to his scientific life.

Born in 1929, Ehlers studied both mathematics and physics in Hamburg in the 1950s, and he finally chose physics because he could study general relativity with Pascual Jordan, one of the pioneers of quantum physics. At this time, interest in general relativity among theoretical physicists was beginning to revive after decades of neglect. Jordan was one of a handful of senior figures around the world who felt it was time to begin to understand general relativity, in order ultimately to generalize it into a full quantum theory of gravity. Key goals were to understand gravitational waves and what we now call black holes, and Jordan and his school, including Ehlers, were among the pioneers in this revival.

After visiting positions at several universities in Germany and the United States, culminating in a professorship in 1967 at the University of Texas at Austin, Ehlers moved to Munich to become a Member of the Max Planck Institute for Physics and Astrophysics in 1971. Institute director Ludwig Biermann asked Ehlers to join the Astrophysics part of the institute, because the institute was just beginning the gravitational wave activities that would eventually lead to Germany's GEO600 detector. In 1978 Ehlers organized the Ninth Texas Symposium on Relativistic Astrophysics, the principal international meeting where relativists and astrophysicists meet and update one another on their recent research. When the Astrophysics part of the Max Planck Institute moved into a new building in Garching outside Munich in 1979, Ehlers and his group, as well as the gravitational wave experimenters, went with it. Ehlers' clear commitment to astrophysics reflected his clear belief that the most important questions in general relativity were those that would be tested by astronomical observations.

Ehlers nevertheless remained a deeply mathematical physicist, and he always insisted that the great physical and astrophysical questions about relativity theory should be answered with as much rigour and care as possible. But always the important questions for him were those that the Universe itself posed. The discovery in 1974 of the first pulsar in a binary system, by Russell Hulse and Joseph Taylor, was a watershed for relativity, because it was immediately clear that the system would provide the first clean observational test of gravitational wave theory: the two stars would gradually spiral closer to one another as gravitational waves carried energy away. Ehlers quickly grasped how important this result would be, and just as quickly pointed out that the state of the theory of gravitational radiation itself was by no means satisfactory; relativity could not properly be tested against the observations until relativists sorted out the theory.

For the next ten years, Ehlers pushed his own research associates and scientists around the world to do this, with considerable success. The award of the 1993 Nobel Prize to Hulse and Taylor, the building of giant gravitational wave detectors around the world since the 1990s, and the use of modern supercomputers to predict gravitational wave emission from neutron stars and black holes all rest on secure theoretical foundations, thanks in part to Ehlers' insistence that even the complex mathematics of general relativity should be done carefully and rigourously.

Always looking ahead for the big challenges, Ehlers in the late 1980s took up research into another of Einstein's predictions, the bending of light by gravity. Again he was motivated by recent astronomical discoveries of gravitational lensing, where telescopes see multiple images of the same object, created as light takes multiple paths to the Earth through the gravitational field of an intervening galaxy. But again the theory needed work, and Ehlers stimulated young scientists in Garching to do it better. Today gravitational lensing is a central tool in astronomy, used among other things to prove that the Universe contains far more dark matter than it does stars and visible galaxies. The nature of this dark matter is not known, but it certainly is not composed of the protons, electrons, and neutrons that dominate the world we experience. Ehlers' young associates have gone on to make important and leading contributions to this branch of astronomy.

Ehlers' work at the junction between mathematics and physics had strong influences on the development of mathematics as well. He initiated a number of new research directions in analysis and differential geometry. Notable among these was his theory of reference systems, called "frame-theory". This provides a crucial mathematical link between concepts from classical physics and the geometric language of general relativity, and it has been successfully used to understand the precise relations between the different ways that Newton´s and Einstein´s theories of gravity would describe the same physical system. This is a key question, because many of the tests of the correctness of general relativity rely on measuring some of the small ways in which motions in the Solar System differ from those expected on the basis of Newton's theory of gravity. Ehlers had a rare ability to formulate fundamental physical questions in a precise mathematical language. His influence on research on the mathematics of Einstein's equations will be felt for many years to come.

In 1990 Ehlers had what he later described as the one good political idea in his life: he proposed that the Max Planck Society should create a research institute dedicated to research on gravitation. The reunification of Germany had created a need to expand the Max Planck system into former East Germany, and Ehlers felt that an institute in Potsdam, near Berlin, would not only make sense scientifically but would also finally allow Germany to make a visible and practical repudiation of the Nazis' personal vilification of Einstein, which had driven Einstein away from Berlin and Germany and had completely stopped relativity research in Germany. He used his scientific prestige to open political doors, and the result was the opening in 1995 of the AEI in Potsdam.

His vision for the research scope of the AEI showed again his perceptiveness and interest in relativity as a whole, even in work that was far from his own research. He wanted all of relativity under one roof: astrophysical research into black holes and gravitational waves, mathematical research to keep providing rigorous answers to questions raised by astronomical discoveries, and research designed to lead finally to a quantum theory of gravity, the goal that had motivated the revival of relativity in the 1950s and which even today is still not met. Today the AEI actually has two roofs: its theory branch in Potsdam/Golm, and its experimental branch in Hannover, which operates the GEO600 gravitational wave detector and plays a key role in the development of future detectors on the ground and in space. Employing two hundred staff, hosting a further two hundred scientific visitors each year, housing some of the world's fastest supercomputers, operating the GEO600 detector, hosting numerous conferences and workshops, publishing its own scientific journal and editing others, the AEI amply justifies Ehlers' initial vision that relativity best makes progress by keeping all its sub-fields connected and in communication.

In recent years Ehlers spent more time pursuing his life-long interests in the history of science and the meaning and importance of science to society. He engaged in public debates and wrote numerous articles. He strongly believed that rational thought and the scientific process were key ingredients of a civilized society, but he wanted society to understand the process as a human one, as an ongoing search for an ever deeper reality rather than as a way of manufacturing "laws" written in stone.

Naturally, Jürgen Ehlers won many honours in his lifetime: the Max Planck Medal from the German Physical Society in 2002, the Volta Gold Medal of Pavia University in the "Einstein Year" 2005, and recently the Chancellor's Medal of Charles University in Prague (2007). He was a member of Berlin-Brandenburg Academy of Sciences, the Mainz Academy of Sciences and Literature, the Leopoldina, and the Bavarian Academy of Sciences. In 1995 his scientific colleagues elected him President of the International Society for General Relativity and Gravitation for three years. But despite these honours and his considerable influence, Ehlers will be remembered by those who knew him as a modest man and a gentleman, a mentor who led by his example and by his deep scientific insight, a leader who always showed respect for his colleagues and co-workers.

Jürgen Ehlers will be deeply missed by his scientific colleagues, and of course incomparably more by the family he left behind: his wife Anita, his children Martin, Kathrin, David and Max, and five grandchildren.

The directors of the Albert Einstein Institute

## Geometric Analysis and Gravitation

The department "Geometric Analysis and Gravitation" is concerned with the physical concepts and mathematical models that allow the description of space and time and gravitational phenomena. The methods employed come from differential geometry, the theory of nonlinear partial differential equations and numerical analysis with a special emphasis on Einstein's field equations in General Relativity. During the last few years the department has evolved and expanded in several ways: Traditional areas of strength have been continued such as the research in cosmology, on asymptotically flat models for isolated gravitating systems and on the interaction of matter fields with gravity. In numerical relativity new themes have been investigated where progress in the mathematical analysis can add to the understanding of computational issues, the collaboration with numerical astrophysics has been intensified through joint projects and joint appointments. New research directions have been taken up in areas of theoretical mathematics that underpin General Relativity, such as geometric variational problems as well as deformations of metrics and submanifolds. These new lines of research have also led to an increasingly close collaboration with the section "Quantum Gravity and Unified Theories".

### Co-operations and institutional support

Close scientific connections have been continued and newly developed with the other divisions at the AEI and to the nearby Universities in Berlin and Potsdam. This has been achieved at the individual level through the appointment of scientists with overarching research interests and at the institutional level through the creation of and participation in collaborative research structures (International Max Planck Research School "Geometric Analysis, Gravitation and String Theory", Special Research Center "Space-Time-Matter" of the German Research Foundation DFG, Berlin Mathematical School in the DFG "excellence initiative"). The intensified collaboration has led to exciting new research projects and has been instrumental in attracting excellent scientists both at the senior and junior levels, leading in particular to an increased number of PhD students. Particular examples are the collaboration of M. Ansorg and L. Rezolla in numerical relativity, joint workshops and PhD supervision with Potsdam University (C. Bär, Differential Geometry) and with Free University Berlin (K. Ecker, Analysis) as well as a joint project of H. Nicolai and G. Huisken on membranes in the DFG research center "Space-Time-Matter".

The work of the department has greatly benefited from the recent completion of the extension building at the AEI, bringing the projects in numerical analysis back into close proximity with the other scientists of the institute and offering crucial office space for visitors. The guest program of the institute, the Leibniz program and the external funding sources allow us to continue close national and international collaborations with many other groups of scientists. Extra funding by the Max Planck Society allowed the establishment of a partner group in Cordoba, Argentina, led by S. Dain. The Humboldt Senior Research Prizes to L. Simon, A. Ashtekar and J. Bičák also greatly boosted the scientific activities at the department.

### Members and visitors

During the last few years, many young scientists have left the division for more senior positions elsewhere. It is fortunate for our division that after the retirement of B. Schmidt, A. Rendall has accepted a W2-Professorship at the division, turning down a W3 position elsewhere. The joining of R. Bartnik as an external scientific member and the appointment of L. Andersson as a (visiting) professor have strengthened our division greatly. The visit of M. Choptuik strengthened the numerical expertise of the division in a direction that is exciting for both the mathematically and the physically inclined scientists of the institute.

Members of the division have taught many courses at universities, at the International Max Planck Research School or at special events such as the annual vacation course. They participated in the organization of several international conferences and workshops. In the following we describe research directions that have been of particular interest in the last two years and provide some visions for future research.

**Research directions**

The research group in Geometric Analysis has expanded with a particular view towards a large spectrum of geometric evolution equations. A key role is played by the Einstein equations, a hyperbolic system of quasilinear evolution equations exhibiting an overwhelming range of phenomena in its solutions. They are related in various ways to many other quasilinear hyperbolic, elliptic and parabolic equations such as the vanishing mean curvature equation for the worldsheet of d-branes, the Hamilton-Ricci-flow for evolving Riemannian metrics, the Yamabe-flow of conformal deformations, the mean curvature flow and the inverse mean curvature flow of hypersurfaces. The structure and properties of solutions to these flows has been thoroughly investigated with results on their existence and regularity, their asymptotic behavior and on the structure of possible singularities. Longterm goals are a precise geometric understanding of initial data sets for the Einstein equations, of horizons of black holes in space-times and of isoperimetric inequalities that can be established via geometric flows.

Several projects are concerned with efforts to control qualitative and quantitative properties of solutions to Einstein's field equations that describe particular physical phenomena, an effort which will still play a central role in mathematical relativity in the years to come. The goal is to obtain an overview over physically and conceptionally important features of specific solutions, such as their radiative characteristics, the development and structure of singularities and horizons, etc. Moreover, properties of the solution manifold such as the stability behaviour of these phenomena and the existence of an inherent principle of 'cosmic censorship' need to be understood. Working out these properties necessarily goes hand in hand with identifying the structural aspects of the field equations which control them. The results obtained depend on the physical situation which is to be modelled. While large part of the work in the department refers to asymptotically flat solutions, cosmological solutions are considered as well and often the coupling of the Einstein equations with matter models plays an important role. Moreover, analytical studies are complemented by numerical investigations. While a large part of the present numerical efforts is concerned with pragmatic approaches to the two black hole problem, they also deal with principal questions concerning the use of analytical and numerical methods as complementary tools for the analysis of space-times. The power of this combination has been demonstrated by earlier successes, but its enormous potential remains to be exploited.

Higher dimensional models of gravity constitute one of many subjects of investigation that illustrates the close interaction between physical concepts and analytical and geometrical mathematical methods. New insights in string theory, as well as purely mathematical considerations, have led to intense work on higher dimensional solutions of the Einstein equations. These developments established higher dimensional gravity as an important field of its own and inspired the study of new mathematical structures. Among the new phenomena which have been explored are higher dimensional black holes, which turn out to have a rich geometrical and topological structure, and also give rise to interesting new dynamical problems that have to be understood from an analytical point of view. Further, ideas from string theory including brane worlds have inspired studies of higher dimensional cosmological models and their dimensional reduction. These studies have encountered a rich variety of phenomena such as inflationary behavior and accelerated expansion, related to intricate analytical properties of solutions to the governing differential equations.

Two specific research themes, geometrical variational problems and numerical studies in relativity are highlighted in special reports on pp. 37 and pp. 40.

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 we detect them and how they are generated by black holes and neutron stars. Within the GEO project, scientists at AEI/Golm work with their colleagues at AEI/Hannover and our partners elsewhere in Europe and the USA as part of the LIGO Scientific Collaboration (LSC), which analyzes the pooled data taken by the three large LIGO detectors in the USA and the GEO600 detector operated by AEI/Hannover, and which joins with the Italian- French Virgo project to perform a joint analysis including their data as well. As is reported elsewhere in this volume, the large LIGO and Virgo detectors are currently (end of 2007) being upgraded in sensitivity, and they will be upgraded again in three years, increasing their reach in space by a factor of more than 10.

Some of our scientists work with large supercomputers and with the Einstein@Home project (described in the report of Bruce Allen's division) to analyze the data that already exists and to prepare for even more sensitive searches in the future. Other 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.

Scientists at AEI/Golm are also increasing their activity in preparing for data from the LISA project, a joint space mission of the European Space Agency and NASA. LISA will be the most sensitive gravitational wave detector ever operated, and the analysis of its data presents special challenges.

### Numerical studies in general relativity

The report by Luciano Rezzolla (p. 46) describes the work done by the numerical relativity group, which performs supercomputer studies of black holes and neutron stars. Both of these kinds of objects are endpoints of the evolution of massive stars, and the normal processes of stellar evolution sometimes form binary systems containing two such objects in orbit around one another. Under the right conditions, the two objects might be formed in such a tight orbit that the loss of energy to the gravitational waves emitted by their orbital motion will gradually bring them closer and closer together, until they spiral together and merge. During the last few thousand orbits, taking a few minutes, the gravitational wave emitted by such events might be detectable by the upgraded LIGO and Virgo detectors dozens of times per year. The aim of the numerical simulations is to be able to provide “template” signals to guide the searches for these events, and then to be able to interpret the physics of the actual mergers by comparing the detected signals with the simulations.

The goal of colliding inspiralling black holes has been pursued by scientists all over the world for more than thirty years, and previous annual reports from the AEI have given progress reports on how the research was going. Scientists have systematically surmounted one difficulty after another, removing numerical instabilities, choosing the right coordinate conditions and formulations of Einstein’s equations, implementing memory-saving techniques like mesh refinement, and experimenting with different ways of isolating the infinitely strong gravitational fields at the center of the black holes (the so-called singularities) from affecting the computational domain. The AEI’s Cactus Computational Framework allowed scientists around the world to pool their expertise and the successful solutions, gradually assembling pieces of the overall solution. But still the goal remained elusive: it was difficult to simulate two black holes merging if one started more than one orbit before the merger, which was not a long enough time to extract real physical information.

During the last couple of years, the field has finally experienced its breakthrough. Former AEI scientist Bernd Brügmann, then at Penn State University and now at Jena, became the first to model more than a single orbit. Frans Pretorius, working at Caltech (now at Princeton) with a code that was entirely of his own construction, then performed a simulation in which two black holes orbited around one another several times before smoothly merging. Finally, two further groups found a way to do even longer simulations more efficiently: one group was led by former AEI scientists Manuela Campanelli and Carlos Lousto, then at the University of Texas at Brownsville (and now at Rochester Institute of Technology); the other group, led by Joan Centrella at NASA Goddard Spaceflight Center, also contained two former AEI scientists, John Baker and Michael Koppitz. The technique both groups independently devised was an adaptation of the “puncture” method for representing black holes numerically, which had been invented by Brügmann and Steve Brandt at the AEI a decade ago but had up to this point been applied only to non-moving black holes. The technique works beautifully, and now allows simulations to remain stable and accurate even while performing ten or twenty orbits before merger. All the techniques patiently assembled over many years by these scientists and many others are still being used: the “breakthrough” was in finding the last piece of the puzzle, the final technique that would work with all the others and enable long-duration simulations.

The breakthrough has led to greatly increased activity in this field. Scientists are exploring parameter space, looking for new physical effects (like the kicks that are given to the final black hole by the asymmetric emission of gravitational radiation), incorporating the gravitational wave predictions of these simulations into search algorithms for gravitational waves, and adapting these techniques to studying the more complex physics when neutron stars merge with each other and with black holes. The AEI activity in these areas, much of it world-leading, is described in the articles by Luciano Rezzolla (p. 46) and Badri Krishnan (p. 53).

### Data analysis for ground- and space-based detectors

By the end of 2007, the LIGO and GEO detectors had completed the so-called S5 data run, which accumulated a total of more than a year of data during which at least three of the four detectors were taking data at the same time. The Virgo detector joined into this run in its last 6 months, providing further sensitivity. Although the large detectors are now being upgraded, while the GEO600 and smaller LIGO detector monitor the sky in "Astrowatch" mode, the analysis of the S5 data is far from complete.

AEI scientist Maria Alessandra Papa is the overall data analysis coordinator for the LSC, and jointly leads the combined analysis of LSC and Virgo data. During the period covered by this report she also led the LSC's data analysis team that specifically searched for long-duration gravitational wave signals from spinning neutron stars. Among other accomplishments, this group has set new strong limits on the symmetry of the neutron star in the Crab Pulsar, from the fact that an exceptionally sensitive observation of this pulsar has not detected any gravitational waves. In her report (p. 43), Dr Papa describes the AEI's role in this activity, and the scientific significance of the results obtained so far.

Scientists in the gravitational wave group also prepare for future observations. The report by Krishnan, already referred to above, describes how the numerical simulations of black hole mergers will improve the sensitivity of future searches. The group is also devising more and more efficient methods for using its supercomputer resources to do deep searches for spinning neutron stars where no radio pulsars are known.

The most dramatic preparations for future searches are taking place for LISA. LISA is one of the most important space missions of the next decade, a collaboration between the European Space Agency (ESA) and NASA in the USA. It is currently planned for launch in 2018, but intensive work on the project is already going on at the AEI and elsewhere. AEI/Hannover is a principal contractor for the LISA precursor satellite LISA Pathfinder, which is described elsewhere in this report. At AEI/Golm we have for the last several years played a leading role in the development of data analysis methods for the future project. Although data analysis for LISA will draw on the experience of the ground-based gravitational wave detectors (the LSC and VIRGO), there are special challenges that come from the extremely high sensitivity we expect LISA to have.

Since gravitational wave detectors continuously record all the waves encountering the detector from all directions, LISA will have to disentangle a confusion of superimposed signals. The challenge will be to separate them and study them individually. Only with a robust signal analysis system that can separate expected and unexpected signals can LISA fulfil its scientific potential. The Astrophysical Relativity Division is putting more and more activity into LISA studies, supported by a new grant from DLR, the German space agency. The report by Stanislav Babak (p. 49) describes this emerging field of research.

Bernard F Schutz

## Quantum Gravity and Unified Theories

As in previous years, work in the division Quantum Gravity and Unified Theories has concentrated on two main topics, 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. Such a unified theory should encompass the well-established standard models of elementary particle physics and of cosmology. Because of the unresolved conceptual and mathematical difficulties that must be overcome, the division aims to represent the major approaches, most notably superstring and M-Theory on the one hand, and canonical approaches (canonical and loop quantum gravity) on the other. In fact, AEI is one of the few institutions worldwide in which both approaches are pursued at an equally high level, and at which there exists a significant "interdisciplinary" exchange between these competing approaches. Since at this time there is no clear favourite among the different candidate models that have been proposed, the strategy of our division is thus to keep all viable options open, and to encourage diversity in pursuing the scientific goals. This diversity is also helped by the close collaboration that exists with the Geometric Analysis and Gravitation division on topics of common interest, in particular the theory of relativistic (super-)membranes.

### Main research areas of scientific work

Presently, the approach to quantum gravity that has the most adherents within the scientific community is superstring theory, with its extensions supermembrane and M(atrix) theory. It is a descendant of modern particle physics, but where particle theories run into insurmountable problems in the description of gravity, string theory proposes a radical modification at short distances: In this theory, the fundamental building blocks are not point-like particles, but one-dimensional extended objects called relativistic strings (or, if fermions are included, superstrings) or even supersymmetric extended objects with two spatial dimensions, called supermembranes.

What makes the theory a compelling candidate for a unified theory is the identification of quantized excitations of the relativistic strings with the different point-particles of conventional quantum field theory - in this way, the bewildering diversity of matter particles and interactions in the standard model of particle physics could be reduced to the physics of just one truly elementary constituent, the string. Also, in any string theory containing closed strings, this particle spectrum will contain a massless spin-two particle, whose self-interactions coincide with those of Einstein's theory at the lowest non-trivial (cubic) order. This is the base of string theory's claim to being a theory of quantum gravity. Still, while superstring theory is currently the only ansatz that succeeds in removing the inconsistencies of perturbatively quantized general relativity, the connection with real physics is still far from clear. The main task facing string theorists today is to find a non-perturbative formulation of the theory (which is sometimes dubbed M Theory). This problem, together with its many ramifications, has defined one of the main and most successful areas of activity of the Division.

A very different approach to finding a theory of quantum gravity is canonical gravity, or more specifically, Loop Quantum Gravity. Here, the aim is to find a background independent theory of quantum general relativity by directly implementing the basic principles underlying Einstein's theory, thus avoiding problems faced by perturbative approaches like string theory. Just as the absence of background structures in Einstein's classical theory of general relativity has forced physicists to re-think age-old and cherished notions of space and time, the attempts to quantize geometry without reference to any specific spacetime background have led to completely new ideas about the structure of space and time at very short distances. Much of the groundbreaking work in this field over the past few years has been done at AEI. Most recently, the formalism has been applied to cosmology, where it has spawned an entirely new field of research now called Loop Quantum Cosmology. During the last year, this has become one of the most active fields of research at AEI. However, true to its aim of fostering diversity, AEI researchers have been involved in other aspects of canonical gravity as well, in particular in the physics and mathematics of classical and quantum gravity in (2+1) spacetime dimensions.

Over the past two years, significant progress has been made on many fronts. There is no room here for a complete list of results and achievements, but the following deserve to be mentioned in particular:

- The AdS/CFT correspondence has been further developed to the point where there exists a consistent interpolation between the weakly and strongly coupled regimes of both gauge theory and string theory. The results obtained by AEI researchers (such as the so-called “BES equation” derived at AEI yielding the above interpolation) have established AEI as an international leader in this very competitive research area, and for the first time bring within reach a full proof of this correspondence.

- Progress in loop quantum gravity concerns in particular work towards a rigorous formulation of the theory with the aim of properly defining and implementing the hamiltonian constraint. The latter is the central problem of and the key to understanding canonical quantum gravity, and its underlying physics. Yet another aspect of the canonical quantization program, and also a topic of interest in pure mathematics, the theory of 3-manifolds, is reviewed in the accompanying article by D. Giulini (p 56).

- Searching for a unification of all interactions is almost synonymous with the search for a fundamental symmetry of nature. A very promising candidate is the hyperbolic Kac Moody algebra E10. Over the last two years it has been possible to understand many features of this still most enigmatic mathematical object and their implications for supergravity and unification. A noteworthy advance in this program was the extension of previous results to fermionic degrees of freedom.

- Much progress was also made in more traditional areas of string theory research, for instance in string field theory (a scheme extending standard quantum field theory methods to string theory). A very active area of research concerns D branes and boundary conformal field theories described in the overview article by S. Fredenhagen (p. 59). These are not only of interest in order to understand the non-perturbative sector of string theory, but also for model building to establish contact with the standard model of particle physics.

Hermann Nicolai

## Laser Interferometry and Gravitational Wave Astronomy

During the last two years, routine 24 hours science data taking has begun at all large gravitational wave detectors in the world including GEO600. The last two years were dominated by the fifth LSC data taking run (S5) in coincidence with three LIGO detectors. From January 21st, 2006 onwards, the GEO600 detector has participated in this data taking activity. Three full time operators were hired and are now responsible for routine maintenance and operation of GEO600, leaving more time for the scientists for detector characterization and performance improvements. Around its sensitivity maximum above a few hundred Hertz GEO was within a factor of three of the LIGO Hanford 2 km detector. During science operation an overall instrumental duty cycle of about 95% was achieved. After a strategic decision within the LSC on October 17th, 2006, GEO was put into night and weekend data taking, to enable investigations necessary for future detector operations. Data analysis of the S5 data run is currently going on while the large interferometers LIGO and Virgo are being upgraded to the enhanced state with twice the sensitivity to go online in 2009 as an intermediate step towards the Advanced detectors in 2014. During the upgrade time, GEO600 is in Astrowatch mode in 24 hour operation with minimal time used for detector characterization and improvement.

AEI will provide the pre-stabilized laser systems for the Enhanced LIGO and Advanced LIGO gravitational wave observatory as a contribution to LIGO and has been granted subsystem responsibility for this system. The necessary power stability of the lasers is a very stringent requirement for advanced interferometers. We have been able to improve our results down into the low $10^{-9}$ range over the complete ground-based gravitational wave detection band, setting a new record for power stability achieved anywhere.

Planning for third generation observatories (like the Einstein Gravitational Wave Telescope E.T. in Europe) has commenced and the research for these observatories, in particular the use of non-classical states of light, has made tremendous progress. At the end of 2007, a Design Study for E.T. was approved by the European Commission in the FP7 program to commence in summer of 2008. Thermal noise and thermo-refractive noise in test masses and suspensions are a major noise source in advanced gravitational wave detectors. Over the last two years, we have, in collaboration with Jena, been able to demonstrate Fabry-Perot and Michelson interferometers with total losses of less in 2000 ppm, using all-reflective cavity couplers and beam splitters based on Diffractive Optics. Non-classical states of light are expected to be important ingredients of future generations of gravitational wave observatories. Over the past two years we have been working on the generation of significant amounts of squeezing in the audio detection band of ground based gravitational wave detectors and of possible control schemes for such delicate states of light. We have now demonstrated a completely coherent control scheme for squeezed vacuum states that avoids control fields near the signal frequency and the corresponding contamination with classical laser noise. By carefully removing all parasitic interferences from scattered light, we have now been able to push the lower frequency limit of squeezing down to

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 University of Hannover. The MPG committed to provide stable research funding for both of the planned divisions and the University agreed to provide a new building with 4000 $m^2$ of lab and office space, equipped with basic scientific inventory.

way below 10 Hz for broadband squeezing extending to above10 MHz. We obtained a new record of 10 dB of vacuum squeezing, that, applied to a gravitational wave observatory, would provide a high frequency sensitivity improvement equivalent to 10 times larger circulating laser power, but without the corresponding thermal load.

The LISA space mission for low-frequency gravitational wave observations has been in the mission formulation phase of its lifecycle during the last two years and has just been unanimously approved as first large L1 mission candidate in the ESA Cosmic Visions program for a launch in 2018. We have intensely participated in all aspects of the mission formulation together with ESA, NASA and EADS Astrium. In particular, we have accompanied paper studies by laboratory breadboarding experiments, concentrating first on critical components, with the goal to bring them all together in the next stage. A unique laser characterization laboratory allows us to test all features of laser systems relevant for LISA. Fundamental limitations of the photodiodes and amplifiers have been identified and a breadboard design has been developed that operates near these limits and exceeds the LISA requirements. For the phasemeter, we have built a prototype based on fast analogue-digital conversion and Field Programable Data Array hardware that forms the basis for ongoing experiments on multifrequency operation, laser ranging and data transmission. We have also demonstrated the necessary offset phase lock for LISA and are currently testing nonreciprocal optical noise in optical fibers and the picometer-level stability of angular actuators.

The LISA Pathfinder technology demonstration space mission has transitioned from planning into the production and testing of flight hardware. Over the last few years we have begun to prepare for LISA Pathfinder operations. In particular we have started to write data analysis software to be used in real time after launch. This comprises both algorithms software in software, that will developed in use with the real data from the interferometer prototype from the very beginning.

A new space related activity for AEI has developed over the last few months and that is the application of precision interferometry to satellite geodesy missions. Previous geodesy missions like GRACE have produced spectacular results about the structure and time variability of the earth gravity field, using microwave techniques for the intersatellite ranging. Exactly those technologies developed for LISA and LISA pathfinder, i.e. drag free control and inter-spacecraft laser interferometry, are perfectly suited for follow-on missions with greatly improved resolution. We at AEI have begun to study the interferometry aspects of such a mission in collaboration with the Geodesy department of the Leibniz Universität Hannover.

Karsten Danzmann

## Observational Relativity and Cosmology

The most important research area of this new AEI Hannover Division is the development and implementation of data analysis algorithms to search for the four different expected types of sources (burst, stochastic, continuous wave, and inspiral) in data from ground-based gravitational wave detectors. As part of an international data-sharing collaboration, group members currently have full access to data from the most sensitive five detectors instruments available (3 x LIGO, 1 x Virgo and 1 x GEO). This access to the world's best data will continue in the future through several international collaborative data-sharing agreements.

Searches for weak gravitational wave signals are very compute-intensive. In some cases, the lack of computing resources makes the searches substantially less sensitive than would be possible using the same experimental data, but with infinite computing power. For this reason, two of the major projects within the Division during 2006 and 2007 were directed towards increasing the computing power available for such searches.

### ATLAS Computing Cluster

The ATLAS Computing Cluster is a dedicated computing facility, which provides very large numbers of compute cycles for data-intensive processing. It is number 58 on the Top-500 list of the world's most powerful computers, and is the sixth fastest computer in Germany. ATLAS is described in more detail in the Research Highlights Section of this report (see p. 71).

### Einstein@Home

The Einstein@Home project is a volunteer distributed computing project, organized in the same way as the famous Seti@Home search for extra-terrestrial intelligence. Members of the public sign up for Einstein@Home and donate computer time on their home and office PCs. If it were listed on the Top-500, Einstein@Home would be one of the ten most powerful computers in the world. Einstein@Home is also described in more detail in the Research Highlights Section of this report (see p. 72).

### LISA Pathfinder data analysis system

The Division has the lead responsibility to deliver the data analysis system for the upcoming LISA Pathfinder satellite mission, scheduled for launch in 2010. LISA Pathfinder will demonstrate the key new technology elements needed for the LISA low-frequency gravitational wave detector described elsewhere in this report. The LISA Pathfinder data analysis system will be used to carry out the day-to-day analysis of data from LISA Pathfinder. It is a complete GUI-based integrated analysis system (GUI = Graphical User Interface) which uses a central database as a repository for all code and data structures. This system allows analysis pipelines to be designed by 'hooking together' graphical analysis elements. The output from any analysis (including raw and reduced satellite data and analysis code) can then be used an input for further analysis. This capability is extremely important because the experimental program of LISA Pathfinder takes place over a period of less than a single year, and is not entirely determined in advance. The experiments carried out in a given day or week are instead 'steered' by the results from previous days and weeks of investigation. Hence the data analysis system has to provide a high degree of flexibility and integration.

### New template placement methods

An common feature of many gravitational wave searches is that they use a 'bank' of templates to search for different waveforms. The optimal way to create such a bank (where to place the grid points in parameter space) has been an important research topic during the past decade. Particularly when the dimension of the parameter space is large, the optimal solution to this problem is not known. Recent theoretical work in the Division proposes a new Monte-Carlo like method that places templates at random in parameter space, but with a density controlled by the metric that describes the distance between templates in terms of putative loss of signal-to-noise. The work characterises the resulting template bank, and shows that it can achieve nearly-optimal coverage. Moreover, by sacrificing a controlled fraction of the coverage, for example by only covering 95% of the parameter space, these random template placement methods can achieve results that use significantly fewer templates than the minimum number needed for 100% coverage. A very complete theoretical characterization of the statistical properties of these random template banks has now been carried out, and these random template banks are now being used for some of the searches underway in this Division.

### Binary inspiral searches

Prof. Sukanta Bose from the University of Washington (USA) spent a sabbatical year at AEI Hannover working with students and postdocs on techniques and code to carry out a fully-coherent binary inspiral search, optimally combining data from the three LIGO detectors, the GEO600 detector and the Virgo detector. Bose has been working on these methods for several years, and during his year at the AEI, the work reached fruition and was incorporated into the standard LSC binary inspiral analysis pipeline. Related work at AEI Hannover included the development of improved Markov-Chain Monte-Carlo (MCMC) methods. These methods can be used to give the best predictions of the parameters of detected astrophysical systems, such as masses, inclination angles, polarizations and arrival times. In particular, the combination of the MCMC methods with the coherent filtering will enable the most accurate post-detection characterization of systems, providing Bayesian probability distributions of the parameter-space values. Other ongoing work includes the incorporation of waveform catalogues from Numerical Relativity simulations, described elsewhere in this report, into the binary inspiral search pipeline.

### Continuous wave searches

About a decade ago, seminal work by Schutz and his collaborators determined the optimal statistic (called the F-statistic) to use in searching for Continuous Wave (CW) sources. Recent work in the Division has provided new insight into the global parameter space structure in the maximum of the F-statistic. This in turn suggests new improved methods of searching for CW signals, which take advantage of these global correlations to reduce the number of points in parameter space that need to be searched. Work is currently underway on a new Correlation Statistic, which makes use of this global correlation structure. This could potentially replace current Hough and stack-slide incoherent search methods, providing greater sensitivity at lower computational cost. Improved understanding of these global correlations also leads to new methods of vetoing instrumental lines and artefacts, whose global correlation structure does not agree with that which is expected for a real astrophysical source.

### Expected signals from gravitars

For a uniform population of neutron stars whose spin-down is dominated by the emission of gravitational radiation (called 'gravitars') an old argument of Blandford states that the expected gravitational-wave amplitude of the nearest source is independent of the deformation and rotation frequency of the objects. Recent work in the Division has improved and extended this argument to set upper limits on the expected amplitude from neutron stars that also emit electromagnetic radiation. The results are also being used to design an Einstein@Home search for gravitars in LIGO data.

Bruce Allen

## Duality and Integrable Structures

This independent junior research group was newly established in August 2006. Niklas Beisert, the author of this overview article, returned to Potsdam from an assistant professorship at Princeton University in order to lead the group. The group is funded by the Max Planck Society with an initial duration of 5 years. Its research focuses on the integrable structures that have recently been identified in gauge and string theories. The aim is to deepen our understanding of these models on which classical and modern particle physics is founded.

### Main research areas

The main research topic of the group is the integrable structure which has been found in the context of string/gauge duality. Integrability is a hidden symmetry which can be found in some theoretical physics models and which vastly simplifies the exact determination of their spectrum and other observables. For example, interacting four-dimensional gauge theories like QCD are usually accessible only by perturbative methods (using Feynman graphs) or approximate numerical methods (such as lattice gauge theory). In integrable models – like planar N=4 maximally supersymmetric gauge theory – specialised methods (e.g. the Bethe ansatz) provide a window to exact results at finite coupling strength.

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. Therefore the precision of feasible computations is limited. In some cases, this has changed in the recent couple of years with the discovery of integrable structures in gauge theories. Making use of methods related to integrable spin chains, such as the Bethe ansatz, we can now perform computations efficiently with a high precision. Research in this group centres on investigating and applying these integrable structures.

In this context the maximally supersymmetric (N=4) gauge theory plays a central role. In 't Hooft's planar limit strong evidence for complete integrability was found. Furthermore, we have proposed Bethe equations which have deepened our understanding of this model. The main motivation for studying N=4 gauge theory is tied to string theory. It is part of the key example for a gauge/string duality and the conjectured AdS/CFT correspondence. This duality is also one of the subjects being investigated in the Quantum Gravity & Unified Theories division of the institute with which close collaborations exist. Applying integrability has led to many new insights into the duality. Members of this group have contributed to establishing the integrable structures in N=4 gauge theory and its string theory dual as well as to the comparison of both models.

Our understanding of integrable structures in these two types of models is far from complete. A goal of the group is to put the recently found powerful methods onto firm ground and to extend their range of applicability. We would also like to contribute to a better understanding of how the structures relate to earlier results in integrable models. These were obtained mainly in the context of condensed matter physics where spin chain models are used to describe aspects of ferromagnetism and superconductivity. We hope that we can improve this exciting connection between condensed matter and particle physics.

## Achievements

A first aim for the research group was to gain full strength in 2007. To that end two experienced junior researchers, A. Agarwal and T. McLoughlin, have joined in Autumn 2007. Furthermore, three students have started their studies within the group: one doctoral student, one diploma student continuing as a doctoral student and one exchange student from Russia who is working towards his master degree.

The young group has already received excellent recognition by the scientific community: The group leader has been awarded by the European Physical Society with the prestigious 2007 Gribov medal for his work on integrability properties of a four-dimensional quantum field theory. Furthermore a Sloan Research Fellowship was granted by the Alfred P. Sloan Foundation. The results obtained by the group were presented at international conferences such as the Solvay Workshop to celebrate the 75 anniversary of the Bethe Ansatz, at Strings 2006 in Madrid, at the 12th Itzykson Meeting in Paris as well as at several others. Lecture series for graduate students were given at a string school in Saalburg, a school of the EU MRTN Network ENIGMA and at the Isaac Newton Institute in Cambridge.

A major scientific event during the period under review was the "Workshop on Integrability in Gauge and String Theory". It was hosted by the AEI Potsdam on July 24-28, 2006 and organised by the group leader and Matthias Staudacher (Quantum Gravity and Unified Theories division). It brought together physicists from several different disciplines, and it was unanimously regarded as highly inspiring. Follow-up conferences took/take place in Paris and Utrecht in 2007 and 2008. See page 85 for more details.

## Research highlights

The research performed by the group can be grouped into three main topics:

Perhaps the most important project dealt with the formulation of the "worldsheet" scattering matrix of AdS/CFT. We have proposed an exact expression which interpolates smoothly between string and gauge theory and which has since passed many consistency tests. For explanations and more details, please refer to the research highlight at page 74.

The key to deriving the aforementioned S-matrix were symmetries. In several publications we have made good progress in understanding its symmetries and their mathematical formulation in terms of bi- and Hopf algebras. The goal of this research is to extend the integrable system toolkit to this very special system where they are still lacking. This is not only relevant to the context of string theory and high energy physics, but also for condensed matter theory: Namely, we were able to show that, curiously, the S-matrix also provides the integrable structure to the one-dimensional Hubbard model. In the two-dimensional version the latter is a key model in studies of superconductivity.

The third project is again of relevance not only to string/gauge theory but potentially also to condensed matter physics. It concerns the Heisenberg spin chain – a basic model of magnetism. In the antiferromagnetic regime this system has been studied thoroughly already, but not so in the ferromagnetic regime. This regime is important to string theory because the spin chain states describe spinning string configurations. Together with the diploma student T. Bargheer we have derived a large class of such states and used it to study the issue of stability with respect to quantum fluctuations. Although some states are unstable, we have found that the instabilities do not lead to inconsistencies. Our work shows concretely that instead there exist a state with lower energy to which the unstable states can decay to.

Niklas Beisert

## Rotating Stars and Black Holes in General Relativity: Unexpected Features of Simple Configurations

### Introduction

Einstein's theory of general relativity is one of the most beautiful and powerful conceptions in modern physics. It combines differential geometric structures with the physical reality of gravity. Since the discovery of the black hole at the centre of our galaxy in 2004, general relativity has deepened its fundamental role in astrophysics.

As a particular application of relativity we consider figures of equilibrium of rotating, self-gravitating fluids. This field of research is motivated by astrophysics: neutron stars are so compact that Einstein's theory of gravitation must be used for calculating the shapes and other physical properties of these objects. The corresponding theory was developed in the context of questions concerning the shape of the Earth and celestial bodies. Many famous physicists and mathematicians have contributed, among them Newton, Riemann, Poincaré and Chandrasekhar. Within Newton's theory of gravitation, the shape of the body can be inferred from the requirement that the force arising from pressure, the gravitational force and the centrifugal force (in the corotating frame) be in equilibrium.

### The free boundary value problem

The basic mathematical task to be solved for equilibrium fluid figures in general relativity is given by a specific free boundary value problem of the stationary and axisymmetric Einstein equations. These symmetries – stationarity and axisymmetry – are described by appropriate Killing vector fields defined on the space-time manifold. Writing the line element in coordinates that are adapted to the Killing vectors, the Einstein equations yield a system of coupled elliptic differential equations for four metric potentials. The entire geometric structure of the space-time manifold is contained in these metric potentials. They determine the physical reality such as the structure of electromagnetic fields and the motion of particles.

In the interior of the fluid body, the Einstein equations are subject to specific source terms of the gravitational field and differ therefore from the vacuum field equations that are valid outside. Nevertheless, it is possible to introduce coordinates globally such that all metric potentials are continuous and differentiable at the fluid's surface. In choosing these coordinates, one obtains transition conditions to be satisfied by all metric potentials. The corresponding numerical schemes (described below) are specifically tailored to the careful treatment of these transition conditions. However, the shape and location of the surface is not given beforehand, but is determined by the requirement of vanishing pressure. Thus a free boundary value problem arises. The mathematical problem is completed by fall-off conditions at infinity that ensure asymptotic flatness of the solution.

### Numerical treatment

The numerical scheme to solve the above free boundary value problem is based on a so-called multidomain spectral technique, in which – similarly to the splitting up of light into elementary components in spectroscopy – unknown functions are written in terms of a sum of specific basis functions (here we use Chebyshev polynomials). The key idea is the introduction of several regions which cover the entire spatial domain such that in each of these regions all metric potentials are analytic functions with respect to appropriately chosen coordinates. These subdomains do not overlap, but rather possess common boundaries along which all metric potentials are differentiable. In order to realize the spectral representation of the potentials, each subdomain is specifically mapped onto a square (of unit side length). The mappings used are similar to the introduction of spherical coordinates through which the interior of a shell is obtained as the image of a rectangular region on which the spherical coordinates are defined. Likewise, the exterior of a shell can be described as an image of a rectangular region by introducing *compactified* spherical coordinates.

However, since the fluid's surface shape is not known beforehand, an associated unknown one-dimensional function is also involved in these coordinate mappings. This function as well as all metric potentials are written in terms of a truncated series of Chebyshev polynomials with respect to the coordinates defined on the squares. Einstein's field equations together with transition, boundary, regularity and asymptotic fall-off conditions yield a complete set to determine all spectral Chebyshev coefficients. The solutions are obtained iteratively using the so-called Newton-Raphson scheme. However, some effort is needed to create a suitable "initial guess", i.e. some starting values for the spectral coefficients for which the scheme converges to a physically reasonable solution, which corresponds e.g. to a rotating star or to a two body system consisting of a central black hole and a surrounding fluid torus. We provide these data by interpreting the solution of a known configuration in Newtonian gravity as a weak relativistic limit. In this manner we gradually depart from Newton's theory and explore the strong gravitational regime of general relativity.

By the numerical method described above we obtain accuracies close to machine precision. This permits a detailed parameter study of the entire solution space containing the fluid configurations of a particular type of matter.

### Rigidly rotating and homogeneous fluid configurations: from spheroidal to toroidal topology

As a first application we investigate the solution space of uniformly rotating, homogeneous and axisymmetric relativistic fluid bodies. They represent first rough models for the description of strongly gravitating Neutron stars in astrophysics. It turns out that not all relativistic homogeneous and uniformly rotating configurations are connected parametrically to each other in a continuous way, but the solution space can be divided up into distinct classes. The corresponding picture contains familiar analytically known solutions: (i) the (inner and outer) Schwarzschild solution describing a nonrotating homogeneous star in a static space-time, (ii) the relativistic disc of dust solution and (iii) the so-called Maclaurin spheroids being the best known fluid bodies in Newtonian Gravity (Maclaurin 1742).

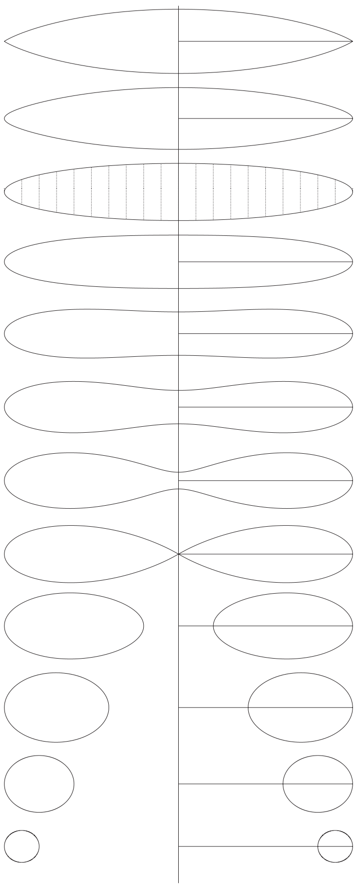


**Fig.1:** Transition of rigidly rotating and homogeneous fluid configurations from spheroidal to toroidal topology. Displayed are the meridional cross-sections of the corresponding surface shapes. The uppermost fluid body rotates at the mass shedding limit and the hatched shape corresponds to a particular Maclaurin spheroid.

Apart from these solutions the classes are characterized by further limiting cases: (i) a limit of strong rotation when the star starts to shed mass away from its equatorial edge (for which reason the star's surface shape develops a cusp there), (ii) a limit of infinite central pressure configurations and (iii) Newtonian limits which are different from the Maclaurin spheroids. A remarkable feature is the transition from spheroidal to toroidal topology of the fluid bodies (see figure 1). Even more striking is the observation that the toroidal configurations permit a continuous parametric transition to a maximally rotating black hole in vacuum (described by the so-called extreme Kerr solution).

### Black holes surrounded by fluid rings

In a further application of our pseudo-spectral scheme we study axially symmetric and stationary spacetimes containing a black hole surrounded by a torus of matter. It turns out that the matter ring can affect the properties of the central object drastically. If the torus is highly relativistic and quickly rotating, it strongly drags the surrounding space-time and the objects therein along its orbital motion. As a consequence, a central counter-rotating black hole can possess opposite signs of angular momentum and angular velocity. Surprisingly, a particular local mass parameter of the black hole – the so-called Komar mass – can then assume negative values. In this highly relativistic space-time the geometry in the vicinity of the black hole is deformed so strongly that it interferes with the positive intrinsic mass of the black hole and yields a negative Komar value.

As a rigorous analytic result we find that black holes, whose horizon geometry degenerates, possess a universal rotation rate. In particular, the ratio of the magnitude of the angular momentum to the horizon area is always $(8\pi)^{-1}$.[1] Further investigations, which are currently in progress, aim at proving that this constant is a general upper bound for arbitrary stationary and axisymmetric black holes surrounded by matter. As a consequence, even in the presence of matter, the black hole mass parameter introduced by Christodoulou and Ruffini shows the familiar properties known from the pure vacuum case (which is described by the famous Kerr solution): a black hole with given horizon area acquires more and more mass as the angular momentum is increased and assumes a final maximal mass in the maximally rotating limit when the horizon geometry degenerates.

Marcus Ansorg

[1] Here we use units in which the speed of light as well as Newton's constant of gravitation are equal to unity.

## Geometric Variational Problems

### Variational problems

Nature always extremizes action. Formulated in other words this *principle of least action* means that if there occurs some change in nature the amount of action necessary for this change must be as small as possible. Motivated by this principle the mathematical discipline *Calculus of Variations* was developed. There one tries to optimize various properties of a given problem. One of the simplest examples of such a problem is to find the curve of shortest length connecting two points. Another example is given by the famous *Brachistochrone problem.* It asks for the curve which is traced out by a point particle acted on only by gravity and which connects two given points in a vertical plane in the shortest amount of time.

### Minimal surfaces

A more difficult variational problem leads to *minimal surfaces*. These are surfaces which extremize area among all other surfaces. One way to visualize them is to dip a wire frame into a soap solution and then withdraw it. Minimal surfaces play an important role in both mathematics and physics.

When dealing with variational problems the first question which arises naturally is if there exists a solution of the problem at all. One way to rephrase this question in the case of minimal surfaces is as follows: Is it true that every "reasonable" wire frame can be spanned by at least one minimal surface? This mathematical question became widely known as the *Plateau problem*. The solution of this problem turned out to be extremely difficult and it was only solved eighty years ago by the mathematicians Jesse Douglas and Tibor Radó. Douglas was awarded one of the first Fields medals for his research on minimal surfaces.

Instead of looking only for minimal surfaces in euclidean space one can generalize this and look for minimal surfaces in arbitrarily curved manifolds. One application of minimal surfaces where this generalization plays a very important role is in general relativity. A three-dimensional spacelike slice of a four-dimensional spacetime which represents an isolated system (such as stars, galaxies or black holes) is a curved object which approximately looks like euclidean space outside some very large ball. In some of these cases minimal surfaces arise as the horizons of the black holes of these slices.

One reason why it is difficult to find minimal surfaces is due to the fact that the area functional is invariant under parameter changes. These are deformations which leave the shape of the surface invariant. One way to overcome this problem is to find another action integral which is invariant under a smaller set of deformations and whose solutions (so called critical points) can be shown to yield minimal surfaces.

### Harmonic maps

Following this procedure one is naturally led to consider the *Dirichlet energy* for maps from a surface into a Riemannian manifold. In the case of maps between surfaces one can illustrate the meaning of this energy by considering one surface as being made of rubber and the other surface as being made of marble. Then the map between these two objects prescribes how one "applies" the rubber onto the marble and the Dirichlet energy of this map represents the total amount of elastic potential energy resulting from tension in the rubber. The critical points of the Dirichlet energy are called *harmonic maps*.

In the last century a lot of mathematical work has been done in order to obtain some criteria which ensure that a variational problem has a solution. Since the Dirichlet energy is still invariant under a large set of deformations these criteria fail to hold for maps from a surface. These deformations can completely distort the coordinates on the surface while leaving the angles unchanged and keeping the energy fixed. This new difficulty was overcome in a groundbreaking work of Jonathan Sacks and Karen Uhlenbeck. They considered a family of energy functionals which approximate the Dirichlet energy and for which the existence of critical points can be shown with the above mentioned criteria. After having found critical points for the approximating functionals they performed a careful analysis of the limiting process of a sequence of those critical points and as a result they showed that in the end one ends up with a limiting object which consists of finitely many harmonic maps connected by necks. After imposing an additional topological condition on the target manifold Sacks and Uhlenbeck were moreover able to show the existence of a harmonic map from a surface into the target manifold. What was left over in their analysis was to show that during the limiting process no energy is lost. By the picture described above this corresponds to the fact that in the limit the necks connecting the harmonic maps carry no energy.

In a recent work I was able to show that there is no energy lost in the above limiting process if one considers only critical points of the approximating functionals which arise by an explicit construction (so called *saddle points*). The fact that there is no energy lost during such a limiting process turned out to be of great importance in the work of Tobias Colding and William P. Minicozzi II on the Ricci flow.

### Willmore surfaces

Another very important variational problem which is closely related to minimal surfaces is to find critical points of the *Willmore energy*. For a better understanding of this energy we need the notion of curvature. The curvature of a geometric object (for example a curve or a surface) can intuitively be considered as the amount by which the object deviates from being flat. For a stiff wire the elastic bending energy is the integral of the curvature squared. The Willmore energy is the corresponding energy for surfaces. One reason for its importance is that minimal surfaces are critical points thereof and therefore the critical points (so called Willmore surfaces) are generalizations of minimal surfaces.

The Willmore energy arises naturally in various areas of science. For example in general relativity the Willmore energy appears as the main term in the *Hawking mass* whereas in molecular biology it is known as the *Helfrich model* and it arises as the surface energy for lipid bilayers.

By a well-known mathematical theorem all two-dimensional surfaces without boundary can be classified by the number of "holes" they have. For example the surfaces which have no hole are topologically equal to a sphere and the surfaces with one hole are topologically equal to a torus (or doughnut). Another mathematical theorem tells us that among all surfaces without boundary in euclidean space the sphere has the lowest Willmore energy. Since the sphere is a surface with no hole, a natural question which then arises is if there also exists a surface with minimal Willmore energy if we restrict our attention to all surfaces which have one hole. This question was answered positively by Leon Simon and was later on generalized to surfaces with an arbitrary number of holes by Matthias Bauer and Ernst Kuwert.

As in the case of minimal surfaces one can now ask if there also exist Willmore surfaces in arbitrarily curved manifolds. In a joint research project in progress with Jan Metzger and Felix Schulze we are interested in finding a foliation of a three-dimensional spacelike slice of an isolated system outside a bounded region by Willmore surfaces with prescribed area. Here a foliation means a collection of surfaces that do not intersect but cover the whole exterior region. It actually turns out that the surfaces we construct are critical points of the Hawking mass. The existence of a foliation of the exterior region of an isolated system by minimal surfaces subject to an area constraint (so called *constant mean curvature surfaces*) has been proved by Gerhard Huisken and Shing-Tung Yau. With the help of this foliation they were able to define a *center of mass* for such a system. For the foliation by critical points of the Hawking mass we also try to show the existence of a corresponding center of mass. This would then give a nice relation between the quasilocal Hawking mass and the center of mass.

Tobias Lamm

## Analysis of Data taken by the most sensitive Gravitational Wave Detectors

### LSC Data Analysis

The years 2006 and 2007 have been very exciting years for gravitational wave research: in November 2007 the American LIGO detector system completed its 5th science run (S5), lasting 2 years at a sensitivity that not only reached but often surpassed its design sensitivity goal [1].

The AEI's own shorter-baseline GEO600 detector [2], operated as a German-British partnership with the Universities of Glasgow and Cardiff in the UK, and the University of Hannover in Germany, has been pooling its data with LIGO since the first science run in 2002. The two projects have fully integrated their data analysis activities within the LIGO Scientific Community (LSC). In fact, in the past two years the present author (M.A. Papa), leader of the AEI/Golm gravitational wave group, has served as the overall data analysis coordinator for the entire LSC.

The experimental efforts of GEO and of LIGO have a long history of cooperation, and GEO600 also serves as a testbed for the technologies that will be used in the next generations of detectors. The GEO600 detector is located near Hannover. Since the end of S5 in October 2007 it has been operated in "astrowatch-mode" to ensure some coverage for the strongest gravitational wave events, while the network of long-baseline LIGO detectors are off the air for an important sensitivity upgrade. The upgraded 'enhanced' detectors are expected to become operational in 2009, with a sensitivity improvement of a factor of ≈ 2 with respect to the original design sensitivity goal.

During the final 5 months of S5 the long-baseline Virgo [3] detector, located in Pisa, has also joined forces with the LSC, through a groundbreaking data sharing agreement. The reorganization of the data analysis efforts under the aegis of these two projects have been coordinated by the data analysis coordinators of the two Collaborations. This agreement will carry through to the next science run of the enhanced detectors.

The sensitivity band of these ground-based detectors extends between 50 Hz and 1500 Hz. In this band we expect gravitational wave signals from compact binary systems, at various stages of their evolution: during their inspiral, the coalescence/merger phase and from the oscillations of the object that forms after the merger. We expect gravitational waves to be emitted in association with supernova collapse events; we also expect emission of continuous gravitational waves and a stochastic gravitational wave background. Given the expected rarity and low signal-to-noise-ratios (SNR), the searches for the different signals can be carried out largely independently of one another.

One of the most interesting LSC results of the S5 run concerns the implications for the origin of the gamma-ray burst GRB 070201 from

LIGO observations [5]. GRB 070201 was an intense, hard burst localized within an area aligned on the sky with one of the spiral arms of the M31 galaxy, which is our Milky Way's nearest large neighbouring galaxy, also known as the Great Galaxy in Andromeda. Some astronomers suggested that the burst had occurred in the galaxy, while others believed it to have been much further away and only coincidentally superimposed on the galaxy's sky location. Short gamma-ray bursts may be produced in the merger phase of binary neutron star systems or neutron star-black hole binaries, and during S5 a 1.4-1.4 solar mass inspiral could have been detected from its gravitational waves at a distance up 30 Mpc. Since M31 is at approximately 800 kpc, GRB 070201 could well have produced a detectable gravitational wave signal if it was, in fact, inside the galaxy. An inspiral search was carried out on the available data for systems with component masses in the range 1-3 and 1-40 solar masses respectively. No signal was found, thus excluding the possibility that the burst was due to a binary neutron star or neutron star-black hole inspiral signal in M31, with a confidence level greater than 99%. The search also excluded various companion mass – distance ranges significantly further than M31, as shown in Figure 3 of [5].

In general the sensitivity of the S5 searches is such that one should not expect to detect a binary inspiral signal with about a year of data. The events are expected to be so rare that, at S5 sensitivity, the expected detection rates are of 1 event per 400 to 25 years for 1.4-1.4 solar mass systems; 1 event every 2700 to 20 years for 5-5 solar mass systems; and 1 event every 450 to 3 years for 10-10 solar mass systems. The range of values is due to the uncertainty on the astrophysical rate of occurrence of such events. The enhanced detectors are expected to achieve an improvement in strain sensitivity of a factor of $\approx 2$. With a horizon distance of 60 Mpc to neutron star systems the expected rates grow to 1 event every 60 to 4 years of actual observing time. In five years a further upgrade to the so-called 'advanced detectors' will bring LIGO to a horizon distance of 450 Mpc to neutron star systems, increasing the expected detection rates to between several to of order even hundreds of events per year of observing time. As discouraging as the current projections may be for the S5 data that is currently under analysis, one must bear in mind that the astrophysical predictions on the expected rates are based on a rather long chain of assumptions that rely on the correctness of stellar evolution models and that the actual direct observational data from non-gravitational-wave telescopes is rather small, and in the case of black-hole systems completely non-existent. The current searches are therefore providing important constraints, even though they are not surprising.

There are many circumstances in which short bursts of gravitational waves are expected, lasting from a few ms to a few seconds involving the merger phase of a binary system or the collapse of a stellar core. Due to the nature of this type of event, typically catastrophic, the shape of the gravitational wave signal is poorly known. Hence the most sensitive phase-coherent search techniques cannot be used and one resorts to the use of more robust, but generally less sensitive, excess-power and power-tracking based methods. Preliminary estimates of the reach of such searches in S5 predict that for signals with significant energy content around 180 Hz, a 50% detection efficiency is achieved for signals generated by converting of order 5% of a solar mass to gravitational wave energy at the distance of the Virgo cluster (the nearest rich cluster of galaxies), or $2 \times 10^{-8}$ of a solar mass at the center of our own Milky Way galaxy. On the other hand estimates of the expected amplitude of burst signals, mostly from numerical simulations, vary quite widely and scenarios exist which predict emission that is detectable in S5. For example [4] predicts for black hole mergers the emission of up to 3% of solar masses in gravitational waves. A system of this type formed by two 50 solar mass black holes at ≈ 100 Mpc would produce gravitational waves which could be detected with 50% efficiency in S5. AEI graduate student Christian Ott, who got his PhD during 2007, has predicted a new mechanism for gravitational wave emission from supernovae, which might lead to energies as high as $10^{-4}$ of a solar mass [10].

Thanks to the advances made by the numerical relativists in the estimation of the waveforms from compact coalescing objects, in the near future it will be possible to carry out searches for inspiral, merger and ringdown phases of the binary evolution and extend the reach of the searches to higher mass systems. These two aspects are expected to yield very significant gains in detectability of such systems and are actively pursued by the LSC and in particular at the AEI.

A landmark result from just the first year of S5 is the upper limit on continuous gravitational wave emission from the Crab pulsar. This is the first pulsar for which the direct gravitational wave upper limit is lower than that can be inferred from the observed spindown measurement from radio observations. The gravitational wave upper limit will beat the spindown upper limit by a factor of a few. This constraints the energy lost in gravitational waves to a few percent of the total lost energy, and it is the tightest constraint to date.

The most promising searches for continuous wave signals are the ones for previously unknown objects, which look for a fast rotating, close-by object, with a high ellipticity. Blind searches of this type are extremely compute-intensive. Hence the LSC carries out its deepest blind searches with Einstein@Home, a public distributed computing project that uses compute cycles donated by the general public. Einstein@Home is the second largest public compute project in the world and delivers an average 100 Tflops of compute power continuously [11]. In S5, the most sensitive Einstein@Home blind searches are expected to yield a detectability range of 1 kpc for gravitational waves at 150 Hz from object with an ellipticity of $10^{-5}$. The sophisticated hierarchical search techniques deployed on Einstein@Home have been developed at AEI in the past 8 years [9, 6, 7, 8]. The project is led by Bruce Allen, the new director at AEI/Hannover.

An isotropic stochastic background of gravitational radiation is expected due to the superposition of many unresolved signals, both of cosmological and astrophysical origin. With S5 data upper limits are expected to lie below those that may be inferred for a gravitational wave background from the big bang nucleosynthesis model. This is another landmark result.

M. Alessandra Papa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## Progress in Computer Modelling of Black Hole and Neutron Star Collisions

### Modelling of black hole binaries

Numerical relativity has made great strides in recent years, with the first long-term stable evolutions of binary black holes allowing for the measurement of accurate gravitational waveforms from the late inspiral and plunge. Many of the techniques that are crucial to such simulations, such as equation formulations, gauges, numerical methods, have long been used and often originated within the AEI numerical relativity group. As such, we have been well placed to take full advantage of the current "gold-rush" in binary black hole results.

The merger of a binary black hole system provides a fertile ground for new physics results. Beyond the obvious interest in gravitational waveforms for detection purposes, there is a strong astrophysical need to understand the late inspiral and in particular the outcome of the merger process. Over the last year, the AEI group has carried out a systematic study of black-hole binaries having spins aligned with the orbital angular momentum. This is a configuration which is believed to be of particular astrophysical interest as there may be tendencies towards alignment during the inspiral. We have evolved more than 50 models through their last quasi-circular orbits and merger to determine physical parameters of the remnant: the emitted mass and angular momentum, the final spin, and the recoil velocity which can result from the asymmetric emission of gravitational radiation. Our studies have determined that the recoil velocities due to spin asymmetries are much larger than those that can be produced through asymmetries in the masses, with a predicted maximum of approximately 450 km/s for black holes with maximal, anti-aligned spins.

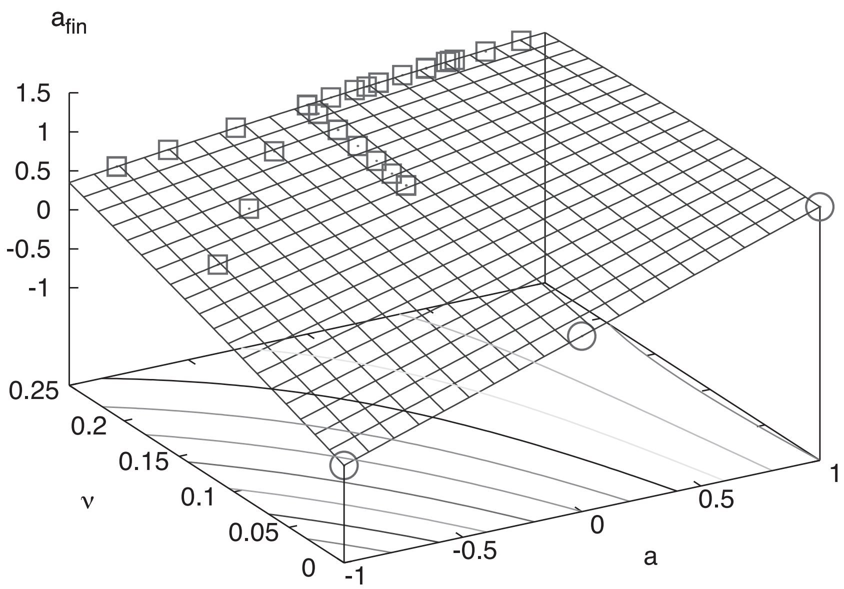



Fig.1: Global dependence of the final spin on the symmetric mass ratio and on the initial spins as predicted by the analytic expression. Squares refer to numerical-relativity estimates while circles to the EMRL constraints.

Particularly useful results of the simulations carried out are a set of simple analytical fits which can be used to relate the final black hole parameters to those of the initial inspiralling bodies. Given an arbitrary pair of equal-mass binaries with aligned spins, we have shown through numerical simulations in full general relativity that the final spin and recoil velocity can be determined to by simple quadratic and cubic functions which fit our more than 50 data points to excellent accuracy. Combining these results with unequal-mass simulations from our own and other groups, we have determined a very general formula for the spin of the merger product from a general initial configuration. An example of the excellent matching between prediction and numerical results is shown in Figure 1.

Together with the scientific developments, the group has also undertaken major technical developments to further improve the accuracy and efficiency of our codes by reducing systematic errors in wave extraction at a finite radius, and to allow for longer simulations which can be accurately matched to post-Newtonian results.

### Modelling of neutron stars

Over the last few years, the group has developed a new code, the Whisky code, for the solution of the relativistic hydrodynamics and magnetohydrodynamics (MHD) equations in a generic and curved background spacetime. The Whisky code uses state-of-the-art techniques in the solution of the hydrodynamic equations, is fully integrated with the other components of the Cactus code and thus provides the opportunity of investigating the solution of the Einstein equations in realistic, non-vacuum spacetimes.

A number of important results have been obtained with this code in the study of the dynamics of isolated neutron stars. A first one has been obtained by computing the gravitational-wave emission from the birth of a rotating black hole. Because of the many scales involved and of the modest efficiency in the gravitational-wave emission, this problem is a very challenging one and progress has been slow over the years. Yet, exploiting a series of new developments and the use of adaptive mesh refinement techniques, it was possible for the first time to calculate the gravitational radiation produced from a fully 3D calculation well after the black-hole quasi-normal ringing. Another important application of the Whisky code has been in the accurate simulations of the dynamical barmode instability, which develops when a rapidly and differentially rotating star loses an axisymmetric shape and develops a "bar" to reach an energetically more favourable configuration. An example of this instability is shown in Figure 2, which shows a bar-deformed neutron star. The accurate simulations performed with Whisky have shown that generic nonlinear mode-coupling effects appear during the development of the instability and these can severely limit the persistence of the bar deformation and eventually suppress the instability.

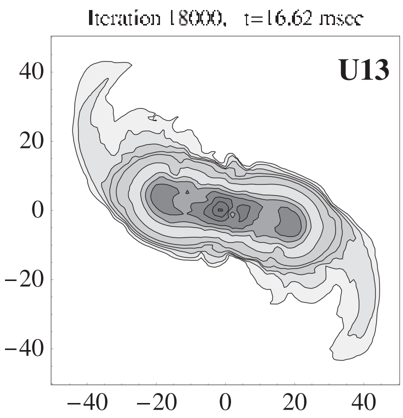



Fig.2: Snapshot of the evolution of a rapidly rotating star that develops a bar-mode instability. The star is initially axi-symmetric but it rapidly develops a cigar-shape as the instability develops.

### Interfacing simulations with data analysis

The accurate modelling of the late inspiral and merger of black hole binaries, and the direct connection of the merger to the ringdown, have long been sought gravitational wave data analysis. The recent breakthroughs in numerical relativity have opened the road to a power combination of analytical methods and numerical calculations so as to obtain "complete" waveforms which match the post-Newtonian predictions with the numerical results of the full Einstein equations.

A concrete example of the synergy between perturbative and nonlinear calculations is offered by the recent construction of phenomenological and "complete" waveforms. Using numerical waveforms from both the AEI and the Jena numerical relativity groups (who collaborate within a German SFB research network) relative to non-spinning equal-mass black holes, the data-analysis groups at the AEI and at the University of the Balearic Islands, have generated a phenomenological family of gravitational-wave templates matching both the slow post-Newtonian inspiral with the rapid and nonlinear inspiral and merger. The resulting waveforms, which are explicitly described by the physical parameters of the binary, have then been compared with the original hybrid waveforms and shown to be not only effectual in detecting the signals from black-hole coalescences, but also faithful in estimating the parameters of the binary. The new template family has also been tested through a search using the sensitivities of different ground-based interferometers, and exploiting the three stages of the black hole coalescence. The comparison with other template-based searches has shown that the newly produced templates are significantly more sensitive for a substantial mass-range and can provide a potentially large improvement in the event-rate of ground-based interferometers. This is summarized in Figure 3, which reports the distance at which an equal-mass binary can be detected with a signal-to-noise-ratio of 8 by the different detectors.

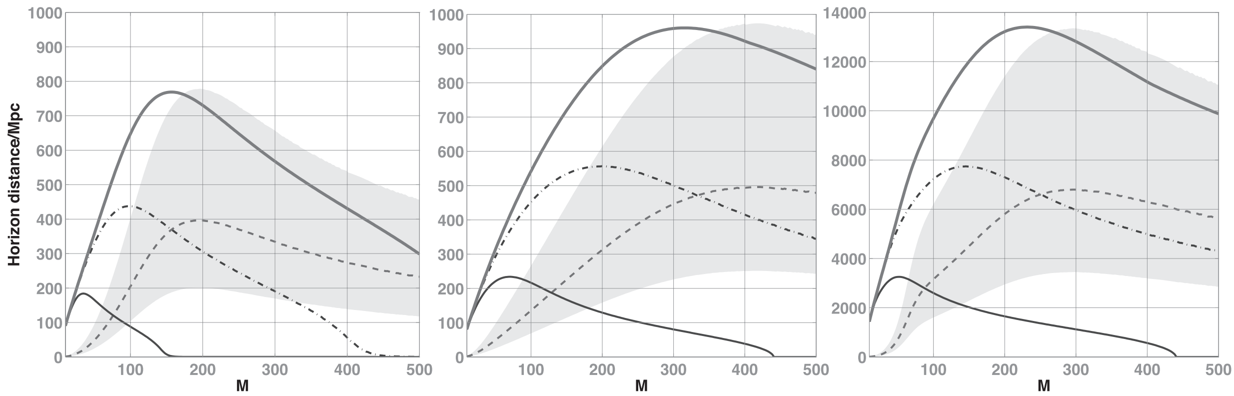
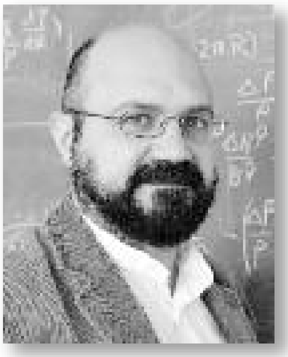



Fig.3: Distance at which an equal-mass binary can be detected with a SNR of 8 by LIGO (left plot), Virgo (middleplot) and Advanced LIGO (right plot). Different lines refer to different approaches and the thick solid (red) line to a search using the new phenomenological templates.

## Modelling of gravitational collapse

AEI graduate student Christian Ott's work deserves special mention here. Working with collaborators from around the world, he has contributed significantly to the study of possible instabilities of the core of a star collapsing and leading to a supernova explosion. Astronomers have long known that many of these explosions originate from the collapse of the interior of a massive star, but it is still difficult to explain in detail how the collapse gets turned around into an explosion that drives off most of the star, leaving behind a neutron star or black hole. Ott and collaborators have studied in particular the acoustic oscillations of the innermost core of the collapse, when it is halted by nuclear forces at high densities. These vibrations, in fact, with frequencies of several hundred Hz, could, under special conditions, provide enough energy to the outer layers to blow them away. As reported elsewhere in this report, Ott's work has won special recognition with a prestigious science prize from the city of Potsdam.

Part of the credit for the numerous scientific successes goes to state-of-the-art computing facilities. Making use of 900.000 EUR granted



from the MPG, the group has purchased and installed a new supercomputing cluster, Damiana, which has been intensely used for these simulations. With its 198 nodes, each with 4 cores, an Infiniband network and 70 TB of disk storage, Damiana has scored 192 in the top-500 world-wide ranking and is the 5th fastest machine among German scientific Institutes.

Images and animations of our most recent simulations can be found at *http://numrel.aei.mpg.de/Visualisations*

Luciano Rezzolla

## LISA Science at AEI

### Data Analysis Development for LISA

AEI/Golm has been awarded a grant from the DLR (the German space agency) totalling more than 1 million Euros to build a national German collaboration on LISA and investigate data analysis methods for extracting the maximum astrophysical information from future LISA data. This grant is a supplement to the even bigger award to AEI/Hannover for LISA Pathfinder technology design and study.

AEI/Golm plays the role of the main contractor on the national level and currently subcontracts five research groups across Germany. These include two groups at Jena University that model the signal from binary massive black holes (MBH); one at Heidelberg University that does large computer simulations modeling the merger of galaxies and studying the so-called 'last parsec problem' (how two MBH from the merged galaxies finally come close enough together for gravitational wave (GW) energy-loss to make them merge in a time shorter than the age of the Universe); a group in Bremen (at ZARM) that studies environmental influence on LISA measurements (from the Sun and its wind) and other secondary noise sources; and a group at Würzburg University that studies current evidence for MBH's through optical, X-ray, and gamma-ray observations.

The AEI focuses on designing data analysis algorithms for LISA. LISA will face special problems that current ground-based detectors do not have: the high sensitivity of LISA means that it will simultaneously observe many strong sources, and these must be separately identified and studied. The AEI's work on this problem at present is mainly (but not entirely) done via organization and participation in a series of Mock LISA Data Challenges (MLDC).

### Mock LISA Data Challenge

At the LISA International Science Team (LIST) meeting of December 2005, in Pasadena, the Working Group on Data Analysis (LIST-WG1B, co-chaired by Bernard Schutz of the AEI) established a task-force to organize several rounds of mock data challenges, with the dual purpose of fostering the development of LISA data analysis tools and capabilities, and of demonstrating the technical readiness already achieved by the gravitational-wave community in distilling a rich science payoff from the LISA data output. The LISA Mock Data Challenges were proposed and discussed at meetings organized by the US and European LISA Project that were attended by a broad cross section of the international gravitational-wave community. These challenges are meant to be blind tests, but not really a contest.

The Mock LISA Data Challenge (MLDC) Taskforce has been working since the beginning of 2006 to formulate challenge problems of maximum efficacy, to establish criteria for the evaluation of the analyses, to develop standard models of the LISA mission (orbit, noises) and of the LISA sources (waveforms, parametrization), to provide computing tools such as LISA response simulators, source waveform generators, and a Mock Data Challenge file format, and more generally to provide any technical support necessary to the challengers, including moderated discussion forums and a software repository. The activities of the MLDC Taskforce can be tracked on the WG1B website, http://www.tapir.caltech.edu/dokuwiki/listwg1b:home.

Submitted results are evaluated by the task force and the results are presented at conferences and LIST meetings. N. Cornish (Montana State University), S. Babak (AEI) and M. Vallisneri (JPL) are the code developers for the waveform generation, for the pipeline to produce a data set and for the results evaluation tools. The software project is called lisatools and is open source in the Google Code repository (http://code.google.com/p/lisatools/). The novelty of using Python and XML in the pipeline led to article [1].

### AEI participation in MLDC

- **Galactic binaries**
  Reinhard Prix and John Whelan are working on adapting the techniques used in ground based gravitational wave astronomy to LISA data analysis. In the ground-based data we expect to have a continuous almost monochromatic signal coming from a single rapidly spinning neutron star with deviations from axial symmetry. This signal is similar to the one expected in LISA from the white dwarf binaries, which is an almost monochromatic signal with a very slow change in frequency due to emission of gravitational waves and/or to mass transfer within the binary. We expect to have tens of millions of signals present simultaneously in the data and they stand above the instrumental noise. At low frequencies the number of signals is so big and Doppler modulation is not sufficient to resolve each signal individually, so the gravitational waves create a confusion noise that can obscure other signals. At higher frequencies signals are not so numerous and we can distinguish them by Doppler modulation.

- **Massive Black Hole binaries**
  Stanislav Babak and Edward Porter are involved in the search for gravitational wave signals from MBH binaries in the MLDC data sets. Such sources should be visible to LISA through-out the Universe. The strength of the signal will allow us to measure the source parameters with high accuracy. Currently we have two independent search algorithms that both have pros and cons. The first method (the most successful so far) was designed by E. Porter (AEI) and N. Cornish (Montana State University) and is based on the Metropolis-Hastings sto-

chastic search. The basic idea is to construct a chain in the parameter space which would bring you to the global maximum of the likelihood (true parameters of the signal). The second method was designed by S. Babak and E. Porter and it is two stage method: we use a stochastically built coarse bank of templates to study the likelihood across whole parameter space and we follow the candidates using a second step.

- **Extreme Mass Ratio Inspirals (EMRIs)**
  S. Babak and E. Porter in collaboration with J. Gair (Cambridge) and L. Barack (Southampton) are developing a method for detecting EMRIs in the LISA data. EMRIs are result of the capture a stellar-mass compact object (like a black hole or a neutron star) by the MBH in the center of a galaxy from the surrounding star distribution. The signal from EMRIs is long-lived and has a complicated structure. This leads to complications in detecting such signal: the likelihood surface has a lot of local maxima spread widely across the parameter space and the main problem is to find the global maxima. The search method, which is proven to be successful in case of the single source in the instrumental noise, is based on the stochastic Metropolis-Hastings search combined with harmonic identification algorithms (the signal is represented by multiple harmonics of the three fundamental evolving orbital frequencies).

### Cosmology with LISA

Recently several groups simultaneously realized the importance of including higher order post-newtonian (PN) corrections to the amplitude of the gravitational wave signal from inspiralling massive black hole binaries. The majority of those corrections correspond to emission of gravitational wave signals at frequencies multiple of the orbital frequency of the binary. For the adiabatically evolved circular orbits the main contribution comes from the second orbital harmonic. It is generally true that the higher PN order corrections do not bring much of an increase in the signal-to-noise ratio (unless the fundamental frequency is out of the LISA observing band). However the higher modes change the phase of the signal and help to decouple (de-correlate) some parameters and, therefore, improve parameter estimation of the binary system. In particular they help to estimate better the location of the source on the sky and its distance. Measuring the location of the source well in advance of the merger makes it possible to conduct simultaneous gravitational wave and electromagnetic observations of the coalescence event and hopefully will allow us to identify the host galaxy. Optical observations will allow us to measure the red shift to the object and gravitational wave observations will give us a very accurate estimation of the distance to the source. By using these events LISA will be able to determine rather accurately the 'redshift-distance' relationship, which in turn will allow us to map the geometry of the Universe and measure the amount of dark energy in the universe, and possibly its evolution with time as the universe has expanded.

The LISA mission will consist of three identical spacecraft flying in a triangular formation

Another related question, which is also addressed at AEI, was the accuracy of measurement of the parameters of signals if there is a failure of one of the links between LISA spacecraft (due, for example, to the failure of a laser). The use of higher harmonics makes such a loss less disastrous. In addition at AEI we have proposed an alternative method for localizing sources: using a null stream for a particular direction on the sky.

### BEPAC report

The US National Academy of Sciences convened a committee (BEPAC: the Beyond Einstein Program Assessment Committee) to asses the five proposed missions in NASA's Beyond Einstein program (LISA, Constellation-X, Joint Dark Energy Mission, Inflation Probe, and Black Hole Finder probe) and to recommend which of these five should be developed and launched first, using a funding wedge that is expected to begin in February 2009. The criteria for these assessments include:

- Potential scientific impact within the context of other existing an planned space-based and ground-based missions;

- Realism of the preliminary technology and management plans, and of the cost estimates.

The report came out very positively for LISA. On grounds of readiness to spend money in 2009, BEPAC's main recommendation was that the "U.S. Department of Energy should pursue the Joint Dark Energy Mission (JDEM) as the first mission in the 'Beyond Einstein' program". However, BEPAC said that LISA had clearly won the competition among the projects on purely scientific grounds: "LISA, in the committee's view, should be the flagship mission of a long-term program addressing Beyond Einstein goals". The main reason LISA is not the first priority is technical readiness – because LISA Pathfinder has not yet flown, and because other technologies are still not fully tested, the committee argues that it is too risky to accelerate the timescale of LISA. However, the committee strongly recommended that NASA invest additional Beyond Einstein funds in technology development of the LISA program in the short term, and in the long term adhere to ESA's launch schedule for a start in 2018.

While no space mission is totally secure until it is launched, the BEPAC appraisal reflects the high scientific priority that LISA has in both Europe and the USA, and has done much to reinforce LISA's position in the agencies' development plans.

Stanislav Babak

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## Improving Gravitational Wave Searches by studying the Sources

### The NINJA project

As described in the report by Luciano Rezzolla, numerical simulations of binary black hole spacetimes are reaching a level of maturity where they can play an important role in guiding the ongoing gravitational wave searches. Thus far, most of these searches have been informed by analytic calculations that predict the emitted radiation from the binary system when the black holes are far enough apart (inspiral phase) and later after they have fully merged (ringdown phase). The results of the successful numerical simulations now go beyond this and allow us to probe the merger of the holes, where the system reaches the strongest possible gravitational fields in Einstein's theory. To achieve this, the ongoing efforts at the AEI to model the inspiral, merger and ringdown phases using a single coherent model will play an important role. However, even before many of the often subtle issues in waveform modeling are fully resolved, numerical relativity can already play an important practical role in informing gravitational wave searches.

Perhaps the most important way this can happen is to address the question: are our present gravitational searches for binary black holes missing any significant population of astrophysical signals? Many of the gravitational wave searches involve a number of non-trivial steps such as coincidence of candidate events between different detectors, and signal based vetoes for rejecting false positives. Are the thresholds and choices of these algorithms too strict, or are they overly conservative and thereby unnecessarily restricting the search sensitivity? Furthermore, there are a number of searches which aim to detect binary black hole coalescence. These include matched filter searches which rely on detailed information about the expected signal waveform, and also burst searches for short duration transients which assume as little as possible about the signal. How do these very different searches compare over a wide range of parameters? Which are the most effective search techniques?

A simple way of addressing these kinds of practical questions is just by injecting the correct gravitational wave signals in noise, and to search the resulting data by various different search pipelines. A number of AEI members (S. Husa, B. Krishnan, L. Santamaria, J.T. Whelan) have played an active role in such an effort known as the NINJA project. NINJA stands for "Numerical Relativity Injection Analysis", and the goal of this project is to study the sensitivity of data analysis pipelines to binary black hole numerical relativity waveforms buried in simulated Gaussian noise. The project is getting underway, and is expected to present its first results in the fall of 2008. Apart from the technical interest, an important side effect of this project will be to foster interactions between the numerical relativity and gravitational wave data analysis communities. A closer interaction between these communities is essential in order to maximise the scientific potential of gravitational wave searches.

### Gravitational waves from accreting neutron stars

One of the key outstanding questions in neutron star astrophysics is why neutron stars seem to spin much slower then they can, based on our current understanding of the structure of neutron stars. This is most clearly seen in the Low Mass X-ray Binary (LMXB) systems in which a neutron star is in a binary orbit around a companion low mass normal star. Gas flows from the normal star onto the neutron star, heating up and emitting the X-rays that give these systems their name. This process is called accretion. The incoming gas spirals onto the neutron star and therefore also makes it spin faster and faster. Astronomers believe that all the most rapidly rotating neutron stars (seen as pulsars) have been spun up in this way.

However, there is a puzzle: the current record on the neutron star spin frequency is 716 Hz while the best neutron star models predict that they could spin faster than 1 kHz without breaking up. Although 700 Hz is an astonishingly rapid spin for an object with a mass greater than that of our Sun, the puzzle still remains: what stops them being spun up even faster? One of the viable suggestions for resolving this discrepancy is that emission of gravitational radiation acts as a brake on the neutron star spin; the spin-up of the neutron star by accretion of matter from its companion is balanced at some point by the loss in angular momentum due to the emission of gravitational radiation. Thus, accreting neutron stars are among the important targets for current and future generations of gravitational wave detectors.

The direct detection of gravitational waves from accreting neutron stars will open for the first time a wealth of opportunities for studying the physics of neutron star interiors. For example, the gravitational wave frequency alone will carry important information on the mechanism responsible for gravitational wave emission. Even a negative result, where a sufficiently sensitive search fails to detect gravitational waves teaches us a lot about the astrophysics of neutron stars. The problem however is that these gravitational wave searches are very challenging. The parameter space is very large and the computational burden of these searches can be prohibitive. This is compounded by the uncertainty on the parameters of these sources from other astrophysical observations. Narrowing down the range of parameters from astrophysical observations and modelling is expected to be critical for the detectability of gravitational waves from these sources.

In recent work, B. Krishnan and B.F. Schutz, in collaboration with A. Watts (currently in Amsterdam) and L. Bildsten (Santa Barbara, California), have investigated the astrophysical and data analysis issues in the detectability of these signals. This work is an example of the increasingly important interplay between astrophysics and gravitational wave data analysis. It requires an extensive survey of known LMXBs, working out the best parameter uncertainties from known observations, and figuring out the most appropriate data analysis algorithm for estimating the detectability. Such studies are also important from the perspective of designing the next generation of gravitational wave detectors and can be used to make informed decisions on the various tradeoffs involved.

Figure 1 compares the expected signal amplitudes from a number of potential sources with the best case sensitivity of gravitational wave

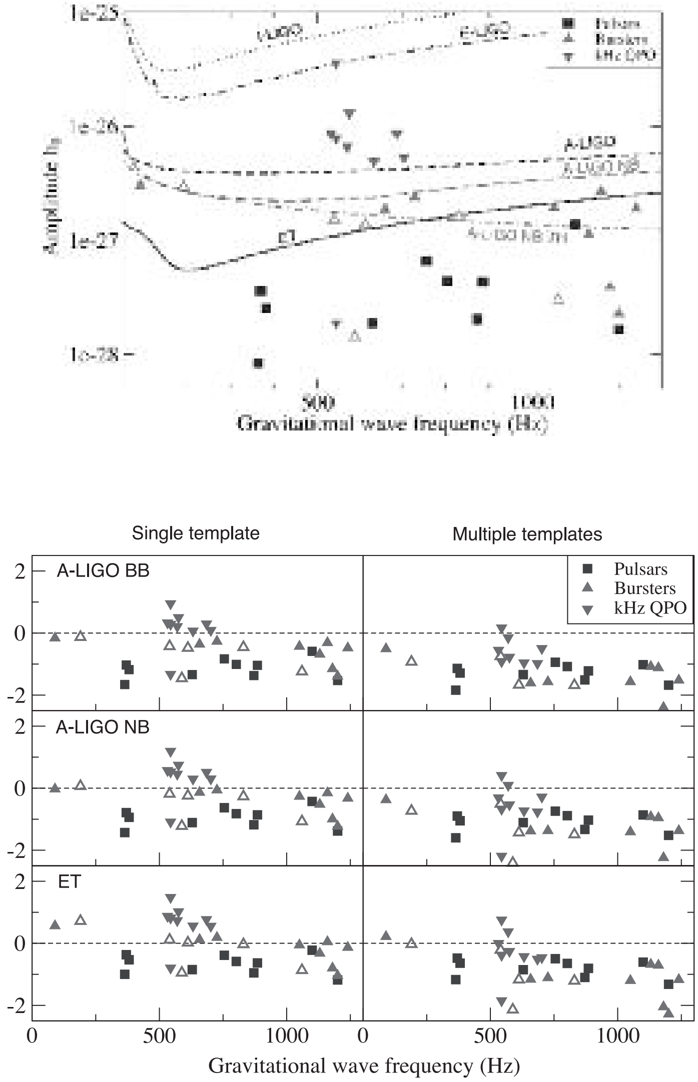



Fig.1: The top panel shows best case detectability of gravitational waves from a number of accreting neutron stars. The bottom panel shows the projected ratio of the predicted amplitude to the expected sensitivity for the sources, taking data analysis limitations into account, for the broad- and narrow-band configurations of the Advanced LIGO detectors, and the third generation Einstein Telescope.

searches using data from a number of current and future detectors. It shows that given sufficiently good astrophysical information, gravitational waves from LMXBs are indeed detectable, even by the Enhanced LIGO detectors which are expected to be operational in the very near future. The second panel of the figure includes the effects of data analysis limitations, and shows the ration of the predicted to detectable amplitudes. The plots on the left show the best case scenario, while the plots on the right show the reduction in this ratio when presently foreseen data analysis and astrophysical realities are taken into account. Even in this case, we see that there are still sources which are detectable or nearly detectable with the Advanced LIGO detectors. It demonstrates that while the detection problem is indeed challenging, it is far from insurmountable. It is hoped that this work will drive further developments in this area with improved astrophysical modeling and data analysis methods.

Badri Krishnan

## On the Rôle of 3-Manifold Topology in Canonical Quantum Gravity

Quantum gravity as well as 3-dimensional geometry and topology are central research themes at the AEI. In the following I wish to draw attention to a topic that connects these two themes in a truly fascinating fashion. Much of what I can say here has been partially known and partially conjectured for some time, but recent years have witnessed substantial progress in the theory of 3-manifolds, which now allows to make much stronger and much more complete statements concerning the issues I will talk about.

### Topological fingerprints and gauge symmetries

All canonical formulations of Einstein's field equations have in common that spacetime is viewed as time evolution of a 3-dimensional manifold, $M$, with certain geometric structures defined on it. The stacking according to the evolution parameter of these 3-dimensional structures is then what builds up *spacetime*. There are different formulations according to what structures are considered as fundamental dynamical fields, but all formulations agree that the group of diffeomorphisms of $M$ act as symmetries. This group, which we call Diff ($M$), consists of all bijective self-maps of $M$ which are smooth in both directions. More precisely, Diff ($M$) acts as *gauge* symmetries, meaning that any two states of the system which merely differ by an action of Diff ($M$) are to be considered as physically indistinguishable. This may be interpreted as saying that the points of $M$ have no physical identities other than those defined by the values of observable dynamical fields.

Einstein's equations do not impose any restriction on the topology of $M$, so that, in principle, all 3-manifolds may occur as spatial topologies. The space of physical states is parametrised by the fields on $M$ in a redundant fashion. The operation of identification under the action of Diff ($M$) partly removes this redundancy, but thereby also introduces non-trivial topological features into the true (i.e. non redundant) space of physical states. This is roughly sketched in figure 1, where the richer topological features of the lower space are generated through certain identifications on the topologically trivial upper space, here along all left-tilted and all right-tilted lines respectively. The method to go from the redundant to the true space of states is usually called *reduction*. The topological features inherited through reduction turn out to be strong characteristics of $M$'s own topology, so that one may say that $M$ leaves its 'topological fingerprints' in the reduced space of classical states. Interestingly, this is also true in the quantum theory that is based on the canonical formulation (canonical quantum gravity).

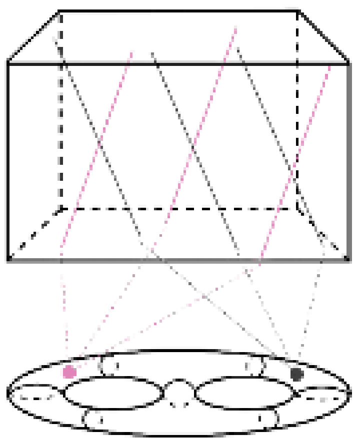


**Fig.1:** Redundant (top) and true (bottom) space of states.

What is the mathematical structure of this information and how rich is it? A brief answer to the second part of this question is that it is *surprisingly* rich; indeed, often it is rich enough to considerably narrow down the class of manifolds $M$ it came from, and sometimes it can even determine $M$ completely. The first part of the question is much harder to describe. In principle, the mathematical structure is that of a discrete group which may – and generally will – be infinite and non-commutative. However, in practice one is only given *a presentation*, that is, generators and relations, and there is no universal method to algorithmically determine the group (up to isomorphisms) from its presentation. Under unfavourable circumstances this may even be impossible.

More concretely, the groups we have in mind here are the so-called *mapping-class groups* (MCG) of the underlying 3-manifold *M*. They enter into the canonical reduction scheme through the requirement that *all* diffeomorphisms shall be gauge transformations, not just the ones that can be built up from infinitesimal ones. Standard reduction schemes just consider the latter, thereby leaving the job of reducing all of Diff (*M*) unfinished. To complete the job, we have to reduce those residual gauge symmetries that were not taken care of by the standard scheme. These just form the MCG, the structure of which we wish to understand more.

**Structure of mapping-class groups**

To understand the structure of MCG it is useful to think of *M* (which we assume to be connected) as being built up from simpler pieces. This can be done by cutting *M* along embedded 2-spheres in such a way that each time two components result; one says that the 2-spheres must be 'splitting'. Moreover, each component must be different from a 3-ball since merely cutting out a 3-ball is a trivial operation that does not simplify the remaining piece. One says that the splitting 2-sphere must be 'essential' (not bounding a 3-ball). This procedure of cutting along splitting essential 2-spheres stops after finitely many steps and the resulting pieces are (up to permutation) uniquely determined. These pieces, after closing off their 2-sphere boundaries by filling in 3-balls, are examples of so-called *prime manifolds*, so-named in analogy to

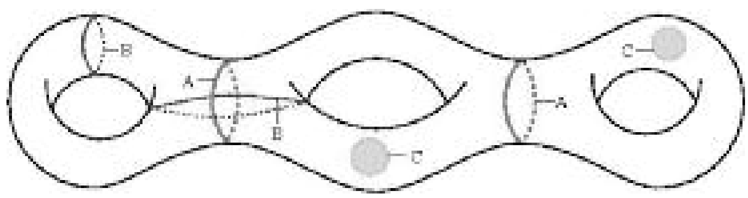



Fig.2: Connected sum of three tori.

the prime numbers into which any integer can be uniquely decomposed. According to their definition, prime manifolds are characterised by the property that they do not contain splitting essential 2-spheres, that is, each splitting 2-sphere bounds a 3-ball. A manifold which is not prime is called *reducible*. A reducible manifold is said to be the *connected sum* of its prime manifolds. An analogous situation in two dimensions is depicted in figure 2. Here a Riemann surface of genus three is presented as connected sum of three 2-tori. In figure 2 the circles (1-spheres) of type A are splitting and essential, whereas circles of type B are not splitting and those of type C are splitting but not essential (bounding the shaded discs). In two dimensions, next to the 2-sphere, the 2-torus is the only (closed orientable) prime manifold. In contrast, in three dimensions, there is a countable infinite number of prime 3-manifolds.

A general method has been found that allows to write down (finite) presentations of the MCG of reducible manifolds, provided presentations for the MCG of its primes are given. To some extent it uses the analogy of an irreducible manifold with a finite collection of particles (the primes) from different species. Particles of the same species (corresponding to diffeomorphic primes) have the same internal symmetry groups and may be permuted among each other. The symmetry group of this collection of particles is then easily written down in terms of permutations and internal symmetries (in terms of a semidirect product). This is not yet the MCG, but it is a substantial part of it (more precisely: a quotient). In most cases the full MCG is an extension thereof by transformations which do not have an analogy in the particle picture, but which can nevertheless be explicitly described.

Many prime manifolds can be are conveniently represented as solid polyhedra in 3-space with suitably identified faces. An example is presented in figure 3, where opposite faces of the solid cube are identified after a 90 degree screw motion, so that edges with equal (lower case) letters and vertices with equal (upper case) letters are identified. What is particularly nice about such pictures is that they often allow to read off the relevant MCG in terms of the geometric symmetries of the polyhedron, which in figure 3 is just the octahedral symmetry group known from crystallography.

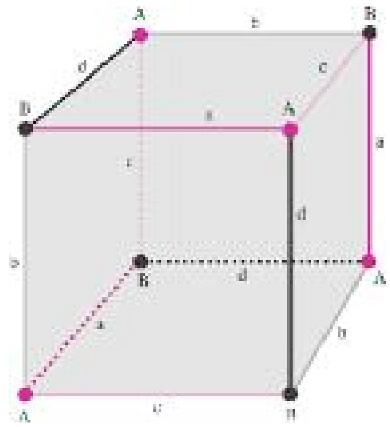


**Fig.3:** Representation of a prime manifold as solid polyhedron (cube) with boundary identifications.

### A simple but non-trivial example

At this point an example may be useful. The simplest prime 3-manifold is the real projective space, denoted by $RP^3$. It can be represented by a 3-ball whose points on its 2-sphere boundary are identified in pairs in an antipodal fashion. Accordingly, the connected sum of two $RP^3$ can then be represented by a solid spherical shell like in figure 4, where the figure must be thought of as rotating about the horizontal symmetry axis so as to produce a 3-dimensional object. On each of the two bounding 2-spheres antipodal points are to be identified in pairs. The dashed circle in figure 4 then corresponds to a 2-sphere along which the connected sum of the two $RP^3$'s is taken. The two solid horizontal line segments in figure 4 become a single connected closed curve (circle), showing that the whole space is fibred by circles. One may show that $RP^3$ has no inner symmetries in MCG so that in the particle picture only the exchange between the two $RP^3$'s remain, which form the two element group $Z_2$, the additive group of integers modulo 2. This exchange transformation, call it $E$, is easily visualised in figure 4 by a transformation that exchanges the inner and outer 2-spheres in a way that is compatible with their antipodal identifications. It turns out that there is only one more generator of MCG, call it $S$, which can roughly be described in terms of figure 4 as pushing the inner 2-sphere to the right, until it reaches the outer 2-sphere and reappears on the left (due to the antipodal identification) and finally comes back to its original position. This generates another two-element group $Z_2$ which together with the group of exchanges forms the free product $Z_2 * Z_2$, whose generators are $E$ and $S$ and whose relations are $E^2 = 1$ and $S^2 = 1$. This is an infinite and non-commutative group (not to be confused with $Z_2 * Z_2$, which is finite and commutative) that characterises the MCG of the connected sum of two $RP^3$'s.

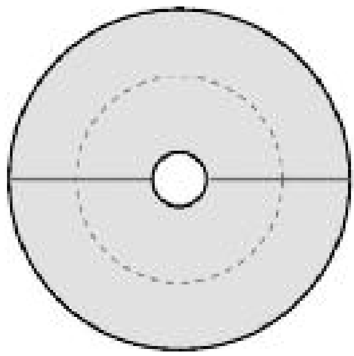
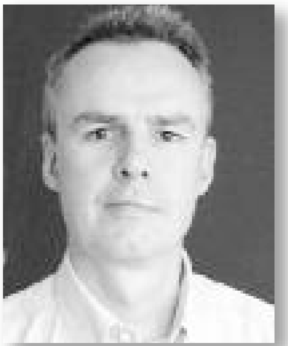


**Fig.4:** Connected sum of two real projective spaces.

### The rôle of the MCG in quantum gravity

The implementation of this MCG in quantum theory is made by the requirement that observables should commute with its action on state space. This forces the space of states to decompose into so-called coherent sectors, one sector for each unitary irreducible representation of the MCG. For $Z_2 * Z_2$ there are four one-dimensional unitary irreducible representations (each $Z_2$ being represented by $\pm 1$) and a one-parameter family of two dimensional ones, in each of which the exchange operation $E$ has eigenvalues $\pm 1$, corresponding to 'bosonic' (+1) and 'fermionic' (-1) subspaces, and the $S$ operation that mixes them to a degree that depends on the representation parameter. Simple examples like this already suggest a rich topology-induced sectorial structure of quantum gravity, much richer than in Yang-Mills gauge theories, where the analogue is known as $\theta$-sectors. This can be explicitly worked out for few other examples, which generically show a rapid increase in algebraic complexity. Fortunately, it turns out to be possible to derive a number of general results that clarify the overall structure to some extent. This, too, highlights that diffeomorphism groups are far more complex objects than groups of gauge symmetries in ordinary (Yang-Mills) gauge theories. To understand the physical relevance of this difference remains one of the central issues in quantum-gravity research.



Domenico Giulini

## The World-Sheet Approach to D-brane Dynamics

### D-branes in string theory

Fig.1: An open string attached to a D-brane.

String theory started out as a theory of strings, as the name suggests. It was realised later that also other, higher-dimensional objects appear. In particular, so-called Dirichlet-branes, or D-branes for short, were considered, which microscopically are described by the condition that open strings can end on them (see the illustration in figure 1). They come in all dimensionalities, from point-like over string-like or membrane-like objects up to space-filling branes. These branes can be thought of as a collective, solitonic excitation of closed string modes – indeed the effective field theory that describes the interaction of closed strings at low energies (a supersymmetric version of gravity or supergravity theory) has solitonic solutions where the energy is localised on certain lower-dimensional subspaces. This means that branes are not just put into string theory because we are bored to only look at strings alone, but they are inevitably part of the theory. D-branes played a prominent role in the second string revolution in the 1990s and they lie at the heart of the famous AdS/CFT conjecture that relates gauge field theory and string theory. Furthermore D-branes have enlarged our possibilities to construct string models which come close to the description of the real world – they offer fascinating options in brane-world scenarios and open up a door for brane cosmology providing new models of the early universe.

### The world-sheet description of strings

To investigate the properties of D-branes we study open strings on them, in some sense we can use the open strings as probes to learn more about the branes. An open string, as it moves, sweeps out a two-dimensional surface in space-time, much as a point particle follows a one-dimensional world-line through space-time. The motion of the string can be parameterised by a map from an infinitely long strip of finite width into the space-time (see the illustration in figure 2).

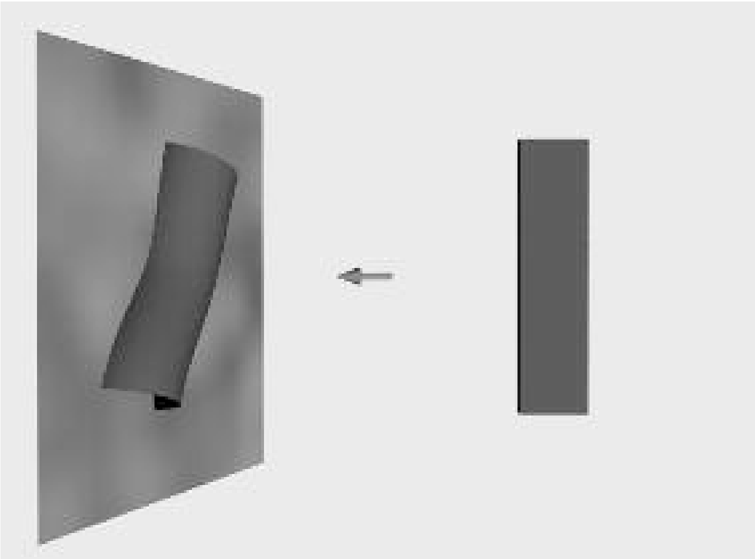


Fig.2: As it moves in space-time, an open string sweeps out a two-dimensional surface. This surface can be parameterised by specifying a map from a strip into space-time.

From the point of view of the strip (which we will call the world-sheet), we are considering a two-dimensional field theory where the fields have the interpretation of coordinates in the target space. This field theory has to satisfy some constraints that are related to the fact that the theory in the end should not depend on the specific choice of the parameterisation, but only on the image of the world-sheet in space-time. In particular the theory on the world-sheet has to be conformally invariant. A conformal transformation on the world-sheet is a transformation that leaves all angles invariant, just like the famous Mercator map of the earth (see figure 3).

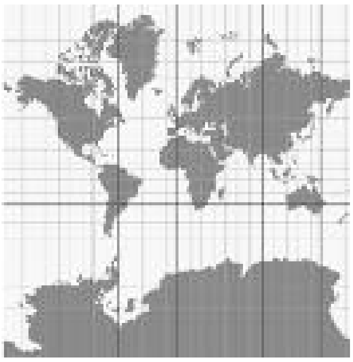


Fig.3: The Mercator projection provides a conformal map of the surface of the earth, so that at any point angles are preserved (but not lenghts or areas as can be seen from the over-sized antarctica).

We are thus led to consider two-dimensional conformal field theories to describe a string moving in some background space-time. The construction of such theories becomes more and more complicated as the relevant scale on which the background varies comes closer to the typical size of a string. This can be easily understood: for structures that are large compared to the string, the finite extension of the string does not play a big role and manifests itself just in the existence of higher string excitations (the higher harmonics of the strings). When we want to resolve very small distances, however, the string experiences the background in a completely different way than a point particle would do, and a perturbative construction around the particle limit is not possible. Why are we so concerned about tiny structures? String theory, or better superstring theory, needs 10 space-time dimensions in its simplest formulation to be consistent. The only way how to make string theory compatible with the dimensionality four of our world is thus to hide six dimensions, for example by making them so small that they are unobservable by our technical possibilities. On the other hand, if the six extra dimensions are not observable, nothing prevents us from replacing the field theory corresponding to these six dimensions by an arbitrary conformal field theory (with the right number of degrees of freedom to make the theory consistent) where the fields do not have a direct geometric interpretation. From the world-sheet point of view it does not really matter where the fields came from. The conformal field theory specifies an abstract background for the motion of the string which only in some cases or some limits may have an effective geometric description. What we have said about the world-sheet description is true for closed strings as well as for open strings. A D-brane is then defined as a conformal boundary condition in a two-dimensional conformal field theory. In most cases these abstract D-branes do not have a geometric interpretation.

### Non-geometric behaviour

Let us illustrate the non-geometric behaviour of strings in an example. A famous symmetry of string theory is the so-called T-duality. It says in its simplest form that the theory of a closed string moving in a background in which one dimension is curled up to a circle of radius $R$ is equivalent to a string in the same background where the radius is changed to the inverse radius $1/R$ (in units of the so-called self-dual radius which is determined by the string length). How can we understand that? There are different ways of exciting the string. It can oscillate and these oscillations are independent of the radius of the circle. Furthermore it can move along the circle where due to quantum effects the possible momenta and energies of the string are quantised – the energy gaps between the excitations are the larger the smaller the radius becomes. In contrast to a point particle the string has also the possibility to wind around the circle. Obviously these excitations come in discrete steps, it can wind around the circle once, twice, three-times and so on. The energy of a winding string becomes higher when the radius is growing. What happens in T-duality then is that the winding modes of the theory with radius $R$ are mapped to the momentum modes of the theory with circle $1/R$ and vice versa. From the spectrum of string excitations we therefore cannot distinguish whether the radius is large or small, this is an example where the geometric description is at least ambiguous.

Now consider open strings in such a background, and let us choose the radius of the circle to be the self-dual radius. In the circle direction we would now have two choices for boundary conditions for the open string ends: they might be fixed to a certain point on the circle (corresponding to a D-brane that looks point-like in the circle direction) or they might move freely along the circle (corresponding to a D-brane that looks one-dimensional on the circle). A detailed analysis of the underlying conformal field theory now reveals that there are far more possibilities to put boundary conditions to the open string ends. In fact it is even possible to continuously deform the boundary condition with fixed open string ends to the one where the ends move freely. This large class of boundary conditions does not have a direct geometric interpretation on the circle.

### Hilly landscape of boundary conditions

In order to improve our understanding of D-branes, it is important to work out a map of possible boundary conditions – and investigate whether some of the boundary theories are connected as in the example above where we could transform one boundary condition into the other. There can also be situations where the boundary theories are connected, but where during the flow from one to the other we pass through non-conformal boundary conditions. We can imagine the space of all not necessarily conformal boundary conditions for a given two-dimensional field theory as a landscape with hills and valleys, and the conformal boundary conditions are those that belong to extremal points, like the peak of a hill, the bottom of a valley or a saddle-point. If we are away from the extremal points, the boundary theory is not invariant under scale transformations, and one can investigate how the theory changes when we change the scale. Scale invariant theories look the same if you step back or if you take a magnifying glass, just like a fractal looks the same independent of how much you zoom into it. Non-invariant theories on the other hand do change when we zoom in or out, and we can draw the path in the space of boundary theories that we explore when we change the zoom. This transformation of the theory induced by the scaling is called 'renormalisation group flow'. This flow can be imagined to follow the gradient lines in the landscape, just like a very slow ball with high friction (see the illustration in figure 4).

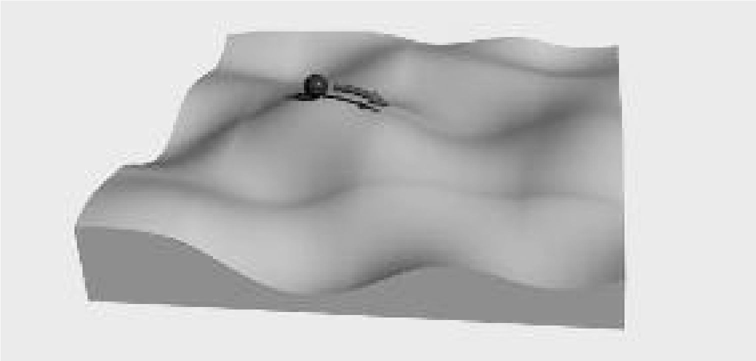


Fig.4: The conformal boundary conditions (and thus the D-brane configurations) can be imagined as extremal points in a hilly landscape – a peak of a hill, a bottom of a valley or a saddle-point. The renormalisation group flow that connects two extremal points correspond to the slow movement of a ball with very high friction that prevents the ball from overshooting the bottom of a valley.

Much work has been done to understand boundary conditions in two-dimensional conformal field theories in the last years. The results are not only relevant for string theory, but also have a relation to statistical physics and condensed matter physics. Recently we have made progress in the question of how this landscape of boundary conditions changes when the field theory is changed in the bulk. In other words we investigated how the space of possible D-brane configurations changes if the background space is deformed. A simple example of that is again a string moving in one dimension on a circle. At the selfdual radius the landscape of boundary conditions is flat and we have a large set of possible boundary conditions. Changing the background space can mean here to change the radius of the circle. The landscape then deforms and chains of hills and valleys are formed such that when we started with a generic boundary condition, the change in the radius would drive our boundary theory into a valley (see the illustration in figure 5).

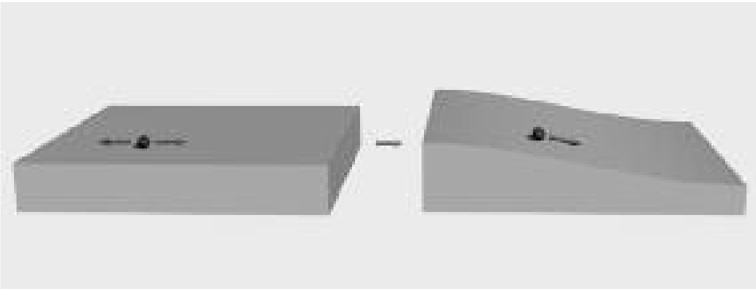


Fig.5: The landscape of boundary conditions for strings moving on the circle at the selfdual radius is flat (left picture), and boundary conditions can be smoothly deformed just as a ball can be moved without energy on a flat surface. When the radius is deformed, the scenery changes and there is a hill on one end and a valley at the other end.

### Time-dependent D-brane dynamics

What is the use of mapping out this landscape? Is there anything in string theory that corresponds to the renormalisation group flows from a hill to a valley? The conformal boundary conditions correspond to possible time-independent D-brane configurations. Being on top of a hill signals an instability of this configuration, and one might ask what happens when a mode corresponding to some unstable direction is excited. This is not yet completely understood, but the picture one should have in mind is the following: whereas the renormalisation group flows correspond to a slowly rolling, classical ball with high friction, the full open string theory should be thought of as a quantum mechanical ball without friction: it can overshoot valleys and it can quantum mechanically tunnel through hills. The dynamical processes that are connected with a flow from a hill to a valley could be decays of D-branes or D-branes forming bound states. Finally due to the emission of open and closed string radiation the system will settle in some bottom of a valley, but the whole process will in general be extremely complicated.

Time dependence in string theory is poorly understood, but its understanding is of fundamental importance, both conceptually and phenomenologically, when one wants to describe cosmological setups. A better understanding of the D-brane scenery and the possible dynamical relations that can be obtained from world-sheet methods should be useful to make progress in this direction.

Stefan Fredenhagen

# Laser Interferometry and Gravitational Wave Astronomy Division

## Nonclassical Light at the AEI: A "Squeezed" Review

Nonclassical states of light, such as squeezed states, have been an active field of research ever since their first experimental generation in the 1980s. In 2003 a new project was launched in Hannover. The ambitious goal of this project was to investigate – and eventually overcome – the so-called quantum limit in laser interferometric gravitational wave detectors. This limit stems from the fact that the minimum noise a light field carries in its two orthogonal quadratures (amplitude $X_1$ and phase $X_2$) is governed by Heisenberg's Uncertainty Principle. A coherent light field would therefore carry minimum – but nonzero – noise of equal strength (conveniently normalized to value of 1) in its amplitude and phase. A further reduction of the noise in one quadrature is only possible at the cost of increasing the noise in the other quadrature – such that the product of the variances satisfies the Heisenberg relation. In a phase-space diagram, which illustrates the quantum noise of a state, the circular shape of the coherent minimum uncertainty state would appear to be squeezed into an elliptical shape.

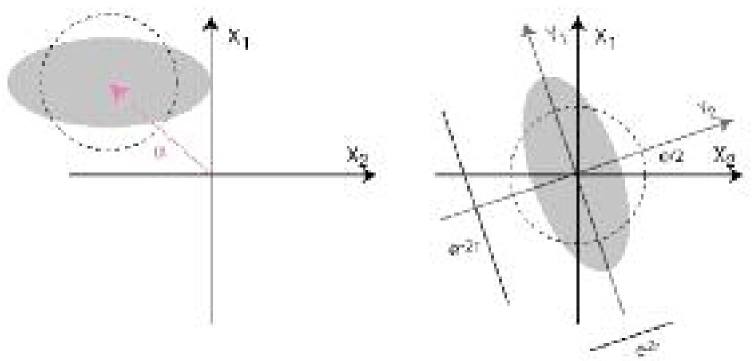



**Fig.1:** Phase-space representation of squeezed states. The left figure shows an amplitude-squeezed bright state with some coherent amplitude (red). In the right figure some arbitrary quadrature has been squeezed on a vacuum state.

The application of squeezed light for gravitational wave detection has been proposed more than 25 years ago. It is known that the quantum noise impinging on the detector of a gravitational wave interferometer originates from the vacuum-mode reflected off the dark port of the interferometer. Replacing the vacuum mode in this "open port" of the interferometer by a squeezed vacuum mode would then reduce the quantum noise observed by the detector. The compatibility of squeezed light with interferometric gravitational wave detection has already been experimentally demonstrated in 2005. In a sophisticated tabletop-experiment a dual-recycled Michelson-interferometer (scaled to 1/1000 of the GEO600 detector) has been operated fully controlled. Injection of a squeezed field into the dark port of the interferometer manifested the expected effect on the signal-to-noise ratio of an injected signal. Due to the reflection off the signal-recycling cavity the squeezed vacuum would experience a frequency-dependent phase-shift which needs to be compensated. The preparation of the squeezed vacuum field in this state-of-the-art experiment included the implementation of a frequency dependent orientation of the squeezing-ellipse in phase-space to counteract the frequency dependent behaviour of the detector's signal-recycling cavity. The frequency dependent character of the squeezed light has been confirmed by full quantum state tomography.

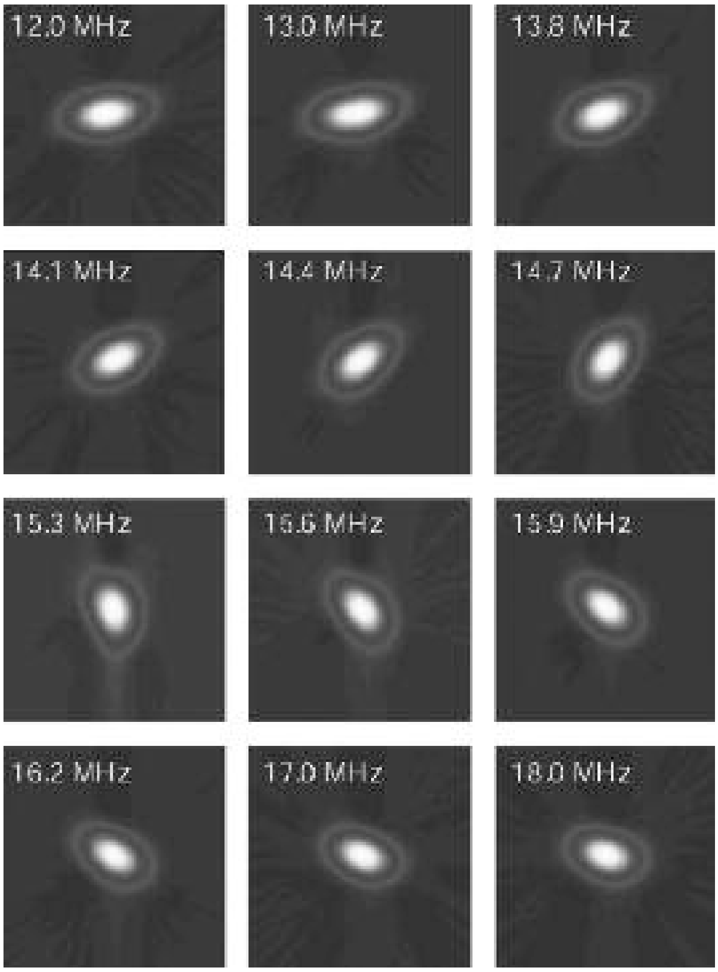



Fig.2: Measured Wigner-functions of one squeezed state at various sideband frequencies. The rotation of the Wigner-functions illustrates the frequency-dependent nature of this state's squeezing.

After this successful proof-of-principle demonstration of the power of squeezed states for gravitational wave detection, the project faced two major problems, both dealing with the real-world applicability of squeezed states. One was the strength of squeezing routinely achievable. While in the early days of squeezed states, 0.5 dB of nonclassical noise reduction was "a lot", various improvements of the squeezed light sources, together with new materials, allowed us to generate squeezing with a noise suppression of roughly 3.5 dB (equivalent to roughly a factor of two, on a linear scale) by the end of 2005. What everybody really envisaged was the magic number of 10 dB of nonclassical noise suppression, which could finally be achieved in 2007. This achievement was made possible by thoroughly minimising optical losses, using a monolithic squeezed light source, pushing the homodyne visibility beyond 99.8 percent and by utilising high-finesse modecleaners on all beams to reduce high-frequency phase noise. The application of squeezed light with a nonclassical noise suppression of 10 dB in a gravitational wave detector would instantly increase the observable volume of the universe by a factor 30.

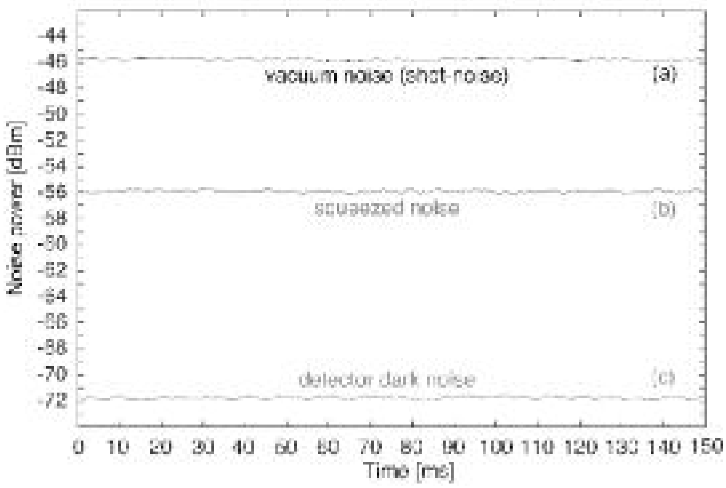



Fig.3: The plotted states' noise is ten times smaller than the noise of a vacuum state ("open port"). This corresponds to a nonclassical noise suppression of 10 dB. The vacuum-noise is sometimes regarded as the "shot-noise", because it can be thought of as originating from the statistically distributed arrival times of individual photons "crackling" onto the detector.

The second problem unfolds when looking at the spectrum of a squeezed state. Classical laser noise prevented the observation of squeezing at frequencies of the gravitational wave detection band for long times. GEO600 is sensitive in the frequency-regime between 10 Hz and 10 kHz where no squeezing could be generated. This problem was solved by introducing a new coherent control scheme using two subcarrier fields for complete control without introducing any laser-noise into the squeezed field. A thorough reduction of stray light entering the detector further reduced excess noise. At the end of a laborious period squeezing down to a frequency as low as 1 Hz could finally be demonstrated, covering the complete detection band of the GEO600 detector.

### Squeezing more out of GEO600

Currently, work on the construction of a squeezed light source for the actual integration into the GEO600 detector is being done. All of the know-how acquired in Hannover will go into this single source of squeezed light which will feature a performance in terms of squeezing strength as well as frequency range, far outperforming any other squeezed light source in the world. This squeezed light source (termed "GEO-squeezer") is planned to be built in the clean-room laboratories at the AEI in Hannover on a dedicated board of approximately 1 $m^2$ of size. It is planned that this "integrated setup" (consisting of three phase locked lasers, one hemilithic squeezed light source constructed from $MgO:LiNbO_3$, modecleaners, one homodyne-detector for characterization and all supporting optics and electronics) will be carried to the GEO600site as one functional unit.

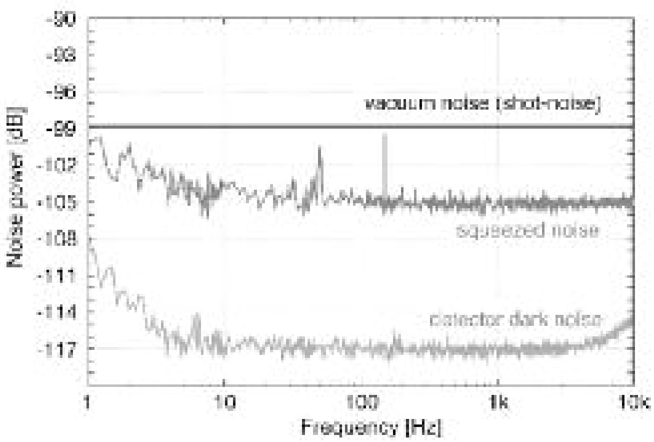



Fig.4: A spectrum showing squeezing over the entire detection band of the GEO600 gravitational wave detector.

### Quantum communication and the problem of decoherence

The continuing research on the construction of better sources for squeezed light also brought forth squeezed light sources that allowed experiments in the field of quantum information.

Continuous variable quantum information processing represents an appealing alternative to the traditional qubit based approaches. Many important quantum information processing primitives could be implemented deterministically with only linear optics, opticalparametric amplifiers (squeezers) and balanced homodyne detection. In a real-world application of a typical quantum information protocol the effect of decoherence heavily degrades the nonclassical properties of the states. One of the key techniques for quantum-information processing and for long-distance quantum communication is the so-called distillation of quantum states. This term describes the process of extracting from a large number of decoherent (and therefore useless) quantum states a smaller number of strongly nonclassical states, thereby forming the building block of what is to become a quantum repeater, which will allow for the distribution of e.g. entangled states over large distances of several thousand kilometers.

The first successful demonstration of a two-copy distillation protocol for squeezed states was conducted in 2006. In the subsequent investigation the protocol exhibited a number of interesting features that have been thoroughly investigated. The techniques developed could be of great use when addressing the distillation of entangled states.

Alexander Franzen

## Laser Systems for Gravitational-Wave Detection in Space

While the first generation of ground-based gravitational-wave detectors such as GEO600 take data, work on the space-based gravitational wave detector Laser Interferometer Space Antenna (LISA) and its technology demonstrator mission LISA Pathfinder is progressing well.

The ESA/NASA collaborative mission LISA is to be launched in 2018 and aims to measure gravitational waves with frequencies between 0.1 mHz and 1 Hz. Since this frequency regime is inaccessible from earth, LISA forms an ideal complement to the ground-based detectors.

### The space-based gravitational-wave detector LISA

LISA consists of three satellites separated by five million km in a triangular configuration that orbits the sun following the earth. Similar to the ground-based interferometers LISA works in principle as a Michelson interferometer. Coherent light is sent along two long paths, reflected, and combined (interfered) again. Length changes of the two paths change the interference pattern - those interference pattern changes can reveal gravitational waves.

Unlike ground-based detectors, LISA cannot use mirrors to reflect light back from one satellite to another. Instead, one satellite sends laser light to the other two satellites. There the light is detected and the phase of the received light is measured and transferred to local lasers that send light back to the first satellite. Here, the phase of both received light beams is compared and can reveal gravitational waves.

The phase measurements on board the satellites require every satellite to carry its own precision clock as phase reference. Unfortunately, the clocks available are by far not precise enough for the detection of gravitational waves. As a resort, the clocks will be compared between spacecraft and the clock jitter between spacecraft will be removed in post-processing. In order to compare clock information between spacecraft, the clock information will be imposed on the laser light and sent to the distant satellites where it can be compared to the local clock.

Currently it is envisaged for LISA to use the LISA Pathfinder laser that will be discussed below. Since LISA requires 30 times more power than LISA Pathfinder, optical amplifiers will be used to boost the power of the LISA Pathfinder laser. These optical amplifiers, as well as other components in the optical chain between satellites, can alter the clock information that is transmitted from satellite to satellite due to changes in e. g. temperature, length, or power. For the clock jitter removal to work properly, this additional noise must be very small and negligible compared to the clock jitter itself.

We have built a test setup to investigate optical amplifiers. Our setup measures by how much the clock information that is transmitted through the amplifiers is altered. Laser Zentrum Hannover e. V. has supplied different amplifier breadboards that are being tested in our laboratory. The challenges we had to meet include a good thermal isolation of the setup to fight temperature drifts, very low-noise electronics, and we had to develop our own phase measurement system. The commercially available phase measurement system we initially used was not sensitive enough.

An intermediate result of our measurements is shown in figure 1. In principle, the requirement has been met. We will further improve the setup and investigate the effect of power changes on the phase characteristics of optical amplifiers, among other relationships.

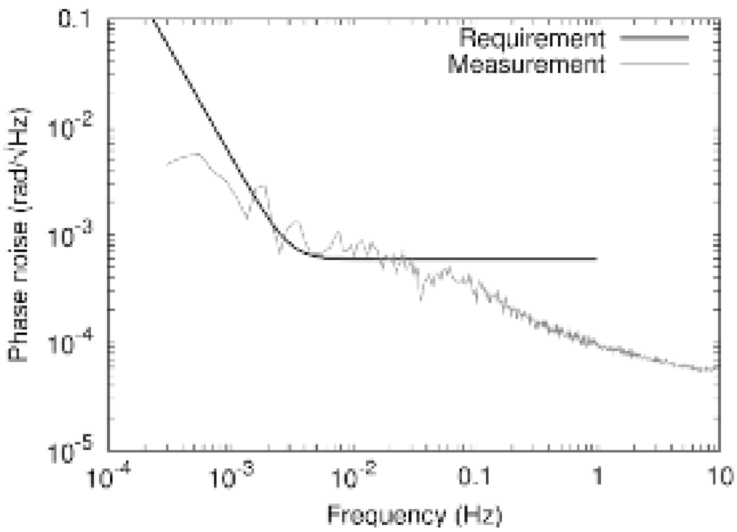



Fig.1: Phase characteristics of a breadboard optical amplifier.

## LISA's technology demonstrator LISA Pathfinder

Since LISA poses many technical challenges that cannot be all verified on earth, the technology demonstrator mission LISA Pathfinder will be flown. The launch of this ESA mission is currently scheduled for 2010. As LISA, LISA Pathfinder also requires a precise laser. In particular, the power and frequency (colour) of the laser light must be stable.

LISA's interferometer arms are defined by so-called test masses – metal cubes inside the satellites. In both LISA and LISA Pathfinder, a small fraction of laser light will be reflected from a test mass to measure its position. Light reflected from a test mass exerts a force on that test mass. Varying light powers would cause varying forces on the test mass. Hence, the light power must be stable. Not only that, a change in laser frequency would mimic length changes between test masses. Hence, the laser frequency must also be stable.

To achieve best power and frequency stability, an intrinsically stable laser design has been chosen – a so-called nonplanar ring oscillator. In space projects, it is common practise to build multiple versions of hardware. The version that will fly on the mission is called flight model. The first hardware that is built is called breadboard. Usually the breadboard shows the principle functionality of the component, but it is not space qualified, not light-weight or compact. A big step towards the flight model is achieved with the so-called engineering model. It is a flight model look-alike. Ideally, it is as similar to the flight model as possible while using less expensive components that have not the same qualification level as parts for flight models.

Fig.2: Engineering model of the LISA Pathfinder laser.

The laser for LISA Pathfinder is at the engineering model level. After this version of the laser was built by Tesat Spacecom it was sent to our institute for an independent inspection. A picture of the laser is shown in figure 2. For the laser tests at our institute the laser was placed on a temperature stabilized base plate and placed in a vacuum chamber. Then, among other properties, the power fluctuations and frequency fluctuations were measured. The power fluctuations were relatively easy to measure. A photo detector was used to measure the laser output power and a spectrum analyzer was used to obtain the graph from figure 3. The laser fulfils the requirement.

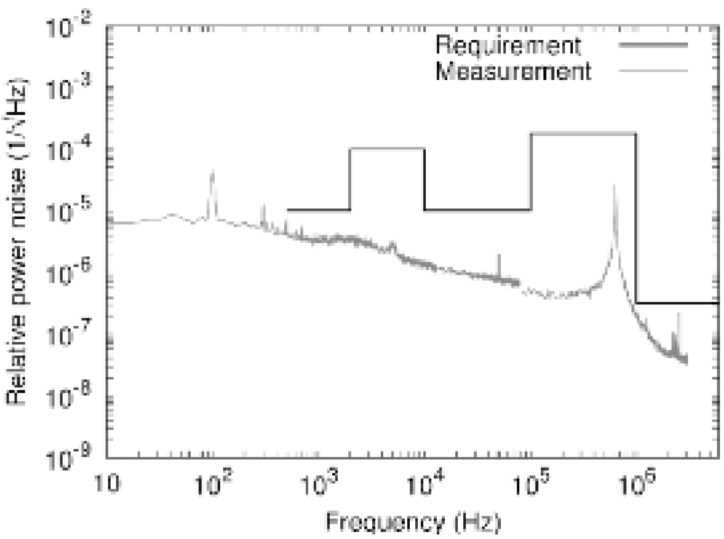



Fig.3: Power fluctuations of the LISA Pathfinder laser.

The frequency fluctuations were more difficult to determine, since laser frequency cannot be measured directly to the precision required - the light field oscillates too fast. Therefore, a stable frequency reference was used and the difference frequency between the stable laser and the laser under test was measured.

The stable frequency reference is a setup filling a complete optical table in the institute. The heart of this setup are so-called optical resonators placed in vacuum chambers with thermal shields. These optical resonators define stable frequencies. The difference frequency between light from a laser and a frequency defined by an optical resonator was measured and actively fed back to the laser, such that it always stayed on the resonator frequency. The measurement result is shown in Figure 4. The measured frequency fluctuations fulfilled the requirement.

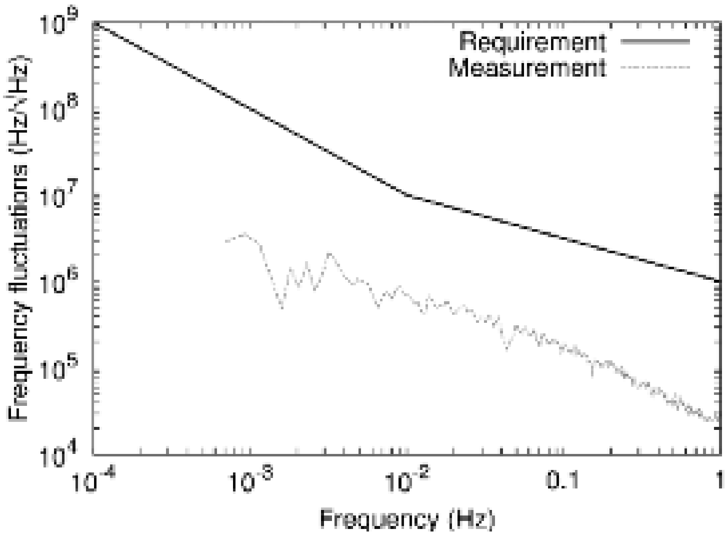



Fig.4: Frequency fluctuations of the LISA Pathfinder laser.

This measurement method relies on the fact that the frequency fluctuations of the reference laser are much smaller than those of the laser under test. In order to verify this, a second laser was stabilized in frequency to a second, independent optical resonator. Then, the frequency fluctuations of both independently stabilized lasers were measured against each other - and found to be orders of magnitude below the frequency fluctuations of the laser under test.

Besides the laser for LISA Pathfinder that has been tested at the institute, more and more engineering models will arrive at our institute for thorough testing and investigation of compatibility between the components. For this purpose, a complete laboratory has been reserved and dedicated to these tests.

In the future engineering models will be replaced by flight models until as many components as possible and their interplay have been characterized to ensure a successful mission.

Michael Tröbs

## Bringing Massive Computing Power to the Search for Gravitational Waves

This section highlights two different projects, the newly-constructed ATLAS computing cluster at AEI Hannover, and the Einstein@Home project. In different ways, these two projects address the same issue: very sensitive searches for weak gravitational wave signals require extremely large numbers of computing cycles.

### ATLAS

The most important research tool of the new Division is a specialized computing facility for data-intensive data analysis. During 2006 and 2007, a facility for this purpose was designed and constructed in the basement of the AEI Hannover Laboratory building. Starting in late 2007, a specialized computer cluster, ATLAS, was installed into this facility.

ATLAS is a general-purpose compute cluster, primarily intended for the analysis of gravitational-wave detector data. It has 5368 CPU cores in compute nodes with 2GB of memory per core, and 1.2 Petabytes (1.2 x $10^{15}$ Byte) of disk storage space (central and distributed). The main design goal was to provide very high computing throughput at very low cost, primarily for 'trivially parallel' analysis. However ATLAS can also efficiently run highly-parallel low-latency codes.

According to the June 2008 Top-500 list, ATLAS is the 58th fastest computer in the world and the 6th fastest in Germany. It is currently the fastest computer in the world based on Gigabit Ethernet. ATLAS makes use of a mixture of 1Gb/s and 10Gb/s ethernet switching provided by an American start-up company, Woven Systems. This innovative technology is unique because it provides dynamic routing of packets through a switching fabric which is dynamically reconfigured on the microsecond time scale, to avoid congestion in the mid-level fabric of the switch.

The ATLAS computing cluster

To put some of these numbers into perspective, ATLAS's data storage capacity (1.2 PB) is about 25% of the total data storage capacity of CERN, and is enough to store several copies of every web page indexed by the Google search engine. The design of ATLAS allows every byte of this data to be examined in the space of just a few hours.

Henning Fehrmann, Bruce Allen and Carsten Aulbert (f.l.t.r.)

ATLAS is located in a custom-designed data center in the basement of the AEI Laboratory building. The compute servers and storage servers are mounted in sealed racks which transfer the heat from the computers into water. Chilled water is provided by a dedicated chilling plant consisting of three external 200kW chillers and a heat-exchanger system. All the cluster-room electrical power is provided by a dedicated 640kW UPS system. This provides a minimum of six minutes runtime if mains power is lost, so that the computing systems can be smoothly shut down without any data loss or file system corruption.

ATLAS is used by scientists within the AEI and by members of the LIGO Scientific Collaboration (LSC) from outside the AEI. It is (by about a factor of three) the most powerful computing facilities within the LSC and is being used to carry out inspiral, burst and Continuous Wave (CW) analysis of one year of triple-coincident data from the LIGO S5 Science Run.

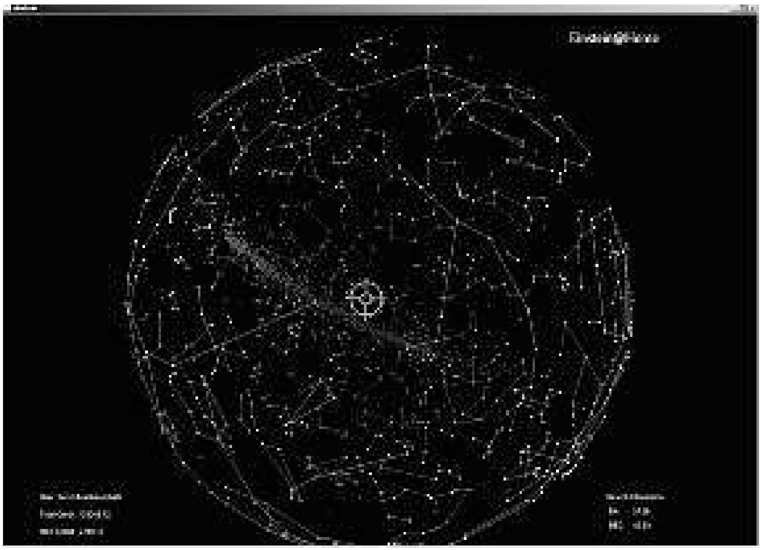
### Einstein at Home

The Division plays a leading role in the development and operation of the Einstein@Home project, which uses computer time volunteered by the general public to carry out a large-scale blind search for unknown continuous gravitational wave sources. Working in close collaboration with AEI scientists based in Golm, a new search method has been implemented which combines the most sensitive coherent F-statistic technique with the current state-of-the-art Hough incoherent search technique. A first search using approximately 3000 hours of LIGO data from the start of the S5 run is just being completed, and a second search using 5000 hours from latter part of the S5 run was recently launched.

The Division is currently porting the main Einstein@Home Continuous Wave search application to run on the graphics-coprocessor boards found in many modern desktop PCs. These graphics coprocessor boards contain floating-point pipelines which can perform operations at hundreds of Gigaflops, more than an order of magnitude faster than the general-purpose floating point units inside the computer's CPU. This porting process is non-trivial because the graphics coprocessors are typically organized to perform SIMD operations (SIMD = Single Instruction Multiple Data) on hundreds or thousands of different data objects. But it is worth the effort, because this promises to increase the CPU power available to Einstein@Home by up to an order of magnitude. It also provides a case study for the future of large-scale cluster computing, where CPUs are expected to contain tens to hundreds of tightly-coupled cores, each with independent floating point units.

The Einstein@Home project gets more than 200 million CPU hours per year of processing power from the general public. However these results then need postprocessing. The postprocessing of results from

Einstein@Home search of S4 data has been completed and published (unfortunately no CW sources were found) and the postprocessing of the first S5 results currently is underway on the ATLAS cluster.




Einstein@Home screensaver

The Division is preparing to launch a new type of Einstein@Home search, for radio pulsars in very-short-period binaries, using radio data from Arecibo, the largest radio telescope in the world, obtained from the PALFA Collaboration. Current blind 'acceleration' searches for new radio pulsars use 5-minute data segments. The analysis loses sensitivity if the pulsar is in a binary with a period shorter than ten times this observation time, or 50 minutes. By using the tremendous processing power of Einstein@Home, we can demodulate for all possible signals from binaries with periods as short as ten minutes. Significant numbers of such short-period systems are expected to occur in our Galaxy. They are the most relativistic binaries and are therefore important for gravitational wave science. For example the shortest-period binaries set the strongest limits on the expected rate of binary inspiral signals, a benchmark source for ground-based detectors. They will also serve as important LISA calibration sources.

Bruce Allen

## Probing the String/Gauge Duality with Integrable Spin Chains

### Spectrum of gauge theories and duality to strings

One of the oldest dreams of theoretical particle physics is to compute the masses of hadrons, in particular those of the proton and neutron, from a fundamental theory. The hadrons are composite particles made from a few quarks surrounded by a dense cloud of virtual particles, such as gluons and further quarks (figure 1). The main obstacle in computing their masses is that quantum chromodynamics (QCD), the theory of the interactions between quarks and gluons, is strongly coupled in the low-energy regime relevant to hadron masses: Standard perturbative quantum field theoretical computations using Feynman diagrams are designed for weak interactions between the particles. To access the intermediate-coupling regime many perturbative orders of Feynman diagrams would have to be evaluated. Unfortunately, higher-order calculations are excessively challenging and the available data is far from sufficient to probe the strong-coupling regime. Even if this was possible, the mathematical series defined by the Feynman diagrams is merely asymptotic and does not define an approximate number when the coupling is too strong.

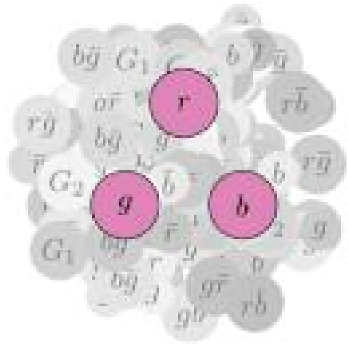


**Fig.1:** A hadron made from three quarks is surrounded by a dense cloud of virtual quarks and gluons.

We have recently achieved to overcome these obstacles and have computed particle masses albeit in a slightly different context relevant to the understanding of dualities between gauge and string theories. The gauge theory model in question ($N$ = 4 SYM) is a highly supersymmetric variant of QCD. Ten years ago J. Maldacena made the remarkable conjecture that this $N$ = 4 SYM model is exactly dual to a supersymmetric string theory on a curved spacetime (called $AdS_5 \times S^5$). A similar duality is expected to hold also for less (super)symmetric models. The duality promises to shed light onto the strong-coupling behaviour of QCD (where string-like effects have been observed) as well as on quantum gravity (in the guise of string theory). However, it appears very hard to prove or even test the conjecture because the easily-accessible weak-coupling regime of one model is mapped to the hardly-accessible strong-coupling regime of the other.

The $N$ = 4 SYM model is simpler than QCD in some respects, namely it is a conformal field theory (CFT). Conformal symmetry poses strong constraints on the observables of the theory, e.g., all particles must be exactly massless. Note that the notion of particle mass is replaced by the so-called conformal dimension in a CFT. We thus aim to compute the spectrum of conformal dimensions of composite particles.

### Planar limit and integrability

A further simplification comes about with the planar limit introduced by G. 't Hooft, where a majority of Feynman diagrams (those with self-intersections when drawn on a plane) becomes irrelevant. The corresponding concept in string theory is the absence of string interactions where pieces of string split up or join. For composite particles it implies that all constituent particles have to chain up linearly in some internal space. A composite particle is thus characterized uniquely by the sequence of spins of the constituent gluons and quarks (figure 2);

such an object is called a spin chain which is known and applied predominantly in condensed matter theory for a description of magnetism and superconductivity. In addition, the emergent one-dimensionality of the chain in the otherwise three-dimensional field theory model makes the duality to the one-dimensional objects of string theory more apparent.

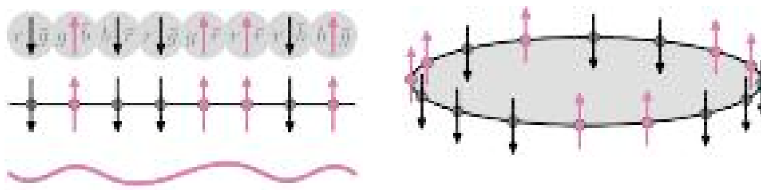


Fig.2: *Left:* Particles combine to form a spin chain. Similarly, a piece of string resembles a spin chain.
*Right:* a closed spin chain.

The planar limit not only makes the Feynman series properly convergent, but in $N = 4$ SYM it also leads to several additional surprising properties. One of them is the apparent exact integrability which simplifies the computation of the spectrum of conformal dimensions drastically. Some of the milestones in this field of research until the end of 2005 include: Integrable structures were discovered in $N = 4$ SYM (2002/2003) and the dual string theory (2003/2004). Integrability was then applied to set up Bethe equations which determine the leading-order spectrum of $N = 4$ SYM efficiently (2002/2003). The counterpart to describe the spectrum in classical string theory are spectral curves (2004/2005). The next step consisted in promoting these structures to asymptotic Bethe equations which reproduce successfully quantum corrections in both types of models (2004/2005). These developments have laid the foundation for the determination of conformal dimensions in the intermediate-coupling regime and thus to a very non-trivial confirmation of the string/gauge duality. In most of these discoveries AEI scientists as well as frequent visitors to the institute have played a pioneering role (see also the AEI Annual Reports 2003-2005).

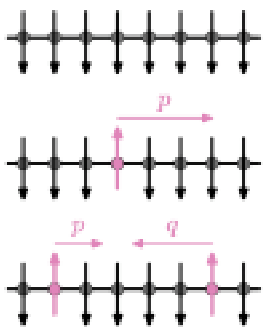



Fig.3: *Top:* Ferromagnetic vacuum.
*Middle:* One magnon with momentum **p**.
*Bottom:* Two magnons about to collide and scatter.

**Scattering picture**

The asymptotic Bethe equations are most naturally obtained from a scattering picture, the so-called asymptotic coordinate Bethe ansatz, which was applied by M. Staudacher (2004) to N = 4 SYM: In the spin chain one starts with a (ferromagnetic) vacuum state where all spins are perfectly aligned. In this vacuum one flips a single spin and attributes to it a certain momentum along the chain (figure 3). This excitation of the vacuum is commonly referred to as a magnon particle. States consisting of more than one magnon are determined through a scattering matrix describing the phase shifts due to scattering processes of the particles (figure 4). The scattering matrix is the main ingredient for setting up the asymptotic Bethe equations to determine the spectrum. Curiously, one obtains an identical picture from the physical excitations in string theory (Frolov et al, Arutyunov et al, Hofman & Maldacena 2006) (figure 5). Thus one can prove the matching of spectra by showing that the scattering matrices for both types of models agree.

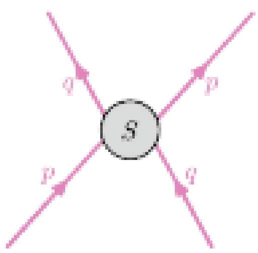



Fig.4: Two particles scatter (scattering matrix)and scatter.

The next crucial step consisted in applying symmetry (which is the same for both models) to the determination of the scattering matrix (Beisert, 2005). It turned out that the scattering matrix is completely constrained up to one overall function in the magnon momenta and the coupling constant, the so-called dressing phase. Thus the two models can possibly only differ in this function, and the goal was to obtain both phase functions and compare them.

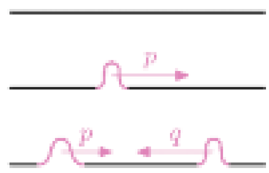



Fig.5: *Top*: a straight piece of string. *Middle:* a moving lump as an excitation. *Bottom:* two lumps about to scatter.

### Dressing phase and interpolation

The main development of 2006 in this research field was the proposal for a phase function which interpolates smoothly between perturbative string and gauge theory. First R. Janik (Jagiellonian U., Cracow) assumed crossing symmetry, which is a feature of most known scattering matrices, to set up an equation for the phase. Next G. Arutyunov (Utrecht U.) and S. Frolov (AEI) demonstrated that the perturbative phase for string theory apparently obeys this equation. Finally, the author of this research highlight made proposals for the complete phase for perturbative string theory (with E. Lopez, U.A. Madrid, and R. Hernandez, CERN) and for perturbative $N = 4$ SYM (with B. Eden, Utrecht U., and M. Staudacher, AEI). We argued that the proposals agree with all previous results, in particular with the crossing equation and with a remarkable fourth-order calculation (Feynman diagrams with four loops) in $N = 4$ SYM performed independently and simultaneously (Bern et al). Furthermore we demonstrated that our two proposals are the strong- and weak-coupling expansions of one and the same function (figure 6). Consequently, the spectrum of conformal dimensions following from the asymptotic Bethe equations will interpolate smoothly between weak and strong coupling in full agreement with the string/gauge duality. Our proposal thus shows that there exists a minimal interpolation between gauge and string theory consistent with all available data. Whether the proposal actually applies to the $N = 4$ SYM model remains to be proved rigorously, but already several follow-up studies have verified predictions based on our proposal.

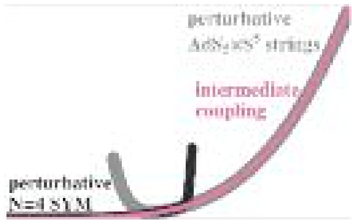



Fig.6: A function interpolating smoothly between the perturbative gauge and string theory (with weak- and strong-coupling expansions)

### Finite size and algebraic formulation

Two of the main developments which were pursued at the AEI in 2007 dealt with finite-size effects and with the algebraic formulation of integrability. Finite-size effects refer to the fact that the asymptotic Bethe equations do not describe the spectrum for finite-length spin chain states exactly, but only up to some minute corrections. M. Staudacher and A. Rej (AEI/IMPRS) together with collaborators from U. Hamburg and INP St. Petersburg found further compelling evidence for this fact by discovering an inconsistency of some finite-length predictions of the asymptotic Bethe equations with predictions of a different method. The goal in this context is thus to find equations to replace the asymptotic Bethe equations which describe the exact spectrum of scaling dimensions with all finite-size corrections. Two of the promising approaches are called the thermodynamic Bethe ansatz and non-linear integral equations. A group of AEI scientists is actively working on the latter method, and has already published initial steps in this direction.

On a different account, the key to deriving the scattering matrix discussed above were symmetries. An extended study of the symmetries performed at the AEI led to the discovery that the scattering matrix is equivalent to the R-matrix of the one-dimensional Hubbard model (an important model in condensed matter theory and for the study of superconductivity). The finding shows that the integrable structure of the Hubbard model is in fact based on the supersymmetry algebra su(2|2) – quite to the surprise of condensed matter theorists. It demonstrates once again that there exist close ties between high-energy and condensed matter theory and that results in the area of integrable systems can be inspiring to both fields.

In general, integrable structures are intimately related to hidden infinite-dimensional symmetry algebras of Yangian or quantum affine type. For example we have shown that the scattering matrix displays a Yangian symmetry. With F. Spill (Humboldt U., Berlin) we have then identified and studied the bialgebra that underlies that classical limit of the scattering matrix. For a complete mathematical description it remains to properly quantize the bialgebra to a Yangian and to determine its universal R-matrix.

Niklas Beisert

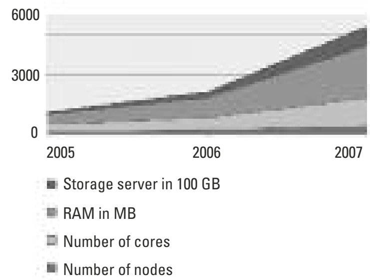
## Activities and Highlights of the IT Department in 2006 and 2007

During the past years a strong focus was laid on stability, redundancy and reliability. As result the IT services are available 24 hours on 7 days a week 52 weeks per year. Unplanned down times were almost caused by power failures outside the Institute or due to construction work in the buildings. Only a few shut downs were necessary for upgrades, hardware exchanges or the move of servers to new computer rooms. Nevertheless the IT department is proud to have reached an all over all uptime of about 99% and that holds true for both branches in Hanover and in Potsdam.

This result is worth to mention, taking into account that in 2006 the IT department had to manage a lot of exiting projects in addition to keep the infrastructure running smoothly. The planning and finally the move of the IT infrastructure into the extension building in Potsdam was the most time consuming project. The Numerical Relativity group moved back from Benzstraße to the MPI Campus in Golm, the server and storage systems moved from their cramped and badly cooled facilities to the new server rooms. The clusters moved from various places to the spacious and optimal air-conditioned new cluster rooms. The cluster Belladonna for example returned to the campus from its exile at the Astrophysical Institute Potsdam, where it has been hosted during the last year.

With the establishment of the new department of Prof. B. Allen in Hanover begin of 2007 the demand for additional and different computer infrastructure grew. But also the need for communication tools increased, enabling easy and ad hoc communication between AEI members in Hanover and Potsdam. Since long time audio-conference systems are in daily use and nowadays more and more video conference techniques play an important role. Another big challenge for the IT department is to unify IT devices and tools in Hanover and Potsdam.

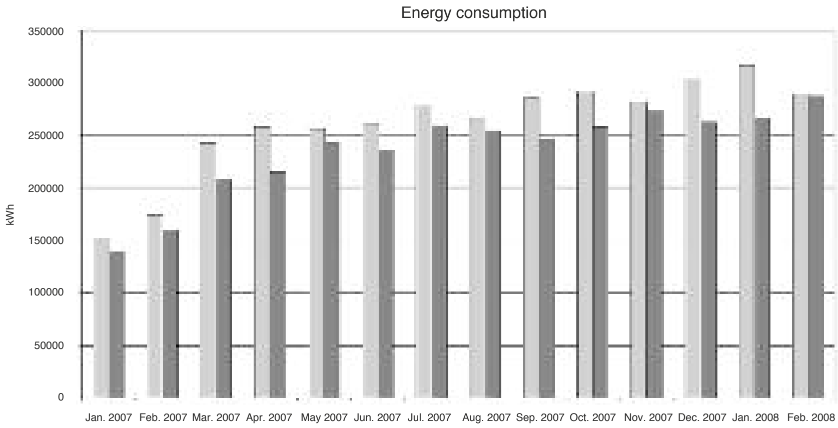
### High Performance Computing




| Purchase date | Cluster name | Number compute nodes | per node # cores/ memory/ disk space/ processor type | Total storage capacity | Highlights | Main user group |
|---|---|---|---|---|---|---|
| 12.2005 | Belladonna | 64 | 4/8 GB/ 80 GB/ AMD Opteron 275 | 16 TB | Infiniband Interconnect network | Numerical Relativity group |
| 11.2006 | Morgane | 615 | 2/2 GB/ 160 GB/ AMD Opteron 185 | 120 TB | Mirrored storage of compute nodes, cascaded network | Gravitational Waves group only |
| 12.2006 | Damiana | 168 | 4/8 GB/ 250 GB/ Intel XEON 5160 Woodcrest | 50 TB | Infiniband Interconnect network, rank #192 in TOP 500 list in June 2007 | Numerical Relativity group |
| 04.2007 | Tuffstein | 4 | 4/4 GB/ 260 GB/ Intel XEON 5130 Woodcrest | 4,5 TB | Per node a GRAPES6-BLX64 card | Astrophysical Relativity division |
| 01.2008 | Damiana extension | 28 | 4/8 GB/ 250 GB/ Intel XEON 5160 Woodcrest | | | Grant from the D-Grid project (Astro-Grid) |

Top: Overview of the increase in computer power and disk space 2005-2007
Left: Overview of the high performance compute clusters that have been purchased during the last two years.

The table (preceding page) gives an overview of the high performance compute clusters that have been purchased during the last two years. All clusters (except for Tuffstein) were funded by the central administration of the Max Planck Society. The money for the 28 additional nodes of the Damiana cluster was granted by the D-Grid Project. With this extension Damiana became part of the D-Grid resources.




The clusters' energy consumption for power and cooling in 2007/2008. The increase of energy consumption corresponds to the installation of the clusters Morgane and Damiana begin 2007 and the extension of Damiana by 28 nodes in January 2008.

Power
Cooling

Tuffstein is a rather special cluster. It consists of four GRAPE nodes with fast communication. When it is used for a parallel calculation it can achieve ~0.5 Teraflops; i.e. it is equivalent to a "regular" Beowulf-alike cluster of a bit more than 400 PCs.

### Events

Being responsible for the technical infrastructure, the IT department is involved in all events at AEI. The streaming of conference talks on the Internet was first performed during the Einstein Conference in 2005. Since then we are streaming and archiving whole conferences. The streams are archived and can be accessed via the WEB.

For more information on High Performance Computing please visit *http://supercomputers.aei.mpg.de*

Christa Hausmann-Jamin

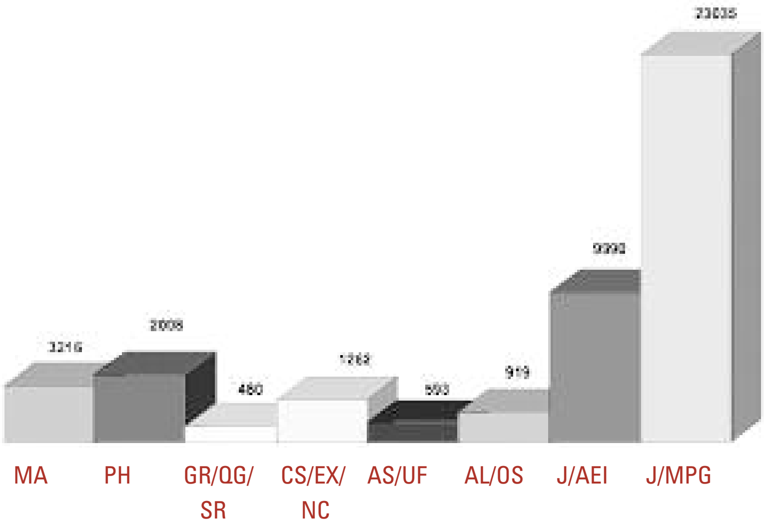
## Activities and Highlights of the Library in 2006 and 2007

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 by appointment. Two librarians manage the library: Mrs. Elisabeth Schlenk, the head of the library, and Mrs. Anja Lehmann.

The collection increases continuously. By the end of 2007 our catalogue listed 8.478 monographs and conference reports, 9.990 bound journal volumes, 140 printed journal subscriptions and online access to journals covered by the so called 'Grundversorgung', i.e. the Max Planck Society (MPG) secured a permanent right to full text access to at least 23.035 journal titles.

As library tasks became daily routine we tried to find new challenges to facilitate and to optimize the convenience of the library for the scientists.

An example is the eDoc server (http://edoc.mpg.de). The intention of the electronic document server is to increase the visibility of the intellectual output of the MPG and to add to the worldwide virtual repository of high-quality scientific information. In September 2002 we started with the project and since that time we are a so-called power user (2670 documents stored; most of them with full text files and OpenAccess).




**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:** Physics, **QG:** Quantum Gravity, **SR:** Special Relativity, **UF:** Unified Field Theory & Other Theories of Gravitation, **J/AEI:** bound journal volumes at AEI, **J/MPG:** online access to journals at MPG

With the foundation of the Max Planck Digital Library (MPDL) in January 2007 a further step towards centralization was taken. The MPDL is a scientific service unit within the MPG responsible for the strategic planning, development and operation of the digital infrastructures necessary for providing the institutes with scientific information and for supporting web-based scholarly communication.

In this context our institute participates in a new pilot project called 'Publication Management' (PubMan). PubMan can be regarded as the continuation of eDoc but the design is still in progress. The various pilot institutes should be recruited by 'Early Adaptors'. Headed by the AEI library we build a 'PubMan Cluster' with the two other institutes on the campus to bundle the activities, to allow networking synergies and to create an optimal testbed for adaption by other Max Planck Institutes.

In respect to the various visions of its activities (Catalogue Enrichment, e-Books, Virtual Library, Open Access, Document Ordering, Electronic Resource Management) the MPDL tries to strengthen the role of the librarians to act as longstanding and knowledgeable interlocutors. But even if we agree with these visions the needs of the scientists in our institute have top priority.

Elisabeth Schlenk

## Open Access

Open access (OA) means barrier-free access to all academic work on the Internet. Scientific publications and data are accessible online free of charge for any interested user. It is a current and trend-setting topic with many supporters worldwide and a mission for modern, online publishing of academic work with great potential and advantages for all parties involved: researchers, authors, and the publishers. Exorbitant cost for journals, long publication processes and restricted access to published articles were the initial motivations for the development of OA.

Three declarations mark the milestones of the OA-movement: the Budapest Declaration (February 2002), the Bethesda Declaration (June 2003) and the Berlin Declaration on Open Access (October 2003). The Berlin Declaration is the most comprehensive one because besides research organizations also museums, archives and libraries are involved. The integration of substantial raw data could turn out to be a significant attribute for transparency, quality assurance and scientific value. Organizations signing the Berlin Declaration are interested in the further promotion of the new open access paradigm to gain the most benefit for science and society. Therefore they intend to make progress by

- encouraging our researchers/grant recipients to publish their work according to the principles of the open access paradigm;
- encouraging the holders of cultural heritage to support open access by providing their resources on the Internet;
- developing means and ways to evaluate open access contributions and online-journals in order to maintain the standards of quality assurance and good scientific practice;
- advocating that open access publication be recognized in promotion and tenure evaluation;
- advocating the intrinsic merit of contributions to an open access infrastructure by software tool development, content provision, metadata creation, or the publication of individual articles.

Establishing open access as a worthwhile procedure ideally requires the active commitment of each and every individual producer of scientific knowledge and holder of cultural heritage.
Open access contributions including original scientific research results, metadata, raw data, source materials, digital representations of pictorial and graphical materials, scholarly multimedia material must satisfy the following conditions:

- Authors and right holders of such contributions grant to all users a free, irrevocable, worldwide, right of access to, and a license to copy, use, distribute, transmit and display the work publicly and to make and distribute derivative works, in any digital medium for any responsible purpose, subject to proper attribution of authorship (community standards, will continue to provide the mechanism for enforcement of proper attribution and responsible use of the published work, as they do now), as well as the right to make small numbers of printed copies for their personal use.

- A complete version of the work and all supplemental materials, including a copy of the permission as stated above, in an appropriate standard electronic format is deposited (and thus published) in at least one online repository using suitable technical standards (such as the Open Archive definitions) that is supported and maintained by an academic institution, scholarly society, government agency, or other well-established organization that seeks to enable open access, unrestricted distribution, inter operability, and long-term archiving.

There are two main currents in the open access movement:

1. **Green Road to OA**
   Authors publish in a subscription journal, but in addition make their articles freely accessible online, usually by depositing them in either an institutional repository (such as eDoc) or in a central repository (such as arXiv). The deposit can be in the form of a peer-reviewed postprint or a non-peer-reviewed preprint.
   One barrier for that way is the assignment of copyright and the scientific organizations are in demand to help and to negotiate acceptable license agreements.

2. **Gold Road to OA**
   Authors publish in open access journals (such as Journal of High Energy Physics) that make their articles freely accessible online immediately upon publication.

This way of publication requires an adequate appreciation by referees, appointment committees and scientific institutions and it is a way that can be paved by established scientist.

For the last years the OA-movement is growing continuously. In the discussion on the OA-policy publishers, authors, readers and librarians represent and voice their respective interests.

Reasons to publish in Open Access journals are:
- raised visibility
- higher citation/impact factor
- will be reviewed by content and not by the jornal-title
- authors keep the copyright
- are not limited by page
- multi medial illustrations
- allows complex links to other sources and innovative forms of publication
- allows full-text search
- can be translated automatically
- allows a complete overview on a specialist area
- low-priced (for users/readers free of charge)
- sustained and provided worldwide

The Directory of Open Access Journals (DOAJ, *http://www.doaj.org*) contains 3000 open access journals (December 2007), i.e. quality controlled scientific and scholarly electronic journals that are freely available on the web.

**The Open Access movement within the Max Planck Society**

The Max Planck Society is a leading advocate of Open Access paradigm in Germany and on the international level. While independent Open Access policies are pursued at individual Max Planck Institutes it is the responsibility of the Max Planck Open Access Unit to support the institutes in these activities and to help formulate a coherent Open Access policy for Max Planck Society as a whole.

Main tasks of the Max Planck Open Access Unit are:

- Support of the Berlin Process which was started in 2003 with the first Berlin Conference and the instigation of the Berlin Declaration

- Assistance of the Open Access activities at the Max Planck Institutes, e.g. via the Max Planck Open Access Network

- Coordination of the Max Planck Open Access policy within the German Research Alliance

- Advocacy of the Open Access paradigm nationally and internationally

- Communication and co-operation with publishers to support the set-up of sustainable business models which facilitate Open Access compliant publishing by scientists

The Max Planck Open Access Unit's long term aim is to assist in making all knowledge produced at the Max Planck Institutes freely available via the internet and by this help to achieve the goal set by the Berlin Declaration "to constitute a global and interactive representation of human knowledge, including cultural heritage and the guarantee of worldwide access."

Elisabeth Schlenk

For further information please visit:
*http://www.soros.org/openaccess/g/index.shtml*
(Budapest Declaration)

*http:// www.earlham.edu/~peter/fos/bethesda.htm*
(Bethesda Declaration)

*http://oa.mpg.de/index.html*
(Berlin Declaration on Open Access)

*http://mpdl.mpg.de/*
(Max Planck Digital Library
Contact: Dr. Christoph Bruch, bruch@mpdl.mpg.de)

### Workshop "New Frontiers in Numerical Relativity"
### AEI Golm, 17 - 21 July 2006

The numerical relativity group has organized a workshop with the goal of exploring and understanding the "New Frontiers in Numerical Relativity". The workshop has taken place at the AEI campus in Golm, and was focused on the numerous issues that revolve around numerical relativity, such as: formulations of the Einstein equations, initial data, multiblock approaches, boundary and gauge conditions, and of course relativistic fluids and plasmas.

Almost 20 years since the homonymous meeting held at Urbana-Champaign ("Frontiers in Numerical Relativity", 1988), the meeting saw the enthusiastic participation of a great part of the community, with 127 participants present (in 1988 they were 55) and with a large majority being represented by students and postdocs. The programme was organized so as to have few talks with ample time dedicated to discussions, which were then continued over breaks, meals and late evenings. An overview of the conference and a downloadable version of the talks can be found on the webpage of the conference *http://numrel.aei.mpg.de/nfnr.*

Luciano Rezzolla

### Workshop "Integrability in Gauge and String Theory"
### 24 - 28 July 2006

The last five years have seen significant progress in applying the methods of integrable systems to cutting-edge problems in gauge and string theory. This workshop was the first scientific meeting focussing exclusively on this young research area. The workshop was co-organised by Niklas Beisert (Dualities and Integrable Structures Group) and Matthias Staudacher (Quantum Gravity and Unified Theories Division) and it was hosted at the AEI in Potsdam. A joint session with the 11th Marcel Grossmann meeting on general relativity took place at the Freie Universität Berlin. Please refer to our contributions in this report for further information on the scientific background.

The purpose of the workshop was to gather the active researchers in this field and to create motivation and inspiration for future research. However, we considered it equally important to bring them together with some of the established experts in integrable models from condensed matter and mathematical physics, as well as other related areas in order to exchange ideas. Among the 86 participants were almost all leading scientists working on the narrower subject and around 20 experts from related fields.

The talks were selected in accordance with these aims: Two thirds of the talks were on specialised topics, but they almost all contained a generally accessible introduction. The remaining talks gave a pedagogical introduction into several important aspects of related fields in order to establish a common ground for discussions between the participants from the various backgrounds. These included reviews of integrability as such (Reshetikhin), AdS/CFT & integrability (Klebanov, Minahan, Polchinski), integrability in Quantum Chromo Dynamics (Gorsky), unitarity & twistor methods (Bern, Kosower), the Hubbard chain & condensed matter (Göhmann) as well as correlation functions (Maillet).

The scientific programme stimulated many discussions between the participants for which the breaks and the social events provided ample time. The feedback we have received after the conference was unanimously positive, highlighting the high quality of the presented talks and the generally pleasant atmosphere. It was even stated by some participants that they had never been at a workshop where such a large group of people sat with such enthusiasm through every single lecture. We can thus call the event a full success. Continuations of this workshop took place in Paris (Saclay/ENS) in June 2007, and in August 2008 in Utrecht. Another iteration is planned for summer 2009 at the AEI.

More information can be found on the webpages of the conferences *http://int06.aei.mpg.de* and *http://int09.aei.mpg.de*

Niklas Beisert & Matthias Staudacher

**LISA Astro-GR@AEI Meeting**
**18 - 22 September 2006**

The idea for this meeting was to bring together astrophysicists and experts in general relativity and gravitational-wave data analysis to discuss sources for LISA, the planned Laser Interferometer Space Antenna. More specifically, the main topics were EMRIs and IMRIs; i.e., the inspirals of stellar-mass compact objects (white dwarfs, neutron stars, and stellar-mass black holes) into massive black holes (MBHs) in galactic nuclei. IMRIs are similar, but the inspiralling object is an intermediate-mass BH.

Roughly two-thirds of the meeting were devoted to talks (broad, review talks for the first two days of the meeting and more specific talks on recent work in the latter half), while one-third was devoted to group discussion of a few questions that participants agreed to be especially vital.

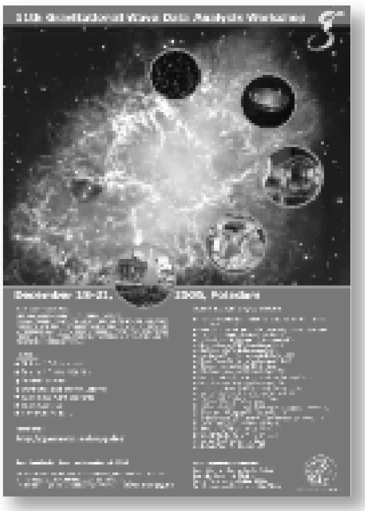
On the astrophysics side, talks generally dealt with stellar and gas dynamics in dense clusters, including the Galactic Centre, PN astrophysical modelling of sources, mass segregation, resonant relaxation, models of the so-called “S” stars found at the Galactic Centre, the general problems of determining rates, including tidal binary separation (almost zero eccentricity LISA EMRIs), the relevance of axisymmetric perturbations to it, etc.

On the data analysis side, there were several talks on using EMRIs and/or IMRIs to test General Relativity and/or the nature of the central massive object. Conceptually, tests of a theory generally fall into 2 categories: tests of consistency and comparisons of rival theories.
The meeting was so successful that it was suggested to repeat it and it will take place in 2008 at the AEI again.

Most of the talks (movies and slides) are available on-line at
*http://www.aei.mpg.de/~pau/LISA_Astro-GR@AEI*

Pau Amaro Seoane

**GWDAW11**
**18 - 21 December 2006**
The 11th Gravitational Wave Data Analysis Workshop (GWDAW11), organized by the Albert Einstein Institute, took place in December 2006 in Potsdam. About 130 scientists took part in this 4-day workshop and the proceedings which are now being published by IOP collect about 50 contributed papers. The workshop was structured in nine sessions: Status of Gravitational Wave Detectors, Detector Characterization studies, Burst searches, searches for continuous signals, searches for signals from binary inspirals, searches for a stochastic gravitational wave background, LISA data analysis and a poster session comprising more than twenty posters. Each session is focused on two “hot-topics” of particular interest and with two Chairs/discussion moderators.



GWDAW11 came in the middle of the fifth science run (S5) of the LIGO detectors, after a full year of data-taking at design sensitivity. LIGO was starting to probe astrophysically plausible scenarios for the emission of detectable gravitational wave signals. In the absence of a detection, the upper limits on the strength of gravitational waves were beginning to add information to what was previously known by electromagnetic observations.

One of the highlights of this workshop was the presentation by the LIGO Scientific Collaboration of a search for continuous waves from the Crab pulsar. Gravitational wave emission is constrained by the measured spindown measurements for the object: no more energy can go in gravitational waves than that which is lost by pulsar spindown. For most known pulsars this spindown upper limit on the strength of gravitational radiation is orders of magnitude higher than the upper limits that can be set with current gravitational wave observations. However for the Crab pulsar the gravitational wave observations which coherently combine about 9 months of data from the network of S5 LIGO detectors constrain the gravitational wave emission more strongly than the electromagnetic observations do. The gravitational wave upper limit also constrains the tri-axial ellipticity that this young pulsar could have supported since its crust solidified a thousand years ago.

The Virgo detector was in the final stages of commissioning with several engineering runs completed. The TAMA detector low frequency performance was being enhanced and another data run is foreseen by the end of 2007. The IGEC2 Collaboration presented results from the analysis of 131 days of data in coincidence among the three bar detectors EXPLORER, AURIGA and NAUTILUS. Studies were underway to analyze data in coincidence among bar and interferometer networks.

Space-based detectors were getting more attention, with the LISA Pathfinder mission planned for launch in 2010 and LISA in 2018. The special difficulties associated with data analysis for LISA were being addressed through the competitive mechanism of Mock LISA Data Challenges, and the results of the first challenge were presented and discussed at this workshop.

The different sessions and the presentations at GWDAW11 reflect this incredible richness of activities. The complete set of presentation slides can be found at the conference site
*http://gwdaw11.aei.mpg.de/program.html*

Maria Alessandra Papa

## Workshops organized by the Geometric Analysis and Gravitation Division

Several international workshops were organized by the division Geometric Analysis and Gravitation with the dual aim of disseminating the research done at AEI and bringing in know-how from related areas of mathematics and physics. One of these highlighted the links between certain aspects of geometric analysis and string theory. Another focussed on bringing mathematical approaches to bear on a topic with astrophysical motivations (helical symmetry). A third was concerned with points of contact between the theory of partial differential equations and the dynamics of the gravitational field.

### Workshop on Geometric and Renormalisation Group Flows
### 22 - 24 November 2006

The workshop brought mathematicians and physicists together with interests in “Geometric Flows”, “Renormalisation Group Flows” and “Entropies”. Motivation for the workshop were parallel developments in Geometric Analysis on the one hand, where parabolic evolution equations such as Ricci flow and mean curvature flow were successfully used to deform and classify certain manifolds and submanifolds including a resolution of the famous Poincaré conjecture, and on the other hand in String Theory, where these flows occur as first order approximations to Renormalisation Group Flows. Insights on the physics side such as the “c-theorem” on the monotonicity of certain entropy quantities translate directly into crucial analytical monotonicity formulae such as Perelman's entropy estimate for Ricci Flow and led to intensive interaction between mathematicians and physicists at the workshop. Lectures by I. Bakas, M. Carfora, K. Ecker, K. Smoczyk, A. Tseytlin, B. Wilking, E. Woolgar and A. Zamolodchikov to a mixed audience were deliberately given with a strong overview component to bridge the gap between different backgrounds and to identify issues of mutual interest. Followup conferences are planned in 2007 at the ESI in Vienna and at the Banff research station in 2008.

Gerhard Huisken

**Workshop on helically symmetric systems**
**10 – 12 January 2007**

The workshop was organized by Jiři Bičák (Charles University Prague) and Bernd Schmidt (Albert Einstein Institute) in the days January 10 - January 12, 2007. During these 3 days 17 talks were given, followed by long-standing discussions. Many discussions took place also during the reception in the evening of the first day and during coffee breaks. There were 25 official participants from United States, Germany, Austria, Czech Republic and France but the lectures and discussions were followed by additional 10-15 members and guests at the Einstein Institute from different research group since the topic is of interest to both mathematical and numerical relativists and also to modelers of gravitational wave forms from binary systems.

A helical Killing vector generates time translations in a rotating frame in which both components of a binary system are at rest. Intriguing mathematical problems arise because under helical symmetry the equations like simple wave equation change from elliptic to hyperbolic outside the so-called "light cylinder". Since in binary systems of two black holes or neutron stars gravitational radiation appears only at the order $(v/c)^5$ one can compute radiation for most of the time of inspiral from a stationary post-Newtonian orbit. Exact helically symmetric spacetimes (as solutions of full Einstein's field equations), cannot, however, be asymptotically flat since there is an infinite amount of energy in both incoming and outgoing waves which are necessary to preserve the helical symmetry. Despite this fact one can find a Noether current and charge associated with the helical Killing vector which is finite. This enables one to formulate thermodynamics of helically symmetric systems. The most recent studies construct numerically helically symmetric data inside a limited region and join them to waveless formulations outside. Various toy models like scalar wave equation with nonlinear pieces which can mimic nonlinear terms from Einstein's equations or simple gravitational theories like Nordstrom's theory are studied to understand helically symmetric solutions of full general relativity.

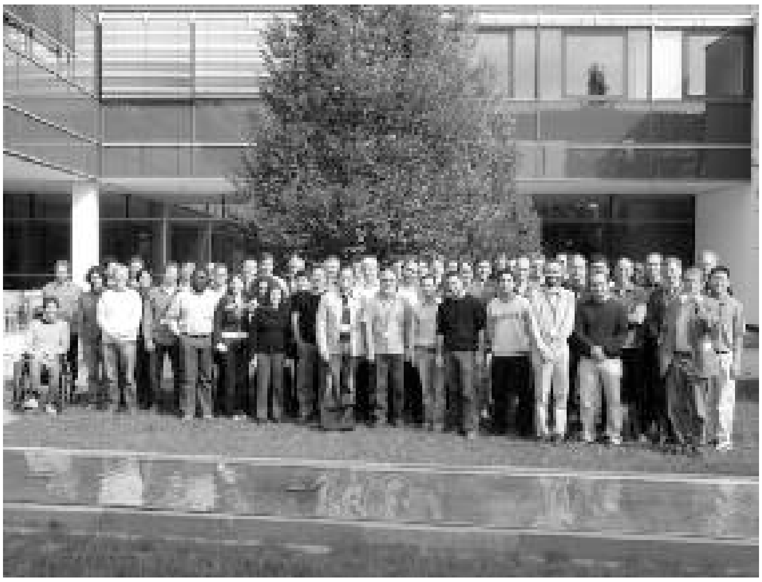
The workshop profited in particular from the presence of two leaders in the field, Prof. John Friedman from Center of Gravitation and Cosmology, University of Wisconsin-Milwaukee, and Prof. Richard Price from University of Texas, Brownsville and several members of their groups. Interaction between them as well as with more mathematically oriented relativists from AEI and other parts of Europe brought up many new interesting ideas and plans for future work.

More information about the workshop can be found at
*http://www.aei.mpg.de/~workshop/helical/index.html,*
where also all the lectures are given as pdf files.

Jiři Bičák

### Workshop on Evolution Equations and Self-Gravitating Systems 12-14 September 2007

This workshop was organized by Lars Andersson (AEI), Mihalis Dafermos (Cambridge, UK), Alan Rendall (AEI) and Igor Rodnianski (Princeton). The aim was to bring together researchers from the fields



of nonlinear evolution equations and general relativity interested in a number of related topics. These include the stability and long-time behaviour of solutions, formation of singularities and gravitational collapse. Eleven lectures covered various aspects of the dynamics of isolated systems and cosmological models. Most of these belonged to the area of nonlinear hyperbolic and kinetic equations. They were complemented by one survey talk on astrophysical issues (by Nils Andersson) and one on numerical issues (by Frans Pretorius). A surprise came in the talk of Igor Rodnianski who explained his resolution of a foundational issue concerning the initial value problem for the Einstein equations. It was well known to experts in the field that there was a discrepancy in the differentiability assumptions required to treat the two fundamental questions of existence and uniqueness. Rodnianski presented an elegant way in which this blemish in the theory can be removed.

This workshop has stimulated the interaction between the theory of nonlinear evolution equations and general relativity. The area of research has since been supported further by a related conference on Hyperbolic Equations in Relativity in Bordeaux in June 2008.

Alan Rendall

## Through the Eyes of a Visitor

It was in January 1997 when I left warm Mallorca for a post-doctoral position at the new born Albert Einstein Institute. I had been awarded a Marie Curie Training and Mobility fellowship and I was excited to start working on a completely new topic for me, Gravitational Wave Astronomy, with one of the world leaders in this field, Prof. Schutz. At that time the Institute was located in Schlaatzweg in between Babelsberg and Potsdam S-Bahn stations. It was occupying two floors of the Haus der Wirtschaft, the proto-library was just one room, but my office was very spacious, like a dancing hall, just in front of Frau Schlenk's office, who was providing me regularly with delicious chocolates and cakes. Space was not an issue then. The group was small and all post-docs and PhD students used to hang out together. The same year more people arrived, among them Maria Alessandra Papa with whom I became a close collaborator, working on data analysis for LIGO and GEO.

Many things have happened since then! The Institute has grown, it has moved to its present location in Golm and it is recognized as the leading Institute for Gravitational Physics in Europe. It has an army of persevering scientists, enthusiastic staff members, an amazing visitor program, excellent computing facilities and the library is now admirable. The institute has benefited a lot also from its new wing extension, the atrium, a warm place for social events as well as for stimulating discussions, and the new coffee machine (although I do not drink coffee), but dancing halls are no longer affordable office space.

Once I heard somebody say that you know which day you arrive at AEI, but you never know when you will leave. This clearly applies to me. I remained a post-doc in the Astrophysical Relativity division until 2002 when I took a faculty position in Mallorca. But since then I have been a regular long term visitor, giving me the opportunity to interact with the growing group at AEI and feeling always as one of its members. These last 10 years have been really exciting for the field of gravitational waves physics, with the completion and operation of the gravitational wave detectors GEO600 near Hannover and the American LIGO, that could at any time observe signals from astronomical sources, and the enormous progress in simulating the merger of two black holes. The AEI is a key player in the LIGO Scientific Collaboration and in the upcoming LISA space-based detector. The activities of the waves group are amazing, with 'marathonian' workdays participating in telephone-conferences with our international colleagues. Moreover, the Merlin-Morgane computer cluster at AEI has become one of the workhorses of the GEO-LIGO data analysis collaboration. It is well maintained by Steffen Grunewald who always keeps an eye in case I make a mess with my jobs.

The Institute has kept growing with two more divisions in Hannover, as well as the number of containers at the GEO side. I still remember the time in which there were no toilets nor running water at the GEO detector in Ruthe and I was doing my shifts in the control room. It was freezing and somebody offered me the 'GEO-bicycle' that was twice my size! But do not think I always complain about the weather in Germany. Springs and summers both in Golm and in Hannover are fantastic. You can enjoy the Sanssouci Park or the Herrenhäuser Gardens, swim in the lakes, take a bike trip admiring the surroundings, while it snows in Mallorca every time AEI scientists visit me.

Last year I was a guest of the Observational Relativity and Cosmology division in Hannover in the completely renovated building. I was impressed by the fantastic labs supplied with modern experimental equipment and the large basement waiting to host the new AEI supercomputing cluster. Video-conference facilities also allowed to attend any seminar or meeting independently of where it was taking place and to have very fruitful discussions. I was amazed to see the interaction of experimentalists and theorists, and also among the different divisions. You should only be warned to get some lunch before the group meeting starts in Prof. Allen's office, because the discussions could get very exciting. In case of starvation, Callinstraße is very conveniently located, one just needs to walk at most 5 minutes and there are plenty of choices. Golm has a long way to go in that respect, but that is compensated by the cheery morning welcome from Frau Pappa.

Alicia next to the GEO600 detector in Ruthe / Hannover

This year I came back to Golm. The first things I noticed were that the campus has expanded, the train station seems to be closer and the connections with Potsdam have improved (something that all scientists appreciate a lot). The visit is once more productive and stimulating. There are many exciting projects going on in the Astrophysical Relativity division. Many of those are related to the fact that the GEO-LIGO 5th science run just finished a few months ago, there is plenty of data to be analyzed and many group members are involved in the Mock LISA Data Challenges. The waves group is developing data analysis techniques as well as theoretical studies of gravitational wave sources. All sky searches for unknown rotating neutron stars is one of the key AEI projects I am interested in, working very closely with Badri Krishnan and Maria Alessandra Papa. Moreover, Bruce Allen is the leader of the Einstein@Home project, a distributed-computing effort that uses the idle CPU time of computers across the world, to search for these signals. Massive black hole mergers and captures of compact objects are some of the other topics I am interested in and AEI has many experts, including Stas Babak and Ed Porter. The simulation of the merger of two black holes has potentially important implications for detecting these signals and a lot of work is currently taking place at AEI at the interface of the gravitational wave and the numerical relativity groups and also with astrophysicists on interpretation of the results. So I am looking forward to the day in which I will come back and in the atrium we will all celebrate the detection of the first gravitational wave!

Alicia M. Sintes, Universitat de les Illes Balears. Spain

## Short Notices

### The Institute's Kuratorium

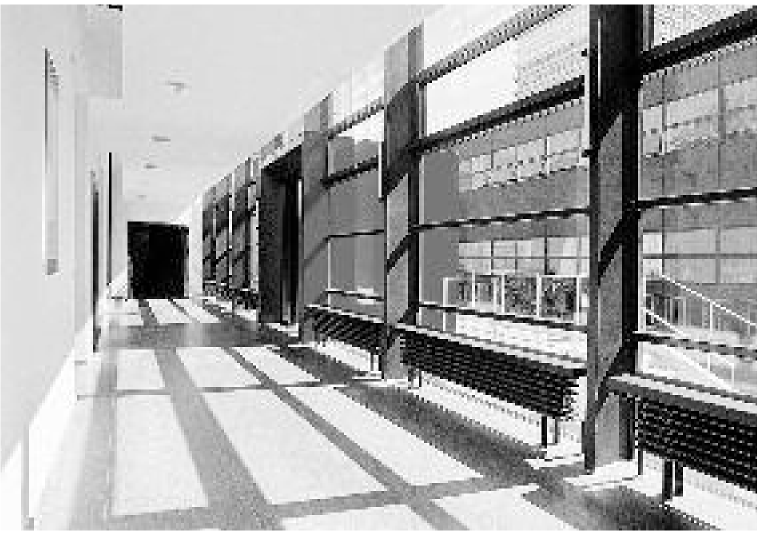
For the period 2007-2012 the AEI Kuratorium has been re-constituted. New members are the President of the Leibniz University Hannover, Erich Barke, the President of Potsdam University, Sabine Kunst, the Director of the Einstein Forum Potsdam, Susan Neiman, the Science Editor of the Frankfurter Allgemeine Sonntagszeitung, Ulf von Rauchhaupt, and Lutz Stratmann, Minister for Science and Culture in Niedersachsen. On the other hand Ulrich Kasparick, Wolfgang Loschelder, Friedrich-Carl Wachs and Dieter Wiedemann resigned. (For a complete list of the members of the Kuratorium please see page 116.)

In November 2006 the Kuratorium met in Hannover where Karsten Danzmann gave an overview talk about gravitational wave research. Harald Lück gave a virtual tour through the gravitational wave detector GEO600, followed by a real tour through the new building of the AEI Hannover.

In 2007 the meeting took place in Golm on December 7, right after the meeting of the Institute's Fachbeirat. The Chairman of the Fachbeirat, Garry Gibbons, reported to the Kuratorium about the progress the AEI had made during the last two years. Bernard Schutz gave a survey of the LISA project and Bruce Allen presented the distributed computing project Einstein@Home.

### Inauguration of the New Buildings of the AEI Hannover

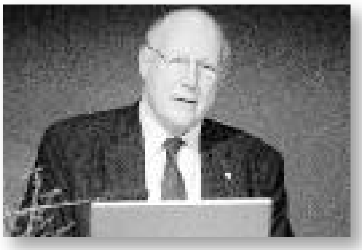
On September 16, 2006 the Centre of Experimental Gravitational Physics, the new home of the AEI Hannover and the Institute of Gravitational Physics of the Leibniz Universität Hannover (LUH), has been inaugurated and presented to the public. It consists of the two buildings Callinstraße 36 and 38, with an area of about 4000 m².



The new building in Hannover

These have been completely reconstructed to fit the demands of modern research. In the lab building, clean-room containers for optical experiments, labs with clean room conditions, and a large hall for the construction of a new gravitational wave detector prototype have been set up.

The inauguration celebration started with welcome addresses by Karsten Danzmann and Erich Barke, president of the LUH. Then followed greeting addresses by Lutz Stratmann, minister for science and culture of Lower Saxony, and by Martin Stratmann, chairman of the chemistry, physics and technology section of the Max Planck Society.



Martin C. E. Huber,
former president of the EPS

The "Festrede" (speech) was delivered by Martin Huber, former president of the European Physical Society, on "LISA – the Rosse Telescope of the 21st Century". The musical accompaniment was provided by the Das Neue Ensemble, Hannover, presenting compositions of Karlheinz Stockhausen in the arrangement of Stephan Meier with electronic sounds of pulsars and gravitational wave signals.

### Einstein@Home Event at AEI Golm, 18 December 2006

In 2005 the LSC released the APS World Year of Physics flagship project Einstein@Home. It allows people from the general public to contribute computing time to the analysis of data from gravitational wave detectors. Nowadays Einstein@Home is the third largest of about 45 public volunteer computing projects and the most powerful single computing facility of the whole LSC. As it relies only on the time contributed by volunteers, making and keeping contact to present and potential contributors is crucial for the project. Thus we decided to bring people from the general public together with the scientists and developers behind Einstein@Home in this event.

Bernard F. Schutz, Bruce Allen (at that time U. of Wisconsin-Milwaukee), and Brian O'Reilly (LIGO Livingston Observatory) gave lectures covering the history, presence and future of gravitational wave science in general, the LIGO instruments and the Einstein@Home project.

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.

### Exhibition "Metamorphosen der Farbe" at the Max Planck Campus in Golm

For two months Silke Britzen displayed about 30 of her colourful paintings at the central building of the Max Planck Campus in Golm. On August 24, 2007, the exhibition with paintings of flowers and landscapes was opened by the AEI's managing director Hermann Nicolai. Annette Strathoff, an artist from Potsdam, gave an introductory talk about Silke Britzen's work.

In the last years quite a few exhibitions took place in the central building, but most of them displayed images coming from science – photographs or simulations. Silke Britzen's exhibition however, which was still shown during our Open Day, appealed to people not necessarily interested in science and scientific images.

Silke Britzen herself is both an artist and a scientist: she studied fine arts and physics and is working on active galactic nuclei and black holes at the Max Planck Institute for Radio Astronomy in Bonn.

### GEO600 and LISA at the Deutsches Museum

In May 2006 the Deutsches Museum in Bonn showed an exhibition about gravitational wave detection in cooperation with the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) and the AEI. Sascha Skorupka from AEI Hannover gave a public talk on the occasion of the opening event. The AEI provided hands-on exhibits, films and simulations as well as texts illustrating the operating mode of a laser interferometer and the basics of gravitational wave detection. A life-scale model of a LISA satellite was the impressive highlight of the exhibition.

The LISA satellite was the centerpiece of the exhibition

### Open Day at the Research Campus Golm

On September 1st, 2007, the institutes on the Research Campus in Golm opened their doors for the public again. As 2007 was the German 'Year of Mathematics', the Albert Einstein Institute installed a mathematical playground in the atrium with interactive exhibits that were built in the Hannover workshops. During the whole day the atrium was overcrowded with kids and their parents playing with mathematical hands-on experiments: they discovered that the curve of fastest descent is the 'brachistochrone' curve and learned about minimal surfaces by making soap bubbles.

Carla Cederbaum (AEI) and a (very) young mathematician

For the first time we organized a VIP tour on the campus which was attended by more than 50 politicians from the City of Potsdam and from Brandenburg. Many of them visited the campus for the first time.

### Vacation Courses at AEI Golm
### 06 - 17 March 2006, 19 - 30 March 2007

The 2 weeks vacation course on Gravitational Physics, which the AEI started in 1999 together with the University of Potsdam has become a regular activity of the Institute. It is meant for students who have achieved their "Vordiplom". As in the years before, there were two lectures in the mornings and the afternoons were used to go through the material of the lectures.

In 2006, H. Friedrich and M. Ansorg gave an "Introduction into General Relativity". Two other lecture series were given by H. Nicolai on "Introduction to supersymmetry and supergravity" and by S. Theisen on "Kaluza Klein theories". In the afternoon B. Schutz, L. Rezzolla, M. Ansorg, D. Pollney and B. Szilági gave presentations about gravitational wave research and numerical simulations at AEI. In 2007, the first course again was about "Introduction into General Relativity" (H. Friedrich). The two other lecture series were given by M. Ansorg ("Rotating black holes and neutron stars") and L. Andersson ("Cosmological models").

In 2006, 69 participants attended the vacation course: 20 came from the Berlin-Potsdam area and another 49 from all over Germany. In 2007 we had 19 from the Berlin-Potsdam area and another 37 from all over Germany. Once more the AEI could provide some financial support.

## Living Reviews in Relativity

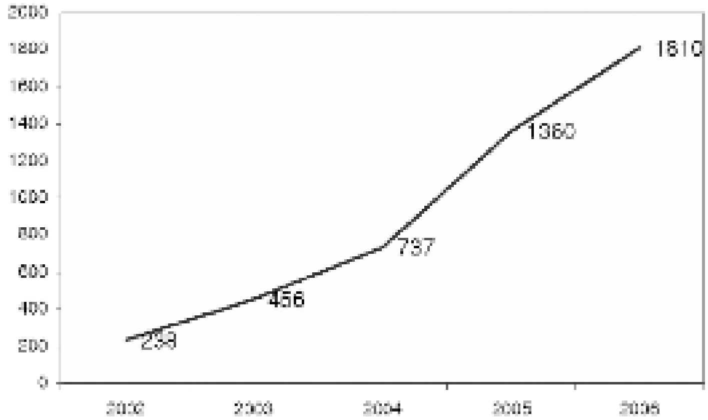
While approaching its tenth anniversary in 2008, Living Reviews in Relativity has successfully continued the unique concept of regularly updated, high-quality review articles online. The journal's reputation among physicists and open access publishers eventually inspired partners from outside the field, to start their own journals in cooperation with the Max Planck Society. A first sister journal, Living Reviews in Solar Physics (LRSP), was started in 2004 at the Max Planck Institute for Solar System Research, with back office support at the AEI. In 2006, Living Reviews in European Governance (LREG) went online with first articles in the field of political science. LREG is published within the EU funded frameworks CONNEX and NewGov. A fourth journal, Living Reviews in Landscape Research (LRLR), has been online since June 2007. Published by the Leibniz Centre for Agricultural Landscape Research (ZALF), it has an interdisciplinary approach, reviewing interactions of environmental, economic and social subjects in landscape research.

In acknowledgement and support of these developments, the Living Reviews project was granted financial support by the Heinz Nixdorf Foundation, which was extended until the end of 2008. Thus, we were able to employ research programmers who develop specialized open source tools for electronic publishing, as well as broaden the support for the journal family. With the restructuring of the Max Planck Society's digital information services, Living Reviews became associated with the Center for Information Management in the Max Planck Society (ZIM) in 2001, and part of the newly founded Max Planck Digital Library (MPDL) in 2007. Our vision for the future here includes central web hosting and applications in combination with local scientific and editorial work at institute level. As one of the first open access publications, we will continue to promote free information in science publishing.

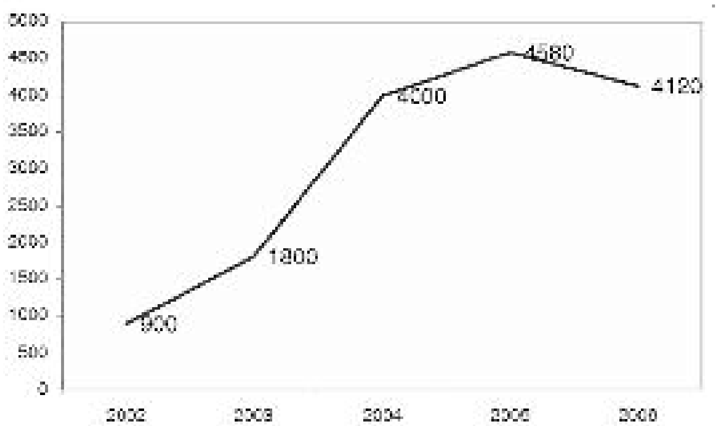
Living Reviews has designed its own publication software suite, the ePublishing Toolkit (ePubTk), for article processing, content management, and the reference database. ePubTk is continuously being adapted to the technical evolution of the internet, as well as to new challenges of the journals from other fields of science. To support the growing journal family, we have recently finished the development of a web based editorial management system (EIMS), which allows to monitor the editorial process, as well as the submission of articles and referee reports online.

The journal's concept and software has been presented at various workshops and conferences, among others, at the Berlin Conference on Open Access to Knowledge in the Sciences and Humanities (Golm, March 2006), at ELPUB 2006: 10th International Conference on Electronic Publishing (Bansko, June 2006), and at the PKP Scholarly Publishing Conference 2007 (Vancouver, July 2007). A special highlight was the invitation by Frankfurt Book Fair to present the journal to a group of Chinese publishers. We gladly accepted this opportunity to introduce the concept of Open Access together with the e-publishing group of Humboldt University Berlin. We also promoted the journal at the 11th Marcel Grossman meeting (Berlin, July 2006) with an info desk.

Currently, the journal maintains 56 articles online, of which 19 have been updated by a major revision. Altogether, 75 reviews have been published since 1998. Living Reviews' searchable reference database now contains more than 14,800 reviewed records from our publications. Even after fine tuning our statistic tools, and thus more exact numbers than in previous reports, we can prove a very high visibility not only in the gravitational physics community. Over 2,000 downloads of PDF article versions per month, currently about 620 subscribers to our newsletter, and more than 2,550 articles citing Living Reviews, demonstrate its value as an outstanding resource.



Citations of Living Reviews.



Average article downloads (per month).

The need for up-to-date review journals in physics has been expressed by readers who feel that "in a time of such rapid expansion in scientific knowledge, it is more important than ever to keep things together and enable people to get an overview without drowning them in details. The Living Reviews in Physics are an excellent step into this direction." (Weblog 2006) Also, the importance of open access to these information online has been emphasized:

"The articles that have been published in Living Reviews have enormously helped me to complete and submit a good dissertation. These free articles you are providing are like treasures to young African scientists like me since generally we do not have access to very good books on relativity and on the astrophysics of compact objects even at the library of the university. Moreover, the standard texts on relativity are usually very expensive so unaffordable. Thus, I am grateful to you for the great job you and the researchers are doing." (Mail from Mauritius, 2006)

Frank Schulz

## Cooperations and Outside Funding

AEI's research is characterized by worldwide collaborations with universities and research institutes. Research projects are funded by the following institutions and foundations:

### Alexander von Humboldt-Stiftung - AvH (Humboldt Foundation)

In the years 2006/2007 the AEI hosted four Humboldt-Prize laureates (Kellog S. Stelle, Adam Schwimmer, Jiři Bičák and Vladimir Kazakov) and one Friedrich Wilhelm Bessel-Award laureate (Soo-Jong Rey). Another two laureates, Hirosi Ooguri (Humboldt-Prize laureate) as well as Ruben Minasian (Friedrich Wilhelm Bessel-Award laureate), are supposed to come to the AEI in 2008.

In October 2004 the prestigious Sofja Kovalevskaja-Prize was awarded to Yanbei Chen. The award enabled him to establish an independent research group on Theoretical Gravitational wave Physics at the AEI which collaborates closely with the divisions of Astrophysical Relativity and Laser Interferometry & Gravitational Wave Astronomy.

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

The German Aerospace Center (DLR) funds the technology demonstration space mission for LISA, LISA Pathfinder. The AEI Hannover serves as Co-PI within the LISA technology package (LTP) architect team, and is largely responsible for the laser system and interferometry layout.

The German D-Grid Initiative is going to build a general and sustainable Grid-infrastructure that will be available to all scientists in Germany.

The AEI is involved in three projects of that initiative and gets financial support for its work on the German Astronomy Community Grid (GACG), the Horizontal Integration of Resource- and Service Monitoring in D-Grid (D-MON) and the D-Grid Integration Project (DGI).

The core task of the GACG is to develop a framework and appropriate standards for collaborative management of astronomy-specific grid resources within the required infrastructure. D-MON's vision is to realize a Grid wide monitoring architecture across several underlying, heterogeneous systems taking in consideration multiple resource providers and virtual organisations. The DGI integrates the infrastructure, middleware tools and e-Science methods developed in the different community projects in one common D-Grid platform.

In 2008 the DGI-2, a follow-up project of the DGI, will start. It intends to put the sizable grid infrastructure, created in DGI, on a sustainable basis for long-term use. The AEI will be involved in two work packages of this project.

Within the German-Israeli Project (DIP) Applications of string theory to particle physics and to Gravity a bi-national center for the study of string theories is going to be established.

**Deutsch-Akademischer Austauschdienst – DAAD (German Academic Exchange Service)**

The DAAD supports the collaboration between the Numerical Relativity Group of the AEI, SISSA and the Universitat de les Illes Balears. By funding the travel costs to Italy and Mallorca several times a year the programme provides the researchers from AEI with support for a steady exchange with both research institutions.

**Deutsche Forschungsgemeinschaft (DFG)**

- Special Research Centers ("Sonderforschungsbereiche" (SFB)):

– SFB Transregio 7 Gravitationswellen-Astronomie: Gravitational wave activities in Germany are funded by the Deutsche Forschungsgemeinschaft (DFG) through the Sonderforschungsbereich Transregio (SFB/TR 7) "Gravitational Wave Astronomy" comprising the Universities of Tübingen, Jena, and Hannover and the Max Planck Institutes for Gravitational Physics and Astrophysics. It is running up to twelve years.

– SFB 407 Quantenlimitierte Messprozesse: The Laser Interferometry and Gravitational Wave Astronomy Division participates in this project which the Laser Zentrum at Hannover, the Physikalisch-Technische Bundesanstalt at Braunschweig and the Institute for Quantum Optics at Hannover University are also involved in.

– SFB 647 Raum-Zeit-Materie: The special research area entitled Space-Time-Matter funded by the Deutsche Forschungsgemeinschaft (DFG) is a collaboration between the divisions 'Geometric Analysis and Gravitation' and 'Quantum Gravity and Unified Theories' of AEI, the Humboldt University and 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.

- Leibniz-Programme

  In 2003 the Leibniz Prize – the most prestigious German research prize - was awarded to Gerhard Huisken. The prize money can be spent for personnel and travel over a period of seven years. Currently seven scientists are paid by these funds.

**European Gravitational Observatory – EGO**

EGO is currently funding a fellowship for a study on Signature of Spins in Gravitational Waves from binary black-hole evolutions and construction of accurate and complete template banks.

**European Commission (EC)**

The institute currently participates in three EU-projects: Superstrings, Forces Universe and ILIAS.

- Superstrings (Superstring Theory) is a four year follow-on to the former EU Research Training Network Superstrings and aims at further developing string theory as a unified theory of the physical forces in order to understand its implications.

- Forces Universe (Constituents, Fundamental Forces and Symmetries of the Universe) aims at gaining further insights into the fundamental structure of the universe, namely its basic constituents, the forces mutually acting on them and the symmetries which underlie its theoretical description.

- ILIAS (Integrated Large Infrastructures for Astroparticle Science) is an Integrated Infrastructure Initiative that has pulled together all of Europe's leading infrastructures in Astroparticle Physics to produce a focused, coherent and integrated project in order to improve the existing infrastructures.

**ESA and NASA**

The Laser Interferometer Space Antenna (LISA) is funded jointly by ESA and NASA. The mission studies the mergers of supermassive black holes, tests Einstein's Theory of General Relativity, probes the early Universe, and searches for gravitational waves – its primary objective. Three of the ten European members of the LISA Science Team are from the Institute.

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

The German-Israeli foundation is currently evaluating a proposal for a joint research project of the Quantum Gravity Division together with the University of Tel Aviv entitled String Theory Meets Gauge Dynamics.

**INTAS**

The International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union is funding the project Current Topics in String Theory. It deals with string and field theoretic aspects of supersymmetric theories, in particular targeting at the aim to learn about field theory beyond perturbation theory and about string theory in non-trivial backgrounds.

**Volkswagen-Stiftung (VW Foundation)**

The VW foundation supported the laser development for GEO600 and 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 group and the Laser Zentrum Hannover.

Constance Münchow

## Appraisals and Prizes

### Medal of Charles University for Jürgen Ehlers

In acknowledgement of his outstanding achievements as one of the world's leading specialists in the general theory of relativity and cosmology Jürgen Ehlers was awarded the Commemorative Medal of the Faculty of Mathematics and Physics of Charles University (Prague).

Jiri Bicák presents the medal of the Charles University to Jürgen Ehlers.

### Karsten Danzmann has become Member of the Akademie in Mainz

The Akademie der Wissenschaften und der Literatur Mainz has elected Karsten Danzmann as a new member in 2007. Following the example of Gottfried Wilhelm Leibniz, the aim of the Akademie in Mainz is to support science and literature. The academy's main focus lies in long-term projects in fundamental research.

### Bernard F. Schutz was appointed Member of the Leopoldina

Bernard F. Schutz was appointed member of the Deutsche Akademie der Naturforscher, Leopoldina in 2006. The Leopoldina (founded in 1652) is the oldest scholar's society of natural sciences in Germany. Their members are outstanding scientists in their specific disciplines, coming from more than 30 countries. Becoming a member of the Leopoldina is one of the most prestigious awards for scientists in Germany.

### Amaldi Gold Medal for Bernard F. Schutz

In 2006 Bernard F. Schutz was awarded the Amaldi Medal in gold for his outstanding contributions in the research field of gravitational physics in Europe. The medal, named after the Italian physicist Edoardo Amaldi (1908-1989), is awarded by the Italian Society of General Relativity and Gravitation (SIGRAV - Società Italiana di Relatività Generale e Fisica della Gravitazione) every two years since 1998.

### Gribov Medal for Niklas Beisert

For his important contributions to a better understanding of a four-dimensional quantum field theory the European Physical Society (EPS) awarded Niklas Beisert the Gribov Medal in 2007. The Gribov Medal is awarded every two years by the EPS to a young physicist for outstanding work performed in the field of theoretical particle physics and/or field theory. Niklas Beisert is the first European scientist working in Europe who was awarded with the Gribov Medal.

### Otto Hahn Medal for Bianca Dittrich

Bianca Dittrich received the Otto Hahn Medal of the Max Planck Society for one of the best thesis in theoretical physics in her year of finishing completed at a Max Planck Institute. The topic of her thesis concerned the construction observables for General Relativity, that is, quantities that are spacetime diffeomorphism invariant.

### Kristina Giesel received Michelson Prize

Kristina Giesel was awarded the Michelson prize of the University of Potsdam for the best thesis within the mathematical and natural sciences completed at the University of Potsdam in 2006-2007. The topic of her thesis concerned the classical limit of a particular approach towards combining the principles of quantum mechanics and General Relativity, called Loop Quantum Gravity.

### Potsdam's Young Researcher's Prize for Christian D. Ott

In 2007 the Young Researcher's Prize of the City of Potsdam was awarded for the first time. Christian D. Ott received the prize in recognition of his research and doctoral dissertation on gravitational collapse, super nova explosions, and gravitational radiation.

### Roelin Prize for Markus Pössel

The Hanno and Ruth Roelin Prize for science writing was awarded to Markus Pössel at the annual meeting of the German Astronomical Society in 2007. Pössel received this award for his popular science writing, particularly for his book 'Das Einstein-Fenster' and for the AEI web portal Einstein Online.

### Bernd Reimann receives Publication Award

On the occasion of the 'Leibniz Kolleg' at the University of Potsdam in 2006, the publication award for young researchers was awarded to Bernd Reimann in recognition of his outstanding achievements in numerical relativity.

### Xanthopoulos Prize for Thomas Thiemann

Thomas Thiemann shared (together with Martin Bojowald, a former member of AEI, now at PennState) the Vasilis Xanthopolous Prize 2007 for their groundbreaking work on loop quantum gravity. This prize is awarded every three years by the Foundation for Research and Technology - Hellas (FORTH) and the General Relativity and Gravitation Society.

## Academic Achievements

### New Director at AEI Hannover

Following inconclusive efforts to recruit a second Director during 2001-5, a second Division "Observational Relativity and Cosmology" was established in late 2006 under the direction of Prof. Dr. Bruce Allen. Research in this second Division is focused on the direct observational consequences of Einstein's General Theory of Relativity, particularly as it relates to astrophysics and cosmology.

Prof. Allen remains Adjunct Professor of Physics (20% appointment) at University of Wisconsin-Milwaukee where he has been a Professor of Physics since 1997. He also holds a position as Honorary Professor of Physics at Leibniz University Hannover. Allen is a world leading expert in gravitational wave data analysis and the leader of the distributed computing project Einstein@Home.

### New Leader of the Gravitational Wave Group

Maria Alessandra Papa took a new position as leader of the Gravitational Wave Group at AEI in January 2007. Dr. Papa previously divided her time between the AEI and the University of Wisconsin where she held a tenured Senior Scientist position in physics department. She is the Data Analysis Coordinator for the LIGO Scientific Collaboration (LSC) and has co-chaired the LSC continuous gravitational wave searches working group for many years. LISA data analysis will also be one of activities of the Gravitational Wave Group in Golm.

### New Max Planck Research Group at AEI

Niklas Beisert was awarded a special grant from MPG in 2006 to set up an Independent Junior Research Group (Selbstständige Nachwuchsgruppe) on "Duality and Integrable Structures". Since 1969 the Max Planck Society has been supporting gifted, young scientists and researchers through its Independent Junior Research Groups, which run for a limited period of time.

The main research topic of the group is the integrable structure which has been found in the context of string/gauge duality. Integrability is a hidden symmetry which can be found in some models and which vastly simplifies the exact determination of their spectrum and other observables. Beisert's group collaborates closely with the "Quantum Gravity and Unified Theories" division at the AEI.

**Doctoral Thesis**

Carsten Aulbert has finished his doctoral thesis on "Finding millisecond binary pulsars in 47 Tucanae by applying the Hough transformation to radio data" under the supervision of Prof. Bernard Schutz. He was awarded his Dr. rer. nat. from the Universität Potsdam in 2006.

**Doctoral Thesis**

Florian Beyer was awarded his Dr. rer. nat. from the Universität Potsdam in 2007. He wrote his doctoral thesis on "Singularities and asymptotics in cosmological models with positive cosmological constant" under the supervision of Prof. Helmut Friedrich.

**Doctoral Thesis**

Joshua Bode has finished his doctoral thesis on „Mean curvature flow of cylindrical graphs" under the supervision of Prof. Gerhard Huisken and Prof. Klaus Ecker. He was awarded his Dr. rer. nat. from the Freie Universität Berlin in 2007.

**Doctoral Thesis**

Johannes Brunnemann has finished his doctoral thesis on "Singularities of classical general relativity within the framework of loop quantum gravity" under the supervision of Prof. Thomas Thiemann. He was awarded his Dr. rer. nat. from the Universität Potsdam in 2006

**Doctoral Thesis**

Alexander Bunkowski has finished his doctoral thesis on "Laser interferometry with gratings" supervised by Jun.-Prof. Dr. Roman Schnabel. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in December 2006.

**Doctoral Thesis**

Simon Chelkowski has finished his doctoral thesis on "Squeezed light and laser interferometric gravitational wave detectors" supervised by Jun.-Prof. Dr. Roman Schnabel. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in June 2007.

### Doctoral Thesis

Aydin Demircioglu was awarded his Dr. rer. nat. from the Universität Potsdam in 2007. He wrote his doctoral thesis on "Reconstruction of Deligne classes and cocycles" under the supervision of Prof. Christian Bär.

### Doctoral Thesis

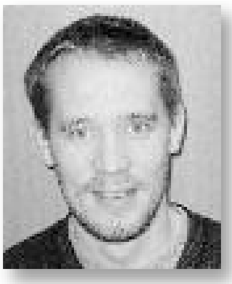
Antonio Francisco García Marín has finished his doctoral thesis on "Minimisation of optical pathlength noise for the detection of gravitational waves with the spaceborne laser interferometer LISA and LISA Pathfinder" supervised by Dr. Gerhard Heinzel. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in July 2007.

### Doctoral Thesis

Kristina Giesel was awarded her Dr. rer. nat. from the Universität Potsdam in 2007. She wrote her doctoral thesis entitled "On the consistency of loop quantum gravity with general relativity" under the supervision of Prof. Thomas Thiemann.

### Doctoral Thesis

André Grimpe has finished his doctoral thesis on "Analysis and manipulation of atomic and molecular collisions using laser light" supervised by Prof. Dr. Achim Großer. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in July 2006.



### Doctoral Thesis

Jan Harms has finished his doctoral thesis on "The Detection of gravitational waves - data analysis and interferometry" supervised by Jun.-Prof. Dr. Roman Schnabel. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in July 2006.

### Doctoral Thesis

Stefan Hild has finished his doctoral thesis on "Beyond the First Generation: Extending the Science Range of the Gravitational Wave Detector GEO600" supervised by Dr. Harald Lück. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in February 2007.

**Doctoral Thesis**

Amos Koeller was awarded his Dr. rer. nat. from the Freie Universität Berlin in 2007. He wrote his doctoral thesis entitled "On the singularity sets of minimal surfaces and a mean curvature flow" under the supervision of Prof. Gerhard Huisken and Prof. Klaus Ecker.

**Doctoral Thesis**

Bernhard List has finished his doctoral thesis on "Evolution of an extended Ricci flow system" supervised by Prof. Gerhard Huisken. He was awarded his Dr. rer. nat. from the Freie Universität Berlin in 2006.

**Doctoral Thesis**

Frank Löffler was awarded his Dr. rer. nat. from the Universität Potsdam in 2006. He wrote his doctoral thesis on "Numerical Simulations of Neutron Star - Black Hole Mergers" under the supervision of Prof. Ed Seidel and Prof. Luciano Rezzolla.

**Doctoral Thesis**

Michaela Malec has finished her doctoral thesis on "Commissioning of advanced, dual-recycled gravitational-wave detectors: simulations of complex optical systems guided by the phasor picture" supervised by Dr. Benno Willke. She was awarded her Dr. rer. nat. from the Leibniz Universität Hannover in January 2006.

**Doctoral Thesis**

Christian D. Ott was awarded his Dr. rer. nat. from the Universität Potsdam in 2007. He wrote his doctoral thesis on "Stellar iron core collapse in 3+1 general relativity and the gravitational wave signature of core-collapse supernovae" under the supervision of Prof. Ed Seidel.

**Doctoral Thesis**

Ajith Parameswaran has finished his doctoral thesis on "On aspects of gravitational-wave detection: Detector characterisation, data analysis and source modelling for ground-based detectors" supervised by Dr. Alessandra Maria Papa. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in December 2007.

**Doctoral Thesis**

Bernd Reimann was awarded his Dr. rer. nat. from the Universität Potsdam in 2006. He wrote his doctoral thesis on "Gauge conditions in numerical relativity" under the supervision of Prof. Bernard Schutz.

**Doctoral Thesis**

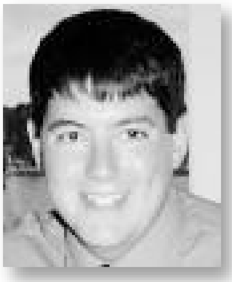
Luciano Ribichini has finished his doctoral thesis on "Thermal noise investigations in gravitational wave research" supervised by Dr. Harald Lück. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in July 2007.

**Doctoral Thesis**

Aureliano Skirzewski was awarded his Dr. rer. nat. from the Humboldt-Universität Berlin in 2006. He wrote his doctoral thesis on "Effective equations of motion for quantum systems" under the supervision of Dr. Martin Bojowald.

**Doctoral Thesis**

Sascha Skorupka has finished his doctoral thesis on "Rauschuntersuchungen an hochstabilen Lasersystemen für die wissenschaftliche Weltraummission LISA" supervised by Dr. Gerhard Heinzel. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in June 2007.



**Doctoral Thesis**

Joshua R. Smith has finished his doctoral thesis on "Formulation of instrument noise analysis techniques and their use in the commissioning of the gravitational wave observatory GEO600" supervised by Dr. Harald Lück. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in July 2006.

**Doctoral Thesis**

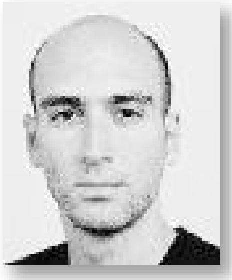
Luca Spani Molella has finished his doctoral thesis on "Nonlinear spectroscopy of closed degenerate two-level systems" supervised by Dr. Rolf-Hermann Rinkleff. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in July 2006.

### Doctoral Thesis

Vinzenz Wand has finished his doctoral thesis on "Interferometry at low Frequencies: Optical phase measurement for LISA and LISA Pathfinder" supervised by Dr. Gerhard Heinzel. He was awarded his Dr. rer. nat. from the Leibniz Universität Hannover in May 2007.

### Doctoral Thesis

Anil Zenginoglu was awarded his Dr. rer. nat. from the Universität Potsdam in 2007. He wrote his doctoral thesis on "A conformal approach to numerical calculations of asymptotically flat spacetimes" under the supervision of Helmut Friedrich.

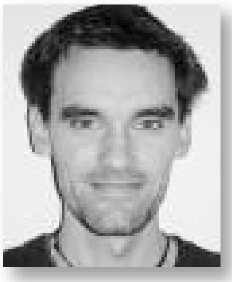


### Doctoral Thesis

Benjamin Zwiebel has finished his doctoral thesis on "The psu(1,1|2) spin chain of N=4 supersymmetric Yang-Mills Theory" under the supervision of Niklas Beisert. He was awarded his PhD from Princeton University in 2007.

### Diploma Thesis

Till Bargheer graduated in physics from the Universität Kiel in 2007. He wrote his diploma thesis "Two-cut solutions of the Heisenberg Ferromagnet" under the supervision of Niklas Beisert.



### Diploma Thesis

Michael Britzger graduated in physics from the Leibniz Universität Hannover in December 2007. He wrote his diploma thesis "Dreiport-Gitter-Resonator mit Power Recycling" under the supervision of Jun.-Prof. Dr. Roman Schnabel.

### Diploma Thesis

Johannes Brödel graduated in physics from the Technische Universität Dresden in 2006. He wrote his diploma thesis "beta functions and T-duality with Ramond-Ramond fields" under the supervision of Stefan Theisen.

### Diploma Thesis

Katrin Dahl graduated in physics from the Leibniz Universität Hannover in November 2007. She wrote her diploma thesis "Laserinduzierter, polarisationsabhängiger Übergang von Absorption zu Transparenz im Cäsium" under the supervision of Dr. Rolf-Hermann Rinkleff.

### Diploma Thesis

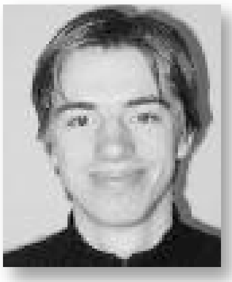
Marina Dehne graduated in physics from the Leibniz Universität Hannover in January 2007. She wrote her diploma thesis "Untersuchungen zum Self-Injection Locking eines Hochleistungs-Ringlaser" under the supervision of Dr. Benno Willke.

### Diploma Thesis

James Di Guglielmo graduated in physics from the Leibniz Universität Hannover in October 2006. He wrote his diploma thesis "Entangled states of light" under the supervision of Jun.-Prof. Dr. Roman Schnabel.

### Diploma Thesis

Jessica Dück graduated in physics from the Leibniz Universität Hannover in January 2007. She wrote her diploma thesis "Neue Methoden zur Leistungsrauschmessung von Hochleistungslasern" under the supervision of Dr. Benno Willke.



### Diploma Thesis

Roland Fleddermann graduated in physics from the Leibniz Universität Hannover in October 2006. He wrote his diploma thesis "Komponentencharakterisierung für LISA. Rauscharme Spannungsreferenzen und Reziprozität einer Glasfaser" under the supervision of Dr. Gerhard Heinzel.

### Diploma Thesis

Daniel Friedrich graduated in physics from the Leibniz Universität Hannover in November 2006. He wrote his diploma thesis "Michelson-Interferometer mit diffraktivem Strahlteiler" under the supervision of Jun.-Prof. Dr. Roman Schnabel.

**Diploma Thesis**
Philine Hüttig wrote her diploma thesis on "Cosmology as a geodesic motion" under the supervision of Marija Zamaklar. She graduated in physics from Humboldt Universität Berlin in 2006.

**Diploma Thesis**
Alexander Khalaidovski graduated in physics from the Leibniz Universität Hannover in March 2007. He wrote his diploma thesis "Der optische Kerr-Effekt im Fabry-Perot-Interferometer" under the supervision of Jun.-Prof. Dr. Roman Schnabel.

**Diploma Thesis**
Joachim Kullmann graduated in physics from the Leibniz Universität Hannover in September 2007. He wrote his diploma thesis "Aufbau einer laserinterferometrischen Positionsauslesung für die LISA-Testmassen" under the supervision of Dr. Gerhard Heinzel.

**Diploma Thesis**
Malte Prieß graduated in physics from the Leibniz Universität Hannover in November 2007. He wrote his diploma thesis "Data analysis in gravitational wave physics" under the supervision of Dr. Jan Harms.

**Diploma Thesis**
Aiko Samblowski graduated in physics from the Leibniz Universität Hannover in May 2007. He wrote his diploma thesis "Verschränkung kontinuierlicher Variablen von Seitenbändern optischer Felder" under the supervision of Jun.-Prof. Dr. Roman Schnabel.

**Diploma Thesis**
Vera Spillner wrote her diploma thesis "On the stability of a flux vacuum - probing the stability of $P^4_{(1,1,1,6,9)\ 18}$" under the supervision of Stefan Theisen. She graduated in physics from Humboldt Universität Berlin in 2006.

**Diploma Thesis**
Stefan Zieme graduated in physics from Humboldt Universität Berlin in 2007. He wrote his diploma thesis "Bethe equations and the Ads/CFT correspondence - nesting and dressing" under the supervision of Stefan Theisen.

**Master Thesis**
Moritz Mehmet graduated in physics from the Universität Oldenburg in March 2006. He wrote his master thesis "Gequetschtes Licht bei 532 nm" under the supervision of Jun.-Prof. Dr. Roman Schnabel.

### The Fachbeirat of the AEI

The Fachbeirat is the Institute's scientific advisory and assessment Board, made up of internationally renowned physicists. The Fachbeirat advises the President of the Max Planck Society (MPG) on how effectively the Directors are managing the work of the Institute. Their advice helps the Directors to establish priorities and improve their management. The Fachbeirat is the main tool used by the MPG to evaluate its research institutes to ensure appropriate and effective development of funds. Every two years the members of the Fachbeirat meet for several days to evaluate the Institute and to prepare a report to the President of the MPG.

**Current members of the Fachbeirat are:**

Prof. Dr. Constantin Bachas
Laboratoire de Physique Théorique de l'Ecole Normale Supérieure, Paris

Prof. Dr. Joan Centrella
Gravitational Astrophysics Laboratory, NASA Goddard Space Flight Center

Prof. Dr. Klaus Fredenhagen
II. Institut für Theoretische Physik, Universität Hamburg

Prof. Dr. Piotr Chrusciel
UFR Science et Techniques, Université de Tours

Prof. Dr. Gary Gibbons
Department of Applied Mathematics and Theoretical Physics, Cambridge University

Prof. Dr. James Hough
Department of Physics and Astronomy, University of Glasgow

Prof. Dr. Sterl Phinney
Theoretical Astrophysics, California Institute of Technology

Prof. Dr. Richard M. Schoen
Department of Mathematics, Stanford University

Prof. Dr. Stefano Vitale
Department of Physics, University of Trento

Prof. Dr. Robert Wald
Enrico Fermi Institute, University of Chicago

Prof. Dr. Clifford M. Will
Department of Physics, Washington University

### The Board of Trustees of the AEI

The Board of Trustees is primarily intended to inspire confidence and create good relations between the Institute and the public. After all, a scientific organisation is dependent on the public interest in the opportunities offered by research and even on the public's willingness to bear the burden of research.

Members of our Board of Trustees are representatives of politics, the media, business, and of science and research:

## Scientists and Support Staff (Potsdam & Hannover) at the AEI and the University of Hannover – based on 1st June 2008

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| Prof. Dr. Karsten Danzmann | Laserinterferometry and Gravitational Wave Astronomy |
| Prof. Dr. Gerhard Huisken | Geometric Analysis and Gravitation |
| Prof. Dr. Hermann Nicolai | Quantum Gravity and Unified Theories |
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| Prof. Dr. Kenneth Strain | University of Glasgow |

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| | |
|---|---|
| Dr. Niklas Beisert | Duality and Integrable Structures (funded by the Max Planck Society) |
| Dr. Yanbei Chen | Theoretical Gravitational Wave Physics (funded by the Humboldt Foundation) |

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Prof. Lars Andersson (AEI Golm)
Dr. Marcus Ansorg (AEI Golm)
Dr. Peter Aufmuth (University of Hannover)
Dr. Stanislav Babak (AEI Golm)
Prof. Dr. Helmut Friedrich (AEI Golm)
Dr. Hartmut Grote (AEI Hannover)
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Dr. John Whelan (AEI Golm)
Dr. Benno Willke (University of Hannover)
Dr. Walter Winkler (AEI Hannover)

### Junior Scientists

Dr. Ido Adam (AEI Golm)
Dr. Abhishek Agarwal (AEI Golm)
Dr. Paul T. Allen (AEI Golm)
Dr. Dumitru Astefanesei (AEI Golm)
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Dr. Henning Fehrmann (AEI Hannover)
Dr. Stefan Fredenhagen (AEI Golm)
Dr. Lisa Freyhukt (AEI Golm)
Dr. Ehud Fuchs (AEI Golm)
Dr. Antonio Francisco Garcia Marin (AEI Hannover)
Dr. Bruno Giacomazzo (AEI Golm)
Dr. Kristina Giesel (AEI Golm)
Prof. Dr. Domenico Giulini (AEI Golm)
Dr. Stefan Goßler (University of Hannover)
Dr. Steffen Grunewald (AEI Golm)
Dr. Jan Harms (AEI Hannover)
Dr. Jörg Hennig (AEI Golm)
Dr. Martin Hewitson (AEI Hannover)
Dr. Sascha Husa (AEI Golm)
Dr. Fumiko Kawazoe (AEI Hannover)
Dr. Dong-Hoon Kim (AEI Golm)
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Dr. Mikolaj Korzynski (AEI Golm)
Dr. Michael Kroyter (AEI Golm)
Dr. Gerrit Kühn (AEI Hannover)
Dr. Tobias Lamm (AEI Golm)

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### Junior Scientists

Dr. Lucy MacNay (AEI Golm)
Dr. Teresia Mansson (AEI Golm)
Dr. Lorenzo Mazzieri (AEI Golm)
Dr. Christopher Messenger (AEI Hannover)
Dr. Jan Metzger (AEI Golm)
Dr. Paola Leaci (AEI Golm)
Dr. Tristan McLoughlin (AEI Golm)
Dr. Francesco Nicolo (AEI Golm)
Dr. Huy Nguyen (AEI Golm)
Dr. Miquel Nofrarias (AEI Hannover)
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Dr. Carlos Palenzuela (AEI Golm)
Dr. Ajith Parameswaran (AEI Hannover)
Dr. Carlos Peralta (AEI Golm)
Dr. Maria Jesus Pareja (AEI Hannover)
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Dr. Jens Reiche (AEI Hannover)
Dr. Christian Röver (AEI Hannover)
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Dr. Benjamin Sheard (AEI Hannover)
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Dr. Kentaro Somiya (AEI Hannover)
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Dr. Luca Spani Molella (AEI Hannover)
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Dr. Bob Taylor (AEI Hannover)
Dr. Michael Tröbs (AEI Hannover)
Dr. Linquing Wen (AEI Golm)
Dr. Martin Wijnholt (AEI Golm)
Dr. Shin Yoshida (AEI Golm)
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Benjamin Bahr (AEI Golm)
Aneta Barbos (AEI Golm)
Till Bargheer (AEI Golm)
Nicolas Behr (AEI Golm)
Michael Britzger (University of Hannover)
Johannes Brödel (AEI Golm)
Oliver Burmeister (University of Hannover)
Carla Cederbaum (AEI Golm)
Claudia Colonnello (AEI Golm)
Katrin Dahl (University of Hannover)
Marina Dehne (AEI Hannover)
James DiGuglielmo (AEI Hannover)
Jessica Dück (AEI Hannover)
Juan Jose Esteban Delgado (AEI Hannover)
Cecilia Flori (AEI Golm)
Roland Fleddermann (AEI Hannover)
Alexander Franzen (AEI Hannover)
Daniel Friedrich (University of Hannover)
Erich Gärtig (University of Hannover)
Felipe Guzmán Cervantes (AEI Hannover)
Boris Hage (University of Hannover)
Muxin Han (AEI Golm)
Florian Hanisch (AEI Golm)
Alexander Haupt (AEI Golm)
John Head (AEI Golm)
Christian Hillmann (AEI Golm)
Thorsten Kellermann (AEI Golm)
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Johannes Tamborino (AEI Golm)
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## Scientists and Support Staff (Potsdam & Hannover) at the AEI and the University of Hannover – based on 1st June 2008

### Diploma Students

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Christian Gräf (University of Hannover)
Michael Jasiulek (AEI Golm)
Tahir Evren Kendi (University of Hannover)
Peter Koroteev (AEI Golm/ITEP Moscow)
David Link (AEI Golm)
Thomas Marquardt (AEI Golm)
Philipp Mösta (AEI Golm)
Ernesto Nungesser (AEI Golm)
Markus Otto (University of Hannover)
Bogdan Papiniu (University of Hannover)
Henning Ryll (University of Hannover)
Lucia Santamaria (AEI Golm)
Carsten Schneemann (AEI Golm)
Sebastian Steinlechner (University of Hannover)
Tobias Westphal (University of Hannover)

### Research Programmers

Dr. Alexander Beck-Ratzka (AEI Golm)
Ingo Diepholz (AEI Hannover)
Robert Engel (AEI Golm)
Dr. Ralf Kähler (AEI Golm/ZIB)
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### Support Staff (Funding Source)

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| Dörte Bange | Coordinator IMPRS on Gravitational Wave Astronomy (AEI Golm) |
| Almuth Barta | System & Database Administrator (AEI Golm) |
| Anna Barta | Technical Helpforce (AEI Golm) |
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| Hannes Bernien | Scientific Helpforce (University of Hannover) |
| Stefan Bertram | Precision Mechanic (University of Hannover) |
| Sarah Blum | Secretary Assistant (AEI Golm) |
| Elisabeth Börner-Schlenk | Librarian (AEI Golm) |
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| Marc-Rainer Brinkmann | Operator GEO600 (AEI Hannover) |
| Nico Budewitz | Cluster System Administrator (AEI Golm) |
| Christian Büdenbender | Scientific Helpforce (AEI Hannover) |
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| Miranda Dettwyler | Technical and Scientific Editor Living Reviews (AEI Golm/MPDL) |
| Jan Diedrich | Precision Mechanic (University of Hannover) |
| Andreas Donath | System & Network Administrator (AEI Golm) |
| Claus Ebert | IT Help Desk Coordinator (AEI Hannover) |
| Marco Ehlert | Network Administrator (AEI Golm) |
| Ronny Esterluß | IT Help Desk Assistant (AEI Golm) |
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| Marco Pino Gajardo | Web Programmer, PR Assistant (AEI Golm) |
| Brigitte Gehrmann | Administrative Assistant LISA (AEI Hannover) |
| Christine Gottschalkson | Secretary (AEI Golm) |
| Walter Grass | Technician (AEI Hannover) |
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| Klaus-Dieter Haupt | Building Manager (University of Hannover) |
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| Christel Hausmann-Jamin | Head of IT Department (AEI Golm) |
| Sabine Hausner | Administration (AEI Golm) |
| Katharina Henke | Administrative Assistant (AEI Golm) |
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## Scientists and Support Staff (Potsdam & Hannover) at the AEI and the University of Hannover – based on 1st June 2008

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| Matthias Linden | Scientific Helpforce (AEI Hannover) |
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| Jonas Matthias | Scientific Helpforce (University of Hannover) |
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| Constance Münchow | Third Party Funds Manager (AEI Golm) |
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| Markus Paul | Trainee IT (AEI Golm) |
| Henning Perl | Technical Helpforce (AEI Hannover) |
| Michaela Pickenpack | Technician (University of Hannover) |
| Dr. Markus Pössel | Adjunct Public Outreach Scientist (AEI Golm) |
| Alexander Post | Technical Helpforce (AEI Hannover) |
| Susann Purschke | Guest House Manager (AEI Golm) |
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| Maximilia Richter | Technical Helpforce (AEI Hannover) |
| Christoph Rollwagen | IT Help Desk Assistant (AEI Golm) |
| Christiane Roos | Head of Administration (AEI Golm) |
| Karin Salatti-Tara | Secretary (AEI Hannover) |
| Grace Saupe | Cleaning Service (University of Hannover) |
| Jan Scharein | Web Developer (AEI Golm) |
| Philipp Schauzu | Precision Mechanic (University of Hannover) |
| Matthias Schlenk | Lecture Assistant (University of Hannover) |
| Ute Schlichting | Secretary (AEI Golm) |
| Manuela Schneehufer | Human Resources (AEI Golm) |
| Babett Schöppe | Accounting (AEI Golm) |
| Beatrice Schütze | Administrative assistant (AEI Golm) |
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| Andrea Seesko | Library Assistant (AEI Golm) |
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| Kristina Trien | Technical Helpforce (AEI Hannover) |
| Gerrit Visscher | Scientific Helpforce (AEI Hannover) |
| Malte Vogt | Scientific Helpforce (University of Hannover) |
| Andreas Weidner | Research Engineer (AEI Hannover) |
| Michael Weinert | Operator GEO600 (AEI Hannover) |
| André Werthmann | System Administrator (AEI Golm) |
| Susanne Witte | Human Resources (AEI Golm) |
| Ramona Wittwer | Accounting (AEI Golm) |
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| Heiko zur Mühlen | Electronic Technician (University of Hannover) |
| Manfred Zimpel | Administration (AEI Hannover) |
| Karl-Heinz Zwick-Meinheit | Research Engineer (University of Hannover) |

## Guest Scientists in Potsdam-Golm (2006)

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| Abdikamalov, Ernazar | SISSA, Trieste |
| Akhmedov, Emil | ITEP, Moscow |
| Angelantonj, Carlo | Turin University |
| Armendariz-Picun, Cristian | Syracuse University |
| Arnlind, Joakim | Royal Institute of Technology, Stockholm |
| Arun, K.G. | Raman Research Institute, Bangalore |
| Ashtekar, Abhay | Pennsylvania State University |
| Athanassenas, Maria | Monash University, Australia |
| | |
| Babiuc, Maria | University of Pittsburg |
| Backdahl, Thomas | University of Linköping |
| Bakas, Ioannis | University of Patras |
| Barausse, Enrico | SISSA, Trieste |
| Bär, Christian | Universität Potsdam |
| Bazhanov, Vladimir | Australian National University, Canberra |
| Beguin, Francois | University Paris Sud |
| Beig, Robert | Universität Wien |
| Bellettini, Giovanni | University of Rome II |
| Belov, Dimitriy | Imperial College, London |
| Beyer, Horst | Louisiana State University |
| Bičák , Jiri | Charles University, Prague |
| Bishop, Nigel | University of South Africa |
| Bizon, Piotr | Cracow University |
| Boels, Rutger | Oxford University |
| Bojowald, Martin | Pennsylvania State University |
| Bose, Sukanta | Washington State University |
| Brendle, Simon | Princeton University |
| Brink, Lars | Chalmers Technical University |
| Britzen, Silke | MPI für Radioastronomie |
| Brizuela Cieza, David | CSIC, Madrid |
| Brügmann, Bernd | Universität Jena |
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| Cao, Zhoujian | Chinese Academy of Sciences, Beijing |
| Chassande-Mottin, Eric | CNRS, Paris |
| Chirenti, Cecilia | University of Sao Paulo |
| Choptuik, Matthew | University of British Columbia |
| Choquet Bruhat, Yvonne | CCR, Jussieu |
| Chrusciel, Piotr | University Tours |
| Conlon, Joseph | DAMTP Cambridge, UK |
| Conrady, Florian | Pennsylvania State University |
| Costa, Joao | Lisbon University |
| Crowder, Jeff | Jet Propulsion Laboratory, Pasadena |
| Cutler, Curt | Jet Propulsion Laboratory, Pasadena |
| | |
| Dadhich, Naresh | IUCAA, Pune |
| Damour, Thibault | Institute des Hautes Etudes Scientifiques, Paris |
| de Gosson, Maurice | Blekinge Institute of Technology, Sweden |
| de Wit, Bernard | Utrecht University |
| Dhurandhar, Sanjeev | IUCAA, Pune |
| Diener, Peter | Louisiana State University |
| Dittrich, Bianca | Perimeter Institute, Waterloo |
| di Vecchia, Paolo | NORDITA, Copenhagen |
| | |
| Ecker, Klaus | Freie Universität, Berlin |
| Englert, Francois | University of Brussels |
| | |
| Fan, Xilong | Beijing University |
| Farrar, Glennys | New York University |
| Favata, Fabio | ESA |

## Guest Scientists in Potsdam-Golm (2006)

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|---|---|
| Fischer, Arthur | University of California |
| Font, Anamaria | UAM, Madrid |
| Francia, Dario | University of Rome |
| Frauendiener, Jörg | Universität Tübingen |
| Frieben, Joachim | Universität Potsdam |
| Frolov, Sergey | Trinity College Dublin |
| Gaberdiel, Matthias | ETH, Zürich |
| Gair, Jonathan | Cambridge University |
| Galajinsky, Anton | Tomsk Polytechnic University |
| Gao, Peng | Pennsylvania State University |
| Garecki, Janusz | University of Szczecin |
| Garfinkle, David | |
| Ghoshal, Debashis | Harish-Chandra Research Institute, Allahabad |
| Goda, Keisuke | MIT, Cambridge, MA |
| Goodale, Tom | Cardiff University |
| Govindarajan, Tupil R. | Institute of Mathematical Science, Chennai |
| Gran, Ulf | Catholic University, Leuven |
| Gromov, Nikolay | ENS, Paris |
| Grotowski, Joseph | University of Brisbane |
| Guenther, Christine | Pacific University |
| Gundlach, Carsten | University of Southampton, UK |
| Gürkan, Atakan | University of Amsterdam |
| Guzman, Francisco | Louisiana State University |
| Hahn, Atle | Universität Bonn |
| Hamber, Herbert | University of California, Irvine |
| Heinzle, Mark | Institut für Theoretische Physik, Wien |
| Henn, Johannes | Theoretical Physics Laboratory of Annecy-Le-Vieux |
| Henneaux, Marc | University of Brussels |
| Hertog, Thomas | CERN, Geneva |
| Hikida, Yasuaki | DESY, Hamburg |
| Hofmann, Stefan | Perimeter Institute, Waterloo |
| Hoppe, Jens | Royal Institute of Technology, Stockholm |
| Houart, Laurent | University of Brussels |
| Hubeny, Veronika | Durham University |
| Husa, Sascha | University of Pittsburgh |
| Hwang, Hyung Ju | Duke University |
| Ishidoshiro, Koji | Tokyo University |
| Isidro, Jose | University of Valencia |
| Ivashchuk, Vladimir | Center for Gravitation and Fundamental Metrology, Moscow |
| Iyer, Bala | Raman Research Institute, Bangalore |
| Jabbari, Shahin | IPM, Tehran |
| Janik, Romuald | Jagellonian University, Krakow |
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| Jasiulek, Michael | Humboldt-Universität Berlin |
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| Kazakov, Vladimir | ENS, Paris |
| Khalili, Farit | Moscow State University |
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| Kim, Nakwoo | Seoul National University |
| Kofron, David | Charles University, Prague |
| Korotkin, Dimitrii | Concordia University, Montreal |
| Koslowski, Tim | Universität Würzburg |
| Kostov, Ivan | CEA, Saclay |

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| Kowalski-Glikman, Jerzy | University of Wroclaw |
| Kreiss, Heinz-Otto | University of California, LA |
| Krolak, Andrzej | Academy of Sciences, Warsaw |
| Kumar, Prem | University of Wales, Swansea |
| Kupi, Gabor | Astronomisches Recheninstitut, Heidelberg |
| Kyrian, Karel | Charles University, Prague |
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| Lavrelashvili, George | A. Razmadze Mathematical Institute, Tbilisi |
| Li, Chao | California Institute of Technology |
| Loizelet, Julien | University Tours |
| Looney, Padraig | Trinity College, Dublin |
| Lopez, Esperanza | UAM, Madrid |
| Lotze, Karl-Heinz | Universität Jena |
| Löffler, Frank | SISSA, Trieste |
| Lukierski, Jerzy | Wroclaw University |
| Lundholm, Douglas | Royal Institute of Technology, Stockholm |
| Lusanna, Luca | University of Florence |
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| Maeda, Hideki | Waseda University, Japan |
| Mahapatra, Swapna | Utkal University, Bhubaneswar |
| Maharana, Karmaveda | Utkal University, Bhubaneswar |
| Martelli, Dario | CERN, Geneva |
| Maubon, Julien | University of Nancy |
| McLoughlin, Tristan A. | Pennsylvania State University |
| Meissner, Krzysztof | Warsaw University |
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| Meyer, Frank | LMU, München |
| Miller, Cole | University of Maryland |
| Minasian, Ruben | CEA, Saclay |
| Mino, Yasushi | California Institute of Technology |
| Moncrief, Vincent | Yale University |
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| Mottola, Emil | Los Alamos National Laboratory |
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| Newman, Ezra Ted | University of Pittsburgh |
| Nicolini, Piero | University of Trieste |
| Niedermaier, Max | University Tours |
| Nikolov, Nikolay | Institute for Nuclear Research and Nuclear Energy, Sofia |
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| Orlando, Domenico | Ecole Polytechnique, Paris |
| Ott, Christian | Steward Observatory, Tucson |
| Owen, Benjamin | Pennsylvania State University |
| Oz, Yaron | Tel Aviv University |
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| Papadimitriou, Ioannis | DESY, Hamburg |
| Paulot, Louis | University of Brussels |
| Pawelczyk, Jacek | Warsaw University |
| Perelomov, Askold | ITEP, Moscow |
| Petkou, Anastasios | University of Crete |
| Pfister, Herbert | Universität Tübingen |
| Pilc, Marian | Charles University, Prague |
| Pletsch, Holger | University of Wisconsin, Milwaukee |
| Ponce, Marcelo | University of Montevideo |
| Popov, Alexander | Universität Hannover |
| Potting, Robertus | University of Algarve |

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| Rangamani, Mukund | Durham University |
| Reshetikhin, Nicolai | University of California, Berkeley |
| Reuter, Martin | Universität Mainz |
| Rey, Soo-Jong | Seoul National University |
| Rideout, David | Hamilton College, Clinton |
| Ringström, Hans | Royal Institute of Technology, Stockholm |
| Roenne, Peter | Niels Bohr Institute, Copenhagen |
| Rosquist, Kjell | Stockholm University |
| Rossi, Julio | CSIC, Madrid |
| Runkel, Ingo | Kings College, London |
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| Sahlmann, Hanno | Pennsylvania State University |
| Samtleben, Henning | ENS, Lyon |
| Schäfer, Gerhard | Universität Jena |
| Schellekens, Bert | NIKHEF, Amsterdam |
| Schnabl, Martin | CERN, Geneva |
| Schnetter, Erik | Louisiana State University |
| Schubert, Christian | University of Texas-Pan American, Edinburgh |
| Schweigert, Christoph | Universität Hamburg |
| Schwimmer, Adam | Weizmann Institute, Rehovot |
| Seidel, Edward | Louisiana State University |
| Semerak, Oldrich | Charles University, Prague |
| Serban, Didina | CEA, Saclay |
| Sesum, Natasa | New York University |
| Shnir, Yakov | Universität Oldenburg |
| Simon, Walter | Universität Wien |
| Sinestrari, Carlo | University of Rome II |
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| Skorupka, Sascha | AEI Hannover |
| Sladek, Pavel | Charles University, Prague |
| Smilga, Andrei | University of Nantes |
| Smirnov, Vladimir | DESY, Hamburg |
| Sokatchev, Emery | Theoretical Physics Laboratory of Annecy-Le-Vieux |
| Stephan, Christoph | CPT, Marseille |
| Stewart, John | Cambridge University |
| Szabo, Richard | Heriot-Watt University, Edinburgh |
| Szybka, Sebastian | Cracow University |
| | |
| Tagne, Roger | University of Douala |
| Takou, Etienne | University of Yaounde |
| Tambornino, Johannes | Universität Aachen |
| Tetsadjio, Erick | University of Yaounde |
| Then, Holger | Universität Ulm |
| Thies, Michael | Universität Nürnberg |
| Thornburg, Jonathan | Universität Wien |
| Tod, Paul | Oxford University |
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| Varadarajan, Madhavan | Raman Research Institute, Bangalore |
| Vardarajan, Suneeta | University of New Brunswick, Canada |
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| Velazquez, Juan | MPI für Mathematik in den Naturwissenschaften, Leipzig |
| Vieira, Pedro | ENS, Paris |
| Vigelius, Matthias | University of Melbourne |
| Vikman, Alexander | LMU, München |
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## Guest Scientists in Potsdam-Golm (2006)

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| Vyatchanin, Sergey | Moscow State University |
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| Winicour, Jeffrey | University of Pittsburgh |
| Woolgar, Eric | University of Alberta |
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| Yankielowicz, Shimon | Tel Aviv University |
| Yoshida, Shin | Florida Atlantic University |
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| Zarembo, Konstantin | Uppsala University |
| Zhu, Zong-Hong | Beijing University |
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| Zofka, Martin | Charles University, Prague |

## Guest Scientists in Potsdam-Golm (2007)

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| Ahmedov, Bobomurat | Uzbekistan Academy of Sciences |
| Akhmedov, Emil | ITEP, Moscow |
| Alcubierre, Miguel | UNAM, Mexico |
| Alessandroni, Roberta | University of Rome |
| Alexander, Tal | Weizmann Institute, Rehovot |
| Alic, Dana | West University of Timisoara |
| Alikakos, Nicholas | University of Athens |
| Ammann, Bernd | University Henri Poincaré, Nancy |
| Andersson, Ole | Uppsala University |
| | |
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| Baiotti, Luca | Tokyo University |
| Banados, Maximo | University of Santiago, Chile |
| Barack, Leor | University of Southampton |
| Barausse, Enrico | SISSA, Trieste |
| Bartnik, Robert | University of Canberra |
| Bastianelli, Fiorenzo | University of Bologna |
| Baulieu, Laurent | LPTHE, Paris |
| Bazhanov, Vladimir | Australian National University, Canberra |
| Behrend, Juliane | Universität Heidelberg |
| Beig, Robert | Universität Wien |
| Belov, Dimitriy | Imperial College, London |
| Bernuzzi, Sebastiano | Parma University |
| Bethke, Siegfried | MPI für Physik |
| Beyer, Horst | Louisiana State University |
| Bianchi, Massimo | University of Rome II |
| Bičák , Jiři | Charles University, Prague |
| Bieri, Lydia | ETH, Zürich |
| Bishop, Nigel | University of South Africa |
| Bizon, Piotr | Cracow University |
| Bojowald, Martin | Pennsylvania State University |
| Bolejko, Krzysztof | Warsaw University |
| Borot, Gaetan | Ecole Normale Superieure, Paris |
| Brendle, Simon | Princeton University |
| Brink, Lars | Chalmers Technical University |
| Britto, Ruth | University of Amsterdam |
| Buchert, Thomas | Paris Observatory |
| Buchmüller, Wilfried | DESY, Hamburg |

## Guest Scientists in Potsdam-Golm (2007)

| | |
|---|---|
| Cabezas, Esther | University of Valencia |
| Caputo, Maria-Cristina | University of Texas |
| Carrera, Matteo | Universität Freiburg |
| Centrella, Joan | NASA/GSFC, Greenbelt MD |
| Chen, Sophie Szu-Yu | University of Berkeley |
| Chirenti, Cecilia | University of Sao Paulo |
| Cho, Yongmin | Seoul National University |
| Choptuik, Matthew | University of British Columbia |
| Chrusciel, Piotr | Tours University |
| Corvino, Giovanni | Parma University |
| Dahl, Mattias | Royal Institute of Technology, Stockholm |
| Dain, Sergio | University of Cordoba |
| Damour, Thibault | IHES, Paris |
| Davies, Melvyn B. | Lund Observatory |
| De Felice, Fernando | University of Padova |
| de Pietri, Roberto | Parma University |
| Devchand, Chand | Universität Potsdam |
| Diener, Peter | Louisiana State University |
| Döring, Andreas | Imperial College, London |
| Dowker, Fay | Imperial College, London |
| Dutta, Suvankar | Harish-Chandra Research Institute, Allahabad |
| Dwivedi, Siddharth | Indian Institute of Technology |
| Engle, Jonathan | University of Marseille |
| Fairhurst, Stephen | Cardiff University |
| Fan, Xilong | Beijing University |
| Feingold, Alex | State University of New York at Binghamton |
| Foerste, Stefan | University of Durham |
| Font, Anamaria | UAM, Madrid |
| Forini, Valentina | University of Perugia |
| Frauendiener, Jörg | Universität Tübingen |
| Fredenhagen, Klaus | Universität Hamburg |
| Freire, Alex | University of Tennessee |
| Freitag, Marc | University of Cambridge, UK |
| Frolov, Sergey | Trinity College, Dublin |
| Gair, Jonathan | University of Cambridge, UK |
| Garay, Inaki | Warsaw University |
| Garecki, Janusz | University of Szczecin |
| Gauntlett, Jerome | Imperial College, London |
| Ghoshal, Debashis | Jawaharlal Nehru University, New Delhi |
| Gibbons, Gary | DAMTP, Cambridge, UK |
| Gizon, Laurent | MPI für Sonnensystemphysik |
| Gleiter, Herbert | Forschungszentrum Karlsruhe |
| Glowna, Frank | Universität Jena |
| Govindarajan, Tupil | Institute of Mathematical Science, Chennai Rangachari |
| Grana, Mariana | CEA, Saclay |
| Gromov, Nikolay | ENS, Paris |
| Grunau, Hans Christoph | Universität Magdeburg |
| Guenther, Christine | Pacific University |
| Guerlebeck, Norman | Charles University, Prague |
| Guha, Partha | Bose National Centre for Basic Sciences, Calcutta |
| Gurkovsky, Alexey | Moscow State University |
| Haack, Michael | LMU, München |
| Hafner, Dietrich | University of Bordeaux |
| Hamber, Herbert | University of California, Irvine |
| Hannam, Mark | Universität Jena |
| Hebecker, Arthur | Universität Heidelberg |

## Guest Scientists in Potsdam-Golm (2007)

| | |
|---|---|
| Heinzle, Mark | Institut für Theoretische Physik, Wien |
| Hogan, Craig | University of Washington, Seattle |
| Hopman, Clovis | Leiden Observatory |
| Hoppe, Jens | Royal Institute of Technology, Stockholm |
| Hough, James | University of Glasgow |
| Humbert, Emmanuel | Nancy University |
| Husemoller, Dale | MPI für Mathematik |
| Husemoller, Dale | MPI für Mathematik |
| Hwang, Hyung Ju | Duke University |
| | |
| Isenberg, Jim | University of Oregon |
| Isidro, Jose | University of Valencia |
| Iyer, Bala | Raman Research Institute, Bangalore |
| | |
| Jaramillo, Jose | Astrophysical Institute of Andalusia |
| | |
| Kazakov, Vladimir | ENS, Paris |
| Khurana, Deepak | Indian Institute of Technology |
| Kim, Nakwoo | Seoul National University |
| Kleinknecht, Konrad | Universität Mainz |
| Kleinschmidt, Axel | University of Brussels |
| Klose, Thomas | Uppsala University |
| Koch, Herbert | Universität Bonn |
| Kofron, David | Charles University, Prague |
| Komorowski, Peter | University of Western Ontario |
| Koroteev, Peter | ITEP, Moscow |
| Korzynski, Mikolaj | Warsaw University |
| Kotikov, Anatoly | Joint Institute for Nuclear Research, Dubna |
| Kovacs, Stefano | Trinity College, Dublin |
| Kozameh, Carlos | University of Cordoba |
| Kreimer, Dirk | IHES, Bures-Sur-Yvette |
| Kreiss, Heinz-Otto | University of California |
| Kurusch, Ebrahimi-Fard | MPI für Mathematik |
| Kuwert, Ernst | Universität Freiburg |
| Kuzenko, Sergei | University of Western Australia |
| | |
| Lattimer, James | Stony Brook University, New York |
| Lämmerzahl, Claus | Universität Bremen |
| Lavrelashvili, George | A. Razmadze Mathematical Institute, Tbilisi |
| Levin, Yuri | Leiden Observatory |
| Lewandowski, Jerzy | Warsaw University |
| Li, Chao | California Institute of Technology |
| Li, Yuxian | Universität Freiburg |
| Lim, Woei-Chet | Princeton University |
| Lipatov, Lev | Universität Hamburg |
| Löffler, Frank | Louisiana State University |
| Lousto, Carlos | University of Texas at Brownsville |
| | |
| Malec, Edward | Cracow University |
| Malhotra, Karan | Indian Institute of Technology |
| Manca, Gian Mario | Parma University |
| Mars, Marc | University of Salamanca |
| Meissner, Krzysztof | Warsaw University |
| Meziane, Ahmed | University of Oran |
| Miao, Haixing | University of Western Australia |
| Micallef, Mario | University of Warwick |
| Miller, Cole | University of Maryland |
| Minasian, Ruben | CEA, Saclay |
| Mingireanu, Florin | Louisiana State University |
| Moncrief, Vincent | Yale University |
| Monnier, Samuel | University of Geneva |

## Guest Scientists in Potsdam-Golm (2007)

| | |
|---|---|
| Montero, Pedro | University of Valencia |
| Müller, Reto | ETH, Zürich |
| | |
| Nagar, Alessandro | Polytechnic University of Turin |
| Neilsen, David | Brigham Young University, Provo |
| Newman, Ezra Ted | University of Pittsburgh |
| Ni, Wei-Tou | National Tsing Hua University |
| Nikolov, Nikolay | Institute for Nuclear Research and Nuclear Energy, Sofia |
| Nowak, Sebastian | University of Wroclaw |
| Nussinov, Shmuel | Tel Aviv University |
| | |
| Okawa, Yugi | DESY, Hamburg |
| Ortiz, Omar | University of Cordoba |
| Ott, Christian | Steward Observatory, Tucson |
| Oz, Yaron | Tel Aviv University |
| | |
| Pal, Supratik | IUCAA, Pune |
| Papadopoulos, George | Kings College, London |
| Parameswaran, Ajith | AEI Hannover |
| Pasquetti, Sara | Neuchatel University |
| Pawelczyk, Jacek | Warsaw University |
| Perelomov, Askold | ITEP, Moscow |
| Pfeiffer, Harald | California Institute of Technology |
| Phinney, Sterl | California Institute of Technology |
| Plefka, Jan | HU Berlin |
| Potting, Robertus | University of Algarve |
| | |
| Quella, Thomas | University of Amsterdam |
| | |
| Rabinovici, Eliezer | The Hebrew University, Jerusalem |
| Restuccia, Alvaro | University of Caracas |
| Reula, Oscar | University of Cordoba |
| Rey, Soo-Jong | Seoul National University |
| Ridout, David | DESY, Hamburg |
| Ringström, Hans | Royal Institute of Technology, Stockholm |
| Rosly, Alexei | ITEP, Moscow |
| | |
| Sahlmann, Hanno | Utrecht University |
| Saijo, Motoyuki | University of Southampton |
| Samtleben, Henning | ENS, Lyon |
| Sauerbrey, Roland | Forschungszentrum Dresden-Rossendorf |
| Schäfer, Gerhard | Universität Jena |
| Schnetter, Erik | Louisiana State University |
| Scholtz, Martin | Charles University, Prague |
| Schubert, Christian | University of Texas-Pan American, Edinburgh |
| Schützhold, Ralf | Technische Universität Dresden |
| Schwimmer, Adam | Weizmann Institute, Rehovot |
| Sedrakian, Armen | Universität Tübingen |
| Seel, Alexander | Universität Hannover |
| Seidel, Edward | Louisiana State University |
| Seidel, Edward | Louisiana State University |
| Send, Wolfgang | Institut für Aeroelastik, Göttingen |
| Serban, Didina | CEA, Saclay |
| Sintes Olives, Alicia | University of the Balearic Islands, Mallorca |
| Skorupka, Sascha | AEI Hannover |
| Smilga, Andrei | University of Nantes |
| Sonnenschein, Jacob | Tel Aviv University |
| Sotani, Hajime | University of Thessaloniki |
| Spani-Molella, Luca | AEI Hannover |
| Stark, Dylan | Louisiana State University |
| Stavridis, Adamantios | CNRS, Paris |

## Guest Scientists in Potsdam-Golm (2007)

| | |
|---|---|
| Stelle, Kellogg | Imperial College, London |
| Stergioulas, Nikolaos | University of Thessaloniki |
| Stieberger, Stephan | Universität München |
| Struwe, Michael | ETH, Zürich |
| Szulc, Lukasz | Warsaw University |
| | |
| Tarabrin, Sergey | Moscow State University |
| Theis, Ulrich | Universität Jena |
| Thornburg, Jonathan | Universität Wien |
| | |
| Uggla, Claes | Karlstad University, Sweden |
| Ullmer, Brygg | Louisiana State University |
| | |
| Valiente Kroon, Juan Antonio | Queen Mary College, London |
| Valluri, Sree Ram | University of Western Ontario |
| van Elst, Henk | FH Karlsruhe |
| Vasiliev, Misha | Lebedev Institute, Moscow |
| Velazquez, Juan | MPI für Mathematik in den Naturwissenschaften |
| Vidotto, Francesca | University of Padua |
| Vitale, Stefano | University of Trento |
| Vulcanov, Dumitru | Timisoara University |
| | |
| Wald, Robert | University of Chicago |
| Watts, Anna | MPI für Astrophysik |
| Wellig, David | ETH, Zürich |
| Weth, Tobias | Universität Gießen |
| Will, Clifford | Washington University |
| Williams, Ruth | DAMTP, Cambridge, UK |
| Winicour, Jeffrey | University of Pittsburgh |
| | |
| Yankielowicz, Shimon | Tel Aviv University |

## Guest Scientists in Hannover 2006 – 2007

| | |
|---|---|
| Adelberger, Eric | University of Washington, USA |
| Anderson, David | University of California, Berkeley |
| Anderson, Stuart | LIGO |
| Arun, K.G. | Raman Research Inst., Bangalore |
| Ballmer, Stefan | California Institute of Technology |
| Bastarriha, Mikel | University of Glasgow |
| Bogenstahl, Johanna | University of Glasgow |
| Bork, Rolf | California Institute of Technology |
| Bose, Sukanta | Washington State University |
| Cochrane, Paul | |
| Colon, Luis | |
| Corda, Christian | EGO, Cascina |
| Freise, Andreas | University of Birmingham |
| Grynagier, Adrien | Universität Stuttgart |
| Hallam, Jonathan | |
| Heng, Ik Siong | University of Glasgow |
| Huber, Martin | Paul Scherrer Institut, Villingen |
| Kelemen, Peter | CERN, Geneva |
| Khalili, Farid | University of Moscow |
| King, Péter | California Institute of Technology |
| Klimenko, Sergey | University of Florida, Gainsville |
| Kuroda, Kazuaki | Nat. Res. Lab., Japan |
| Kutuvantavida, Yasar | ENSIETA, Brest |
| Li, Guangyu | Purple Mountain Observatory, Nanjing |
| Lucia, Santamaria | Universität Jena |
| Mantovani, Maddalena | EGO, Cascina |
| Marka, Szabolcs | Columbia University, New York |
| Mitra, Sanjit | Observatoire de la Côte d'Azur, Nice |
| Owen, Benjamin | Pennsylvania State University |
| Palomba, Christiano | INFN Rome |
| Pankow, Chris | University of Florida, Gainesville |
| Perrela, Antonio | |
| Romano, Joseph | Stanford University |
| Sanjuan, Josep | IEEC, Barcelona |
| Sintes Olives, Alicia M. | Universitat de les Illes Balears, Palma |
| Talukder, Dipongkar | Washington State University |
| Torrie, Calum | University of Glasgow |
| Vitale, Stefano | University of Trento |
| Vyatchanin, Sergey P. | |
| Wang, Feng | |
| Wette, Karl | Australian National University, Canberra |
| Wisemann, Alan | University of Wisconsin |
| Xia, Yan | |

## Publications by the Institute

Max-Planck-Institut für Gravitationsphysik (Ed.) — Living Reviews in Relativity, Living Reviews in Relativity 9 (2006),10 (2007) http://www.livingreviews.org

## Publications by AEI Members and Guest Scientists


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Abbott, B. and the LIGO Scientific Collaboration (author list S2) — Search for gravitational waves associated with 39 gamma-ray bursts using data from the second, third, and fourth LIGO run. arXiv: 0709.0766

Abbott, B. and the LIGO Scientific Collaboration (author list S3) — Search for gravitational-wave bursts in LIGO's third science run. Classical and Quantum Gravity 23 (2006) S29-S39. arXiv: gr-qc/0511146

Abbott, B. and the LIGO Scientific Collaboration (author list S3) — A joint search for gravitational wave bursts with AURIGA and LIGO. arXiv: 0710.0497

Abbott, B. and the LIGO Scientific Collaboration (author list S3/S4) — Upper limits on gravitational wave emission from 78 radio pulsars. Physical Review D 76, 4, Seq. No.: 042001 (2007). arXiv: gr-qc/0702039

Abbott, B. and the LIGO Scientific Collaboration (author list S3/S4) — Search for gravitational waves from binary inspirals in S3 and S4 LIGO data. Physical Review D 77, 6, Seq. No.: 062002. arXiv: 0704.3368

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Abbott, B. and the LIGO Scientific Collaboration (author list S4) — Upper limit map of a background of gravitational waves. Physical Review D 76, 8, Seq. No.: 082003 (2007). arXiv: astro-ph/0703234

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C. McGuire, M. McHugh, K. McKenzie, J. W. C. McNabb, S. McWilliams, T. Meier, A. Melissinos, G. Mendell, R. A. Mercer, S. Meshkov, C. J. Messenger, D. Meyers, E. Mikhailov, S. Mitra, V. P. Mitrofanov, G. Mitselmakher, R. Mittleman, O. Miyakawa, S. Mohanty, G. Moreno, K. Mossavi, C. MowLowry, A. Moylan, D. Mudge, G. Mueller, S. Mukherjee, H. Müller-Ebhardt, J. Munch, P. Murray, E. Myers, J. Myers, T. Nash, G. Newton, A. Nishizawa, F. Nocera, K. Numata, B. O'Reilly, R. O'Shaughnessy, D. J. Ottaway, H. Overmier, B. J. Owen, Y. Pan, M. A. Papa, V. Parameshwaraiah, C. Parameswariah, P. Patel, M. Pedraza, S. Penn, V. Pierro, I. M. Pinto, M. Pitkin, H. Pletsch, M. V. Plissi, F. Postiglione, R. Prix, V. Quetschke, F. Raab, D. Rabeling, H. Radkins, R. Rahkola, N. Rainer, M. Rakhmanov, M. Ramsunder, K. Rawlins, S. Ray-Majumder, V. Re, T. Regimbau, H. Rehbein, S. Reid, D. H. Reitze, L. Ribichini, R. Riesen, K. Riles, B. Rivera, N. A. Robertson, C. Robinson, E. L. Robinson, S. Roddy, A. 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## Institute Colloquia 2006/2007 at AEI Potsdam-Golm

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|---|---|
| Bala Iyer (Raman Research Institute, Bangalore) | The 3.5PN generation of gravitational waves from inspiralling compact binaries / 19 January 2006 |
| Markus Antonietti (MPI for Colloids and Interfaces) | Colloid chemistry, and how to explain it to black hole physicists / 9 February 2006 |
| Stefano Vitale (University of Trento) | LISA Pathfinder: tracing Einstein's geodesics for LISA / 8 March 2006 |
| Benoit Mours (LAPP-Annecy) | Status and plans for Virgo / 26 April 2006 |
| Thibault Damour (IHES) | Gravitational wave signals from black holes and strings / 30 May 2006 |
| Glennys Farrar (New York University) | Ultrahigh energy cosmic rays / 28 June 2006 |
| Anton Zeilinger (University of Vienna) | Entanglement: A philosophical curiosity becoming a resource in quantum communication and quantum computation / 20 September 2006 |
| Fritz Haake (University of Duisburg-Essen) | Universal spectral properties in quantum chaos / 15 November 2006 |
| Friedrich Wagner (MPI of Plasma Physics, Greifswald) | Fusion and the physics behind magnetic confinement / 6 December 2006 |
| Melvyn Davies (Lund Observatory) | The astrophysics of stellar clusters / 17 January 2007 |
| Anna Watts (MPI for Astrophysics, Garching) | Developments in neutron star astrophysics and implications for gravitational wave emission / 14 February 2007 |
| Jiři Bičák (Institute of Theoretical Physics, Charles University, Prague) | The role of exact solutions of Einstein´s field equations in general relativity and astrophysics – variations on selected themes / 28 February 2007 |
| Laurent Gizon (MPI for Solar System Research) | Solar oscillations / 15 March 2007 |

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| Claus Lämmerzahl (ZARM, Bremen) | The Pioneer-Anomaly – how good is the experimental confirmation of general relativity? / 25 April 2007 |
| Marc Freitag (Cambridge University) | The tumultuous lives of binary stars in a galactic nucleus / 2 May 2007 |
| Guinevere Kauffmann (MPI for Astrophysics, Garching) | The growth of supermassive black holes in galaxies / 9 May 2007 |
| Carl Brans (Loyola University, New Orleans) | Exotic smoothness and spacetime models / 16 May 2007 |
| Siegfried Bethke (MPI for Physics, Munich) | The Large Hadron Collider project / 30 May 2007 |
| Clovis Hopman (Leiden Observatory) | Stellar dynamics near massive black holes / 6 June 2007 |
| Yuri Levin (Leiden University) | Double feature: 1. Magnetar oscillations, and 2. Detecting gravitational waves using pulsar timing arrays / 5 September 2007 |
| Ortwin Gerhard (MPI for Extraterrestrial Physics) | Collisionless dynamical models of elliptical galaxies / 17 October 2007 |
| Ralf Schützhold (Technische Universität Dresden) | Emergent horizons in the laboratory / 7 November 2007 |
| Craig Hogan (University of Washington) | New physics and cosmology with gravitational wave detectors / 14 November 2007 |
| Konrad Kleinknecht (Johannes-Gutenberg Universität Mainz) | Climate change and human energy consumption / 21 November 2007 |

## Invited Conference Talks

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|---|---|
| Ajith, P. | Phenomenological template bank for black hole coalescence waveforms / 27 July 2006 / 11th Marcel Grossmann Meeting, Freie Universität Berlin |
| Ajith, P. | Gravitational-wave burst vetoes using known instrumental couplings / 18 December 2006 / GWDAW 11, Potsdam |
| Ajith, P. | Phenomenological template bank for black-hole coalescence waveforms / 20 December 2006 / GWDAW 11, Potsdam |
| Amaro-Seoane, P. | A review of GW sources + Astrodynamics / 27 August 2007 / JENAM 2007 |
| Ananth, S. | Perturbative relations between gauge theory and gravity / 3 July 2007 / Eurostrings 2007, Crete |
| Aufmuth, P. | Gravitationswellen / 29 September 2006 / 1. Dillinger Physiktage "Relativität und Kosmologie", Dillingen |
| Aufmuth, P. | Gravitational Waves and Gamma-Ray Bursts / 28 March 2007 / Workshop „Short Gamma-Ray Bursts", Tegernsee |
| Aufmuth, P. | Detection of Gravitational Waves - Results so far / 24 March 2006 / 70. Jahrestagung der DPG, München |
| Aufmuth, P. | Zum aktuellen Stand der Gravitationswellenforschung / 9 March 2007 / DPG-Frühjahrstagung, Heidelberg |
| Bahr, B. | On the physical inner product of Loop Quantum Gravity / 23 March 2006 / DPG-Frühjahrstagung, München |
| Bahr, B. | On the physical inner product of Loop Quantum Cosmology / 23 April 2006 / 11th Marcel Grossmann meeting, Berlin |
| Beisert, N. | The S-Matrix of AdS/CFT / 29 August 2006 / 38th International Symposium Ahrenshoop, Berlin Schmöckwitz |
| Beisert, N. | The S-Matrix of AdS/CFT / 20 October 2006 / Solvay Workshop, Bethe Ansatz, 75 years later, Brussels |
| Beisert, N. | Integrability and the S-Matrix in AdS/CFT / 20 December 2006 / 12th IFT-UAM/CSIC Christmas Workshop, Madrid |
| Beisert, N. | The Worldsheet S-Matrix of Planar N=4 Gauge Theory / 20 February 2007 / PNPI Winter School, St. Petersburg |
| Beisert, N. | Integrability in AdS/CFT /16 March 2007 / IWTHEP Roorkie |
| Beisert, N. | Integrability in AdS/CFT / 11 May 2007 / Workshop Gauge Theories, Strings and Geometry, Solvay Institute, Brussels |
| Beisert, N. | Symmetries Related to AdS/CFT Integrability / 20 June 2007 / Integrability in Gauge and String Theory, SPhT Saclay and ENS Paris |
| Beisert, N. | Strong/Weak Interpolation in the Spectrum of AdS/CFT / 26 June 2007 / Strings 2007, Madrid |
| Beisert, N. | Integrability in AdS/CFT II: S-Matrix and Algebraic Aspects / 24 September 2007 / Isaac Newton Institute |
| Beisert, N. | Anomalous dimensions and integrability in AdS/CFT / 28 September 2007 / DESY, Hamburg |

## Invited Conference Talks

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| Beisert, N. | Spectral Curve for the Heisenberg Ferromagnet and AdS/CFT / 10 December 2007 / Isaac Newton Institute |
| Beisert, N. | Integrability in AdS/CFT / 14 October 2007 / La Londe les Maures |
| Beisert, N. | Integrability in AdS/CFT /11 May 2007 / Workshop Gauge Theories, Strings and Geometry, Solvay Institute, Brussels |
| Berg, M. | Volume Stabilization by Quantum Corrections / 3 April 2006 / Eurostrings Conference, Cambridge |
| Beyer, F. | Conformal infinity and global properties of cosmological models with positive cosmological constant / 8 September 2006 / JINR, Dubna, Russia |
| Beyer, F. | A new code for simulating future asymptotically de-Sitter spacetimes with spherical topology / 6 November 2006 / FaMAF, Cordoba, Argentina |
| Bieli, R. | Accelerated expansion by non-minimally coupled scalar fields / 24 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Burmeister, O. | Interferometrie mit diffraktiver Optik / 16 March 2006 / DPG-Frühjahrstagung, Frankfurt |
| Burmeister, O. | High Reflectivity Waveguide Coatings / 7 October 2006 / LIGO-VIRGO Thermal Noise Workshop, Cascina |
| Burmeister, O. | Recent Progress in all Reflective Interferometry / 27 October 2006 / 3rd ILIAS GW Annual General Meeting, London |
| Chelkowski, S. | Squeezing the Quantum Noise in Gravitational Wave Interferometers / 1 March 2006 / ILIAS Meeting, Gran Sasso |
| Chelkowski, S. | Anwendungen gequetschten Lichts in der Gravitationswellen-Interferometrie / 14 March 2006 / DPG-Frühjahrstagung, Frankfurt |
| Chelkowski, S. | Squeezed Field Injection for GEO-HF / 13 October 2006 / GEO Meeting, Glasgow |
| Chelkowski, S. | Generation of Squeezed States for Gravitational Wave Detectors / 21 March 2007 / LSC Meeting, Baton Rouge |
| Chrusciel, P.T. | The mathematics of gravitation / 13 May 2006 / Symposium „90th Anniversary of General Relativity“, Warsaw University |
| Danzmann, K. | Low Frequency Gravitational Waves / 12 January 2006 / Royal Astronomical Society Topical Meeting, London |
| Danzmann, K. | LISA in 2006 / 19 June 2006 / 6th International LISA Symposium, GSFC, Washington DC |
| Danzmann, K. | Gravitational Wave Observations in Space / 21 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Danzmann, K. | LISA and LISA Pathfinder / 24 August 2006 / Relativistic Astrophysics Meeting, Santorini |
| Danzmann, K. | The LISA Mission / 7 November 2006 / Beyond Einstein Presentation, Academy of Sciences, Washington DC |
| Danzmann, K. | LISA in Europe and the United States / 18 December 2006 / GWDAW 11, Potsdam |

## Invited Conference Talks

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| Danzmann, K. | Laser Interferometry in Space / 8 May 2007 / Conference in Lasers and Electrooptics (CLEO), Baltimore |
| Danzmann, K. | Science with LISA / 11 June 2007 / Int. Workshop "From Quantum to Cosmos", Bremen |
| Danzmann, K. | The Future of Gravitational Wave Astronomy / 11 August 2007 / Pennsylvania State Centre for Gravitational Physics Symposium |
| Danzmann, K. | Listening to Gravitational Waves from Space / 26 September 2007 / Garching, Gravitational Astronomy Annual Meeting |
| Danzmann, K. | Lasers in Space / 27 September 2007 / Hannover |
| Danzmann, K. | The Future of Gravitational Wave Detection in Space / 20 October 2007 / LIGO Science Collaboration Meeting |
| Ehlers, J. | Gödel, Relativity Theory and the Concept of Time / 5 May 2006 / Int. Conference in memory of Kurt Gödel, Barcelona |
| Ehlers, J. | Jordans Beiträge zur Entstehung der Quantenmechanik / 5 June 2006 / Max-Planck-Institut für Wissenschaftsgeschichte, Berlin |
| Ehlers, J. | Das Unendliche in der Physik / 1 December 2006 / Internat. Fachtagung über Unendlichkeit, Tübingen |
| Ehlers, J. | What is background independence? / 20 December 2006 / Conference on Foundations of Physics, Goa |
| Ehlers, J. | Principles of General Relativity / 25 May 2007 / Department of Physics, Charles University Prague |
| Ehlers, J. | The Importance of gravitation for physics and related sciences / 11 June 2007 / Int. Workshop "From Quantum to Cosmos", Bremen |
| Ehlers, J. | On the relations between field equations and equations of motion in Newtonian and Einsteinian gravity / 18 October 2007 / Int. conference on Myron Mathisson, Warsaw |
| Ehlers, J. | Max Born als Gestalter der Quantenmechanik / 12 December / Symposium zum 125. Geburtstag von Max Born, Berlin |
| Ehlers, J. | Physics as a human attempt to understand Nature / 3 September 2007 / Int. conference on "Human persons and the God of Nature", Oxford |
| Fleddermann R. | Charakterisierung rauscharmer Spannungsreferenzen für LISA / 16 March 2006 / DPG-Frühjahrstagung, Frankfurt |
| Fleddermann R. | Low Noise Voltage References and Reciprocity of a Fiber / 15 December 2006 / LISA WG2, Golm |
| Fleddermann R. | Charakterisierung rauscharmer Spannungsreferenzen für LISA / 21 March 2007 / DPG-Frühjahrstagung, Düsseldorf |
| Flori, C. | Valuations in the language of Topos Theory / 23 June 2006 / 11th Marcel Grossmann meeting, Berlin |
| Flori, C. | Not just True or False / 3 November 2006 / Berlin, Germany |
| Fredenhagen, S. | Boundary flows induced by bulk deformations / 14 March 2007 / Conference „Beyond the standard model", Bad Honnef, Germany |

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| Fredenhagen, S. | Bulk and boundary perturbations / 11 May 2007 / UK meeting on Integrable Models and CFT, London |
| Fredenhagen, S. | Symmetries of perturbed conformal field theories / 27 August 2007 / Conference "Symmetries of string theory", Ascona (Switzerland) |
| Fredenhagen, S. | Bulk and boundary perturbations / 11 May 2007 / UK meeting on Integrable Models and CFT, London |
| Friedrich, H. | Is general relativity ‚essentially understood'? / 23 March 2006 / 70. Jahrestagung der DPG, TU München |
| Friedrich, H. | Asymptotically flat space-times / 6 November 2006 / Workshop on global problems in Relativity, Cordoba, Argentina |
| Friedrich, H. | The nature of Einsteins field equations, properties of their solutions, and approaches to their numerical calculation / 4 October 2007 / Workshop on "Conceptual Problems in Computational Gravity", CMA, University of Oslo |
| Garcia Marin, A.F. | Interferometry for LISA and LISA Pathfinder / September 2006 / XXIXth Spanish Relativity Meeting (ERE 2006), Palma de Mallorca |
| Giacomazzo, B. | WhiskyMHD: A New Numerical Code for General Relativistic Magnetohydrodynamics / 29 March 2007 / Workshop on „Short Gamma-Ray Bursts", Ringberg Castle, Tegernsee |
| Giacomazzo, B. | Gravitational waves emission from the collapse of differentially rotating neutron stars / 2 April 2007 / Conference "Problemi Attuali di Fisica Teorica" (Present Problems in Theoretical Physics), Vietri sul Mare, Italy |
| Heinzel, G. | LISA and LISA Pathfinder / 21 April 2006 / Spacepart 2006 Beijing |
| Heinzel, G. | Achieving the mid-high end of the LISA sensitivity band with the LISA short arm / 21 June 2006 / 6th International LISA symposium, GSFC |
| Heinzel, G. | The LTP Interferometer / 25-29 June 2006 / Morningside GR meeting, Beijing |
| Heinzel, G. | Technologies for LISA / 25-29 June 2006 / Morningside GR meeting, Beijing |
| Heinzel, G. | The LISA Instrument / 27 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Heinzel, G. | Space-Based Gravitational-wave interferometers / 11 June 2007 / NSF-DFG Astrophysics research Conference Washington DC |
| Heinzel, G. | LISA and LISA Pathfinder - potential contributions to satellite gravimetry / 13 April 2007 / Workshop on the Future of Satellite Gravimetry, ESTEC/ESA Noordwijk, The Netherlands |
| Heinzel, G. | The LTP Interferometer / 12 July 2007 / 7th Edoardo Amaldi Conference on Gravitational Waves, Sydney, Australia |
| Heinzle, J. M. | Accelerated Expansion from Pure Gravity in Higher Dimensions / 13 January 2006 / Workshop „Mathematical Aspects of General Relativity", Mathematisches Forschungsinstitut Oberwolfach |
| Hewitson, M. | GEO Status Report / 3 June 2006 / LSC Meeting, Boston |

## Invited Conference Talks

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| Hewitson, M. | Data and Detector Characterisation at GEO600 / 18 December 2006 / GWDAW11, Potsdam |
| Huisken, G. | The isoperimetric concept of mass and geometric flows / 12 June 2006 / ETH Zurich |
| Huisken, G. | The concept of mass in General Relativity / 11 September 2006 / Hermann-Weyl-Konferenz, Bielefeld |
| Huisken, G. | Mean curvature type flows and an isoperimetric concept for mass and quasi-local mass in GR / 20 September 2006 / Scuola Normale Superiore, Pisa |
| Huisken, G. | An isoperimetric concept for the mass and quasi-local mass via surface flows / 25 October 2006 / Stanford University |
| Huisken, G. | The isoperimetric inequality and the mass in General Relativity / 23 March 2007 / Erwin Schrödinger Institut, Wien |
| Huisken, G. | Mean curvature type flows and an isoperimetric inequalities / 26 March 2007 / University of Warwick, UK |
| Huisken, G. | Isoperimetric Inequalities Related to Mass and Energy in General Relativity / 27 May 2007 / 3rd Symposium on Analysis and PDE at Purdue University |
| Huisken, G. | Sharp isoperimetric inequalities via inverse mean curvature flow / 4 October 2007 / Columbia University |
| Huisken, G. | Isoperimetric Inequalities Related to Mass and Energy in General Relativity / 27 May 2007 / 3rd Symposium on Analysis and PDE at Purdue University |
| Huisken, G. | A connection between Willmore engergy and isoperimetric inequality via inverse mean curvature flow / 19 June 2007 / C.I.R.M. Luminy, France |
| Käppeli, J. | How to count the microstates of black holes / 14 February 2006 / 1st northern german string workshop, DESY Hamburg |
| Käppeli, J. | How to count the microstates of supersymmetric black holes / 13 June 2006 / Strings 2006 Workshop, Shanghai, China |
| Käppeli, J. | Topological amplitudes in hybrid string theory / 16 June 2006 / 06 Strings Conference, Hangzhou, China |
| Kim, D.H. | A mode-sum approach to the self-force in curved spacetime / 22 September 2006 / LISA Astro-GR@AEI, AEI, Golm |
| Kim, D.H. | Calculations of the Self-Force in Kerr Spacetime via the Mode-Sum Method / 17 March 2007 / 23rd Pacific Coast Gravity Meeting, California Institute of Technology, Pasadena, USA |
| Kim, D.H. | A mode-sum approach to the self-force in the Kerr geometry / 11 June 2006 / 9th Capra Ranch Meeting on Radiation Reaction, University of Wisconsin-Milwaukee, USA |
| Kleinschmidt, A. | Hidden Symmetries, Fermions and M-Theory / 6 April 2006 / Eurostrings 2006, Cambridge |
| Kleinschmidt, A. | Infinite-dimensional R-symmetry in supergravity / 8 August 2006 / International Congress on Mathematical Physics 2006, Rio de Janeiro |
| Kleinschmidt, A. | Integrating the E10 Model / 28 August 2006 / 38th Ahrenshoop Symposium, Berlin Schmöckwitz |

## Invited Conference Talks

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|---|---|
| Kleinschmidt, A. | M-theory dynamics and Kac-Moody algebras / 14 March 2007 / Conference "Beyond the Standard Model", Bad Honnef, Germany |
| Kleinschmidt, A. | The supersymmetric dual graviton / 5 July 2007 / Eurostrings 2007, Kolymbari, Greece |
| Kleinschmidt, A. | Constrained E10 geodesics and supergravity / 28 August 2007 / Ascona, Switzerland, "Symmetries of String Theory" conference |
| Krishnan, B. | Improved Hough search for continuous gravitational waves / 20 March 2006 / Meeting of the LIGO Scientific Collaboration, Hanford |
| Krishnan, B. | Applications of Dynamical Horizons in Numerical Relativity / 27 July 2006 / 11th Marcel Grossman Meeting, Berlin |
| Krishnan, B. | Applications of Dynamical Horizons in Numerical Relativity - Trapped surfaces and multipole moments / 22 November 2006 / Workshop "From geometry to Numerics", Institut Henri Poincare, Paris |
| Krishnan, B. | Fundamental properties and applications of quasi-local horizons / 10 July 2007 / 18th International Conference on General Relativity and Gravitation, Sydney, Australia |
| Krishnan, B. | Searching for periodic gravitational waves from neutron stars / 10 September 2007 / Workshop on "Matter at Extreme Densities and Gravitational Waves from Compact Objects", European Center for Theoretical Studies in Nuclear Physics and Related Areas, Trento, Italy |
| Kroyter, M. | Universal regularization of string field theory / 8 December 2006 / HRI, Allahabad |
| Lamm, T. | Conservation laws for fourth order systems in four dimensions / 20 September 2006 / DMV-Meeting Bonn |
| Lamm, T. | Conservation laws for fourth order systems in four dimensions / 5 January 2007 / AMS Meeting New Orleans |
| Lück, H. | GEO status / 16 March 2006 / DPG-Frühjahrstagung, Frankfurt |
| Lück, H. | GEO status / 29 May 2006 / GWDAW-VESF meeting, Isola d'Elba, Italy |
| Lück, H. | Status of the gravitational-wave detector GEO600 / 12 March 2007 / Rencontres de Moriond, Gravitational waves and experimental gravity, La Thuile |
| Lück, H. | GEO status; Plans for E.T. / 9 & 12 July 2007 / Amaldi conference, Sydney |
| Meier, T. | Bedeutung des Überlapps von Pump- und Lasermode bei nicht-planaren Nd:YAG Ringsoszillatoren / 13 March 2006 / DPG-Frühjahrstagung, Frankfurt |
| Meier, T. | Laser and R&D in Hannover / 27 March 2006 / GEO-Meeting, Hannover |
| Müller-Ebhardt, H. | Test-mass State Preparation and Entanglement in Laser Interferometers / 21 March 2007 / LSC Meeting, Baton Rouge |
| Nicolai, H. | Unification and E10 / 12 May 2006 / 90th Anniversary of General Relativity, Warsaw, Poland |
| Nicolai, H. | Hidden Symmetries and Cosmological Singularities / 24 July 2006 / 11th Marcel Grossmann meeting, Berlin |

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| Nicolai, H. | Quantum gravity for beginners / 24 August 2006 / Relativistic Astrophysics Meeting, Santorini |
| Nicolai, H. | Kaluza Klein Consistency and Gary`s Hat / 26 August 2006 / Cambridge-Mitchell Symposium, DAMTP, Cambridge |
| Nicolai, H. | Maximal supersymmetry: an introductory survey / 16 October 2006 / Conference “30 years of supergravity”, ENS, Paris |
| Nicolai, H. | Singularities, symmetries and higher order curvature terms / 23 January 2007 / Workshop on Singularities, KITP, UCSB Santa Barbara |
| Nicolai, H. | Quantengravitation: Fragen, Ansätze, Herausforderungen / 8 March 2007 / DPG-Tagung, Heidelberg |
| Nicolai, H. | Conformal Symmetry and the Standard Model String Theory: Achievements and Perspectives / 16 April 2007 / Jerusalem and Tel Aviv |
| Nicolai, H. | Quantum Gravity: an Introductory Survey Philosophical and Formal Foundations of Modern Physics / 24 April 2007 / Les Treilles, 23-28 April 2007 |
| Nicolai, H. | The Supermembrane Spectrum Aspects of Membrane Dynamics / 15 June 2007 / Stockholm, Sweden |
| Nicolai, H. | Quantum Gravity: an Introductory Survey / 24 April 2007 / Philosophical and Formal Foundations of Modern Physics, Les Treilles, 23-28 April 2007 |
| Nicolai, H. | The supermembrane spectrum / 15 June 2007 / Aspects of Membrane Dynamics, Stockholm, Sweden |
| Nicolai, H. | Presentation of the Potsdam Node / 1 Juli 2007 / EU Midterm Meeting, Kolymbari, Kreta |
| Nicolai, H. | E10 and KE10: on Overview / 28 August 2007 / “Symmetries in String Theory”, Monte Verita, Ascona |
| Nicolai, H. | E10 and KE10: re-inventing M theory? / 24 October 2007 / Quantum Gravity in the Southern Cone, Punta del Este, Uruguay |
| Nicolai, H. | E10, KE10 and Unification / 13 December 2007 / Miami 2007: celebrating 10 years of AdS/CFT, Fort Lauderdale, USA |
| Pai, A. | Best Chirplet-chain: Detecting unmodelled gravitational wave chirps / 27 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Pai, A. | Source Tracking and Beamforming of LISA / 21 September 2006 / LISA Astro-GR@AEI, AEI, Golm |
| Pai, A. | BestNET-CC: Extension of BCC search to GW interferometer networks / 20 December 2006 / GWDAW11 |
| Papa, M.A. | Gravitational Wave Astronomy from Ground and Space / 13 July 2007 / GRG18 and Amaldi7 Conferences |
| Papa, M.A. | Status of LSC, Virgo Data Analysis / 23 July 2007 / LSC/Virgo Collaboration Meeting, MIT, Boston |
| Peeters, K. | Holographic decays of large-spin mesons / 14 February 2006 / 1st Northern German String Workshop |

## Invited Conference Talks

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|---|---|
| Prix, R. | Observing Gravitational Waves from Spinning Neutron Stars / 19 May 2006 / 363rd Heraeus Seminar "Neutron Stars and Pulsars", Bad Honnef |
| Prix, R. | The (multi-IFO) F-Statistic Metric / 22 March 2006 / LSC Meeting, Hanford |
| Prix, R. | Status of Einstein@Home / 27 March 2006 / GEO Meeting, Hannover |
| Prix, R. | The multi-IFO F-statistic / 28 March 2006 / GEO Meeting, Hannover |
| Prix, R. | Search for gravitational waves from neutron stars: first results from Einstein@Home / 22 April 2006 / APS Meeting, Dallas |
| Prix, R. | Search for unknown spinning Neutron Stars: Optimal Detector Network / 28 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Prix, R. | Optimal parameter-space covering for continuous-wave searches / 19 December 2006 / GWDAW11 |
| Prix, R. | First Mock LISA Data Challenge: F-statistic continuous-wave search / 19 December 2006 / GWDAW11 |
| Prix, R. | Einstein@Home Hierarchical Search / 24 May 2007 / LSC-Virgo meeting, PISA |
| Radke, T. | A Cactus User Portal with GridSphere / 9 March 2007 / Astro-RG Workshop at OGF20, Manchester, U.K. |
| Rehbein, H. | Improving Advanced LIGO Sensitivity using a Local Readout Scheme / 21 March 2007 / LSC-Virgo Collaboration, Baton Rouge |
| Rendall, A. D. | Accelerated cosmological expansion and k-essence / 13 January 2006 / Mathematical Institute, Oberwolfach |
| Rendall, A. D. | Mathematics of accelerated cosmological expansion / 25 May 2006 / Kings College London |
| Rendall, A. D. | Models for accelerated cosmological expansion / 26 August 2006 / International Congress of Mathematicians, Madrid |
| Rendall, A. D. | Theoretical approaches to gravitational radiation / 9 October 2006 / Conference on multiscale problems, TU München |
| Rendall, A. D. | Late-time oscillatory behaviour in cosmological spacetimes / 8 November 2006 / University of Cordoba, Argentina |
| Rendall, A.D. | Asymptotics of expanding cosmological models / 20 July 2007 / ICIAM07, Zurich |
| Saez, M.I. | Optimal Regularity for the Pseudo Infinity Laplacian / 10 July 2006 / Workshop Calculus of Variations |
| Saez, M.I. | Optimal Regularity for the Pseudo Infinity Laplacian / 9 January 2007 / Universidad Catolica de Chile |
| Schnabel, R. | Quetschlichtquellen für die Laserinterferometrie und für die Quanteninformation (Gruppenbericht) / 13 March 2006 / DPG-Frühjahrstagung, Frankfurt |
| Schnabel, R. | Generation and Control of Squeezed Light Fields / 26 May 2006 / GWADW 2006 workshop, Elba |

## Invited Conference Talks

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| Schnabel, R. | Squeezed States / 20 July 2006 / meeting of the European Graduate College, Stirling, UK |
| Schnabel, R. | Squeezing the Quantum Noise of Gravitational Wave Laser-Interferometers / 27 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Schnabel, R. | Experimental Demonstration of Continuous Variable Purification / 27 September 2006 / Workshop on Classical and Quantum Interference, Olomouc, Czech Republic |
| Schnabel, R. | Preparing Squeezed States for Gravitational Wave Detector / 11 March 2007 / 42d Rencontres de Moriond, La Thuile, Italy |
| Schnabel, R. | Squeezed States At Frequencies Down To 1 Hz / 31 March 2007 / International 10th Conference on Squeezed States and Uncertainty Relations (ICSSUR), Bradford, UK |
| Schnabel, R. | Demonstrating Purification and Distillation of Squeezed States / 13 April 2007 / Continuous Variable Quantum Information Processing workshop, St. Andrews, UK |
| Schnabel, R. | Preparing Squeezed States for Gravitational Wave Detectors / 19 September 2007 / Frontiers in Optics, San Jose, Kalifornien,. |
| Schneemann, C. | Initial data for hyperboloidal Brill waves / 6 September 2006 / XXIX. Spanish Relativity Meeting, Palma de Mallorca |
| Schutz, B. F. | Using Gravity to Test Gravity and Observe the Universe / 12 May 2006 / Warsaw |
| Schutz, B. F. | Looking Back on 40 years in Relativity / 25 August 2006 / Relativistic Astrophysics Meeting, Santorini |
| Schutz, B. F. | Gravitational Physics: At the Heart of Modern Physics Research / 4 September 2006 / Amaldi Prize Lecture, Torino, Italy |
| Schutz, B. F. | Current Searches for Gravitational Waves / 6 September 2006 / University of the Ballearics, Mallorca |
| Schutz, B. F. | LISA Data Analysis / 19 September 2006 / Albert Einstein Institute, Golm |
| Schutz, B. F. | LISA and its Successors / 30 September 2006 / University of Florence, Italy |
| Schutz, B. F. | Cosmography with LISA / 17 May 2007 / McMaster University |
| Schutz, B. F. | Fundamental Physics in ESA´s Cosmic Vision Program / 12 June 2007 / Bremen |
| Shankaranarayanan, S. | Entanglement as a source of black-hole entropy Field / 13 December 2006 / Theoretic Aspects of Gravity-V, Goa, India |
| Shankaranarayanan, S. | Power-law corrections to black-hole entropy via entanglement / 10 May 2007 / Workshop on “Dynamics and thermodynamics of black-holes and naked singularities-2”, Milan, Italy |
| Skorupka, S. | Einflüsse von Strahlverschiebung und -verkippung auf die Frequenz stabiler Resonatoren / 16 March 2006 / DPG-Frühjahrstagung, Frankfurt |
| Spani Molella, L. | Nonlinear Spectroscopy of Closed Degenerate Two-level Systems / 20 September 2006 / XIV International Summer School on Quantum Electronics, Laser Physics and Applications, Sunny Beach, Bulgaria |

## Invited Conference Talks

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| Tchapnda, S.B. | On surface symmetric spacetimes with collisionless and charged matter / 12 September 2006 / GIRAGA XI seminar, University of Yaounde I |
| Tchapnda, S.B. | On the geodesic completeness for the surface symmetric Einstein-Vlasov-Maxwell system / 9 November 2006 / workshop on global problems in relativity, FaMAF Cordoba Argentine |
| Vahlbruch, H. | Squeezed Light in the acoustic frequency band / 29 March 2006 / GEO-Meeting, Hannover |
| Vahlbruch, H. | Squeezed light detection at low frequencies / 9 October 2006 / GEO-Meeting, Glasgow |
| Vahlbruch, H. | Squeezing the Quantum Noise in Gravitational Wave Interferometers / 25 October 2006 / Ilias Meeting, London |
| Wanner, G. | LTP Alignment Simulation / 11 December 2006 / WG2-Meeting in Golm |
| Wanner, G. | LTP Alignment Simulation-Use of OptoCad and QPD.c in the LTP Alignment Simulation / 13 March 2007 / Sim-Group-Meeting in Hannover |
| Wanner, G. | LTP Alignment Simulation/21 March 2007/DPG-Frühjahrstagung, Düsseldorf |
| Wanner, G. | LTP Alignment Simulation / 24 April 2007 / Performance-Meeting no.3, Friedrichshafen |
| Whelan, J. T. | Stochastic Background Search with ALLEGRO and LIGO Science Data / 28 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Whelan, J. T. | Preliminary Results of LIGO-ALLEGRO Stochastic Background Search / 20 December 2006 / GWDAW11 |
| Whelan, J. T. | LIGO-Virgo Stochastic Searches / 24 May 2007 / LSC-Virgo Joint Meeting, Cascina |
| Willke, B. | Status of GEO600 / 21 March 2006 / LSC Meeting, Hanford WA USA |
| Willke, B. | Option for a enhanced power LIGO laser / 22 March 2006 / LSC Meeting, Hanford WA USA |
| Willke, B. | German contribution to Advanced LIGO / 28 March 2006 / Glasgow, UK |
| Willke, B. | Laser Charakterisierung und Laserstabilisierung / 30 June 2006 / LZH-summer school, Hannover |
| Willke, B. | Stabilized High Power Laser for Advanced Gravitational Wave Detectors / 25 July 2006 / 11th Marcel Grossmann meeting, Berlin |
| Willke, B. | Characterization and Stabilization of High-Power Solid-State Lasers / 29 January 2007 / ASSP, Vancouver |
| Willke, B. | Lasers for Interferometric Gravitational Wave Detectors / 11 June 2007 / DFG-NSF Astrophysics Research Conference, Washington |
| Willke, B. | Status of the Advanced LIGO PSL development / 21 March 2007 / LSC meeting, Baton Rouge |
| Willke, B. | Characterization and Stabilization of High-Power Solid-State Lasers / 26 February 2007 / Quantum 2007, Hannover |

## Invited Conference Talks

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|---|---|
| Zenginoglu, A. | The Hyperboloidal Evolution Problem / 28 July 2006 / 11th Marcel Grossmann Meeting, Berlin |
| Zenginoglu, A. | Numerical evolutions near spatial infinity / 8 September 2006 / Spanish Relativity Meeting, Palma de Mallorca |

## Lectures and Lecture Series given by AEI Members

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|---|---|
| Ananth, S. | Introduction to quantum field theory, part 1 / 18 July 2007 / Compact course, AEI |
| Ananth, S. | Introduction to quantum field theory, part 2 / 19 July 2007 / Compact course, AEI |
| Ananth, S. | Introduction to quantum field theory, part 3 / 20 July 2007 / Compact course, AEI |
| Aufmuth, P. | GEO600 – the British-German gravitational wave detector / 10 February 2006 / National Manager and Progress Meeting, Hannover |
| Aufmuth, P. | GEO600 – der deutsch-britische Gravitationswellendetektor / 22 February 2006 / Geophysik Meeting, Hannover |
| Aufmuth, P. | GEO600 – the British-German gravitational wave detector / 2 May 2006 / Leibniz Universität Hannover |
| Aufmuth, P. | GEO600 – der deutsch-britische Gravitationswellendetektor / Graduiertenkolleg, TU Kaiserslautern |
| Aufmuth, P. | GEO600 – der deutsch-britische Gravitationswellendetektor / 8 February 2007 / Institut für Hochfrequenztechnik, TU Braunschweig |
| Aufmuth, P. | GEO600 – the German-British gravitational wave detector / 21 May 2007 / AG Theoretische Hochenergiephysik, Universität Bielefeld |
| Aufmuth, P. | Ground based gravitational wave detection / 13 June 2007 / Graduiertenkolleg „Eichtheorien“, Universität Mainz |
| Aufmuth, P. | An der Schwelle zur Gravitationswellenastronomie / 20 July 2007 / Lehrerfortbildung Astronomie, Universität Jena |
| Bahr, B. | Ideen und Konzepte der Ideen und Konzepte der Loop Quantengravitation / 20 September 2006 / Visit of the JDPG, AEI |
| Beisert, N. | Integrability in AdS/CFT / 10 September 2006 / Doktorandenschule Saalburg, Wolfersdorf |
| Chrusciel, P.T. | Lectures on Mathematical Relativity / 3 July 2006 / Summer School at Beijing University |
| Danzmann, K. | Physik I mit Experimenten / winter term 2005/6 / Leibniz Universität Hannover |
| Danzmann, K. | Physik II mit Experimenten / summer term 2006 / Leibniz Universität Hannover |

# Lectures and Lecture Series given by AEI Members

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|---|---|
| Danzmann, K. | Gravitationsphysik / winter term 2006/7 / Leibniz Universität Hannover |
| Danzmann, K. | Gravitationsphysik und Laserinterferometrie II / summer term 2007 / Leibniz Universität Hannover |
| Danzmann, K. | Physik I mit Experimenten / winter term 2007/8 / Leibniz Universität Hannover |
| Ehlers, J. | Kosmologie; Teilchenphysik / 20, 22 February 2006 Ferienakademie der Bischöflichen Studienförderung Cusanuswerk, Papenburg |
| Ehlers, J. | Differential Geometry for Physicists / 2-13 January 2007 / Lecture course, IUCAA, Pune |
| Ehlers, J. | Mass in General Relativity / 15 January 2007 / IUCCA, Pune |
| Ehlers, J. | Allgemeine Relativitätstheorie / 25 April 2007 / AEI |
| Ehlers, J. | Theorie und Erfahrung in der Gravitationsphysik / 11 June 2007 / Oldenburg |
| Ehlers, J. | Introduction to General Relativity / 4-6 July 2007 / Int. School Enrico Fermi on Atom Optics and Space Physics, Varenna |
| Ehlers, J. | Der Beginn der „Neuen Quantenmechanik“ / 30 August 2007 / MPI für Wissenschaftsgeschichte, Berlin |
| Friedrich, H. | Grundbegriffe der Gravitationstheorie / 6 March 2006 / AEI, Ferienkurs Gravitationsphysik |
| Friedrich, H. | Die Einsteinschen Feldgleichungen / 25 October 2006 / University of Potsdam |
| Friedrich, H. | Grundbegriffe der Gravitationstheorie / 19 March 2007 / AEI, Ferienkurs Gravitationsphysik |
| Huisken, G. | The isoperimetric inequality, geometric evolution equations and the mass in General Relativity / 18 August 2006 / winter school Australian Mathematical Sciences Institute |
| Huisken, G. | Common aspects of geometric partial differential equations of second order I / 19 September 2007 / AEI |
| Kleinschmidt, A. | Einführung in die Stringtheorie II / 18 April 2007 / Humboldt University, Berlin |
| Lamm, T. | Geometrische Variationsprobleme / 17 April 2007 / FU Berlin |
| Nicolai, H. | Einführung in die Supersymmetrie / 13 March 2006 / AEI, Ferienkurs Gravitationsphysik |
| Nicolai, H. | Einführung in die Theorie der Kac-Moody Algebren (drei Vorlesungen) / 6 June 2006 / Universität Hannover |
| Nicolai, H. | Introduction to BKL cosmology / 30 January 2007 / Theory group, UCLA, Los Angeles |
| Nicolai, H. | Einführung in die kosmologische Störungstheorie (4 Vorlesungen) / 31 May 2007 / Universität Hannover |

## Lectures and Lecture Series given by AEI Members

| | |
|---|---|
| Nicolai, H. | E10 for Beginners (two lectures) / 17 October 2007 / University of Buenos Aires, Argentina |
| Rendall, A.D. | Nichtlineare hyperbolische Gleichungen / 18 April 2006 / Freie Universität Berlin |
| Rendall, A.D. | A tour of PDE concepts I / 26 October 2007 / First of three IMPRS lectures. The others were on 30th October and 2nd November |
| Schutz, B. | Gravitational Radiation / summer term 2006 / Leibniz Universität Hannover |
| Schutz, B. | Gravitational Radiation / summer term 2007 / Leibniz Universität Hannover |
| Schnabel, R. | Gequetschtes Licht für die Gravitationswellenastronomie / 19 November 2007 / Kolloquium, Universität Rostock, |
| Schnabel, R. | Nichtklassisches Licht / winter term 2005/06 / Leibniz Universität Hannover |
| Schnabel, R. | Nonclassical Interferometry / summer term 2006 / Leibniz Universität Hannover |
| Schnabel, R. | Quantenoptik / winter term 2006/07 / Leibniz Universität Hannover |
| Schnabel, R. | Nonclassical Interferometry / summer term 2007 / Leibniz Universität Hannover |
| Schnabel, R. | Quantum Optics / winter term 2007/08 / Leibniz Universität Hannover |
| Schneemann, C. | Betrachtungen zur Wurfparabel / 3 August 2006 / Deutsche Schülerakademie Grovesmühle |
| Schneemann, C. | Licht und Materie / 9 August 2007 / Deutsche Schülerakademie Braunschweig |

## Popular Talks given by AEI Members

| | |
|---|---|
| Ananth, S. | Lie algebras in particle physics / 30 January 2007 / Chennai Mathematical Institute |
| Aufmuth, P. | Wie klingt das Universum? / 27 April 2006 / Girls' Day, Hannover |
| Aufmuth, P. | Astronomie mit Gravitationswellen / 3 May 2006 / Volkssternwarte Recklinghausen |
| Aufmuth, P. | Wie klingt das Universum? - Einstein, Schwarze Löcher und die Wellen aus dem All / 21 May 2006 / IdeenPark 2006, Hannover |
| Aufmuth, P. | Einsteins Gravitationswellen und ihr Nachweis durch GEO600 / 23 May 2006 / Schiller-Gymnasium, Heidenheim |
| Aufmuth, P. | GEO600 & LISA: Gravitationsphysik in Hannover / 6 July 2006 / Exkursion des AEI Potsdam, Hannover |
| Aufmuth, P. | Wie die Zeit vergeht - Einsteins Zwillinge und das Schwarze Loch / 22 August 2006 / Sommercampus 2006, Hannover |

## Popular Talks given by AEI Members

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|---|---|
| Aufmuth, P. | Schwarze Löcher und Dunkle Materie - Was hält das Universum zusammen? / 8 November 2006 / Marie-Curie-Gymnasium, Ludwigsfelde |
| Aufmuth, P. | Wie die Zeit vergeht - Zeit, Uhren, Einstein, Licht und Schwerkraft / 12 and 19 January 2007 / Grundschule an der Feldbuschwende, Hannover |
| Aufmuth, P. | GEO600 - der deutsch-britische Gravitationswellendetektor / 6 February 2007 / Senioren des VDE Hannover, Ruthe |
| Aufmuth, P. | GEO600 - Auf der Suche nach Gravitationswellen / 28 February 2007 / Gymnasium Andreanum, Hildesheim |
| Aufmuth, P. | GEO600: Auf der Suche nach Einsteins Gravitationswellen / 22 March 2007 / Volkshochschule Gütersloh |
| Aufmuth, P. | Gravitationswellen: Die Zukunft der Astronomie / 26 April 2007 / Zukunftstag, Hannover |
| Aufmuth, P. | GEO600: An der Schwelle zur Gravitationswellen-Astronomie / 26 May 2007 / Sternfreunde Jena e.V., Ruthe |
| Aufmuth, P. | GEO600: Auf der Suche nach Gravitationswellen / 20 June 2007 / Matthias-Claudius-Gymnasium, Gerden |
| Aufmuth, P. | GEO600 – der deutsch-britische Gravitationswellendetektor /28 June 2007 / Leistungskurs Physik, Landschulheim am Solling |
| Aufmuth, P. | Einsteins Wellen: Signale aus dem dunklen Teil des Universums / 29 June 2007 / PhysikClub, Albert-Schweitzer-Schule, Kassel |
| Aufmuth, P. | Einführung in den Studiengang Physik / 23 July 2007 / Sommeruniversität, VHS Schaumburg, Rinteln |
| Aufmuth, P. | Angewandte Relativitätstheorie: Gravitationswellenforschung / 23 July 2007 / Sommeruniversität, VHS Schaumburg, Rinteln |
| Aufmuth, P. | GEO600: Dem Echo des Urknalls auf der Spur / 14 September 2007 / 25. DVGW-Fachexkursion, Hannover |
| Aufmuth, P. | Blitzschnell durch den Kosmos? – Reisen zu anderen Planeten, zu Sternen und Schwarzen Löchern / 12 October 2007 / IdeenExpo, Hannover |
| Aufmuth, P. | Gravitationsphysik in Hannover: Relativitätstheorie & Gravitationswellen / 14 November 2007 / Schillerschule, Hannover |
| Aufmuth, P. | Von Äpfeln und Schwarzen Löchern. Schülervorlesungsreihe „A Theory of Everything" / 24 November 2007 / Physikalischer Verein, Frankfurt |
| Bahr, B. | Einsteins Erbe: Auf der Suche nach der Quantengravitation / 13 July 2006 / Lessing-Gymnasium, Frankfurt |
| Bahr, B. | Quantengravitation / 9 November 2006 / Marie-Curie-Tag 2006, Marie-Curie Gymnasium, Ludwigsfelde |
| Bahr, B. | Quanten der Raumzeit / 10 June 2006 / Tag der offenen Tür, Potsdam |
| Bahr, B. | Quanten der Raumzeit / 1 September 2007 / Tag der offenen Tür, Potsdam |
| Danzmann, K. | Sounds of the Universe / 14 February 2006 / Caixa Museum, Barcelona |

## Popular Talks given by AEI Members

| | |
|---|---|
| Danzmann, K. | Auf der Suche nach Gravitationswellen / 24 March 2006 / BKB Hannover |
| Danzmann, K. | Einstein im täglichen Leben / 28 March 2006 / EXPO-Cafe, Hannover |
| Danzmann, K. | Das Universum hören / 9 May 2006 / Nacht der Wissenschaften, Hannover |
| Danzmann, K. | Einstein Heute: Der Klang des Universums / 17 July 2006 / European Science Open Forum, München |
| Danzmann, K. | Einstein und die Gravitation / 14 September 2006 / MINT-Schülertagung, Hannover |
| Danzmann, K. | Die Zukunft der Gravitationswellenastronomie / 15 September 2006 / AEI Hannover |
| Danzmann, K. | Laserinterferometrie auf der Erde und im Weltraum / 1 December 2006 / Exkursion der Studienstiftung, Hannover |
| Danzmann, K. | Das Universum hören mit Gravitationswellen / 23 February 2007 / Akademie der Wissenschaften und Literatur, Mainz |
| Danzmann, K. | Einstein und die moderne Optik / 15 May 2007 / Festvortrag Kaiser-Friedrich-Preis, Goslar |
| Danzmann, K. | Experimente zur Relativität / 19 June 2007 / Hermann von Helmholtz Abendvortrag, Braunschweig |
| Danzmann, K. | Einstein und die moderne Optik /15 May 2007/ Kaiserpfalz, Goslar |
| Danzmann, K. | Der Klang des Universums/19 June 2007/ Hermann von Helmholtz Symposium, Braunschweig |
| Ehlers, J. | Einstein und der Zeitbegriff / 27 April 2006 / Ev. Studierendengemeinde Potsdam |
| Ehlers, J. | Allgemeine Relativitätstheorie / 29 September 2006 / Lehrerfortbildung, Akademie Dillingen |
| Ehlers, J. | The Standard Model of the Universe / 19 January 2007 / Planetarium Bombay |
| Ehlers, J. | Art und Reichweite physikalischer Naturkenntnis / 23 March 2007 / Urania Berlin |
| Ehlers, J. | Einstein und der Zeitbegriff / 5 October 2007 / Bruno H. Bürgel-Sternwarte, Berlin |
| Ehlers, J. | Was Physiker tun / 11 October 2007 / Gymansium Eichwalde |
| Guzman Cervantes, F. | LISA y LISA Pathfinder: Interderometria en el Espacio para la Deteccion de Ondas Gravitacionales / 17 January 2007 / University Costa Rica, San Jose |
| Hillmann, C. | (Quanten)Physik der Mikrowelle / 9 November 2006 / Marie-Curie-Gymnasium, Ludwigsfelde |
| Hillmann, C. | Quantenphysik zum Anfassen: Die Mikrowelle / 11 July 2006 / Leibnizschule, Offenbach |

## Popular Talks given by AEI Members

| | |
|---|---|
| Hillmann, C. | Quantenphysik zum Anfassen: Die Mikrowelle / 12 July 2006 / Lessing-Gymnasium Frankfurt |
| Hillmann, C. | Quantenphysik zum Anfassen: Die Mikrowelle / 12 July 2006 / Humboldtschule, Bad Homburg |
| Hillmann, C. | Quantenphysik zum Anfassen: Die Mikrowelle / 12 July 2006 / Immanuel-Kant-Schule, Rüsselsheim |
| Huisken, G. | Isoperimetrische Ungleichungen in Analysis, Geometrie und Physik / 14 December 2007 / Berlin Brandenburgische Akademie der Wissenschaften |
| Koppitz, M. | Das Albert-Einstein-Institut / 29 September 2006 / Bruno H. Bürgel-Sternwarte, Berlin |
| Nicolai, H. | Vorstellung der Abteilung Quantengravitation für Studenten der HU / 21 April 2006 / Humboldt Universität, Berlin |
| Nicolai, H. | After Dinner Speech, Eurostrings 2006 / 5 April 2006 / Trinity College, Cambridge, UK |
| Nicolai, H. | Alles relativ? Ein kleiner Streifzug durch die Gravitationsphysik / 6 November 2007 / AEI Kolloquium für Rotary Club Potsdam |
| Schutz, B. F. | From the Big Bang to Big Business: How we got Here / 14 February 2006 / Urania, Berlin |
| Schutz, B. F. | Gravitational Waves: Geometry in Motion / 2 May 2006 / 8th JL Synge Lecture, Dublin |
| Skorupka, S. | Erbebende Raumzeit - Gravitationswellen und ihre Messung / 26 January 2006 / Herschelschule, Hannover |
| Skorupka, S. | Laser lauschen dem Beben der Raumzeit / 24 April 2006 / Abendvortrag zur Night of Innovations, Hannover Messe |
| Skorupka, S. | Erbebende Raumzeit - Gravitationswellen und ihre Messung / 26 April 2006 / FH Braunschweig |
| Skorupka, S. | Erbebende Raumzeit - Gravitationswellen und ihre Messung / 3 May 2006 / Deutsches Museum Bonn |
| Skorupka, S. | Erbebende Raumzeit - Gravitationswellen und ihre Messung / 5 September 2006 / AEI-Hannover für VW-Stiftung |

## Guided Tours at GEO600

| | |
|---|---|
| Aufmuth, P., Grote, H., Hild, S., Lück, H., Willke, B. | GEO600: The German-British gravitational wave detector<br>Introductory talk and guided tour |
| Appr. 410 visitors | 27 January 2006 / 3 February 2006 / 22 February 2006 / 1 March 2006 / 2 March 2006 / 9 March 2006 / 11 March 2006 / 29 August 2006 / 25 October 2006 / 13 December 2006 / 24 January 2007 / 6 February 2007 / 8 February 2007 / 21 May 2007 / 26 May 2007 / 8 June 2007 / 20 June 2007 / 28 June 2007 / 29 June 2007 / 15 August 2007 / 22 August 2007 / 4 September 2007 / 14 September 2007 / 18 September 2007 / 26 September 2007 / 13 October 2007 / 20 October 2007 / 25 October 2007 / 6 December 2007 / 12 December 2007 |

## 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 research institutes of the Max Planck Society perform basic research in the interest of the general public in the natural sciences, life sciences, social sciences, and the humanities. In particular, the Max Planck Society takes up new and innovative research areas that German universities are not in a position to accommodate or deal with adequately. These interdisciplinary research areas often do not fit into the university organization, or they require more funds for personnel and equipment than those available at universities. The variety of topics in the natural sciences and the humanities at Max Planck Institutes complement the work done at universities and other research facilities in important research fields. In certain areas, the institutes occupy key positions, while other institutes complement ongoing research. Moreover, some institutes perform service functions for research performed at universities by providing equipment and facilities to a wide range of scientists, such as telescopes, large-scale equipment, specialized libraries, and documentary resources.

As of 1.1.2008 there are 76 institutes and 3 additional research facilities employing approximately 13,000 people. Included in this are approximately 4,700 scientists and 6,400 student assistants, fellows of the International Max Planck Research Schools, doctoral students, postdoctoral students, research fellows and visiting scientists.

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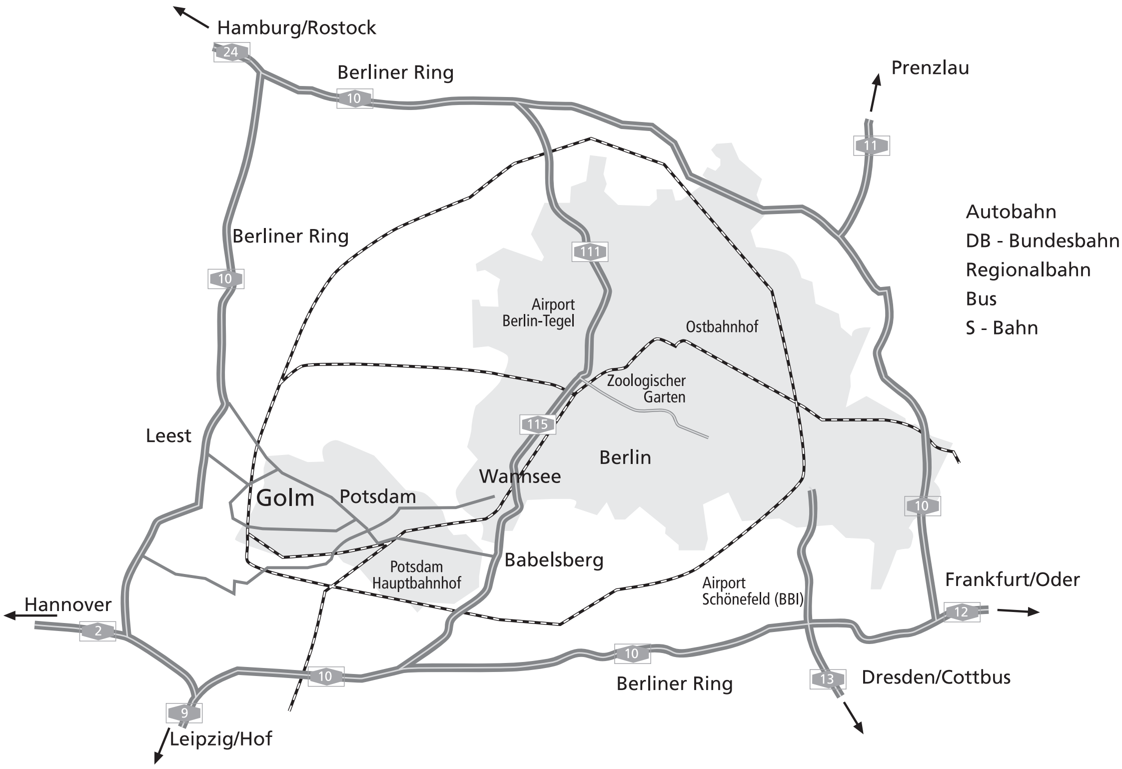
## How to get to the AEI in Hannover

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 transfer to Regionalbahn RB 21 (direction Berlin-Spandau) leaving once every hour to Golm (+ 10 minutes walk) or take Bus 606 straight to the Max Planck Campus.

By train:
Take any train going to "Potsdam Hauptbahnhof", then transfer to Regionalbahn RB 21 and 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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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!