MAX-PLANCK-GESELLSCHAFT

Annual Report
2003

Max-Planck-Institut für
Gravitationsphysik
Albert-Einstein-Institut

Max-Planck-Gesellschaft
zur Förderung der Wissenschaften e.V.

Report by the Managing Director

This volume presents a survey of the activities of the Albert Einstein Institute during 2003. This was a challenging year for the Institute, during which we had to cope with funding restrictions and intense competition from other institutions for some of our brightest young scientists. It was also a year in which we consolidated some important accomplishments: tangible progress toward the detection of gravitational waves; construction of our new laboratories in Hannover; the start of our research collaboration (a *Sonderforschungsbereich*) with the Universities of Jena, Tübingen, and Hannover and with the Max Planck Institute for Astrophysics; the start of the construction of the first space mission that the AEI has contributed to, LISA Pathfinder; preparations for our new International Max Planck Research School; the installation of a cluster supercomputer (called PEYOTE) to support our work on black hole simulations; and the expansion of our activities in electronic publishing. We hosted a number of workshops and meetings, and we had a very successful visit from our external scientific review committee (the *Fachbeirat*). Most important of all, our scientists were able to make significant progress in research in all our divisions. All the developments I mention here are described in more detail elsewhere in this report.

In last year's annual report we celebrated the opening of our experimental branch in Hannover. AEI/Hannover is a cooperation with the University of Hannover; it operates the GEO600 gravitational-wave detector and does research that will lead to new detectors, such as the high-profile NASA-ESA space mission called LISA. During 2003 the Institute's laboratories in Hannover were completed. We now have world-class facilities, including a high-specification clean room, a large laboratory for the construction of a prototype gravitational wave detector to test advanced technology, and many smaller laboratories for table-top investigations. Work also started on the renovation of our office space, so that by the end of next year our Hannover facilities will be complete.

One of the experimental activities in Hannover that has important implications for the future is our work on the LISA Pathfinder mission. LISA Pathfinder (originally called SMART-2) is a mission of the European Space Agency (ESA) to test the measurement and control technology that is needed for the LISA space-based gravitational wave detector. LISA is planned for launch around 2013, but LISA Pathfinder will go up in 2007. Its success is important for building confidence that the ultra-precise measurements required for LISA can be done reliably in space. As co-PIs for the experimental package on this mission, the team at AEI/Hannover is building the expertise it needs to participate in LISA itself a few years later.

Collaboration is at the heart of scientific research, and the AEI supports a number of formal and informal collaborations with scientists and research institutes around the globe. Of particular importance to us is the new *Sonderforschungsbereich* (SFB: special research area) in Gravitational Waves. The grant for this was awarded last year and was mentioned in our annual report. The activities began during 2003: we appointed new research staff and began to coordinate our research with our university partners in Jena, Tübingen, and Hannover, and with the Max Planck Institute for Astrophysics in Garching. The SFB supports research in three of the four divisions of the AEI.

One of our most important collaborations is, of course, the GEO600 detector. We operate this on behalf of our partner universities, Glasgow and Cardiff in the UK. We also collaborate very closely with the American

LIGO project, which operates three detectors at two locations in the USA. During 2003 the joint LIGO-GEO data analysis team completed and submitted for publications four papers as a result of studying the data taken during our first ”science run” in 2002. The detectors were still under development, so their sensitivity was far from their operational goal, but nevertheless the data analysis resulted in new upper limits on the strength and population of several potential sources of gravitational waves. The data analysis exercise also demonstrated that the international community can organize itself effectively to perform high-quality searches for these weak signals. One of the four international analysis teams is led by the AEI. During 2003 there were a further two science runs, generating much more data with higher sensitivity, and papers reporting much stronger upper limits will be published in 2004.

Also during 2003 the GEO experimental team made a significant advance, installing and controlling the first large-scale detector to use the technique called signal recycling. This technique was invented by the GEO team and has been incorporated into the design of the Advanced LIGO detector, scheduled for installation after 2007. Demonstrating how to make such an interferometer work in GEO was a significant milestone on the road to the greatly improved sensitivity of Advanced LIGO, and it took a great effort over several months by a dedicated team of scientists from the AEI and Glasgow University. Given these advances and steady progress in commissioning the LIGO detectors, we may be no more than a year away from reaching design sensitivity for the current generation of interferometers. After that, the first detections of gravitational waves will depend on Nature’s cooperation: we will be entering uncharted territory with few astronomical observations to guide our expectations.

Another important initiative which we reported on last year is the International Max Planck Research School (IMPRS) for Geometric Analysis, Gravitation and String Theory. This is a collaboration with the University of Potsdam and the Free University of Berlin. (Our former partners at the Humboldt University in Berlin are no longer part of the project due to staff movements.) Our first lectures begin in 2004, but in 2003 we began recruiting students and planning the operation of the graduate school. We have had more than 50 applications, and more than 70% of the students we have accepted so far come from outside Germany.

The AEI reinforced its position as a world leader in numerical relativity – approaching problems like the computer simulation of collisions between black holes – by installing a new supercomputer cluster called PEYOTE. In 2003 we installed 64 dual-processor nodes connected by high-speed links to allow the processors to work together on complex problems. We are planning to expand PEYOTE in steps during the next two or three years to reach more than 200 nodes. The computer supports the work of scientists in both the Astrophysical Relativity and the Geometrical Analysis divisions. Funding for this very fast computer was provided by the Max Planck Society, through its computing committee (called the BAR). Along with the MERLIN Cluster for gravitational wave data analysis, which was described in last year’s report, the AEI now has two teraflop-class computers to support the work of its scientists.

In previous reports we have often mentioned the AEI’s electronic journal, *Living Reviews in Relativity*. As reported last year, this is now supported by central Max Planck Society funds, and during 2003 we founded a sister journal, *Living Reviews in Solar Physics*, published by the Max Planck Institute for Aeronomy. Using our central support, the AEI editorial staff will support the back-office work for both journals, but the editorial boards of the two journals will be completely independent. We restructured our web site (*www.livingreviews.org/*) into a portal for both journals. The first articles for Solar Physics are expected to be published in mid-2004. We also cooperated with others in the Max Planck Society to organize in October of 2003 the Berlin Meeting on Open Access Publishing, which resulted in the Berlin Declaration, a document which commits its signatory institutions to implement policies to support open-access publishing in the sciences and in the cultural regime. This declaration was signed not only by the Max Planck Society but also by all the important scientific research organizations in Germany and many in other countries.

As in previous years, we also organized workshops and meetings at the AEI itself. Of particular note was the workshop called ”Strings Meet Loops”, where the two principal paradigms for quantum gravity met and presented their different points of view. Actually, in a number of areas there are indications of convergence between these approaches, as if they are actually contrasting views of very similar approaches to quantum gravity, but it will take much more work to see if there is a common meeting ground, or indeed if either of these approaches will eventually turn out to be the right way to unite Einstein’s theory of gravity with the quantum theories of physics that govern atomic and nuclear processes.

In September 2003, the AEI hosted another meeting, the Symposium on the Future of Gravitational Physics and Astronomy, which was designed to provide a perspective on the field of gravitational wave experiments, in order to assist in our search for a director for the second experimental division at AEI/Hannover. This search is on-going, and I hope that in the next annual report we will be able to report some concrete progress.

Our external scientific review committee, the *Fachbeirat*, also visited us in September 2003. Their job is to report to the President of the Max Planck Society on the quality and effectiveness of our scientific work. I am pleased to say that their report was positive and very supportive of our research goals, and this has already helped us in securing some of the resources that we need to maintain our work, as described below. During the year we also had our annual meeting of our *Kuratorium*, a body of community leaders who can advise us on problems that we encounter and help us to communicate our results more effectively to the general public. Again a significant part of the discussion was about resources to support our research.

Resources for research have, unfortunately, become more of a problem than they have been in the past. Germany’s economy is not performing well at present, and funding for science has been pinched. While not as drastic as the funding cutbacks that have happened in other countries at other times, the reductions set in place for 2003 have forced us to re-examine our priorities and to shelve some planned developments. Prospects for 2004 are not so gloomy, however, and it seems possible that in 2003 we saw the worst of the restrictions. Provided funding is available to the Max Planck Society, we can expect in 2004 that our gravitational wave data analysis group will be put on more secure foundations and that our delayed extension building will start.

The extension building is sorely needed. As reported last year, we have rented external office space to accommodate some of our scientists. The crunch will get worse in 2004 when the students of the IMPRS arrive and when Professor Gerhard Huisken begins to use his Leibniz Prize funding to support visitors and scientists. Our space problems were alleviated temporarily during 2003 by a staffing fluctuation: Professor Ed Seidel, who founded our numerical relativity group, moved to Louisiana State University in the USA to head their Center for Computation and Technology, and a number of staff in his research group accompanied him. This prestigious appointment is both a plus and a minus for us: we lose Ed as a day-to-day leader of the numerical relativity group, but we gain a new partner in numerical relativity, because Ed will be building further on the already strong LSU research team in this area. LSU is set to become one of the leading centers for computational science in the USA, and their close connection to the AEI will bring long-term benefits.

We reported last year that a number of our younger scientists have moved to permanent jobs in universities. This is normal, and it is a reflection on the quality of our scientists that they are sought after for some of the best jobs in their fields. But it also represents a challenge to the AEI, because often our departing staff tell us that they would prefer to stay in our rich research environment, but the attractiveness of the other offers is too much to pass up. In particular, other institutions are able to offer much higher rates of pay and much better career promotion prospects. The Max Planck system and German universities in general recognize that they are at a competitive disadvantage with respect to universities and research institutions in some other European countries and particularly in the USA, but the reforms that are needed to help us to compete better seem to be slow in coming. We can therefore expect to continue to see these pressures in future years, both in terms of staff leaving and in the difficulty of attracting new staff of high quality to replace those who leave. Our leading research position, our world-class permanent research staff, and our superb research facilities offset many of these disadvantages, but we cannot expect to be entirely immune from these difficulties.

In June 2004 I will step down from the position of Managing Director, to be replaced by Gerhard Huisken. I want to take this opportunity to thank all the staff of the AEI, both the scientists and especially the support staff, who have made it a pleasure for me to oversee the running of the Institute. The dedication of the support staff – in the administration, the secretariat, the library, the computer support division, and in public relations/education/external relations – is a vital element of the success of the AEI. We scientists are very fortunate to be supported by staff who take pride in their work with us and who understand what we need in order to be productive. Professor Huisken has my very best wishes for his tenure as Managing Director.

Bernard F. Schutz
(Managing Director)

News Items

Academic Achievements

Lists AEI

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 a operated by the Hannover branch.

The year 2003 was a year of consolidation for the AEI after its expansion in 2002. The Institute continued to grow, not only in Hannover but also in Golm, as new collaborations and external funding provided support for more scientists. Our new laboratories in Hannover were finished and we began to move our experimental work into them. We made significant progress in developing the gravitational wave detector GEO600, we began working on the payload for the LISA Pathfinder satellite (due for launch in 2007), and we installed a new cluster supercomputer to support numerical simulations of black hole collisions.

It was also a year in which the Institute had to cope with funding restrictions (in common with all publicly supported German research organizations) and with some important staff changes. It weathered these challenges well and continues to be the largest institute of its kind in the world, and a focal point for worldwide research into Einstein's theory of gravity and its implications in fundamental physics and astronomy.

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 worldwide network of such instruments is nearing completion, including the AEI's own 600 m detector, GEO600. These experiments could soon directly observe signals from distant astronomical sources that are carried by the gravitational field itself.

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 in 2003 had four divisions: three for theoretical research in Golm (near Potsdam), and the first of two planned experimental physics divisions in Hannover.

- The Astrophysical Relativity Division (Golm/Schutz) specializes in the applications of relativity in astronomy. It has two main groups, one concerned with the search for gravitational radiation and the other with the computer simulation of black holes and their dynamics. The gravitational radiation group analyzes data from the GEO600 gravitational wave detector and its international partners and performs theoretical studies to understand sources of gravitational waves. The numerical relativity group is the largest in the world, and is a leader in the development of collaboration software and Grid utilities that support teams of people making effective use of large parallel supercomputers for solving equations in physics.

- 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 within the next 5 years. The Division also plays a leading role in the development of the LISA space-based gravitational wave detector, which will be launched in 2013 jointly by the European Space Agency (ESA) and the US space agency NASA. Danzmann is the European Project 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 2007 to test the measurement and control systems designed for LISA.

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.

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 2003 and of seminars given at the AEI in 2003 show how rich the intellectual environment is.

The AEI and German Universities

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

In order to help to make Germany attractive to young students, the AEI participates in at least three different cooperative initiatives. 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 two SFBs (*Sonderforschungsbereich* = special research area), in which it collaborates with scientists at German universities in areas of mutual interest. These research grants, which run for many years and can involve hundreds of scientists, are a principal source of support for university research. The AEI is particularly pleased that in 2003 an SFB began which joined it with the Universities of Jena, Hannover, and Tübingen and the Max Planck Institute for Astrophysics in Garching in a wide-ranging research program in gravitational wave astronomy, which will help to develop a university research community supporting the experimental activities of GEO600.

The AEI's third initiative is its International Max Planck International Research School (IMPRS) in Geometric Analysis, Gravitation, and String Theory, in cooperation with Potsdam University and the Free University of Berlin. This school, which will enrol its first students in 2004, will not only offer new opportunities to German students to study at the frontiers of theoretical physics, but it will 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 2003 we announced the foundation of our sister journal, *Living Reviews in Solar Physics*.

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.

- Very soon, supercomputers will be large enough to do realistic calculations in general relativity, to perform long simulations of black holes and neutron stars merging, possibly to perform realistic calculations of the formation of neutron stars and black holes, and probably to explore mathematical questions, such as the development of singularities, that have not been solved analytically so far. This work will aid in the discovery and interpretation of gravitational waves and should also raise new questions in mathematical relativity, offering new opportunities for research there.

- 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 – 8-meter-class optical telescopes, optical interferometers, and survey instruments – 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 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?

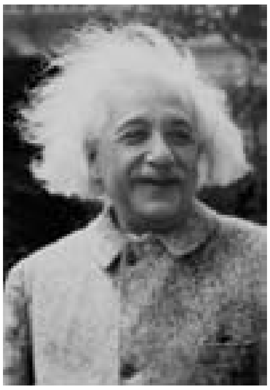
The work of the AEI in 2003, as described in these pages, should be seen in the light of these challenges and opportunities. In almost every case, scientists at the AEI are addressing issues that lie at the heart of progress on these questions. A Max Planck Institute is a long-term investment in a research field, and for gravitational physics the prospects for the future are especially exciting.

Bernard F. Schutz

Competing Giants: Einstein, Hilbert and the Origin of General Relativity:

„Großes wirket ihr Bund, Größeres wirket ihr Streit“[*]

From 1912 to 1915 Albert Einstein was occupied almost exclusively with the “problem of gravitation”. On November 25, 1915 he presented to the Prussian Academy in Berlin his gravitational field equation, the hard core of general relativity. Five days earlier David Hilbert, the leading mathematician of the time, had communicated to the Royal Academy of Sciences in Göttingen a paper entitled ”The foundations of Physics” which, so it seems (see below), also contained that equation, though only implicitly.



Albert Einstein (1879 - 1955)

Before relating some of the history of this remarkable near coincidence I note that Hilbert never claimed priority, and apart from a short period of irritation on Einstein’s part, the two great men were fond of each other, as is shown by letters.

Rather then discussing the irrelevant question of priority I find it interesting to trace and compare the entirely different trains of thought which led these scientists to two different theories which both contain the same gravitational field equation.

David Hilbert (1862 - 1943)

Hilbert’s interest in physics seems to have originated in a joint seminar with his friend Hermann Minkowski in 1905 on the then hot topic of electrodynamics, simultaneous with but independent of the work of the still unknown patent clerk Einstein. His interest was renewed and intensified around 1914 by the developments in the ”old” quantum theory, Gustav Mie’s attempt to create a non-linear, special relativistic electrodynamic theory which was intended to explain the structure of charged particles, and Einstein’s work towards a theory of gravitation which was to generalize his special theory.

In the summer of 1914 (end of June, beginning of July) Einstein gave during one week six long lectures in Göttingen on the status of his work. He was enthusiastic about the fact that Felix Klein and, in particular, David Hilbert completely understood him. These lectures apparently provoked Hilbert trying to create a field theory, which extends Mie’s ansatz by incorporating gravitation along Einstein’s ideas.

There seems to be no detailed record of Einstein’s Göttingen lectures, but his long paper ”The formal basis of General Relativity” of November 1914 contains the essentials of that status. It gives first essentially all those aspects of general relativity, which concern classical, non-gravitational, local physical laws, taken over from special relativity as usual. In particular Einstein asserted that with any material process there is associated a stress energy momentum tensor density $T^{\alpha\beta}$ whose covariant divergence vanishes. Observing that this law is not a conservation law he formulated, as a requirement which the gravitational field equation should satisfy, that ”there must exist a (non-tensorial) complex of gravitational quantities $t^{\alpha\beta}$ such that $T^{\alpha}_{\beta} + t^{\alpha}_{\beta}$ has vanishing ordinary divergence.” Einstein considered the validity of such a law as a physically necessary link, which relates the gravitational field equation to non-gravitational physics by giving rise to an integral conservation law for the total energy and momentum of an isolated system. Throughout his work on general relativity he stuck to this postulate; I shall abbreviate it as (E1). A second condition (E2) which Einstein required of the gravitational field equation was that it should not depend on, or single out, a class of coordinate systems related by linear transformations. Since inertia and gravity cannot be distinguished locally – recall Einstein’s elevator argument – the law for gravity and therefore the theory as a

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[*] In view of my topic I could not resist quoting this sentence, which was cited by Max Planck in his reply to Einstein’s inauguration speech at the Prussian Academy in Berlin on 2 July 1914. Planck inverted Schiller’s phrase, which was, roughly ”Great things they can accomplish in contest, greater ones in league.”

whole was to admit a large class of nonlinear coordinate transformations, to be found along with the field equation. Thirdly (E3), he wanted the equation to be ”causal” in the unusual sense that the components of the metric tensor with respect to an allowed coordinate system should be determined uniquely everywhere by their values in the region occupied by matter. Note that Einstein's formulation does not refer to uniqueness of the field in terms of initial data, but to matter being the ”cause” of the field, and that it presupposes tacitly that a coordinate system can be specified prior to the assignment of fields. Finally, he wanted the field equation to reduce, under appropriate conditions, to Poisson's equation of Newton's gravitation theory; requirement (E4).

The main problem Einstein addressed and apparently solved in the 1914 paper was to find an equation satisfying his conditions (E 1,2,3,4). He began by arguing that generally covariant field equations cannot satisfy his causality condition (hole argument). He than managed to find coordinate conditions and a field equation which apparently satisfied all of his conditions. Since these arguments were wrong there is no use in discussing them except for two points. Einstein derived the gravitational part of his field equation by varying an action integral, and for this reason he was able to satisfy his requirement (E1). (Euler-Lagrange equations always imply an ordinary conservation law.) Finally, he got the desired Newtonian limit in the same way as in his later work by linearising the field equation at the Minkowskian background metric. I shall continue the Einstein part of the story after the Hilbert part.

Hilbert's first note on the foundations of physics was published on March 31, 1916, with the submission date November 20, 1915. Only in 1997 the science historian Leo Corry discovered in the Göttingen Archives the set of the first page proofs of the original version of that paper. That unpublished version contained a theory of coupled gravitational and electromagnetic fields based on three axioms and a few additional assumptions. The first two axioms state that the field equations for the gravitational potential $g_{\alpha\beta}$ and the electromagnetic potential q_α result from an action principle whose density is a generally invariant function of these potentials and their derivatives. This, said Hilbert, expresses in the simplest way Einstein's fundamental idea of general invariance, though – as he remarks – Einstein uses Hamilton's principle only in a secondary role, and his action is by no means generally invariant and does not contain the q's. Hilbert then states without proof as his ”Leitmotiv” what later became known as Emmy Noether's second theorem. In the case under discussion it states that the 14 Euler-Lagrange expressions satisfy identically 4 first-order differential equations, the generalized Bianchi identities. From this mathematical theorem Hilbert concluded that if the basic equations of Physics are to have the character of determinateness in Cauchy's sense, then it is necessary to complete the 14 Euler-Lagrange equations of which only 10 are essentially independent, by 4 non-invariant coordinate conditions. Thus for Hilbert, at least originally, the breaking of general invariance as a basic property of the theory is necessary since one wants the equations of physics to determine the future from initial data, a causality requirement quite different from Einstein's (E3). To find such coordinate conditions, Hilbert introduced by long calculations an ”energy conservation law” in the form of 4 ordinary divergence equations which hold if and only if the spacetime coordinates satisfy 4 coordinate conditions. These conditions are then stated as axiom III. This line of reasoning is quite similar to Einstein's (E1).

Unfortunately, in the page proofs a part of one page is missing which contained one numbered equation. Comparison with the published paper makes it nearly certain that the missing equation gives the action density as a sum of a gravitational and an electromagnetic contribution, with the first part specified as the Ricci scalar denoted as K. Be that as it may, later in the original manuscript the gravitational equation was given as the Euler-Lagrange equation resulting from the variation of the $g^{\alpha\beta}$. However, the variational derivative of K was not computed, and so the much debated ”trace term” of the field equation was not exhibited.

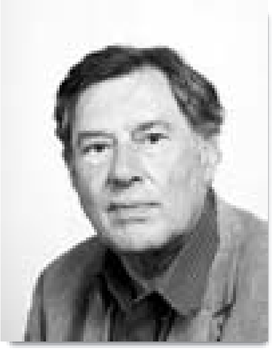
In the published version the axioms I and II and Noether’s identity appeared as in the proof version, but the arguments about causality, axiom III and the need for coordinate conditions were omitted. Instead a different, also non-invariant energy conservation law was derived solely from the first two axioms. (In 1918 Felix Klein showed that this conservation law, though it looks quite different from Einstein’s, is equivalent to the latter modulo identities.) The published note contains the gravitational field equation in explicit form, with the Einstein tensor on the left hand side, accompanied by wrong assertions about its derivation and uniqueness.

Thus, Hilbert’s published first note, in which all of Einstein’s papers of 1915 are cited, provides the first generally covariant, Lagrangian field theory of gravitation, electromagnetism and charged matter, with a Mie type stress energy momentum tensor. The theory was never elaborated; difficulties turned up and the theory did not influence the development of physics.

I briefly return to Einstein. In October 1915 he seems to have realised that his former approach to the field equation had been wrong. In the following month he essentially completed his general theory of relativity in four steps. On November 4 he formulated a theory invariant under unimodular transformations, on the 11th he changed it to become generally invariant, though with an energy tensor restricted to have vanishing trace. Then, on the 18th, followed the perihelion paper and on the 25th he arrived at his final, generally covariant field equation with an unrestricted energy tensor. During this period as before he was guided by the four requirements described above, but he no longer used his former, misleading causality argument. On November 28, 1915 he wrote to Arnold Sommerfeld: ”It is of course easy to write down the generally covariant field equations, but difficult to recognize that they generalize Poisson’s equation and satisfy the conservation laws”. In contrast to Hilbert, Einstein wisely considered a fundamental, field theoretic description of matter as not yet possible and therefore kept the matter tensor unspecified. He formulated the well known three classical tests, which gave empirical support to his theory.

During the critical period of November 1915 Einstein and Hilbert exchanged several letters, but they talked past each other, each one being very much concentrated on his own approach.

It emerges that general relativity as a physical theory is due to Einstein. Hilbert provided the invariant action density for the gravitational field. In his second note, submitted on December 23, 1916 he explained how causality in his (and the modern) sense should be understood in a generally covariant theory, and he illustrated that with an initial-value formulation for the vacuum gravitational field. His contribution to physics contained, as he later proudly wrote, ”an enduring core”.



Jürgen Ehlers

Geometric Analysis and Gravitation Division

The description of astronomical objects by means of mathematics is one of the oldest human endeavours. To forecast the motion and appearance of the moon, the planets and the stars Greek mathematicians developed the first basic concepts of geometry still valid today, their theory of conic sections was used centuries later by Kepler to formulate his laws of motion for the planets. Following the discovery of infinitesimal calculus in the 17th century the development of analysis made it possible to formulate laws of equilibrium and laws of motion in terms of variational principles, culminating in particular in the variational interpretation of the Einstein field equations in General Relativity by David Hilbert.

The second half of the 20th century has seen tremendous progress both in gravitational physics and in mathematics: On the side of physics black holes have developed from a theoretical and mathematical curiosity to very real objects of observation, gravitational lensing has become an important observational tool, cosmological models interact with particle physics, and gravitational waves are within reach of modern detectors. On the other hand mathematical analysis has developed a deep understanding of nonlinear elliptic and parabolic partial differential equations arising from geometric variational problems, differential geometry has developed methods to link local curvature properties of surfaces and spaces to global properties of their shape, and numerical simulations allow detailed quantitative predictions from complex mathematical models. A main task for the Division "Geometric Analysis and Gravitation" is the pursuit of basic research on mathematical methods relevant for the modelling of gravitation and the investigation of specific models for concrete physical phenomena using modern mathematical techniques.

Since Galilei, Brahe and Kepler the theory of gravitational attraction between celestial bodies has benefited from lively interaction between astronomical observation, theoretical physics and mathematical modelling. In recent times the search for unified theories and new developments in String Theory and M-Theory have suggested many new connections between mathematics and physics, the interpretation of observations in astrophysics and gravitational wave experiments require new methods in theoretical and numerical analysis. The other divisions of the Albert Einstein Institute provide continuous exposure to these developments and benefit in turn from the mathematical expertise offered here.

The Role of Mathematics in the Description of Gravitation

Newton’s theory of gravitation is usually formulated in the language of differential equations. It had tremendous impact on the mathematical theory of dynamical systems, potential theory and partial differential equations, but also on the calculus of variations, hamiltonian mechanics and symplectic geometry. From a physical point of view Newton’s theory of gravitation is accurate enough in many situations and for many purposes - only in extreme situations where very strong forces or high velocities occur, or where extreme accuracy is required Einstein’s theory of gravitation has to be used. The mathematical formulation of Einstein’s theory of gravitation uses both differential equations and geometry, since the background where the differential equations have to be formulated and solved is no longer Euclidean space but a curved four-dimensional space-time. In fact, the equations proposed by Einstein have to be interpreted as a balance between curvature and physical non-gravitational fields, as a variational equilibrium between geometry and matter! This intrinsic linkage of analysis, geometry and physics in

Einstein's general theory of relativity leads to beautiful and challenging mathematical concepts and models which lie at the heart of the work of the Division "Geometric Analysis and Gravitation".

After the main framework of Einstein's theory has been established during the last decades it has now become possible to ask specific questions about characteristic phenomena of general relativity like rotating neutron stars, collapse of stars into black holes, gravitational waves emanating from the collision of heavy objects, or conditions in the early universe. Such specific questions make it necessary to identify and study new mathematical structures representing classical physical concepts, for example mass, energy and momentum, in the geometric setting of general relativity, both in a global and in a localised context. Moreover, the difficulties arising from the questions posed often make it necessary to invoke sophisticated mathematical tools such as weak solutions of differential equations or concepts from geometric measure theory allowing generalised surfaces with possible singularities. In other situations it may be advantageous to reformulate the original mathematical description in a more natural way, for example with the help of conformal equivalences. Difficult mathematical problems arise in particular concerning the solvability of nonlinear wave equations and related stability questions, the description of physically consistent initial data in the framework of three-dimensional differential geometry, differential equation models for matter coupled to the Einstein equations, formation of singularities, and concerning the relation of Einstein's theory to the classical theory of Newton in the limit of weak fields.

Geometric Evolution Equations

A recurring theme in the study of general relativity is the evolution of geometric structures in time: When using a Hamiltonian formulation of general relativity, where space-time is considered in a suitable (3+1)-splitting of space and time, the Einstein equations give a prescription for the evolution of a three-dimensional curved space in time, driven by its own geometry and the matter fields present in the system. It has proven to be very fruitful to carefully study the change of geometric data on the 3-dimensional slices as time evolves in order to understand the overall behaviour of the system. Similarly, when tracking the horizon of a black hole through space-time one is naturally led to the study of 2-dimensional surfaces evolving in a 4-dimensional ambient space. Apart from their direct occurrence in the evolution of a physical system just illustrated, families of surfaces satisfying natural rules of deformation are an important mathematical tool in analysing the properties of a higher-dimensional space: suitably chosen families of 2-dimensional spheres can provide a natural radial coordinate system around an isolated gravitating system, thereby helping both theoretical and numerical investigations. Evolving submanifolds also appear in String Theory and M-Theory where some of the underlying equations model the evolution of vibrating strings and membranes. The systematic investigation of deformation laws for surfaces and curved spaces is an important research project in the division "Geometric Analysis and Gravitation".

In 2003 specific progress was made on the evolution of hypersurfaces by their mean curvature. For surfaces in Euclidean space which have the sum of the lowest two principal curvatures positive everywhere, a surgery procedure was devised which allows the continuation of the flow past singularities in a controlled way. As one application arising from this flow with surgery a complete classification of all 3-surfaces of positive scalar curvature in Euclidean 4-space was obtained. The result highlights a close analogy of mean curvature flow with the Ricci-flow of Riemannian metrics employed by G. Perelmann in his attack on the Poincare-Conjecture and geometrisation of 3-manifolds.

Geometric Variational Problems

Since the calculus of variations was initiated by Newton, Leibniz and the Bernoulli brothers and since Huygens demonstrated the power of variational principles in the foundations of geometrical optics, variational principles for geometrical structures have governed large parts of physics. In general relativity they become apparent not only in the Hilbert action for the Einstein equations and the variational properties of geodesics, but also in the Hamiltonian formulation of the Cauchy problem and in the construction of optimal gauges with the help of maximal or constant mean curvature slices as well as harmonic maps. Needless to say, variational principles are also present in the formulation of various models of matter.

In recent years variational principles have also been successfully applied to understand the inner structure of Cauchy data on a three-dimensional Riemannian manifold: An early starting point was the proof of the positive mass theorem with the help of minimal surfaces and the discovery of deep links between the mass of asymptotically flat three-manifolds to the Yamabe variational problem in the conformal geometry of closed three-manifolds. After Bray had recently discovered how the flow by surfaces along their inverse mean curvature can be used to compute and estimate Yamabe invariants of certain 3-manifolds, a student showed how inverse mean curvature flow can be used to give a direct proof for the existence of conformal metrics of constant scalar curvature on a compact 3-manifold.

A specific variational integral studied last year in this section is the Willmore energy of a 2-dimensional surface, given by the integral of the square of the mean curvature over the surface. This functional has intriguing invariance properties and plays an important role both in Differential Geometry and General Relativity, see the article by Martin Schmidt in this report.

The Freedom to Choose Natural Coordinates

A key feature of the Einstein equations is their general covariance. This means that they take the same form in any coordinate system or, expressed in geometrical language, that they are invariant under diffeomorphisms. Considered in the abstract, this is a beautiful property of the equations. On the other hand it leads to practical difficulties when pursuing the study of the Einstein equations by means of purely mathematical methods or using computer calculations. One part of this problem is that of the choice of a good time coordinate. In general relativity there is no preferred way of splitting the four-dimensional space-time into time and three-dimensional space. It is possible to cut up space-time into a family of three-dimensional slices, each of which can be thought of as "All of space at a particular time". While it belongs to the essence of general relativity that there is no one way of doing this which is singled out and everyone is free to choose their own slicing of space-time, a good and geometrically natural choice of slicing can help towards an elegant and useful description of solutions to Einstein's equations. A good choice of slicing involves certain elliptic or parabolic differential equations for the height of the slice above a given initial slice. Several projects by PhD students on surfaces of prescribed mean curvature made substantial progress in this context during 2003.

Once a suitable 3-slice of space-time is constructed, the question of natural coordinate systems arises again, this time inside the 3-slice itself. Using the techniques from geometric evolution equations described earlier researchers at the AEI have been able to construct good two-dimensional spherical slices inside each 3-slice, providing a natural radial coordinate at least in the exterior region of space-times modelling isolated systems. In a joint project with the SFB283 in Tübingen during 2003 a PhD student developed theoretical and numerical methods for the construction of 2-surfaces of constant mean curvature in asymptotically flat slices.

The search for good initial data sets modelling systems containing black holes leads to boundary value problems involving the horizon of the black hole. In new work it was shown how the trapped surface condition can be written as a non linear boundary condition for the constraint equations. Under appropriate assumptions existence and uniqueness of solutions in the exterior region for this boundary value problem was shown.

Cosmology and Symmetry

In cosmology it is common to use very special highly symmetric models of the universe (homogeneous and isotropic). The actual universe is not perfectly symmetric. The presence of irregular distributions of matter breaks the symmetry. In the symmetric models there is a preferred choice of slicing which is determined by the condition that it too be symmetric. In more realistic, less symmetric, models this is no longer the case. If we want to study the structure of models of this kind it is necessary to make some intelligent choice of slicing. There are various criteria for a slicing to be good. This depends of course on the application in which it is to be used. It is desirable to identify some condition which will invariantly determine a unique slicing, or at least a very restricted family of slicings, in any space-time of the class to be studied. In studying cosmological models it is desirable to have a slicing which covers all of the space-time and where the individual slices do not ”run into the big bang”. In other words it should not be possible to reach the big bang by moving along the slice, which should correspond to moving in space. Work was continued on different ways to obtain good slicings both near the big bang and in the expanding direction.

A kind of slicing which is very simply defined is a Gaussian one. Each slice is obtained by following geodesics starting orthogonal to a given slice for a definite time. This slicing has a very bad reputation in general relativity since it often breaks down due to formation of caustics in the family of geodesics. It turns out, however, that in forever expanding space-times with positive cosmological constant this problem can be avoided under rather general circumstances. In 2003 very general solutions of the Einstein vacuum equations with positive cosmological constant in any dimension were constructed. No symmetry assumptions were required. At late times these spacetimes can be covered by a global regular Gaussian slicing and indeed they were constructed in this form. The mathematical tool used to obtain these results is the theory of Fuchsian equations which had previously been used to investigate the structure of spacetime singularities.

The Analysis of Asymptotically Flat Space-Times

Asymptotically flat space-times provide the most important models for far fields of isolated gravitating systems such as one or several stars, black holes etc. Most observable general relativistic effects are analysed in the context of such space-times. Moreover, the only rigorous concept of gravitational radiation we know is associated with the asymptotic regime of these space-times, called 'light-like infinity', which is approached by following light rays which escape to infinity. It is therefore important to control these space-times in their entirety in terms of an abstract analysis as well as in terms of concrete calculations. The abstract analysis provides results about their general structure and asymptotic behaviour which are necessary to work out the general theory and to clarify conceptional questions. However, it also provides information about the properties of the field equations and the well-posedness of the boundary value problems for the field equations which form the basis for the global numerical calculation of such space-times.

Much of the global analysis of asymptotically flat space-times has been done in terms of the 'conformal field equations'. These equations govern the evolution of the metric relations after the latter have been scaled down to achieve a finite coordinate description of the asymptotic regime. It is one of the many surprises of Einstein's equations that they imply useful equations for the conformally rescaled field. Some of the work at the AEI is concentrating on working out the various facets and the geometric content of the conformal field equations.

During his stay at the AEI one postdoctoral visitor analysed some of the features of the 'conformal constraints', the subsystem of the full set of conformal field equations which must be satisfied in particular by the initial data for the time evolution problem. The results obtained so far present a first step towards solving the conformal constraints directly in the conformal picture. Such methods are urgently needed for the numerical calculation of asymptotically flat space-times.

Past and future light-like infinity, which are most important for the discussion of radiation phenomena, meet at 'space-like infinity'. Understanding the behaviour of gravitational fields in that region is critical for controlling the evolution of complete space-times, including their asymptotics. This has been an open problem for a long time which continues to be central in the research of the AEI. During 2003 a detailed desciption was given of our present understanding of the relations between the behaviour of asymptotically flat Cauchy data for Einstein's vacuum field equations near space-like infinity and the asymptotic behaviour of their evolution in time at null infinity.

The 'cylinder at space-like infinity' has been introduced to provide a setting for analysing the evolution of the gravitational field near space-like infinity in a finite picture and with precise control on the asymptotic smoothness. The subsequent analysis gives increasing evidence that all expectations projected on this setting will bear out. In new work it was shown that the spin-2 equations on Minkowski space in the gauge of the `regular finite initial value problem at space-like infinity' imply estimates which, together with the transport equations on the cylinder at space-like infinity, allows one to obtain for a certain class of initial data information on the behaviour of the solution near space-like and null infinity of any desired precision.

Numerical Methods

Given the strong interplay between astrophysical phenomena and mathematical methods and models, there is a strong need to make detailed quantitative predictions for particular initial conditions for Einstein’s equations. In view of the nonlinear structure and geometric invariance of these equations in three space and one time dimension, the development of numerical methods meets tremendous difficulties, both from a theoretical and from a practical point of view. The numerical work pursued in the Geometric Analysis and Gravitation division complements the work in the Astrophysical Relativity division. It focuses on specific conceptual and theoretical issues of numerical simulations, for example in efforts to simulate solutions of the conformal approach to the Einstein equations or in collaboration with the SFB 382 in Tübingen on the computation of optimal foliations of three-dimensional slices of space-time.

Specific projects adress the numerical simulation of solutions to the Einstein field equations using the conformal approach. In this reformulation of the Einstein equations it is important to closely link mathematical analysis with the numerical methods, for example in choosing suitable curvature variables and in determining the growth behaviour of constraint violating modes. During 2003 computer algebra was applied in a MathTensor based framework to problems commonly arising in this context, such as the derivation of 3+1-splits, manipulation of evolution equations and automatic code generation. Particular emphasis was put on working with abstract index tensor quantities as much as possible. In collaboration with other groups worldwide a major effort was made to develop standard testbeds for Numerical Relativity.

Einstein's Equations with Matter

Vacuum solutions of the Einstein field equations can be treated from a purely geometric point of view, they model important physical phenomena such as the propagation of gravitational waves and black holes. Most realistic physical models however involve matter and its interaction with itself and the geometry of space-time. There are several projects being pursued at the Geometric Analysis and Gravitation division investigating gravitating systems with various forms of matter.

Understanding of the asymptotic behaviour of solutions of the Einstein-Vlasov equations with positive cosmological constant and plane or hyperbolic symmetry was further refined. In addition it was shown that in the case of spherical symmetry the presence of a positive cosmological constant leads to a qualitative change in behaviour. When the cosmological constant is zero cosmological spacetimes with this symmetry always recollapse. When the cosmological constant is positive a large proportion of the models expand forever and have an asymptotic behaviour similar to that in the plane symmetric case.

Elastic selfgravitating bodies in the context of general relativity continued to be another area of research in the group. A workshop on this topic in October 2003 brought together scientists from several related fields, compare the special report on this event.

Gerhard Huisken

Astrophysical Relativity Division

The scientists in the Astrophysical Relativity Division concentrate their research on understanding how Einstein's theory of gravity, general relativity, helps us to understand the Universe that astronomers see around us. Modern astronomical observatories have revealed a rich variety of phenomena that need relativistic gravitation for their explanation: black holes, neutron stars, gravitational lenses, and the acceleration of the expansion of the Universe itself. Among these phenomena, the AEI's scientists focus on two related areas where the potential for scientific progress is especially promising: the detection of gravitational waves and the numerical study of collisions involving black holes and/or neutron stars.

Gravitational Wave Detection

The AEI's Laser Interferometry and Gravitational Wave Astronomy Division is developing the GEO600 gravitational wave detector, located near Hannover. Details of this detector and of associated collaborations on technology development with the American LIGO project can be found in the report of that division. In the Astrophysical Relativity Division, our scientists are responsible for analyzing the data from the GEO600 and LIGO detectors. This is a wide-ranging responsibility, involving not only looking for a variety of sources but also using the data to understand the workings of these very complex detectors.

Fortunately, we do not work on this job alone. We work with our partners in the GEO600 project in Britain (at Glasgow, Cardiff, and Birmingham Universities) and in Spain (at the University of the Balearics). In addition, we have a data-sharing agreement with the LIGO project, under which a large team of scientists from both projects looks for various gravitational wave sources in the data from all the detectors in both projects.

The year 2003 was a landmark for these projects, because the first papers analyzing data from these interferometers were written and accepted for publication. The data that was analyzed was only a short stretch of data taken at a time when the detectors were still being commissioned, so their sensitivity was far from their ultimate design goal. Therefore the analysis was designed only to set upper limits on possible gravitational wave sources; we do not expect the first detections until the detectors have operated at design sensitivity for a year or more. Nevertheless, the activity of analyzing the data was an important exercise for the community, and the publications represent a statement of confidence in our analysis procedures and in the detectors at the time the data was taken.

Later in this volume there is a report from Prof Maria Alessandra Papa and Prof Curt Cutler that gives more details of this analysis. The data-analysis teams are large, consisting of more than one hundred scientists altogether, and organizing their work was a significant challenge. The first papers have over four hundred authors, including analysts and hardware scientists from both LIGO and GEO. Prof Papa is the co-chair of the analysis team devoted to looking for gravitational waves from spinning neutron stars, and her team showed that the fastest-spinning neutron star known, the pulsar PSR J1939+2134, is so smooth that its average deformation is smaller than a few centimetres; anything larger would have radiated gravitational waves strong enough to have been seen in our short observation. While interesting in itself, this result also shows the potential for these kinds of observations: when the detectors operate next year with hundreds of times better sensitivity and take data for many months rather than weeks, we will begin to be sensitive to average irregularities smaller than a millimetre, a deformation that is certainly possible in many spinning neutron stars.

Our MERLIN cluster supercomputer was enlarged this year to 180 dual-processor nodes (giving it a peak computing power greater than a teraflop) and has a huge disk data storage capacity. Merlin has become one of the workhorses of the GEO-LIGO data analysis collaboration and is used at virtually 100% of its capacity, every day of the year.

Dr Papa leads the team that has developed the AEI's search software for unknown neutron stars, a difficult computing problem that has been described in previous annual reports. This software is now the standard for the GEO-LIGO data analysis, and is being extended to look for neutron stars in binary systems and for other applications. During 2003 Dr Papa was also named overall data analysis coordinator for the GEO project, with responsibility for ensuring that the GEO contributions to the joint GEO-LIGO data analysis were adequately supported and on time.

While much of the division's work on gravitational waves is devoted to data analysis, we also maintain a strong research activity in theoretical questions, because theory and observation are closely connected in this field. Indeed, our postdoctoral research scientists who work on data analysis are also expected to work on theoretical questions for half of their research time.

A particular highlight of this activity has been work on gravitational wave sources that the upcoming LISA space-based gravitational wave detector will see. Cutler and division director Prof Bernard Schutz are members of the LISA International Science Team, which oversees the development of this project. LISA is a joint mission of NASA and ESA, expected to be launched in 2013, and at present the team is working hard to develop a final specification for the mission before going into the detailed design phase. Part of that specification is understanding what sources are likely to be seen, which of them have high priority for the mission design, and what data analysis challenges there might be in detecting them in LISA data.

One of the most interesting sources, and unfortunately the most challenging to detect, is the signal from a compact object (such as a black hole formed from the collapse of a giant star) as it spirals around and eventually into a massive black hole in the center of a distant galaxy. We know that our own Milky Way has a black hole with the mass of 2.6 million suns, and astronomers believe that this is fairly typical. During the LISA mission we expect every year that there will be perhaps dozens of signals from such events involving similar black holes within the volume of space LISA can search. But picking these signals out of the noise background will be a challenge because they have a very complex form. The work at the AEI on this problem has been described in the article by Papa and Cutler.

Numerical Solutions of Einstein's Equations

The other major activity in the Astrophysical Relativity Division is the effort to solve Einstein's equations on a computer in order to study situations that are not amenable to analytic solution. One problem in particular is especially important from the point of view of the gravitational wave detectors: the merger of two black holes as they spiral together from a circular binary orbit. While rare, these events are expected to be seen both by ground-based detectors and by LISA, and an adequate theoretical understanding of the gravitational wave signature of these events will greatly assist their detectability.

Representing on a computer two black holes orbiting about one another is immensely challenging. It requires a large supercomputer with enough memory and speed to approach solving the problem, and it requires software that solves Einstein's equations with accuracy and stability. With the installation of the PEYOTE supercomputer cluster at the AEI, we have a computer that can solve all but the largest simulations. But we are still limited by software: through a process of trial and error, scientists at the AEI and around the world are gradually learning what is required to simulate black holes in orbit over long periods of time. These problems, and our attempts to solve them, are described in two further contributions in this volume, so I will not go into further detail here.

Our numerical relativity group has seen big changes in 2003. The leader and founder of the group, Prof Edward Seidel, moved to Louisiana State University in the USA to take on the director position at that University's Center for Computation and Technology. This center operates one of the largest supercomputers at any American university, and has a brief to develop computational science across all disciplines at the university. We congratulate Ed on his new position and we welcome the fact that this establishes a new and very promising collaboration partner for the AEI. Ed was accompanied to Louisiana by Prof Gabrielle Allen, who led the Cactus development group at the AEI. We are currently in a process of restructuring the activities and leadership of the group, with the aim of continuing to maintain our group as the largest and most active in the world. Denis Pollney and Michael Russell have assumed acting leadership of the science and computing sides of our numerical relativity activities. Look for further developments in next year's annual report!

Bernard F. Schutz

Quantum Gravity and Unified Theories Division

The following is an overview of the scientific activities in the Quantum Gravity Division over the past year 2003. In comparison with previous years the scientific output has again increased. Much of this work involved not only members of the division, but also scientists from partner institutions all over the world. These collaborations and numerous contacts were made possible by the AEI visitor program and various third party grants. The international standing of the group is well reflected in the large number of invitations extended to members of the division to speak or lecture at national and international schools and conferences. These included graduate and undergraduate courses at universities in Germany, more advanced workshops such as the RTN Winter School on Strings, Supergravity and Gauge Theory in Torino, as well as invited plenary talks at the major international conferences such as the Xth Marcel Grossmann Meeting in Rio de Janeiro, STRINGS'03 in Kyoto, the ESI Workshop on 2d Gravity, etc.

The Division continues to make great efforts towards attracting young talents and thereby training the next generation of highlevel theorists. The new International Max Planck Research School (IMPRS) "Geometric Analysis, Gravitation and String Theory", although officially due to start only on 1 January 2004, began to show its positive impact already in 2003 with an increased number of applications and the arrival of new PhD students. At the time of writing, the IMPRS coordinator, J. Plefka, has received already more than 50 applications, many of which came from abroad. Of the IMPRS funded students accepted so far, more than 70% carry a foreign passport.

Research in the division in 2003 covered a diverse range of subjects ranging from string theory and quantum field theory to canonical quantum gravity and loop quantum cosmology. The substantial progress that was made in all of these areas will be described in more detail below. In several of these AEI now hosts some of the world's leading expertise, a fact also recognized in the 2003 Fachbeirat Report. Special mention should be made here of the contributions of the AEI group to the subject of string/gauge theory duality. According to some leading specialists (not from AEI!), the discovery of a hidden integrability structure in maximally supersymmetric Yang Mills constituted last year's most important achievement in this field of research, cf. the sections on plane wave and spinning strings below, and the special feature by G. Arutyunov in this volume. Another highlight, and in a very different field of research, was the award of the First Prize in the GRG Essay Competition to M. Bojowald, whose work was even described in the Science Section of the New York Times (the first time ever that AEI made it into the NYT!).

In September 2003, AEI hosted a Workshop "Strings Meet Loops". This was a "world premiere", because never before had there been a meeting of this type whose primary purpose was to bring together researchers working on string theory on the one hand, and on canonical and loop quantum gravity on the other, and to enhance exchange of ideas between the two communities. Besides the talks, which were mainly addressed "to the other side", there were many lively discussions and frank exchanges, as well as probing questions from the participants representing the different viewpoints. By all accounts, the meeting was a great success, and there are now good prospects that a follow-up meeting will soon be organized in the USA. The event has also been covered in the April 2004 issue of Bild der Wissenschaft (see also the article by H. Nicolai and M. Pössel in this volume).

1. String/Gauge Theory Duality

An important theme for the string approach to quantum gravity continues to be the intriguing duality between string theories and gauge theories (see the special feature by M. Staudacher in the 2002 Annual Report). Work in this direction, the so-called AdS/CFT correspondence, promises to deepen our understanding of the fundamental meaning of strings, and might allow us to probe the difficult non-perturbative regime of this theory of quantum gravity. The number of AEI articles written in 2003 on this subject totals some 25 publications, which to date have garnered already some 400 citations. Special mention deserves the work of our graduate student N. Beisert, who in less than a year co-authored seven papers, and wrote another three by himself; these papers account for one half of the mentioned citations.

1.1. AdS/CFT, Plane Wave Strings and BMN Gauge Theory

In 2002 much progress had been achieved - in part by AEI members - for a simplified version of the AdS/CFT correspondence, which involves a Penrose contraction limit of the curved Anti-de-Sitter metric. Two comprehensive reviews of this Plane Wave/BMN gauge theory duality were written by AEI scientists last year (J. Plefka and A. Pankiewicz). In 2003, a multitude of important new results concerning the duality were obtained in numerous AEI papers. Special mention deserves work on BMN matrix theory by Kim, Klose and Plefka, which was shown to arise as a consistent Kaluza-Klein reduction of N=4 super Yang-Mills theory. This also allowed to gain added insight into certain recently discovered integrable structures, to be discussed shortly. We should also mention progress in plane-wave string field theory computations on the light cone (Pankiewicz), and difficult state-of-the-art calculations for correlation functions in N=4 gauge theory, both in the perturbative (Arutyunov) and non-perturbative (instantonic) regime (Kovacs).

1.2. Spinning Strings, Spin Chains and Integrability

In a generalization of the BMN approach, it was recently argued that semi-classical methods applied to AdS strings may be directly compared to perturbative gauge theory calculations of anomalous dimensions for certain large charge operators. The necessary techniques for performing such calculations were developed in ground-breaking papers and shown to match the string predictions (N. Beisert, M. Staudacher, in collaboration with C. Kristjansen from Copenhagen, and with Uppsala scientists J.A. Minahan and K. Zarembo). The underlying reason for this remarkable progress may be traced to integrable structures on both the string and the gauge side of the AdS/CFT duality. On the string side this was first understood, in joint work with Frolov, Tseytlin and Russo in a beautiful AEI paper (Arutyunov). On the gauge side the integrable structures were found to apply to the complete set of fields at the one-loop level, and strong evidence was found that integrability extends to higher loops (Beisert, Kristjansen, Staudacher). Lastly, an explicit one-loop match between the string and gauge integrable structure was discovered. Further progress in this rapidly evolving area of research is to be expected in the near future.

2. Loop Quantum Cosmology

Progress in loop quantum cosmology proceeded along two main lines in work by M. Bojowald, G. Date and K. Vandersloot. While in previous years isotropic models have been studied where it could be shown for the first time how quantum geometry can remove cosmological singularities, a detailed study has also been done for anisotropic models to test the robustness of the results. Exact methods are now available which show that the singularity is removed in essentially the same way as in isotropic models, but with some additional subtleties. This gives further indications that the mechanism is generic and does not depend on symmetries. The most interesting anisotropic model, which has been studied in several approaches, is the so-called Bianchi IX or Mixmaster model. Its classical behaviour is chaotic and very complicated close to the singularity, which can be traced back to a curvature divergence there. A detailed investigation of loop modifications of this model showed that the singularity is not only removed, but that close to it the behaviour simplifies such that the system is no longer chaotic, with important implications for the general structure of initial or final states of a classical universe.

The second main line is a phenomenological investigation of loop quantum cosmological models, where a first comparison with cosmological observations has been done. Since there are many different scenarios one can use to test the theory, this is a vast area which fortunately is now being investigated by several groups around the world. In particular the basic observation that loop modifications inevitably lead to an early inflationary phase with different dynamics also of matter fields has been looked at in more detail. Even if an inflation field with a suitable potential is included, there are differences to the standard scenario at early times which may leave an imprint on the cosmic microwave background at large scales.

With the number of applications growing, it is also important to understand the foundation of loop quantum cosmology. This has been achieved by employing the mathematical technique of Bohr compactifications which highlights the new features of loop quantum cosmology as compared to the Wheeler-DeWitt quantization. In addition, it also illustrates how loop quantum cosmology arises as a simple model of full quantum geometry which has all the same essential features.

For a more detailed review, see the companion article by M. Bojowald in this volume.

3. Other Aspects of String Theory/Supergravity

Detailed knowledge of the low-energy effective action of string theory is very important for studying its phenomenological and cosmological implications. Together with A. Westerberg (CERN and Karlstad) K. Peeters continued the analysis of higher-derivative term in the effective action. Important observations were made concerning the possible role of Lorentzian string perturbation theory in an unambiguous evaluation of string amplitudes at higher order in the number of external fields. As spin-off new symbolic and numerical computer tools were developed which will play an essential role for further investigations in this long-term research programme.

In collaboration with I. Antoniadis and P. Vanhove (CERN) and R. Minasian (Paris), S. Theisen has studied the hypermultiplet moduli space of type II strings compactified on Calabi-Yau manifolds. Supersymmetry restricts this space to so-called quaternionic manifolds. In a first step, the simplest situation, namely the universal hypermultiplet, which is part of any such compactification, at the perturbative level, was studied. While the quaternionic structure, combined with various perturbative symmetries, allows for two possible solutions, a string loop calculation was needed to decide which of the two solutions is realized in string theory. In collaboration with A. Schwimmer (Weizman Institute), S. Theisen continued the analysis of anomalies of conformal field theories within the framework of the AdS/CFT correspondence. This was done for arbitrary dual gravity actions in odd dimensions, exploiting only the symmetries, i.e. those diffeomorphism which induce a Weyl rescaling on the boundary where the degrees of freedom of the conformal field theory are localized. Universal features of Weyl anomalies of arbitrary conformal field theories with a holographic dual in any even dimension could be identified. Among other things, it was shown that these theories are not generic but the allowed contributions to the anomaly, i.e. the solutions to the Wess-Zumino consistency conditions, satisfy universal relations.

D-branes are of central importance in string theory, both for the role they play in string dualities, and for the description of gauge theories with open strings. For the compactified theory branes in curved backgrounds must be considered. K. Peeters and M. Zamaklar, together with P. Meessen (SISSA) have analysed the algebraic description of D-branes in such backgrounds. Using a variety of techniques, the following remarkable result was proven: physical consistency, i.e. the requirement to reproduce the supergravity multiplet and the brane BPS relations, demands the inclusion of new fermionic brane charges. Branes in curved backgrounds, and in particular on products of group manifolds were further considered by M. Zamaklar in collboration with G. Sarkissian (ICTP).

A. Pankiewicz continued and completed the construction and analysis of light-cone string field theory on a plane gravitational wave background, and was able to resolve a puzzle concerning the seeming non-uniqueness of light-cone string field theory in the plane wave background. A different (covariant) approach to string field theory has been pursued by E. Fuchs. In studying the Siegel gauge and other possible gauge choices he succeeded in finding the form of the similarity transformation that transforms between different gauge choices including mid-point gauge.

In work with M. Cvetic (Univ. Pennsylvania) and C. Jeschek, K. Behrndt derived the different constraints on the fluxes depending on the structure group of internal space, and derived the resulting 4d superpotential as function of specific flux components. Considering deSitter vacua in N=2 gauged supergravity with non-compact R-symmetry one can also derive the general time dependent multi-center black hole solutions, which couple to an arbitrary number of vector multiplet. With S. Mahapatra (Utkal Univ, India) vacua of deSitter type were derived, which correspond to a saddle point in the potential, where the unstable mode approaches on a regular supersymmetric vacuum from both sides.

In work with A. Sinkovics and K. Skenderis, S. de Haro looked at the computation of the leading corrections to D-brane solutions due to higher derivative terms in the corresponding low energy effective action. They were able to develop several alternative methods for analyzing the problem and to integrate the equations of motion in the presence of an R^4 term. They also analysed the thermodynamic properties of the solutions and the corrections to lowest-order solutions.

4. Physics and Geometry in Three Dimensions

Physics and geometry in three spacetime dimensions are of special interest, because they furnish (sometimes exactly solvable) toy models in quantum field theory and quantum gravity, and it may well be that these theories, once they are better understood, may even serve as building blocks of some yet to be constructed theories describing the real world. Not only is the geometry of 3-manifolds a key area of research in modern mathematics, but there is also a large class of models (including Einstein gravity in three dimensions), which stand a chance of being exactly solvable both at the classical as well as the quantum level. Furthermore, the maximally extended supersymmetric field theories exhibit their ”most symmetric” form in three spacetime dimensions, with scalar potentials of an unprecedented complexity and richness of structure.

Pure gravity in three dimensions is topological. It is exactly soluble at the classical level (in that one can rather explicitly describe the space of classical solutions). Yet, in spite of its simplicity the theory is non-trivial. When the cosmological constant is negative this theory has black hole solutions, whose topology can be rather intricate. In work by K. Krasnov, the thermodynamics of a general 2+1 dimensional black hole is studied, using an analytic continuation procedure that was proposed in his earlier work. The moduli space of black holes is then identified with the Teichmüller space at a certain genus. The free energy of the black hole turns out to have the interpretation of the Kähler potential on the Teichmüller space. One thus gets an interesting thermodynamical interpretation of the classical Teichmüller theory.

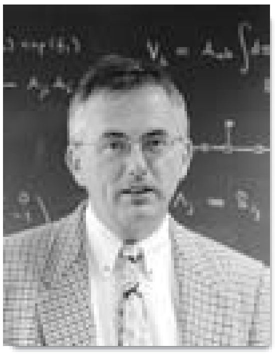
One can also add point particles that are described as lines of conical singularities. This can be done for any sign of the cosmological constant. As shown by t' Hooft for positive cosmological constant, the resulting dynamics of these point particles is very non-trivial. When the cosmological constant is negative, point particles can collide to form black holes via the Matschull process, yielding a toy model of gravity with all essential elements of such a theory. Indeed, it describes both black holes and simple matter, as well as processes involving these ingredients. It is of considerable interest to quantize this theory, with motivations coming from both physics and mathematics. Such conceptual questions as the origin of black hole entropy and information loss can then be addressed already at the level of this simple theory, as shown by Krasnov. Mathematically the problem of quantization of 2+1 gravity with negative cosmological constant is related to the problem of understanding of quantum invariants of hyperbolic manifolds, a topic of current interest.

A second development concerns the construction of gauged supergravities in 2+1 dimension and the exploration of their vacuum structure. Maximal gauged N=16 D=3 supergravity models had been constructed for the first time at AEI by Nicolai and Samtleben in 2000. These models, being the most symmetric ones known in three dimensions, have very special properties not encountered in their higher-dimensional cousins. Due to the on-shell duality between vectors and scalars in three dimensions, the choice for possible gauge groups is larger than in higher dimensions. New results in 2003 included a proof of a surprising equivalence between Yang Mills and Chern Simons gauge theories in three dimensions, the analysis of non-semisimple gauge groups and the discovery of gauged supergravities with complex gauge groups without analogue in dimensions D>3, and a novel description of certain Kaluza Klein theories in terms of a three dimensional gauged supergravity with an infinite dimensional non-semisimple gauge group.

All these models feature very intricate potentials. For the maximal theory these are functions on the $E_{8(+8)}/SO(16)$ coset manifold of scalar fields, which are of an analytic complexity not encountered in any scalar field potential so far. The determination of stationary points, candidates for possible vacua, is therefore a considerable challenge that suggests employing computer aid. The challenge was taken up by T. Fischbacher, a PhD student, who was able to develop powerful new tools that make symbolic as well as numerical calculations with large Lie group representations possible. The main new idea is to employ algorithms from relational database systems and, where applicable, a highly specialized dense term encoding which is optimized towards finding simplifying term reductions.

5. (Super)Gravity and Infinite Dimensional Symmetries

Infinite dimensional symmetry groups and Lie algebras continue to be a source of fascination, especially in connection with the hidden symmetries of Einstein's theory. Following up on previous work by Damour, Henneaux and Nicolai, where an extension of the BKL approach in terms of an expansion in spatial gradients had been proposed in which the original BKL approximation would just be a first step, the indefinite Kac Moody Lie algebras E10 and E11 were further investigated by T. Fischbacher and H. Nicolai. The level decompositions of these algebras were carried to unprecedented heights (in particular, up to level 28 for E10), also substantially extending existing results on the root multiplicities of these Lie algebras. The higher level representations of E10 are expected to be related to the higher order spatial gradients in an extension of the standard BKL approach. The underlying software tools that allow the study of these and other algebras to be taken to a previously unreached depth have been made publicly available as part of the LambdaTensor package by T. Fischbacher. Finally, subalgebras of hyperbolic Kac Moody algebras were studied in work by H. Nicolai and A. Feingold (Binghamton).



6. Outlook

Although this brief summary cannot do justice to all the work done in the Quantum Gravity Division during the past year, it hopefully shows its breadth and variety. Indeed, encouraging diversity appears to be the best strategy in tackling the challenge of quantum gravity, at least as long as the correct theory remains shrouded in mystery.

Hermann Nicolai

Laser Interferometry and Gravitational Wave Astronomy Division

The experimental branch of the Albert Einstein Institute is located in Hannover. It is operated as a joint undertaking with the University of Hannover. Currently one division is in operation, but a second division is foreseen for the near future. The year 2003 was the second year of operation for this division and many important events happened during this year. The construction of our new laboratory building was finished in the fall of 2003 and by Christmas of 2003 all our experiments where moved into the new lab building. This new building gives us almost 2000 m^2 of experimental area, a large high-bay lab, 8 optics labs, 5 clean room labs, including one with a formal class 100 certification, plenty of cleaning and preparation rooms and several offices. Most of our offices where moved into temporary quarters provided by the University as the renovation of our office building has also begun at the end of 2003. We expect to move back into our renovated office building in the fall of 2004. This should then give us enough room for the expected expansion of the Hannover branch of the Albert Einstein Institute. Scientifically, we have seen major accomplishments on GEO600, culminating in the third science run S3 in coincidence with LIGO. We were very happy about the final approval of LISA Pathfinder (formerly SMART-2) the technology precursor for the LISA mission, and the start of hardware development for this mission and we have seen a major expansion of our non-classical light interferometry group, including first experimental results.

The final goal of all activities of the Albert Einstein Institute in Hannover is the observation of gravitational waves and the development of gravitational wave astronomy. This comprises the development and operation of large gravitational wave detectors on the ground as well as in space, but also a full range of supporting laboratory experiments in quantum optics, atomic physics and laser science. Our ground based detector GEO600 has been built as a German-British collaboration comprising Max Planck Institute for Gravitational Physics, Max Planck Institute for Quantum Optics, University of Hannover, Laser Zentrum Hannover (LZH), University of Glasgow and University of Cardiff. We are part of the LIGO science collaboration LSC, contributing to the working groups concentrating on lasers and the second generation upgrade of the LIGO observatory (advanced LIGO) and we are members of the LIGO I collaboration by providing mutual data access to our own GEO600 data. We are collaborating with the French-Italian VIRGO project through the EGO (European Gravitational Observatory) consortium. Gravitational wave activities in Germany are funded by the Deutsche Forschungsgemeinschaft (DFG) through the Sonderforschungsbereich TR7 "Gravitationswellenastronomie" comprising the Universities of Jena, Tübingen and Hannover and the Max Planck Institutes for Gravitational Physics and Astrophysics. For the space detector LISA we are part of an international collaboration of ESA and NASA, with payload contributions from European national member states. For LISA pathfinder (formerly SMART-2), the technology demonstration space mission for LISA to be launched by ESA in 2007, we are co-PIs of the payload LISA Technology Package (LTP).

GEO600 – A Ground Based Gravitational Wave Detector

GEO600 is a laser interferometer with 600m long arms that incorporates advanced second generation technology wherever possible. It has been built on land owned by the state of Niedersachsen and administered by the University of Hannover. Financial contributions have been obtained from the state of Niedersachsen, the Volkswagen foundation, the British PPARC, the German BMBF and the Max Planck Society.

During the year 2003 we concentrated on commissioning GEO600 in its full dual recycled configuration with final optics suspended from all-monolithic fused-silica suspensions. An additional feed forward system for the suppression of low frequency disturbances was installed to reduce residual coupling of longitudinal motion. A thermally adaptive optics control system was installed to correct and fine tune in-situ the radius of curvature of the main optics. A new lock acquisition scheme for detuned dual recycling was developed that first locks in a far-detuned state where the acquisition is much easier, and then tunes the signal recycling frequency down to the operating range. After the very successful installation of high bandwidth auto alignment systems and drift controls for all major degrees of freedom of the main interferometer, we finally managed to also include the signal recycling mirror in the auto alignment system. The mechanical dissipation in the monolithic suspension system was measured and found to be consistent with model calculations, and predictions for the thermal noise behavior of GEO600 due to the silicate bonded monolithic test mass suspensions were made. The data acquisition system computer hardware was refitted with faster and more reliable servers. A fully automatic SMS alert system for the status of the detector, the data acquisition and infrastructure was implemented. Preparatory work has now been completed to synthesize an analog artificial pulsar signal with arbitrary pulsar parameters and to hardware inject it into the interferometer with an electrostatic mirror drive. The calibration of the sensitivity of GEO600 is now handled by an autonomous online calibration method using hardware injection of calibration signals. The whole data acquisition system is now running with the duty cycle close to a 100%.

All these efforts made it possible to participate in the S3 science data taking run in coincidence with LIGO in December 2003 and January 2004. GEO was finally running in an extremely stable and reliable way with the duty cycle of all systems in lock of larger than 98% during 14 days of data taking. For the first time, the full configuration with power and signal recycling was used in GEO600 during this run. The signal recycling was tuned with a bandwidth of a few hundred Hz centered around 1 kHz to be optimized for a pulsar search for near millisecond pulsars, in particular the known binary pulsar PSRJ1939+2134. Within its measurement band, GEO600 reached a sensitivity equivalent to a linear spectral density of strain $h < 3 \cdot 10^{-21}$ m/√Hz in line with the expecta-tions for this state of commissioning. This represents an amplitude sensitivity improvement of a factor of 20 compared to the S1 run in the year before. The data is currently being analyzed, searching for burst, inspiral, pulsar and stochastic signals. The preliminary search, processing GEO S3 data with two LAL (LSC analysis library) compliant burst search algorithms has been finished.

Advanced LIGO and EGO

The first generation of large gravitational wave detectors is going into operation now. Their sensitivity will not necessarily be sufficient for serious astronomical observations. The observatories were always foreseen to go through a series of well planned upgrades with ever increasing sensitivity. We have been actively participating in all the LSC working groups developing the design of advanced LIGO, the second generation upgrade of LIGO. The systems design is now been finished and incorporates several GEO600 technologies, like multiple pendulum vibration isolation, monolithic suspensions signal recycling and resonant sideband extraction. The Advanced LIGO proposal is now under review by the National Science Foundation (NSF) and the proposal assumes a hardware contribution from the GEO collaboration in the fields of high power lasers, signal recycling, and suspensions. These developments will also be usable in GEO Upgrade, the next generation detector system to be installed in the GEO600 observatory, and in Advanced VIRGO, which should be realized in a comparable time scale to Advanced LIGO. In Europe we have an intense interaction between GEO and VIRGO and all resonant detector groups developing concepts for a third generation European Gravitational Observatory under the umbrella of the EGO consortium.

Prototype Interferometer, Laboratory Research, and Advanced Techniques
The Garching prototype interferometer concluded its last year of operation in 2003. It was operated by the remaining small group of AEI personnel located in Garching and was used to test thermal tuning of the signal recycling resonance frequency and bandwidth. In-situ tuning and reliable locking of the signal recycled prototype interferometer was demonstrated by thermally changing the index of refraction of a solid etalon signal recycling mirror. The prototype is now dismantled and the vacuum system will be transferred to Hannover, where current work on thermal tuning is concentrating on full-sized GEO optics and the problem of achieving homogeneous heating and lateral homogeneity of the etalon transmission.

Our laser development work in collaboration with the Laser Zentrum Hannover (LZH) is aiming at the development of high-power high-stability laser systems suitable for the next generation of gravitational wave detectors. We have made further progress in understanding the noise behavior of miniature monolithic diode pumped Nd:YAG ring lasers. Using a single-mode diode as the pump source, and feeding back to the pump current, we could suppress the frequency noise by more than 30 dB, measured with an independent out-of-loop reference cavity. This resulted in a simultaneous intensity noise reduction of the non-planar ring oscillator by an equal 30 dB without any additional actuation. This clearly demonstrates the correlated origin of these two noise processes which so far was hidden by the multi-mode nature of most pumps and the non-optimal overlap of pump and active volume. In this set-up we could also show that direct pump light stabilization results in intensity noise reduction of the ring oscillator of more than 20 dB and the simultaneous frequency noise reduction of the same order of magnitude without any additional actuation. This has not being possible in conventionally pumped NPROs. On the high power front we have now been able to reliably injection lock an 80 W power oscillator to a high stability oscillator finishing electronics works and commissioning of the laser system. A traveling laser team from the AEI performed noise characterization measurements at Hannover and Stanford to prepare the laser down-select in the LSC lasers working group, selecting the Hannover design as the conceptual base line design. We have made major progress on the power noise suppression and are reliably achieving a relative intensity noise of the 12 W GEO-type laser of better than $10^{-8}/\sqrt{\mathrm{Hz}}$ between 30 Hz and 10 kHz as measured in an independent out-of-loop detector.

Thermal noise is expected to be a serious obstacle for the sensitivity of future generations of gravitational wave detectors. The thermal noise on and near the mechanical mirror resonances has already been observed, but the off-resonant thermal noise far away from the suspension and mirror resonances can still only be predicted by modeling calculation. We have measured the mechanical dissipation in our silicate-bonded monolithic suspensions and mirrors and are making predictions for the thermal noise limits to be verified on GEO600. On a small laboratory prototype we have seen the influence of various cross coupling spurious noise sources and now are optimizing it to look for high-frequency off-resonant thermal noise in dielectric mirror coatings.

Our interferometer modeling effort now also includes the E2E modal model used by LIGO, which now simulates the complete GEO600 power recycled Michelson. Our software environment Finesse is now being expanded to include the optical spring effect in high-power signal-recycled interferometers like GEO600, which is responsible for non-classical behavior of the interferometer sensitivity. In independent quantum mechanical calculations we have verified that the existing GEO600 detector in detuned signal recycling mode could have a sensitivity within a limited band that is considerably better than the standard quantum limit. Lately, we have included the beam splitter in the coupling equations to evaluate the input /output relation of a dual recycled laser interferometer like GEO600. This leads to a bright port-dark port coupling, responsible for a bright port contribution to the noise density of the output field, making technical laser noise more important than expected before.

New optical media with very steep negative or positive dispersion can be realized through coherently prepared superpositions of quantum states in atomic systems. Such systems have potential applications in future gravitational wave detectors through applications such as white light cavities and coherently-narrowed cavity resonances. We have studied the probe and the coupling laser absorption spectrum of a degenerate two level atomic system in a closed transition, which can exhibit narrow features at the line centre, where the probe and coupling field have the same frequency. For the closed 4→5 hyperfine transition in the Cs D-line we could demonstrate experimentally that the probe beam shows electromagnetically induced absorption and the coupling beam transparency at resonance with the double dispersive structure for the probe laser including an extremely steep negative dispersion at resonance. We also found a double structure with inverted narrow feature for the parametric dispersion of the coupling laser. For the 3→2 hyperfine transition in the same line, we found induced transmission for both pump and coupling laser consistent with our calculations.

New interferometer topologies including multiple arm cavities, ring cavites and reflective and diffractive optics are being investigated both theoretically and experimentally. Locking and control techniques for three-mirror cavities by using multiple subcarriers were theoretically modeled and demonstrated in a table-top setup. The work is now being expanded to include four-mirror arm cavities and their tuning and noise behavior. All-reflective interferometer designs using diffractive beam splitters and cavity couplers are being investigated. Grating designs compatible with low-loss dielectric coatings are being designed in collaboration with the University of Jena and first test gratings to be used as Fabry-Perot couplers were obtained from Jena at the end of 2003.

We are developing fundamental concepts for the third generation of laser interferometric gravitational wave detectors. By using non-classical light and QND techniques we are aiming to reduce the quantum noise in interferometric measurements and to bring the sensitivity of gravitational wave detectors beyond the standard quantum limit. We have created squeezed light in OPA (Optical Parametric Amplifier) based sources and will apply this light in table-top interferometers. In 2003 we have made considerable experimental progress in generating the squeezed light. We are now able to generate squeezing down to sideband frequencies only 80 kHz away from the carrier. We have shown theoretically that optical spring signal recycled gravitational wave detectors benefit from squeezed light over the full bandwidth by the squeezing factor achieved externally. We have theoretically analyzed the behavior of squeezing enhanced high frequency detectors and proposed a suitable filter cavity design to generate the appropriate frequency dependence of the squeezing angle.

LISA and LISA Pathfinder (formerly SMART-2): Laser Interferometers in Space

LISA is a collaborative ESA/NASA project for a gravitational wave detector in space with 5 million kilometers armlength, comprising three space craft at the corners of an equilateral triangle. A joint international LISA science team (LIST) has been appointed by ESA and NASA with 10 members from each side of the Atlantic. We have been involved in LISA from the very beginning and three of the ten European members of the LIST are from the Albert Einstein Institute. During 2003 we have concentrated on redefining the baseline concept for interferometric measurement in the LISA constellation and have revisited the optical bench design. In particular the question of laser stabilization by locking to the average LISA arm length using unity gain above the inverse delay time has been discussed and we have performed an experimental demonstration using an electrical delay line model.

Most of our experimental work during 2003 was focused on LISA Pathfinder (SMART-2) the technology precursor mission for LISA to be launched in 2007 by ESA. Experimental work on the hardware has now started after the approval of the mission by ESA in 2003 and we are Co-PIs of the technology payload LISA Technology Package (LTP). We have designed and prototyped the key elements of the LISA pathfinder interferometric measurement system, in particular the heterodyne interferometer, the photodiode electronics AD converter, the phasemeter, differential wave front sensing, software for laser power and frequency control, AOM drivers with frequency generation. We have reached (in collaboration with Glasgow) noise curves for the LISA Pathfinder interferometers below the specifications necessary for the mission. The flight model of the LISA pathfinder interferometer including laser modulation and phasemeter will largely be built based on our prototypes and results. A complete engineering model of the optical bench and interferometry is currently going through environmental and performance testing and we are preparing to place a contract with German industry for the Industrial Architect Function for the final implementation of the LISA Technology Package on LISA Pathfinder.

Karsten Danzmann

Surfaces of Minimal Curvature

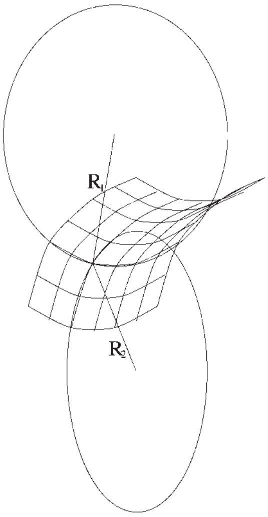


Fig. 1:
A point on a surface with two approximating circles.

The Willmore Functional

Hamilton's principle describes those trajectories, which obey the dynamical law of classical mechanics, as the minimizers of an action associated to all possible trajectories. The calculus of variations provides tools for the search and investigation of the minimizers of such actions defined on trajectories ore more general geometrical objects. The Willmore functional is an example of an action defined on closed surfaces embedded into the three dimensional space. It measures the total curvature in the following way: At all of its points the surface may be approximated up to second order by two circles. The inverse of the radii of these circles are called principal curvatures. The mean of these principal curvatures is called mean curvature. It is a function on the surface, whose dimension is the inverse of a length. Now the Willmore functional is the integral over the surface of the square of the mean curvature. Since the dimension of the square of the mean curvature is the inverse of area, it cancels with the dimension of the integral over the surface. Therefore this Willmore functional is dimensionless and does not depend on the size of the surface. Furthermore, this functional is invariant under all conformal transformations of the ambient space including rotations and translations.

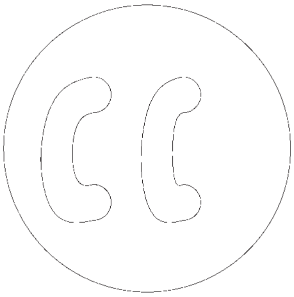


Fig. 2:
A sphere with two attached handles.

The Topological Types of Closed Surfaces

All functionals, which are integrals over squares of principal curvatures, have this feature. But due to a Theorem of Gauß, the integral over the product of the principal curvatures over a closed surface is a multiple of 4π. It describes the topological type of the surface. From the topological point of view, two surfaces coincide, if they can be mapped continuously onto each other. Almost hundred years ago Dehn and Heegard showed that each closed orientable surface is topologically isomorphic to a sphere with finitely many attached handles. The number of handles is called genus g and completely determines the topological type.

The Theorem of Gauß mentioned above states, that the integral over the product of the two principal curvatures over a closed surface is equal to $(1\text{-}g)4\pi$. From the variational point of view the latter functional is of minor interest.

Physical Applications of the Willmore Functional

Summing up, the Willmore functional is the natural measure of the total curvature of a surface. It appears in Physics as a bending energy of biomembranes and in the pseudolocal mass of Hawkins, which measures the total gravitational mass included in a closed surface sitting inside a 3-dimensional slice. In the neighbouring Max-Planck-Institute of Colloids and Interfaces biomembranes of genus two were investigated, which are good candidates for the minimum of the total curvature. The latter concept of pseudolocal mass links the geometry of surfaces with the theory of general relativity.

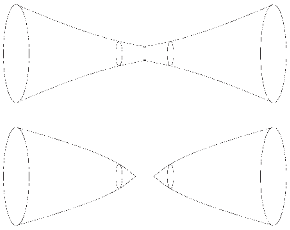


Fig. 3:
Neckpinching of a surface.

On the Existence of a Minimizer

Since the deformations of a closed surface preserves the genus, it is natural to look for the minimizer of the Willmore functional on surfaces of fixed genus. A soap bubble is a physical example of such a minimizer. Indeed, the round sphere is the unique minimizer of surfaces of genus zero. It is even the minimizer of all closed surfaces. For higher genus the investigation of the corresponding minimizers becomes more involved. Even the existence of such minimizers is not clear. L. Simon proved the existence of a minimizer for surfaces of genus one. Kuwert and Schätzle extended the proof to arbitrary genus.

One of the major difficulties is the possible existence of a sequence of surfaces of fixed genus, with smaller and smaller necks and decreasing total curvature. In the limit the neck pinches off. This could mean that all surfaces, whose total curvature is equal to the infimum of the total curvatures of the surfaces of fixed genus, have lower genus.

Fixing the Conformal Class

A map of surfaces is called conformal, if the angles between arbitrary lines on the surface is preserved. The conformal classes are the corresponding equivalence classes identifying those surfaces, which can be mapped conformally onto each other. There exists some kind of classification of all conformal classes. The surfaces of genus zero have only one conformal class. The surfaces of genus one have a 2-dimensional manifold of conformal classes. Finally, the surfaces of genus g ($g > 1$) have a (6g-6)-dimensional manifold of conformal classes. Instead of the surfaces we investigate the conformal mappings from a given surfaces into the 3-dimensional space. In this manner we obtain all surfaces of a fixed conformal class. Consequently, the genus is preserved under limits, since only spheres can pinch off. One might expect, that the proof of the existence of a minimizer becomes easier. Indeed, with the help of the so called Weierstrass representation of conformal mappings we were able to prove that the space of all conformal mappings with bounded total curvature is compact.

Martin Schmidt

Relativistic Kinetic Theory

Vlasov Matter

Particles are different objects depending upon the physical situation. For instance, the particles are atoms and molecules in a neutral gas or electrons and ions in a plasma. In stellar dynamics the particles are stars and in cosmology they are galaxies or even clusters of galaxies.

Mathematical models of particle systems are often described by kinetic. The purpose of kinetic theory is to model the time evolution of a collection of particles. A characteristic feature of kinetic theory is that its models are statistical and the particle systems are described by distribution functions, which at any time represent the probability to find a particle in a given position, with a given momentum. A distribution function contains a wealth of information and macroscopic quantities are easily calculated from this function.

The time evolution of the system is determined by the interactions between the particles which rely on the physical situation. We can divide them into two categories: collisional particles and collisionless particles.

In the first case, the driving mechanism for the time evolution, for instance in a neutral gas, is the collision between particles and this physical situation is modeled by Boltzmann equations. In the second case, which is the topic in this review, collisions between particles are sufficiently rare to be neglected. This situation is modeled by Vlasov equations. For this reason, matter considered in this physical situation is said to be collisionless matter or Vlasov matter. For a plasma the interaction between particles is through the electric charges and in the stellar and cosmological cases the interaction is gravitational. Naturally combinations of interaction processes are also considered but in many situations one of them is strongly dominating and the weaker processes are neglected.

Vlasov-Poisson and Vlasov-Maxwell Systems

One fundamental system which describes collisionless particles is the Vlasov-Poisson system. This models particles both in plasma physics case and stellar dynamics depending upon the sign of the mean Newtonian potential generated by the particles collectively. The applications of this system are restricted to the situations where the relativistic effects are negligible, i.e., low velocities and weak fields. Otherwise in general the dynamics has to be described by the relativistic Vlasov-Maxwell system in plasma physics and by the Einstein-Vlasov system in stellar dynamics.

The two Vlasov-Poisson models are very similar to each other and no substantial difference arises in the question of global existence of classical solutions, which is by now well-understood. As opposed to this, the relativistic models have very different structure and so far they have been considered separately. In the gravitational case, global existence of (asymptotically flat) solutions for the Einstein-Vlasov system is known only for small data with spherical symmetry. For the relativistic Vlasov-Maxwell system, global existence results are available under different smallness assumptions (small data, almost neutral data and nearly spherically symmetric data). One of these results has been proved by S. Calogero and states that for small data the relativistic Vlasov-Maxwell system has global solutions with no incoming radiation (math-ph/0211013). Moreover these solutions are shown to emit outgoing radiation at a rate which is similar to the Bondi mass loss formula in General Relativity.

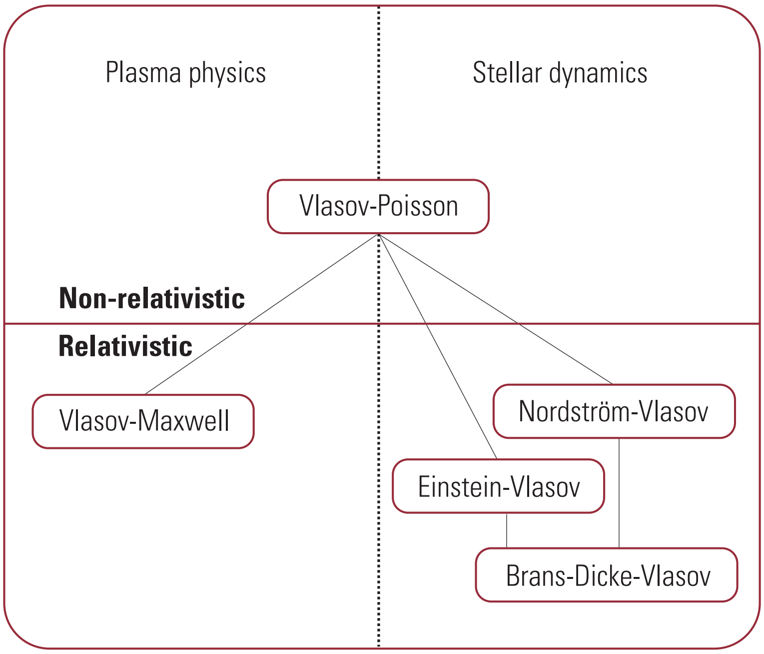


Fig. 1:
Relations between various Vlasov systems in different physical situations.

Another aspect of the problem which is of interest is the behaviour of the solutions of the relativistic models when the speed of light goes to infinity. In this case it is important to show that these limits are solutions of Vlasov-Poisson systems. This has been proved both in the gravitational and plasma physics case. Especially, the case of two space dimensions of the relativistic Vlasov-Maxwell system has been proved by H. Lee.

The Einstein-Vlasov System

In a particle system, each particle is driven by self-induced fields which are generated by all particles together. In gravitational physics, the fields are described by the Einstein equations. That is, the Vlasov equation is coupled to the Einstein equations by using the energy-momentum tensor. One application of the Vlasov equation to this self-gravitating system is cosmology. The simplified cosmological models are those which are spatially homogeneous. Spatially homogeneous spacetimes can be classified into two types: Bianchi models and other models called Kantowski-Sachs models. They can be distinguished by certain symmetric groups and are well known in the literature.

In the absence of a cosmological constant, it is known that solutions of Bianchi type IX and Kantowski-Sachs models cannot expand forever, while the other Bianchi types force the volume to be monotone. As a matter of fact, if the Bianchi type is IX or the model is Kantowski-Sachs, then it has curvature singularities after finite proper time both in the past and in the future directions. All other Bianchi types which are expanding at some time have a curvature singularity at a finite time in the past and all these are future geodesically complete. The detailed picture of the asymptotics of the spatially homogeneous cosmological models without a cosmological constant has not yet been achieved in general.

When a positive cosmological constant is present, Bianchi IX and Kantowski-Sachs models have complicated features. They have both expanding and recollapsing phases. It has been shown that there are chaotic behaviours between expanding and recollapsing phases. Consider the dynamics of expanding cosmological models in the presence of a positive cosmological constant. At late times Bianchi models (except IX) with a cosmological constant must expand exponentially. This kind of exponential expansion is called inflation. The inflationary models of the universe involve a very rapid expansion close to the big bang. Also the fact that the expansion of our universe seems to be accelerating follows from observations of supernovae of type Ia. This expanding cosmological model in the presence of a cosmological constant has been studied by H. Lee; The global existence of solutions for the Einstein-Vlasov system and the causal geodesic completeness of the spacetime towards the future have been proved and also the asymptotic behaviour of solutions at late times in various aspects are investigated (gr-qc/0308035).

The Nordström-Vlasov System

A different relativistic generalization to the Vlasov-Poisson system in the stellar dynamics case has been considered recently by S. Calogero in his PhD thesis at the Albert Einstein Institute. In this model the Vlasov dynamics is coupled to a relativistic scalar theory of gravity which goes back, essentially, to Nordström. More precisely, the gravitational theory corresponds to a reformulation of Nordström’s theory due to Einstein and Fokker. For these reasons, the resulting system has been called Nordström-Vlasov system. Although this model has no direct physical applications, scalar fields play a major role in modern theories of classical and quantum gravity. For example, the Brans-Dicke gravitational theory, which is continuously tested against general relativity, is a combination of Einstein's and Nordström's theory. The Nordström-Vlasov system is also interesting in a pure mathematical sense. A purpose of studying this model is that one may reach a better understanding of a class of systems consisting of hyperbolic and transport equations.

In a series of papers by S. Calogero, H. Lee and coauthors, a theory of classical and weak solutions to the Nordström-Vlasov system has been established. Particularly interesting are the proofs of global existence and uniqueness in two dimensions by H. Lee (math-ph/0312014) and in three dimensions in spherical symmetry by S. Calogero, H. Andréasson

and G. Rein. In fact both these solutions describe models that contain matter and gravitational waves at the same time.

Furthermore, in order to justify this model as a genuine relativistic generalization of the (gravitational) Vlasov-Poisson system, it is necessary to indicate the relation between the solutions of the two systems. We have proved that in the non-relativistic limit, i.e. as the speed of light goes to infinity, the solutions of the Nordström-Vlasov system converge to solutions of Vlasov-Poisson system in a pointwise sense (math-ph/0309030).

Simone Calogero & Hayoung Lee

The Gravitational Wave Group

The astrophysical relativity division has a group of about 10 members who do research on gravitational waves (GWs); we work on the theory of wave generation, develop codes to analyse data from GW experiments, and help analyse the data. We share with the University of Cardiff the primary responsibility for analysing GW data from the GEO600 detector, and we play important roles within the LIGO Scientific Collaboration (LSC), analysing GW data from the U.S. LIGO detectors. We also enjoy close ties to the LISA mission, a joint ESA/NASA project to fly a laser interferometer GW detector in space; launch is currently planned for 2013.

First Science Data from GEO and LIGO

The year 2003 was a very exciting one for gravitational-wave detection. The data analyses of the first science run (S1) of LIGO and GEO600 were completed. (The S1 run lasted just over two weeks, between August and September 2002, during which all the LIGO detectors and the GEO detector were operating in coincidence). The LIGO detectors also had their second and third science runs, S2 and S3, and GEO600 operated in coincidence with LIGO for the last part of the S3.

Thanks to a complete data sharing agreement between GEO600 and LIGO, the data analysis is performed jointly by teams of scientists across the two projects. Different search techniques are employed for different astrophysical sources. Four teams have been set up to coordinate searches for the four general types of sources: coalescing compact binaries; continuous gravitational waves from rapidly rotating neutron stars (NSs); short bursts (lasting of order milliseconds) of GWs from, e.g., supernovae or hypernovae; and a stochastic GW background generated in the very early universe. Each of the four groups has two chairpersons, an experimentalist and a theorist, who coordinate the activities of the group and are ultimately responsible for delivering correct, high-quality scientific papers.

Being part of a large collaboration comes with a price: with more than 360 authors and thirty institutions scattered all over the world, in order to function, the LSC has to be a very structured organization. Collaboration meetings are held regularly three times a year and the working groups have weekly conference calls and usually meet face-to-face in between the general collaboration meetings. The astrophysical search software has to be developed in an agreed upon environment, must comply to precise coding specifications and at any time must be visible to the entire collaboration. Specific data formats have been put in place for the input data, the intermediate analysis products and the output of the searches. The group's scientific programmer, Bernd Machenschalk, is responsible for maintaining the group's web pages, keeping the various collaboration software installations up to date and converting the prototype software developed by the scientists to the required format once it has been tested. Keeping all the necessary infrastructure up to date and participating in the decisions to define new standards and revisit obsolete ones, requires a substantial investment of resources, both in terms of manpower and time.

Since the detectors have not yet reached their design sensitivities (though they are rapidly approaching these goals), no actual detections were expected from the data analyzed so far. However, upper limits - often considerably stronger ones than previously possible - were placed on source strengths and rates. Also, the exercise of analyzing the early science data provided an extremely useful "stress test" of the data analysis pipelines.

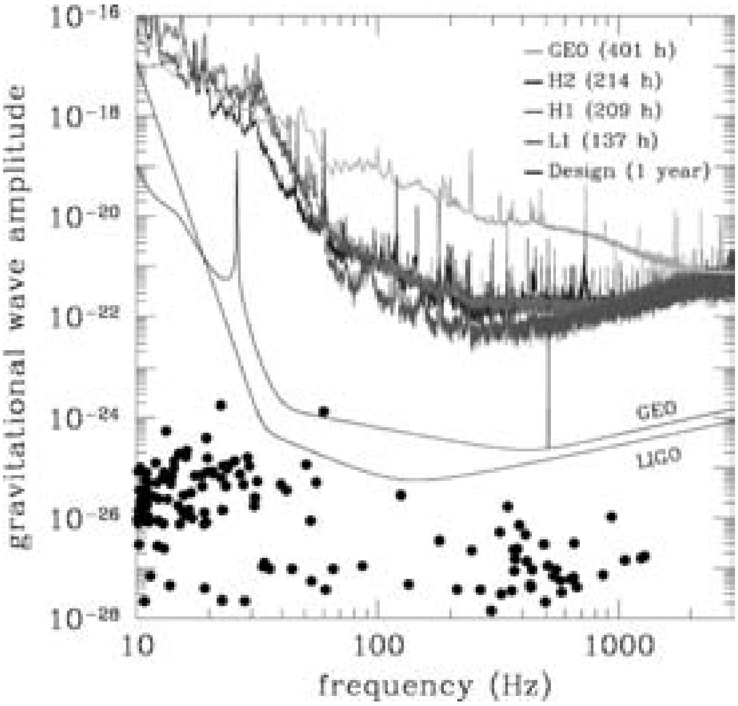


Fig. 1:
The upper curves in this diagram show the sensitivity of the LIGO and GEO detectors to continuous GWs from rapidly rotating neutron stars, during the S1 run. The GW amplitude (vertical axis) is shown as a function of the GW frequency (horizontal axis); a point on any of the curves tells you what GW amplitude a source emitting at that frequency would need to have, to be detectable by the given detector during the S1 run. The two lower curves represent the design sensitivities of LIGO and GEO, for 1-year observing runs. The black dots represent upper limits on the strengths of all known, isolated, rapidly rotating neutron stars, based on their measured spin-down rates. The arrow points to J1939+2134, the fastest known pulsar. The S1 run placed an upper limit on the GW amplitude of this pulsar at about 10^{-22}.

The Search for Continuous GWs from Rotating Neutron Stars

Prof. Papa (permanent staff member at AEI) is the data analysis chairperson of the LSC continuous wave signals group; the AEI plays a central role in these analyses, leading the efforts of the continuous waves group, which produced the first of the upper limit papers. This paper placed an upper limit on the amplitude of gravitational waves from the fastest known pulsar, J1939+2134, of about 10^{-22}. (There were about four hundred authors on this paper, which was accepted for publication in Physical Review D at the end of 2003.) In the continuous waves group, two different analysis approaches are being used. To search for GWs from previously known NSs, the University of Glasgow has developed a time-domain technique employing Bayesian statistics. The AEI has developed a complementary, frequency-domain technique, first suggested by Prof Schutz and collaborators, that uses frequentist statistics. The AEI's code can be used both to search for GWs from known NSs and to conduct an all-sky search for GWs from unknown NSs.

LIGO's S2 run started Feb 14th, 2003, and lasted for two months. The analysis of this data is underway and is broader in scope than for the

S1: upper limits will be set on the strength of GWs from all known isolated pulsars; there will be a wide-frequency, all-sky search for GWs from previously unknown NSs; and there will be a targeted search for a GW signal from the binary system SCO-X1. In the S2 analyses, a new technique (new, that is, to the GW community) is being used to cover long observation times, large portions of the sky and spin-down parameter ranges: the Hough transform. The Hough transform is widely used in pattern recognition in digital image processing. At the AEI we have adapted this method to search for tracks of possible continuous wave signals in the time-frequency plane composed of successive FFT-ed data segments. The effort to develop the software for this search is led by Prof Sintes (former AEI post doc, now faculty member at the University of the Balearic Islands and visitor at AEI every year for about six months) in collaboration with AEI post doc Badri Krishnan and M.A. Papa, and has been ongoing since 2000. It is very exciting to finally be using this technique on real data.

The analysis of a larger data set, while also searching for a much wider class of sources, has brought new challenges. Dr Reinhard Prix at AEI, together with Prof Ben Owen and Dr Ian Jones (both now at Penn State University), is working hard on optimal placement of search templates on parameter space in order to control the computational cost of the searches. Recognition of instrumental noise artefacts has become important in order to identify and eliminate large noise outliers; to this end Dr Yousuke Itoh has designed and implemented tests aimed at distinguishing the shape of a signal outlier from a large noise disturbance. Also the pipelines have become more complex; they involve a hierarchy of stages that use candidates obtained from the analysis of one detector's data as triggers for follow-up searches with data from other detectors.

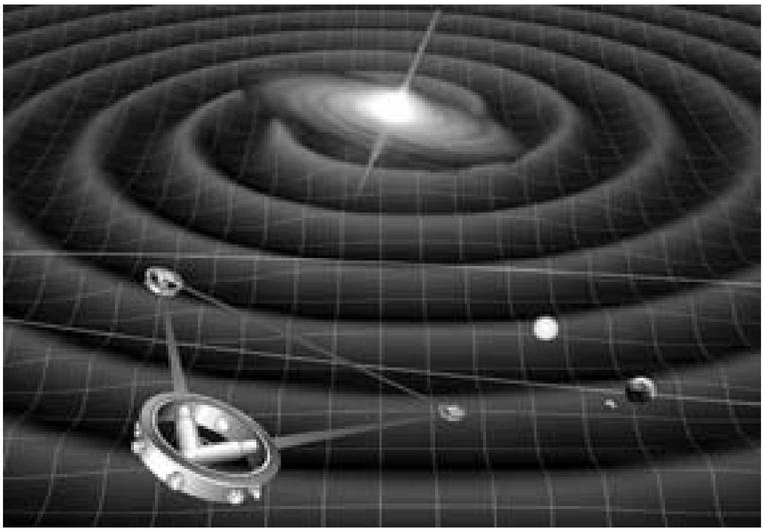
The MERLIN Computer Cluster

Our MERLIN cluster is crucial to our data analysis work. We had 146 dual-CPU nodes delivered at the end of 2002, and 32 more were added in 2003, so that MERLIN is now a 356-CPU computing facility. Its overall design, and indeed every component, were specified by AEI scientists after extensive benchmarking and testing of commodity parts. This allowed us to achieve a formidable price to computing power ratio. The cluster is completely managed by AEI staff and has a dedicated system administrator, Dr Steffen Grunewald, who also supports all the group's specific IT needs and is responsible for GEO600 data management and storage. In fact MERLIN provides not only computing power, but also constitutes the main European storage facility for fast retrieval of GEO600 and LIGO data. Several tens of TB of data are redundantly distributed across the nodes of the cluster, ensuring fast access during the analysis and a robust and cheap archival system. (More generally, the AEI manages the transfer of GEO data from Hannover, where the data files are produced, to the large tape facility at ZIB, where the data are permanently archived.)

Research on LISA Sources

Both Prof Schutz and Prof Cutler (another permanent staff member in the Astrophysical Relativity Division) are members of the LISA International Science Team (LIST). In 2003, theoreticians in the LIST generally concentrated their efforts on one fascinating but problematic LISA source: captures of stellar-mass compact objects (COs) by supermassive black holes (SMBHs) at the centers of galaxies. The COs spend their last few years, prior to plunge, on highly relativistic orbits extremely close to the SMBH event horizon; the GWs they emit will encode all the details of these extremely relativistic orbits (which, for example, exhibit perihelion precession of order one radian per orbit).

However, at any instant, the GW amplitude of even the strongest source is expected to lie roughly an order of magnitude below the detector noise, so something akin to matched filtering will be required to dig the waveforms out of the LISA noise. Matched filtering requires us to construct theoretical template waveforms that are accurate in phase to within about 1 radian - for a 13-parameter space of waveforms, each of order years long and containing about 100,000 GW cycles! The number of templates needed to adequately cover parameter space is so vast that a straightforward implementation of matched filtering - using year-long templates as filters - is completely impractical. Instead some (presumably) hierarchical scheme must be found.



The Laser Interferometer Space Antenna LISA is expected to take off in 2013.

Cutler and Leor Barack (an AEI postdoc until May, 2003) have sketched such a scheme; it begins by coherently searching short stretches of data (about three weeks long) to look for promising "candidates." Each three-week stretch will generate a list of possible (parameters of) capture waveforms. In each such list, almost all entries will be noise events - spurious "signals" due result of random fluctuations of the noise - but the true GW signals will be recognizable since they will appear with the same parameter values in each three-week segment. A key step in gauging the efficacy of the scheme is computing how many distinct three-week data stretches there are (i.e., how many templates are needed to cover a three-week stretch of data). This involves calculating a natural volume element on the space of waveforms, and then integrating it over the parameter space. Barack and Cutler have developed a computer code to do this, using approximate, analytic versions of the capture waveforms. Several papers on this topic are planned (some in collaboration with members of Kip Thorne's group at Caltech, with whom Cutler and Barack hold regular teleconferences); the first was submitted for publication in 2003.

Cutler and Barack were also among the co-authors on an extensive report to the LIST in Dec. 2003, that estimated LISA's detection rate for such capture sources, including the effective loss in sensitivity imposed by limited computer power. For realistic computing power, the above hierarchical search method was estimated to be a factor 3 times less sensitive than the optimal search method one could use with infinite computing power. This loss is much less severe than had been feared. Even with this effective loss in sensitivity, it was estimated that LISA should detect hundreds of capture sources per year.

Maria Alessandra Papa and Curt Cutler

Highlights from the Numerical Relativity Group

The last year has been a time of great progress and great change in the numerical relativity group, both in terms of the science and technologies we have introduced, but also in the look of the group.

Science

Simulation work has concentrated on the final orbit of binary black hole initial data. The accuracy of our simulations has improved markedly over the last year, allowing us to establish that members of a particular family ("puncture data") of binary Black Holes (BHs) constructed to be in stable quasi-circular orbits, actually coalesce in times on the order of half an orbital cycle. Evolutions of a new binary black hole initial data family, provided by the Meudon group through the EU Astrophysics Network collaboration (see below), show indications of orbital behaviour closer to what is expected in physically realistic inspirals. This family of data sets will be pushed forward in the coming year.

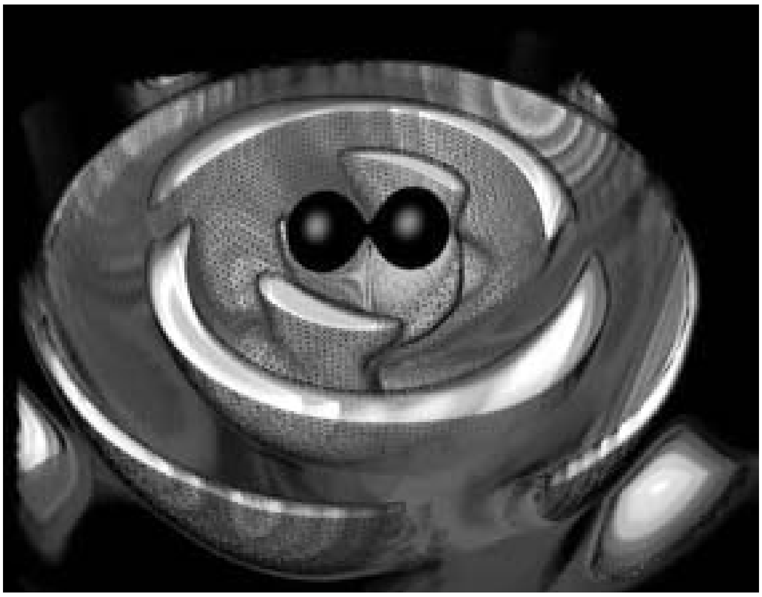


Fig. 1:
Gravitational waves emitted during the merger of a pair of equal mass black holes, simulated on the numerical relativity group's PEYOTE cluster. The merger of black hole systems is expected to be one of the prime candidates for early detection by the GEO600 detector.

Our ability to extract physical information from these simulations has been greatly improved through the implementation of two new tools: a fast apparent horizon finder, and an event horizon finder. The new apparent horizon finder is able to determine the location of outermost trapped surfaces within a couple of seconds processor time, a vast improvement on previous technologies, and allows us to find horizons at each timestep, leading to much finer grained analysis and control of simulations. It has also been augmented to computer quantities arising from the isolated horizon formalism of Ashtekar and Krishnan, which will provide alternate measures of physically relevant quantities such as angular momenta. The new event horizon finder acts as a post-processor, and is able to determine the causal structure of the spacetime to high accuracy. This year marks the first time the event horizons of truly 3D black hole inspirals could be examined, and opens a promising avenue for future research.

These analysis tools have also found use in the other main body of simulation work within our group: simulations of neutron star collapse to a black hole. Here the Whisky code, another product of our EU network collaboration, has been used to follow the collapse of rotating neutron stars. Once an apparent horizon is detected, signalling the formation of a black hole, the central singularity is removed using newly developed hydro excision techniques, and the evolution can be followed to determine the final state.

The various independent measures of horizon dynamics which we have available allow for strong cross-checking and verification of the physical accuracy of these models. All of these numerical simulations require large amounts of computer power, due to the high resolutions required in the central region, while at the same time requiring that artificial boundary conditions be placed in the wave zone. This year has seen the introduction of one of the most promising techniques for getting around this problem in numerical codes, "mesh refinement". This allows for additional grids to be placed at various locations within the simulation domain. The grids are of higher resolution than the underlying grid, allowing fields to be represented with much greater accuracy in regions where there are large gradients, such as near the centres of black holes or collapsing neutron stars. For example, using eight nested grids of successively doubled resolutions, could allow for outer grid boundaries at 100M with a central resolution of 0.01M, to be run on only 32 nodes of a cluster computer. With a uniform grid, the largest supercomputers which we run on would only allow for a tenth the resolution and be impossibly expensive to run. As such, mesh refinement promises to provide a huge advance in the accuracy and efficiency of the physics runs which we are able to perform. Mesh refinement was introduced as a driver layer called "Carpet" for the Cactus infrastructure around which all of our physics codes are based. This has allowed us to use all of our evolution codes with mesh refinement, almost without modification. Further, analysis tools such as horizon finders and wave extraction were quite simple to transform to the new underlying grid structure.

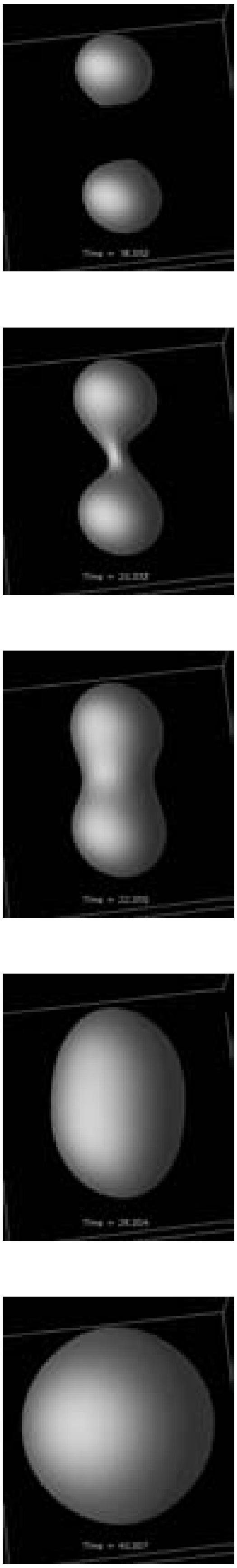


Fig. 2:
Event horizons represent the surface within which no light can ever escape from a black hole. This sequence of images shows the evolution of the event horizons as a pair of black holes merge.

Collaborations

The numerical relativity group is highly collaborative, and works with many other groups in Germany and around the world. It supports a large user community outside the AEI with its Cactus Einstein Toolkit and makes most relativity modules available to external groups. It is very involved in computational and Grid projects in Germany and worldwide, as described in the computation section. Its most important external scientific collaborations are sketched here.

This year marked the end of the 3-year European Network on Sources of Gravitational Waves, led by the AEI. In September, the network hosted a summer school for gravitational wave research, where AEI members were active in presenting a number of well-received lectures and tutorials. A proposal for a new European Network project called GWEN, again led at the AEI by Ed Seidel, is currently under review. If successful, GWEN, or the Gravitational Wave European Network, will expand the network to 20 sites including three US partners.

Within Germany, the DFG funded SFB-Transregio Gravitational Wave Astronomy has provided an opportunity for collaborative work with a number of German institutions and sponsored a number of events. In particular, the numerical relativity group hosted a workshop on spectral methods in October, attended by researchers from around Germany and the US (see also the article by P. Aufmuth in this volume).

In December of 2003, the 2nd Workshop on Formulations of Einstein's Equations was held in Mexico City, sponsored by a DFG-CONACYT grant. This workshop was a meeting point for a larger collaboration among a number of research groups, aimed towards establishing standardised tests for numerical relativity codes (see p. 73).

An important and very close link has been developed over this year with the newly founded Center for Computation and Technology (CCT) at Louisiana State University. Ed Seidel has taken up the CCT directorship and a professorship in the Department of Physics and Astronomy at LSU. But he keeps a (partial) C3 appointment at AEI, and remains actively involved, helping to advise students and postdocs, and maintains responsibilities in leading external projects (EU Network, GriKSL, GridLab, GWEN).

Gabrielle Allen (also jointly appointed; see computation section), Peter Diener, Francisco Guzman, and a number of students and computer scientists have also joined LSU. The physics effort will be carried out through a very close collaboration between AEI and LSU, which is strengthened now by joining forces with the existing Lehner/Pullin relativity group at LSU. The CCT will further be able to provide important additional resources for support of the Cactus framework and other computational projects. The result of this new alliance will be to produce a broader research group, spanning both institutions and building on the strengths of each. Frequent visits back and forth have already occurred, and with emerging teleconferencing technologies supported by the AEI's computational science group, we look forward to continuing work on joint projects and forging new ones together.

Denis Pollney

Computer Science and Numerical Relativity

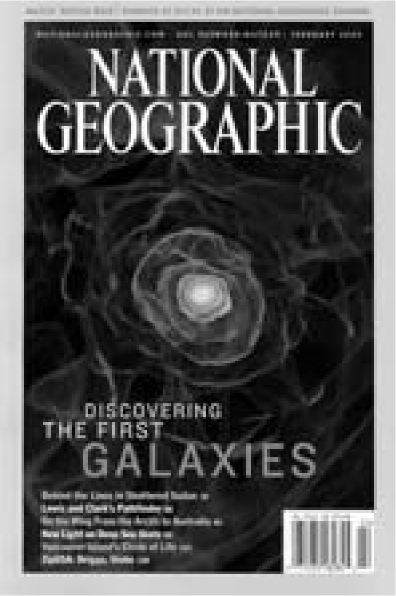
The Numerical Relativity group includes a strong computer science component, which supports the work and computational direction of the physicists, and uses their scientific applications to drive research projects in programming environments, visualization, and Grid computing.

The open source Cactus Framework, developed at the AEI, remains at the core of the computational research and development in the group, both as the primary tool for the physics research and as the motivating application for a number of international Grid and computer science projects.

The AEI is a key partner of the European 5th Framework GridLab project, which is developing practical technologies for applications to exploit computational Grids. The AEI leads the development of the Grid Application Toolkit (GAT), the central component of the GridLab project, which provides application developers with a useable interface for leveraging many different Grid services. The programming API developed for the Grid Application Toolkit has led to the creation of a Grid Application Programming Interface working group at the Global Grid Forum. The AEI also leads the development and implementation of new Grid scenarios for numerical relativity and other Cactus applications. A set of Cactus GAT thorns have been developed which closely integrate the GAT in Cactus, these will be further developed to provide Grid functionality transparently to any Cactus application.

Through GridLab, the AEI has developed GridSphere, a Grid portal development framework. GridSphere is based on the emerging ”portlet model” from the Web portal community, and provides portlets which interact with GridLab and other services such as job submission, resource brokering, information finding and data transport. GridSphere 1.0 was released in September 2003, and has since been adopted by a number of Grid and application projects around the world. To support the work of the numerical relativists, a “Cactus Portal” is being developed with GridSphere, based on the ongoing NSF Astrophysics Simulation Collaboratory project of which AEI is a member.

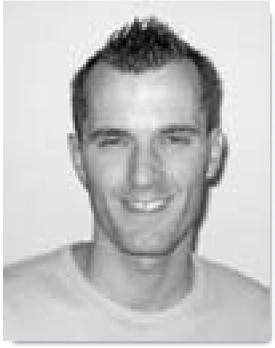
The Cactus Portal will be tailored to supporting large scale numerical relativity simulations on the groups major computational resources, providing features such as customized job submission, tracking and notification.



Through the German GriKSL project, led by Edward Seidel, two joint positions in scientific visualization, and through GridLab, the AEI continues its close collaboration with the Konrad-Zuse Institute (ZIB). The scientific visualization work has been critical for the numerical group to visualize its large, complex data sets. Techniques have been developed, for example, to visualize data generated using the Carpet mesh refinement driver in Cactus. Work of the GriKSL project has extended provided new capabilities to remotely visualize partial records and downsampled versions of large data files, say at NCSA in the US, without having to transfer the files themselves, which is prohibitive. Work of this group has also been used in many magazine and newspaper articles worldwide, and on television programs. For example, the Feb 2003 cover of National Geographic had an image generated by Ralf Kähler (ZIB/AEI) in our group.

At Supercomputing 2003, in Phoenix, Grid-enabled Cactus simulations were demonstrated migrating across the GridLab testbed. A black hole simulation, started via the GridSphere portal using the GridLab resource broker, was interactively checkpointed and then moved and restarted on a new resource. As the GridLab technologies mature in 2004 we expect that such capabilities will be used by the physicists to make more efficient use of our distributed supercomputing resources, implementing scenarios such as job migration, task farming and spawning.

As described in the Numerical Relativity article, several members of the computer science group, Gabrielle Allen, Tom Goodale and Ian Kelley have accompanied Seidel to take up positions in the new Center for Computation and Technology at Louisiana State University. Gabrielle Allen, now an associate professor in Computer Science at LSU, retains a part time position at AEI, and is still very active in AEI and EU research projects, connecting the two institutes closely. Cactus and GridLab projects continue, joint applications for supercomputing resources in US and Germany continue, and new proposals are currently either planned or under review in both the US and Europe for framework interoperability, Cactus development, and Grid computing. This close connection will provide many new opportunities for widely disseminating AEI technologies such as Cactus, GridSphere, and the Grid Application Toolkit.



Gabrielle Allen & Michael Russell

Integrable Structures of the Gauge/String Correspondence

Gauge/String Correspondence

One of the fundamental questions of modern theoretical physics is the connection between gauge and string theories. In 1997 J. Maldacena conjectured a new surprising relation between gauge theories and strings and challenged theoretical physicists to prove it. According to the AdS/CFT duality conjecture, certain quantum supersymmetric conformal field theories have a dual formulation in terms of a closed superstring theory on the Anti-de-Sitter (AdS) background. To fully appreciate the non-triviality of this conjecture we recall that closed string theory contains gravity, and it now appears to have an alternative description in terms of a non-gravitational theory!

The fundamental example of the gauge-string duality involves four-dimensional maximally supersymmetric Yang-Mills theory and type IIB superstring propagating in the AdS_5 x S^5 space-time, which is the product of a five-dimensional Anti-de-Sitter space and a five-sphere. Although not realistic from the point of view of a particle physicist, this duality pair provides us with a nice ”theoretical laboratory”. Due to some simplifying features, we have a good chance to verify whether these apparently different theories indeed describe the same physics. Hopefully we will gain deeper understanding of the nature of the gravity force. Last but not least we can hope to shed some light on a dual ”stringy” description of the gauge theory of strong interactions.

Already a first inspection shows that both theories mentioned above possess the same amount of symmetry, which can be taken as an initial evidence that they indeed might relate to each other in a non-trivial way. However, this reasoning is kinematical, and the real question is whether these theories also share the same dynamical features.

This is much harder to answer. By duality *strongly* coupled Yang-Mills theory is equivalent to *weakly* coupled string and vice versa. Because of a lack of adequate theoretical methods we neither have much insight into the strongly coupled regime of the gauge theory, nor on the structure of the spectrum of strings propagating in a curved space-time. Fortunately, due to so far unknown reasons, parts of the gauge and the string spectra, both accessible by existing mathematical tools, seem to allow for a direct comparison.

In the past two years, initially advanced by pioneering teamwork at the AEI, a remarkable picture identifying a certain region of the perturbative, i.e. accessible by the usual weak coupling expansion techniques, spectrum of the Yang-Mills theory with stringy excitations begun to emerge. It is based on the important observation that in certain regimes gauge and the string theories become integrable and therefore admit explicit solutions. The integrable structures governing the dynamics on both sides of the correspondence appear very different but nevertheless can be shown to agree in a mathematically highly intricate and non-trivial way. This provides a number of explicit high-precision tests of the duality conjecture and hopefully will explain its mechanism and its range of validity. Let us now take a bird's-eye view of the fascinating structures of gauge and string theories and discuss their relation.

Integrable Structure of Gauge Theory. Spin Chains.

The gauge theory in question is of a special type - it is invariant with respect to conformal transformations. Conformal symmetry naturally extends relativistic Poincaré invariance and reflects the idea that at certain instances matter might appear to be structureless to an observer.

In the quantum theory, however, one faces the well-known problem of infinities. To have meaningful, i.e. at least in principle measurable physical quantities, quantum theory requires renormalization of the parameters of the bare theory. Usually this well-defined mathematical procedure introduces dimensional parameters, which break the conformal invariance of the classical theory. Are there theories whose classical conformal invariance survives quantization? No realistic example of such non-trivial four-dimensional theory is known to date. The situation changes dramatically if one looks for gauge theories which are both conformally invariant and supersymmetric. Supersymmetry and conformal invariance combine into the larger group of *superconformal* transformations. A celebrated example of a quantum superconformal theory in four dimensions is the one we are concerned with here - Yang-Mills theory with the maximum number of possible supersymmetries (for a more detailed description see the special feature by Matthias Staudacher in the AEI Annual Report 2002).

The basic physical quantities of this theory are the local, gauge-invariant composite operators, i.e. the operators constructed as products of elementary fields. They transform in unitary irreducible representations of the superconformal group. Therefore, to each operator one can associate scaling (conformal) dimension. Additional labels relate to space-time and internal symmetries. In general, due to quantum fluctuations, scaling dimensions get shifted from their classical values and acquire an "anomalous" piece. It should be stressed that the existence of anomalous dimensions is one of the most important concepts of conformal field theory as the knowledge of the dimensions is equivalent to the knowledge of its spectrum. At the same time calculation of anomalous dimensions proved to be one of the hardest problems of quantum field theory. There exists an enormous literature on the calculation of scaling dimensions in gauge theories, and in particular in the QuantumChromoDynamics. Until recently little was known about the general behaviour of anomalous dimensions in super Yang-Mills theory.

A significant breakthrough was recently achieved by the AEI team who realized the privileged role of the *dilatation operator*. This operator is one of the generators of the superconformal group and its spectrum provides the scaling dimensions. Careful study of the dilatation operator revealed, quite remarkably, that it appears highly constrained by the symmetries of the theory. The AEI scientists found a very efficient way to solve these constraints and, therefore, to generate the anomalous dimensions, even at higher orders of perturbation theory!

Further wonderful insight into the structure of conformal gauge theory stems from the observation that a composite operator can be naturally interpreted as a closed (closeness is required by gauge invariance) spin chain - a one-dimensional lattice with the topology of a circle and a spin variable attached to each lattice site. In this picture every elementary field entering a composite operator is treated as a spin degree of freedom which transforms irreducibly under superconformal symmetry. The dilatation operator acting in the space of composite operators is naturally identified with the Hamiltonian of the spin chain. This would not be so surprising by itself, but it turns out that in an important limiting case (where the rank of the gauge group tends to infinity) the spin chain becomes integrable! Integrability means that there is a sufficiently large set of local mutually commuting integrals of motion (charges), which includes the Hamiltonian. In 2003 AEI scientists discovered the miraculous fact that integrability of the gauge theory persists at higher orders of perturbation theory and can be naturally described in terms of the integrable spin chains with long-range interactions.

The importance of this observation is difficult to overestimate. Indeed, the dilatation operator can be thought of as a matrix operating in the space of composite operators of the same classical dimension. Its eigenvalues are the scaling dimensions we are interested in.

For operators of sufficiently small dimensions the matrix can be diagonalized by hand or by a computer. As its rank grows this becomes rapidly unfeasible. Fortunately integrability saves the day - there are efficient methods, based on existence of local commuting charges, which allows one to determine the spectrum of the Hamiltonian (and simultaneously the one of all the commuting charges). To conclude, in the regime we consider the gauge theory is integrable and admits a marvelous description in terms of the integrable spin chains.

Let us now turn our attention to the string side of the story.

Spinning Strings and Neumann Integrability

Our string theory can be described by a non-linear two-dimensional sigma-model whose target space is a supersymmetric extension of the bosonic $AdS_5 x\ S^5$ space-time. Since the corresponding action is highly non-linear and contains fermions, the quantization problem appears to be extremely complicated; at present the full spectrum of the quantum string is beyond our reach. However certain regions of the quantum spectrum can be well approximated by semiclassical string configurations. Typically these configurations are solutions of the classical string equations of motion (supplemented by the so-called Virasoro constraint), which carry ”large” energy and spins.

Picking one such solution one can approximately determine the string spectrum by performing a semiclassical quantization around it. Thus, we are led to the problem of studying *”spinning” strings*, i.e. classical strings rotating in the background space-time with large angular momenta. It turns out that the bosonic sigma-model describing propagation of our classical string is a two-dimensional integrable model which can be thought of as a non-trivial matrix generalization of the famous sine-Gordon equation.

What are the relevant spinning string configurations? As in the flat space-time the simplest configurations are those corresponding to *rigid* strings, i.e. to strings whose shape is independent of time. These configurations carry finite energy and can be viewed as solitons of the sigma-model. A remarkable fact about these solitonic solutions discovered at the AEI in the last year is that they are naturally classified in terms of periodic solutions of the *Neumann integrable system*. This is a finite-dimensional integrable system describing a three-dimensional harmonic oscillator constrained to move on a two-sphere (or a hyperboloid in the non-compact case). Historically this model, discovered by C. Neumann in 1859, is one of the first examples of a completely integrable Hamiltonian system. It is really fascinating to see how it reappearing in the modern context of string theory on a curved background.

We remark that the Neumann system inherits its integrable structure from that of the two-dimensional sigma-model. Rigid strings appear to be of two types - folded, with the topology of a rod, and circular, with the topology of a circle.

Strings Made of Spins

As we have seen in a certain regime both gauge and string theories can be described as integrable systems. Apparently these systems appear to be very different. In the first case we deal with a *quantum* integrable spin chain, while in the second one we have an integrable *classical* sigma-model. Is their any way to compare them?

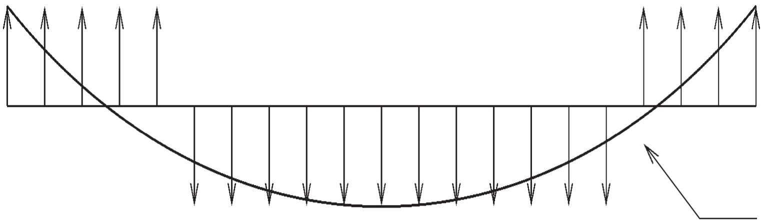


Fig.1:
A composite gauge-invariant operator viewed as a spin chain. Stringy excitations can be visualized as spin states averaged over

The space-time energy and the commuting components of the angular momentum (spins) label string configurations very similar to that the scaling dimension and the Lorentz (internal) spins label composite operators in the Yang-Mills theory. Thus, in both gauge and string theories these labels specify a unitary irreducible representation of the superconformal group and, therefore, allow for a direct comparison. Once again, to stay within the semi-classical picture, the strings must be highly rotating and energetic. On the gauge theory side this requirement amounts to taking the so-called thermodynamic limit where the effective spin chain becomes infinitely long.

Using sophisticated techniques from the theory of integrable systems AEI scientists, partially in collaboration with colleagues from Uppsala University, found a stunning agreement between gauge theory anomalous dimensions, approximated at low orders of perturbation theory, and the energies of the corresponding spinning string configurations. We furthermore demonstrated that this agreement extends to the eigenvalues of an infinite number of higher commuting charges, whose very existence render both theories integrable. Thus, we were indeed able to identify stringy excitations inside perturbative Yang-Mills theory! Every elementary field contributes a "quantum" of dimension and spin. "Long" composite operators are considered to be made of many quanta, and a wave approximation corresponds to considering excitations of the continuous string world-sheet.

We will end this review by noting that the above approach to gauge/string duality, based on the study and comparison of integrable structures, is a highly promising and rapidly developing area of research. Future results and developments might shed new light on the fundamental problem of quantum gravity.

Gleb Arutjunov

Loop Quantum Cosmology

If we follow our expanding universe backward in time, it becomes denser and denser until eventually, according to general relativity, the energy density will become infinite and the universe will run into a singularity: the classical theory breaks down at this point and can no longer tell us what the further evolution would be. Thus, classically there is no meaning to the question as to what happens before or at this point, ”before” does not even exist since there is no time. The singularity of the classical theory is not only a boundary of the classical universe but also a boundary to our understanding.

It has long been speculated that quantizing general relativity will help to push through this barrier. In fact, there are similar, though much simpler, situations in quantum mechanics. For instance, the hydrogen atom is unstable in a classical description: after a short amount of time the electron will fall into the nucleus and the atom collapses radiating away all its energy. Quantum mechanics then tells us that this does not happen; there is rather a ground state of a finite energy beyond which the atom cannot fall. Formal analogies can be used to argue that something similar should happen if we try to describe the fate of the whole universe in a quantum theory. Instead of having a diverging energy density, the universe will reach a well-defined state of finite energy and continue its evolution in the quantum regime where a classical space-time picture does not necessarily apply.

These formal expectations cannot give us precise information and we will have to use a quantum theory of gravity to find out exactly what will happen to the universe. There are two important requirements if we want to describe such extreme physical situations. First, we will have to deal with very strong fields which requires a non-perturbative quantization: a perturbation expansion, though simpler to perform, would not bring us close enough to the singularity. Secondly, the metric of space becomes singular since the whole space collapses into a single point. This means that our theory should better be background independent, i.e. the full metric should be quantized not just some part from which an artificial background has been subtracted.

Both these requirements make the development of such a theory very complicated since, for one thing, we do not know other examples of similar physical theories which could guide us. Yet, such a theory has been constructed systematically over the past 15 years or so and is known as loop quantum gravity. Within this framework loop quantum cosmology is defined, which focuses on the evolution of the universe as a whole.

The basic methods of loop quantum cosmology have been laid out in 2000, soon followed by first physical applications: For the first time it could be proven that a particular realization of quantum gravity would be non-singular in a generic way. Energy densities remain finite, and the theory does not stop but instead brings us to a branch of the universe preceding the big bang. This branch is collapsing and will eventually bounce to enter our expanding branch, but in the transition region it can only be described quantum theoretically; there simply is no classical space-time. This is the reason why the classical theory has to stop there since its very foundation ceases to be available.

There were soon further, unexpected consequences of the detailed description of the quantum theory. Inflation, which is important for our understanding of the formation of structure like galaxies in our universe, was seen to be a natural and unavoidable consequence of the quantization.

This fact opens up the exciting prospect that consequences of a quantum theory of gravity can be tested by comparing with cosmological observations, mainly of anisotropies in the cosmic microwave background, which are sensitive to the behaviour in the very early universe.

The past year has seen a substantial increase in activities related to loop quantum cosmology, with now several research groups around the world. The main work focuses on a rather peculiar behaviour of densities at small scales which is responsible for the fact that they do not become infinite. This behaviour has been extracted from the general loop quantization and is therefore characteristic for the effects which have to be expected. It modifies Einstein's classical equations in a special way which can be studied comparably easily. In particular, the modified equations predict that the very early universe expands in an accelerated manner, which gives rise to the inflationary phase mentioned before. Such a behaviour has been postulated long before, but now seen for the first time as a consequence of quantum gravity. The modifications, however, do not give us precisely what had been expected before, but imply subtle changes to the standard scenarios. This translates to differences in the process of structure formation which can be observable and may even explain some recent observations of the WMAP satellite (a so-called loss of power at large scales) that would be puzzling otherwise.

If we go closer to the classical singularity, even before the usual realm of inflation, the structure of space becomes very complicated. The classical universe does not only approach a singularity, spelling its own demise, but does so in a chaotic manner. This scenario has been studied extensively, including work at the AEI. However, the smaller the volume becomes the less trustworthy the classical theory will be, and we have to see what quantum gravity tells us about this regime. With loop quantum cosmology it is now possible to do just that. It turns out that the quantum universe not only is non-singular, but much more tranquil: Its evolution simplifies once the volume becomes very small such that the dynamics is no longer chaotic. This observation also provides an important consistency test for the theory. The classical scenario suggests a fractal initial state which has structure at arbitrarily small scales. Loop quantum gravity, on the other hand, predicts a discrete space such that there is a smallest scale for structure in the universe. From the information about the loop quantum universe one can derive when the complicated behaviour and the fragmentation of space leading to the fractal state stops. As it turns out, this happens just at the right time for the discreteness of loop quantum gravity to be consistent.

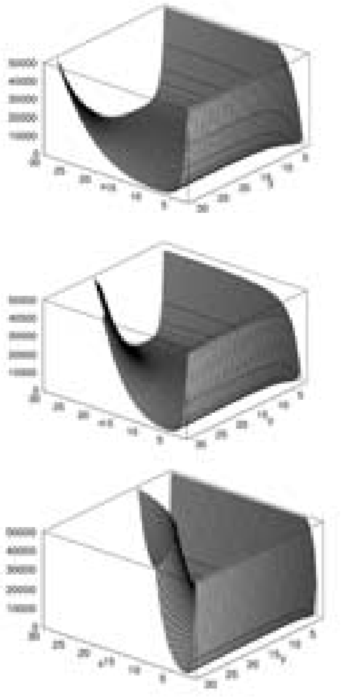


Fig. 1:
Classical potential at decreasing volume (top to bottom): The walls remain of infinite height and just move closer to the classical singularity (right corner).

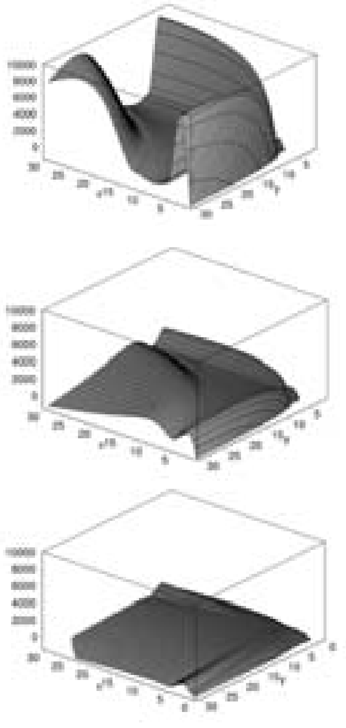


Fig. 2:
Quantum potential with walls of finite height which break down once the universe has shrunk below a certain size.

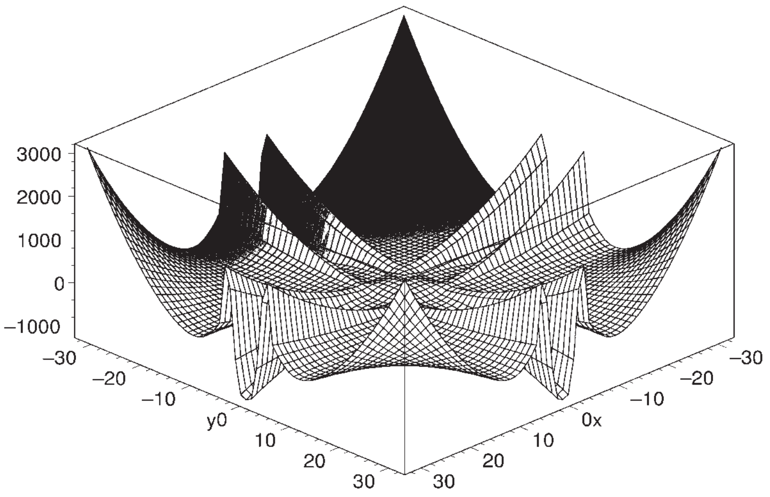


Fig. 3:
Full quantum potential with walls of only finite height and well-defined behaviour around the classical singularity (center).

All these effects described so far are consequences of general mathematical properties which are crucial for a background independent quantization. Modifications to the classical equations have been derived, rather than put in by hand having special applications in mind. For such a procedure it is very important to understand the mathematical structure completely, where some remaining gaps have been filled this year using the mathematical technique of Bohr compactifications. This essential step completes our understanding of how the far-reaching physical applications are consequences of the basic mathematical formalism.

The simplest cosmological models are now rather well-understood and it remains to test the consequences in more complicated, and more realistic, models and to look out for new effects. Loop quantum gravity has matured to a theory which is not only distinguished by being perfectly well-defined mathematically, but which also has sometimes astonishing consequences for physics.

Martin Bojowald

Squeezed Light for Gravitational Wave Interferometers

In 2003 a new research project has been launched in Hannover. The goal of this project is to investigate and, eventually, to overcome the so-called quantum limit in laser interferometric gravitational wave (GW) detectors. Since laser interferometers use laser light to measure the tiny length changes induced by gravitational waves, the measurement sensitivity of laser interferometers is limited by the statistics of the quanta of the light field, known as photons. The quantum limit can also be regarded as a certain amount of quantum noise entering our measurement device, which is given as a fundamental property of physics itself. It is interesting to note that the quantum noise effects gravitational wave measurements in two different ways: Shot noise arises from uncertainty due to quantum fluctuations in the number of photons at the interferometer output, where a photo diode absorbs all the photons to gain the GW signal. Radiation-pressure noise arises from uncertainties in the mirror positions due to quantum fluctuations of the light field inside the interferometer masking the length change due to a gravitational wave signal. Quantum noise is regarded as a fundamental noise source in GW detectors and also in any other measurement device.

Fig. 1:
The Hannover squeezing experiment. The left perspex box houses the green (532 nm) light generator, the other two boxes house two squeezed light sources.

To illustrate this: it is physically impossible to reduce both types of quantum noise (shot noise and radiation-pressure noise) simultaneously. But, fortunately, it is possible to squeeze one form of quantum noise, then at the expense of the other, to meet the requirement of Heisenbergs Uncertainty Principle. Indeed such squeezed states of light were first generated about 15 years ago, and are now being researched again to improve GW interferometers.

In our experiment in Hannover we use non-linear crystals to squeeze the quantum noise of a laser beam of 1064 nm wavelength. Squeezing of quantum noise is possible only in a non-linear process; in an optical experiment that means, radiation fields of different wavelengths need to interact. Here we use strong laser radiation at the second harmonic frequency (532 nm) to pump the crystal. Squeezed light is then generated in a so-called optical parametric process.

To improve the sensitivity of GW interferometers, squeezed states of special shape are required and especially those are not yet demonstrated. One important point is, that the light must be squeezed at frequencies for which gravitational waves are expected, i.e. in the acoustic band from 10 Hz up to 10 kHz. Until now squeezed light has been generated mainly above 1 MHz due to technical difficulties at lower frequencies. We have developed a special common noise cancellation technique that recovers squeezed noise buried by technical laser noise, see the improvement at low frequencies from (d) to (b) in Fig. 2. Currently we hold a world record having demonstrated squeezed states at frequencies down to 80 kHz (not shown here). Our goal is to reach and cover the complete acoustic band, as mentioned above.

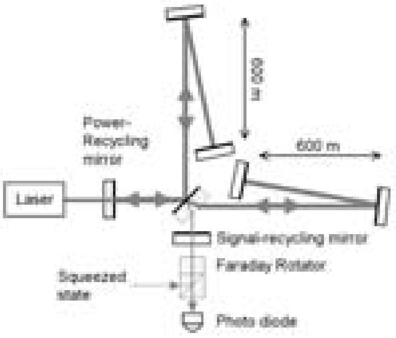


Fig. 3:
The laser interferometer topology of the GEO600 detector plus a Faraday rotator to inject squeezed states of light for an upgraded future design of the detector.

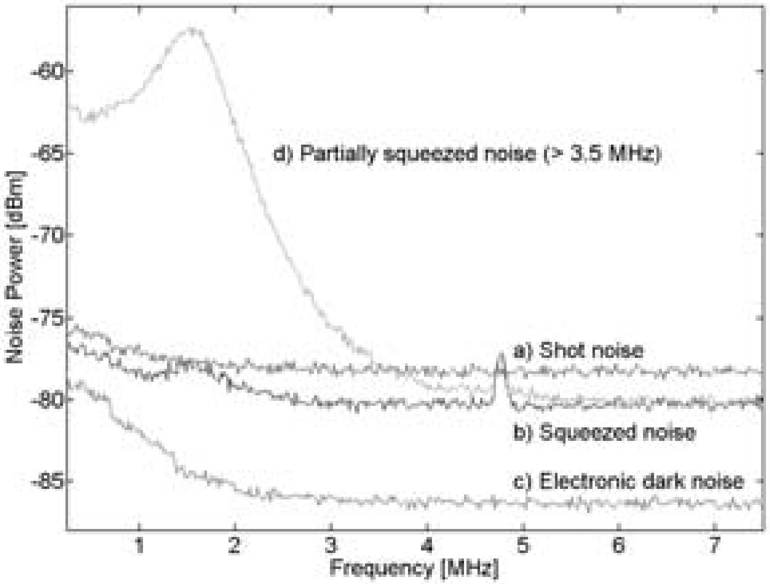


Fig. 2:
In this measurement squeezing has been observed wherever curves (b) and (d) fall below the shot noise reference. In case of (b) squeezing is demonstrated down to a frequency of 250 kHz.

Once appropriate squeezed states are available for GW interferometers they will be coupled into the signals output port of the detector. We have shown that not only conventional Michelson interferometers but also power- and signal-recycled interferometers like GEO600 and even more sophisticated interferometers of second and third generation GW detectors will gain from such squeezed states. Fig. 4 shows calculations of signal-normalized spectral noise densities of the GEO600 detector, without squeezed light input (upper curve) and squeezed light input included (lower curve). In both cases just the quantum noise contributions have been taken into account, whereas seismic, thermal and other types of noise have been neglected. The quantum noise spectrum without squeezed light input already reveals two dips where the quantum noise is lowered. These dips are called the opto-mechanical and the optical resonance and are a special feature of the signal-recycling topology of GEO600. The highly motivating result from our theoretical analysis is, that squeezed states enable further reduction of the noise floor over the entire frequency band. In Fig. 4 we have assumed a squeezing factor of two on a linear scale which has been demonstrated already; higher squeezing factors will result in even better noise performances.

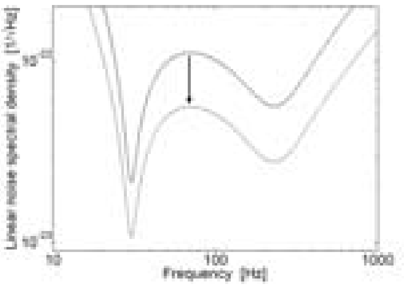


Fig. 4:
Modelled quantum noise performances of the GEO600 detector. The curves show the reduction of quantum noise over the entire frequency spectrum if squeezed states are injected into the interferometer. Here a linear squeezing factor of two has been assumed which corresponds to -6 dB in variance.

Roman Schnabel

Laser Research for Gravitational Wave Detectors

The Albert Einstein Institute strives to gain the most fundamental insights into the universe. To do so, many members of the institute are working on opening a new window to our view of the cosmos: the detection of gravitational waves. The groups in Hannover have the challenging and exciting task of developing techniques, which will allow gravitational wave detection in the near future. Since 2001 the Hannover institute already operates one of the first generation gravitational wave detectors, GEO600 (see schematic in Fig. 1), which is localised in Ruthe near Hannover (see annual reports 2001 and 2002).

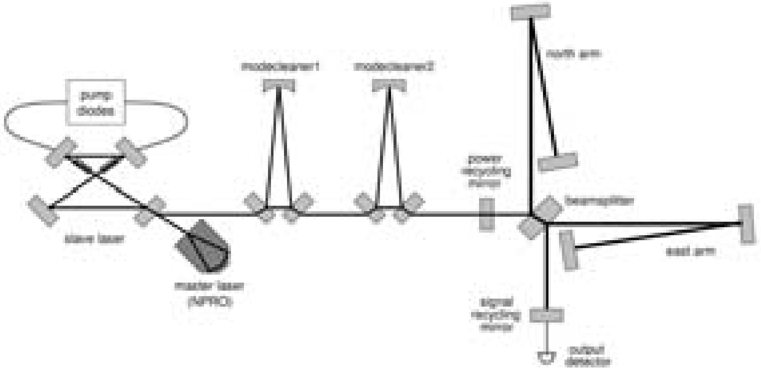


Fig. 1:
Schematic of the GEO600 optical layout

GEO600 is a complex experiment, consisting of many intricate subsystems: The arms of the Michelson interferometer present one of the largest ultra-high vacuum systems currently existing in Europe. The 200 plus feedback control loops determine the behaviour of the detector; they are effectively the brain of GEO600. Photodetectors and environmental monitoring quasi constitute the eyes and ears. The very heart of GEO600 though is the laser system, the ultra-stable light source which initially brings the interferometer to life. The laser group in Hannover is devoted to the development of this laser system and of optimal stabilisation schemes for it. To do so, we strive towards a fundamental understanding of the physical processes, which cause noise in lasers.

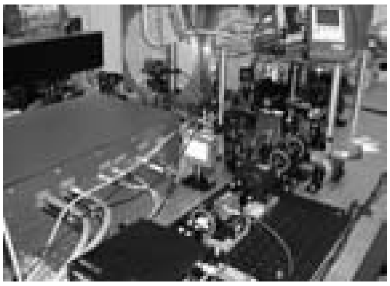


Fig. 2:
The injection locked laser system for GEO600 (lab system)

The light source for GEO600 is a laser diode pumped solid state injection locked laser system (Fig. 2), which emits infrared light (wavelength 1064 nm). It consists of a high stability Nd:YAG master laser (a non-planar ring oscillator, NPRO) with an output power of 800 mW, and a slave laser (a quasi-monolithic Nd:YAG laser in bowtie configuration) with lesser stability characteristics, but higher output power of 12 W. Together the two form a ”team”, and by a technique called injection locking we receive the best of both worlds: A high stability high power laser system. Yet by itself the injection locked system is not stable enough to be used as the GEO600 light source. Therefore a major goal of our group is to hone this system so it fulfils the challenging specifications of GEO600. This is achieved by active stabilisation of the observables of the laser system, namely the laser frequency, the laser power and the laser beam geometry and position.

In the GEO600 laser system we have implemented a frequency stabilisation, which keeps the output ”colour” of the laser light constant to a value smaller than 10^{-14} in a wide frequency band. This means that the frequency of the laser light varies with less than one part in 100 trillion! Naturally a ”change of colour” in this order of magnitude is far from being visible. But this frequency stability is crucial for the operation of the gravitational wave detector, as frequency fluctuations can produce signals, which feign arm length changes caused by gravitational waves.

Light exhibits the so-called wave-particle-duality, i.e. sometimes it behaves like it is made up of discrete particles (photons), in other experiments it shows wave-like phenomena. Besides this, laser light is of a special nature. When using the photon picture we can see that the photons emitted by a laser do not arrive at regular intervals, but in ”bunches” - laser light obeys the Poisson statistics. So when this light is detected by a photodetector (as it finally is in GEO600), we measure a mean constant value, but also fluctuations of the light power. These fundamental fluctuations are called shot noise, they have their origin in the quantum nature of light and can therefore not easily be evaded. - When laser light hits a mirror, due to the Poisson statistics the arrival of photons is as irregular as rain hitting an umbrella. The momentum transferred to the mirror by the photons then varies over time, this effect is called radiation pressure noise, which sets an additional limit to the attainable sensitivity of the gravitational wave detector. Techniques to overcome the so-called standard quantum limit (the combined limit of shot noise and radiation pressure noise) are presented in the article of Roman Schnabel in this report (see page 53).

Technical power noise of the laser system usually lies much higher than the above mentioned fundamental noise sources. We have to actively stabilise the output power of the injection locked laser system, as power noise ultimately limits the detection sensitivity of the gravitational wave detector. Power stabilisation of the injection locked laser system is realised by detecting a part of the output power and feeding back the derived control signal to the pump current of the slave laser. With this method we currently achieve the lowest ever power noise in this kind of laser system in the frequency regime from 100 Hz to 10 kHz (Fig.3). The relative intensity noise of $10^{-8}/\sqrt{(\mathrm{Hz})}$ means that the output power of the laser system fluctuates only to one part in one hundred million. This nearly complies with the specifications for gravitational wave detectors of even the second generation!

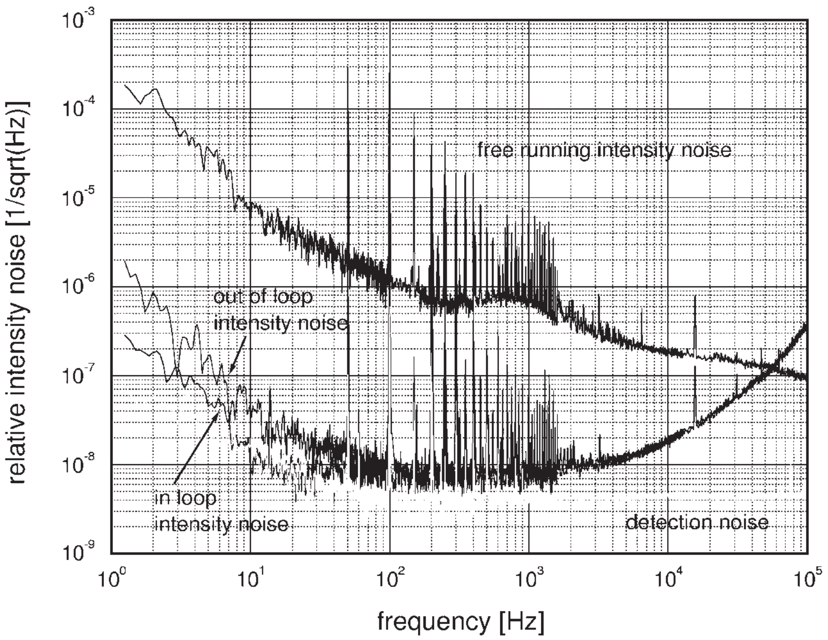


Fig. 3:
Relative intensity noise of the injection locked laser system of GEO600 (lab system) with active power stabilisation.

The beam positions and the beam geometry of the laser at the detector site have to be held constant with respect to the interferometer geometry. The interferometer is made up of suspended mirrors, and these mirrors define the ”space” the light may take up. The laser light only enters the interferometer if it geometrically ”fits” into it, though. By the technique of differential wavefront sensing and an intricate autoalignment system the laser beam is held stable on the interferometer input.

The stabilised laser system was long term tested in the Institute in Hannover before installation at the site of the gravitational wave detector in 2000. Since then the laser system has run constantly with a duty cycle of more than 99% and only occasional maintenance work (change of laser diodes etc.). A second identical laser system is in operation in the laser lab in Hannover, where new stabilisation techniques are developed and improvements are tested before implementation in GEO600.

Hardly ever are noise processes completely uncorrelated to one another. In our solid state laser systems we often unintentionally introduce noise in one observable when we stabilise another. This is then due to non-vanishing transferfunctions between the observables. To be able to develop optimal stabilisation schemes we have to characterise our laser systems by measuring all possible transferfunctions. In the course of this characterisation we discovered that the pump current of an NPRO can be used to tune its frequency. Obviously changing the pump current of a laser results in a change of the output power of the laser, too. One could now suspect another unwanted coupling between observables, but sometimes coupling comes in handy: Using the pump current as the actuator for frequency stabilisation (current lock) of a conventional NPRO, we not only obtain frequency noise reduction, but also a small amount of intensity noise suppression. This result inspired investigations of the fundamental causes of these noise correlations.

For this we constructed a model NPRO (Fig. 4). Its single mode pump source has an optimised geometry and thereby permits an enhanced overlap of the pump and the laser mode in the crystal.

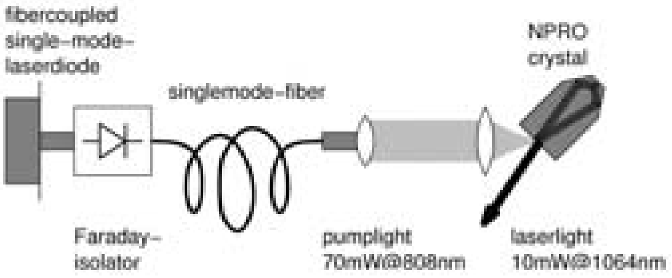


Fig. 4:
Schematic of the model NPRO with single mode laser diode pump source

The current lock experiments on this system yield an equal amount of frequency and intensity noise reduction without the necessity to even directly detect the intensity. On the other hand, the detection of pump light intensity fluctuations and feedback to the pump current (pump light stabilisation) results in NPRO intensity stabilisation and also in NPRO frequency noise suppression, without having detected frequency fluctuations at all (Fig. 5).

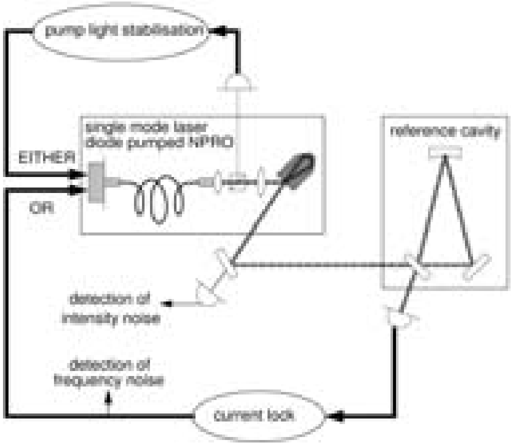
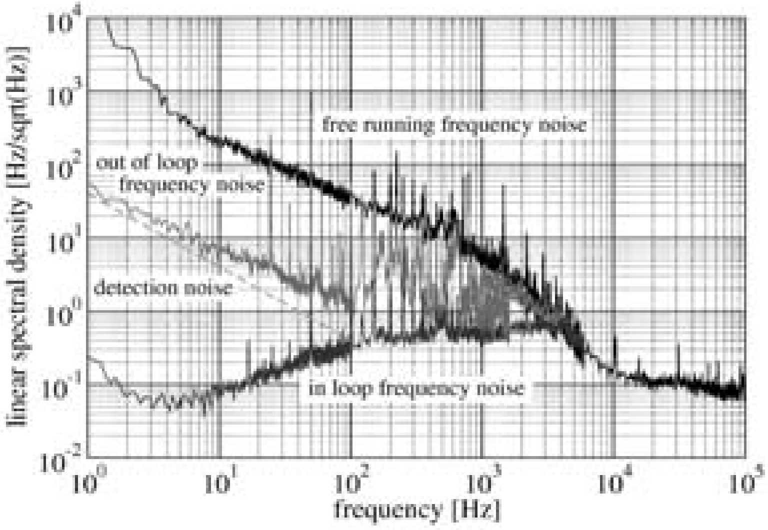


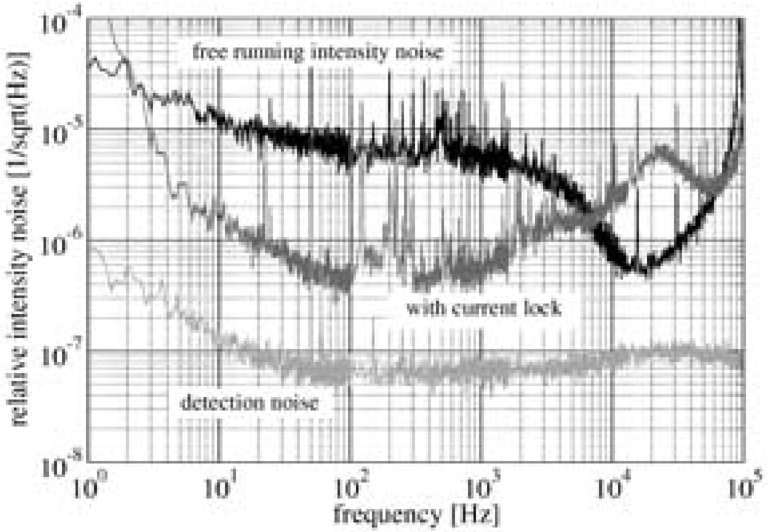
Fig. 5:
Stabilisation schemes (either current lock or pump light stabilisation) for the single mode laser diode pumped NPRO

These results are unprecedented - never before has simultaneous stabilisation in frequency and intensity by detection of only one of the two observables been realised! Exemplary results (in this case of current lock) can be seen in Fig. 6.

Fig. 6:
Results of the simultaneous stabilisation of the model NPRO with current lock:



(a) frequency noise



(b) intensity noise

For gravitational wave detectors of the second generation the light power will have to be increased from currently around 10 W to approximately 200 W. This requires innovative new designs and even more stabilisation skills. Work is presently being pursued to build these lasers, the challenge of stabilisation will soon fall to us. Our perpetually growing understanding of noise processes in and stabilisation techniques for solid state laser systems leaves us well prepared for the tasks to come.

Michèle Heurs

Activities and Highlights of the IT Department in 2003

As in previous years the members of the IT department were faced with several tasks, and many projects had to be continued. New projects and developments were started. The two most notable ongoing processes happened in the cluster computing area. MERLIN, a BEOwulf cluster, was installed at end of 2002 and is used for data analysis by the Gravitational Wave Group, which is involved in an international project with the LIGO Scientific Collaboration (www.ligo.org). Additional funds from the Max Planck Society allowed to extend the number of compute nodes of MERLIN. Final configuration of MERLIN (since midyear 2003): 180 dual processor compute nodes, 4 access nodes, per node 3 x 120 GB disk space, 36 TB of disk space available for distributed data storage.

Since 2002, Dr. Steffen Grunewald, system administrator of MERLIN, has tested, amended and supplemented both software and networking environment of the MERLIN cluster. This included the development of tools to guarantee optimum performance of the whole cluster for the full range of its tasks: data storage, exchange and analysis within the LIGO Scientific Collaboration, in particular within the British-German GEO600 Working Group. For more details on the scientific usage of MERLIN, see article by C. Cutler and M.A. Papa in this volume.

MERLIN

Configuration of MERLIN

Type of Cluster:	BEOwulf
Compute nodes:	180 (dual processor AMD Athlons, 1 GB RAM, 3 x 120 GB local disk space)
Access nodes:	4 (dual processor AMD Athlons, 2 or 3 GB RAM, 2 x 80 GB local disk space)
Distributed data storage:	40 TB
Network:	100 Mbits/sec Ethernet provided by 26 Fast Ethernet switches with uplinks to a Gigabit Ethernet backbone switch
Operating System:	RedHat
Remark:	The data analysis software was designed in such a way that all CPUs can work on their maximum speed, reducing inter-node data exchange to a minimum.

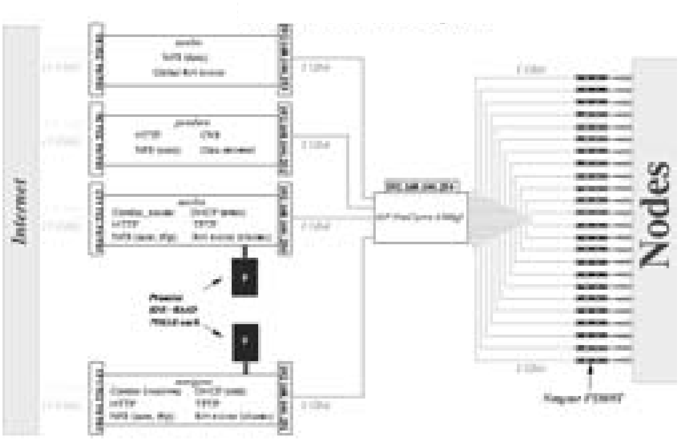


Fig. 1:
Global cluster layout of MERLIN

The second in-house cluster of the AEI is called PEYOTE. PEYOTE is the name of a cactus in Middle/South America but it can also be taken as an abbreviation of Parallel Execute Your Own Theoretical Equations. While MERLIN analyses experimental data, PEYOTE is used for numerical simulations of Einstein's equations, for example to describe the collision of black holes. The CACTUS toolkit (www.cactuscode.org) is the software mainly used for this purpose. The first part of the PEYOTE cluster was installed in April 2003. As this installation was very successful already eight months later PEYOTE was extended to 128 compute nodes. Configuration of PEYOTE at the time of writing: 128 dual processor compute nodes, 8 extra dual processor compute nodes for testing or running smaller jobs, 8 storage nodes with a total of 12 Terabytes of central disk space.

Dr Holger Naundorf, system administrator of PEYOTE, is responsible for keeping the cluster running and for supporting the scientists. This includes updating and refining the software environment to make the most efficient use of the available resources. For more details about numerical simulations running on PEYOTE, see article by D. Pollney in this volume.

Fig. 2:
One part of PEYOTE
(64 nodes)

It should be mentioned that much effort was necessary to prepare the two computer rooms for the clusters. Both rooms formerly were normal offices and it was a big challenge for the technicians to install powerful enough cooling systems. As both rooms are rather small this was not an easy task to do.

For the scientists running simulations on PEYOTE the visualization of the results is very important. As the ORIGIN 2000 with its high performance graphics engine was no longer available the institute had to find new solutions. The institute received additional money for the prototyping of new, sophisticated user interfaces (tangible devices). These serve as both representation and control of digital parameters, data sets, computing resources, and other digital content. The devices should offer benefits including simplified interaction, enhanced manipulation of digital parameters, ease of migration between desktop and projection environments, and ease of user authentication to grid computing resources. Tangible devices are a relatively new technique that has been received enthusiastically by the international community. In the "GridLab" research project Dr Brygg Ullmer, researcher at ZIB (Zuse Institute Berlin), is working on these user interface approaches for scientific visualization, largely targeted at AEI astrophysicists as end-users. Unfortunately no money was available for a new virtual reality projection system, so that the scientists still depend on a rather old-fashioned system, which has been in service since 1997.

Since the end of 2003 a new security concept has been implemented. The main philosophy of this concept is to allow only trusted and authorized users access to systems of the AEI in a convenient manner. These constraints have led to the need to implement a DMZ (Demilitarized Zone). An additionally installed VPN (Virtual Private Network) now helps the users to access the AEI computers and the data on them from any place of the world in a secure manner. This facility is very important for the members of the Teilinstitut in Hannover. Using VPN they have easy access to for example the online catalogue of the library at the AEI in Potsdam.

As traveling is very time consuming for the scientists, the IT department continued investigating in AccessGridNodes (AGN), an advanced videoconference technique.

PEYOTE – the AEI's numerical simulations cluster

Configuration of PEYOTE

Type of Cluster:	High Performance Compute Cluster
Compute nodes:	128 + 8 (dual processor INTEL XEONs, 2 GB RAM, 120 GB local disk space)
Access nodes:	2 (dual processor INTEL XEONs, 4 GB RAM, 72 GB /300 GB local disk space)
Storage nodes:	8 (dual processor INTEL XEONs, 4 GB RAM, 72 GB internal local disk space, 1.5 TB data storage)
Total data storage:	12 TB (8 x 1.5 TB)
Networks:	High speed interconnect network: Gigabit Ethernet, provided by Gigabit switch E600 from Force10 Networks Storage network: 100 Mbits/sec Ethernet for the compute nodes Gigabit network for the storage nodes Management network: 100 Mbits/sec Ethernet
Operating System:	RedHat
Remark:	Having three different networks allows to run administrative tasks on the cluster without interfering with the two other networks. The scientists connect to the cluster by logging into an access node and submit their jobs to a queuing system, which then starts the calculations on the nodes.

Tangible devices made by
Brygg Ullmer, Zuse Institute Berlin

A grant from the BAR (Beratender Ausschuss Rechenanlagen, a central service of MPG) for a standard videoconference (VC) system for all three institutes of the Max Planck Campus supported this idea. In several cases external scientists could participate in a workshop or seminar via AGN or VC, not to mention the easy way of continuation of the collaboration with Ed Seidel and Gabrielle Allen (now LSU).

Christa Hausmann-Jamin

Activities and Highlights of the Library in 2003

The library of the Albert Einstein Institute is a specialized library offering services firstly to scientists working at the institute in Golm and the Teilinstitut in Hannover. Scientists from outside the institute are welcome and may use the library by making an appointment. Scientists and students working at the two other Max Planck Institutes on the campus or at the University of Potsdam located in Golm may use the library in the same way as the scientists at the institute, but they may not participate in the library loan service. Two librarians are managing the library: Elisabeth Schlenk as the head of the library and Anja Lehmann.

The annual growth rate in 2003 of the library holdings increased in line with the budget and our holdings list 6.959 monographs and conference reports, 8.786 bound journal volumes and 140 scientific journals subscriptions.

The membership in the North Rhine Westphalia Consortium, Bielefeld, we signed in 2002 to get online access to MathSciNet was renewed as well as the membership in the Zentralblatt MATH-Konsortium in order to support the German and European Mathematical Societies.

The generous setting encourages scientists to use the library as a reading room and not only to carry out the books and journal issues for use in their offices. To avoid permanent use of the reading places as alternative office space, the computer department received a multi-media station that can be used by everyone. In addition, six permanent working places for students were arranged for the three scientific departments.

The members of the Library Committee are Dr. C. Cutler, Prof. H. Friedrich (Chairperson), M. Koppitz and Dr. M. Staudacher. They check the publisher's catalogues, brochures and new title announcements for relevant monographs. They study sample copies of new journal titles for possible subscription, classify the new books and discuss new developments or necessary changes regarding the demands of the library in regular meetings. Mrs. Hausmann-Jamin, Prof. Theisen and Prof. Huisken support the library committee in terms of the selection of new books and other relevant media in their fields of activity.

Besides the classical services, namely the supply of the library holdings, the procurement of literature for the scientists at the Institute is another main task of the library. In 2003 we started to supply the scientists working in the Teilinstitut with the same services we offer in Golm. In general we do this by ordering the requested journal articles or monographs via the internet server (SUBITO) located at the University Library in Göttingen. We receive those articles within 24 hours as email files and we save them for further internal requests. Other libraries from which we receive requested literature are not only those of the various Max Planck Institutes, but also those of the universities in Berlin and Potsdam, of the Astrophysical Institute in Potsdam and the

National Library Preussischer Kulturbesitz in Berlin. The search in online databases (SciSearch, INSPEC, MATH, BIBLIODATA, CONF) through the host STN Karlsruhe is also a service offered by the library.

New tasks for the librarians will arise from discussions within the Max Planck librarian community concerning a web based catalog called Max Planck Virtual Library (VLib). The goals of VLib are: (i) to provide integrated access to information resources relevant for Max Planck end users and to enable simultaneous searches, and (ii) to improve inter-resource navigation through a context sensitive reference-linking system as defined by Max Planck requirements. As an information portal VLib is launched as the comprehensive access point to information resources for Max Planck users, and it establishes the capacity for seamless navigation from references to other resources or instances. In its current version, VLib is a step forward on the pathway to a mature Virtual Library for the Max Planck Society, which will allow a maximum of integration, navigation, and personalization. The system will be further developed and improved by the ZIM (Heinz Nixdorf Center for Information Management in the Max Planck Society).

The discussion of the future of both electronic and printed media is still ongoing. Contracts between the Max-Planck-Society and Elsevier (Science Direct) and Springer have been signed; other publishers (Wiley, Kluwer, AIP, IOP) will follow. Nevertheless the policy of our library is to place electronic access at the scientists' disposal irrespective of usage. The scientists should have the possibility to use the electronic resources whenever they need them.

We are still one of the pilot institutes for the eDoc Server. This service is provided by the ZIM. The intention of the electronic document server is to increase the visibility of the intellectual output of the Max Planck Society and to add to the world-wide virtual repository of high-quality scientific information. Universities, research institutions and other cultural institutions are willing to provide public access to results from publicly-funded research and educational material as well as to objects of cultural heritage. Based on the revolution in information technology, new ways for communicating scientific and scholarly information are rapidly evolving. The Max Planck eDoc Server is one way of exploiting the new technologies for the more effective communication of the research results. It does not replace established and proven practices of peer-review and certification: repositories like this may exist in parallel to traditional journal publication, as they serve as building blocks for new, evolving practices of communication and evaluation of research results. As a result of this new system the institute has to change the workflow regarding the documentation of publications within the next year. In the meanwhile Anja Lehmann is registering the institute publications adding links for online versions and abstracts not only in our OPAC (Online Public Access Catalog) but also in the eDoc Server.

The library is represented in the following national associations: Deutscher Bibliotheksverband e.V., Sektion Brandenburg (Board Member) and Arbeitsgemeinschaft der Spezialbibliotheken. Focusing on the developments in the new media area the Max Planck librarians established different committees. Frau Schlenk was elected for a period of two years to represent the librarians of the CPT Section in the Sprecherrat of the MPG, in the IRC (Information Resource Council) and IPC (Information Provision Council)

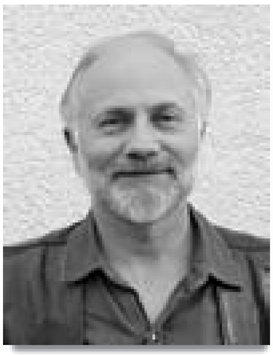
Elisabeth Schlenk

LSC Meeting at Hannover


"A lazy afternoon in the lecture hall."

Gravitational wave detection is a joint effort of scientists all over the world. They work together in the LIGO Scientific Collaboration (LSC), founded in 1997 as a forum for organizing research, publications and all other scientific activities. At present the LSC comprises about 450 scientists from LIGO, GEO600, TAMA300, and ACIGA. Twice a year the LSC organizes a meeting at the US American sites, at Hanford (WA) or Livingston (LA).

In 2003, the LSC broke with tradition and convened at Hannover from 18 to 21 August. Meetings were held at the University of Hannover using lecture rooms throughout the main hall for plenary and breakout sessions. 140 participants discussed the latest achievements in detector commissioning and future plans. The data analysis sessions were of special interest since the results of the first scientific data acquisition runs (S1 and S2) were presented. Other sessions concentrated on thermal noise issues and laser development. Another important topic was the use of squeezed light for future gravitational wave detectors. In addition to the crowded sessions, three evening tours were available to see the GEO600 site and the interferometer. Close to two dozens of people loaded on the bus each evening for the 25 minute ride to the observatory.



Obviously the meeting was a success, not only on behalf of the fine weather, but above all on the excellent coordination of sessions and resources by Benno Willke. Konrad Mors ensured that everyone could connect to the web and email services. During the breaks, Klaus Haupt and his team supplied the participants with snacks and refreshments. At the traditional conference dinner people enjoyed a delicious buffet of German and international favourites in the Maritim Grand Hotel.

Peter Aufmuth

A Tale of two Theories: Strings Meet Loops at AEI in October 2003

In media reports of the more enthusiastic variety, quantum gravity has been styled the Holy Grail of physics. Certainly, the comparison is apt in two respects: The quest for a theory, quantum gravity has proven long and difficult. Roughly a century after the birth of both quantum theory and of Einstein's general relativity, a description of reality that fully incorporates both the geometrical nature of gravity and the principles of the quantum world is still out of reach. Secondly, like the legendary knights of old, the physicists and mathematicians involved in the modern quest have ridden off in quite different directions in pursuit of their elusive goal - there is a variety of candidate recipes for the quantization of gravity, with string theory and loop quantum gravity the most prominent among the lot.

Contributing to both difficulty and diversification is the fact that, unlike the development of quantum theory in the early 1900s, with its lively interplay between theory and experiment, the search for quantum gravity has to make do without direct experimental guidance. The energy scales at which quantum gravity effects can be expected are much too high for current (and foreseeable) technology. Instead of direct experimental feedback, guidance is provided by theoretical principles, with the direction of research crucially dependent on what importance is attached to what principle. For instance, string theory starts out as the elementary particle physicist's approach to quantum gravity, namely by generalizing from point particles to one-dimensional ”strings” the quantum theoretical approach that has proven so successful in the standard model description of the electromagnetic and electro-weak forces. On the other hand, loop quantum gravity, the classical relativist’s approach, takes as its guiding principle the covariance that is the basic feature of Einstein’s theory, aiming at a geometrized version of standard quantization procedures. So far, the two approaches have not noticeably converged - on the contrary, as each has been developed further, from string theory to the mysterious ”M-theory” and from the canonical-geometrical quantization approach to spin-networks and loops, a veritable language gap has developed: each theory has its own central concepts and techniques, and a string theorist talking to his loop colleague of D-branes, K3 and T-duality has as little chance to be understood as he has of understanding that colleague’s report on the latest advances concerning coherent loop states and the Lewandowski-Thiemann-Hamiltonian. The result: two communities of scientists, a string community and a (substantially smaller) loop gravity community, working away on their respective programs, in parallel, in pursuit of the same problem, but with little intergroup communication. Strings are strings and loops are loops, and never the twain shall meet?

A peculiar situation, thought both AEI’s Hermann Nicolai and Abhay Ashtekar, director of Penn State University’s Center for Gravitational Physics and Geometry. They came up with the idea of a meeting to promote communication and, hopefully, fruitful discussion between the two camps, for which the AEI - aptly described by one distinguished visitor as ”a modern version of Camelot for carrying out gravitational physics” (cf. p. 69 of this report) - would prove a fitting venue: the three-day conference ”Strings meet Loops”, held in late October 2003 and attended by fifty researchers from both sides of the Atlantic and, more importantly, from both sides of the conceptual divide.

The backbone of the conference was formed by a series of review talks - non-technical, and, as the organizers had exhorted their speakers, primarily addressed to the other community. The opening talk was an introductory exposition by Hermann Nicolai, who compared and contrasted the successes claimed by both camps as well as the shortcomings of the two approaches.

First at bat for the loop quantum gravity side was Abhay Ashtekar, one of the pioneers of the loop quantum gravity approach. He painted a broad picture of quantum geometry, its motivations, techniques and applications. Subsequent speakers supplemented this with excursions into more specialized areas, from the more technical aspects of the Hamiltonian constraint (Jerzy Lewandowski) to the intricacies of spin foams (Laurent Freidel). Rounding off the presentation was a talk on cosmological applications by Martin Bojowald, last year’s winner of the GRG Essay Competition, and currently the principal investigator of AEI’s loop quantum gravity group. Cosmology is one of the most important touchstones for any theory of quantum gravity: the Big Bang singularity is one of the pathological features of classical general relativity that a full quantum treatment can be hoped to cure, and loop quantum gravity can boast of some recent progress in this area that might even lead to testable predictions.

On the string side, the picture was more diversified, with different talks focussing on different facets of the theory and its applications. Two talks explored the aftermath of string theory’s ”1995 Revolution”, the net of dualities weaving together the different versions of string theory to form the all-inclusive and still rather mysterious M-theory:

Bernard de Wit with a lucid account of BPS states and their properties, and Jan Plefka tying in the eleven-dimensional supermembrane and matrix models - hinting at a possible explanation of what the letter ”M” might stand for. Closer to classical general relativity was Kaspar Peeters' talk on effective field theories of gravity, and on the guidance that string theory or, more generally, supersymmetry gives for their construction. Venturing off in an entirely different direction, Marc Henneaux talked about ‘cosmological billiards’ and the infinite dimensional symmetries revealed by recent studies of cosmological solutions in Einstein's theory and its generalizations. One talk was actually a live telecast from Rutgers university, with D-brane specialist Michael Douglas holding forth on the care and feeding of the myriads (10^{200}, to be more precise) of vacuum solutions that string theory admits.

The last talk, by Max Niedermaier, on integrable quantum gravity in two dimensions, served as a useful reminder that, beyond the string-loop-dichotomy, there are yet more approaches to questions of quantum gravity.

However, the talks themselves were only one part of this symposium - true to its aim of furthering discussion and the exchange of ideas, there was a generous allotment of discussion time for each talk. While the majority of questions both during and after the talks dealt with issues of clarification - a clear sign of the participants' earnest efforts to wrap their minds around the other camp's ideas -, there were also probing questions concerning each theory's conceptual foundations, highlighting the differences between strings and loops not only in physics, but also in philosophy: what about the semi-classical states, to pick a question from the string camp – can loop quantum gravity compute the scattering of gravitons? Or, as a counter-query, what about the multitude of possible string vacua – can a theory with so many possible consistent universes to choose from still claim to be a truly scientific theory in the commonly accepted sense of the word?

Of course, a three-day meeting cannot give in-depth knowledge of two complex fields. But all participants agreed that the meeting was a great success, not only because of the exceptionally good talks, but even more because it provided a good glimpse over the fence and opened up new vistas. In that way, everybody had something to take home: a considerably broadened perspective and hopefully many new ideas about the different ways of doing quantum gravity.

Hermann Nicolai and Markus Pössel

Annual Meeting of the SFB / Transregio 7 ”Gravitational Wave Astronomy”

In 2002, several experimental and theoretical physicists, astrophysicists and mathematicians from all over Germany have agreed on close collaboration on all aspects of gravitational waves. Since January 1st, 2003 the Deutsche Forschungsgemeinschaft (DFG) is supporting this project with the installation of a new Sonderforschungsbereich (SFB) ”Gravitational Wave Astronomy – Methods, Sources, Observation”. It is designed as a ”Transregio”, with the participation of the Universities of Jena, Tübingen and Hannover as well as the Max Planck Institute for Astrophysics in Garching and the Max Planck Institutes for Gravitational Physics in Golm and Hannover. The DFG is financing approximately 25 positions for, at first, the next four years, with sizable sums for equipment and resources. Prof Dr Gernot Neugebauer from the Friedrich-Schiller-Universität Jena is the Speaker of the ”SFB/Transregio 7”.

Gernot Neugebauer (University of Jena), Speaker of the SFB transregio

The SFB is divided into three project areas: A. Analysis of the gravitational field equations (three projects), B. Structure and dynamics of compact objects (six projects), and C. Detection of gravitational waves (four projects). The further development of theory and experiment of gravitational radiation requires the use of new mathematical methods, the refined study of compact astrophysical objects (neutron stars, black holes, binary systems, or supernovae), and the improvement of gravitational wave detectors (e.g., by using diffractive optics, resonant sideband extraction, cryogenic cooling, and quantum non-demolition techniques).

On February 21st, 2003 the opening ceremony of the SFB took place at the hotel "Schwarzer Bär" at Jena. Words of welcome came from the President of the DPG, Prof. Roland Sauerbrey, and from the head of the Friedrich-Schiller-Universität, the Rector Prof. Dr. Karl-Ulrich Meyn and the Registrar Dr. Klaus Kübel. Dr. B. Steffens and Dr. J. Komusiewicz represented the Thuringian Ministry for Science, Research and Art. A chamber music ensemble supplied the supporting programme. Later in the evening, the scientists hotly discussed the exciting news from WMAP on the cosmic microwave background and the implications for our model of the Universe.

The first Annual Meeting of the SFB took place on October 10, 2003 at the University of Tübingen. The participants discussed the start of their projects and agreed to establish workshops and a summer school in order to support the bond between the different groups.

Peter Aufmuth

MERLIN Performing Magic for Albert Einstein

For several years now the AEI is participating in a worldwide search for gravitational waves, one of the effects of Albert Einstein's General Theory of Relativity, which could not have proven directly yet. After the award of the Nobel Prize for Physics to Hulse and Taylor in 1993, the quest for gravitational waves has been supported by the construction and operation of earth-bound wave detectors all over the world. The AEI does not only operate one of them (the GEO600 detector located in Ruthe near Hannover, consisting of a Michelson interferometer with an arm length of 600 metres, run by German and British researchers) but also takes active part in the LIGO Scientific Collaboration.

Interferometers, unlike optical or radio telescopes, cannot be pointed to a selected area of the sky. Thus to extract possible signals from a pointlike source (e.g. a rapidly rotating neutron star or a pair of black holes falling into each other) from lots of ”meaningless noise” (in terms of the scientific goals), the data set has to undergo several steps of CPU intensive processing.


M.A. Papa, data analysis coordinator for the GEO project, featuring MERLIN’s countdown.

Fortunately, the scientists at the AEI and their collaborators have found a way to split up this huge amount of compute load into handy chunks which can be worked on rather independently by lots of CPUs which don’t have to communicate with each other very fast. This way an expensive supercomputer could be replaced by a farm of loosely coupled ”standard” PCs, each equipped with two Athlon MP processors and some harddisks which together form a large cluster storage pool. This pool will hold some weeks of raw data from GEO600 as well as several stages of processing results.
Using funds from the Land Brandenburg, a two-level network infrastructure consisting of a fast Gigabit Ethernet backbone and 26 switches connecting the individual nodes to it could be realized.

On July 2nd 2003, all 180 nodes of the MERLIN cluster had been delivered and put on the shelves in the room prepared with power supplies, cooling devices and network cabling. The Minister for Science, Research and Culture of the Land Brandenburg, Prof. Johanna Wanka – member of our Board of Trustees -, had agreed to inaugurate the cluster. After words of welcome by the managing director of the AEI, Bernard Schutz, and speeches by the minister herself and the leader of the data analysis research group, Maria Alessandra Papa, all three of them pressed the ”red button” to wake up the 180 compute nodes, which are controlled - and provided with the necessary data and instructions - by four head nodes. A growing noise of CPU fans and harddisks, together with an incrementing counter on the control screen, showed that the new tools of the gravitational wave searchers had smoothly started operating.


Minister Johanna Wanka, M.A. Papa, and Bernard Schutz pushing the ”red button”.

With the help of MERLIN, the researchers hope to gain another proof of Einstein’s theory, to open a new window to the otherwise invisible parts of the Universe and eventually find the ”Holy Grail” of physics.

Steffen Grunewald

Through the eyes of a visitor

My yearly visits to the AEI have left me many fond memories. Many things have changed since the time I was its first visitor at the initial headquarters in Babelsberg. In the temporary headquarters on Schlaatzweg, I practically had a whole wing of a modern office building to myself. But the view out my office window gave me the companionship of an old city neighbourhood. Children, glad to escape the notorious Babelsberg cobblestones, skateboarded on the smooth patio below as if that were its purpose. Today, the new building in Golm is in a rural setting and overcrowded as a result of the rapid growth of the Institute. The view out the window is of falcons and fields, which for some is likely to change after construction of a much deserved new wing. But some things seem never to change. The original staff members Frau Roos and Frau Schlenk are just as youthful and enthusiastic, as well as the founding director Jürgen Ehlers.

As visitors from the U.S. without a car, my wife Susan and I have particularly enjoyed a life style which can be characterized as "old Europe" in the best sense of the term. We enjoy the mall free life of shopping in small groceries and outdoor markets, buying just enough to fit into our knapsacks. The guesthouse on Reuterstraße in Babelsberg is strategically located to be exactly the same time away from the Institute by public transportation as by bike. Susan heads off in the morning by train for an artist workshop in Berlin while I bike to Golm along the most cobblestone free route possible through Babelsberg. Upon awakening one morning to view my first snowstorm here, I hesitated about this course until I noticed an old lady placing her granddaughter on the back of a bicycle to take her to school. I have since felt obliged to follow her example and not miss this combination of morning exercise and peaceful contemplation the day's work while pedalling through Sanssouci. We rent a double apartment in Reuterstraße so that Susan can use one bedroom as her studio. One day I got more than my fill of exercise and contemplation when I returned to find that a housekeeper who was not aware of this arrangement had locked the individual bedroom doors. Until then I thought I had been clever to leave the cumbersome bedroom key in our bedroom cabinet. It took another round trip to get a spare key from the porter in Golm.

The Institute is a modern version of Camelot for carrying out gravitational research. Everything is supplied to carry out unfettered work: computers, supplies, library and especially the inspiration and advice of a collection of colleagues not to be rivaled anywhere in the world. I remember once sitting along the bank of the Grand Canal and marveling at how the cargo and passengers on the passing boats supplied a sense of the entire Chinese nation. In a similar way, the stream of visitors through the Institute reflects the activity of the international community of relativists. This atmosphere is not wasted, as evidenced by the productive research described (elsewhere) in this annual report.

You never feel neglected when you arrive at the Institute in the morning. If you miss a cheery welcome from Frau Pappa you will surely be compensated by the deluge of email from "new friends" when you log on to your computer. The honour of being on the Institute's emailing lists attracts more well-wishers than you might want to imagine. If it is Monday, and you are visiting the geometric analysis and gravitation group, the week begins in Gerhard Huisken's office enjoying coffee and refreshments served up by Frau Lampe, in preparation for the 10:30 seminar. On most other days, the morning is undisturbed time to get lost in research.

Eventually my appetite, or that of my nearby colleagues Bernd Schmidt and Helmut Friedrich, interrupts this reverie and a roundup of reinforcements marches into the Institute Canteen. This cafeteria offers one taste of home rarely found in European restaurants - healthy and free local tap water. Since water is more critical to survival than food, what more need be said?

The informal gatherings at lunch or afterward over coffee provide a good opportunity to make new acquaintances and find out what people are doing. There are even more informal self-organizing occasions that you should ask about, like the Thursday night pub sessions somewhere along the train route from Golm to Griebnitzee, the Friday happy hour, the Saturday night at the Kino and the annual ski trip. The ultimate in informality is the Fasching party, where the accompanying photo shows us over-indulging as colliding black holes.

Two black holes and
"the machine that goes 'Ping'"
at the Fasching Party.

I have had a highly satisfying professional experience at the Institute. My work on simulating black holes and gravitational waves lies at the interface of the mathematical relativity and astrophysical relativity groups. It has given me the opportunity to interact with a broad group, with expertise ranging from mathematical foundations to the new phenomenology being developed to usher in the age of gravitational wave astronomy. Visitors to the Institute soon learn that there is so much going on that it would be self-defeating to attend every lecture and participate in every workshop. But there is never any over-saturation of intellectual stimulation and the spirit of creative struggle.

IT'S CAMELOT!

Jeffrey Winicour
University of Pittsburgh

Leibniz Prize for Gerhard Huisken

Gerhard Huisken was awarded a Leibniz Prize in February 2003. The Gottfried Wilhelm Leibniz Prize is the highest honour awarded in German research. The Leibniz Programme of the Deutsche Forschungsgemeinschaft (DFG) aims to improve the working conditions of outstanding scientists and academics, expand their research opportunities, relieve them of administrative tasks, and help them employ particularly qualified young researchers.

Gerhard Huisken among the winners of the Leibniz Award 2003.

Huisken has received the award for the discovery and development of new mathematical models describing the motion and deformation of surfaces and higher dimensional geometric spaces. Such deformations have applications in the description of evolving interfaces in mathematical physics and in the investigation of curved spacetimes in Einsteins General Theory of Relativity.

The award for Gerhard Huisken is valued at _1.55 m over the next five years.

Martin Bojowald wins Gravity Research Foundation Award

Martin Bojowald

The “First Award of the Gravity Research Foundation Essay Competition, 2003” was awarded to Martin Bojowald in recognition of his essay on "Initial Conditions for a Universe" (gr-qc/0305069). In recent years, a new formulation of quantum cosmology has been developed which is based on quantum geometry, a candidate for a theory of quantum gravity. Here, the dynamical law and initial conditions turn out to be linked intimately, in combination with a solution of the singularity problem.

Two Otto Hahn Medals for AEI PhD students in 2003

Stefan Fredenhagen

Hanno Sahlmann

Graduate students Stefan Fredenhagen and Hanno Sahlmann won Otto Hahn Medals in 2003. Since 1978 the Max Planck Society has annually honoured young men and women for outstanding scientific achievement (in their PhD theses) by awarding them this valuable medal. In addition to a research stipend, the award confers entitlement to preference for grants enabling recipients to research abroad for one year. The award is presented during the General Meeting of Max Planck Society in the following year.

Stefan Fredenhagen was awarded for the development of new methods for the investigation of renormalization group fluxes in two-dimensional quantum field theories. Hanno Sahlmann received the award for important new insights in the connection between canonical quantum gravitation and quantum field theory at curved background space times.

Annual Meeting of the Kuratorium, September 1, 2003

The Ministry for Education and Research (BMBF) officially announced the "Einstein Year 2005" in order to celebrate 100 years of Relativity. At the annual meeting of the Institute's Board of Trustees, Jürgen Renn (director at the Max Planck Institute for the History of Science) presented the planned activities. One of the most popular events in 2005 will be a big Einstein exhibition in Berlin, which is organized by the Max Planck Institute for the History of Science. Besides participating in the exhibition and other public events, the AEI organizes a scientific conference on "Geometry and Physics after 100 Years of Einstein's Relativity" as well as other activities.

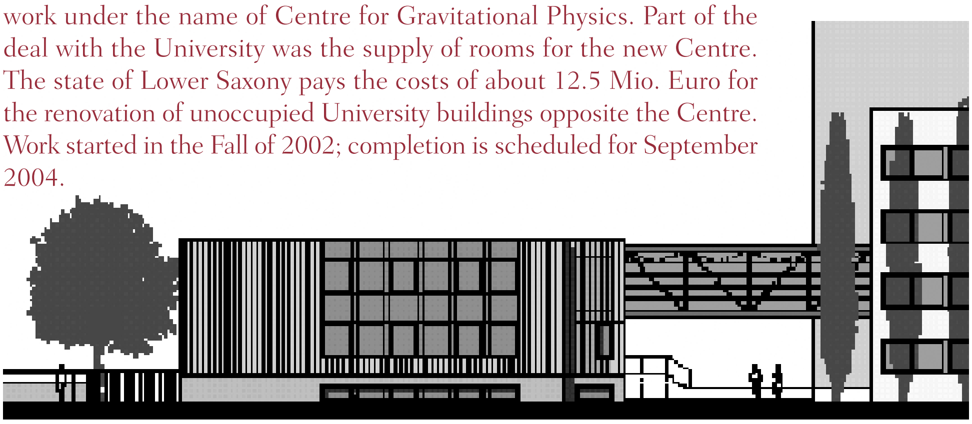
The chairman of the AEI's Fachbeirat, James Hartle, gave a report on the Institute's development in science. He discussed the problem of brain drain that is virulent in theoretical physics: many gifted scientists leave the AEI (and Germany) to take up appointments at universities and research centres abroad.

An important point in managing director Bernard Schutz' overview was the Institute's role in national and international projects. He described the SFB transregio, the LIGO Scientific Collaboration, LISA and other co-operations. In addition to these project-based collaborations more than 150 scientists visit the AEI every year thanks to the Institute's generous visitor program.

Hermann Nicolai gave a talk about the International Max Planck Research School (IMPRS) on Geometric Analysis, Gravitation and String Theory, a joint project with the Free University of Berlin and Potsdam University. IMPRS' are, above all, meant to promote international collaboration and to significantly increase the interest amongst foreign applicants for earning a Ph.D. degree in Germany.

New Rooms for the AEI Hannover

In 2002, the experimental part of the AEI has been established in Hannover. Together with the Division of Spectroscopy of the Institute for Atomic and Molecular Physics of the University of Hannover both work under the name of Centre for Gravitational Physics. Part of the deal with the University was the supply of rooms for the new Centre. The state of Lower Saxony pays the costs of about 12.5 Mio. Euro for the renovation of unoccupied University buildings opposite the Centre. Work started in the Fall of 2002; completion is scheduled for September 2004.



Artist's view of the new Centre for Gravitational Physics: a covered footbridge links the office building (on the left) and the experimental part (on the right), as seen from the Callinstraße.

The building opposite the AEI Hannover has been reconstructed completely to contain labs with clean room conditions, a huge hall suited for the installation of large facilities, and some offices. All the rooms are supplied with modern experimental equipment. In December 2003 AEI members moved their experiments to the new rooms. Then the reconstruction of the former AEI building (Callinstr. 38) started. It will contain mainly offices, a lecture room, and student labs. Those concerned had to move into alternate quarters (Am Kleinen Felde 30) in the vicinity of the University main building and have to return after the renovation.

DPG Meeting at Hannover

From March 24 to 28, 2003, the German Physical Society (DPG) held her 67th Annual Meeting in Hannover. About 1200 scientists listened to more than 600 talks. Karsten Danzmann presented the first results of LIGO and GEO600, the interferometric gravitational wave detectors. Many participants used the opportunity to visit GEO600 at Ruthe.

Participants of the DPG meeting took the opportunity to take a look at GEO600.

Workshop "Apples with Apples" in Mexico City

A number of numerical relativity groups around the world have been recognizing the need for a standardized way of comparing existing codes, formulations of the Einstein equations and numerical methods. At a first meeting in 2002 in Mexico City, first concrete ideas in this direction have been formulated and a collaboration of numerical relativists has formed to empirically study what works and what does not work in numerical relativity with solid scientific methods - in other words to compare apples with apples. A web site (*www.appleswithapples.org*), results repository and mailing lists have been established to organize this effort, and further contributors have been accumulated. After presenting our methods in a first paper, a second workshop took place in Mexico City in December 2003, funded by a bilateral DFG/CONACYT travel grant. The format of this second workshop largely followed the first one, with talks and discussion sessions accompanied by generously scheduled 'work sessions' for collaboative work and informal discussion in subgroups. This format has proven exceptionally successful and has been enthusiastically acclaimed by most participants. The main purposes of the second workshop was to discuss first results and prepare their publication in a second paper, the discussion of tests for boundary treatments in numerical relativity, and the organization of future activities. AEI members and long-time guest Jeffrey Winicour played important roles in all discussions. One organisational result was the creation of an eight-people steering committee, which includes Denis Pollney, Sascha Husa and Jeffrey Winicour. A plan was worked out to produce a results paper, with Sascha Husa chosen as lead author, responsible for completing the paper.

Workshop on Spectral Methods

At the first yearly SFB/TR7 meeting, October 9-10, 2003 in Tübingen, "spectral methods" turned out as one of the buzzwords that appeared in many talks. When the potential availability of funding for further workshops in 2003 was announced, a bold team consisting of A. Zenginoglu (AEI), J. Frauendiener and S. Husa (later joined by C. Schneemann (AEI)) started to apply for support for a workshop on "pseudospectral methods in numerical relativity", to take place at AEI from October 27-29. Remarkably, this workshop, which consisted of lectures and "practical hands-on coding sessions", and was prepared in only three weeks, worked out well for participants and organisers. This was possible only through the heroic efforts of A. Zenginoglu, C. Schneemann and J. Ventrella (LSU), who developed the hands-on exercises and also because a number of experts were already present at AEI, as guests, students or postdocs in various groups, e.g. Joachim Frieben, Reinhard Prix and Otto Kreiss.

Meeting on "Relativistic Elasticity"

On 09./10. October 2003 a small workshop on "Relativistic Elasticity" was organized by R. Beig and B. Schmidt. Its main goal was to introduce mathematicians working in classical elasticity to relativistic elasticity and on the other hand, for the relativists, to learn about the methods used in classical theory. The following talks were given: Relativistic Elasticity - an Introduction (J. Ehlers, AEI), The Regularity of Minimizers in Elasticity (J. Ball, Oxford), Selfgravitating Static Elastic Bodies (B. Schmidt, AEI), How Large can a Mountain on a Neutron Star be? (C. Cutler, AEI), Perfectly Pinned Neutron Superfluid in Elastic Solid Star Crust (B. Carter, Paris), The Incompressible Limit in Non-relativistic Elastodynamics (T. Sideris, Santa Barbara), Local Evolution for Relativistic Elasticity (R. Beig, Vienna), Rigidity Estimates in Elasticity and for nearly Umbilical Surfaces (S. Müller, Leipzig), Post-Newtonian Theory of Astronomical Elastic Deformable Bodies (M. Soffel, Dresden). The meeting was well appreciated by the participants as many interesting discussions showed.

Vacation Course, 3.-14. March 2003

The two 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 done their "Vordiplom" and took place in the lecture hall of the Max Planck campus in Golm. In 2003 the first course was held about "Introduction into General Relativity" (Jürgen Ehlers, Bernd Schmidt). The second course led by Thomas Thiemann - was entitled "Introduction into canonical quantization of General Relativity".

For the first time 70 students (26 from Berlin-Potsdam, 49 from all over Germany) took part in the vacation course. Once more the AEI could provide some financial support. The courses were again greatly appreciated such that continuation is planned.

Jordan Symposium

On the initiative of Jürgen Ehlers, the Akademie der Wissenschaften und der Literatur (Mainz), the AEI and the Max Planck Institute for the History of Science (Berlin) organized an international symposium in memory of Pascual Jordan. The symposium was held during October 29 to 31, 2003 at the Mainz academy.

Pascual Jordan (1902-1980) was one of the founders of quantum mechanics. In collaboration with Max Born and Werner Heisenberg he formulated in 1925 the basic laws of matrix mechanics. In 1927 Jordan created, at about the same time as Dirac, the transformation theory, a common framework for matrix mechanics, wave mechanics and other versions of quantum mechanics. This work prepared the way towards the comprehensive Hilbert space formulation. In the following years he was one of the leading figures in developing the early versions of quantum field theory. After world war II, Jordan founded a seminar on general relativity at the university of Hamburg, which became a center for GR in Germany. Jordan's activities during the Nazi era, but also his political engagement in the mid fifties in the German Federal Republic made him a controversial public figure. (See also Ehlers' essay on Jordan in the annual report of the AEI for 2002.)

During the symposium some of Jordan's major scientific contributions, his interaction with colleagues and students, his role as a communicator of science and his political activities have been reviewed and, sometimes, heatedly discussed.

Campus Info Day

On May 6, 2003, the AEI organized a Campus Info Day on behalf of all the scientific institutes on the Golm campus. These include two other Max Planck Institutes (for Colloids and Interfaces, and for Molecular Plant Physiology), and the Fraunhofer Institute for Applied Polymer Research.

The idea was to increase communication among the staff of the different institutes, who normally see one another only in the canteen. There are many areas of overlapping interests, particularly in chemistry and computing, and the Info Day was an opportunity for staff to get to know what related work was going on elsewhere on the campus. Each institute had about 45 minutes to present a survey of its interests and expertise, and the formal presentations were then followed by a social event with snacks, beer, and wine. It is hoped that the event will be repeated periodically so that we can keep track of changing research directions.

Open Day at the Max Planck Campus on August 30, 2003

On a sunny Saturday in August, the three Max Planck Institutes and the Fraunhofer Institute for Applied Polymer Research held the Open Day at the campus in Golm. This event took place for the third time and can be called tradition meanwhile.

The Minister for Science, Research and Culture of Brandenburg, Prof. Johanna Wanka gave an address in the central building of the campus. She visited the institutes and met young visitors in a special children's area. Here the children discovered physics, mathematics, chemistry and biology in a playful way.

The institutes provided lots of experiments and games explaining science. Some children puzzled about geometrical forms and the secret of gravitation for a long time. The AEI placed emphasis on the understanding of geometry providing games like the Tower of Hanoi, Devil's Knot or Lucifer's Friend. As in 2002 the children area was one of the most frequented places. Besides this program especially organized for young people, the AEI presented an insight into the theory of relativity, the world of gravitational waves and the research on black holes. The program ranged from talks about the basics on Einstein's theory to supercomputer simulations and a virtual tour showing the gravitational wave detector GEO600 via video conference.

Prominent politicians and young scientists at the Open Day.

Living Reviews BackOffice
... spreading the Living Reviews concept to other areas of research

'Living Reviews' is a unique editorial concept for the publication of high quality scientific content. 'Living' review articles are (a) as the name suggests, review articles, providing insightful surveys on research progress in the fields they cover and guiding readers to the most important literature in the field (b) solicited from experts in the field by an international editorial board and subject to peer review and (c) most important, 'living' which means that the articles are regularly updated by their authors to incorporate the latest developments in the field. This concept has been introduced first with the electronic journal Living Reviews in Relativity, which is being published by the AEI since 1998. To transfer the Living Reviews concept to other areas of research, the Living Reviews BackOffice, a joint project between the AEI and the Heinz Nixdorf Center for Information Management in the Max Planck Society (ZIM), has been founded. 2003 has been a very successful year for the BackOffice, as the first Living Reviews sister journal in the MPG could be established, important software development work has been completed, and last but not least the successful publication of Living Reviews in Relativity has been continued. In the following individual areas of the BackOffice activities are being reviewed:

Living Reviews in Relativity

... highly valued information resource for the relativity community

Seven new review articles have been published in 2003, including three updates. 15 new authors have accepted the invitation to write and maintain a 'living' review article. Overall, 60 new articles are now in preparation. At a glance, the journal's position in the field can be impressively verified by the following numbers (Status Sep 2003): The total number of article downloads grew to about 30.000 with an increase of 48% in 11 months. In the same time the number of articles and preprints citing reviews published in LRR increased by 60% to 920. More than 700 readers are subscribed to the journal's mailing list which announces the publication of new articles.

The annual LRR editorial board meeting was held on 19 September at the AEI, with board members Bernard Schutz, Bobby Beig, Bala Iyer, Joachim Wambsganss, Cliff Will and the Living Reviews staff attending.

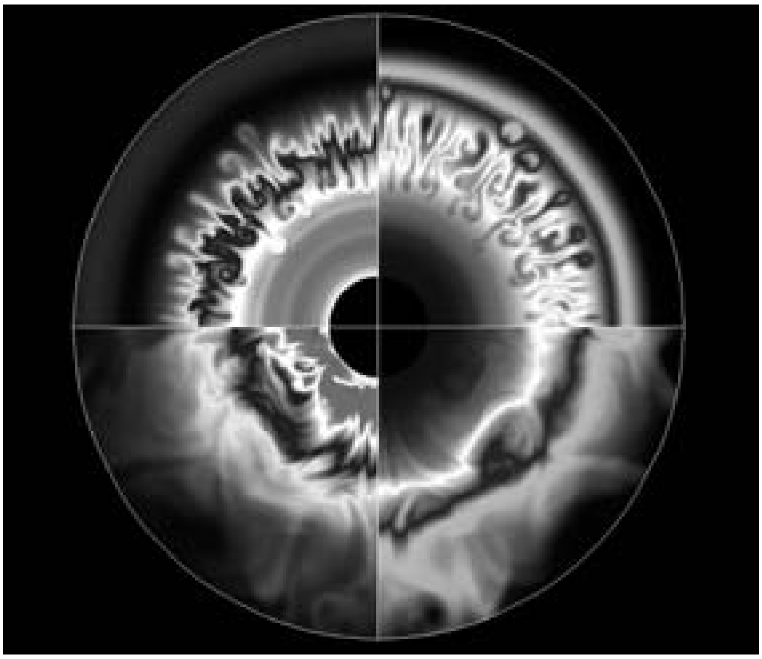


Image from a 'living' review on "Gravitational Waves from Gravitational Collapse" by K. New

LIVING REVIEWS

in solar physics

Living Reviews in Solar Physics

... first Living Reviews sister journal in the MPG

The most important result of our work in 2003 was undoubtedly the founding of Living Reviews in Solar Physics. An editorial board of internationally renowned experts in the field has been recruited by editor-in-chief Sami Solanki, which met for the constituting editorial board meeting of the new journal on 14 March 2003 in the Max Planck Institute for Aeronomy, Katlenburg-Lindau. Meanwhile about 50 article topics are in preparation. The web site for the new journal has been established. The former base url of Living Reviews in Relativity () is now the Living Reviews portal site, with the individual journals available at and respectively.

Software development

... making Living Reviews publishing tools available to the public

Living Reviews offers an advanced web presentation for its articles. The overhaul and generalization of the publishing software was an important part of the BackOffice work in 2003. Since November 2003 the new software (ePublishing Toolkit / ePubTk) is in production for Living Reviews in Relativity.

Besides streamlining and optimizing the internal article processing work flow, also many new features for the online version of articles have been introduced with the new software, such as automatic tracking of amendments, support of special types of footnotes, indexes for figures and movies and so on. ePubTk processes articles written in LaTeX with bibliographies prepared in BibTeX. Many hooks are provided for configuration using technologies like XML/XSLT, TeX or Python, in order to achieve different functionalities and layout for the various presentation formats (HTML, PDF, PS). ePubTK 1.0 is available under the GNU public license.

MoWGLI

... cutting edge research on semantic markup of scientific articles

As Living Reviews contribution to the EU-funded MoWGLI project (Mathematics on the Web – Get it by Logic and Interface), Dr. Romeo Anghelache developed the authoring tool **Hermes**, which converts LaTeX sources to XML. Hermes (current version 0.8.3) is prepared to handle arbitrary TeX and LaTeX mathematical expressions in LaTeX written documents. It outputs a mixture of presentation and content MathML, depending on the macros used in the source document. Hermes complements the LaTeX system: it helps the authors to enrich the semantics of their work, preserving the rendering quality. Its main purpose is to assist the authors of scientific articles in making their work available to the public, on the Internet. A complete volume of Zentralblatt Mathematik has already been converted to XML using this tool, also the test conversion of Living Reviews in Relativity articles has been very successful. Hermes is acknowledged by the W3C and is available under the GNU public license.

... more highlights

In 2003 Living Reviews has been submitted to the annual scholarly publishing award granted by the Association of Learned and Professional Society Publishers. It has been shortlisted in the category of "Publishing Innovation", together with strong competitors like Nature's Signaling Gateway. The Living Reviews BackOffice was present at the Berlin Open Access Conference (Berlin, 22-24 Oct 2003), with both an information display and a talk held by Bernard Schutz – attracting a lot of attention on this important conference.

Christina Weyher

Resources:

Living Reviews:
http://www.livingreviews.org

Living Reviews BackOffice:
http://www.zim.mpg.de/projects/livrevbo/index.html

ePublishing Toolkit:
http://www.zim.mpg.de/projects/toolkit/index.html

Hermes:
http://relativity.livingreviews.org/Info/AboutLR/mowgli.html

Academic Achievements

Doctoral Thesis

Simone Calogero finished his doctoral thesis on “Models for isolated systems of collisionless matter” supervised by Dr. habil. Alan Rendall. He was awarded his PhD from the Università degli studi di Milano, Italy.

Doctoral Thesis

Thomas Dramlitsch completed his doctoral thesis on “Distributed computations in a dynamic, heterogeneous Grid environment” supervised by Prof. Ed Seidel. He was awarded his PhD from the Universität Potsdam.

Doctoral Thesis

Thomas Fischbacher was awarded his PhD from the Humboldt-Universität Berlin. He wrote his doctoral thesis on “Mapping the vacuum structure of gauged maximal supergravities - an application of high-performance symbolic algebra” supervised by Prof. Hermann Nicolai.

Doctoral Thesis

Andreas Freise was awarded his PhD from the Universität Hannover. He wrote his doctoral thesis on ”The next generation of interferometry: Multi frequency modelling, control concepts and implementation” under the supervision of Dr. Benno Willke.

Doctoral Thesis

Hartmut Grote was awarded his PhD from the Universität Hannover. He wrote his doctoral thesis on ”Making it Work: Second Generation Interferometry in GEO600!” under the supervision of Dr. Harald Lück and Dr. Benno Willke.

Doctoral Thesis

Gerd Lanfermann completed his doctoral thesis on “Nomadic Migration: a service environment for autonomic computing on the Grid” supervised by Prof. Ed Seidel. He was awarded his PhD from the Universität Potsdam.

Doctoral Thesis

Ari Pankiewicz finished his PhD thesis on ”Strings on planes wave backgrounds” supervised by Prof. Stefan Theisen. He was awarded his PhD from the Humboldt-Universität Berlin.

Doctoral Thesis

Markus Pössel was awarded his PhD from the Universität Hamburg. His doctoral thesis on “Hidden symmetries in five-dimensional supergravity” was supervised by Prof. Hermann Nicolai.

Doctoral Thesis

Thomas Quella completed his PhD thesis on “Asymmetrically gauged coset theories and symmetry breaking D-branes - New boundary conditions in conformal field theory” at Humboldt-Universität Berlin. His thesis was supervised by Prof. Hermann Nicolai.

Doctoral Thesis

Volker Marcel Quetschke was awarded his PhD from the Universität Hannover. He wrote his doctoral thesis on ”Korrelationen von Rauschquellen bei Nd:YAG Lasersystemen” under the supervision of Dr. Benno Willke.

Diploma Thesis

Johannes Brunnemann has completed his diploma in physics at the Humboldt-Universität Berlin. The thesis was written at the AEI under the supervision of Dr. habil. Thomas Thiemann on ”Spectral Analysis of the Volume Operator in Canonical Quantum General Relativity”.

Diploma Thesis

Stefan Hild graduated in physics from the Universität Hannover. He wrote his diploma thesis under the supervision of Dr. Harald Lück and Dr. Andreas Freise on ”Thermisch durchstimmbares Signal-Recycling für den Gravitationswellendetektor GEO600”.

Diploma Thesis

Bernd Reimann wrote his diploma thesis at the AEI under the supervision of Prof. Ed Seidel on ”Maximal Slicing of Schwarzschild”. He completed his diploma in physics at the Universität Potsdam.

Diploma Thesis

Matthias Rudolf graduated in physics from the Universität Hannover. He wrote his diploma thesis under the supervision of Dr. Rolf-Hermann Rinkleff on ”Gitterunterstützter Diodenlaser mit externem Resonator”.

Diploma Thesis

Rafal Swiderski wrote his diploma thesis at the AEI under the supervision of Prof. Gerhard Huisken on ”Inverser mittlerer Krümmungsfluss und das Yamabe-Problem in der konformen Geometrie”. He graduated in mathematics from the Universität Tübingen.

Diploma Thesis

Vinzenz Wand graduated in physics from the Universität Hannover. He wrote his diploma thesis under the supervision of Dr. Gerhard Heinzel and Dipl.-Phys. Sascha Skorupka on ”Heterodyninterferometrie und Phasenauslesung für die wissenschaftliche Weltraummission SMART-2”.

The Fachbeirat

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.

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Ramona Wittwer	Accountant (Golm)
Dietlind Witzger	Charwoman (Golm)
Rui Zhu	Programmer (Golm)
Heiko zur Mühlen	Electronic Technician (Hannover)
Karl-H. Zwick-Meinheit	Electronic Technician (Hannover)

Guest Scientists in Golm

Aichelburg, Peter Christian	Universität Wien	01/10/2003-31/10/2003
Alic, Daniela	University of Timisoara	01/10/2003-31/12/2003
Allen, Bruce	University of Wisconsin	22/06/2003-12/12/2003
Andersson, Lars	University of Miami	01/12/2003-31/12/2003
Armano, Michele	Carlo Gavazzi Space SpA, Milan	08/02/2003-11/02/2003
Armoni, Adi	CERN, Geneva	15/08/2003-25/08/2003
Asada, Hideki	Hirosaki University	20/05/2003-25/05/2003
Ashtekar, Abhay	Pennsylvania State University	26/10/2003-01/11/2003
Astone, Pia	University of Rome	30/03/2003-04/04/2003
Athanassenas, Maria	Monash University, Australia	06/01/2003-20/01/2003
		15/09/2003-26/11/2003
Bartnik, Robert	University of Canberra	12/09/2003-02/11/2003
Barve, Sukratu	Physical Research Laboratory, Ahmedabad	30/06/2003-10/08/2003
Baulieu, Laurent	LPTHE, Paris	07/11/2003-15/11/2003
Becerril, Ricardo	University of Michoacana, Mexico	25/06/2003-03/07/2003
Beig, Robert	Universität Wien	01/09/2003-20/09/2003
Berezin, Victor	Institute for Nuclear Research, Moscow	04/01/2003-28/02/2003
Bernal, Argelia	CINVESTAV, Mexico	28/07/2003-15/08/2003
Bicak, Jiri	Charles University, Prague	01/09/2003-30/12/2003
Bishop, Nigel	University of South Africa, Pretoria	21/01/2003-04/02/2003
		02/06/2003-23/06/2003
ˇ		01/08/2003-05/10/2003
Bondarescu, Ruxandra	NCSA, Champaign-Urbana	18/12/2002-12/01/2003
Boyarsky, Alexey	Niels Bohr Institute, Copenhagen	22/09/2003-29/09/2003
		13/10/2003-31/10/2003
Buric, Maja	University of Belgrade	01/06/2003-30/06/2003
Calabrese, Gioel	Louisiana State University	16/06/2003-22/06/2003
Chen, Yanbei	California Institute of Technology	10/01/2003-25/01/2003
		23/02/2003-26/02/2003
Coccia, Eugenio	University of Rome	31/03/2003-04/04/2003
Conrady, Florian	Universität Heidelberg	03/05/2003-10/05/2003
Cote, Jean-Claude	National Research Council, Canada	31/08/2003-15/09/2003
Cvetic, Mirjam	University of Pennsylvania	04/01/2003-09/01/2003
D'Alessandro, Marco	University of Rome	08/12/2003-12/12/2003
de Riese, Mathias	Universität Hamburg	05/01/2003-12/01/2003
Deshingkar, Shrirang	University of South Africa, Pretoria	18/08/2003-31/08/2003
de Wit, Bernard	Utrecht University	15/10/2003-21/11/2003
Diener, Peter	Louisiana State University	05/11/2003-15/11/2003
Dijkstra, Fokke	Utrecht University	23/05/2003-28/05/2003
Domainko, Wilfried	Institut für Astrophysik, Innsbruck	25/05/2003-29/05/2003
Englert, Francois	University of Brussels	07/12/2003-14/12/2003
Evslin, Jarah	INFN, Pisa	15/01/2003-22/01/2003
Feingold, Alex	State University of New York at Binghamton	07/03/2003-15/03/2003
Flume, Reinald	Universität Bonn	15/09/2003-15/10/2003
Font, Anamaria	University of Caracas	01/10/2003-31/12/2003
Freidel, Laurent	Perimeter Institute, Waterloo	28/10/2003-02/11/2003
Geroch, Robert	University of Chicago	01/04/2003-14/04/2003
Giesel, Kristina	Universität Dortmund	12/05/2003-17/05/2003
Giulini, Domenico	Universität Freiburg	26/10/2003-01/11/2003
Green, Michael	DAMTP, Cambridge, UK	23/11/2003-26/11/2003
Gundlach, Carsten	University of Southampton, UK	20/01/2003-24/01/2003
Günther, Uwe	Forschungszentrum Rossendorf	03/02/2003-08/02/2003
Hawley, Scott	University of Texas at Austin	05/05/2003-30/05/2003
Hein, Bernhard	Universität Tübingen	09/03/2003-13/03/2003
		19/10/2003-23/10/2003
Helling, Robert	DAMTP, Cambridge, UK	04/08/2003-15/08/2003
Henneaux, Marc	University of Brussels	26/10/2003-30/10/2003
Hewitson, Martin	Glasgow University	29/09/2003-01/10/2003
Hollands, Stefan	University of Chicago	16/12/2003-20/12/2003
Hoppe, Jens	Royal Institute of Technology, Stockholm	05/03/2003-11/03/2003
		11/04/2003-30/04/2003
		26/06/2003-06/07/2003
Howe, Paul	Kings College, London	01/12/2003-14/12/2003
Huff, Robert	Rice University	15/05/2003-17/07/2003
Hujeirat, Ahmad	Max-Planck-Institut für Astronomie, Heidelberg	27/01/2003-28/01/2003
Iorgov, Mykola	Bogolyubov Institute for Theoretical Physics, Kiev	09/04/2003-19/04/2003
Iyer, Bala	Raman Research Institute, Bangalore	18/09/2003-23/09/2003
Janssen, Michael	University of Minnesota	04/01/2003-19/01/2003
Jorjadze, George	A. Razmadze Mathematical Institute, Tbilisi	11/11/2003-11/12/2003
Kapferer, Wolfgang	Institut für Astrophysik, Innsbruck	25/05/2003-29/05/2003
Kaplunovsky, Vadim	University of Texas at Austin	20/07/2003-26/07/2003
Kazakov, Vladimir	ENS, Paris	21/07/2003-17/08/2003
Keller, Rainer	Universität Stuttgart	09/07/2003-10/07/2003
Keurentjes, Arjan	University of Brussels	03/11/2003-09/11/2003
Khalatnikov, Isaak	Landau Institute for Theoretical Physics, Moscow	02/09/2003-30/11/2003
Klingenberg, Wilhelm	Durham University, UK	01/12/2003-31/12/2003
Kobras, Daniel	Universität Tübingen	05/05/2003-09/05/2003

Guest Scientists

Kokkotas, Kostas	Aristotle University, Thessaloniki	25/01/2003-09/02/2003
Kol, Barak	Hebrew University of Jerusalem	10/02/2003-11/02/2003
Korotkin, Dimitrii	Concordia University, Montreal	04/12/2003-08/12/2003
Kostov, Ivan	CEA, Saclay	15/07/2003-09/08/2003
Kreiss, Heinz-Otto	University of California, Los Angeles	01/10/2003-31/10/2003
Kristjansen, Charlotte	Niels Bohr Institute, Copenhagen	01/10/2002-31/03/2003 22/10/2003-07/11/2003
Kroeger, Pawel	Universidad Tecnica Valparaiso	20/01/2003-22/01/2003
Krtous, Pavel	Charles University, Prague	10/11/2003-29/11/2003
Kuba, Martin	Masaryk University, Brno	07/07/2003-14/07/2003
Kuwert, Ernst	Universität Freiburg	09/03/2003-13/03/2003
Lavrelashvili, George	A. Razmadze Mathematical Institute, Tbilisi	04/04/2003-03/05/2003
Lee, Bum-Hoon	Sogang University, Seoul	15/12/2002-15/02/2003
Lerche, Wolfgang	CERN, Geneva	14/12/2003-20/12/2003
Leski, Szymon	PAN, Warsaw	23/01/2003-25/01/2003
Lewandowski, Jerzy	Warsaw University	26/10/2003-31/10/2003
Lindner, Peggy	Universität Stuttgart	09/07/2003-10/07/2003
Louko, Jorma	University of Nottingham	31/03/2003-06/04/2003
Lun, Toni	Monash University, Australia	22/04/2003-04/06/2003
Mack, Katherine	California Institute of Technology	27/06/2003-22/08/2003
Madore, John	University of Paris (South)	06/06/2003-30/06/2003
Maison, Dieter	MAX-PLANCK-INSTITUT für Physik, München	29/10/2003-31/10/2003
Majumdar, Parthasarathi	Institute of Mathematical Sciences, Chennai	16/07/2003-02/08/2003
Matos, Tonatiuh	CINVESTAV, Mexico	11/07/2003-11/08/2003
Matschull, Hans-Juergen	Universität Mainz	18/03/2003-23/03/2003
Metzger, Jan	Universität Tübingen	26/01/2003-30/01/2003 18/05/2003-22/05/2003 28/07/2003-31/07/2003
Moncrief, Vincent	Yale University	21/11/2003-30/11/2003
Mukhanov, Slava	Universität München	01/06/2003-03/06/2003
Müller, Matthias	Universität Stuttgart	09/07/2003-10/07/2003
Nerozzi, Andrea	Portsmouth University	06/04/2003-13/04/2003 02/11/2003-29/11/2003
Niedermaier, Max	University Tours	26/10/2003-01/11/2003
Noundjeu, Pierre	University of Yaounde	05/09/2003-29/11/2003
Odintsov, Sergei	Tomsk University	16/01/2003-14/02/2003
Oechslin, Roland	MAX-PLANCK-INSTITUT für Astrophysik, Garching	24/05/2003-29/05/2003
Oeckl, Robert	Centre de Physique Theorique, Marseille	07/05/2003-09/05/2003
Palenzuela, Carlos	Universitat de les Illes Balears, Mallorca	24/02/2003-02/03/2003
Perelomov, Askold	ITEP, Moscow	13/04/2003-16/04/2003
Pfister, Herbert	Universität Tübingen	19/10/2003-29/10/2003
Powell, Gavin	Cardiff University	10/08/2003-09/11/2003 13/08/2003-21/08/2003
Preunkert, Marc	Universität Tübingen	26/10/2003-09/11/2003
Quella, Thomas	Geneva University	01/11/1999-31/01/2003 27/02/2003-08/03/2003
Reall, Harvey	Queen Mary University of London	06/05/2003-09/05/2003
Renn, Jürgen	MAX-PLANCK-INSTITUT für Wissenschaftsgeschichte, Berlin	04/01/2003-19/01/2003
Ruchayskiy, Oleg	IHES, Paris	18/10/2003-24/10/2003
Sachs, Ivo	Universität München	24/11/2003-30/11/2003
Sahlmann, Hanno	Pennsylvania State University	03/01/2003-19/01/2003 27/10/2003-01/11/2003
Samtleben, Henning	Utrecht University	13/02/2003-20/02/2003 30/11/2003-03/12/2003
Sarbach, Olivier	Louisiana State University	03/11/2003-09/11/2003
Sathyaprakash, Bangalore	Cardiff University	18/06/2003-20/06/2003
Savvidis, George	National Research Center Demokritos, Athens	19/03/2003-27/03/2003
Schubert, Christian	University of Texas - Pan American, Edinburgh	14/06/2003-17/06/2003
Schutz, John	La Trobe University, Australia	22/09/2003-30/09/2003
Schweizer, Thomas	IFAE, Barcelona	01/06/2003-30/06/2003
Sen, Asoke	Assam University, Silchar	26/11/2003-28/11/2003
Serban, Didina	CEA, Saclay	15/07/2003-07/08/2003
Shomer, Assaf	University of Amsterdam	11/05/2003-14/05/2003
Siemens, Xavier	University of Wisconsin	11/08/2003-16/08/2003 21/10/2003-30/10/2003
Simon, Leon	Stanford University	13/07/2003-02/08/2003
Sinestrari, Carlo	University of Rome II	16/03/2003-12/04/2003 18/05/2003-24/05/2003 22/06/2003-04/07/2003 14/09/2003-19/09/2003
Sintes-Olives, Alicia	Universitat de les Illes Balears, Mallorca	24/02/2003-31/08/2003
Sochichiu, Corneliu	Instituto Nazionale de Fisica Nucleare, Rome	08/12/2003-19/12/2003
Sokatchev, Emery	Theoretical Physics Laboratory of Annecy-Le-Vieux	01/12/2003-04/01/2004
Sonnenschein, Jacob	Tel Aviv University	07/10/2003-21/10/2003
Stewart, John	Cambridge University	26/03/2003-23/04/2003
Sutton, Patrick	Pennsylvania State University	21/08/2003-25/08/2003

Guest Scientists

Szabolk, Marka	California Institute of Technology	22/08/2003-26/08/2003
Takahashi, Ryoji	Theoretical Astrophysics Center, Copenhagen	05/05/2003-09/05/2003
		08/09/2003-12/09/2003
Tegankong, David	University of Yaounde	04/03/2003-31/05/2003
Tiglio, Manuel	Pennsylvania State University	12/03/2003-14/03/2003
Turcu, Gabriela	University of Timisoara	15/07/2003-15/09/2003
Urena, Luis	Sussex University	22/06/2003-21/07/2003
Valluri, S. Ram	University of Western Ontario	11/08/2003-14/08/2003
Vanhove, Pierre	CERN, Geneva	07/06/2003-13/06/2003
Vulcanov, Dumitru	University of Timisoara	09/01/2003-19/02/2003
		02/05/2003-09/06/2003
		01/09/2003-04/11/2003
Whelan, John	Loyola University New Orleans	31/05/2003-17/08/2003
Will, Clifford	Washington University, St. Louis	18/09/2003-23/09/2003
Winicour, Jeffrey	University of Pittsburgh	01/02/2003-31/03/2003
		01/10/2003-31/10/2003
Wulkenhaar, Raimar	MAX-PLANCK-INSTITUT für Mathematik in den Naturwissenschaften, Leipzig	01/12/2003-02/12/2003
Zarembo, Konstantin	Uppsala University	04/08/2003-13/08/2003
Zhang, Yang	University of Science and Technology of China, Hefei	01/08/2003-31/08/2003
Zhuk, Alexander	University of Odessa	27/01/2003-10/02/2003
Zink, Burkard	Max-Planck-Institut für Astrophysik, Garching	24/05/2003-29/05/2003

Guest Scientists in Hannover

Cagnoli, Geppo	University of Glasgow	20/07/2003-25/07/2003
Chen, Yanbei	Caltech	09/02/2003-21/02/2003
Churches, David	Cardiff University	03/09/2003-05/09/2003
Crooks, David	University of Glasgow	03/09/2003-05/09/2003
Dranilishin, Shtefan	Moskow University	18/08/2003-31/08/2003
Hewitson, Martin	University of Glasgow	21/03/2003-05/04/2003
		27/04/2003-31/05/2003
		10/08/2003-27/10/2003
Khalili, Farid	Moskow University	18/08/2003-27/08/2003
Parson; Mattew	University of Glasgow	17/08/2003-22/08/2003
Plissi, Michael	University of Glasgow	20/07/2003-25/07/2003
		03/09/2003-05/09/2003
Reitze, David	Louisiana State University	23/10/2003-27/10/2003
Vyatchanin, Sergey	Moskow University	18/08/2003-27/08/2003
Gordon-Wilson, Arlene	Bar-Ilan University, Ramat Gan	19/10/2003-26/10/2003
Goren, Chani	Bar-Ilan University, Ramat Gan	19/10/2003-26/10/2003

Publications by the Institute

Max-Planck-Institut für Gravitationsphysik (Ed.)	Living Reviews in Relativity, Living Reviews in Relativity 6 (2003), http://www.livingreviews.org

Publications by AEI Members and Guest Scientists

Abbott, B., Abbott, R., Adhikari, R., Allen, B., Amin, R., Anderson, S.B., Anderson, W.G., Araya, M., Armandula, H., Asiri, F., Aufmuth, P., Aulbert, C., Babak, S., Balasubramanian, R., Ballmer, S., Barish, B.C., Barker, D., Barker-Patton, C., Barnes, M., Barr, B., Barton, M.A., Bayer, K., Beausoleil, R., K Belczynski, K., Bennett, R., Berukoff, S.J., Betzwieser, J., Bhawal, B., Billingsley, G., Black, E., Blackburn, K., Bland-Weaver, B., Bochner, B., Bogue, L., Bork, R., Bose, S., Brady, P.R., Brau, J.E., Brown, D.A., Brozek, S., Bullington, A., Buonanno, A., Burgess, R., Busby, D., Butler, W.E., Byer, R.L., Cadonati, L., Cagnoli, G., Camp, J.B., Cantley, C.A., Cardenas, L., Carter, K., Casey, M.M., Castiglione, J., Chandler, A., Chapsky, J., Charlton, P., Chatterji, S., Chen, Y., Chickarmane, V., Chin, D., Christensen, N., Churches, D., Colacino, C., Coldwell, R., Coles, M., Cook, D., Corbitt, T., Coyne, D., Creighton, J.D.E., Creighton, T.D., Crooks, D.R.M., Csatorday, P., Cusack, B.J., Cutler, C., D'Ambrosio, Danzmann, K., Davies, R., Daw, E., DeBra, D., Delker, T., DeSalvo, R., Dhurandar, S., Díaz, M., Ding, H., Drever, R.W.P., Dupuis, R.J., Ebeling, C., Edlund, J., Ehrens, P., Elliffe, E.J., Etzel, T., Evans, M., Evans, T., Fallnich, C., Farnham, D., Fejer, M.M., Fine, M., Finn, L.S., Flanagan, E., Freise, A., Frey, R., Fritschel, P., Frolov, V., Fyffe, M., Ganezer, K.S., Giaime, J.A., Gillespie, A., Goda, K., González, G., Goßler, S., Grandclément, P., Grant, A., Gray, A.C., Gretarsson, A.M., Grimmett, D., Grote, H., Grunewald, S., Guenther, M., Gustafson, E., Gustafson, R., Hamilton, W.O., Hammond, M., Hanson, J., Hardham, C., Harry, G., Hartunian, A., Heefner, J., Hefetz, Y., Heinzel, G., Heng, I.S., Hennessy, M., Hepler, N., Heptonstall, A., Heurs, M., Hewitson, M., Hindman, N., Hoang, P., Hough, J., Hrynevych, M., Hua, W., Ingley, R., Ito, M., Itoh, Y., Ivanov, A., Jennrich, O., Johnson, W.W., Johnston, W., Jones, L., Jungwirth, D., Kalogera, V., Katsavounidis, E., Kawabe, K., Kawamura, S., Kells, W., Kern, J., Khan, A., Killbourn, S., Killow, C.J., Kim, C., King, C., King, P., Klimenko, S., Kloevekorn, P., Koranda, S., Kötter, K., Kovalik, J., Kozak, D., Krishnan, B., Landry, M., Langdale, J., Lantz, B., Lawrence, R., Lazzarini, A., Lei, M., Leonhardt, V., Leonor, I., Libbrecht, K., Lindquist, P., Liu, S., Logan, J., Lormand, M., Lubinski, M., Lück, H., Lyons, T.T., Machenschalk, B., MacInnis, M., Mageswaran, M., Mailand, K., Majid, W., Malec, M., Mann, F., Marin, A., Márka, S., Maros, E., Mason, J., Mason, K., Matherny, O., Matone, L., Mavalvala, N., McCarthy, R., McClelland, D.E., McHugh, M., McNamara, P., Mendell, G., Meshkov, S., Messenger, C., Mitselmakher, G., Mittleman, R., Miyakawa, O., Miyoki, S., Mohanty, S.,	First upper limits from LIGO on gravitational wave bursts. Classical and Quantum Gravity (accepted). E-print-Archive: gr-qc/0312056

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Invited Conference Talks Given by AEI Members

Aufmuth, P.	The Search for Gravitational Waves. Status and Perspectives / 10 June 2003 / 4th International Conference on Physics Beyond the Standard Model, Tegernsee (Germany)
Bojowald, M.	Two-dimensional models in loop quantum gravity / 23 September 2003 / Workshop on Gravity in Two Dimensions, ESI Vienna (Austria)
Bojowald, M.	Classical solutions for Poisson Sigma Models on a Riemann surface / 9 October 2003 / Workshop on Gravity in Two Dimensions, ESI Vienna (Austria)
Bojowald, M.	Loop quantum cosmology / 30 October 2003 / Symposium ”Strings meet Loops”, AEI, Golm (Germany)
Cutler, C.	Gravitational Waves from Neutron Stars with Large Toroidal B-fields / 17 March 2003 / 67. Physikertagung der DPG, Hannover (Germany)
Cutler, C.	Gravitational Waves from Neutron Stars / 5 April 2003 / American Physical Society April meeting, Philadelphia (USA)
Cutler, C.	How Large Can a Mountain on a Neutron Star Be? / 9 October 2003 / Workshop on Elasticity, AEI, Golm (Germany)
Dain, S.	Initial data for black hole collisions / 11 February 2003 / Mathematical Aspects of General Relativity, Mathematisches Forschungsinstitut Oberwolfach (Germany)
Dain, S.	Trapped surfaces as boundaries for the constraint equations / 7 July 2003 / Workshop on Penrose Inequalities, The Erwin Schrödinger Institute for Mathematical Physics, Vienna (Austria)
Dain, S.	Trapped surfaces as boundaries for the constraint equations / 7 August 2003 / Numeric and analytic properties of the vacuum Einstein equations, Tübingen (Germany)
Dain, S.	Trapped surfaces as boundaries for the constraint equations / 13 August 2003 / Seventh Hungarian Relativity Workshop, Sárospatak (Hungary)
Danzmann, K.	The LISA Mission / 14 February 2003 / IoP Discussion Meeting on Gravitational-Wave Astronomy, London (UK)
Danzmann, K.	Gravitationswellenastronomie: Die ersten großen Detektoren gehen in Betrieb / 23 March 2003 / 67. Physikertagung der DPG, Hannover (Germany)
Danzmann, K.	GEO and VIRGO Joint Research and Development in EGO / 5 June 2003 / VIRGO Council Meeting, Pisa (Italy)
Danzmann, K.	Optical Technology Development in Europe / 25 June 2003 / SE7 Meeting at Goddard Spaceflight Centre, Washington (USA)
Danzmann, K.	LISA, a space based interferometer / 7 July 2003 / 5th Eduardo Amaldi Conference on Gravitational Waves, Pisa (Italy)
Danzmann, K.	Status of GEO600 /19 August 2003 / LSC Meeting, Hannover (Germany)
Danzmann, K.	Gravitationswellenastronomie / 18 September 2003 / Astroteilchen-Workshop, Karlsruhe (Germany)
Danzmann, K.	Space Detection of Gravitational Waves / 6 October 2003 / 8th Astroparticle, Particles, Space Physics, Detectors and Medical Physics Applications, Como (Italy)
Danzmann, K.	LISA and LISA-Pathfinder, an Observatory for Low Frequency Gravitational Waves / 7 October 2003 / ESTEC Future Missions Jamboree, Nordwijk (The Netherlands)
Danzmann, K.	The European Advanced Gravitational Wave Detector Network / 25 November 2003 / APPEC Meeting, München (Germany)
Friedrich, H.	Asymptotically Simple Spacetimes / 18 June 2003 / First Joint Meeting RSME-AMS, Sevilla (Spain)
Friedrich, H.	Conformal Einstein Evolution / 25 June 2003 / Program on: Nonlinear Hyperbolic Waves in Phase Dynamics and Astrophysics, Isaac Newton Institute, Cambridge (U.K.)

Invited Conference Talks Given by AEI Members

Friedrich, H.	Asymptotics of data and solutions for Einsteins equations / 7 August 2003 / Workshop on Numerical and analytical properties of the Einstein equations, Tübingen (Germany)
Friedrich, H.	Smoothness at null infinity and structure of initial data / 1 September 2003 / International Banach Center Warsaw (Poland)
Friedrich, H.	Smoothness at null infinity and structure of initial data / 26 September 2003 / Workshop on the Cauchy problem for the Einstein equations, CRM, Université de Montreal (Canada)
Heng, I.S.	Status of GEO burst analysis efforts / 18 December 2003 / 8th Annual Gravitational Wave Data Analysis Workshop, Milwaukee (USA)
Huisken, G.	Surgery for mean curvature flow / 12 May 2003 / Conference on Geometry and Topology, Mathematisches Forschungsinstitut Oberwolfach (Germany)
Huisken, G.	Surgery for geometric evolution equations / 14 June 2003 / Annual Meeting of the Canadian Mathematical Society, University of Alberta, Edmonton (Canada)
Huisken, G.	Surgery for geometric evolution equations / 19 June 2003 / Conference in honour of E. Calabi, Palermo (Italy)
Junker, W.	Quantum field theory of the electromagnetic vector potential on curved spacetimes / 7 September 2003 / Workshop on Mathematical and Physical Aspects of Quantum Field Theories, Heinrich-Fabri-Institut, Blaubeuren (Germany)
Krasnov, K.	Black Hole Entropy in 2+1 dimensions / 27 May 2003 / Black Holes IV, Honey Harbour (Canada)
Krasnov, K.	Aspects of Negative Cosmological Constant gravity in 2+1 dimensions / 2 July 2003 / Workshop on 3D Gravity, Edinburgh (Great Britain)
Krishnan, B.	Isolated and Dynamical Horizons and Their Applications / 10 June 2003 / Gravitation: A decennial perspective, Pennsylvania State University (USA)
Krishnan, B.	Dynamical horizons: Energy, angular momentum, fluxes and balance laws / 8 April 2003 / APS April meeting, Philadelphia (USA)
Nicolai, H.	E10 and E11 and low levels: searching for a fundamental symmetry / 9 July 2003 / STRINGS 2003, Kyoto (Japan)
Nicolai, H.	Chern-Simons vs. Yang-Mills gaugings of 3d supergravities / 10 April 2003 / Workshop on New Developments in Gauge and String Theories, Siena (Italy)
Nicolai, H.	Cosmological Billiards / 29 July 2003 / Workshop on Cosmological Perturbations on the Brane", D.A.M.T.P., Cambridge (U.K.)
Nicolai, H.	Gauged supergravities in three dimensions: a panoramic overview / 24 August 2003 / Conference on Symmetries and Mysteries of M-Theory, Göteborg (Sweden)
Nicolai, H.	The hyperbolic Kac Moody algebra E10 at low levels: searching for a fundamental symmetry of physics / 18 October 2003 / Colloquium in memoriam Peter Slodowy, Mathematisches Seminar, Universität Hamburg (Germany)
Nicolai, H.	The elusive theory of quantum gravity: loops vs. strings / 29 November 2003 / Triangle Seminar on Particle Physics, Vienna (Austria)
Peeters, K.	The Ramond-Ramond sector of string theory beyond leading order / 28 August 2003 / 36th Ahrenshoop Symposium on the Theory of Elementary Particles, Akademie Berlin-Schmöckwitz (Germany)
Peeters, K.	Supergravity description of string diagrammatics / 29 October 2003 / Symposium "Strings meet Loops", AEI, Golm (Germany)
Plefka, J.	The Plane Wave String/Gauge Theory Duality / 25 March 2003 / 67. Physikertagung der DPG, Hannover (Germany)
Plefka, J.	Plane-wave matrix theory from N=4 Super Yang-Mills on RxS**3 / 25 June 2003 / Amsterdam Workshop on Strings and Quantum Gravity, University of Amsterdam (The Netherlands)

Invited Conference Talks Given by AEI Members

Plefka, J.	Plane-wave matrix theory from N=4 Super Yang-Mills RxS**3 / 16 July 2003 / Workshop Strings in the Phyrenees, Benasque (Spain)
Plefka, J.	The Plane-Wave String/Gauge Theory Duality / 29 August 2003 / 36th Ahrenshoop Symposium on the Theory of Elementary Particles, Akademie Berlin-Schmöckwitz (Germany)
Plefka, J.	The Plane Wave String/Gauge Theory Duality / 25 September 2003 / Desy Theory Workshop 2003, Hamburg (Germany)
Plefka, J.	Perspectives on M-Theory / 31 October 2003 / Symposium ”Strings meet Loops”, AEI, Golm (Germany)
Plefka, J.	N=4 Super Yang-Mills and Strings on Plane Waves / 28 February 2003 / 4th Jena Workshop on Gauge Fields and Strings, Jena (Germany)
Rendall, A.D.	Late-time asymptotics of expanding cosmological models / 23 June 2003 / Isaac Newton Institute, Cambridge (U.K.)
Rendall, A.D.	Simplification of the Einstein equations due to a cosmological constant / 17 September 2003 / Jahrestagung der Deutschen Mathematiker-Vereinigung, Rostock (Germany)
Ringström, H.	On the asymptotics of Gowdy / 11 February 2003 / Mathematical Aspects of General Relativity, Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach (Germany)
Ringström, H.	On a wave map equation arising in general relativity / 18 June 2003 / First Joint Meeting RSME-AMS, Sevilla (Spain)
Ringström, H.	On a wave map equation arising in general relativity / 29 July 2003 / XIV International Congress on Mathematical Physics, University of Lisbon (Portugal)
Rüdiger, A.	Laser Interferometer GW Detectors - A dwarf and a giant (GEO 600 and LISA) / 26 September 2003 / Thinking, Observing and Mining the Universe, Sorrento (Italy)
Schnabel, R.	Squeezed Light Enhanced Michelson Interferometer / 5 February 2003 / The 2003 Aspen Winter Conference on Gravitational Waves and their Detection, Aspen Center for Physics (USA)
Schnabel, R.	Manipulating the Quantum Noise: Squeezing Entanglement and Teleportation / 6 February 2003 / The 2003 Aspen Winter Conference on Gravitational Waves and their Detection, Aspen Center for Physics (USA)
Schutz, B.F.	Catching flies and journalists with Richard Price / 1 March 2003 / The PriceFest, University of Utah (USA)
Schutz, B.F.	Sources of gravitational waves: an overview / 23 April 2003 / Astrogravs Meeting: The Astrophysics of Gravitational Wave Sources Workshop, The Inn and Conference Center Adelphi, Maryland (USA)
Schutz, B.F.	Gravitational wave detection and radio astronomy / 23 March 2003 / Dutch Astronomy Conference, Niemegen (The Netherlands)
Schutz, B.F.	Confronting theory with gravitational wave observations / 10 June 2003 / Penn State Decennial Relativity Meeting, Center for Gravitational Physics and Geometry, Pennsylvania State University, Philadelphia (USA)
Schutz, B.F.	Gravitational waves: sources and physics / 7 July 2003 / 5th Amaldi Meeting, Pisa (Italy)
Schutz, B.F.	The gravitational wave: sources and backgrounds / 16 July 2003 / The International Astronomical Union General Assembly XXV, Sydney (Australia)
Schutz, B.F.	The future role of prestigious print journals / 20 October 2003 / Open Access Conference Berlin (Germany)
Schutz, B.F.	Living Reviews: innovative electronic publishing for the sciences / 21 October 2003 / Open Access Conference Berlin (Germany)
Seidel, E.	Enabling Science and Engineering Applications on the Grid / 13 February 2003 / Ohio Supercomputer Center, Ohio State University (USA)

Invited Conference Talks Given by AEI Members

Seidel, E.	Solving Einsteins Equations: Colliding Black Holes, Neutron Stars, and More / 14 February 2003 / Ohio Supercomputer Center, Ohio State University (USA)
Staudacher, M.	Plane wave strings, integrable spin chains, and N=4 gauge theory / 12 April 2003 / European Superstring Network Meeting, Siena (Italy)
Staudacher, M.	Integrable Super Spin Chains and Rotating Superstrings / 17 September 2003 / Baku International Conference on Gauge Fields and Strings, Baku (Azerbaijan)
Staudacher, M.	Integrable Super Spin Chains and Rotating Superstrings / 15 December 2003 / Università Autonoma, Madrid (Spain)
Tanimoto, M.	Harmonics on Compactified Homogeneous Manifolds and their Applications in General Relativity / 20 December 2003 / 5th Workshop on Singularity and Spacetime and Related Physics, Keio University, Yokohama (Japan)
Willke, B.	Status of GEO600 / 7 July 2003 / 5th Eduardo Amaldi Conference on Gravitational Waves, Pisa (Italy)

Lectures and Lecture Series Given by AEI Members

Aufmuth, P.	An der Schwelle zur Gravitationswellen-Astronomie / 7 January 2003 / Großes Physikalisches Kolloquium, Universität zu Köln (Germany)
Aufmuth, P.	Astronomie mit Gravitationswellen / 23 January 2003 / Physikalisches Kolloquium, Universität Siegen (Germany)
Aufmuth, P.	Detection of Gravitational Waves with GEO600 / 29 January 2003 / Seminar über Teilchen- und Astrophysik, Universität Zürich (Switzerland)
Aufmuth, P.	Gravitationsforschung in Hannover / 17 March 2003 / Deutsche Management Akademie, Hannover (Germany)
Aufmuth, P.	GEO600 – Nachweis von Gravitationswellen / 26 June 2003 / Heinrich-Heine-Universität, Düsseldorf (Germany)
Danzmann, K.	Physik für Studierende des Maschinenbaus / Wintersemester 2002/03 / Universität Hannover (Germany)
Danzmann, K.	Laserinterferometrie und Gravitationswellendetektoren / Sommersemester 2003 / Universität Hannover (Germany)
Danzmann, K.	Physik für Studierende des Maschinenbaus / Wintersemester 2003/04 / Universität Hannover (Germany)
Danzmann, K.	Gravitationswellen-Astronomie: Die dunkle Seite unseres Universums / 23 January 2003 / Physikalisches Kolloquium, Gesamthochschule Kassel (Germany)
Danzmann, K.	LISA and SMART-2 Technology / 27 January 2003 / ESTEC, Nordwijk (The Netherlands)
Danzmann, K.	Laserinterferometric Gravitational Wave Detectors on the Ground and in Space / 26 February 2003 / Colloquium, Lund Laser Centre, Lund (Sweden)
Danzmann, K.	Quantenrauschbegrenzte Laserfelder und Interferometrie / 8 March 2003 / SFB 407 Review, Universität Hannover (Germany)
Danzmann, K.	Interferometry for LISA / 27 March 2003 / NASA Technology Readyness and Implementation Plan Review at JPL, Pasadena (USA)
Danzmann, K.	Gravitational Wave Astronomy - The first large detectors are going into operation / 29 April 2003 / Kolloquium, Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München (Germany)
Danzmann, K.	Gravitational Wave Astronomy - The first large detectors are going into operation / 7 May 2003 / Kolloquium, DESY Zeuthen (Germany)
Danzmann, K.	Physik in Hannover / 8 May 2003 / Fachbereichspräsentation, Universität Hannover (Germany)
Danzmann, K.	LISA and SMART-2: Technology and Future / 9 May 2003 / DLR Programmausschuß-Sitzung, Bonn (Germany)

Lectures and Lecture Series Given by AEI Members

Danzmann, K.	LISA Technology / 15 May 2003 / LTP Architect Meeting, Trento (Italy)
Danzmann, K.	Technology Development for LISA and SMART-2 / 16 May 2003 / ESTEC Technology Review, Nordwijk (The Netherlands)
Danzmann, K.	Gravitationswellen / 22 May 2003 / Physikalisches Kolloquium, Universität Marburg (Germany)
Danzmann, K.	Gravitational wave astronomy: detectors on the ground and in deep space / 26 May 2003 / Colloquium, Università Napoli, Neapel (Italy)
Danzmann, K.	Forschung am Max-Planck-Institut für Gravitationsphysik / 14 July 2003 / Max-Planck-Gesellschaft Generalverwaltung, München (Germany)
Danzmann, K.	Gravitationswellenastronomie: Die ersten großen Detektoren gehen in Betrieb / 20 October 2003 / Kolloquium, Universität Bielefeld (Germany)
Danzmann, K.	Gravitational Wave Astronomy: The Dark Side of the Universe / GSI Kolloquium, Darmstadt (Germany)
Danzmann, K.	LISA and LISA-Pathfinder / 28 November 2003 / ESTEC, Nordwijk (The Netherlands)
Ehlers, J.	Einführung in der Allgemeine Relativitätstheorie / 3 March 2003 / AEI- Ferienkurs, Golm (Germany)
Huisken, G.	Monotone quantities, singularities and surgery for mean curvature flow / 7 May 2003 / ETH Zürich (Switzerland)
Nicolai, H.	Low level representations for indefinite Kac Moody algebras: searching for the symmetries of M theory / 22 April 2003 / Humboldt Universität Berlin (Germany)
Plefka, J.	N=4 Super Yang-Mills and Strings on Plane Waves / 7 January 2003 / RTN Winter School on Strings, Supergravity and Gauge Theory, Turin (Italy)
Plefka, J.	Introduction to the AdS/CFT correspondence / 23 January 2003 / Graduiertenkolleg, Universität Heidelberg (Germany)
Rendall, A.D.	Allgemeine Relativitätstheorie / 15 April 2003 / Technische Universität Berlin (Germany)
Ribichini, L.	The seismic isolation chain of the Hannover thermal noise experiment / 15 December 2003 / Cascina (Italy)
Schmidt, B.	Einführung in der Allgemeine Relativitätstheorie / 3 March 2003 / AEI-Ferienkurs, Golm (Germany)
Schnabel, R.	Non-Classical Light / Wintersemester 2003/04 / Universität Hannover (Germany)
Schutz, B.F.	Introduction to gravitational waves / 19 May 2003 / Frascati Spring School (Italy)
Schutz, B.F.	Physics and astrophysics of gravitational waves / 9 September 2003 / WE-Heraeus Summer School, Grundlagen und neue Methoden der theoretischen Physik, Seifhennersdorf (Germany)
Schutz, B.F.	Estimating the strength of gravitational waves / 13 September 2003 / BritGrav 3, Ambleside (Great Britain)
Schutz, B.F.	Understanding Lense-Thirring and its relation to inflation / 14 September 2003 / BritGrav 3, Ambleside (Great Britain)
Schutz, B.F.	Physics and astrophysics of gravitational waves / 4 November 2003 / Universität Hannover (Germany)
Staudacher, M.	Plane Wave Strings, Integrable Spin chains and N=4 Gauge Theory / 18 June 2003 / V. International Workshop, Lie Theory and its Applications in Physics, Varna (Bulgaria)
Theisen, S.	Matrix models and gauge theories / 20 January 2003 / Bonn International Graduate School, Bonn (Germany)

Lectures and Lecture Series Given by AEI Members

Theisen, S.	Lectures on supersymmetric gauge theories and matrix models / 1 April 2003 / University of Western Australia, Perth (Australia)
Theisen, S.	Introduction to String Compactification / 7 July 2003 / 3rd Summer School on Geometric and Topological Methods for Quantum Field Theory, Villa de Leyva (Columbia)

Popular Talks Given by AEI Members

Aufmuth, P.	Visionen von Raum & Zeit / 6 March 2003 / Galerie K9 aktuelle Kunst, Hannover (Germany)
Aufmuth, P.	Horchposten ins All - der Gravitationswellendetektor GEO600 / 13 March 2003 / Naturwissenschaftlicher Verein Osnabrück (Germany)
Aufmuth, P.	Gravitationswellen: Theorie, Quellen, Nachweis / 21 May 2003 / Hölty-Gymnasium, Wunstorf (Germany)
Aufmuth, P.	Allgemeine Relativitätstheorie und Gravitationswellen / 22 October 2003 / Herbstuniversität, Universität Hannover (Germany)
Aufmuth, P.	Das GEO600-Projekt / 27 November 2003 / Helene-Lange-Schule, Hannover (Germany)
Beisert, N.	Relativitätstheorie & Co / 6 June 2003 / Emil-Krause-Gymnasium, Hamburg (Germany)
Danzmann, K.	Die dunkle Seite unseres Universums / 8 May 2003 / Urania Berlin (Germany)
Danzmann, K.	Was ist gute Forschung? / 21 June 2003 / Evangelische Akademie Lokkum (Germany)
Danzmann, K.	Physik ist Zukunft / 22 October 2003 / Herbstuniversität, Universität Hannover (Germany)
Ehlers, J.	Modelle in der Physik / 20 February 2003 / Berlin-Brandenburgische Akademie der Wissenschaften (Germany)
Ehlers, J.	Neue Erkenntnisse und offene Fragen der Kosmologie / 7 April 2003 / Urania Berlin (Germany)
Ehlers, J.	Die Raumzeit ist tatsächlich krumm / 1 October 2003 / Festvortrag anlässlich eines Schülerfestes, DESY, Hamburg (Germany)
Ehlers, J.	Gravitationswellen / 6 November 2003 / Curie-Gymnasium, Ludwigsfelde (Germany)
Fischbacher, T.	Supergravity, Group Theory and Symbolic Algebra / 6 May 2003 / Campus Information Day, Max-Planck-Campus, Golm (Germany)
Fischbacher, T.	Einsteins krumme Touren / 4 June 2003 / Albrecht-Thaer-Gymnasium Hamburg (Germany)
Fischbacher, T.	Einsteins krumme Touren / 5 June 2003 / Allee-Gymnasium Hamburg (Germany)
Nicolai, H.	Die vereinheitlichte Theorie - heiliger Gral oder Ende der Physik? / 24 April 2003 / Schloss Poppelsdorf, Bonn (Germany)
Nicolai, H.	Die seltsame Welt der Quanten / 30 August 2003 / Tag der offenen Türen, Max-Planck-Campus, Golm (Germany)
Pössel, M.	Trödelprinzip und krumme Touren: Einführung in die Relativitätstheorie / 30 August 2003 / Tag der offenen Türen, Max-Planck-Campus, Golm (Germany)
Schutz, B.F.	Einsteins heritage: relativity in the universe / 15 May 2003 / Stettin University (Poland)
Skorupka, S.	Gravitationswellen: ein neues Fenster ins Weltall / 30 August 2003 / Tag der offenen Türen, Max-Planck-Campus, Golm (Germany)
Skorupka, S., Heurs, M.	Unter Strom! Weihnachtsvorlesung / 18 December 2003 / Universität Hannover (Germany)

Popular Talks Given by AEI Members

Skorupka, S., Heurs, M.	Unter Strom! Weihnachtsvorlesung / 19 December 2003 (three times) / Universität Hannover (Germany)

Guided Tours at GEO600

Aufmuth, P., Goßler, S., Grote, H., Lück, H., Willke, B.	The gravitational wave detector GEO600. Introductory talk and guided tour 14 January 2003 / 17 January 2003 / 10 February 2003 / 11 February 2003 / 27 February 2003 / 7 March 2003 / 26 March 2003 / 17 April 2003 / 26 April 2003 / 15 May 2003 / 23 May 2003 / 3 June 2003 / 20 June 2003 / 30 June 2003 / 2 July 2003 / 14 July 2003 / 11 August 2003 / 28 August 2003 / 13 November 2003

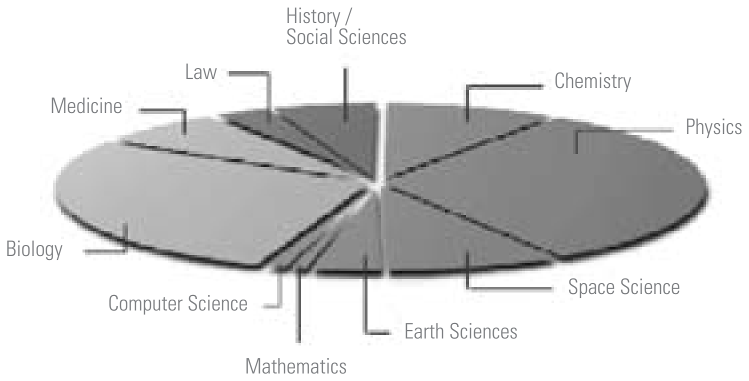
The Max Planck Society: Profile and Organisation

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 1.12.2003 there are 77 institutes, research centres laboratories and project groups employing approx. 12,000 people, among them about 3,500 scientists and scholars. In addition, there were also about 8,000 doctoral candidates, post-doctoral fellows and guest scientists and scholars from abroad.

About 95 % of Max Planck Society expenditure is met by public funding from the Federal Government and the states. The remaining 5 % comes from donations, members contributions and from funded projects. The 2003 budget - as for 2002 - was an estimated E1.24 billion. The planned budget for 2004 is E 1.33 billion.



Distribution of the budget of the Max Planck Society

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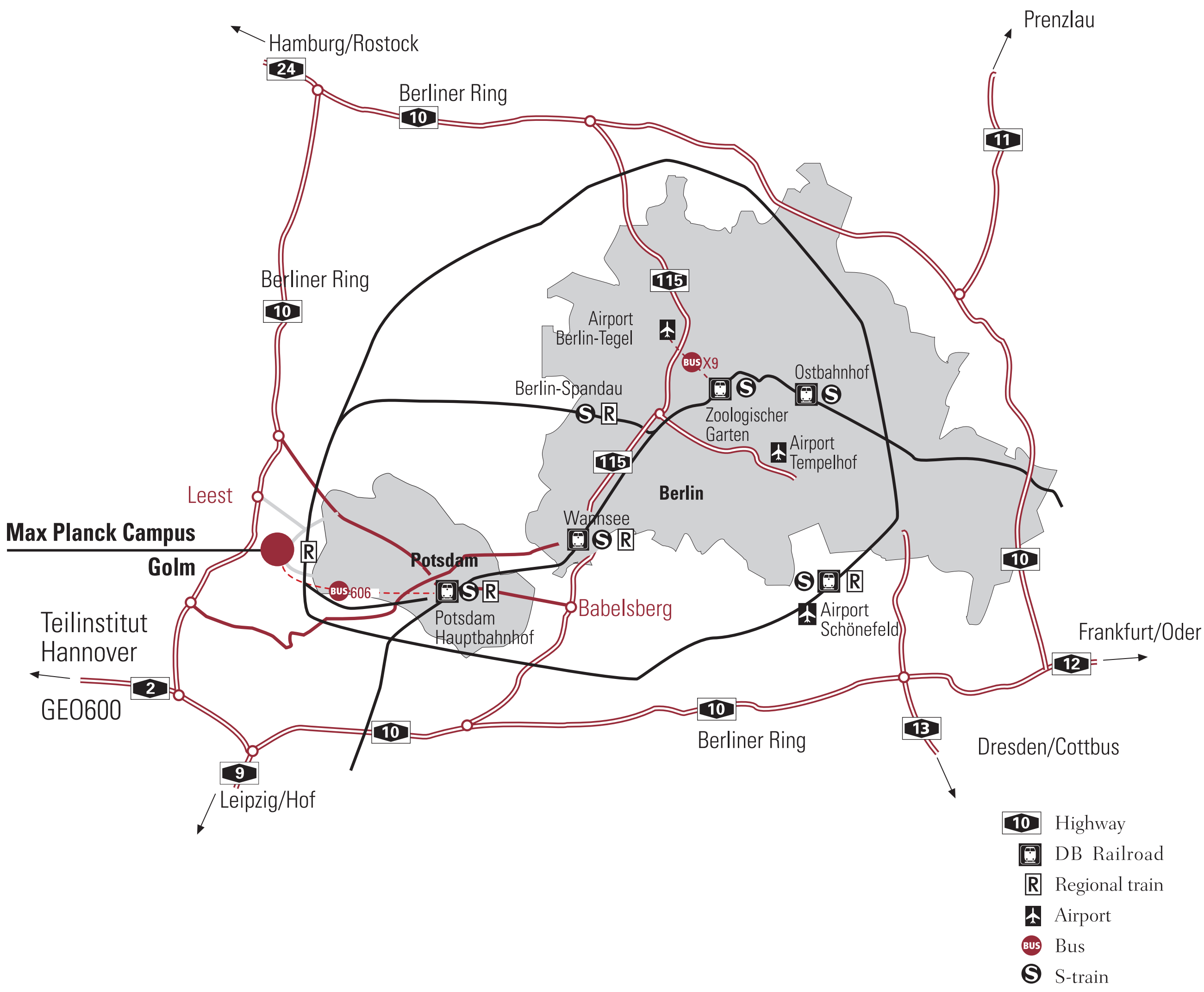
How to get to the AEI in Hannover

From the airport:
Take the S-Bahn no. 5 to the Central Station ("Hauptbahnhof"). Leave the Central Station direction "City"; walk along the Bahnhofstr. 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 Golm



From the airports:

Tegel: Bus X9 to train station "Zoologischer Garten"
Schönefeld: Train "Airport Express" to "Zoologischer Garten"
Tempelhof: Underground U6 (direction Alt-Tegel) to "Friedrichstraße"

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!