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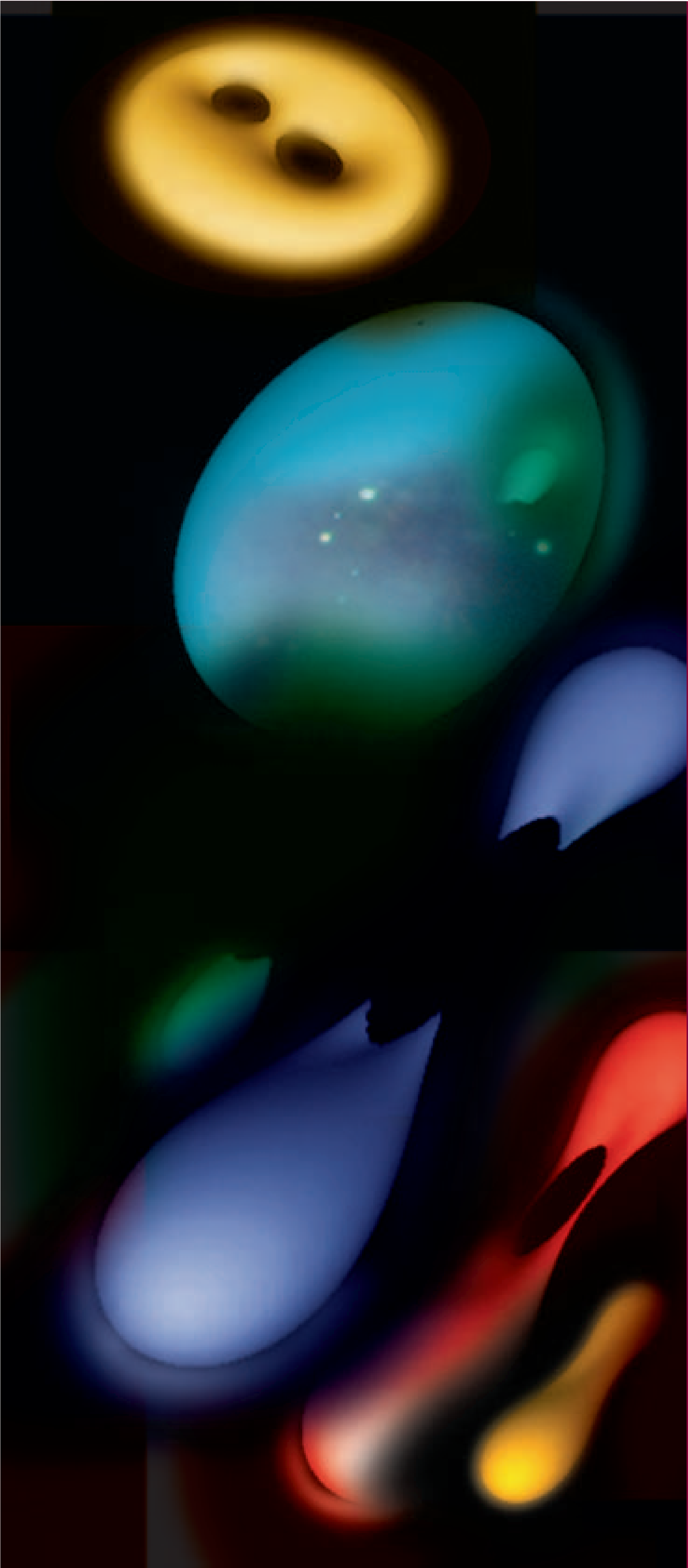

Annual Report 2002

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

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

Report by the Managing Director

During 2002 the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) took two very important steps: two new Directors began their work - Gerhard Huisken and Karsten Danzmann - and we officially opened the new branch of the Institute for experimental gravitation in Hannover. In addition the Institute broadened its research collaborations by winning several new external research grants; celebrated the award of the prestigious Leibniz Prize to Professor Huisken; acquired and analyzed the first "science" data from its gravitational wave detector GEO600; installed a new teraflop computer for gravitational wave data analysis; hosted the 2002 Reimar Lüst lecture; and saw several of its younger researchers go on to permanent and tenure-track positions at important universities around the world. Unfortunately, just as I began my second term as Managing Director in June (taking over from Hermann Nicolai), we also began to see the first darkening clouds of restraints on science funding in Germany.

I am particularly happy to welcome Gerhard Huisken as the Director of the renamed Geometrical Analysis and Gravitation Division, taking over from our retired founding Director Jürgen Ehlers; and Karsten Danzmann as the Director of the Laser Interferometry and Gravitational Wave Astronomy Division, the first of two divisions which are planned for our new branch institute in Hannover. Huisken moved to Golm from Tübingen University, where he had been a professor in mathematics. Danzmann retains his professorship in physics at Hannover jointly with his directorship of the AEI; he has been managing the GEO gravitational wave group in Hannover on behalf of the Max Planck Society for nearly ten years. Readers can learn more about their work and their plans for their divisions in their articles in this volume. It is a special pleasure to record that Gerhard Huisken was awarded the Leibniz Prize in December of this year. This is Germany's highest research honor, and it will give Professor Huisken more than one and a half million Euros to support his research in the next five years.

The founding of AEI/Hannover was reported in last year's annual report, but 2002 was the first official year of its existence. Its opening is a landmark step not only for the AEI but also for gravitational physics research worldwide. For the first time there is a full research institute dedicated to the development of the experimental techniques needed for present and future generations of gravitational wave detectors. Established in cooperation with the University of Hannover, the new institute is a tribute to the vision and flexibility of the Max Planck Society. Recognizing that gravitational wave research will have a long and productive future, the Society gathered the resources and talents that already existed in Germany, placed them into an institutional framework that gives them maximum effectiveness, and committed itself to doubling the size of the effort by opening a fifth AEI division in Hannover as soon as possible. Our search for the Director for that division is going on now.

I would especially like to record here my thanks to the many people who made the expansion of the AEI happen. The President and Vice-President of the Society, the Rector of the University of Hannover, the officials of the Society and of the University who negotiated the agreement, my astronomy and physics colleagues in the Society who so strongly supported the proposal: all made key contributions that enabled the expansion to take place. The official inauguration took place in Hannover on 17 May, at which time the directors were able to thank many of these individuals personally.

I am sure that the accomplishments of AEI/Hannover in the future will more than justify the confidence that the Society and University have shown in our research.

AEI/Hannover operates the GEO600 gravitational wave detector in collaboration with Glasgow and Cardiff Universities in the UK, and we work closely with the American LIGO project. During August and September 2002 GEO600 and the LIGO instruments participated in a 2-week science run, whose data is now being analyzed by four joint "upper-limit" teams, the name reflecting our expectation that the detectors do not yet have the sensitivity to make real detections. The results of this analysis will be released in 2003.

The analysis will be assisted by the latest addition to the AEI's computing facilities: the Merlin Cluster. Funded by grants from the Max Planck Society and the State of Brandenburg, the 128-node (256-processor) cluster computer has a peak computing capacity exceeding 1 teraflop. The gravitational wave data-analysis group at AEI/Golm designed the computing nodes down to the last chip. The computer worked on the same day it was turned on, and has functioned nearly flawlessly ever since. It will be the workhorse of our searches for radiation from pulsars and other spinning neutron stars. In connection with this computer, the AEI signed a cooperation contract with the Konrad-Zuse-Institut in Berlin (ZIB), under which ZIB will store a complete set of GEO data on tape and make it accessible to AEI scientists for analysis.

The AEI broadened its research collaborations with some new external research grants. The EU-funded GridLab and MoWGLI projects and GriKSL (funded by the German research network DFN) were described in last-year's report; all three projects started in 2002. Another major research grant is the AEI's participation in a Sonderforschungsbereich (special research area) for Gravitational Wave Astronomy, which was awarded in December 2002 to the AEI and its research partners: the universities of Jena, Hannover and Tübingen, and the Max Planck Institute for Astrophysics in Garching. Coordinated by the University of Jena, the grant will help build a community of university scientists in Germany who can support the experimental activity on GEO600. The grant has 13 different projects and could run for as long as twelve years, so it represents a major step forward in building a gravitational wave community in German universities.

During 2002 the AEI was also informed of the success of its application to establish an International Max Planck Research School in Geometric Analysis, Gravitation, and String Theory. The school, a partnership with Humboldt University, will attract students from Germany and around the world for its English-language graduate-school-style instruction. We could receive our first students by the beginning of 2004.

The German-Israeli Foundation is already supporting the AEI's cooperation with the Universities of Tel Aviv and Jerusalem and has now approved a new project with the title "Learning from Each Other: The String Theory - Gauge Theory Connection". This collaboration with the University of Tel Aviv starts in 2003 and lasts for three years.

In September the AEI hosted the 2002 Reimar Lüst Lecture, named in honor of the well-known physicist and astrophysicist and former President of the Max Planck Society. The lecture was given by Pierre Ramond of the University of Florida, one of the founders of string theory. The Golm campus' Open Day, also in September, was again a great success, particularly the children's corner! I would like to thank all the AEI staff who helped make this day a success.

Each year sees the departure of members of staff for other positions, and the arrival of new faces. Among the departing staff who have moved to tenured or tenure-track positions, I want to congratulate Miguel Alcubierre (moved to the University of Mexico), Bernd Brügmann (Penn State University), Adrian Butscher (University of Toronto), Manuela Campanelli and Carlos Lousto (University of Texas at Brownsville), Renate Loll (University of Utrecht), Marc Mars (University of Salamanca), Volker Schomerus (CEA Saclay) and Alicia Sintes (University of the Balearics, Mallorca).

The Institute's pioneering electronic journal, Living Reviews in Relativity, was placed on a stable financial footing for the next 3-5 years with an agreement for financial support from the Max Planck Society's Heinz Nixdorf Center for Information Management (ZIM). Under this agreement the ZIM supports two staff to service the core editorial (back-office) needs of a family of Living Reviews journals. We expect that Living Reviews in Relativity will be joined by its first sister journal in another subject early in 2003. The ZIM-supported staff also work with the staff of the ZIM itself to develop a suite of software that will allow other institutes to publish their research results or begin new electronic journals without the support of our back-office staff. Living Reviews' usage figures for 2002 are very encouraging: the journal is clearly widely read in relativity and is becoming a standard reference for scientists in related fields like astronomy and theoretical physics. There are more details in the article by Christina Weyher later in this volume.

A measure of the AEI's success, but an unfortunate one, is that we have completely outgrown our building, which we only moved into in 1999. There is no surplus space on the campus or nearby, so we have rented office space for 20 scientists several kilometres away in a building operated by the PanMedium company. There is more about the move of the Cactus/GridLab/GriKSL group to PanMedium later in this report.

Our office-space problems are going to get worse before they get better, because the AEI continues to grow (such as through the Leibniz Prize award and the International Max Planck Research School), while the start of building our promised extension in Golm has been delayed to after the end of 2003. The delay in this building was the first sign of the worsening financial climate that is now very apparent in the Max Planck Society. As we look forward to 2003, these restrictions on research funding in Germany are a serious cause for concern.

However, the Institute's research has considerable forward momentum and we have a significant amount of external funding, so I am cautiously optimistic that we are in a robust enough condition to weather any likely storms in the immediate future. But a long-term reduction in research spending would be another issue. Gravitational physics research is a rapidly growing field, particularly in the USA and the UK. So many positions have opened at American universities recently that there may not be enough qualified candidates to fill them: as noted above, three AEI staff members took tenure-track jobs in the US in 2002.
The US National Science Foundation currently spends about 20% of its total physics budget (not including astrophysics) on gravitational physics alone. Against such competition, it will be difficult to maintain the quality of the AEI's research and staff if we are handicapped by serious shortfalls in funding.

Against all the background of new developments, projects, staff changes, and financial concerns, the real work of the Institute went on very satisfactorily in 2002: the scientific research that is the everyday activity of our scientific staff. The scientific highlights of all this work are described in the separate articles devoted to each Division.

In closing I would like to thank all the staff of the AEI, both the scientists and our hard-working support staff, for their cooperation and enthusiasm during 2002. I look forward to an exciting and productive 2003!

Bernard F. Schutz
(Managing Director)

The Institute

Research Overview

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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.

The year 2002 was a key one for the development of the Albert Einstein Institute (AEI). Two new Directors began their work, and the Institute opened a second branch in Hannover. Professor Gerhard Huisken moved to the AEI from Tübingen University, filling the vacancy created by the retirement of Jürgen Ehlers as leader of the mathematical work at the Institute. Professor Karsten Danzmann of Hannover University took up a joint appointment as the first Director of the new Hannover branch. AEI/Hannover is an exciting cooperation between the Max Planck Society and the University of Hannover, which will secure the future of research in Germany in experimental gravitational wave physics. The two sites of the AEI will eventually be home to five scientific divisions with a total working population of approximately 170 scientists (including guests) and 40 support staff. Gravitational physics is one of the major growth areas in worldwide physics research today, and the enlarged AEI is in a strong position to play a central role in this research for decades to come.

As a result of the enlargement of the AEI, the GEO600 gravitational wave detector became part of the Institute. This past year has also been an important year for the development of this detector. Its sensitivity increased significantly during the year, it set new records for reliability and unattended operation, and it acquired its first "science" data in coincidence with the American LIGO detectors. The results of the analysis of this two-week data run will be released in 2003.

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 2002 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. The numerical relativity group is the largest in the world, and is a leader in the development of software (called Cactus) that allows 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 has long been 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. With its new Director, Gerhard Huisken, the Division will broaden 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.

- 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 is a joint project of 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 is participating in the SMART-2 technology mission, which will be launched by ESA in August 2006.

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. It maintains an extensive guest scientist program. The lists in this report of guest scientists for 2002 and of seminars given at the AEI in 2002 show how rich the intellectual environment is. The experimental laboratories in Hannover, still under construction during 2002, will likewise be among the most modern and sophisticated in the world. During 2003 the AEI will develop its computer system to integrate the two sites together as fully as possible.

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 - all of these must happen if the research environment is to be productive.

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 staying in Germany more 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 during 2002 it joined with the Universities of Jena, Hannover, and Tübingen in a successful application for an SFB 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 that it won approval in 2002 to establish an International Max Planck Research School (IMPRS) in Geometric Analysis, Gravitation, and String Theory, in cooperation with Humboldt University and Free University in Berlin, and the University of Potsdam. This school, which could accept 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. IMPRSs are a very successful recent innovation by the Max Planck Society. They offer instruction in 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 with the help of the ZIM we expect to announce early in 2003 the establishment of a sister journal in a different subject.

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. Some of these are -

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 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 in string theory today is justified, then in only a few years we may see the emergence of a coherent but mathematically complex theory of all the forces of nature. Already exciting and radical ideas are emerging about how string theory might alter our notions of gravity, explain the Big Bang, and predict completely new phenomena. Work to understand the theory and explore those of its 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 2002, 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

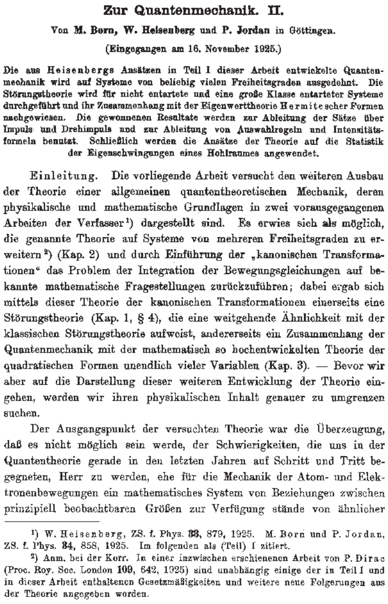
Pascual Jordan - Originator of Quantum Field Theory and Founder of a Relativity School

Quantum Field theory and General Relativity are considered as forming the basis of present day physics. Among the few physicists who have contributed to both these theories is Pascual Jordan (1902 -1980). Since these theories form the main subjects of research at the Albert Einstein Institute and since the core out of which this institute developed consisted largely of former members of Jordan's seminar, it seems appropriate to devote these pages to the memory of this great physicist.

The very first foundation stones of the building of quantum field theory have been laid down by Pascual Jordan, then 22 years old, who had just finished his PhD. Already in the first 1925 paper by Born and Jordan, in which Heisenberg's seminal ideas were transformed into the germ of consistent quantum theory, it was Jordan who insisted that not only particle variables, but also electromagnetic field should be reinterpreted as matrices. This step enabled him to derive within the new theory Heisenberg's stipulation according to which the absolute squares of those matrix elements which represent the electric moments of an atom, give the transition probabilities between stationary states. Following the same idea, Jordan showed, in the famous three-man-paper by Born, Heisenberg and Jordan, that energy fluctuation formula for black body radiation, which had been derived in 1909 thermodynamically by Einstein, followed straight forwardly without use of thermodynamics, if the field was treated as quantized, i.e. matrix-valued. Initially these ideas of Jordan's were viewed sceptically by Heisenberg and others.

Pascual Jordan (left) and Wolfgang Pauli (right), 1955

In the years following his habilitation in 1927 in Göttingen Jordan pursued his favourite idea according to which quantized fields, not particles, should be taken as fundamental. The discrete, atomistic properties of matter should follow from the non-commutativity of the fields. Moreover, these fields should be defined on (1+3) dimensional space time; and therefore the multi-dimensional configuration spaces of Schrödinger's many particle wave mechanics should be avoided, Jordan maintained. These ideas were substantiated in papers with Oskar Klein (Bose fields), Eugen Wigner (Fermi fields) and Wolfgang Pauli (source free relativistic quantum electrodynamics). In the first two of these papers the creation and annihilation operators were introduced, called originally Jordan-Klein matrices for bosons and the Jordan-Wigner matrices for fermions.



Zur Quantenmechanik. II.

Von **M. Born, W. Heisenberg** und **P. Jordan** in Göttingen.

(Eingegangen am 16. November 1925.)

Die aus Heisenbergs Ansätzen in Teil I dieser Arbeit entwickelte Quantenmechanik wird auf Systeme von beliebig vielen Freiheitsgraden ausgedehnt. Die Störungstheorie wird für nicht entartete und eine große Klasse entarteter Systeme durchgeführt und ihr Zusammenhang mit der Eigenwerttheorie Hermitescher Formen nachgewiesen. Die gewonnenen Resultate werden zur Ableitung der Sätze über Impuls und Drehimpuls und zur Ableitung von Auswahlregeln und Intensitätsformeln benutzt. Schließlich werden die Ansätze der Theorie auf die Statistik der Eigenschwingungen eines Hohlraumes angewendet.

Einleitung. Die vorliegende Arbeit versucht den weiteren Ausbau der Theorie einer allgemeinen quantentheoretischen Mechanik, deren physikalische und mathematische Grundlagen in zwei vorausgegangenen Arbeiten der Verfasser[1]) dargestellt sind. Es erwies sich als möglich, die genannte Theorie auf Systeme von mehreren Freiheitsgraden zu erweitern[2]) (Kap. 2) und durch Einführung der „kanonischen Transformationen" das Problem der Integration der Bewegungsgleichungen auf bekannte mathematische Fragestellungen zurückzuführen; dabei ergab sich mittels dieser Theorie der kanonischen Transformationen einerseits eine Störungstheorie (Kap. 1, § 4), die eine weitgehende Ähnlichkeit mit der klassischen Störungstheorie aufweist, andererseits ein Zusammenhang der Quantenmechanik mit der mathematisch so hochentwickelten Theorie der quadratischen Formen unendlich vieler Variablen (Kap. 3). — Bevor wir aber auf die Darstellung dieser weiteren Entwicklung der Theorie eingehen, werden wir ihren physikalischen Inhalt genauer zu umgrenzen suchen.

Der Ausgangspunkt der versuchten Theorie war die Überzeugung, daß es nicht möglich sein werde, der Schwierigkeiten, die uns in der Quantentheorie gerade in den letzten Jahren auf Schritt und Tritt begegneten, Herr zu werden, ehe für die Mechanik der Atom- und Elektronenbewegungen ein mathematisches System von Beziehungen zwischen prinzipiell beobachtbaren Größen zur Verfügung stände von ähnlicher

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[1]) W. Heisenberg, ZS. f. Phys. **33**, 879, 1925. M. Born und P. Jordan, ZS. f. Phys. **34**, 858, 1925. Im folgenden als (Teil) I zitiert.

[2]) Anm. bei der Korr. In einer inzwischen erschienenen Arbeit von P. Dirac (Proc. Roy. Soc. London **109**, 642, 1925) sind unabhängig einige der in Teil I und in dieser Arbeit enthaltenen Gesetzmäßigkeiten und weitere neue Folgerungen aus der Theorie angegeben worden.

The famous three-man-paper by Born, Heisenberg and Jordan

A dominant feature in Jordan's work on quantum mechanics and quantum field theory is the use of non-commutative algebraic structures. He pursued his interests in this area of mathematics in many publications, quite separately from physics. The theory of Jordan algebras originated in Jordan's attempts to eliminate from the quantum formalism those operations which do not admit of a direct physical interpretation, such as $a\,b$, in contrast to $[a,b]_\pm$.

In the mid forties Jordan's interest turned to General Relativity. This may have been connected with his early interest in the critical discussion of the foundations of mechanics by the physicist and philosopher Ernst Mach. What caught specifically Jordan's attention were two speculative hypothesis which had been put forward in 1937 by Paul Dirac. In order to explain some large dimensionless numbers in cosmology, Dirac proposed the possibilities that the strength of gravity slowly decreases in inverse proportion to the age of the universe and the mass of the universe increases as the square of the world's age. In contrast to most colleagues Jordan was attracted by these ideas. He developed a

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HERAUSGEBER PROF. DR. WILHELM WESTPHAL

Band 107

PASCUAL JORDAN
SCHWERKRAFT
UND WELTALL

Grundlagen der theoretischen Kosmologie

Zweite, erweiterte Auflage
Bearbeitet unter Mitwirkung von E. Schücking

Mit 13 Abbildungen

FRIEDR. VIEWEG & SOHN · BRAUNSCHWEIG 1955

generalization of Einstein's theory of gravity in which the part of Newton's constant is taken by a scalar field. As it turned out, such scalar-tensor theories had already been set up by several authors, and for a while they served as competitors to Einstein's theory. With a lot of energy and much fantasy Jordan tried to find empirical support for his theory in some features of the earth's crust, in volcanism, in the properties of the moon and double stars, and in connection with star formation. These efforts have not been successful, and there is no reason to recall them in detail at present. However, in the cause of these activities Jordan felt the need to go deeper into General Relativity and to simplify the formalism underlying Einstein's theory. In the first part of his book "Schwerkraft und Weltall" (1952, 1955) he presented General Relativity in a way that differed considerably from traditional textbooks. In line with his preference for algebra, he gave an elegant axiomatic characterisation of covariant differentiation which was later found independently by J.L. Koszul, and in order to treat various exact solutions without much computation, he proved several lemmas concerning what later came to be called direct or warped product metrics, conformally related metrics and dimensional reduction formulas. In order to distinguish physical gravitational waves from coordinate waves, Jordan used the curvature tensor, in contrast to Einstein's original treatment based on a pseudo-energy-tensor. Also, he clearly describes - I think for the first time in a textbook - Einstein causality in connection with Chauchy's initial value problem for special and general relativity, referring to the early work of Stellmacher. In his account of cosmology Jordan not only covers the Friedman-Lemaitre models, but gives many interesting details about motions of particles and light propagation, and he discusses briefly the work by Gamow, Alpher, and Hermann on primodial element formation which ten years later was to become a major ingredient of cosmologies standard model.

I have mentioned these topics because they indicate Jordan's wide ranging interests, his way of looking at things in a new way, and his ability to excite interest in students. It is thus not astonishing that Jordan's seminar on General Relativity and cosmology which began in the mid fifties and was carried on at the university of Hamburg for about fifteen years attracted many talented students, several of whom later attained professorships or research positions in physics or mathematics. At the post war time when General Relativity had almost been forgotten not only in Germany, Jordan recognized the importance of this field for future research. Due to Jordan and his students and collaborators the renaissance of General Relativity around 1955 took place not only in Syracuse, Princeton, Paris, London, Dublin, Leningrad and Warsaw, but also in Hamburg. Without this germ-cell of General Relativity in Germany a relativity group would presumably not have been created at a Max Planck Institute, and the Albert Einstein Institute would not have come into existence.

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".

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: Following the groundbreaking 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 there have been many further applications of geometric variational principles to the modelling and to the theoretical understanding of physical phenomena and concepts. Examples include the construction of a center of mass in asymptotically flat manifolds with the help of constant mean curvature surfaces solving the isoperimetric problem, the use of outward-minimising 2-spheres in the proof of the Penrose inequality and the establishment of the concept of a quasi-local mass.

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, leading to several projects in the division.

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 one particular piece of work 2002 it was possible to show that radial coordinates obtained from the so called inverse mean curvature flow are asymptotically regular and resemble the behaviour of Euclidean polar coordinates. It is a longterm hope to construct in this way "normal coordinates near infinity" for isolated gravitating systems, in which all relevant physical invariants of an isolated system can be expressed in terms of geometric invariants.

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.

In past years information was obtained on good slicings in space-times which are symmetric in two spatial directions and variable in the other space direction. In a project 2002 the dynamical behaviour of Gowdy space-times in the expanding direction was determined for general initial data. An unsuspected qualitative phenomenon was discovered: the basic unknowns can be represented by points of the hyperbolic plane and in this picture the solutions settle down to motion on circles at late times.

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. Extending work done previously at the AEI, in which space-like infinity is represented by a cylinder, a new class of obstructions was found to the smoothness of the asymptotic structures for a specific class of initial data. This discovery will have important consequences for further studies.

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. The work mentioned above is part of this, further evidence comes from an analysis of the linearization of this setting. This study provides complete information about the evolution near space-like infinity. It shows that in general logarithmic singularities occur in the asymptotic structure but also that under suitable conditions on the initial data full asymptotic smoothness is obtained. The analysis also provides important tools for attacking the full non-linear problem.

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. See also the report on research highlights.

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.

Apart from classical descriptions involving ideal fluids there has been strong interest last year in models involving other matter. In one project initial data were constructed for the spherically symmetric Einstein-Vlasov-Maxwell system, including cases with a regular central region and an external matter-free region which is isometric to part of the extreme Reissner-Nordström solution. On another note the asymptotic behaviour of plane symmetric solutions of the Einstein-Vlasov equations with positive cosmological constant was analysed, with the results lending support to the cosmic no hair conjecture. In a doctoral dissertation the existence of solutions of the Vlasov-Maxwell system with no incoming radiation was demonstrated. In addition there was interest in matter models motivated from string theory: Fuchsian techniques were used to construct general solutions without symmetry of the Einstein equations coupled to matter motivated by string theory in arbitary dimensions and of the vacuum Einstein equations in space-time dimension at least eleven. For all these solutions the detailed structure of the initial big bang singularity was determined. As this last project shows, there is a strong relation between different matter models and cosmological questions as discussed above. The relation of various models of fluids to each other and aspects of their numerical treatment were the theme of a two-day workshop in October. New interesting and challenging problems arise when an elastic selfgravitating body is considered in the context of general relativity. The short time existence problem for elastic relativistic bodies was approached from the theory of symmetric hyperbolic systems and static solutions with suitable boundary conditions were constructed.

Gerhard Huisken

Astrophysical Relativity Division

As in previous years, research in the Astrophysical Relativity Division of the AEI has concentrated on two main themes. One is the numerical solution of Einstein's equations, and in particular computer simulations of the collisions of two black holes. The second theme is the detection and study of gravitational radiation. In both areas there have been exciting advances in the scientific results and important developments in computer software that supports the scientific work.

Numerical Simulations

The numerical simulations group of the Astrophysical Relativity Division, led by Prof Ed Seidel, undertakes large-scale computer simulations of colliding black holes and develops the software needed to perform the simulations. Black holes are arguably the simplest phenomena in general relativity: their properties depend on only a few numbers, such as their mass and spin, and their gravitational fields are independent of the kind of material that originally formed them. Therefore, a simulation does not need to take into account fluid dynamics or other astrophysics: pure vacuum gravity is all one needs. The collision of two black holes is therefore one of the "cleanest" dynamical processes in all of Nature, but because of the complexity of Einstein's equations, it has been difficult to achieve a detailed understanding of it. In 2002 we continued to advance the state of this art through advances in our computer techniques and our software. I give a short description here and refer to the article by Seidel later in this volume.

The black-hole collision problem has increased urgency from the fact that gravitational wave detectors will begin operating soon, and binary black hole mergers are among the most likely sources that they will see in early observations. The so-called in-spiral phase of the orbit, where the two holes move in roughly circular orbits that gradually shrink as the orbit emits gravitational waves, is reasonably well-understood. But at some point the orbit becomes unstable, and the two holes suddenly change course and plunge together, as if they had just fallen off a cliff. This crucial transition, and the subsequent merger, are the target of our numerical simulations. During 2002 we built on the advances in techniques that were reported in the last annual report and performed the longest-duration simulations we have ever done. These simulations are beginning to yield physical insights, although there are still limitations due to the limitations of our numerical techniques.

In 2002 some key younger members of our numerical group moved on to jobs at other universities. Miguel Alcubierre moved to a tenure-track position at the University of Mexico; Bernd Brügmann moved to a tenure-track position at the Penn State University, a major center for gravitational physics research in the USA, accompanied by post-doc Wolfgang Tichy; Manuela Campanelli and Carlos Lousto have moved to tenure-track positions at the University of Texas at Brownsville, where they are helping to build a major gravitational-wave research center with the help of NSF and NASA research grants; and Scott Hawley moved to the University of Texas at Austin to join the numerical relativity group of Fachbeirat member Richard Matzner. We are pleased to see our scientists getting such good positions and developing their careers.

The Black Hole Simulations

Last year we described the modifications in the form of the equations that we put on the computer and the new ways we devised for handling coordinate conditions, both of which yielded simulations that lasted longer and remained accurate. In 2002 we put these developments to the test in a full simulation of the merger of two black holes, with the goal of examining the initial conditions that were our best approximation to the disposition of two equal-mass black holes at the end of their gradual inspiral orbital phase and the beginning of their plunge together. A series of simulations was performed on many machines, including a new supercomputer at the National Center for Supercomputer Applications (NCSA) in the USA. We provided a special visualization of one of these runs to the American television network The Discovery Channel, who used the visualization in a television transmission during the summer.

The most important result of these simulations is that the black holes fall together and merge within less than half an orbit for a variety of initial separations. This is unexpectedly rapid, but it is completely consistent with the results we had obtained last year from the Lazarus simulations, which were analytic extensions of shorter-duration numerical simulation. The conclusion we are led to is that the initial conditions for the simulation may not be correct: the initial velocities of the black holes may be smaller than they would be in a realistic orbit.

Finding the right initial data is inherently an extremely difficult task. Since the two-body problem cannot be solved analytically in general relativity, we do not know the right velocity to maintain the holes in circular orbits at any given separation. If we had the computer resources to do several orbits we could experiment until we found the right orbital parameters. But at present the initial separations and speeds are educated guesses. The result of our simulations is to point the direction in which those guesses should be corrected.

Several methods for producing initial data exist. Within the EU-funded project on sources of gravitational waves, coordinated by Ed Seidel, there are new initiatives producing data in different ways, that we hope will be closer to the correct values. Work is underway to incorporate these new initial data into our next simulations.

A New Cluster Computer

As reported last year, our plans to acquire an in-house supercomputer fell through when SGI could not deliver the machine we had ordered. After a long process of re-defining our requirements and re-obtaining funding from the central computer committee of the Max Planck Society (the BAR), we were ready by the end of 2002 to order the first 64 dual-processor nodes of a new cluster computer system. Unlike the Merlin Cluster, which has just been installed for gravitational wave data analysis (see below), the numerical relativity computer must have a very fast internal communication network as well as high-performance computing nodes. The second 64 nodes will probably be acquired later in 2003.

The Cactus Computational Toolkit Becomes a Grid Computing Tool

Last year's report described the new developments in Cactus to interface it to Grid computing, and in particular the newly-awarded GridLab grant. GridLab began officially on 1 January 2002, and the collaboration has been very active. Frequent telephone conferences, combined with occasional collaboration meetings, have led to a definition of the specification of the software under construction and an apportionment of tasks. GridLab is interfacing not only Cactus to the Grid but also Triana, the data-analysis software environment constructed at Cardiff University for the GEO project. The activity will lead to an interface between Cactus and Triana that should open the facilities of each environment to users of the other.

The Cactus group again gained international recognition in 2002 by winning three awards at the Supercomputing 2002 conference in Baltimore, based on a giant calculation performed at the meeting that linked thousands of processing nodes together. It was the only group that gained such a large degree of recognition. Also notable at SC2002 was the fact that keynote speeches by three prominent science policy-makers, among them the Director of the National Science Foundation, Rita Colwell, used our black-hole simulations (especially the Discovery Channel visualization) to make points about the effectiveness of investment into supercomputing.

Cactus news and code can be obtained from the website
http://www.cactuscode.org

Gravitational Waves

The other major activity in the Division during 2001 was research in support of GEO600 and the other large gravitational wave detectors that are being built in several locations around the world; this group is led by Prof Curt Cutler. Gravitational waves are the last great prediction of Einstein not yet verified directly by experiment or observation, and their direct detection by these instruments will be a landmark for physics. But in fact the indirect evidence for gravitational waves is strong, so it is not expected that they will be much different from the theoretical predictions. The main interest in detecting them is astrophysical: they open a completely new window on astronomy and the Universe. Gravitational waves can come to us from the dark, hidden parts of the Universe: black holes, the first fraction of a second of the Big Bang, the interiors of supernova explosions, and perhaps even some of the mysterious dark matter itself. A more detailed discussion of the work of this group can be found in Prof Cutler's article in this volume.

Data Analysis Software

The largest activity in the AEI group is in the development of data analysis software for the gravitational wave projects and the coordination of parts of the data analysis. During August and September 2002 the GEO600 detector and its American partners, the LIGO project, performed a two-week "science run" called S1, in which all four detectors in the system were run as continuously as possible, taking data. The sensitivity of the detectors was still some orders of magnitude worse than their goals, since commissioning had only recently started, but the data were useful in giving the data-analysis teams practice in handling the analysis and in making judgements on the significance of what they saw.

The data analysis was organized within the LIGO Scientific Collaboration (LSC). Four teams were established to set upper limits on four different kinds of sources: unexpected bursts, coalescing binary signals, pulsars, and a stochastic background. GEO contributes to all the teams, and AEI scientist Maria-Alessandra Papa is the theory chair of the pulsar team. By the end of 2002 the teams had exchanged data and arrived at preliminary conclusions. The first releases of results are anticipated for early 2003.

The Institute strengthened its data-analysis team in 2002 in order to prepare for the extra work that full-time data analysis brings. Joining us as system manager for the Merlin Cluster computer (see below) was Steffen Grunewald. Our new pulsar analysis code programmer is Bernd Machenschalk, who replaces Steve Berukoff, who returned to the US to study for a PhD at Penn State. Our in-house Triana programmer is Rui Zhu, who will help GEO scientists to use Triana and will develop graphical tools for them. Also during 2002 one of the earliest members of our data analysis group, Alicia Sintes, left to take a professorship at the University of the Balearics in Mallorca. Alicia will remain leader of the detector characterization group within GEO. We already have a collaboration with Mallorca, which is a member of the EU Network for sources of gravitational waves. We look forward to increasing our collaboration with them in the future.

Big Computers

Data analysis, particularly the search for pulsar signals, is even hungrier for computer power than numerical relativity. While numerical relativity requires massive computing for limited-duration runs, signal analysis requires massive computing continuously. To do a reasonable search of wide areas of the sky for unknown gravitational-wave pulsars requires a dedicated multi-teraflop system. Together with our partners in Cardiff and Birmingham Universities in the UK, we at the AEI are building a system of computing clusters that will be able to do such an analysis.

Funding for a large cluster was awarded by the Max Planck Society in 2001, as reported last year. In consultation with visiting professor Bruce Allen of the University of Wisconsin at Milwaukee, our team led by Maria-Alessandra Papa designed the computing nodes of our cluster down to the last chip, testing samples of each component and then testing an integrated computer to ensure that they worked together properly. The emphasis was on getting as much computing speed as possible for the available funding: the price-to-performance ratio was the key test, and performance was measured on samples of the code we expect to run on the machine. In particular, communication between nodes is not important to our codes and was given a low priority.

Christened MERLIN, the cluster was delivered in December 2002 and within a couple of days was fully functional. The installation went completely according to plan, which is a tribute to the hard work and planning undertaken by the team. With a peak computing power of more than one teraflop and an immense multi-terabyte disk-storage capacity, the computer will be the workhorse of our data analysis endeavours.

Gravitational Wave Astronomy

The goal of detecting gravitational waves is, of course, to learn more about the Universe, and therefore within the Division we maintain an active research program in gravitational wave astrophysics.

During 2002 Curt Cutler devised a novel and interesting model for the emission of gravitational radiation by neutron stars. Reasoning that the strong dipolar magnetic fields of pulsars may, as in the Sun, be accompanied by strong internal magnetic fields that stretch in a band around the equator of the star (called toroidal fields), Cutler pointed out that such toroidal fields actually can pull in the waist of a star, making the shape of the neutron star's solid crust resemble a prolate American football rather than the normally-assumed oblate (pancake-shaped) form. Given a strong enough internal field and fast enough rotation, this distortion would make the star unstable and cause it to flip, so that the long axis of the football lies in the equator of rotation. Such an object would be a strong source of gravitational waves, and could moreover explain in a natural way why the external dipole magnetic field of pulsars is not aligned with their spin axes. The numbers suggest that the fastest pulsars, called millisecond pulsars, may well be affected by this instability, and could therefore be radiating gravitational waves at their spindown limit. This would make one or two of them accessible to GEO600 when it implements signal recycling in narrow-band mode.

Our interest in the space-based LISA project continues to be strong from the theory side as well as the experimental side. A key issue for LISA data analysis is how to do matched filtering for signals from small black holes falling into the massive black holes at the centers of galaxies. These signals are interesting from a number of points of view: they are expected to be abundant, they will allow us to get information on the mass distribution of central black holes, and most of all they will be an excellent test of general relativity and in particular the uniqueness theorem for black holes. Such signals test relativity because the objects perform thousands of orbits before falling into the central hole, and these effectively map out the geometry outside the black hole with exquisite precision.

However, because the objects make so many orbits, gradually shrinking towards the central hole as they lose energy to gravitational waves, the signals are very complicated, and one needs a detailed understanding of how these objects radiate in order to predict them and construct filters. Until now, the radiation problem has not been solved for small bodies orbiting rotating (Kerr) black holes. But during 2002 Leor Barack of the AEI and his Israeli collaborator Amos Ori made an enormous step forward by showing how, at least in principle, to solve the problem. This meant regularizing the infinities that crop up in the usual approaches to the problem. The method still has to be translated into a working computer program, but we are confident that this can be done in the near future.

Bernard F. Schutz

Quantum Gravity and Unified Theories Division

Research in the quantum gravity division over the past year covered a broad range of subjects in supergravity and superstring theory as well as alternative approaches to the quantization of gravity. Amongst others research topics included the study of string motivated problems in gravitational physics, such as the study of specific solutions of Einstein's equations in the context of compactifications of higher dimensional theories of (super)gravity, the connection between gravity and gauge theories, and the physics of non-commutative space-times. Much progress was made in canonical quantum gravity - also called loop quantum gravity, or quantum general relativity - , especially concerning the construction of candidates for semiclassical states. In addition, new activities were started in BKL cosmology, with special emphasis on the hints it might provide of new "hidden symmetries" of Einstein's theory and its generalizations. New areas of common interest to both the Quantum Gravity and Geometric Analysis and Gravitation divisions were explored, in particular physics and geometry in three space time dimensions. In two separate articles in this report on canonical gravity (Thiemann) and the string/pp-wave correspondence (Staudacher) two examples of the frontline research being done at AEI will be highlighted in more detail.

As in previous years a substantial part of the work was done in collaboration with scientists from other institutions and from many different countries. The necessary visits were usually funded by the AEI visitor program; in addition the quantum gravity division continues to receive support from independent agencies, such as DFG, GIF and EU networks. There is a considerable number of scientists coming to AEI with their own funds. Members of the division are frequently invited to speak or lecture at international schools and conferences. These activities included graduate and undergraduate lectures at Potsdam University, Humboldt University and Technical University Berlin; advanced courses at various Schools in Bad Honnef funded by the Heraeus Foundation, such as the one on "Aspects of Quantum Gravity", March 2002 (see e.g. the published lecture notes [AEI-2002-087]; and finally invited contributions to major conferences, such as the Cambridge Strings 2002 Conference. Members of the division participate in organizing various meetings, such as the EU Midterm meeting of the EU network "Superstrings" at Ringberg Castle in June 2002 and the RTN Meeting in Leuven, Sept. 13-19, 2002 of the EU network "The quantum structure of spacetime and the geometric nature of fundamental interactions". Last but not least they serve as editors on the boards of leading journals such as Classical and Quantum Gravity, Communications in Mathematical Physics and the (electronic) Journal of High Energy Physics.

Young researchers, and PhD students in particular, played an important part in the ongoing research activities. Training them to do research on the frontiers of science continues to be a main priority in the division. These activities as well as the links with the Berlin and Potsdam Universities will get a further boost with the advent of the International Max Planck Research School "Geometric Analysis, Gravitation and String Theory" that will start in January 2004 with the joint participation of the Quantum Gravity and Geometric Analysis and Gravitation divisions.

Loop Quantum Gravity

Over the past few years much progress was made towards formulating a truly background independent theory of quantum gravity. These developments, many of which have taken place at AEI are based on a reformulation of canonical gravity in terms of connection variables rather than the original metric variables. In recent work the associated holonomies have been taken as the basic variables, and for this reason, the field has now come to be called Loop Quantum Gravity (LQG). Recent work has shifted to an analysis of the classical limit of the theory with the aim of bridging the gap that still exists between LQG in its present form and the more conventional formulation of general relativity in terms of a metric. There are now two candidate sets of semiclassical states for LQG, one of which was developed at AEI [AEI-2000-026,027,028,029,030 and AEI-2001-011]. In [AEI-2002-045] it was shown that this set of states and another one that was originally viewed as independent are actually special cases of a more general scheme for constructing coherent states for a given theory, thus unifying both frameworks. This general construction was then applied in publications [AEI-2002-049] and [AEI-2002-050] to the problem of deriving a standard quantum field theory on curved space-time as a limit from the theory, resulting in a first contact between these two entirely different quantum field theory categories.

BKL Cosmology and Infinite Dimensional Symmetries

While the behaviour of Einstein's field equations near a spacelike (cosmological) singularity in the framework of the ideas developed by Belinski, Khalatnikov and Lifshitz (BKL) has been a subject of intense study already for a long time (see also previous AEI reports), a new development was the application of these ideas in the context of the models that one obtains from superstring and M-theory, and this has led to new and important insights. Not only do the models, which are candidates for a unified description of the fundamental forces have problems in accommodating de Sitter space (and thus an inflationary universe), but they also, and without exception, exhibit the chaotic oscillations of the metric near the spacelike singularity first found by BKL in the context of Einstein gravity. There is a deep connection with the theory of indefinite, and more specifically hyperbolic Kac Moody algebras, which is still very incompletely understood, like these algebras themselves. Namely, the space of (the logarithms of) the diagonal metric degrees of freedom can be identified with the Cartan subalgebra of an indefinite Kac Moody algebra. The effective dynamics of the diagonal metric degrees of freedom can then be described as a relativistic billiard taking place in the Weyl chamber of an associated Kac Moody algebra, where the walls against which the reflections take place have a profound group theoretical meaning. In particular, the maximally extended supergravity in D=11 in this way can be shown to be related to the maximal hyperbolic Kac Moody algebra E_{10}. [AEI-2002-054, AEI-2002-084, AEI-2002-092]. It was furthermore realized that the BKL analysis represents only the very first step in an expansion that also provides intriguing hints of a much larger hidden symmetry of Einstein's theory and other theories, generalizing the well known Geroch group (whose action is only describable so far on very special solutions admitting two commuting Killing vectors).

Gravity and Supergravity in Three and More Dimensions

Gravitational physics and supergravity theories in three dimensions and their connections with the geometry of hyperbolic manifolds and the Thurston program of classifying them were studied in an internal two day workshop at AEI, which was jointly organized by the Quantum Gravity and Geometric Analysis and Gravitation divisions.

Much progress was made in studying the extremal structure of the scalar field potentials of maximal gauged supergravities in three space-time dimensions [AEI-2002-004, AEI-2002-52], a follow-up project on the first construction of such theories in the previous year at AEI. These potentials are arguably the most complicated potentials ever studied in the context of supergravity (and perhaps beyond), and the fact that results can be obtained at all is largely due to the presence of the exceptional symmetry group E_8 and its "miraculous" properties. The other key ingredient in this investigation was the development and astute use of symbolic computer programs, in particular the development of entirely new LISP codes. A package for explicit symbolic and numerical Lie algebra and Lie group calculations that is likely to be useful in many other contexts was presented in [AEI-2002-065]

Superstringers are well known to like dimensions other than four, but of course the implications of higher dimensional supergravity and superstring theories on physics in four spacetime dimensions must be further analyzed in view of the ultimate goal of explaining the standard model of particle physics. In this vein, reductions of supergravity theories to four dimensions from higher dimensions in the context of M-theory were also studied. One way to obtain four-dimensional field theories with N=1 supersymmetry (which many theorists believe to be "just around the corner") is to reduce 11-dimensional supergravity on a space with G(2) holonomy. In realistic models we need a non-Abelian gauge group as well as chiral fermions and both properties require singular internal spaces. While in [AEI-2002-028] a new G(2) space is constructed, which is less symmetric than the known ones, in [AEI-2002-053] a space is obtained which describes three intersecting 6-branes and which therefore might give rise to the standard model of elementary particle physics.

The PP-Wave/String/Gauge Theory Correspondence

A recurring theme in string theory is the connection between gauge fields and strings. In modern language one is looking for a dual formulation of gauge theory in terms of string theory, which is expected to exist at least in the limit of a very large gauge group. A novel concrete proposal for such a duality was introduced last year by Berenstein, Maldacena and Nastase (BMN). Here IIB superstrings are considered in a planar gravitational wave background and are conjectured to be dual to a specific large isospin sector of maximally supersymmetric U(N) Yang-Mills theory in the limit $N \rightarrow \infty$. The string model is readily quantized in this background and its free spectrum may be related in a one-to-one fashion to gauge invariant operators of large isospin in the planar limit of the field theory. In particular the planar scaling dimensions of the gauge theory operators agree with the free string spectrum order by order in a perturbative loop expansion. At the AEI important contributions to this area of research were made - specifically addressing the question of plane wave string interactions and its relation to the non-planar sector of the gauge theory.

On the gauge theory side of the correspondence the publication [AEI-2002-036] established the fact that the gauge theory limit in question represents a novel type of double-scaling limit under which diagrams of all genera survive. The consequences of this insight were analyzed in [AEI-2002-061, AEI-2002-104] resulting in a gauge theory prediction for the higher-genus corrections to the string spectrum.

On the string side, important contributions to the form of the three-string vertex in light-cone plane wave string field theory were made in [AEI-2002-064, AEI-2002-086]. These results lay the basis for an analogue computation of higher genus corrections to the spectrum from string interactions. Investigations on algebraic issues of this novel gauge theory limit were addressed in [AEI-2002-040, AEI-2002-089].

An extension of the BMN proposal to less supersymmetric models was given in [AEI-2002-016].

Similarly, supermembranes propagating in an eleven dimensional plane-wave lead to a mass-deformed Yang-Mills quantum mechanics which is expected to give a partonic description of M-theory, also known as Matrix theory. Unlike Matrix theory in flat backgrounds, the spectrum of this novel matrix theory can be computed perturbatively and the existence of protected multiplets was demonstrated in [AEI-2002-074, AEI-2002-051].

Superconformal Field Theories

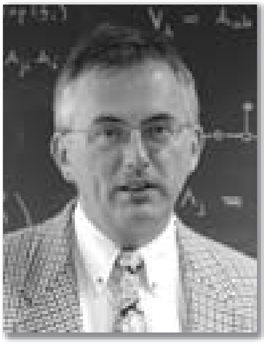
Dynamical properties of superconformal field theories were also studied in the context of this duality conjecture, such as the behavior of a class of local composite operators in N=4 SYM with a non-trivial mixing under renormalization. The corresponding one-loop mixing problem was resolved by identifying the actual quasiprimary operators. The anomalous dimension of one of them (interpreted as dual to a supergravity bound state) appeared negative and suppressed with respect to the anomalous dimensions of others. A general mechanism responsible for this suppression at any order of perturbation theory was revealed. A partial non-renormalization theorem was proven for the four-point correlators of 1/2 BPS operators in N=4 SYM. This is a dynamical mechanism which restricts the possible form of the amplitude beyond the superconformal Ward identities. By using the effective 5d description of the compactified type IIB supergravity it was possible to compute some supergravity-induced four-point amplitudes and showed that they indeed enjoy the structure predicted by partial non-renormalization.

The quantization of conformally invariant supersymmetric gauge theories requires gauge fixing. This requires a modification of the transformation of the fields under those generators of the conformal group which are broken by the gauge fixing. The requisite modifications were computed in various conformally invariant N=4 and N=2 theories, with a discussion of the restrictions this imposes on the form of the effective action. In this way one can recover the AdS space which appears in the AdS/CFT correspondence (hep-th/0210007). Further work concerned the comparison of gravitional couplings which can be computed via string theory and the matrix model. The present result also provided a check of a recent proposal concerning instanton corrections of certain gravitational couplings in Seiberg-Witten theory (hep-th/0211216).

D-Branes and Noncommutative Gauge Theories

During the last year significant progress was made on the construction of exactly solvable open string theory. In particular, explicit formulas were obtained for the coupling of closed strings to a large class of new symmetry breaking branes on group manifolds. As a spinoff, the results of (hep-th/0203161) can be applied to construct e.g. non-trivial defect lines in 2D condensed matter systems and branes in a various coset theories (hep-th/0212119), including cosmological models.

Two other results concern the study of bulk and boundary RG flows in 2D conformal field theory. In (hep-th/0205011) a new and widely applicable rule was proposed to predict flows which are generated by relevant boundary operators in coset conformal field theory. This rule generalizes the “Absorption of the boundary spin principle” previously used to summarize the results from the renormalization group analysis of the Kondo model. The rule captures many interesting dynamical properties of D-branes in strongly curved string backgrounds. Bulk flows with constant central charge were studied in (hep-th/0211063).



In particular, a new quantity was introduced that decreases in such flows and showed that the latter agrees with space-time energy in asymptotically flat backgrounds.

Noncommutative gauge theories, which were a hot topic in recent years, were also further studied at AEI. In particular, local and global anomalies were examined for gauge theories on non-commutative space-time. To resolve the ambiguity in the definition of the current it was necessary to introduce a modified analytic structure of the amplitudes as compared to the commutative case. In particular it was argued that the pion must also decay in a non-commutative theory. (hep-th/0203165, JHEP 0206:050,2002)

Hermann Nicolai

Laser Interferometry and Gravitational Wave Astronomy Division

The year 2002 was the first year of operation of this division. January 1st of 2002 marks the foundation of the Teilinstitut Hannover of the Albert Einstein Institute, which from now on will comprise two sites, one in Golm, concentrating on theoretical activities and one in Hannover, concentrating on experimental research. Currently just one division is operating in Hannover, but the second experimental division will be built up over the next few years. Construction of a new laboratory building for the Albert Einstein Institute in Hannover has begun in December 2002 and construction of an office building is expected to begin in the fall of 2003. Activities in experimental gravitational research have begun in the Max Planck Society in the pioneering days of the field in the 1970s and we are pleased to see that they now find a permanent home in the enlarged Albert Einstein Institute.

The final goal of all activities of the Albert Einstein Institute in Hannover is the detection 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 is built in a German-British collaboration comprising Max Planck Institute for Gravitational Physics, Max Planck Institute for Quantum Optics, University of Hannover, Laserzentrum Hannover (LZH), University of Glasgow, and Cardiff University. We are part of the LIGO Science Collaboration (LSC), were we contribute in the working groups concentrating on the second generation upgrade of the LIGO observatory (LIGO II) 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 now funded by the Deutsche Forschungsgemeinschaft (DFG) through the Sonderforschungsbereich Transregio (SFB/TR6) Gravitationswellenastronomie comprising the Universities of Tübingen, Jena and Hannover and the Max Planck Institutes for Gravitational Physics and Astrophysics. For the space detector LISA we are a part of an international collaboration of ESA and NASA with payload contributions from European national member states. For SMART II, the technology demonstration space mission for LISA, to be launched by ESA in 2006, we are part of the LISA technology package (LTP) architect team, and largely responsible for the laser system and interferometry layout.

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 and financial contributions have been obtained from the state of Niedersachsen, the Volkswagen Foundation, the British PPARC, the German BMBF and the Max Planck Society.

In the year 2002, we made big steps towards the final configuration of all components of the interferometer. Built on the experience obtained during the first engineering run, from December 28th of 2001 till January 14th of 2002, we made important changes that improved the sensitivity. In particular, the stray light level in the interferometer and on the detection bench could be reduced considerably. The power recycled Michelson is now locked using an electrostatic drive, the auto-alignment system for the Michelson interferometer is now feeding back to the intermediate mass with 10Hz bandwidth for two degrees of freedom for all suspended GEO mirrors, and all long-term drifts are stably compensated by an automatic drift control system. Active vibration isolation has been implemented in the tanks in the GEO end stations. All important mirrors are now suspended as triple pendulums with all-monolithic fused silica lower stages and feedback from triple reaction pendulums. Very high Q-factors (several hundred million) are reached for the violin modes of the fused silica suspension wires and techniques have been developed to selectively damp these modes and to tune their resonance frequencies even in-situ after welding. With the installation of the signal recycling mirror the complete core interferometer is now in its final configuration and ready for operation. What remains in 2003 is the installation of additional output optics, in particular an output telescope for beam shaping into the output mode cleaner. Work on the data acquisition system is now complete and a fully automatic self-diagnostic and alerting system has been implemented. Work has been completed on the design of a radiation pressure calibrator for the displacement sensitivity of GEO600. This can be used to inject mock astrophysical signals, in particular signals from pulsars, into the detector and to verify the data analysis algorithms designed to search for them. Detector characterization with the goal to improve the performance of the detector as well as to develop tools for the validation of data analysis is an important activity. This involves a huge amount of environmental data and the analysis of their correlation with signatures in the detector data stream.

Modeling of laser interferometric gravitational wave detectors by time and frequency domain simulations turned out to be indispensable to develop operating procedures for the interferometer. The dynamical behavior of an interferometer with dual recycling and many radiofrequency sidebands on the optical carrier can not be intuitively predicted and requires a modular software approach. This is still very much work in progress, but the good system performance of GEO600 would not have been possible without this work.

All of these efforts culminated in two data taking runs in 2002, the E7 run in January and the S1 run in August, both in coincidence with the two LIGO sites in Hanford and Louisiana. During the S1 run we reached an overall duty cycle for all systems in lock and operating properly of over 98%. The longest continuous uninterrupted lock period was more than 121 hours long and the best sensitivity reached was equivalent to a linear spectral density of strain $h<7\cdot10^{-20}\ 1/\sqrt{\mathrm{Hz}}$ for signal frequencies above 1kHz. With these sensitivities we could obtain the first astrophysical results, in particular the absence of any NS-NS mergers within a range of 300pc and an upper limit for the energy loss of the binary pulsar PSRJ1939+2134. These result were obtained without a signal enhancing mirror and still with preliminary main optics. Final optics has now been installed and we are currently preparing the detector for the next data taking run in spring of 2003, with the sensitivity expected to be much better than before.

LIGO II, EGO and EURO

The first generation of large gravitational wave detectors is going into operation now. Their sensitivity will not necessarily be sufficient for first serious astronomical observations and maybe not for a first detection. The observatories were always foreseen to go 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 LIGO II, the second generation upgrade of LIGO. The systems design has now been finished and incorporates several GEO600 technologies, like multiple pendulum vibration isolation, monolithic suspension, signal recycling and resonant sideband extraction. In Europe, we have intense interaction between GEO and the VIRGO project, which is now under the umbrella of EGO, the European Gravitational Observatory consortium, with the long-term goal of a 3rd generation detector in Europe (EURO) to complement LIGO II.

Prototype Interferometer, Laboratory Research and Advanced Techniques

The Garching 30m prototype interferometer has been relocated into the basement of the Max Planck Institute for Quantum Optics in Garching and its arms shortened to 12m. It is operated by a small group of AEI personnel located in Garching and it is currently used to test thermal tuning of the signal recycling resonance frequency by thermally changing the index of refraction of a solid etalon signal recycling mirror. Currently the servo for finesse control of the signal recycling cavity is being developed. Extension of this technique suitable for installation in the UHV system of GEO600 and using GEO600-size mirrors is being developed in Hannover.

Our laser development work in collaboration with the Laserzentrum Hannover (LZH) is proceeding along several development lines, all aiming at the development of high-power, high-stability, laser systems suitable for the next generation of gravitational wave detectors. On the high-stability path, we have made considerable progress in understanding the noise behavior of miniature monolithic diode-pumped NdYAG-ringlasers. We were able to improve both power and frequency noise by feeding back to the pump diode current, we could show that an independent stabilization of the pump diode intensity really leads to reduction of the ringlaser output noise if a single mode pump diode is used, as opposed to a pump diode array, demonstrating the limiting effect of mode beating noise. On the high power front we now have available 80W of output power from a NdYAG-slave laser, with almost refraction limited beam quality and 20W of power from a Vanadate laser locked to a high stability master laser. We are responsible for the LSC lasers working group and lead the advanced LIGO laser development effort.

Thermal noise is expected to be a serious limit for the sensitivity of future generations of gravitational wave detectors. While the thermal noise on and near the mechanical resonances has already been observed in our prototype interferometer and other laboratory experiments the off-resonant thermal noise far away from the system resonances can still only be predicted by modeling and calculations. We are trying to measure and characterize the thermal noise in the wings far away from resonance in a laboratory experiment, using small mirrors suspended from a multiple pendulum as a miniature Fabry-Perrot cavity. Over the last year, we have made further improvements to the setup after a detailed mechanical model of our pendulum chain, taking all degrees of freedom into account, has shown that the coupling between the various degrees of freedom is much more severe than anticipated. A completely new multiple stage suspension has been designed and installed and in particular the moments of inertra of the last pendulum stages increased considerably, and additional vertical isolation has been installed. The influence of radiation pressure noise due to laser amplitude fluctuations has been studied and an auto-alignment system has been installed that now permits stable and reproducible locking of the whole system.

Our interferometer modeling software environment FINESSE has been expanded by the inclusion of higher order TEM modes. This made it possible to calculate the auto alignment signals for a dual-recycled interferometer. It also shows that the error signals, derived from the demodulation of a power recycled Michelson Interferometer, are only correct if higher TEM01 modes are included. TEM02 modes turned out to make the interferometer two orders of magnitude more sensitive to frequency noise than had been assumed before, finally explaining some strange system behavior. We have also achieved considerable progress in the modeling of dual-recycled interferometers by combining FINESSE and our optical design environment OPTOCAD and FFT wavefront propagation calculations, finally showing that the expected mode healing effect due to dual recycling is much more robust than anticipated and leads to large gains even in the presence of a strong thermal lense. The final dual recycling configuration for GEO600 was calculated this way, and the model strategy for lock acquisition in the final high gain dual recycling environment developed.

The standard quantum limit is now no longer regarded as a fundamental limit for the sensitivity of the gravitational wave detectors. We have started an experimental and theoretical activity aimed at the operation of interferometers with non-classical light and at the development of interferometric techniques to go below the standard quantum limit of laser interferometric gravitational wave detectors. Our model calculations show clearly that the quantum noise of GEO600 in the detuned recycling mode will be considerably below the standard quantum limit for signal frequencies around 100Hz, even if losses of a few hundred ppm are included and coherent light is used at the input. We will refine these calculations and include the influence of squeezed light at the input and output of the interferometer. In parallel we are developing OPA-based sources of squeezed light for applications in table-top interferometers.

New optical media with negative or very steep positive dispersion at a point of vanishing absorption can be realized through coherently prepared superpositions of quantum states in atomic systems. In a strongly driven two-level system on the Ca resonance line we could achieve a residual absorption of less than 0.3% per cm at a point of strong negative dispersion. With increasing laser power, the absorption in these systems drops faster than the dispersion. So far our available laser power has not been high enough to reach a parameter range that would make a white-light resonator possible. Consequently, we have investigated several other atomic systems for their suitability as transparent negative dispersive media. It turned out that the strongly driven two-level system is the simplest to realize, but the largest figure of merit can be obtained in a four-level system with indirect pump rate into one of the excited levels. In closed two-level systems in Cs we have also studied electromagnetically induced absorption and realized a double dispersive profile shift of the probe with a very narrow dispersive resonance of a few kHz width in the center.

LISA and SMART II: Laser Interferometers in Space

LISA is a collaborative ESA/NASA project for a gravitational wave detector in space with 5 Million km armlength, comprising three spacecraft at the corners of an equilateral triangle. A joint international LISA science team (LIST) has been appointed by ESA and NASA, with 10 members and a co-chair from each side of the Atlantic. We are participating in the project and three of the 10 European members of the LIST are from the Albert Einstein Institute. During 2002 we have concentrated on refining the science requirements for LISA and defining the base line mission. In a long standing question of the feasibility of phase-locking of lasers when time delay interferometry is used has now been settled. A time-domain algorithm for removal of laser and USO noise is now the baseline and requirements for the allowable error of the armlength difference determination could be specified. Several alternatives for ranging methods are being investigated, in particular pseudo-random noise ranging with the potential for submeter ranging errors.

Most of our experimental work has been focused on SMART II, the technology precursor mission for LISA, which is supposed to be launched in 2006. We are part of the LISA Technology Package Architect team, are responsible for provision of the laser system, have designed the interferometry layout for the SMART II optical bench, and built a breadboard phase read-out system for SMART II. After a detailed comparative study of various interferometer concepts for SMART II, we have performed a trade-off between polarizing versus nonpolarizing and heterodyne versus homodyne interferometers. The base line SMART II nonpolarizing heterodyne interferometer will now determine distance and two angles for the relative displacement of the two free-flying test masses in SMART II plus an additional read-out of one test mass relative to the optical bench. That can be used to test an optical readout scheme as an alternative to the capacitive readout which is the base-line of SMART II. The complete interferometry has been built and tested as a laboratory setup including a breadboard type phasemeter that is using an FFT algorithm. An engineering model of a laserhead, suitable for use on SMART II, has been obtained and has undergone complete testing and characterization. We are currently negotiating our national German contribution to SMART II with ESA and the other member states.

Karsten Danzmann

Geometric Analysis and Gravitation Division

Out to Infinity and Back to the Basics

The numerical relativity group within the division for Geometric Analysis and Gravitation currently consists of Christiane Lechner, who joined in November 2001, and Sascha Husa.

Compactification as a Road to Infinity

Our current work is focused on developing numerical relativity techniques for isolated systems. In this effort we maintain and seek to extend close collaboration with mathematical relativists and mathematicians. A key theme in our work is compactification: Using conformal methods a spacetime of infinite extent can be mapped to a finite grid in a well defined way, bypassing many ambiguities of approximating gravitational radiation problems within a finite physical domain. While our main project is to apply Friedrich's conformal field equations to numerical simulations, side projects deal with the characteristic approach and with critical collapse.

A major effort in the year 2002 has been the development of a new parallel code to solve the conformal field equations and other evolution systems in 3D. The new code is based on the Cactus computational toolkit, which is developed at AEI. This has become necessary both for computational reasons, e.g. to have a portable code available for distributed computing architectures, but even more it has become important to test different evolution systems, and use new features that are more easily supported in a new code designed with previous experiences in mind. Many of the technical problems one faces in the conformal approach to numerical relativity are analogous to or actually the same as those in the standard 3+1-setup. Comparing our formulations of the Einstein equations with more standard formulations forms an integral part of our research. To this end we have coded different evolution systems such as the ADM and BSSN systems, and direct comparisons of results proves helpful and stimulating.

The development of compactification techniques naturally leads one to consider curvature variable based systems for the Einstein equations, which is an aspect interesting by itself, even without regarding compactification. Recent work has been devoted to studying the effects of introducing curvature variables into a numerical simulation, and we have gained new insights that we hope will provide fruitful guidance for future work where we will focus on the effects of compactification.

Computer Algebra for Numerical Relativists

Much effort has successfully been devoted to develop computer algebra techniques for tensor manipulations in a 3+1 context and automated generation of code. In numerical relativity, the complexity of the equations themselves - and not just of their space of solutions - is an essential element of complexity of the field. Deriving and implementing a new formulation of the equations is thus a considerable effort. Also, mathematical analysis and numerical relativity experience have shown that bringing the Einstein equations into a form which is suitable for numerical treatment is actually far from trivial and is still not fully understood. Considering evolution problems, it turns out that obtaining a well-posed problem is by far not sufficient. Well-posedness does not rule out exponential growth which may result from constraint violating modes or a bad gauge. Curing such problems typically requires modifying the evolution equations, taking into account the effects on associated systems equations such as the propagation system for the constraints of the theory. This leads to the necessity to analyse and code many different systems of equations. However, from 3+1 splits to deriving the constraint propagation system, from discussing hyperbolicity to coding, much of this effort can be automated. Computer algebra makes it easier to focus on algorithms, detached from a particular system of equations. Stressing a more abstract point of view is not only mathematically more appealing but also increases flexibility, which benefits scientific productivity. Remarkably, in the field that uses computers to solve the Einstein equations, the use of computers to manipulate those equations has rarely been pursued systematically.

In the last year S. Husa and C. Lechner have built up a Mathematical/MathTensor-based framework, which they have used to generate Cactus-based codes for the ADM, BSSN and conformal field equations. The conformal field equations form a quite complicated system of equations, and abstract index computer algebra has proven invaluable for many calculations such as 3+1 splits, manipulation of equations, propagation of constraints. The techniques we developed can also be used for other systems, and will also form a basis for new collaborations. An essential problem for the numerical simulation of isolated systems is to control the initial-boundary value problem. This problem is still not well understood within general relativity, but will become an important issue in the next year. First, however, a good understanding of the simpler problem without boundaries has to be obtained. As is customary in numerical relativity, we have carried out numerical tests on the three-torus, that is with periodic boundary conditions. At this time we are close to finishing a paper with coauthors from more than ten groups on a suite of code tests with periodic boundaries. In this work, we were able to give important input and unveil some of the subtleties when working with periodic boundaries. In this effort, communication with Alan Rendall and Hans Ringstrøm has been very fruitful.

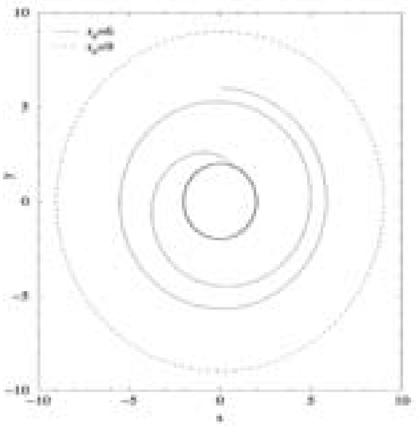


Figure 1
The orbit traced by a particle (modeled as a polytropic object with fixed radius), initially at r=6, as it is captured by a black hole (solid line). Overlaid in the figure is the orbit traced by a particle initially at r=9 (dotted line). The central circle indicates the location of the horizon (r=2).

Particles for LISA

In collaboration with the Pittsburgh numerical relativity group Sascha Husa has worked on aspects of the numerical treatment of the characteristic initial value problem. In recent work they have studied the fission of a white hole as a precursor to black hole merger studies, and they have developed a code that simulates the nonlinear interaction of a particle with the gravitational field. The latter is the starting point for simulations of very unequal mass black holes (Fig.1), which are particularly relevant for the future LISA gravitational wave detector in space.

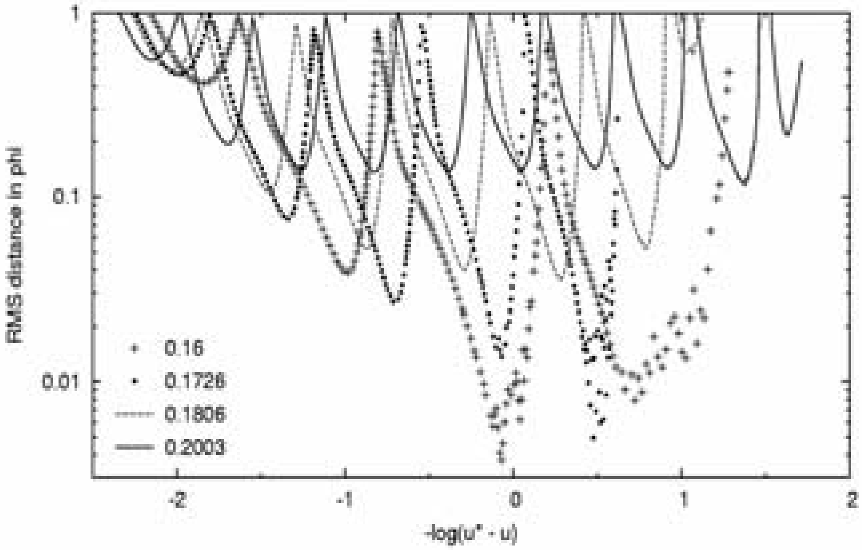


Figure 2
For a set of coupling constants a distance function between a continuously self-similar solution and the discretely self-similar critical solution of a sigma-model is shown versus time. This illustrates an approach in phase space which is interpreted in analogy to a heteroclinic loop bifurcation in dynamical systems, where a fixed point collides with a limit cycle in phase space as the coupling constant tends to a critical value.

In another collaboration, with Jonathan Thornburg at AEI and with a group at the University of Vienna, we are studying critical collapse of a harmonic map matter model, focussing at the transition between continuously and discretely self-similar gravitational collapse (Fig.2 p.36)

Sascha Husa

Initial Conditions for Stars and Black Holes

Initial Value Formulation

The aim of physics is to make predictions; that is, knowing a system at some time we want to predict its behavior in the future. The physical laws are encoded as differential equations, the behavior of a particular system corresponds to a particular solution of the corresponding differential equation. That is, in order to make predictions we need to have appropriate solutions. Sometimes, when the system is simple enough, it is possible to find explicit solutions. By this I mean solutions that can be written in terms of some finite number of elementary functions (like powers, trigonometric functions, etc.). However, when the system is complicated, it is in general impossible to find this kind of solution. There exists a more general procedure for solving a certain class of differential equations which precisely takes into account the idea of making predictions. Instead of trying to obtain the solution at once, we split the problem in two parts. Firstly, we solve the part of the equations which does not involve time. This part of the equations is called the constraint equations. The corresponding solutions are called the initial conditions. They describe the system at a given instant of time. Secondly, we evolve in time the initial conditions with the other part of the equations called the evolution equations. Then we can predict how the system will behave in the future. The whole procedure is called the initial value formulation. Not all differential equations admit an initial value formulation. However, the equations that occur in physical laws do admit one, in agreement with our hope that it is possible to make predictions in nature.

Stars and Black Holes

The physical systems I am interested in are astrophysical systems formed by massive stars or black holes. It is expected that many such systems exist in the universe. Moreover, these systems are expected to have the following two properties. Firstly, gravitational radiation will be emitted by them and the new gravitational wave detectors will be able to measure it. Secondly, these systems are completely described by the Einstein field equations. By this I mean that there exist solutions of the Einstein equations that can, for example, reproduce the gravitational wave forms emitted by them. The ultimate goal is to find these solutions and compare the wave forms with the result of the measurements.

The most appropriate method to find these solutions is through an initial value formulation. However, in contrast with other theories, the Einstein equations are non-linear. This makes them difficult to solve. The corresponding evolution equations have to be solved numerically with computers (see report by Edward Seidel). Even to find solutions of the corresponding constraint equations is complicated, since they are also non-linear. My work is concerned with the problem of how to find appropriate solutions of the Einstein constraint equations that can describe, in some approximate way, this class of astrophysical systems.

Solving the Constraint Equations

How can one obtain initial conditions for an astrophysical system? We can not prepare such initial conditions in a laboratory: we have no control over such massive bodies. However, it is expected that such systems at some time will have a particularly simple configuration. For example, consider the one of two black holes which were, at some point in the past, separated by a large distance. In such a case, the initial conditions will approximately be the sum of the initial conditions for two isolated black holes. It turns out that initial conditions for isolated black holes are simple and they are very well understood. Of course, it is not easy to make precise the concept of "approximately the sum" for a non-linear equation, this is precisely the point where the difficulty arises.

We can think of initial conditions for the Einstein equations given as a picture of the space time at a given time. For this kind of system, the space is divided in two regions. One compact region which contains the sources (the stars or the black holes) and its exterior which is unbounded. The exterior region is called the asymptotic region. The fields behave very differently in these two regions, so it is natural to study them separately.

I found a procedure for constructing a large class of initial conditions such that the fields have a remarkably simple behavior in the asymptotic region. This behavior is very similar to the multipolar expansion in the Newtonian theory of gravitation or electromagnetism. One of the main interests in these kind of initial conditions is that they can be evolved with the Conformal Field Equations developed by H. Friedrich. This will allow us to analyze in great detail the structure of the whole space time in the asymptotic region.

The region which contains the sources is more complicated than the asymptotic region. The stars and black holes behave differently in the source region. In the case of stars there is matter in this region - a fluid for example. The interface between the matter and the vacuum is difficult to handle because some fields are discontinuous there (Fig.1). I have analyzed this problem and have found initial conditions that can describe stars in which the mass density does not vanish at the interface - like the sun for example.

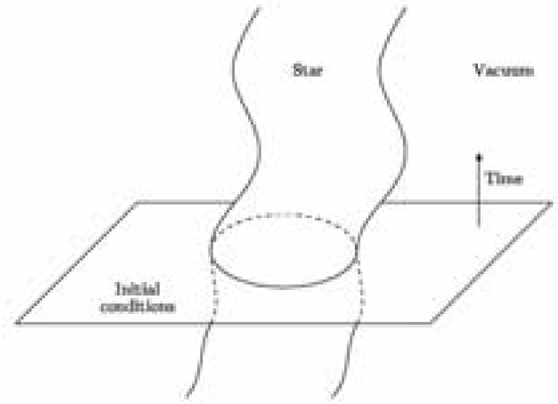


Figure 1
Schematic representation of the initial conditions for a star and its future evolution. The plane represents the initial conditions - it is a picture of the star at a given instant of time. The lines represent the boundary of the star as it evolves in time.

In general, for black holes we can make the assumption that there is also vacuum in the source region. However, in this case, the topology can be non-trivial (see Fig.2). In fact the simpler way of obtaining initial conditions for black holes involves a non-trivial topology. Using the topology showed in Fig.2, I have constructed initial conditions that can describe a collision of two or more black holes. These initial conditions are such that when the separation distance between the black holes is large enough they reduce to the initial conditions of two isolated black holes with intrinsic spin.

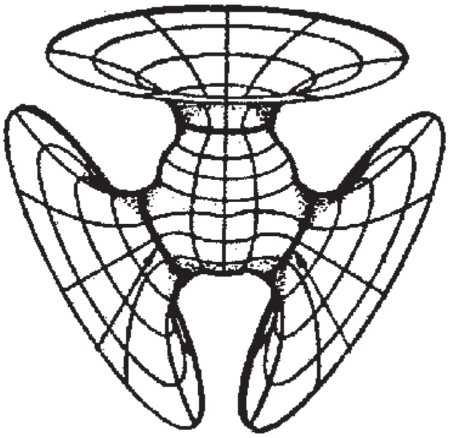


Figure 2
The topology of the initial conditions for two black holes.

Finally, I want to say a few words about the techniques used in order to obtain these results. The constraint equations can be reduced to elliptic equations. For these type of equations there exists a well developed theory. One of the most important parts of this theory consists of certain inequalities, called elliptic estimates, which control the behaviour of the solution in terms of the behaviour of the sources.
I have used the elliptic estimates together with the Schauder fixed point theorem to prove existence and regularity of solutions for the constraint equations.

Sergio Dain

Astrophysical Relativity Division

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 analyze data from GW experiments, and help analyze the data. We share with the University of Cardiff the primary responsibility for analyzing GW data from the GEO600 detector, and we play important roles within the LIGO Scientific Collaboration (LSC), analyzing GW data from the U.S. LIGO detectors.

Gravitational-Wave Pulsars

Our group's largest effort concerns the search for so-called gravitational-wave pulsars: rapidly rotating neutron stars (NSs) that emit nearly periodic gravitational waves. The GW emission could be due to tiny mountains in the NS crust, excited oscillation modes, or other effects. Searching for such signals within the data stream represents a major technical challenge, since 1) the signals are expected to be at least four orders of magnitude smaller than the instrumental noise (at any instant), and so must be "dug out" of months-long stretches of data by matched filtering or related techniques, and 2) it is possible that the strongest sources are previously-unknown neutron stars, which requires searching over a huge set of possible source positions, spin frequencies, and spin-down rates.

In searching for previously unknown NSs, the basic idea is to simulate the signal from a GW pulsar with a certain position (two angular coordinates on the sky), orientation (two angles), spin rate, and spin acceleration, and then use this simulated signal as a filter on the data. One then repeats again and again, each time for slightly different possible values of the physical parameters. However a straightforward implementation of this idea would require many orders of magnitude more computational power than is realistic, and so we have devised a more efficient technique, based on the Hough Transform of particle physics data analysis. We now have a powerful and flexible software package, which is capable of searching both for unknown GW pulsars and for GWs from known pulsars, such as the Crab and PSR 1937+21. This software development effort has been led by staff member Maria-Alessandra Papa, but many other members of the group have contributed very significantly as well.

Our new Computer Cluster: MERLIN

One of our group's major achievements this year was the construction of a 128-node computer cluster, named MERLIN, dedicated to searching for GW pulsars signals buried in GEO and LIGO data. This supercomputer was designed in-house, and built from off-the-shelf components. After exhaustive benchmarking about 20 different platforms, we converged on dual AMD Athlon CPUs as giving the best price-performance ratio for our particular application. By economizing wherever it was reasonable to do so (e.g., by choosing inexpensive networking, since inter-node communication is minimal in our application, and by choosing shelves instead of rack-mounting), we were able to put together a blazingly fast (about 1 Teraflop) supercomputer for about 250K Euro (The BAR gave us about 200K, and we gratefully received an additional 50K grant from Land Brandenburg). Our vendor delivered 128 nodes in boxes on Dec. 9, and thanks to very careful advance planning and testing, the nodes were on the shelves, booted (with all software installed), and basically operational within a couple days. MERLIN is now in very active use, running our GW pulsar searches. Like the development of our pulsar code, our supercomputer construction effort was led by M.-A. Papa - again with many other group members also devoting a lot of their time. In particular, we benefited enormously from the help of Prof. Bruce Allen, who visits our group for 6 months every year, and who had already constructed two clusters of his own at his home institution, the University of Wisconsin at Milwaukee. We also now have an excellent, full-time cluster administrator, Steffen Grunewald, appointed this year.

Maria-Alessandra Papa with one shelf of MERLIN, our new computer cluster for GW pulsar searches.

Other Highlights

Besides the GW pulsar search, our group has contributed actively to GEO detector characterization efforts: the analysis of early GEO data in order to understand and improve detector performance. And researcher Soma Mukherjee has co-led the search for short GW bursts (e.g., from supernovae in nearby galaxies) in GEO data. The latter is closely related to detector characterization, since reliably identifying GW bursts requires being able to discriminate them from transient instrumental noise that might mimic them.

As a final highlight from the year, I mention important work by our EU-supported postdoctoral research fellow, Leor Barack, concerning the capture of compact stellar-mass objects (white dwarfs, neutron stars, and black holes) by supermassive black holes (SMBHs) at the centers of galaxies. During the last decade, it has been a major theoretical challenge to compute the exact trajectory of the smaller body as it spirals into the SMBH. The problem is that gravitational radiation emitted by the smaller body acts back on it, and (when the smaller body is idealized

as a point particle) this back-reaction force is formally infinite, so the problem is to "regularize" the back-reaction force. Many theory groups around the world have been working on this, and the last stumbling blocks have now been cleared away by Barack and his collaborator, Amos Ori, in a paper to be published in Physical Review Letters. It remains to turn their procedure into working code, but a complete algorithm is now available. This problem is astrophysically important because such captures will be an extremely interesting source for the LISA detector, a GW detector in space that we hope will be launched, as a joint ESA-NASA mission, around 2011.

Curt Cutler

Numerical Relativity

The numerical relativity group has been active in numerous projects in the last year. First and foremost, the major focus of the group has been on 3D binary black hole (BH) evolutions. We continued our development of techniques for better quality evolutions - including refinements to the BSSN evolution system, better gauge conditions, and better excision techniques for removing the black hole singularity - and we demonstrated them by carrying out a second-order convergent, 3D simulation of a head-on binary black hole simulation that ran for over 5000 M* and produced very accurate waveforms!

*The unit M denotes the time it takes light to travel a distance equal to one-quarter of the diameter of the black hole. Typical orbital times near black holes are less than 100 M.

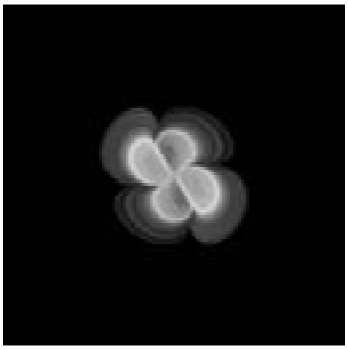
Testing the Last Stable Orbit

Building on this success, and the introduction of a technique that creates a corotating frame that follows orbiting binaries, we began to systematically study the evolution of the so-called "Pre-ISCO" sequence of orbital configurations of equal mass black hole binaries. This sequence, constructed by the group, builds on previous work of Greg Cook and Tom Baumgarte to provide astrophysically motivated initial data for black holes in circular orbits, starting with the Baumgarte Innermost Stable Circular Orbit, or "ISCO", and moving out to configurations more than twice as far away. With a co-rotating frame, orbiting BH evolutions should be similar to evolutions of head-on collisions.

Combining all of these methods, for the first time in the community, we were able to study the orbital dynamics of black hole binaries. Our preliminary results show that not only does the ISCO system coalesce very rapidly in a virtual plunge, but all configurations studied to date (out to roughly twice the distance of the ISCO) coalesce well before an orbit is achieved. These are very demanding simulations, requiring long run times and large (100GB+) machines, and the results are being studied for sensitivity to gauges, slicings, boundaries, and resolution. However, to test the accuracy of the ISCO, we are collaborating with the Paris/Meudon group in our EU Astrophysics Network to evolve their more sophisticated binary BH initial data of equal mass BHs, with co-rotating spin configurations. To date, two configurations starting inside their definition of the ISCO (which is more widely separated than the Baumgarte data) have been evolved to coalescence, and we are working to extend these results.

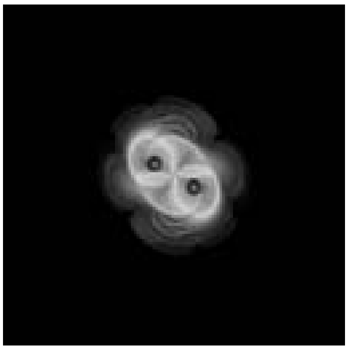
Developing a hydrodynamic code

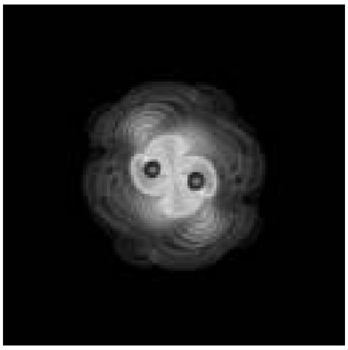
In collaboration with different nodes in the EU Astrophysics Network project, coordinated by the AEI, we have most importantly developed a completely new GR hydrodynamics code in Cactus that is being used by many groups in our collaboration. This code can be used with either fixed backgrounds or with our best Einstein equation evolvers, and it inherits all Cactus based codes and techniques described above. Projects just underway include study of rotating neutron star (NS) oscillation modes, binary NS coalescence, stellar core collapse, and accretion onto BHs. We have also developed 3D Klein-Gordon field evolvers, that use the same spacetime-matter coupling routines, provided in Cactus, as the GR hydrodynamics codes, and have reproduced older results for spherically perturbed boson stars, but with our 3D code. We expect in the next year to move these relativistic matter projects to maturity.



New Numerical Tools

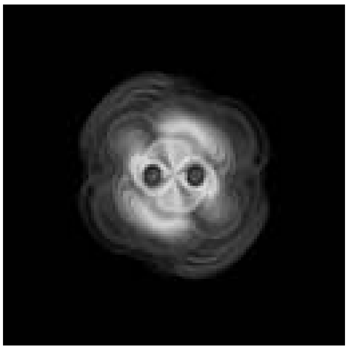
Further, we have developed a completely new apparent horizon finder, which is significantly faster (more than a dozen times) than our previous finder, and also a new 3D event horizon finder that can now be used to study event horizons of our binary BH evolutions. In collaboration with Tübingen, we have successfully tested a 3D adaptive mesh driver thorn in Cactus, called Carpet, on the fully coupled Einstein and matter field codes. In the most advanced test to date, with 5 nested refinement levels, we reproduced a rotating core collapse calculation performed previously by the Garching group in the Wilson approximation. This spring we are addressing issues needed to bring this into full production on parallel architectures, including parallel I/O and use of all analysis tools described above.



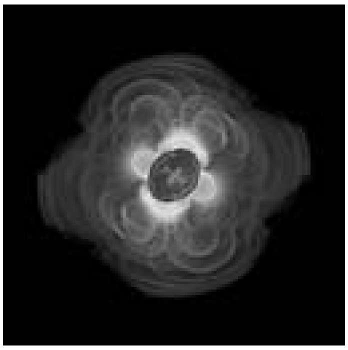


Collaboration and Outreach

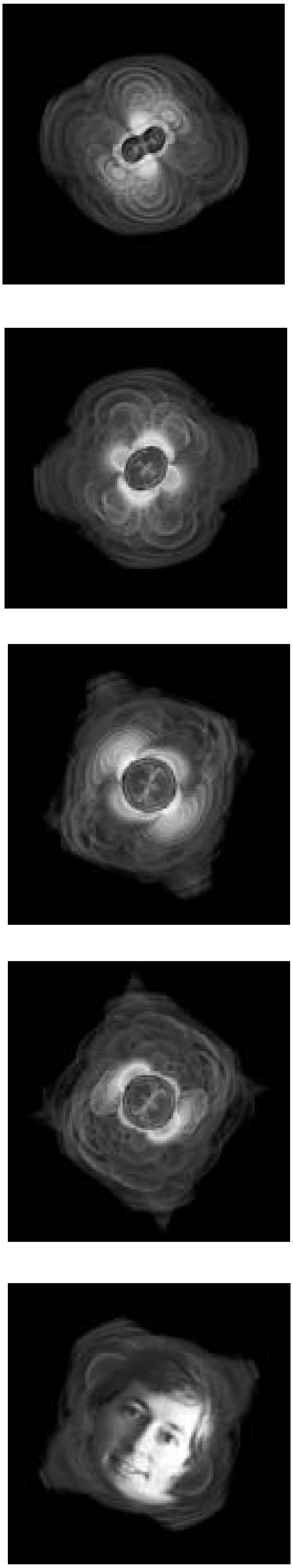
In addition to all these different physics activities, the group was very active in leading and developing open collaborations worldwide. The successful EU Astrophysics Network is entering its last year, and a follow-on application is planned for this spring, expanding the existing project to at least 14 partners (from the current 10). The group is part of the new German SFB collaboration, and the codes and techniques described above will be available to all groups in these collaborations. The AEI also participates in the NSF "ASC" project, led by Washington University.



We were the primary sponsor of a unique meeting focused on evolution systems for numerical relativity in Mexico City in May, 2002, hosted and organized by former group member Miguel Alcubierre. A dozen groups worldwide openly shared their work on the stability and accuracy of evolution systems, and jointly developed a series of tests that should be used to compare different formulations and methods. Numerical experiments, supported by the Cactus group, were compared on a daily basis for two weeks. A community web site, found at http://www.appleswithapples.org, has been developed to help promote open testing and cooperation in the community. A follow-up workshop is now planned for December, 2003.



Finally, the group's scientific results were widely disseminated to the public. Not only did our work and visualizations grace the covers and internal pages of such prominent international magazines such as Science et Vie, Scientific American, National Geographic, Geo, and others, a beautiful scientific visualization of one of the pre-ISCO binary BH simulations was produced, in collaboration with NCSA, for the Discovery Channel which prominently featured our work in a special show on the Universe. This video was also shown by Director Rita Colwell of the NSF, by DOE Science Division Director Raymond Orbach, and others, in keynote presentations at major scientific meetings around the world last year.



Computational Science

The numerical relativity group has grown dramatically in recent years, largely due to the acquisition of significant extramural funding supporting the group's computational science efforts from the European Commission, the DFN-Verein, Microsoft, and others. As a result, the Computational Science group has grown to about the same size as numerical relativity itself, requiring the acquisition of additional space as described elsewhere in this report.

Cactus user community

Development of the Cactus framework is one of the activities of the group, and its adoption has continued to spread across different communities. In relativity, Cactus is used not only by both the numerical and mathematical relativity groups at AEI, but also by most nodes of the EU Network and by many other numerical relativity groups in the US, Mexico, Australia, South Africa, and Japan. In 2002, a major revision of the support for Einstein's equations was carried out to make it easier for different groups to share and collaborate on modules. Cactus is also gaining users in nonrelativistic astrophysics, climate modeling, chemical engineering, and plasma physics.

External funding

Two grants reported last year began to support our research in 2002. The DFN-Verein sponsors the GriKSL project to develop grid-based remote I/O and visualization techniques, which is key to enabling the numerical relativity group to use machines around the world. GriKSL, built on the previous DFN funded project called "TIKSL", supports researchers at both AEI and ZIB-Berlin in a two-year collaboration.

The AEI group has emerged as one of the leading groups worldwide in Grid development. Last year saw the start of GridLab, a 6M Euro Grid project funded by the European Commission, and led by Jarek Nabrzyski in Poland. The centerpiece of GridLab is a Grid Application Toolkit, or GAT, that will allow researchers to endow any of their scientific applications (particularly Cactus) with the ability to find computational resources and to use them in innovative ways. We are also developing Grid portals, which will make finding, accessing, ultizing, and tracking grid resources and processes much easier.

Outreach and consultation

Along with these activities, the group is very active in the Global Grid Forum, co-leading the Applications Research Group, and in organizing Grid workshops and tutorials around the world, etc. It also organizes innovative demonstrations of its technology development at major conferences, including in the last year iGrid in Amsterdam and SC2002 in Baltimore. Our success at SC2002 is detailed elsewhere in this report.

Gratifyingly, group members find themselves in increasing demand as experts in Computational Science and Grid computing. We have been asked to give many talks at meetings worldwide, to join panels to advise the European Commission, NSF, and others on directions to take in these fields, and to be in review and advisory boards for various projects and centers in different countries.

Ed Seidel

This image series depicts a sequence from a general relativistic numerical simulation of orbiting black holes done in March 2002 on the NCSA Itanium Linux Cluster. In the first time ever 3/4 of a full orbit could be computed, showing the merger of the initial two black holes and the ripples of space-time, known as gravitational waves, which emerge from this event (AEI / ZIB).

Quantum Gravity and Unified Theories Division

Quantum Gravity and Gauge Theory

Among theoretical physicists, a majority today believes that string theory is currently the most promising approach to formulating a theory of quantum gravity. Of course only the future can tell whether the string ansatz will eventually lead to a final theory unifying all matter and all forces, including gravity, and whether it will explain the evolution of our beautifully intricate universe. While this does not mean that other ideas for formulating a quantum version of Einstein's theory of relativity should not be pursued as well (and researchers at the AEI are indeed also working on non-string models such as loop quantum gravity), it is widely felt that the immense world-wide effort to develop string theory is justified. In fact, even if string theory either should turn out to be the wrong theory of nature, or even if it will be ultimately superseded by a different framework, it has already had significant impact on the development of the exact sciences: For one, there has been huge and broad benefit for research into pure mathematics. Furthermore, our understanding of standard quantum (point-particle) field theory has been much enhanced. This year research carried out at the AEI has provided an interesting new example of the latter.

Nature employs gauge theories ...

Out of nature's four forces, three are well described on microscopic scales by quantum field theory: The electromagnetic, weak and strong forces. Intriguingly, these quantum field theories are all of a very special type, they are gauge theories. Here "gauge" indicates a certain built-in redundancy of the local degrees of freedom of the theory which renders the theory beautifully symmetrical. In order to perform computations, however, we frequently need to fix the redundancy in order to not overcount the number of degrees of freedom, but then we are paying a price since we destroy the simplicity and symmetry of the system. These subtle, non-linear theories are well under control in certain situations (the so-called perturbative regime), leading to a number of high-precision predictions which have been verified with ever increasing accuracy at particle accelerators around the world. However, there are many other questions involving the application of these gauge theories to experiment which remain currently out of reach: In the domain opposite to the perturbative region, the strong-coupling regime, theoretical physics lacks powerful mathematical techniques for extracting predictions. A prime example is the theory of strong interactions, QuantumChromoDynamics (QCD), where we would like to be able to compute hadronic spectra from first principles, but are so far unable to do so as this would require us to work in the non-perturbative regime.

Gravity seems different ... or not?

The fourth of nature's forces, gravity, is different from the just mentioned ones in that attempts to directly describe it on small scales by a quantum field theory have utterly failed. On the other hand we know that nature is quantum mechanical at small distances, and this leads to the riddle of quantum gravity: Einstein's classical theory of gravitation, General Relativity, stubbornly resists naive quantization. The reason why string theory is so attractive to modern theorists is that quantum gravity is automatically built in, and matter and forces, of precisely the just discussed gauge type, appear very naturally when one imposes that the strings should move in four-dimensional space-time: The four forces are from the beginning inseparably intertwined. This natural interweavement is exciting and just what we are looking for; unfortunately, there are a huge number of discrete choices influencing the details of the emerging gravity-matter system, and it is unknown what principle, if any, leads to the correct choice describing our world. With experiments currently unable to help deciding this issue, we are led to gain deeper insights into the general structure of string theory by testing it in various cleverly designed "thought experiments".

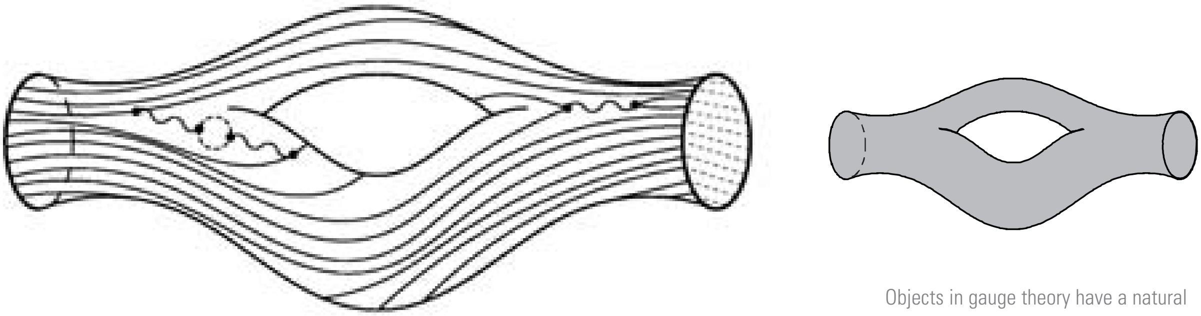
Thought experiments ...

One type of such a thought experiment involves the consideration of strings moving through simpler spaces or "backgrounds", which do not necessarily resemble our world, but allow us to improve our understanding of string dynamics. The strings that physicists are considering are subject to a symmetry between fermionic and bosonic degrees of freedom termed supersymmetry. In the backgrounds that resemble nature only one such symmetry is expected; incidentally, the search for this symmetry has been one of the chief motivations for building the Large Hadron Collider at CERN, Geneva, to go in operation in a few years time. One expects strings to be simpler when the background contains more than one such supersymmetry, but there is an upper limit on the number of supersymmetries. In the maximal case, there are very few possible backgrounds. One is a ten-dimensional flat space-time, which is the background in which superstrings have been first discovered. A further maximally supersymmetric background is built from a five-dimensional Anti-de-Sitter space where a five-dimensional sphere is attached at each space-time point: It has been one of the big theoretical discoveries in recent years that superstring theory on that particular curved ten-dimensional background appears to be described as well by a certain four-dimensional flat-space gauge quantum field theory with, here as well, the maximum number N=4 of possible supersymmetries. (For more details, I refer to the contribution of Stefan Theisen to the AEI Annual Report 2000). This "duality" leads to numerous new insights into both string theory but also into gauge theory. Most importantly, it raises the important point of whether more realistic string theories might also have a dual gauge theory description, which, if established, might be of immense value to the study of quantum gravity. In turn, this might also be crucial for overcoming our calculational difficulties with strongly coupled gauge theories, as discussed above. It should be stressed, however, that much of this duality remains conjectural. Firstly, there are great technical difficulties in understanding the string-spectrum on curved spaces and secondly, there is the problem of having to deal with strongly coupled gauge theories. As a result the duality has only been tested in a small "window", in particular the so-called supergravity limit where the most interesting string oscillations, distinguishing strings from particles, are absent.

Interacting strings from gauge theory at the AEI ...

The year 2002 has seen important progress on recovering the stringy aspects directly from the N=4 gauge theory. It had been shown that there is a third maximally supersymmetric background in which superstrings can live, the so-called plane wave background. Interestingly, it can be obtained from the above Anti-de-Sitter space (with attached five-spheres) by a certain limiting procedure familiar to relativists, the Penrose limit.

Taking the above string-gauge duality at face value, this limit should have a correspondence in the gauge theory formulation. The exciting, simplifying feature of the limit is that, as opposed to the original curved space, the spectrum of oscillating, non-interacting string states can now be calculated exactly! Even better, a team in Princeton argued how to recover this free spectrum by perturbative calculations on the gauge theory side, finding stunning agreement. However, one mystery of their proposal was that it remained very unclear how to find the string interactions from the gauge theory. This issue was resolved in teamwork at the AEI in a number of research papers: Carefully performing the limit on the (perturbative!) N=4 gauge theory leads to the discovery of stringy corrections to the free spectrum.



Objects in gauge theory have a natural interpretation as strings built from bits, indicated by lines in the left figure and give rise to continuous strings (right) when a certain limit is taken.

Interestingly, as the techniques involve developing certain diagrammatic techniques, one is able to reformulate the perturbation theory such that one can "see" how the strings emerge from the field theory (see figure). That strings might be directly derived from gauge theory had been first proposed by Gerard 't Hooft in 1973, and this year's progress is certainly to date the most concrete implementation of his pioneering ideas.

In summary, unearthing the connections between string theories, which manifestly contain quantum gravity, and gauge theories, which naively do not seem to contain gravity, certainly allows us to gain deeper insights into both types of theories. Ending on a optimistic note, one might hope that eventually the quantum nature of all four of nature's forces may be studied by gauge theory methods.

Matthias Staudacher

Topical Review: Loop Quantum Gravity

Loop Quantum Gravity (LQG) is an attempt to construct a mathematically rigorous, background independent, non-perturbative Quantum Field Theory (QFT) of gravity and all known matter in four spacetime dimensions (see e.g. [AEI-2001-119], [AEI-2002-087] for recent reviews).

Here background independence means that the theory does not assume the existence of an a priori distinguished (background) metric on which all fields propagate, rather the metric tensor is a dynamical quantum operator which has to interact in tandem with matter according to (a quantum version of) the Einstein equations. LQG therefore manifestly implements, at the quantum level, the fundamental features of Einstein's theory of gravity, General Relativity (GR): (1) Gravity is Geometry, (2) Geometry gets curved where and when Matter is located and (3) Matter is accelerated where and when Geometry is curved. It also implements the fundamental ingredient of Quantum Theory (QT), namely that the metric operator is subject to the Heisenberg uncertainty principle.

Non-perturbativeness is actually implied by background independence: When one tries to apply the usual rules of QFT on background metrics to the gravitational field itself by expanding the theory around a fixed metric, say the Minkowski metric, one ends up with a mathematical disaster, a so-called non-renormalizable theory which lacks any predictive power. From the viewpoint of LQG this is not surprising because the perturbative expansion of the theory around the background metric destroys, by definition, the fundamental background independence of the theory. As a consequence the usual rules of QFT which have been so successfully applied to, e.g., the standard model, have to be replaced by a more general, more fundamental theory. LQG is a candidate for such a theory.

Since the usual rules of QFT had to be generalized and since there are no experiments to date which are sensitive to quantum gravity effects (see, however, below) the only guiding principle for the construction of the theory has been mathematical consistency, making a mathematically rigorous framework mandatory. LQG has matured over the past fifteen years into a serious candidate theory for quantum gravity. Among the most promising results are:

i) a rigorous mathematical formulation on a novel type of Hilbert space,

ii) the prediction of a discrete Planck scale geometry (that is, the smooth geometry that we see in everyday life is a mathematical idealization, the true geometry has a granular structure, detectable only at tiny length scales of the order of 10^{-33} cm),

iii) a consistent, semi-classical, microscopic derivation of the Bekenstein-Hawking entropy for arbitrary black holes and

iv) a mathematically consistent formulation of the quantum Einstein equations.

One of the unsolved problems in LQG is the demonstration that the classical limit of the theory is indeed GR. Due to the background independence, this must be a difficult task because the theory does not know about any classical metric per se, the typical states of the theory describe a wildly fluctuating, chaotic metric on which no classical matter could propagate. The idea for how to determine the classical limit is to construct non perturbative states which are in a very precise sense concentrated, in accordance with the Heisenberg uncertainty principle, on a given classical metric. Such states are called coherent states in quantum theory.

Over the past three years a general construction scheme for coherent states has been developed in [AEI-2000-027], [AEI-2002-045] and then was applied to LQG. In [AEI-2000-026], [AEI-2000-028], [AEI-2000-029], [AEI-2000-30], [AEI-2001-011] we have constructed a completely new family of coherent states (for so called non-Abelean gauge theories, see figures 1,2,3 taken from [AEI-2000-028]) and confirmed their semiclassical properties. We then applied them in [AEI-2002-049], [AEI-2002-050] to the restricted problem of how to obtain ordinary (free) Matter QFT on Minkowski space from non perturbative LQG where Geometry and Matter interact.

While the analysis is far from complete, the results so far obtained are very promising: not only do we recover the correct classical limit but we also can compute the LQG corrections on, say, light propagation. Depending on the choice of the coherent states, these effects, if existent, could actually be experimentally verified using gamma ray bursts. These are flashes from the edge of the universe of which one measures the time of arrival difference of light with different frequencies due to the extremely weak energy dependence of the speed of light predicted by LQG. Much more work is required, e.g. one has to understand the physical significance of different choices of coherent states. However, once these issues are resolved we hope to be able to investigate whether LQG is a physically realistic quantum theory of GR.

Thomas Thiemann

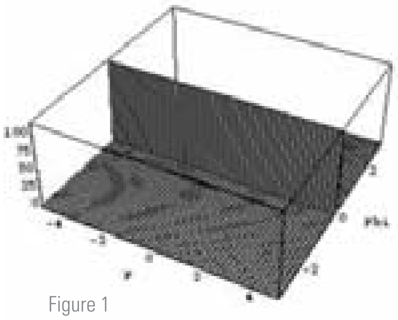


Figure 1
The probability amplitude of a non-perturbative coherent state of LQG. Displayed is only the dependence with respect to one of infinitely many degrees of freedom, given in terms of a configuration variable Phi and a momentum variable P. We plot the amplitude for states labelled by P as a function of Phi. The peak is very sharp around Phi=0 and independent of P as it should be.

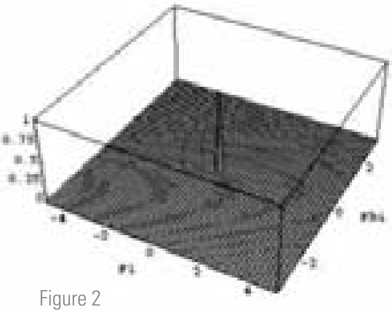


Figure 2
The overlap function of two non-perturbative coherent states of LQG for one degree of freedom in phase space. We plot the overlap of two states, one peaked at Phi=P=0, the other peaked at Ph1,P1, as a function of Ph1,P1. The peak is very sharp around Ph1=P1=0 as it should be.

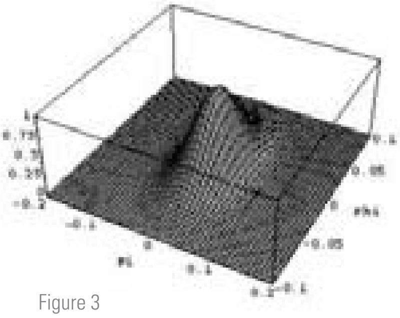
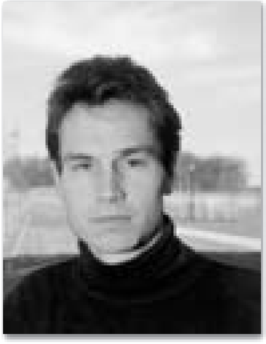


Figure 3
Figure 3 is the same as figure 2 but we have zoomed in as to resolve the details of the peak. It clearly has a Gaussian shape as one expects from coherent states. The width of the peak can be tuned and scales with the Planck length, that is 10^{-33} cm, in physical applications.



Laser Interferometry and Gravitational Wave Astronomy Division

Laser Interferometry in Space

One part of the Hannover group is working for the Laser Interferometer Space Antenna (LISA) and its technology demonstration mission SMART II. LISA is envisaged as an ESA/NASA collaborative project, aiming at a launch in 2011. It consists of 3 spacecraft in a triangular formation with 5 million km arm length. Its purpose is to detect and observe gravitational waves with frequencies between 0.001 and 1 Hz. These frequencies are inaccessible to ground-based detectors such as GEO600 due to gravitational disturbances that cannot be shielded. As such LISA is complimentary rather than competitive with the ground-based detectors.

A great variety of sources is expected to be "visible" for LISA, ranging from nearly certain sources such as super massive black hole binary mergers to highly speculative ones. While other groups, some of them in the AEI, study the expected sources and their astrophysical aspects, our group deals with some of the challenging experimental aspects of LISA. The basic principle of LISA is similar to that of ground-based detectors: measure the distance between test masses with a laser interferometer. The test masses must be free of external influences other than gravitation ("free falling") in the measurement frequency band. While the absolute distance is not important, fluctuations of this distance are measured to very high precision (picometer variations of 5 million km). The test masses are enclosed in "cages" inside each spacecraft. Electrodes around them sense the test mass position with respect to the spacecraft and generate control signals to correct the spacecraft position accordingly. At the heart of LISA are three key technologies that cannot fully be tested on the Earth:

(i) The free-floating test masses with associated capacitive sensors
(ii) The micro-Newton thrusters that correct the spacecraft position and associated control algorithms
(iii) Precision laser interferometry in space

The SMART II satellite will be launched by ESA in 2006 as a technology demonstration mission. It contains two free-floating test masses, thrusters and control algorithms, and a laser interferometer. The aim is to verify the "quietness" of the test mass by measuring the distance between two of them. Our work in Hannover is mainly concerned with the interferometry. While for LISA the arm length is 5 Million km and varying with time, in SMART II we have a distance of only 30 cm. Hence the techniques and requirements are somewhat different. Nevertheless, many key components of laser interferometry in space must be used and can be tested now. Our first task was to design the optical layout for the SMART II interferometer in collaboration with Astrium Friedrichshafen, RAL, the University of Glasgow and others. After comparing many possibilities one of our designs was chosen (see Figures 1 and 2). It is based on a heterodyne Mach-Zehnder interferometer and measures the distance between the two test masses (x1-x2) and the distance between one test mass and the optical bench (x1). Two auxiliary interferometers produce the phase reference and a measure of the laser frequency noise.

As an additional feature that was originally not required, we incorporated the technique of “differential wavefront sensing” into the interferometer. This technique, which is used in a slightly different form very successfully in GEO600 and other ground-based detectors, uses phase-modulated light, quadrant photodiodes and phase-sensitive detection to measure the relative co-alignment of two interfering beams (see Figure 3).

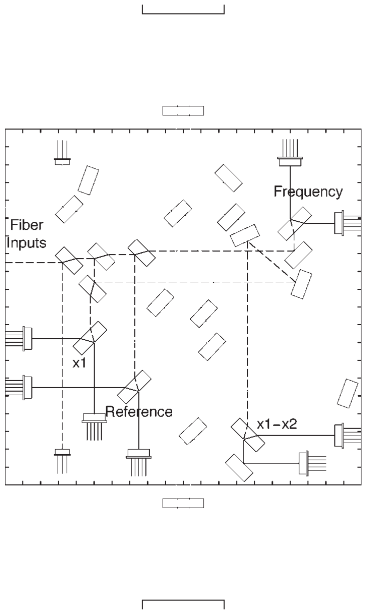


Figure 1
Sketch of the optical bench in the baseline design

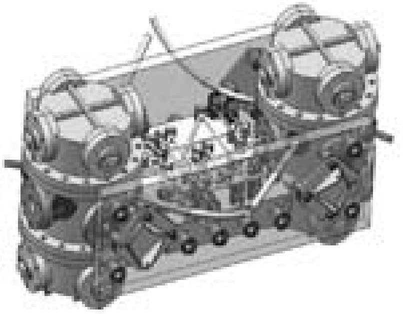
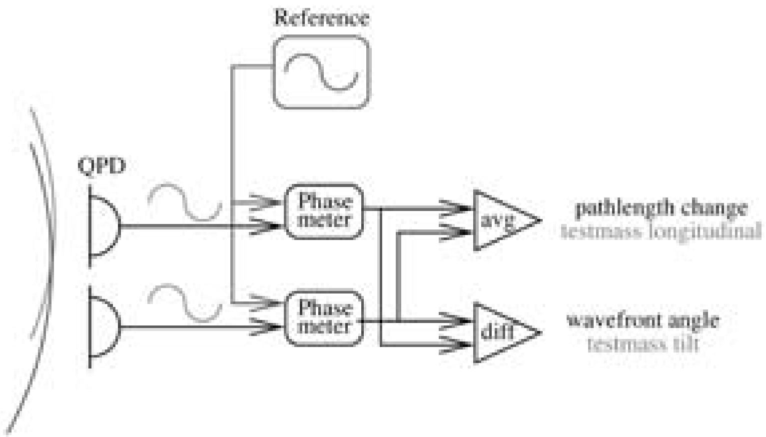


Figure 2
CAD drawing of the SMART-2 test mass enclosures with the optical bench in the centre (drawing by Astrium Friedrichshafen).

Figure 3
Principle of differential wavefront sensing: By a phase sensitive measurement on a split photodiode, the angle between two interfering wavefronts can be measured.



In SMART II one of the two beams has been reflected by a test mass, while the reference beam has not, such that a measurement of the test mass angular orientation is obtained. This alignment measurement has much lower noise than the corresponding output from the test mass capacitive sensors and thus yields not only a valuable diagnostic tool, but can also be used as error signal to stabilize the test mass alignment. Simultaneously we constructed a table-top prototype interferometer in our laboratory. While we could use standard optical components, all the electronics for the acousto-optical modulator drivers, heterodyne frequency generation and the phase meter were designed and built in our institute. Up to now these are the only working components of their kind in Europe and will serve both for testing the engineering model of the optical bench and also as starting point for the construction of flight electronics. We used our prototype to verify our predictions of the output signals, to demonstrate the basic functionality and to investigate various noise sources (many of which become important at the 1 pm level).

Figure 4 shows some intermediate results from our prototype. The noise level of the phase meter is already within the specifications. For the interferometer noise, we never planned or expected to get low noise at low frequencies in our unstabilized laboratory environment. The curve shown in Figure 4 was measured using two complementary outputs from one beam splitter, which should have a fixed phase difference of 180 degrees. This simplified interferometer is a valuable tool to investigate the influence and coupling mechanism of various disturbances such as fluctuations in laser beam power, frequency or alignment.

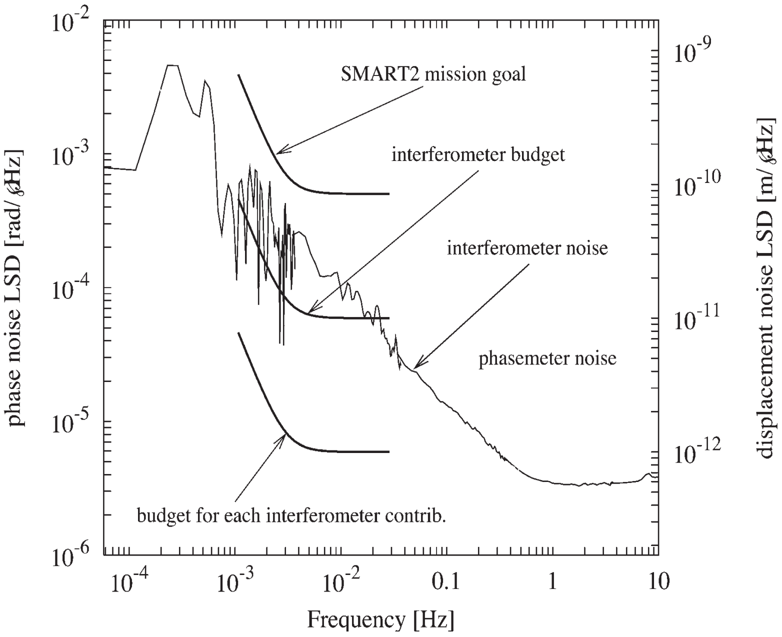


Figure 4
Noise level of our table-top prototype interferometer.

Using the experience gained in these experiments, the optical bench working group (which includes the AEI as interferometer specialists) will now proceed to produce an engineering model of the optical bench, do a comprehensive set of qualification tests with it and finally produce the so-called "flight model" (the real thing).

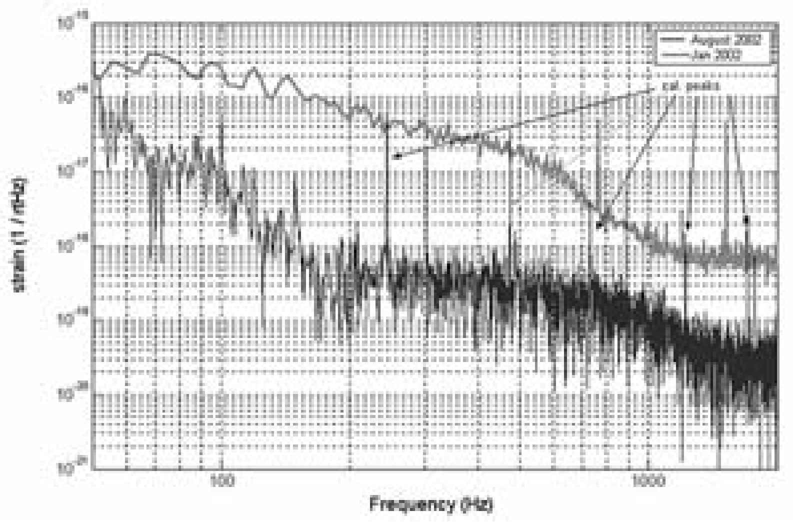
Converting a table-top experiment into space-compatible hardware is a lengthy and interesting process which for me, being new in the field of spacecraft design, occasionally holds big surprises. Imagine you build a very delicate optical instrument. After final testing and calibration, you drop it from 1m height on the concrete floor, and you have to make sure that it will still work perfectly afterwards without touching it any more. This describes the difficulties that we are facing at the moment. It becomes even more complex by the fact that different parts are manufactured in different countries and have to be assembled and tested in a certain order. Some of the most difficult design problems are related to the final ground testing rather than the in-orbit operation. How much easier is it to work on the table-top! But even there we are facing some challenging problems, mainly related to the low frequencies (0.1 mHz to 1 Hz for LISA). At these frequencies, all measurements become inconveniently lengthy, and thermal drifts play a very important role.

Soon the design of the SMART II interferometer will be finalized. The construction of the engineering and flight models will be carried out by industry, and our contribution will mainly be in consulting and participation of the testing procedures. Our laboratory work will then move on the even more challenging problems of the interferometry for LISA.

Gerhard Heinzel

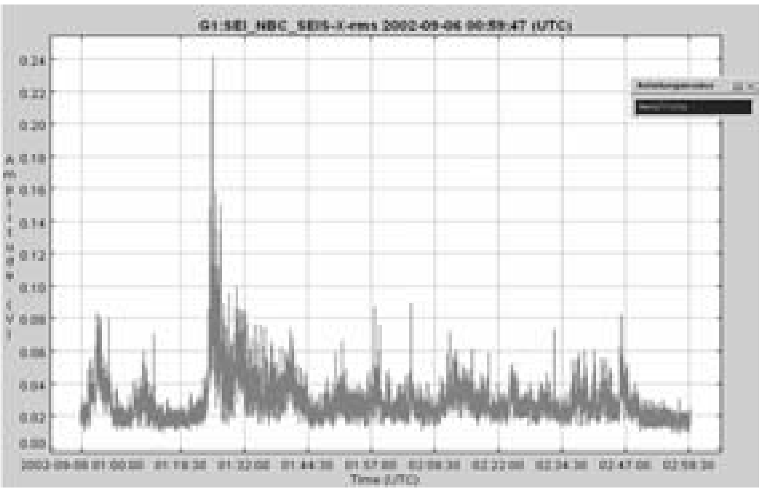
The Gravitational Wave Detector GEO600 in 2002

When the year 2002 started, the GEO600 team was in the middle of a data taking run: "E7", the 7th engineering run. For us it was actually the second one, but we used the same names as our American colleagues of the LIGO project who ran their detectors in coincidence. We started in the last days of 2001 during a hurricane and the seismic noise was way above the usual level. The locking performance, meaning how well and often we can keep the interferometer at the proper operating point, was terrible. We kept optimizing the interferometer over the whole run. Three 8 hour shifts a day, 7 days a week, and after 17 days with the weather improving after a few days we finished with a respectable duty cycle of 77%. We had stored almost one TByte of data on the tapes. The test run was a big success. The real work for the detector characterization people started after the engineering run. A Terabyte of data cannot be analyzed "by hand", so computer codes had to be written that search the data for unwanted events like glitches or instationary behaviour in order to find out where they came from and finally find a cure for the problems. The sensitivity of GEO600 during E7 was far too low to search for real astrophysical sources, but the period between E7 and the first Science Run (S1), which was planned for the summer, was ideal to test the analysis pipelines on the acquired data. Encouraged by the results of E7, the GEO600 team worked towards S1 during the following months, improving the sensitivity and reliability and fixing some bugs we discovered during the data run. There was not much time left and many subsystems had to be improved or newly implemented.



Comparison of the sensitivity of GEO600 during E7 and S1. Above frequencies of about 2kHz GEO600 is shot noise limited. The excess noise between 100Hz and 1 kHz can be attributed to scattered light.

(i) The main optics of GEO600 are suspended as triple pendulums with active damping of the pendulum resonances at the uppermost stage. This active damping system also allows us to remotely control the optics via a computer to point them into the right direction. And it is the basis for a digital automatic alignment system which keeps all of the mirrors well aligned without any human interference. During E7 the automatic alignment system only worked at very low frequencies, up to about 0.1 Hz, which caused problems when the seismic noise increased. Using actuators at the intermediate mass and elaborate control electronics we brought this frequency to about 10Hz and increased the stability of the whole interferometer.



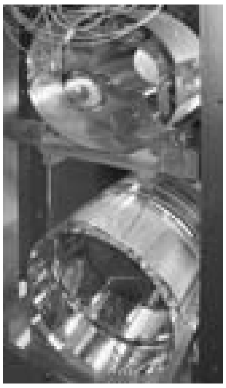
Data of one of the seismometers during one of the few losses of lock in the S1 run. This event was an earthquake in Sicily, Italy (magnitude 5.6) on the 6th of September at 01:21:27 UTC.

(ii) The support structure for the pendulums rests on three legs which include an active and a passive damping stage. The active stage is completely digital and works at frequencies from 0.3 Hz to 5Hz to suppress strong seismic noise around the pendulum resonances. These active seismic isolation stages have been completed for the most sensitive optical components and are now continuously working.

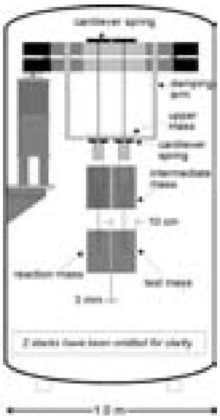
(iii) GEO600 uses so called Power Recycling to enhance the light level in the interferometer. The more light in the interferometer the more signal. During E7 the power enhancement was limited to a factor of only 13 where we expected 200. Although we knew this must come from some optical losses in the interferometer it took a while to spot that a wrong anti-reflex coating at the back of the test-beam-splitter was the point of failure. The specifications claimed less than 50ppm of residual reflection and we found it to be 7%! After we exchanged it for a better one the power increased to the desired 200W.

(iv) Problems with spikes in the laser power could be tracked down to the electronics and solved. After some other corrections and improvements the performance got better and better and the detector now worked fully automated. On the 5th of August the electronic lab-book shows a page titled "Locking over weekend: excellent". Just in time for the 1st Science run, S1, which we started at 2 pm on the 24th of August. This time we were more confident in the performance and manned only two 8h shifts a day. At night we ran an automatic alarm system. If something failed and the interferometer could not get back to proper operating conditions within a short time the "expert on duty" got an SMS alert on the mobile phone. But for the first 121h there was no reason to worry at all. It was the longest locking time of one of the big interferometers ever. We were happy and proud. Apart from minor difficulties S1 was a great success. The American detectors also worked well and when the Japanese joined in with the 300m TAMA detector for 2 days at the end of August we had five detectors running in science mode for the first time. S1 ended at the 9th of September. GEO600 achieved a duty cycle of 98.5% and the sensitivity could be improved by an order of magnitude with respect to E7. Despite the improvements GEO600 is still more than two orders of magnitude above the design sensitivity. So far we operated the detector without the features which will make up for the smaller size and bring the sensitivity to a level comparable to "the big ones" and time got short again before the next data taking run early in 2003.

(v) Signal Recycling, which enhances the signal strength of gravitational waves in a certain frequency range at the cost of other frequencies needed to be installed. The additional mirror it requires was suspended shortly after S1. Unfortunately this mirror makes it much more difficult to bring the interferometer to the correct operating point and so far we could only lock the interferometer for very short times. Not yet enough to tell what the sensitivity will be.



Left figure:
Monolithically suspended mirror with reaction pendulum. The comblike structure on the reaction mass is the electrostatic drive for the longitudinal control of the interferometer. At the intermediate mass the coils and magnets that are used for longitudinal control and for the fast autoalignment system can be seen.



Right figure:
Triple pendulum suspension for the main optics of GEO600. Two cantilever springs which are attached to a hexagonal frame structure support the triple pendulum chain. The damping of pendulum resonances is done at the upper mass. A reaction pendulum is hung 3 mm behind the mirror pendulum to provide a seismically isolated actuator basis. Forces are applied with magnet-coil actuators between the intermediate masses and with electrostatic actuators between the mirror and the reaction mass. The fast autoalignment system uses the intermediate mass drives.

(vi) Thermal noise of the suspension or the mirror itself can be reduced by avoiding mechanical dissipation. We employ a technique called hydroxide catalysis bonding and welding to attach the mirrors to fused silica fibres to form a low-loss monolithic last stage. During S1 only two of the main mirrors were suspended by glass fibres and right before Christmas we suspended the three remaining optics monolithically. After all of the optics were installed and aligned we found that yet another set of mirrors failed to meet the specifications: the radii of curvature of two mirrors (666m and 687m instead of 640m each) proved to be too far apart to allow a good interference minimum. Currently we are checking options for thermal corrections. Now the next science run of GEO600 and the other detectors worldwide is only weeks away and the whole GEO600 team is very excited to see the outcome. By the rate the sensitivity of all the detectors worldwide is improving it seems only a matter of (short?) time until gravitational waves will be detected.

Harald Lück

Opening Ceremony of the Centre for Gravitational Physics in Hannover


Karsten Danzmann and Hermann Schunk at the press conference.

On May 17th, 2002 the opening ceremony of the experimental part of the AEI took place at the "Neues Rathaus" (New City Hall) of Hannover. The event, well organised by MildeMarketing (Potsdam), started with a press conference where the newly founded centre of gravitational physics was presented to the public. Karsten Danzmann, Bernard Schutz, Ludwig Schätzl (President of the University of Hannover), Hermann Schunck (ministry official at the BMBF), Herbert Walther (director at the MPQ) and Herbert Welling (board of the "Laser Zentrum Hannover") talked about history, assignment, goals and organisation of the Centre.


Visitors with safety goggles in the Central Building of GEO600.

Starting at 3 p.m., the ceremony took place in the decorated "Bürgersaal" of the New City Hall. The Mayor of Hannover, Herbert Schmalstieg, welcomed the large number of participants from all over the world. Words of welcome came from the Managing AEI Director at the time Hermann Nicolai, the Minister for Science and Culture of Lower Saxony Thomas Oppermann, Hermann Schunck, Ludwig Schätzl, Herbert Walther, and the President of the DPG Roland Sauerbrey. Karsten Danzmann gave the ceremonial lecture on "Gravitational wave astronomy: Light from the dark side of the Universe". The closing words came from Herbert Welling, who is well known for having supported for years the participation of the University of Hannover in gravitational wave detection.


Herbert Schmalstieg, Thomas Oppermann and Herbert Welling at the ceremony.

A choice of quotations: Ludwig Schätzl: "Main areas of research like this one have a lighthouse effect on the university scene." Hermann Nicolai: "The fast and uncomplicated foundation of the Centre for Gravitational Physics proves to the international community that the German landscape of research is able to react to present-day challenges." Thomas Oppermann: "The foundation of the Centre for Gravitational Physics is a great chance for the science site Hannover. Therefore, in spite of a tense financial situation, I made the quick decision to make 12.5 million Euro available for the renovation. This is also a result of the very trusting and uncomplicated cooperation between the Max Planck Society and the state of Lower Saxony."


Members of "Das Neue Ensemble": Malte Rettberg, Stephan Meier, Udo Grimm (not shown: Juliane Wolf).

Members of "Das Neue Ensemble" of Hannover, well-renowned for their interpretation of contemporary music, supplied the supporting programme. They first performed three pieces of the "Zodiac Cycle" of Karlheinz Stockhausen, rearranged by their conductor Stephan Meier with the inclusion of gravitational wave signals. The rousing performance delighted even lovers of classical music. During the following reception the short GEO movie produced by MildeMarketing was shown. A shuttle transport to Ruthe was available in the afternoon. A large number of participants took the chance to visit the gravitational wave detector GEO600 in bright sunshine thus rounding off a successful event.

Peter Aufmuth

Reimar-Lüst-Lecture 2002 at the AEI

A very special event at the AEI in 2002 was the Reimar-Lüst-Lecture, named in honor of the former President of Max Planck Society. This lecture takes place once every year at a chosen Max Planck Institute and is meant to disseminate highlights in the natural sciences and the humanities in a field represented in the Max Planck Society to a wider audience. It is thus a semi-popular lecture on a special advanced topic of current interest to be delivered by a distinguished and internationally renowned scientist. This year, we were happy not only that the choice for the fifth such lecture had fallen on our institute, but also to be able to welcome as the speaker Professor Pierre Ramond, a Distinguished Professor of Physics and Director at the Institute for Fundamental Theory at the University of Florida. Professor Ramond is known worldwide as the father of the "fermionic half" of the superstring (and the name patron of such arcane notions as the "Ramond-Ramond-charge"), and for his numerous and seminal contributions to the theory of elementary particles, such as the explanation of the tiny neutrino masses by the so-called "seesaw" mechanism.

It was a special honor to all of us that Professor Reimar Lüst and his wife were personally present at the lecture (f.l.t.r.: G. Huisken, B. Schutz, H. Nicolai, P. Ramond, R. Lüst, Mrs. Lüst, J. Ehlers).

Professor Ramond is also the author of the well known introductory textbook "Field Theory: a Modern Primer", as well as several other best selling popular books.

In his lecture "Strings and the Mysteries of Elementary Particle Physics", he not only gave a wide ranging review of 30 years of superstring theory, but also sketched a vision of what a future unified theory of physics might look like. He emphasized the role of symmetries in such theory, and the compelling beauty of the exceptional groups in particular, whose ultimate role in the scheme of things is still unknown. True to his reputation as a speaker, Professor Ramond captivated the audience with a lecture that was edifying, fascinating and entertaining at the same time.

Hermann Nicolai

The First Meeting of our Board of Trustees

On the 10th of January 2002 a band of illustrious guests visited the Albert Einstein Institute: our "Kuratorium" (board of trustees) met for the first time. For a list of the members please see p. 74.

Hermann Nicolai welcomed the members of the Kuratorium, and the representatives from the general administration of the Max Planck Society. The Secretary General, Barbara Bludau, started the meeting with an overview over tasks and potentialities of boards of trustees: The Kuratorium may help to integrate the institute into the scientific and political community and may give advice concerning public relations activities. Strong relationships between the Kuratorium and the institute lead to joint projects and members of the Kuratorium may also support the institute's fundraising activities.

In order to inform the Kuratorium about the institute, Hermann Nicolai gave a presentation about structure and research activities of the AEI. Later on this was followed by a tour through the institute. This "real-time" tour through the institute in Golm was completed by a live video transmission from GEO600 giving an impression of the project. Karsten Danzmann explained the gravitational wave detector located in Ruthe near Hannover and gave an overview on the LISA project.

The members of the AEI's Kuratorium visit the institute (f.l.t.r: W. Loschelder, F.-C. Wachs, P. Deuflhard, M. Krause, J. Wanka, D. Wiedemann, R. Yogeshwar, R. Emmermann, K. Strassmeier, U. Kasparick, B. Bludau)

The members of the Kuratorium elected Peter Deuflhardt (president of the Konrad-Zuse-Zentrum für Informationstechnik Berlin) for chairman, and Ranga Yogeshwar (head of the science division at the Westdeutscher Rundfunk Köln) for vice chairman.

There was an intense discussion about the reasons for becoming a member of the AEI's Kuratorium and about their plans to get involved into the institute's activities. One outcome of this brainstorming was the first "Potsdam Astronomy Day", organized by Klaus Strassmeier, the director of the Astrophysical Institute Potsdam, that took place on 21 October on the Telegraphenberg (see report on p. 64).

We are looking forward to a good cooperation with all members of our Kuratorium and to the stimulating effects this may bring.

Elke Müller

Blind Date at the Event Horizon

Blind Date - Projects at the interface between Art and Science1: in spring 2002 the Brandenburgische Kunstverein invited four other artists and me to take part in an unusual exhibition under the title "Blind Date", the project was based on an interdisciplinary cooperation between an artist and a research institute in Potsdam. I worked together with the Max Planck Institute for Gravitational Physics. At the first meeting with the physicians in Golm, I showed some examples of my artistic installations via web page (www.susanneweinrich.com) and was confronted with first prejudices ("oops, she doesn't paint"). We agreed that the project should not be an illustration of physical terms and processes, because such visualizations are part of the scientist´s work. During Werner Benger´s presentation of Black Holes, the term "Event Horizon" stuck to my mind.

"Blind Date" Malte Brekenfeld+Deutsches Institut für Ernährungsforschung/Tilman Küntzel+ Potsdam-Institut für Klimafolgenforschung/Via Lewandowsky+Fraunhofer Institut für BiomedizinischeTechnik/ Igor Sacharow-Ross+Geoforschungszentrum Potsdam/ Susanne Weirich + Max-Planck-Institut für Gravitationsphysik vom 02.11.2002 – 01.12.2002 in the Kutschstall Potsdam

Susanne Weirich: "Ereignishorizont", 2002 (Lightbox with b/w transparency 80x120 cm & monitor, Video-CD, 20 min.-loop b/w) Camera: Alexander Sass, Photo: Anne Lacour, Sound: Nils Dorband, Advice: Werner Benger, Kelly Davis, Nils Dorband, Thanks to Robert Bramkamp, HFF Potsdam, Boris Kremer, Jacobine Motz, Elke Müller, Anja Neraal and to all portrayed actors.

The idea of an "Event Horizon" I could associate etymologically with the discovery of the horizon in painting, with Caspar David Friedrich's figures shown from behind, the definition of an "event" in literary texts etc. Our next meetings took either place at the institute in Golm or at my studio in Berlin. Three young physicians, Werner Benger, Kelly Davis, and Nils Dorband contributed to the art project, which should become a medial installation. They have been adviced by Elke Müller, and the curator Boris Kremer.

How to produce a piece of art?

We considered and discussed form and character of the artistic project: will there be sound,integrated video, what kind of pictures will be used or will it be about producing our own images? Depending also on the architecture the location offers: Will the pictures/videos be shown on monitors or projected on beams? During our discussions the term "event horizon" always came to our mind. What is an "event" in physical terms, what is a "horizon"? What kind of rules could be established? The metaphoric site of the scientific terminology was projected onto different contexts. How is an "event" concerned with memory, history and time? Referring to this we also analyzed science fiction films, like "The Fifth Element" (Luc Besson, F 1997), "Total Recall" (Paul Verhoeven, USA 1990) and "Blade Runner"(Ridley Scott, USA 1982) and we found examples in mythological literature: "Orpheus and Eurydice". Orpheus knows the rules for leaving the underworld; Eurydice does not. She crosses the event horizon and cannot return. We collected, produced or "found" material for the artistic debate. "The Red Squirrel" ("La Ardilla Rocha", Julio Medem, Spain 1993), a film, which I watched by chance in that time, played a later role: again it deals with lost memory, portraits of people's back, perspectives from behind.

Photo session at the AEI

Editing of the video-portraits

Suddenly everything fits together

Photoshooting on the Andreas Bridge

My concept consists of two elements: first, a light box with a black-and-white transmitted light motif of a person shown from behind, and second, a monitor on the opposite wall, showing black-and-white, cross-fading portraits of people's faces. The physicians agreed that the art concept also harmonizes from the physical point of view. Later Nils Dorband, wearing a black leather, jacket is posing as a model on different bridges in Berlin, imitating the opening sequence from "La Ardilla Rocha": a man from behind in a semi close-up shot, leaning over the balustrade of the bridge, in front of him the surge of the sea, the horizon. In our light box it is the River Spree, without any horizon. During one day the scientific and administrative staff at the Albert Einstein Institute was then filmed to show their portraits on the monitor. They have been asked to sit silently for one minute in front of the camera. Their gazes do not fix the camera, but pass it. In case of the "Event Horizon" I tried to find a typology, emerging from many, nearly unmoved faces. Later a second series of portraits, artists and performers, was filmed at my studio in Berlin. Both sequences were edited to a succession of fades and dissolves. One portrait stays for 10 to 25 seconds, it fades and the next portrait becomes visible. The visual sequence is accompanied by an asynchronous, stochastic soundclip. It is a digital processed alienated progression by Nils Dorband from Gluck´s opera "Orpheo ed Euridice".

The optical layout of the installation

The light box with the portrait of someone's back and the opposite monitor are both framed by a wooden wall. Thus the spectator is standing between a rhythmic moved video-image and a luminous fixed-image. The people, portrayed by the camera, look towards the figure shown from behind, however without facing it. They seem to fix a point in endlessness. It arises an emphatic, though constructed mapped "We". It is a "We", which doesn't seem to know its constitutive common denominator. However, the connective element is getting noticeable in the collating sequence. It is the frequent magic moment during the cross fading from one face to the other. For a short moment, out of two faces emerges a third dimension. The installation is an interaction of different conditions limiting events, giving them a horizon.

Susanne Weirich

"All men by nature desire knowledge." (Aristotle) Open Day at the Max Planck Campus

On a sunny Sunday, September 8th, the three Max Planck Institutes organized the second Open Day at the campus in Golm.
Already before the official start of the manifold schedule of events at 10.00 am the whole campus with its institutes, bureaus and laboratories was filled with people. By the end of the day the number of visitors was estimated at around 2,000. Families, teacher, students, pupils and people from in and around Potsdam found their way to our campus in Golm. They all came to find out more about the current topics of physics, biology and chemistry. The miscellaneous programme offered something special for everybody.

The directors of the AEI gave lectures on Einstein´s space-time theory, the relativistic universe and gravitational waves. Information about Grid-Computing, the Global Positioning System and Supercomputers gave an insight into the world of gravitation. Our colleagues from Hannover spared neither time nor expenses to come with a lot of equipment to Golm. As usual they gave fascinating and intelligible information about their work with GEO600. New posters illustrated the structure and functioning of the laser interferometer. A highlight was the virtual guided tour through GEO600 in Ruthe, where scientists watch out for gravitational waves. Our fellows from the ZIB demonstrated unique simulations of colliding black holes at the immersadesk. All demonstrations and lectures were crowded and the visitors were keen on talks and discussions with the referees. We also invited colleagues from the AIP, who held an interesting exhibition around solar physics and star formation. Relevant material and experiments beamed the visitors into the realm of cosmology.

Young researcher (predoc) at the Open Day

Peter Aufmuth demonstrating the principles of laser interferometry with a working scale-model of a Michelson interferometer

This year the Open Day was not only designed for adults but also, and that was brand new, for the little ones. All institutes contributed to a zone in the foyer, which was especially created for children aged 4-12. Potty experiments were prepared to make kids familiar with scientific topics. The institutes wanted to give them an easy understanding of gravity, optics, botany and density. Touching, smelling, hearing and seeing - with all senses natural sciences should make sense to the kids. From the first second until the last one many "small scientists" gathered around the tables curious for little handicraft works and experiments, which was pure fun and caused a lot of laughter and surprise. Even fathers, mothers, uncles, aunts, grandmothers and grandfathers were sitting around the booth and showed much interest in the astonishing experiments.

As a prize the young talents got a gaudy scientist´s ID with their personal photo that they proudly presented to their parents and friends. Some kids visited the different stations several times and tossed even difficult tasks. Thus the children discovered natural sciences in a playful way and recognized that they were not boring at all.

And who knows, whether the Albert Einstein Institute will not welcome one of them as an excellent postdoc or professor in ten or twenty years?

Katharina Zesch

Through the Eyes of a Visitor

I've been a frequent visitor to the AEI, to work with the researchers preparing to analyze gravitational wave data for the GEO600 experiment. So I was delighted to receive an invitation from the Alexander von Humboldt Foundation to spend the last half of 2002 visiting the AEI as a Bessel Prize Fellow.

The AEI GEO group is responsible for searching the GEO600 data for signals from pulsars. The group also leads the LIGO Scientific Collaboration pulsar-search and upper-limit efforts, and during the past couple of years I'd learned enough about this subject to take part in some of the work myself.

Part of the plan, during the past couple of years, has been for the AEI to set up a dedicated computing facility to search the GEO600 data for pulsars. In the past, I'd played an active role in this. Setting up computer clusters is a professional hobby of mine. Five years ago I designed and built a 48-node cluster in Milwaukee, which was used to search for binary inspiral signals in data from the LIGO 40-meter prototype experiment, and two years ago I designed and managed the construction of a 300-node cluster (Medusa) which is used by my research group and by many members of the LIGO Scientific Collaboration. Prior to this visit, I had helped the AEI group to present a computing-cluster plan to the BAR, and when funding was approved, I had also helped to finalize the design of the system. And I also took part in choosing the name MERLIN for the yet-to-be-born cluster!

MERLIN and the computer wizard.

I had also followed this process closely because my wife Dr. Maria-lessandra Papa is the MERLIN project leader. The BAR had approved funding, but some of the details of the software and hardware still needed to be finalized, and a couple of critical technical people (Steve Berukoff and Dr. Holger Naundorf) were no longer available for this. So soon after my arrival in June 2002, I offered to help oversee the final stages of the design and acquisition process for MERLIN. Although the room renovations, air conditioning and electrical work had already been completed, the final system and networking design was incomplete, and a lot of testing was needed.

This project turned out to be the central activity of the six months that I spent at the AEI. During this time, I helped to interview and hire Dr. Steffen Grunewald, who is among the most talented computer system administrators that I have known, and I worked closely with Andreas Donath and Thomas Feg to network and set up the most important "head nodes" and servers in anticipation of the cluster's arrival. I also helped to write and critique the technical bid specs and to evaluate the offers from the different vendors.

The cluster itself (146 dual processor compute nodes, 146 GB of memory, and 36 Terabytes of disk space) was finally delivered late in the afternoon of Monday December 9th. A number of volunteers helped us to unbox the nodes, but because the machines had been sitting in a cold truck for more than a day, we decided to leave them indoors until Tuesday morning to warm up (see photo 1). On Tuesday morning, we finished the cluster installation in just a few hours. The real test, the final proof that we had prepared well, was that the cluster was up and running its commissioning and burn-in tests by Tuesday at noon.

In the end, it was apparent that the technical team at Pyramid GMBH, who had assembled the nodes to our specifications, had done their job very well. We had only a handful of isolated failures within the first few days, and since that time the cluster has been up and running. In fact, as I write these lines (in February 2003) Marialessandra has been using the cluster very intensively to obtain the first GEO and LIGO upper limits on the gravitational waves emitted by known pulsars!

Bruce Allen
University of Wisconsin, Milwaukee

Max Planck Medal for Jürgen Ehlers

In 1929 Max Planck and Albert Einstein were the first who received the Max Planck Medal - the highest distinction the German Physical Society can bestow upon a theoretical physicist. In March 2002 the founding director of the AEI, Jürgen Ehlers, was awarded this prestigious prize on the occasion of the annual meeting of the German Physical Society. The award honours Jürgen Ehler's numerous outstanding contributions to general relativity starting with his PhD work in 1957, and also his key role in establishing our institute. It is also noteworthy that this is the first time that the Max Planck Medal was awarded in the field of general relativity.

Jürgen Ehlers at the 2002 annual meeting of the DPG

Cactus group wins prizes at SC2002

The world of supercomputing researchers meets once a year, and this year SC2002 took place in Baltimore. As in the past, the Cactus group prepared a demonstration of our latest technology. This time we gave a demonstration of several different applications (one of which, of course, was a Cactus application running a black hole simulation) making use of a huge Grid test-bed that we coordinated. This test-bed consisted of over 7500 processors distributed across 14 countries on 5 continents, running most known operating systems, even including a Sony Playstation II in Manchester, England. The demonstration won three major prizes at SC2002, including "Most Geographically Distributed Application", "Most Heterogeneous Application", and also the "Bandwidth Challenge" competition, where our colleagues at Lawrence Berkeley Labs used Cactus in conjunction with the application to stream more than 15Gbits/sec to the show floor while visualizing a live black hole simulation running at Berkeley.

AEI scientist Denis Pollney @ work

Software for Supergravity: Thomas Fischbacher nominated for the Heinz Billing Award 2002

The Heinz Billing Award for the Advancement of Scientific Computation was bestowed at the GWDG congress in Göttingen on November 21, 2002. Thomas Fischbacher from the Albert Einstein Institute was one of the three finalists. The award was given to the Software Group of the Max Planck Institute for Psycholinguistics (Njimegen, Netherlands) for their development of a unique novel software environment for the establishment of one of the largest Internet databases for multimedial language resources. Fischbacher developed (and made available under a free license) the LISP-based software package "LambdaTensor", which can be used to carry explicit calculations with Lie algebras and Lie groups (in particular, but not limited to the exceptional symmetries) to

F.l.t.r.: Prof. K. Kremer, Chairman of the Heinz-Billing-Vereinigung, Dr. F. Jenko, MPI of Plasma Physics, T. Fischbacher, AEI, R. Dirksmeyer, MPI for Psycholinguistics, winner of the 2002 Heinz Billing Award (together with H. Brugman and D. Broeder) a level of complexity far out of reach of previous existing tools. These complex mathematical structures play an important role in various approaches to find a unified quantum theory of gravity and gauge interactions as well as in other branches of high energy physics. Therefore, it is expected that Thomas Fischbacher's software will find broad application in the field of supergravity and grand unification research.

Computer Science at PanMedium

The computer science researchers in the Numerical Relativity group successfully attained two new external grants in 2002, the German-funded GriKSL project, and the EU-funded GridLab project. The ensuing large expansion of the group necessitated locating additional office space, and eventually the new PanMedium site in the north of Potsdam, was chosen and the group relocated in June 2002. PanMedium is a technology center providing infrastructure to local businesses and institutes. Although further than wished from the main AEI site, the new offices are ideally served in terms of technical and logistical needs - thanks to the work of the Computer Division a network of 34Mbits is now in place between the two sites.


PanMedium - from military tradition to computer science

PanMedium, located on the Nedlitzer Straße which connects Potsdam with Spandau, occupies a former army barracks, the "Rote Kasernen". The striking red building has a long military tradition, built with a then modern military architecture in 1892 to house the Potsdam garrison; the barracks were later used by the Russian army up until 1993.

The group now occupies eight offices at PanMedium, including two conference rooms, with several spare desks for the frequent visitors from the numerical relativists. The furniture and infrastructure at PanMedium are deliberately planned to provide a good working atmosphere: wireless networking, ample deployment of white boards together with comfortable sofas and tables encourage hot-desking and close interactions and discussions.

While the group do miss their former day-to-day closeness with the physicists, the remote location actually motivates their prime areas of research; the development of techniques, toolkits, and frameworks for geographically distributed collaborations! Along with visits between sites, phone calls, emails, chat and more recently video conferencing keep the entire Numerical Relativity group well coordinated. The weekly Thursday night group get-together in a local bar also helps!

Potsdam Astronomy Day

On 21 October 2002 Potsdam astronomers gathered together on the Telegrafenberg to introduce themselves to one another. Three institutes participated: The Astrophysical Institute of Potsdam (AIP), which organized the meeting, the University of Potsdam, and the AEI. Although all share overlapping interests in astronomy, their geographical separations prevent easy day-to-day contact. The purpose of the meeting was to present as broad a range of research as possible, and to encourage individuals to make further contacts to follow up subjects that they would be interested in building collaborations around.


Klaus Strassmeier, Director at the AIP with Bernard F. Schutz, director at AEI

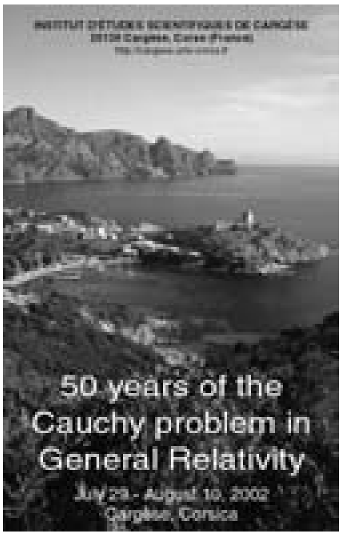
The day showed the astonishing range of work that is taking place in Potsdam, from work on the Sun, to studies of stars and extra-solar planets, to investigations of black holes and cosmology. New equipment also figures strongly in Potsdam research: gravitational wave detectors, satellites, new ground-based telescopes, and large computers. The AEI mathematicians were represented by Alan Rendall, who explained their work on singularities. The day finished with a dinner in Potsdam that allowed a more informal discussion of future collaborations. It is intended to organize such meetings regularly.

50 Years of the Cauchy Problem in General Relativity

Together with Piotr Chrusciel from the University of Tours in France, Helmut Friedrich organized a summer school on "50 years of the Cauchy problem in general relativity'', which took place July 29 - August 10, 2002, in Cargese on Corsica, France.

The title was chosen to commemorate the publication in 1952 of a fundamental paper by Y. Choquet-Bruhat on the Cauchy problem for Einstein's field equations but the purpose of the summer school was to give an introduction to certain up-to-date techniques in mathematical relativity. General relativity passed through a very productive period in the 1960's and 1970's when the importance of the asymptotic behaviour of gravitational fields for the notion of gravitational radiation was recognized, singularity theorems were proven, and black holes and their physical consequences were analysed in detail. However, many problems arising in that period had to remain without answers.

In particular, due to non-availability of the proper technical tools, questions about the field equations and the detailed behaviour of their solutions in the large were most often not accessible. In recent years, however, this has changed and there has been some substantial progress in the analysis of the Einstein equations and the structure of space-times on large scales. It therefore appeared necessary to provide an opportunity for young relativists to get access to the most recent results, the underlying new techniques, and in particular, to the specialists. The organizers were successful in bringing together almost all the experts who contributed to these developments. The school met with an interest by students and young researchers which was quite unexpected by the organizers and, sadly enough, forced them to reject almost half of the applicants because of the space limitations of the conference center. In spite of the temptations of the blue water and the beach, the interest lasted through the whole meeting and demonstrated clearly the success of the school but also the fact that such a meeting was long overdue.



Vacation Course

The 2-weeks vacation course on "Gravitational Physics", which the AEI started in 1999 together with the University of Potsdam, took place for the fourth time from March 4 to March 15. It is meant for students who have done their "Vordiplom". The structure of the course was, as in the years before, two lectures in the morning; the afternoon to go through the material of the lectures. The course took place in the lecture hall of the Max Planck Campus in Golm.

As already the years before, Jürgen Ehlers and Bernd Schmidt gave an "Introduction into General Relativity". The second lecture series was this time given by Bernd Brügmann on "Numerical Relativity". In the afternoon there were computer labs in rooms of the university. About 25 students from the Berlin-Potsdam area and another 25 from all over Germany participated. Again the AEI could provide some financial support. The course was again greatly appreciated such that continuation is planned.

The Library in 2002

With the appointment of Prof. G. Huisken the annual growth rate of the library holdings increased significantly in 2002. 25 journal titles in the field of mathematics were ordered, part of them also as back volumes, some even from beginning. One of the results of that development was the drop of requests for literature from external libraries. Monographs were selected from an extract of the library catalogue in Oberwolfach and the main part of the ordered books belong to the field of partial differential equations, geometry, differential geometry and manifolds, and cell complexes. At the end of year our library holdings consisted of 6.508 monographs and 8.050 bound journal volumes.

As another remarkable innovation the AEI library now participates in the North Rhine Westphalia Consortium, Bielefeld and received online access to MathSciNet, a comprehensive database covering the world's mathematical literature since 1940.

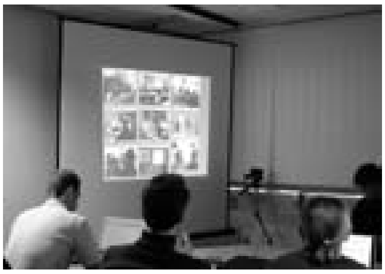
Besides all the normal work the librarians had to deal with, they decided to participate in the pilot phase of the eDoc Server project. This service is provided by the Heinz Nixdorf Center for Information Management in the Max Planck Society (ZIM). The intention of the E-Document Server is to increase the visibility of the intellectual output of the Max Planck Society and to add it 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 planned Max Planck E-Document Server is one way of exploiting the new technologies to more effectively communicate 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 the evaluation of research results. As a result of applying this new system the institute has to change the workflow regarding the documentation of publications within the next year. In the meantime Anja Lehmann is registering the institute's publications including links for online versions and abstracts not only in our Online Public Access Catalog (OPAC) but also in the eDoc Server.

Computer Infrastructure News

The nearly entire new crew of the IT department, including two trainees to train as IT specialists, was faced with several ongoing processes and projects which needed to be continued or finished in a rather short time. One project ended in the successful story of the prototype of the Gravitational Wave Cluster built up in 2001 and tested thoroughly in 2002. These tests were mainly done by specially written bench mark programs, trying to reproduce the tasks the system will have to solve in production. An application had been written to the BAR by the GEO group in June and money was granted for a 128 dual processor nodes system, the GEO600 MERLIN Cluster, in late summer (for details see p.59). Finally the cluster was delivered and put into operation begin of December 2002 without any problem worth to be mentioned. Since then MERLIN does its work continuously and fulfils the given requirements to the complete satisfaction of the GEO scientists.

The other remaining ongoing process was the replacement of the ORIGIN. Begin of the year the scientists of the various groups of the AEI finally decided to go for a Linux based compute cluster. It had taken a lot of effort before all parties involved were convinced that it is worth to leave the area of propriety systems and to probably no longer being able to make use of the experiences they have on these systems since long. Knowing all the disadvantages the AEI has send an application to the BAR and asked for a 256 dual processor nodes cluster in summer. The members of the BAR were not that optimistic as the AEI scientists and only granted money for a 64 nodes cluster with the option of purchasing another 64 nodes after the first 64 nodes cluster will have demonstrated to run satisfactory for a while. The invitation to tender is in progress since then. The first part of the high performance compute cluster will be delivered about March 2003.

Another challenge for the IT-group was the move of the Science Computing group and the members of the GridLab project to the Red Barracks (Rote Kasernen) in Potsdam and there into the rooms of PanMedium (for details see p.62). Not only that the IT equipment for both groups needed to be moved, also a dataline between PanMedium and the building of the AEI had to be planned and installed. It was a hard period of time discussing the pros and cons of different technical solutions with various parties involved. One of the technical solutions that was discussed thoroughly was the idea to establish a radio link between the two buildings. But as the buildings are not in inter visibility too many third parties would have been involved and the cost estimations were getting higher and higher. With much effort of the people of PanMedium and support of the IT department of the University of Potsdam a data link of 34 MBit/s was finally established by PanMedium begin of September, which the AEI is leasing till then. That was a big relief for the scientists working in PanMedium. The temporary established 2 Mbit/s line was not working fast enough for transmitting data from the servers at the AEI to the workplaces in PanMedium. The scientists travelled back and forth from PanMedium to AEI to get their work done conveniently. The other activities were more or less daily work, as increasing of compute capacity on the desks of the scientists, increasing the mobility for people on travel by buying high performance laptops, increasing the ability of communication with partners not in the same place by installing video conference systems and an AccessGridNode. The later should last but not least increase the communication between the AEI in Golm and the AEI in Hannover without the need of travelling.



A scene of an AccessGridNode conference in December 2002, held by the scientists of the GridLab project at the AEI. Every participating party, which normally are not at the same place but somewhere else in the world, has a similar display as on the picture, so that the attendees can see each other and can talk to each other. In this case the parties were in the US, The Netherlands, Poland and Germany.

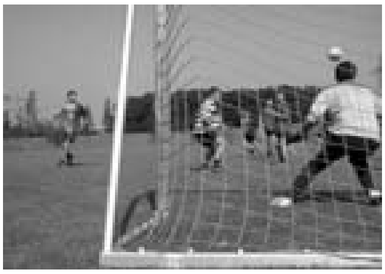
Science Day 2002 on Potsdam Telegraphenberg

On June 27th we participated again in the "Science Day", an annual event for pupils in Brandenburg. As the last time it was very well organized by the University of Potsdam. Together with the universities and other research institutes we presented our science in a popular way in order to interest the pupils for gravitational physics. Peter Aufmuth and Sascha Skorupka from our experimental branch in Hannover and Carsten Aulbert from the institute in Golm entertained lots of young people telling them about the mysteries of the universe. They had a small laser interferometer with them and explained its functionality while the large GEO600 experiment was shown in a film. Furthermore, Peter Aufmuth gave a very well attended lecture on gravitational wave detection.

Sascha Skorupke at the 2002 Science Day

Sports

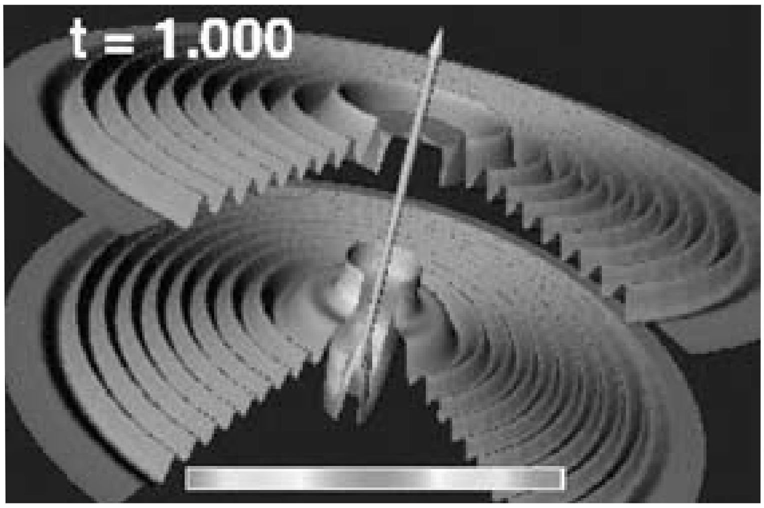
Sports at AEI! A never-ending story, and one that, in 2002, had its high as well as its low points. The performance of AEI's soccer team at the Golm campus tournament on September 4 was not quite as brilliant as its ardent fans had hoped. If the team had planned to emulate the German "Nationalelf", they succeeded only insofar as that team didn't win its major competition in 2002, either. The tournament opened with our team valiantly defending itself against Plant Physiology I, who managed to land but a single goal. An almost identical game, with the same outcome, was later played against Interface I. As a final effort, our team managed a 1:1 draw against Fraunhofer I. In the end, from an optimistic point of view, the AEI team narrowly missed the qualification for the next round; from a pessimistic point of view, they just as narrowly missed being last in their group.


The AEI team narrowly missed the qualification for the next round

The Golm campus tournament was followed less than a week later by a sports event of a different sort, less well attended but certainly no less colourful: The first inofficial one day cricket tournament pitting a united Max Planck campus cricket team against a team from Potsdam university on September 8. Of two 10 over matches, lasting an overall 3 hours, the first was won with 39 to 31 runs by the Potsdamers, who in their turn were mercilessly trashed by the Max Planck team in the second match, with 60 to a pitiful 28 runs. While the tournament was, unaccountably, not as popular among spectators as its side-show event (the "Open Day 2002"), it was deemed a great success by all participants.

Living Reviews in Relativity
... high-quality scientific publishing at the AEI

Since 1998 the Max Planck Institute for Gravitational Physics has published an innovative international physics journal, Living Reviews in Relativity, at http://www.livingreviews.org. Living Reviews in Relativity is solely web-based and publishes review articles embracing all aspects of current relativity research. The journal is offered as a free service to the scientific community. Living Reviews articles are solicited by an international editorial board and are subject to strict peer-review. The journal's editorial concept is unique in that it asks authors to maintain their review articles: depending on the progress of research in a particular subject, articles are revised periodically (hence the word 'living' in the journal title). Therefore readers are always guaranteed to find up to date information on the latest developments in the field.



Still from a Living Reviews article on "Numerical Approaches to Spacetime Singularities" by B.Berger

Living Reviews in Relativity takes full advantage of the electronic medium: Articles are presented in a highly functional online viewing environment. Authors are encouraged to enhance the presentation of their articles by providing active links to online resources, by incorporating animations, figures, graphs or even program code. Further services are provided, such as an online searchable reference database, which collects all references being cited in Living Reviews articles. Entries in the reference database are linked back to the citing article context. Through this mechanism, users will not only know that a particular reference has been cited, but also how it has been evaluated by the Living Reviews author - since the annotating article text is only one click away from the database search result.

Seven new review articles have been published in 2002, including 2 updates of earlier articles. More than 20 new authors have accepted the invitation to write and maintain a 'living' review article. Major efforts have been made to revise the Living Reviews web site. The entrance pages of the journal have been restructured in order to improve its usability and appearance. In December 2002 the new web site went online. A new option for article downloads was added. Since January 2002, PDF versions of all review articles have been available for download.

There is no doubt that now, after 5 years of publication and with a steadily broadening coverage of article topics, Living Reviews in Relativity is established among the scientific community as a high-quality resource for reviews: A recent usage analysis confirms that the web site traffic is still growing impressively: within one year (2001-2002) the overall number of article downloads has more than doubled! Each article being published in Living Reviews in Relativity is being downloaded on average more than 600 times. Also, more than 600 times 'living' reviews have been cited by other articles and article preprints, as a research in Science Citation Index and arXiv has shown. Acknowledging its conformance to "strict criteria as to editing, review and international character", Living Reviews in Relativity was granted "recognized journal status" by the European Physical Society in October 2002.

Living Reviews BackOffice

... spreading the Living Reviews concept to other fields

The Living Reviews concept yields benefits in fields well beyond the area of relativity. It constitutes an effective research tool for fields where multidisiplinarity and an increasing amount of grey literature pose great challenges for staying up to date and identifying the most valuable information resources. 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. The BackOffice provides advice and an editorial infrastructure to Max Planck Institutes who wish to publish their own Living Reviews journal. The BackOffice's main areas of activity are:

- To facilitate the foundation of a family of LR-type journals, by sharing the knowledge and experience gained with Living Reviews in Relativity, and by providing Max Planck Institutes with the core technical infrastructure and services for the production of the journals.
- To generalize and innovate web-publishing tools developed for Living Reviews in Relativity.
- To explore the future sustainability of a highly valued open access resource like Living Reviews in Relativity and coming sister journals.

With the help of the Living Reviews BackOffice, a first new Living Reviews journal is already in an advanced stage of preparation. The work of the Living Reviews BackOffice at the AEI is being supported by the ZIM with the equivalent of two full-time positions. Christina Weyher has been appointed the project manager.

MoWGLI

... adding machine-understandable meaning to mathematics
in Living Reviews articles

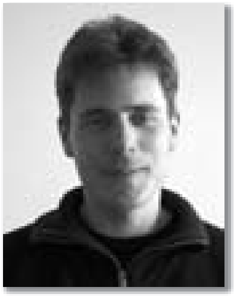
In March 2002 the EU-IST project MoWGLI (Mathematics on the Web - Get it by Logic and Interface), whose consortium of international research teams Living Reviews joined two years ago, started off. The goal of the project is to add machine-understandable meaning to mathematics in electronic documents. Going beyond the mere presentation of mathematical contents in electronic documents (Living Reviews articles in our case) these contents will be made accessible for advanced searching and retrieval, export and further evaluation. Since October 2002 Dr. Romeo Anghelache, an experienced XML programmer, has reinforced the Living Reviews team to work on the MoWGLI project. During the first year of MoWGLI, we have explored what a digital library built up by the different MoWGLI project groups will look like. A taxonomy of metadata for Living Reviews articles and its mathematical objects has been developed. Currently tools to export mathematical contents from the LaTeX format in which Living Reviews authors submit their articles to an semantically marked up MathML format are being evaluated.

Christina Weyher

Resources:
Living Reviews in Relativity
(http://www.livingreviews.org)
Heinz Nixdorf Center for Information Management
in the Max Planck Society (http://www.zim.mpg.de)
MoWGLI project (http://www.mowgli.cs.unibo.it)

Academic Achievements

Bernard Schutz was named "Honorarprofessor" at the University of Hannover on March 17, 2002 in "recognition of his scientific work and the close cooperation with the University of Hannover."



Doctoral Thesis

Stefan Fredenhagen was awarded his PhD from the Humboldt-Universität Berlin. He wrote his doctoral thesis on "D-brane dynamics in curved backgrounds" supervised by Dr. Volker Schomerus.

Doctoral Thesis

Hanno Sahlmann completed his PhD thesis on "Coupling matter to loop quantum gravity " supervised by Dr. habil. Thomas Thiemann. He was awarded his PhD from the Universität Potsdam.

Doctoral Thesis

Norma Quiroz finished her PhD thesis on "Dirichlet Branes on Orientifolds" supervised by Prof. Stefan Theisen. She was awarded her PhD from the Centro de Investigación y de Estudios Avanzados del IPN (Mexico).

Diploma Thesis

Simon Borger graduated in physics from the Universität Hamburg. He wrote his diploma thesis at the AEI under the supervision of Dr. Alicia Sintes on "Parameter estimation for gravitational wave measurements from compact binary systems taking into account both the inspiral and the ringdown ".

Diploma Thesis
Christian G. Böhmer has completed his diploma in physics at the Universität Potsdam. The thesis was written at the AEI under the supervision of Prof. Bernd Schmidt on "General; Relativistic Static Fluid Solutions with Cosmological Constant".

Diploma Thesis
Jan Harms has completed his diploma in physics at the Universität Hannover. The thesis was written under the supervision of Dr. Carlo Nicola Colacino and Dr. Roman Schnabel on "Quantum Noise in the Laser-Interferometer Gravitational Wave Detector GEO600"

Diploma Thesis
Sven Herden graduated in physics from Hannover University. He wrote his diploma thesis under the supervision of Dipl.-Phys. Michèle Heurs and Dipl.-Phys. Volker Quetschke on "Vergleichende Untersuchung von Hochleistungs-YAG-Lasern".

Diploma Thesis
Frank Seifert finished his diploma thesis at the AEI in Hannover on "Entwicklung einer quantenrauschbegrenzten Leistungsstabiliserung für ein Präzisionslasersystem" supervised by Dipl.-Phys. Michèle Heurs and Dipl.-Phys. Volker Quetschke.

Diploma Thesis
Johannes Brunnemann has completed his diploma at Humboldt University Berlin. His thesis on “Spectral Analysis of the Volume Operator in Canonical Quantum General Relativity” was written under the supervision of Dr. habil. Thomas Thiemann.

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.

Current members of our Fachbeirat:

Prof. Dr. Robert Beig
Institut für Theoretische Physik
Universität Wien

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

Prof. Dr. Hubert Goenner
Institut für Theoretische Physik
Georg-August-Universität Göttingen

Prof. Dr. James Hartle
Physics Department
University of California at Santa Barbara

Prof. Dr. Wolfgang Hillebrandt
Max-Planck-Institut für Astrophysik
Garching

Prof. Dr. Richard Matzner
Center for Relativity Theory
University of Texas at Austin

Prof. Dr. Roger Penrose
Mathematical Institute
University of Oxford/UK

Prof. Dr. Gerard 't Hooft
Institute for Theoretical Physics
Universiteit Utrecht

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Verch, Rainer	Universität Göttingen	28/01/2002-28/01/2002
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Zarembo, Konstantin	Uppsala University	05/08/2002-20/08/2002
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Allen, G.	Cactus and Numerical Relativity / 13 May 2002 / Workshop on Formulations of Einstein Equations, Mexico City (Mexico)
Cutler, C.	Continuous Gravitational Waves from Neutron Stars / 22 September 2002 / Menorca (Spain)
Dain, S.	Asymptotically Flat Initial Data with Prescribed Regularity at Infinity 31 May 2002 / Workshop on General Relativity, Standford (USA)
Dain, S.	Asymptotically Flat Initial Data with Prescribed Regularity at Infinity 1 August 2002 / Summer school on: "50 Years of the Cauchy Problem in General Relativity", Cargese, Corsica (France)
Dain, S.	Initial data for stationary space-times near space-like infinity 8 August 2002 / Summer school on: "50 Years of the Cauchy Problem in General Relativity", Cargese, Corsica (France)
Dain, S.	Initial data for fluid bodies in general relativity / 11 October 2002 / Workshop on Relativistic and Nonrelativistic Fluids, Albert Einstein Institute, Golm (Germany)
Danzmann, K.	Optical technologies for laserinterferometry / 15 January 2002 / OPTICON II, Paris (France)
Danzmann, K.	Integration flow for LISA / 30 January 2002 / NASA Science Engineering Workshop III, Washington, DC (USA)
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Danzmann, K.	LISA: technology and future / 19 July 2002 / 4th International LISA Symposium, Pennsylvania (USA)
Danzmann, K.	Gravitational wave astronomy / 10 September 2002 / Astro-Particle European Coordination Symposium, Paris (France)
Danzmann, K.	Fundamental physics in Space / 24 September 2002 / Deutsche Gesellschaft für Luft- und Raumfahrt Annual Meeting, Stuttgart (Germany)
Danzmann, K.	Laserinterferometry in Space / 5 November 2002 / HYPER Symposium, Paris (France)
Ehlers, J.	Gravitationslinsen / 20 February 2002 / Akademie Mainz (Germany)
Ehlers, J.	Aktuelle Probleme der Gravitationsphysik / 20 March 2002 / Frühjahrstagung der DPG, Festvortrag anlässlich der Verleihung der Max-Planck-Medaille, Leipzig (Germany)
Ehlers, J.	Gravitationslinsen / 18 April 2002 / Kolloquium Universität Mainz (Germany)
Ehlers, J.	Gravitationslinsen / 27 May 2002 / Kolloquium Universität Heidelberg (Germany)
Ehlers, J.	Bilder und Symbole in der Physik / 15 July 2002 / Evangelische Studiengemeinschaft Heidelberg (FEST) (Germany)
Ehlers, J.	Light cones in Cosmology / 29 July 2002 / Summer school on: "50 Years of the Cauchy Problem in General Relativity", Cargese, Corsica (France)
Ehlers, J.	Das Standardmodell der Kosmologie / 11 November 2002 / Festvortrag Akademie Mainz (Germany)
Fischbacher, T.	LambdaTensor - numerische und symbolische multilineare Algebra auf dünn besetzten Tensoren / 21 November 2002 / GWDG-Tagung, anlässlich der Heinz-Billing-Preisverleihung, Göttingen (Germany)

Invited Conference Talks Given by AEI Members

Friedrich, H.	The problem of the floating fluid ball in general relativity 11 October 2002 / Workshop on Relativistic and Nonrelativistic Fluids, Albert Einstein Institute, Golm (Germany)
Heinzel, G.	Interferometry for the LISA technology package (LTP) aboard SMART-2 / 22 July 2002 / 4th International LISA Symposium, Pennsylvania (USA)
Huisken, G.	Neckpinching in mean curvature flow / 5 May 2002 / JDG 2002: 5th Conference on Geometry and Topology, Harvard (USA)
Huisken, G.	Mean curvature flow in Geometry and Physics / 14 May 2002 / Ehrenpromotion Prof. Olga Ladyzhenskaya, Universität Bonn (Germany)
Junker, W.	Quantenfeldtheorie in gekrümmter Raumzeit / 21 March 2002 / 66. Physikertagung der Deutschen Physikalischen Gesellschaft, Leipzig (Germany)
Junker, W.	Introduction to microlocal analysis and QFT on curved spacetime / 12 July 2002 / Erwin-Schrödinger-Institut Wien (Austria)
Kristjansen, C.F.	Strings on PP Waves and Gauge Theories / 29 November 2002 / 16th Nordic Network Meeting on Fields, Strings and Branes, Copenhagen, NORDITA (Denmark)
Lopez, E.	Non-planar anomalies and the Green-Schwarz mechanism / 27 May 2002 / Workshop at the Basque Country University, Bilbao (Spain)
Lopez, E.	Non-planar anomalies and the Green-Schwarz mechanism / 4 June 2002 / Euresco Conference 2002, Bad Herrenalb (Germany)
Lopez, E.	Non-planar anomalies and the Green-Schwarz mechanism / 21 June 2002 / Network meeting, Tegernsee (Germany)
Lück, H.	GEO600 detector status / 8 February 2002 / 2nd TAMA Symposium, Tokio (Japan)
Lück, H.	GEO600: Ultrahochvakuum für die Detektion von Gravitationswellen 11 March 2002 / DPG Frühjahrstagung, Fachverband Vakuumphysik, Regensburg (Germany)
Nicolai, H.	The principal subalgebra of a hyperbolic KM algebra / 30 January 2002 Ramanujan International Symposium on "Kac Moody Lie Algebras and Applications", Chennai (India)
Nicolai, H.	Maximal gauged supergravities in three dimensions / 17 April 2002 / Michigan Center for Theoretical Physics, Ann Arbor (USA)
Nicolai, H.	E10 and the BKL limit of M Theory / 20 July 2002 / STRINGS 2002, 14 -21 July, Cambridge (UK)
Nicolai, H.	The minimal unitary representation of E8(8) / 27 August 2002 / 35th International Symposium Ahrenshoop "Recent developments in String/M Theory and field theory", Akademie Berlin-Schmöckwitz (Germany)
Papa, M.A.	Status report for the Continuous Waves Upper Limit working group 21 July 2002 / LSC meeting, Hanford (USA)
Perlick, V.	Gravitationslinseneffekt und Raumzeit-Geometrie / 22 March 2002 66. Physikertagung der DPG, Leipzig (Germany)
Plefka, J.	Wilson Loops in N=4 Super Yang-Mills Theory / 8 March 2002 / PIMS Pacific Northwest String Seminar, Vancouver (Canada)
Plefka, J.	Maldacena-Wilson Loops / 21 March 2002 / GIF Meeting, Humboldt-University Berlin (Germany)
Plefka, J.	A new double scaling limit of N=4 Super Yang-Mills and PP-Wave Strings / 06 June 2002 / Euresco Conference 2002, Bad Herrenalb (Germany)
Plefka, J.	A new double scaling limit of N=4 Super Yang-Mills and PP-Wave Strings / 19 June 2002 / EU Network Meeting, Schloss Ringberg (Germany)

Invited Conference Talks Given by AEI Members

Plefka, J.	N=4 Super Yang-Mills in the BMN limit / 27 August 2002 / 35th International Symposium Ahrenshoop "Recent developments in String/M Theory and field theory", Akademie Berlin-Schmöckwitz (Germany)
Plefka, J.	N=4 Super Yang-Mills in the BMN Limit / 14 September 2002 / RTN Workshop "The quantum structure of space-time", Leuven (Belgium)
Rendall, A.D.	Introduction to the Cauchy problem for the Einstein equations 24 June 2002 / Conference on Numerical Relativity, Institute for Mathematics and its Applications, Minneapolis (USA)
Ringström, H.	On the expanding direction of Gowdy vacuum spacetimes / 30 July 2002 / Summer school on: "50 Years of the Cauchy Problem in General Relativity", Cargese, Corsica (France)
Schmidt, M.U.	Ein Beweis der Willmore-Vermutung / 19 September 2002 / DMV Tagung Halle (Germany)
Schnabel, R.S.	Optical Experiments Beyond the Quantum Limit: Squeezing, Entanglement and Teleportation / 14 May 2002 / International Conference on Quantum Optics 2002, Minsk (Belorussia)
Schutz, B.F.	Simulations of Black Holes using High-Performance Networking / 22 May 2002 / Brussels (Belgium)
Schutz, B.F.	Sources of Gravitational Waves / 01 June 2002 / Greek Relativity Meeting 2002, Chalkidiki (Greece)
Schutz, B.F.	Gravitational Wave Astronomy / 15 June 2002 / Advances in General Relativity and Cosmology, Elba (Italy)
Seidel, E.	GridLab: Enabling Engineering and Scientific Applications on the Grid 29 May 2002 / HLRS Metacomputing Workshop, Stuttgart (Germany)
Seidel, E.	Numerical Relativity and its Application to Gravitational Wave Astronomy 10 June 2002 / Gravity, Astrophysics and Strings at the Black Sea (First Advanced Research Workshop), Kiten (Bulgaria)
Seidel, E.	Problem Solving Environment for Science and Engineering Grid Applications / 28 June 2002 / VECPAR 2002, Porto (Portugal)
Seidel, E.	What I Really Want from High Speed Networks, Now and in 5-10 Years Time / 17 September 2002 / European Commission, Brussels (Belgium)
Sintes, A.M.	Matlab experience with the data / 20 February 2002 / GEO600 Data Analysis Workshop, Albert Einstein Institute, Golm (Germany)
Sintes, A.M.	The Hough transform routines / 22 February 2002 / GEO600 Data Analysis Workshop, Albert Einstein Institute, Golm (Germany)
Staudacher, M.	Maldacena-Wilson Loops / 12 February 2002 / European Superstring Theory Network Meeting, Cambridge (UK)
Staudacher, M.	Index Puzzles in Susy Gauge Mechanics / 9 March 2002 / PIMS Pacific Northwest String Seminar, Vancouver (Canada)
Staudacher, M.	A New Double-Scaling Limit of N = 4 Super Yang-Mills Theory and PP-wave Strings / 28 June 2002 / 3rd International Sakharov Conference, Moscow (Russia)
Thiemann, T.	Quantum Dynamics of Loop Quantum Gravity / 24 June 2002 / 3rd International Sakharov Conference, Moscow (Russia)
Thiemann, T.	Introduction to Loop Quantum Gravity / 4 July 2002 / GRG 11, Tomsk (Russia)
Thiemann, T.	The Structure of UV Singularities in Loop Quantum Gravity / 14 August 2002 / ESI Workshop on Algebraic QFT, Vienna (Austria)
Thiemann, T.	Towards the QFT on CST Limit of Loop Quantum Gravity / 06 December 2002 / 11. Workshop on Algebraic QFT, Göttingen (Germany)
Weyher, C.	Living Reviews - Neue Wege der wissenschaftlichen Kommunikation / 13 March 2002 / IUK 2002, Ulm (Germany)
Weyher, C.	Living Reviews Back Office / 25 June / Fritz Haber Institute, Berlin (Germany)

Invited Conference Talks Given by AEI Members

Willke, B.	Gravitationswellenastronomie - ein neues Beobachtungsfenster zum Weltall / 27 March 2002 / 93. MNU-Bundeskongress, Hannover (Germany)
Willke, B.	GEO600 status report / 24 July 2002 / VIRGO Meeting, Cascina (Italy)

Lectures and Lecture Series Given by AEI Members

Allen, G.	Scientific Computing / 10 June 2002 / Gravity, Astrophysics and Strings at the Black Sea (First Advanced Research Workshop), Kiten (Bulgaria)
Allen, G.	Developing HPC Scientific and Engineering Applications: From the Laptop to the Grid / 17 November 2002 / Supercomputing 2002 High Performance Networking and Computing Conference, Baltimore (USA)
Aufmuth, P.	Gravitational Waves - Sources and Detectors / 10 April 2002 / Laser Zentrum Hannover (Germany)
Aufmuth, P.	GEO 600 - ein Observatorium für Gravitationswellen / 11 June 2002 Universität Kiel (Germany)
Aufmuth, P.	Wie klingt eine Supernova? Astronomie mit Gravitationswellen / 28 October 2002 / Universität Giessen (Germany)
Aufmuth, P.	Introduction to current experimental research: Experimental gravitational physics / 5 December 2002 / Universität Hannover (Germany)
Aufmuth, P.	GEO600 - An der Schwelle zur Gravitationswellen-Astronomie / 11 November 2002 / Universität Oldenburg (Germany)
Colacino, C. N.	Kurzeinführung in die Kosmologie / Wintersemester 2002/03 / Universität Hannover
Colacino, C.N.	The GEO600 project / 17 May 2002 / Università di Roma II (Italy)
Colacino, C.N.	Gravitational waves: theory and experiments / 8 October 2002 / Graduiertenkolleg der Freien Universität Berlin und der Universität Dresden (Germany)
Danzmann, K.	Experimentalphysik I für Studierende der Chemie und Biochemie / Wintersemester 2001/02 / Universität Hannover (Germany)
Danzmann, K.	Experimentalphysik II für Studierende der Chemie und Biochemie / Sommersemester 2002 / Universität Hannover (Germany)
Danzmann, K.	Physik für Studierende des Maschinenbaus / Wintersemester 2002/03 Universität Hannover (Germany)
Danzmann, K.	Gravitationswellendetektoren auf der Erde und im Weltraum / 9 January 2002 / Johann Wolfgang Goethe-Universität, Frankfurt a.M. (Germany)
Danzmann, K.	Gravitational wave research in Hannover / 10 January 2002 / AEI Kuratorium, Golm (Germany)
Danzmann, K.	Gravitationswellendetektoren auf der Erde und im Weltraum 16 January 2002 / Gesellschaft für Schwerionenforschung, Darmstadt (Germany)
Danzmann, K.	Laserinterferometrie und Quantenmessungen / 23 January 2002 Evaluationskolloquium, Universität Hannover (Germany)
Danzmann, K.	Gravitationswellenforschung in der Max-Planck-Gesellschaft 24 January 2002 / MPG-Komitee, Dresden (Germany)
Danzmann, K.	Gravitationswellendetektoren auf der Erde und im Weltraum / 13 February 2002 / Westfälische Wilhelms-Universität, Münster (Germany)
Danzmann, K.	Optical bench and laser development for SMART-2 / 20 February 2002 ESTEC, Nordwijk (Netherlands)
Danzmann, K.	LISA and SMART-2 / 25 February 2002 / Astrium Space, Friedrichshafen (Germany)
Danzmann, K.	The LISA technology package / 1 March 2002 / Deutsches Zentrum für Luft- und Raumfahrt, Bonn (Germany)

Lectures and Lecture Series Given by AEI Members

Danzmann, K.	Gravitational wave astronomy with LISA / 25 March 2002 / ESTEC, Nordwijk (Netherlands)
Danzmann, K.	Gravitationswellendetektoren auf der Erde und im Weltraum / 7 May 2002 / Universität Stuttgart (Germany)
Danzmann, K.	Gravitationswellendetektoren auf der Erde und im Weltraum / 22 May 2002 / Universität Essen (Germany)
Danzmann, K.	Laserinterferometrische Gravitationswellendetektoren auf der Erde und im Weltall / 3 June 2002 / Universität Würzburg (Germany)
Danzmann, K.	Interferometry on SMART-2 / 6 June 2002 / University of Trento (Italy)
Danzmann, K.	Technologies for laserinterferometry / 4 September 2002 / SFB Evaluation, Universität Jena (Germany)
Danzmann, K.	A European gravitational wave network / 10 September 2002 / Astroparticle Physics European Coordination Symposium, Paris (France)
Danzmann, K.	LTP on SMART-2 / 25 October 2002 / DLR Program Committee, Bonn (Germany)
Danzmann, K.	LISA science requirements for laser stabilization / 19 November 2002 Laser Zentrum Hannover (Germany)
Danzmann, K.	Gravitationswellenastronomie - Die erste Detektorgeneration geht in Betrieb / 22 November 2002 / Technische Universität Darmstadt (Germany)
Danzmann, K.	Gravitationswellenastronomie: Die erste Detektorgeneration geht in Betrieb / 22 November 2002 / Gesellschaft für Schwerionenforschung, Darmstadt (Germany)
Danzmann, K.	Fundmental physics in Space / 28 November 2002 / Deutsches Zentrum für Luft- und Raumfahrt, Köln (Germany)
Ehlers, J.	Vorlesungen über allgemeine Relativitätstheorie / 18 January 2002 Physik-Combo der Universitäten Leipzig, Halle, Jena für Doktoranden und Diplomanden, Jena (Germany)
Ehlers, J.	Einführung in die allgemeine Relativitätstheorie / 4 March 2002 Ferienkurs, gemeinsame Veranstaltung des AEI mit der Universität Potsdam (Germany)
Ehlers, J.	General Relativity and Cosmology / 7 October 2002 / Workshop on Cosmology, veranstaltet von den Universitäten Dresden und HU Berlin, Lohmen (Germany)
Ehlers, J.	Erinnerungen an Pascal Jordan / 30 October 2002 / DESY, Hamburg (Germany)
Friedrich, H.	Einstein equations, conformal structure, and the asymptotic behaviour of space-time / 3 August 2002 / Summer school on: "50 Years of the Cauchy Problem in General Relativity", Cargese, Corsica (France)
Friedrich, H.	Einführung in die mathematische Theorie der Schwarzen Löcher / 16 October 2002 / Universität Potsdam (Germany)
Heinzel, G.	The LISA space-borne gravitational wave detector and its SMART-2 technology demonstration satellite / 3 October 2002 / National Astronomical Observatory of Japan, Mitaka (Japan)
Heinzel, G.	The LISA space-borne gravitational wave detector and its SMART-2 technology demonstration satellite / 4 October 2002 / University of Tokyo (Japan)
Heinzel, G.	The LISA space-borne gravitational wave detector and its SMART-2 technology demonstration satellite / 9 October 2002 / National Astronomical Observatory of the Chinese Academy of Science, Beijing (China)
Heinzel, G.	The LISA space-borne gravitational wave detector and its SMART-2 technology demonstration satellite / 10 October 2002 / Beijing Normal University (China)

Lectures and Lecture Series Given by AEI Members

Nicolai, H.	An introduction to the quantum supermembrane / 28 February 2002 271. WE-Heraeus-Seminar "Aspects of quantum gravity: from theory to experimental search", Physikzentrum Bad Honnef (Germany)
Nicolai, H.	Introduction to gauged supergravities in D=3 / 27 June 2002 / Humboldt University, Berlin (Germany)
Nicolai, H.	Two lectures on maximal supergravity / 6 September 2002 / School on Mathematical Physics, Kopaonik (Serbia)
Plefka, J.	Supersymmetrie und Strings / 5 April 2002 / Universität Hannover (Germany)
Plefka, J.	Stringtheorie / 8 April 2002 / VIII. Heidelberger Graduiertentage (Germany)
Rendall, A.D.	The Einstein-Vlasov system / 29 July 2002 / Summer school on: "50 Years of the Cauchy Problem in General Relativity", Cargese, Corsica (France)
Rideout, D.P.	Cactus Framework: Overview, Design Principles, and Architecture 22 August 2002 / Niels Bohr Summer Institute: Beaming and Jets in Gamma Ray Bursts, Copenhagen (Denmark)
Schnabel, R.	Introduction to current experimental research: Experiments with squeezed light / 28 November 2002 / Universität Hannover (Germany)
Schomerus, V.	D-branes in curved backgrounds / 17 January 2002 / European Winter School, RTN 2002, Utrecht (The Netherlands)
Sintes, A.M.	General Physics / 8 April 2002 / Balearic Islands University (Spain)
Sintes, A.M.	Mathematical Methods / 8 April 2002 / Balearic Islands University (Spain)
Thiemann, T.	Lectures on Loop Quantum Gravity / 26 February 2002 / WE-Haeraeus Seminar, Bad Honnef (Germany)
Thiemann, T.	Einführung in Hintergrund-unabhängige QFT / 10 October 2002 Technische Universität Berlin (Germany)

Popular Talks Given by AEI Members

Aufmuth, P.	Der Klang des Universums - Astronomie mit Gravitationswellen 15 March 2002 / Astronomischer Arbeitskreis Kassel (Germany)
Aufmuth, P.	Gravitationswellen / 13 June 2002 / Geschwister-Scholl-Gymnasium, Garbsen (Germany)
Aufmuth, P.	Sternenklang und Urknallecho - GEO und LISA: Horchposten ins All 27 June 2002 / Science Day on Telegraphenberg, Potsdam (Germany)
Aufmuth, P.	Auftakt zum Konzert der Sterne - Der Gravitationswellendetektor GEO600 / 5 November 2002 / Naturwissenschaftliche Mindener Vortragsgesellschaft, Minden (Germany)
Aufmuth, P.	Gravitationswellen: Quellen und Detektoren / 15 November 2002 Gymnasium Andreanum, Hildesheim (Germany)
Aufmuth, P.	Astronomie mit Gravitationswellen - Neue Horchposten ins All 20 December 2002 / Astronomie Stiftung Trebur / Volkshochschule Rüsselsheim, Trebur (Germany)
Danzmann, K.	Gravitationswellen: Warum? / 21 January 2002 / Albert Einstein Institute Press Day, Hannover (Germany)
Danzmann, K.	Horchposten im All: Gravitationswellendetektoren lauschen dem Klang des Universums / 21 February 2002 / Hölty-Gymnasium, Wunstorf (Germany)
Danzmann, K.	Was wird von Studienanfängern der Physik insbesondere im Fach Mathematik erwartet? / 14 February 2002 / Didaktischer Arbeitskreis Schule - Universität, Universität Hannover (Germany)

Popular Talks Given by AEI Members

Danzmann, K.	Gravitationswellenastronomie in Hannover / 17 May 2002 / AEI Inauguration, Hannover (Germany)
Danzmann, K.	Die dunkle Seite unseres Universums / 10 July 2002 / Siemens Lecture, Carl Friedrich von Siemens Stiftung, München (Germany)
Danzmann, K.	Weiße Zwerge - Schwarze Löcher / 8 September 2002 Max Planck Campus Open Day, Golm (Germany)
Danzmann, K.	Hörbare Astrophysik / 9 October 2002 / Autumn University, Universität Hannover (Germany)
Danzmann, K.	Aufzucht und Pflege von Gravitationswellen / 2 November 2002 Saturday Morning Lecture, Universität Hannover (Germany)
Danzmann, K.	Die dunkle Seite unseres Universums / 6 December 2002 / Braunschweig (Germany)
Danzmann, K.	Physik ist Zukunft: Von Schwarzen Löchern bis zum Quantencomputer 11 December 2002 / Winter University, Universität Hannover (Germany)
Ehlers, J.	Über die Rolle der Mathematik in der Physik / 9 April 2002 / Urania Berlin (Germany)
Ehlers, J.	Raum und Zeit in der Relativitätstheorie / 7 June 2002 / Schulvortrag anlässlich der Hauptversammlung der MPG, Gymnasium Berlin-Steglitz (Germany)
Ehlers, J.	Warum hat Einstein die Raumzeit gekrümmt? / 8 September 2002 Max Planck Campus Open Day, Golm (Germany)
Fredenhagen, S.	Das frühe Universum / 2 June 2002 / AIP Open Day, Potsdam (Germany)
Heurs, M.	Was ist Licht? / 9 October 2002 / Autumn University, Universität Hannover (Germany)
Heurs, M.	Was ist Licht? / 11 December 2002 / Winter University, Universität Hannover (Germany)
Huisken, G.	Analysis, Geometrie und Gravitation / 11 June 2002 / Gymnasium Köthen (Germany)
Koppitz, M.K.	Kollidierende Schwarze Löcher / 25 January 2002 / AEI Golm (Germany)
Nicolai, H.	101 Jahre Quantentheorie / 15 May 2002 / Rotary Club Potsdam (Germany)
Quetschke, V.	Was ist ein Laser? / 9 October 2002 / Autumn University, Universität Hannover (Germany)
Quetschke, V.	Was ist ein Laser? / 11 December 2002 / Winter University, Universität Hannover (Germany)
Schutz, B.F.	Gravity from the Ground Up / 16 January 2002 / John F. Kennedy School, Berlin (Germany)
Schutz, B.F.	Relativity in Astronomy / 21 January 2002 / Albert Einstein Institute Press Day, Hannover (Germany)
Schutz, B.F.	Einsteins Erbe: Das relativistische Universum / 8 September 2002 Max Planck Campus Open Day, Golm (Germany)
Skorupka, S.	Gravitationswellenastronomie - Ein neues Fenster ins All 8 May 2002 / Universität Hannover (Germany)
Skorupka, S.	Gravitationswellen und ihre Messung / 9 October 2002 Autumn University, Universität Hannover (Germany)
Skorupka, S.	Gravitationswellen und ihre Messung / 11 December 2002 Winter University, Universität Hannover (Germany)
Skorupka, S., Heurs, M.	... und es wird Licht. Weihnachtsvorlesung / 19 December 2002 (two times) / Universität Hannover (Germany)
Skorupka, S., Heurs, M.	... und es wird Licht. Weihnachtsvorlesung / 20 December 2002 (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 4 January 2002 / 18 January 2002 / 21 February 2002 / 28 February 2002 / 18 March 2002 / 19 March 2002 / 25 March 2002 / 14 April 2002 / 23 April 2002 / 24 April 2002 / 2 May 2002 / 7 May 2002 / 17 Mai 2002 / 14 June 2002 / 17 June 2002 / 18 June 2002 / 24 June 2002 / 25 June 2002 / 27 June 2002 / 2 July 2002 / 9 July 2002 / 31 July 2002 / 9 August 2002 / 10 August 2002 / 11 September 2002 / 12 September 2002 / 25 September 2002 / 11 October 2002 / 21 October 2002 / 29 October 2002 / 31 October 2002 / 1 November 2002 / 7 November 2002 / 15 November 2002 / 20 November 2002 / 27 November 2002 / 29 November 2002 / 6 December 2002

The Max Planck Society: Profile and Organisation

The Max Planck Society for the Advancement of the Sciences (the Max-Planck-Gesellschaft) is an independent, non-profit organisation which promotes fundamental scientific research in service of the common. It maintains about 80 Max Planck Institutes in the natural and life sciences as well as in the humanities.

The Max Planck Society is particularly interested in new, promising fields of research which the universities are only able to accommodate insufficiently, if at all. The reasons for this are either due to the fact that the interdisciplinary character of such research cannot fit into the universities' organisational framework or because the universities cannot afford the necessary staff and facilities. Max Planck Institutes therefore complement the work of the universities in important fields of research.

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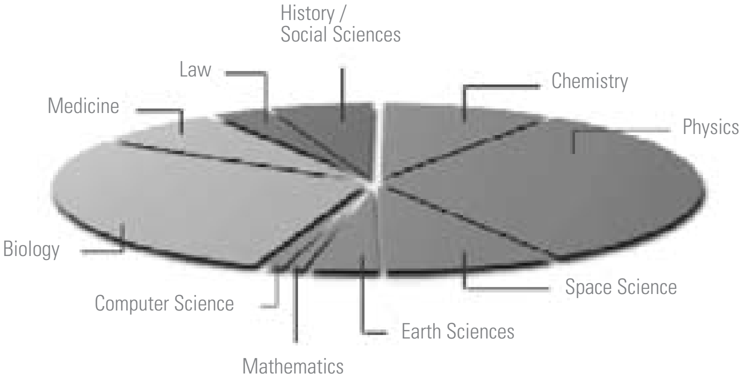

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Note

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!

Masthead

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vizualisation: Werner Benger (ZIP/AEI)
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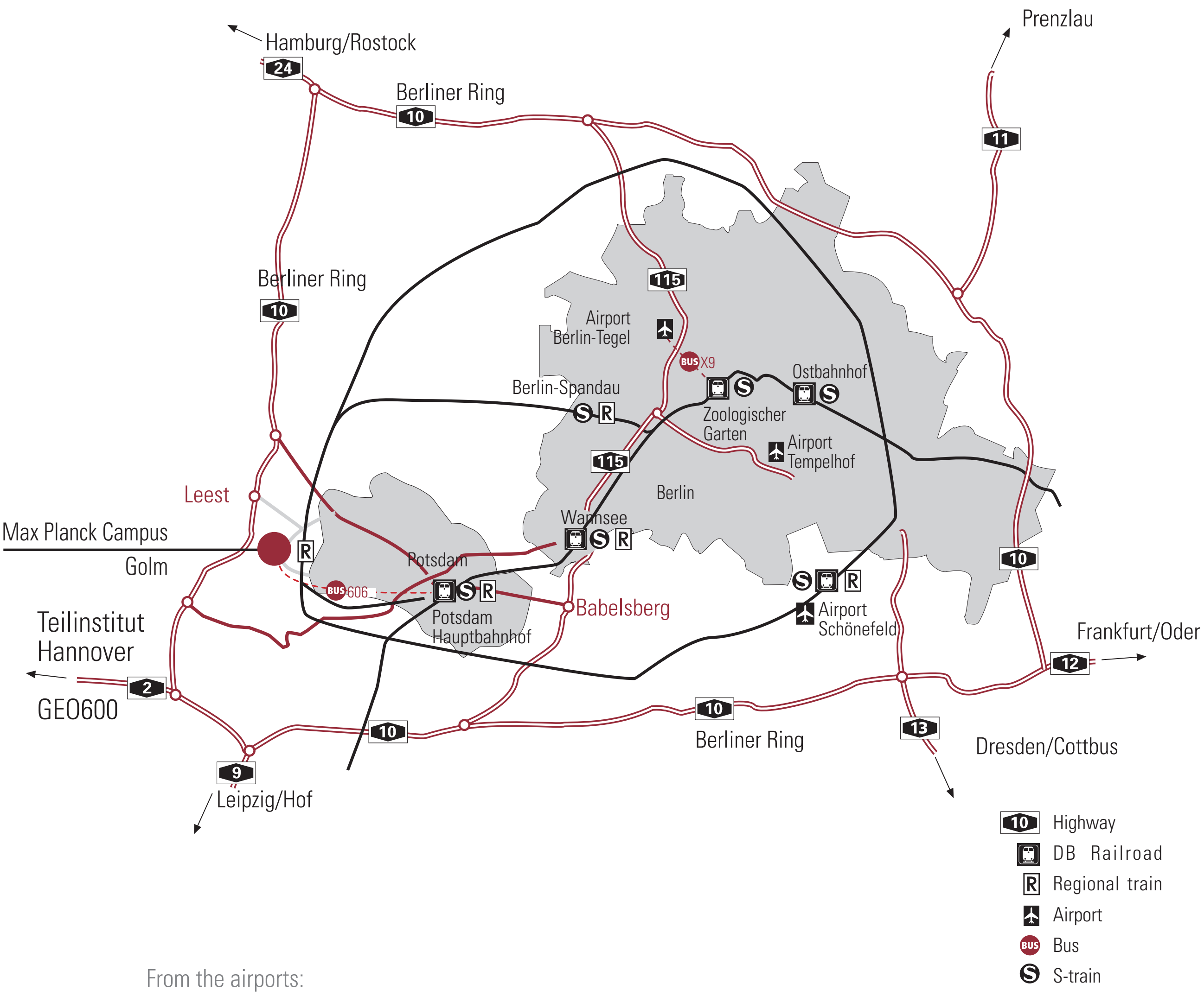
p. 56: Top: Peter-René Lindermann/
Brandenburgischer Kunstverein Potsdam e.V
Bottom: Susanne Weirich
p. 57: Top: Susanne Weirich
Portrait S. Weirich: Peter-René Lindermann
p. 58: Little girl: Katja Schulze/MPI of Colloids and Interfaces
"Through the Eyes of a Visitor": Sebastian Frenkel
p. 61: J. Ehlers: D. Fischer, Physik Journal;
Billing Award: Gesellschaft für wissenschaftliche Datenverarbeitung mbH Göttingen (GWDG)
p. 62: Bottom: Matthias Hassenpflug/AIP
p. 69: Schätzl/Schutz: Frank Gaudlitz/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