MAX-PLANCK-GESELLSCHAFT

Annual Report 2001

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

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

Preface by the Managing Director

The annual report 2001 reviews the important developments that took place over the past year at the Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut). Most prominent among these were the enlargement of the institute by two experimental divisions in Hannover, the appointments of two new directors, Gerhard Huisken and Karsten Danzmann, with the appointment of a second director for the Hannover Teilinstitut still pending, and the third meeting of the AEI Fachbeirat, our external scientific review committee, in September 2001. With its three theoretical and two experimental sections, AEI will cover an unusually broad range of subjects, ranging from pure mathematics over string theory and quantum gravity, and numerical relativity and its astrophysical applications all the way to the mechanics and control of gravitational wave detectors and quantum optics devices. To run such an institute will be an interesting experience and a mighty challenge for the future!

With the appointment of Gerhard Huisken to become head of the Geometric Analysis and Gravitation division, the long search for a successor to our founding director Jürgen Ehlers (now "director emeritus") was at last brought to a happy end. Gerhard Huisken, an eminent mathematician, is known worldwide for his numerous contributions to pure mathematics and mathematical physics, in particular for his proof of the celebrated Penrose conjecture. (We were particularly pleased that Prof. Huisken declined an offer from one of the most important American universities in order to accept the offer of the Max Planck Society.) The inclusion of pure mathematics into the research canon of AEI opens many new perspectives for the development of mathematical relativity, but will at the same time enable AEI to preserve and further develop its traditional research directions in that area, as was also emphasized by the Fachbeirat in its recent report.

On the experimental side, our new colleague Karsten Danzmann has acquired an international reputation for his groundbreaking work on gravitational wave detectors, especially on the GEO600 detector, which is now part of AEI. He and Bernard Schutz will represent AEI in the international collaborations on the next generation of gravitational wave detectors (LIGO II and LISA, in particular), thereby ensuring the institute a leading role in future developments and discoveries, above all in the first detection of gravitational waves. As an AEI director Danzmann will remain a full professor at Hannover University.

The new Teilinstitut Hannover was officially made a part of AEI with the effective date of 1 January 2001. Exciting as it was, this enlargement of the institute "in one stroke" by more than 80 scientists and technical staff has meant a lot of extra work for and considerable strain on our administration, which was originally designed only to handle a much smaller institute consisting of three divisions. To cope with this required many hours of overtime work for our administrative staff, sometimes close to the legal limit! Here I would like to especially thank Frau Roos and her staff for the excellent work, and for managing the task so as to smooth out the "phase transition" in such a way that the scientific work was largely unaffected by it. Meanwhile, a new "Geschäftsordnung" has been approved, clarifying the administrative structures within the enlarged institutes, and we hope that this together with new appointments for administrative staff will make life easier for all parties concerned.

In September 2001, the AEI Fachbeirat for the third time took a very thorough look at the institute. As we have received their report only very recently, I refrain from presenting its contents in detail here, save to say that it is a very positive report overall. We are very grateful for the detailed insight and specific recommendations which as in previous years will be of great help to us. I would like to take this opportunity to thank all members of the Fachbeirat, and especially its former chairman, Norbert Straumann, and the present one, Jim Hartle, for their dedicated work on behalf of our institute.

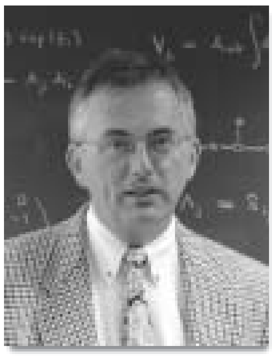
With the addition of two new divisions, and the broadening scientific scope of AEI, one of the challenges for the future will be to maintain and foster scientific cohesion of the institute. As a first step, we have started a new "institute seminar" which takes place once a month. Its purpose is to inform AEI scientists of what is happening in the other divisions by asking scientists to present their work in non-specialist terms to the rest of the institute.

Of course, not everything went according to plan. The deal for AEI's new supercomputer, which was due to be delivered last year, unfortunately fell apart. In addition to the legal wranglings this required especially the numerical relativity group to revise their planning and to look for makeshift solutions, at considerable extra cost to AEI. Secondly, the promised extension of our institute building will be delayed by at least one year due to a shortfall in the budget of Max Planck Society. Since the extra space had already been taken into account for our planning for autumn 2003 and after, all divisions of AEI will have to cope with an acute shortage of office space, forcing us to cancel numerous planned visits within the AEI visitor program as well as not being able to accept as many new PhD students as we had intended. Moreover, there will be no office space available in Golm for our Hannover colleagues in the near future.

The AEI Kuratorium was constituted at last in 2001, and we are delighted that the prominent personalities whom we had asked to participate have all accepted (see the appendix for a list of members). Meanwhile the Kuratorium had its first meeting (in January 2002), and we hope that this will be the beginning of a long and fruitful collaboration, which will also help to make AEI better known among the general public. Indeed, the institute has been quite successful in the PR domain. There were a number of newspaper articles explaining gravitational physics and the institute's activities to the public. In particular, the institute and its scientific work featured very prominently in the popular journal "Sterne und Weltraum" (a special issue on gravitation appeared in May 2001). An open day for all three Golm Max Planck institutes and the Fraunhofer Institute on 30 June 2001 attracted more than a thousand visitors, a remarkable turnout in view of the Golm campus' outside location at the periphery of Potsdam.

A very special highlight was the nomination of Jürgen Ehlers for the Max Planck Medal for the year 2002, which he will receive during the annual meeting of the German Physical Society in Leipzig in March 2002. This is the highest distinction the German Physical Society can bestow upon a theoretical physicist. The 2002 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 perhaps also noteworthy that this is the first time that the Max Planck Medal is awarded in the field of general relativity.

In June 2002, my colleague Bernard Schutz will take over again as managing director of the institute. Finally, I would like again to thank the staff of AEI for their loyalty and dedication over the past year.



Hermann Nicolai
(Managing Director)

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Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

The Albert Einstein Institute (AEI) 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. In 2001 the Institute began the establishment of a branch in Hannover devoted to experimental gravitation. The two sites will eventually be home to five scientific divisions with a total working population of approximately 170 scientists (including guests) and 40 support staff. The enlarged AEI will be in a strong position to take advantage of the blossoming of research in gravitation that can be expected during the coming decades.

Background: 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. And in recent years the most striking technological advances have been in the design and construction of gravitational wave detectors, which should soon directly observe signals 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. 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 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 2001 had three divisions for theoretical research in Golm (near Potsdam) and a research group in Hannover that will form the core of the new experimental branch there.

- The Astrophysical Relativity Division 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 will analyze data from the GEO600 gravitational wave detector (see below), beginning with test data taken at the very end of 2001. The numerical relativity group is the largest in the world, and is a leader in the development of software that allows effective use of large parallel supercomputers for solving equations in physics.

- The Quantum Gravity Division 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.

- The Geometric Analysis and Gravitation Division extends the techniques that have unlocked the basic meaning of the theory. In particular, extensive and successful investigations concerning the local and global properties of solutions to Einstein's equations have been carried out, deepening our understanding of the theory and developing new tools for solving problems in it. The presence on the AEI staff of experts in both mathematical and numerical relativity offers a unique opportunity for mutual stimulation and cooperation. The development of quantum gravity will surely require new and unexpected mathematics. Challenging as general relativity has been to mathematicians, it is fair to say that string theory today requires the invention of a still larger variety of mathematical structures.

- The Laserinterferometry and Gravitational Wave Astronomy Division in Hannover, in cooperation with its partners in Glasgow and Cardiff in the UK, is building an ultra-sensitive gravitational wave detector. Located on an agricultural station of the University of Hannover near Ruthe, the detector consists of two 600 m long arms perpendicular to one another, shaped like an "L". The GEO collaboration is a world leader in detector technology. Their optical and mechanical systems will be used not only in GEO600 but are also expected to go into the other major detectors, being built in the USA and Italy. The group also plays a leading role in the development of the LISA space-based gravitational wave detector, which during 2001 became a joint project of the European Space Agency (ESA) and the US space agency NASA. Formerly part of the Max Planck Institute for Quantum Optics in Garching, the Hannover group was transferred administratively to the AEI at the beginning of 2001. In 2002 it will become one of the two divisions of the new Hannover branch of the AEI.

No other institute brings together these important branches of gravitational physics research. It was part of Professor Ehlers' original concept of the AEI that it should mix scientists in these disciplines together and reap the benefits from the resulting cross-fertilization. In pursuit of this aim, for example, the AEI in Golm does not group offices of people working in the same division together: all subjects, plus visitors, are distributed throughout the Institute. The challenge of the future will be to ensure that the experimental activities in Hannover are also integrated into this environment.

To support this work the AEI provides 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 2001 and of seminars given at the AEI in 2001 show how rich the intellectual environment is. 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.

Role and Activities of the AEI

It is natural that an institute that is as large as the AEI in relation to others in its field will be seen as a focus for world-wide work in relativity. In fact, a good fraction of the world community of scientists working in relativity has already visited the AEI in its first 6 years. Since 1998, as a further service to this community, the AEI publishes a new kind of free electronic journal, called Living Reviews in Relativity. This is described later in this volume.

The AEI has organized a number of small informal workshops, choosing areas of its own research where it seemed that a critical problem could benefit from bringing together the experts from around the world. With its extensive guest scientist program, the institute can respond quickly to such needs. Furthermore, over the last years the AEI hosted a couple of important conferences: Strings '99 brought great excitement and attention to the Institute. With some of the world's most prominent theoretical physicists attending and discussing the deepest challenges in fundamental physics, the meeting captured the interest of the press and the general public. In 2000 the AEI hosted the Third International LISA Symposium, a meeting devoted to studying the science and technology of the LISA spacebased gravitational wave mission. LISA is a Cornerstone of the European Space Agency's program for the 21st century, and has been adopted as a joint mission with NASA. In 2001 the Fourth CAPRA Meeting on Radiation Reaction was hosted by the Institute. More details about this event are contained in a report by Lior Burko elsewhere in this volume.

The AEI occupies a key position in relativity in Germany as well. 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 active groups at German universities, the focus of the development of classical relativity in the 1960's through the 1990's was outside Germany. To strengthen the field of relativity in Germany the AEI is in the process of applying for a SFBtransregio (Sonderforschungsbereich) together with the relativity groups of Jena and Tübingen.
Today, increasing numbers of German students are going abroad to study the subject at an advanced level. Through its annual vacation courses in relativity, the AEI provides students the opportunity to learn relativity here, and those who want to pursue the subject further now have the opportunity to do work at the AEI in one of the most active

research environments in the subject anywhere. 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.

The AEI also trains many young German and foreign postdoctoral scientists. 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 German universities, 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.

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, 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. 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 2001, 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

Theory Ahead of Experiment:
The Origin of Gravitational Wave Research

In his celebrated Einstein biography Abraham Pais begins the section on gravitational waves as follows: "At no time during GR9 did I sense more strongly how much General Relativity belongs to the future than when I listened to the plenary lectures by Kip Thorne from Pasadena and Vladimir Braginsky from Moscow on the present state of experiments designed to detect gravitational waves. So far such waves have not been found but perhaps, Thorne said, they will be observed in this century."

Though GR9 took place 20 years ago and gravitational waves have not yet been observed the feeling that gravitational wave research has a bright future seems even more justified now than in 1980, in view of the progress which has been made in improving the sensitivity of gravity wave detectors as well as in analysing possible sources. Indeed, one antenna is operating already, and three more sensitive ones are expected to begin taking data within a year. It may therefore be of interest at this time to remember how gravitational wave research originated.

Henri Poincaré, 1854 - 1912

The term 'gravitational wave' (onde gravifique) first appeared in 1905 when Poincaré proposed the first Lorentz-invariant equation for the gravitational field. He pointed out, that this field has to propagate with the speed of light and thereby corrected Laplace's estimate of 1805 according to which the speed with which the force of gravity is transmitted exceeds that of light by a factor of at least 7×10^6. Poincaré's and similar attempts failed to account for Mercury's "anomalous" perihelion advance; they were discarded when Einstein completed his general theory of relativity and obtained the correct value for the perihelion advance at the end of 1915.

One month after the publication of his monumental work "Die Grundlage der Allgemeinen Relativitätstheorie" (Annalen der Physik, 1916) Einstein laid the basis for the theory of gravitational waves. On nine pages he

- derived the linearized form of his field equation, which is expected to hold approximately for weak gravitational fields,
- deduced that gravitational fields due to material sources can be represented by retarded potentials,
- showed that plane gravitational waves are transverse and have two independent states of polarisation,
- derived a formula for the power, emitted by a small source in the form of gravitational waves (quadrupole formula).

This paper represents one of the rare examples where almost all basic aspects of a new field of research were addressed, if not solved, in one stroke.

In view of this it is of minor importance that 1) the issue of coordinate choice or "gauge", though mentioned, was clarified only later, partly by Hilbert (1917) and finally by Eddington (1922); 2) due to a computational error, the power loss formula was not quite right.

In his second paper on gravitational waves, published in 1918, Einstein gave the correct power loss formula. He also characterised the kinematical structure of plane gravitational waves as angle-changing deformations

Arthur Stanley Eddington, 1882 - 1944

of the surfaces orthogonal to the direction of propagation, and specified their strength by two dimensionless amplitudes which have been used for this purpose ever since. Moreover, he computed the energy which a small body absorbs from an infalling gravitational wave.

At the time of his two gravitational wave papers Einstein was also very much concerned with quantum theory. Having derived that internal motions within bodies should lead to an energy loss by gravitational radiation, he at once doubted the physical validity of this result for thermal motions of atoms. It appears, he wrote in both papers, that the quantum theory will have to modify not only Maxwell's electrodynamics, but also his new theory of gravitation. It should be noted that in 1916 he also wrote his famous paper on the interaction of atoms with radiation, combining Bohr's concept of stationary states with the idea of transition probabilities.

Only one physically important ingredient of gravitational radiation theory had not yet been considered by 1918: the reaction of radiation on their sources. That question was first addressed by Eddington in 1922. Eddington computed the gravitational radiation power loss of a rotating rod by using Einstein's quadrupole formula referred to above. Then he applied the same formula which Einstein had used to calculate energy absorption from an incident wave, however now using the gravitational field produced by the rod itself, to determine directly the reaction of the emitted radiation on the emitting body. (Similarly to, but independent of Poincaré he showed why Laplace's argument gave an answer incompatible with the effect of retardation within the body.) He obtained the same result as in the first calculation, of course; but analysing the conditions of validity of the approximations involved led him to the very important conclusion that the result was trustworthy only if the motion of the rod was determined essentially by solid state forces, not by gravitational ones. Solving the problem thus raised turned out to be very difficult. Only after much work and many controversial discussions between 1975 and 1985 a solution was found that is at least consistent within perturbation theory.

In the "dark age" of relativity theory between 1925 and 1955 not much occurred in that field. What happened during the "renaissance", particularly in gravitational radiation theory after about 1960, is a complicated story not to be told here.

In conclusion I wish the very best success to our experimental colleagues who are trying hard and with many ingenious ideas to find gravitational waves, and thus to break at long last the dominance of theory in this field.

Jürgen Ehlers

Geometric Analysis and Gravitation Division

The force of gravity is a mutual attraction between all bodies in the universe. However, among all observations of nature, the ones whose explanation is most dependent on an understanding of gravitation are those belonging to the domain of the astronomer. It is clearly a task for an institute for gravitational physics to apply physical theories to provide this understanding. In so far as there are aspects of this question which cannot be treated by existing theories it is important to encourage new theoretical progress. An equally important goal is to reach an optimal understanding of the existing theories and the ways in which they are applied. This is the central theme of the Geometric Analysis and Gravitation Division of the AEI. Apart from its considerable intrinsic interest, the research of the Division provides a solid foundation and technical resources for the other research directions mentioned above, which are pursued by the other three Divisions of the institute.

Gravity According to Newton and Einstein

The two theories of gravitation which are extensively and successfully applied are those of Newton and Einstein. Einstein's theory, general relativity, is the most accurate. At the same time Newton's theory is good enough for many purposes. In general the difference between the predictions of the two theories only becomes practically important in the presence of extreme conditions, like very strong forces or high velocities, or when exceptionally high precision is required. The work of the Geometric Analysis and Gravitation Division is mainly concerned with Einstein's theory. However Newton's theory is not neglected either since it is not only widely applicable, but also contributes to the conceptual understanding of Einstein's theory.

The Role of Mathematics

Both theories of gravitation, Newton's and Einstein's, have been around for a long time. The structure of the models themselves is well understood. What is much more difficult is to understand how the models lead to predictions in particular situations. In mathematical terms, the equations of the theory are well understood but it remains to understand their solutions in sufficient generality. It follows naturally from this that a central preoccupation of the research of the Geometric Analysis and Gravitation Division is to understand the properties of solutions of the Einstein equations which are general enough. In particular, the aim is to do this for solutions which give physically realistic models of characteristic phenomena of general relativity such as black holes, gravitational waves and the big bang as well as more familiar types of object, such as stars and galaxies. In understanding solutions of Einstein's equations it is essential to make use of sophisticated mathematical techniques. Indeed it is often necessary to invent new mathematical tools, since known mathematics does not apply.

Numerical Methods

From the above it can be seen that there is a need for a strong interplay between abstract mathematics and applicable physics, particularly astrophysics, in the work of the Division. Since pencil and paper work cannot suffice to make precise quantitative predictions about real phenomena, computer calculations also naturally come in. For this reason, in addition to its mathematical investigations, the Geometric Analysis and Gravitation Division pursues numerical work complementary to that done in the Astrophysical Relativity Division. Naturally, the former is more focused on conceptual and theoretical issues, in keeping with the general orientation of the research of the Geometric Analysis and Gravitation Division.

The Pervasive Influence of 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 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 spacetime into time and three-dimensional space. It is possible to cut up spacetime into a family of three-dimensional slices, each of which can be thought of as ‚all of space at a particular time'. However it belongs to the essence of general relativity that there is no one way of doing this which is singled out. Everyone is free to choose their own slicing of spacetime. Given one slice it is possible to generate new slices by deforming the original one and the ways of doing this are more or less unlimited.

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 is 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 spacetime of the class to be studied. In studying cosmological models it is desirable to have a slicing which covers all of the spacetime 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. In past years information was obtained on good slicings in spacetimes which are symmetric in two spatial directions and variable in the other space direction. Although many things were known about the properties two kinds of good slicings, called CMC (constant mean curvature) and areal, there were still a lot of gaps in our knowledge. In 2001 work at AEI lead to a better understanding of the mutual relationship of these two kinds of slicing, with the result that many of the gaps could be filled. This means that we now have a good understanding of slicings of spacetimes with this kind of intermediate symmetry which have good properties. An important role in linking the two slicings was played by the notion of PMC (prescribed mean curvature) slicings, which were introduced in a PhD thesis written at AEI and submitted in 2001.

The Conformal Field Equations

In ongoing work at AEI applying the conformal field equations to study the global structure of solutions of the Einstein equations modelling isolated systems it is important to understand the global properties of certain coordinate systems which play a distinguished role in these problems. In particular this is the case for the class of conformal Gauss coordinates. These generalize ordinary Gauss coordinates, which are well-known for their tendency to break down and not cover all of spacetime. Thus it is interesting that in relevant cases this does not happen for conformal Gauss coordinates. It has been shown that in the Schwarzschild solution, which of course contains a black hole singularity, these coordinates have excellent global properties. This is a good indication that they are likely to be an effective tool for investigating general asymptotically flat spacetimes using the conformal field equations. Following the success of numerical calculations using the conformal field equations in calculating the evolution of weak gravitational waves in 2000, the natural task for 2001 was to extend this work into the regime of strong fields.

The Problem of Initial Conditions

When the strength of the initial conditions is turned up it is seen that the numerical calculation breaks down after a finite time and it is to be supposed that the cause of this is a breakdown of the coordinates. A strategy to overcome this is to modify the coordinate conditions being used by the introduction of a parameter and then optimise in this parameter to see which value gives the longest-lived numerical evolution. This has been tried and significant improvements in the time of existence have been attained. Nevertheless this is a problem which needs to be examined further. One question which presents itself when turning up the strength of the initial conditions is to find an invariant criterion for when data should be considered strong. A good possibility is to use the presence of an apparent horizon, which should identify initial conditions which are going to evolve to form a black hole. In 2001 apparent horizons were found in initial conditions for the conformal field equations using a programme belonging to the Cactus software of the Astrophysical Relativity Division at AEI. One of the difficulties in working with the Einstein equations as a system of evolution equations is that the initial conditions cannot be given freely; they have to satisfy the constraint equations. The latter are nonlinear and not easy to solve. In 2001 it was shown how to construct initial conditions describing an isolated system whose asymptotic properties far from the source can be described in great detail. A new method of constructing initial conditions for the conformal field equations was also investigated.

More Cosmology and Further Directions

Returning to cosmology, the aim is of course not only to have a good time coordinate but also to describe what the time dependence of the spacetime geometry on this time coordinate is. Already generalizing from the standard models of cosmology to those which are homogeneous but not isotropic gives rise to challenging problems. In 2001 progress was made in understanding this question in collaboration between AEI with researchers in Sweden and the UK. Information was obtained about the situation where the matter content of spacetime is described by a collisionless gas. The problem was formulated in the language of dynamical systems and from that point mathematical theory was available which could be applied to elucidate various features of the behaviour of the cosmological models under study, both near the big bang and in phases of unlimited expansion. More information on recent progress in understanding the dynamics of cosmological models is described in the contribution of Hans Ringström to this report. A new project started in 2001 concerns relativistic and non-relativistic elasticity. At present all known static solutions of Einstein's field equations describing isolated systems are spherically symmetric. The goal is to demonstrate the existence of static solutions describing self-gravitating bodies of arbitrary shape. As a first step it was possible to do this in the framework of Newtonian theory of gravity. Other work in the Division concerns the stability of stellar models. In this context progress was made in understanding the stability of the Kerr black hole. In continuing work on gravitational lensing a criterion was obtained for the occurrence of multiple imaging with infinitely many images.

Alan Rendall

Astrophysical Relativity Division

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. 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 2001 we continued to advance the state of this art through advances in our computer techniques and our software. I give a short description here because there are two articles that go into more detail 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 2001 we made great progress on extending the duration of our simulations, so that they are beginning to explore the physics of these mergers.

Lessons from the Lazarus Project

In our report for the year 2000, we described how a group of AEI scientists calling themselves the "Lazarus Project" managed to breathe new life into prematurely dead numerical simulations (hence the name they chose for their project). During 2001 the Lazarus group explored a wider range of parameter space and found some interesting and surprising results.

One surprise is that there is quite a lot of emitted radiation, amounting to several percent of the total mass-energy of the black holes. This is good news for gravitational wave detectors. The second surprise is how rapidly the holes merge. Even when they are started from orbits with larger radii than we expect for the last stable orbit, they very quickly plunge together and merge, taking less than half an orbit to do so. The emitted burst of radiation contains only one or two cycles before it begins to show the rapid decay characteristic of the ringdown.

This rapid plunge is also the puzzle. It is not possible to calculate accurately yet the correct starting conditions for the two black holes. Ideally we wish them to start from perfectly circular orbits that have gradually been shrinking until they reach the last stable orbit. We don't yet know, however, when the holes have similar masses, where that last orbit is, nor what the orbital speeds of their circular orbits at any given distance should be. It could be that the quick plunge happens because we are not starting the holes off with as much circular velocity as they would have in a real merger. Or it could be that the plunge starts at a larger distance than we expect, and our simulations have not reached that starting point yet. The answers to these questions will come only from further extensive simulations.

Full Numerical Simulations

The progress that we reported last year, that we had found a formulation of the numerical equations that allowed our simulations to run for much longer, has borne considerable fruit in 2001. The AEI group has succeeded extending the duration of their simulations long enough to follow the entire plunge and merger, including the ringdown. This will permit us to make detailed comparisons with the Lazarus results, a check on both methods.

The simulations have suggested a solution to the puzzle posed by the Lazarus simulations. It turns out that the initial orbital motion of the black holes, as revealed by the rotation of the coordinate system that follows them, is significantly less than it was expected to be. This is a problem with the so-called initial data, the starting point for the calculations. It is not trivial to generate this data, because it must be at least approximately a representation of what we would find from a full simulation of the in-spiraling orbit starting at a much larger separation, a simulation that is well beyond our capabilities at the moment. The AEI group has been using initial data generated by two different methods, but this is the first time that they have been checked to see if they represent what they are supposed to represent. The answer seems suspiciously like "no".

New initial data sets are now available from a group in Paris, a part of the EU network collaboration described below and elsewhere. We hope that these might be far more accurate and could therefore solve the problem and resolve the questions that have been raised by both the Lazarus and the fully numerical simulations. This will be an active research area in 2002.

The EU Network

2001 saw the start of a new European Union research network coordinated at the AEI. Its official title is "Theoretical Foundations of Sources for Gravitational Wave Astronomy of the Next Century: Synergy between Supercomputer Simulations and Approximation Techniques". The 10 participating institutions are coordinating their work on numerical techniques, simulations of black hole collisions, simulations of neutron star collisions, and studies of perturbed spacetimes. As mentioned above, this work is already leading to improved initial data for in-spiralling black holes.

More information is on the website http://www.eu-network.org/

Big Computers

The AEI group uses a variety of powerful computers: the AEI's own 64-processor Silicon Graphics Origin 2000 computer (doubled in size from 1999), supercomputers at the Garching Computer Center of the Max Planck Society and the Leibniz Computer Center in Munich, various supercomputers at the National Center for Supercomputing Applications (NCSA) in Illinois, and others. As reported last year, we negotiated the purchase of a new Origin3000i machine from SGI, using a grant from central Max Planck Society computing funds. However, during 2001 SGI informed us that they could not deliver a machine to the agreed specification; problems with the processors, among other issues, led to cancellation of the contract. After considerable negotiation, a compensation package was agreed with SGI that allowed us to continue to use our current Origin 2000. We expect to find a new vendor for our replacement machine in 2002. The delay was costly, however, because it meant that many calculations designed to test improvements in our algorithms and to examine the properties of solutions obtained on larger supercomputers will not be able to be done in-house. They will be delayed by having to be done on machines at other institutes, or they will just not be done at all.

The Cactus Computational Toolkit Becomes a Grid Computing Tool

Cactus was first publicly released in 1999, after undergoing considerable development within the collaboration starting in early 1997. Cactus is a framework that allows many users at many sites to collaborate on a single computer simulation code, and it provides them with a large variety of tools that they need to move their programs from single workstations to today's large parallel computers. The popularity of the program is growing rapidly, and it occupies a central place in the worldwide computer initiative called Grid Computing, which aims to make access to computers easier over great distances. Most of the numerical relativity groups in the world use and contribute to Cactus, and there are other users from fields as diverse as astrophysics and chemical engineering. Cactus played a central role in the numerical simulations of the Lazarus Project, and is the framework in which fully numerical mergers will be simulated. The Cactus group is led by Dr Gabrielle Allen, whose article later in this volume describes the remarkable successes of the group in 2001.

In 2001 the AEI group were awarded a major grant from the European Union to develop the Grid capabilities of Cactus. The grant is to the GridLab collaboration, a group of several European institutes aiming to develop a Grid Applications Toolkit (GAT), which is a standard interface that allows programs like Cactus to access services that are being developed for the Grid by programs like Globus. The Cactus GAT will allow Cactus users to move jobs from one supercomputer to another, to check the speed of the internet for large data transfers, to obtain intermediate results from simulations that are running, and to obtain notification - even on their cellphones - when something goes wrong with a simulation. The GridLab collaboration also will create a GAT for Triana, the data analysis software that GEO has developed for gravitational wave data.

More information about Gridlab can be found on the website http://www.gridlab.org/

The Cactus group also gained international recognition in 2001 by winning two prestigious awards at the Supercomputing 2001 conference. One, for high-bandwidth performance, showed how to use the internet to link two remote supercomputers in a single calculation and get almost the same performance as if they had been next to one another, despite the fact that they had to continually exchange data with one another. The second award was the Gordon Bell Prize, given to Cactus for its present Grid capabilities. Earlier in the year the group had linked 4 remotely located supercomputers in the USA for a demonstration of how a large calculation in numerical relativity can make optimum use of such resources, distributing its calculation and even migrating from one computer to another.

Cactus is a good illustration of a phenomenon that occurs in many front-line fields of science. The scientists find that they do not have the technology they require to do the research, and so they invent it themselves. Once invented, the new technology acquires a life of its own as other users want to employ it. This fruitful interplay between pure science and technical spinoffs has a long history in the experimental sciences, but one sees it increasingly frequently in software, most strikingly of course with the World Wide Web. Cactus is free software supported by AEI staff, but as its user base grows we expect that it will be essential to form a private company or some other arrangement to continue supporting the program.

Cactus news and code on 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. 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.

Data Analysis Software

The largest activity in the AEI group is in the development of data analysis software for the gravitational wave projects. The AEI role in GEO600 is to coordinate data acquisition and analysis. It also makes contributions of software to other gravitational wave projects. The data to be analysed include both signal data and data taken to characterize the operation of the detector. In fact, the latter kind of data are the most important in the present phase of detector development, and Dr Alicia Sintes coordinates the detector characterisation working group of GEO, whose responsibility is to allow the experimenters to get information from the detector that will help them to improve its performance. In parallel with this, the group led by Dr Maria Alessandra Papa has been developing software particularly suited to the search for long-duration signals, such as those expected from spinning neutron stars. This software has several components. Some of them have been contributed to the LIGO Algorithms Library (LAL), a joint repository of software for the analysis of gravitational wave data; the remaining components are expected to go into the library next year. This software will be used by both LIGO and GEO for their pulsar searches. In both of these activities, creating innovative software plays a major role.

The pulsar search group has fully implemented its Coherent Demodulation technique for performing what are effectively narrow-band spectral searches (Fourier transforms) on very long stretches of data, in such a way that the calculation can exclusively use data local to only one processor in a parallel-processor computing system. Usual parallel implementations of Fourier transforms for large data sets require all the data to be held in the memory of the machine, and require at least one time-consuming step of data exchanges between processors. The AEI methods act serially on the data and do not require data exchanges, so they are much faster, and they permit pulsar searches to take place on

inexpensive cluster parallel computers rather than on expensive shared-memory supercomputers.
In addition, when searches with such phase-preserving methods are still too expensive, because there are too many signal waveforms to search for, the AEI has developed the Hough Transform incoherent search method, which looks for patterns in short-term power spectra that follow the way we expect pulsar signals to change their apparent frequency as our detector moves around the Sun. The Hough transform will be finished and tested next year.

The AEI is further developing the signal-analysis tools in the software system Triana, which was created at Cardiff and is one of the two applications being interfaced to Grid technology by the Gridlab project mentioned above. This gives scientists a quick-look capability to monitor data coming from the detector and diagnose and fix faults, even if they are working at remote locations.

To prepare for the analysis of data for pulsar signals, the AEI was awarded a grant from the Max Planck Gesellschaft to build a cluster computer dedicated to this job. During 2001 the group went through an extensive specification exercise, determining the kind of processors best suited to the job (price to performance ratio, based on tests using the actual code to be run), and deciding the other specifications of the processor units. During 2002 the system will be purchased, ready for the expected data runs in the second half of that year.

Gravitational Wave Astronomy

Also active in the gravitational wave group are studies of gravitational wave sources and of the kind of information that gravitational wave observations can return about them. Among the most significant: Prof Curt Cutler has studied the physics and astrophysics of neutron stars as gravitational wave sources, and has in particular asked how strong their radiation can be if conventional equations of state are used to describe their structure and the density irregularities that they can sustain. The answers are disappointing: crustal deformations cannot be large enough to radiate a significant fraction of the observed spindown loss of energy. The radiation could be larger if neutron stars have solid cores or if they are more compact quark stars, but neither of these are popular models of neutron stars at present.

The LISA project, a proposed space-based gravitational wave detector, was a major interest at the AEI in 2001, as in previous years. LISA made an important step forward, becoming a joint mission of the European Space Agency (ESA) and of the US NASA space agency. As part of the agreement between the agencies, an international team of scientists was established to coordinate studies of LISA. This is called the LISA International Science Team (LIST). The European chairman of this team is Karsten Danzmann, who leads the Hannover group and will become a Director of the AEI in 2002. Both Cutler and Schutz were appointed to LIST. Schutz is the European chair of the sources and theory working group of the LIST, which will address theory issues crucial to the design of the detector.

Bernard F. Schutz

Quantum Gravity and Unified Theories Division

As in previous years, the research done in the quantum gravity division of AEI covers a broad range of subjects, and as such reflects the diversity of the different approaches to the challenge of quantizing gravity and unifying it with the other forces in nature. The following is a brief overview of the results obtained and the successes achieved over the past year 2001. Besides the work done at AEI, a good part of this research was based on collaborations between the members of the division and the numerous visiting scientists, made possible by the AEI visitor program and various third party grants, such as EU networks. As can be seen from the relatively large number of PhD students presently working in the division, much emphasis is put on the training of young researchers. Moreover, members of the quantum gravity division are frequently invited to speak or lecture at national and international schools and meetings.

Canonical Quantization of Gravity

AEI continues to be one of the main places in the world for research in canonical quantum gravity. The latter is a more conservative approach than string theory in that it is not based on a modification of Einstein's theory at short distances, but rather applies the prescriptions of canonical quantization to the theory as it is. Even so, the recent developments, many of which have occurred at AEI, have shown that one must go a considerable distance beyond the established canonical methods in order to develop a truly background independent theory of quantum gravity. Over the past year, further advances were made towards constructing a satisfactory system of coherent states for canonical quantum general relativity. Understanding the connection between truly "quantum" states of the gravitational field and its (semi-)classical excitations is very important in view of the fact that any theory of quantum gravity must not only describe the quantum phase just after the big bang, but also account for the semi-classical state of the present universe. In [AEI-2001-011] the mathematical properties of a concrete proposal towards such semi-classical states were further investigated. The following properties could be established: overcompleteness, peakedness, saturation of the Heisenberg uncertainty bound, eigenstate property for suitable annihilation operators, Ehrenfest theorems, small fluctuation property. In a future publication these states will be used in a first physical application, in order to study the effect of the fluctuations of the quantum metric operator on the propagation of light. The preprint [AEI-2001-119], which also appeared in 2001, is the most comprehensive and update review of the subject available at the moment, and at the same time an introduction to modern canonical quantum general relativity, sometimes called loop quantum gravity. Such a review was badly needed, as the only other concise treatment had already appeared more than 10 years ago.

Path Integral Quantization

The path integral quantization of gravity, where one sums over all "histories" with a suitably weighted measure, has received new impetus by work done at AEI in 2001. A novel "continuum" approach was developed and further studied in refs. [AEI-2001-020, AEI-2001-070,AEI-2001-120, AEI-2002-011]. It is based on a new type of non-perturbative Wick rotation which maps gauge fixed real Lorentzian metrics to real Euclidean metrics. As an application, a non-perturbative path integral for gravity in two space-time dimensions was evaluated to demonstrate the validity of the proposal. Using the Wick rotation, divergent modes of the Euclidean gravitational action in higher dimensions were identified. It was shown that this divergence does not survive in the non-perturbative path-integral, but is cancelled by a term coming from the Faddeev-Popov determinant contributing to the effective measure.

Supermembranes and M-Theory

Today's main challenge in finding a unified formulation of superstring and M-theory is the search for the fundamental degrees of freedom, since it has become clear that string theory is more than a theory of only strings. During the past year the study of the most prominent candidate in this quest so far, the eleven dimensional supermembrane, was continued (the much discussed M(atrix) theory can be considered as a regulator for this theory, as had already been shown in 1987). Following the construction of light cone supermembrane vertex operators in the previous year, the computation of four graviton scattering amplitudes in membrane theory compactified on a d-dimensional torus was undertaken in [AEI-2001-012], where in addition the specific kinematic form of the resulting quantum correction to 11d supergravity in terms of a quartic combination of Riemmann tensors could be established. Nevertheless, the amplitude suffers from a divergence due to an unbounded integral over the membrane worldvolume. Attempts in resolving this problem via a restriction of the path integral to the fundamental domain of the toroidal membrane worldvolume have been undertaken, but necessitate further study. An interesting aspect would be the appearance of a generalized modular invariance for the torus amplitude, in which the SL(2,Z)) group of string theory is replaced by an SL(3,Z). Vertex operators for open membranes (which can end only on hypersurfaces of dimension 9,5 or 1) were determined [AEI-2001-064], which also reviews the subject at an introductory level. The underlying symmetries of M-theory may play an equally important role in the search for its final formulation; a step in this direction was a novel construction of the minimal unitary representation of the exceptional group E8(8) in [AEI-2001-108].

Gauged Supergravity

The construction of gauged N=16 and N=8 supergravity theories in three space time dimensions was completed in [AEI-2001-017] and [AEI-2001-058]. The resulting theories exhibit a rich structure; in particular, the maximal N=16 theory admits all the exceptional Lie groups in various real forms as possible gauge groups. These results raise the question of possible vacua, which are given by stationary points of the corresponding scalar field potentials that show up at second order in the gauge coupling constant. However, the complicated structure of these potentials, mainly due to the $E_{8(+8)}$/SO(16) coset structure of the 128 supergravity scalars, is so far beyond the capabilities of existing symbolic computer algebra packages; furthermore, the large number of different possible gauge groups for N=16 D=3 supergravity makes an analysis by hand unfeasible. This spurred the development and implementation of symbolic algebra tools that can conveniently and efficiently handle the general manipulations required for the analysis of these potentials. In a first application, the case of maximal compact gauge group SO(8)xSO(8) was investigated and five nontrivial stationary points were found (the results of this analysis have meanwhile appeared in [AEI-2002-004]).

Conformal Field Theory

Conformal field theory is the abstract framework for string theory, and is arrived at by describing string theory not only as a theory of one-dimensional obejcts moving in some target space-time, but rather a conformally invariant field theory living on a two-dimensional world sheet with the string traget space coordinates as the basic fields. Here, work at AEI focused on the study of non-compact conformal field theories, namely those with a continuous spectrum of primary fields, with special emphasis on boundary Liouville theory [AEI-2001-124, AEI-2001-128] and SL(2,C)/SU(2) WZNW models [AEI-2001-146]. Liouville field theory is a universal model that appears in the context of non-critical string theories, gravity in two space-time dimensions, and D-branes physics, and is therefore a natural starting point for many studies. The SL(2,C)/SU(2) WZNW model is the second easiest non-compact CFT beside Liouville theory, and in the context of string theory, it is used to study string theory on backgrounds that contain an three dimensional Anti-de Sitter (AdS) space.

D-Branes

D-branes arise as a special case of conformal field theories, namely on worldsheets with boundaries (BCFT's). They have gained considerable importance over the last years; in particular, during the last years, branes on group manifolds have been studied in great detail, mainly because they can serve as a starting point for the analysis of branes in a large number of exactly solvable string backgrounds. Technically, this proceeds through coset and orbifold constructions of conformal field theory. In [AEI-2001-026] a method was proposed to construct the low energy effective action of branes in coset models by a reductions from the theory on group manifolds. This was then generalized in [AEI-2001-136]. The latter work contains a detailed analysis of classical solutions and a geometrical interpretation of the associated condensation processes. [AEI-2001-102], on the other hand, deals with so-called orbifold models (orbifolds are manifolds with certain singularities). For a large class of such theories, the factorization constraints of the open string sector were solved explicitly, allowing the computation of open string scattering amplitudes in curved backgrounds with orbifold singularities. Branes in non-compact curved backgrounds were investigated in [AEI-2001-146]. At the example of the Euclidean three-dimensional AdS space, interesting new techniques were developed that permit the construction of compact and non-compact branes in such backgrounds. The specific results for branes in AdS space disproved several conjectures that had been formulated in the literature before.

Other aspects of D-brane physics that were investigated include off-shell open string at one loop [AEI-2001-054]. This allows one to better understand in what way open strings change when one goes off-shell, as well as to consider corrections to the effective tachyon potential. For example, it was found that the R-R sector contributes only to the kinetic terms of the tachyon one-loop effective action. Further, the open string was quantised in the presence of a tachyon and found to to have a discrete spectrum with a rather unusual moding. Stable non-BPS D-branes in string theory compactifications with N=2, D=4 supersymmetry were investigated in [AEI-2001-115]. Several new kinds of branes were found, including torsion charged D-branes as well as stable non-BPS D-instantons.

Finally, branes were also studied in the context of supergravity solutions of branes partially wrapped on supersymmetric cycles using gauged supergravity. The construction of all possible realizations of twisted branes in terms of gravity solution was completed in last summer using M5-branes. Many new Anti-de-Sitter solutions of 11 dimensional supergravity were found. In [AEI-2001-145] particular D5-branes wrapped on 3-cycle in Calabi-Yau 3-manifold were found. In ten dimensions, there is a new solution with a G2-holonomy manifold with nonvanishing torsion.

ADS/CFT Correspondence

A recurring theme in theoretical physics concerns 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, and versa vice. It had been conjectured that Yang-Mills theory should be dual to a string theory, at least in the limit of a very large gauge group. Remarkably, a first precise proposal for such a duality has been made a number of years ago: the AdS/CFT correspondence between conformal field theories and string theory on Anti-de-Sitter spaces. However, this duality, while quite plausible, remains still largely conjectural. Observables protected by supersymmetry agree, but few dynamical tests of the correspondence for unprotected quantities have been performed.
An extremely interesting set of observables are the so-called Maldacena-Wilson loops. In a joint project at AEI important new insights concerning the direct comparison between supergravity and gauge theory predictions for these objects were obtained. For the first time a full two-loop perturbative calculation was performed. It was shown that the result is completely finite, strongly supporting some non-rigorous conjectures [AEI-2001-106, AEI-2001-140].
In [AEI-2001-35, AEI-2001-055, AEI-2001-107] general implications of the conformal supersymmetry as well as dynamical properties of the stress-tensor multiplet in higher dimensional quantum conformal field theories were investigated. The operator product expansion (OPE) of two N=2 R-symmetry (short) multiplets is determined by the possible superspace three-point functions that two such multiplets can form with a third, a priori long multiplet. It has been shown that the shortness conditions on the former put strong restrictions on the quantum numbers of the latter. In particular, no anomalous dimension is allowed unless the third supermultiplet is an R-symmetry singlet. This phenomenon explains many non-renormalization properties of correlation functions, including the one of four stress-tensor multiplets in N=4 four dimensional super Yang-Mills theory. The structure of the four-point correlation function of the lowest-dimension 1/2 BPS operators in the supersymmetric (2,0) six-dimensional theory was studied in [AEI-2001-138].

Non-Commutative Field Theories

Quantum field theories on non-commutative space-times arise very generally as low-enery effective field theories of string theory, but they are also of interest in their own right. One of the most remarkable features of non-commutative field theories is the non-separability between infrared and ultraviolet degrees of freedom and, as a consequence of it, the appearance of infrared divergences in the perturbative expansion. Of special relevance is the study of non-commutative gauge theories. In the absence of supersymmetry, the leading infrared divergences induce the theory to become unstable. In [AEI-2002-010], it is shown that the contribution of the leading infrared divergent terms to the effective action can be completed in a gauge invariant way. The resulting effective action, which involves open Wilson line operators, can be derived from closed string exchange between two stacks of D-branes.

Hamiltonian Methods

For the derivation of conserved charges associated with gauge symmetries, there exist presently two approaches, namely the Lagrangian method and its Noether machinery on the one hand, and the Hamiltonian formalism based on symplectic geometry on the other hand. The so-called covariant phase space methods unify both formalisms by constructing a suitable symplectic structure. However, for spacetimes with boundaries, this symplectic structure is ambiguous and a case by case prescription is needed. In [AEI-2001-062], this problem is cured by proposing a new and unambiguous definition of the symplectic structure which takes the boundary contributions properly into account. This allows to reformulate the dynamic in a new covariant Hamiltonian form and to unify several methods used to derive the charges of a gauge theory. Many examples are studied, from higher-dimensional non-abelian Chern-Simons theories to gravity and eleven dimensional supergravity. The covariant methods can also be used to recompute the central charge of the Virasoro algebra living on the horizon of a black hole. This provides a simple and powerful tool to derive the entropy of a black hole.

Hermann Nicolai

Laserinterferometry and Gravitational Wave Astronomy Division

Experimental gravitational wave research has a long history in the Max Planck Society, beginning in the pioneering days of the field in the 1970s. Since 1994 this research was concentrated at the Außenstelle Hannover of the Max Planck Institute for Quantum Optics, but on January 1st, 2001 this Außenstelle was administratively transferred to the Max Planck Institute for Gravitational Physics in anticipation of a restructuring that will give experimental gravitational physics a permanent home in the Albert Einstein Institute, which will then consist of two sites, one in Golm and one in Hannover. In particular the administration in Golm had to suffer from an immense additional workload due to this restructuring, but most of the growing pains are now hoped to be over. Since January 1st, 2002 the status of the Außenstelle has changed again and it is now officially a Teilinstitut of the Max Planck Society and the old gravitational wave group has now become the fourth division (Abteilung) of the Albert Einstein Institute. A second experimental division will be built up in Hannover over the next few years. An agreement between the Max Planck Society and the University of Hannover and the state government of Niedersachsen concerning the allocation of resources personnel, infrastructure and buildings has been signed. Construction for the new laboratory building for the Albert Einstein Institute in Hannover is expected to begin at the end of the year 2002. We hope that this can serve as a model case for collaboration between the Max Planck Society and Universities in the future.

The research activities of the Albert Einstein Institute in Hannover are aimed at the development of laser interferometric gravitational wave detectors on the ground as well as in space. This includes the full spectrum of laboratory fundamental research to support and bring forward these detectors in the future. For the ground detector we're a part of a German-British collaboration (GEO600) 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're a part of the LIGO Science Collaboration (LSC) where we contribute in the working groups concentrating on the second generation upgrade of the LIGO Observatory (LIGO II), and we're members of the LIGO I collaboration by providing mutual data access to our own GEO600 data. Recently, planning for a third generation European detector (EURO) has begun, supported by funding agencies from Britain, France, Germany and Italy. For the space detector we're a part of an international collaboration, the LISA project (Laser Interferometer Space Antenna), a collaborative space project by ESA and NASA, with payload contributions from European national member states. We're also contributing towards SMART II, a technology demonstration space mission for LISA, to be launched by ESA in 2006.

GEO600: A Ground-Based Gravitational Wave Detector

After it became clear that the original GEO project calling for the construction of a three kilometer detector had to be postponed because of financial difficulties, a new project, called GEO600, was created. GEO600 is a somewhat smaller but more flexible instrument that is designed to incorporate next generation detector technology from the very beginning. Financial contributions have been obtained from the state of Niedersachsen and the British PPARC, the BMBF and the Max Planck Society. GEO600 has been built on land owned by the state of Niedersachsen and administered by the University of Hannover. Construction began in the fall of 1995.

The year 2001 was an exciting year for GEO600, because it marks the completion of major hardware installation, and the begin of the first data taking period on December 28th of 2001. Starting on that date, GEO600 was run in continuous 24 hour operation for 17 days in coincidence with the two LIGO sites in the US. The detector stayed in lock for an average 77% of the time during this test run, with in-lock times approaching 97% during the last few days. GEO600 was operating in near-to-final configuration during this run, only the sensitivity enhancing signal recycling mirror was not installed. The mirrors at the ends of the arms were the final ones suspended by fused silica fibers as monolithic triple pendulums. The near mirrors are still preliminary test optics, but will be replaced soon as will the beam splitter and power recycling mirror. The excellent in-lock performance is due to the fact that the complete dynamical behavior of the interferometer is under the control of an intelligent wave front and auto alignment system. The auto alignment intelligence checks the status of all subsystems and the interferometric orientation of all relevant wave fronts, keeps all 200+ control loops in their operating range and takes the complete system through an automatic autonomous relock sequence after a loss of lock due to a burst disturbance.

The GEO600 test run also proved the performance of our data acquisition and storage system for the first time. Complete data sets including environmental monitoring data, were transferred through a radio link into the backbone of the Hannover computer net, and stored in the frame format agreed with the LIGO and VIRGO projects. Joint data analysis of the coincident data streams from LIGO and GEO600 from the first test run is now under way. The goal is to set upper limits for the event rates and signal strengths of various astrophysical sources and of geocentric origin. No real astronomical gravitational wave signals are expected at this time though, because this was an engineering run aimed at testing the system engineering aspects of the detector. Due to the absence of a signal recycling mirror it could not have a good sensitivity. Nevertheless, a supernova in our own galaxy should have been detectable with this sensitivity.

Currently the detector is under maintenance. We are planning to install the signal recycling mirror in time for the next test run in summer, which should also take place in coincidence with the two LIGO sites. Over the fall the remaining test optics will be removed and all the final optics installed for the begin of science data taking early in 2003.

LIGO II and EURO

While the first generation of large gravitational wave detectors is going into operation, it is commonly assumed that their sensitivity will not be sufficient for serious astronomical observations and maybe not even for a first detection. The observatories were always planned to go through series of upgrades with ever increasing sensitivity. Planning is already rather advanced for LIGO II, the second generation upgrade of LIGO I. LIGO II is planned to improve the sensitivity by at least one order of magnitude over LIGO I. It is largely based on GEO600 technology incorporating multiple pendulum vibration isolation, monolithic suspensions, Signal Recycling and Resonant Sideband Extraction. The GEO team has been invited to become equal partners in this enterprise and we are presently participating in the systems design of LIGO II. In Europe we have an intense interaction between GEO and the VIRGO project, in particular concerning laser development and thermal noise suppression. Efforts are on the way to define a future pan-European project for a third generation gravitational wave detector called EURO. Following a charge from the funding agencies CNRS, MPG, PPARC and INFN a group of experts from France, German, Italy and the UK have undertaken a short study and outlined the EURO vision. Further progress is expected after VIRGO and GEO go into operation.

The 30 m Prototype, Laboratory Research, and Advanced Techniques

Our thirty meter prototype was the first suspended mirror interferometer operating with both power and signal recycling. From 1983 till 2000 it was located in the basement of the Max Planck Institute for Astrophysics in Garching. Due to building construction and restructuring, the 30 m prototype had to be dismantled and removed from its old site. It has now been set up again in the basement of the Max Planck Institute for Quantum Optics in Garching, even though its arms had to be shortened to 12 meters. It is operating again as a rejuvenated interferometry test bed for advanced concepts and it will continue to be operated for a few years as long as the AEI keeps a small personnel contingent in Garching, remaining from the days when the gravitational wave group was still part of the Max Planck Institute for Quantum Optics. The twelve meter prototype interferometer is being used to test thermally tunable signal recycling on a suspended mirror interferometer, a technique that should give a laser interferometer not just tunability but the ability to change the bandwidth of the detector in real time during the observational campaign without a need to open up the vacuum system and change optics. If successful, this technique will be adapted and transferred to the large GEO600 detector. Thermally tunable signal recycling is also worked on in the Hannover laboratory. Here we concentrate more on the technical and constructional details of thermally tuning the resonant frequency of a solid Fabry-Perot etalon mirror, whereas in Garching the emphasis is on the systems aspects of running an interferometer with such a piece of output optics.

The physics of high power diode-pumped Nd-YAG lasers in injection-locked master-slave configuration has been of interest for gravitational wave detectors for many years. Through a collaboration with the Laser-zentrum Hannover (LZH) we now have available at the GEO site a 14 Watt single mode laser, which exists in several versions in the laboratory as well as on the site of GEO600 in Ruthe where it is running in routine 24-hour operations. The laser system is controlled by an intelligent autonomous lock control system through several stages of frequency stabilization. It reaches a frequency noise better 100 μHz/$\sqrt{\text{Hz}}$ throughout the operational frequency range before injection into the interferometer. The relative amplitude noise is now better 10^{-7} 1/$\sqrt{\text{Hz}}$, even though the complete cross coupling of all noise processes has not been completely understood as yet. The GEO600 laser system has been adopted by several other research labs and is now also serving as the power stage for the VIRGO detector. The development of a 200 Watt laser system for the next generation detectors has begun in Hannover, Stanford and Australia and we expect to contribute to these efforts by chairing the LSC lasers working group.

Thermal noise is expected to be a serious limitation for the sensitivity of future generations of gravitational wave detectors. Because of technical complexity, cooling will only be implemented at a later time. Our approach for GEO at present is to reduce mechanical dissipation in the test masses and suspensions in order to concentrate the thermal mechanical noise in narrow frequency ranges around the mechanical eigenfrequencies of the system and to shift these frequencies outside of the measurement band. Largely based on work at the University of Glasgow, a fully monolithic lower stage of the test mass suspension made from fused silica has been developed for GEO600. Synthetic fused silica fibres can now be pulled on site in a computer controlled and reproducible fashion. Mechanical Q factors of these suspensions are so high that the violin modes of these suspension fibres have to be damped via a coating made from amorphous teflon.

In a separate laboratory experiment, we are trying to measure and characterize the thermal noise in the wings far away from resonance, where they are expected to eventually dominate the mid-frequency noise of GEO600. This lab experiment uses small mirrors of a few grams mass suspended from a quadruple pendulum as a miniature Fabry-Perot cavity in order to make the displacements caused by off-resonant thermal noise somewhat larger and easier to measure. A three dimensional active vibration isolation system based on Piezo motors improves the isolation around a few Hertz and is now also installed in GEO600. The experiment is backed by a detailed model calculation of all relevant noise sources that agrees rather well with the experiment at frequencies above a few hundred Hertz. At lower frequencies an excessive spurious noise source still remains to be identified.

In order to explore possibilities for future generations of gravitational wave detectors, we have intensified our efforts in interferometer modeling and simulation. Our software package FINESSE is now widely used also in other projects and permits the convenient simulation of interferometer layouts of considerable complexity. Currently we are concentrating on promising arrangements with four mirror triple-cavities in the arms and no recycling mirrors.

The standard quantum limit has for many years been regarded as a fundamental limit for the sensitivity of gravitational wave detectors. Braginsky and coworkers in Moscow have suggested several elaborate quantum non-demolition (QND) readout schemes to overcome this limitation. Recently, work by Buonanno and Chen from Caltech has suggested that even conventional interferometers can surpass the standard quantum limit. Motivated by this, we have begun a full quantum mechanical simulation of GEO600 that shows in preliminary results that even GEO600 in its present configuration should be able to go below the standard quantum limit if we operate it in its detuned signal recycling mode. But unfortunately, this low frequency range should be covered by off-resonant thermal noise. We are exploring ways how to make these parametric quantum effects usable for actual observations.

Coherently prepared superpositions of quantum states in atomic systems can be used to change the optical properties and create new optical media with non-classical properties like very steep positive or negative dispersion and vanishing or enhanced absorption. These media could potentially be useful in future generations of gravitational wave detectors. We have set up two facilities to characterize dispersion and absorption of optical ensembles simultaneously, a triple-laser heterodyne interferometer and a Mach-Zehnder interferometer with phase modulated reference. In a 3-level system in Cesium we were able to create electromagnetically induced transparency with very steep positive dispersion near the two-photon resonance and demonstrated parametric dispersion of the pump laser as a function of detuning of the probe laser. We could demonstrate negative dispersion with greatly reduced absorption in a strongly driven 2-level system in Calcium and are exploring ways to make this usable for a white-light resonator. A degenerate 2-level system shows a completely different behavior from a true 2-level system. We were able to show for a closed degenerate 2-level system in Cesium that both electromagnetically induced transparency and electromagnetically enhanced absorption with very steep negative dispersion can be produced, dependent on the angular momentum of the involved transitions.

LISA AND SMART II: Laser Interferometers in Space

The LISA project for a gravitational wave detector in space with 5 Million kilometers arm length has made tremendous progress over the last two years. A three space-craft version of LISA using solar electric propulsion and launched in August 2011 as a collaborative ESA/NASA mission is the baseline. A joint international LISA science team (LIST) has been appointed by ESA and NASA with ten members and a co-chair from each side of the Atlantic. We are pleased that three of the ten European members of the LIST are from the Albert Einstein Institute.

During 2001 the science requirements for LISA were revisited and compared to the design sensitivity curve for the mission. While most of the original assumptions were confirmed, an extension of the usable frequency range to below 10^{-4} Hz and a slight improvement of the sensitivity around a mHz were deemed scientifically useful. It is currently investigated how these goals can be achieved. We have participated in this exercise and have also investigated the amplitude and phase stability of laser systems suitable for the LISA mission.

During 2001 the SMART II mission as a technology precursor for LISA was approved by the European Space Agency. Several technology development activities and two system level studies were started in this year. We are participating in these activities as part of the LISA Technology Package Architect team to help coordinate all these activities and also as part of the optical bench and interferometry team to define a laser interferometric read-out of the position of the two free-flying test masses on board of SMART II. Laboratory investigations of the laser and interferometry read out system for SMART II are just beginning and in 2001 we have set up a laboratory test environment for these activities.

Karsten Danzmann

More information on LISA and SMART II can be found in the web under http://www.sci.esa.int.

Mathematical Cosmology

In the standard picture of cosmology, one assumes the universe to be spatially homogeneous and isotropic. Roughly speaking, this means that at one "instant in time", an observer considers the universe to look the same regardless of at which spatial point he is located (homogeneity) and in which direction he is looking (isotropy). With a standard choice of matter model, one then gets the following conclusions. A big bang, with arbitrarily strong gravitational fields, took place in the finite past, and in the future the universe will expand indefinitely or recollapse. The restrictions imposed are obviously strong, but not completely uncalled for. A combination of observations and philosophical preconceptions yield strong support for the standard model. However, the question arises to what extent a similar picture is true in more general situations. Is the existence of a singularity simply a consequence of the symmetry assumptions? Furthermore, even though the standard model is consistent with observation, it is of interest to analyse to what extent the observations imply that our universe is close to the standard one. Finally, one would like to know to what extent one can deduce isotropy and homogeneity as a consequence of the equations.

The question concerning the existence of singularities in general is, at least partially, answered by the singularity theorems of Hawking and Penrose. These theorems state that cosmological spacetimes under quite general conditions have a singularity. However, the existence of singularities is here equated with causal geodesic incompleteness. Thus, questions such as whether the gravitational fields become unbounded or not as one approaches a singularity remain unanswered. Furthermore, examples, for instance the Taub spacetimes, see below, indicate that equating the existence of a singularity with causal geodesic incompleteness is not always satisfactory. Another approach to the problem is to consider Einstein's equations as an initial value problem. This is in general very difficult and usually one confines oneself to considering situations with symmetry. However, with this point of view one has the possibility of saying something concerning the behaviour of the gravitational fields close to the singularity. This is the approach under discussion here.

One argument supporting the assumption that the universe is isotropic is the fact that the cosmic microwave background radiation is very nearly isotropic. Examples show however that this fact does not imply that the universe is almost isotropic. This emphasizes the importance of trying to find out to what extent the observational results confines the possible models. For this reason it is also important to understand somewhat more general models than the standard ones, so that one has something with which to compare. Even within the class of spatially homogeneous spacetimes, most models do not isotropize, so it is not to be expected that this will be the case in general. The question of whether homogenisation is to be expected has not been analysed in any greater detail due to the limited understanding of sufficiently general spatially inhomogeneous solutions, but see below for a further discussion of this topic.

The Structure of the Singularity

Before I started working at the AEI, my work was mainly concerned with the study of spatially homogeneous spacetimes of Bianchi class A, Bianchi IX in particular. There are many reasons for wanting to study Bianchi IX. First of all, there is a subclass called the Taub spacetimes. The members of this subclass have singularities both to the future and to the past in the sense of causal geodesic incompleteness, but the curvature remains bounded as one approaches a singularity. In fact, one can extend the spacetime beyond the singularities in inequivalent ways. This represents a pathological behaviour, and one would like to prove that solutions in general behave better. The first result I obtained concerning Bianchi IX was that all solutions except those of Taub type exhibit curvature blow up at the singularity, and thus inextendibility.

Another reason for wanting to study the Bianchi class A spacetimes is the BKL conjecture due to Belinskii, Khalatnikov and Lifschitz. This is a conjecture concerning what the generic behaviour of solutions should be close to the singularity. The picture presupposes a foliation of spacetime by spatial slices. The idea is then that the behaviour at different spatial points should decouple and that at each spatial point, the behaviour should be that of a spatially homogeneous spacetime. The model for the general behaviour at a spatial point is supposed to be Bianchi IX. The behaviour is conjectured to be oscillatory and to be such that the matter becomes unimportant close to the singularity.

There are exceptions depending on the matter model. For instance, if the matter model is a stiff fluid, the behaviour should be convergent and the matter important. In the case of Bianchi IX with a perfect fluid matter source, I was able to confirm all these conjectures. The step from spatially homogeneous to spatially inhomogeneous solutions is big, and the difficulties one has to face even when trying to answer basic questions concerning existence are considerable.

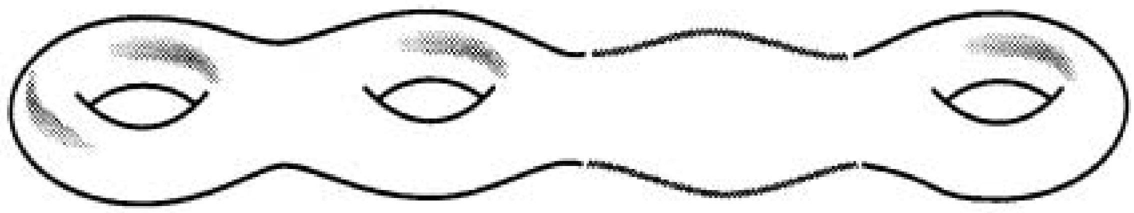
However, progress has been made. Recently, the so called Fuchsian techniques have been used to construct a large class of spacetimes with prescribed behaviour at the singularity. In fact, these techniques have been applied successfully in cases without symmetry. Unfortunately the methods depend on the fact that the behaviour is convergent, so the general case with oscillatory behaviour cannot be corroborated in this way. Furthermore, it is not clear how big the constructed set of solutions is in terms of initial data.

One class of spatially inhomogeneous spacetimes that has received considerable attention is the Gowdy vacuum spacetimes. This is probably due to the fact that analysing this class is on the borderline of what is doable and what is not. A Gowdy spacetime has a two dimensional symmetry group acting on spatial slices, so that the effective number of spatial dimensions is one. The numerical studies indicate that the behaviour is convergent as one approaches a singularity, and by the Fuchsian techniques, a large class of solutions have been constructed with the expected asymptotic behaviour.

However, one would like to have a condition on initial data yielding solutions with the desired asymptotics. This is of interest both in itself and as a starting point for further analysis. Last year I was able to give such a condition. It should perhaps be pointed out that, just as for the Fuchsian analysis, this result relies heavily on the fact that the behaviour is convergent. How to approach the general situation with oscillatory behaviour is a question which is far from being answered.

The Behaviour in the Expanding Direction

Very interesting developments have taken place the last few years concerning the behaviour of solutions to Einstein's vacuum equations in the expanding direction. In fact, a picture of how the behaviour should be under quite general circumstances has emerged, due to work of Fischer and Moncrief. Unfortunately, this is not the place to describe the ideas in detail, but let me mention that they contain fascinating connections between the Einstein flow and the topology of 3-manifolds. A natural starting point for testing these ideas is to consider spatially homogeneous spacetimes. This motivated me to consider Bianchi VIII in the expanding direction. The rough asymptotics were obtained prior to my arrival at the AEI, but a more detailed analysis was carried out 2001. The main ideas of Fischer and Moncrief were confirmed in this case, and one obtains surprisingly detailed information concerning the asymptotics. In particular, the topology of compactified Bianchi VIII solutions is a Seifert fibered space of a special type. An example to have in mind is the unit tangent bundle over a higher genus surface with a hyperbolic metric (Fig. 1).



(Fig.1)

Consider the Riemannian metric induced on the spatial hypersurfaces of homogeneity, it turns out that the fiber direction expands much more slowly than the orthogonal directions, and that one can give the precise rates of expansion. There have been several results concerning the expanding direction in the last few years, even in cases without symmetry, but here I will confine myself to Gowdy vacuum spacetimes. Due to numerical work by Moncrief and Berger, the picture is quite clear. The interesting conclusion is that all solutions seem to homogenize. In fact, given a general solution one can find a spatially homogeneous solution such that the difference between the solution one started with and the spatially homogeneous solution decays to zero. Last year I was able to prove that for solutions with small enough energy, the difference between the solution and its average converges to zero. In this sense one also gets the conclusion that the solution homogenizes. However, it would be of interest to show that the average behaves like a homogeneous solution of the equations. The final goal is of course to remove the small data restriction. This would yield a very interesting example of homogenisation caused by Einstein's equations.

Hans Ringström

Binary Black Holes in the Numerical Simulations Group

A detailed description of the inspiral and plunge of a pair of orbiting black holes is one of the most pressing problems facing relativity today. The reason is a very pragmatic one, and can be found in the first paragraph of any paper in the field of numerical relativity within the last decade: very soon (within 2002, in fact) gravitational wave detectors such as LIGO and GEO600 will come on line and begin collecting data. The most promising candidate for detection by the first generation of these detectors are the strongest possible gravitational wave sources, the coalescence of a pair of black holes. The detectors need to know what to look for, and further how to interpret what they've seen, and for that, accurate physical models of binary black hole mergers are the key.

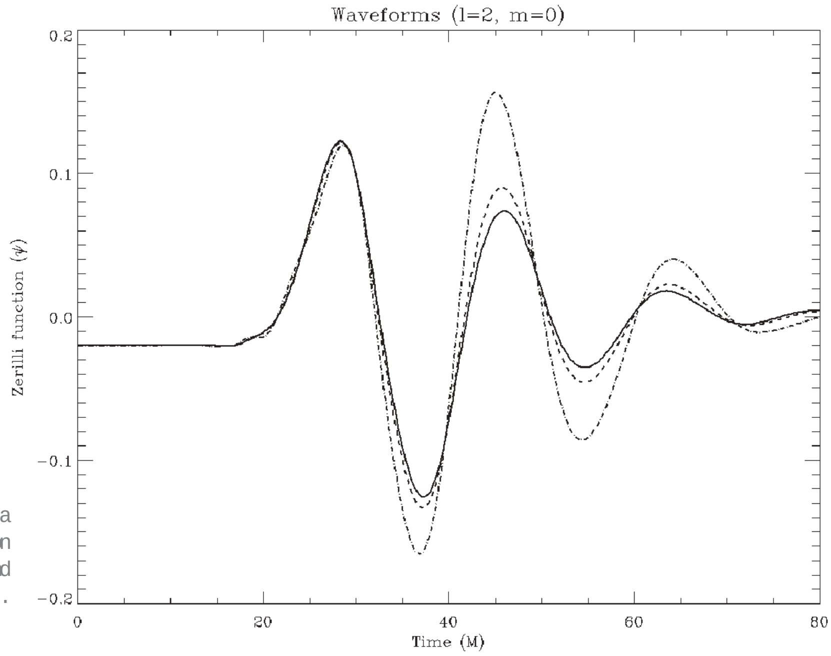
The scenario is something like this. A binary system is formed by some mechanism, most likely as a pair of black holes coming close enough together to be captured by each others gravitational pull. As the bodies orbit, they emit gravitational radiation which has the gradual effect of circularising their paths. They slowly spiral towards each other, until finally reaching a point at which they can no longer maintain their quasi-circular paths. From this innermost stable circular orbit (ISCO) the bodies plunge together, coalescing into a single black hole which rings down like a struck bell. The first phase of this process, the slow inspiral, is reasonably well understood and can be accurately modelled using ("post-Newtonian") corrections to Newtonian theory. The final part of the process, the ringdown, is well modelled using perturbation theory for a single black hole. But it is the period in between these two stages, the last few quasi-circular orbits followed by the plunge to merger, where the gravitational wave emission will be the greatest, and it is exactly this region where the approximations can not be trusted and the full non-linearity of the theory of relativity comes into play.

A main focus of the numerical simulations group at the AEI, led by Ed Seidel, is the evolution of the full system of Einstein equations for binary systems of black holes or neutron stars through the plunge, and the extraction of accurate gravitational wave information. This is a problem that has been at the heart of numerical relativity since the 1970s, when its complexity was often underestimated. It has taken that amount of time to get to our current state, where we are just beginning to be able to handle evolutions of astrophysically interesting systems for periods of time that might be characterised as useful.

The groundwork for the current progress in numerical simulation at the AEI was laid in the previous year, with studies of the Baumgarte-Shapiro-Shibata-Nakamura (BSSN) formulation of the Einstein equations carried out largely by Miguel Alcubierre. Until recently, the numerical evolutions in general relativity were performed using the Arnowitt-Deser-Misner (ADM) formulation. Persistent stability problems with this system of equations have lead researchers to consider alternative ways of expressing the equations, and one simple modification, BSSN, has proven particularly successful in terms of its stability compared to ADM. The innovations of the BSSN system are first to conformally decompose the metric and extrinsic curvature, and second to introduce a set of three new variables which are evolved independently. The resulting system is not symmetric hyperbolic as would be ideally desired on mathematical grounds, but does possess some obvious advantageous over ADM in terms of the decomposition of the evolution equations into wave-like parts.

Furthermore, the extra variables introduced in the BSSN system provide a clear expression for a shift condition ("gamma-freezing"), which fixes the gauge in a manner analogous to the minimal distortion shift that has often been advocated for numerical relativity, but rarely fully implemented in 3D. This shift condition is the crucial ingredient in solving the "grid stretching" problem that has long plagued numerical simulations that have used singularity avoiding slicings, and has been the primary limit to their lifetimes. The gamma freezing shift has the further benefit of asymptotically driving the system to a stationary state, allowing the numerical evolution to settle down.

The application of these ideas has resulted in a major step forward in the stability of our numerical evolutions. In the previous year, distorted single black holes were shown to evolve for an essentially unlimited amount of time. This year, similar results have been obtained for the head-on collision of black holes by Peter Diener, who evolved such a system for more than 5000M before stopping the run. Importantly, gravitational wave forms extracted from the head-on collision were found to converge to second order, a strong confirmation of the accuracy of the code in addition to the stability.

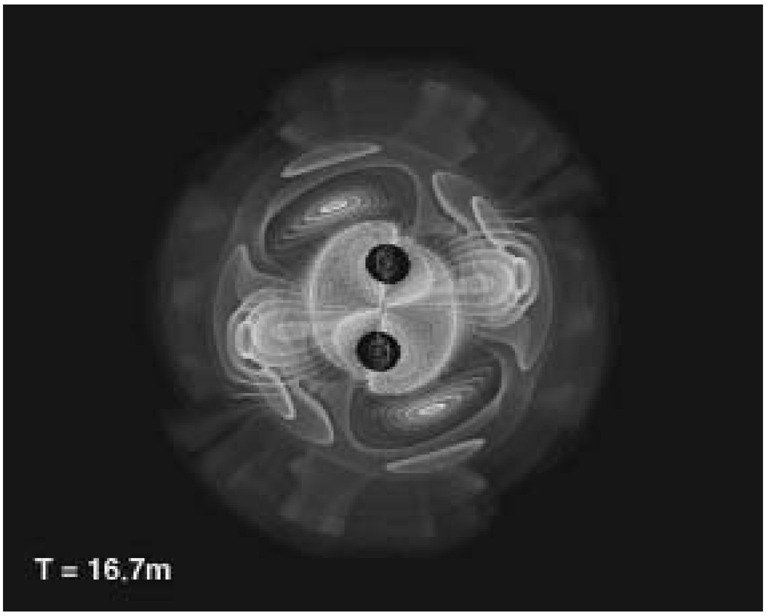


Gravitational waves from a binary black hole head-on collision, showing second order convergence.

A good part of the success of the head-on collision can be carried over to the case of inspiralling black holes possessing angular momentum, through a further modification of the shift condition. By applying a rotational component to the shift with the right angular velocity, the numerical grid is effectively rotated along with the bodies, and from this perspective appears to be head-on. This technique has been applied to various scenarios of inspiralling black hole initial data, and has resulted in evolution times as long as 150M, where before only 20-30M would have been possible.

This work has received some attention, and recently resulted in a generous allocation on a Linux supercluster at the NCSA (Illinois) where a high resolution inspiral simulation was carried out by Frank Herrmann, Thomas Radke and Denis Pollney, and visualised by Werner Benger (AEI/ZIB) for a television production by the Discovery Channel. This particular run was one of the largest of its kind, carried out on 256 processors of the Pentium cluster, producing more than a half-terabyte of data over a two day period, and testing the limits of both numerical codes and hardware in the process. The need for more efficient gridding techniques, such as adaptive mesh refinement (currently being studied by Scott Hawley and Nils Dorband) will certainly become critical as we move to larger scale models.

Further work will be carried out in 2002 to refine the wave-forms from these inspiral evolutions, ideally to a point where they can be handed over to the "Lazarus" code of Manuela Campanelli, Carlos Lousto (UT Brownsville), and John Baker (NASA-Goddard), all recent members of our group at the AEI. The Lazarus project is designed to pick up the pieces when the fully nonlinear simulations die, using the numerically generated data to seed a perturbative approach, generating accurate late-time waveforms, and promises to be an excellent tool for the practical study of the properties of gravitational waves.



A pair of inspiralling black holes showing their apparent horizons and a component of the gravitational radiation. (AEI / ZIB)

Though we might currently claim to be making good progress in modelling the late stages of evolution, a continuing problem for numerical relativity is to specify appropriate initial data for binary systems. Evolutions are not yet stable enough to begin from the well-separated post-Newtonian regime and carry on for multiple orbits to the plunge. Instead, simulations are started with the bodies much closer together, using initial data that we hope approximates a pair of orbiting black holes in a pre-plunge, quasi-circular, configuration. Determining such data in the nonlinear regime has proven to be a difficult problem. It inevitably involves approximations, and the results can vary disturbingly depending on which approximation is used. The simulations described above have been based on initial data which was specified using an effective potential method of Cook, which until lately has provided a best guess at how closely bound orbital configuration might look. Our own simulations, however, have raised some important questions about the quality of these data sets as genuinely quasi-circular. In particular, the angular velocities and short durations before coalescence indicate that they are much closer to plunging than might be expected.

A number of efforts are under way in the group to study evolutions based on alternative initial data possibilities. Bernd Brügmann, Peter Diener, Michael Koppitz, and Denis Pollney are developing codes for solving the constraint equations for pairs of superposed boosted Kerr-Schild black holes. Meanwhile, Wolfgang Tichy, Manuela Campanelli, Bernd and Peter have developed numerical methods for generating black hole initial data from post-Newtonian expansions. And finally, the promising innermost stable circular orbit initial data set generated by the Meudon group in Paris has been imported to our codes by Michael Koppitz, and we're currently making some first attempts to evolve this data.

This last project is an example of a collaboration which has been facilitated by the EU funded "Sources for Gravitational Waves" project, involving ten European institutions and headed by Ed Seidel. The project recently held its mid-term review meeting in Southampton, where it was agreed by all that the collaboration has been a great success in terms of building a close and active community of researchers in Europe. Further examples which particularly impact our work at the AEI are the post-Newtonian collaborations with Jena and Meudon (Paris), and the rapid progress which has been made in developing a relativistic hydrodynamics code on top of our existing vacuum code, by Ian Hawke in collaboration with SISSA (Trieste).

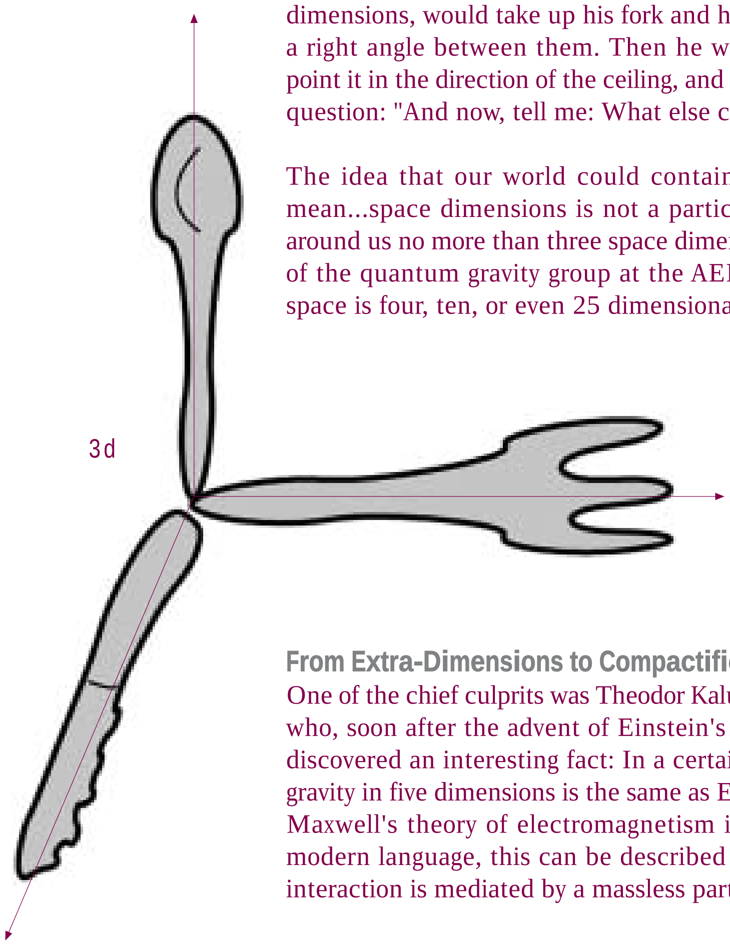
Of course, the size and complexity of the problems that we are trying to solve can only be handled with a solid computational infrastructure. The Cactus team, headed by Gabrielle Allen, has provided a great complement to our physics team this year. Most noticeable to the scientists has been the maturing of a number of very useful tools for controlling and visualising our simulations which have found their way into day-to-day use. The interaction between physics and computational science sides of our group has proven to be a great benefit to both.

Denis Pollney

The Allure of Extra Dimensions

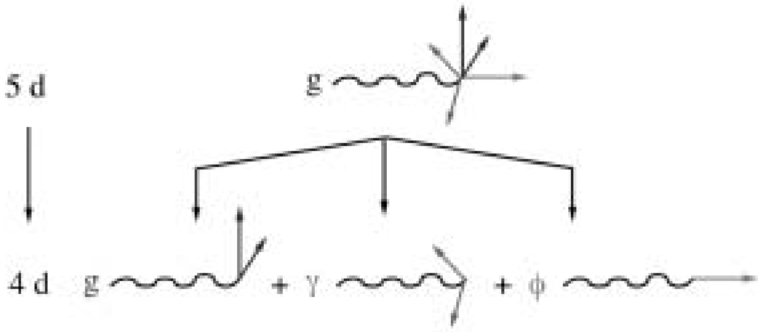
When I was a PhD student, there was a certain notable professor who, whenever a lunch discussion touched upon the subject of extra dimensions, would take up his fork and his knife in one hand, forming a right angle between them. Then he would reach for his teaspoon, point it in the direction of the ceiling, and follow this up with the simple question: "And now, tell me: What else can I do?"

The idea that our world could contain more than three cutler...I mean...space dimensions is not a particularly intuitive one. We see around us no more than three space dimensions - yet much of the work of the quantum gravity group at the AEI deals with worlds in which space is four, ten, or even 25 dimensional. How did this come about?



From Extra-Dimensions to Compactification

One of the chief culprits was Theodor Kaluza, a German mathematician who, soon after the advent of Einstein's theory of General Relativity, discovered an interesting fact: In a certain sense, Einstein's theory of gravity in five dimensions is the same as Einstein's gravity coupled with Maxwell's theory of electromagnetism in four dimensions! In more modern language, this can be described as follows: The gravitational interaction is mediated by a massless particle called a *graviton*. In four dimensions, this particle has two physical degrees of freedom. These are analogous to the two polarizations of the *photon*, the particle that mediates electromagnetic interactions. However, the graviton and the photon have different spin (2 and 1 respectively) and their dynamics are described differently - gravitation obeys Einstein's equations and electromagnetism the equations formulated by Maxwell in the late nineteenth century. As a general fact, particles in a higher-dimensional spacetime have more degrees of freedom, for instance, a five-dimensional graviton has *five*. Remarkably, these five degrees of freedom decompose in a natural way into those of a spin 2, a spin 1 and a spin 0 particle in four dimensions, which can be identified with a four-dimensional graviton, photon, and scalar field (fig.1).

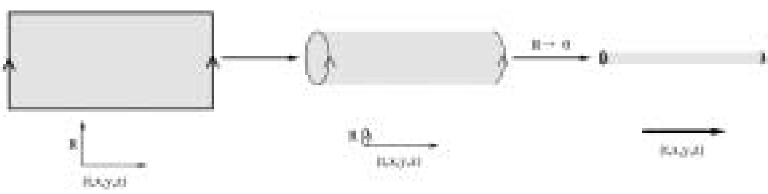


The five degrees of freedom of a five-dimensional graviton give rise in four dimensions to a graviton g (two degrees of freedom), a photon g (also called graviphoton, with another two degrees of freedom) and a scalar field f (one degree of freedom).

Consequently, the Einstein equations in five dimensions reduce to the Einstein and Max-well equations in four dimensions, as well as to field equations for the additional scalar field.

Still, Kaluza could not have given our fork-and-knife-wielding professor a satisfactory answer as to why we encounter only three of the space dimensions in our daily lives. In his theory, the fact that particles can only move in three space dimensions, but not in the additional fourth space dimension, had to be put in by hand.

It was up to the Swedish mathematician Oskar Klein to come up with a mechanism, known as "compactification", to justify the "invisibility" of the extra dimension a few years later: The idea is to assume that the extra dimension is a small circle, of radius *R* less than 10^{-17}cm. Then, just as a hair looks almost one-dimensional when seen with the naked eye, or as a pipeline looks one-dimensional for the air-craft pilot flying high above, the five-dimensional spacetime with one tiny rolled-up space dimension would be indistinguishable from a four-dimensional spacetime as far as the macroscopic inhabitants of that space are concerned (fig.2).



Assuming that the extra dimension *R* is a very small circle, the five-dimensional spacetime is reduced to an effectively four-dimensional one.

After some initial excitement, the concept of extra dimensions à la Kaluza and Klein fell by the wayside, as most physicists focussed their attention on the then-emerging quantum theories, and later, on the successful development of four-dimensional quantum field theories.

Eleven Dimensions at the AEI

Recently, however, with the emergence of supergravity and superstring theories, there has been a veritable renaissance of higher-dimensional physics as additional dimensions come about in a very natural way in those theories. In many ways, the picture is now more complicated than in Klein and Kaluza's time. Then, the focus was on the basic forces of gravity and electromagnetism; at present, there is the whole standard model of elementary particle physics to take into account - in addition to the photon, further spin 1 particles such as the gauge bosons $W^{\pm}$ and Z^0 responsible for the so-called weak interaction, as well as eight gluons associated with the strong nuclear force, need be taken into account. The basic idea of "unification by extra dimensions", with all these particles included in the degrees of freedom of some higher dimensional graviton, is still appealing: A natural extension of Klein's minute circle S^1 is to consider small two-dimensional spheres S^2, small tori T^2, or a number of more involved geometrical possibilities for several extra dimensions. Edward Witten has shown that the smallest internal space which could produce at least all force-carrier particles of the Standard Model is given by the product of a circle, a sphere and a so-called four-dimensional projective plane, in the language of mathematics: $S^1 \times S^2 \times CP^2$ (the symmetry group of this manifold is precisely the "gauge group" of the Standard Model, $[U(1) \otimes SU(2)]_{electroweak} \otimes SU(3)_{strong}$). The number of required extra dimensions would then be at least 1+2+4=7, which together with our known four dimensions gives eleven spacetime dimensions quite a ***M***agic number, as we will see below.

Although this correspondence is somewhat encouraging, there is a much more fundamental problem to be solved - in the standard model, electromagnetism, weak and strong force are all described as quantum theories. For gravity, no complete quantum theory is known. The run-of-the-mill techniques from standard quantum field theory, which can so successfully be applied to the other forces, fail for gravity in four, five, or higher dimensions because the theory is "non-renormalizable". This basically means that a quantum calculation of a given scattering process will require an infinite number of constants to be fixed before any predictions can be made - leading to a theory that cannot predict anything at all.

One promising attempt to cure this inconsistency is given by superstring theory. This theory indeed not only contains gravity at a quantum level, but it also *predicts*, for the first time in the history of physics, the *dimensionality of spacetime*. This is good news - the bad news is that the required dimensionality is *ten*. More modern developments, far from reducing the number of needed dimensions, add one further dimension: The picture that emerges is that, through a web of dualities, the ***M***other of all superstring theories is *eleven*-dimensional. (This ***M***other theory is commonly called ***M***-theory, and has yet to be fully understood or even described.) Therefore, as soon as we consider quantum gravity from a superstring perspective, we necessarily need to take into account higher space dimensions - and to explain why, in everyday life, we experience only three-dimensional space. Extra dimensions figure prominently in the research done by the quantum gravity group at the Albert Einstein Institute, where the consequences for ***M***-theory and especially for its effective low energy approximation, *eleven*-dimensional supergravity, have long been a focus. In particular, the extra dimensions imply the existence of some *hidden symmetry groups*, analogous to the so-called "Ehlers group" of ordinary general relativity in four dimensions. One of the main results obtained at the institute concerns the fact that these hidden symmetries appear to exist independently of any specific compactification mechanism - they are a direct consequence of the higher dimensional nature of the theory, not of the ways in which the additional dimensions have been effectively eliminated. In the course of this research, new techniques for dealing with extra-dimensional supergravity have been developed that involve coordinate splittings and field redefinitions and that give tantalizing hints of certain new geometrical concepts, closely related to the so-called exceptional Lie algebras, that might hold the key to the hidden symmetries. Work is still in progress in this area - not only in eleven but also in five dimensions, where the structure of the minimal supergravity is simpler, although hopefully rich enough to shed some light on the new structures involved. Through this research, we expect to better understand the mechanisms which underlie a theory invariant under these hidden symmetries. Hopefully, this might open a new window onto the still ***M***ysterious ***M***-theory.

A New Alternative: Brane-World Scenarios

Another more recent development of research into the nature of extra dimensions concerns the necessity, or non-necessity, of Kaluza-Klein compactification - until very recently the only viable approach to recovering a four-dimensional universe from a higher-dimensional world. Currently, an alternative involving so-called "brane-world scenarios" is attracting more and more interest in the string theoretical community. The basic idea is to assume that our universe is the boundary of a five (or more) dimensional spacetime. The matter particles that we see around us, as well as the force carriers that mediate the electromagnetic, strong and weak interactions, are all thought to be confined to the boundary. Only the graviton would be able to travel in the higher-dimensional bulk, as shown in the illustration (fig.3).

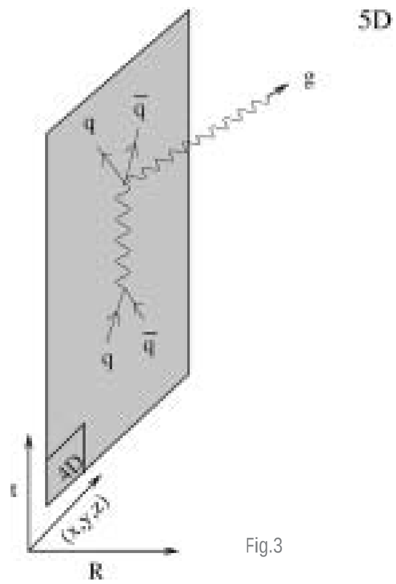


Fig.3

In the brane-world ansatz, matter (represented here by a quark-antiquark scattering) is restricted to a four-dimensional subspace while gravity is allowed to travel in the extra dimensions.

This new idea does not completely eliminate compactification from the picture - on the contrary, from the ***M***-theory point of view, a mixed Kaluza-Klein/brane-world scenario for the reduction from eleven to four dimensions seems likely, with the small step between ***M***-theory in eleven dimension to a particular ten dimensional superstring theory (the so-called heterotic $E_8 \otimes E_8$ theory) being described by a brane-world picture and the further reductions down to four dimensions being due to the more familiar Kaluza-Klein mechanism.

As opposed to the Kaluza-Klein picture, the extra dimensions in brane-world models are not necessarily small, or even compact - they could possibly be of infinite extension! This new freedom is mainly due to the basic hypothesis that our world couples weakly to the bulk space - only the very weak gravitational force reaches out into the void. Consequently, the study of gravitational interactions holds the only hope for uncovering experimental evidence for this type of extra dimension. In particular, the presence of additional dimensions causes small deviations from Newton's law of gravity. For instance, in the model formulated by Lisa Randall and Raman Sundrum, the large extra dimensions lead to correction of the "inverse square law" by a term proportional to the inverse of the quartic power of the distance - in contrast to a Kaluza-Klein setup which predicts an exponential decay at large differences. In principle, these deviations could be checked in future precision measurements of the gravitational force at small distances.

Of mathematical interest are some of the *conceptual* changes that are a consequence of a brane-world scenario. One natural consequence of the presence of the extra dimensions turns out to be a modified definition of the gravitational energy and angular momentum. In four-dimensional general relativity, one can define in a reasonably observer-independent way the *total* energy of an isolated system. However, it is not possible to define a *local* density of the energy associated with the gravitational field. This is a direct consequence of the equivalence principle: Locally, an observer in free fall will not feel any gravitational field, and not measure any non-zero gravitational energy. But what if our universe is a brane-world, say, the boundary of a five-dimensional spacetime?

Research carried out at the AEI has shown that, in such a situation, there is indeed a natural way to define a local gravitational energy density - not for the bulk of the five-dimensional spacetime, in which the equivalence principle still forbids such a definition, but on that boundary of spacetime that is our universe. There (and only there), additional constraints known as "junction conditions" have to be satisfied. Using these, one construct the gravitational energy density in terms of the metric and other local fields. The same kind of analysis has been applied to the angular momentum density and to other, related charges.

"And now,...?"

The simple idea of extra dimensions gives rise to a fantastically rich spectrum of new ideas related to unifications, dualities, hidden symmetries, boundary physics, and many other interesting concepts. Many of these ideas are explored here at the AEI. It is however still unclear whether these higher dimensions are just a powerful mathematical tool to define theories in a unified way or if they have physical reality. If the latter, then there is the further challenge of understanding what the exact shape of the extra dimensions is, and how exactly it comes about that they are so different from our everyday three spatial dimensions. Hopefully, future experiments will help answer these questions, and also the still pending lunch-time question of a certain notable professor.

Sebastián Silva

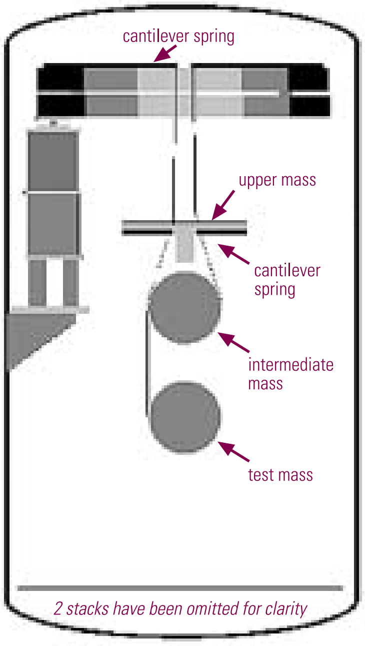
First Coincidence Test Operation of the Gravitational Wave Detectors GEO600 and LIGO

A very exciting period started in 2001 for the scientists of the experimental group of the AEI: The gravitational wave detector GEO600 had it first test operation and started the transition from a construction project to a physical observatory. GEO600 is part of an international network of ground-based laser-interferometric gravitational wave detectors. These detectors will be searching for gravitational waves from a number of different astrophysical sources like supernovae explosions, non-symmetric pulsars, inspiralling binary systems of neutron stars or black holes and remnants of the big bang; and, possibly most exciting, unknown sources that may produce gravitational waves of detectable strength.

Six laser interferometric gravitational wave detectors are currently under construction: Three interferometers of the LIGO project in the USA (interferometers with 4km baseline at each of the two sites in Washington and Louisiana, plus an additional interferometer with 2km baseline at the site in Washington), one detector of the French-Italian VIRGO project in Pisa (Italy) with 3km baseline, the TAMA interferometer in Japan with a baseline of 300m and the British-German GEO600 detector with 600m armlength in Germany. An 80m prototype interferometer with the option to extend it to a large-scale detector is under construction by the ACIGA project in Australia.

The GEO600 detector was designed based on the experience with two prototypes: the 10m interferometer at the Glasgow University and the 30m interferometer at the Max-Planck-Institut für Quantenoptik in Garching, near Munich. The construction of GEO600 started in 1995 as a German/British collaboration on a site near Hannover in Germany. At that time only a small fraction of the GEO scientists was working in Hannover. As the detector was growing, the number of scientists, engineers and workshop staff in the Hannover GEO group was growing as well and by the end of 2001 the major part of the German experimental effort in gravitational wave research was based in Hannover, where at the beginning of 2002 the first experimental division of the AEI was founded.

Based on the constraint that the length of the vacuum pipes could not exceed 600m, advanced techniques had to be adopted for GEO600 to make its sensitivity comparable to the sensitivity of the detectors with several kilometers armlength. The main noise sources that limit this sensitivity are the seismic motion of the ground, the thermal noise in the mirrors of the Michelson interferometer and its suspension, and the shot noise due to the quantum nature of the laser light. Pendulums are commonly used to reduce the coupling of ground motion into the displacement of the mirrors. Masses suspended as pendulums do not follow a motion of their suspension point very well if the frequency of the excitation is above the resonance frequency of the pendulum. This effect is used in the suspension system of GEO600 where two vertical spring stages are combined with three horizontal pendulum stages to reduce the transfer of ground motion to a displacement of the suspended mirror by more than ten orders of magnitude at frequencies above 50Hz.



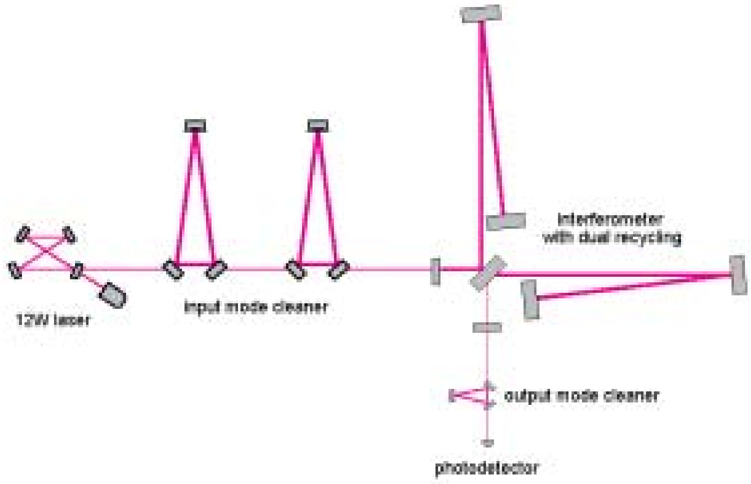
The multiple pendulum suspension system of GEO600. Three two-layer seismic isolation stacks support a structure called rotational stage from which the mirror (test mass) is suspended via two vertical cantilever spring stages and three pendulums for horizontal isolation of the mirror from ground motion. The last pendulum stage is made entirely from fused silica to reduce thermal noise. A reaction pendulum is placed close to the main pendulum to allow length control of the interferometer from a seismically isolated actuator.

Above this Fourier frequency the sensitivity of GEO600 will be limited by thermal noise which is reduced as much as possible by the choice of the mirror material, its treatment, the bonding techniques and the material used for its suspension. As governed by the fluctuation-dissipation theorem, the energy in the thermally excited motion of the mirror is proportional to the mechanical losses in the mirror or its suspension. Hence extremely high mechanical quality factors are needed. The mirrors in GEO600 are made from very high purity fused silica and are suspended from fused silica fibers. A technique called hydroxide catalysis bonding which was developed at Stanford University and optimized within GEO is used to connect the mirrors to these fibers.

Finally, at frequencies above 300Hz the sensitivity is limited by shot noise which is due to the nature of light that follows Poissonian statistics in its arrival time on the photo detector. In conventional interferometer designs, this noise source can only be reduced by increasing the laser power inside the interferometer, for which an upper limit is set by the acceptable thermal loading of the interferometer. In GEO600 however, a technique called signal recycling is used that allows a reduction of the effect of the shot noise for a specific Fourier frequency and a bandwidth around this. The center frequency and the frequency band for the shot noise reduction can be chosen to optimize the detector for a given type of astrophysical source.

These three techniques, the multiple pendulum seismic isolation, the low loss monolithic suspension technique and signal recycling will improve the sensitivity of GEO600 and concepts based on these techniques are adopted as the baseline design of a second generation detector which is planned to be a joint LIGO-GEO project.

By the end of 2001 the GEO600 detector had reached an installation status which allowed us to have a first test run: The 12W laser was in place and the two so-called modecleaners which are used as spatial filters for the laser light were operating reliable and under automatic alignment control. These modecleaners are optical ringcavities with suspended mirrors, a round trip length of 8m and a Finesse of approx. 2000. The light that was filtered by the modecleaners was then injected in the power recycling cavity, yet another cavity, which is formed by the suspended power recycling mirror and the interferometer functioning as the second mirror of this cavity. To reflect the injected light like a mirror, the interferometer has to be stabilized at the "dark-fringe" operating point at which no light leaves the output port but all the light is reflected. In the December 2001 installation status two of the interferometer mirrors (due to folded arm design the GEO600 interferometer has four mirrors) were installed in their final form whereas for the beamsplitter, the power recycling mirror and the other two mirrors, test optics on test suspensions were used. Furthermore the signal recycling mirror and the output mode-cleaner were not installed.



The optical layout of GEO600: The light of a 12W laser is spatially filtered by to suspended input modecleaners and injected into the power recycling cavity. Power recycling enhances the light power in the folded arm interferometer. Signal sideband produced by a gravitational wave will be enhanced by the signal recycling mirror and leaves the interferometer towards the photodetector which is shielded from light in higher order modes by the output modecleaner.

In this configuration the detector was continuously operated for 17 days, starting December 29th 2002, with scientists working day and night shifts in the detector control room. At the same time the three LIGO detectors were running in coincidence. From the GEO600 perspective this coincidence run had three goals: We wanted to

- gain experience how to operate the detector for a longer period and see what duty cycle was achievable,
- take data that could be used for detector characterization purposes and to test the data analysis pipeline and the astrophysical search codes
- provide scientific data to the LIGO scientific community (which GEO is a member of) to set together with the data from the LIGO detectors upper limits on the distribution of some astrophysical sources.

All these goals were met and the test run was a great success. The most impressive result was the duty cycle of 77% that could be achieved. During the course of the test run approx. 900 GByte of detector and environmental data were recorded, which allows the detector characterization group to get a complete picture of the detector behavior over more than two weeks of operation. For a detector like GEO600 with more than 200 feedback control loops it is impossible to get such an overall picture by using only standard laboratory techniques based on spectrum analyzers and oscilloscopes. The primary goal for this group of experimentalists and theorists is now to understand the detector and to improve it. Once the detector comes closer to its design sensitivity the detector characterization group will concentrate on the false alarm recognition and vetoing.

The GEO600 control center was manned round the clock during the test run.

All the data sets acquired by the four detectors will be calibrated and passed to the data analysis codes in early 2002. This will be the first test of the data analysis pipeline and will teach us how to do the statistical and follow up analysis of the "events" found by the search codes. As a result we might be able to set an upper limit on the distribution of some astrophysical sources.

Birds-eye view of GEO600.

While the data sets are analyzed the detector commissioning and optimization will continue. We plan to install the signal recycling mirror in April 2002 followed by an optimization of the detector sensitivity. In summer 2002 the next coincidence run with the LIGO detectors is planned. After that all the test optics will be replaced by the final optics and the output modecleaner will be installed. Once in the final configuration, we will optimize the detector performance to reach the final sensitivity and start longer data runs by the end of 2002.

All the experimentalists of the Albert Einstein Institute in Hannover are very excited. The detector we have been working on for so many years is reaching a sensitivity that makes it into an astrophysical instrument and may allow us to detect the first gravitational wave soon.

Benno Willke

Computational Science Highlights

Computational science highlights from 2001 in the Numerical Relativity group include two prizes for high performance computing, awards of two major research grants, and successful demonstrations and tutorials in a number of international conferences. Thomas Dramlitsch, Ed Seidel and Gabrielle Allen were members of an international team which won a Gordon Bell Prize in high-performance computing for the work described in their paper "Supporting Efficient Execution in Heterogeneous Distributed Computing Environments with Cactus and Globus". The special category award was presented during SC2001, a yearly conference showcasing high-performance computing and networking, this year held in Denver, Colorado.

The prize was awarded for work on concurrently harnessing the power of multiple supercomputers to solve Grand Challenge problems in physics which require substantially more resources than can be provided by a single machine. This work is important, not only for the possibilities which are pointed to for large scale simulations, but also for load balancing across a single machine with heterogeneous processors as well as exploiting cheap resources, such as idle networked workstations, for higher throughput. The group enhanced the communication layer of Cactus, adding techniques capable of dynamically adapting the code to the available network bandwidth and latency between machines. In addition, the Globus Toolkit was used to provide authentification and staging of simulations across multiple machines. In a series of experiments performed at the start of 2001, the group ran a gravitational wave simulation across a virtual supercomputer built up from three separate SGI

Origin 2000 machines totalling 480 processors at the National Center for Supercomputing Applications in Illinois and a 1024 processor IBM SP2 at the San Diego Supercomputing Center in California. This virtual resource contains differing network bandwidth between processors, from, extremely fast (200MB/s) connections between processors in the same machine, through Gigabit Ethernet (125MB/s) connecting together the Origin 2000s, to the OC-12 (77MB/s) connection between the two different sites.

A second prize involving Cactus was awarded to John Shalf of the Lawrence Berkeley Laboratory in California. Shalf's team, including Peter Diener from the Albert Einstein Institute, won the High-Performance Bandwidth Challenge at the SC2001 conference. They sustained a network saturation rate of 3.3 gigabits per second for the transfer of data from a live simulation of the collision of two black holes. Two major research grants were awarded to the group in 2001, both scheduled to start in 2002. The GriKSL project in collaboration with the Konrad-Zuse-Zentrum in Berlin, has been awarded 418.200 Euros by the Deutsches Forschungsnetz Verein (DFN) to continue the development of techniques and tools for numerical relativity which exploit high speed networks.

The GridLab project which starts in January 2002, is funded by the EU under the Fifth Call of the Information Society Technology (IST) Program. GridLab brings together twelve institutions in Europe and the USA with Sun Microsystems and Compaq to develop a easy-to-use, flexible, generic and modular Grid Application Toolkit (GAT), enabling todays applications to make innovative use of global computing resources. The project is grounded by two principles, (i) the co-development of infrastructure with real applications and user communities, leading to working scenarios, and (ii) dynamic use of grids, with self-aware simulations adapting to their changing environment. The Albert Einstein Institute receives 881.000 Euros from the total funding of 5.1 million Euros for the GridLab project.

AEI's Thomas Dramlitsch, Ed Seidel and Gabrielle Allen were members of an international team which won a Gordon Bell Prize in high performance computing. The special category award was presented during SC2001, a yearly conference showcasing high-performance computing and networking.

In 2001 members of the Cactus Team gave successful demonstrations of new technologies at HPDC10 in San Francisco and at SC2001 in Denver. At Denver, in collaboration with the Applications Research Group of the Global Grid Forum (co-chaired by Ed Seidel), the Cactus Team demonstrated applications running on a large testbed comprising

7242 processors assembled from 26 machines in three different continents. New grid aware applications running on the testbed included a simulation portal able to start and track Cactus jobs on any machine, and the spawning of independent tasks from a Cactus simulation to different machines.

Gabrielle Allen

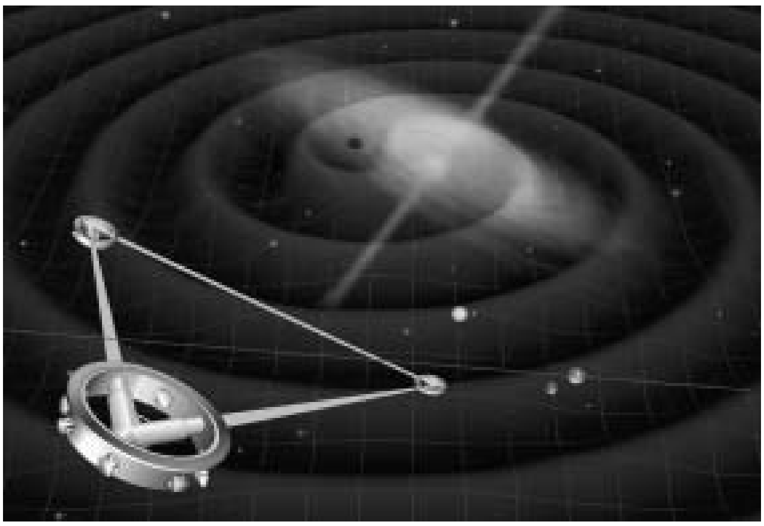
GriKSL - project http://www.zib.de/Visual/projects/GriKSL/
GridLab - project http://www.gridlab.org
Testbed - http://www.aei.mpg.de/~allen/TestBedWeb/PR/

Fourth Capra Meeting on Radiation Reaction

The Capra meetings on radiation reaction are annual gatherings, the fourth of which was hosted by Carlos Lousto at the Albert-Einstein-Institut in Golm, Germany, May 28-31, 2001. The first meeting in this series was held in 1998 at a ranch in northeastern San Diego county in California. This ranch was once owned by Frank Capra, the director of such movies as "Mr. Smith Goes to Washington" and "It's a Wonderful Life". Capra was a Caltech alumnus, and donated the ranch to Caltech. In the tradition of the "Texas" meetings, each meeting in this series is called a "Capra" meeting, even if the venue is rather removed from Capra's ranch. Summaries of previous Capra meetings appeared in Matters of Gravity, No. 14 (Fall 1999: Capra2 by P. Brady and A. Wiseman) and No. 16 (Fall 2000: Capra3 by E. Poisson).

The Capra meetings focus on radiation reaction and self interaction in general relativity. The motivation for this topic is twofold. First, the two-body problem in general relativity is as yet an unresolved problem. Even the restricted two-body problem, where the mass ratio of the two bodies is extreme, lacks in understanding. It is this restricted problem which the Capra meetings focus on. In the limit of infinite mass ratio, a test mass moves along a geodesic of the spacetime created by the massive body. When the mass ratio is finite, the energy-momentum of the small mass acts as an additional source for spacetime curvature, which affects the motion of the small mass itself. Specifically, the small mass now moves along a geodesic of a perturbed spacetime. An alternative viewpoint is to construe the motion of the small mass as an accelerated, non-geodesic motion in the unperturbed spacetime of the big mass. This acceleration is then caused by the self force of the small mass. Although for many interesting cases it is sufficient to restrict the discussion to linearized perturbations (thanks to the high mass ratio), there still remains an inherent difficulty: the metric perturbations typically diverge at the coincidence limit of the field's evaluation point and the source of the perturbations. It is the removal of this divergence, or the regularization problem of the self force, which constitutes the greatest hurdle in the solution of the restricted two-body problem.

The second motivation stems from the prospects of detecting low-frequency gravitational waves with the Laser Interferometer Space Antenna (LISA), which is currently scheduled to fly as early as 2011.



Artists impression of current LISA configuration.

One of the most interesting potential sources for LISA is the gravitational radiation emitted by a compact object spiraling into a supermassive

black hole, like those in galaxy centers.
The typical mass ratio is then 10^{5-7} which makes the restricted two-body problem relevant. During the last year of inspiral (the LISA integration time) the system can undergo (1-5) x 10^5 orbits. In order to generate accurate templates which track the system over so many orbits, it is required to compute the orbital evolution (due to both dissipative and conservative effects) to high accuracy, which requires the inclusion of self interaction.

Twenty talks, covering many aspects and approaches to the problem, were given at the fourth Capra meeting. The following short description is greatly biased by my own understanding and taste. A full list of the talks, including the online proceedings of the meeting (namely, links to the slides used by the speakers), appears at the meetings web page:

http://www.aei-potsdam.mpg.de/~lousto/CAPRA/Capra4.html.

Capra meeting participants in a relaxed mood in the Max Planck Campus central patio.

A number of different approaches for the calculation of the self force have been suggested. These are approaches for the computation of the "tail" part of the self force [1,2]. M. Sasaki, Y. Mino, and H. Nakano presented progress obtained in Power-Expansion Regularization.
M. Sasaki described, in addition to Power-Expansion Regularization also an alternative approach of Mode-by-Mode Regularization, and also discussed the problems of extending the work to Kerr background, and the difficult gauge problem. Y. Mino described in great detail the mathematical techniques which are needed for Power-Expansion Regularization. H. Nakano showed how to apply this approach for the computation of the self force acting on a scalar charge in circular orbit around a Schwarzschild black hole [3]. L. Barack described his work with A. Ori on the extension of Mode-Sum Regularization to the gravitational case [4], and L. Burko discussed work with Y.-T. Liu on how Mode-Sum Regularization can be applied for the case of a static scalar charge in the spacetime of a Kerr black hole, even without knowledge of the Mode-Sum regularization function [5]. W. Anderson presented progress obtained with É. Flanagan and A. Ottewill in the approach of normal neighbourhood expansion. A. Ori presented work with E. Rosenthal on extended-body models, and showed how to re-derive the Abraham-Lorentz-Dirac equation (in flat spacetime) using such models, based on momentum considerations. This approach appears to be very promising also in curved spacetime. C. Lousto discussed ξ-function regularization [6]. In all these different approaches to the self force there was significant progress since the previous Capra meeting, although clearly much more

work is still needed.
A second, exciting direction which was emphasized for the first time in the fourth Capra Meeting, is the need for demonstrating the connection between the different methods. This is important not just in order to demonstrate the consistency and viability of the different approaches, but also in order to compare their computational effectivenesses, and perhaps even allow for a synergy of two or more approaches. S. Detweiler proposed a (short) list of benchmark problems, which he encouraged all the people who are working in this field to consider, in order to confront and compare the different approaches. Specifically, this list includes the problem of a scalar charge in circular orbit around a Schwarzschild black hole, and the calculation of gauge invariant quantities in the gravitational analogue. It is hoped that much insight can be gained by such comparisons. For the former benchmark problem one can already compare the work by Nakano, Mino, and Sasaki [3] with earlier work by Burko [7] and hopefully other researchers will consider this problem too. A different way of comparing different approaches is to compare the infinities which are removed. Specifically, in the approach of Power-Expansion regularization one computes the direct part of the self force. In Mode-Sum Regularization one typically computes the so-called regularization function using local integrations of the Green's function. As the two should agree, work is now in progress to show just that.

Other interesting talks were given by A. Wiseman, who showed that the self force on a static scalar charge in Schwarzschild spacetime is exactly zero also when the scalar field is not minimally coupled (despite earlier results by Zel'nikov and Frolov [8]), and by B. Whiting, who discussed how to extend the Chrzanowski method to the time domain, and perhaps also include sources. G. Schäfer described work with Damour and Jaranowski on a post-Newtonian approach to radiation reaction, J. Levin discussed the fate of chaotic binaries, C. Glampedakis described work with D. Kenneck on a 'circularity theorem' for spinning particles in Kerr spacetime, J. Pullin described a code in the time domain to obtain radiation reaction waveforms, N. Andersson described r-modes as a source of gravitational radiation, and C. Cutler described gravitational wave damping of neutron star precession. S. Detweiler talked about gravitational self-force on a particle in Schwarzschild spacetime, E. Poisson described work with M. Pfenning on the self force in the weak-field limit [9], and B. Sathyaprakash discussed resummation techniques for the binary black hole problem.

Lior Burko
University of Utah

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Open Day at the Max Planck Campus

On June 30th, the three Max Planck Institutes and the Fraunhofer Institute for Applied Polymer Research staged their first joint Open Day on the campus in Golm. Our advertising for this event was quite successful and on that sunny Saturday about 1500 people came to the campus and enjoyed guided tours through the institutes, popular talks and demonstrations.

At the AEI we offered several popular talks on strings (Ari Pankiewicz), colliding black holes (Michael Koppitz), Einstein's legacy (Bernard Schutz), gravitational waves (Carsten Aulbert), gravitational lensing (Volker Perlick), and many demonstrations of colliding black holes and neutron stars at the immersadesk (Werner Benger and Ralf Kähler). Elisabeth Schlenk offered a guided tour through the library and child care that she organized together with Anja Lehmann.

An attentive audience of young & old folk listening to Markus Pössel expanding on time travel - some busily taking notes!

In the lounge Markus Pössel's demonstrations on time travel using a billiard attracted many amused spectators. We had the poster systems about the AEI and LISA ready and our colleagues from Hannover brought a lot of interesting exhibits about gravitational wave research, e.g. a power unit for LISA - only 2 centimetres long and a full-scale model of GEO's pendulum suspension. Karsten Danzmann and Harald Lück demonstrated the functioning of a laser interferometer and explained the GEO600 and LISA projects. Our visitors and our staff enjoyed this Open Day very much and we are planning to organize such an event at least biannually.

Elke Müller

Through the Eyes of a Visitor

I visited, as invited researcher, the Max Planck Institute for Gravitational Physics, Albert Einstein Institute (AEI), for the months of March and April 2001. It was also for me the first time to visit Germany. Arrived by plane at Tegel Airport in Berlin, the first thing I noticed was that the temperature had dropped from about 30°C at my departure, to 2°C, hard to adapt. Fortunately, Alan Rendall was there to take me quickly, by bus and train, to the Institute.

We changed train at Potsdam and arrived at Golm railway station. We then had to follow by foot, in the cold, the path of about 1 km, and then I saw the Max Planck Campus for the first time. I noticed its isolation from the town. As I learned later, the white house we first met was the Guesthouse where I will stay, and the other buildings were the 3 Institutes and the Central building of the Max Planck Campus.

Alan Rendall brought me directly to the Max Planck Institute for Gravitational Physics, Albert Einstein Institute, as I could read the inscription at the entrance. Once inside the Institute, the low temperature outside changed into a warm reception; that was my first contact with the powerful administrative organisation of the Institute. Let me give a presentation of the AEI, as I saw it through its different compartments, from the beginning to the end of my visit.

The Reception

At my arrival: my keys (Guesthouse and office), my room in the Guesthouse, my office at the Institute (cleaned everyday), my new addresses (post-mail, phone, e-mail), my mail-box, even an introductory password for my personal computer, were ready.

This confirmed the good impression I had, when I saw on the Internet Homepage of the Institute, before leaving my Country, that my visit was planned several months earlier, with the precise dates of arrival and departure, as communicated by myself to the Institute.

The Room in the Guesthouse

Nicely and efficiently equipped, without any excess. Almost all instructions concerning accommodation, communications, surgery, time-table of bus and train, summary on each Institute of the Max Planck Campus, are ready in a copy-book. Cuts of electricity and water are planned several weeks earlier. Unfortunately, I had a room with a sharing bathroom. I had to share it with a total of 6 other visitors, staying for a short time, one after the other, in the next room: not easy. Due to a massive arrival of new guests, I was asked to change room for the last night to spend: also not easy.

The Administrative Staff

An efficient team of young Ladies (in majority), ready to answer even by phone or e-mail, to all kind of administrative questions and other such as mailing, banking,...

The Light Equipment (materials)

Almost all you could desire for your daily work is stocked in a room open to all the staff of the Institute. Initially located at the second floor of the Institute, it finally moved to the ground floor, right in front of my office. In some very rare cases where you don't find what you want, the incomparable Frau Brigitte Hauschild will provide it to you, after saying: "Dear guest, you will have all you want", and it was true. You can make at the Institute as much photocopies as you desire.

The Restaurant

Located in the Central building, it is a nice meeting point for almost all the staff of the 3 Institutes of the Max Planck Campus. After Lunch, the staff of the AEI usually meets for coffee, possibly with cakes, at the ground floor of the Institute, where a giant photograph of Albert Einstein confirms the name of the Institute. Lunch and coffee times are always moments for fruitful discussions between scientists. It was always a pleasure to listen to Bernd Schmidt, to Alan Rendall, and some other highly qualified researchers. Knowing a total of about 3 words in German, I succeeded nevertheless in the Restaurant to order what I wanted by gesture to the staff of the Restaurant. I even succeeded this way to buy some food for the evenings and weekends, when the Restaurant is closed, avoiding at the beginning of my stay; to go out of the Campus in the cold. Given the important number of visitors that are generally English speaking, what about training all the staff for some essential words in English?

The restaurant terrace is a favorite lunch spot on sunny days.

The Monthly Meeting of the Staff

It is a one hour meeting that takes place every first Wednesday of the month. A very good idea. During this meeting cleverly chaired by the remarkable head of administration, Frau Christiane Roos, and sometimes co-chaired by the managing director, Hermann Nicolai, every new scientific guest introduces himself (or herself), and some devoted members of the administrative staff can be congratulated. A real stimulation for all. Permanent Scientists can know this way who is exactly the new visitor and visitors whose periods of stay coincide can know each other. Quite naturally, a sympathetic "hi" is therefore always exchanged between two scientists of the Institute that cross each other in the campus.

The Library

Very well supplied in books and journals of high level coming from all over the world, the library of the Institute covers several floors and is still growing. The library is powerfully managed by computer. If you want an article that exceptionally is not in the Library, the efficient Frau Elisabeth Schlenk will download it from an internet site somewhere in the world wide web and bring it to you at your office within 2 hours. From that time, the article will be catalogued at the library.

The airy and spacious AEI library.

The Scientists

There are permanent scientists and an impressive number of visitors coming from all over the world. Permanent scientists, the administrative staff and long term visitors have their photographs and names on 2 boards at the ground floor of the Institute. There are several teams of researchers, specialized in different aspects of gravitational physics, that is based on the relativity theory founded by Albert Einstein. You have specialists on pure relativity, on astrophysics, on numerical relativity...., in the Institute. Recall that Einstein said: "What is incomprehensible is that the world be understandable". He expressed that way the fact that one often has to overcome incomparable scientific difficulties to understand the real structure of a phenomenon that finally seems to be quite normal. So is Nature. To Einstein who sometimes thought that things were too complicated and should not be made the way they are, a colleague, exasperated by all of that shouted: "Einstein, stop telling God what to do!" Therefore, one can easily understand why there should exist several specialized teams at the Institute, to look at different aspects of the general relativity theory, known to be not easy. Also recall that a journalist asked Professor Eddington, an eminent specialist of relativity theory, the following question: "Professor, is it true that only three persons really understand the relativity theory of Albert Einstein?" After a moment of perplexity, the professor answered: "I don't see who is the third person". The professor meant that after Albert Einstein and himself, he really didn't see a third person able to understand that theory.

In the Institute, one has to choose carefully between the widely announced titles of conferences of high level, delivered almost every day by either permanent or visiting scientists. One can also see on the boards, announcements for conferences and seminars on close areas, to be held all over the world. In addition to the library quoted above, scientists rely on a powerful computer support. Each office of the Institute has at least one improved computer and a department called "Computer Support" is ready to intervene at any moment if necessary, and it always informs the users a long time earlier, if a disconnection of the computer system is planned, in order to save works or information. Every scientist is free to stay in his (or her) office, as long as he (or she) desires, even on holidays, and they do so. It is usual to see a researcher in front of his computer after midnight. Scientists of the Institute can connect with each other by e-mail or by phone, using the list of phone numbers one can find in each office or in the internet homepage of the Institute. Every scientist, permanent or visitor, has a mailbox at the Institute. I had the pleasure to find in mine, as every other scientist I suppose, the journal "Gravitation - Urkraft des Kosmos", a special issue of the popular astronomy journal "Sterne und Weltraum". Although everything inside is in German, I could nevertheless discover the photographs of eminent scientists as: Laplace, Newton, Einstein (naturally), Maxwell, Lorentz, Michelson, Mach, Minkowski, Eddington, Schwarzschild, Hubble, well known by every researcher in gravitational physics.

From time to time the Institute issues a booklet indicating articles about new and significant developments in the area, to be found on the homepage of the Institute. I even printed some between those indicated by the booklet "Living Reviews in Relativity".
I have to deplore the poor representation of the Sub Saharian Black Africa in this highly qualified Research Center where one can see Scientists from all over the world. I was alone from that Region during the two months of stay....I would also encourage the Institute to organize more seminars for undergraduate students.

Conclusion

When I left the Max Planck Institute for Gravitational Physics, Albert Einstein Institute on April 28, 2001, I was sure that I will come again.

Norbert Noutchéguémé,
University of Yaounde I (Cameroon)

Robert Helling wins Dietrich Rampacher Prize

In order to encourage early graduations, the Max Planck Society honours its youngest doctoral candidate - usually about 26 or 27 years old - with the "Dietrich Rampacher Prize" for the superior promise shown by his or her doctorate. In 2000 this prize was awarded to Robert Helling who received the award during the annual general meeting of the Max Planck Society 2001 in Berlin. The prize was endowed by a Supporting Member of the Max Planck Society in 1985.

Adam Schwimmer wins Humboldt Research Award

One of the prestigious Humboldt Research Awards in 2001 was given to Adam Schwimmer from the Weizmann Institute in Jerusalem. Prof. Schwimmer devotes his grant to work on string theory and quantum field theory at the AEI together with Stefan Theisen. The Alexander von Humboldt Foundation grants up to 150 Humboldt Research Awards annually to foreign scientists and scholars with internationally recognized academic qualifications. The research award honours the academic lifetime achievements of the award winners. Furthermore, award winners are invited to carry out research projects of their own choice in Germany in cooperation with German colleagues for periods of between six months and one year.

Volkswagen Foundation Supports Collaboration With Scientists from Cameroon

The year 2001 saw the start of a project funded by the Volkswagen Foundation and led by Alan Rendall (AEI) and Norbert Noutchéguemé (Department of Mathematics, University of Yaounde I, Cameroon). This followed a visit to AEI by Noutchéguemé which he describes elsewhere in this report. The aim of this project is to carry out research into the applications of the theory of partial differential equations to the study of the dynamics of self-gravitating collisionless matter. The project will run for three years and apart from supporting the collaboration of Noutchéguemé and Rendall will contribute to the training of five graduate students from Yaounde. Three of them will spend extended periods at AEI with a view to obtaining their doctorates. This project will help to maintain a centre of mathematical excellence in Yaounde.

XIII'th workshop "Beyond the Standard Model" Bad Honnef, March 12-15, 2001

This was the yearly meeting of the theoretical high energy physics community in Germany and neighbouring countries with an emphasis on physics beyond the standard model. In the past the format consisted of presentations of recent results, where one of the purposes of the

The Physikzentrum Bad Honnef.

meeting was to give young researchers (doctoral students and postdocs) the chance to present their results and to introduce themselves to the community. The organizer of the 2001 meeting (Stefan Theisen) changed this format by inviting four senior lecturers to give a 90 minute pedagogical introduction to to current areas of research. The topics chosen were (1) large extra dimensions, (2) cosmology, (3) field theory in non-commutative space-times and (4) conformal field theory and D-branes. The rest of the time was filled with shorter presentations and discussion sessions.

VIIth Summerschool "Grundlagen und Neue Methoden der Theoretischen Physik" Saalburg, September 3-14, 2001

This school, which was funded by the Heraeus foundation, was the seventh school for doctoral students founded and organized by O. Lechtenfeld (Hannover), J. Louis (Halle), S. Theisen (Golm) and A. Wipf (Jena). The purpose of the school is to introduce students to recent methods of theoretical physics, which are not covered in special courses at their home university. The need for such a school arose from the fact that there are many small physics departments which cannot offer courses to cover all recent developments in theoretical physics. The school consists of 11 days of two 90 minute lectures. In the afternoon the students solve homework problems which are discussed in the evening. The attendance is limited to 35 students.

EU-RTN Network Meeting

The Quantum Structure of Spacetime and the Geometric Nature of Fundamental Interactions, Corfu Sept. 13-20, 2001 was part of the three week 2001 Corfu Summer Institute on elementary particle physics. The meeting was jointly organized by D. Lüst, K. Kounnas and S. Theisen. The format of the meeting, which stressed its partly pedagogical nature, consisted of invited introductory lectures, shorter presentations by participants and daily discussion sessions. The proceedings will be published as special volumes of Fortschritte der Physik.

Workshop on the Conformal Structure of Spacetimes Tübingen, April 2 - 4, 2001

J. Frauendiener and H. Friedrich organized a workshop on "The Conformal Structure of Spacetimes: Geometry, Analysis, Numerics" which took place April 2 - 4, 2001, in Tübingen. The talks where mainly concerned with geometrical studies of conformal structures in the large, the construction and structure of initial data, the analysis and the numerics of the conformal field equations, and the numerics based on characteristic initial value problems. While the organizers had planned to have a very small specialized workshop, the news about it spread very quickly and in the end the capacity of the conference time/place was exhausted by 24 talks and ca. 50 participants.

Vacation Course Gravitational Physics

The 2-weeks vacation course on "Gravitational Physics", which the AEI started in 1999 together with the University of Potsdam, took place for the third time from March 5 - 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 gave an "Introduction into General Relativity". Bernd Schmidt lectured on the "Mathematical foundations". The second lecture series was this time split: Helmut Friedrich talked on "Gravitational Radiation of isolated systems" and Alan Rendall on "Cosmological Models". 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.


Hermann von Helmholtz, 1821 - 1894

Helmholtz Institute for Supercomputational Physics

The AEI is one of seven institutes in the Potsdam area that have joined in 2001 to found a new institute, the Helmholtz Institute for Supercomputational Physics. The central objective of the Helmholtz Institute is to teach programming on supercomputers. The courses will be given in form of a four week summer school held at the University of Potsdam in Germany. The curriculum focuses on the methods required for a successful numerical solution of modern problems in physics using parallel computers. These methods are applied to current problems in computational physics, as in hydrodynamics, numerical relativity, astrophysics, climate research, structure formation, and spatio-temporal dynamics of complex systems, as they are actively studied in the joining institutions of the Helmholtz Institute. The Helmholtz Institute is funded by the Ministerium für Wissenschaft, Forschung und Kultur Brandenburg. The summerschool 2001 on "Tools to Simulate Turbulence on Supercomputers" was held with over thirty participants from August 27 to September 21 at the Campus in Golm of the University of Potsdam. The participants were welcomed by the directors of the Helmholtz Institute, Prof. Jürgen Kurths and Prof. Günther Rüdiger, and by the minister of research in Brandenburg, Prof. Johanna Wanka. Scientific Director was Axel Brandenburg, NORDITA Copenhagen, with Scientific Assistant Wolfgang Dobler, University of Newcastle upon Tyne. The AEI supported this years school with access to its 64 processor SGI/Origin 2000 computer, and the Cactus group of the AEI contributed several tutorials on Cactus. On August 31, there was a visit to the AEI with presentations by Bernd Brügmann and Ed Seidel, and a 3d visualization demo by Gerd Lanfermann.

See http://hisp.agnld.uni-potsdam.de/ for further information.

Computer Infrastructure News

The pleasant anticipation the members of the institute have had in 2000 concerning the possibility to purchase an Origin3000i/SN-Itanium parallel computer from SGI with the coming Itanium processors of Intel turned into disappointment as the promise of SGI to build systems with these processors did not become true. The enormous time delay that resulted from this flop was a big disadvantage for the researchers, although another 32 CPUs and 8 GB RAM have been added to the existing Origin 2000. On the other hand the time was used to go on looking for interesting alternatives, which had the chance for further development in the meantime. Especially Linux based compute clusters have matured enough that they are taken into account now. For the final design of the Origin replacement, the decision making process is still underway. The most important point in this is the type of network interconnects suitable for the applications to be run on the cluster. The design of another type of computer cluster was more successful. The institute was granted money by the BAR to be able to expand the AEI's prototype cluster-type parallel computer which will be used to search for Gravitational Waves. The purpose of this Cluster Computer is to analyze the enormous amounts of good quality data that will be produced by the GEO600 gravitational wave detector in the sub-institute in Hannover. A lot of benchmarks of the required algorithms have lead to a complete and very specific list of hardware parts that fulfill the requirements (high performance, low costs per CPU, low heat emission) for this cluster. The tests on the hardware are now finished and the next step, the design of a suitable software environment for the search algorithms is in progress. The cluster is expected to be purchased during the summer of 2002, to start analyzing the data provided by Hannover. To be able to store the masses of data coming from the GEO600 detector, the institute also has purchased a dedicated RAID server with a capacity 1 TB.

Less spectacular but nevertheless as well as important is the purchase of Window 2000 servers and clients systems. Window 2000 Server and Window 2000 Advanced Server systems have been installed. New services, for example Active Directory, have been tested thoroughly by members of the support group. As some people have left the group in the last quarter of 2001, these investigations have not yet lead to productive work.

20 workstations from Dell with Dual Xeon P4 processors with a clock rate of 1.7 GHz could be bought as well. Most of these systems have replaced old DEC-stations and SGI-Indy's and thus have updated the computer power on the desks of the scientists. The number of notebooks has increased steadily due to the growing need for mobile work places.

Time has been spent on reconfiguring the network, especially with respect to increasing security. The network has been divided into a private and public network. NAT (Network Address Translation) helps to combine the two parts. One reason to do so, is to make the computer systems of the institute less visible to and less accessible from the outside world. People from outside the AEI now can only log in into a few dedicated systems. Although this makes life of the scientists, who are used to work from all over the world on data stored on systems of the institute, less convenient, it is worth the trouble.

Librarians Meeting at the AEI

In May 2001, the AEI hosted the 24th Annual Max Planck Society Librarians Meeting with about 110 participants. The purpose of these meetings is to discuss new aspects in librarianship and information management.

Do 110 librarians make up a critical mass of learning ? In May 2001 the AEI had the chance to find out.

Ernst von Biron, representing the General Administration in Munich, gave an overview on the data bases and e-journals infrastructure the Society provides for the institutes. External specialists gave talks about new trends in general librarianship and colleagues from various Max Planck Institutes talked about concrete questions. As in the previous

years, we focussed on the development of the new media (e.g. e-journals, web-OPACs, document delivery systems, metadata, library systems). Librarians from the three sections of the Max Planck Society presented their work and explained how they deal with special items. The group also discussed solutions for every day problems such as handling credit cards, fundraising, interloan services and many more. The participants enjoyed very much a social programme showing the beautiful landscape of Potsdam and a nice barbecue on the Campus. These social events were funded by several companies - our partners in librarianship that displayed their products in an exhibition in the central building. The talks given during the meeting were published in a conference transcript.

Sports

"Mens sana in corpore sano", and only veritable spoilsports would point out that this quote's author was Ancient Rome's most famous satirist. Such historical subtleties aside, sport has long had its place at the Albert Einstein Institute, and although the negotiations for the institute's own yacht appear to have reached an impasse, lots of other sporting activities have taken place during the past year.

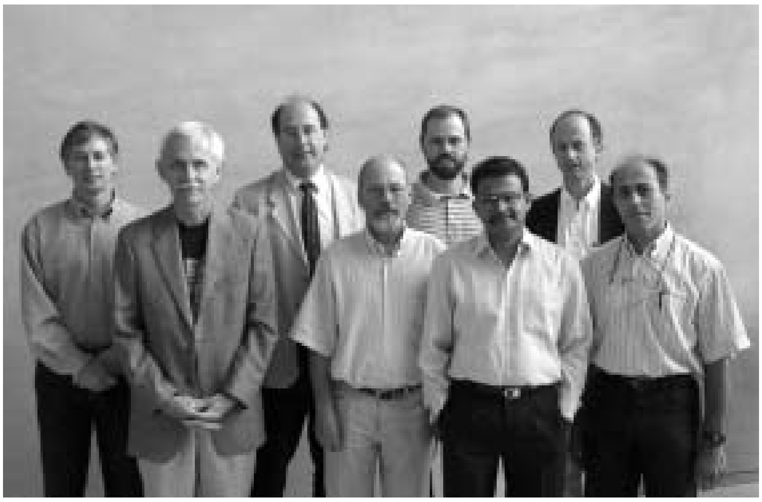
The Golm impromptu cricket team at one of the regular Thursday meets.

Every Wednesday, institute members can be seen vigorously playing football, risking, if not life and limb, then at least the occasional tooth. Sadly, though, the institute's team was not able to repeat previous year's near-triumph in the Golm Campus Football Tournament; a failure that football spokes-persons have blamed on the absence of key players, poor pitch conditions, and the fact that the other teams somehow managed to score more goals. Thursday is cricket day: AEI's flannelled fools have been at it with verve and panache, and would like to thank the caretaker, Peter Westermeier, for his great patience in retrieving those balls that enthusiastic batsmen had managed to propel onto various roofs or into other inaccessible parts of the Campus landscape. If that's not enough, there's always the possibility of joining the AEI Jogging Club, whose members regularly flock to the surrounding Brandenburg countryside. Whether such feats of physical exertion would have found favour in the eyes of good ol' Albert is another matter. That great mind fondly described his own favourite pastime, sailing, as "the sport which requires the least amount of energy".

Challenges for Living Reviews in Relativity: MoWGLI and Living Reviews BackOffice

The electronic journal Living Reviews in Relativity being now online in its fourth year, has continued to become a primary entry point for students, lecturers and researchers alike for up-to-date, refereed information on the current status of research in gravitational physics. Combining the quality and reliability of a classical scholarly journal with the advantages of the electronic format, Living Reviews in Relativity has been developed into an invaluable research tool for scientists of the relativity community, which is impressively shown by a steadily growing web site traffic, several hundred downloads per article and enthusiastic feedback from authors and readers.

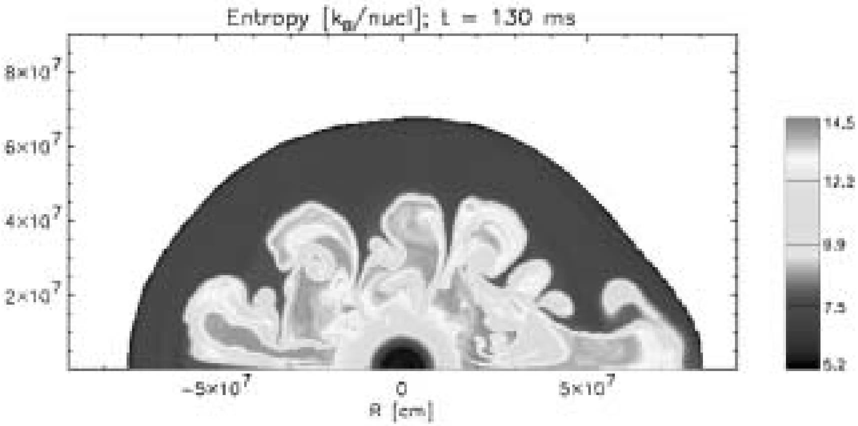
Living Reviews in Relativity is published by the Max Planck Institute for Gravitational Physics and is provided as a free service to the scientific community. One of the most important features of Living Reviews is that its articles are revised and updated periodically by their authors as the research field develops. Articles remain current as long as their research areas remain active. This is the significance of the word 'living' in the journal's title. Living Reviews articles are written by experts in their field and are presented online in a well-integrated hypertext viewing environment. As an electronic journal, Living Reviews encourages its authors to include Web links to important scientific resources: articles available in electronic form elsewhere, Web sites of scientific institutions and projects, Web-based bibliographies or databases, preprints and the like. Articles may include an unlimited number of colorful figures and animations, graphics, tables or even program code.



Members of the editorial board of Living Reviews in Relativity. From left to right: Ed Seidel, Cliff Will, Bernard Schutz, Bernd Schmidt, Bernd Brügmann, Bala Iyer, Joachim Wambsganss, Robert Beig.

Six new review articles have been published in 2001, of which 3 are already updates of earlier article versions. 21 new authors have accepted the invitation to write and maintain a 'living' review, so that Living Review is currently cooperating with more than 100 authors. The editorial board, which advises the journal's overall development and is responsible for suggesting article topics, choosing authors and referees, has been further extended. Joachim Wambsganss (Potsdam University) and Robert Beig (University of Vienna) have joined it, improving the journal's expertise in the fields of Physical Cosmology and Mathematical Relativity.

In 2001 Living Reviews in Relativity has also seen some staff transitions. Theresa Velden, Managing Editor of the journal for three years, has left the institute in August 2001 after being appointed to become the Executive Director of the newly founded *Heinz Nixdorf Center for Information Management within the Max Planck Society (ZIM)*, which has set up to support researchers and research processes in the area of information management. Christina Weyher, who had been working as part-time editorial assistant for Living Reviews for the last four years, took over Theresa's position as Acting Managing Editor.



Animation from a living review on "Numerical Hydrodynamics in General Relativity" by J.A. Font.

Two major projects have been started in 2001: First, Living Reviews in Relativity is joining an international consortium of research teams in the EU-IST project **MoWGLI** (**M**athematics **o**n the **W**eb: **G**et it by **L**ogic and **I**nterface). The involvement of Living Reviews into the MoWGLI project is motivated by the possibility to explore ways for the content-mark-up of mathematical information as it is presented in its review articles, making it available for semantic search, and for re-use and evaluation, e.g. in math algebra systems. The journal will develop a LaTeX-based authoring tool, and serve as a showcase to demonstrate how content-mark-up in mathematics improves the usability and information depth of electronic science journals. The 30-month MoWGLI project has been positively evaluated by the European Commission in November 2001, and is going to start in March 2002. The journal will be granted financial support for a two-years programmer position.

The second project, even more important, is the *Living Reviews BackOffice*. From the very beginning Living Reviews was not only intended to become a primary reference for the relativity community, but also to serve as a prototype for a larger family of Living Reviews journals in many fields. With the *Living Reviews BackOffice* we will now share our software developments and our experience in setting up an electronic journal with other Max Planck Institutes. The institutes will be enabled to publish a high-quality, peer-refereed Living Reviews journal in their own field with a minimal investment of resources. The *BackOffice* will provide the electronic publishing service and the technical infrastructure to manage and maintain the electronic journal, whereas the partner institutes will take care of the scientific input. The *Living Reviews BackOffice* will operate in close cooperation with the *Heinz Nixdorf Center for Information Management within the Max Planck Society*, for which the *BackOffice* will additionally serve as a test bed in development of advanced electronic publishing technologies. The next year will be used to gradually transform the editorial office of Living Reviews in Relativity into the *Living Reviews BackOffice*.

Christina Weyher

EditorLR@aei.mpg.de, +49-331-567 7441

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 2001

New Director at the AEI

Karsten Danzmann, head of the AEI Außenstelle in Hannover and full professor for physics at the University of Hannover accepted the position of a director at the AEI. With the establishment of his division on Laserinterferometry and Gravitational Wave Astronomy, the AEI in Hannover was officially founded at the beginning of 2002. Prof. Danzmann is the European Co-Chair of the LISA International Science Team of the joint ESA/NASA project LISA (Laser Interferometer Space Antenna) and the ESA-appointed LISA Mission Scientist. He is also Co-PI of the German-British GEO600 ground-based gravitational wave detector project. As an AEI director he remains a full professor at the University of Hannover.

New Director at the AEI

Research areas in the Geometric Analysis and Gravitation Division (formerly Classical and Mathematical Relativity Division) have been expanded with the start of the new director: Gerhard Huisken has accepted the offer of the Max Planck Society and now fulfils the position of a director at the AEI. Gerhard Huisken was a full professor for mathematics at Tübingen University and is on the editorial board of several mathematical journals, such as "Journal für die Reine und Angewandte Mathematik", "Mathematical Research Letters" and "Annals of Mathematics".

Doctoral Thesis

Oliver Henkel was awarded his PhD from the Universität Potsdam. He wrote his doctoral thesis on "Prescribed Mean Curvature foliations in cosmological spacetimes with matter" supervised by Dr. habil. Alan Rendall.

Doctoral Thesis

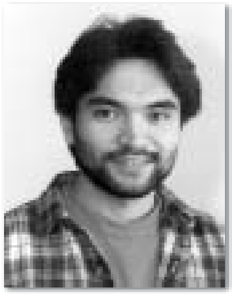
Kilian Koepsell completed his PhD thesis on "Maximal Supergravity and Exceptional Symmetries" supervised by Prof. Hermann Nicolai. He was awarded his PhD from Hamburg University.

Doctoral Thesis

Alessandra Rocco finished her PhD thesis at the AEI in Hannover on "Negative dispersion without absorption in atomic ensembles" supervised by Dr. Rolf Rinkleff. She was awarded her PhD from Hannover University.

Doctoral Thesis

Emanuel Scheidegger was awarded his PhD from the Ludwig-Maximilians-Universität in München. Supervised by Prof. Stefan Theisen the thesis was written on "D-branes on Calabi-Yau Spaces".



Doctoral Thesis

Ryoji Takahashi was awarded his PhD from the Universität Potsdam. He wrote his doctoral thesis on "Numerical Study of 3D Rotating Black Spacetimes" under the supervision of Prof. Ed Seidel.

Doctoral Thesis

Oliver Winkler completed his PhD thesis on "Mathematical methods for a semiclassical limit of quantum general relativity" supervised by Dr. habil. Thomas Thiemann. He was awarded his PhD from Humboldt University Berlin.

Diploma Thesis

Mihai Bondarescu graduated in physics from the Freie Universität Berlin. He wrote his diploma thesis at the AEI under the supervision of Prof. Ed Seidel on "Embeddings of Black Hole Surfaces in Flat Threedimensional Space".

Diploma Thesis

Christoph Dehne has completed his diploma in physics at Hamburg University. It was written at the AEI under the supervision of Dr. habil. Renate Loll on "Konstruktionsversuche eines quantenkosmologischen, dynamisch triangulierten Torusuniversums in 2+1 Dimensionen".

Diploma Thesis

Thomas Wildhagen graduated in physics from Hannover University. He wrote his diploma thesis at the AEI in Hannover under the supervision of Dipl.-Phys. Michèle Heurs on "Langzeit-Frequenzstabilisierung eines Nd:YAG-Lasersystems auf molekulares Jod".

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.

Members of the Fachbeirat in 2001:

Prof. Dr. Robert Beig
Institut für Theoretische Physik
Wien

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

Prof. Dr. Hubert Goenner
Institut für Theoretische Physik
Göttingen

Prof. Dr. James Hartle
Physics Department
Univesity 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

Prof. Dr. Kip Thorne
LIGO 130-33
California Institute of Technology, Pasadena

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

The Board of Trustees

In 2001 a Board of Trustees (Kuratorium) was appointed at the AEI. The Board of Trustees is primarily intended to inspire confidence and create good relations between the Institute and the public. After all, a scientific organisation is dependent on the public interest in the opportunities offered by research and even on the public's willingness to bear the burden of research.

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

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Prof. Dr. Gerhard Huisken	Geometric Analysis and Gravitation
Prof. Dr. Hermann Nicolai	Quantum Gravity and Unified Theories
Prof. Dr. Bernard F. Schutz	Astrophysical Relativity

Director Emeritus

Prof. Dr. Jürgen Ehlers	Classical and Mathematical Relativity

Scientists

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Dr. Jan Plefka (AEI Golm)
Dr. Alan Rendall (AEI Golm)
Albrecht Rüdiger (AEI Garching)
Dr. Rolf-H. Rinkleff (AEI Hannover)
Roland Schilling (AEI Garching)
Prof. Bernd Schmidt (AEI Golm)
Dr. Volker Schomerus (AEI Golm)
Prof. Edward Seidel (AEI Golm)
Dr. Matthias Staudacher (AEI Golm)
Prof. Stefan Theisen (AEI Golm)
Dr. Thomas Thiemann (AEI Golm)
Dr. Wolfgang Tichy (AEI Golm)
Dr. Andreas Wicht (AEI Hannover)
Dr. Benno Willke (AEI Hannover)
Dr. Walter Winkler (AEI Garching)

Doctoral Students

Carsten Aulbert (AEI Golm)
Werner Benger (AEI Golm/ZIB Berlin)
Simone Calogero (AEI Golm)
Ernst Nils Dorband (AEI Golm)
Thomas Dramlitsch (AEI Golm)
Thomas Fischbacher (AEI Golm)
Stefan Fredenhagen (AEI Golm)
Andreas Freise (AEI Hannover)
Stefan Goßler (AEI Hannover)
Hartmut Grote (AEI Hannover)
Andreas Hartl (AEI Golm)
Frank Herrmann (AEI Golm)
Michèle Heurs (AEI Hannover)
Ralf Kähler (AEI Golm/ZIB Berlin)
Karsten Kötter (AEI Hannover)
Michael Koppitz (AEI Golm)
Gerd Lanfermann (AEI Golm)
Volker Leonhardt (AEI Hannover)
Michaela Malec (AEI Hannover)
Ari Pankiewitz (AEI Golm)
Markus Pössel (AEI Golm)
Thomas Quella (AEI Golm)
Volker Quetschke (AEI Hannover)
Norma Quiroz (AEI Golm)
Luciano Ribichini (AEI Hannover)
Hanno Sahlmann (AEI Golm)
Sascha Skorupka (AEI Hannover)
Luca Spani Molella (AEI Hannover)
Michael Tröbs (AEI Hannover)
Uta Weiland (AEI Hannover)

Post-Docs (internally funded)

Dr. Gleb Arutjunov (AEI Golm)
Dr. Adrian Butscher (AEI Golm)
Dr. Carlo N. Colacino (AEI Hannover)
Dr. Sergio Dain (AEI Golm)
Dr. Arundhati Dasgupta (AEI Golm)
Dr. Ian Hawke (AEI Golm)
Dr. Scott H. Hawley (AEI Golm)
Dr. Keita Kawabe (AEI Garching)
Dr. Nakwoo Kim (AEI Golm)
Dr. Christine Lechner (AEI Golm)
Dr. Esperanza Lopez (AEI Golm)
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Dr. Marc Mars (AEI Golm)
Dr. Soumya Mohanty (AEI Golm)
Dr. Soma Mukherjee (AEI Golm)
Dr. Shigeo Nagano (AEI Hannover)
Dr. Denis Pollney (AEI Golm)
Dr. David Rideout (AEI Golm)
Dr. Hans Ringström (AEI Golm)
Dr. Alicia Sintes Olives (AEI Golm)
Dr. Keisuke Tanaguchi (AEI Golm)
Dr. Juan A. Valiente Kroon (AEI Golm)

Post-Docs (AEI Golm, externally funded)

Dr. Leor Barack
European Union
Dr. Manuela Campanelli
European Union
Dr. Peter Diener
European Union
Dr. Bénédicte Ponsot
European Union
Dr. Sebastián Silva
European Union

Diploma Students

Cintia Andrade Alvarenga de Caux (AEI Hannover)
Christian Böhmer (AEI Golm)
Simon Borger (AEI Golm)
Johannes Brunnemann (AEI Golm)
Jan Harms (AEI Hannover)
Sven Herden (AEI Hannover)
Bernd Reimann (AEI Golm)
Vinzenz Wand (AEI Hannover)

Support Staff

Almuth Barta	Computer Administration (AEI Golm)
Sven Borngräber	Computer Systems Support (AEI Golm)
Paul Collins	Scientific Helpforce (AEI Hannover)
Sascha Curth	Computer Systems Support (AEI Golm)
Harald Dimmelmeier	Technical Editorial Assistant Living Reviews (AEI Golm)
Ralf Döhler	Computer Systems Support (AEI Golm)
Andreas Donath	Computer Systems Support (AEI Golm)
Thomas Feg	Computer Systems Support (AEI Golm)
Elke Geisler	Secretary for EU Projects (AEI Golm)
Christine Gottschalkson	Secretary (AEI Golm)
Walter Grass	Technician (AEI Hannover)
Klaus-D. Haupt	Electronic Technician (AEI Hannover)
Brigitte Hauschild	Secretary (AEI Golm)
Katharina Henke	Administrative Assistant (AEI Golm)
Stefan Hild	Scientific Helpforce (AEI Hannover)
Babette Iserhot	Accounting (AEI Golm)
Ian Kelley	Programmer (AEI Golm)
Gisela Klausewitz	Library Assistant (AEI Golm)
Annegret Klassert	PR Assistant (AEI Golm)
Angelika Klawitter	Secretary (AEI Hannover)
Sabrina Kraatz	Trainee (AEI Golm)
Anne Lampe	Secretary (AEI Golm)
Anja Lehmann	Library Assistant (AEI Golm)
Bernd Matthias	Scientific Helpforce (AEI Hannover)
Manuela Minckert	Personnel Office (AEI Golm)
Dr. Elke Müller	Scientific Coordination & PR (AEI Golm)
Constanze Münchow	Administrative Assistant (AEI Golm)
Nils Murray	Scientific Helpforce (AEI Hannover)
Holger Naundorf	Computer Administration (AEI Golm)
Vera Oßwald	Editorial Assistant Living Reviews (AEI Golm)
Christina Pappa	Charwoman (AEI Golm)
Susann Purschke	Guest House Manager (AEI Golm)
Thomas Radke	Programmer (AEI Golm)
Christiane Roos	Head of Administration (AEI Golm)
Jörg Roscher	Personnel Office (AEI Golm)
Elisabeth Schlenk	Librarian (AEI Golm)
Ute Schlichting	Secretary (AEI Golm)
Stanislaw Schreiber	Trainee (AEI Golm)
Dennis Suichninski	Trainee (AEI Golm)
Andre Thüring	Scientific Helpforce (AEI Hannover)
Susann Weber	Administrative Assistant (AEI Golm)
Andreas Weidner	Electronic Technician (Garching)
Andre Werthmann	Computer Systems Support (AEI Golm)
Christina Weyher	Acting Managing Editor Living Review (AEI Golm)
Dietlind Witzger	Charwoman (AEI Golm)
Ramona Wittwer	Accounting (AEI Golm)
Heiko zur Mühlen	Electronic Technician (AEI Hannover)
Karl-H. Zwick-Meinheit	Electronic Technician (AEI Hannover)

Guest Scientists

Ahn, C.	Kyungpook National University	29/01/2001-17/02/2001
Akemann, G.	MPI für Kernphysik, Heidelberg	29/01/2001-31/01/2001
Allen, B.	University of Wisconsin	01/06/2001-30/11/2001
		16/12/2001-24/12/2001
Ambjørn, J.	Niels Bohr Institute, Copenhagen	21/05/2001-11/06/2001
Andreasson, H.	Chalmers University, Göteborg	04/04/2001-06/04/2001
Andric, I.	Theoretical Physics Institute, Zagreb	16/12/2001-19/12/2001
Ansorg, M.	Universität Jena	06/09/2001-07/09/2001
		01/10/2001-05/10/2001
Argyres, P.	Cornell University	27/07/2001-27/07/2001
Armoni, A.	CERN, Geneva	15/11/2001-23/11/2001
Asada, H.	Hirosaki University	25/09/2001-01/10/2001
Austing, P.	Oxford University	28/01/2001-03/02/2001
Babak, S.	Cardiff University	17/09/2001-27/09/2001
		22/11/2001-28/11/2001
Baiotti, L.	SISSA Trieste	14/05/2001-26/05/2001
Balasubramanian, R.	Cardiff University	17/09/2001-28/09/2001
		18/11/2001-28/11/2001
Beetle, C.	University of Utah	14/05/2001-22/05/2001
Beig, R.	Universität Wien	24/06/2001-14/07/2001
		19/08/2001-21/09/2001
Bičak, J.	Charles University, Prague	15/01/2001-28/02/2001
		04/09/2001-31/10/2001
Bishop, N.	University of South Africa	27/11/2001-22/12/2001
Bizon, P.	Cracow University	02/04/2001-30/06/2001
Bludman, S.	DESY, Hamburg	11/12/2001-12/12/2001
Brandt, F.	Universität Hannover	01/10/2000-31/03/2001
Camarda, K.	University of Kansas	04/06/2001-09/06/2001
Carey, A.	University of Adelaide	09/06/2001-13/06/2001
Cello, G.	University of Urbino	23/10/2001-26/10/2001
Chrusciel, P.	Tours University	01/07/2001-14/07/2001
		15/09/2001-26/09/2001
Churches, D.	Cardiff University	31/05/2001-03/06/2001
Colacino, C.	Universität Hannover	25/10/2001-26/10/2001
Das, S.	University of Winnipeg	02/05/2001-09/05/2001
Davies, R.	Cardiff University	17/01/2001-02/02/2001
Dereli, T.	Lancaster University	07/04/2001-12/04/2001
de Wit, B.	Utrecht University	28/01/2001-23/02/2001
		18/03/2001-06/04/2001
		30/09/2001-05/10/2001
d´Inverno, R.	University of Southampton	20/05/2001-27/05/2001
Dreyer, O.	Pennsylvania State University	08/01/2001-12/01/2001
Dupuis, R.	University of Glasgow	11/01/2001-25/01/2001
Faye, G.	Universität Jena	24/07/2001-31/07/2001
Fiske, D.	University of Maryland	09/04/2001-20/04/2001
Flanagan, E.	Cornell University	12/08/2001-17/08/2001
Foerste, S.	Universität Bonn	30/08/2001-06/09/2001
Font, A.	University of Caracas	24/09/2001-26/09/2001
Frauendiener, J.	Universität Tübingen	15/10/2001-25/10/2001
Freidel, L.	ENS, Lyon	26/02/2001-05/03/2001
Friedman, J.	University of Wisconsin	02/05/2001-31/05/2001
Garecki, J.	University of Szczecin	10/09/2001-20/09/2001
Ghoshal, D.	Harish Chandra Institute, Allahabad	14/05/2001-30/06/2001
Gibbons, G.	DAMTP, Cambridge	11/09/2001-15/09/2001
Goenner, H.	Universität Göttingen	11/09/2001-14/09/2001
Guidi, G.	University of Urbino	23/10/2001-26/10/2001
Hanauske, M.	Universität Frankfurt	10/06/2001-15/06/2001
Hansen, J.	Theoretical Astrophysics Center, Copenhagen	02/09/2001-09/09/2001
Hartle, J.	University of Santa Barbara	10/09/2001-15/09/2001
Hawkins, E.	Pennsylvania State University	28/02/2001-07/03/2001
Herger, I.	Utrecht University	15/02/2001-21/02/2001
		01/04/2001-06/04/2001
Hillebrandt, W.	MPI für Astrophysik, Garching	13/09/2001-14/09/2001
Hobill, D.	University of Calgary	28/04/2001-05/05/2001
Husemoller, D.	MPI für Mathematik, Bonn	26/01/2001-28/01/2001
		05/08/2001-12/08/2001
Itoh, Y.	Tohoku University, Sendai	01/11/2000-31/01/2001
Iyer, B.	Raman Research Institute, Bangalore	06/09/2001-10/09/2001
Jansen, N.	Theoretical Astrophysics Center, Copenhagen	02/09/2001-09/09/2001
		03/02/2001-31/05/2001
		27/04/2001-31/05/2001
Joseph, S.	Talbot Laboratory, Urbana	22/06/2001-05/07/2001
Kalogera, V.	Harvard University	14/01/2001-21/01/2001
Kanatczikov, I.	Tallin Technical University	02/05/2001-08/05/2001
Käppeli, J.	Utrecht University	19/03/2001-23/03/2001
Keurentjes, A.	LPTHE, Paris	28/05/2001-01/06/2001
Kiefer, K.	Universität Köln	08/08/2001-09/08/2001

Guest Scientists

Klemm, D.	Milan University	12/11/2001-12/12/2001
Kokkotas, K.	Aristotele University, Thessaloniki	01/04/2001-15/04/2001
Kostov, I.	CEA, Saclay	24/02/2001-02/03/2001
		05/04/2001-08/04/2001
Kötter, K.	Universität Hannover	31/05/2001-02/06/2001
Krasnov, K.	University of Santa Barbara	04/06/2001-12/06/2001
Kristjansen, C.	Niels Bohr Institute Copenhagen	06/03/2001-16/03/2001
Krtous, P.	Charles University, Prague	17/09/2001-06/10/2001
Kurowski, K.	Poznan University	27/02/2001-02/03/2001
Kuzenko, S.	University of Western Australia	01/02/2001-31/03/2001
Lang, C.	Universität Graz	09/04/2001-13/04/2001
Lau, S.	University of North Carolina	01/08/2001-23/08/2001
Lehner, L.	University of British Columbia, Vancouver	27/03/2001-01/04/2001
Lewandowski, J.	Warsaw University	03/07/2001-18/08/2001
Lledo, F.	RWTH Aachen	09/08/2001-15/08/2001
		28/03/2001-12/04/2001
Lowe, D.	Brown University, Providence	28/05/2001-08/06/2001
Ludwiczak, B.	Poznan Supercomputing Center	27/02/2001-02/03/2001
Madore, J.	University of Paris (South)	01/05/2001-31/05/2001
Maharana, J.	Institute of Physics, Bhubaneswar	01/02/2001-31/07/2001
Malec, E.	Cracow University	20/08/2001-10/09/2001
		25/11/2001-04/12/2001
Marronetti, P.	University of Texas at Austin	09/04/2001-21/04/2001
Massaioli, F.	CASPUR/Rome University	18/04/2001-28/04/2001
Matos, T.	Centro de Investigación y Estudios Avanzados, Mexico	08/01/2001-12/01/2001
Matzner, R.	University of Texas at Austin	10/09/2001-18/09/2001
McArthur, I.	University of Western Australia	30/09/2001-09/10/2001
Minasian, R.	CHPT, Paris	02/08/2001-19/08/2001
Misner, C.	University of Maryland	06/11/2000-30/04/2001
Moncrief, V.	Yale University	28/02/2001-19/03/2001
		16/08/2001-09/09/2001
		29/12/2001-14/01/2002
Montero, P.	SISSA Trieste	14/05/2001-26/05/2001
Nagy, G.	University of Cordoba	10/03/2001-10/04/2001
		01/06/2001-31/12/2001
Newman, E.	University of Pittsburgh	05/04/2001-12/04/2001
Noutcheguеme, N.	University of Yaounde	05/03/2001-29/04/2001
Nunez, D.	Universidad Nacional Autónoma de México	07/01/2001-14/01/2001
Ogievetsky, O.	Marseille University	17/11/2001-17/12/2001
Olive, D.	University of Wales	03/06/2001-15/06/2001
O´Murchadha, N.	University College Cork	05/04/2001-11/04/2001
Owen, B.	University of Wisconsin, Milwaukee	28/07/2001-17/08/2001
Palomba, C.	University of Rome	18/04/2001-28/04/2001
Pawlowski, T.	University of Warsaw	10/07/2001-30/07/2001
Penrose, R.	University of Oxford, UK	11/09/2001-14/09/2001
Pfister, H.	Universität Tübingen	14/10/2001-19/10/2001
Pioline, B.	LPTHE, Paris	15/07/2001-28/07/2001
Price, R.	University of Utah	01/04/2001-06/04/2001
Pullin, J.	Louisiana State University	26/05/2001-07/06/2001
		12/12/2001-16/12/2001
Rasio, F.	University of Cambridge, USA	14/01/2001-21/01/2001
Recknagel, A.	Kings College, London	20/07/2001-30/07/2001
Rein, G.	LMU München	03/04/2001-07/04/2001
Reis, N.	University of Oxford, UK	20/06/2001-29/06/2001
Reisenberger, M.	Universidad de la Republica, Montevideo	28/06/2001-18/07/2001
Rezzolla, L.	SISSA/ISAS, Trieste	01/07/2001-04/08/2001
Rosly, A.	ITEP, Moscow	20/02/2001-27/02/2001
		23/11/2001-30/11/2001
Runkel, I.	LPTHE, Paris	15/06/2001-24/06/2001
Russell, M.	University of Chicago	26/02/2001-04/03/2001
		02/04/2001-02/05/2001
Samtleben, H.	ENS, Paris	03/01/2001-08/01/2001
		28/02/2001-04/03/2001
		17/07/2001-25/07/2001
Sathyaprakash, B.	Cardiff University	23/08/2001-23/08/2002
Schäfer, G.	Universität Jena	25/10/2001-25/10/2001
Schmidt, W.	MPI fürAstrophysik Garching	15/10/2001-17/10/2001
Schneider, R.	Rome University	31/05/2001-01/06/2001
Schroer, B.	Freie Universität Berlin	15/06/2001-30/06/2001
Schücking, E.	New York University	14/08/2001-21/08/2001
Schweitzer, M.	CNRS, Strasbourg	18/06/2001-08/07/2001
Schwimmer, A.	Weizmann Institute, Rehovot	01/08/2001-31/10/2001
Semenoff, G.	University of British Columbia,Vancouver	25/02/2001-26/02/2001
		24/11/2001-08/12/2001
Shoemaker, D.	Massachusetts Institute of Technology	04/05/2001-06/05/2001
Sibold, K.	Universität Leipzig	09/07/2001-13/07/2001

Guest Scientists

Simon, W.	Universität Wien	02/08/2001-02/09/2001
		25/11/2001-04/12/2001
Smolin, L.	Imperial College London	10/10/2000-10/05/2001
Stergioulas, N.	University of Thessaloniki	15/03/2001-18/03/2001
Tahvildar-Zadeh, S.	Rutgers University, USA	26/05/2001-03/06/2001
Taniguchi, K.	Observatoire de Paris	29/09/2001-25/12/2001
Thorne, K.	California Institute of Technology	11/09/2001-15/09/2001
Tiglio, M.	Pennsylvania State University	20/11/2001-15/12/2001
Tomasiello, A.	SISSA, Trieste	13/05/2001-04/06/2001
Trittmann, U.	Ohio State University	23/09/2001-27/09/2001
Tucker, R.	Lancaster University	07/04/2001-12/04/2001
van Elst, H.	London University	17/04/2001-27/04/2001
Varadarajan, M.	Raman Research Institute, Bangalore	29/10/2001-08/11/2001
Vecchio, A.	Birmingham University	31/05/2001-01/06/2001
Vetrano, F.	University of Urbino	23/10/2001-25/10/2001
Villegas, H.	University of British Columbia	01/10/2001-19/10/2001
Vulcanov, D.	University of Timisoara	15/01/2001-16/02/2001
		01/05/2001-15/05/2001
		01/09/2001-03/10/2001
Wald, R.	University of Chicago	11/09/2001-16/09/2001
Waldron, A.	Brandeis University	22/07/2001-27/07/2001
Weiland, U.	Universität Hannover	31/05/2001-02/06/2001
Wetterich, C.	Universität Heidelberg	12/10/2001-18/10/2001
Whiting, B.	University of Florida	20/05/2001-02/06/2001
Will, C.	Washington University, St. Louis	06/09/2001-09/09/2001
Winicour, J.	University of Pittsburgh	01/10/2000-31/03/2001
		01/10/2001-31/12/2001
Yoshida, S.	Tohoku University, Sendai	01/11/2000-31/01/2001
Zagermann, M.	Universität Halle	17/12/2001-20/12/2001
Zanotti, O.	SISSA, Trieste	14/05/2001-26/05/2001
Zhang, C.	University of Zululand	10/04/2001-10/05/2001
Zhou, S.	NASA Goddard Space Flight Center	26/06/2001-03/07/2001
Zlochower, Y.	University of Pittsburgh	05/03/2001-29/03/2001
		01/11/2001-30/11/2001

Publications by the Institute

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Publications by AEI Members and Guest Scientists

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Invited Conference Talks Given by AEI Members

Aufmuth, P.	Sphärensinfonie mit Paukenschlägen - Gravitationswellenastronomie 14 August 2001 / 6. Internationale Astronomiewoche, Arosa (Switzerland)
Aufmuth, P.	Wie fängt man Gravitonen? - Gravitationswellenobservatorien 16 August 2001 / 6. Internationale Astronomiewoche, Arosa (Switzerland)
Aufmuth, P.	Der Klang des Universums - Astronomie mit Gravitationswellen 11 October 2001 / Astrobux 2001, Buxtehude (Germany)
Beyer, H.R.	On the stability of the Kerr black hole / 29 March 2001 DPG Frühjahrstagung, Bonn (Germany)
Brügmann, B.	Making Waves with Black Holes / 31 May 2001 / 4th CAPRA Meeting on Gravitational Radiation Reaction, AEI, Golm (Germany)
Butscher, A.	The Conformal Constraint Equations / 02 April 2001 / International Workshop on the Conformal Structure of Spacetime, Tübingen (Germany)
Butscher, A.	Exploring the Conformal Constraint Equations / 10 December 2001 CMS Winter Meeting, Toronto (Canada)
Campanelli, M.	The Lazarus project: plunge waveforms from binary black hole mergers 05 February 2001 / Winter Aspen Meeting, Aspen Colorado (USA)
Campanelli, M.	The Lazarus Project / 31 May 2001 / 4th CAPRA Meeting on Radiation Reaction, AEI, Golm (Germany)
Cutler, C.J.	Gravitational Wave Damping of Neutron Star Precession / 31 May 2001 4th CAPRA Meeting on Radiation Reaction, AEI, Golm (Germany)
Cutler, C.J.	Overview of Gravitational Wave Sources / 20 July 2001 / GR16, Durban (South Africa)
Cutler, C.J.	Remarks on Gravitational-Wave Backgrounds / 13 December 2001 GWDAW2001, Trento (Italy)
Cutler, C.J.	Gravitational Waves from Neutron Star Mountains / 14 December 2001 GWDAW2001, Trento (Italy)
Dain, S.	Asymptotically flat and regular Cauchy data / 03 April 2001 Workshop: The Conformal Structure of Spacetimes, Tübingen (Germany)
Dain, S.	Asymptotically Flat Initial Data with Prescribed Regularity at Infinity 20 July 2001 / GR16, Durban (South Africa)
Danzmann, K.	Technologies for fundamental physics in space / 23 February 2001 Hyper Symposium, Florence (Italy)
Danzmann, K.	The LISA mission / 26 March 2001 / DPG Symposium on fundamental physics in Space, Bonn (Germany)
Danzmann, K.	Gravitational wave detectors / 11 June 2001 / International Conference on Laserspectroscopy (ICOLS) Snowbird, Utah (USA)
Danzmann, K.	Laser interferometers in space / 10 July 2001 / 4th Edoardo Amaldi Conference on Gravitational Waves, Perth (Australia)
Danzmann, K.	Gravitational Wave Astronomy / 14 September 2001 / Joint European Gravitational wave astronomy and National Astronomy Meeting (JENAM), Munich (Germany)
Danzmann, K.	Gravitational Wave Detectors in Space / 16 October 2001 / Optical Society of America Annual Meeting, Long Beach, California (USA)
Danzmann, K.	The LISA mission: recent developments / 17 October 2001 / The LISA mission: recent developments Second NASA Science Engineering Workshop, Pasadena, California (USA)
Danzmann, K.	Laserinterferometrische Gravitationswellendetektoren 15 November 2001 / Raumfahrt-Kolloquium, Aachen (Germany)
Dasgupta, A.	Miracles on the Path to Quantum Gravity / 14 December 2001 / National Conference on Contemporary issues in nuclear and particle physics, Calcutta (India)
Ehlers, J.	Comments on Cosmology / 23 - 25 July 2001 / Symposium on Cosmology, Cape Town (South Africa)

Invited Conference Talks Given by AEI Members

Ehlers, J.	Podiumsdiskussion "Grundprobleme der Theoretischen Physik" 29 September 2001 / Symposium "100 Years Werner Heisenberg - Works and Impact", Alexander von Humboldt Stiftung, Bamberg (Germany)
Friedrich, H.	Aspects of conformal Einstein evolution / 3 April 2001 / Workshop: The Conformal Structure of Spacetimes, Tübingen (Germany)
Nicolai, H.	Exceptional Lie Groups and Unified Field theories 20 January 2001 / Colloquium in memoriam Erich Kaehler, Universität Hamburg (Germany)
Nicolai, H.	The principal SO(1,2) subalgebra of a hyperbolic Kac Moody algebra 28 September 2001 / Symposium "100 Years Werner Heisenberg - Works and Impact", Alexander von Humboldt Stiftung, Bamberg (Germany)
Nicolai, H.	Conference Summary Talk / 12 October 2001 / DESY Theory Workshop "Gravity and Particle Physics", Hamburg (Germany)
Plefka, J.	Vertex Operators for the Supermembrane / 19 March 2001 GIF Miniworkshop, Hebrew University, Jerusalem (Israel)
Plefka, J.	Vertex Operators for the Supermembrane / 11 April 2001 Sustring Workshop, Heraklion (Greece)
Plefka, J.	Wilson Loops in N=4 Super Yang-Mills / 10 October 2001 DESY Theory Workshop 2001, Hamburg (Germany)
Ponsot, B.	Boundary Liouville field theory: boundary three point function 23 September 2001 / Conference for the 70th birthday of Prof. Matynian, Nor-Amberd (Armenia)
Rendall, A.D.	Asymptotic decoupling of solutions of the Einstein equations 21 May 2001 / Mathematisches Institut, Oberwolfach (Germany)
Rendall, A.D.	Applications of the theory of evolution equations to general relativity 21 July 2001 / GR16, Durban (South Africa)
Rendall, A.D.	The non-relativistic limit of the Einstein-Vlasov system 13 December 2001 / Erwin-Schrödinger-Institut, Vienna (Austria)
Schomerus, V.	Brane dynamics in CFT backgrounds / 9 January 2001 Strings 2001, Mumbai (India)
Schomerus, V.	Elements of String Phenomenology with Unseen Dimensions 26 March 2001 / DPG Frühjahrstagung, Bonn (Germany)
Schomerus, V.	Brane dynamics in CFT backgrounds / 28. September 2001 CFT and integrable models, Bologna (Italy)
Schomerus, V.	Fuzzy worlds in a stringy universe / 12 October 2001 / DESY Theory Workshop "Gravity and Particle Physics", Hamburg (Germany)
Schomerus, V.	Open strings and fuzzy gauge theories / 18 May 2001 University of Marseille (France)
Schutz, B.F.	Living Reviews in Relativity: A Living Electronic Journal 25 June 2001 / Continuity and Change in Scientific Communication Conference, Amsterdam (Netherlands)
Schutz, B.F.	LISA: Pioneering Space Gravitational Wave Detection 20 July 2001 / GR16, Durban (South Africa)
Schutz, B.F.	LISA Science Update / 20 July 2001 / GR16, Durban (South Africa)
Schutz, B.F.	Lighthouses of Gravitational Wave Astronomy / 7 August 2001 Lighthouses of the Universe Conference, Garching (Germany)
Schutz, B.F.	Cosmology with Gravitational Waves/ 10 October 2001 / DESY Theory Workshop "Gravity and Particle Physics", Hamburg (Germany)
Schutz, B.F.	LISA as a Tool for Cosmology / 13 November 2001 RESCEU Conference, Tokyo (Japan)
Schutz, B.F.	Low Frequency Sources: Three Highlights and a Shadow 15 December 2001 / GWDAW 2001, Trento (Italy)

Seidel, E.	Dynamic Grid Computing in Science and Engineering 29 May 2001 / International Conference on Computer Science (ICCS 2001), San Francisco (USA)
Seidel, E.	GridLab: Dynamic Grid Computing for Science and Engineering 16 July 2001 / Global Grid Forum II, Washington, DC (USA)
Seidel, E.	3D Mergers of Binary Black Holes / 21 July 2001 NR2001, Krugersdorp (South Africa)
Seidel, E.	Numerical Relativity / 24 August 2001 American Physical Society, Boston (USA)
Seidel, E.	Dynamic Grid Computing / 28 September 2001 LBNL, Berkeley, CA (USA)
Seidel, E.	GridLab: Dynamic Grid Computing / 2 October 2001 University of Utah, Salt Lake City, UT (USA)
Seidel, E.	GridLab / 9 October 2001 / Global Grid Forum III, Frascati (Italy)
Seidel, E.	Grid Testbeds in EU and US from an Application Point of View - What's Real, What's Just Around the Corner / 23 October 2001 / Asia-Pacific Grid Workshop, Tokyo (Japan)
Seidel, E.	Dos and Donts of Building Grand Challenge Application Teams 6 December 2001 / NSF Workshop on eScience Applications, University of Illinois, Chicago, IL (USA)
Sintes , A.M.	The Hough Transform Algorithm - code status report / 16 August 2001 LIGO LSC meeting 9, Hanford Observatory (USA)
Sintes, A.M.	GEO 600 Detector Characterization / 14 December 2001 GWDAW-2001, Trento (Italy)
Staudacher, M.	Dimensionally Reduced D=10 N=1 Yang-Mills Theories / 19 March 2001 / GIF Miniworkshop, Hebrew University, Jerusalem (Israel)
Staudacher, M.	Dimensionally Reduced D=10 Super Yang-Mills Matrix Models 21 June 2001 / Matrix Models 2001, Sixth Claude Itzykson Meeting, Saclay (France)
Staudacher, M.	Dimensionally Reduced D=10 Super Yang-Mills Theories 20 July 2001 / GR16, Durban (South Africa)
Theisen, S.	Introduction to the AdS/CFT correspondence / 10 October 2001 DESY Theory Workshop "Gravity and Particle Physics", Hamburg (Germany)
Thiemann, T.	Applications of Coherent States in Quantum General Relativity 14 June 2001 / Banach Center, Warsaw (Poland)
Valiente-Kroon, J.A.	Polyhomogeneous expansions close to null and spatial infinity 3 April 2001 / Workshop: The Conformal Structure of Spacetimes, Tübingen (Germany)
Willke, B.	Current Status of GEO / 10 July 2001 / 4th Edoardo Amaldi Conference on Gravitational Waves, Perth (Australia)

Lectures and Lecture Series Given by AEI Members

Aufmuth, P.	Der Klang des Universums - Astronomie mit Gravitationswellen 13 November 2001 / Fachhochschule Flensburg (Germany)
Aufmuth, P.	Introduction to current experimental research: Experimental gravitational physics / 6 December 2001 / Universität Hannover (Germany)
Aufmuth, P.	Gravitationswellen: Der Klang des Universums / 7 December 2001 Universität Karlsruhe (Germany)
Aufmuth, P.	Introduction to current experimental research: Sources of gravitational waves / 13 December 2001 / Universität Hannover (Germany)
Danzmann, K.	High stability lasers for space applications / 2 February 2001 Astrium Space, Ottobrunn (Germany)
Danzmann, K.	The status of LISA / 2 March 2001 / ESTEC, Nordwijk (Netherlands)
Danzmann, K.	Gravitational wave astronomy / 8 March 2001 / ESO, Garching (Germany)
Danzmann, K.	Gravitational waves / 29 March 2001 / Pennsylvania State University, Pennsylvania (USA)
Danzmann, K.	Die Zukunft der Gravitationswellenforschung / 5 April 2001 MPI für Physik komplexer Systeme, Dresden (Germany)
Danzmann, K.	Laser pointing and aquisition for LISA / 15 May 2001 / ESTEC, Nordwijk (Netherlands)
Danzmann, K.	Gravitational wave research / 12 September 2001 / AEI, Golm (Germany)
Danzmann, K.	Laser interferometry in space / 21 September 2001 / Bosch-Satcom, Backnang (Germany)
Danzmann, K.	Laser interferometric gravitational wave detectors / 12 October 2001 MPI für Quantenoptik, Garching (Germany)
Danzmann, K.	Gravitationswellen-Astronomie / 6 December 2001 / Universität Bremen, Bremen (Germany)
Danzmann, K.	LISA integration flow / 11 December 2001 / University of Trento (Italy)
Danzmann, K.	Physik III / Wintersemester 2000/2001 / Universität Hannover (Germany)
Danzmann, K.	Physik IV / Summersemester 2001 / Universität Hannover (Germany)
Danzmann, K.	Physik für Chemiker / Wintersemester 2001/2002 / Universität Hannover (Germany)
Ehlers, J.	Einführung in die Allgemeine Relativitätstheorie / 5 - 9 March 2001 Ferienkurs AEI, Potsdam (Germany)
Ehlers, J.	Advanced Lectures on General Relativity (Combo-Lectures) 26 - 27 October 2001 / Universität Leipzig (Germany)
Ehlers, J.	Advanced Lectures on General Relativity (Combo-Lectures) 30 November - 1 December 2001 / Universität Halle (Germany)
Friedrich, H.	Ausgewählte Themen der Relativitätstheorie / 5 January 2001 / Universität Potsdam (Germany)
Friedrich, H.	Gravitationsstrahlung / 12 March 2001 / Ferienkurs AEI, Potsdam (Germany)
Friedrich, H.	Ausgewählte Themen der Relativitätstheorie / 15 April 2001 Universität Potsdam (Germany)
Friedrich, H.	Ausgewählte Themen der Relativitätstheorie II / 17 April 2001 Universität Potsdam (Germany)
Friedrich, H.	Lie-Gruppen: Grundlagen und Anwendungen / 15 October 2001 Universität Potsdam (Germany)
Junker, W.	Quantum Field Theory in Curved Spacetime / 26 October 2001 Institute für theoretische Physik der Universitäten Leipzig, Halle und Jena (Germany)

Lectures and Lecture Series Given by AEI Members

Nicolai, H.	Einführung in die Kosmologie / 2 April 2001 / Humboldt Universität, Berlin (Germany)
Nicolai, H.	Introduction to Supersymmetry and Supergravity / 7 May 2001 Workshop on Superstrings, Quaid-i-Azam University, Islamabad (Pakistan)
Nicolai, H.	Einführung in die Supersymmetrie / 3 September 2001 Saalburg (Germany)
Nicolai, H.	An introduction to hyperbolic Kac Moody algebras / 20 December 2001 Humboldt Universität, Berlin (Germany)
Plefka, J.	Übungen zur Allgemeinen Relativitätstheorie / 24 April 2001 Humboldt Universität, Berlin (Germany)
Plefka, J.	Das kosmologische Standardmodell / 2 July 2001 / Humboldt Universität, Berlin (Germany)
Plefka, J.	M-Theory / 25 September 2001 / Steilkurs Advanced Topics in String Theory, Universität Halle (Germany)
Rendall, A.D.	Kosmologische Modelle / 12 March 2001 / Ferienkurs AEI, Potsdam (Germany)
Rendall, A.D.	The Einstein-Vlasov system / 17 June 2001 / Conference on kinetic theory, Anogia, Crete (Greece)
Schomerus, V.	Strings, Branes, and Gauge Theory / 29 January 2001 / MPI für Physik, München (Germany)
Schomerus, V.	Strings, Branes, and Non-commutative Geometry / 17 March 2001 Keio University (Japan)
Schomerus, V.	Open Strings and Brane Noncommutative Geometry / 13 July 2001 Lisbon school on superstrings II, Lisbon (Portugal)
Sintes, A.M.	Physics / 26 March 2001 / Universitat Illes Balears, Palma de Mallorca (Spain)
Theisen, S.	Introduction to Calabi-Yau Manifolds / 2 April 2001 / Spring School on Superstrings and Related Matters, Trieste (Italy)
Theisen, S.	Introduction to Strings and the AdS/CFT Correspondence / 29 June - 6 July 2001 / Universidad Simon Bolivar and Universidad Central de Venezuela, Caracas (Venezuela)
Theisen, S.	Introduction to Strings and the AdS/CFT Correspondence / 9 - 27 July 2001 / Summer School on Geometrical and Toplogical Methods for Quantum Field Theory, Villa de Leyva (Columbia)
Theisen, S.	Calabi-Yau manifolds and string duality / 24 - 29 September 2001 Halle (Germany)
Willke, B.	Introduction to current experimental research: Gravitational wave detectors / 14 December 2001 / Universität Hannover (Germany)

Popular Talks Given by AEI Members

Aulbert, C.	Gravitationswellen - ein neues Fenster zum Universum / 30 June 2001 Albert Einstein Institute Open Day, Golm (Germany)
Danzmann, K.	Die dunkle Seite des Universums / 19 January 2001 Planetarium Mannheim (Germany)
Danzmann, K.	Können wir das Universum hören? / 28 May 2001 Magnus Haus, Berlin (Germany)
Ehlers, J.	Hatte Einstein Recht? / 1 July 2001 / Tag der offenen Tür, Universität Würzburg (Germany)
Ehlers, J.	Wird durch Physik Wirklichkeit erkannt? / 24 January 2001 URANIA, Berlin (Germany)
Ehlers, J.	Allgemeine Relativitätstheorie: Lehrerfortbildungsvortrag 27 March 2001 / Stuttgart (Germany)
Ehlers, J.	Allgemeine Relativitätstheorie: Lehrerfortbildungsvortrag 28 March 2001 / Stuttgart (Germany)
Fredenhagen, S.	Das frühe Universum / 18 June 2001 / Philippe-Cousteau-Oberschule, Berlin (Germany)
Fredenhagen, S.	Das frühe Universum / 19 June 2001 / John-Lennon-Oberschule, Berlin (Germany)
Fredenhagen, S.	Das frühe Universum / 19 June 2001 / Max-Reinhardt-Oberschule, Berlin (Germany)
Husa, S.	Was ist ein schwarzes Loch? / 19 June 2001 / Johann-Gottfried-Herder Oberschule, Berlin (Germany)
Koppitz, M.K.	Kollidierende Schwarze Löcher / 19 June 2001 / Albert-Einstein-Oberschule, Berlin (Germany)
Koppitz, M.K.	Kollidierende Schwarze Löcher / 19 June 2001 / Ernst-Friedrich-Oberschule, Berlin (Germany)
Koppitz, M.K.	Kollidierende Schwarze Löcher / 20 June 2001 / Heinrich-Hertz-Oberschule, Berlin (Germany)
Koppitz, M.K.	Kollidierende Schwarze Löcher / 30 June 2001 / Albert Einstein Institute Open Day, Golm (Germany)
Nicolai, H.	Die Entstehung des Universums / 19 December 2001 Wilhelm-Foerster-Sternwarte Berlin (Germany)
Pankiewicz, A.	Von Teilchen zu Strings / 19 June 2001 / Otto-Nagel-Oberschule Berlin (Germany)
Pankiewicz, A.	Von Teilchen zu Strings / 21. June 2001 / Heinrich-Hertz-Oberschule, Berlin (Germany)
Pankiewicz, A.	Von Teilchen zu Strings / 30. June 2001 / 30 June 2001 / Albert Einstein Institute Open Day, Golm (Germany)
Perlick, V.	Gravitationslinsen - Lichtbrechung im All / 30 June 2001 Albert Einstein Institute Open Day, Golm (Germany)
Pössel, M.	Zeitreisen - was sagt die moderne Physik? / 19 March 2001 URANIA Berlin (Germany)
Pössel, M.	Zeitreisen - Physik oder Science Fiction? / 12 December 2001 Wilhelm-Foerster-Sternwarte Berlin (Germany)
Quella, T.	Leben wir am Rand der Welt? Bran-Welt-Szenarien 1 July 2001 / Humboldt Universität Berlin -Studienstiftungswochenende, Egsdorf (Germany)
Quella, T.	Leben wir am Rand der Welt? Bran-Welt-Szenarien / 19 June 2001 Stauffenberg-Oberschule, Berlin (Germany)
Quella, T.	Leben wir am Rand der Welt? Bran-Welt-Szenarien 20 June 2001 / Philippe-Cousteau-Oberschule, Berlin (Germany)

Popular Talks Given by AEI Members

Schutz, B.F.	Einsteins Erbe: Das relativistische Universum / 4 April 2001 URANIA, Berlin (Germany)
Schutz, B.F.	Max-Planck-Institut für Gravitationsphysik: Einführung / 07 May 2001 Albert Einstein Institute Institute Librarians Day, Golm (Germany)
Schutz, B.F.	Einsteins Erbe: Das relativistische Universum / 30 June 2001 Albert Einstein Institute Open Day, Golm (Germany)
Schutz, B.F.	Black Holes / 16 October 2001 / Berlin British School, Berlin (Germany)
Skorupka, S.	LISA - Ein neues Fenster ins All / 11 September 2001 Abendgymnasium Hannover (Germany)
Skorupka, S.	Die Welt ist Klang. Weihnachtsvorlesung / 20 December 2001 Universität Hannover (Germany)
Skorupka, S.	Die Welt ist Klang. Weihnachtsvorlesung / 21 December 2001 (three times) / Universität Hannover (Germany)
Thiemann, T.	Combining Quantum Mechanics and General Relativity / 23 October 2001 / University of Waterloo, Ontario (Canada)

Guided Tours at GEO600

Aufmuth, P., Goßler, S., Grote, H., Lück, H., Willke, B.	The Gravitational Wave Detector GEO600. Introductory Talk and Guided Tour / 30 January 2001 / 5 February 2001 / 9 March 2001/ 21 June 2001 / 5 July 2001 / 22 August 2001 / 29 August 2001 / 5 November 2001 / Ruthe (Germany)

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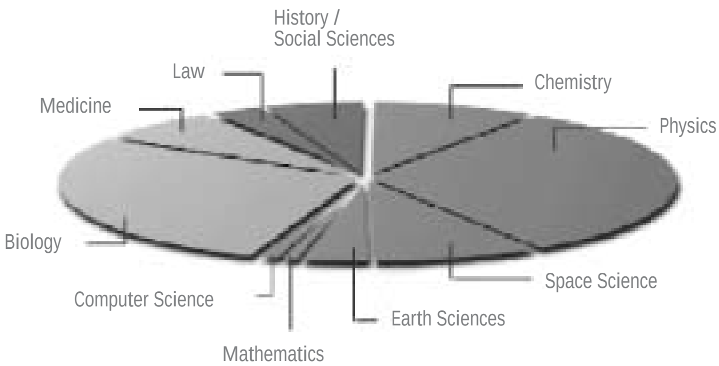

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Address:
Max-Planck-Gesellschaft
zur Förderung der Wissenschaften e.V.
Postbox 10 10 62
80084 Munich, Germany
Phone +49-89-2108-0
Fax +49-89-2108-1111

www.mpg.de

Contacts

AEI Golm

Office:
Ute Schlichting
Tel.: +49-331-567 7220
Fax: +49-331-567 7298
office@aei.mpg.de

Library:
Elisabeth Schlenk
Tel.: +49-331-567 7400
Fax: +49-331-567 7499
library@aei.mpg.de

Computer Systems:
Christa Hausmann-Jamin
Tel.: +49-331-567 7302
Fax: +49-331-567 7298
christa.hausmann-jamin@aei.mpg.de

Administration:
Christiane Roos
Tel.: +49-331-567 7600
Fax: +49-331-567 7699
christiane.roos@aei.mpg.de

Public Relations:
Dr. Elke Müller
Tel.: +49-331-567 7303
Fax: +49-331-567 7298
elke.mueller@aei.mpg.de

AEI Hannover

Administration:
Marlen Kölling
Tel.: +49-511-567 3543
Fax: +49-511-567 2784
marlen.koelling@aei.mpg.de

Public Relations:
Dr. Peter Aufmuth
Tel.: +49-511-567 2386
Fax: +49-511-567 2784
peter.aufmuth@aei.mpg.de

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Published:
May 2001 by the
Max-Planck-Institut für Gravitationsphysik
(Albert-Einstein-Institut)

Addresses:
Max-Planck-Institut für Gravitationsphysik
(Albert-Einstein-Institut)
Am Mühlenberg 1
D-14476 Golm, Germany

Callinstraße 38
D-30167 Hannover, Germany

Editorial team:
Dr. Elke Müller (AEI)
Susanne Milde, Sascha Rieger (MildeMarketing)

Graphic design:
focus werbeagentur potsdam + MildeMarketing

Print:
Christian & Cornelius Rüss Potsdam

Photo credits:
“Preface”: Library of American Congress
“The Institute”, “Through the Eyes...” : Peter Frenkel
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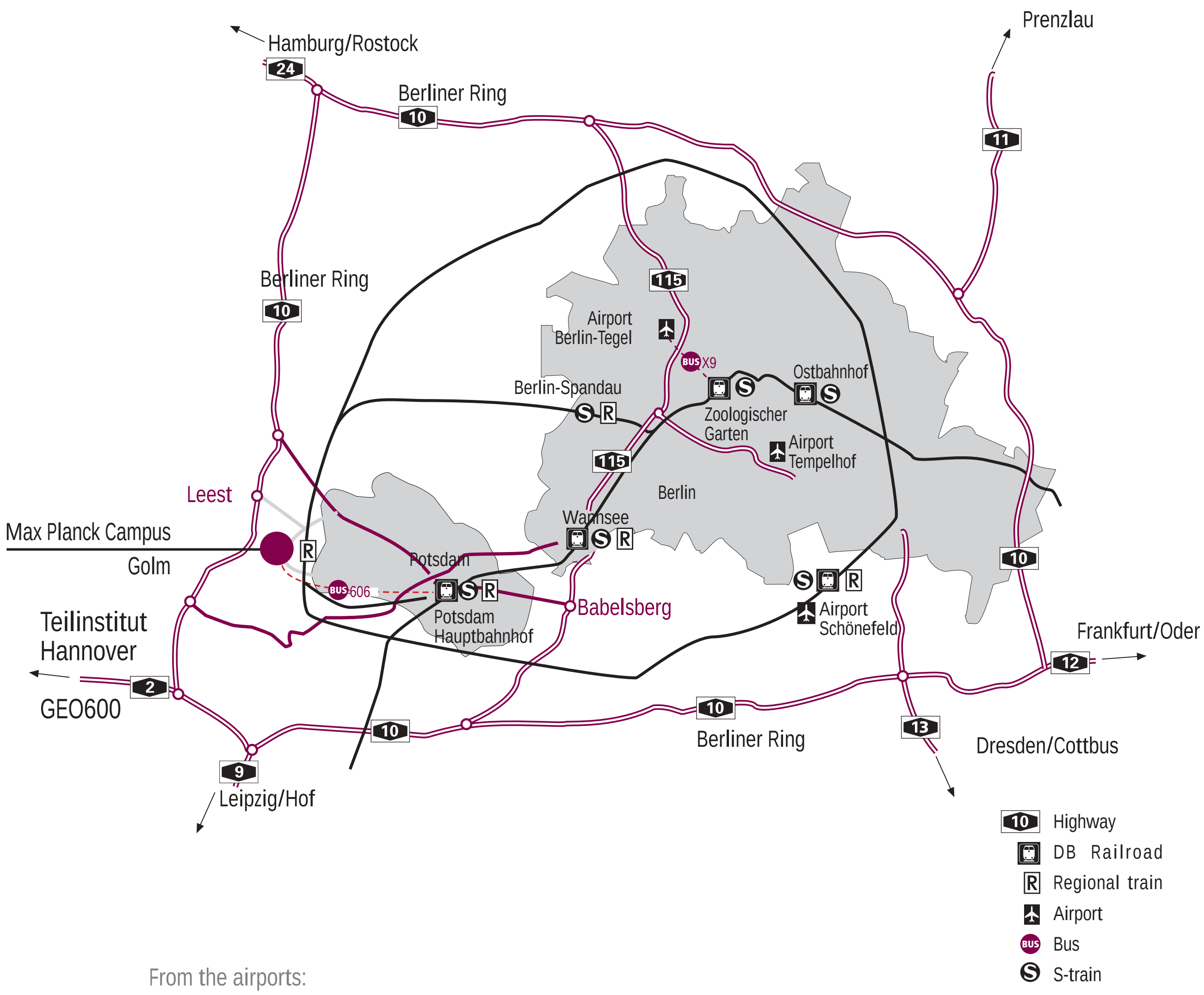

From the airports:

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:

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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