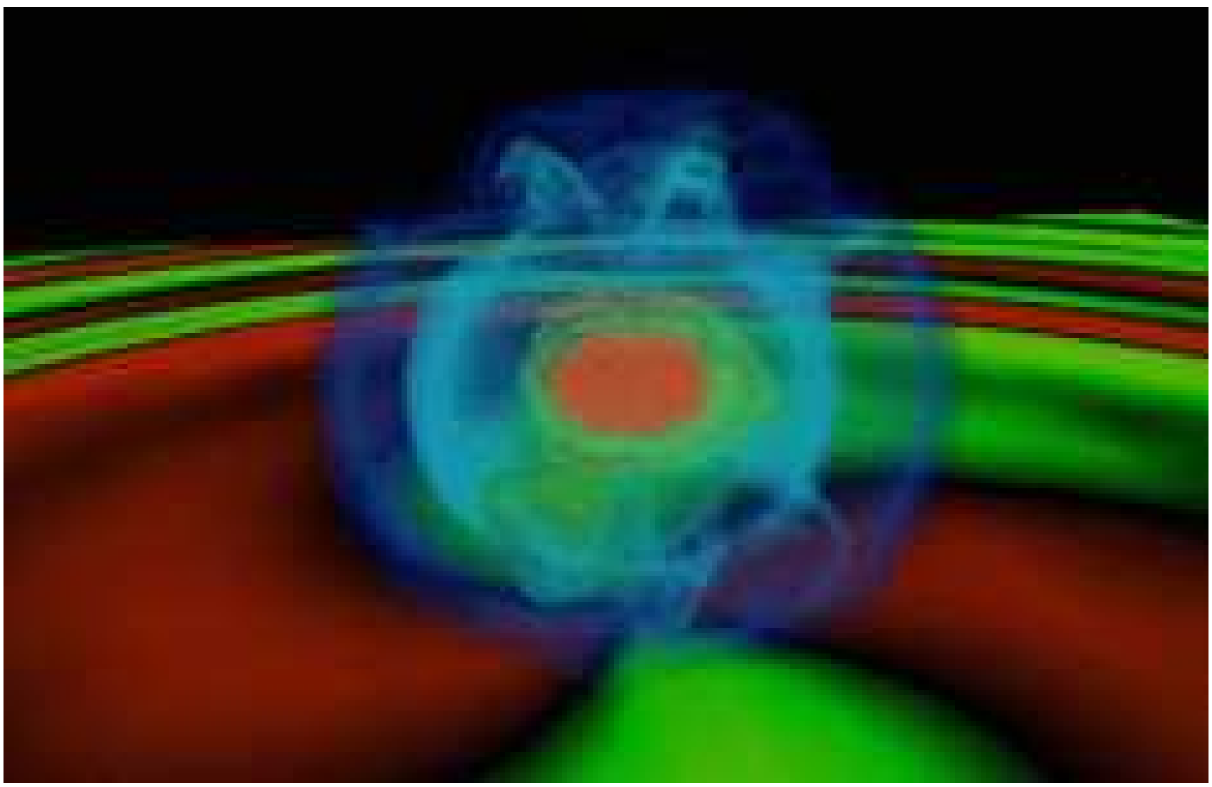
IOP Institute of Physics
Gravitational Physics Group

Newsletter of the Gravitational Physics Group of the Institute of Physics

January 2008



Contents

The cover picture shows the collapse of an iron core to form a neutron star, emitting gravitational waves in the process. Numerical simulation by Christian Ott in collaboration with H Dimmelmeier (Ott et al. Class. Quantum Grav. **24** (2007) S139–S154). For a review of the status of the mathematical foundations of numerical relativity, please see the article contributed by Oliver Rinne in this Letter. Photo credit: The Albert Einstein Institute.

1 Welcome From The Chair

Contributed by Elizabeth Winstanley, Chair of GPG, University of Sheffield

Welcome to the third newsletter from the Gravitational Physics Group of the Institute of Physics!

Once again the Group has been very active in 2007, organizing and supporting scientific meetings in areas as diverse as Low-Energy Quantum Gravity, and LISA science. As well as reports on those meetings in 2007, in this newsletter there are announcements of some of the meetings we will be organizing or supporting in 2008. However, the programme for 2008 is not yet complete, so volunteers to organize meetings in Gravitational Physics are always welcome, as are suggestions for topics we should be covering or activities we should be supporting.

In 2008 there are two new developments particularly of interest to research student members. Firstly, for those who have recently finished their PhD, in 2008 we will be awarding for the first time a Thesis Prize in Gravitational Physics. Secondly, for those who are still working towards a PhD, the Institute of Physics has a new Research Student Conference Fund, and we have some money available to support student members attending conferences in Gravitational Physics. There are more details of both these schemes later in the newsletter.

Details of how to join both the IOP and the Group are at the end of the newsletter. The success of the Group depends entirely on the membership as well as the committee! We will be looking for new committee members at the AGM in Spring 2008, so please contact me or any of our committee members if you are interested in getting involved. The Group exists to serve you, the Gravitational Physics community, so please help us to maintain an exciting programme of activity and to be an effective forum for discussion.

Finally I would like to thank the Newsletter Editor, Ian Jones, for his hard work in producing three excellent newsletters. We will be looking for a new Newsletter Editor for next year, so volunteers are welcome!

2 Announcements

2.1 Annual General Meeting

This year the Annual General Meeting of the Gravitational Physics Group will take place at the BritGrav meeting at the University of York, on 19th March 2008. The exact location and time will be announced closer to the event.

2.2 Student Seminar Program

The Gravitational Physics Group of The Institute of Physics has recently launched a new initiative: The UK Postgraduate Student Seminar Exchange Programme. The idea behind this programme is to provide new opportunities for UK PhD students in Gravitational Physics, for networking and giving seminars at other UK universities. We will maintain an open, web database of student talks complete with titles, abstracts and contact information. Students can register by sending me (Paul Abel) an email with their details. They can then scan the list and decide which talk they are interested in, make contact with the other student and contact us to ask for funds to cover their travel costs.

Each student participating will have to make all the arrangements for the student visiting his/her institution, including organising a room, data projector and inviting members of their group/department to attend. This will then be reciprocated. For more information, please visit the scheme website by following the 'Student Seminars' link from the Group's main page:

`http://gp.iop.org`

If you have a research student who might be interested, please encourage them to email me (Paul Abel, `pga3@le.ac.uk`) their contact details along with their proposed title of the talk and an abstract.

2.3 Research Student Conference Fund

This is a new fund set up by the Institute of Physics to provide financial support to research students to attend international meetings and major national meetings. Research students who are members both of the Institute and the Gravitational Physics Group will be eligible to apply for support to attend conferences in Gravitational Physics. Students may apply for up to £250 during the course of their PhD. Students may apply more than once, for example they may request the full amount or decide to request a smaller amount and then apply for funding again for another conference at a later stage. Grants will normally cover only part of the expenses incurred in attending a conference and are intended to supplement grants from other sources. A total budget of £1190 is available in 2008 to support student attendance at Gravitational Physics conferences.

Further details of the scheme and information on how to apply, including deadlines and an application form, can be found on the website:

`http://www.iop.org/activity/grants/`

All applications must be submitted to the Institute of Physics centrally, and not directly to the Gravitational Physics Group.

2.4 Gravitational Physics Group Thesis Prize

Attention all recent PhD graduates and their supervisors!

The 2008 Gravitational Physics Group Thesis Prize will be made for excellence in postgraduate research and communication skills in gravitational physics. All members of the IoP Gravitational Physics Group who passed their PhD viva voce exam between 30th September 2006 and 1st October 2007 are entitled to enter the competition and the winner will receive £250.

Please note that the student **must** be nominated by their supervisor. We *do not* accept nominations from any other party. Furthermore, the student's external PhD examiner must be willing to comment on the student's research, quality of the student's thesis and and the student's ability to cogently communicate their work (evidenced by their viva performance and/or seminars). Students and their supervisors are advised to consult the external examiner before entering the competition.

Please see

`http://gp.iop.org`

for further information.

3 Forthcoming Meetings

3.1 BritGrav VIII

The eighth British Gravity Meeting will be held in the Department of Mathematics, University of York 18-19 March 2008, organised by Chris Fewster, Atsushi Higuchi and Bernard Kay. As usual there will be no registration fee and the programme will be composed largely of short talks, with post-docs and graduate students given priority if necessary. Classical and Quantum Gravity have kindly agreed to sponsor an evening reception and a prize for the best student talk. There will also be some financial support for graduate students, thanks to the IoP Gravitational Physics Group.

Registration will open in early January 2008 and further details will appear on the BritGrav 8 website at

`http://maths.york.ac.uk/www/BritGrav8`

Please send any enquiries in the meantime to Chris Fewster, `cjf3@york.ac.uk`.

3.2 Classical and Quantum Gravity Scientific Meeting

Members of the Editorial Board of Classical and Quantum Gravity will be convening for their annual meeting in London in May and will be taking the opportunity to hold a one day conference to present and discuss their latest research. The meeting will cover the broad range of subjects represented on the Board. Some external speakers have also been invited. The provisional speaker list includes;

V Balasubramanian, University of Pennsylvania, USA
D Garfinkle, Oakland University, USA
G Gonzalez, Louisiana State University, USA
N A Robertson, Stanford University, USA
V P Frolov, University of Alberta, Edmonton, Canada
J M M Senovilla, Universidad del Pais Vasco, Bilbao, Spain
R M Wald, University of Chicago, USA
D Wands, University of Portsmouth, UK

The meeting will take place from 09.45am to 5.00pm on Thursday 22nd May 2008 at the Strand campus, Department of Mathematics, King's College, London, UK. It is organised by George Papadopoulos of King's College London (e-mail `george.papadopoulos@kcl.ac.uk`.

All interested are welcome to attend. There is no registration, but interested parties should contact the organizer to be added to a mailing list for updates.

3.3 Quantum Geometry and Quantum Gravity Conference

The international conference 'QG2 2008 - Quantum Geometry and Quantum Gravity' will be held at the University of Nottingham during the week 30 June–4 July, 2008. The focus of the meeting is on quantum gravity (including loop quantum gravity, spin foams and other discrete approaches, lower-dimensional quantum gravity and perturbative quantum gravity) and quantum geometry (including physical aspects of non-commutative geometry, non-commutative field theory, quantum groups and deformed special relativity). The organisation is coordinated by John Barrett (Nottingham), and the scientific committee consists of researchers from UK, continental Europe and North America. The meeting is supported by the European Science Foundation, the Gravitational Physics Group and the Mathematical and Theoretical Physics Group of the Institute of Physics and Classical and Quantum Gravity. More information is available at the conference website:

`http://www.maths.nottingham.ac.uk/conferences/qgsquared-2008/`

4 Recent Meetings

4.1 Low-Energy Quantum Gravity Meeting

Contributed by Bernard Kay, Ian Moss, Elizabeth Winstanley (organizers)

This was an informal two-day discussion meeting at the University of York, 19-20th July 2007, with pedagogical talks on a variety of topics in Low-Energy Quantum Gravity. The sessions were attended by just under 40 people, the majority of whom were PhD students or young researchers, mainly from the UK, but there were also a few European visitors. The meeting was the second joint venture between the Gravitational Physics and Mathematical & Theoretical Physics Groups of the IOP. We hope it will not be the last!

The first speaker was David Toms (Newcastle), who discussed a recent paper by Robinson and Wilczek in which they state that quantum gravity effects can alter the running of gauge coupling constants. David gave a critical analysis of their work which prompted a great deal of discussion. Next, Calvin Smith (University College Dublin) gave an overview of the subject of quantum energy inequalities, which bound total negative energies in quantum field theory in curved space. Jorma Louko (Nottingham) discussed recent work on accelerated particle detectors, in particular the smearing required to give a regular transition probability. The last speaker on the first day was Jean Alexandre (King's College London), who also gave us much to discuss that evening. He presented a new non-perturbative, time-dependent, string theory configuration which does not require extra dimensions.

The second day started with Karl-Henning Rehren (Goettingen), who reviewed his work on algebraic holography, a structural approach to the AdS/CFT correspondence, which relates ordinary (i.e. non-gravitational) quantum field theories in the AdS bulk to ordinary conformal field theories on the conformal boundary. Next, Remo Garattini (Bergamo) discussed a multi-gravity approach to space-time foam, the 'multi-gravity' aspect arising from gravity with N spin-2 fields, where $N > 1$. In the afternoon, the AdS/CFT theme was taken up by Veronika Hubeny (Durham) who gave a very accessible introduction to the subject and then described the connection between 2-point functions in the boundary CFT and bulk geodesics. The last talk was by Atsushi Higuchi (York) who gave a critical analysis of a 1994 paper by Starobinskii and Yokohama, concerning the infra-red divergence in de Sitter space, a topic which has very recently been taken up by Woodard.

Those talks which were given electronically can be viewed online at:

`http://winstanley.staff.shef.ac.uk/LEQG.html`

We are grateful to the University of York for hosting the event and providing us with an excellent selection of places to eat and drink in the city! We are also grateful to the Nuclear and Particle Physics Division of the Institute of Physics for financial support.

4.2 UK Fundamental Theory Meeting

Contributed by Neil Lambert, Kings College London

The past few years has enjoyed a great influx of young theoretical physicists from around the world into permanent academic posts in the UK. These researchers often meet and interact with each other at international conferences and workshops; yet at present there is no such avenue established within the UK itself, and thereby no easy means to promote active collaboration these researchers. Therefore in an attempt to improve the situation we plan to organise a regular series of meetings of UK researchers involved in fundamental physics theory.

These meetings will cover topics which are at the forefront of modern theoretical physics. Currently a large number of researchers are actively pursuing various disciplines such as string theory, general relativity, particle physics and quantum field theory. The primary objective of these meetings is to provide an avenue for the dissemination of recent advances in these areas and to allow for a synthesis of ideas so as to promote further progress. The meetings will consist of 2-3 seminars each day as well as informal discussion sessions. The seminar speakers will be encouraged to be as interactive as possible so as to foster a rich research environment.

The first such meeting was on 9-10 November 2007 in King's College London and was possible in part by a grant from the IOP Gravitational Physics group. Details of the meeting can be found on the website http://www.maths.dur.ac.uk/~dma0mr/UK_Meeting_2007

It was attended by over 50 physicists from across the UK. The seminar topics were numerical techniques in relativity and field theory, black hole and ring solutions in string theory, string theory and the LHC, phase transitions in gauge theory, universal entropy bounds from adS/CFT, and integrability in N=4 super-Yang-Mills. The organisers are grateful to the IOP for its support and are currently planning the next meeting for 2008.

4.3 13th International Symposium on Particles, Strings and Cosmology

Contributed by Arttu Rajantie, Imperial College London

The 13th International Symposium on Particles, Strings and Cosmology was organised at Imperial College from 2 to 7 July 2007. The programme consisted of five days of scientific talks, followed by a day of public talks celebrating the 50th anniversary of the arrival of the late Nobel Laureate Abdus Salam at Imperial College. The conference was part of Imperial College's centenary celebrations.

The scientific programme included 32 plenary talks, 75 parallel talks and a number of posters, and covered all main areas of particle physics, string theory and cosmology. Plenary speakers included Stephen Hawking, the 1999 Nobel Laureate Gerard't Hooft and several fellows of the Royal Society.

To maximise the benefit to the whole physics community, we have put all the talk slides on the conference web site

http://www.pascos07.org

The plenary talks were also recorded on video and we are currently in the process of making them available on the web as well. The proceedings of the conference will be published by the American Institute of Physics.

The conference was funded by registration fees as well as contributions by PPARC-STFC, Centre for Theoretical Cosmology (Cambridge), Institute for Particle Physics Phenomenology, Institute of Physics (HEPP and GR groups and NPP division) as well as the Physics Department of Imperial College. The conference was attended by 199 registered participants of whom 29 were from Imperial College and 37 were students. With speakers' expenses being less than anticipated, we were able to reduce the registration fee from the originally planned £300 to £250. The fee covered refreshments, reception on Monday, lunch on Wednesday and the conference dinner on Thursday. Student participants were charged a reduced registration fee of £150. The funding from the IoP Gravitational Physics group was used to partly fund this discount. Registration fees were waived for a small number of participants from developing countries.

The feedback from participants has been overwhelmingly positive, and we believe PASCOS-07 was a very successful conference.

Organising Committee: S.A. Abel (IPPP, Durham), C.R. Contaldi, P.D. Dauncey, G.J. Davies, M.J. Duff, T.W.B. Kibble, A. Rajantie (chair), R.J. Rivers, K.S. Stelle, H. Stoica and T. Wiseman.

4.4 BritGrav VII

Contributed by Edward Andersson, University of Cambridge

BritGrav 7 (the Seventh British Gravitational Conference) was held on the third and fourth of April at the Centre for Mathematical Sciences of the University of Cambridge. It was organized by Dr Edward Anderson with help from Dr Mihalis Dafermos, Professor Gary Gibbons, Dr John Stewart and Ms Cheryl Billington.

The Conference started with a session on formalism for classical general relativity chaired by Professor Malcolm MacCallum. There was then a session on quantum gravity chaired by Dr Edward Anderson, one on black holes chaired by Dr Jorma Louko, one on numerical relativity and gravitational waves chaired by Dr John Stewart, one on mathematical relativity chaired by Dr Mihalis Dafermos, then one concluding the mathematical relativity and also covering exact solutions of general relativity chaired by Dr Carsten Gundlach and finally a session on cosmology chaired by Dr Ian Jones. Over 70 people took part.

BritGrav 7 was sponsored by the IOP. The journal 'Classical and Quantum Gravity' also sponsored a drinks reception and buffet on the evening of the first day. BritGrav is very much oriented for the benefit and contribution of the junior people in the field (research students and postdocs), as part of which 'Classical and Quantum Gravity' also sponsored a prize for the best student talk, won this year by Mr Gustav Holzegel of the University of Cambridge for his talk 'Positive mass and isoperimetric inequalities'.

4.5 NPPD'07: The Institute of Physics Nuclear and Particle Physics Divisional Conference

Contributed by Diana Shaul, Imperial College London

The IoP's NPPD conference was held this year at the University of Surrey from the 3rd to the 5th April. For the first time, the Gravitational Physics Group participated in this conference, with a dedicated half day parallel session on the morning of Thursday 5th April, and joint plenary session in the afternoon. We joined the rest of the conference delegates in a very well attended poster session the evening before our session, which was followed by a sumptuous conference dinner laid on by the University of Surrey.

Although only a half day session, a broad range of gravitational physics topics was deftly covered by our invited speakers. Imperial College's Professor Andrew Jaffe started off the GPG morning session with a talk on the CMB. Dr Dean Morgan from the University of Sheffield followed, discussing the potential of astrophysical neutrinos to be used as a probe of quantum gravity. The prospects for the detection of gravitational waves from compact objects was then covered by Professor John

Miller, of both SISSA (Trieste) and the University of Oxford. The session was rounded off by Dr Charles Wang of the University of Aberdeen, who returned to the prospect of experimental investigation of quantum gravity, but this time using matter wave interferometry.

Professor Sheila Rowan from the University of Glasgow opened the last session of the conference with a comprehensive talk on future gravitational wave detectors, followed by Professor Tim Sumner, from Imperial College, who rounded off the conference with a discussion of experimental searches for dark matter.

The NPPD conference is held only once every 3-4 years and this time the general theme was *Future Facilities*. This conference provided an excellent opportunity for the communities that fall under the NPPD umbrella to come together and discuss their work in an atmosphere of open dialogue.

4.6 LISA: Experimental and Theoretical Challenges and Annual General Meeting

Contributed by Elizabeth Winstanley, University of Sheffield

This half-day meeting followed the Group's AGM on 21st February 2007, in the Institute of Physics, London, and covered a broad spectrum of LISA science activity. We were particularly pleased to welcome Oliver Jennrich, LISA Project Scientist from ESA, who gave us an overview of the whole of LISA science and updated us on the status of the project in the ESA programme. The rest of the afternoon involved two talks on experimental aspects, and two on theoretical developments.

On the experimental side, Christian Killow (Glasgow) talked about the technological challenges of realizing the ultra-stable interferometric measurements that will be required for LISA, and Christian Trenkel (Astrium) discussed the interplay between LISA as a gravitational wave detector and other aspects of fundamental physics.

As well as the extensive experimental challenges of LISA science, the meeting covered the significant theoretical advances required for LISA, particularly the need for accurate modelling of those gravitational wave sources for which LISA is searching. Nils Andersson and Leor Barack (both Southampton) brought us up-to-date with developments in modelling two such sources: the merger of super-massive black holes and extreme mass-ratio inspirals.

The meeting attracted a very mixed audience of about 40 members and guests, including a good number of PhD students.

5 Contributed Articles

5.1 Status of Formulations for Numerical Relativity

Contributed by Oliver Rinne, DAMTP and King's College, Cambridge

The last couple of years have seen a series of remarkable successes in numerical relativity, including (but not limited to) the first complete simulations of the inspiral, merger and ringdown of binary black holes [1]. To a large extent, these successes are due to an improved understanding of the mathematical properties of Einstein's field equations. One of the fundamental features of general relativity is its coordinate invariance. However in a numerical simulation, a particular choice of coordinates has to be made. There are many ways to do this, and as a result there exist a variety of different formulations of Einstein's equations, with very different properties. Typically a function representing "time" is introduced and spacetime is foliated with respect to the level surfaces of this function. Einstein's equations then split into evolution equations, and constraint equations that must be satisfied within the hypersurfaces. Here I shall focus on the case in which the hypersurfaces are spacelike – the *Cauchy formulation*. Among the many formulations in this class, two have emerged as being particularly robust in numerical evolutions and are currently the favourite choices for the binary black hole problem: the BSSN system [2] and formulations based on (generalized) harmonic coordinates [3].

Any formulation suitable for numerical treatment must be well posed. In the absence of boundaries, this means that given initial data on an initial hypersurface and data in the source terms, a unique solution of the field equations exists and it depends continuously on the data. Subject to certain technicalities, the Cauchy problem is well posed if and only if the system of partial differential equations is strongly hyperbolic. This is an algebraic property that can be checked in a straightforward way. One of the oldest and most popular approaches to the Cauchy problem is the ADM formulation [4], in which the fundamental variables are the induced metric on the spatial hypersurfaces and their extrinsic curvature. We now know that ADM is only weakly hyperbolic and therefore ill posed [5], thus explaining the instabilities seen in numerical evolutions using this system. The much more stable BSSN system is derived from ADM but differs from it essentially in the introduction of new variables related to the momentum constraints. This modified system has been shown to be strongly hyperbolic, at least for certain coordinate conditions [6]. Formulations based on harmonic coordinates take a rather different approach. Here the spacetime coordinates obey the wave equation (with a source in the generalized harmonic case). The Einstein equations can then be rewritten as a set of (coupled) wave equations for the *spacetime* metric. Wave equations are well understood mathematically, in particular they are strongly (even symmetric) hyperbolic. This fact was used in the first proof of well posedness of the Cauchy problem for Einstein's equations by Fourès-Bruhat [7].

Ideally one would like to evolve a compact source on an unbounded spatial domain. Unfortunately computers are finite and so the domain has to be truncated. Boundary conditions must be supplied at this artificial timelike boundary. Such boundary conditions are not arbitrary; for instance, they must be compatible with the constraint equations, and they should be *absorbing*, i.e. they should not cause any spurious reflections of gravitational radiation. Having chosen a set of boundary conditions, the question arises whether the associated *initial-boundary value problem (IBVP)* is well posed. This is much more difficult than the Cauchy problem and has attracted considerable interest since the work of Stewart [8]. The first well-posed IBVP for Einstein's equations was formulated by Friedrich and Nagy [9]; it is based on a tetrad formalism. Much progress has been made recently for the generalized harmonic formulation. Various concepts of well posedness have been proven for constraint-preserving boundary conditions [10]. Attention is now focussing on improved higher-order absorbing boundary conditions, motivated by a study of the linearized Bianchi equations by Buchman and Sarbach [11]. Results on the well posedness of such improved boundary conditions have been obtained [12]. The situation for the BSSN system is much less satisfactory. Boundary conditions that are currently being used are not even compatible with the constraints, let alone absorbing for gravitational radiation, and their well posedness is unclear.

Of course well posedness is not the only property needed to make a formulation of the Einstein equations suitable for numerical solution. Most schemes adopt a *free evolution* approach, whereby the constraints are only solved initially. Analytically, this is fine because the constraints are preserved by the evolution equations. However, numerical evolutions have traditionally suffered from exponentially growing violations of the constraints. One might hope that by adding multiples of constraints to the evolution equations, one could arrange for the constraints to be damped. Because the constraints are typically of the same derivative order as the evolution equations, this procedure modifies the principal part of the evolution equations and thus potentially endangers hyperbolicity. It is one of the fortunate coincidences of the generalized harmonic formulation that the Einstein constraints are equivalent to a set of harmonic constraints of lower derivative order. Thus constraint damping can easily be achieved [13]. This has been crucial for the success of numerical evolutions based on this formulation. No constraint damping is normally applied to the BSSN system; nevertheless violations of the constraints appear to be under control in numerical simulations. This has been partially understood in terms of an analysis of the constraint propagation system [14].

Another criterion for a useful formulation is its flexibility in specifying the coordinates. Since in a numerical evolution the spacetime is typically not known *a priori*, it is not feasible to fix the coordinate chart before starting the simulation. Instead, the coordinates are coupled to the dynamical fields such that the resulting solution has desirable properties, for instance that spacetime singularities are avoided or that steep gradients do not form. Examples of such coordinate conditions are those that force the spatial hypersurfaces to be maximal or that minimize the distortion of the spatial coordinates. Traditionally such coordinate conditions have been formulated in the context of the ADM formulation. They typically take the form of elliptic equations for the lapse and shift but hyperbolic driver equations have been developed that enforce the elliptic equations asymptotically [15]. Such driver conditions are used in current binary black hole simulations based on the BSSN formulation. In contrast, relatively little is known about suitable coordinate conditions in the generalized harmonic framework. Here the coordinates are specified through the *gauge source functions*, the source terms in the wave equations that the coordinates obey. Pretorius [3] suggested evolving the gauge source functions by wavelike equations. This idea has recently been refined in [16] in order to asymptotically enforce a large class of coordinate conditions that have been successfully used in the ADM approach.

It is impossible to cover more than a tiny fraction of all the work on formulations for numerical relativity in such a short article but I hope to have demonstrated that there has been an encouraging convergence between analytical and numerical results. More work is needed on improved boundary conditions, in particular for the BSSN system. More flexible coordinate conditions are another concern, in particular in the generalized harmonic approach.

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5.2 The Status of Searches for Gravitational Waves From Known Pulsars

Contributed by Matt Pitkin, University of Glasgow, on behalf of the LIGO Scientific Collaboration

One of the main types of target for current and future gravitational wave detectors are spinning neutron stars. Provided they have some sustainable asymmetry about their rotational axis they will produce periodic (also known as continuous) gravitational waves. Such an asymmetry could be from, for example, a crustal deformation of the star, a fluid mode oscillation, or precession. Theoretically any *long-lived* periodic signals from a deformed neutron star will be very weak as the maximum sustainable deviations of the star from asymmetry are small. However, current detector sensitivities mean that with precisely targeted coherent searches, using many months of data, we can start to reach into the range where a real signal could live.

To perform such a coherent search we need a very well characterised target, which luckily we have available for neutron stars that are seen as millisecond pulsars by the radio community. Within the sensitive frequency band of current detectors (between $\sim$50–1500 Hz) there a now over 150 known millisecond, or young, pulsars for which information on their frequency evolution and position exists. Assuming that any gravitational wave signal is closely locked to the phase evolution of the electromagnetic signal, and the source parameters obtained from radio observations are well enough defined, we can search for signals from many of these objects. For these searches a triaxial neutron star emitting at twice the rotation frequency is assumed.

Prior to the operation of the current generation of large scale interferometric gravitational wave detection only two pulsars had been targeted: the Crab pulsar (PSR J0534+2200) and PSR J1939+2134. More recently these *known pulsar searches* have been performed on data from the first science run (S1) of the LIGO and

GEO 600 gravitational wave detectors in 2001 onwards. Initially only the then fastest known pulsar, PSR J1939+2134, with a gravitational wave frequency of ~ 1283 Hz was searched for [1]. Since then the LIGO Scientific Collaboration (LSC) has formed a collaboration with Michael Kramer and Andrew Lyne of Jodrell Bank Observatory to provide specific pulsar parameter information over the subsequent science runs. This information allowed 28 isolated pulsars to be searched for with the second science run [2], and 78 isolated pulsars *and* pulsars in binary systems in the third and fourth runs (S3 and S4) [3]. It has also meant that any timing glitches in the pulsars could be monitored for. These searches have not detected a signal from any pulsar, but have allowed upper limits on the level of gravitational wave emission to be set. The most stringent 95% degree-of-belief limit on the gravitational wave amplitude for a pulsar from these runs was $h_0^{95\%} = 2.6 \times 10^{-25}$ for PSR J1603−7202. The upper limits on amplitude can also be cast as limits on the star's quadrupole moment, which, assuming a specific moment of inertia, can give the pulsar's equatorial ellipticity. The tightest limit on this is just under 10^{-6} (for a moment of inertia of $10^{38}\,\mathrm{kg\,m^2}$) for PSR J2124−3358 (cf. maximum theoretical values for exotic neutron/quark stars of between 10^{-2}–10^{-4} [4].)

Another way to look at these results is to see how they compare to the so called spin-down limit. This is set by equating the total kinetic energy lost as the pulsar spins-down with that available for gravitational wave emission. For the majority of known pulsars within the searches the direct gravitational wave limits are of order hundreds of times worse than the spin-down limits (assuming no external power supply.) However, for many pulsars within globular clusters the spin-down is obscured by accelerations within the cluster and no spin-down limit can be set, making the direct gravitational wave observation results unique. Also for the young, fast spinning-down pulsar in the Crab nebula (J0534+2200), the combined S3 and S4 upper limit is actually only 2.2 times larger than that set via spin-down arguments.

From 4th Nov 2005 to 1st Oct 2007 the LSC performed the fifth science run (S5) with the LIGO detectors at design sensitivity. The search for known pulsars within this data is currently ongoing with the hope of including as many of the observed millisecond pulsars as possible. The design sensitivities of the detectors show that the spin-down limit for the Crab pulsar would be beaten after several months of observation. Because of this, preliminary results for this pulsar have already been produced and do indeed beat the spin-down limit. This is providing a way to constrain the energy budget of the pulsar and the surrounding nebula. The search for the Crab pulsar has also been extended to include a small frequency range around that of the precisely targeted search to account for physically motivated mechanisms that potentially could shift the frequency. With the S5 run it is expected that for many pulsars we will be able to set limits on the ellipticity in the 10^{-7} range and approach the spin-down limit for a couple of other pulsars.

Known pulsar searches are not the only continuous wave searches. Both fully coherent and semi-coherent, all-sky, all-frequency, searches (and hierarchical combinations of both) have been, and are continuing to be, performed on LIGO and GEO 600 data. These can be far more computationally demanding than the known pulsar search, but with the majority of neutron stars not seen as pulsars they are essential. However, due to the far larger parameter space being searched they are unable to be as sensitive as the known pulsar searches. Because of the large computational demand, the coherent and hierarchical all-sky searches have been set up as a very successful distributed computing project, called Einstein@Home (see http://einstein.phys.uwm.edu), to make use of people's idle PCs. This has already been used to search S3 (see http://einstein.phys.uwm.edu/FinalS3Results) and S4 data, and is currently being used on S5 data. Other coherent searches are targeted at potential neutron stars within supernova remnants (e.g. Cas A, SN1987a), which have a decreased computational burden and allow deeper searches within the data than the all-sky search. These may also be used to target globular clusters, which have a high density of millisecond pulsars, and the galactic centre. With the start of data sharing with the Virgo detector this will also be included in searches.

The future prospects for pulsar searches will be greatly improved with the planned upgrades to the current generation detectors. We will be able to probe below the spin-down limit for several pulsars, offering the real prospect of a detection, therefore providing information on the star's equation of state. We will also be reaching levels where less exotic models of the maximum sustainable pulsar ellipticity lie.

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5.3 Some Current Topics On Mathematical General Relativity

Contributed by Juan A. Valiente Kroon, School of Mathematical Sciences, Queen Mary, University of London

The mathematical study of the Einstein field equations (EFE) has experienced great developments in recent years. These developments have been fuelled by a close interaction of mathematical relativists with experts in other areas of applied mathematics —most notably experts on partial differential equations. Nevertheless, some of the most important problems in the area still open.

Arguably, the most important open problem in classical General Relativity remains, to provide a proof of the so-called *Cosmic Censorship Conjecture* (CCC)—see

[9] for a simple discussion of the issues surrounding CCC. In the case of asymptotically flat spacetimes —i.e. spacetimes describing isolated systems— the *weak Cosmic Censorship Conjecture* asserts that naked singularities —i.e. singularities that can be seen by an observer at infinity— should not occur generically. The requirement of genericity is very important here as there are a number of examples of spacetimes containing naked singularities.

A traditional way of developing intuition on the behaviour of solutions to the EFE has been the construction of so-called *exact solutions* —i.e. solutions explicitly expressible in terms of *elementary functions*. Unfortunately, the nature of this approach is not adequate for addressing issues of generic behaviour in solutions to the EFE. Thus, one is in need of devising a systematic way of constructing solutions. The alternative to the construction of exact solutions has been to consider suitable initial value problems for the EFE —on which initial data on, say, an asymptotically flat 3-dimensional hypersurface is prescribed— for which existence and, say, uniqueness of solutions can be asserted. The consideration of an initial value problem is, of course, also a first step towards the implementation of a numerical simulation. With regards to the initial value problem for the EFE, the *strong Cosmic Censorship Conjecture* states that for generic initial data for the EFE, there exists a unique solution which cannot be extended any further —i.e. the whole information about the spacetime is contained —in some sense— in the initial data. The proof of CC has big implications for causality.

Although there are some proofs of the CCC for certain specific scenarios like the spherically symmetric Einstein-scalar field [1] system and the Gowdy spacetimes [6], a proof for generic spacetimes still lies many years ahead. There are nevertheless a number of problems whose resolution would constitute a milestone in the quest towards a proof of CC. Most notably, one has the so-called problem of the *non-linear stability of the Kerr spacetime* —that is to provide a proof of the intuitively reasonable assertion that if one starts from some initial data set which is close (in a mathematically precise sense) to initial data for the Kerr spacetime the resulting spacetime will exist and will have a global structure similar to that of Kerr. In particular, such a proof would show rigorously the existence of (global) dynamical black hole spacetimes. By *global* it is meant that the existence of a solution is asserted not only in a neighbourhood of the initial surface —i.e. locally— but one obtains —in the sense of the strong Cosmic Censorship— the whole so-called *maximal development*.

Some years ago, Christodoulou & Klainerman [2] provided a proof of a similar statement for the Minkowski spacetime. Namely, that if one starts from initial data for the EFE which is close to data for the Minkowski spacetime, then a maximal development exists and has global properties equivalent to those of Minkowski spacetime —in particular, no black holes are formed! In recent years there have been a number of simplifications and extensions of this proof —see e.g. [4]. A property that the proof of the non-linear stability of Minkowski spacetime was not able to show was the so-called *peeling behaviour* of the resulting spacetime. The peeling behaviour is a certain prescription for the decay of the Weyl tensor —which in a vacuum spacetime describes the *free gravitational field*— suggested by the studies of the linearised theory and exact solutions —see e.g. [7] for a more complete discussion. Following the seminal work on the asymptotic behaviour of the spacetime in the 1960's [5], it has been conjectured that the peeling behaviour would be a property of spacetimes describing isolated bodies. The results of Christodoulou & Klainerman brought these issues to the forefront. There has been some amount of work towards establishing the conditions under which a spacetime will satisfy the peeling behaviour —and more generally when it will be *asymptotically simple*, see e.g. [3]. A spacetime is said to be asymptotically simple if it admits a (conformal) compactification which is similar to that of the Minkowski spacetime and by means of which it is possible to introduce the notion of *null infinity*. In particular, an asymptotically simple spacetime has a smooth null infinity. The smoothness of null infinity is closely related to the asymptotic behaviour and decay of the spacetime: if null infinity is smooth, then the spacetime peels. There are strong indications that the peeling behaviour is actually not generic, and that strong conditions on the initial data for the EFE are required to have a solution with peeling —see e.g. [8]. These issues may be of relevance in the discussion of the non-linear stability of the Kerr spacetime, in particular when discussing the decay of the spacetime at late times.

Finally, it is important to clarify the relevance of the work carried out by the community of mathematical relativists in view of the recent dramatic new developments in the simulations of black hole spacetimes. Given that most numerical simulations are not designed for the discussion of global aspects of spacetimes —in particular because they only calculate a *finite* part of it in both space and time —general (rigorous) discussions of the global behaviour of spacetimes and of their asymptotics act as warranty of the correctness of many of the techniques adopted by the numerical community, like excision or the extraction of radiation at a finite distance. On a more conceptual level, proofs of the various aspects of Cosmic Censorship would exhibit the exceptional internal consistency of General Relativity.

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6 Financial Report for 2007

Contributed by Elizabeth Winstanley, University of Sheffield

This is the first year of a new funding system for Institute of Physics Groups. We now operate on an annual budget, the sum we have available for 2007 being £4200, a significant increase on our previous Institute allocations.

The major part of our expenditure is organizing, or providing grants to, scientific meetings. This year we were involved in the NPPD Division Conference, BritGrav 7, and the Low-Energy Quantum Gravity meetings. We also made grants to PASCOS07 and the UK Fundamental Theory Meeting. The total amount spent on these scientific meetings this year was £2742. As a result of our increased budget this year, we were able to have a longer scientific meeting following the AGM in February. At the same time, this increased the costs of the meeting to £760.

As ever, we endeavour to keep committee expenses to a minimum, this year these totalled £414. To keep costs down, we have been conducting most committee business by e-mail and have a summer telecon instead of a face-to-face meeting. There are also sundry expenses (such as posting the annual general meeting announcement), amounting to £144.

In total, we spent just under our total budget for 2007. Our budget for 2008 has been set at £3500. In addition, we have been allocated £1190 to be spent on student bursaries, as part of the Research Student Conference Fund (see separate article in this newsletter).

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To Contribute to the Next Newsletter

If you would like to contribute an article to the next newsletter please email Ian Jones at

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8 How To Join

For Those Already Members of the IoP

- The easiest way to join the Gravitational Physics Group is to go to:

  `http://members.iop.org/login.asp`

- After logging in (using your membership number), click on 'My Groups' and then it is straightforward to add/remove groups.

- For IoP members without web access, the simplest way to join a group is to amend your membership renewal form. Alternatively, write to the following address:

  Membership Department,
  The Institute of Physics,
  76 Portland Place,
  London.
  W1B 1NT

- Note that you do not pay for the first group you join!

For Those Who Are Not Members of the IoP

- If you would like to go join the Institute you should go to:

  `http://www.iop.org/Membership/How_to_Join/index.html`

  from where it is possible to apply online.

- Application forms are also available by writing to the Institute at the above address.

This newsletter is also available on the web and in larger print sizes.
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