Newsletter of the Gravitational Physics Group of the Institute of Physics

January 2007

Contents

Cover picture of the Anglo-German gravitational wave detector GEO600 near Hanover, Germany. Data from this detector is currently being analysed (jointly with data from the American LIGO detectors) in the search for gravitational waves.

1 Welcome from the Chair

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

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

It's been a busy year for the Group, as highlighted by the articles in this newsletter. There have been exciting developments on both the theory and experimental side of Gravitational Physics over the past twelve months, ranging from string theory and brane-world gravity, to the latest data from gravitational wave experiments. The Group has organized or supported scientific meetings in all these areas, with more planned for 2007. As well as reports on past and future meetings, I'm pleased to welcome in this newsletter more contributed articles, keeping members up to date with the latest developments.

One particular new activity to which I would like to draw members' attention is the Student Seminar Exchange programme. Supervisors, please encourage your students to sign up to this, which I hope will be a most useful opportunity for interactions between students in different research groups and for students to advertise their work. More details can be found below.

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 February 2007, so please contact me or any of our committee members if you are interested in getting involved. In particular, volunteers to organise meetings in gravitational physics are always welcome, as are suggestions for topics we should be covering or activities we should be supporting. 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.

2 Announcements

2.1 Student Seminar program

Contributed by Paul Abel, University of Leicester

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 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:

`http://groups.iop.org/GP/student_seminar_exchange.html`

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. The deadline for Spring and Summer entries are 12th January 2007 and 30th March 2007, respectively.

2.2 ESF network in Quantum Geometry and Quantum Gravity

Contributed by Jorma Louko, University of Nottingham

A new European Science Foundation network in Quantum Geometry and Quantum Gravity is now active and will run until July 2011. The main purpose of the network is to stimulate interaction between researchers in different areas of quantum geometry and apply the results to the study of quantum gravity. The network provides funding for conferences and workshops, with the option of joint organisation with other bodies. It also provides travel grants for scientists, including PhD students, to travel between European institutions. The network comprises currently nine countries, including UK. Other European countries are eligible to join. The network steering committee is chaired by John Barrett from the University of Nottingham. More information is available at the website,

`http://www.maths.nottingham.ac.uk/qg/`

3 Forthcoming meetings

3.1 BritGrav VII

The seventh annual BritGrav meeting will take place on the 3rd and 4th of April 2007 at the Centre for Mathematical Sciences, Wilberforce Road, Cambridge CB3 0WA. The organizers are Edward Anderson, Mihalis Dafermos, Gary Gibbons and John Stewart. The meeting will receive some financial support from the IOP and Classical and Quantum Gravity. The meeting will consist of a series of 15-minute talks. If there are more talks than slots available, preference will be given to junior researchers in the field (research students and postdocs). Registration is free. To register, email Dr Edward Anderson (ea212@cam.ac.uk). Please see the BritGrav website at

`http://www.srcf.ucam.org/~ea212/Britgrav7`

for further details.

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

For the first time, the Gravitational Physics Group will be participating in the Nuclear and Particle Physics Division Conference at the University of Surrey. There will be a mixture of plenary and parallel sessions. All the Gravitational Physics sessions will be held on Thursday 5th April, so that members can attend BritGrav 7 (see above) beforehand. We are planning a wide-ranging programme in line with the Conference theme of 'Future Facilities'. In particular, we will be covering future ground and space-based gravitational wave detectors as well as future fundamental physics experiments in space. There will also be an update on current gravitational wave detectors and other aspects of gravitational physics.

Further details will be available on the IOP website. A special rate will be available to Gravitational Physics Group members to enable them to attend just on Thursday 5th April.

3.3 LISA: Experimental and Theoretical Challenges and Annual General Meeting

This half-day meeting will be held at the Institute of Physics (London), starting from 2pm on Wednesday 21st February 2007. It will be preceded by the Group's AGM at 1.45pm. The afternoon science meeting will cover a broad spectrum of LISA science activity, ranging from experimental and technological advances to theoretical source modelling. Amongst the speakers currently planned are: Oliver Jennrich - LISA Project Scientist (ESA), Leor Barack (Southampton) and Christian Killow (Glasgow). Members will receive a formal AGM notice in the New Year, and further details will be available on the Group's web-site. All welcome!

4 Recent meetings

4.1 Brane-World Gravity: Progress and Problems

Contributed by Andrew Mennim, University of Portsmouth

The Institute of Cosmology and Gravitation at the University of Portsmouth hosted a two-week international conference at the end of September on the subject of brane-world gravity. The conference began with a three-day meeting which was followed by a workshop; about 80 delegates attended. The programme and slides from most of the talks can be found on the conference website:

`http://www.icg.port.ac.uk/brane06/`

Invited speakers were Cliff Burgess, Cedric Deffayet, Gary Gibbons, Ruth Gregory, Panagiota Kanti, David Langlois, James Lidsey, Kei-ichi Maeda, Nick Mavromatos, Lefteris Papantanopoulos, Valery Rubakov, Misao Sasaki, Tetsuya Shiromizu, Jiro Soda, Kellogg Stelle and Takahiro Tanaka.

Brane-world models have been studied intensively for the last decade. Originally motivated by the existence of branes in string theory, brane-worlds have been of interest to the particle physics community because they offer new ways to explain hierarchies, and because of the new phenomenology for colliders and cosmic ray showers resulting from the possibility of a low Planck mass. They have also inspired relativists and cosmologists because they represent a very geometrical way to modify gravity and to change the cosmological history of the universe. The conference focussed on the gravitational and cosmological aspects of brane-worlds, the aim being to review recent progress in the field and to spark discussions and collaborations on the outstanding issues.

The themes discussed in the meeting were cosmology and the evolution of cosmological perturbations in brane-worlds, the Dvali–Gabadadze–Porrati (DGP) model and its possible problems with ghosts, the nature of black holes in brane-worlds and possible collider signatures, possible solutions to the cosmological constant problem using six-dimensional brane-worlds, and links between the phenomenological models and fundamental physics ideas like string theory. The meeting ended with a discussion of the outstanding issues, identifying projects for study during the workshop and beyond. About half of the delegates remained for the workshop. The workshop involved two talks each day with time in between for delegates to discuss the themes raised and form collaborations.

Some interesting subjects and outstanding questions were discussed, resulting in an advance in understanding and new collaborations. Effective actions are very useful tools in higher-dimensional physics, but it is important to understand in which circumstances they are effective; for Kaluza–Klein theories this is entirely understood but for non-homogeneous configurations there are additional subtleties. Understanding the quantum vacuum state for the early universe in the Randall–Sundrum model with inflation on the brane is important for predicting possible cosmological signatures; it was argued by some that the initial state could be and by others that it must be very close to the usual four-dimensional result. Perhaps most contentious was the issue of ghost states in the DGP model. Some delegates presented work showing that the model has a ghost state either in the spin-two or spin-zero sector, but it was argued by others that this does not necessarily invalidate the model because the energy scale associated is on the limit of where one can trust an effective four-dimensional description.

Financial support was provided by the Gravitational Physics Group of the Institute of Physics and the Particle Physics and Astronomy Research Council, as well as the University of Portsmouth.

4.2 Meeting in honour of Andrew Chamblin

Contributed by Harvey Reall, University of Nottingham

On Saturday October 14, a 1-day scientific meeting was held in honour of Andrew Chamblin, who died earlier this year at the age of 36. The meeting took place in the Winstanley lecture theatre at Trinity College, Cambridge and was followed by a banquet. The speakers were Raphael Bousso, Robert Caldwell, Roberto Emparan, Gary Gibbons, Stephen Hawking and Clifford Johnson. They spoke on subjects related to Andrew's research interests, and shared memories of working with Andrew. The meeting was attended by 110 people. The organizers are grateful to PPARC and the Mathematical and Theoretical Physics and Gravitational Physics groups of the IOP for financial support.

4.3 Maxwell 150 years on: the impact of his science

Contributed by Charles Wang, University of Aberdeen and RAL

James Clerk Maxwell was described in a message to our conference by one well-known scientist as 'the greatest physicist since Isaac Newton'. That puts him ahead of some 177 Nobel Prize winners in physics, reason enough to celebrate the 150th anniversary of his appointment as Professor of Natural Philosophy at Marischal College. A very successful meeting to mark the event was held by the University of Aberdeen on 7th–9th September.

The meeting was opened at Marischal College by Professor Ian Halliday, President of the European Science Foundation and Chief Executive of the Scottish Universities Physics Alliance (SUPA). One-and-half days were devoted to invited talks on current developments in areas of modern science that have evolved from Maxwell's work, supplemented by posters contributed by participants. A capacity audience consisting of over 70 researchers and research students heard leading speakers from across the UK, from Europe and North America, thanks in part to sponsorship from the IoP Gravitational Physics Group and CCLRC Centre for Fundamental Physics. Areas covered by the talks included classical and quantum gravity, fundamental physics and space science; the posters widened this spread, with strong submissions from several UK universities. The breadth of coverage stimulated a cross-fertilisation of ideas and broadened everyone's appreciation of the enormous influence of Maxwell's work.

The final afternoon of the meeting took place at King's College and was devoted to public lectures on Maxwell at Aberdeen and the impact of his work. The public announcement of the institution of the James Clerk Maxwell Chair in Mathematical Physics gave the meeting a positive start and the following speakers did not disappoint the expectation of an audience of around 200. Media coverage both in local papers and on Radio Scotland prior to the event raised the profile of Maxwell's achievements and his association with the University of Aberdeen. In all, the meeting was highly successful and among its legacies are improved contacts between professionals, students or simply those interested in physics and calls for further meetings along similar lines. Further details can be found at the event website:

`http://www.abdn.ac.uk/maxwell/`

4.4 BritGrav V

Contributed by Charles Wang, University of Aberdeen and RAL

The 5th British Gravity Meeting (BritGrav 5) was held at St Catherine's College Oxford during 20–23 September 2005. The Meeting continued to provide an informal environment for the exchange of ideas and results from researchers in theoretical and experimental gravity. Current PhDs and postdocs from UK universities and beyond were particularly encouraged to participate in the meeting. This year's programme is more extended as part of the Einstein centenary celebration. Keynote speakers were:

Prof. Jerry Griffiths (Loughborough University)
Prof. Ray d'Inverno (University of Southampton)
Prof. Graham Hall (University of Aberdeen)
Prof. Chris Isham (Imperial College, London)
Prof. James York (Cornell University, USA)

In addition, a public lecture was delivered by Prof. Malcolm A. H. MacCallum (Queen Mary College, London).

BritGrav 5 has received supported from the CCLRC Centre for Fundamental Physics and IOP Gravitational Physics Group and Nuclear and Particle Physics Division. The 'Best Student Talk Prize' was sponsored by the journal, Classical and Quantum Gravity. The Meeting was well attended by 73 participants including 30 research students. Further details are available at the Meeting website at:

`http://www.sstd.rl.ac.uk/britgrav5/`

4.5 BritGrav VI

Contributed by Jorma Louko, University of Nottingham

The 6th British Gravity Meeting, BritGrav 6, was held at the University of Nottingham on 4-5 April 2006. The meeting was hosted by the Quantum Gravity Group (John Barrett, Kirill Krasnov, Jorma Louko) in the School of Mathematical Sciences.

The scientific programme consisted of 29 talks, each of 15 minutes' duration, selected by the local organisers from abstracts submitted by the approximately 40 participants. The first day of the meeting focussed on classical, numerical and astrophysical relativity, while in the second day the topics moved to quantum issues. Approximately half of the talks were by research students, one by an undergraduate student, three by postdocs and the rest by academic staff. Most of the participants came from the British Isles but there were also participants from Austria, Canada and Russia. Talk titles and abstracts are available at the meeting website:

`http://www.maths.nottingham.ac.uk/QG/britgrav/`

Financial support for the local organising costs (refreshment breaks and the conference info pack) and for the travel expenses of research students from UK and Ireland was provided by the Institute of Physics Gravitational Physics Group. A welcome reception and a Best Student Talk Prize were sponsored by Classical and Quantum Gravity.

The Best Student Talk Prize was awarded to Brynmor Haskell from the University of Southampton, for a talk entitled 'Detecting mountains on neutron stars.'

4.6 Classical and Quantum Gravity Scientific Meeting

Contributed by Judith Adams, Institute of Physics Publishing, Bristol

In May, 17 members of the Editorial Board of Classical and Quantum Gravity (CQG) came to the UK for their annual meeting. This year, as well as discussing editorial matters the Board also took the opportunity to discuss their scientific research, in a one day meeting held on 25th May.

Board member George Papadopoulos organised the meeting at his home institution of King's College London, and CQG was very pleased to make an open invitation to all those interested in attending. The Board consists of 29 internationally eminent scientists, who act as ambassadors and editors across the full breadth of the journal's scope. The opportunity to hear them speak in the UK attracted a high number of delegates from across the country, leading to a lively and wide-ranging meeting.

Editor-in-Chief Robert Wald (University of Chicago) opened the day's proceedings by presenting some recent work in quantum field theory in curved spacetime, followed by Alan Rendall (Albert-Einstein-Institut, Golm) who discussed the mathematics of accelerated cosmological expansion. Representing the experimentalists amongst the Board, Norna Robertson (Stanford and Glasgow Universities) gave a talk on the suspension design of Advanced LIGO and the morning session then closed with a presentation from an external speaker, Ulf Gran (KU Leuven), who talked on the classification of supersymmetric backgrounds.

Following a lunch break in the sunshine on The Strand delegates reconvened for the afternoon session, beginning with a talk from former Board member (1987-1996) Paul Townsend (Cambridge University) discussing the Yang monopole. José Senovilla (Universidad del País Vasco) followed with a talk on trapped submanifolds, horizons and symmetries, and Susan Scott (Australian National University) discussed the predictions of the singularity theorems of Penrose and Hawking.

Former CQG Editor-in-Chief Kelly Stelle (Imperial College) opened the second session of the afternoon with a talk on M-theory on Calabi-Yau 5-folds, with Valeri Frolov (University of Alberta) ending an enjoyable and interesting day with a presentation about the gravitational field of gyratons. The speakers and attendees then retired to a nearby pub to continue their discussions over a drink, before heading out to an Italian restaurant.

The organisers thank the IOP gravitational physics group for help in promoting the event.

About the journal: Classical and Quantum Gravity (www.iop.org/journals/cqg) welcomes high-quality submissions in all aspects of gravitational physics and the theory of spacetime. Members of the Institute of Physics are entitled to a discounted personal subscription to CQG. Please contact judith.adams@iop.org for further information.

4.7 LISA meeting

Contributed by Sheila Rowan, University of Glasgow

The Gravitational Physics Group of the IoP sponsored jointly with the Royal Astronomical Society a well attended Discussion Meeting on LISA -Gravitational-Wave Astronomy in Space. This two day meeting was held on 12th and 13th January 2006 in the Geological Society Lecture Theatre, Burlington House, Piccadilly.

The meeting was targeted at presenting some aspects of LISA, the interferometric gravitational wave antenna in space, to the wider astronomical community. With the planned launch of a technology demonstration mission in 2009, the expected launch of LISA is coming closer. LISA has great potential for the detection of gravitational waves from a number of sources including massive black holes both forming and interacting with each other, along with the detection of white dwarf binary systems. The mission is thus of high importance for the future of gravitational wave astronomy.

The meeting was opened with a welcome by Prof Keith Mason, had a series of talks introducing the LISA mission, and the expected sources and potential science which the mission will enable. Representatives from both NASA and ESA attended and presented the current status of the mission, which is a joint mission split between the two agencies, and there were also a number of talks describing the status of hardware developments for both the LISA and LISA Pathfinder missions, finishing with closing remarks from Prof Dave Southwood, Director of Science at ESA.

5 Contributed articles

5.1 The LISA mock data challenge

Contributed by Oliver Jennrich, LISA Project Scientist, ESA/ESTEC

Data analysis for LISA is a challenging task that presents many open questions and research opportunities. To support the development of a data analysis system for LISA, the idea of a LISA Mock Data Challenge (MLDC) was brought up, inspired by similar activities for the ground-based gravitational wave project LIGO.

In the MLDC, participating groups are asked to extract the parameters of a reduced number of sources in a simulated LISA-like data-stream and to share the results and the methodology with other participating groups. The MLDC has dual purposes - on the one hand it allows to demonstrate the level of technical readiness already achieved by the gravitational-wave community in distilling a rich science payoff from the LISA data output, on the other hand it serves as a focus to further develop LISA data analysis tools and capabilities.

The first LISA Mock Data Challenge (MLDC) has been released on June 30th, 2006 and it is foreseen that first results will be presented to the broad community and discussed in a dedicated session at the 11th Gravitational-Wave Data Analysis Workshop (December 18-21, 2006, at the Albert Einstein Institute, in Golm, Germany)

Further rounds of the MLDC will include more challenging data analysis problems, both in the number of sources and the realism of the data-streams and the instrumental noise. Currently the plan is to launch these rounds by the end of 2006 with a completion date in 2007. Further information, including all relevant documents, datasets and source codes for the first round of the MLDC can be obtained at the MLDC website (http://astrogravs.nasa.gov/docs/mldc/)

As interest in LISA goes much further than the gravitational wave community, researchers are invited to join the LISA International Science Community (LISC), an informal researcher network maintained by the LISA International Science Team for the purpose of exchanging information with the wider science community. Currently, the LISC has about 200 members from more than a hundred different institutions located all over the world and it maintains a webportal at (http://www.lisa-science.org/). The aim of this portal is to share information with LISC members, to encourage communication among them, and to support LISC members interested in learning more about LISA science or in engaging in LISA advocacy and outreach by offering a repository of helpful resources.

5.2 Search templates for binary black holes

Contributed by B S Sathyaprakash, Cardiff University

The last few years have seen a remarkable progress in the computation of the late-time dynamics of binary black holes and the waveform emitted during their inspiral and merger. On the one hand, post-Newtonian (PN) approximation schemes have provided unprecedented insight into the description of these systems during their adiabatic inspiral. On the other, numerical relativity has provided the first full calculations of the highly non-linear merger phase of the evolution.

With the completion of the 3.5PN calculations [1], the inspiral part of waveform is pretty much on solid ground (for a recent review see [2]). The coefficients that were previously unknown in the binding energy and gravitational wave flux have now been computed using dimensional regularization, thereby resolving all ambiguities in the evolution of the system to 3.5PN order. The current status is that the waveform is now known to order $(v/c)^7$ in the phase and order $(v/c)^5$ in amplitude in the case of two non-spinning black holes in quasi-circular orbit. Imprint in the signal at such high PN orders are the various non-linear effects which take a specific form in general relativity. These include the tails of gravitational waves, tails-of-tails, the presence of logarithmic terms in the PN expansion, spin-orbit and spin-spin couplings, the presence of higher harmonics (i.e. harmonics other than twice the orbital frequency that appear in amplitude corrections to the waveform), etc. Therefore, the waveform provides a testbed to check general relativity against other theories of gravity [3].

The highest order corrections contribute only a fraction of a cycle over tens of thousands of cycles indicating that the neglected terms contribute insignificantly to the phase evolution. Therefore, we can reliably use these waveforms as detection templates in a matched filter search for inspiralling binary systems. However, the search must still restrict to the inspiral phase as the complicated dynamics associated with the merger of black holes cannot be handled by PN methods, which essentially assume that the system evolves (quasi-) adiabatically. This means that the PN waveforms are excellent detection templates for those systems which merge at frequencies above the heart of the detector's sensitivity bandwidth. Given that the current ground-based interferometers have their best sensitivity at about 200 Hz this means that the PN templates are accurate enough to search for binaries whose total mass is smaller than about 20 $M_{\odot}$. For heavier systems, the merger part of the signal would be more dominant than the inspiral part and the PN schemes are not quite accurate in this regime. However, improved signal models, such as the Effective One-Body (EOB) approach are good enough to capture the early part of the merger [4, 5].

Progress in numerical relativity has allowed the computation of signals emitted during the merger, followed the by quasi-normal mode oscillations of the final black hole. Several groups [7] have succeeded in making this breakthrough for systems with equal masses. The shape of the signal is very much along the lines predicted by the EOB models. The crucial difference between numerical results and EOB is in the amount of energy emitted during merger, being 3% and 0.7% of the total mass, respectively. Nevertheless, it is quite remarkable that analytical schemes, such as the EOB, were on the right ballpark figure both in the case of emitted energy and the evolution of the phase. The factor of 4 increase in the predicted energy means that the current best detectors (the LIGO 4km interferometers at Hanford and Livingston) are sensitive to binary black hole mergers at distances up to 600 million light years for binary black holes of mass in the range of $[20, 60]M_{\odot}$.

There is now a surge of activity to compute numerical relativity waveforms from more asymmetric systems and to employ these templates in the search for binary black holes of masses in the range 20-100 $M_{\odot}$. There have also been computations of the higher order effects of the black hole spins on the dynamics and the emitted waveform, as well as the extension of the EOB approach to generic orbits.

The current searches are most advanced in the case of non-spinning binary black holes but have begun to include the effect of spins in a phenomenological way. This has been possible thanks to casting the phase evolution in a greatly simplified form in the Fourier domain, yet with little loss of detection efficiency [6]. Soon these searches will be replaced by the use of more accurate physical templates which are crucial in measuring the parameters of any candidate events. The search for spinning black hole binaries is computationally expensive. Current searches for non-spinning systems typically take about 75,000 CPU hours for each month of data - resources that are not too hard to find. With the inclusion of spin effects the demand will grow by more than an order-of-magnitude, warranting the use of hierarchical and/or sub-optimal searches.

In summary, the recent progress in understanding the dynamics of black holes has brightened the prospect of detecting these systems in data from interferometric gravitational wave detectors. The challenges we currently face mostly lie in improvising and automating the search algorithms and data analysis pipelines so that they can efficiently search the parameter space of binary black holes.

References

[1] T. Damour, P. Jaranowski, and G. Schäfer, Phys. Lett. B **513**, 147 (2001);
Y. Itoh, T. Futamase, and H. Asada, Phys. Rev. D **63**, 064038 (2001);
L. Blanchet, G. Faye, B.R. Iyer, and B. Joguet, Phys. Rev. D **65**, 061501(R) (2002); Erratum ibid. D **71**, 129902 (2005);
Y. Itoh and T. Futamase, Phys. Rev. D **68**, 121501(R) (2003);
Y. Itoh, Phys. Rev. D **69**, 064018 (2004);
L. Blanchet, T. Damour, and G. Esposito-Farèse, Phys. Rev. D **69**, 124007 (2004);
L. Blanchet, T. Damour, G. Esposito-Farèse, and B.R. Iyer, Phys. Rev. Lett. **93**, 091101 (2004);
Y. Itoh, Class. Quantum Grav. **21**, S529-S534 (2004);
L. Blanchet and B.R. Iyer, Phys. Rev. D **71**, 024004 (2005)

[2] L. Blanchet, Liv. Rev. Rel. **5**, 3 (2002)

[3] K.G. Arun, B.R. Iyer, M.S.S. Qusailah, B.S. Sathyaprakash, Phys. Rev. D **74**, 024006 (2006); Class. Quant. Grav. **23**, L37-L43 (2006);

[4] A. Buonanno and T. Damour, Phys. Rev. D **59**, 084006 (1999);
A. Buonanno and T. Damour, Phys. Rev. D **62**, 064015 (2000)

[5] T. Damour, B.R. Iyer, and B.S. Sathyaprakash, Phys. Rev. D **63**, 044023 (2001); Erratum ibid. D **72**, 029902 (2005)

[6] A. Buonanno, Y. Chen and M. Vallisneri, Phys. Rev. D **67**, 024016 (2003);
A. Buonanno, Y. Chen, and M. Vallisneri, Phys. Rev. D **67**, 104025 (2003);
Y. Pan, A. Buonanno, Y. Chen, and M. Vallisneri, Phys. Rev. D **69**, 104017 (2004);
A. Buonanno, Y. Chen, Y. Pan, and M. Vallisneri, Phys. Rev. D **70**, 104003 (2004);
A. Buonanno, Y. Chen, Y. Pan, H. Tagoshi, and M. Vallisneri, Phys. Rev. D **72**, 084027 (2005)

[7] F. Pretorius, Phys. Rev. Lett., **95**, 121101 (2005); J.G. Baker, J. Centrella, Dae-Il Choi, M. Koppitz, J. van Meter, Phys. Rev. D **73**, 104002 (2006). M. Campanelli, C.O. Lousto, Y. Zlochower, Phys. Rev., D **73**, 061501 (2006).

5.3 Renaissance in Laser Ranging Tests of Gravity

Contributed by Slava G. Turyshev, Jet Propulsion Laboratory, California Institute of Technology

The scientific potential of lunar laser ranging (LLR) led to the placement of retroreflector arrays on the lunar surface by the Apollo astronauts and the unmanned Soviet Luna missions to the Moon. The first deployment of such a package on the lunar surface took place during the Apollo 11 mission in the summer of 1969 and

LLR became a reality. Additional retroreflector packages were set up on the lunar surface by the Apollo 14 and 15 astronauts. Two French-built retroreflector arrays were on the Lunokhod 1 and 2 rovers placed on the Moon by the Soviet Luna 17 and Luna 21 missions, respectively.

Since 1969 until the present day laser reflectors are being reliably used for Earth-Moon ranging. In fact, today the LLR retroreflectors are the most accurately known positions on the Moon. However, because of the tight laser link budget and the complexity of the observational task, only few terrestrial laser ranging stations (e.g. McDonald Observatory, Texas, US; Grasse, France; Apache Point, New Mexico, US) are capable to routinely carry out the measurements, currently possible at cm-level [1, 2, 3].

The current Moon reflectors require no power and still work perfectly after 37 years. As we plan the next steps in the solar system exploration, LLR technology is expected to guide spacecraft to a precise location on the Moon and to navigate trips on its surface. LLR measurements will help future human and robotic missions to the Moon by providing information on the lunar orbit, rotation and orientation that must be accurately known for manned missions to our celestial neighbour. For these purposes, lunar-bound missions will carry both passive laser retroreflectors and also laser "beacons" pointed at Earth, where laser shots are to be received by multiple terrestrial ground stations.

The experience from the longest running Apollo-era experiment suggests that there is enormous science potential in lunar ranging data to further our understanding of the Moon's internal structure and the dynamics of the Earth-Moon system. LLR provides valuable information on lunar science, provides lunar orbit (ephemeris) and rotation/orientation, tests relativity, and is sensitive to information on Earth geophysics and geodesy. A wider geographic distribution of retroreflectors or transponders than the current retroreflector distribution would be a benefit; the accuracy of the lunar science parameters would increase several times. The lunar science includes interior information: measuring tidal response, tidal dissipation, and core effects. Gravitational physics includes the test of strong equivalence principle (any violation was recently limited to be less then 2 parts in 10^{13}) and limits on variation of the gravitational constant ($\dot{G}/G < 9 \times 10^{-13}$ yr^{-1}) [1, 2, 3]. Other experiments performed are those testing geodetic precession, PPN parameters β and γ, verification of Newton's inverse-square law and search for dark matter the solar system.

A bright transponder source on the Moon would open lunar ranging to many earth satellite laser stations which cannot detect the current weak signals from the Moon. Resulting Earth geophysics and geodesy results would include the positions and rates for the Earth stations, Earth rotation, precession rate, nutation, and tidal influences on the orbit. From the tidal response at the expected mm accuracy, inferences can be made on a solid or liquid lunar core and its size and oblateness. The new experiments may also detect free global oscillations of the Moon as a response to large quakes or meteoroid impacts for a comprehensive modelling of elastic parameters of the lunar interior. Parameters from gravitational physics could be modelled with vastly improved accuracy.

As far as installation is concerned, lunar retroreflectors are the most basic instruments, with no power requirements. Deployments are very simple: deliver, unfold, point toward the Earth and walk away. Retroreflectors should be placed far enough away from astronaut/moonbase activity that they will not get contaminated by dust.

Transponders, on the other hand, require development. Optical transponders detect a laser pulse and fire a return pulse back toward the Earth. They give a much brighter return signal accessible to more stations on Earth. Active transponders would require power and would have more limited lifetimes. Transponders can also be used to good effect in asynchronous mode, wherein the received pulse train is not related to the transmitted pulse train, but the transponder unit records the temporal offsets between the two signals.

One can think about the contribution of smaller retroreflector arrays (or random-scatter arrays) for the use on automated spacecraft and larger ones for manned missions. For transponders, lifetime is important and internal time delays require thought and good design. One benefits from co-locating passive and active devices and use a few LLR capable stations ranging retroreflectors to calibrate the delay vs. temperature response of the transponders.

The most favourable deployment location of the laser beacons are near the poles or the lunar limb as these locations are more suited for the tracking of lunar librations in latitude and longitude, respectively, than the current ones close to the sub-Earth point. Because of the lunar librations, laser shots from a fixed mounted instrument on the Moon must be spread over a cone of approximately 20° pointed at the Earth's mean position. Alternatively, the laser must be mounted on a pivoted platform to maintain Earth-pointing. We estimate that the received pulse strength from a 50 mJ laser is 3 orders of magnitude larger than a ranging signal from Earth reflected from the largest of the lunar retroreflectors (the approximately 0.5 m^2 Apollo 15 reflector). Such laser shots could be received by most existing satellite laser ranging stations having receiver mirror diameters larger than 1m. From the use of multiple stations, systematic measurement errors can be identified and removed. Using picosecond laser shots, measurement accuracies at mm-level can be accomplished.

Since LLR is a valuable working lunar investigation continually operating at the Moon for more then 37 years (i.e., living legacy of the Apollo program), return to the Moon provides an excellent new opportunity. The primary focus of planned missions will be lunar exploration and preparation for trips to Mars, but these missions will also provide opportunities for science, particularly if new laser retroreflectors are placed at more widely separated locations (one at zero longitude and zero latitude would also be useful).

New reflectors on the Moon (and later active ranging on to Mars) can offer significant navigational accuracy for space vehicles on their approach to the lunar surface or during their flight around the Moon, but they also will contribute significantly to fundamental and gravitational physics research.

Lunar transponders can be a prototype demonstration for later laser ranging to Mars. Active optical transponders on the lunar surface are attractive not only because of the strong return and insensitivity to lunar orientation effects, but also because these may become increasingly important space architecture. A lunar installation would provide valuable early feedback on their operational characteristics.

Optical ranging has demonstrated strong scientific results based on the improved range accuracy for the Moon and has potential for good accuracy for Mars and also interplanetary distances [1]. We emphasise that existing capabilities in laser ranging, optical interferometry and metrology, in combination with precision frequency standards, atom sensors, and drag-free technologies are critical for the space-based tests of fundamental physics; as a result, of the recent progress in these disciplines, the entire area is poised for major advances. Furthermore, many other tests will become possible with development of an optical architecture that would allow proceeding from meter to centimetre to millimetre range accuracies on interplanetary distances. Retroreflectors and transponders with a narrower return pulse width (than existing retroreflectors) would improve range accuracy and with available technology would provide mm-level accuracies up to 2 AU distances.

The work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References

[1] Williams, J. G., Turyshev, S. G., Boggs, D. H., "Lunar Laser Ranging Tests of the Equivalence Principle with the Earth and Moon." *Lect. Notes Phys.*, to be published, (2006) [arXiv:gr-qc/0507083].

[2] Williams, J. G., Turyshev, S. G., Murphy, T. W., Jr., "Improving LLR Tests of Gravitational Theory." *International Journal of Modern Physics D* **13**(3), 567-582 (2004), [arXiv:gr-qc/0311021].

[3] Williams, J. G., Turyshev, S. G., Boggs, D. H., "Progress in Lunar Laser Ranging Tests of Relativistic Gravity." *Phys. Rev. Lett.* **93**, 261101 (2004) [arXiv:gr-qc/0411113].

5.4 The Birmingham Detector for very High Frequency Gravitational Waves

Contributed by Mike Cruise, University of Birmingham

We can expect gravitational waves to exist over a wide range of frequencies just as electromagnetic waves do and therefore there may be several different spectral regions for gravitational wave astronomy. This is already well recognised in the different science cases for LIGO at audio frequencies and LISA at very low frequencies, but just as in electromagnetic astronomy we should try to explore other spectral regions if either the technology exists for very high sensitivity or there is a compelling science case.

A growing number of cosmological theories predict gravitational waves generated by bubble collisions between phase transitions in the early universe, amplification of quantum fluctuations during inflation, decay of cosmic strings and other exotic mechanisms. These all happened during an era where the physics is quite uncertain and the wave spectrum often peaks in the Mega Hertz or Giga Hertz region, that is at frequencies where the movement of masses in response to the waves is not a likely detection strategy. In addition, gravitational theories employing higher dimensions are beginning to predict possible oscillation modes of the extra dimension stimulated by stellar mass infall into Massive Black Holes, again at these very high frequencies.

The way forward seems to be to use the interaction between the gravitational wave and an electromagnetic field. EM fields can be generated with high intensities in the laboratory and extremely small amplitude modes can be detected with modern electronics. In principle the gravitational wave can alter the frequency, amplitude or polarisation state of the EM field and many papers in the 1960's and 70's explored these possibilities.

We have built two nominally identical prototypes at Birmingham of a detector that uses a polarisation transition at 100 MHz. The basic principle is that a vector which is parallel transported around a closed path in a curved spacetime suffers a rotation when it arrives back at the starting point. The vector used in the detector is the electric vector of a microwave field following a path around a rectangular loop of waveguide. There is a resonance effect whereby, for gravitational waves in a very narrow frequency band, sequential circuits of the loop cause a cumulative rotation that improves the sensitivity linearly and we have measured angular rotations of order 10-11 rads/root Hz, corresponding to GW amplitudes of 10-15 per root Hz. The two detectors can be used in correlation to study stochastic backgrounds and they can be moved on their trolleys to change the overlap function. The current version is fully operational under computer control as a testbed to develop the sensitivity further, hopefully to levels at which a meaningful search for cosmological backgrounds might be carried out. Because the detector measures spacetime curvature rather than strain we are also interested in its operation in higher dimensional gravities where it might open up completely new possibilities for novel observations.

5.5 Can Planck scale physics be accessible by experiment?

Contributed by Charles Wang, University of Aberdeen and RAL

A new Letter to appear in Classical and Quantum Gravity has outlined the possibility of investigating Planck scale physics using the latest quantum technology [1].

One hundred years ago, when Planck introduced the constant named after him, he also introduced the Planck scales, which combined this constant with the velocity of light and Newton's gravitational constant to give the fundamental Planck time $\sim 10^{-43}$ sec, Planck length 10^{-35} m and Planck mass 10^{-8} kg. Experiments on quantum gravity require access to these scales. To access these scales directly using accelerators would require 10^{19} GeV accelerators, well beyond any conceivable experiments. Physics on the large scale is based on Einstein's theory of general relativity (GR), which interprets gravity as the curvature of spacetime. Despite its tremendous success as an isolated theory of gravity, GR has proved problematic in integration with physics as a whole, in particular the physics of the very small governed by quantum mechanics. There can be no unification of physics, which does not include them both. Superstring theory and its recent extension to the more general theory of branes is a popular candidate, but the links with experiment are very tenuous. Loop quantum gravity attempts to quantise GR without unification, and has so far received no obvious experimental verification.

The lack of experimental guidance has made the issue extremely evasive, though various attempts have been made to relate the loss of matter wave coherence to quantum spacetime fluctuations. The new paper presents a new approach to the gravitational decoherence near the Planck scale, made possible by recently discovered conformal structure of canonical gravity by one of the authors. The curvature of spacetime produces changes in proper time, the time measured by moving clocks. For sufficiently short time intervals, near the Planck time, the proper time fluctuates strongly due to quantum fluctuations. For longer time intervals, proper time is dominated by a steady drift due to smooth spacetime. Proper time is therefore made up of the quantum fluctuations plus the steady drift. The boundary separating the shorter time scale fluctuations from the longer time scale drifts, is marked by a cut-off time that defines the borderline between semi-classical and fully quantum regimes of gravity. This is close to the Planck time. For almost a century it has been widely perceived that the lack of experimental evidence for quantum gravity has presented, and will continue to present, a major barrier to its breakthrough. However, armed with the sensitivity of modern matter wave interferometers at the quantum level, the possibility of using a 'macroscopic' instrument to investigate Plank scale physics is now a real possibility. Following the recently formulated conformal decomposition in full canonical gravity, the authors have investigated gravitational decoherence due to ground state gravitons and have demonstrated that the resulting conformal field can lead to observable effects by causing quantum matter waves to lose coherence.

This is equivalent to a gravitational analogue of the Brownian motion whose correlation length is given by the Planck length up to a scaling factor. With input from recent matter wave experiments, it has been shown that the minimum value of this factor to be well within the expected range for quantum gravity theories. This suggests that the sensitivities of advanced matter wave interferometers may be approaching the fundamental level due to quantum spacetime fluctuations and that investigating Planck scale physics using matter wave interferometry may become a reality in the near future.

However, the upper bound of quantum gravitational decoherence calculated using current experimental data is already within the expected range. It is a very good sign and strongly suggests that the measured decoherence effects are converging towards the fundamental decoherence due to quantum gravity. Therefore, a proposed ESA space mission flying an atom wave interferometer with significantly improved accuracy will be able to investigate Planck scale physics.

References

[1] C. H.-T. Wang, R. Bingham and J. T. Mendon "Quantum gravitational decoherence of matter waves", *Classical and Quantum Gravity* **23**, L59-L65 (2006)

6 Financial report

Contributed by Elizabeth Winstanley, University of Sheffield

The Group receives an annual allocation from the Institute of Physics. Up to 2006, this was made up of two parts: a basic allocation at a flat rate for all groups and an additional amount per group member. In 2006 our total allocation was £2197. We carried forward a balance of £2849, giving us a total budget of just over £5000.

We have supported six scientific meetings this year, totalling £3875 (some of this money was paid out of last year's budget). This will continue to be the bulk of our expenditure. The AGM and scientific meeting in February cost £337.

As ever, we endeavour to keep committee expenses to a minimum, so far this year these have totalled £675. There are also sundry expenses (such as posting the annual general meeting announcement and the production of the newsletter), amounting to £103 to date. It is likely that we will only have a very small balance remaining at the end of the year, in accordance with new Institute financial requirements.

The Institute is moving to a bidding model for Group budgets, starting in 2007. I am pleased to say that our allocation for 2007 has been increased substantially to £4200. As a result of this, we will be offering a wider programme of talks as part of the scientific meeting on the same day as the AGM, and will also be able to support more scientific meetings.

7 Contact details

Committee members of the Gravitational Physics Group

Paul Abel	University of Leicester pga3@leicester.ac.uk
Bob Bingham	Rutherford Appleton Laboratory R.Bingham@rl.ac.uk
David Burton	University of Lancaster d.burton@lancaster.ac.uk
Andreas Freise	University of Birmingham adf@star.sr.bham.ac.uk
Ian Jones (Newsletter editor)	University of Southampton D.I.Jones@soton.ac.uk
Harvey Reall (Honorary treasurer)	University of Nottingham Harvey.Reall@nottingham.ac.uk
Sheila Rowan	University of Glasgow s.rowan@physics.gla.ac.uk
Diana Shaul (Honorary secretary)	Imperial College, London diana.shaul@imperial.ac.uk
Ron Wiltshire	University of Glamorgan rjwiltsh@glam.ac.uk
Elizabeth Winstanley (Chair)	University of Sheffield E.Winstanley@sheffield.ac.uk

To find out more about the Group

- You can visit out internet site:

  `http://www.iop.org/Our_Activities/Groups_and_Divisions/Subject_Groups/Gravitational_Physics/page_2035.html`

- Or you can email the Group Secretary Diana Shaul:

  `diana.shaul@imperial.ac.uk`

To contribute to the next newsletter

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

`D.I.Jones@soton.ac.uk`

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/Our_Activities/Groups_and_Divisions /Subject_Groups/Gravitational_Physics/page_2035.html`

  from where it is possible to apply online.

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