MATTERS OF GRAVITY

*******Anniversary Edition*******

The newsletter of the Topical Group on Gravitation of the American Physical Society

Number 18 **Fall 2001**

Contents

Editor

Jorge Pullin

Department of Physics and Astronomy
Louisiana State University
202 Nicholson Hall
Baton Rouge, LA 70803-4001
Phone/Fax: (225)578-0464
Internet: `pullin@phys.lsu.edu`
WWW: `http://www.phys.lsu.edu/faculty/pullin`

ISSN: 1527-3431

Editorial

Well, it is ten years since Peter Saulson put together the first Matters of Gravity. A lot has happened since. The Topical Group was formed and MOG became its official newsletter. As a celebration, we decided to invite several prize-winners to give us a reflection of their fields in the last and forthcoming decades. Finally, Gary Horowitz, Carlo Rovelli (Xanthopoulos winners), Jens Gundlach (Pipkin prizewinner), our former editor Peter Saulson and TGG founder Beverly Berger accepted the challenge.

Otherwise not much to report here. If you are burning to have Matters of Gravity with you all the time, the newsletter is now available for Palm Pilots, Palm PC's and web-enabled cell phones as an Avantgo channel. Check out `http://www.avantgo.com` under technology→science. The next newsletter is due February 1st. If everything goes well this newsletter should be available in the gr-qc Los Alamos archives (`http://xxx.lanl.gov`) under number gr-qc/yymmnnn. To retrieve it send email to gr-qc@xxx.lanl.gov with Subject: get yymmnnn (numbers 2-17 are also available in gr-qc). All issues are available in the WWW: `http://www.phys.lsu.edu/mog`
A hardcopy of the newsletter is distributed free of charge to the members of the APS Topical Group on Gravitation upon request (the default distribution form is via the web) to the secretary of the Topical Group. It is considered a lack of etiquette to ask me to mail you hard copies of the newsletter unless you have exhausted all your resources to get your copy otherwise.

If you have comments/questions/complaints about the newsletter email me. Have fun.

Jorge Pullin

Correspondents

- John Friedman and Kip Thorne: Relativistic Astrophysics,
- Raymond Laflamme: Quantum Cosmology and Related Topics
- Gary Horowitz: Interface with Mathematical High Energy Physics and String Theory
- Richard Isaacson: News from NSF
- Richard Matzner: Numerical Relativity
- Abhay Ashtekar and Ted Newman: Mathematical Relativity
- Bernie Schutz: News From Europe
- Lee Smolin: Quantum Gravity
- Cliff Will: Confrontation of Theory with Experiment
- Peter Bender: Space Experiments
- Riley Newman: Laboratory Experiments
- Warren Johnson: Resonant Mass Gravitational Wave Detectors
- Stan Whitcomb: LIGO Project

We hear that...

Jorge Pullin pullin@phys.lsu.edu

Robert Wald has been elected to the National Academy of Sciences.

Jens Gundlach won the Pipkin award of APS "For identifying, and providing a solution to, an unrecognized weakness in the Cavendish technique for measuring the gravitational constant G; improving the accuracy of G by an order of magnitude, representing one of the largest incremental increases in accuracy ever obtained in the history of such measurements."

James Faller won the Keithley award of APS "For the development of sensitive gravitational detectors and their successful application to the study of physics and geophysics."

Lawrence Krauss won the Lilienfeld prize of APS "For outstanding contributions to the understanding of the early universe, and extraordinary achievement in communicating the essence of physical science to the general public."

Juan Maldacena won the Basilis Xanthopoulos award.

Hearty congratulations!

Matters of Gravity and the Topical Group in Gravitation

Beverly Berger, Oakland University berger@oakland.edu

As "Matters of Gravity" celebrates its 10th year as the "voice" of gravitational physics, it also celebrates its 7th year as the official newsletter of the American Physical Society's Topical Group on Gravitation (TGG).

The first mention of the TGG actually appeared in the Spring 1994 issue of MOG with my open letter to the gravitational physics community stating that "the time has come to create a TGG within the APS ... Such a group would allow us to define and promote our interests and enhance our visibility within the larger community of physicists. Construction of LIGO and the Grand Challenge Supercomputing Project on the two black hole problem are only two examples of the significant developments in our field that render such advocacy essential." The required 200 signatures to petition the APS to form the TGG were eventually obtained. The TGG came into existence when its formation was approved by the APS Council in April 1995.

All units (divisions, topical groups, forums) within the APS are supposed to have newsletters. It was natural, therefore, that the well-established, well-regarded, and reliably published MOG become the newsletter of the TGG. In fact, the one exception made to the "plain vanilla" bylaws of the TGG was to allow the editor of the newsletter to be someone other than the Secretary / Treasurer of the topical group. Thus Jorge Pullin was prevailed upon to continue his excellent stewardship of the newsletter. The first "official" TGG issue of MOG appeared in Fall 1995.

Since its beginnings in 1995, the TGG has been an unqualified success. Its membership has grown from its initial 200 or so to approximately 550. The TGG has increased the visibility of gravitational physics within physics by its active participation in the APS April Meetings, starting with the 1996 meeting. This has been achieved by the TGG's sponsorship of sessions of invited talks on recent developments in gravitational physics both on its own and jointly with the Divisions of Astrophysics, Particles and Fields, Computational Physics, and the Topical Group in Fundamental Constants and Precision Measurement. For the first time this past April, the TGG provided travel grants to encourage students to attend the April Meeting.

Many distinguished gravitational physicists have been elected to the TGG leadership. Past chairs include Kip Thorne, Abhay Ashtekar, Rai Weiss, and Cliff Will. Jim Isenberg was the first Secretary / Treasurer with Jim Bardeen, Sam Finn, Leonard Parker, Fred Raab, David Shoemaker, Bob Wald, Mac Keiser,Steve Carlip, Peter Saulson, John Friedman, and Bob Wald serving on the Executive Committee. The current officers are Bob Wald (Chair), Richard Price (Chair Elect), John Friedman (Vice Chair), and David Garfinkle (Secretary / Treasurer). The current executive committee consists of Ted Jacobson, Jennie Traschen, Eanna Flanagan, Gabriela Gonzalez, and Matt Choptuik.

In what we hope will be the very near future, the APS will award the first Einstein Prize in Gravitational Physics. This prize was developed due to the initiative of the TGG leadership. All APS prizes must be approved by the APS Council (including the name of the prize) and must have a substantial endowment. After some discussion over the naming of the prize, the APS Council authorized the TGG to conduct a fundraising campaign for the prize's endowment. This campaign is in progress.

The TGG has also exercised its right, as an APS unit, to name APS Fellows. Since the TGG formed, it has named approximately 10 fellows.

More information about the TGG may be found at its web page, and in the various issues of MOG.

http://gravity.phys.psu.edu/~tggweb/

10 Years in Gravitational Wave Detection

Peter Saulson, Syracuse University saulson@phy.syr.edu

Looking back ten years in the field of gravitational wave detection is especially handy, since the life span of Matters of Gravity roughly coincides with the life span of LIGO (the Laser Interferometer Gravitational Wave Observatory, in case anyone doesn't know) as an approved project. There is of course a long pre-history to LIGO – the inception of the idea, planning and feasibility studies, technology development, and, not least, lobbying the physics community, the NSF, and Congress to earn approval. Still, life changed for all of us when LIGO was approved.

I vividly remember the moment when I learned that the construction of LIGO had been approved. Abhay Ashtekar, who has always been much better plugged in than I, greeted me in the hallway of the Physics Building at Syracuse University with an outstretched hand and a big grin. As he shared the news, I confess that my own feeling was not the unalloyed happiness that showed on his face. I think I mumbled something like, "Oh, shit, now we have to make it work." It was a time in my life when the technological hurdles facing LIGO seemed especially daunting. Today, when a great many bullets have already been dodged, the fear that I felt seems much less justified.

While I'm confessing my old fears, perhaps I should mention another moment when the enormity (literally) of what we have taken on in LIGO came home to me. It was several years later, during my first visit to the LIGO site at Hanford WA, when I walked through the then-empty experimental hall at the vertex, euphoniously called the LVEA (Laser and Vacuum Equipment Area.) Even more than the 4 km arms, the vastness of this workspace brought home to me the magnitude of what we had persuaded the American taxpayer to support. Now that the Hanford LVEA and the one at its sister site at Livingston LA have been filled with their vacuum chambers and then in turn with the optics for LIGO's interferometers, the scale seems fully appropriate. LIGO is big, but it is big for a good reason - to maximize our chances of detecting gravity waves.

Of course, the detection of gravity waves remains to be accomplished. But much along the way has been done successfully, and with a certain amount of style. The aforementioned remote laboratories have been built, equipped, and staffed. All three of LIGO's interferometers have now been installed. They are in various stages of commissioning; the 2 km interferometer at Hanford (the first of the three to be installed) has "locked" in essentially its full servo configuration, and the 4 km interferometer at Livingston has gone almost as far. The servo engineering that has made this possible is a real tour de force, with gains (and signs!) of feedback switching as the interferometer progresses through a series of states approaching the full Power-Recycled Fabry-Perot Michelson configuration. A few years ago we didn't know how to do this, but now it works.

Now that the interferometers are moving into a state where they function, work is commencing on understanding their performance. It must be said that at present the noise levels are substantially poorer than the design performance of the initial LIGO interferometers. But some of the reasons are well understood, so it is reasonable to hope that what is a huge gap at the present will start to close rapidly. Of course, it is hard to predict how quickly the last order of magnitude will be crossed.

This technical progress could only have come about through progress in the social organization of LIGO. The first proposal for LIGO in 1987 (the one before the successful 1989 proposal) listed 18 members of the team. Now, a scan of the LIGO roster reveals over 180 names of staff at Caltech, MIT, Hanford and Livingston (including only one name of the original 18.) Growth of this magnitude could not have been effectively managed without leadership by people experienced with large projects. This expertise came to LIGO in the person of Barry Barish and of the colleagues he brought with him to LIGO from high energy physics in the middle of the last decade.

The social/scientific structure has grown in another important way as well. LIGO is now organized into two bodies. The staff above constitute the LIGO Laboratory, the group responsible for ensuring that the LIGO interferometers function properly. Direction of LIGO's scientific program lies in a larger body called the LIGO Scientific Collaboration (or LSC), consisting (in a recent count) of 112 scientists, engineers, and technicians from within the Lab, plus an additional 239 members from 27 other groups from across the U.S. and, indeed, the rest of the world. And the LSC continues to grow; at its last meeting in August, two new groups joined.

In addition to the dramatic growth of the number of people working on LIGO, another important change has taken place in the style of work. With the installation of the LIGO interferometers at the Observatories, the focus of work has shifted toward the sites. In addition to the staff that have moved to Washington or Louisiana, this has meant a great deal of travel by experts based at Caltech and MIT. Some non-Lab LSC groups have also been a big presence at the sites. I had a chance to view this process first-hand in 2000 when I spent a sabbatical year at the Livingston Observatory. A substantial chunk of the important work was being done by the group from the University of Florida, who supplied the interferometers' Input Optics. Another important presence was that of the growing group at neighboring LSU, who are vital participants in the commissioning work.

Looking back, I must confess that one of my most vivid impressions from that year at Livingston was yet another epiphany of the magnitude of LIGO's work. Early on, I realized that we needed a set of design documents for reference while we worked on commissioning the interferometer. I searched LIGO's on-line Document Control Center, and by the time I was done I had found a bookshelf full of subsystem descriptions, analyses, and plans. This brought home to me not only the complexity of LIGO as a scientific instrument, but the remarkable intensity and quality of the work it has taken to produce it. Visit a LIGO site and marvel at its size, as I did at first; then pause to admire even more the richness of labor it has taken to turn that site into a gravitational wave detector.

Even as commissioning of the interferometers goes on, work has been progressing on preparing to collect and analyze data to search for gravitational waves. Here is another massive effort, largely invisible to outsiders, that has almost completed the data analysis system that will enable the 24/7 search for the gravitational wave needles in the haystacks of data that LIGO will produce.

Over the past year or two, the interferometers have been exercised in a set of Engineering Runs that practiced collecting data for extended periods, while the software has been tested in a set of Mock Data Challenges that practiced analyzing the data. These parallel efforts will come together in an Upper Limit Run, now scheduled for around New Years. We will run the interferometers for two weeks, collect the data, and analyze that data to the point of being able to make scientific claims about the presence (or, more likely, absence) of gravitational wave signals in it. Throughout 2002, LIGO plans to intersperse interferometer improvement with data-taking periods, until full-time operation at design sensitivity is achieved.

While all this has been going on, LIGO has been preparing increasingly detailed plans for a new set of interferometers to be installed at the sites after the initial LIGO Science Run has been completed. Advanced LIGO will have roughly an order of magnitude better strain sensitivity than the initial interferometers, which ought to be enough to guarantee that known sources (especially binary neutron star inspirals) will be within reach of detection.

Most of this review has focused in a rather parochial fashion on the American effort, but it needs to be stressed that equally impressive work is going on at a number of other places around the world. A Japanese 300-meter interferometer, TAMA, has already started operating, and is showing remarkable performance. The British-German GEO 600-meter interferometer near Hannover is almost completely installed; it features advanced mirror suspensions and optics that will pave the way for parts of Advanced LIGO. The 3-km VIRGO interferometer near Pisa (a joint French-Italian project) is also well along; it is demonstrating advanced seismic isolation systems that will let it probe to lower frequencies than any other instrument yet built. One other admirable development should be stressed - the remarkable extent to which scientific cooperation is being maintained between all of these nominally competing efforts. LIGO and GEO have become especially close, with the GEO team having joined the LSC and a full reciprocal data exchange agreement having recently been concluded.

The past decade has seen another remarkable occurrence on the way to the establishment of the science of gravitational wave detection. An interferometer in space has been a gleam in a few pairs of eyes for almost as long as LIGO has, but now it appears well on the road to becoming a reality. The LISA project garnered strong European support several years ago, and appears to be marching inexorably toward becoming a key part of the NASA program as well. With a projected sensitivity that easily places it in a position to study a range of interesting sources, LISA has also been blessed with a remarkable degree of support from the astronomical community.

With any luck, the next 10 year review will be able to look back on the detection and study of gravitational waves.

Ten years of general relativity, some reflections

Carlo Rovelli, Centre de Physique Theorique, Marseille carlo@rovelli.org

Ten years of *Matters of Gravity* (thanks a lot, Jorge!), ten years of research in general relativity. It has been a period of triumph for GR: We have seen evidence for gravitational emission from binary pulsars, with theory and observations matching with a level of accuracy previously found only in quantum field theory. We have been enchanted by the gravitational lensing images. Black holes have moved from exotic theoretical hypothesis to realistic objects in the sky. Last month, I got lost in a trip, and could trace my way back thanks to a small electronic device that wouldn't work without taking GR's corrections into account. Particle physicists, that not long ago kind of looked down at GR, nowadays use Einstein's spacetimes in every other paper. Observational cosmology has exploded, relativistic astrophysics is solidly established; the problem of quantizing the theory is now recognized as perhaps the main problem in theoretical physics, and the papers devoted to it keep growing. Large resources are being invested internationally in the search for gravitational waves and computational GR ... The list of successes could continue. How long a road from the sleepy and a bit esoteric GR community, when black holes were badly understood exotic theoretical hypotheses, the only experimental support came from the three "classic tests" and the rest of physics looked at us with suspicion, if it payed any attention at all. It has been a breathtaking decade.

Many problems remain open, and so much remains to be done. And there are also some dangers ahead. We are all holding our breath waiting for the gravitational waves. We are solidly beyond our colleagues involved in this adventure and we are optimistic, but also a bit concerned: the community has taken some risks with this search, and if it took too long, it wont be good for all of us. Great efforts are been put in computational GR. Again, let's hope for the better, but we should keep in mind the experience with computational lattice QCD, where great skills and money were expended, and great hopes raised, with far less results than hoped for. Excitement is high in my own field, loop quantum gravity, where the feeling is that perhaps we are having true glimpses into the quantum structure of spacetime. But let us not forget how many tentative quantum theories of gravity have claimed victory and then were proven unsatisfactory.

The worst danger, I think, is that theoretical physics, and sometimes even experimental physics, is nowadays often so far removed from the actual final experimental outcome (the only final arbiter), that the temptation is dangerously high to keep selling for good whatever we have. I am afraid that some portion of physics have moved down this dangerous path. But success, I think, can only be granted by scrupulous intellectual honesty. The high respect and the credibility that science enjoys rely on the intellectual honesty of the scientists. Several people now begin to suspect that something has got wrong on this in the last decade. At a recent conference I had a conversation with a brilliant young researcher. In the conversation, two theories were mentioned: GR and some particular supersymmetric theory in high dimension. Casually, I said that at least we knew that one of the two was experimentally supported. My young friend asked which one. I thought he was joking, but he was not. In his mind there was absolutely no understanding of the distinction between a theory whose novel peculiar predictions have found a huge wealth of empirical support, and a complex theoretical hypothesis that for the moment has no empirical support whatever.

The distinction between what we have learned about the world on the one hand, and our attempts to understand more on the other hand, is the rock over which science bases its strength. I am afraid that this distinction is becoming a bit obfuscated in some areas of theoretical physics, and hypotheses are too often sold for facts. This may increase funding, positions and political power in the short run, but it is a recipe for disaster in the long run. I think that the theoretical physics community should seriously react against this attitude, which is endangering its own position in the world. I have heard many scientists repeating this privately in the corridors of the conferences. Perhaps they should say it more vocally and more publicly.

As a result of the successes of GR (and also of the overwhelming and unexpected empirical success of the particle physics standard model), the relation between the GR community and the rest of physics has much changed in this decade. Ten years ago, the divide between the GR community and the rest of theoretical physics was sharp. Outside our small community, spacetime was unquestionably flat and non dynamical. Today, some basic ideas of GR pervade large parts of theoretical research. GR is being finally universally accepted as a component of our present understanding of the world.

But, as we know well, GR is much more than a theory of gravity, namely much more than the specific theory for a specific physical interaction. It is a rethinking of the notions of space and time, which involves the entirety of our understanding of the world. In my opinion, the deepness and the richness of the shift in perspective produced by GR is far from being fully understood and fully absorbed. GR does not claim only that spacetime is curved and satisfies certain equations. Rather the most far reaching physical consequence of the theory, which follows from the invariance properties of its equations, is the discovery that no physical meaning can be attached to the coordinates, and physical localization can therefore only be defined relationally. Dynamical objects are physically localized only with respect to each others. This is a huge conceptual jump out of Newtonianism, which brings our understanding of spacetime back to Cartesian (and Aristotelian) relational notions of space. The Newtonian localization with respect to space (that allows Newton to define acceleration as absolute) is reinterpreted in GR as localization with respect to a particular dynamical object: the gravitational field.

In my opinion, Einstein's discovery that the gravitational field and the spacetime metric are the same entity, is not well expressed by saying that there is no gravitational field, just a curved spacetime. Rather, it is better expressed by saying that there is no spacetime, just the gravitational field. The gravitational field is, dynamically, a field like the others. But the fields do not live over a spacetime, they leave, so to say, over each other.

I think that this profound change of perspective on the world, has not yet been completely absorbed. The hardest part to digest is not the relational nature of space; it is the relational nature of time. To this, many instinctively resist. Giving up the idea of an external flowing time along which things happen is hard, as it was hard giving up the idea of the center of the universe, or the idea of absolute rest. I am convinced that this change of perspective reflects a deeper understanding of the physical structure of the world and will stay with us for a while in the physics of the future.

But while the Einstein equations are being widely used in fundamental physics, this conceptual revolution is still little understood. World famous theoreticians still search the fundamental theory over a background Minkowski spacetime (perhaps in high dimensions). In my opinion, they have not understood what we have learned about the world with GR.

Large sectors of basic physics still expect to be thought again from scratch at the light of this conceptual revolution. Classical Hamiltonian mechanics has proven flexible enough to consistently extend to general covariant physics (where there is no canonical time and no Hamiltonian). But thermodynamics and statistical mechanics still wait to find a formulation sufficiently general to take the GR revolution into account. And of course, so does quantum theory. In the XXth century, quantum theory and general relativity have changed in depth our understanding of the world; we are still far from a consistent picture of the physical world that can take the two conceptual novelties into account. The great scientific revolution opened by the XXth century is not over: the cards are one the table and expect to be put in the right order. Could there be a more exciting period for researching in fundamental physics?

Tabletop gravity experiments

Jens Gundlach, University of Washington gundlach@npl.washington.edu

The past fifteen years of laboratory-scale gravitational experimentation have been marked by many new and exciting developments. The field received a lot of impetus by the hypothesis of a "fifth force" [1] in 1986. This very testable new force would have been a blatant violation of the equivalence principle. The evidence for the 5^{th} force was partially based on a reanalysis of the torsion balance data of Baron Eötvös of the early 1900's. Immediately several groups around the world started to do Eötvös-type experiments. The availability of new technologies combined with many new and creative ideas quickly led to several refined measurements by which the 5^{th} force in its postulated form could be conclusively ruled out. However, the physics community was once again reminded of the importance of the equivalence principle which lies at the foundation of general relativity. Tests of the equivalence principle become particularly important for grand unification schemes, most of which predict an equivalence principle breakdown at some level. In addition it is generally believed that the standard model of particle physics can only be complete with the existence of new particles which could exist at high masses as well as at the ultra low energies. The latter frontier being covered by laboratory-gravity tests.

Most equivalence principle tests compare the acceleration of different materials towards another source mass. The difference in test mass composition is chosen to maximize the new interaction's charge, which could be e.g. baryon number, lepton number or combinations thereof. The source mass could be a mass in the lab, a nearby hill, mountains, the entire earth, the Sun, the Milky Way or even cosmological structures. Several types of instruments were developed. One of the more exotic devices consisted of a perfectly buoyant hollow copper sphere in water tank placed at a cliff [2]. Others compared the rate of free fall of different masses [3]. By far the most sensitive and versatile devices proved to be torsion balances. Here new concepts as well as quantitative understanding led to tremendous advances. Our group at the University of Washington, called the Eöt-Wash group, developed a torsion balance that is installed on a continously rotating turntable. As seen from a restframe, turning with the turntable, the signal is modulated at the rotation frequency of the turntable. The technical difficulty lay in producing the required extremely constant rotation rate. We also introduced a multipole analysis that proved very practical in eliminating gravitational torques that could have been mistaken for an equivalence principle violation. The differential acceleration sensitivity between different materials that we are now achieving is $\Delta a < 5 \times 10^{-15} m/s^2$. This limits equivalence principle violations with infinite range and baryon number as its charge to be at least 10^9 times weaker than gravity. Together with another experiment, in which a 3 ton source was rotated about a stationary pendulum, we now can set new limits on equivalence principle violations for ranges from the cm-range [4] to infinity [5]. Riley Newman's group at UC Irvine also has a long and successful tradition of torsion balance experiments probing gravity. He has pioneered cryogenic torsion balances that will have phenomenal intrinsic sensitivity [6].

In the last few years the $1/r^2$-law of gravity at very short ranges came under close scrutiny. Several theorists [7] argued that it might be possible for some of the unobserved extra dimensions in string theory to be compactified close to a mm-radius rather than at Planck length. For two such dimensions the $1/r^2$-force law would break down below the mm-scale, precisely at a length range where limits from previous experiments were weak. A group at the University of Colorado and another group at Stanford University built micromechanical oscillator plates which would be brought into resonance by a close-by parallel moving source plate if the $1/r^2$-law were violated. Both groups use sophisticated mechanical vibration isolation techniques, as well as an electrostatic shield between the source and the sensor. Our approach involved a torsion balance. We built a pendulum consisting of a horizontal disk with 10 holes drilled in it. Below the pendulum we located a similar horizontal disk also with 10 holes. This source disk was mounted on a slowly rotating turntable. Gravity causes the pendulum to be deflected 10 times per revolution. We placed another disk below the source disk that has 10 holes exactly out of phase with the upper disk. This disk was designed to exactly cancel the gravity signal, assuming $1/r^2$ holds. With this setup we were able to tell that a $1/r^2$-violation must have a Yukawa range shorter than $\approx$0.2mm for a strength about equal to gravity [8].

Contrary to the equivalence principle and the $1/r^2$-tests several new measurements of the gravitational constant G were motivated by a disagreement in experimental results. One well respected measurement deviated by $\approx 42\sigma$ from the accepted value. This situation forced an increase in the uncertainty of the accepted value of G by a factor of 12 (now 0.15%) [9]. In addition Kuroda [10] discovered that torsion fiber anelasticity, a material property, had led to a bias in many previous measurements. Several measurements were initiated, each with new approaches to minimize systematic uncertainties. Torsion balances continued to dominate. Using our experience from the equivalence principle tests we built a continuously rotating balance. Uncertainties with the torsion fiber were avoided by regulating the turntable velocity so that the fiber was not twisted. The gravitational signal was derived from the turntable acceleration. We discovered that a thin vertical plate pendulum eliminated the difficult pendulum metrology issues most measurements had. Rotating the attractor masses on a coaxial turntable transformed our signal to a higher frequency. Our result is about 250ppm higher than the accepted value and has an uncertainty of 14ppm [11]. Another group [12] led by Terry Quinn at the BIPM in Paris eliminates the anelasticity problem by using a torsion strip instead of a round fiber. A four-fold attractor-pendulum configuration is used. The likelihood of unknown systematic error is reduced by using two independent torque measurements: electrostatic feedback and a calibrated deflection. Their result has been submitted for publication. Riley Newman's group has operated a torsion balance at 2K [13]. The group was able to show that at these temperatures anelasticity corrections are small and well understood. They also use a flat plate pendulum. Two copper rings as attractors simplify their metrology issues. The apparatus is located at a remote site to reduce noise. The group expects to announce results soon.

References:

[1] E. Fishbach et al., Phys. Rev. Lett. **56**, 3 (1986).

[2] P. Thieberger, Phys. Rev. Lett. **58**, 1066 (1987).

[3] K. Kuroda and N. Mio, Phys. Rev. **D42**, 3903 (1990), T.M. Niebauer, M.P. McHugh, J.E. Faller, Phys. Rev. Lett. **59**, 609 (1987).

[4] G. L. Smith et al., Phys. Rev. **D61**, 022001 (1999).

[5] Y. Su et al., Phys. Rev. **D50**, 3614 (1994).

[6] M.K. Bantel and R.D. Newman, Class. Quantum Gravity **17**, 2313 (2000).

[7] For example: N. Arkani-Hamed, S. Dimopoulos, and G. Dvali, Phys. Lett **B429**, 263

(1998).

[8] C.D. Hoyle et al., Phys. Rev. Lett. **75**, 2796 (2001).

[9] P.J. Mohr and B.N. Taylor, J. Phys. Chem. Ref. Data **28**, 1713(1999).

[10] K. Kuroda, Phys. Rev. Lett. **75**, 2796 (1995).

[11] J.H. Gundlach and S.M. Merkowitz, Phys. Rev. Lett. **85**, 2869 (2000).

[12] T. Quinn et al., Meas. Sci. Technol. **10**, 460 (1999).

[13] R. Newman and M. Bantel, Meas. Sci. Technol. **10**, 445 (1999).

String Theory: The Past Ten Years

Gary Horowitz, UC Santa Barbara gary@cosmic.physics.ucsb.edu

Given a choice between summarizing the past decade of achievements in string theory or speculating about what string theory might look like a decade from now, I have chosen the first option. Indeed, given the rapid progress over the last decade, I find it hard to guess where string theory will be even a few years from now.

Ten years ago, it was common (and correct) to distinguish the two main approaches to quantum gravity by saying that string theory [1] was perturbative, and background dependent while the other approach [2] was non-perturbative and background independent. In light of this, it is not surprising that most relativists were not interested in string theory. Today, this distinction is no longer applicable. As we will discuss, there is now a complete, non-perturbative and background independent formulation of the theory, at least for space-times with certain asymptotic boundary conditions.

Let me begin by summarizing the situation ten years ago. At that time, there were five perturbatively consistent string theories. They were all based on the idea that particles are just different excitations of a one-dimensional extended object – the string. They all included gravity, supersymmetry, and required ten spacetime dimensions. These theories differed in the amount of supersymmetry and type of gauge groups that were included. In addition to perturbations about Minkowski spacetime, nontrivial classical solutions were known, including space-times in which six of the spatial dimensional are compactified. In some cases, the resulting four dimensional effective theories were in qualitative agreement with observations. It was also known that spacetime is seen differently in string theory than in general relativity or ordinary field theory. In particular, flat spacetime with one direction compactified into a circle of radius R is completely equivalent to a spacetime with a circle of radius ℓ_s^2/R where ℓ_s is a new dimensional parameter related to the string tension. This is possible since the string is an extended object and has winding states in addition to the usual momentum states.

One of the main things that has changed over the past decade is that we now know that string theory does not just involve strings. Higher (and lower) dimensional objects (called branes) play an equally fundamental role. Using these branes, convincing evidence has been accumulated that all five of the perturbative string theories are just different limits of the same theory, called M theory. (There is no agreement about what the M stands for.) There is yet another limit in which M theory reduces to *eleven dimensional* supergravity.

Without a doubt, the main achievement of string theory over the past decade has been an explanation of black hole entropy [3] For a class of near extremal four and five dimensional charged black holes (with the extra spatial dimensions compactified on e.g. a torus) one can count the number of microstates of string theory associated with the black hole. One finds that in the limit of large black holes, the number is exactly the exponential of the Bekenstein-Hawking entropy. The black holes can include angular momentum, and several different types of charges, so the entropy is a function of several parameters. The string calculation reproduces this function exactly. Even more surprising, it was shown that the radiation calculated in string theory agrees exactly with the Hawking radiation from the black hole, including the distortions of the thermal spectrum arising from the greybody factors [4].

By exploring these black hole results, Maldacena was led to his famous "AdS/CFT" conjecture [5]. This states that string theory (or M theory) on space-times which asymptotically approach anti de Sitter (AdS) space is completely described by a conformally invariant field theory (CFT) which lives on the boundary of this spacetime. This is a remarkable conjecture which states that an ordinary field theory in a fixed spacetime can describe all of string theory with asymptotically AdS boundary conditions. Since only the asymptotic boundary conditions on the metric are fixed, this constitutes a background independent formulation of the theory. Since the CFT can be defined non-perturbatively, this is also a non-perturbative formulation. The AdS/CFT conjecture is a concrete implementation of the idea that quantum gravity should be "holographic" [6], i.e., the true degrees of freedom live on the boundary, but can describe all physical processes in the bulk. This was originally suggested by the fact that black hole entropy is given by the horizon area, but now applies to all quantum gravity processes, not just black holes. This conjecture has withstood a number of nontrivial checks. It can be used to derive new predictions about strongly coupled CFT, or learn about quantum gravity. For example, one immediate consequence is that the formation and evaporation of a small black hole in AdS can be described by the unitary evolution of a state in the CFT.

There is much that remains to be done. Major open questions include: (1) Develop a dictionary to translate spacetime concepts into field theory language and vice versa. (Only a few entries in this dictionary are currently known.) In particular, find a "spacetime reconstruction theorem" which allows us to reconstruct a semiclassical spacetime from certain states in the CFT. (2) Extend the AdS/CFT conjecture to other boundary conditions including asymptotically flat space-times. (3) Calculate the entropy of all black holes (including Schwarzschild) exactly and understanding why it is always proportional to the horizon area.

References:

[1] J. Polchinski, *String Theory*, in 2 vols., Cambridge Univ. Press (1998).

[2] C. Rovelli, "Loop Quantum Gravity", Living Reviews 1 (1998), gr-qc/9710008

[3] A. Strominger and C. Vafa, "Microscopic Origin of the Bekenstein-Hawking Entropy", Phys. Lett. B379 (1996) 99, hep-th/9601029; G. Horowitz, "Quantum States of Black Holes", in *Black Holes and Relativistic Stars*, ed. R. Wald, U. of Chicago Press (1998), gr-qc/9704072; A. Peet, "TASI Lectures on Black Holes in String Theory", hep-th/0008241.

[4] J. Maldacena and A. Strominger, "Black Hole Greybody Factors and D-Brane Spectroscopy", Phys. Rev. D55 (1997) 861.

[5] J. Maldacena, "The Large N Limit of Superconformal Field Theories and Supergravity", Adv. Theor. Phys. 2 (1998) 231, hep-th/9711200; O. Aharony, S. Gubser, J. Maldacena, H. Ooguri, and Y. Oz, "Large N Field Theories, String Theory and Gravity", Phys. Rept. 323 (2000) 183, hep-th/9905111.

[6] G. 't Hooft, "Dimensional Reduction in Quantum Gravity", gr-qc/9310026; L. Susskind, "The World as a Hologram", J. Math. Phys. 36 (1995) 6377, hep-th/9409089.

Fourth Capra Meeting on Radiation Reaction

Lior Burko, California Institute of Technology burko@tapir.caltech.edu

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

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

The second motivation stems from the prospects of detecting low-frequency gravitational waves with the Laser Interferometer Space Antenna (LISA), which is currently scheduled to fly as early as 2010. One of the most interesting potential sources for LISA is the gravitational radiation emitted by a compact object spiraling into a super-massive black hole, like those in galaxy centers. The typical mass ratio is then 10^{5-7}, which makes the restricted two-body problem relevant. During the last year of inspiral (the LISA integration time) the system can undergo $(1-5)\times 10^5$ orbits. In order to generate accurate templates which track the system over so many orbits, it is required to compute the orbital evolution (due to both dissipative and conservative effects) to high accuracy, which requires the inclusion of self interaction.

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

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

A number of different approaches for the calculation of the self force have been suggested. These are approaches for the computation of the "tail" part of the self force [1,2]. M. Sasaki, Y. Mino, and H. Nakano presented progress obtained in Power-Expansion Regularization. M.

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

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

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

References:

[1] Y. Mino, M. Sasaki, and T. Tanaka, Phys. Rev. D **55**, 3457 (1997)

[2] T. C. Quinn and R. M. Wald, Phys. Rev. D **56**, 3381 (1997)

[3] H. Nakano, Y. Mino and M. Sasaki, gr-qc/0104012

[4] L. Barack, gr-qc/0105040

[5] L. M. Burko and Y. T. Liu, Phys. Rev. D **64**, 024006 (2001)

[6] C. O. Lousto, Phys. Rev. Lett. **84**, 5251 (2000)

[7] L. M. Burko, Phys. Rev. Lett. **84**, 4529 (2000)

[8] A. I. Zel'nikov and V. P. Frolov, Sov. Phys. JETP **55**, 191 (1982)

[9] M. J. Pfenning and E. Poisson, gr-qc/0012057

Workshop on Numerical Relativity
Ngonyama, Krugersdorp Game Reserve

Michael Koppitz, Albert Einstein Institute koppitz@aei-potsdam.mpg.de

The Numerical Relativity 2001 workshop was organised as a sister-conference to GR16, allowing many of the participants of that conference to get involved in more in-depth discussions of the numerical side of their work. As an added bonus, the workshop was held at the N̈gonyama Lion Lodge(http://www.afribush.co.za/) in a game park near Johannesburg, with patrolling wildlife to ensure that delegates did not stray too far from the conference venue.

After an introduction by Nigel Bishop, the stage was handed over to the AEI/Golm group for the first session. Ed Seidel summarized work going on in the EU-Network (http://www.eu-network.org) collaboration on numerical relativity, and then focussed on work carried out at the AEI on colliding black holes. Denis Pollney summarized gauge conditions which have proven crucial to extending the life of evolutions both with and without excision. Carlos Lousto and Manuela Campanelli closed the session off with a descriptionthe Lazarus project, which combines full numerical studies of the plunge of two black holes with the perturbative treatment starting in the linear regime. They discussed the details of the idea, pointed out the inherent self-tests this method provides how well it passes this tests, and showed recent results obtained with this method, including the first full treatment of the binary black hole system starting from the ISCO down to the ring down of the final black hole. Later in the week, colliding black holes were also demonstrated by Richard Matzner (Texas/Austin), who demonstrated his group's grazing collision results.

Initial data methods were discussed over the afternoon. Peter Diener (AEI/Golm) presented his results using an adaptive mesh technique combined with a multi-grid solver to solve the initial data problem for two black holes with the Kerr-Schild approach. Nina Jansen (Tac/Copenhagen) used a similar solver to compare initial data sets in terms of the behavior of the ADM mass as a function of separation. Phillipe Grandclement (Observatoire de Paris/Meudon) presented a new approach to the initial data problem, using multi-domain spectral methods and a helical killing vector field to simplify the problem. Micheal Koppitz (AEI/Golm) summarized the efforts underway at the AEI to generate new sets of initial data for binary black hole systems, emphasizing the strong need for comparison between sets.

The important role of constraints in the evolution equations was emphasized in the interesting talks of Hisa-aki Shinkai (RIKEN/Japan) and Oscar Reula (Cordoba). Raymond Bursten, Anthony Lun, and Elizabeth Stark (Monash University) described their use of the electromagnetic parts of the Weyl tensor as well as the Bianchi identities, to improve certain aspects of the conventional 3+1 evolution system. Luis Lehner (British Columbia) also underlined the need for a better understanding of boundary problems and non-principal terms of the evolution equations.

Florian Siebel (MPI für Astrophysik/Germany) reported on fully relativistic evolution of a neutron star using characteristic methods, and Motoyuki Saijo (University of Illinois/Champaign) reported on simulations of fate of the collapse of super-massive stars. Marcelo Salgado (UNAM/Mexico) presented a scalar-tensor model for neutron star collapse. Shin'ichirou Yoshida (SISSA/Trieste) described numerical studies of rotation modes of differentially rotating neutron stars. John Miller (SISSA/Trieste) gave an illuminating presentation of the influence of shocks in domain significant to the r-mode instability.

The advantages of the technique of Padé approximants for post-Newtonian calculation were described by Bala Iyer (Raman Institute/Bangalore) Carsten Gundlach (Southampton) described the methods used for his studies of critical collapse of perfect fluids. Jose Martin-Garcia (Southampton) reported on a new formalism to calculate nonspherical linear perturbations around a general spherical background containing a perfect fluid. It is independent of the equation of state and can therefore model physically interesting problems. David Hobill (University of Calgary) presented recent studies of both sub-and super-critical Brill waves emphasising the creation and evolution of trapped surfaces for super-critical initial data. Mihai Bondarescu (AEI/Golm) presented his work on embeddings of 2d surfaces (in particular, apparent horizons) in Minkowski space.

On the technical front, Garielle Allen and Thomas Radke (AEI/Golm) gave a two hour introductory tutorial on the Cactus Computational Toolkit, its underlying idea and benefits of using it even for small scale computers and laptops. They explained how to obtain, compile and run Cactus and presented some of its features, especially its integration with visualization tools. During the open discussion session, adaptive mesh refinement (AMR) was identified as a urgent requirement for bringing numerical relativity into the realm of real physics problems, and it was good to see AMR work being carried out on a number of fronts. In addition to the work of Diener and Jansen already mentioned, Scott Hawley (AEI/Golm) presented his implementation of Berger-Oliger type mesh refinements. Dae-Il Choi (NASA Space Flight Center/Houston) showed AMR evolutions of strong Brill waves demonstrating how the refined grid followed the wave very well.

Alternative approaches to 3+1 were also discussed. Nigel Bishop (University of South Africa/Pretoria) reported on results obtained by evolving a neutron star orbiting around a Schwarzschild black hole using characteristic techniques. Ray d'Inverno (Southampton) summarized recent work on Cauchy-Characteristic matching techniques, in particular cosmic string evolutions and progress on an axisymmetric code. Ruth Williams (Cambridge) discussed discrete techniques involving space-times tessellated by polygons. Carlos Sopuerta (University of Portsmouth) suggested a technique of using a background metric to do the 3+1 split of Einstein's equations in situations where the system under study is sufficiently known already. Osvaldo Moreschi (Cordoba) described work on Robinson-Trautman space-times, for perturbations specified at null infinity. Jörg Frauendiener (Universität Tübingen/Tübingen) discussed boundary conditions, evolution schemes, and technical problems arising when implementing the conformal field equations.

Sash Husa (AEI/Golm) reported on the current status of the treatment of the conformal field equations and discussed some possible future strategies. (Notable attendees to this latter session were the conference site's resident hippos, who had until then refused to make an appearance but listened attentively to the final day's talks from across the pool.)

All in all it was an enjoyable week, not only for the physics that were discussed, but also the fun location and Nigel Bishop and the local organisers should be commended for putting it all together.

Denis Pollney was of great help in preparing this report.

Workshop on Canonical & Quantum Gravity III

A. Ashtekar (Penn State), J Lewandowski (Warszaw), J. Wiśniewski (Penn State)
ashtekar@gravity.phys.psu.edu lewand@aei-potsdam.mpg.de jacek@gravity.phys.psu.edu

For a third time, a sizable portion of the gravity community gathered in Warsaw to discuss recent advances. Participation of excellent physicists working on exciting topics, not limited just to the field of canonical or quantum gravity, created a vibrant atmosphere in the meeting. The workshop was sponsored by Banach Center of Mathematics of Polish Academy of Sciences (PAN). It was organized by Jerzy Lewandowski, Jacek Jezierski (Warsaw University), Jerzy Kijowski (Center for Theoretical Physics PAN, Warsaw) and Abhay Ashtekar (Penn State) who served as a scientific advisor. Over 90 participants from 12 countries attended about 60 talks. Workshop was divided into two parts. First week was devoted to problems in classical general relativity; its title was "Null Structures and other Aspects of Classical Gravity". Second week was devoted to problems of "Quantum Gravity". In between the two parts was a one day celebration of Ted Newman's birthday, with talks by Aichelburg, Ashtekar, Penrose, Stachel and Trautman as well as interesting after dinner reminiscences in the evening, in Palac Staszica. The organization of that day was directed by Bialynicki-Birula, with the help of Demianski, Nurowski, Tafel and Trautman.

By far the most extensive application of the null-cone structures being the subject of the first part of the meeting is the Null Surface Formulation (NSF) of the Einstein's theory started about 10 years ago by Newman and his collaborators. According to this theory, the space-time is a secondary object defined as the set of solutions of certain 3rd order ODE. The recent development indicates relations with Cartan's theory of differential equations (Newman, Nurowski, Kozameh) and applications to the gravitational lensing (Fritelli, Tod). NSF is a relative of the Twistor program, the advantage of the NSF being that it applies to real, not necessarily analytic space-time of the Lorentz signature. However, in one of his three talks Penrose reported on his recent attempt to construct the twistor space for a generic curved space-time of the $(+,-,-,-)$ signature! An exciting application of the twistors that bridges the classical and the quantum theories is the Bialynicki-Birula twistor Wigner-function introduced for the participants of the workshop by its inventor. Twistor spaces corresponding to anti-self-dual metrics in the $(+,+,-,-)$ signature with covariantly parallel spinor were characterized before the audience by Dunajski. A recent discovery of Damour, Henneaux, Julia and Nicolai traces the roots of the BKL BKL behavior near space-time singularities (in the dimensions greater/equal 4) to the structure of the fundamental Weyl chamber of some underlying hyperbolic Kac-Moody algebra. This intriguing result and its consequences were presented in a comprehensive lecture by Henneaux, one of the three talks on singularities (Bizon, Aichelburg). Another major topic was the novel, quasi-local generalization of the black hole theory, provided by "isolated horizons" (IHs). The mechanics and geometric invariants including geometric conditions that distinguish the Kerr horizon among all IHs were discussed (Beetle, Krishnan, Lewandowski, Pawlowski). An interesting result shown by Racz was his proof of the existence of a Killing vector in the case of the bifurcate IHs. Related formulations of the mechanics of the null shells and scri were explored by Chrusciel, Kijowski and Tafel. In the area of the traditional black hole theory, Jacobson argued that "black hole entropy is not about black holes". The recent progress in understanding of the Penrose inequality was discussed by Frauendiener. The "canonical" theme of the workshop was underlined by the Beig's talk on the motion of the point particles in general relativity and constraint equations.

Other subject covered were "32 Double Coverings of $O(p, q)$ for $p, q > 1$" (Trautman), "The Hopf fibration – five times in physics" (Urbantke) and "Real Sources of Holomorphic Coulomb Fields" (Kaiser).

The main topic discussed in the second, quantum, part of the Workshop was "quantum geometry". Recent advances within this approach in meeting that challenges of quantum gravity were reviewed by Ashtekar in his lecture on the Newman day. A focal point of research in the canonical approach during last several years has been the semi-classical sector of the theory. Thiemann and his collaborators (Winkler, Sahlmann) explored the idea of construction of semi-classical states by gluing the coherent states defined on SU(2). Another approach follows from Varadarajan's embedding of the free Maxwell theory Fock space into the U(1) analog of the polymer-like excitations Hilbert space of the quantum geometry. A generalization to the SU(2) theory described in the second of Ashtekar's talk provides a natural candidate for the Fock flat space-time vacuum and a starting point to bridge the background independent, non-perturbative approach and perturbative results. A third way to extract a semi-classical information from the non-perturbative sector was the subject of Bojowald's talk. By a quantum symmetry reduction, and by exploiting discreteness of volume in quantum geometry, he obtained a substitute for the familiar Wheeler-DeWitt equation that naturally resolves the big-bang singularity. A second focal point was provided by the lively discussions on "spin foam models", which provide a path integral approach to the quantum gravity, based again on quantum geometry. The idea initiated by Reisenberger and Rovelli and has drawn a great deal of attention because of the recent finiteness results by Perez, Crane and Rovelli which, roughly speaking, are analogous to the finiteness claims of perturbative string theory. All principal researchers (except Baez and Crane) in the area reported on the status of their work. The promising idea of providing the space of the spin-foams with the Hopf algebra structure was explained by Markopoulo. The issue of observables in quantum geometry was discussed by Pullin. A third focal point to the workshop was provided by simplicial Lorentzian gravity. Many of the frequently asked questions were exhaustively answered by Loll, Ambjorn and Jurkiewicz.

To provide a balance, there were several talks on the nearby areas, particularly quantum groups (Woronowicz, Zapata, Kowalski-Glikman), branes (Meisner, Pawelczyk, Louko), 2+1-gravity (Bengtsson, Freidel, Wisniewski), the theta functions (Mourao), as well as the talks on the status of the other issues of the quantum theory, such as general covariance (Fredenhagen), gravitational quantum state reduction (Penrose), gravitational collapse (Hajicek), technical and conceptual issues in approaches based on histories (Dasgupta, Kuchar), QCD on the lattice (Kijowski), pre-canonical quantization (Kanatchikov). Especially instructive was the lecture by Woronowicz on the representations of the quantum Lorentz group. Those of us who apply the quantum groups in everyday work, could ask the master about some subtleties and other possible ways of q-deforming.

In summary, the atmosphere of the meeting was most stimulating due to active participation of both, experienced as well as young researchers. Interactions between different areas of research in mathematical/quantum gravity and at the same time avoiding the overload of big conferences seemed to be an advantage. Hopefully, the Warsaw workshops CQG have already become a tradition and future ones will again bring excellent researchers and lecturers.