MATTERS OF GRAVITY

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

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Contents

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Editorial

This newsletter is horribly late, you have only the editor to blame. We celebrate the World Year of Physics with our Topical Group in stronger shape than ever. We have 729 members, up from 654 last year and 591 the year before. This makes us the second largest topical group. We constitute 1.68% of the APS membership. To put this in perspective, the smallest division has 1,144 members.

The next newsletter is due September 1st. All issues are available in the WWW:
`http://www.phys.lsu.edu/mog`
The newsletter is 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. A hard-copy 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 think a topic should be covered by the newsletter you are strongly encouraged to contact the relevant correspondent. If you have comments/questions/complaints about the newsletter email me. Have fun.

Jorge Pullin

Correspondents of Matters of Gravity

- John Friedman and Kip Thorne: Relativistic Astrophysics,
- Bei-Lok Hu: Quantum Cosmology and Related Topics
- Gary Horowitz: Interface with Mathematical High Energy Physics and String Theory
- Beverly Berger: 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
- Peter Saulson: former editor, correspondent at large.

Topical Group in Gravitation (GGR) Authorities

Chair: Jim Isenberg; Chair-Elect: Jorge Pullin; Vice-Chair: Éanna Flanagan; Secretary-Treasurer: Patrick Brady; Past Chair: John Friedman; Delegates: Bei-Lok Hu, Sean Carroll, Bernd Bruegmann, Don Marolf, Gary Horowitz, Eric Adelberger.

Message from the Chair

Jim Isenberg, University of Oregon jim-at-newton.uoregon.edu

I hope you're not already sick of hearing about Einstein and the 100th anniversary of his "miracle year". We're only one month into it, and it remains our job to tell the public how important and revolutionary his work of 1905 (and 1915) has turned out to be for our understanding of how the universe works. The up and running Speakers Program is doing a great job of helping us to convey this to the public. (We thank all of those helping with this program, especially Danika Mogilska and Richard Price). The special evening session (Einstein's Legacy: What We Know and Don't Know) at the April APS meeting in Tampa will help reinforce this message in the minds of other physicists as well.

Of course one way we can view the present Einstein hoopla is as a sort of warm up for the BIG centenary celebration in 2015. It is fun to think about what we might know about gravitation by then, 100 years after Einstein published his paper introducing General Relativity. We all hope that detecting gravitational radiation will be relatively routine by 2015. Might we even hope that numerical simulations will catch up by then? We should know more and more about the very early cosmos, and the seeds of clumping into galactic structure. On the other end of cosmology, might we have a good model for the apparent acceleration of cosmic expansion? It would be great to know a lot more than we do about the interface of gravitation and quantum phenomena. Likely it is too optimistic to expect an observable manifestation of this interface. On the mathematical side, can we hope to have resolved whether cosmic censorship (in either the weak or strong form) is true for Einstein's gravitational field equations?

Regardless of your attitude on centenaries, this one gives us a good excuse to read some of the original papers which Einstein wrote in 1905 (and later). Just this past week, I reread "On the Electrodynamics of Moving Bodies", and "Does the Inertia of a Body Depend upon its Energy Content". I wouldn't recommend them to Oprah's Book Club (then again, why not?) but I found them to be very interesting reading.

One other anniversarial type note: This is the 10th anniversary of the founding of our Topical Group in Gravitation. I think it is fair to say that the group has been very successful in advocating and publicizing work in gravitational physics. Those of us who agree should give a very big thank you to Beverly Berger, whose inspiration and dogged efforts ten years ago are responsible for the existence of GGR.

One mark of our success is the increasing number and geographical range of our signature "regional meetings". Starting with the annual spring Pacific Coast Gravity Meeting (first held 20 years ago) these have spread to the annual fall Midwest Gravity Meeting (first held in 1991), the annual spring Eastern Gravity Meeting (first held in 1997), and now the newly inaugurated Gulf Coast Gravity Meeting (to be held this month). For those of you haven't attended one of these, i highly recommend them as a great way to learn about new results in our field, and a great way to introduce graduate students to the world of gravitational physics research.

Einstein@Home: a mega-computer for gravitational waves

Bernard Schutz, Albert Einstein Institute schutz-at-aei.mpg.de

With the help of the American Physical Society, the gravitational wave community is hoping to enlist home computers all over the world in the search for gravitational waves. The initiative, named Einstein@Home, is one of APS's World Year of Physics 2005 projects. After the official release of the software in the first quarter of 2005, anyone will be able to visit the APS website http://www.physics2005.org/ and download a screensaver that will enable any idle computer to become a part of the global gravitational wave data analysis network.

Einstein@Home is being developed by a team of scientists and programmers from the LIGO Scientific Collaboration (LSC), led by Bruce Allen of the University of Wisconsin Milwaukee (UWM). The idea for the project arose in discussions in 2003 between James Riordon of the APS and members of the gravitational physics community. Riordon wanted to use the "Einstein Year" to provide some practical help to physics, not just public relations, and he thought that a screensaver could be the ideal vehicle. The GW community certainly needs practical help: the sensitivity of the search for gravitational wave pulsars will be limited by the available computer power, and even the several teraflops of cluster computers available within the LSC can make only a small dent in the problem.

Einstein@Home could make a real breakthrough in the available computer power. Even in the preliminary testing phase of the software, enough users signed up for it that it could deliver more CPU cycles than any other LSC computer. The screensaver is designed to give the computer's owner a sense of participating in an important project. It displays a rotating globe of the constellations, on which are shown all the known pulsars, the current sidereal locations of the LIGO and GEO600 detectors (whose data will be analyzed), and the place on the sky where the computer is currently doing its search for pulsars. Each computer gets a small amount of data from an Einstein@Home server, does the analysis, and returns the result. Even if the computer is temporarily disconnected from the internet (say, a laptop PC), the analysis will be completed and the software will wait for the next opportunity to update itself. Users get feedback about how much they have contributed to the effort, and they can even join teams that compete to provide more and more cycles!

It is no coincidence that the project's name resembles that of SETI@Home. The SETI project (Search for Extraterrestrial Intelligence) originated the screensaver-for-science idea, and it has so far managed to engage hundreds of thousands of computers in the analysis of short stretches of radio telescope data for possible non-random signals. The SETI software inspired an open-source product, called BOINC, written by SETI@Home developer David Anderson. Einstein@Home is based on the BOINC tools. In fact, the Einstein@Home team has made significant contributions to BOINC itself. Scientists from LIGO, UWM, and the Albert Einstein Institute in Germany have participated in the project.

The Einstein@Home software will run on PCs, Macs, and Linux machines. Bruce Allen is hoping not only that members of the general public will catch GW fever and sign on, but also that university groups will install the screensaver in their computer instruction labs and on their departmental workstations. Even typical computers sold in today's mass market deliver performance within factors of 5 or better of the chips used in many high-performance clusters, so most university physics departments can deliver a good fraction of the dedicated computer power at any of the LSC computer installations. If Einstein@Home can achieve one hundred thousand users (which certainly seems possible), it might well turn out that the first gravitational wave source to be discovered will be a pulsar found by someone's home PC!

We hear that...

Jorge Pullin, LSU pullin-at-lsu.edu

The SIGRAV (Italian Society of General Relativity and Gravitation) has awarded the 2004 Amaldi Medal to *Roger Penrose*. The Amaldi medal is a European Prize for Gravitational Physics. It is awarded biannually and recognizes an European scientist who has given outstanding contributions to general relativity and gravitational physics.

Dieter Brill was elected vice-chair of the Topical Group. Vern Sandberg was elected secretary/treasurer. Vicky Kalogera and Steven Penn were elected to the executive committee.

GGR members Larry Ford, Jacqueline Hewitt, Ted Jacobson, Alan Kostelecky, Corinne Manogue, Ho Jung Paik, John Price were elected fellows of the APS.

Hearty Congratulations!

100 Years ago

Jorge Pullin pullin-at-lsu.edu

German and English versions of Einstein's 1905 paper "On the electrodynamics of moving bodies" are available at http://www.phys.lsu.edu/mog/100

What's new in LIGO

David Shoemaker, LIGO-MIT dhs-at-ligo.mit.edu

Since the last MOG, the LIGO Laboratory and more broadly the LIGO Scientific Collaboration (LSC) has been working on technical issues in both data analysis and in instrument science. This note will concentrate on the instruments, complementing the last MOG LIGO report which described the first observation publications.

Initial LIGO

The LIGO interferometers, installed in the observatories in Livingston, Louisiana, and Hanford, Washington, have interleaved observation with commissioning over the past few years. Since completing the S3 run in January of 2004, all the interferometers have been going through a mixture of tuning and the addition of new elements to bring them to the desired sensitivity.

An important step forward has been the commissioning of the Hydraulic External Pre-Isolator, at the Livingston observatory. This system was originally designed as an element of the Advanced LIGO seismic isolation system, but was pressed into early application to reduce the excessively large ground motion in the 0.2 - 10 Hz band at Livingston. It is an active seismic isolation system, using inertial sensors and actuators in all six degrees of freedom to reduce the motion of the structure supporting the original seismic isolation 'stack'. It delivers about a factor of ten reduction in motion – enough to permit the Livingston interferometer to lock during the day and through the passage of trains on a nearby track. This should increase the uptime of the detector, and also allows commissioning during the day.

Another new element in the interferometers is a Thermal Compensation System. This is again an Advanced LIGO element brought to bear on initial LIGO. The notion is to deliver heat to the interferometer optics to change their focal length (via dn/dt). This can be used on 'cold' optics to compensate for an initially slightly incorrect radius of curvature, and/or to compensate for excessive focusing in a 'hot' optic already distorted by the main sensing laser beam; Gaussian or 'doughnut' profiles, or more complex forms for spatially varying absorption, are possible. Using the TCS, significant improvements in the quality of the modulation sidebands have been made along with reductions in feedthrough of oscillator phase noise. We are still installing the TCS system, and still learning how to use it, but it has already and will clearly lead to further reduced shot noise and other sensing noises.

A variety of other details have been worked to reduce the noise contributions. Higher gain control loops for the 'auxiliary' servo loops, improved methods to balance the actuators on the suspensions, modifications of the filtering in photo-detector amplifiers, and lower-noise oscillators for the modulation/demodulation systems have all helped. The best sensitivity to date is in the Hanford 4k instrument, and is shown in Figure 1. The sensitivity is within a factor of two of the goal across the entire target sensitivity of the instrument, and we understand well the remaining limits. We are working on propagating the improvements to all interferometers.

The plan for further data collection and improvements calls for a one-month observation run, S4, to start in early 2005, followed by a push to bring all the instruments to the goal for the initial LIGO instruments. Then the S5 run, currently planned to start late in 2005, is targeted to collect one year of integrated observation with the initial LIGO detector.

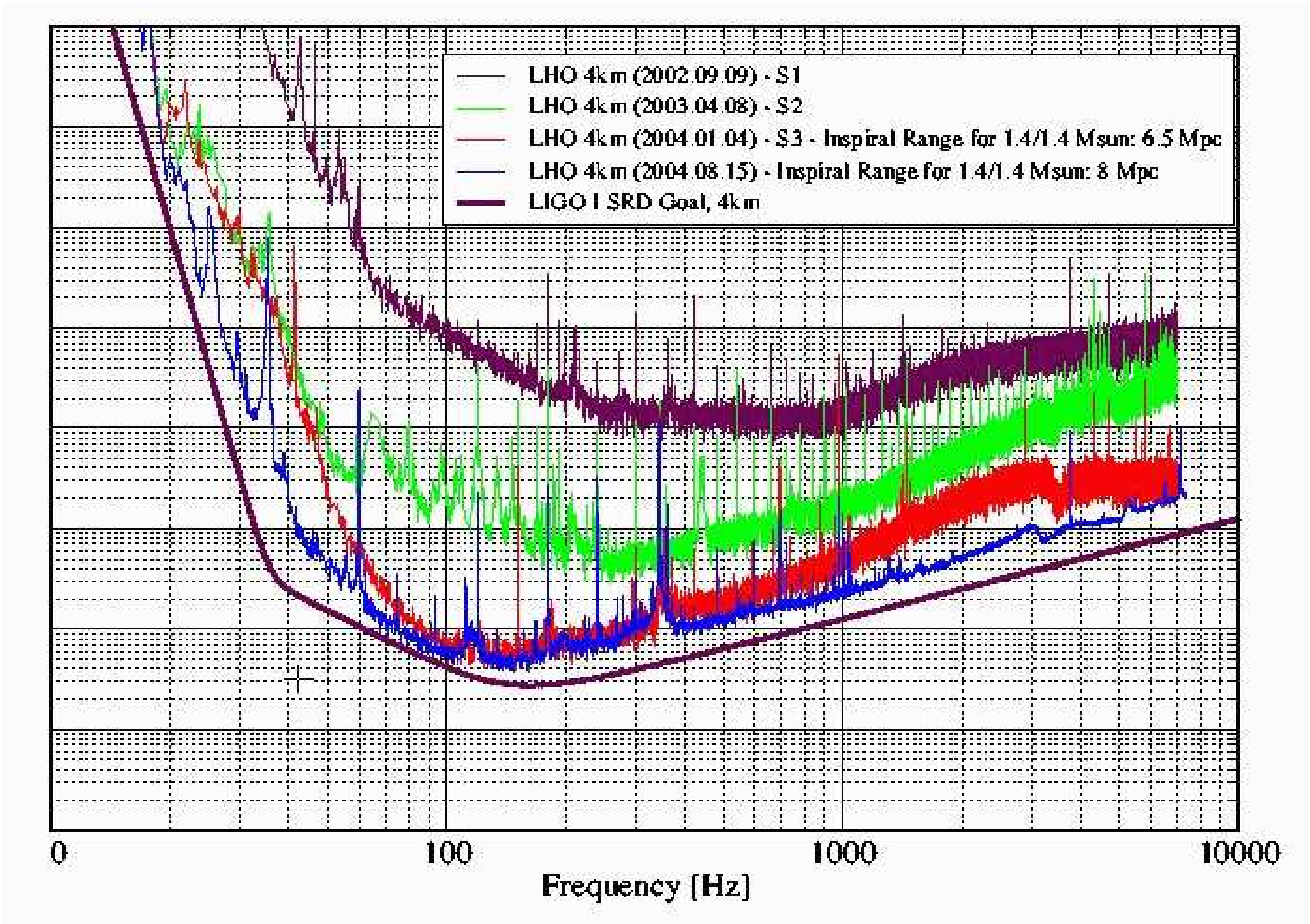

Figure 1: Caption: The strain sensitivity of the LIGO Hanford 4km gravitational wave detector, showing its evolution with continued commissioning. The bottom-most measured curve dates from August, 2004. The smooth line at the bottom is the goal for the sensitivity of the instrument, as laid out in the Science Requirements Document ('SRD'). (LIGO G040439-00)

Advanced LIGO

The other significant effort in instrument science is to bring Advanced LIGO forward. An important milestone was passed in October, when the National Science board reviewed the Advanced LIGO proposal. They recommended to the director of the NSF that Advanced LIGO be funded as requested. There are certainly significant hurdles yet to be passed before funding is received, but this is a necessary and very important step toward the realization of Advanced LIGO.

A number of the subsystems have made nice advances recently. The pre-stabilized laser, led by the Albert Einstein Institut Hannover, saw their partners Laser Zentrum Hannover achieve the required 200 watts of laser power from the prototype laser power head for Advanced LIGO. The high-power test facility at Livingston came on line, and the Input Optics subsystem led by the University of Florida started tests of modulator and isolator materials at realistic power levels. Efforts in the LIGO Laboratory included optical coating development, which explored parameter space of dopants and found lower mechanical losses, important for the thermal noise. Both the requirements for optical losses and uniformity for the thermal compensation, and successes in making coatings meeting them, were realized. A full mode-cleaner style prototype from the Caltech suspension group was installed at the MIT LASTI facility and characterized, and the quadruple suspension development, led by the UK/Glasgow with lots of Caltech/MIT participation, moved forward. The prototype isolation system at Stanford, with LSU's leadership, was prepared and then operated in vacuum with new control laws. The 40m interferometer configuration testbed at Caltech was able to lock all degrees of freedom, leading the way to tests of the locking of Advanced LIGO and comparison with models.

One significant point to mention is the choice of substrate for Advanced LIGO's test mass optics. We had been looking very carefully since 2001 at two materials: fused silica, which is the traditional material for fine optics, and used in initial LIGO; and sapphire, a very hard, high density, low-mechanical loss material. Careful consideration of both the performance measures (e.g., they exhibit different thermal noise 'signatures', and different net noise levels for a given coating thermal noise), and practical questions (e.g., the ability to manufacture and install complete systems on a schedule) were taken into account. Curiously, the cost for either option was the same – so this was not a net criterion. The Lab has adopted the recommendation from this study group to use fused silica as the baseline material, and this allows the quad suspension group to move forward with dimensions and density for the test mass. A closing note on this choice is that, since the internal thermal noise is considered to be quite low for fused silica, any extra improvements in coating thermal noise will lead to similar improvements in the Advanced LIGO sensitivity. A nice challenge!

The coming year will see further full-scale prototyping and testing, development of readout systems for the interferometer testbed, development of the complete Advanced LIGO model in the 'e2e' package, and further progress in the other subsystems. And, we hope, good news on the Advanced LIGO funding timescale.

Frame-dragging in the news in 2004

Clifford Will[1] , Washington University, St. Louis cmw-at-howdy.wustl.edu

Frame-dragging made headlines twice during 2004. First, on April 20, came the long-awaited launch of Gravity Probe-B, the joint project of NASA, Stanford University and Lockheed-Martin to measure the dragging of inertial frames (Lense-Thirring effect), using an array of orbiting gyroscopes (see Bill Hamilton's article in MOG, Fall 2004). By the middle of August, the mission had completed the commissioning and calibration phase, and commenced science operations. Now at the mid-point of the 10-month science phase, the spacecraft and instruments are performing as expected [1]. It is too early to know whether the relativistic effects are being measured in the amount predicted by general relativity, because an important calibration of the instrument exploits the effect of the aberration of starlight on the pointing of the on-board telescope toward the guide star (IM Pegasi), and completing this calibration requires the full mission data set. In addition, part of the measured effect includes the motion of the guide star relative to distant inertial frames. This is being measured separately by Irwin Shapiro's group at Harvard/SAO, using very long baseline interferometry (VLBI), and the results of those VLBI measurements will be strictly embargoed until the GPB team has completed its analysis of the gyro data.

Meanwhile, on October 21, Ignazio Ciufolini and Erricos Pavlis made science headlines with a paper in *Nature*, in which they claimed to have measured frame-dragging to between five and 10 percent [2], using laser ranging to the Earth-orbiting satellites LAGEOS I and II.

This is not the first report of a measurement of frame dragging using the LAGEOS satellites. In 1998 and 2000, Ciufolini and colleagues reported measurements of the relativistic effect with accuracies ranging from 20 to 30 percent [3,4,5]. What makes this newest report different from the rest?

The idea behind the LAGEOS experiment is to measure the precession of the orbital plane caused by the dragging of inertial frames. For the LAGEOS satellites, the precession is about 31 milliarcseconds (mas) per year. The satellites, launched mainly for geophysical purposes, are massive spheres studded with laser retro-reflectors, and as such are not as strongly affected by atmospheric drag and radiation pressure as are complex satellites with solar panels and antennae, and can also be tracked extremely accurately using laser ranging.

Unfortunately, Newtonian gravity makes a whopping $126^{\circ}\,\mathrm{yr}^{-1}$ contribution to the precession. This haystack must be subtracted off, in order to find the relativistic needle buried within. The Newtonian precession depends primarily on the so-called even zonal harmonics J_n of the Earth's gravity field, with J_2, J_4, J_6 ... contributing in ever decreasing amounts. These moments have been measured over the years using a variety of Earth-orbiting satellites, but have never been known accurately enough to permit a simple subtraction of the Newtonian precession.

In their earlier work, Ciufolini *et al.* tried an alternative method. Noting that the orbit of LAGEOS II had a small eccentricity, they argued that, if one measured the two precessions together with the perigee advance of LAGEOS II, all of which depend on frame dragging and the zonal harmonics, and if one adopted the existing values of the harmonics for $n = 6$ and higher, then one could use the three observables to measure the two poorly known J_2 and J_4, and the unknown relativity parameter. This was the basis of the results presented in

[1]Full disclosure: the author chairs NASA's Science Advisory Committee for Gravity Probe-B

Refs. [3,4,5]. Unfortunately, the perigee precession is strongly affected by non-gravitational perturbations, and so it is difficult to assess the errors reliably. A number of experts argued that the 20 to 30 percent errors assigned by Ciufolini *et al.* were too small by factors as high as five [6,7].

But then along came CHAMP and GRACE. Europe's CHAMP (Challenging Minisatellite Payload) and NASA's GRACE (Gravity Recovery and Climate Experiment) missions, launched in 2000 and 2002, respectively, use precision tracking of spacecraft to measure variations in Earth's gravity on scales as small as several hundred kilometers, with accuracies as much as ten times better than had been obtained previously. GRACE consists of a pair of satellites flying in close formation (200 kilometers apart) in polar orbits. Each satellite has on-board accelerometers to measure non-gravitational perturbations, satellite to satellite K-band radar, to measure variations in the Earth's gravity gradient on short scales, and GPS tracking to measure larger scale variations in Earth's gravity.

With the dramatic improvements in J_n obtained by CHAMP and GRACE, Ciufolini could now treat J_4 and above as known (well enough), drop the troublesome perigee advance, and use the two LAGEOS precessions to determine J_2 and the relativity parameter. This is what Ciufolini and Pavlis reported in the recent *Nature* paper [2].

While all this is valid in principle, the big question is the treatment of errors. Iorio [8] has criticized the error analysis on a number of grounds, including (i) adopting one GRACE/CHAMP Earth solution for the analysis, rather than analyzing many solutions for the zonal harmonics and seeing how the relativity parameter varies; (ii) inadequate treatment of correlations among the zonal harmonics in the GRACE/CHAMP solutions; and (iii) inadequate treatment of temporal variations in the low-order harmonics $\dot{J}_4$ and $\dot{J}_6$. Iorio suggests that the $2-\sigma$ errors should be more like 30 percent [9]

With results from GPB not expected until well after the end of the mission in July, and with this lingering discussion of errors in the LAGEOS solutions, we may not have a solid answer about these measurements of frame dragging before the end of the Einstein year.

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Cosmic (super)strings and LIGO

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Through much of the last two and a half decades, cosmic strings were of great interest to the cosmology and high energy physics communities. Unlike other simple topological defects, such as monopoles and domain walls, strings do not cause cosmological disasters. Indeed, cosmic strings formed at the GUT scale would lead to cosmological density perturbations of the right amplitude to seed the formation of galaxies and clusters. Thus, cosmic strings became a leading candidate for structure formation. For a review see [1].

Cosmic strings were also appealing because their cosmological evolution (at least the gross features) turned out to be quite simple. Regardless of the details of the initial conditions, a string network in an expanding universe will quickly evolve toward an attractor solution called the "scaling regime". In this regime, the energy density of the string network becomes a small constant fraction of the radiation or matter density, and the statistical properties of the system, such as the correlation lengths of long strings and average sizes of loops, scale with the cosmic time.

The attractor solution is possible due to reconnections, which for field theoretic strings, essentially always occur when two string segments meet. Reconnections produce cosmic string loops, which in turn decay by radiating gravitationally. This takes energy out of the string network, converting it to gravitational waves. If the density of string in the network becomes large, then strings will meet more often, producing extra loops. The loops then decay gravitationally, removing the surplus energy from the network. If, on the other hand, the density of strings becomes too low, strings will not meet to often enough to produce loops, and their density will start to grow. Thus, the network is driven toward an equilibrium.

During the 1990s, cosmic microwave background data showed that strings could not give rise to the density fluctuations that seed structure formation. These observations placed upper limits on the string tension below the GUT scale, relegating strings to (at most) a sub-dominant role in the seeding of structure formation. As a result of these discoveries, the cosmology community's interest in cosmic strings dwindled through the late 1990s, and into the millennium. Recently, however, a few developments have contributed to a resurgence of interest in cosmic strings.

In 2000, Damour and Vilenkin found that cosmic strings could lead to the production of sizable gravitational wave bursts [2]. These bursts may detectable with first generation ground-based interferometric gravitational wave detectors, such as LIGO and VIRGO, at design sensitivity. Remarkably, they found values of the string tension that would result in a measurable signal, that are below the upper limits placed by cosmic microwave background observations.

The bursts we are most likely to be able to detect are produced at cosmic string cusps. These are regions of string which acquire phenomenal Lorentz boosts, and emit a powerful burst of gravitational waves in the direction of motion of the string. The formation of cusps on cosmic string loops and long strings is generic, and their gravitational waveforms simple and robust [3].

More recently, Jones, Stoica and Tye [4], and Sarangi and Tye [5] realized that string theory inspired inflation scenarios lead to the production of cosmic strings. Thus, the very exciting possibility arises [6] that a certain class of string theories may have consequences observable in the near future: Just like ordinary field theoretic strings, the cosmic superstrings formed could lead to the production of a detectable gravitational wave signal.

Fortunately, much of what was learned about the evolution of field theoretic cosmic string networks can be applied to the evolution of cosmic superstrings. Aside from the possibility of forming more than one type of string, the most significant difference is that cosmic superstring interactions are probabilistic. Pairs of strings do not always reconnect when they meet. Furthermore, strings in higher dimensional spaces may more readily avoid intersections [7]. The net effect is to lower the reconnection probability. If there is only one type of string, the network still enters a scaling regime [8], albeit at a density higher by a factor inversely proportional to the reconnection probability [9]. It turns out that the smaller reconnection probability of superstrings actually *increases* the chances of detection through the production of gravitational wave bursts [9]

Finally, there are direct observations that suggest a gravitational lens produced by a long cosmic string [10], as well as an oscillating cosmic string loop [11].

The LIGO Scientific Collaboration is currently involved in the development of a templated search for bursts from strings. At the end of February 2005, the collaboration plans to start its fourth science run (S4). The interferometers are within factors of a few from design sensitivity. Although with current sensitivities a detection seems unlikely, it may become possible to place constraints on the types of fundamental particle theories that describe our world.

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The first gulf coast gravity conference $(GC)^2$

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There is a pronounced drift of relativity into the region from Texas to Florida, a range of states that does not fit into the reach of the other regional meetings. For that reason there is now yet another regional meeting: The Gulf Coast Gravity Conference.

The first such meeting took place Feb. 11 and 12 at the University of Texas at Brownsville, organized by Carlos Lousto, and was attended by relativists from Texas (UT Austin as well as Brownsville), Louisiana (LSU and LIGO), and Florida (Florida Atlantic University). As in other regional meetings, this was a meeting in which everyone got the same short time to talk, and in which students were giving their first talk in front of "outsiders."

The first day's focus was numerical relativity, and showed that the present state of the field has both convergence of some results and controversy about others. There was agreement about plunge radiation. Results reviewed by UTB's Manuela Campanelli from the Lazarus project (numerical relativity plus perturbation theory) showed about 2.5% of the mass-energy and about 12% of the angular momentum radiated in the late stage of infall. Recent results from LSU, reported by Peter Diener, were in good agreement with the conclusion about radiated energy and reasonable (all things considered) agreement about angular momentum.

There was a useful lack of agreement about initial data, however. Pedro Maronetti of FAU, reporting recent results, showed an efficient way of doing short term evolutionary tests of initial data to see whether the thin-sandwich initial data advertised for circular orbits really does give circular orbits. His recent results, for neutron stars, were in good agreement with circular orbits. Results reported by Peter Diener, from Bowen-York initial data for circular orbits sort of suggested the opposite for black holes. Is it thin-sandwich vs Bowen-York, or something else. It will be interesting to watch how answers to this question develop.

The UTB numerical relativity team, Joseph Zochlower (fourth order codes), Mark Hannam (initial data), and Bernard Kelly (reference frames for Lazarus), gave updates on the many refinements that now characterize the state of the art in numerical relativity. Steve Lau, of UTB, reported on work on radiation boundary conditions indicating that reflections off an outer boundary could be eliminated in principle, and probably greatly reduced in practice.

The second day of the conference contained several talks related to my own recent obsession: an "intermediate" approximation for black hole inspiral: an approximation appropriate to the later-than-PN, too-soon-for-numerical relativity approximation. I showed the efficiency of a new numerical technique we were using. Chris Beetle has reported on a general mathematical result for how Kepler's law would come out of the intermediate approximation, and Mike McLaughlin showed how some modern applied mathematics could be used to reduce the computational infrastructure that our method might require.

In the afternoon, Rayesh Nayak described the orbital dynamics that are the basis of LISA, and we had talks on data analysis by Alexander Dietz of LSU, and by students Andres Rodriguez (LSU), and Arturo Jimenez, and Charlie Torres (UTB). The widely varying approaches described were a reminder of how difficult this problem will be, and on how open the questions remain.

The prize for the best of an exceptionally good set of student talks was won by Napoleon Hernandez of UTB for his presentation "Towards the computation with Dirac Delta sources for the Teukolsky equation."

Imagining the future: gravitational wave astronomy

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On October 27-30, 2004, a group of 64 gravitational wave astronomers and astronomers from traditional fields of astronomy and astrophysics, representing 20 different institutions, convened at Penn State for a workshop to speculate on the future of gravitational wave astronomy. The purpose of the workshop was to begin a conversation in the community about the future evolution of the field of gravitational wave physics and astronomy, and to consider how this new observational science will fit into the toolbox of modern astronomers. The active pursuit of imagining the future, working outside of the confines of today's vexing research problems, helps to illuminate the road ahead so the needs of the field can be addressed in advance of the time when progress will be hindered or facilitated by the nature and quality of the infrastructure supporting the community as a whole. This type of endeavor is typically known as *strategic planning*.

The attendees were asked to consider a time two decades in the future, when gravitational wave astronomy is an established (but perhaps still adolescent) observational science that regularly contributes to our view of the Universe as an active component of multi-messenger astronomy. To facilitate discussion and debate oriented toward considering the future of the field, six questions were posed:

- What will it mean to be a "gravitational wave astronomer"?
- What will be the interplay between gravitational wave astronomy and other, now conventional, forms of astronomy?
- What will be the interplay between instrumentation, observation, and science in the field?
- What will be the role of individual observatories vs. global networks?
- What will be the critical technologies used in gravitational wave detection?
- What infrastructure will best contribute to broad participation, community growth, and the best possible science?

After several days of open discussion and debate centered on these questions, several key findings emerged.

First, it is likely that in 20 years there may not be people who self-identify as "gravitational wave astronomers." Instead, practitioners will become either instrumentalists or astronomers who tap gravitational wave astronomy as one element in a suite of tools used to probe the Universe. Today, the growth of multi-messenger astronomy is evident from cross-communication between electromagnetic bands and astroparticle astronomy. In an era where gravitational wave observations and detections are routine, it is not unreasonable to expect that gravitational astronomy will simply be another element which strengthens our ability to probe high energy astrophysical systems as part of multi-messenger observing campaigns.

Data products and data access were discussed at great length. Currently gravitational wave astronomy is operating with data products in which instrumental noise and astrophysical signal strength are comparable at best, and data analysis efforts require the expertise of people intimately familiar with the detectors. In the future, as instrumentation evolves and sensitivity increases, this model of data control will become less desirable. Data products should become broadly available to the astronomical community as a constituent of the multi-spectrum information accessible for research efforts.

International collaborations will play an increasingly important role in the construction and operation of gravitational wave observatories. Large collaborations which span the globe already play a vital role in the community, as readily evidenced by the existing networks of bar detectors and the emerging network of interferometric observatories. These networks facilitate the growth of technology, the sharing of expertise, and increase the capacity to pursue fundamental and large scale science initiatives. International networks will only continue to grow in the future of gravitational wave astronomy.

Over the next two decades, it is desirable to see undergraduate and graduate astronomy curricula evolve to include observational gravitational wave science as part of the suite of tools available to the modern astronomer. This is not a suggestion to inundate astronomy curricula with deep courses in general relativity, but to establish a curriculum which encompasses the fundamental science which can be learned from gravitational wave observations. This finding has been summarized by the mantra "Less $G_{\mu\nu}$, more Rybicki & Lightman!"

Lastly, attention needs to be paid to Research and Development and budgets established to support emerging technologies. An agreed upon rule of thumb for R&D budgets in growing astronomical fields is $5 - 10\%$ of the total budgetary support in the field; estimates at the workshop suggested gravitational wave astronomy currently expends on order of $1 - 2\%$. Critical technologies which should bear scrutiny as we advance toward regular gravitational wave observations of the Universe are high power and high stability lasers, quantum non-demolition techniques, development of advanced materials, and computation and data analysis infrastructure.

A white paper summarizing the key findings and open debates left by the conference is in preparation, and will be posted to `arxiv.org` when it is completed. The program of the conference and the talks which were presented to encourage discussion have been posted online at the Center for Gravitational Wave Physics at Penn State, linked at http://cgwp.gravity.psu.edu/events/GWA/.

It was intended that this workshop would be only the first of many such discussions the community will have with itself over the next decade. We strongly encourage everyone to consider these initial findings and whether they agree or disagree with them, to carry on the discussions and debates with your colleagues and groups at your home institutions, and to participate in future strategic planning events like this.

VI Mexican School on Gravitation and Mathematical Physics

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The Division of Gravitation and Mathematical Physics of the Mexican Physical Society organized its VI school, November 21-28th, near Playa del Carmen, in the Mexican Riviera. These schools take place every other year and are focused on a special topic. This year the school was named "Approaches to Quantum Gravity". The setting was specially welcoming, being an all inclusive resort that allowed the participants to fully enjoy the amenities of the hotel (and the beach), while focusing on the scientific program of the school.

The idea of the organizers was to have top class representatives from at least three approaches to quantum gravity deliver lectures for graduate students and non-experts. The overall opinion is that the goal was achieved and the school was rather successful. There were about 100 participant in total, with about half of them students from both Mexico and abroad.

The speakers were chosen to cover the two main approaches to quantum gravity, namely string theory and loop quantum gravity, as well as other approaches and related subjects. On the stringy side the courses were delivered by R. Kallosh and A. Peet, together with plenary talks by A. Guijosa and E. Caceres. On the loop side, the invited speakers for the courses were A. Ashtekar and C. Rovelli. Ashtekar had to cancel at the last minute so he was replaced by the author, M. Bojowald and L. Smolin. There were also plenary talks by M. Bojowald, A. Perez and L. Smolin, on loop related issues. On the 'other approaches category' there was a course on time-space non-commutativity by A.P. Balachandran and a course on selected classical topics by P. Chrusciel. The list of distinguished plenary speakers also included J. Barrow, A. Linde and R. Wald, who spoke on variable fundamental constants, inflationary cosmology and QFT on curved space, respectively.

String Theory was very well represented by R. Kallosh and A. Peet who delivered set of lectures on "De Sitter vacua and the String Landscape" (Kallosh) and "Black Holes in String Theory" (Peet). They gave a very though overview of recent research results and the cutting edge research on the subject. R. Kallosh first motivated the need for a theoretical explanation for the value of the positive cosmological constant observed. She then described a recent model she has been working on that involves choosing certain vacua from the string landscape, that is, from the very large set of possible vacua for the theory. Kallosh also described recent work on black holes and the search for the fundamental degrees of freedom of the theory. The set of lectures delivered by A. Peet were particularly illuminating. She described the basics of string theory, with some clarifications that answer some common misconceptions outsiders sometimes have. She described in detail the D-brane approach to BH entropy, AdS-CFT correspondence and the newly discovered fuzzball solutions. She ended the set of lectures with an inspiring challenge for the participants of the school.

On the loop side of the school, the author introduced the basics of loop quantum geometry, Bojowald applied the formalism to cosmological solutions, arriving at the so called loop quantum cosmology, and Smolin described the challenges and possible resolutions for the dynamics of the theory. C. Rovelli gave a very nice set of lectures on the white-board, motivating and building loop quantum gravity from scratch. The courses were complemented by lectures on black holes, spin foams and phenomenological aspects of loop quantum cosmology.

The day before the school ended, R. Wald moderated a discussion panel where the theme was Strings *vs.* Loops. The discussion was polite but lively, and questions like "what are fundamental degrees of freedom in string theory?" and "how does one make sense of spatially smeared operators in LQG?" were discussed. The general agreement was that the discussion was very civil, but there was not enough time to discuss some more controversial issues.

The school ended by an inspiring lecture by Lee Smolin who discussed various possible experimental indications for the need of a quantum theory of gravity and a new length scale as a fundamental entity. For more information on the program of the School see
http://www.nuclecu.unam.mx/~gravit/EscuelaVI.