MATTERS OF GRAVITY

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

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Contents

Editor

Jorge Pullin

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

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Editorial

Not much to report here. Just to remind people that the year 2005 is the "year of physics" commemorating Einstein's remarkable year of 1905. The Topical Group has set up a committee chaired by Richard Price to coordinate activities. There is a worldwide site http://www.physics2005.org. I want to encourage the readership to suggest topics for articles in MOG. In the last few issues articles were solicited by myself. This is not good for keeping the newsletter balanced. Either contact the relevant correspondent or me directly.

The next newsletter is due February 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 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 of Matters of Gravity

- 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
- 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: John Friedman; Chair-Elect: Jim Isenberg; Vice-Chair: Jorge Pullin; Secretary-Treasurer: Patrick Brady; Past Chair: Richard Price; Members at Large: Bernd Bruegmann, Don Marolf, Gary Horowitz, Eric Adelberger, Ted Jacobson, Jennie Traschen.

We hear that...

Jorge Pullin, Louisiana State University pullin@phys.lsu.edu

Saul Teukolsky was elected to the National Academy of sciences.

Bill Unruh was elected to the American Academy of Arts and Sciences.

Yvonne Choquet-Bruhat and Jimmy York were awarded the Dannie Heinemann prize of the American Physical Society.

Hearty congratulations!

Update on a busy year for LIGO

Stan Whitcomb, LIGO-Caltech, on behalf of the LIGO Scientific Collaboration
whitcomb_s@ligo.caltech.edu

2003 marks another important year for LIGO as it continues the transition from construction and commissioning to full science data-taking. The first papers describing searches for gravitational waves using data from the first Science Run between the LIGO and GEO detectors are being submitted, a second Science Run has been accomplished with an order of magnitude improvement in sensitivity, commissioning activities to bring the detectors to their design performance are making good progress, and planning for an even more sensitive set of detectors ("Advanced LIGO") is well underway.

Results from LIGO's first Science Run

The first LIGO science run [1], S1, spanned a period of 17 days in August and September 2002; the GEO-600 interferometer also operated during S1. The three LIGO detectors were operating with a noise level about a factor of 100 above the design level, so the probability of detecting any gravitational waves, particularly in such a short run were extremely small. However, the upper limits which could be set from these observations on different types of gravitational waves are typically as good or better than previous direct observational limits.

The LIGO Scientific Collaboration has taken the leadership in analyzing the S1 data, forming four data analysis working groups, each aimed at a particular type of gravitational wave signal. One working group focused on searching for gravitational waves from the inspiral of binary neutron stars. A second one searched for the nearly sinusoidal waves from a millisecond pulsar (J1939+2134). The third one searched for a stochastic background of gravitational waves, while the fourth looked for poorly modeled burst-type sources such as supernovae or GRBs.

In the previous issue of MOG [2], Gary Sanders gave a description of preliminary results from S1, using both LIGO and GEO-600 data. These results have been refined, and four papers, one for each analysis, are in the final stages of preparation prior to submission. The performance parameters of the LIGO and GEO-600 detectors during S1, including their configurations, plots of sensitivity, and tables giving the fraction of time that each detector was operational, are given in a fifth paper. Preprints of these papers are being made available [links at reference 3] as they are approved by the LIGO Scientific Collaboration. The publication of these papers marks a real milestone in LIGO's evolution.

The second Science Run

S1 was the first in a series of progressively more sensitive science runs, interleaved with interferometer commissioning. The second Science Run, S2, took place from February 14 to April 14, 2003. The interferometers showed good reliability for this stage in their development. The duty cycle for the interferometers, defined as the fraction of the total run time when the interferometer was locked and in its low noise configuration, ranged between 37% (for the Livingston interferometer) and 74% (for the Hanford 4 km interferometer). Building on the lessons learned from S1, procedures were put in place to better monitor the performance and the result was better stability of the performance.

Most important, S2 sensitivity was improved by more than an order of magnitude over S1. Typical noise levels for S2 were about a factor of 10 better than in S1 with the 4km interferometer at Livingston having the greatest sensitivity, followed by the 4 km interferometer at Hanford. The increase sensitivity represents the first time the LIGO detectors have had the sensitivity to see potential sources in other galaxies, most notably the Andromeda galaxy. Once again, LIGO would not be expected to see gravitational waves at this level, but it still represents a significant step toward design sensitivity.

The S2 run also involved coincident running with the TAMA-300 detector, following the signing of a new LIGO-TAMA Memorandum of Understanding.

Commissioning progress

Since the end of S2, the commissioning team has been hard at work to complete an ambitious set of improvements and "fixes" to the interferometers at both sites.

At both sites, there have been changes inside the vacuum system. Minor changes to the positions of optics have been made to made to adjust cavity lengths closer to their design values. At Hanford, the input test mass on one arm was replaced because of a lossy AR coating. Baffles have been installed to prevent errant high power laser beams from damaging suspension wires on the input optics.

A number of changes have been made to reduce the coupling of acoustic noise to the interferometers. Steps have been taken to reduce the amount of acoustic noise generated by the air conditioning system and by fans in the electronics racks. Acoustic enclosures have been purchased to surround the most sensitive optical tables. Larger aperture optics and mounts have been installed on the optical tables at the outputs of the interferometer.

The commissioning of the wavefront-sensing alignment systems have been a high priority at both sites. This system was operating to control 8 of 10 angular degrees of freedom on the 4km interferometer at Hanford during S2, and demonstrated how much more stability could be achieved. Good progress has been made on both all interferometers.

As a result of the various changes, the 4 km interferometer at Hanford has achieved its highest sensitivity yet, a range for binary neutron star inspirals of 1.5 Mpc.

Future plans

Two major activities loom on the near-term horizon for LIGO: the third Science Run (S3) and an upgrade to the Seismic Isolation System at the LIGO Livingston Observatory (LLO).

S3 is scheduled for approximately two months in November and December 2003. The commissioning progress described in the previous section should provide a significant sensitivity improvement over S2, though perhaps not as great as the jump between S1 and S2. The more complete implementation of the wavefront-sensing alignment system should give better stability and move the analysis closer to what is expected in full operation.

Immediately after S3, we plan to install an upgrade to the Seismic Isolation System at LLO. Since the beginning of commissioning, the interferometer at LLO has suffered from higher than expected seismic noise due to anthropogenic sources. These large motions occur at low frequencies and often exceeded the ability of the control systems to cope with them. As a result, the duty cycle of the LLO interferometer has been lower than specified. The upgrade consists of active vibration isolation systems installed outside the vacuum system to cope with ground motions in the 0.1-10 Hz range. It has been under development for the past 18 months, initially aimed at Advanced LIGO, but once it was determined that it could help the situation at LLO, its development was accelerated. Hardware is expected to be ready for installation in very early 2004.

Advanced LIGO

The LIGO Laboratory, with strong support from the LIGO Scientific Collaboration, submitted its proposal to the NSF in March, 2003 for Advanced LIGO. The proposed system consists of three nominally identical interferometers – two 4km systems at Hanford, and one at Livingston, and each are tunable through variations of the input power and the signal recycling mirror position. The increase in sensitivity is greater than a factor of 10 over initial LIGO, and also the potential for observation a factor of 4 lower in frequency. The result is that it is anticipated that one will be able to see e.g., 1.4 solar mass neutron star binary inspiral signals to roughly 350 Mpc (for the 3 interferometer detector system), or greater than a factor of 15 further than initial LIGO for this source. This new detector, to be installed at the LIGO Observatories, will replace the present detector once it has reached its goal of a year of observation, with the planning date for first observations presently at 2010. The improvement of sensitivity will allow the one-year planned observation time of initial LIGO to be equaled in just several hours.

The new design involves a complete replacement of the initial detector. The laser power is increased from 10 W to 180 W, to improve the shot-noise limited sensitivity of the instrument – this will be a contribution from the Hannover GEO colleagues. Prototypes have demonstrated over 100 W to date. The input optics, under the leadership of the University of Florida LIGO group, will resemble the initial LIGO design but improved to handle the higher power. The test masses will be made of sapphire, 40 kg in mass to resist the photon pressure fluctuations, and with coatings which must be low optical loss and low mechanical loss (to keep thermal noise low). Sapphire 'pathfinder' pieces of the final size have been fabricated, and show excellent mechanical properties. The test mass suspensions, contributed by our Glasgow GEO colleagues, resemble the GEO 600 design with a final stage using fused silica fibers, again for low thermal noise. The seismic isolation design comes from LSU and Stanford, and uses high-gain servo systems to deliver very low motion in as well as below the gravitational wave band – the low-frequency noise of the interferometer at low power will be limited by the Newtonian background from gravitational gradients. Aspects of the design have been tested in various prototypes, and a complete prototype is in test at Stanford at this time. These mechanical aspects of the design will be tested together at the MIT LASTI full-scale test facility. The gravitational readout system will use a form of DC sensing, moving slightly away from the dark fringe of the interferometer output port, and will make use of the innovations from table-top and suspended signal-recycled interferometer tests made in Australia, Florida, Glasgow, Garching, and Caltech; a complete engineering test of the readout and control system is in development at the 40m Lab at Caltech.

A review of the proposal was held by the NSF in June, and the feedback was quite positive. The materials for the review can be found at http://www.ligo.caltech.edu/advLIGO/, and can serve as a resource for further information. We are excited by the kind of leap forward this instrument should give to the field, and hope that it will be observing in concert with other instruments that can be operating at that time – a second generation VIRGO, and a cryogenically-cooled underground system in Japan as examples. When will it be another ordinary day when a few more gravitational waves sources are logged? We hope around 2010!

LIGO is funded by the US National Science Foundation under Cooperative Agreement PHY-0107417. This work is a collaborative effort of the Laser Interferometer Gravitational-wave Observatory and the institutions of the LIGO Scientific Collaboration. LIGO T030185-00-D.

More information about LIGO can be found at: http://www.ligo.caltech.edu.

References:

[1] MOG article describing S1 performance:

http://www.phys.lsu.edu/mog/mog20/node10.html

[2] MOG article describing S1 results:

http://www.phys.lsu.edu/mog/mog21/node10.html

[3] S1 paper links:

http://www.ligo.caltech.edu/LIGO_web/s1/

First year results from the Wilkinson Microwave Anisotropy Probe (WMAP)

Rachel Bean, Princeton Collaboration rbean@astro.princeton.edu

The cosmic microwave background (CMB), along with the distribution of large scale structure, has become one of the principal tools for deciphering the cosmological content and history of the universe. The WMAP satellite, launched on June 30, 2001, completed its first full year of measurements of the CMB in August 2002, with the data analyzed and published earlier this year. This article presents a brief summary of the approach and key findings from the mission's first results. For further details see [1] and the 12 companion papers referred to within it, in particular this article focuses on the cosmological parameters extracted from the data discussed in [2].

For those not familiar with the CMB, it is comprised of photons that interacted strongly with the plasma of free electrons and baryonic ions in the early universe. At this time the photon mean free path was short and the universe was effectively opaque. As the universe expanded and subsequently cooled below 3000K, 380,000 years after the Big Bang, electrons recombined with nuclei and fewer charged particles were present to interact with the CMB photons, the photons 'decoupled' from the rest of the matter and the universe became transparent. The distribution of temperature and polarization fluctuations that we measure today in the CMB are therefore effectively those imprinted at the epoch of recombination,"the decoupling surface".

Within the last decade, starting with the results from COBE [3], a plethora of experiments have measured the anisotropy in the fluctuations in the CMB temperature. Together they have incontrovertibly detected the first acoustic peak of oscillations in the CMB power spectrum. This peak arises from oscillations in the coupled photon- baryon fluid just prior to when photons decoupled and is direct experimental support for the CMB being decoupled photons and for the standard recombination model. In addition, last year, there was the first detection of anisotropy in the polarization of the CMB [4].

WMAP was created with the aim of extending on previous observations in two main ways: to make a map of the full sky, and to measure the CMB with much improved precision by minimizing systematic errors. The precision is obtained through measuring the CMB over five frequency bands, which allow external contaminants such as dust and point sources to be removed more efficiently. WMAP observes the sky convolved with the beam pattern (the "window function") of the detectors. Imperfect knowledge of the window function is one of the main internal systematics and therefore minimizing this uncertainty by accurate in-flight determination of the beam patterns has also been a key factor in achieving WMAP's precision. Figure 1 shows the improved resolution of the WMAP results in comparison to the only previous full sky map, that of COBE. Also shown is the power spectrum of fluctuations measured by WMAP for temperature-temperature "TT" and temperature-polarization "TE" correlations , in multipoles, l, from spherical harmonic decomposition of the sky,.

One of the key applications of the WMAP data is to constrain cosmological models. A 'standard' model has established itself over the last few decades, consistent with observations

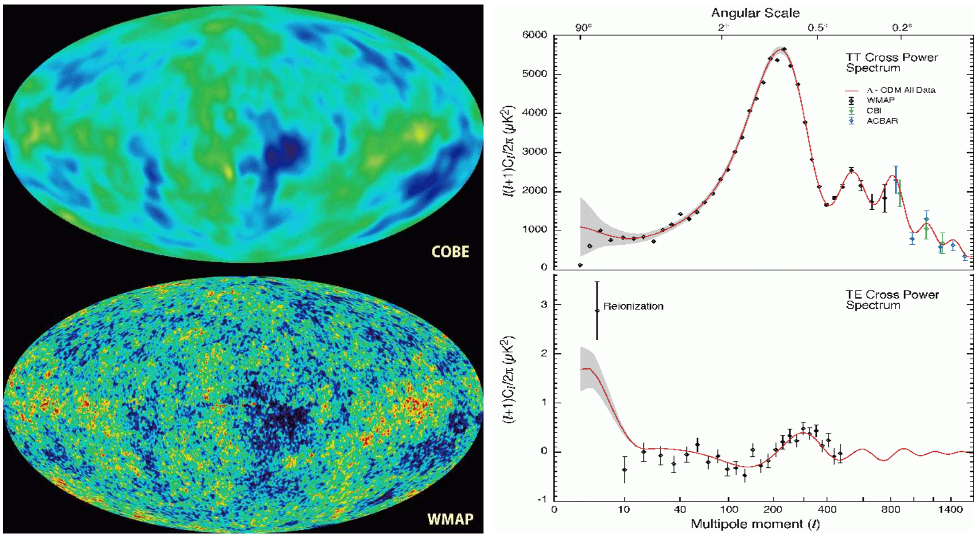

Figure 1: Left panel: An all-sky image of the Universe 380,000 years after the Big Bang. In 1992, NASA's COBE mission first detected tiny temperature fluctuations (shown as color variations) in the infant universe. The WMAP's improved resolution brings the COBE picture into sharper focus. Right panel: The "angular spectrum" of the fluctuations in the WMAP full-sky map. The top curve shows the power spectrum for the temperature fluctuations, while the lower curve shows the cross correlation of temperature with polarization. In each figure the best fit cosmological model is shown in red for the 'standard' scenario discussed in the text. The grey region shows the 'cosmic variance', the inherent statistical uncertainty in the measurements arising from the simple fact that we can only ever measure one sky.

from galactic scales to the largest scales observable, in which the universe is spatially flat, and homogeneous and isotropic on large scales, and comprises radiation, normal matter (electrons, baryons, neutrinos), non-baryonic cold, dark matter, and dark energy.

In addition to the matter constituents, WMAP also tests several important predictions of the inflationary scenario. Inflation predicts that the universe is spatially flat and that fluctuations in radiation and matter energy density are Gaussian with a nearly scale invariant spectrum, $n_s \approx 1$.

WMAP is a critical test of these models, and finds them in good agreement with the data. Under the assumption of flatness the CMB can constrain a range of parameters on its own: the Hubble constant, $H_0 = 100\ h$ km/s/Mpc, is found to be $h = 0.72 \pm 0.05$ (all error bars are at the 68% level), the universe is found to have an age of 13.4 ± 0.03 Gyr. For a measure of the dark matter density today, as a fraction of the critical density (to give flat spatial curvature) Ω_m, WMAP finds $\Omega_m h^2 = 0.14 \pm 0.02$, and similarly for the fractional baryon density $\Omega_b h^2 = 0.024 \pm 0.001$, this latter one in good agreement with constraints from nucleosynthesis. The optical depth to the decoupling surface, τ, determined by the history of recombination and re-ionization, is also constrained although it is highly degenerate with the spectral tilt, n_s. WMAP has made the first measurements of CMB polarization that can be used as an independent measurement of τ and seems to give the strongest evidence yet for an epoch of re-ionization. With TT and TE data combined WMAP finds, $\tau = 0.166^{+0.076}_{-0.071}$ and $n_s = 0.99 \pm 0.04$. The value of τ signals that re-ionization occurred earlier than previously expected, at around a redshift of 17 ± 5. Early re-ionization implies that structure was forming at these redshifts providing evidence against the presence of significant warm dark matter which would suppress structure formation until much later times.

A spectral index close to unity is one finding that is consistent with inflation. In addition to this WMAP also finds that the fluctuations are entirely consistent with Gaussianity, and have placed the tightest constraints yet on the level of non-Gaussianity within the primordial spectrum. Testing the inflationary prediction of flatness is made difficult by the presence of a geometrical degeneracy between the fractional energy densities of spatial curvature and dark energy. A determination of the spatial curvature and dark energy contributions can only be obtained by breaking this degeneracy through the inclusion of independent data sets such as the HST Key Project measurement of $h = 0.72 \pm 0.05$ [5]. The data then shows a strong preference for flatness ($\Omega_{tot} = 1$) finding $\Omega_{tot} = 1.02 \pm 0.02$. In combination with complementary data sets, the WMAP data implies that the universe today is made up of 73% dark energy, 22% dark matter and 4.4% baryons.

The standard models described above employ the smallest number of parameters to fit the data, however the CMB in combination with external data sets can be used to probe beyond these to more exotic models. One good example of this is the placing of constraints on the equation of state of dark energy, w; the additional inclusion of supernovae observations indicates $w < -0.78$, and is entirely consistent with the presence of a cosmological constant Λ which has $w = -1$. WMAP, in combination with the 2dF galaxy [6] and Lyman α [7] power spectra, tends to favor a varying spectral tilt i.e. $\mathrm{d}n_s/\mathrm{dln}\,k \neq 0$. This variation is a prediction of inflation but further analysis and data will help to ascertain if the effect really is arising from subtleties of the primordial spectrum.

WMAP continues to collect data and its planned operation is for at least 4 years. It is hoped that this will lead to even better understanding of systematics, better resolution at smaller scales and improved measurement of the polarization. We are looking forward to an exciting era in cosmology promising the elucidation of the matter content and ionization history of the universe as well as a clearer understanding of the inflationary epoch.

References:

[1] Bennett, C. et al., accepted by ApJ, astro-ph/0302208.

[2] Spergel, D. et al., accepted by ApJ, astro-ph/0302209.

[3] Bennett, C. et al., ApJ, **396**, (1992) L7.

[4] Kovac, J. et al., Nature **420** (2002) 772.

[5] Freedman, W. L. et al., ApJ **553** (2001) 47.

[6] Percival, W. J. et al., MNRAS **327** (2001) 1297.

[7] Croft, R. A. C. et al., ApJ **581** (2002) 20; Gnedin N. Y. et al., MNRAS **334** (2002) 107.

Short-Range Searches for Non-Newtonian Gravity

Michael C. M. Varney, Univ. Colorado, Boulder
Joshua C. Long, Los Alamos Neutron Science Center Collaboration
Michael.Varney@colorado.edu, josh.long@lanl.gov

In 1667, Isaac Newton proposed his famous universal law of gravity:

$$F = -\frac{Gm_1 m_2}{r^2}, \tag{1}$$

where F is the force between test masses m_1 and m_2, r is their separation, and G is the gravitational constant. But how universal is this law? Tests of Newtonian gravity and searches for new macroscopic forces have covered length scales from light-years to nanometers, and it has been found that new forces of gravitational strength can be excluded for ranges from 200 microns to nearly a light-year [1,2]. Limits on new forces become poor very rapidly below 100 microns.

During the last 5-7 years there has been a surge of interest in testing Newtonian gravity at sub-millimeter scales, based on many specific theoretical predictions of modifications to gravity in this regime. Most notable are possible signatures of "large" extra dimensions which could modify gravity directly below the millimeter range [3]. Additional sub-millimeter effects of gravitational strength and substantially stronger are predicted to arise as a consequence of new particles propagating in the extra dimensions [4]. In older string theory-inspired models with low-energy supersymmetry breaking, massive scalar particles including moduli and dilatons are predicted to mediate new short-range forces [5] Other predictions arise in models attempting to explain the observed smallness of the cosmological constant [6].

These developments have motivated a variety of novel table-top experiments, and there has been substantial progress in improving the limits on non-Newtonian effects over the past three years. Experimental results are usually parameterized with the Yukawa interaction. The potential due to gravity plus an additional Yukawa force is given by:

$$V = -\frac{Gm_1 m_2}{r}[1 + \alpha \exp(-r/\lambda)], \tag{2}$$

where α is the strength of a possible new interaction relative to standard gravity and λ is the range. The experiments cover a range of about seven orders of magnitude, from a few nanometers to a few centimeters, use a variety of techniques and confront different backgrounds. The authors thought it would be useful to attempt a short summary of the progress and prospects of tests for new short-range forces, covering a broad range of the recent small experiments. For more detailed reviews of various subsets of the experiments, see Refs. [7, 13, 20].

Low Frequency Experiments: The sensitive and linear response of the torsion balance has made it the instrument of choice for laboratory gravity measurements. Low frequency operation makes for low thermal noise, but presents challenges for vibration isolation which is also important for attaining small test mass separations.

1. Eric Adelberger at the University of Washington, along with Blayne Heckel and graduate students Dan Kapner and C. D. Hoyle (now at U. Trento, Italy), operated an exquisitely

designed “missing mass” torsional pendulum experiment. This experiment provides the limits $\alpha = 10$ at $\lambda = 100$ microns to $\alpha = 10^{-2}$ at $\lambda = 3$ mm, which are the best currently published in that range [2]. The force-sensitive pendulum mass consisted of a 1 mm thick aluminum annulus with an array of 10 equally spaced holes. The source mass was a stack of two copper disks, each a few millimeters thick, with similar arrays of holes and which rotated approximately once every two hours. The source mass torqued the pendulum 10 times per revolution allowing easy discrimination from vibrations associated with the source drive. The source mass and detector pendulum were separated by a 20 micron thick beryllium copper stretched membrane, with a total test mass separation of 197 microns.

Current efforts are underway to allow increased sensitivity and closer test mass separation [2,7]. To facilitate this, a new design utilizing a higher density ring and attractor (copper and molybdenum, respectively) with 22 fold symmetry has been constructed. Noise has been improved by a factor of six over the previous experiment, and a passive “bounce-mode” damper has been employed, allowing test mass separation to be reduced by a factor of 2. This new experiment should be able to probe gravitational strength forces down to 60 microns.

2. The best limits in the range from 3 mm ($\alpha = 10^{-2}$) to 3 cm ($\alpha = 10^{-4}$) still derive from the null-geometry torsion balance experiment of R. Newman and colleagues at the University of California at Irvine [8]. Torque sensitivity was limited by tilt errors and other important systematics included magnetic and seismic effects. Recently, the Irvine group, in collaboration with P. Boynton of the University of Washington, has constructed a torsion pendulum designed to operate at ~ 2 K in a seismically quiet underground site at Hanford [9]. The low temperature allows operation of the pendulum in the tilt-insensitive frequency mode [10], and for superconducting shielding to reduce magnetic backgrounds. The experiment, when operated as a test of the inverse square law (a precision measurement of G is planned first), will be most sensitive to new forces at a range of about 15 cm and in the thermal noise limit is expected to achieve a sensitivity at least two orders of magnitude greater than previous experiments at that range.

3. Ho Jung Paik along with M. Vol Moody and colleagues at the University of Maryland are prototyping the cryogenic ISLES (Inverse Square Law Experiment in Space) project, to be conducted on the International Space Station [11]. In this experiment, two superconducting magnetically levitated niobium test disks are suspended 100 microns on either side of a radially mounted tantalum source disk with thin superconducting shields in between to suppress electromagnetic couplings. The source is nominally 140 mm in diameter and 2 mm thick. The planar geometry permits concentration of as much mass as possible at the short range to be explored, and represents a nearly null geometry for Newtonian background forces. The differential acceleration of the test masses is measured as the source is driven magnetically into small oscillations along its axis at about 0.2 Hz, using a SQUID readout similar to the instrumentation developed for the Maryland superconducting gravity gradiometer. The projected sensitivity, ranging from $\alpha = 10$ at $\lambda = 5$ microns to $\alpha = 10^{-5}$ at 200 microns, is up to 7 orders of magnitude stronger than current limits in this range. This sensitivity is also sufficient to further constrain (or possibly detect) the axion, a light pseudoscalar proposed as a solution to the strong CP problem of QCD.

The low-g environment of the ISS is essential for the magnetic suspension of the test masses, which in turn provides the extremely soft vibration isolation partly responsible for the impressive sensitivity. A further improvement of up to three orders of magnitude might be possible in a free-flyer version of the experiment. Mechanical suspension will be used in the ground-based prototype currently under construction, reducing the projected sensitivity by up to two orders of magnitude relative to the ISS version.

High-Frequency Experiments: Recent experiments designed to operate in the range of a few hundred to a thousand Hz show promise to operate at the thermal noise limit and to attain extremely small test mass separations.

4. Early this year, the authors and their advisor John Price at the University of Colorado published results from their high frequency experiment, giving the current best limits between 20 and 100 microns [12]. Forces greater than 10^4 times gravity at 20 microns and greater than 10 times gravity at 100 microns were excluded.

The apparatus uses a nominally null planar geometry and operates at room temperature under a vacuum of $\sim 10^{-7}$ torr to reduce acoustic backgrounds. A 35 mm $\times$ 7 mm $\times$ 0.305 mm tungsten "diving board" cantilever is driven at the resonant frequency ($\sim$ 1 kHz) of a high-Q ($\sim$ 25500) compound torsional tungsten detector oscillator. The test masses are separated by a 0.06 mm thick gold plated sapphire shield to suppress electrostatic and acoustic backgrounds. The amplitude of the detector mass is read via a capacitive transducer. Measurements were taken at a test mass separation of 108 microns with a test mass overlap area of about 58 mm^2, and were found to be thermal-noise limited.

Recently, the system has been redesigned to make use of a 10 micron thick gold plated copper stretched membrane as an electrostatic shield. This will allow for mass separations of about 50 microns, with the goal of improving the limits at that range by at least an order of magnitude [13]. Possible plans for the future include a 4.2 K version of the experiment, higher Q tungsten detectors, and improved flatness of the test masses.

5. Aharon Kapitulnik's group at Stanford recently published results from their high frequency cryogenic experiment [14]. This experiment utilized a silicon nitride microcantilever with a 50 micron gold cube mounted on its free end as a high Q detector. A planar source mass, consisting of alternating gold and silicon strips, was driven in the direction transverse to the cantilever mode of the detector. The alternating strip design permitted the source to be driven at a frequency below the cantilever resonance, reducing the burden on vibration isolation. Detector mass amplitude was read via an optical fiber. Operating at 10 K, the system obtained a sensitivity of around 8.9×10^{-17} N at a 25 micron source/test mass gap.

A spurious signal, most likely electrostatic in nature, limited the sensitivity of their apparatus. As the phase of this signal was not consistent with a new non-Newtonian force, the results were used to derive limits $\alpha = 10^9$ at $\lambda = 3$ microns to $\alpha = 10^5$ at $\lambda = 10$ microns, the most sensitive in that range. The experiment was designed to be a "null" experiment limited by thermal noise with a predicted sensitivity about an order of magnitude below that of the published results. Re-design of the source mass to remedy the background is in progress.

6. S. Schiller, L. Haiberger and colleagues at the University of Dusseldorf have constructed a room temperature prototype of a high frequency experiment of great potential sensitivity. The detector mass consists of a high purity silicon wafer similar in shape and size to that of the Colorado experiment. The use of silicon is expected to lead to very high Qs, especially in a planned cryogenic version of the experiment. The source mass consists of a variable-

density rotor with a harmonic corresponding to the resonance frequency ($\sim$ 5 kHz) of the detector mass. The source and detector mass are mounted vertically and are separated by a conducting plate serving as an electrostatic shield. Detector oscillations are read out via an optical system.

Recent measurements yielded signals about 10 times the detector thermal noise level, corresponding to a sensitivity ranging from about $\alpha = 10^9$ at $\lambda = 60$ microns to $\alpha = 5000$ at $\lambda = 5$ mm [15]. Improvements to the vibration isolation and thermal stability are under way. The cryogenic experiment is anticipated to reach gravitational sensitivity at 50 microns.

Casimir Force Measurements: For test mass separations below about 10 microns, the Casimir effect, a force which arises between conductors due to zero-point fluctuations of the electromagnetic field, becomes significant. While of experimental interest in its own right, the Casimir force presents a dominant background to experimental searches for new effects at very short ranges, and must either be precisely characterized or suppressed (or both) if these experiments are to attain greater sensitivity.

7. Umar Mohideen and his group at the University of California at Riverside have continued to refine their precision measurements of the Casimir force using AFM techniques. In a recent experiment, a 200 micron diameter gold-plated sphere was attached to an AFM cantilever and suspended above a gold-plated sapphire disk [18] Deflection of the cantilever under the influence of the plate-sphere force was monitored optically, for plate-sphere separations ranging from 0 to 400 nm. While the absolute force errors were slightly larger than for previous measurements, the use of denser test masses led to the strongest constraints yet attained in the range considered ($\alpha = 10^{19}$ at $\lambda = 20$ nm to $\alpha = 10^{14}$ at 100 nm) when the results were compared with theory.

More recently this group has used similar apparatus to measure the lateral Casimir force between a gold-plated sphere and a sinusoidally corrugated gold surface [19]. Good agreement with theory was obtained, though the constraints on new effects are less sensitive. Work continues on third-generation Casimir force experiments with improved precision.

8. V. Mostepanenko's collaboration with Riverside is part of a more general program in which he and his and colleagues have continued to derive constraints on new physics by comparing Casimir force measurements with the most sophisticated theoretical models. Much of their recent work is summarized in a comprehensive review [20]. They have also collaborated with E. Fischbach's group [see below] in deriving constraints in the very short range just above 1 nm [21]. In this regime, the most sensitive limits ($\alpha \approx 10^{25}$) come from a recent Casimir force measurement by Ederth using crossed cylinders [22].

9. A group from the INFN, Padova and Pavia, and the University of Padova run an experiment that is an interesting hybrid of high frequency cantilever and direct Casimir measurement. The force-sensitive detector is a 47 micron thick, 2 cm long silicon cantilever with a 50 nm thick chromium plating. It is driven electrically at its lowest order resonance mode of 138 Hz. The source mass is a 5 mm thick chromium-plated silicon block which is brought to within less than a micron of the detector surface. By optically monitoring the detector resonant frequency shifts induced by the static external force gradient, the group was able to obtain a measurement of the Casimir force to a precision of 15%, the first measurement of this effect for the parallel-plate geometry [16]. Limits on new effects derived from this experiment are

not quite competitive with the most stringent constraints in the relevant range near 1 micron, but an optimized version of this experiment under construction is expected to improve these limits by at least an order of magnitude [17].

10. Ephraim Fischbach and colleagues at Purdue University including Dennis Krause (also at Wabash College) are pursuing experimental and theoretical programs to control the Casimir background in short-range experiments. Sub-micron measurements of the differences in forces between different isotopes of the same element are underway. These are expected be sensitive to new short-range effects as the Casimir force should be dominated by the electronic properties of the test masses and essentially independent of isotope (iso-electronic effect).

In a recent theoretical study [23], this group has quantified the isotopic dependence of the Casimir force, and estimated the fractional difference in Casimir forces between two isotopes of the same element to be on the order of 10^{-4}. This is roughly two orders of magnitude below the resolution of recent Casimir force measurements, lending confidence to the prospect that differences observed in iso-electronic experiments will be due to other effects.

An initial experiment (designed primarily to investigate gross systematics and sample fabrication) used an AFM to measure the forces on a silicon nitride cantilever suspended a few nm above a surface consisting of alternating regions of gold and copper [24] (These metals have very similar electronic properties but different densities.) Results from these measurements were used to set limits of $\alpha \approx 10^{27}$ in the range $\lambda =$ 1-2 nm, slightly more sensitive than the previous limits in that range.

More recently this group has reported the first precise measurement of the Casimir Force between dissimilar metals [25]. This experiment used a more sensitive microelectromechanical apparatus, in which a 600 micron diameter gold-plated sphere was suspended above one side of a .25 mm^2 copper-coated torsional plate. Forces were measured as a function of plate-sphere separations from about 200 to 1200 nm, by observing both the static deflection of the plate and the change in its resonant frequency as it was driven into small oscillations. Comparison of these measurements with a detailed theoretical model leads to the limit of $\alpha \approx 10^{13}$ at $\lambda =$ 200 nm, about a factor of 4 improvement over the previous limit at that range. These results are based on an observed systematic difference between theory and experiment. The group suspects this is based on the imprecise characterization of the optical properties of the metals, and emphasizes the need for better measurements of these properties and better theoretical understanding of the Casimir force for non-ideal objects. Plans to improve the limits by comparing the force on the sphere to two isotopes of the same element are also underway.

In summary, the authors are aware of at least 10 active programs pursuing short range experiments with implications for non-Newtonian gravity. Over the next few years, prospects are good for improving the limits on new effects by several orders of magnitude in the range from nanometers to centimeters. The authors wish to thank all researchers who replied to requests for the latest news.

References:

[1] Fischbach E., Talmadge C., *The Search for Non-Newtonian Gravity* (New York, Springer-Verlag, 1999) 62.

[2] Hoyle C. D., Schmidt U., Heckel B. R., Adelberger E. G., Gundlach J. H., Kapner D. J., Swanson H. E., Phys. Rev. Lett. 86 (2001) 1418; Adelberger E. G., arXiv hep-ex/0202008.

[3] Arkani-Hamed N., Dimopoulos S., Dvali G., Phys. Lett. B 429 (1998) 263; Randall L., Sundrum R., Phys. Rev. Lett. 83 (1999) 4690.

[4] Arkani-Hamed N., Dimopoulos S., Phys. Rev. D 65 (2002) 052003.

[5] Dimopoulos S., Giudice G., Phys. Lett. B 379 (1996) 105; Taylor T. R., Veneziano G., Phys. Lett. B 213 (1988) 450; Kaplan D. B., Wise M. B., J. High Energy Phys. 0008 (2000) 037.

[6] Sundrum R., J. High Energy Phys. 7 (1999) 1; Schmidhuber C., arXiv:hep-th/0207203.

[7] Adelberger E. G., Heckel B. R., Nelson A. E., arXiv hep-ph/0307284.

[8] Hoskins J. H., Newman R. D., Spero R., Schultz J., Phys. Rev. D 32 (1985) 3084.

[9] Newman R., Class. Quantum Grav. 18 (2001) 2407.

[10] Boynton P. E., Class. Quantum Grav. 17 (2000) 2319.

[11] Paik H. J., Moody M. V., Strayer D. M., Proceedings of the 2002 NASA/JPL Workshop on Fundamental Physics in Space (Dana Point, California, May 2002).

[12] Long J. C., Chan H. W., Churnside A. B., Gulbis E. A., Varney M. C. M., Price J. C., Nature 421, (2003) 922.

[13] Long J. C., Price J. C., C. R. Physique 4 (2003) 337.

[14] Chiaverini J., Smullin S. J., Geraci A. A., Weld D. M., Kapitulnik A., Phys. Rev. Lett. 90 (2003) 151101.

[15] Haiberger L., Weingram M., Wenz H., Schiller S., "An experiment to detect gravity at sub-mm scale with high Q mechanical oscillators," presented at the Tenth Marcel Grossmann Meeting on General Relativity, Rio de Janeiro, 2003.

[16] Bressi G., Carugno G., Onofrio R., Ruoso G., Phys. Rev. Lett. 88 (2002) 041804.

[17] Bressi G., Carugno G., Galvani A., Onofrio R., Ruoso G., Veronese F., Class. Quantum Grav. 18 (2001)

[18] Harris B. W., Chen F., Mohideen U., Phys. Rev. A 62 (2000) 052109

[19] Chen F., Mohideen U., Klimchitskaya G. L., Mostepanenko V. M., Phys. Rev. A 66 (2002) 032113

[20] Bordag M., Mohideen U., Mostepanenko V. M., Phys. Rept. 353 (2001) 1.

[21] Fischbach E., Krause D. E., Mostepanenko V. M., Novello M., Phys. Rev. D 64 (2001) 075010.

[22] Ederth T., Phys. Rev. A 62 (2000) 062104

[23] Krause D. E., Fischbach E., Phys. Rev. Lett. 89 (2002) 190406

[24] Fischbach E. et al., Class. Quantum Grav. 18 (2001) 2427

[25] Decca R. S., Lopez D., Fischbach E., Krause D. E., Phys. Rev. Lett. 91 (2003) 050402

Xth Brazilian School of cosmology and gravitation

Mario Novello, CBPF, Rio de Janeiro novello@cbpf.br

In 2002, during the Xth Brazilian School of Cosmology and Gravitation (BSCG), we celebrated the 25th anniversary of the School, which has been organized since 1977 by the Group of Cosmology and Gravitation of the CBPF. To commemorate this unique moment, a web page is being launched with all the 93 lectures and seminars of the first nine schools (the proceedings of the Xth BSCG will be published this year by AIP): more than 4500 pages in pdf format, provided by many of the most important scientists in Cosmology, Gravitation, Astrophysics, and Field Theory. It is an important contribution for students and researchers in these areas, which shows the historical evolution of physics in the last 25 years. This material can be accessed through the page of the Group of Cosmology and Gravitation of the CBPF:

www.cosmologia.cbpf.br

Sixth East Coast Gravity Meeting

David Fiske, University of Maryland drfiske@physics.umd.edu

The Sixth East Coast Gravity Meeting was held at the University of Maryland, College Park on March 29 and March 30, 2003. Thirty-five contributed talks on a wide range of gravity-related topics filled a one and one-half day program, attended by over fifty people from as far north as Maine, as far south as North Carolina, and as far west as California. The meeting was divided into two sessions dedicated to numerical relativity, one session covering classical general relativity and gravitational waves, one session dealing with compact objects, and three sessions touching on topics from the broad category of general relativity and beyond.

As has been the tradition at the East Coast Meetings, a large number of students contributed talks to this year's meeting. In addition to the ten graduate students (from Brown, Maryland, Penn State, and Syracuse) who presented, two undergraduates from Bowdoin College contributed excellent talks. David Mattingly from the University of Maryland was recognized with the Best Student Presentation Award, sponsored by the APS Topical Group on Gravitation. The judges also recognized Monica Skoge, an undergraduate from Bowdoin College, with an Honorable Mention in this year's competition.

Although there are no formal proceedings for the meeting, the program with abstracts remains online at the conference webpage www.physics.umd.edu/grt/ecgm. We have encouraged speakers to provide relevant references to archived papers, and have added active links to those papers so that interested readers can easily follow up on the content of the talks. Speakers still wishing to add such references should send them to ecgm@physics.umd.edu.

The Seventh East Coast Gravity Meeting will be held next year at Bowdoin College in Brunswick, Maine. A link to the conference webpage, when it is available, will appear on the East Coast Gravity Meeting coordinating committee's webpage http://physics.syr.edu/~marolf/ECGM.html. In addition, the coordinating committee is accepting volunteers to host future meetings. Information about the history of the meeting and about volunteering are also available on the committee's webpage.

This year's organizers would like to thank the University of Maryland Department of Physics for contributing financial support.

5th Edoardo Amaldi meeting

Alain Brillet, Virgo Project brillet@obs-nice.fr

The 5th Edoardo Amaldi conference on Gravitational Waves took place in Tirrenia (Tuscany) on July 6th to 11th. The facilities and the organization were excellent. Tours to the site of Virgo, only 15 km away, were organized everyday. Mainly dedicated to experimental activities in the field of gravitational wave detection, the conference attracted more than 250 participants, mostly experimentalists from all the ongoing detector projects.

After a session of overviews, six sessions were dedicated to the detectors (status, advanced techniques, fundamental noise sources, and future detectors), one to theory and sources, and one to data analysis.

Since the last conference two years ago in Australia, the general progress is remarkable: the LIGO large interferometric detectors (2 in Hanford, Wa, and one in Livingston, La) have been all completed and are getting close to the expected sensitivity at high frequency, the construction of Virgo, in Tuscany, has included a successful pre-commissioning period and is now completed, the TAMA and GEO prototype/detectors are also running. If the sensitivity of the interferometers still remains to be improved, particularly in the low frequency range, the good news are that they all demonstrate a good duty cycle: when the site activity stops for an “engineering run” or a “science run”, they do run unattended for hours to weeks. This is quite remarkable, given the complexity and the delicacy of these instruments. The analysis of the first data from LIGO, TAMA, and GEO detectors allows the determination of upper limits on the amplitude and event rate for various possible GW sources. Although these limits are not yet quantitatively interesting, they demonstrate the ability to acquire and store the data, and to filter them with appropriate templates. These studies have also the merit to show that the final sensitivity (after data filtering) is strongly affected by the lack of stationarity of the noise. This has a consequence on the detailed design of the interferometers, that the Tama group has started to take into account: it is important to improve the noise stationarity, as well as the noise spectral density.

GEO plays the double role of a detector, and of an advanced prototype: after a “science run” in coincidence with LIGO, it will implemented as a double recycling interferometer, using advanced technologies in the last suspension stages: monolithic fiber suspensions, controlled damping of the violin modes, thermal control of the curvature radius, The Australian AIGO group also develops advanced instrumentation in collaboration with LIGO and with Virgo.

“Advanced techniques” and “Noise sources” were mainly focused on two points: thermal noise and quantum noise. Thermal noise issues are the most immediate concern: since the previous Amaldi meeting in Perth, it was found that the mirror’s thermal noise, due to the mechanical losses of the reflective coatings, could become relevant, particularly in advanced uncooled detectors like the Advanced LIGO. It may limit the sensitivity if the planned sapphire substrates are not yet available and have to be replaced by silica. If the material of the coating layers cannot be sufficiently improved, it remains the possibility of using non-Gaussian beams, which should provide a lower phase noise level, for the same mirror fluctuations. This thermal noise would anyway become negligible in a cryogenic detector, were quantum noise should be the main limitation. Experimental and theoretical studies were presented on the quantum noise problems. “Quantum locking”, a new idea, which consists in measuring the radiation pressure noise on each mirror and providing active feedback, does not require the use of squeezing or QND techniques. The first large cryogenic prototype, CLIO, is being built, underground, in the Kamioka mountain.

Except for Nautilus and Explorer the acoustic detectors have not been running much in the last years, but good progress has been made in the noise and the bandwidth of the transducers, which will keep them competitive for some more time with the wideband interferometers. A promise for the future is the development of spherical cryogenic detectors: three of them may be built soon, in Leiden (mini-Grail), in Sao Paulo (Mario Schenberg) and in Rome (Sfera), involving two new groups and new countries in the field.

One full session was dedicated to LISA, and to the SMART-2 test flight, foreseen in 2006-2007. The spacecraft will carry two similar but different payloads, one built by NASA and one by ESA. They will both test the functionality and the sensitivity of the interferometers, of the “gravity reference sensors”, and of micro-thrusters to be used later in LISA. The progress on these critical issues is impressive. The collaboration-competition compromise is not yet totally clear.

The session on theory and GW sources was mainly focused on the description of new possible sources to be detected by LISA and by LIGO-Virgo and the corresponding advanced detectors, on the possibility to use LISA signals and their redundancy for testing alternative theories, and on the progress in numerical relativity. Recent achievements, and new investments in computing facilities, should allow soon for an interesting comparison between ”exact” models and real coalescence signals.

The data analysis session became very large, with (too) many (too) short talks, and more than 20 posters. At the next issue of the Amaldi conference (Summer 2005, in Japan), it may be wise to focus on the results of the working detectors (upper limits , noise studies,) and to push other papers towards the GWDAW (Gravitational Wave Data Analysis Workshop) that the community organizes each year in December. The session on future detectors proposed a full description of the Advanced LIGO, and considerations about Japanese and European projects for cryogenic detectors, improved SQUID’s for acoustic detectors, and even a “post-LISA” proposal. Funds and manpower may be limited, but the research field is young, and there is no lack of new ideas!

Pacific Coast Gravity Meeting

Charles Torre, Utah State torre@cc.usu.edu

The 19^{th} Pacific Coast Gravity Meeting (PCGM) was held at the University of Utah, February 28 – March 1. The conference was held in conjunction with a celebration of Richard Price's sixtieth birthday – the Pricefest – which added an additional dimension to the meeting. In particular, the meeting benefited from overlapping with some of the Pricefest events, which included a party at Richard Price's house on Friday night as well as a solemn, respectful tribute dinner for Richard on Saturday night. See John Whelan's article elsewhere in this newsletter for details on the Pricefest.

The format of this meeting was the same as usual for this small, informal regional meeting: a wide variety of 15 minute talks from over 40 participants. The conference was very smoothly run by postdoctoral "volunteers" Chris Beetle and Lior Burko. As always, this conference tries to encourage student participation, and there were twelve student talks at this year's meeting. Nothing is quite so encouraging as money, and a cash prize named after Jocelyn Bell is awarded for the best student talk. For the first time (as far as I know), this prize was funded by the American Physical Society Topical Group on Gravitation. This year's Bell prize was awarded to Henriette Elvang (University of California, Santa Barbara) for her talk on "Bubbles and Black Holes". Last I heard, the 20^{th} Pacific Coast Gravity Meeting will be held in late winter 2004 at Caltech.

Several (overlapping) themes were represented at this year's conference. Here is an attempt to identify those themes and the speakers that go with them. Of course, several talks could be put into more than one category.

The Gravitational Two-Body Problem with talks by John Baker, Chris Beetle, Ben Bromley, Lior Burko, Rachel Costello, Peter Diener, Carlos Lousto, Mark Miller, Richard Price, Charles Torre.

LIGO/LISA with talks by Patrick Brady, Teviet Creighton, Jonathan Gair, Louis Rubbo, Linqing Wen, John Whelan

Experimental Gravity – but not LIGO or LISA with presentations by Eric Berg, Liam Cross, Daniel Kapner, Frank Marcoline, Jason Steffan, Clifford Will.

Gravitational Collapse and Numerical Relativity – but not the 2-body problem with talks by Jay Call, R. Steven Millward, Frans Pretorius, Mark Scheel, Richard O'Shaughnessy.

String Theory, Quantum Gravity, and then some with presentations by Steve Carlip , Yujun Chen , Tevian Dray , Henriette Elvang , Gary Horowitz , Karel Kuchař , Alok Laddha , Chad Middleton , Jorge Pullin.

Mathematical Properties of the Einstein Equations and Their Solutions with talks by Beverly Berger, Simonetta Frittelli, Jim Isenberg, Lee Lindblom.

Other Topics in Field Theory and Gravitation with presentations by Randy Dumse and William Pezzaglia

Astrophysics of Gravitational Wave Sources Workshop

Joan Centrella, NASA-Goddard Joan.Centrella@nasa.gov

On April 24 - 26, 2003, a group of researchers from around the world gathered at the University of Maryland's Inn and Conference Center for the workshop "The Astrophysics of Gravitational Wave Sources." The speakers and attendees represented a broad range of areas within physics and astrophysics: general relativity; optical, X-ray, and G-ray astronomy; theoretical astrophysics; gravitational wave detection; and data analysis. The talks and discussions were stimulating and informative, covering diverse areas of this growing field. In fact, the workshop provided an opportunity for many of those present to meet and interact with each other for the first time.

The meeting began with an overview of gravitational wave sources. This was followed by a presentation on gravitational wave detectors and detection circa 2012, which is the time frame in which the advanced ground-based detectors (probing high frequency sources) and LISA (observing low frequency sources) should be operating. Most of the remaining of the talks focused on the astrophysics of anticipated gravitational wave sources and the scenarios that surround them, including collapses, binaries, and gamma-ray bursts. Black holes - ranging from stellar, to intermediate mass, to supermassive - figured prominently in many presentations. Talks on data analysis and detection, including a report on the recent S1 run of LIGO/GEO, rounded out the program. Electronic versions of many of the workshop presentations can be found online at

http://astrogravs.gsfc.nasa.gov/docs/agws_workshop/presentations/.

These are exciting times. LIGO has just completed its second scientific data-taking run (S2), and plans for advanced ground-based detectors are in progress. The space-based LISA is moving forward strongly as a partnership between NASA and ESA. Gravitational wave astrophysics is a stimulating and fruitful area of interaction for researchers from diverse areas of physics and astrophysics. The presentations at this workshop provided snapshots of this emerging field today, and glimpses of the scientific excitement to come.

Gravitational interaction of compact objects

Matt Choptuik, UBC, Éanna Flanagan, Cornell and Luis Lehner, LSU
choptuik@physics.ubc.ca, flanagan@astro.cornell.edu, lehner@lsu.edu

The "Gravitational Interaction of Compact Objects" conference took place at the Kavli Institute of Theoretical Physics from May 12th to May 14th, 2003. Aside from bringing together researchers in the field to discuss the status of activities in the area, the conference served to "kick-off" a two-month workshop under the same name at KITP. Each day of the conference was divided into sections that focused on specific areas, which ranged from broad themes to particular issues.

The first day consisted of a series of talks to survey the status of different aspects of gravitational wave data astronomy. Fred Raab described the status of the LIGO detectors, and Joan Centrella gave an overview of the possible sources for both space based and ground based detectors. Lee Lindblom reviewed aspects of accretion induced collapse of white dwarfs and the marginal likelihood of detection of gravitational waves from these systems with advanced interferometers. Following these there were four review talks on the dynamics of binary systems. Oliver Poujade reviewed post-Newtonian computations of the gravitational waveform, based on matching a post-Newtonian expansion of the field equations in the near zone to a post-Minkowskian expansion in the far zone. Currently there are regularization ambiguities which arise at post-3-Newtonian order, and Poujade described ongoing attempts to resolve these ambiguities. John Baker described the status of the Lazarus project to simulate binary black holes, and the present efforts and results to obtain complete information from initial data sets describing equal mass spinning black holes. Luis Lehner gave an overview of different approaches to numerical relativity and to the binary black hole problem, and Miguel Alcubierre reviewed the status of binary black hole simulations within the Cauchy approach.

The second day's talks were mostly devoted to the current understanding of specific sources, together with one talk on data analysis. Phil Arras reviewed the generation of gravitational radiation by neutron star Rossby modes and the role gravitational waves can play in determining the observed/inferred properties of neutron stars. He argued that r-modes in low mass X-ray binaries (LMXBs) are a possible candidate for detection with LIGO II. This depends somewhat on unknown properties of the star's viscosity that govern the stability of a steady state solution in which the mode is excited. Detectable gravitational waves from LMXBs may also be produced via inhomogeneities in the crust. Next, Masaru Shibata reviewed the status of his simulations of binary neutron star mergers, presenting simulations of both equal and unequal mass cases which merge after a couple of orbits. Shibata argued that useful physical information should be obtainable from the current codes given larger computers and more efficient computer use. He also discussed incorporation of more realistic physical components like improved equations of state, neutrino cooling etc. Christian Cardall then surveyed the present status of supernovae simulations. He discussed shortcomings in present codes (lower dimensionality, Newtonian dynamics, incomplete physical processes incorporated), and reviewed the five-years Terascale Supernova Initiative which aims to address all these shortcomings.

The subject then switched to gravitational wave data analysis. Patrick Brady discussed data analysis methods for four different types of gravitational wave signals: known waveforms, unknown burst waveforms, periodic signals, and stochastic signals. He presented preliminary results from the analysis by the LIGO Science Collaboration (LSC) of LIGO's first science run, giving upper limits on the event rates of various types of sources.

Peter Meszaros then reviewed current understanding of gamma ray bursts (GRBs), their phenomenology, models for the central engine, and the likelihood of detecting gravitational waves from them. He also described planned detectors which will increase the number of GRBs detected and the accuracy of their sky locations.

Subsequently, Leor Barack highlighted extreme mass ratio binaries, in which neutron stars or solar mass black holes inspiral into supermassive black holes, as important sources for spaced based detectors like LISA. He discussed theoretical problems related to obtaining accurate templates for these inspirals, and recent results which should provide a way to compute such templates for generic orbits around spinning black holes. The day ended with Greg Cook's review talk on methods for solving the constraint equations to obtain initial data for interacting compact binaries. He showed that new methods based on the conformal thin sandwich approach agreed better with post-Newtonian results than did older methods.

On the third day, talks concentrated on pressing issues related to simulations of compact objects and highlighted several promising new ingredients. Two talks discussed ways to improve the availability computational power and the efficiency of its use. Ed Seidel gave an overview of how so-called Grid computing can provide considerable enhanced resources for realistic simulations. Frans Pretorius surveyed the application and promises of adaptive mesh refinement, showing explicit examples both in Cauchy and characteristic implementations.

The next two talks turned to general relativistic hydrodynamics simulations, and treated in depth what will be needed for accurate and realistic results. Mark Miller reviewed the effect on evolutions of the choice of initial data sets used, and discussed how to estimate the associated errors in physical observables that one extracts from the simulation. He illustrated these issues by showing explicit evolutions of multiple orbits of neutron star binary systems. Charles Gammie discussed the incorporation of magnetic fields in simulations, describing the implementation of the magneto-hydrodynamics equations and presenting explicit examples of accretion tori on spinning black hole backgrounds.

The conference then turned to new techniques that address issues which had previously been poorly understood. Jeffrey Winicour described the problems associated to dealing with boundaries, and in particular the issue of obtaining boundary conditions that make the initial/boundary value problem well posed. He described different efforts to achieve a solution of this problem in special cases. Manuel Tiglio described a set of novel techniques which, for linear problems, guarantee numerical stability of the implementation. He also described how the parameter freedom in families of formulations of Einstein's equations could be exploited to minimize the growth of constraint violating modes. He presented explicit examples in test problems where the use of this technique made a considerable improvement.

The conference served to highlight several recent advances in the simulation of compact objects, to review current outstanding problems associated with these simulations, and to improve our understanding of possible methods for overcoming the problems. In addition, it reviewed the context for these simulation and modeling efforts to detect and analyze gravitational wave signals, and the possible payoffs for scientific knowledge. All of the conference talks are available online at

http:/online.kitp.ucsb.edu/online/gravity_c03/.

PriceFest

John T. Whelan, Loyola University New Orleans jtwhelan@loyno.edu

On March 2, 2003, the day after the 19th Pacific Coast Gravity Meeting, the one-day "PriceFest" was held at the University of Utah to celebrate the 60th birthday the day before of Richard Price. The festivities were hosted by Richard's longtime colleague Karel Kuchař (Utah), who likened individual descriptions of Richard to the blind men's descriptions of an elephant in the old parable. Each teacher, collaborator, colleague, or student could describe parts of Richard's trunk, ears, legs and tail, with the whole picture coming from the synthesis of the different perspectives. This theme continued throughout PriceFest, as each speaker presented his or her perspective on Richard's life, work, and personality.

Kip Thorne (Caltech) began with "The Early Richard Price", an account of Richard's days as a Caltech graduate student. He painted a picture of the years between 1965 and 1971 as a time of social and scientific upheaval. Quasars had just been discovered, "black holes" were about to be named, and Tommy Gold had proclaimed at the first Texas Symposium that relativists "might actually be useful to science". Kip described how Richard gained confidence in himself and his work, from TAing a Relativity course despite never having taken one, to deriving the power-law tails which carry away "hair" in black-hole formation in the face of contemporary literature which maintained otherwise. He closed his tribute to an esteemed protégé and family friend with the observation that "each generation of scientists often underestimates what the next generation may achieve."

Jorge Pullin (LSU) continued with "Richard Price, Car Talk and The American Journal of Physics", which explored Richard's role as a pedagogue and communicator of physical knowledge. This consisted mostly of a review of Richard's many contributions to the American Journal of Physics, which are collected at http://www.phys.lsu.edu/faculty/pullin/rhpajp.pdf .

After an interlude in which Richard's sister, who had been unable to attend the banquet the night before, gave her belated contribution to the roast, David Kieda (Utah) continued with "The Hidden Side of Richard Price", the results of a web search which revealed Richard Prices ranging from an 18th century congregational minister to a private eye.

Richard's former officemate Bernard Schutz (AEI, Bernie & the Gravitones) provided the perspective of a contemporary with "Catching Flies and Journalists with Richard Price". A member of the class which came to Caltech immediately after Richard's, Bernie listed as his mentors Kip, Frank Estabrook, and Richard. He credited Richard with teaching him not only how to do research, but also how to deal with the press. At the time this included *Los Angeles Times* writer Jack Smith, who came across a Caltech chalkboard with Price's theorem ("Everything that can be radiated, will be radiated"), Schutz's converse ("Everything that is radiated, can be radiated") and their synthesis ("Radiation does its own thing").

Carlos Lousto (UTB) concluded the fête with "The Late Richard Price", from the perspective of one of Richard's many younger collaborators. The common theme of these collaborations, ranging from quasinormal ringing to quasistationary inspiral, seemed to be the conversion of postdocs (including both the speaker and yours truly) from quantum gravity to astrophysical relativity. Carlos also gave proper credit to the contributions of Richard's dog Sunny.

By the end of the day, the speakers had assembled a picture of a scientist who has had a remarkable impact not only on the field but especially on the people around him.

Gravitation: a decennial perspective

Jorge Pullin, LSU pullin@lsu.edu

On June 8-12 a conference took place at Penn State, coinciding with the 10 years anniversary of the foundation of the Center for Gravitational Physics and Geometry. It sought to give a perspective of events during the last decade and how they shape the future to come in gravitational physics. About 150 people attended the conference.

Plenary lectures included a first day concentrated on aspects of gravitational waves, ranging from the astrophysical, with Ramesh Narayan, to experimental, with Rai Weiss, and numerical with Masaru Shibata as speakers. The second day had talks by Sean Carroll and Gary Horowitz on dark matter and gravitational aspects of string theory respectively. The third day had lectures by Bernie Schutz, on confronting gravitational wave observations with theory and Badri Krishnan and myself on analytical aspects of numerical relativity. On the fourth day Saul Teukolsky spoke about the next ten years in numerical relativity, Carlo Rovelli on spin foam models and Ted Jacobson on quantum gravity phenomenology. The last day had Roger Penrose speaking about the mathematics of general relativity and ended with a panel discussion.

The afternoons had parallel sessions on quantum gravity and quantum field theory on curved spacetime, gravitational wave physics, quantum geometry and its applications, numerical relativity, mathematical relativity and quantum cosmology.

The conference banquet had an after dinner talk by Ted Newman on the blossoming of general relativity in the 60's and 70's. After the talk, with Jim Hartle as master of ceremonies, several people made impromptu remarks about the impact the PSU Center had had in their lives and many highlighted the leadership role Abhay Ashtekar has played as its director.

Let us wish the PSU Center for Gravitational Physics and Geometry ten more years as successful as the first!