MATTERS OF GRAVITY

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

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Editor

David Garfinkle

Department of Physics Oakland University Rochester, MI 48309
Phone: (248) 370-3411
Internet: `garfinkl-at-oakland.edu`
WWW: `http://www.oakland.edu/physics/physics_people/faculty/Garfinkle.htm`

Associate Editor

Greg Comer

Department of Physics and Center for Fluids at All Scales,
St. Louis University, St. Louis, MO 63103
Phone: (314) 977-8432
Internet: `comergl-at-slu.edu`
WWW: `http://www.slu.edu/colleges/AS/physics/profs/comer.html`

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Editorial

The next newsletter is due September 1st. This and all subsequent issues will be available on the web at `http://www.oakland.edu/physics/Gravity.htm` All issues before number **28** are available at `http://www.phys.lsu.edu/mog`

Any ideas for topics that should be covered by the newsletter, should be emailed to me, or Greg Comer, or the relevant correspondent. Any comments/questions/complaints about the newsletter should be emailed to me.

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.

David Garfinkle

Correspondents of Matters of Gravity

- John Friedman and Kip Thorne: Relativistic Astrophysics,
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- Peter Bender: Space Experiments
- Jens Gundlach: Laboratory Experiments
- Warren Johnson: Resonant Mass Gravitational Wave Detectors
- David Shoemaker: LIGO Project
- Peter Saulson and Jorge Pullin: former editors, correspondents at large.

Topical Group in Gravitation (GGR) Authorities

Chair: Éanna Flanagan; Chair-Elect: Dieter Brill; Vice-Chair: David Garfinkle. Secretary-Treasurer: Vern Sandberg; Past Chair: Jorge Pullin; Delegates: Bei-Lok Hu, Sean Carroll, Vicky Kalogera, Steve Penn, Alessandra Buonanno, Bob Wagoner.

The View from the NSF

Beverly Berger, National Science Foundation bberger-at-nsf.gov

My main objective in this note is to tell you about various websites with information relevant NSF's role in the support of gravitational physics research.

For those of you interested in NSF's budget, I recommend two sources of information. The first is the American Institute of Physics FYI: Science Policy News (see `http://www.aip.org/fyi/`). You can subscribe to receive alerts by email or view the archive. For example, see `http://www.aip.org/fyi/2006/141.html` for some background on FY2007 budget prospects. See also `http://www.aip.org/fyi/2007/014.html` for the latest information. The second source is NSF's Office of Legislative and Public Affairs. Click on `http://www.nsf.gov/about/congress/index.jsp` for the latest information on the progress of the President's Budget Request through Congress and on `http://www.nsf.gov/about/budget/` to see the Budget Request for any Fiscal Year (the FY2008 Budget Request will appear in early February) and, correspondingly, what was actually passed.

For those of you planning on submitting proposals or who have awards, an excellent site for learning how to interact with Fastlane is the Fastlane Demonstration Site (`http://www.fastlane.nsf.gov/jsp/homepage/demo_site.html`). You can log in as a fictitious PI and click on all possible buttons to see what happens. Aside: THE PHYSICS DIVISION'S TARGET DATE FOR SUBMISSION IS THE LAST WEDNESDAY IN SEPTEMBER.

To find out what is supported by the Gravitational Physics Program (or any other NSF program), use the Award Search at `http://www.nsf.gov/awardsearch/` . For example you can perform a "key word" search to find all award abstracts containing "Einstein." If you scroll down and click "active awards only," you will find 211 such awards. If you click on Program Information near the top of the page, you can find all awards (past or present) supported by the Gravitational Physics Program. Fill in the relevant Element Code: Gravitational Experiment (1243), Gravitational Theory (1244), Support of LIGO Research (1252), and LIGO Operations and Advanced R&D (1293).

Finally, the main NSF website (`http://www.nsf.gov`) is the starting point to search for funding opportunities outside Gravitational Physics. Clicking on Math, Physical Sciences under Program Areas (top left column on the page) will take you to the website of the Directorate of Mathematical and Physical Sciences. Other Program Areas include Crosscutting (for Major Research Instrumentation, CAREER, REU Sites), International (to see the programs of the Office of International Science and Engineering), Computer, Info. Sci., Eng. (for the CISE Directorate), and Cyberinfrastructure (for the Office of CyberInfrastructure). In addition, the website `http://www.nsf.gov/funding/` allows searching and browsing for active solicitations.

GGR program at the APS meeting in Jacksonville

David Garfinkle, Oakland University garfinkl-at-oakland.edu

We have an exciting GGR related program at the upcoming APS April meeting in Jacksonville, FL. Our chair-elect, Dieter Brill did a remarkable job of putting this program together.

Saturday April 14, 9 am (approx)
Plenary Talk
First Results from Gravity Probe B
Francis Everitt, Stanford University

B6: Saturday April 14, 10:45
Binary Black Holes: Orbits, Mergers and Waveforms
Session Chair: Pedro Marronetti
Carlos Lousto: Spin-orbit interactions in black-hole binaries
Joan Centrella: Binary Black Hole Mergers (draft title)
Pablo Laguna Binary: Black holes and their echoes in the Universe

E6: Saturday, April 14, 15:30
GGR Prize Session
Session Chair: Richard Isaacson
Ronald W. P. Drever: TBA
Rainer Weiss: The current state of LIGO
and the plans for the near term future (tentative)
Gabriela Gonzalez: TBA

H4: Sunday April 15 8:30
Gravity Probe B (preliminary title) (joint with GPMFC)
Session Chair: Clifford Will
John P. Turneaure: The Gravity Probe B Science Instrument
Bradford W. Parkinson: Gravity Probe B & Innovative Space Engineering
George M. Keiser: Gravity Probe B Data Analysis Challenges, Insights & Results

K4: Sunday, April 15, 13:15
Classical and semi-classical gravity
Session Chair: James Isenberg
Robert Wald: Present status of quantum field theory in curved spacetime
James Isenberg: Black Hole Rigidity
Greg Galloway: On the Topology of Higher Dimensional Black Holes

M4: Sunday, April 15, 15:15
History of General Relativity (joint with FHP)
Session Chair: K. Wali
Daniel Kennefick: Traveling at the Speed of Thought –
Proving the Existence of Gravitational Waves
Richard Isaacson: Development of LIGO – a view from Washington

Ted Newman: Survey of the Developments of GR since 1915 - present.

T5: Monday, April 16, 13:30
Gravitational Wave Astrophysics with LISA (joint with DAP)
Session Chair: Joan Centrella
Craig Hogan: Gravitational Wave Backgrounds and Bursts
from Terascale Phase Transitions and Cosmic Superstrings
Sterl Phinney: Gravitational waves as probes of galactic nuclei
and accretion physics
Marta Volontieri: Coevolution of galaxies and massive black holes

Y4: Tuesday, April 17 13:30
Recent developments in quantum gravity
Session Chair: Jorge Pullin
Parampreet Singh: Recent advances in Loop Quantum Cosmology
Simone Speziale: Graviton propagator from loop quantum gravity
Max Niedermaier: The Asymptotic Safety Scenario in Quantum Gravity

Also on the program will be a focus session
"Hydrodynamics and Magnetohydrodynamics Coupled to General Relativity"
featuring an invited talk by John Hawley on his work modeling magnetized accretion about a black hole. The session will include talks on recent advances coupling fluids to gravity, including neutron stars and accretion. Those working in this area are encouraged to submit abstracts.

Other sessions at the APS meeting that may be of interest to gravitational physicists include (but are not limited to) the following:

Plenary Session Monday April 16
String Theory, Branes, and if You Wish, the Anthropic Principle
Shamit Kachru, Stanford University

Cosmology After WMAP
David Spergel, Princeton University

Sunday, April 15 8:30
Precision Experiments and Tests of Fundamental Laws (GPMFC)
Blayne Heckel: CP violation and preferred frame tests using polarized electrons
David Reitze: Science with LIGO
Karl Van Bibber: Axions

Sunday, April 15 10:30
Compact Inspirals (DAP)
Chris Deloye: Inspirals and Gravitational Waves
Ingrid Stairs: The Double Pulsar
Danny Steeghs: White Dwarf Inspirals

Monday, April 16 10:45
Few Body Computational Challenges for Large Scale Astrophysics (DCOMP)
Harald Pfeiffer: Binary black hole coalescence

Tuesday, April 17 10:30
Black Holes of All Sizes (DAP)
Phil Kaaret: Intermediate-Mass Black Holes
Avi Loeb: Supermassive Black Holes
John Miller: Stellar Black Holes

Tuesday, April 17
Gravity and Cosmology (DPF)
D. Huterer: The Accelerating Universe, Dark Energy, and Modified Gravity
D. Kapner: Experimental Results on Gravity at Short Distances
J.Santiago: Gravitation and Extra Dimensions

we hear that . . .

David Garfinkle, Oakland University garfinkl-at-oakland.edu

Rainer Weiss and Ronald Drever are this year's winners of the APS *Einstein Prize* for Gravitational Physics.

Joseph Polchinski and Juan Maldecena are this year's winners of the APS *Dannie Heineman Prize* for Mathematical Physics.

Gabriela Gonzalez is this year's winner of the APS *Edward A. Bouchet Award.*

Ed Seidel has received the Sidney Fernbach award of the IEEE.

Frederick Raab and Jennie Traschen have been elected APS Fellows.

Jorge Pullin has been elected a corresponding member of the *Mexican Academy of Sciences* and the *National Academy of Sciences of Argentina*

Hearty Congratulations!

100 years ago

David Garfinkle, Oakland University garfinkl-at-oakland.edu

Einstein formulated the equivalence principle in "On the relativity principle and the conclusions drawn from it" *Jarbuch der Radioactivitaet und Elektronik* **4** (1907)

The Double Pulsar – A unique gravity lab

Michael Kramer, The University of Manchester michael.kramer-at-manchester.ac.uk

Almost a hundred years after Einstein formulated his theory of general relativity (GR), efforts in testing GR and its concepts are still being made by many colleagues around the world, using many different approaches. To date GR has passed all experimental and observational tests with flying colours, but in light of recent progress in observational cosmology in particular, the question of whether alternative theories of gravity need to be considered is as topical as ever.

Many experiments are designed to achieve ever more stringent tests by either increasing the precision of the tests or by testing different, new aspects. Some of the most stringent tests are obtained by satellite experiments in the solar system, providing exciting limits on the validity of GR and alternative theories of gravity like tensor-scalar theories. However, solar-system experiments are made in the gravitational weak-field regime, while deviations from GR may appear only in strong gravitational fields. It happens that nature provides us with an almost perfect laboratory to test the strong-field regime using binary radio pulsars.

While, strictly speaking, the binary pulsars move in the weak gravitational field of a companion, they do provide precision tests of the strong-field regime. This becomes clear when considering strong self-field effects which are predicted by the majority of alternative theories. Such effects would, for instance, clearly affect the pulsars' orbital motion, allowing us to search for these effects and hence providing us with a unique precision strong-field test of gravity.

Pulsars are highly magnetized rotating neutron stars and are unique and versatile objects which can be used to study an extremely wide range of physical and astrophysical problems. Besides testing theories of gravity one can study the Galaxy and the interstellar medium, stars, binary systems and their evolution, plasma physics and solid state physics under extreme conditions. This wide range of applications is exemplified by the first ever discovered double pulsar [1, 2]. This unique system allows us to test many aspects of gravitational theories at the same time, representing a truly unique laboratory for relativistic gravity. The experiment is conceptually simple: Nature has provided us with two clocks attached to point masses which fall in the gravitational potential of their companion. Measuring the ticks of these clocks while they move through space-time allows us to compare our observations with the predictions of various theories of gravity.

The double pulsar is a system of two visible radio pulsars with periods of 22.8 ms (PSR J0737−3039A, simply called "A" hereafter) and 2.8 s (PSR J0737−3039B, simply called "B" hereafter), respectively. It was discovered and is studied by a large collaboration involving colleagues from Australia, Canada, India, Italy and USA. The double pulsar's short and compact (orbital period of $P_b = 144$ min), slightly eccentric ($e = 0.09$) orbit makes the double pulsar the most extreme relativistic binary system ever discovered, demonstrated by the system's remarkably high value of periastron advance ($\dot{\omega} = 16.8995 \pm 0.0007\,\mathrm{deg\ yr}^{-1}$, i.e. four times larger than for the Hulse-Taylor pulsar!). Only four years after the discovery of the system, most of its timing parameters are determined with a precision that took several decades to achieve in the previously known best relativistic binary pulsars [3]. For instance, we measure that the orbit is shrinking every day by 7.42 ± 0.09 mm, which agrees with GR's prediction of an orbital decay due to the emission of gravitational quadrupole waves within an uncertainty of 1%. Ultimately, the shrinkage leads to a coalescence of the two pulsars in only ~ 85 Myr. This boosts the hopes for detecting a merger of two neutron stars with first-generation ground-based gravitational wave detectors by a factor of several compared to previous estimates [1, 4]. Moreover, the detection of a young companion B around an old millisecond pulsar A confirms the evolution scenario proposed for the creation of recycled millisecond pulsars.

The measured precession of the orbit and the decrease in orbital period of $\dot{P}_{\rm b} = (1.25 \pm 0.2) \times 10^{-12}$ seconds per second are both observed deviations from a pure Keplerian description of the orbit. It is important to note that we do not have to assume a particular theory of gravity when measuring such relativistic corrections, called “post-Keplerian” (PK) parameters. Instead, we can take the observational values and compare them with predictions made by a theory of gravity to be tested. In the double pulsar, as A has the faster pulse period, we can time A much more accurately than B, allowing us to measure a total of five very precise PK corrections for A’s orbit.

The PK parameter, $\dot{\omega}$, is the easiest to measure. When interpreting this advance of periastron in the framework of GR, it provides an immediate measurement of the total mass of the system. The PK parameter γ denotes the amplitude of delays in arrival times caused by the varying effects of the gravitational redshift and time dilation (second order Doppler) as the pulsars move in an elliptical orbit at varying distances with varying speeds. As a result of the gravitational redshift, the pulsar clocks slow down when they ’feel’ the deeper gravitational potential of the companion and speed up when they are further away.

As mentioned, the decay of the orbit due to gravitational wave damping is observed as a change in orbital period, $\dot{P}_{\rm b}$. Two further PK parameters, r and s, are related to a Shapiro delay caused by the curvature of space time near the companion. Their measurement is possible, since – quite amazingly! – we observe the system almost completely edge-on. Hence, at superior conjunction the pulses of A pass the surface of B in only 30,000 km distance, needing to travel an extra length of curved space-time and adding about 100 microseconds to the travel time to Earth. Within GR, we can interprete s as the sine of the orbital inclination angle. With a measurement of $\sin i \equiv s = 0.99974(-0.00039, +0.00016)$, this is indeed very close to an edge-on geometry of $i = 90$deg.

When trying to see whether these PK parameter measurements are in agreement with the predictions of GR or any other theory of gravity, we use that for point masses with negligible spin contributions the PK parameters in each theory should only be functions of the a priori unknown neutron star masses and the well measurable Keplerian parameters. With the two masses as the only free parameters, the measurement of three or more PK parameters over-constrains the system, and thereby provides a test ground for theories of gravity. These tests can be illustrated in a very elegant way [5]: The unique relationship between the two masses of the system predicted by any theory for each PK parameter can be drawn in a diagram showing the mass of A on one axis and that of B on the other. We expect all curves to intersect in a single point if the chosen theory is a valid description of the nature of this system (see figure).

Most importantly, the possibility to measure the orbit of both A and B provides a new, qualitatively different constraint in such an analysis. Indeed, with a measurement of the projected semi-major axes of the orbits of both A and B, we obtain a precise measurement of the mass ratio simply from Kepler’s third law, via $R \equiv M_A/M_B = x_B/x_A$ where M_A and M_B are the masses and x_A and x_B are the (projected) semi-major axes of the orbits of both pulsars, respectively. We can expect the mass ratio, R, to follow this simple relationship to at least 1PN order. In particular, the R value is not only theory-independent, but also independent of strong-field (self-field) effects which is not the case for PK-parameters. Therefore, any

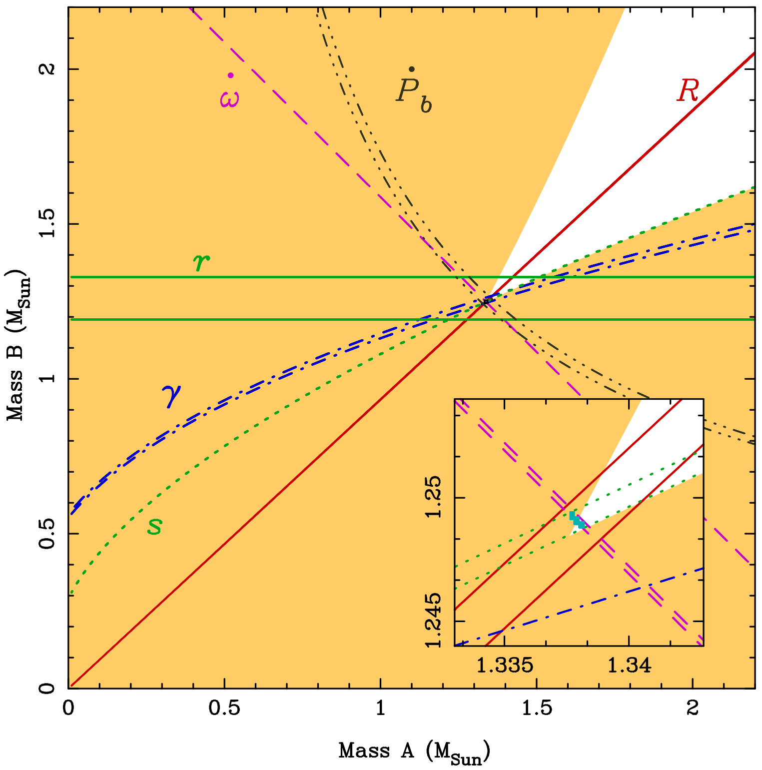

Figure 1: ‘Mass–mass’ diagram showing the observational constraints on the masses of the neutron stars in the double pulsar system J0737–3039. The shaded regions are those that are excluded by the Keplerian mass functions of the two pulsars. Further constraints are shown as pairs of lines enclosing permitted regions as given by the observed mass ratio, R, and the PK parameters shown here as predicted by general relativity (see text). Inset is an enlarged view of the small square encompassing the intersection of these constraints. See Kramer, Stairs, Manchester et al. (2006) for details.

combination of masses derived from the PK-parameters *must* be consistent with the mass ratio derived from Kepler's 3rd law. With five PK parameters already available, this additional constraint makes the double pulsar the most overdetermined system to date where the most relativistic effects can be studied in the strong-field limit. The theory of GR passes this new test at the record-breaking level of 0.05% [3].

The precision of the measured timing system parameters increases continuously with time as further and better observations are made. Soon, we expect the measurement of additional PK parameters, allowing more and new tests of theories of gravity. Some of these parameters arise from a relativistic deformation of the pulsar orbit and those which find their origin in aberration effects and their interplay with geodetic precession. In a few years, we will measure the decay of the orbit so accurately, that we can put limits on alternative theories of gravity which should even surpass the precision achieved in the solar system. On somewhat longer time scales, we will even achieve a precision that will require us to consider post-Newtonian terms that go beyond the currently used description of the PK parameters. Indeed, we already achieve a level of precision in the $\dot{\omega}$ measurement where we expect corrections and contributions at the 2PN level. One such effect involves the prediction by GR that, in contrast to Newtonian physics, the neutron stars' spins affect their orbital motion via spin-orbit coupling. This effect modifies the observed $\dot{\omega}$ by an amount that depends on the pulsars' moment of inertia, so that a potential measurement of this effect would allow the moment of inertia of a neutron star to be determined for the very first time [6, 2]. We do not expect this measurement to be easy, but we will certainly try!

With the measurement of already five PK parameters and the unique information about the mass ratio, the double pulsar indeed provides a truly unique test-bed for relativistic theories of gravity. Again, GR has passed these new tests with flying colours. The precision of these tests and the nature of the resulting constraints go beyond what has been possible with other systems in the past. However, we only just started to study and exploit the relativistic phenomena that can be investigated in great detail in this wonderful cosmic laboratory.

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Theoretical Approaches to Cosmic Acceleration

Mark Trodden, Syracuse University trodden-at-physics.syr.edu

Less than a decade ago, observations of the lightcurves of type Ia supernovae first suggested that the expansion of the universe is accelerating. In the intervening years, a range of further observations [1, 2] have provided firm support for this result, to the extent that, even if we were to ignore the supernova data entirely, the accelerating universe would remain unavoidable.

At the level of cosmological models, described by perfect fluids with phenomenological equations of state, the accelerating universe just requires new parameters to fit the known data. Augmenting the general Cold-Dark-Matter (CDM) cosmology with an extra fluid component, X, with present-day energy density ρ_X and constant equation of state parameter w_X, satisfying $p_X = w_x \rho_X$, the Friedmann equation becomes

$$H^2 = \frac{1}{3M_p^2}\left[\rho_{\rm m}\left(\frac{a_0}{a}\right)^3 + \rho_X\left(\frac{a_0}{a}\right)^{3(1+w_X)}\right] - \frac{k}{a^2}\ . \tag{1}$$

It is to this parametrization (with other parameters determining the initial spectrum of perturbations) that cosmological datasets are fit, perhaps the best-known being the WMAP data.

That such a small number of parameters can provide such a tremendous fit to the evolution of the universe, including its large-scale structure, over its entire history, is a triumph of modern cosmology comparable to the broad successes of the expansion, the discovery of the CMB and the agreement of the abundances of the light elements. However, such an approach, while remarkably useful, does not provide an *explanation* for the origin of cosmic acceleration. Indeed, the biggest impact of the accelerating universe is in its implications for fundamental physics.

Clearly, one possibility is that cosmic acceleration is due to the cosmological constant (with $w_X = -1$). The cosmological constant problem itself – why is the vacuum energy so much smaller than we expect from effective-field-theory considerations? – requires a solution even in the absence of cosmic acceleration, and perhaps the final answer to this problem will yield a value appropriate to lead to late-time acceleration of the universe. Despite continuous theoretical pressure, the status of dynamical solutions to this conundrum has changed little since Weinberg's review article of 1988 [3]. Historically, this has led some researchers to consider an anthropic solution to the problem, although without a specific fundamental framework in which to investigate it.

However, in the context of string theory, the possibility of a *landscape*, containing at least 10^{100} discrete vacua with vacuum energy densities ranging up to the Planck scale, coupled with the mechanism of eternal inflation to populate the landscape, has recently led to a specific implementation of the anthropic argument.

While such a conclusion would seem to limit the testability of the proposal, one hope is that it might be possible for the statistics of the distribution of vacua [4, 5, 6, 7, 8, 9], to allow statistical predictions for other observable quantities, such as the fundamental coupling constants. Should increasingly accurate cosmological observations reveal a dark energy equation of state not equal to -1, or evidence for temporal or spatial variation of the dark energy density, then we will know that a cosmological constant is not the answer and it will be harder to imagine anthropic arguments from the string landscape being the correct answer.

If the cosmological constant is not responsible for dark energy (because it is zero, or much smaller than the dark energy scale), then several possibilities have been suggested for a dynamical origin for cosmic acceleration.

The first of these - *dark energy* [10, 11, 12] - seeks to find an underlying microscopic description of the perfect fluid. The most popular approach to this new dynamical component of the cosmic energy budget is to invoke a new scalar field driving late-time inflation (but without the need for an end, as in the reheating that takes place after early universe inflation). In such a *quintessence* model, the instantaneous effective dark energy equation of state is

$$w_\phi = \frac{\dot{\phi}^2 - 2V(\phi)}{\dot{\phi}^2 + 2V(\phi)} \, . \tag{2}$$

If one assumes that cosmic acceleration is due to such a field, with potential-dominated dynamics, then generally one finds that the scale of the potential ($V^{1/4}$) should be of order 10^{-3}eV, and that the mass of the associated particle be of order the Hubble scale. These scales present obstacles to finding a sensible particle physics model of quintessence. One that does seem to work, with such technically natural parameter values, is if the quintessence field is realized as the pseudo-Nambu-Goldstone boson of some broken symmetry. In this case the unusually small values of parameters required are protected from quantum corrections by the symmetry.

One advantage of a subset of quintessence models is that they exhibit *tracking*. This means that there exist attractors of the dynamical system for which the scalar field tracks the equation of state of the background fluid. It can then be arranged that the field follows the evolution of the universe during radiation domination and then transitions to an accelerating attractor during matter domination. This allows a partial explanation of the coincidence problem, since acceleration is triggered by the onset of matter domination.

Another interesting suggestion has been that it may be possible to explain an accelerated universe by invoking the effects of inhomogeneities on the expansion rate – perturbations may induce an effective energy-momentum tensor with a nearly-constant magnitude. Kolb et. al. [13] have considered sub-horizon higher order corrections to the backreaction, going up to sixth order in a gradient expansion, and suggest that higher order corrections are large enough for the backreaction to generate dark energy like behavior. There have been a number of challenges to this idea (see e.g. [14]), but if a successful mechanism is found it would be an elegant and minimal explanation of acceleration.

A further possibility is that curvatures and length scales in the observable universe are only now reaching values at which an infrared modification of gravity can make itself apparent by driving self-acceleration. This possibility turns out to be incredibly difficult to implement.

Although, within the context of General Relativity (GR), one doesn't think about it too often, the metric tensor contains, in principle, more degrees of freedom than the usual spin-2 *graviton*. However, the Einstein-Hilbert action results in second-order equations of motion that constrain away the scalars and the vectors, so that they are non-propagating. But this is not the case if one departs from the Einstein-Hilbert form for the action. When using any modified action (and the usual variational principle) one inevitably frees up some of the additional degrees of freedom. In fact, this can be a good thing, in that the dynamics of these new degrees of freedom may be precisely what one needs to drive the accelerated expansion of the universe. In many situations though, there is a price to pay.

The problems may be of several different kinds. First, there is the possibility that along with the desired deviations from GR on cosmological scales, one may also find similar deviations on solar system scales, at which GR is rather well-tested. Second is the possibility that the newly-activated degrees of freedom may be badly behaved in one way or another; either having the wrong sign kinetic terms (ghosts), and hence being unstable, or leading to superluminal propagation, which may lead to other problems. These constraints are surprisingly restrictive when one tries to create viable modified gravity models yielding cosmic acceleration.

As an example, one simple way to modify GR is to replace the Einstein-Hilbert Lagrangian density by a general function $f(R)$ of the Ricci scalar R. For appropriate choices of the function $f(R)$ it is then possible to obtain late-time cosmic acceleration without the need for dark energy [15]. However, evading bounds from precision solar-system tests of gravity turns out to be a much trickier matter, since such simple models are equivalent to a Brans-Dicke theory with $\omega = 0$ in the approximation in which one may neglect the potential, and are therefore inconsistent with experiment.To construct a realistic $f(R)$ model requires at the very least a rather complicated function, with more than one adjustable parameter in order to fit the cosmological data and satisfy solar system bounds.

It is natural to consider generalizing such an action to include other curvature invariants [16], and it is straightforward to show these generically admit a maximally-symmetric solution: de Sitter space. Further, for a large number of such models (see e.g. [17]), solar system constraints, of the type I have described for $f(R)$ models, can be evaded. However, in these cases another problem arises, namely that the extra degrees of freedom that arise are generically ghost-like.

An alternative, and particularly successful approach, is that employed by Dvali and collaborators [18, 19, 20] in which an interesting modification to gravity arises from extra-dimensional models with both five and four dimensional Einstein-Hilbert terms. These *Dvali-Gabadadze-Porrati (DGP) braneworlds* allow one to obtain cosmic acceleration from the gravitational sector because gravity deviates from the usual four-dimensional form at large distances. One may also ask whether ghosts plague these models. However, Dvali has claimed that this theory reaches the strong coupling regime before a propagating ghost appears. In fact, Dvali has shown that theories that modify gravity at cosmological distances must exhibit strong coupling phenomena, or else either possess ghosts or are ruled out by solar system constraints.

Current observational bounds are entirely consistent with a cosmological constant, but also with a range of dark energy models and the possibility that a modification to GR is the origin of cosmic acceleration. While it is often stated that one or other of these ideas is the simplest or most natural theoretical explanation, only increasingly accurate observations can settle the question and allow us to make progress. In preparation for these, much theoretical work is necessary to extract concrete predictions with which to distinguish between the various suggestions. A number of authors have already begin to tackle this problem, with one possible answer being that the cross-correlation of kinematical observables with tests involving the linear growth of structure as the universe expands [21]. Whatever the ultimate answer, the accelerating universe looks bound to teach us a deep truth about fundamental physics.

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The Numerical Relativity Data Analysis Meeting

Patrick Brady, University of Wisconsin, Milwaukee patrick-at-gravity.phys.uwm.edu

The *Numerical Relativity and Data Analysis* workshop that was held at MIT on 6-7 November 2006 attracted 67 participants from both the source modeling and data analysis communities. The meeting was structured to encourage significant discussion by having only 4 speakers on the first day and 3 speakers on the second. This meeting had a rather narrow focus, dealing primarily with binary black holes; the organizers hope that future meetings will address other important sources. Based on the hallway conversations, the meeting appears to have succeeded in bringing together researchers from both communities. All the talks, some rough notes from the discussions, and the list of participants are posted on the meeting web site at `http://www.lsc-group.phys.uwm.edu/events/nrda/`

The meeting opened with a status report, by Ulrich Sperhake, on numerical simulations of binary black holes. The talk took a broad view and reported on results from various groups, the technical status of dynamical simulations, and touched on issues of initial data and boundary conditions. The discussion that followed included comments by members of the numerical relativity community about the boundary conditions, waveform extraction methods and radii, and convergence testing to understand the accuracy of the simulations. Data analysts asked a number of questions about accuracy of the current simulations; some of the numerical relativists turned the question around and asked how accurate they need to be. These discussions continued through the coffee break and led very naturally into the second talk.

Duncan Brown summarized the current status of searches for binary black holes using data from gravitational-wave detectors. In his talk, he emphasized that mismatch–fractional loss of signal to noise–is the correct measure of accuracy when discussing simulations of gravitational waveforms for use in searches. This point was immediately picked up by those present; several groups had already started to use the mismatch to understand the accuracy of their simulations. Brown further explained that sophisticated data analysis pipelines are developed to deal with the non-Gaussian nature of the gravitational-wave detector noise. He used this to emphasize that a good match is necessary, but not sufficient in a matched filtering search for signals. Finally, Brown pointed out that we should develop a standard format for publishing data from the numerical relativity community for use in searches for gravitational waves. Pablo Laguna reported that there is already a collaboration (NRwaves) among numerical relativists to collect their waveforms together for the sake of making comparisons between the results.

The next presentation, by Mark Miller, addressed issues of numerical accuracy in simulations. Mark invited the Caltech/Cornell and Jena groups to present a summary of their investigations of accuracy in numerical simulations. He followed that with a nice discussion of how numerical relativity fits together with ongoing data analysis efforts. In this discussion, he also presented a way to think about numerical accuracy. His proposal generated considerable discussion among experts in both numerical relativity and data analysis. Broadly speaking, everybody agreed with trying to quantify the errors in the numerical solutions, but precisely how to define the error remained unclear.

The last talk of the first day was given by Stephen Fairhurst. He discussed the different sources of measurement error that affect gravitational-wave observations. In particular, he emphasized the difference between statistical and systematic (instrumental) errors if the true waveform is accurately known. He explained how these issues feed into current and future searches. In general, the required accuracy of a simulation will depend on the accuracy with which the instrumental response can be calibrated. Fairhurst finished by explaining that this question is best answered by adding numerical waveforms to real data and exploring our ability to detect and measure them.

The first talk of the second day was given by Alessandra Buonanno. She discussed comparisons between approximate analytically computed waveforms and corresponding waveforms computed using numerical relativity. For equal masses, she explained that both approaches (when taken to sufficient accuracy) give very similar waveforms up to the merger regime. It remains an open question to understand the physical origin of the break in the numerically computed spectrum for these equal mass systems and to explore the effects of spin on the waveforms. Buonanno finished by highlighting the need for numerical simulations that start from initial data that is physically close enough to a real inspiral.

The workshop ended with Manuela Campanelli and Patrick Sutton summarizing "what we heard about ......" data analysis and numerical relativity, respectively. Two points resonated through their presentations and the following discussions. First, making data from numerical relativity simulations available for data analysis is highly desirable, although some effort is needed to quantify the errors on these data. Second, this meeting was useful and people would like to meet again to talk in more detail.

Note on the Numerical Relativity Data Analysis Meeting

Peter Saulson, University of Syracuse saulson-at-physics.syr.edu

As I sat in the back row of Rm NW14-1112 at MIT on Tuesday 7 Nov 2006, it suddenly struck me that we were participating in a watershed moment in the history of gravitational physics. Here, in the same room, were two communities who decades earlier had promised to help each other in a grand adventure: the detection of gravitational waves and the use of those waves to explore the frontiers of strong field gravity. Then the difficulties of accomplishing grand things had intervened, and the years passed. But now, look what had been brought to the table. One the one hand, believable gravitational waveforms from multiple orbits of coalescing black hole binaries, checked and now cross-checked by a variety of independent methods and groups. On the other hand, operating interferometers at sites around the globe, collecting data at sensitivities where detecting those black hole waveforms might come any day. (In their back pockets, plans for imminent upgrades of the interferometers that, when completed, might see one of those black hole waveforms EVERY day.)

Not only had each field suddenly reached a new level of maturity and accomplishment, but here were representatives from both sides struggling to understand each other's language in detail, so that the two communities could work effectively together. In real time, I saw numerical relativists adopt the data analysts' "match" parameter as an appropriate measure of error in their calculated waveforms, and gravity wave data analysts learn to read a waveform graph showing $\Psi_4(t)$ instead of $h(t)$.

Watershed moments don't happen often. I've spent twenty-five years working in gravitational wave detection, and I can't recall a scientific conference as transformative as this one. To find a parallel, I have to reach back to my earliest moments in the field, indeed to a meeting that happened before I had even started working in it. When I arrived as a green postdoc in Rai Weiss's MIT lab in the fall of 1981, Rai handed me a copy of the proceedings of the Batelle Seattle Workshop on Sources of Gravitational Radiation, which had been held in the summer of 1978. Reading this proceedings volume was the way that I was introduced to the state of the art of gravitational wave detection, and (at one remove) to many of the people in the field.

The summer of 1978 had been a crucial moment in the history of gravitational wave detection. The community had weathered the controversy over Joe Weber's claims to have detected gravitational waves, and several groups were pressing forward with the new cryogenic bars. In the meantime, the nascent interferometer concept was only beginning to be seen as a possible way forward for the field. The introductory lecture in the Proceedings was a survey of detector technology by Rai Weiss, comparing bars and interferometers on the same basis and against different classes of signals. It clearly makes the bold claim that, if only the interferometer idea can be exploited at its natural scale of multi-kilometer arm length, then a dramatic step in sensitivity could be achieved, enough to make detection of gravitational waves likely.

The early days of numerical relativity are also recorded in several talks in this volume. I'm not the best person to give a summary of those articles, but I'm willing to nominate these words of Larry Smarr as the most prophetic, "This review has only scratched the surface of an immensely complicated subject. I hope it will lead more people to think about these problems and give nonparticipants some flavor of why progress sometimes seems so slow."

One wonderful thing about these Proceedings is that the discussion sessions of the meeting were preserved in semi-verbatim format. The Discussion Session I: Detection of Gravitational

Radiation (transcribed by Reuben Epstein) is a gem. In it, you can see recorded, in real time, the realization that it was a good idea to push interferometers forward. Ron Drever makes the case clearly that interferometers ought to be funded alongside the already well-developed bars. When Steve Boughn raises a sensible caution about proceeding on too many fronts at once, the answers of Ron Drever, Dave Douglass, and Larry Smarr, representing the emerging consensus to move forward with interferometers, are carefully recorded, even down to Boughns undeserved put-down at the hands of Douglass, "I think you will be more optimistic after you get your first cooldown." [laughter] There may have been a long interval yet before LIGO was actually born, but on these pages you can see the gleam in its parents' eyes.

Bob Forward gets the last word of the discussion in 1978, saying "At least now we are able to draw the antenna sensitivity curves and the source [strength] curves on the same graph. Surely [laughter and applause] this means we have come a long way."

In 1978, the field of gravitational wave detection was preparing to consolidate and move forward on two new fronts, interferometric detectors and numerical calculation of waveforms. In 2006, a standing-room-only crowd of scientists again learned to draw sensitivity curves and predicted waveforms on the same scales. Only this time, the ultimate goal is finally in sight.

Unruh and Wald Fest

Carsten Gundlach, University of Southampton cg-at-maths.soton.ac.uk

David Garfinkle, Oakland University garfinkl-at-oakland.edu

"A celebration of the careers and 60th birthdays of Bill Unruh and Bob Wald", held at the University of British Columbia, August 18-20, 2006

The meeting, with about 80 participants, had only four talks per day, with plenty of time for pleasant interactions. The birthday boys helped to pick their own speakers, and apparently felt they could be selective!

Matt Choptuik spoke about "The influence of Unruh and Wald on numerical relativity", a topic of personal interest to your correspondents. Both had long been interested in cosmic censorship. In 1991 Shapiro and Teukolsky famously claimed naked singularity formulation in prolate collapse of collisionless matter because singularities formed in the absence of an apparent horizon, and Wald and Iyer then showed that even slices through Schwarzschild need not have apparent horizons.

Choptuik then embarked on his own detailed study of spherical scalar field collapse, which led to the discovery of critical phenomena in gravitational collapse and a new, relatively "natural" way of creating naked singularities. As a consequence, Hawking conceded his bet with Preskill and Thorne that naked singularities could not form from smooth initial data (for reasonable matter).

In 1993, Gregory and Laflamme conjectured that black strings might become unstable and pinch off to form black holes; this would violate cosmic censorship. Motivated by Horowitz through Unruh, Choptuik, Lehner, Pretorius and Olabarrieta began investigating this numerically in 2003, but the jury is still out.

In 1987 Thornburg wrote up a suggestion of Unruh's now known as black hole excision (although he prefers singularity excision): no boundary conditions are required on a boundary which can be spacelike and stationary at once if it is inside a black hole. This was implemented in 1992 by Seidel and Suen.

Abhay Ashtekar spoke on "The quantum nature of the big bang". This was treated in loop quantum cosmology: a minisuperspace version of loop quantum gravity in which one restricts to a small number of degrees of freedom: in this case Friedmann spacetime with a scalar field so that the degrees of freedom are the scalar field ϕ and the scale factor a. Instead of the Wheeler-de Witt equation one obtains a difference equation for the wave function $\psi(\phi, a)$. This peaks on a semiclassical trajectory which seems to go through a bounce rather than to the big bang singularity. Thus loop quantum cosmology resolves the big bang singularity. It will be interesting to see whether this feature also holds in loop quantum gravity without the minisuperspace approximation.

Jim Hartle spoke on "What's wrong with your quantum mechanics?" He imagined the objections that Bill and Bob, universally asknowledged as deep thinkers and fierce critics, might have to the Gell-Mann-Hartle consistent histories interpretation of quantum mechanics. For each objection, he then presented his response. His message was that *his* quantum mechanics is as applicapable to the whole universe as it is to any ordinary quantum mechanical system. In each case, we divide the possible outcomes for the system into "approximately decohering coarse grained histories" and use the quantum state and the rules of quantum mechanics to find the relative probability of each history.

Roger Penrose gave a public evening lecture “What happened before the big bang?” He pointed out the puzzle of the very special initial conditions of the universe and speculated that these might be connected to the final conditions of a system that has radiated away all of its degrees of freedom.

Kip Thorne gave a review talk on “Quantum non-demolition” which was both rich in historical detail, with much USA-USSR interaction and competition, and quite technical. The field started with the calculation by Braginsky in 1967 of the (standard) quantum limit for a gravitational wave detector, motivated by the experimental work of Weber. He stressed the crucial importance of two unpublished talks Unruh gave in Bad Bentheim in 1981 which changed the focus from the measurement of detector position to that of the classical force, which can be measured to arbitrary accuracy. One current focus of the field is to use LIGO to measure quantum mechanical effects on macroscopic objects such as the mirrors.

Wojciech Zurek gave a review on the “Emergence of the classical world” from quantum mechanics. He reviewed the Everett interpretation in the light of the key questions “what is the preferred basis?” and “why are probabilities the amplitude squared of those states?”.

Ted Jacobson gave a talk on “Black hole entropy.” Wald and Parker showed in 1975 that Hawking radiation is in a thermal state. Unruh showed that the key ingredient is the horizon. Even an accelerated observer, who only has an “acceleration horizon,” sees thermal radiation. Bekenstein proposed that black hole entropy counts the ways in which a black hole could have formed. But how does thermodynamics know about this? Jacobson noted that the Hawking radiation has entropy of its own and therefore must contribute something to the black hole entropy. He then considered the possibility that the entropy of the radiation *is* in fact the entire black hole entropy. A calculation of the contribution of the radiation to the total entropy involves a cutoff and so the answer seems to hinge on the appropriate value of the cutoff to use. At present, it is not clear what that appropriate value of the cutoff is, so it is not clear whether the contribution of the Hawking radiation to the black hole entropy is negligible, as had been assumed, or dominant, as Jacobson seems to think likely.

Dick Bond gave a review talk on “Inflation, gravitational waves and the cosmic microwave background (CMB).” Currently all observations are compatible with cold dark matter and a simple cosmological constant, and large-scale structure seeded by scale-invariant Gaussian density fluctuations seeded by inflation. But much sophisticated observation, analysis and modelling is behind this simple result, and the limits on inflation history and the dark energy equation of state are getting better. One new big goal is to see primordial gravitational waves, through their interaction with CMB photons.

Ralf Schützhold spoke on “Effective horizons in the laboratory.” He noted that though black hole evaporation for stellar mass black holes is too small for us to hope to measure it, there should be analogs of the Hawking effect that are within reach of laboratory experiments. These take place in optical systems and in fluid systems where the medium is moving faster than the wave propagation speed. He presented the most promising such systems and for each system the most promising of the experimental techniques that might be used to detect the analog of the Hawking effect in that system.

Stefan Hollands talked on “Quantum fields in curved spacetime.” He emphasized that many of the ingredients used in specifying a quantum field theory in flat spacetime (spacetime symmetries, natural vacuum state, Euclidean methods, momentum space, S matrix, etc.) are simply absent in curved spacetime. One must therefore use completely different methods for quantum fields in curved spacetime, and Hollands and Wald advocate an algebraic approach that concentrates on the algebra of field operators and views quantum states as simply linear maps from the algebra to the complex numbers. It has been known for some time how to do this for free field theory; however it is only with the recent work of Hollands and Wald that the groundwork has been laid for treating perturbative interacting quantum fields in curved spacetime. In particular, this work allows one to make sense of products of field operators. These algebraic methods also allow one to formulate criteria for physically reasonable quantum states.

Gary Horowitz talked about "Surprises in black hole evaporation." He noted that the standard picture of black hole evaporation within general relativity is that a black hole gives off thermal radiation until it reaches the Planck scale. However, string theory takes place in more than 4 spacetime dimensions and involves extended objects. This gives rise to new possibilities. There are higher dimensional analogs of black holes: black strings and black branes, which can be wrapped around extra spatial dimensions. The horizon can then contain a topologically nontrivial circle. Hawking radiation causes the size of this circle to decrease. When it becomes small enough, there is a tachyon instability. This instability is due to certain modes of the string and causes a change in topology. In the resulting spacetime the black hole is replaced by a "bubble of nothing" and simply disappears. This can occur when the curvature at the horizon is still small compared to the Planck scale.

Cliff Will Birthday Symposium

Eric Poisson, University of Guelph poisson-at-physics.uoguelph.ca

Clifford Will is 60! announced the webpage dedicated to this Symposium, which was held in Saint Louis on Sunday, November 19th 2006, just a few days after Cliff's birthday (November 13th). The Symposium came at the end of the 16th Midwest Relativity Meeting, an always popular event during which all researchers, junior and senior, contribute talks of 15 minutes. It says something about Cliff's standing in the field that this was probably the best attended Midwest Meeting in history, with over 90 participants. The Midwest Meeting was organized by Wai-Mo Suen, Emanuele Berti, Jian Tao, Han Wang, and Hui-Min Zhang from the Department of Physics at Washington University in Saint Louis. The Symposium was organized by Wai-Mo Suen, Richard Price, Bernard Schutz, Ed Seidel, Sándor Kovács, and Alan Wiseman. The Symposium featured hour-long talks by invited speakers Bernard Schutz, Luc Blanchet, Joseph Taylor, Francis Everitt, and Kip Thorne. There was plenty of time between talks for coffee, discussion, and poking fun at Cliff.

The first talk of the morning was by **Bernard Schutz**, who gave what he called the "history talk," an overview of Cliff's career. The talk was titled **Will and Testament**, and it covered Cliff's undergraduate-student days at McMaster University in Hamilton, Canada, his graduate-student days at Caltech (working with Kip, of whom Cliff had never heard before arriving at Caltech — he only sought him out on the advice of fellow Canadian graduate students), his postdoc-days at the University of Chicago (working with Chandra), his assistant-professor days at Stanford University (where he didn't get tenure — see below), and his distinguished career at Washington University in Saint Louis, where Cliff is now James S. McDonnell Professor of Physics. At the end of Bernie's talk, a member of the audience asked whether Cliff had ever been known to be wrong on a serious issue. Bernie answered that to his knowledge, this had never happened. At this moment Leslie, Cliff's wife, raised an eager hand and offered to present many examples of Cliff being in error. The offer was declined, but Cliff explained: "*My students are frequently discouraged by the fact that, when we are in the middle of some complicated post-Newtonian calculations and have a disagreement over the coefficient of some term, I am almost always right. So I tell them not to worry: at home, I've been right 67 times, while my wife has been right 2,782,193 times.*"

The second talk of the morning was given by **Luc Blanchet**, who reviewed **The Wonders of the Post-Newtonian**. This was a fascinating talk during which Luc described the enormous progress that has been accomplished in the last 15 years in the post-Newtonian theory of two-body motion and gravitational-wave generation. This effort has been pursued by a number of people around the world, with Cliff and his collaborators playing an essential role. Among the results obtained by these theorists is this impressive formula that gives the rate at which a two-body system in circular motion loses energy to gravitational radiation:

$$\begin{aligned}\frac{dE}{dt} = \frac{32c^5}{5G}\nu^2 x^5 \Big\{ & 1 + \left(-\frac{1247}{336} - \frac{35}{12}\nu\right) x + 4\pi x^{3/2} + \left(-\frac{44711}{9072} + \frac{9271}{504}\nu + \frac{65}{18}\nu^2\right) x^2 \\ & + \left(-\frac{8191}{672} - \frac{583}{24}\nu\right) \pi x^{5/2} \\ & + \Big[\frac{6643739519}{69854400} + \frac{16}{3}\pi^2 - \frac{1712}{105}C - \frac{856}{105}\ln(16\,x) \\ & \quad + \left(-\frac{134543}{7776} + \frac{41}{48}\pi^2\right)\nu - \frac{94403}{3024}\nu^2 - \frac{775}{324}\nu^3\Big] x^3\end{aligned}$$

$$+\left(-\frac{16285}{504}+\frac{214745}{1728}\nu+\frac{193385}{3024}\nu^2\right)\pi x^{7/2}+\mathcal{O}\left(\frac{1}{c^8}\right)\Bigg\}.$$

Here $x = (GM\omega/c^3)^{2/3}$ is a parameter (defined in terms of the orbital frequency ω and the system's total mass $M = m_1 + m_2$) that loosely represents $(v/c)^2$, the squared ratio of orbital velocity to the speed of light, $\nu = m_1 m_2/M^2$ is a dimensionless mass ratio, and $C \simeq 0.577$ is Euler's constant. The hope is that the observational consequences of this energy loss, which are manifested in the phasing of the gravitational wave, will be verified by gravitational-wave detectors. This will constitute a powerful test of general relativity, and as Luc pointed out, an alternative way of measuring the mathematical constants π and C.

The third and final talk of the morning was given by Nobel laureate **Joseph Taylor**. In his talk, titled **Using and Testing Relativity With Pulsars**, Joe reviewed the exciting history of binary pulsars, which started in 1974 with his discovery (with then graduate student Russell Hulse) of PSR 1916+13, and which has taken a recent spectacular turn with the December 2003 discovery of the double pulsar PSR J0737-3039. The handful of relativistic binary pulsars that have been discovered to date have allowed sensitive tests of general relativity to be performed, tests that probe strong-field and radiative aspects of the theory. Nature could not have been more kind to relativists! During his talk, Joe displayed the abstract page of the first grant proposal in which he described plans for a systematic search for radio pulsars; on this page appears a throw-away comment to the effect that it would be a wonderful discovery if a pulsar could be found within a binary system... Joe also recalled the stimulating discussions he had at Stanford, with Cliff and Bob Wagoner, on the theoretical implications of his recent discovery.

The Symposium then broke for a group picture and lunch. (I went with Cliff, Larry Kidder, and Patrick Brady to a nice place on Delmar Boulevard. I had the chicken.) It resumed in the afternoon with a talk by **Francis Everitt**, titled **Space, Gravity Probe B, and Clifford Will**, in which he reviewed the long history of GPB, as well as the exciting developments that followed its launch in April, 2004. The scientific goal of Gravity Probe B is to measure, for the first time, the precession of test gyroscopes that is produced by the gravity associated with Earth's rotational motion, thereby testing the important relativistic prediction of frame dragging. Francis described the effort that is now underway to analyze the terabyte of experimental data that has been received from the probe to date. He did not report results; for this we will have to wait until the April 2007 meeting of the American Physical Society. Francis also explained Cliff's involvement in the project, mostly in his role as Chair of the NASA Science Advisory Committee for Gravity Probe B.

The second talk of the afternoon was given by **Kip Thorne**. In **Will and Waves**, Kip went a little deeper into historical matters and recounted Cliff's scientific activities as a graduate student. After Cliff spent some time talking with various researchers at Caltech and JPL, he and Kip concluded that the time had arrived (this was 1970) for a new generation of quantitative tests of general relativity. Cliff started to think about a theoretical framework that would facilitate the interpretation of the data, and would allow many alternative theories to be contained within a unified package. In a rapid burst of intense activity, he generalized the parameterized post-Newtonian (PPN) framework that was introduced a few years earlier by Ken Nordtvedt (building on earlier work by Eddington, Robertson, Schiff, and others), and he proceeded to explore its consequences. Cliff's version of the framework included a larger set of free parameters, and it was based on a hydrodynamical description of the matter instead of Nordtvedt's point-mass description.

In a period that started on August 24, 1970 and ended on May 1, 1972, Cliff published 7 papers on this subject, a total of 105 pages in the *Astrophysical Journal*. (And Cliff got married to Leslie just two months before! During his talk, Kip asked Cliff to describe his honeymoon, but Cliff refused to comply.) In a first sequence of papers (Theoretical Frameworks for Testing Relativistic Gravity I, II, and III) he fleshed out the theoretical aspects of the PPN formalism. In a second sequence of papers (Relativistic Gravity in the Solar System I and II — III was submitted when Cliff was a postdoc in Chicago) he compared its predictions with astronomical data and placed bounds on the free parameters. The mature form of the PPN framework, as it is now displayed in Chapter 39 of Misner, Thorne, and Wheeler, was presented in a third sequence of papers (Conservation Laws and Preferred Frames in Relativistic Gravity I and II) co-authored with Nordtvedt. Not bad for a mere graduate student!

Kip went on to describe the reasons why Cliff was not granted tenure at Stanford, a topic that was alluded to by a number of speakers at the Symposium. According to Kip, Stanford's standard for granting tenure was that a candidate had to be one of the top three people working in the field. Kip was asked to comment on Cliff's standing within his peer group. As defined by Stanford, the peer group included Roger Penrose, Stephen Hawking, and Kip Thorne himself. . . Cliff was not granted tenure, but Stanford's loss was WashU's gain.

The last word of the Symposium was left to the man himself: **Clifford Will**. During his **Parting Shots**, Cliff acknowledged the long list of people (colleagues, postdocs, students) with whom he has collaborated and interacted in the course of his career. He remarked that "*what is so great about a career in gravitational physics is the science and the people, rather than the money or the power. I've noticed over almost 40 years in the business that our field seems to have fewer than its share of arrogant, mean-spirited, power-mad individuals, compared with other fields of physics. I attribute this partly to the history of the field. For so long general relativity was thought to be an irrelevant subject, in the backwaters of physics and astronomy, so people who were full of themselves, or out for the glory, would not find it attractive. Now that gravitational physics has re-entered the mainstream of physics, and has even taken on some of the characteristics of 'big science,' with things costing hundreds of millions, like Gravity Probe B and gravitational-wave observatories, I hope that this will not change, and that the field will continue to be populated by the kinds of wonderful colleagues and friends I have encountered over my career.*" Well said.

This concludes my description of the scientific component of the Symposium. The event, however, included also a personal component, in the form of a banquet for friends and family that took place on the Saturday evening. (I had the chicken.) Cliff was paid a moving tribute (in song) by the members of his family (daughters, sons-in-law, and grandchildren) and was gently roasted by a group of his Saint-Louis friends, who complained that he spends way too much time in Paris. He was also (more vigorously) roasted by Alan Wiseman, who described Cliff's tough-love approach toward the mentoring of graduate students. (On a draft of an early research article written by Alan, Cliff crossed out his own name, explaining that he did not want to be associated with that piece of shit. I think he was kidding.)

The banquet's keynote act was a performance by **Clifford and the Silvertops**, a group of illustrious singers (also known as Bernie and the Gravitones) consisting of Bernard Schutz (sporting a fake mustache, singing lead, and playing the role of Clifford), Richard Price, Sándor Kovács, and Kip Thorne (all with white-powdered hair). To the tune of Paul Anka's My Way, they sang

Where there's a Will there's a way

It's **been** a long time **now**
I've **work'd** with Einstein's **theor**y
With **work** and more work, **wow**
No wonder **why** I am so **wear**y

They **asked** was Einstein **wrong**
I told them **no** and I earned **high** pay
For **math** so very **long**
To do it **his** way [The singers point at a lifesize picture of Einstein.]

New **jobs** I've had to **face**
But as to **change** I now say **foo**ey
I **stay**, stay in one **place**
I stay in **France**, I mean Saint **Loo**ey

Geepee **bee**, and geepee **ess**
Gee, whiz I **guess** that we can **now** say
Na**ture** has passed the **test**
She did it **his** way

When I was **young**, Newton was **all**
But then came **post**, and that's not **all**
After the **post**, a host more **post**
Until I **thought** that I was **toast**
A billion **terms**, a can of **worms**
To do it **his** way

Up **north** people are **few**
We almost **never** [5 silent beats] spoke
But **here** to be a **jew**
They made me **learn** to tell a **bad** joke

I've **friends**, I think I **do**
And colleagues **some** who made my **hair** grey
So **long**, so long a**go**
Doing it **his** way

I ruled the **field**, and here's the **thing**
My work, my **book**, I was a **king**
I was the **star** where'er I'd **roam**
But time to **time** I would come **home**
Home to my **life**, home to my **wife**
To do it **her** way [The singers point at Leslie.]

The lyrics to this great song were written by Richard Price, and they are reproduced here with his kind permission. The bold words are emphasized (held longer) to keep beat with the music.

I'll close this report with a personal note. I have a vivid memory of the time when Cliff offered for me to come to Saint Louis and work with him as a postdoc. I was overjoyed! After my time at Caltech this was where I most wanted to be. It has been my great fortune and privilege to work with Cliff, and I am proud to count him as a friend. I am very glad to have been a participant at this Symposium, and I wish Cliff a very happy 60th birthday.

[I thank Richard Price for his permission to reproduce the song's lyrics, and Clifford Will for providing me with the italicized quotes. I thank them both for fact-checking an earlier draft of this report and providing suggestions for improvement.]

Brane-World Gravity: Progress and Problems

Andrew Mennim, University of Portsmouth Andrew.Mennim-at-port.ac.uk

The Institute of Cosmology and Gravitation hosted a two-week international conference at the end of September on the subject of brane-world gravity. The conference began with a three-day meeting which was followed by a workshop; about 80 delegates attended. The programme and slides from most of the talks can be found on the conference website, the URL for which is `http://www.icg.port.ac.uk/brane06/`

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

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

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

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

The local organising committee (Kazuya Koyama, Andrew Mennim and Sanjeev Seahra) would like the thank David Langlois, Roy Maartens, Kei-ichi Maeda, Lefteris Papantanopoulos, Misao Sasaki and David Wands for their help in the organisation of the conference; and the Institute of Physics, and the Particle Physics and Astronomy Research Council for providing financial support.

Workshop on Gravity and Theoretical Physics

Marco Cavaglia, University of Mississippi cavaglia-at-phy.olemiss.edu

The second School & Workshop on Gravity and Theoretical Physics was held at the main campus of The University of Mississippi (Oxford, MS) on January 8-11, 2007.

The purpose of this meeting, the second in a series, was to to bring together researchers and graduate students to exchange ideas on field theory, gravity and related areas. The program consisted of a series of lectures from faculty and senior researchers and shorter talks by graduate students, who were given the opportunity to present their current research. About 20 participants from Mississippi, Alabama and Kentucky attended the workshop. No registration fee was charged and all talks were open to the public. A visit to William Faulkner's Rowan Oak and the local University museum were part of the social activities. This event was possible thanks to the generous support of the Department of Physics and Astronomy of The University of Mississippi.

School lectures were given by Keith Andrew and Brett Bolen (Western Kentucky U.), Luca Bombelli, Vitor Cardoso, Marco Cavaglia and Itai Seggev (U. Mississippi), Lior Burko (U. Alabama - Huntsville) and Ben Harms (U. Alabama - Tuscaloosa). Main topics included finite temperature field theory, statistical geometry, gravitational waves and black hole physics. Student talks covered a wide range of issues, ranging from non-commutative physics to extra-dimensional models and gravitational radiation. The program and the presentations delivered in digital format are available at the school webpage `http://www.phy.olemiss.edu/GR/gravity07/`

The University of Mississippi plans to make this an annual event, with the next school tentatively scheduled for January 2008. For further information, please contact Marco Cavaglia (cavaglia@olemiss.edu).