MATTERS OF GRAVITY

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Editor

Jorge Pullin

Center for Gravitational Physics and Geometry
The Pennsylvania State University
University Park, PA 16802-6300
Fax: (814)863-9608
Phone (814)863-9597
Internet: `pullin@phys.psu.edu`
WWW: `http://www.phys.psu.edu/~pullin`

Editorial

I wanted to remind people to sign up and keep current their membership in the Topical Group in Gravitation. Our membership was oscillating around 600, and we need 1200 to become a division. Please talk to your friends and colleagues in the area about joining.

The next newsletter is due February 1st. If everything goes well this newsletter should be available in the gr-qc Los Alamos archives under number gr-qc/yymmnnn. To retrieve it send email to gr-qc@xxx.lanl.gov (or gr-qc@babbage.sissa.it in Europe) with Subject: get yymmnnn (numbers 2-8 are also available in gr-qc). All issues are available in the WWW:
`http://vishnu.nirvana.phys.psu.edu/mog.html`
A hardcopy of the newsletter is distributed free of charge to the members of the APS Topical Group on Gravitation. 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

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Does the GSL imply an entropy bound?

Warren G. Anderson, University of Wisconsin-Milwaukee
warren@ricci.phys.uwm.edu

Recently, a number of papers have appeared on the gr-qc preprint archive concerning entropy bounds imposed on matter by the generalized second law of thermodynamics (GSL) for spinning and charged black holes[1]. However, the question of whether the GSL implies the existence of such bounds, even for the simple case of a Schwarzschild black hole, is still being debated in the literature. This question, first raised by Bekenstein[2] almost 30 years ago, arises from a *gedankenexperiment*. The goal of this article is to review this experiment and the key results which comprise our current understanding of whether or not the GSL implies an entropy bound for matter.

Let us begin by recalling the GSL: any process involving matter with entropy S_{matter} exterior to a black hole of area $\mathcal{A}$ should satisfy $\delta S_{matter} + \delta S_{BH} \geq 0$, where $S_{BH} = \mathcal{A}/4$ is the Bekenstein-Hawking black hole entropy. The central premise of all the papers reviewed here is that this law should be valid.

Now, consider a *gedankenexperiment* involving a black hole (area $\mathcal{A}$) and a box of proper height b and cross-sectional area A. Far from the black hole, the box is filled with matter, so that the total energy of the box and contents is E and its total entropy S. The box is then lowered adiabatically toward the black hole, so that its entropy S remains constant. Its energy as measured by a distant static observer, E_∞, however, does not; the box is doing work on the agent that is controlling the lowering process. This work is subtracted from the box in the form of a redshift. When the box is a proper height ℓ above the horizon, the energy in the box as measured at infinity is therefore $E_\infty(\ell) = \chi(\ell)E$, where $\chi(\ell)$ is the redshift factor.

Suppose that the box is lowered until it nearly touches the black hole. This is, of course, physically impossible, since the box and/or rope will fail mechanically before this can happen. However, for simplicity we consider this limiting case. In this limit the box is an average proper distance $\sim b$ from the horizon, and the energy of the box is $E_\infty(b) \approx E\ b\ \sqrt{\pi/\mathcal{A}}$. If the box is then allowed to fall freely into the black hole, the entropy of exterior matter will be reduced by $\delta S_{matter} = -S$, but the entropy of the black hole will increase by $\delta S_{BH} = 2\ E_\infty(b)\ \sqrt{\pi \mathcal{A}}$. Putting these entropy changes into the GSL, one gets

$$S/E \leq 2\pi b. \tag{1}$$

This inequality, originally derived by Bekenstein[2], seems to imply a new law of nature: that any matter of energy E confined to a volume whose smallest dimension is b has a fundamental upper bound on its entropy.

The derivation of this bound, however, depends on the box continuing to do work on the lowering agent all the way to the horizon. If this is not the case, the bound might be modified, or even removed. About a year after Bekenstein proposed bound (1), Unruh and Wald[3] pointed out that quantum effects could indeed alter the work done by the box, and hence the entropy bound.

The Unruh-Wald argument goes as follows: an adiabatic lowering process is quasi-static, and can therefore be treated as a sequence of static (i.e., accelerating) boxes. Accelerating observers see the quantum vacuum as a bath of thermal radiation, whose temperature is proportional to the acceleration. Since the bottom of the box is closer to the black hole than the top, it must have a greater acceleration to remain static. Thus, the bottom of the box is exposed to hotter radiation than the top, creating a net upward pressure. This pressure gradient buoys the box against gravity, reducing the net work done by the box on the lowering agent. In fact, since the acceleration (and hence temperature) diverges at the horizon, near the horizon the lowering agent would have to do work on the box (push the box) in order to lower it further. Thus, at some distance above the horizon, where the box stops doing work and the lowering agent starts doing work, the box must float freely above the black hole. Just as for Archimedes' buoyancy, the box floats when its energy is equal to the energy of the displaced fluid (i.e., acceleration radiation).

For a buoyant box, Unruh and Wald[3] showed that the box contributes the minimum entropy to the black hole when dropped from the floating point. For macroscopic boxes, this point is very close to the black hole[4], so we do not avoid the issue of mechanical instability, but again let us consider the limiting case (floating box) since this will minimize the entropy gain for the system. In this limit, the minimum change in black hole entropy is[3]

$$\delta S_{BH} = \frac{A}{T_{bh}} \int_0^b [\rho(l_0, y) - \rho_{ar}(l_0, y)] \chi(l_0 + y) dy + S_{ar}, \tag{2}$$

where T_{bh} is the Hawking temperature of the black hole, ρ and ρ_{ar} are the energy densities of the box and the acceleration radiation respectively, l_0 is the proper height of the bottom of the box above the black hole at the floating point, and S_{ar} is the entropy of the acceleration radiation displace by the box.

Interpretation of Eq. (2) is not difficult. It simply states that the minimum change in black hole energy ($S_{BH}\ T_{bh}$) due to an adiabatically lowered box is the energy of the box at the floating point ($\int \rho dV$) minus the work done by the box against the buoyancy force of the acceleration radiation during lowering ($T_{bh} S_{ar} - E_{ar}$). This interpretation seems reasonable, and until recently Eq. (2) has been accepted as correct in the literature (I will deal with a recent exception a bit later in this article).

However, the conclusions that can be drawn from Eq. (2) regarding entropy bounds seem to depend heavily on the nature of the acceleration radiation (i.e., on ρ_{ar} and S_{ar}). In particular, the crucial assumption seems to be the following: since acceleration radiation is thermal, it should have the maximum entropy density at any given energy density. If this is the case, it has been shown that Eq. (2) implies the GSL without assuming a bound such as Eq. (1)[3,5,6] (although Eq. (1) itself may follow from this assumption together with some other plausible assumptions about the acceleration radiation[6]). Conversely, in those papers[2,4,7] where this maximal entropy density assumption is not made, the GSL is shown to be violated unless an entropy bound exists.

That the resolution of the entropy bound question rests on properties of acceleration radiation is slightly troubling, because in some senses this radiation is not physical. For instance, even though the vacuum expectation value of the stress-energy tensor for an electromagnetic field in Minkowski space vanishes, accelerating observers see that vacuum as a thermal bath of photons. However, these photons clearly carry no energy or momentum on average. One must therefore be careful as to the properties one requires of acceleration radiation.

Recently, Bekenstein[8] has placed even more emphasis on the nature of acceleration radiation. He has pointed out that since the temperature far from the black hole is low, the average wavelength of the radiation can be longer than the height of the box. Therefore, he argues, the acceleration radiation will not behave like a fluid there; rather, one should treat the interaction of the radiation with the box as a scattering process. This can significantly reduce the buoyancy, causing Eq. (2) to be modified. He then finds that an entropy bound of the form (1) is necessary to preserve the GSL, even if the acceleration radiation is assumed to be maximally entropic.

If it is troubling to invoke the properties of acceleration radiation in resolving questions about this *gedankenexperiment*, one might ask how such questions can be resolved in an observer independent way. Such a resolution was originally provided by Unruh and Wald[3], and somewhat elucidated later[9], although it has not played a part in the recent literature. The resolution lies in the fact that accelerating surfaces emit quantum fluxes. These fluxes can have negative energy, and it is just such a flux that is created inside the box due to its accelerating walls. As the box is lowered the energy in the box decreases, since the *negative* energy deposited in the box by the quantum flux is added to the energy density of the box itself. This negative energy is just what one would have to add to the acceleration radiation in order that an initially empty box, lowered adiabatically toward the black hole, should continue to look empty to an observer accelerating with the box. In other words, it preserves the adiabatic vacuum (Boulware) state inside the box. In this picture, the box floats because the negative energy of the accelerating vacuum inside the box cancels the positive energy of the box itself.

Most interestingly, Eq. (2) can be derived by the quantum flux analysis as well. One might suspect, therefore, that this analysis needs to be modified so as not to be at odds with Bekenstein's calculation of the the scattering of acceleration radiation at low temperatures[8]. A natural modification which might be analogous to the scattering process would be the exclusion of long wavelength components of the flux due to the scale set by the size of the box. However, at least in two-dimensional examples, it can been shown that Eq. (2) follows from an exact analysis, regardless of any exclusion of long wavelength components[3]. The question of understanding Bekenstein's modification to (2) without invoking acceleration radiation therefore seems to be open. It is open questions such as this that will need to be resolved before we can truly understand whether or not the generalized second law of thermodynamics implies an entropy bound.

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A lightweight review of middleweight black holes

Ben Bromley, University of Utah
bromley@physics.utah.edu

The observed distribution of black hole masses has a well-known gap. On the one hand we have "black hole candidates" in our own Galaxy with inferred masses between 3 and $10\,M_\odot$, and on the other, there are supermassive black holes which lie in the centers of many, if not most, galaxies with mass in the range of 10^6 to $10^9\,M_\odot$. The mass gap would be filled by "middleweights" of a thousand $M_\odot$, give or take a couple of orders of magnitude.

There are several reasonable ways to form middleweight black holes, including merging of solar-mass black holes in star clusters (Lee 1995), or even more directly from gravitational collapse of density fluctuations in the primordial ooze (Haiman, Thoul & Loeb 1996), although these mechanisms can be suppressed to some degree by supernova-driven ejection of matter. Yet until recently, there was virtually no evidence for the existence of middleweights. This might just be a selection effect: We find black hole candidates in X-ray binary systems because they are local and have a steady source of luminous matter flowing from a companion star. Supermassive holes, the central engines in active galactic nuclei, are observed because they are very bright, feeding off of the gas-rich environments in the centers of galaxies. In contrast, it is unclear what, if any, reservoirs of luminous matter might surround middleweights.

Within the past year, the observational situation changed dramatically. Two groups, Ptak & Griffiths (1999) and Colbert & Mushotzky (1999), reported data which suggest the presence of middleweight black holes in nearby galaxies. Ptak & Griffith used the ASCA satellite to measure the hard X-ray spectrum of the starburst galaxy M82. A compact X-ray source detected in the central region of the galaxy has a luminosity which is two orders of magnitude larger than the brightest black hole candidate, and two orders of magnitude dimmer than a typical active galactic nucleus. Assuming that the accretion flow onto the source is at the Eddington limit, the observed luminosity corresponds to a mass of $460\,M_\odot$.

The Eddington limit does rule out solar-mass black holes, however, it is plausible that the X-ray source is just an unusually dim active galactic nucleus harboring a supermassive hole. Future high angular resolution observations of soft X-rays from an accretion disk around this source (by the Chandra X-ray Observatory, for example) might help distinguish a middleweight from an "ordinary" supermassive hole.

Colbert & Mushotzky used a combination of ROSAT X-ray imaging data and ASCA spectroscopy to examine X-ray sources in 21 nearby galaxies. They determined that a half dozen or so objects in the sample show X-ray emission from compact sources well away from the photometric center of their host galaxies. This adds some spice into the mix since some of these sources also have high luminosities and hence high Eddington masses. A suggestion that these sources are just unusually quiescent active galactic nuclei is significant, since it would be interesting to observe nuclear activity well outside the galactic nucleus.

Of the 21 objects in the sample, ASCA yielded hard X-ray spectra from three spiral galaxies and three ellipticals. The X-ray sources in the ellipticals are all coincident with the photometric centers (within positional errors). While their spectra show features similar to Galactic X-ray binaries, the luminosities are more than an order of magnitude higher, suggesting at least middleweight black holes. However, low-luminosity active galactic nuclei should not be ruled out. In two of the three ellipticals, Hubble Space Telescope observations of circumnuclear disks indicate the presence of supermassive black holes of more than $10^8\,M_\odot$. We may not be able to say much, it seems, from the X-ray flux alone.

The spirals discussed by Colbert & Mushotzky perhaps make for better candidates as hosts of middleweight black holes. Two of them, NCG 1313 and NGC 5408, have an extranuclear X-ray source that is roughly a kiloparsec away from the photometric center of the galaxy. These objects have X-ray fluxes which are also about an order of magnitude greater than expected from known X-ray binaries containing a black hole candidate. The lack of any other evidence for behavior typical of active galactic nuclei, plus the dynamical awkwardness of placing a supermassive black hole in the suburbs of otherwise normal galaxies lends some credence to the idea that the sources are middleweights.

What could be wrong with the middleweight interpretation? The Eddington luminosities suggest mass limits of roughly $10\,M_\odot$, hence the sources might only be pushing the boundary of what we now consider normal black hole candidates of stellar origin (e.g., Fryer 1999). Other possibilities include superluminous sources from which Eddington limits are not useful, and X-ray supernovae which can remain at constant brightness for periods of years. However, sub-Eddington accretion onto a middleweight is reasonable, and with luminosities at a percent or even a tenth of the Eddington limit, the mass of the black holes in NCG 1313 and NGC 5408 becomes interesting.

A middleweight black hole sounds at first like a gift from the heavens for the earth based gravity wave detectors. The frequency of peak sensitivity for these detectors corresponds to strong field processes for holes of a hundred or so $M_\odot$ (Flanagan & Hughes 1998). But middleweights need more than mere existence to be the most fascinating objects in the gravitational night sky. The middleweights must also take part in some process that generates strong waves. The inspiral and plunge of a stellar mass compact object (hole or neutron star) would produce waves of the right frequency, but relatively low amplitude. What would be ideal would be the merger of two middleweights, perhaps as a step toward the formation of a supermassive hole. Whether this is a plausible astrophysical scenario, or a gift that the heavens won't deliver, depends on what sort of processes produce the middleweights, and what astrophysical neighborhoods they inhabit. These questions will be studied in the coming year, but near term answers are likely to be very speculative.

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The physics of isolated horizons

Daniel Sudarsky, ICN-UNAM, Mexico
sudarsky@nuclecu.unam.mx

In the last couple of years there has been substantial progress in various paths toward the elucidation of the deep relationship that emerges in the study of the classical dynamics of black holes, the behavior of quantum fields in background black hole spacetimes, and the ordinary laws of thermodynamics. One of the most successful is the String Theory program which has produced a detailed evaluation of the statistical mechanical entropy of some extremal and near extremal stationary black holes, through the relation of these objects with a certain class of states in the weak gravity sector of the theory. This last feature is what makes the approach somehow unsatisfying to some researchers approaching the question from the gravity point of view, who would like to know, for example, where do the degrees of freedom that account for the black hole entropy reside? i.e., the horizon's surface? its exterior? its interior?.

The second program that has met recently with substantial success is the nonperturbative quantum geometry program also known as "loop quantum gravity" [1].The first step has been to both, generalize and properly define the sector of the theory that is going to be treated. In doing so, Ashtekar and his colleagues [3][4], were guided by the need to start with a well defined action that would be differentiable in the sector under consideration. This leads to the specialization of the notion of Trapping Horizons [2] of Hayward's to that of Isolated Horizons [3] . Physically the idea is to represent "horizons in internal equilibrium and decoupled from what is outside". Essentially, an isolated horizon is defined to be a null 3 surface Δ, with topology $S^2 \times R$, with nonexpanding null tangent vector field l^a which is also a Killing field for the induced metric on Δ, foliated by a preferred set of 2-spheres $\{S\}$ that are marginally trapped, and such that the induced metric on each S is spherically symmetric. The definition includes also the requirement that the horizon be nonrotating which demands among other things that the second null vector field that is normal to the 2-surfaces S of the isolated horizon n^a, be shear free and have a spherically symmetric expansion. Moreover, in defining the class of spacetimes containing isolated horizons one requires that the field equations be satisfied on the horizon, (not so elsewhere in the spacetime).

Here, we must point out that the spacetimes themselves are not assumed to have any Killing field, not even in a neighborhood of the horizon, and as such the class is extremely large, in contrast, say, with the 3 parameter class of stationary black hole solutions of Einstein Maxwell theory, as they include for example black hole spacetimes with nonstationary matter or gravitational waves in the exterior (in these cases the horizon will be isolated for as long as those nonstationary components have not crossed the horizon). Moreover, given that the definition of isolated horizon is semilocal and does not rely, for example, in the existence of asymptotic null infinity, the class of spacetimes containing isolated horizons is not limited to the asymptotically flat case and includes for example cosmological examples such as de Sitter spacetime. The crucial point of the definition is that it is possible to add a surface term to the usual bulk action of general relativity, possibly coupled with suitable matter fields like Maxwell and scalar fields such that the action is differentiable within the corresponding class of spacetimes. This is analogous to the usual addition of a surface term to the bulk action of general relativity on manifolds with boundary formulated in terms of the spacetime metric in such a way that it becomes differentiable on the class of spacetimes with a fixed value of the metric on the manifold boundary. This is a very important, and nontrivial point for the quantization program, because one needs to start with a classical action and configuration space from which one can extract not only the equations of motion but also the symplectic form. This can be achieved through a well defined procedure, once such a differentiable action is provided [5]. The surface term that must be added when the spacetimes under consideration are taken to have an isolated horizon as one of its boundaries and when the gravitational variables are taken to be the soldering form and the spin connection, turns out to be the Chern Simons action for a $U(1)$ connection on Δ. The term itself depends on the value of the horizon area, thus the action is appropriate for a class of spacetimes with fixed horizon area A.

Obviously, if the class of spacetimes under consideration allows other boundaries, one must add the corresponding surface terms to ensure differentiability of the action within the class. The fact that such a differentiable action exists seems to depend completely on the choice of the physical boundary conditions and not so much on the choice of variables, as long as the action is a first order action as in the Palatini formulation.

Equipped with the above structure the procedure to get a Hamiltonian Formulation is straight forward, i.e., consider a foliation of spacetime (which is assumed to have the topology $\Sigma \times R$), introduce lapse and shift and identify the canonical variables, which in this case include, in addition to the ordinary Hamiltonian variables of bulk gravitational sector and possibly the matter fields, the projection of the $U(1)$ connection on the intersection on the isolated horizon with the hypersurface Σ. Thus one has an adequate formulation corresponding to a phase space Γ_A associated with configurations with a fixed value A for the area of the isolated horizon.

The stage is set to look at the "thermodynamics" of these isolated horizons. The first step is to define a notion of surface gravity which at first sight seems to be straight forward given the existence of a null Killing field for the metric of the isolated horizon, however one immediately faces the problem of choice of normalization for this vector field. In the case of stationary black holes, this task is accomplished through the normalization of the Killing fields at asymptotic infinity, and thus, the same strategy is unavailable in the isolated horizon case, because no such Killing field is in general available for the whole spacetime (in general, there is not even an asymptotically flat boundary). The problem is solved by fixing the expansion n^a to coincide with the value it takes in Reissner Nordstrom, and then fixing the normalization of l^a by $l^a n_a = -1$. It is noteworthy fact that such a simple recipe exists which results in the correct value for the surface gravity of the static black holes in Einstein Maxwell Dilaton Theory.

Not so surprisingly, given the high degree of symmetry of the horizon itself, the surface gravity thus defined turns out to be constant on the isolated horizon. Therefore, the zeroth law of "thermodynamics" of isolated horizons holds. Nevertheless, we must note that the identification of the surface gravity of general isolated horizons with a physical temperature is not clear since there is so far no analog to the analysis that established the phenomena of Hawking radiation.

The next step is to define a notion of mass associated with the isolated horizon, which given the general absence of an asymptotically flat boundary can not be taken to be the ADM mass, and, moreover, even when there is such a boundary the fact that there is general matter and gravitational waves in the exterior spacetime the ADM mass would depend on those fields and not only on the isolated horizon itself. Notably the answer lies in the construction of an appropriate hamiltonian, i.e. one that would give the correct equations of motion upon considerations of arbitrary variations within the phase space (i.e. variations that not necessarily vanished at the boundaries and, in particular, at the isolated horizon). Moreover, it will be necessary to consider a new phase space Γ' constructed by taking the union of the phase spaces of isolated horizons for all possible values of the horizon area. This requires the addition of a surface term associated with the isolated horizon boundary, and a choice of lapse and shift corresponding to l/a at the isolated horizon boundary, that is completely analogous to the usual addition of the ADM mass term in association with asymptotically flat boundaries and evolution with a choice of lapse and shift that correspond to a time translation at infinity. The fact that such a boundary term making the Hamiltonian differentiable exists is highly nontrivial, in particular, no such term is known to exist in the case of general internal boundaries with general choices of lapse and shift. This boundary term in the Hamiltonian is naturally identified with the mass of the isolated horizon and coincides with the ADM mass in the case of static black holes in Einstein Maxwel Dilaton theory.

One is then in the position of considering the first law of thermodynamics of Isolated Horizons. A straight forward calculation yields

$$\delta M_\Delta = \frac{\kappa}{8\pi}\delta A + workterms$$

Thus establishing the validity of the first law. We note that the physical process version of the first law is not fully satisfactory because, strictly speaking, the intermediate stages of the process need not contain isolated horizons, and, therefore, do not correspond to points in Γ' Related concerns can be raised about the usual analysis, as well. We note, for example, that through a physical process the ADM mass can not change, so, in this last respect, the Isolated Horizon approach seems more satisfactory.

There is, at present, no analog to the second law for isolated horizons. This is due in part to a problem similar to that mentioned above, namely the fact that in the definition of the notion of isolated horizons one leaves no room for a situation in which the area of the horizon changes. Furthermore, in this case the problem can not be sidestepped even through an approximation because the second law is supposed to have a validity that goes quite beyond the quasistationary regime.

Finally, the program turns out to be very successful in evaluating the statistical mechanical value of the entropy of an isolated horizon. This part starts with the quantization of the appropriate sector, namely the theory associated with the phase space with the standard Ashtekar bulk variables on an hypersurface Σ with boundary S corresponding to the isolated horizon, together with the $U(1)$ connection of the Chern Simons theory on the boundary. The theory is as usual, subject to the constraints which in this case involve the not only the Hamiltonian, diffeomorphism and Gauss constraints, but an additional one, inherited from the conditions defining the isolated horizon, that links the behavior on the $U(1)$ connection on S with that of the soldering form in the bulk, evaluated at S. Having constructed the quantum version of the sector of isolated horizons one looks at the states corresponding to eigenvalues of the area operator for the boundary S (the area of the isolated horizon) lying within the range $A - l_P^2$ and $A + l_P^2$. Then, one takes the maximal entropy density matrix made out of these states, namely the equally weighed totally uncorrelated density matrix constructed from these states, and construct the density matrix describing the horizon degrees of freedom by tracing over the bulk degrees of freedom. Then, the evaluation of the entropy through the standard formula $-tr\rho \ln \rho$ yields, in the case of a large enough horizon area, the result to lowest order is

$$S = \frac{\ln 2}{4\pi\sqrt{3}l_P^2}\gamma A$$

Thus, by selecting the value $\gamma = \ln 2/(\pi\sqrt{3})$ for the Immirzi parameter γ, (which amounts to selecting one among a continuous choice of unitarily unequivalent quantum theories corresponding to the same classical theory), the standard result $S = A/4l_P^2$ is obtained. It is worth to point out that this choice can be made only once, and that the number of different situations that must be accounted by such a choice is infinite so it is a highly nontrivial fact that such a choice exits. For example, it is conceivable that say the choice needed in the case of Reissner Nordstrom black holes would have been different than the choice needed for Schwarzschild black holes.

The program has therefore met with tremendous success so far, and the task of generalizing the setting to account also for rotating black holes is currently under way. More into the future, there is the hope of eventually treating fully dynamical horizons, and of replacing the effective analysis described above with a more fundamental one, in which, starting with the full quantum theory one could single out the appropriate sector of states and carry out the appropriate counting for the evaluation from first principles of the horizon entropy. We look forward to these and other developments resulting from this exciting program, as well as for new insights from other sources, in the hope that eventually we would be in a position to treat even more vexing questions such as those related to the ultimate fate of an evaporating black hole and the issue of information loss.

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LIGO project update

Stan Whitcomb, Caltech
stan@ligo.caltech.edu

Work on the Laser Interferometer Gravitational-wave Observatory (LIGO) continues to progress smoothly. The bake out of the beamtubes at the Hanford site was concluded in May, completing the facilities and infrastructure work there. The bakeout equipment have now been shipped to the Livingston site, and the bakeout of the first beamtube module should start within weeks.

The main activities have now shifted to detector installation at both sites. At Hanford, the seismic isolation installation for the first interferometer is nearly complete, and over half of the optics have been installed in the vacuum chambers. The prestabilized laser has been installed and under test for several months. A major current focus is locking the laser to the mode cleaner, the first step in integrating and commisioning the first detector. At Livingston, the first installations are the seismic isolation system and the prestabilized laser; both are well underway.

At the most recent meeting of the LIGO Scientific Collaoration, held at Stanford in July, the main focus was initial discussion and planning for a improved detectors to replace the current ones starting in 2005. Although there is significant R&D to completely define these detectors, it is clear that significant sensitivity improvements are possible.

Progress on LIGO (including pictures of the installation activities) can be followed in our (nearly) monthly newsletters accessible through our website (http//:www.ligo.caltech.edu).

Worskhop on initial value for binary black holes

Carlos Lousto, Albert Einstein Institute, Golm, Germany
lousto@aei-potsdam.mpg.de

The first (initial) workshop on initial data for binary black holes took place at the new location of the AEI: Golm, June 7-9 1999. It was extremely successful regarding the very high level of attendance and participation. Copies of the related papers (when available) prior to the meeting have been distributed as "precedings", and a certain flexibility in the schedule provided a fertile atmosphere for numerous questions and discussion.

The first day emphasized studies within the conformally flat ansatz for the 3-geometry. G. Cook presented a comprehensive review of the classical results and introduced new developments like the "thin sandwich approach" recently proposed by York[1]. He noted how this approach turns out to naturally include the approximations used by Mathews and Wilson and the "convective" one used by Lousto and Price in the particle limit. Cook also emphasized the need to move beyond the conformally flat ansatz and Bowen-York solutions of the momentum constraints in the quest to find more astrophysically realistic initial data. He also expressed interest in using the "lambda" systems described by Brodbeck, Frittelli, Hübner, and Reula for enforcing the constraints during numerical evolutions.

B. Brügmann presented the black hole punctures approach to initial data based on Ref. [2]. Here the wormhole topology of black hole data is compactified to R^3, which leads to an existence and uniqueness proof and facilitates numerical studies.

C. Lousto described work with R. Price to test the Bowen-York initial data in the black hole plus a particle system, which can be treated perturbatively. The conclusion is that the "longitudinal" ansatz for the extrinsic curvature seems not to be a good representation of an astrophysically realistic scenario [3]. It was noted the interest on extending these studies from headon to generic orbits.

R. Beig described a formulation of the momentum constraints where quantities such as ADM linear and angular momentum are encoded by specific source terms in these equations concentrated at the punctures arising from conformally compactifying spatial infinity. He showed a way of writing down, in the conformally flat case, solutions for these inhomogeneous equations which are of the "Bowen-York"- type. One can then find the general solution, since the methods of Ref. [4] enable one to write down the general "unpunctured" TT-tensor.

The second day of the workshop started with an excellent review of the close limit approach to the final merger stage of two black holes by J. Pullin. He also discussed the last results on perturbations of black holes with angular momentum [5].

E. Seidel gave a comprehensive overview of the projects carried out in the numerical group at AEI. He described the results obtained by evolving (with the CACTUS code) black hole plus brill wave and pure brill wave data. For this latter data it is possible to follow either the scattering of waves leaving back flat spacetime or their collapse to form a black hole and then to obtain the corresponding quasinormal ringing.

M. Campanelli introduced the "Lazarus project" that proposes to marry full numerical techniques to describe well detached black holes with perturbative techniques to continue the evolution once a common horizon encompasses the binary system. The matching is performed by constructing the Weyl scalars on the perturbative slice [6], and evolve them using the Teukolsky equation.

C. Lousto then described the evolution of "exact" Misner data for two initially at rest black holes via the Zerilli and the Teukolsky equations. The results show that while the evolution with the Zerilli equation suffers a premature break down, the evolution with the Teukolsky equation is robust and generates results close to the linear initial data [7]. It Remains open the question whether this behavior also holds for non headon collisions.

R. Price neatly described his solution to the constraints representing two Kerr black holes in an axially symmetric configuration. He used the black hole plus brill wave form of the metric and superposed exact "Kerr" solutions to the momentum constraint. When one imposes this family of solutions, parametrized by the separations of the holes, to have a close Kerr limit, a "pin pole" between the holes appears [8]. Whether this is a generic feature or a consequence of the restrictive ansatz remains an open question.

W. Krivan showed the results of the evolution of the above initial data in the close limit regime where the "pin pole" is safely enclosed by the common horizon [9].

J. Baker discussed a similar approach to the problem, but he assumes the superposition of the holes at the level of the 3-metric and then solves for the extrinsic curvature [10]. Again, the requirement of the holes being kerr-like both when well separated and when close together generates unpleasant features such as discontinuities in the extrinsic curvature.

N. Bishop carefully described the Kerr-Schild ansatz to the initial value problem [11]. This is a quite original approach and has interesting potentialities. One needs still to identify the physical parameters and give explicit solutions for rotating black holes. He also mentioned the related Matzner et al work where two Kerr black holes are explicitly superimposed.

J. Thornburg [12] presented numerical initial data on an Eddington-Finkelstein slice of the spacetime with nonvanishing K. He stressed the benefits of working with 4th order evolution codes.

H. Shinkai exposed his work on how the post-Newtonian expansion can be used to give initial data for a further general relativistic evolution [13]. He applied this approach to binary neutron stars and measured the precision of several PN orders using as a criteria the violation of the Hamiltonian constraint. For the first and second PN expansion he gets around 60% and 45% errors respectively.

G. Nagy discussed about the differentiability of the Cauchy data by studying the constraints in the case of incompressible models of neutron stars. He proved rigorously its C^1 behavior at the boundary. Extension to more realistic equations of state is being undertaken.

P. Hübner presented a review of the conformal approach to GR and highlighted the stable numerical implementation of his evolution code (4th order) due to the explicit first order symmetric hyperbolic formulation [14]. Work is in progress on the question of giving astrophysical initial data and including matter sources.

On Thursday 10th we had two round tables on further work on initial data and other works on subjects related to gravitational radiation. This was planned to finish by 1 p.m. but given the interest of the participants it was extended to the whole afternoon with discussion of new ideas and even some computations!

Details and the full workshop program can be found in
http://www.aei-potsdam.mpg.de/~lousto/WID99.html.

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ITP Conference on strong gravitational fields

Don Marolf, Syracuse University
marolf@suhep.phy.syr.edu

The ITP Conference on Strong Gravitational Fields (Santa Barbara, CA, June 22-26, 1999) was the culminating event of the six month ITP program "Classical and Quantum Physics of Strong Gravitational Fields." The intent of the conference was to focus on those aspects of strong gravitational fields that had been emphasized in the six month program, but to extend the audience far beyond the program participants.

One of the most unusual aspects of the conference was the basic organization. This was to be a "Discussion Conference." The schedule featured a relatively small number of invited talks, each of which was followed by 40 minutes of discussion time. This time allowed time for both an in depth conversation between speaker and audience (and often among the audience members) as well as for short presentations by various participants on topics related to the main talk. I think that everyone was impressed at just how well this format seemed to work and the extend to which the discussions clarified and brought forth important issues from the talks. I was especially told by the less experienced participants that this format allowed them to see more clearly what were the important parts of a given talk. The conference also featured a few (14) contributed presentations, and a panel discussion (Bob Wald, Jürgen Ehlers, Pablo Laguna, and Beverly Berger) on classical relativity. The full audio recordings of all talks, short presentations, and ensuing discussions are available on line at the above URL.

Like the preceding ITP program, the conference had three main foci. One of these was quantum gravity, especially loop quantum gravity and string theory. Review talks on these subjects were given by Gary Horowitz, Joe Polchinski, Rob Myers, Abhay Ashtekar, John Baez, and Carlo Rovelli. Another was classical physics, including Gravitational waves (John Friedman and Eanna Flanagan) and Numerical Relativity (Richard Price and Carsten Gundlach). The third was Mathematical Relativity (Rick Shoen, Hubert Bray). I was very pleased with the degree to which all speakers gave talks that were accessible to broad audiences. As a result, the talks on line at the above URL provide an excellent place for non-specialists to get insight into topics from the recent proofs of the Penrose Inequalities to the status of black hole collision simulations, and from gravitational wave sources to microscopic black hole entropy from both the loop and string points of view. Rather than go into details here, I would strongly urge the reader to go directly to the conference URL above, view the transparencies, and listen to the talks and ensuing discussions. In a few places the audio recordings are a bit rough (due to interference from the nearby airport), but there is no doubt that they will be a useful resource.

The conference webpage is http://www.itp.ucsb.edu/online/gravity_c99/

Yukawa International Seminar

John Friedman, University of Wisconsin, Milwaukee
friedman@thales.phys.uwm.edu

About 150 people gathered under cloudy skies in the old imperial capital, Kyoto, June 28 - July 2, to listen to six days of talks and view an extraordinarily good set of posters, all summarizing theoretical, observational, and experimental work on gravitational waves, black-hole physics, and numerical gravity during the Yukawa International Symposium (YKIS99) on black holes and gravitational waves. Unfortunately, a summary of posters would make this already long review too long to be useful.

In a first session on black holes in a quantum context, Ted Jacobson summarized his work with Corley and Mattingly (e.g., hep-th/9908099). In the usual semiclassical computation of Hawking radiation, the late-time flux arises from modes that, prior to the black hole's formation, are vastly shorter than the Planck length; and one can worry that black-hole radiance would not survive if the universe's small-scale structure does not allow one to make sense of such ultra-high frequency fields. Jacobson and his coworkers address the problem by placing a lattice on a black-hole background, and looking at field theory on the lattice – considering, in effect, quantum field theory on a discrete spacetime. Satisfyingly, the lattice reproduces the Hawking effect with an accuracy that depends on the ratio of the lattice spacing to the black hole radius. A lattice regular at the horizon is not static, and the lattice used is falling inward. The scattering by the lattice of a ingoing to outgoing wave is formally analogous to the Bloch oscillation of an electron in in a crystal with a uniform electric field.

Following this discussion, Gary Gibbons spoke on black holes in unified theories. He noted that classical solutions are important in quantum theories if their quantum corrections vanish, and that commonly requires supersymmetry to cancel the fluctuations of bosons against those of fermions. The Breckenridge-Myers-Peet-Vafa solution provides an example of a BPS black hole with nonvanishing angular momentum, a solution that was used to count states using D-brane techniques (and gave agreement with black-hole entropy). Gibbons and Herdeiro (hep-th/9906098) have completed a substantial study of the solution, finding its geodesics and computing the scattering of a scalar field off this extreme black hole. The solution includes an example of a "naked stable time machine," with spatially unbound geodesics that can travel back in time; but Gibbons and Herdeiro argue that chronology protection may be enforced by the third law of thermodynamics, preventing the formation of an extreme black hole by means of a finite process.

Describing the work led by Israel's group on the nature of the interiors of black holes formed in collapse, Patrick Brady reviewed the linear instability of the Cauchy horizon and the spherical models of black-hole interiors and then turned to more recent work that appears to confirm key features of the earlier models. In particular, Ori and Flanagan have used the Cauchy-Kovalevsky theorem to show that "there exist functionally generic solutions of Einstein's equations containing a null and weak scalar curvature singularity," and work by Barack and Ori and by Israel, Brady, Chambers, Droz and Morsink characterizes more precisely the Weyl curvature near these null Cauchy-horizon singularities.

Andrzej Krolak continued the discussion of the nature of singularities in gravitational collapse, summarizing theorems that characterize Cauchy horizons or restrict the occurence of naked singularities. Here are a few.
Chrusciel and Galloway and Budzynski, Kondracki, and Krolak have shown the existence of a large class of nowhere differentiable Cauchy horizons. Harada, Iguchi, and Nakao showed that generic counterrotation prevents central shell-focusing formation. This is consistent with Rendall's result with cylindrical symmetry that a regular distribution function in phase space prevents naked singularities of the kind apparently seen by Shapiro and Teukolsky, using a singular distribution function for collisionless matter; and consistent with the conjecture that matter described by smooth distribution functions obeys cosmic censorship – that, as in the Newtonian theory, velocity dispersion dissolves naked singularities.

Matt Choptuik summarized work by about 30 people on critical phenomena in gravitational collapse that has led to a coherent picture. Critical solutions are unstable by construction, lying on the boundary between two distinct stable endstates of collapse – black hole or no black hole. Underlying the key features of near-critical collapse is the fact that the critical solutions are "minimally unstable intermediate attractors," solutions whose linear perturbations have a single unstable mode. Critical solutions exhibit discrete self-similarity (an oscillation within a scaling envelope) characterized by a rescaling exponent, for massless scalar, gravitational, and SU(2) Yang-Mills fields; while perfect fluids and multiple-scalar field systems are continuously self-similar. The transition to collapse studied earlier, of, say neutron stars pushed over their upper mass limit by an addition of an arbitrarily small mass, exhibits a mass gap, and Choptuik calls these type I transitions. Examples are massive scalar fields, and colored black holes (variants with horizons of the Bartnik-Mckinnon Y-M Einstein solutions); the latter have overlapping regions in parameter space that correspond to type I and type II solutions. Choptuik's transparencies, with names and details suppressed here are at http://laplace.physics.ubc.ca/People/matt/Doc/ykis99.ps.

Jeffery Winicour described the characteristic treatment of black holes, and the current status of the The Pitt null code, developed by Welling, Isaacson, Gomez, Papadopoulos, Lehner, Bishop, Maharaj, Szylagyi, and Husa. In the vacuum case, a 3-D code has been implemented and tested in a variety of contexts. More recent work (gr-qc/9901056) incorporates a perfect fluid with a 1-parameter equation of state. It has so far passed tests involving localized distributions of matter around a Schwarzschild black hole, and the code is found to be stable and convergent. Modifications are needed to handle shocks, and problems of astrophysical interest remain to be tackled.

Next morning, Kip Thorne began his talk by prodding the theorists to intensify their effort to keep up with the rapid progress of the LIGO experimentalists, and provide an accurate template for inspiral, with no drift in phase over the time of detection. Theorists particularly lag in the NS/BH problem, where spin-induced precession is important. The construction of the two LIGO observatories is essentially complete, and LIGO I sensitivity is to be reached by November, 2001. A LISA date of 2008-2010 is likely (i.e., US support is likely). Thorne emphasized that already for LIGO II with signal recycling, the standard quantum limit may be reached. To reach greater sensitivity, one cannot rely on standard position detectors that ignore correlations, and Thorne reviewed work with Braginsky, Gorodetsky, Matsko, Vy-

atchanin, Khalili, Levin, and Kimble on measurements beyond the SQL. Methods rely on correlations between the photon shot noise and the back-action noise induced by radiation pressure on the test masses. One can modify the input or output optics of current interferometers so that measurements at different times commute and state reduction has no influence on the noise. Thorne's current estimates for LIGO II event rates:
NS/NS, a few/yr; NS-BH a few/month (!); BH-BH, unknown.
Other sources mentioned were r-modes, strongly accreting LMXB's, and accretion induced collapse of white dwarfs.

Seiji Kawamura spoke on the current status of the Japanese detector, TAMA300: a mode cleaner was locked successfully 4 months ago, and a noise spectrum has been obtained. He summarized the recycling arrangement, and ongoing efforts to reduce shot, seismic and thermal noise. Great luck would be needed if there were to be a source strong enough for TAMA300 to detect, but plans are to step up to a much larger, 3-km cryogenic detector in the Kamgoka tunnel.

Next, two talks, by Ed Seidel and Jorge Pullin, on colliding black holes. Seidel noted both the long distance to go before inspiral can be computed and the progress made by the NSF black-hole grand challenge project, in developing a code that handles a variety of initial data sets, giving, in particular a stable 3-D evolution of a set of distorted black holes. The development of the cactus code was outlined, and a general PDE solver, due for public release in August, with an open source code, may be of wide interest to readers of MOG. 10 groups are now using it. Seidel emphasized recent methods (initially due to Shibata and Nakamura) of that give significantly more stable evolution, by promoting badly behaved quantities to independent variables. Although evolutions can be very accurate, by $t = 50M$, every code crashes.

Pullin described work by a number of people on colliding black holes in the close limit (gr-qc/9905081). From a computational viewpoint, binary black hole coalescence has three stages: a post-Newtian inspiral, of about 10^4 orbits, ending at roughly 10-12 M; the plunge; and the ringdown. The key to a perturbative treatment of the ringdown stage is that realization that it is *is* the ringdown stage, that a common, distorted horizon surrounds what were two black holes well before their apparent horizons merge. The evolution of the distorted horizon is what Pullin and his collaborators have treated with remarkable success as a perturbation of a Schwarzschild black hole. The work has included the development of a second-order perturbation formalism and its application to the ringdown problem. The approach serves as a code check for numerical relativity and a way to allow dying codes to run longer; and the ringdown serves in its own right as a source for LIGO. An analogous close limit for neutron stars, with the merged stars regarded as a perturbation of a spherical star has also been recently developed (gr-qc/9903100).

Yasufumi Kojima and I then gave two talks on the recently discovered r-mode variant of the nonaxisymmetric instability that besets rapidly rotating relativistic stars. First noticed by Nils Andersson, in a numerical study, the instability of these axial-parity modes may dominate the spin-down of neutron stars that are rapidly rotating at birth, and the gravitational waves they produce may be detectable by LIGO II with narrow banding from sources out to somewhere between 4 and 20 Mpc. These dramatic implications have led to papers by about 35 authors in the past two years, but because my talk is now on the Web in a version written with Keith Lockitch (gr-qc/9808083), and each of our talks at the ITP can be seen and heard live at http://www.itp.ucsb.edu/online/gravity_c99/, I'll leave it at that. Caveats are the assumption that nonlinear effects will allow the mode to grow until perturbed velocities are of order of the background velocity – that the mode does not transfer its energy to turbulence or to a magnetic field, while its amplitude is small.

Kojima emphasized research he has done, partly with Hosonuma, on the r-modes of of relativistic stars, reporting work that showed a continuous spectrum for nonisentropic stars in a slow-rotation approximation, and Beyer and Kokkotas make the claim precise. In addition, Kojima and Hosonuma have studied the mixing of axial and polar perturbations to order Ω^2 in rotating relativistic stars, again finding a continuous mode spectrum. Kojima obtained a single, second-order equation for the radial behavior of the modes. If the continuous spectrum is a genuine feature of relativistic stars, it would be remarkable, but it may well be an artifact of approximations that force the frequency to be real: In the slow-motion approximation, the continuous spectrum arises from the vanishing of the highest derivative term in the ODE, found by Kojima, that describes the axial-parity modes.

A session devoted to the post-Newtonian computations reported progress on calculations that must provide the highly accurate templates for binary inspiral that are needed to use gravitational-wave detectors for astronomy. Both Cliff Will and Luc Blanchet spoke on the post-Newtonian description of binary inspiral. Luc Blanchet spoke on the post-Newtonian description of gravitational radiation, developed by Damour and colleagues. He emphasized the use of the Hadamard expansion to regularize the infinities that arise at the position of point-particles, when one expresses the multipole moments of the source as integrals extending over the distribution of stress-energy. One's confidence in using this renormalization method relies on a combination of its success and its elegance.

Cliff Will summarized a method called DIRE (Direct Integration of the Relaxed Einstein Equations), based on a framework developed by Epstein and Wagoner and extended by Will, Wiseman and Pati. Like the Blanchet-Damour-Iyer approach, DIRE begins with integrals over source and field. The integrals are finite when one restricts the use of the slow-motion approximation to the near zone and observes that the far-zone integral is bounded for a source that is well-behaved in the distant past. Equations up to 3.5 PN order are obtained, within the assumption that the orbiting bodies are sufficiently small, by isolating terms that neither vanish nor blow up as the size D of a body shrinks to zero, with the remaining terms absorbed into renormalized masses of the bodies. The resulting procedure is well-defined, although the assumption has been checked completely only at 1PN order.

In an enthusiastic update on the prospects for GEO600, Bernard Schutz emphasized the expected performance with signal recycling in both a narrow-band and broad-band mode: a maximum sensitivity of $h < 10^{-22}$ at minimum noise, for frequencies between 100 and 1000 Hz. The state of the project: The vacuum system is complete, and the first mode cleaner is locked and working; interferometry and test optics are expected to be ready by mid-2000, and full sensitivity is to be reached by mid-2001. There has been close collaboration with LIGO, and a memorandum of understanding has been signed for full data exchange between LIGO I and GEO600.

The next day saw two talks on black-hole astrophysics. Nils Andersson summarized work on oscillations of rotating black holes, mentioning his work with Krivan, Laguna, and Papadopoulos on a 2-D code that evolves perturbations on a Kerr background and produces waveforms for black-hole ringing. Andersson emphasized two regimes of outgoing-mode ringing for a given value of l, say $l = 2$, corresponding to the different imaginary parts of the frequencies for $m = \pm l$. It remiains to be seen whether, in the extreme Kerr limit both the retrograde, more quickly dying mode and the prograde, slowly dying mode both have comparable amplitudes (Mashoon and Ferrari suggested that the prograde mode was suppressed). Preliminary work suggests a curious feature of near-extreme Kerr: a sum over harmonics appears to give an oscillation whose damping is described by an envelope with a power-law fall-off that is *slower* than the Price tail. If true, one might never see the Price power law (for $m \neq 0$) in the late-time ringing of a near-extreme black hole.

Shin Mineshige spoke on the dramatic success of the ADAF (advection-dominated accretion flow) model of accretion disks that started with the 1977 work of Ichimaru. In this model, heat is dominantly transported by radial gas motion, and the spectrum is broad-band. Mineshige emphasized the fact that three models of accretion – the standard thin and thick disk models and the ADAF model are all solutions to the same set of equations with different values of optical depth. He reiterated the evidence for a central black hole in ADAF disks, arising from the fact that the emitted power is much smaller (as a fraction of the mass accretion rate) than it should be if matter were falling on a solid surface. And he discussed the observational tests of disk models and a recent model for X-ray novae.

Interspersed with these talks, and continuing through the next morning's sessions were a series of talks on the binary coalescence problem for neutron stars. Eriguchi and Gourgoulhon began these with a discussion of numerical work on Darwin Riemann problems in Newtonian gravity and in GR. The classical Roche, Darwin, and Riemann problems refer respectively to (Roche) the tidal forces on a finite mass orbiting a point mass with its spin and orbital frequencies identical; (Darwin) both masses are finite perfect fluids; (Riemann) the masses can have internal vorticity. The Darwin-Riemann problem that Eriguchi and Gourgoulhon consider has two masses whose spin frequencies are arbitrary, but for which the planes of rotation are aligned with the orbital plane. A series of papers by Uryu and Eriguchi have numerically solved the exact problem for Newtonian polytropes; and Usui, Eriguchi, and Uryu have begun a program to construct quasi-equilibrium models in GR, starting with spacetimes having an exact Killing vector of the form $t^\alpha + \Omega\phi^\alpha$, using a truncated set of field equations that allows a non-radiative field and a smaller set of potentials than one would need for the exact binary system. They thus replace the approximation of spatial conformal flatness by one in which the metric has only a $t - \phi$ off-diagonal term. Bonazzola, Gourgoulhon, and Marck repeat the Mathews-Maronetti-Wilson computation for an $n = 1$ polytrope (adiabatic index $\gamma = 2$), using a multi-spectral method and obtaining agreement with the new MMW code to better than 2%. No innermost stable circular orbit is found for this value of γ. A useful summary of our knowledge of the ISCO was given (see gr-qc/9904040 and Uryu-Eriguchi).

Wai-Mo Suen and Ken-ichi Oohara summarized progress on the numerical simulation of coalescing neutron stars by the NASA Neutron Star Grand-Challenge group and by the Japanese group. Suen's discussion emphasized the extensive code testing that is underway and successes in meeting the Grand-Challenge milestones. A long enough time evolution to model coalescence is still in the future, but Suen reported a computation of head-on collisions using the coupled Einstein and hydrodynamic equations. These runs tested a conjecture of Shapiro that the shock-heating generated by infall, at least for stars falling from infinity, is enough to support the star until neutino cooling sets in (a time long compared to the dynamical timescale). If true, this would give an early cutoff to gravitational-wave emission. However, Suen argued that the dynamical time scale of infall was so short that the shock heating effect might not be important. He showed a simulation of the head-on collision of two 1.4 solar mass neutron stars, and reported finding an apparent horizon in the infalling time scale. Oohara summarized the longer history of the Japanese program, with a full GR code completed in '94. Test runs of on the order of one revolution have been run on a 201^3 grid, with a 10-hr CPU time on a VPP300. Finally, Masaru Shibata has completed and tested on sample problems a related 3-D code for binary coalescence of neutron stars (gr-qc/9908027).

Following the binary-coalescence series, Max Ruffert and Peter Mezaros presented different views on the possible origins of γ-ray bursts. BATSE has revealed about one burst/galaxy/10^6 years, distributed isotropically at distances of order $10^{28} - 10^{29}$ cm., implying luminosities of order $10^53 erg/s$. The duration of bursts varies greatly, ranging from milliseconds to hours. Evidence for a fireball as a common source is good, but fireballs may be produced by mergers of NS-NS, NS-BH, WD-NS, WD-BH, or by a collapsar, a rotating, collapsing "failed" supernova (or possibly a neutron star pushed over its upper mass limit by accretion). Evidence for the collapsar comes from the identification of γ-ray bursts with galaxies that suggest the bursts probably occur in star-forming regions more often than would be expected for the old NS-NS or NS-BH systems. Ruffert and his collaborators (Janka, Eberl, and Fryer, astro-ph/9908290) have run a series of Newtonian simulations of NS-BH and NS-NS mergers incorporating back-reaction of gravitational waves. Using a Lattimer-Swesty equation of state and carefully taking account of neutrino sources and sinks, they confirm BH-NS mergers as a possible source of γ-ray bursts, but find an energy of 10^51 erg requiring Lorentz beaming at the upper end of the possible. Mezaros' even-handed summary reviewed evidence for the fireball model he developed with Rees and others. Fireballs from all of the mechanisms have similar energies, with 10^{54} erg possible via MHD, while less than 10^{erg} is likely if only neutrino annihilation is used (as in the simulations discussed by Ruffert). This leaves coalescence clearly still in the game.

The final two talks, by Bernard Carr and Jun'ichi Yokoyama, concerned primordial black holes. Carr delineated ways that PBH's can be used as a probe of the early universe; in particular, the limit on PBH's set by the absence of observed evaporating black-holes limits the spectral index during inflation. Both Carr and Yokoyama emphasized the possibility that MACHOS are PBH's of mass 0.5 $M_\odot$, the right mass for their having been created in a quark-hadron transition. Should the LMC MACHOS be PBH's, work by Yokoyama and collaborators sharply constrains parameters of inflationary models; and nearby BH-BH coalescence would be frequent, with possibly observable gravitational waves (Nakamura, Sasaki, Tanaka, Thorne). Carr considered a PBH-related test of whether G varies.

Minnowbrook symposium on the structure of space-time

Kameshwar Wali, Syracuse University
wali@suhep.phy.syr.edu

This century, with Einstein's general theory of relativity, space-time assumed a dynamical role in the theory of gravitation. It was a revolution in our ideas and has led to momentous discoveries regarding the large scale organization of matter in the universe. Equally important is the progress we have made in exploring the subatomic world and in the search for an all-unifying theory of fundamental interactions. But problems remain and physics is at cross roads of varying ideas at the "End of the Millenium."

The Minnowbrook Symposium took place on May 28-31 and was organized to bring together the exponents of varying ideas, specifically, 1). Classical general relativity, 2). Recent developments in string theory and the emerging view of space-time, 3). Quantum gravity and generalized quantum field theories and, 4). Non-commutative geometry and its perspective on the structure of space-time at short distances.

The first day of the symposium in the morning began with John Stachel's review of the various space-time structures associated with no-relativistic Galileian, and relativistic Minkowskian theories, and showing how generally covariant space-times are fundamentally different from their predecessors and the implication of this difference on the usual starting point of space-time theories. His talk was followed by two talks on Black Hole Thermodynamics and related problems. Robert Wald, after reviewing some of the established results in black hole thermodynamics, spoke about the major unresolved issues such as whether black hole entropy should be viewed as "residing" in its deep interior, on its horizon, or in its "thermal atmosphere." Ted Jacobson gave an overview of some results and open questions concerning the meaning of black hole entropy and the nature of the holographic bound on the entropy contained within a surface of given area. He dealt with issues such as the role of internal states, entanglement, species independence, renormalization of G and the Second Law of Thermodynamics. He ended up providing a derivation of the Einstein's equation from the proportionality of entropy and area. In the afternoon, Ted Newman spoke about his (and his collaborators) alternate formulation of general relativity in terms of families of characteristic surfaces and a scalar function. With these as fundamental variables, the conventional variables such as the metric tensor become derived concepts and the final equations, although they do not resemble the standard version of GR, yield results identical to those of GR. He was followed by Roger Penrose, who expounded his ideas regarding quantum state-vector reduction, viewing it as a gravitational phenomenon. He discussed both theoretical arguments as well as possible experimental tests (now actively pursued) and presented some new theoretical developments.

The first day ended with a lively panel discussion led by Lee Smolin. Different subgroups got together first to discuss important questions in light of the day's proceedings and issues to be addressed the following days.

The second day began with a session on String Theory and String Theorists' view of Space-time. Due to illness, Joe Polchinski had to cancel his participation at the last minute, but we had two excellent talks by Michael Douglas and Brian Greene that covered some aspects of Polchinski's subject matter. Speaking about D-Geometry, Matrix theory and Noncommutative geometry, Douglas surveyed recent developments in D-branes theory and the nature of space-time as seen by D-branes. Greene presented new geometrical ideas that have emerged out of recent researches in String Theory, ideas involving dualities, mirror symmetry, topology change, and non-commutative geometry, giving rise to an evolving "quantum geometry" or "string geometry." In the afternoon session, Abhay Ashtekar discussed the features of quantum geometry through two specific examples, namely, Einstein-Maxwell theory in 2+1 dimensions and quantum geometry of black hole horizons in 3+1 dimensions. With non-perturbative, complete solution of the problem, one finds unexpected limitations of the classical and semi-classical theory in the first case. In the second case, the horizon geometry is described by the quantum Chern-Simons theory on a punctured 2-sphere, giving rise to states that account for the black hole entropy. John Baez explained how spin network techniques have provided a mathematically rigorous and intuitively compelling picture of the kinematical aspects of loop quantum gravity. For a true understanding of the dynamical aspects of gravity, he said, one needs a model for 'quantum 4-geometry", that is a truly quantum mechanical description of the geometry of space-time. He discussed the notion of " spin foam", as a probable candidate for such a description.

The last and final day began with Alain Connes who described the foundations of non-commutative geometry in terms of spectral triplets and how it has been successful in predicting some features of the standard model. He outlined a "Spectral Action Principle" from which one could derive elementary particle interactions as fluctuations of he metric. Ali Chamseddine took it from there and discussed in some detail examples of non-commutative spaces appearing in the standard model and string theory. He showed how when the spectral action principle is applied to the standard model, internal symmetries merge with space-time symmetries, unifying gravity with the other interactions. Dirk Kreimer discussed recent developments in perturbative quantum field theories pertaining to the role of a Hopf algebra governing their renormalization and how this algebra is related to the Hopf algebra structure of diffemorphisms in the context of non-commutative geometry. The afternoon session was devoted to Discrete as opposed to a continuum space-time picture at short distances. Klaus Fredenhagen spoke about fundamental uncertainty relations for space-time coordinates and how they can be modeled in the framework of non-commutative geometry. Rafael Sorkin described " A Causal Set Dynamics," showing how, starting from certain causality conditions and a discrete form of general covariance, one can derive a very general family of classically stochastic, sequential growth dynamics for causal sets. The resulting theories, according to Sorkin , provide a relatively accessible "half-way house" to full quantum gravity. He noted that non-gravitating matter can also arise dynamically in such theories. The final talk of the session was due to David Finkelstein on Spin, Statistics and Space-time Structure. His basic idea was that below the quark scale, matter, measurement, and space-time can no longer be separated operationally. They fuse into one variable.

The final session organized by Carlo Rovelli was devoted to short presentations on some important topics that were not covered in the other sessions. These included among others, Amanda Peet who spoke briefly on dualities in string theories and their implications, Julius Wess on some recent developments in Quantum Groups and Roger Penrose on Twistors.

From all accounts, the symposium achieved its main purpose in that it provided an opportunity for the presentation of varying points and in-depth discussions on fundamental questions regarding space-time structure. Minnowbrook Conference center with its idyllic surroundings, its seclusion and comfort generated a stimulating and friendly atmosphere among the forty or so participants.

For those interested, the complete information regarding the symposium is located at the following URL:

http://www.phy.syr.edu/research/he_theory/minnowbrook/

If you click on the speaker's name in the program section, you can link to his transparencies (if the click does not work, add the " speaker name.html" (i.e. Penrose.html) to the /minnowbrook link given above.

Black holes II and CCGRRA 8

Jack Gegenberg, Univ. of New Brunswick and Gabor Kunstatter, Univ. of Winnipeg
lenin@math.unb.ca gabor@theory.uwinnipeg.ca

Following a tradition established two years ago, the Black Holes Workshop and the Canadian General Relativity and Relativistic Astrophysics Conference were held consecutively and in nearby locales. Black Holes II: Theory and Mathematical Aspects, took place June 6-9,1999 at the resort town of Val Morin in the Laurentian Mountains north of Montreal, Quebec, followed closely by CCGRRA 8 (June 10-12) at McGill University in Montreal. Both conferences were supported by the Canadian Institute of Theoretical Astrophysics, the Centre de Recherches Mathematiques. Black Holes II also received financial support from the Canadian Institute for Advanced Research. The local organizers for both meetings were Cliff Burgess and Rob Myers. The organizers must be congratulated for putting together two very successful and exciting complementary meetings.

Black Holes II

The talks and discussions in Black Holes II revolved around the nature of and origins of black hole thermodynamics, with discussion often considerably heated by the dialogue between string theorists and relativists. The morning sesssions consisted of three plenary talks and were followed by a sumptious lunch. In the afternoon the contributed talks were presented, and after an excellent dinner, the final plenary session of the day took place. Discussions often continued long into the night in the resort's bar. These discussions sometimes came to definitive and startling conclusions that were rarely remembered by morning.

The first speaker at the workshop was Bob Wald, who set the stage by reviewing the geometric basis of black hole thermodynamics. Abhay Ashtekar continued in this spirit by describing his concept of isolated horizons, and the associated quasi-local definitions of mass and surface gravity. The morning session concluded with Werner Israel's re-appraisal of 't Hooft's brick wall model of black holes.

After interesting contributed talks by Renaud Parentini, Claude Barrabes, Bei-lok Hu and Alessandro Fabbri, Leonard Susskind spoke during the first evening session on how to understand superluminosity in the context of the holographic conjecture.

On the second day, Steve Carlip spoke on his construction of black hole statistical mechanics from states induced on the boundary/event horizon of black holes in spacetimes of arbitrary dimension. Gabor Kunstatter presented a general discussion of 2D black hole thermodynamics followed by a summary of recent calculations of quantum corrections to the thermodynamic properties of charged 2-D black holes. Finally Emil Martinec discussed the interplay of D-branes and black hole thermodynamics in the M-theory context. The afternoon session consisted of contributed talks by Amanda Peet, David Kastor and Daniel Kabat, Jennie Traschen and Simon Ross. The plenary talk in the evening was given by Don Page, who described the thermodynamics of nearly extreme black hole under various assumptions about the degeneracy of the ground state and the density of nearby states.

On the last full day of the workshop, Ted Jacobson forcefully presented his perspective on the question of the 'ultravioletness' of the source of Hawking radiation, provoking lots of discussion from the mixed stringy/ relativist participants. Valeri Frolov described his program for understanding the origin of black hole thermodynamics from the statistical mechanics of the constituent matter fields in 'induced gravity'. Robert Mann then outlined a proceedure for determining the boundary terms in black hole thermodynamics inspired by the AdS/CFT conjecture. That afternoon, the contributed talks were given by Julian Lee, Ivan Booth, Jack Gegenberg, Roberto Casadio and Martin Rainer. The evening talk by Bill Unruh presented the case for taking seriously the sonic analogue of black holes ('dumbholes'). This too sparked considerable debate between those who believed that black hole thermodynamics contained important microscopic properties that were missing in the dumbhole analogy, and those who felt that all the essential (infrared) features were adequately represented in the model.

On the last (half) day of the workshop the only plenary talk was delivered by Juan Maldecena. This talk entailed a discussion on some issues in the AdS/CFT conjecture, in particular on peculiar effects in the boundary CFT. Th e conference closed with three interesting contributed talks, by Finn Larsen, David Lowe and Steve Gubser.

As the participants boarded boarded the bus for Montreal after the last talk, many felt that the controversy pointed to an overall unsettled state of affairs in fundamental physics and signalled interesting times ahead...

CCGRRA 8

Many of the Black Hole II participants went from Val Morin directly to Montreal for CCGRRA 8, where they were joined by many others from across the spectrum of gravitational physics. CCGRRA 8 participants were able to take advantage of Montreal's many fine restaurants and even had the rare opportunity of watching the Expos win a baseball game!

On the first day, we heard from Peter Saulson about progress in building gravity wave detectors. This was followed by Vicky Kaspi's talk on the state of binary radio pulsar timing as a GR effect and then by Jeff Winnicour's discussion of numerically calculating the dynamics of black hole collisions. After lunch, Sharon Morsink demonstrated that certain instabilites in rotating neutron stars may explain the properties of some recently discovered pulsars.

On the second day, Ted Jacobson discussed open questions about black hole entropy, in particular those arising from a conjectured holographic bound. Abhay Ashtekar continued the discussion he begin at Black Holes II, here using quantum geometry to describe black hole thermodynamics, and comparing the result to the stringy discussion. The morning session concluded with an introductory talk by Leonard Susskind on the holographic principle, emphasizing its origins in black hole quantum theory and string theory. Finally, Gilles Fontaine built the case for white dwarfs as a major component of dark matter.

On the last day, we first heard from Lev Kofman on how to build better inflationary models incorportating preheating. This was followed by Bill Unruh's discussion of second order perturbations in the expansion of the universe. The final talk, by Don Page, was on the possibility of testing the many-worlds viewpoint via quantum cosmology.

The contributed talks in the afternoon parallel sessions were in general excellent. Many of these talks were given by grad students and postdocs, and provided an exciting introduction to the breadth and depth of gravitational physics research today. It was clear to all the participants that this conference once again successfully fulfilled the CCGRRA's mandate to bring together Canadian and international researchers in order to discuss the latest developments in Relativity and Astrophysics.

Hartlefest & 15th Pacific Coast Gravity Meeting

Simon Ross, UCSB
sross@cosmic.physics.ucsb.edu

A one-day meeting in celebration of Jim Hartle's 60th birthday was held at the ITP at UCSB on the 25th of February. It was followed by the 15th Pacific Coast Gravity Meeting, which took place on the 26th and 27th. Hartlefest had a relaxed schedule, with four invited speakers representing a few of the areas Jim has been interested in. Most people attended both meetings, making this one of the larger PCGMs, with a packed schedule of fifty-one speakers, and large audiences.

At Hartlefest, Gary Horowitz led off with a discussion of the answers string theory gives to some questions in quantum gravity, and went on to review the recent conjecture by Maldacena relating gauge theory and string theory. He was followed by Karel Kuchar, who supplemented his talk on the quantization of diffeomorphism-invariant systems with some anecdotes about Jim and some fashion tips. Kip Thorne talked about the effect of tides on the calculation of gravitational waveforms from binary systems, and about daring ideas to beat the standard quantum limit in gravity wave detectors by not measuring the positions of the test masses. The closing speaker was Murray Gell-Mann, who gave a non-technical talk on generalized quantum mechanics and how the familiar classical world could emerge as an approximate description.

Following the talks, there was a reception and then a buffet dinner at the ITP. Once all this food and wine had worked their magic, some brave people got up to honor Jim in a variety of entertaining ways. Gary Horowitz and a group of assistants led the audience in singing the relativity hymn (see http://cosmic.physics.ucsb.edu/hymn.html). Matt Fisher presented a version of 'The Cat in the Hat' written with his family in honor of the contributions of Jim and others to the ITP. A large number of people shared their memories of Jim, and everyone had a good time. The scientific part of Hartlefest is on-line at http://www.itp.ucsb.edu/online/hartle_c99/. To encourage a relaxed atmosphere, the after-dinner remarks were not recorded.

The Pacific Coast Gravity Meetings are a popular regional institution. They provide an opportunity to get together with colleagues, catch up on gossip, and hopefully learn some interesting new physics. The organization is very informal, to encourage participation by the widest possible range of people. Anyone who wants to speak can, and all speakers get the same amount of time. In the same spirit, I will attempt to briefly review all the sessions here, although there is clearly a risk that no information will survive the compression.

The meeting opened with a session of talks on cosmology. Daniel Suson, Warner Miller and Kent Harrison focussed on classical aspects of the early universe. David Salopek argued that Hamilton-Jacobi methods are useful for both classical and quantum studies. Richard Woodard made the striking proposal that the incorporation of quantum back-reaction provides a natural mechanism for ending inflation. Later in the meeting, Beverly Berger and Jim Isenberg presented results of numerical studies of cosmological singularities.

With LIGO nearing completion, it was no surprise that there were a number of talks related to production and detection of gravitational waves. Scott Hughes, John Whelan and Lior

Burko discussed different approaches to calculating the effect of radiation reaction on the sources. Richard Price explained the close limit in rotating black hole mergers, in which a perturbed Kerr black hole is used as an approximate description. In a later talk, Alcides Garat argued that there is no conformally flat slicing of Kerr, which complicates the study of these perturbations. William Krivan and Zeferino Andrade discussed the tail in the waveform, which comes from quasi-normal ringing of the resulting object. Patricia Purdue showed tidal effects are gauge invariant, filling in some of the picture Kip Thorne had sketched on the previous day. Lee Lindblom reviewed the r-mode instability of rapidly rotating neutron stars, and discussed detection prospects.

On the detection side, Teviet Creighton considered a surprising noise source: the gravitational attraction between the test masses and wind. Massimo Tinto addressed data analysis and unequal arm lengths in a space-based interferometer. Jolien Creighton and Gabriela Gonzalez discussed ways of dealing with noise in the detectors. Shane Larson gave a talk on using gravity wave signals to limit the mass of the graviton.

There were also talks on more general numerical work. Carsten Gundlach and David Garfinkle used the self-similar critical solution to explain scaling properties observed in numerical studies of gravitational collapse. James Bardeen, James York and Luisa Buchman described the program of constructing a hyperbolic system out of general relativity. Buchman described some numerical results obtained by implementing one of these systems.

The talks on quantum gravity covered a wide range of approaches and issues. Herbert Hamber discussed using a homemade supercomputer built from PCs to obtain results in a Regge theory approach. Jorge Pullin gave a thorough review of the history and recent progress in the quantum geometry program. Bryce DeWitt and Charles Torre described some techniques in the superspace formulation. Alejandro Corichi argued that reconstructing a physical geometry from a point in the phase space may be non-trivial. Sharmanthie Fernando and David Kastor talked about states where the metric must be an operator-valued function. Jennie Traschen demonstrated agreement between a Born-Infeld field theory and a spacetime picture of a string-threebrane system. Kirill Krasnov argued that quantum gravity can be represented as a constrained version of the topological BF theory, which might provide an interesting formal approach to the path integral.

The effects of quantizing fields on a classical background continue to be an active subject for research. Bill Hiscock re-examined the disruption of the chronology horizon in Misner space. Paul Anderson and Brett Taylor discussed backreaction effects in extremal and nearly extremal black holes. Ted Jacobson discussed the effects of changing the dispersion relation for the quantum fields. Michele Vallisneri attributed the Unruh effect to the failure of classical special relativistic ideas in curved backgrounds.

Mathematical aspects of classical gravity were discussed at several points in the meeting. Kristin Schleich proved a theorem relating black hole topology to the topology of scri in asymptotically anti-de Sitter spacetimes. Don Witt talked about the uniqueness of locally static solutions with a cosmological constant. Robert Mann showed that in 1+1 gravity, the two-body problem can be exactly solved. Arthur Fischer talked about general relativity as an unconstrained dynamical system. Frank Estabrook and Andre Wehner offered classical alternatives to general relativity motivated by symmetries. Micheal Martin emphasized the similarity between the contracted Christoffel symbols and a gauge field. Tevian Dray discussed the potential of octonionic fermions to explain the features of the standard model. William Pezzaglia proposed a new approach to spinning particles involving polygeometric spaces.

Leonard Abrams and Homer Ellis proposed alternatives to the Schwarzschild solution.

At the end of the meeting, the Bell prize for the best student talk was awarded to Teviet Creighton of Caltech for his talk on "Atmospheric gravity gradients: a low-frequency noise limit for LIGO". Some information about PCGM is available at:

http://cosmic.physics.ucsb.edu/pcgm.html.

Next year's PCGM will be at Los Alamos National Lab, organized by Warner Miller.

Second Capra workshop on Black Holes and Gravitational Waves

Patrick R Brady, University of Wisconsin-Milwaukee
patrick@gravity.phys.uwm.edu
Alan G Wiseman, University of Wisconsin-Milwaukee
agw@gravity.phys.uwm.edu

An informal workshop took place at University College Dublin, Ireland from 16-20 August 1999. The workshop emphasized theoretical methods to investigate gravitational-wave generation, implications of gravitational-wave astronomy for theorists, and identification of important open problems.

There were 18 participants at the workshop. During the first three days, there were 12 talks by participants. Each talk was 30-50 minutes in duration followed by equal time for discussion. An outing to nearby Powerscourt and Glendalough was organized for Thursday. Friday morning was devoted to informal presentations by the remaining participants. The workshop was a huge success; it was generally agreed that the format made for an excellent atmosphere to share and discuss the many results that were presented.

Steve Detweiler made the first presentation. His work (in collaboration with Lee Brown) uses a Regge-Wheeler formalism to compute the $O(\mu/M)$ corrections to geodesic motion for a particle orbiting a Schwarzschild black hole. He presented preliminary results which indicate that the orbital frequency is reduced at the innermost stable circular orbit when compared to the test particle limit. Detweiler's talk set the tone for the workshop by reporting new results from work in progress, and by encouraging open discussion of the material.

Scott Hughes reported on progress computing the effects of radiation reaction without the use of radiation reaction forces. He showed results for the radiative evolution of orbits and gravitational waveforms generated by small objects in circular, non-equatorial orbits around Kerr black holes. Perhaps the most interesting result is that the tilt angle of inclined orbits changes extremely slowly — more slowly in the strong-field than would be predicted by post-Newtonian theory.

Kostas Glempedakis and Sathyaprakash reported on work in progress at Cardiff. Kostas discussed ongoing work on radiation reaction effects. Sathya discussed the P-approximants: a class of approximate waveforms that model gravitational waves from inspiralling and coalescing compact binaries. The waveforms are constructed using two inputs: (a) two new energy-type and flux-type functions and (b) the systematic use of Padé approximation for constructing successive approximants of these new functions. The new P-approximants have larger overlaps and smaller biases than the standard Taylor-series approximants. They also converge faster and monotonically. The presently available $(v/c)^5$-accurate post-Newtonian results can be used to construct P-approximate waveforms that provide overlaps with the "exact" waveform larger than 96.5%, implying that more than 90% of potential events can be detected with the aid of P-approximants as opposed to a mere 50% that would be detectable using standard post-Newtonian approximants.

Alan Wiseman discussed methods of computing the instantaneous radiation reaction force on scalar charges orbiting Schwarzschild black holes. These calculations utilize the DeWitt-Brehme method of regularization, where the force is computed from the "tail" of the Green's function. He also reported on progress computing the forces both from the mode sum of the Green's function and analytic expressions for the Green's function.

Amos Ori followed Wiseman by presenting a concrete a method of computing the radiation reaction force with a mode sum. Although the contribution of each individual l, m, ω mode to the self-force is finite, the naive sum of these contributions generically diverges (for certain components of the force). Amos presented a new method for regularizing the mode sum. In this method the mode-sum procedure is modified in a suitable way, in order to obtain the correct (and finite) expression for the self-force.

Lior Burko presented simple, though non-trivial, applications of Ori's prescription for mode-sum regularization of self forces. For the cases of static scalar or electric charges in Schwarzschild spacetime, Burko's calculations recover the results known from completely different procedures. Burko also presented results for the self force acting on a scalar charge in circular motion around a Schwarzschild black hole in the strong field regime. The conservative self-force is attractive, and scales like the black hole's mass squared.

Warren Anderson discussed work in progress with Éanna Flanagan. They use dimensional and counting arguments to calculate the contribution to the gravitational radiation reaction force from the normal neighborhood of a massive particle in an arbitrary vacuum spacetime. Their method involves expansions in (geodetic distance)/(radius of curvature) and (particle mass)/(radius of curvature).

Brian Nolan spoke about two subjects. He reported on work on the strength of the central singularity in spherical gravitational collapse. He also gave a brief critical review of attempts to define black holes in arbitrary spacetimes using surfaces foliated by marginally trapped 2-surfaces.

Eric Poisson reported on his own calculation of the Price power-law decay of radiative fields (scalar, electromagnetic, and gravitational) in Schwarzschild spacetime. His approach has the advantage of linking the behavior of the field at future null infinity and near future timelike infinity in a natural way: The two different power indices arise by taking two different limits of a single expression. His method also yields the field's behavior on the event horizon, complete with all multiplicative factors.

Éanna Flanagan talked about the non-detectability of squeezed statistical properties of relic gravitational waves from the early Universe, based on work with Allen and Papa (gr-qc/9906054). He reported, contrary to a claim of Grishchuk (gr-qc/9810055), that even if relic gravitational waves are detected by LIGO/VIRGO or LISA, their squeezed nature will not be detectable. The squeezing is only detectable by experiments whose duration is comparable to the age of the Universe at the time of measurement. The analysis does not rule out indirect detections of the squeezing via measurements of the CMBR, since CMBR photons measure the stochastic background over a time comparable to the age of the Universe at recombination.

Nils Anderson presented recent results concerning the late-time behavior of perturbations in the Kerr geometry. He discussed analytic calculations based on the contribution from the black hole's virtually undamped quasinormal modes that indicated that the field would oscillate with an amplitude that falls of inversely with time (much slower that the familiar power-law tails). The analytic work was supported by numerical evolutions using the scalar field Teukolsky code. He suggested that this is a new (superradiance related) phenomenon in black hole physics.

During a spectacular day in the Wicklow countryside on Thursday, discussion continued on the many aspects of modeling gravitational wave generation from astrophysical systems. At the final session on Friday morning, Dan Kennefick gave a short report on his recent work studying the sociology of the community of theorists working on gravitational waves. The presentation was received with keen interest by the audience, some of whom had participated in one of the issues discussed by Dan. Jolien Creighton discussed an approach to identifying the gauge invariant component of the work done by tidal forces in a binary system. In a short presentation, Patrick Brady suggested that the Kerr-Schild form of black hole spacetimes might be useful when computing approximate expressions for the radiation reaction force on objects orbiting black holes. Finally, Ben Owen discussed the relevance of gravitational radiation reaction for the r-modes of nascent neutron stars.

In conclusion, Adrian Ottewill's excellent organization contributed significantly to the success of the second Capra workshop on gravitational waves. The workshop was wonderfully paced and organized, allowing a great degree of participation by everyone. An atmosphere of lively debate was facilitated by the allotment of equal time for talks and discussion.

And yes, "Capra" does refer to Frank Capra, the American movie director. Frank Capra was a Caltech alumnus and benefactor. The first "Capra" workshop took place last summer at his ranch outside of Los Angeles.

The workshop was supported in part by funds from University College Dublin. More information can be found at http://www.lsc-group.phys.uwm.edu/˜patrick/ireland99/.

Third Edoardo Amaldi Conference on Gravitational Waves

Gabriela González, Penn State
gig1@psu.edu

The EDOARDO AMALDI CONFERENCE ON GRAVITATIONAL WAVES has been designated as the cornerstone conference for the newly formed Gravitational Wave International Community. The Amaldi Conference has been held twice before, in Frascati, Italy, (1994) and at CERN, Geneva, Switzerland, (1997), but takes on a new significance, now that it is the main meeting for the Gravitational Wave International Community.

It was held on the Caltech campus from July 12 - 16, 1999. About 300 participants, from all over the world attended the conference. After the welcome remarks by Caltech president. Dr. D. Baltimore, we heard a very moving and inspiring talk by Ugo Amaldi, son of Edoardo Amaldi, on a life dedicated to broaden the horizon of physics.

The first couple of days were dedicated to overview talks, while workshops on more specialized topics were held later in the week. The conference did not have parallel sessions, which meant that everybody learned much more than the latest developments in their particular areas. This made the conference more interesting than usual, even though the number of talks was more limited.

The overview talks on the status of interferetry and bar detection of gravitational waves (by Ruediger and Coccia, respectively), were a preamble to the very exciting reports on the different projects around the world, and even outside this world (LISA). Most of the interferometers are doing much progress in their construction, while LISA is arousing more interest in NASA. Bar detectors keep taking data and improving their sensistivities getting close to the quantum limit. We all expect that by the next Amaldi conference reports will be on the cooperative enterprise of a world comunnity ready to learn from fresh data from the interferometers.

On the astrophysical side, Kip Thorne (apart from giving a public lecture) lead a discussion session with reports of different scenarios for production of gravitational waves.

On the technical side of interferometers, there was a session with very nice overview talks of the more important issues that limit the detectors' sensitivities: suspensions, thermal noise, optical configurations and quantum limitatins. Even the theorists who attended these talks could follow them: we hope this is becomes a trend that unites the community in their understanding and tackling of all these difficult problems.

There were then workshops on each of those topics, lead by P. Fritschel (configurations), E. Gustafson (lasers and optics), and myself (suspensions and thermal noise). it was clear from these sessions that the field is bubbling with new ideas which need people and time to test, but undoubtedly will result in much improved interferometers.

There was also a session on gravitational wave detection in space, leaded by K. Danzmann, and a workshop on bar antennae, leaded by W. Hamilton. These sessions proved that even such a new field as this has already a history of detectors being pushed to their quantum limits, and future projects to go in space!

The conference ended with a a session on signal processing and data analysis, organized by B. Allen and S. Vitale. We heard about data from satellite experiments, interferometer prototypes, bar detectors, and we learned from the astronomers' experience with the Supernovae

Neutrino Network.

We all thank S. Meshkov, the wonderful secretary, V. Kondrasho, and the web page keeper, B. Kratochwill. The conference's web page is still up, at http://131.215.125.172/ , and can be consulted for abstracts or more information on the program.

Strings 99

Thomas Thiemann, Albert Einstein Institute, Golm, Germany
thiemann@aei-potsdam.mpg.de

This year's major conference on string theory, STRINGSS99, took place in Potsdam, Germany. The conference site was at the University of Potsdam close to the famous Sanssouci Park and the Neues Palais. The meeting was mainily organized by the Albert-Einstein-Institut, Max-Planck-Instititut für Gravitationsphysik, in particular by Olaf Lechtenfeld (University of Hannover), Jan Louis (University of Halle), Dieter Lüst (Humboldt-University Berlin), K. Miesel (University of Potsdam) and Hermann Nicolai (Albert Einstein Institut (AEI)). It was the second meeting of this kind in Europe after Amsterdam in 1997 and enjoyed a record participation number of 380 scientists.

From the scientific point of view, the meeting was one of the more quiet ones with no major breakthroughs reported during the conference, in contrast to the previous one at the ITP, Santa Barbara, where the ADS/CFT correspondence was celebrated. The majority of contributions was rather technical in nature reporting about small progress in various directions.

However, from the political point of view the meeting was even more successful than one could have even dreamt. The local (Berlin, Potsdam and Brandenburg), national (Frankfurter Allgemeine Zeitung (FAZ), Süddeutsche Zeitung etc.) and international (Times, New York Times etc.) press reported about the conference during the entire week, local, national and international broadcasting stations interviewed several scientists mostly from the AEI and it made it even to the first national TV company (ARD) of Germany spending ten percent of its entire time to report about the conference. Furthermore there was a press conference between reporters from all national TV companies and Micheal Green, Stephen Hawking, Hermann Nicolai and Edward Witten as well as public lectures given by Bernard Schutz, Stephen Hawking and Edward Witten explaining their fields of research to public people, students and TV companies. The amount of people that wanted to listen was twice as large as the number of seats. The public interest in quantum gravity, especially by young people, was much higher than to be expected by the declining physics student enrollment numbers in Germany. This week, there is a title page photograph of participants and a corresponding report of the conference in the "Spiegel", a weakly political magazine which is available throughout the world.

The amount of noise and light that this conference created in the national and international press is outstanding. It is hoped that there will be a positive backreaction for at least string theory-, high energy physics- and quantum gravity related physics science throughout at least Europe and Germany in particular. That this happened was no coincidence : The main organizer of the conference, Hermann Nicolai, took action long before the conference started by informing press, broadcasting and TV stations. On the other hand, that they would pick it up with this amount of enthusiasm was still unexpected.

Coming back to science, the main topics of the conference can be subdivided roughly into the following headlines :

i) *Departure from Supersymmetry*

One of the main drawbacks of string theory is that at present there is only a perturbative description, apart from the existence of D-branes which are conjectured to be fundamental excitations at strong string coupling while they are solitons at low string coupling. These objects were famously used in stringy black hole calculations in order to probe quantum black holes (strong coupling) at low coupling. This works well, however, only for BPS-D-branes, that is, D-branes which break half of the supersymmetry and therefore low coupling calculations in such a setting are protected against perturbative corrections through supersymmetry. In practice, this means that in string theory one can trust entropy calculations only for extremal (Reissner-Nordstrøm) black holes. There is an effort therefore to generalize this rather non-physical restriction.

Sen, Schwarz, Gaberdiel and Horava reported about constructions of stable non-BPS D-branes, that is, D-branes which do not saturate the Bogomol'ny bound. This can be done by considering string theories declining from the usual world sheet actions with Dirichlet boundary conditions but GSO projections different from the usual ones. The result are Type 0 theories which are not supersymmertic but contain stable (lightest) D-brane states and enable one to test string dualities beyond BPS configurations.

Related were considerations by Klebanov, Blumenhagen, Sagnotti and Kachru who considered D-brane anti-D-brrane pairs. By employing the Omega projection and using tachyon condensates one removes the instabilities from the theory.

ii) *Brane Worlds*

Famously, the low energy effective action of the closed superstring theories in absence of D-branes contain the Einstein Hilbert term in leading order of the string tension. Antoniadis, Bachas, Ibanez, Ovrut and Verlinde repeated the analysis that led to this result in the presence of D-branes and described possible scenarios that might lead to sub-mm corrections to classical general relativity and might solve the problems of coupling constant unification, stability of the proton and others. Verlinde used "warped compactifications" in order to explain the smallness of the cosmological constant. His analysis suggests that 4d gravity couples to matter on the D3 branes and that there is a close relationship between the 5d Einstein equations and the 4d renormalization group.

iii) *Black Holes*

DeWit described that, if one incorporates higher derivative terms into the computation of the black hole entropy from black p-branes and uses Wald's correction, that one can in fact remove the discrepancy between the quantum statistical entropy and the classical one that was found earlier in certain scenarios like type IIA on a Calabi-Yau 3-fold.

Hawking considered the stability of rotating black holes in AdS spacetimes and found that Kerr black holes are stable.

A very interesting talk was given by Horowitz who considered quasinormal modes of evaporating stringy black holes. A mysterious result is that if one plots the imaginary part of the lowest frequency quasinormal mode against the Schwarzschild radius one finds a linear relation with a coefficient that equals up to 0.2 percent of accuracy the critical exponents that Choptuik found for his critical behaviour analysis of classical black holes with the same matter content. An interpretation is currently not available.

Peet proved a no-hair theorem for stringy black holes corresponding to D-p-branes with $p \leq 1$.

iv) *Renormalization Group Flows*

Gubser and Warner argued that a certain one parameter family of diffeomorphisms in the bulk with parameter r supergravity theory on an AdS background corresponds to a renormalization group flow in the Super-Yang-Mills boundary CFT in the AdS/CFT correspondence. Using this one-parameter family of diffeomorphisms they show that for AdS-metrics of the form $ds^2 = dr^2 + e^{A(r)} dX^2$ where dX^2 is the four-dimensional Minkowski metric one has $A'' \leq 0$. This suggests that $C = 1/(A'(r))^3$ counts the number of degrees of freedom available to the boundary QFT at the energy scale dual to r and that the exppectation value of the energy momentum tensor scales as C (C-theorem).

v) *Wilson Loops*

Ooguri and Sonnenschein considered the problem to compute the vacuum expectation value of the Wilson loop operator in the boundary quantum field theory of the AdS/CFT correspondence. Ooguri found that if one translates the BPS condition of D-branes in the bulk into the boundary theory then one obtains restrictions on the shapes of the loop. For such a special loop one can actually compute the Wilson loop operator expectation value and finds that it is finite at least for large $g^2 N$ where N is the N of the $SU(N)$ gauge group. Sonnenschein found a finite Lüscher term in the Wilson loop expectation value which describes the quantum fluctuations of the string and one might speculate that these fluctuations are therefore finite.

vi) *Non-commutative Gauge Theory*

With great interest people waited for the talks by Seiberg and Witten who considered open string theory with a constant non-vanishing anti-symmetric tensor field. One finds that in the limit of vanishing string tension and longitudinal components of the target space metric the effective action is described most easily to all orders in α' by a Yang-Mills theory in the given background spacetime where the gauge field components take values in a non-commutative algebra rather than in the complex numbers. This description has many technical advantages, for instance in the description of instanton moduli spaces as described by Nekrasov and Schwarz.

vii) *Others*

Staudacher computed Matrix model expectation values by Monte Carlo methods indicating that certain integrals seem to be finite although the matrix model potential has flat directions. Dijkgraaf and Maldacena reviewed topics in the AdS/CFT correspondence. Polchinsky reported about progress in the DLCQ (discrete light cone quantization) of matrix theory and SYM. Hoppe and Yoneya described open problems in the matrix model approach to M-Theory. Douglas, Mayr, Townsend and Karch reviewed various aspects of supersymmetric p-brane actions. Bousso and Gibbons talked about holography indicating that the correpondence between bulk and boundary theories works only in special cases as for example if the background spacetime is AdS. Kallosh and Berkowits tried quantization of superstrings in AdS spaces (using BRST and twistors) and Ramond-Ramond backgrounds respectively. Green and Obers chose instanton matching as their topics and Theisen gave new insights into gravitational and conformal anomalies.

The conference ended in a summary by David Gross who stated that he missed talks that :
• tested the AdS/CFT correspondence beyond $N = \infty$,
• gave a spacetime description of black hole formation and evaporation,
• gave a dual or holographic description of flat space and cosmology and
• gave a non-perturbative and background independent formulation of ?-theory.
He ended the conference with a "hello again" in Michigan next year and probably the Tata institute, Mumbai in 2001.