Peyresq 13

Valeri Frolov - Hidden symmetries of higher dimensional black holes

with the Alberta Separatists...

Motivations: KK & unification, string theory, brane worlds, perspective on 4d

$F \propto r^{-2-k}$, think of as $G(r) \propto r^{-k}$, grows at short distances.

Example: space $= R^3 \times S^1$. Solve exacly using the method of images. KK tower, $m^2 = m_0^2 + n^2/L^2$. For large L too many states. Other idea: brane world scenario.

BH in higher D. In some scenarios can neglect the gravitational field of the brane itself, which leads to study of higher D vacuum black holes.

Hidden symmetries related to separation of variables, conformal Killing Yano tensor. For Killing vector, in adapted coordinates have $g_{\mu\nu,t} = 0$. Hidden symmetries. CKT: $k_{(a\ldots b;c)} = g_{c(a}\tilde{k}_{\ldots b)}$, where $\tilde{k} = div\, k$. Antisymmetric generalization: CKYT. They satsify a nice algebra. Also given a KYT, it's square contracted on all but two indices is a Killing tensor. Along a geodesic, the contraction of a KYT with the geodesic tangent is parallel propagated.

Carter - Relevance of hard steps in our evolution for application of strong anthropic principle

Anthropic principle: a priori probability should be proportional to the number of observers present that are "like us". [We then went on to discuss this at length. Seems Brandon, Lenny, and Bayes agree.]

Dirac said two numbers are large, perhaps they are related. But thenhe went on to say that since we are in a typical place and time, the numbers must always have been related, which implies a time dependence of G.

Ratio of pion to proton mass is constrained to be roughly what it is to within ten or twenty percent in order fo strong interactions to be weak enough for the big bang to preserve some unprocessed hydrogen but strong enough to allow for higher elements.

Example of rock fall blocking traffic on coastal road: Brandon arrived as the fifth car, and made the prediction that it would be cleared when there were about five more cars. He was right.

Is there a reason why the age of the earth is about the same as the lifetime of the sun? If life were easy to form by evolution, it would be hard to understand why we are here only so late. But given that life involves some significant accidents, we should expect to be here only later, a significant portion of the available time. In fact, if there were many "hard" steps, this would enhance the likelihood that we'd appear only later, towards the end. A candidate example of a hard step is the evolution of sex, though it's not clear just how unlikely that is. Brandon thinks it looks like there were one or two hard steps. But recently meteorologists have argued that perhaps the earth will become unsuitable for life in only about a billion more years, whch would put us rather near the end of the available time, favoring a story with more hard steps, perhaps six. There is a mathematical statistics theory in which probabilities of histories subject to hard steps are worked out.

Bill Unruh - Is quantum mechanics non-local?

A sermon, to encourage the believers and try to save the sinners.

Makes no sense in QM, since there is time, and then there are positions of particles. In QFT however we have oeprator fields on spacetime, and the Heisenberg field equations are perfectly causal.

What is the relation between field operator and wave function? Only for single particle states is there a direct relation, and then the positive frequency part of the field mode is like the wave-function of the particle.

"Non-locality": eg for 30 years Stapp has been saying QM is non-local. Has lost almost all the battles but won the war. But has come up with some pretty neat examples. One got Bill interested: Two spin-1/2 particles. If L1+, then R1+. If R1+ then L2+. If L2+ then R2+. But R2+ is $|-\rangle > +\epsilon|+\rangle$, so this almost always leads to a contradiction. But probability for L1+ was ϵ^4. The smaller ϵ is, the closer to being a product state this is, and the smaller the chance of getting L1+, but the greater the probability of a contradiction. Another way to bring out what's happening is to ask whether L1+ a measurement of R2+.

Stapp's argument. Assume a single measurement finds L1+ and R1+, where L and R are spacelike separated. Can "think" of R measurement as being later than L measurement. So could have measured L2 instead. Then would have gotten L2+. But then would almost necessarily have gotten R2+. [Is this in essence the same as Bell's EPR example?]

Counterfactual arguments may be valid, depending on the theoretical structure in which they are embedded. Eg if my parents marreid oher people, whose child would I be? If you believe in matrilineal transmigration of souls, then there is a simple answer. If you believe believe you are genes, it doesn't make sense.

Bell's argument: A,B in left , and C and D in right region. Values all +1 or - 1. On many copies of system prepared the same way, measure mean values of AC, AD, BC, and BD. Assume cannot measure A and B or C and D at the same time. Define $X = \langle AC\rangle + \langle AD\rangle + \langle BC\rangle - \langle BD\rangle$ and $Y = \langle AC + AD + BC - BD\rangle$ where the products are the mean values. If assume that each observable A,B,C,D actually has a definite value in each experiement. Then can use distributivity, so $Y = \langle A(C+D)+B(C-D)\rangle = \pm 2$. If assume also Bell locality (distribution of L values is independent of the R measurement and vice versa), then $X = Y$. Now in QM, $X = Y$. But eigenvalues of $C \pm D$ are $\pm\sqrt{2}$ (both signs in each case). If choose the state and A,B,C,D properly, can get $\langle\rangle_{QM} = 2\sqrt{2}$.

What is the QM classical difference? Not "locality", since Bell made a locality assumption in order to make the hidden variable model more like QM. The real difference is that the sum of the expectation values is not the expectation value of the sum in the hidden variabel model, unlike in QM. So locality is used only "weakly" in the argument.

Tony Leggett, Found. Phys. **33**, 1469 (2003), "Non-local hidden variable theories and QM: An Incompatibility Theorem". (He originally worked out the example many years ago in Nairobi. Shimony convinced him it was worth publishing.) He imagines a model with hidden variables, i.e. each quantity has a value in each trial, with the distribution independent of the settings of the two measurements, but allowing the outcome of L measurements to depend on which R measurement is made, subject to no-signalling, i.e. for which single side statistics are unaffected by other measurement settings. He showed that such a model cannot reproduce quantum statistics.

So entanglement is **not** the same as non-locality!

Rafael asked what is the relation between spacelike commutivity as the condition for causality, and hyperbolicity of the field equation? Bill said how about choosing arbitrary initial conditions, violating the CCRs, then evolve using a causal field equation. This would satisfy "hyperbolic causality", but not commuting outside the light cone... But is there a Hamiltonian that generates this time dependence? Or is the Hamiltonian necessarily non-local? Or does it violate lorentz invariance?

Bei-Lok Hu - Quantum nonlocality? Analysis of entanglement dynamics of two Qbits interacting via a commonelectromagnetic field

Decoherence rate important for quantum computing. Environment induced decoherence is well-studied. Bei-Lok will focus on disentanglement, which he says is distinct from decoherence.

Short time, fast response, low temperature, or non-Ohmic regime is non-Markovian, and most relevant for quantum computing. This regime is prevalent in strongly correlated systems. Want to get more feeling for disentanglement.

Yu and Eberly, PRL '03: two qbits, each intereacting with own em field in a cavity, entanglement disappears in a finite time.

Multi-mode and multi qbit Jaynes-Cummings hamiltonian: each qbit coupled to same em field modes. Dipole and rotating wave approximations (anti-resonant coupling terms are neglected). Specifically two qbits, at r and $-r$. Studied using Grassman variables and coherent states of qbits. The system is integrable, meaning [?] one can sum the perturbative series, and compute the reduced density matrix as a function of time, having assumed initial product states.

A UV cutoff on the field modes is imposed, since in AMO there is a physical cutoff. The audience is having trouble learning what is setting the scale for the distance beyond which the Markovian behavior emerges.

The time evolution eqn for the density matrix has time-dependent functions in it. The question arose whether these depend on the density matrix at earlier times. Charis said they are universal, independent of the initial state. But it does depend on the fact that the state was a product at time $t = 0$.

"Concurrence" is a measure, introduced by Bill Wootters, of entanglement, which applies even for mixed states. In terms of this measure he showed plots of the decay of singlet concurrence when the separation of the atoms has different values. The $r = 10$ (in units of ω_0) case decays rapidly, as in the "sudden death" case. The $r = 0.1$ case decays much much more slowly. For the singlet state, all these r values decay suddenly, with rates inverted in dependence on r. This difference with the singlet case is explained in terms of constructive vs. destructive interference.

[Relation to Andrew Skinner? - Bei-Lok said it's different, but to my recollection it isn't.]

[Could correlations serve rather than concurrence? - No, since the correlations may be classical, not due to entanglement.]

Sorkin - Does quantum gravity give rise to observable nonlocality?

I.e. action at a distance.

Many/most approaches to QG seem to lead to some form of discreteness. Causal sets are in essence discrete, with no background spacetime. Evidence of discreteness? In the example of atomic discreteness, one has eg modified dispersion, fluctuations (e.g. Lambda), scattering/extinction/swerves (cosmic rays?)

Causal sets are Lorentz invariant [please explain this again in a cosmological setting], so don't expect Lorentz-violating dispersion. Swerve: closest thing to geodesic has random bumps. Would lead to diffusion in velocity space. For massive particles there is a unique parameter, a diffusion constant. For massless particles there is an additional energy drift constant. Observational constraints on not spontaneous heating probably give the strongest bounds. Cliff Burgess asked how about the stability of matter: could swerves act to induce proton decay, for example? Rafael said he doesn't know how to treat that problem, and whether or not the locality underlying the picture of swerves applies adequately.

High energy transparency: collisions (in cm frame) might have exponential UV cutoff, the physical picture being that there are no points therefore no interactions.

Discreteness and lorentz invariance necessarily brings in nonlocality. How to explore this? A discrete version of the d'Alembertian. How does a scalar field behave in an expanding cosmos? How about nonlocal QFT?

Most of the rest of this talk: how to put a scalar field on a causal set? Causal set: order (light cone) + number (giving volume) = geometry. For a fluid, the hydrodynamic variables are more or less obviously connected to the underlying discrete degrees of freedom. For a causal set, the relation must be understood in the sense of a Poisson process of sprinkling.

Why discrete spacetime? Rafael's main reason is the finiteness of bh entropy. But another, simple argument, is that just as finiteness of $\hbar$ implies via $E = \hbar\omega$ that energy should manifest discrete properties, the fact that you can form a quantity with dimensions of length $\sqrt{\hbar G/c^3}$ suggests discreteness of length.

Notion of faithful embedding of causal set into manifold: order preserved, volume matches as Poisson process.

Summary:
Discreteness can respect the Lorentz group (kinematic randomness plays a role — Poisson process — and causets require this)

Locality must be abandoned: radical nonlocality at the fundamental level ℓ

Can recover locality at macro scales L.

Residual nonlocality survives at meso, *intermediate* scales λ_0.

An effective meso-theory would be continuous but nonlocal.

Claim: Poisson process sprinkling respecting volume in Minkowski space exists, and is Lorentz invariant. He conjectures that only Poisson will give Lorentz invariant, and even that any uniform sprinkling will be Poisson [not sure what he meant by this, i.e. assuming exactly what]. Even individual realizations of Poisson sprinkling are Lorentz invariant, in the sense that no equivariant (Lorentz-invariant), measurable rule for determining a frame exists, even on a partial domain of space of sprinklings of positive measure. (So with probability 1, a sprinkling will not determine a frame.)

The question arose as to a finite size version of this. Rafael believes that there will be an exponential falloff of LV with size of the region. brandon says if it is instead a power law that could be dangerous. Rafael says this is a good question, needing work [I think].

Now, to nonlocality: suppose try to make an approximate d'Alembertian, using differences among "nearest neighbors"—which can only mean points separated by some finite, fixed (small) number of links. But Lorentz invariance implies that this will entail very separated points as measured in a given frame. In fact there are an infinite number very "far away" near the light cone. If you try to leave these out, the exclusion will violate Lorentz invariance. [talk with Rafael about four null directions determining a frame].

Charis Anastopoulos - Probabilities for time in quantum theory

Probability for arrival time: not clear that there is a unique answer. [I say must be that it is simply detector dependent.]; tunneling time; decay probability. Will address these by using consistent histories formalism.

Projection-valued measure.

Discussions with Brandon after dinner Monday

- The anthropic principles, weak and strong: if i understood... the strong principle is the idea that there is a multiverse in some of the parts of human like organisms could never exist...so surprising coincidences are tolerable if they are required for our existence. the weak principle is the notion that a theory that predicts organisms such as us are typical is more likely to be correct than a theory that predicts we are rare. i said the latter is just Bayesian inference, Brandon said all inference is Bayesian, and said that Hartle's paper rejects this. I must look again at Hartle's paper. [I looked. It's true. And Hartle & Srednicki's point looks correct. I should read it carefully.]

- Life on Mars most likely origin of us. Why? Life appeared on earth very early, just after it was first possible. This is hard to explain unless either it came from somewhere else, or is easy to make life.

- History of BH thermodynamics. I asked about he BCH paper. Brandon said it was a compendium of results they'd mostly obtained before. On surface gravity, Brandon had already proved it constant, as part of uniqueness theorem. He wanted to call it the decay constant, while Hawking wanted the surface gravity, which B said was a very bad name. Steven also wanted to call it epsilon, after the relevant Newman-Penrose constant, but Brandon argued that would convey smallness. I forgot to ask him then why specifically kappa! [I asked later: it was just a suitable/standard letter for a constant quantity.]

- Uniqueness theorems: an incomplete part: it is assumed that the axial Killing vector is spacelike everywhere on and outside the horizon. This has not been proved. It has also not been proved that there is axisymmetry, though Hawking proved it assuming analyticity.

- Carter constant: how he found it. Was pretty complicated algebra. He was lucky because separability of the H-J action depends on having the right r and θ coordinates. BL and Kerr work, but Kerr-Schild don't. (By the way, he said that numerical relativists call "Kerr-Schild" what really is Kerr coordinates.) He also said that Charlie Misner played a key role in his discovery: Charlie was visiting Cambridge and told Brandon that the equation of motion of a charge in the field of an electric dipole has an extra constant of the motion. This encouraged Brandon to look hard in the Kerr case. The fact that the KG eqn separates is even more of a miracle. But he said he showed 10 years later a way to understand it is that it is related to the vanishing of the Ricci tensor. Viz, form a d'Alembertian operator using the Killing tensor in place of the metric, and note that the commutator of this with the usual d'Alembertian involves a term that vanishes iff the Killing tensor condition is satisfied, and which must be zero if the commutator vanishes, plus another term that vanishes if the Ricci tensor vanishes. Then, one gets another quantum number for the solutions, the existence of which is (somehow) equivalent to the existence of another separation constant.

- Ergoregion: I told him the story of Kayll Lake's paper, and my idea of the shape.

- Infinite wrapping of the B-L angle: he said the Kerr-Schild form takes that out. I mentioned Doran coordinates, which he didn't know about. He asked if the wave eqn separates there too, and answered himself that it is true if r and θ are unchanged from B-L.

- I told Brandon about the 2d expansion paper with Renaud. He didn't know this and found it interesting, particularly the more local nature. [His decay constant gives me the idea to relate that to our calculations. It's defined by $\tau = -e^{-\kappa t}\tau_0$, where τ is proper time of ffo and t is Killing time of signals received at infinity. How to determine/write this?]

- Talked about x-ray interferometer telescope perhaps being able in the future to measure decay constant of the galactic bh. This got us into the mass, which Brandon said was known to 1%, but I said I thought not because of the distance scale not being known to this accuracy. [Is this correct? How does it affect the measurement of the mass, if we scale the orbit radii? For circular orbits, $r^3\omega^2 \propto M$. So a distance uncertainty seems tripled in determining the mass.] This got us into the binary pulsar, and I was confused about not being able to get masses there without knowing the distance. But it seems one doesn't need the distance. In the cosmological setting, however, the measurements may have been scaled by the scale factor, which would mean we don't have the intrinsic rates, so don't know the intrinsic luminosity.

- Fluid dynamics Earlier, on Sunday, I showed Bill the frozen in theorem and helicity conservation using forms. Brandon said that a direct analog works for relativistic hydro of one component barotropic fluid, using $(\rho + p)/n$ (the specific energy density) times the 4velocity as the relevant momentum, and its exterior derivative. The hydro eqn of motion is the analog of the perfect plasma eqn, and Kelvin's circulation theorem is the frozen in, and helicity is same.

Cliff Burgess - Extra dimensions and the cosmological constant problem

A solution may lie there...any solution must affect low energy physics, so will have other obervable consequences.

The cc problem throws the validity of naturalness arguments into doubt. Why buy naturalness arguments at the weak scale and not $10^{-3}eV$?

Features of cosmology are hard to embed in a microscopic theory.

Naturalness. The standard model is ugly, the kind of model that only a mother could love. $L_{SM} = m_0^2 H^* H + dimensionless$. Naturalness would require that physics acounts for small value of Higgs mass. In every case except cc where there is a hierarchy, it is satisfactorily explained in a technically natural way. Ways of solving naturalness: compositeness, supersymmetry, extra dimensions. He says this is an exhaustive list.

[Ask Cliff about why there is only one scale, and if high energy conformal symmetry could be understood as a principle...]

[Is it an accident that the lowest particle mass (neutrino) is the same as the cosmological constant scale?]

[Ask Cliff about susy LV. Is it viable/interesting?]

[Ask Cliff about the EFT of vacuum growth, and nonlocal terms.]

The cc problem is already a problem at the electron mass scale! I.e. integrating down from 10^6 eV to $m_\nu = 10^{-2}$ eV, the vacuum energy density picks up $m_e^4 = 10^{32} m_\nu^4$. If can solve the problem at this scale, the rest wil probably take care of itself. (Brandon: "Take care of the pennies, and the pounds will take care of themselves.")

How extra dimensions help. While the 4D vacuum is Lorentz invariant, so the vacuum energy-momentum tensor if present must be proprtional to the metric, and must curve the space a lot. If there are extra dimensions, the 3brane tension can be large, but its gravitational effect could be just to produce a conical defect in the extra dimensions, rather than to produce large curvature on the brane. In particular he will focus on 6 dimensions, KK type (no warping). If tried to analyze this KK mode by KK mode, it would look like you would regenerate the cc problem, but this misses the symmetry of general covariance in the extra dimensions.

6d model: 6D gravity scale $M_g \sim 10$ TeV; KK scale $1/r \sim 10^{-2}$ eV; $M_p \sim M_g^2 r$. This is interesting because need to see deviations from Newton's law at micron scale. This is just right to potentially explain the dark energy in a way consistent with high energy physics and gravity at short distances. Barely.

To solve cc problemin bulk need susy, but this must break on brane, which leaks into bulk, so must break susy in bulk, and the lowest scale it can be is the determined by ...(scale of extra dimensions)?, which is the dark energy scale.

A concrete model of this is a specific 6d sugra model. It has feature that only positive tension branes are needed. He considers a two-brane class of solutions. The metric multiplet has a scalar dilaton. Conical singularities require vanishing dilaton coupling to branes. Brane loops alone cannot generate dilaton couplings. Bulk loops can, but TeV scale modes are suppressed at one loop by 6d susy. [...more discussion i missed...] Cliff thinks the scale invariance of the bulk sugra is critical and protects the brane-dilaton coupling.

I asked if the closeness of the neutrino mass an the cc/KK scale is explained in his model. He said it could be arranged, but is not expected due to contributions of al the KK modes to radiative corrections to the neutrino mass. (I think.) [I asked, and he said indeed this is a technical naturalness problem, but there are models that solve it.]

Seif Randjbar-Daemi - Branes in 6 dimensions

The easy part of the problem: the brane itself, how particles can be localized on the brane.

A simple example in 4+1 dimensions. Rubakov and Shaposhnikov (1983). Scalar field with potential $-m^2\phi^2 + \lambda\phi^4$.

7 dimensions is minimum in which can construct a coset space with symmetry gorup of the standard model.

Avoid no go chiral fermions theorem in 5d. Hyperbolic tangent kink solution. If Dirac field has ϕ as the local mass, there are chiral zero modes. For some reason he claims only one chirality zero mode exists.

$N = 1$ supermultiplets in $D = 6$. graviton: e^r_M, ψ^A_{M+}, B^-_{MN} (field strength is anti-self dual); tensor (dilaton) ϕ, χ^A_-, B^+_{MN}; Yang-Mills A_M, λ^A_+.

Cedric Deffayet - Spherically symmetric massive gravity and the Goldstone picture

Gravity + matter plus an algebraic term coupling the metric to a background metric f, restricted so that at quadratic order you have the Pauli-Fierz mass term for the graviton. There are many such actions. The field equation has an additional stress tensor coming from the variation of L_{fg}. The field equations imply that this is conserved. He agrees that there are fewer solutions of this, and he says also the energy is unbounded below. Nevertheless one can learn something interesting by studying it. He will discuss here spherically symmetric static metrics.

Can reach coordinates in which g has the Schwarzschild form with $e^-\nu$ and e^λ, and f has R-dependent coefficients of the dR^2 and $d\Omega^2$ terms, depending on one function μ.

The first order solutions are equivalent to solving the Pauli-Fierz theory (I think). This reveals the van Dam - Veltman discontinuity, i.e. the metric does not approach Schwarzschild in the limit that the mass term goes to zero. The next order terms, expanding in Newton's constant and in mR, involve $1/m$, and in fact are larger than the zeroth order terms when R is less than the Vainshtein radius $R_V = (R_s m^{-4})^{1/5}$. So the expansion is good when $R \gg R_V$. If instead keep all terms in $z = mR$ you can see that the expansion requires also $R \ll m^{-1}$.

Next look at expansion in m^2 (but not Newton's constant), which turns out to be good in the disjoint range $R_S \ll R \ll R_V$, and in fact he says it gets even better at smaller R.

There is a Goldstone mode way of analyzing it, introduced by Arkani-Hamed, Georgi and Schwarz. Write $f_{\mu\nu} = X^A_{,\mu} X^B_{,\nu} \eta_{AB}$ where X^A are four scalar fields. This is pure gauge. Then make some decomposition of X^A. Gives a way of understanding the Vainshtein mechanism as a kind of dynamical suppression.

The final conclusion was not clear to me.

Brandon Carter - The Anthropic principle continued

$M_* \approx m_p^2$. The basic nature of the array of compact object mass and densities is relatively insensitive to other parameters, but for example the surface temperature of a solar mass star is not, and it must not be too high or radiation pressure would have blown off the rest of the gas in the solar system before planets could form. Another issue is whether there is significant convection in the star.

Next he discussed estimates of the maximum size of animals that can be physically intact under gravitational forces. The maximum volume, for any set of parameters, is around 10^{-17} of the volume of a planet!

Laurent Freidel - A quantum gravity point of view on AdS/CFT

Purpose of this talk? Original motivation was a paper by WItten proposing a CFT definition of 3d QG ... but in 3d we already have an independent formulation of 3d QG. Can we prove/disprove the correspondence in this case? What would have to be shown? And more generally, what exactly does an AdS/CFT type correspondence say?

Several points to address:
What is the exact dictionary?
Is the correspondence to one CFT or to many?
Is on CFT associated to QG or to some sector of it?
Is there a background independent formulation of AdS/CFT?
Should we care, if we are only interested in quantum gravity?
Can we reconstruct bulk QG from a boundary CFT?

"I started as a critic of AdS/CFT and became a new convert."

Key references: Witten (original paper), Skenderis, De Boer and Verlinde (H-J eqn for QG and RG flow), Maldacena (appendix of a paper on non-gaussianity and dS/CFT picture).

Conformally compact means there is a defining function ρ which is a conformal factor that brings infinity to a finite location. The Einstein eqn implies the gradient of ρ can always be chosen to be a unit vector, spacelike to asymptotically AdS, timelike for dS. For AdS, $\rho = e^{-r/\ell}$, where r is proper distance on hyperbolic slices. The constant r surfaces have extrinsic curvature that is just ℓ^{-1} times their metric, up to order ρ^2. Thus, if you have a functional of the constant ρ surfaces, its radial derivative corresponds to variational derivative wrt a conformal rescaling of the metric. In the limit at infinity, $\partial_r \Psi \sim (2/\ell) \int_{\Sigma_0} h_{ij} \delta\Psi/\delta h_{ij}$.

AdS/CFT is an equivalence between the QG partition function with fixed Dirichlet bc and the gnerating functional of connected correlation functions of the CFT: path integral of $e^{iS_{bulk}}$ over all bulk fields with fixed boundary values.

Conformal dimension: under $\gamma \to \rho^{-2}\gamma$ we have $\phi_i \to \rho^{d-\Delta_i}\phi_i$. (This scaling is determined by solving the field eqn asymptotically for the field. Bill Unruh was complaining that there may be fields that don't fall off in this way. Laurent said there is no problem.) To each ϕ_i is "associated" an operator O_i in the CFT such that

$$\Psi_{\Sigma_0} = Z_{CFT}(\phi_i) = \langle \exp(i \int_{\Sigma_0} \phi_i O_i) \rangle.$$

Three puzzles: 1. Divergences arise on the LHS even in the classical level. 2. Background independence: without a classical spacetime, where is the boundary? 3. The two sides do not satisfy the same equations: the LHS satisfies the second order WdW eqn, while the rhs satisfies a first order conformal Ward identity.

Address in pure gravity. Laurent says the boundary limit of a metric perturbation is a perturbation to the bdy metric, and the variation of the boundary action wrt this is the bdy stress tensor, and therefore this can be computed by leaving the bdy metric fixed, but adding to the bdy action the metric perturbation contracted with the stress tensor. Thus the stress tensor is the CFT operator associated to the asymptotic metric perturbation.

Radial WdW equation is equivalent to the Symanzik RG eqn in the CFT. He says there is a conformal anomaly in the CFT in even dimensions. So in the standard AdS5/CFT there is an anomaly, and he says this determines the 't Hooft coupling. This is news to me!

Looking at the wave function of the bulk, evolved out to the asymptotic geometries, the radial WdW eqn has a pair of solns of WKB form where there is a universal, ρ dependent phase, multiplies by a ρ independent functional. The latter is identified with the CFT partition function. One of the two solns corresponds to the opposite extrinsic curvature. Dropping that, one gets "the" CFT partition function of the correspondence.

My talk

Afterwards Albert asked again: (a) on a fixed background, why can't you argue that the entropy goes up by the usual argument of varying the thermal density matrix, although the area is constant. And, why wouldn't then same argument imply that the entropy in the outside goes down? I am confused. One issue is how far away the energy can be to run this argument. I should reconstruct the analysis of this, required to be a small perturbation to justify use of the variational formula. But probably the issue remains. There should be a good resolution. I need to think about it more...

Renaud Parentani - Initial conditions and interpretation of solutions to the Wheeler-de Witt equation

How to pose the "initial conditions" for the WdW equation? What does it even mean? I.e. how should the solution be chosen? Part of the problem is that we don't have a satisfactory statistical interpretation of this wf. Several have been proposed. Hawking/Page '86 (square of norm), Vilenkin '89 (current), 3rd quantization. None is fully predictive and free of inconsistencies. The square of the norm interpretation is "bound to fail; that is, there are inconsistencies". The Vilenkin interpretation is intrinsically approximate; it can sometimes be used. The 3rd quantization interpretation is incompletely specified.

Plan: compare the solns of the WdW eqn to those of the corresponding Schrödinger eqn. Compare with molecular physics techniques. The lesson will be how to correctly apply the Born-Oppenheimer approximation to the Universe. And, while both norm *and* current define probabilities for molecules, neither will be suitable for he Universe.

3+1 Hamiltonian decomposition of a generally covariant theory, reviewed. The Quantum mechanically, the Hamiltonian constraint imposes spatial diffeomorphism invariance of the wavefunction. The Hamiltonian constraint "pastes together the spatial slices". It is very complicated. For nearly homogeneous and isotropic situations the spatial constraints can be algebraically solved. (cf. an appendix of Parentani & Massar).

Work in "position" a representation. The wf is $|\psi(a)\rangle$, i.e. an a-dependent matter ket. The goal is to identify transition amplitudes from the wf, and then interpret them.

Historically, understanding transition amplitudes (by Born) was a crucial step in understanding the probabiity interpretation of qm. He considered an initial momentum eigenstate, which is scattered into multiple wavevectors. Then Schrödinger's charge density interpretation of the wf was obviously untenable. He said the asymptotic form of the wf gives probabilities.

Compare solutions of Schödinger eqn with a *given* $a(t)$ and WdW eqn, both with the same a-dependent matter Hamiltonian. The "best" way to compare is in instantaneous energy eigenstates $|\chi_m(a)\rangle$ with energies E_m. One can write the Schrödinger eqn for the coefficients of the state in this basis. The eqn involves $\langle\partial_t\chi_m|\chi_n\rangle = \langle\chi_m|\partial_t H|\chi_n\rangle/(E_m = E_n)$. One can use a as the time, even for the Schrödinger eqn. Time drops out except through an $\dot{a}$ factor multiplying the energies. To first order in non-adiabaticity he then derives the transition amplitude form an initial eigenstate.

Now consider the same Hamiltonian in the WdW eqn. Extract a WKB phase analogous to that which appears in solving the Schrödinger eqn. The remaining coefficients $C_n(a)$ satisfy a *second* order eqn. These describe *both* $n \to n'$ transition amplitudes, *and* corrections to WKB. To separate these one needs to make a double expansion. This can be done by analogy with a method used in molecular dynamics.

Introduce a doubling of the freedom, $C_n\psi_n + D_n\psi*_n$. Then impose an extra eqn to determine the extra freedom: $C_n\psi_n - D_n\psi*_n$ plays the role of an "energy", identifying C_n as the "forward" and D_n as the "backward" time generators. [I'm skipping many details here.] They satisfy an identity $\sum|C_n|^2 - |D_n|^2 = const.$. Examples of this doubling are the Dirac eqn, and a molecule in an external electric field.

For WdW, when the D-terms are neglected, the sum of the squares of the C's is constant, and the solution describes a pair of solutions, one evolving forward and one backward in a. This is not yet the Schrödinger eqn, since different matter energy states are evolving in different geometries (a). If matter state is peaked on one energy, then one recovers, working to first order in the energy spread, the Schrödinger eqn.

The D-terms are exponentially suppressed as long as evolution is far from a turning point. Actually both C and D type non-adiabatic transitions are exponentially suppressed. But the D type are more suppressed, because the sum rather than the difference of WKB momenta enter the exponent, so "all the matter int he universe" suppresses the transition.

How to interpret the unusual case in which D terms appear? The sum of the $|C_m|^2$ is then always *greater* than one, so cannot be interpreted as probabilities. What to do? Look to molecule for guidance.

The molecular position R plays the role of a. The sum of difference of squares of C and D is again constant. The sum of squares of C is again greater than one. How should this be interpreted? Must correct for mismatch of sign of R and t. When D terms can be neglected, there is a Vilenkin current interpretation. When they cannot, there is no probability interpretation.

How should we conceive phsyics in the presence of the D terms? And in their presence, what is the meaning of assigning a state in that regime?

Sorkin - Part II

An effective meso-theory would be continuous but nonlocal. Illustrate this claim with a scalar field on a fixed causet, and show how to recover the wave equation.

The problem is that almost all the nearest neighbors are not "near" in a given frame in which a given field is slowly varying. But the problem is not as hopeless as it seems: in 2d, $a + c - b - d$ corresponds to d'Alembertian. So, even if b and c are boosted to the far past, still only $a-d$ and $c-b$ enter, so no large separations need enter. Can also represent this as an alternating sum over layers to the past.

For technical convenience related to evaluating integrals, he layers the set according to the number of intervening elements. Start in 2d, then one that works is $\partial^2\phi \leftrightarrow B(i,k)\phi(k)$, where B is $4/\ell^2$ times $-1/2$ if $i = k$, then $1, -2, 1$ for succeeding layers toward the past. Claim: the expectation value of this at finite ℓ converges to the wave operator as ℓ goes to zero, but the fluctuations diverge. (Proving this involves showing that the expectation values of levels in the sum can be written as a double integral over null coordinates of an exponential e^{-uv/ℓ^2} times the field.) The reason for the large fluctuations is that one is sampling small number of points in the limit ℓ to zero. To fix this, sample out to some finite proper time λ_0 to the past, even in the ℓ to zero limit.

To implement this, define $B(x-x')$ as the kernel for the whole operator in the continuum limit. Look at the form of this, and see how to introduce the finite length, and what this corresponds to at the discrete level. One arrives at an expression that, while not proved rigorously as before to converge to the wave operator, looks like it should, and in simulations appears to do so. There is a 4d analog of this, though the theorem about converge has not been proved, and the precise form of the nonlocal kernel has not been worked out.

Could explore consequences of the nonlocal continuum expression, as well as discrete model. Eg David Rideout is looking at wave propagation, to see the wave analog of swerves. Stability is shown in the 2d case in the massless case (where the free fields are same as for usual wave operator, but are affected differently by sources and curvature), and seems consistent with Rideout's discrete simulations. Laurent asked about the massive case, and Rafael said he wasn't sure.

How about QFT? New approach to renormalization? This nonlocality doesn't remove infinities (he said the UV diverges are even harder — the reason was that the integral kernel of wave operator is the second derivative of a delta fucntion, which somehow becomes smaller in the nonlocal case, hence its inverse is larger (or something like this)), but perhaps it will allow an invariant (Lorentzian) cutoff.

How big is λ_0? Must balance fluctuations against non-locality. If L is Hubble length, and ℓ is Planck length, then to get fluctuations at each point* below order unity need λ_0 greater than $(\ell^2 L)^{1/3}$, which turns out to be of order nuclear dimensions. This means the theory could already be ruled out... [* But should we smear over some volume? His answer: maybe so.]

How to approach the problem of dynamics of the causet? Are there general principles that might lead to a determination? Eg. causality? How about writing down analogs of curvature invariants? But how to write them? A solution to both of these is to refer to the world function $\sigma(x,y) = |d(x,y)|^2/2$. Note $\partial^2\partial^2\sigma$ is proportional to R. There is a discrete analog of the world function, which can be used in this way.

Cliff asked, what about fermions? Answer: what is a vector? Cliff: how about in the continuum limit? Rafael: Yes, that should be straightforward. Cliff: In this framework, precision QED measurements may provide the most stringent constraints. [...even though electroweak is so much smaller]

How about constructing a qft using the continuum limit? Could it be unitary?

Albert Roura - Back-reaction from non-conformal fields in de Sitter spacetime

Isotropic fluctuations of weakly and strongly non-conformal fields. Use low energy effective field theory approach to quantum gravity. There are suggestions that secular screening of the cc could occur, in chaotic inflationary models (at one loop [what was that loop, involving an inflaton line converting to a graviton? does it come from the scalar squared term, with one of the scalars the background value?]), or even in pure gravity (at two loops and higher). Quantizing the metric perturbations brings complications with observables. The potential gauge dependence of the screening effects that had been seen has been pointed out, and in some cases gauge dependence is established.

With no quantized metric perturbations, there are no gauge ambiguities, and interesting effects still occur. Historically the first was Starobinsky inflation, which is driven by trace anomaly of a large number of conformal fields. (This involves scales beyond the validity of EFT. [Why?])

Claims have been made that there are significant IR effects due to weakly non-conformal fields, eg non-local terms associated with massless fields ($\ln(k^2/\mu_0^2)$), with light ($m \ll H$) massive fields ($m^4 a^4 \ln a$), and running of cc from heavy massive fields. Albert will report on work investigating such issues.

His framework is to consider semiclassical homogeneous isotropic evolution form initial states, using the CTP effective action. He used a covariant regularization procedure. He considered a scalar field with mass and curvature coupling. Technically advantageous to transform to conformally flat space. For the weakly non-conformal case they get the integro-differential eqn for $a(t)$, and then they solve it using a perturbative expansion in $(l_P H)^2$.

The solution tends asymptotically to the self-consistent de Sitter solution, with a slightly shifted cc. If you look inside to see the qualitative expanation, in the massless case you get a power suppression of a divergent log $\omega^2 \ln(\omega^2)$. In the (light) massive case, the log is cancelled by a $\ln a$ term.

In the storngly non-conformal case, one can make an adiabatic expansion in inverse powers of the mass, obtaining a local curvature expansion.

Daniel Arteaga - Adiabatic propagation of interacting particles

Motivation #1: Transplanckian problem, modified dispersion near the Planck scale, interaction might be relevant for transPlanckian problem, dispersion appears when interaction occurs.

Motivation #2: Dispersion relations from poles of propagators? $G(\omega, p) \sim -i/2\omega(-\omega + E_p - i\Gamma_p)$, physical interpretation of these energies and decay rates, influence of background field (eg curved spacetime).

Minkowski vacuum: symmetries and interpretation are clear. In general, will use adiabatic approximation, in which decay rate is slow compared to energy and mass and the energy is much greater than the time scale of changing background. Assume exact spatial homogeneity. Also use an asymptotic state approximation, in which "particle" states are identified by expanding field operator as $\sqrt{Z(t)/\omega(t)}(a(t) + a(t)^\dagger)$. Also make Gaussian truncation on CTP generating functional, and a formal expansion in the large-N approximation.

One quantity to compute is the time evolution of the energy. The qualsilocal propagation yields and expected formula, in which the mean energy goes as a time dependent adiabatic energy parameter, a Bose factor $(1+n_k)$, and a decay factor with decay constant evaluated at the midpoint of the time interval. The tme dependent energy and decay rate are expressed in terms of the retarded Green function.

Adiabatic evolution in cosmology. Works same way.

Looked at a mode with a light field and fields of mass m and $M > m$. DeSitter background evolution allows for transitions from an m state to an M state, decaying the state.