Quantum Gravity and Black Hole: Questions on Lecture 1 and 2

January 15, 2016

1 The problem of quantum gravity

1.1 Gravity as an effective theory

1. Pg 4 (item 1 and 2): what symmetries? of the low energy theory? what tell us the especific order in derivatives?

2. Why does a spin 2 particle transform like the symmetric traceless rep of $SO(D-2)$? Explain in general equations (1.2) and (1.3). $SO(D-2)$ because it is massless, so we can choose a reference frame in which the 4-momentum is $p^\mu = (a, a, \vec{0})$ and we have the freedom to rotate the last $D-2$ components. I forgot how to show the representation has to be traceless.

3. Large diff. transformations are mentioned. Why do we always neglect them (generalizes to gauge transformations as well)?

4. Why choosing the action up to 4th order in derivatives?

5. It seems odd to think that the formalism is not good for considering the cosmological constant, since I would say it should be considered as a very low energy phenomenon locally.

6. Am I right to suppose that EFT results will depend on the scale of new physics? If so, how do we deal with that not knowing what scale is that?

   ANSWER FROM EVAN: The whole spirit of EFT is the decoupling of IR from UV physics. If your results are very sensitive to your cutuff then there is no real sense in which the IR and UV have decoupled. As long as you can write your EFT as an expansion in some dimensionless coupling $\nu = m/\Lambda$, where Λ is the UV scale and m is some other physical scale in the problem, then (for $\nu \ll 1$) you are pretty much guaranteed that the UV corrections are small. The scale of new physics Λ then sets the size for corrections to IR physics at a given energy scale. An example where this is NOT the case is the so-called η problem in supergravity, or the Higgs hierarchy problem: scalar masses are not protected from loop corrections, so they pick up a contribution that depends on the UV cutuff.

7. Am I right to think that gravity EFT should be the low-energy limit of a Quantum Gravity theory out there? If so, shouldnt people feel awkward by the fact it does not solve the cosmological constant problem?

   ANSWER FROM EVAN: Depends who you talk to. This relates to Vafa's idea of the 'swampland'.

8. Is it obvious from (1.5) that the theory non-renormalizable? I see it with the development around flat space but it seems clear to him even before that.

9. New physics must appear at or below the Planck scale to save unitarity." Why is this so?

10. I dont quite understand the idea of a new degree of freedom coming from the fact we are considering higher order derivative terms. I used to have the idea that particles are irreducible representations of the Poincar group and, therefore, their degrees of freedom are specified before any sort of dynamics. So, I guess, my question is: what is a dynamical degree of freedom as opposed to a fundamental one (like the polarizations of the gravitons)?

ANSWER FROM EVAN: The DOF are always there in the metric, and so are 'fundamental' but are not always propogating/dynamical. This comes up A LOT in modified gravity. See Kurt Hinterbichler's review 1105.3735v2 for a good discussion of this.

The Einstein-Hilbert action is the unique action for a massless spin-2 particle. This massless spin-2 particle is only the transverse traceless part of the metric. When you modify gravity, you give dynamics to the scalar or vector parts of the metric . An example where this is easy to see is F(R) gravity: you can perform a conformal transformation which rewrites F(R) gravity as Einstein-Hilbert + a scalar field. This scalar field is precisely the trace of the metric, which would have been totally decoupled from the physics before (and so not 'dynamical'). If you don't impose conditions on F(R), i.e. $\partial_R F(R) > 0$ and $\partial_R^2 F(R) > 0$, this scalar will be 'ghostly'.

11. In what sense can we say that the last term of (1.19) is a prediction of Quantum Gravity? It has the same order of 1/r-term only if we consider Planck length scales! But in that case, we are not anymore in a low-energy regime in which EFT is sensible. So, again, how is it a prediction?!
12. Regarding quantum gravity being weakly coupled or strongly coupled, what does it mean that both options are realized in different corners of string theory?
13. I feel curious about GR in a lattice. Could someone comment on that?

1.2 Quantum gravity in the UV

1. I don't understand in what sense gauge transformations acting at ∞ are true symmetries (for neither the gauge thy or gravity examples).
2. He states that a symmetry is a transformation which maps a physical state to a *different physical state* in the same Hilbert space, while a gauge transformation maps a physical state to a *different description* of the same physical state. A way to write (this is from [1]):

$$|a\rangle \to |b\rangle = U|a\rangle \tag{1}$$

where U is a unitary transformation, is a symmetry if

$$\langle a|A|a\rangle = \langle b|A|b\rangle. \tag{2}$$

or equivalently $U^{-1}AU^{-1} = A$. A gauge transformation is when two states $|a\rangle$ and $|b\rangle$ are *literally* the same state, i.e. have the same quantum numbers.

How does this translate into a statement about the action? My understanding is that 'true symmetries' are those that remain after gauge fixing. However, I think things are a little more subtle then I thought: look at the link I mentioned [1]: the first answer says "in a path-integral formalism you only notice the difference [between gauge and true symmetries] with "large" transformations, and locally the action is the same."

What is special about large gauge transformations? What is special about large diffeomorphisms?

3. If I understand well, people would seek for a UV complete theory that reduces to the low-energy gravity EFT. In other words, something that when coarse grained recovers the low-energy limit given by EFT. Now, why is this considered a good strategy? What sort of guarantee do we have that there are not classes and more classes of Uv complete theories that reduce to the same gravity EFT? (I know I am being picky, but I guess that is the idea of this reading course after all!) One example of this: dilaton gravity, GR or modified gravity all recover Newtonian gravity in the low-energy limit (as they should). However, we would not say that those 3 different theories are on equal foot, because we have evidence that goes beyond classical newtonian gravity. If we did not have this evidence, one could have found first modified gravity and thought that to be the ultimate theory beyond newtonian one. In summary, while theory and experiment cannot walk together anymore, things are really turvy from my perspective.

4. Gauge symmetry vs true symmetry: to understand this issue better, maybe this example (if correct) can help. Consider a particle in a plane with a potential given by $V \sim r^{-1}$ in a circular orbit. We can describe the particle by two dof: r, θ. Now, since this problem has a $O(2)$ symmetry - true symmetry - we know that we can go from one to other physical state by shifting θ, but the dynamics is the same. A redundant description of this system would consider now $r \to re^{i\phi}$. In that case, the particle would in principle be described by r, θ, ϕ. Now, since the dynamics depends on the modulus of r, we have the same dynamics as before, but particles could be in principle distinguished by different ϕ. This would be called a redundant dof.
5. Why gauge symmetries are true symmetries only asymptotically (infinity) but locally they are redundant? Can this be rephrased as: global vs local symmetry? If so, I got it.
6. I don't understand the affirmation written in page 12: "To construct diff-invariant physical observables we need to tie them to infinity"
7. given the first paragraph of page 12, how is that we can do cosmology using correlation functions?
8. if we need to tie observers to infinity to have, in principle, a gauge invariant correlation functions, how do we do that for compact spaces?
9. What is the the physical part of $T_{\mu\nu}$? And so, why is it not a Lorentz tensor?
10. Regarding the graviton appearing in the UV theory with other DOFs or being an emergent DOF, what does it mean for string theory to simultaneously realize both?
11. (emergent spacetime): two possibilites: can I say one of them is SUSY and/or dilaton gravity and the other is full string theory?
12. pg.13 A look ahead the part where he says that: Unlike other EFTs (eg the pion Lagrangian), the Einstein action contains an enormous amount of information about the UV completion infrared hints about the ultraviolet. Much of this information is encoded in the thermodynamics of black holes, so that is our starting point, and will be the basis of the first half of the course.
    Why exactly cant we see these hints in other theories? Where exactly is the difference in gravity with the Black Holes? In a generic QFT, is there a general form that IF facts can give us hints about the UV completion?

2 The laws of black hole thermodynamics

1. Why the different nomenclature for $r_{\pm}$?
2. Why, if there were a naked singularity, would physics outside the black hole depend on the UV? Why could the naked singularity spit out visible very heavy particles?
3. No hair theorem doesnt hold for every black hole (AdS, not Einstein gravity) so what happens in these cases?
4. Does Hawking radiation have the same entropy as a black hole? Because it can come out and possibly we can put it back so it doesnt seem possible that the radiation process increases entropy since the reverse would decrease it. Then the entropy is constant and the radiation goes away with the black holes entropy.

References

[1] http://physics.stackexchange.com/questions/13870/gauge-symmetry-is-not-a-symmetry