The Reference Frame

Supersymmetric world from a conservative viewpoint

Tuesday, April 12, 2016

ER=EPR isn't Everett-Copenhagen duality

Susskind's new paper may be funny but it's surely dumb

The last hep-th paper today is a rather hi-tech paper by Suvrat Raju that explains a reason why the 2015 "Born rule" pro-firewall paradox by Marolf and Polchinski attempting to find a problem with the state dependence in quantum gravity isn't really a paradox.

MP have argued that a very low-energy, sub kT excitation in the CFT may create a big change near the event horizon of the AdS black hole which shouldn't be possible in statistical physics. Raju shows – by a highly quantitative analysis of AdS correlators – that no group of observers may simultaneously "create the excitation" and "observe the data containing the paradox". Because of causality, the paradox cannot be made real. If some readers like to look for my name, check the acknowledgements of Raju's paper.

But the rest of this blog post will be dedicated to a new, weird paper about ER=EPR by Lenny Susskind which is a written version of his recent lecture at IAS Princeton.

I have previously conjectured (see e.g. the word "signature" in comments here) that the ER-EPR Correspondence paper by Maldacena and Susskind was really found by Maldacena while Susskind has contributed his signature, the endorsement by the elders, and his youthful excitement for bullšiting.

It was based on some stories I've read about the creation of the ER=EPR paper – Maldacena sent the idea by e-mail and Susskind reply something like "Yup I like it". Moreover, I know that this is how "our" not too important paper was created, too. But I was also building on the style of the ER=EPR paper which is very serious in some sense I will discuss below.

That was very different than the things that Susskind likes to write about topics that are close to the foundations of quantum mechanics, e.g. in his and Bousso's crazy 2011 conflation of the Everett multiple Universes and the cosmological ones.

At any rate, Susskind's new paper today

> Copenhagen vs Everett, Teleportation, and ER=EPR

drowns the ER-EPR correspondence, i.e. the idea from the Maldacena-Susskind paper

Cool horizons for entangled black holes

in an ocean of silly comments by which the "interpreters of quantum mechanics" love to contaminate journals, popular books, and Internet servers.

Both papers are "nominally" about ER=EPR. But let me point out some staggering differences between the two papers concerning the foundations of quantum mechanics that you simply cannot overlook. First, let me list some things that *cannot* be found on the 49 pages of the paper by Maldacena and Susskind:

> MS: the paper is doing "just" serious physics within the limits defined by postulates of quantum mechanics and totally avoids pop-science "soft physics" words such as:
>
> Interpretation of quantum mechanics, Copenhagen, metaphysical, Everett, many worlds, relative state (interpretation), non-locality (in any positive sense), simulate, shocked, baffling, confusing, unsatisfying (about quantum mechanics), consensus, über-observer or single observer, and it also avoids popular-text quotes by physicists and the "angry/childish" capitalization of regular words.

You may guess why I wrote about the absence of these things in the Maldacena-Susskind paper. Susskind's own new paper has all of these things.

> Susskind's paper:
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> 1. It uses the word "interpretation" (of quantum mechanics) 18 times.
> 2. Copenhagen: 19 times
> 3. metaphysical (interpretation): once
> 4. Everett: 15 times
> 5. many worlds: 2 times
> 6. relative-state (interpretation): 13 times (with/without hyphen)
> 7. non-locality: 3 times (all say that "it exists")
> 8. simulate: 6 times (simulating QM, entanglement, classical physics; simulating something means to fake it in some way, right? Physics is about the real, not fake, stuff)
> 9. shocked (QM shocked you): 2 times
> 10. baffling: once
> 11. confusing (QM or observers): 2 times
> 12. unsatisfying (observer in CFT): once
> 13. consensus: once
> 14. über-observer: 5 times
> 15. single external observer: once
> 16. popular quotes by physicists: Bohr, Feynman, Dirac, Everett, Graham, DeWitt, Einstein, Schrödinger, and his cat
> 17. excessive capitalization: two words (THE OBSERVER); by itself, that's 10 points to Lenny's crackpot index according to the rule #7; and I am generously not counting

the words on pages 5-38 that are written using bigger fonts than pages 1-4 ;-)

Do you know why "your" paper with Maldacena avoids all these things, Lenny? Because serious physics papers simply have to. Serious physics papers should really avoid these things entirely, and ER=EPR does, despite its being about rather conceptual things. Papers that not only fail to avoid them but that seem to be so filled with this stuff that they're basically all about this stuff should probably be counted as papers in the full-fledged crackpot category.

A serious physics paper doesn't talk about "interpretations" of quantum mechanics. There is only one new quantum mechanical framework that was discovered in the mid 1920s and that has superseded classical physics (i.e. the old framework of physics that describes the state of Nature as "objectively existing even in the absence of observations") and it doesn't leave any room for multiple "interpretations". The word "interpretation" has been actively coined and used only by those who tried to deny quantum mechanics, its validity, or its completeness – in one way or another. To talk about "interpretations" doesn't mean to do detailed work in quantum mechanics; it means to deny the theory.

This framework is defined by several universal postulates that always hold. All the predictions are predictions of the results of observations. Observations always affect the physical system. What is an observation must always be specified for the theory to produce any predictions. Observations always measure an observable. An observable is always represented by a linear operator on the Hilbert space. Possible results of the observation are always given by the spectrum (set of eigenvalues) of the operator. The state of the system is given by a pure state (vector) or a mixed state (density matrix) which evolve unitarily with time. Probabilities are always computed as squared absolute values of the complex probability amplitudes, i.e. the coefficients in the decomposition of the state to the basis of eigenstates of the measured operator. Every measurement brings the system to an eigenstate corresponding to the measured eigenvalue. This fact cannot be decomposed to any "deeper or more detailed mechanism" because it follows from the probabilistic character of the amplitudes, and is the reformulation of Bayes' theorem within the framework.

That's it. Quantum mechanics is perhaps "conceptually harder" than classical physics but it is not a bizarre incomprehensible philosophy requiring hundreds of pages of clarifications, confusions, arguments, wisdom from self-described philosophers, or any of these stuff.

There is really just "one interpretation" and it's the set of rules (a dozen of rules or so) that were described two paragraphs ago. These axioms were largely discovered by folks working close to Niels Bohr and his institute in the Danish capital which is why the term "Copenhagen" (originally introduced by Heisenberg who was soon sorry about the words he chose) is sometimes associated with the general principles of quantum mechanics. The precise choice of a quantum mechanical theory requires one to pick some observables, Hilbert space (it is automatically given as a representation of the algebra of the observables), and a Hamiltonian and/or an S-matrix. There's a lot of diversity. But the general principles sketched two paragraphs above are always the same. Even in quantum gravity where people discuss things like ER=EPR, they're the same.

One may be confused when he's learning quantum mechanics but once he understands what the theory says, there is nothing *permanently confusing* about quantum mechanics. There is nothing *permanently shocking* (in the quote that Susskind reproduced, Bohr only says that quantum mechanics should have shocked you at least once). Quantum mechanics may look baffling but (as

Dirac said in the quote that Susskind also reproduced at the beginning), it was gradually losing the baffling quality among the likes of Dirac. Dirac hoped that everyone would be gradually getting "intimately familiar" with the rules of quantum mechanics but this "hope" doesn't seem to work too well. (Susskind also quotes Feynman who thought that all the criticisms of quantum mechanics and claims that something is missing are incorrect but "he isn't quite sure".)

Susskind also pays some lip service to all the pop-media crap about non-localities. Compare these sentences:

> Maldacena+Susskind, first two sentences: Spacetime locality is one of the cornerstones in our present understanding of physics. By locality we mean the impossibility of sending signals faster than the speed of light.
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>
> Susskind: Quantum mechanics requires a kind of non-locality called Einstein-Podolsky-Rosen entanglement. EPR does not violate causality, but nevertheless it is a form of non-locality.

You don't need intelligence above IQ of 100 – a PhD in comparative literature is enough – to see that the two papers don't quite agree about the validity of locality in Nature.

Sorry but there is no non-locality involved in EPR. Locality holds and, as Maldacena and Susskind said in the first sentence of their ER=EPR paper, it is really one of the cornerstones of our present understanding of physics. And within special relativity, locality is a necessary condition for causality – they are basically equivalent. So the statement that causality holds even if locality is violated is simply incompatible with relativity.

The ER=EPR paper totally clearly explains why there's ultimately no non-locality in either ER or EPR. In EPR (entanglement), one could think that the correlations imply some non-locality. But the probabilities may be calculated to be independent of events that are spacelike-separated. The correlations displaying themselves despite the randomness of the measurements don't allow one to influence spacelike-separated points because the observer can't influence even "his own" measurement – because it's truly random.

Similarly, the Einstein-Rosen bridges (ER) seem to connect two faraway regions of the spacetime. They're wormholes so one could imagine that through the wormholes, one can send some information or another influence that influences the people living outside the other throat. But it's impossible because the ER bridge is a non-traversable wormhole. You can jump into it – and meet the people who jumped from the other side – but you can never get out again. The "jump into the ER bridge" is exactly as irreversible as the "jump into any black hole". You can get in but you can't get out. The information or influence can't get out on the other side of the bridge which is why non-local influences aren't enabled.

The paradox you could have been afraid of at the beginning is beautifully shown not to be there. In both languages, ER and EPR, you need to do some work to prove it – but the work on both sides may be said to be seemingly different but ultimately equivalent. Locality is preserved both in the ER and EPR pictures and the ER=EPR paper dedicates whole sections to that fact. Instead, Susskind himself prefers some pop-science fog that "there is a form of non-locality, anyway". There is none.

Even more conceptually, the observer. The laws of quantum mechanics are laws describing statistical relationships between observations. So it must be *predetermined* what we count as observations. In other words, the agents that perform them – the observers – must exist and they must know whether they observed (or will observe) something, what they observed (or will observe), and what the result was (will be). Every observation always includes some (in practice, tiny) approximation – the assumption that certain amplitudes permanently lose their ability to re-interfere in the future. In principle, this is never the case. One can always imagine a "more precise" observer who takes this neglected interference into account and may predict his own observations in a more accurate way, including these fine interference effects that the "sloppier" observer neglected.

Quantum mechanics can in no way get rid of this dependence on an observer and his perspective. If it could get rid of it, it wouldn't be quantum mechanics. It would be, by definition, classical physics! But classical physics is wrong. Also, trying to pretend that there is just "one universal" observer in physics, or one "über-observer", in physics means to deny that the "dirty" choice about what is the observer (or observation) and what isn't simply *has to be made*.

The Maldacena-Susskind paper uses the term "observer" 9 times and it isn't afraid of it. The observers are needed. They are connected both with the world lines in the spacetime – observers as used in general relativity – as well as with the measurements in quantum mechanics – observers as needed, even more fundamentally, in quantum mechanics. But they're there. Physics papers ultimately have to refer to them.

On the other hand, Susskind's new paper uses the word "observer" basically as a slur and it contains lots of "dreams" about some über–observer or "single external observer", a Führer that makes observers irrelevant. He can provide us with some "unique correct" – i.e. observer-independent i.e. classical – perspective again. Sorry, nothing like that is possible. Because this "observer-independence" occupies such a huge portion of Susskind's paper, it's enough to conclude that Susskind's paper is just pop-science rubbish.

And I could continue with the rest of the "interpreters" jargon and discourse. Susskind's paper contains much of this garbage.

In reality, the ER-EPR correspondence doesn't deviate from the universal postulates of quantum mechanics in *any way* whatsoever. It is not true that EPR is closer to Copenhagen and ER is closer to Everett, or vice versa. (In footnotes, Susskind admits that the fans of Everett don't agree at all what the interpretation actually is. In a copy of a paper that Susskind owns, Everett added a handwritten comment "bullšit" to DeWitt's interpretations of the Everett interpretation. All of these things are just a pile of ill-defined and inconsistent muddy thinking. Susskind seems to know about this fact. But he also claims that this Everett junk is meant to "improve" standard quantum mechanics. The schizophrenia behind all of this is staggering.)

OK, why isn't ER=EPR changing anything about postulates of quantum mechanics? Because ER=EPR is nothing else than two different ways of picking a basis of a Hilbert space and assigning "spacetime geometric pictures" to the basis vectors. At the end, it's nothing else than the method to pick *two algebras of field operators* (with a different classical spacetime geometry) that can be represented by the same Hilbert space.

The relevant Hilbert space (a tensor factor of the "full Hilbert space" for a given superselection sector) may be written as $\mathcal{H} = \mathcal{H}_1 \otimes \mathcal{H}_2$. The Hilbert spaces $\mathcal{H}_1, \mathcal{H}_2$ may be thought to be isomorphic to one another. $\mathcal{H}_1$ has the basis of eigenstates $|\psi_i\rangle$. We may think about the states of two independent black holes,

$$|\psi_i\rangle_1 \otimes |\psi_j\rangle_2$$

and use them as the basis of the full Hilbert space. On this Hilbert space $\mathcal{H}$, we may define (at least approximately) the action of the algebra of operators, namely field operators that basically live on the spacetime with two black holes.

However, the very same Hilbert space $\mathcal{H}$ admits another algebra of field operators that are defined on a topologically different spacetime background, namely one with the two regions connected by the Einstein-Rosen bridge. The most important state – the simplest basis vector of another basis – is the maximally entangled state

$$\frac{1}{\sqrt{N}} \sum_i |\psi_i\rangle_1 \otimes |\psi_i\rangle_2.$$

This state (with some unitary transformations or reflections added) is the closest representation of the "vacuum state" on top of the classical spacetime with the ER bridge. And additional "excitations" of this maximally entangled vacuum-like state may be added to complete the state into a basis. All these "excitations" will be entangled relatively to the 1-2 decomposition and may be understood as particles created on top of the Einstein-Rosen bridge. They are excitations of the Einstein-Rosen spacetime.

The point of ER=EPR is that the specification of the Hilbert space does *not* define the right "spacetime geometry" uniquely, a general fact that we already know from T-dualities, U-dualities, mirror symmetry, and even the AdS/CFT correspondence itself. There is a new ambiguity. It is up to *conventions* whether you think about the Hilbert space as a representation of the algebra of field operators upon a spacetime with 2 independent black holes; or a spacetime with 1 ER bridge. Just like you can decide whether your spacetime is $M^6 \times K3$ and type IIA strings live on it, or it is $M^6 \times T^4$ inhabited by heterotic strings, you can make your choice whether there are two isolated black holes or one ER bridge. Whenever you have two descriptions, one of them is better for "some states" (if the $K3$ volume is large, the $K3$ description is more helpful; if the entanglement of the state is near-maximal, the ER bridge is a more useful description) but in principle, both descriptions are always OK.

But in the case of both descriptions, it's still quantum mechanics – Copenhagen, if you wish. You need to describe predictions as predictions for observations. Observations need to specify an observable. An observation always collapses the state to an eigenstate. The measurement of a complete set of observables for one subsystem (the first one) always eliminates the entanglement because it uniquely picks the state $|\psi\rangle_1$ and the state of the composite system has to be $|\psi\rangle_1 \otimes |\psi\rangle_2$ for some other factor $|\psi\rangle_2$.

Susskind contradicts pretty much all these things. While some of the toy model examples are OK, something like every other sentence of his article is just wrong. It would be far too much work to try to correct everything he writes. I didn't have a problem with a *single* sentence in the original ER=EPR paper. The contrast is absolutely amazing.

On the last page of the regular text, Susskind says that the AdS/CFT just "seemed" compatible with the Copenhagen interpretation because all observations within either the AdS bulk or the CFT may be imagined to be observations done by an external observer who couples the CFT degrees of freedom to some "external ones". Great. But it in no way follows from the AdS/CFT correspondence that the regular observers "in the bulk" are prohibited. The normal observers *do* live in the bulk. But they still follow the general axioms of quantum mechanics – or the "Copenhagen interpretation", a would-be slur against quantum mechanics that Susskind apparently likes as well.

> What all of this suggests to me, and what I want to suggest to you, is that quantum mechanics and gravity are far more tightly related than we (or at least I) had ever imagined. The essential nonlocalities of quantum mechanics—the need for instantaneous communication in order to classically simulate entanglement—parallels the nonlocal potentialities of general relativity: ER=EPR.

I am sorry but this last paragraph is a shameful attempt to steal credit from others. The fact that there is a very tight link between the spacetime geometry described by GR at low energies; and intrinsically quantum mechanical features of reality such as entanglement was coined by others many years ago, see e.g. Van Raamsdonk, the entanglement glue, 2009. For Susskind to say that this basic philosophy is "suggested" by him now, in 2016, is pretty outrageous. The only thing he is adding is that there is some non-locality, and this addition is just wrong, as carefully explained by "his" paper with Maldacena.

I've been a great fan of Susskind – partly because I viewed him as one of the guys (and perhaps the most funny older physicist) who always have common sense, see the big picture, and can point out the mistakes that someone is trying to bring under impressive jargon. I wouldn't have believed that he would become the #1 propagator of the stinky anti-quantum "interpretation" garbage across the field of quantum gravity.

Lenny is undoubtedly a better entertainer than e.g. Juan and I appreciate it but you know what I would choose if I had to choose between the entertainment value and solid science.

P.S.: At the beginning, I mentioned Suvrat Raju's new paper. I am confident that he is right that the restrictions imposed by causality are *a* reason why the Marolf-Polchinski paradox can't be fully realized – why the MP claim about a contradiction is flawed. I am less certain that the observations on the causality are a *necessary ingredient* for showing that the Marolf-Polchinski argument fails – mainly because I don't feel certain that the MP excitation allows one to stay in the "smaller" PR Hilbert space associated with a particular effective QFT description.

I am willing to believe that Suvrat understands these matters much better than I do, as he has passed all tests I've tried on his papers or pictures, and he clearly writes things that I *couldn't*. He probably knows why his disproof of MP is sort of the "minimum" argument one has to make. So if one ignores my uncertainty about some aspects of his paper, it's great that he doesn't get discouraged. I would. You know, he uses a careful analysis of causal relationships, light cones, and so on.

That takes place in the context where e.g. Lenny is willing to obfuscate the very fact that locality holds even on a simple Minkowski background (basically in non-gravitational QFT). Fog such as Lenny's ambiguous statements about locality is just too foggy. I think that folks like Lenny simply cannot possibly appreciate work such as Suvrat's because Lenny *wants* to be permanently confused about rather elementary questions. And I've been asking this question for quite some time – how many people in the world can actually understand and appreciate important contributions in cutting-edge theoretical physics in general and some conceptual advances in quantum gravity in particular? Does it make sense to deepen our understanding further at all, or is homo sapiens just too stupid a species at this point?

Luboš Motl at 9:49 AM