Comments on Papadodimas-Raju

Santa Barbara Gravity Workshop II
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Attractive features of PR:

- Incorporates the expectation that typical states do not have firewalls

- Provides a framework for spacetime from entanglement, ER=EPR

- Passes some nontrivial tests

Main point here: make more precise the nature of the *state-dependence.*

Ordinary QM: The system is in a state $|\Psi>$. We have a basis $|i>$. The probability of finding the system in a given basis state is

$$\left|<i|\Psi>\right|^2 = <\Psi|P_i|\Psi>$$

The probability of finding a given excitation is

$$\sum_{i \in S} \left|<i|\Psi>\right|^2 = <\Psi|P_S|\Psi>$$

where S is the set of all states with the given excitation and background. The `background-dependence', i.e. the black hole or whatever is being excited, is all built into i and S. P_S is a linear operator, which does not depend on $|\Psi>$.

This is the Born rule, and PR modify it.

PR: $\widetilde{A}_p = g^{mn} A_m e^{\frac{-\beta H}{2}} A_p^\dagger e^{\frac{\beta H}{2}} |\Psi_E\rangle\langle\Psi_E| A_n^\dagger$

Here, $g_{mn} = \overline{A_m A_n^\dagger}$, $|\Psi_E> = U|\Psi>$, $U = \exp(i\theta^m A_m)$, and the θ^m are determined by

$$<\Psi|U^{-1} A_p U|\Psi> = \overline{A_p}$$

This last step may be well defined (N equations for N unknowns, if we only act with untilded A's) but it introduces a complicated $|\Psi>$ dependence into operators, e.g. P_S: it modifies the Born rule.

One symptom (Marolf): it is possible to find states

$$|0\rangle, \ |exc\rangle$$

such that, according to PR, the first is definitely unexcited and the second is definitely excited yet

$$\langle 0|exc\rangle = 1 - \varepsilon,$$

not zero. In ordinary QM, this is not possible. E.g., what is the excitation probability for

$$\alpha|0\rangle + \beta|exc\rangle\,?$$

(Note $\alpha^2 + \beta^2 \neq 1$, rather $\alpha + \beta \approx 1$.) The PR formula gives an answer, but it's not simple: plug this into equation determining U (previous slide), the answer is a complicated function of α, β, and $|exc\rangle$.

Is this a bug or a feature?

Isn't a sharp change in the rules of quantum mechanics at the horizon as bad as a firewall?

Perhaps not – maybe it is a property of the transition functions relating different observers.

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- Systems entangled with other systems. Unlike ordinary QM, this requires new rules.

- Excitations of tilded operators.

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What fundamental framework might give rise to this scenario? Demote state-dependence to field-dependence: third quantization!