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String theory and the information paradox

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String theory, as a consistent quantum theory that contains gravity, is the obvious arena to solve the apparent discrepancy — posed by black holes — between general relativity and quantum coherence. Progress has been done in trying to identify the (quantum) microstates that are counted by the entropy of a bh macrostate. Indeed, duality properties of the theory and AdS/CFT correspondence allow to describe the theory in very different regimes, and thus to connect situations in which different properties may be scrutinized. So a weak coupling regime of strings and branes, where states can be identified and counted, is dually connected with a strong coulpling regime described by supergravity and where bh are expected.

Charges may be identified by topological properties of BPS — and near BPS — states. Their multiplicity in the first regime, matches correctly [1] with the Bekenstein entropy of the extremal — and near extremal — bh with the same charges in the supergravity regime. And the decay spectra, when averaged over the many degenerate quasi BPS states, coincides with the Hawking one in the evaporation of the corresponding nearly extremal bh. This agreement gave confidence of the comprehensive description of bh in a unitary quantum framework as well as an understanding of their thermodynamics. Let me however remark that while the string-brane regime should deal with individual microstates, bh supergravity solutions should be associated with the macrostates given by the incoherent superposition of the quantum microstates that are counted by the entropy. The bh induced loss of quantum coherence would then be a natural consequence of the decoherence implied in the bh macrostate definition. The decay of each aformentioned quasi BPS state, for instance,will be characterized by a well defined multiple correlation spectrum — calculable in a weak coupling regime — that carries the whole information of its identity. It's only the averaging over the (many) quasi BPS states with same masses and charges that will produce the Hawking spectrum that coincides with that of the bh (macrostate) in the corresponding strong coulping regime.

The consistent picture described still leaves unclear the nature of the microstates in the bh regime which are dually connected with those identified and counted in the string-brane regime. They cannot, of course, be themselves identified with bh objects having their event horizon and thus an entropy that microstates have not. In order to clarify this issue, there have been recent attempts to extend the preceeding analysis by discussing "regular bh" microstates, with geometries that would ressemble the bh ones beyond a certain radius but having no metric singularity nor event horizon. They should somehow give rise, in a classical limit, to bona fide black holes. Let me breafly sketch some results.

In order to match a BPS microstate multiplicity in a 2-charge situation for which bh have zero horizon area (vanishing Bekenstein entropy), a profile function for string excitations has been introduced [2] giving rise to metrics that resemble to bh ones down to a radius beneath which the metric appears regularized by the profile function so no singularity at the origin is generated. That radius is considered to define a "stretched horizon" of a sort of "fuzzy bh" state, and its area would measure a sort of Bekenstein entropy that would match the multiplicity of the corresponding string states. These regular states are however assigned to be microstates of an horizonless macrostate. The extention to non vanishing horizon macrostate has been proposed [3] by an AdS/CFT correspondence and a merge of three charge microstates, giving rise again to metrics that — as before — appear as bh ones regularized by different profile functions (actually long throats with regular caps). It is yet unclear, however, if supergravity metric configurations are sufficient to describe these fuzzball sates or if it is necessary to go beyond the metric description of string states to reliably identify and distinguish the microstates in this bh regime.

Despite these hints, I find that it is still far from trivial to understand how an average procedure over microstates with regular metric may give rise to a macrostate with singularity and event horizon. To seize better the problem, let me first remark that microstates being regular, any quantum state — coherent superposition of microstates — is regular as well. Let's start considering a potentially collapsing well defined quantum mechanical state (an imploding coherent shell, 2 — or 25 — particles impinging from far away, etc.). On the basis of what said before, this pure state should not produce a bonafide bh (with its singularity and event horizon) even if its energy and angular momentum distributions are such that a bh should be expected on a general relativistic ground.

This is indeed suggested in some recent quantum treatments. Ashtekar et al. [4] set a Fock quantization of the $1+1$ dimension CGHS model in which the quantum geometry appears as a functional of the matter field and may be studied through some approximations that suggest that the vacuum state of a Minkowski metric is pure and large quantum fluctuations make that the quantum space-time does not end at a future singularity as happens in the semiclassical case. Another approach for a consistent quantum treatment of a collapse and evaporation process is represented by transplankian collision in a superstring framework. Resuming a procedure proposed long ago [5], preliminar results of a new analysis [6] seem to show regular scattering amplitudes as well as non singular induced metric that, however, have a classical interpretation only for impact parameters larger than a critical value b_c proportional to the Shwarzchild radius of the scattering process. For $b < b_c$ the scattering amplitude developes new absoption terms and the metric becomes complex thus suggesting a quantum tunneling interpretation.

We see that despite recent progress, further work is needed in order to understand the complex problem posed by classical black holes to a consistent quantum theory of gravitation. To my point of view [7], string theory indicates that the solution of the apparent paradox lies in its basic pregeometric quantum nature due to which the very concept of space time, its metric and thus general relativity appear only in a classical limit. Or, said in other words, it is the theory, in its rich and complex nature, that may justify in which conditions space time concepts as locality and geometry may emerge. And up to which level the conditions for this emergence preserve the basic quantum coherence of the theory.

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