ER=EPR and TGD

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Abstract

One objection against ER=EPR correspondence proposed by Susskind and Maldacena is that it seems to be conflict with the linearity of quantum mechanics. Superposition of pairs defining entangled state is accompanied by wormhole unlike the state pairs in superposition. In TGD framework this problem is not encountered. Magnetic flux tubes serve as correlates of entanglement irrespective of the character of entangled systems. The superposition holds by strong form of holography (SH) for fermionic states at partonic 2-surfaces and quantum classical correspondence (QCC) implies that the geometry and topology of space-time surface correlate with the quantum numbers of fermionic states and also with their entanglement properties. Entanglement makes states genuinely 3-dimensional despite SH but does not imply emergence of 3-space or space-time.

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1 Introduction

ER=EPR correspondence proposed by Leonard Susskind and Juan Maldacena in 2014 [B1] (see https://arxiv.org/abs/1306.0533 and https://en.wikipedia.org/wiki/ER=EPR) has become the most fashionable fashion in theoretical physics. Even the idea that space-time could emerge from ER-EPR has been proposed.

1.1 EPR

EPR (Einstein-Podolsky-Rosen) paradox (see https://en.wikipedia.org/wiki/EPR_paradox) states that it is possible to measure both position and momentum of two particles more accurately than Heisenberg Uncertainty Principle allows unless the measurement involves instantaneous transfer of information between particles denied by special relativity. The conclusion of EPR was that quantum theory is incomplete and should be extended by introducing hidden variables. The argument was based on classical physics view a bout microcausality.

Later the notion of quantum entanglement became an established notion and it became clear that no classical superluminal transfer of information is needed. If one accepts the basic rules of quantum measurement theory - in particular tensor products of distant systems - EPR paradox disappears. Entanglement is of course a genuinely non-nonlocal phenomenon not encountered in classical physics and one could wonder whether it might have classical sace-time correlate after all. State function reduction becomes the problem and has remained the ugly duckling of quantum

theory. Unfortunately, this ugly duckling has become a taboo and is surrounded by a thick cloud of messy interpretations. Hence the situation is still far from settled.

1.2 ER

ER (Einstein-Rosen) bridge (see `https://en.wikipedia.org/wiki/Wormhole`) in turn is purely classical notion associated with general relativity theory (GRT). ER bridge is illustrated in terms of a fold of space-time. Locally there are two sheets near to each other and connected by a wormhole: these sheets are actually parts of the same sheet. Along the bridge the distance between two systems can be very short. Along folded sheet it can be very long. This suggest some kind of classical non-locality in the sense that the physics around the two throats of wormhole can be strongly correlated: the non-locality would be implied by topology. This is not in accordance with the view of classical physics in Minkowski space-time. At time EPR and ER were proposed, there was no idea about possible connection between these two ideas. Both notions involve unexpected non-locality and one might however ask whether there might be a connection.

In some sense ER=EPR could be seen as kind of victory for Einstein. There could be after all a classical space-time correlate for entanglement and for what happens state function reduction for a system induces state function reduction in distant entangled system. It however seems that quantum theory does not allow a signal travelling along the wormhole throat connecting the entangled systems.

What ER= EPR says that maximal entanglement for blackholes is somehow dual to Einstein-Rosen bridge (wormhole). Susskind and Maldacena even suggests that this picture generalizes to entanglement between any kind of systems and that even elementary particles are connected by Planckian wormholes.

The next step has been to argue that entanglement is more fundamental than space-time, and that space-time would emerge. The attempts to realize the idea involve holography and already this means introduction of 2-D surfaces in 3-D space so that the argument becomes circular. To my opinion the emergence of space-time is doomed to remain one of the many fashions of theoretical physics, which last few years and are then lost to sands of time. These fashions reflect the deep crisis of theoretical physics, which has lasted for four decades, and are as such a good sign telling that people at least try.

The motivation for following TGD inspired arguments was one of the arguments against ER=EPR: ER=EPR does not conform with the linearity of quantum mechanics. The state pairs in the superposition defining entangled state are unentangled (separable) and there should be no wormhole connecting the systems in this case. In an entangled state there should be wormhole. This makes sense only if the space-time geometry couples to quantum dynamics so that one must give up the idea that one has Schödinger amplitudes in fixed background and linear superposition for them. This looks weird even in GRT space-time.

2 The counterpart of ER=EPR in TGD framework

2.1 Some background about TGD

Before discussing what ER-EPR corresponds in TGD few words about quantum TGD are in order [K1]

1. The formulation of TGD in terms of geometry of "world of classical worlds" (WCW) consisting of 3-surfaces, which are holographically related to 4-D space-time surfaces. This holography is implied by General Goordinate Invariance (GCI). One can say that space-time surfaces as preferred extremal of Kähler action are analogous to Bohr orbits and that classical theory is an exact part of quantum theory.

   What I call strong form of GCI (SGCI) implies strong form of holography (SH) stating that string world sheets and partonic 2-surfaces dictate the dynamics. A slightly weaker form of SH is that the light-like orbits of partonic 2-surfaces, which are metrically 2-dimensional and lead to a generalization of conformal invariance dictate the dynamics. The additional degrees of freedom would be discrete and label conformal equivalence classes of the light-like orbits.

2. Quantum states are described as spinor fields in WCW - WCW spinors correspond to fermionic Fock states. Zero energy ontology (ZEO) is an important element of the picture and means that physical states are replaced by analogs of physical events- pairs of states whose members reside at the boundaries of causal diamond (CD) with opposite conserved quantum numbers: this guarantees conservation laws. CD is obtained from causal diamond of M^4 defined as intersection of future and past directed light-cones by replacing its points with CP_2 and has light-like boundaries. Quantum measurement theory based on ZEO resolves the basic paradox of quantum measurement theory and extends it to a theory of consciousness.

3. Quantum classical correspondence (QCC) is an essential element of quantum TGD and relates to quantum measurement theory: the results of measurements are always interpreted classically. In particular, space-time surfaces as preferred extemals of Kähler action (the lift of Kähler action to twistor space brings in cosmological constant term to 4-D Kähler action in dimensional reduction) define classical correlates for quantum states. Conserved fermionic quantum numbers identified as eigenvalues for Cartan algebra of symmetries are equal to the corresponding classical charges assignable to Kähler action. Already this implies that space-time interior is different for unentangled fermion *resp.* entangled fermion pairs.

2.2 ER=EPR in TGD does not lead to problems with the linearity of quantum theory

The TGD variant of ER=EPR has been part of TGD for two decades but have remained un-noticed since superstring hegemony has dominated the theory landscape. There are still many profound ideas to be re-discovered but their realization in the framework of GRT is practically impossible since they relate closely the vision about space-times as 4-surfaces in $M^4 \times CP_2$. What ER=EPR then corresponds in TGD.

1. In TGD framework one gets rid of blackholes. One can say that they are replaced by the regions of space-time with Euclidian signature of the induced metric. This is of course something completely new from GRT viewpoint. One can say that these regions correspond to 4-D counterparts for the lines of scattering diagrams. Minkowskian and Euclidian space-time regions are separated by light-like 3-surfaces at which the induced 4-metric is singular in the sense that its determinant vanishes. The 4-D tangent space of space-time surface becomes locally 3-D. These surfaces can be identified as light-like orbits of partonic 2-surfaces starting from and and ending at the light-like boundaries of CD.

2. The orbits of partonic 2-surfaces replace blackhole horizons and can be regarded as carriers of fundamental fermionic quantum numbers and therefore elementary particle numbers. For instance, elementary particles can be seen as pairs of wormhole contacts connected at both sheets by a magnetic flux tube carrying monopole flux so that a closed flux tube results. SH implies that all data about quantum state can be assigned with these 2-D surfaces at future and past ends of CD. There could be wave function in discrete degrees of freedom assignable to the light-like orbits (their conformal equivalence classes).

3. Wormholes of GRT are replaced with the magnetic flux tubes, which can be homologically trivial or non-trivial. In the latter case wormhole throat behaves effectively as magnetic charge and these are expected to be relevant for elementary particles. The magnetic flux tubes, which are homologically trivial are nearly vacuum extemals and gravitational interactions are expected to be mediated along them.

4. The counterpart of ER=EPR is that magnetic flux tubes serve as spacetime correlates of entanglement long scales. In CP_2 scales wormhole contacts serve in the same role: for instance, gauge bosons correspond to entangled fermion-antifermion pairs at opposite throats of the wormhole of length about CP_2 size.

   This should follow from QCC and the challenge is to understand why un-entangled wormhole throats are not connected by magnetic flux tube but entangled ones are.

   The key point is SH. The linearity of quantum theory need to hold true only at the orbits of partonic 2-surfaces and at string world sheets for second quantized induced spinor fields. In

the interior of space-time it need not hold true. As a matter, fact it cannot be true since QCC demands that different fermionic Fock states correspond to different space-time interiors.

The dependence of fermionic Cartan charges on fermionic quantum numbers and entanglement implies the dependence of corresponding classical conserved charges on fermion state. The natural conjecture is that entanglement demands fermionic strings connecting the partonic 2-surfaces assignable to magnetic flux tubes. Interior degrees of freedom would code for the conserved charges of fermionic states.

5. In TGD framework there is no need to assume a signal between two systems during state function reduction even classically. The magnetic flux tubes fuse the wormhole throats to single system behaving like single particle. Indeed, TGD as a generalization of string model replaces point-like particles with 3-D surfaces and by SH these are replaced with the (conformal equivalence classes of the orbits of) partonic 2-surfaces.

6. This picture does not imply the emergence of space-time. The entanglement between fermionic states associated with different partonic 2-surfaces breaks the effective 2-dimensionality of the theory predicted otherwise (note that discrete degrees of freedom associated with light-like 3-surfaces are however possible). Entanglement forces genuine 3-dimensionality of the dynamics rather than emergence of 3-space.

The conclusion is that due to SH at space-time level the superposition for fermionic Fock states (also that in orbital WCW degrees of freedom) is consistent with QCC. Notice that fundamental space-time spinor fields identified as induced spinor fields are localized at string world sheets having boundaries at the orbits of partonic 2-surfaces (besides SH and number theoretical vision also the well-definedness of em charge for spinor modes demands this) and therefore cannot as such correspond to the spinor fields of QFT limit. These correspond to the modes of the classical imbedding space spinor fields characterizing the ground states for the representations of supersymplectic algebra acting as isometries of WCW and its extension to Yangian algebra with genetors multi-local with respect to partonic surfaces and generating naturally strongly (perhaps maximally) entangled states. In fact, in TGD framework the entanglement would be always algebraic by number theoretic universality and would be maximally negentropic in p-adic sense although it need not be maximal in real sense.

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