How do AdS/CFT- and TGD based holographic dualities relate?

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Abstract

The article *"Traversable wormhole dynamics on a quantum processor"* by Jafferis et al published in Nature received a lot of media attention. My original reaction was due to frustration caused by the media hype. What was done was a quantum computer simulation of the so-called SYK (Sachdev-Ye-Kitaev) model proposing AdS/CFT duality for a particular condensed matter system. The attempts to understand what is involved soon led to a realization that since TGD predicts the analog of AdS/CFT holographic duality, the quantum computational aspects of the experiment should be understandable also using the holographic duality of TGD. This raises the question whether can one translate the notions of AdS holography to TGD holography. In particular, what could be the TGD counterparts for the notions of wormhole and negative energy shock waves needed to stabilize the wormhole. This article deals with these kinds of questions and leads to a rather detailed view of TGD based holography.

1 Introduction

The most recent really heavy hype is by "Quantum gravity in Lab" movement and involves publicity stunt related to the article *"Traversable wormhole dynamics on a quantum processor"* [D1] (`https://cutt.ly/w0n9FAY`) by Jafferis et al published in Nature.

Already the title of the article has a very high hype content. The tweet of the journal Quanta (a popular journal usually satisfying very high standards) published the following tweet:

Physicists have built a wormhole and successfully sent information from one end to the other". The stormy reception of the article and of the tweet forced Quanta to change the tweet to " *Experimental physicists built the mathematical analog of a wormhole inside a quantum computer by simulating a system of entangled particles*".

The Quanta article contains for instance the statement

The team developed quantum software that could reproduce wormhole inspired teleportation on both quantum computers.

This statement was later corrected to

Experimental physicists built the mathematical analog of a wormhole inside a quantum computer by simulating a system of entangled particles.

This statement is still far from an honest statement telling only what was actually done:

Physicists have simulated a model of wormhole in a system argued but not proven to obey AdS/CFT duality by using a quantum computer. This simulation had been done already earlier using an ordinary computer.

Peter Woit commented in Not Even Wrong this hyper-superhype rather critically (`https://cutt.ly/30n9bLG`). Also Scott Aaronson, who is one of quantum computation gurus, expressed his very critical views shared by most quantum computation professionals (`https://cutt.ly/z0n9RSr`). Here is the core part of Scott Aarronson's commentary.

> *Tonight, David Nirenberg, Director of the IAS and a medieval historian, gave an after-dinner speech to our workshop, centered around how auspicious it was that the workshop was being held a mere week after the momentous announcement that a wormhole had been created on a microchip (!!) in a feat that experts were calling the first-ever laboratory investigation of quantum gravity, and a new frontier for experimental physics itself. Nirenberg speculated that, a century from today, people might look back on the wormhole achievement as today we look back on Eddington s 1919 eclipse observations providing the evidence for general relativity. I confess: this was the first time I felt visceral anger, rather than mere bemusement, over this wormhole affair. Before, I had implicitly assumed: no one was actually hoodwinked by this. No one really, literally believed that this little 9-qubit simulation opened up a wormhole, or helped prove the holographic nature of the real universe, or anything like that. I was wrong.*

There is also a very nice popular article "The truth about wormholes and quantum computers" representing a harsh criticism (`https://cutt.ly/Z0n9YMh`).

The combination of all kinds of fashionable pop science related to quantum computation, quantum gravitation, wormholes, EPR= EP, AdS/CFT, etc.... yields this kind of media events. It has been rather frustrating to witness the stagnation of theoretical physics to pop science during these more than four decades. Critics however agree that when one drops all this irrelevant hype away, the work of quantum computer pioneers satisfies the highest standards. It is regrettable that excellent experimentation and engineering is not enough for funding but must be iced with a sugar layer of bad theoretical physics.

Although this kind of hypes do not deserve the attention they receive, I decided to look what I could learn and how could I relate AdS/CFT view of the experiment to TGD view in which holographic duality forced by a 4-D general coordinate invariance is also central and defines quantum classical correspondence in the sense that classical physics becomes an exact part of quantum theory and is realized as Bohr orbitology equivalent to holography. The general aspects of TGD based holography are discussed in [L20, L8, L12]. The aspects related to consciousness and quantum biology are discussed in [L15, L10, L9, L13]. Could one perhaps analyze the experiment in the TGD framework or suggest something analogous and maybe learn something new about TGD itself? This indeed turned out to be the case.

2 Traversable wormhole dynamics on a quantum processor

In the following I summarize my amateurish understanding of the various notions involved with the experiment. These include AdS/CFT duality, traversable wormholes, and negative energy shock waves mentioned in the abstract.

2.1 Abstract of "Traversable wormhole dynamics on a quantum processor"

Here is the abstract of the article "*Traversable wormhole dynamics on a quantum processor"* Daniel Jafferis et al [D1] (`https://cutt.ly/w0n9FAY`).

The holographic principle, theorized to be a property of quantum gravity, postulates that the description of a volume of space can be encoded on a lower-dimensional boundary.
The anti-de Sitter (AdS)/conformal field theory correspondence or duality is the principal example of holography. The Sachdev-Ye-Kitaev (SYK) model [D2] (`https://cutt.ly/60n5zq5`) for $N \geq\geq 1$ Majorana fermions has features suggesting the existence of a gravitational dual in AdS_2, and is a new realization of holography.
We invoke the holographic correspondence of the SYK many-body system and gravity to probe the conjectured ER=EPR relation between entanglement and spacetime geometry through the traversable wormhole mechanism as implemented in the SYK model.
A qubit can be used to probe the SYK traversable wormhole dynamics through the corresponding teleportation protocol. This can be realized as a quantum circuit, equivalent to the gravitational picture in the semiclassical limit of an infinite number of qubits.
Here we use learning techniques to construct a sparsified SYK model that we experimentally realize with 164 two-qubit gates on a nine-qubit circuit and observe the corresponding traversable wormhole dynamics. Despite its approximate nature, the sparsified SYK model preserves key properties of the traversable wormhole physics: perfect size winding, coupling on either side of the wormhole that is consistent with a negative energy shockwave, a Shapiro time delay causal time-order of signals emerging from the wormhole, and scrambling and thermalization dynamics.
Our experiment was run on the Google Sycamore processor. By interrogating a two-dimensional gravity dual system, our work represents a step towards a program for studying quantum gravity in the laboratory. Future developments will require improved hardware scalability and performance as well as theoretical developments including higher-dimensional quantum gravity duals and other SYK-like models.

There is a long list of questions to be answered.

1. What does the term AdS_2 holography mean? How does it relate to ordinary, "real" quantum gravitation?

2. What does "traversable wormhole" mean?

3. What does the negative energy shockwave, argued to open the wormhole for quantum teleportation, mean in general relativity? What interaction between quantum computers, modelled as blackholes, does the negative energy shock wave correspond at the level of the quantum computer system?

2.2 What does AdS/CFT duality mean?

My non-specialist's view of AdS/CFT is the following.

1. AdS/CFT is not part of string theory.

2. It is not a proposal to describe gravitation but gauge interactions in terms of effective gravitation assigned to effective $AdS_n \times S^{10-n}$. AdS_5 would have 4-D Minkowski space as boundary and standard model would be dua to a theory of effective gravitation in AdS_5.

3. The fact that has been forgotten is that the list of physics successes of AdS/CFT duality is rather short. Even if AdS/CFT is regarded as mathematically well-defined, this does not save it from the ultimate fate of unrealistic theories.

4. The basic statement is a field theory with conformal symmetries at the boundary of AdS (say 4-D Minkowski space) is dual to a theory of gravitation in the interior of Ads.

5. In the beginning AdS/CFT with $n = 5$ so that the boundary is 4-D Minkowski space and QFT has conformal invariance in 4-D sense, was tried to apply QCD, to nuclear physics and many other cases. The natural idea was to deduce predictions from the physics of the AdS side. The attempts failed.

Why did AdS/CFT fail?

1. The probable reason is that the basic mathematical framework, although very probably correct using physics standards of rigor, does not correspond to the physical situation.

   For instance, one can argue that AdS is a pathological space-time geometry having time-like loops violating cosmic censorship and spoiling the initial value problem. In fact, the SYK model simulated in the experiments, postulates an interaction between blackholes, which prevents the occurrence of these time-like loops and this interaction would make possible quantum teleportation!

2. The real reasons for the failure could be at a much deeper level. Quantum field theory (QFT) itself is to be blamed. QFT relies on the notion of a point-like particle and fails (of course divergence problems and the non-existence of path integral have tried to tell this to us for more than half a century).

3. The idea that 4-D conformally symmetric field theory is something fundamental rather than mere approximate QFT limit is probably wrong. Also the Einsteinian view of gravitation has a fundamental problem: one loses basic conservation laws of special relativity. Both sides of the duality a might be sick.

2.3 What are traversable wormholes in GRT?

One can learn of traversable wormholes from the thesis of Alex Simpson [B1] (`https://cutt.ly/e0n9KJF`). The thesis describes a family of solutions of Einstein' equations characterized by one parameter a. The solutions have time translations and rotations as symmetries and in contrast to naive expectations the radial coordinate varies from $-\infty$ to $+\infty$ rather than from 0 to $+\infty$.

The general solution of the family is given by

$$ds^2 = (1-2GM/X)dt^2 - dr^2/(1-2GM/X) + (r^2+a^2)(d\theta^2) + sin^2(\theta)d\theta^2) \ ,$$
$$X = (1-2GM/(r^2+a^2)^{1/2}) \ .$$

The coordinates r and t vary in the range $(-\infty, +\infty)$. $r_s = 2GM$ is Schwartschild radius.

Some comments are in order.

1. $a = 0$ gives Schwarzschild solution and in this case $r = 0$ corresponds to a single point as the singularity of spherical coordinates. For $a \geq = 0$, $r = 0$ corresponds to a sphere with radius a. In the TGD framework this would be obtained if there is a magnetic monopole flux through the monopole throat.

2. The study of radial geodesics provides information about the object. One has for the radial velocity $dr/st = \pm(1-X)$. For $a \geq r_s$ this is always non-vanishing. Therefore the radiation from $r \leq 0$ blackhole can propagate to $r \geq 0$ blackhole.

   For Schwartschild solution with $a = 0$, dr/dt vanishes at Schwartschild radius so that light cannot classically escape from blackhole interior.

   For $a \leq r_s$, dr/dt vanishes for two radii $r_\pm = \pm(r_s^2 - a^2)^{1/2}$ so that these acts as horizons and the two blacholes are isolated.

It is known that the traversable wormholes are not stable without a condition requiring a negative vacuum energy density. I must admit that in the case of AdS/CFT duality I do not really know what is the strict meaning of wormhole. One should deform the AdS metric just like one deforms the Minkowski metric to obtain the analogues of blackhole and wormhole.

2.4 What negative energy shock waves are and why they are needed?

The basic objection against the idea of quantum gravitational view of teleportation is that wormholes are unstable against splitting. Neither space ships nor information can travel from blackhole to another one. Wormholes are not traversable: geodesics cannot connect the blackholes but stop at the horizon.

The introduction of the article "Traversable wormholes via a double trace deformation" by Gao et al [B3](`https://cutt.ly/40n91CH`) describes how traversable wormholes might be generated.

The conditions making wormholes traversable would look like follows.

1. Negative energy shock waves are needed to open the wormhole throat so that classical signals can propagate between the blackholes and make quantum teleportation possible. One says that the wormhole becomes traversable. What do these negative energy shock waves mean in GRT context?

2. Quantum gravitational deformation of metric such would make the average energy density negative. The first problem is that QFTs do not allow this. Second problem is that after the sad fate of superstring theory, no generally accepted theory of quantum gravitation exists. The third problem, not usually noticed, is that the notions of energy and other Poincare charges are lost in GRT: this problem was the starting point of TGD for 45 years ago.

3. One can however forget these little nuisances and assume that negative energy densities are possible. Negative energy condition means technically that there exists an infinitely long null geodesic going through the blackhole-like entity such that the integral of the trace of energy momentum tensor is negative along the geodesic. This means that negative energy signals can propagate through the entire geodesic and make possible classical communications necessary for teleportation.

   The averaged null energy condition (ANEC), presumably stating the vanishing or even non-negativity of the trace, is said to fail if this is the case. It is also mentioned that physically the failure of the condition implies that light-rays focused at the other end of the wormhole, defocus at the other end. I didn't quite understand how this follows from the condition.

4. The existence of this kind of defocusing of geodesics is excluded by several conditions. As already noticed, the averaged null energy condition (ANEC) denies their existence. Neither does the generalized second law, stating that the area of blackhole horizon increases, allow them. It would seem that the hopes for traversable wormholes are rather meager.

5. Here however AdS_2 would come to rescue. Before continuing, notice that AdS_2 duality is not for gravitation but for the gravitational dual of a conformally invariant QFT, such as gauge theories. Therefore we can allow things which we would be condemned as nonsense in real quantum gravitation.

   The problem is that AdS has 1 time-like dimension but has closed time-like directions. AdS is imbedded in 3-D space as analog of hyperboloid with line element $ds^2 = dt_1^2 + dt_1^2 - dz^2$ containing 2 time-like directions and a 2-sphere with time-like metric containing circular time loops.

   These time-like loops imply at the level of AdS a violation of cosmic censorship and global hyperbolicity. As a consequence, the standard initial value problem with 3-D initial data is ill-defined since the signals from the surface of initial data return back. This also implies that the blackhole horizon extending through the wormhole intersects itself. The radial direction for AdS between the blackholes is time-like and effectively a compact circle. One has a causal anomaly. This is bad.

6. One must save the causality. The postulated interaction between the boundaries of the wormhole comes to rescue at this time and solve the problem that we have created. This interaction would save causality and would also imply failure of ANEC, and therefore make the wormhole traversable. Negative energy is interpreted in terms of effective Casimir effect.

   Of course, it would be much easier to not postulate at all the AdS duality and be satisfied with the fact that we have been able to simulate certain quantum model using quantum computers.

It must be added that the cosmic censorship hypothesis is in conflict with the existence of exotic smooth structures even in flat R^4 since they imply the existence of closed time-like geodesics. Dimension $D = 4$ is indeed completely exceptional in this sense and this should be important as an important message by theoreticians. I have discussed the possible existence and interpretation of smooth exotics in the TGD framework where holography also fixes the smooth structure [L12].

3 The TGD view of experiments

In the following I describe a possible TGD based interpretation of the experiment.

3.1 The TGD counterpart of AdS/CFT duality

TGD is a proposal, which solves the energy problem of general relativity and generalizes string models by replacing strings with 3-D surfaces. In the TGD framework, 4-D general coordinate invariance leads to a holography and analog of AdS/duality having interpretation as quantum classical correspondence.

1. In the TGD framework, light-like 3-surfaces appear as fundamental objects and are metrically effectively 2-D [L16]. These 3-D objects are related by holography (forced by general coordinate invariance in TGD) to 4-D objects defining space-time as a 4-D surface in $H = M^4 \times CP_2$.

   These 3-D surfaces possess a conformal symmetry, which is much larger than the usual 2-D conformal conformal symmetry, which is already infinite-D. The light-like boundary of $\delta M^4_+ \times CP_2$ also allows symplectic transformations as symmetries. They are assumed to act as isometries of "world of classical worlds" (WCW) [K1] [L19]. The Kac-Moody group assignable to isometries of H is assumed to act as symmetries of light-like 3-surfaces.

2. In AdS/CFT, the dimensions related by holography can be argued to be wrong: in AdS_5 one has $4 \to 5$ and AdS_5 is non-physical unless one wants to believe in the emergence of space-time, a second fashionable but remarkably unsuccessful idea.

3. In TGD, the holography corresponds to $3 \to 4$, which is the case also in the duality proposed between blackhole horizon and interior. In this duality everything has precise physical meaning and both sides of the duality can be tested unlike in AdS/CFT duality for which AdS can be claimed to be a highly fictitious notion.

The basic aspects of the TGD counterpart of horizon-interior duality are as follows.

1. The TGD variant of duality is forced by the 4-D general coordinate invariance and is not a separate principle.

2. In quantum theory this duality corresponds to Bohr orbitology: space-time surface is analogous to Bohr orbit of 3-surface generalizing the notion of particle.

3. Classical theory as Bohr orbitology becomes an exact part of quantum theory.

4. This duality leads to what I call zero energy ontology (ZEO) in which these 4-D Bohr orbits replace time=constant snapshots as basic objects. This leads to a solution of the basic paradox of quantum measurement theory and has profound implications in quantum biology and theory of consciousness [L6, L15, L1, L4].

3.2 Magnetic flux tubes as TGD counterparts of traversable wormholes

Could the traversable wormholes have TGD analogues and could they provide a dual or a classical correlate for the quantum description as the quantum classical correspondence suggests. One must remember that the TGD view of quantum differs considerably from the standard view.

1. TGD view of space-time, manysheeted space-time, predicts topological field quantization and the notion of field body [L6]. The notion of magnetic body (MB) consisting of flux tubes and flux sheets is in a central role in TGD, in particular in TGD inspired biology and model of brain [L11, L9, L2, L10, L3].

2. The number theoretic vision of TGD predicts hierarchy of dark matter as phases of ordinary matter labelled by values of effective Planck constant: dark matter would reside at the field body, in particular at MB. These phases of ordinary matter might be highly relevant for quantum computation [L14, L18], which is in the standard framework formulated using standard quantum mechanics.

3. TGD predicts zero energy ontology (ZEO) [L1, L4, L7]. One prediction is that the TGD counterpart of ordinary state function reduction (SFR) reverses the arrow of time. Could this give rise to quantal versions of time loops?

In TGD monopole flux tubes are natural candidates for traversable wormholes.

1. Wormholes of GRT are not stable. Monopole flux tubes are stabilized by the fact that monopole flux is conserved: the flux tube cannot be split.

2. If one has a pair of flux tubes with opposite fluxes connecting two systems, reconnection can split the flux tube pair to U-shaped flux loops. This is a basic mechanism in the TGD inspired quantum biology [L17].

3. Could the reconnection of flux tube loops to a flux tube pair generate an analogue of a traversable wormhole with classical signals propagating along the flux tube pair and making possible quantum teleportation?

4. Could thus involve "big" SFR changing the arrow of time and giving rise to effective negative energy signals propagating backwards in time?

3.3 Trying to build a quantitative picture

Could this correspondence be made more quantitative and detailed. Could one assign to wormhole throats and entire wormhole scales which are analogous to r_s and the parameter a and could the condition $a \geq r_s$ have an analog in TGD framework.

The first trial starts from wormhole contacts as they are identified in TGD.

1. The expectation is that at least for elementary particles the wormhole throat radius is of order CP_2 radius and therefore extremely small. Mass would be of order $M = 10^{-4} m_{Pl}$ and could correspond to a mesoscopic mass: a water blob of size $\sim 10^{-4}$ meters has mass of order m_{Pl} . Could this give some idea how to proceed?

2. The Earth's gravitational field has a key role in TGD inspired hydrodynamics [L5] and quantum biology since gravitational quantum coherence is possible in even astrophysical scales [L11, L9]. Gravitational Compton length $\Lambda_{gr} = h_{gr}/m = GM/v_0$ defines a fundamental quantum gravitational size scale. One has a scale of about .45 cm for Earth mass M_E and $v_0 = c$. Intriguingly, this scale corresponds to the size of snowflakes, whose physics is poorly understood.

The condition $a \geq r_s$ for the traversability need not generalize as such in the TGD framework. Therefore it is better to start from the physical picture rather than trying to mimic wormhole physics.

1. This kind of condition should tell when the reconnection for U-shaped flux tubes is possible. This suggests that the parameter a characterizes the length of the U-shaped flux tubes connecting the two quantum systems. This length scale should be more than half the distance between the two systems as analogues of blackholes so that the half-distance $d/2$ would be the counterpart of r_s and the typical length of the U-shaped flux tube would be the counterpart of a. The length of the flux tube depends on the value of h_{eff} and on the p-adic length scale assignable to the flux tube.

2. For an ordinary wormhole, the formula $a \geq r_s$ guaranteeing traversability can be satisfied if the mass parameter m decreases below a but remains unaffected. This would correspond to a generation of negative vacuum energy reducing m below $a/2G$. Does this have any generalization to the TGD framework?

3. Now the distance d between the systems could decrease or the length of U-shaped flux tubes could increase so that reconnection becomes possible.

The postulated interaction between the two systems should give rise to the analog of negative energy shock wave.

1. In the TGD framework, the reconnection of flux tubes could be the interaction generating a communication line. The GRT analogue for the negative energy shock wave could be Hawking radiation. The system at right would receive positive energy and the system at left would receive negative energy, or equivalently, send positive energy.

   In the experiment considered, the positive energy received by the system at right would serve as a metabolic energy feed and would change the distribution of values of h_{eff} in it. The values of h_{eff} would tend to increase. Therefore also entanglement negentropy content of the system would increase meaning that entanglement is created. At the left side the opposite would occur. One can say that information is transformed between the two systems.

2. Could "big" SFR (BSFR, that is the ordinary SFR) in the scale of the entire system be involved. This would imply a change of the arrow of time and one could say that the system at right sends negative energy signals to the system at left and gets positive energy as a recoil acting as metabolic energy. This mechanism is a basic metabolic mechanism in the TGD inspired quantum biology. The energy for dark analogs of Hawking photons would be large although frequencies could be small. For $h_{gr} = GM_E m/v_0$, the energies would be in visible range for frequencies of order 10 Hz.

   The simplest interpretation is that the first BSFR creates reconnection and maximal entanglement between the systems and and the second BSFR corresponds to de-reconnection and the quantum measurement destroying the entanglement. The classical communication during the entanglement period induces the transfer of internal entanglement. One could see this phenomenon also as quantum tunneling for information.

3.4 The picture based on effective Planck length identified as a p-adic length scale

Could one interpret this picture in terms of an analogue of Schwartschild radius associated with an effective Newton's constant G_{eff} much larger than G so that one might speak of strong gravitation?

A possible explanation for the very large effective value of G_{eff} is based on the TGD view of space-time as a network of nodes connected by flux tubes along with interactions are mediated. All fluxes, including also the gravitational flux, flow along the flux tubes and therefore the flux which is conserved along the flux tube is preserved if flux tube thickness remains constant. This means that gravitational interaction as also other interactions is either absent or if present, and much stronger than Newtonian gravitation, which replaces these fluxes with the total flux over the entire solid angle.

1. The Schwarzschild radius $r_s = 2GmM$ for masses in the length scale of say water blog with mass of order Planck mass $m \sim M_{Pl}$ is ridiculously small. It seems that one must replace G with an effective gravitational constant G_{eff}, which corresponds to a mesoscopic length scale.

2. p-Adic length scale hypothesis comes to the rescue here. p-Adic length scale hypothesis states that p-adic length scales are of the form $L_p = \sqrt{p}R$, where R is CP_2 radius. One can regard L_p as an analogue of Planck length and define an effective gravitational constant G_{eff} as

$$G_{eff} = \frac{L_p^2}{\hbar_{eff}} \quad . \tag{3.1}$$

For instance, $h_{eff} = h_{gr}$ can be considered.

3. This would give for the effective Schwartschild radius $r_{s,eff}$, which corresponds to Compton length of order $L_{c,dark} = \hbar_{eff}/m$:

$$r_{s,eff} = 2G_{eff}m = 2\frac{L^2_{p,dark}}{\hbar_{eff}}m = \frac{GM}{\beta_0} = \frac{r_s}{2\beta_0} = \Lambda_{gr} \quad . \tag{3.2}$$

This gives gravitational Compton length which for Earth mass which does not depend on m and for the Earth mass $M = M_E$ is about .45 cm.

One could require self-consistency in the sense that one has

$$\frac{\hbar_{eff}}{m} = \Lambda_{gr} = r_{s,eff} \quad . \tag{3.3}$$

1. This allows to solve $\hbar_{eff}$ as

$$\frac{\hbar_{eff}}{\hbar} = \sqrt{2}\sqrt{L_p m/\hbar} \quad .$$

2. This suggests a consistency test. $\hbar_{eff} = \hbar_{gr} = GM_E m/\beta_0$, $\beta_0 \leq 1$ is a reasonable first guess consistent with TGD inspired quantum biology.

Let the mass of the analog of blackhole (say water blob) be of order $m_{Pl}x$, x not far from unity. Let the p-adic length scale be in the range of biologically most interesting p-adic length scales $L(k)$, $p \simeq 2^k$ corresponding to 4 Gaussian Mersennes $M_{G,k} = (1+i)^k - 1$, $151, 157, 163, 167$. $L(167)$ corresponds to scale 2.5 μ, the size of the cell nucleus. These Gaussian Mersennes represent a number theoretic miracle.

3. One obtains

$$\frac{\hbar_{eff}}{\hbar} = \sqrt{x}\sqrt{2L(k))/L_{Pl}} \quad .$$

For $k = 167$ one has $\hbar_{eff} \sim 10^{12}x^{1/2}$. For proton mass m_p, $\beta_0 \simeq 1$ and $x = 1$, This is by a factor of order 10^{-2} smaller than $\hbar_{gr} = GMm_p/\beta_0 \simeq 10^{14}$.

4. The scaling $L(167) \to L(167+26) = L(193) = 2^{13}L(167)$ gives $L(193) \simeq 2x^{1/2}$ cm, which is $4x^{1/2}$ times the gravitational Compton length $\Lambda_{gr} = GM_/\beta_0$ for Earth for $\beta_0 = 1$. For $x = 1/16$, which corresponds to one obtains the correct order of magnitude $m = m_{Pl}/16$.

3.5 A connection with an old problem of classical TGD

45 years ago, one of the first things to do when I had got the basic idea of TGD was to look whether one could obtain Schwartschild metric as a spherically symmetric stationary solution of field equations assignable to some action principle. A more modest challenge was the attempt to understand whether the Schwartschild metric allows an embedding as a 4-surface in $M^4 \times S^2$ (later identified as $M^4 \times S^2 \subset M^4 \times CP_2$). This problem is discussed in [K2].

1. Using the coordinates $(u = cos(\Theta), \Phi)$ for S^2, spherical coordinates (m^0, r_M, θ, ϕ) for M^4, and coordinates (t, r, θ, ϕ) for X^4, the simplest trial for embedding would be $(u = u(r), \Phi = \omega t)$. In M^4 degrees of freedom one has $r_M = r$. The simplest guess for the relationship between M^4 and X^4 time coordinates is $m_0 = kt$ fails, and one must have $m^0 = kt + f(r)$ to get the radial part of Schwartschild metric correctly.

2. The time component g_{tt} of Schwartschild metric is given by

$$g_{tt} = 1 - R^2\omega^2 sin^2(\Theta) = 1 - R^2\omega^2 sin^2(\Theta_0) - 2R^2\omega^2 sin(\Theta_0)cos(\Theta_0)\frac{C}{r} + O(1/r^2) \ . \quad (3.4)$$

   Assume for convenience $R^2\omega^2 sin^2(\Theta_0) \simeq 0$ and $k \simeq 1$.

3. By comparing with the Schwartschild metric having $g_{tt} = 1 - 2GM/r$, one obtains the condition

$$r_S = 2GM = 2R^2\omega^2 sin(\Theta_0)cos(\Theta_0)C \ . \quad (3.5)$$

   The condition that the electron's p-adic mass scale comes out correctly in p-adic mass calculations gives $R^2 = x10^8 L_{Pl}^2$, where x is not far from unity. One would have the condition $\omega^2 sin(\Theta_0)cos(\Theta_0)C/M \sim 10^{-8}$.

4. The naive original guess was that CP_2 radius corresponds to Planck length: $R = L_{Pl}$. Much later, when I had ended up with the hierarchy of effective Planck constants $h_{eff} = n$, $h = n_0 h_0$, $n_0 = (7!)^2$, came the realization that $R = L_{Pl}$ could be true after all and that CP_2 and one could have the value of R that I had identified could be "dark" in TGD sense: $R = L_{Pl,dark} = (\hbar_{eff}/\hbar_0)L_{Pl} = n_0 L_{Pl}$.

5. This picture generalizes. One can also consider larger values of $L_{Pl,dark}$ and therefore of $G_{dark} = L_{Pl,dark}^2/\hbar_{eff}$. By the above argument one could assign these values to monopoles flux tubes.

3.6 A modest attempt to undestand the results of the simulation in the TGD framework

Is this very rough picture consistent with the more detailed description of the simulation (`https://cutt.ly/O0n93BU`)?

1. Prepare an entangled state between two copies of H: one is the left side of the wormhole, and the other is the right side of the wormhole. This entangled state is dual to a wormhole at time $t = 0$. The devised through learning small SYK-like system has 7 Majorana fermions on the left and 7 Majorana fermions on the right; encoding all 14 fermions in superconducting qubits requires 7 qubits.

   Comment: the initial state is quantum entangled. If the existence of flux tube pair(s) serves as a correlate for entanglement, BSFR changing the arrow of time must take place.

2. Evolve the wormhole backwards in time according to H. This moves the horizons of the left and right mouths of the wormhole.

   Comment: The time evolution backwards in time could correspond to a sequence of SSFR ("small" SFRs as counterparts for "weak" measurements preserving the arrow of time). What could the motion of the wormhole mouths correspond to? Suppose that the half-distance d between the two systems corresponds to the parameter r_s and the length L of flux U-shaped flux tubes corresponds to the parameter a. If this is the case, the motion would correspond to the decrease of the length of the U-shaped flux tubes so that the condition $L \geq d/2$ as an analogy for the condition $a \geq r_s$ ceases to be true and the U-shaped flux tubes become too short to reconnect anymore.

3. Prepare two maximally entangled qubits: call the first one the reference qubit and the other the probe qubit. We later attempt to send the probe qubit through the wormhole, and we will be able to check if it made it through by comparing against the reference qubit. These two additional qubits bring the total circuit size to 9 qubits.

   Comment: this step could correspond to a BSFR changing the arrow of time to normal.

4. Swap the probe qubit with one of the qubits in the left quantum system of the wormhole. This inserts the entanglement probe qubit into the wormhole. Evolve the wormhole forwards in time according to H. As this happens, the information of the probe qubit gets chaotically scrambled throughout the entire quantum system.

   Comment: This step could correspond to a time evolution by SSFRs with the standard arrow of time.

5. Apply an entangling interaction between the two sides of the wormhole. In the gravitational dual, this corresponds to sending an energy shockwave through spacetime. We can apply an interaction that gives this shockwave negative energy to prop open the wormhole and make it traversable, or we can choose a positive energy shockwave to close the wormhole and prevent information from getting across.

   Comment: This step could correspond to a reconnection of U-shaped flux tubes to a flux tube pair connecting the two systems and entangling them, perhaps maximally.

6. Evolve the wormhole forwards in time according to the Hamiltonian H. As this happens, information of the probe qubit undergoes further chaotic dynamics. The dynamics refocus the information onto the right side of the wormhole.

   Comment: this step could be a BSFR followed by a sequence of SSFRs with standard arrow of time. The entanglement would become visible for the observer with a standard arrow of time.

7. Measure the amount of entanglement between the rightmost qubit of the right system and the reference qubit. More entanglement means more information was transferred from the left system to the right system. In our experiment, we observed more entanglement when a negative energy shockwave was used compared to a positive energy shockwave, which is consistent with the interpretation that some quantum information was transferred via the traversable wormhole mechanism.

3.7 Some questions to ponder

There are still some questions related to the interpretation of TGD to be considered.

1. In the TGD framework, the expectation is that the radial coordinate r for the family of blackhole-like objects corresponds to the radial coordinate of $E^3 \subset M^4$ and is therefore non-negative.

   One can however ask whether one could have parallel space-time sheets connected by a wormhole contact with an Euclidean signature of the induced metric and whether the negative values of r could be natural for the radial coordinate at the other space-time sheet. Both sheets would be covered by a single coordinate.

2. One must also ask whether the connected space-time sheets could correspond to opposite arrows of time, which changes in "big" state function reductions (BSFRs). If so, wormhole contacts would mediate interaction between quantum states with opposite arrows of time. The wormhole throat with Euclidean signature does not have a definite arrow of time and could mediate this interaction. In this picture elementary particles, at least bosons, would be pairs of particles with opposite arrows of time. Can this make sense?

4 How do AdS/CFT holography and TGD holography relate to each other?

In the experiment considered, the so-called SYK model (Sachdev-Ye-Kitaev) [D2] (`https://cutt.ly/60n5zq5`) was simulated using a quantum computer. The model is constructed to realize AdS_2/CFT correspondence and the quantum computer simulates the 1-D quantum system dual to wormhole in 2-D AdS_2.

The thesis *Holographic quantum matter: toy models and physical platforms* [B2] (`https://cutt.ly/w0n3w0e`) of Etienne Lantagne-Hurtubise gives a nice description of the SYK model and the following comments are based on the introduction of the thesis.

What I see as a problem is that the space AdS_2 is completely fictitious so that the physics at this side cannot be tested. However, TGD also predicts holographic duality between 3-D surfaces as boundaries of space-time surfaces and identifiable as outer boundaries of physical objects and the interior of the space-time takes the role of AdS. In particular, the system considered in the experiment should allow TGD based dual description.

TGD should give a classical description of quantum dynamics coded by 3-D data holographically in terms of classical physics in the interior of space-time surface. Therefore the challenge is to also describe the reported findings.

There are obvious questions to be answered. How closely AdS/CFT and TGD holography could relate and how do they differ? Could there exist some kind of AdS/CFT-TGD dictionary?

1. AdS/CFT correspondence predicts $4 \to 5$ holography for AdS_5 interpreted as an emergent 5-D space-time. M^4 would carry gauge fields and for gravitational holography one would have $3 \to 4$. Skeptics could argue that there is total mess: for instance, what happens to the general relativistic description of gauge fields using 4-D space time? Should one have $3 \to 4$ gravitational holography followed by $4 \to 5$ for gauge fields?

2. TGD predicts $3 \to 4$ holography. Instead of AdS one has space-time but is realized as a 4-D surface. Light-like 3-surfaces with extended conformal symmetries due to their metric 2-dimensionality defined boundaries of 4-D space-time surfaces and contain holographic data defining the space-time surface and also the data defining the fermionic part of quantum state.

   4-D general coordinate invariance implies almost exact holography and classical deterministic dynamics becomes an exact part of quantum TGD: one has what one might call Bohr orbitology. This picture has a number theoretic counterpart at the level of M¡sup¿8¡/sup¿: associativity assigns 4-D surface of M¡sup¿8¡/sup¿¡sub¿c¡/sub¿ to the roots of rational polynomials represented as 3-D mass shells in $M^4 < sub > c < /sub > \subset M < sup > 8 < /sup >< sub > c < /sub >$.

4.1 Do the time loops of AdS has time-like loops have a TGD counterpart?

AdS time loops have indeed TGD countepart. The reason is that 4-D space-times are completely exceptional.

1. 4-D, and only 4-D, space-times allow exotic smooth structures [L12]! A continuum of exotic smooth structures are possible. Exotic smooth structure can be always regarded as ordinary smooth structure apart from a discrete set of points.

   Exotics break cosmic censorship so that global hyperbolicity fails and the initial-value problem becomes ill-defined because of time-like loops. Time-like loops are a heavy counter argument against AdS/CFT duality. They are however encountered also for the TGD variant of the holographic duality.

   Could it be that time-like loops are not a nuisance but something fundamental forcing the space-time dimension to be $D = 4$.

2. In the TGD framework holography predicts the smooth structure of the space-time surface so that the non-uniqueness is not a problem.

   The discrete set of points spoiling the standard smooth structure is an analogue for a set of point-like defects. Outsides this set the standard smooth structure fails. The proposal [L12] is that this set of points is assignable to particle reaction vertices in TGD and have a topological interpretation. Two partonic 2-surfaces with opposite homology charges (monopole fluxes) touch at defect point and fuse together to a single particle 2-surface.

3. This makes possible time loops which are essential for understanding pair creation in TGD. It is essential that the interiors of the orbits of wormhole contacts have an Euclidian signature: this is obviously a completely new element when compared to AdS/CFT. The boundaries between these Euclidian regions and Minkowskian regions of the space-time surface are light-like and correspond to the orbits of wormhole throats at opposite Minkowskian sheets [L12]. The creation of a fermion pair would correspond to a change of the time direction of the fermion at the defect point of the exotic smooth structure.

4. Could exotic smooth structures make possible quantum computations as evolution forth-and-back in space-time in the TGD framework? Could the time loops serve as microscopic classical correlates for this and could the defects give a topological realization for what happens. Note that wormhole throats can in principle have large sizes and scale like h_{eff} and can be very large for gravitational Planck constant h_{gr}.

5. Could wormholes correspond in the TGD framework to magnetic flux tubes? Or could they correspond to light-like orbits of wormhole throats/partonic 2-surfaces appearing analogous to lines of topological counterparts of Feynman diagrams? Orbits of wormhole contacts identified as orbits of pairs of wormholes give rise to light-like orbits of wormhole throats, which are always paired. Fermionic quantum numbers are associated with the light-like lines of the wormhole throat. They represent building bricks of elementary particle orbits. Could these structures be seen as analogues of wormholes?

4.2 What is the TGD counterpart of time reversal of the SYK model?

Time reversal is central in the SYK model.

1. Time reversed of time evolution as unitary time evolution with Hamiltonian having opposite sign is central in the model. This notion is somewhat questionable since usually one requires that the energy eigenvalues are positive. In TGD, this time evolution could correspond to a sequence of SSFRs in the reversed time direction following BSFR.

2. Shock wave in the wormhole appears as a negative energy signal. This could correspond to time reversed classical signals having effectively negative energy and propagating along the flux tube or the counterpart of the wormhole in TGD. Time reversal would be induced by BSFR.

3. One could also interpret the time reversed evolution in terms of a generation of Hawking radiation. Negative energy particles falling to the blackhole would correspond to the time reversed signal propagating from right to left after BSFR has occurred in the experiment considered.

4.3 TGD counterparts of scrambling time evolution and descrambling as its time reversal

Scrambling means generation of quantum chaos [B4] (`https://arxiv.org/abs/2206.02053`). Descrambling does the opposite and is in conflict with the second law unless the arrow of time changes. For a unitary time evolution descrambling can be considered if the negative of Hamiltonian makes sense.

Scrambling corresponds to a random unitary time evolution inducing mixing as dispersion of entanglement in the entire system. Actually a sequence of scramblings characterized by scrambling times described by random Hamiltonians is assumed to take place. Scrambling time is assumed to depend on blackhole entropy $S = A/4G\hbar = 4\pi GM^2/\hbar$ roughly as

$$T_s = t_s \times O(S^{1/2} log(S)),$$

where $t_s = r_s = 2GM$ is Schwarzschild time. Blackholes are assumed to be very fast scramblers.

1. A sequence of "small" state function reductions (SSFRs) as the TGD counterparts of "weak" measurements of quantum optics, generalizes Zeno effect to a subjective time evolution of self. The sequence of SSFRs as analog of a sequence of unitary time evolutions

Scrambling could correspond to a sequence of SSFRs as an analogue for a sequence of random unitary evolutions in TGD. Since one has a sequence of SSFRs, scrambling might correspond to the emergence of thermodynamics chaos.

An alternative interpretation of chaos is an increase of complexity. Mandelbrot fractal is complex but not chaotic in the thermodynamic sense. Could scrambling correspond to an effective increase of the extension of rationals during the sequence of SSFRs? More and more roots of polynomials defining light-cone propertime a=constant hyperboloids become visible at the increasing space-time surface inside the CD. This option does not look plausible.

2. De-scrambling time evolution is in conflict with intuition. In TGD, de-scrambling could correspond to scrambling with an opposite arrow of time emerging in "big" SFR (BSFR) and therefore dissipation with a reverse arrow of time looking like self-organization for an observer with an opposite arrow of time. This process is fundamental in biology and would correspond to processes like healing. BSFR corresponds to a "death" or falling asleep in TGD inspired theory of consciousness and self lives forth and back in geometric time.

3. It is interesting to look for the TGD counterpart of scrambling time T_s. For $\hbar \to \hbar_{gr}$, where $\hbar_{gr} = GM^2/\beta_0$ is the gravitational Planck constant and $\beta_0 \leq 1$ is a velocity parameter, one obtains for blackhole entropy $S \simeq \beta_0$ and blackhole entropy is equal to β_0 and smaller than 1 and practically zero.

$$T_s = t_s \times 4\pi\beta_0 log(\beta_0) \ ,$$

where $t_s = r_s$ is Schwarzschild time. In the recent case one would have $t_s \to t_{s,dark} = G_{eff}m = \Lambda_{gr} = GM/\beta_0$, $m \sim m_{Pl}$. For $M = M_E$ the Scwartschild time t_s would be 1.5 ns.

4. Scrambling time would be negative for $\beta_0 \leq 1$: could the interpretation be that scrambling takes place with the opposite arrow of time? Or could it be that the pair of BSFRs leads from the value of time at the initial moment to a smaller value of time identified as the M^4 time assignable to the tip of CD? The runner would reach the goal geometrically before she started. This can be imagined in ZEO.

   One must of course take the expression for the scrambling time with a big grain of salt and as found in the previous posting, TGD allows us to consider a more general picture in which the correspondence with blackholes is not so concrete.

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