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0.1 Is the QFT type description of gravitational interactions possible?

In TGD Universe graviton is necessarily a bi-local object and the emission and absorption of graviton are bi-local processes involving two wormhole contacts: a pair of particles rather than single particle emits graviton. This is definitely something new and defies a description in terms of QFT limit using point like particles. Graviton like states would be entangled states of vector bosons at both ends of string so that gravitation could be regarded as a square of YM interactions in rather concrete sense. The notion of emergence would suggest that graviton propagator is defined by a bosonic loop. Since bosonic loop is dimensionless, IR cutoff defined by the largest CD present must be actively involved.

The connection with strings is via the assignment of wormhole contacts at the ends of a stringy curve. Stringy diagrams would not however describe graviton emission. Rather, a generalization of the vertex of Feynman diagram would be in question in the sense that three string world sheets would be glued together along their 1-dimensional ends in the vertex. This generalizes similar description for gauge interactions using Feynman diagrams. In the microscopic description point like particles are replaced with 2-D partonic surfaces so that in gravitational case one has stringy 3-surfaces at vertices.

At QFT limit one can hope a description as a bi-local process using a bi-local generalization of the QFT limit so that stringy degrees of freedom need not be described explicitly. There are hopes about success, since these degrees of freedom have been taken into account in the spectrum of modes of the induced spinor field and reflect themselves as quantum numbers labeling fermionic oscillator operators. Also modified gamma matrices feed information about space-time surface to the theory.

0.1.1 What one really means with strings?

Before continuing is it is good take critical attitude to the proposed picture. What one really means with string is the first question.

1. Stringy curves appear in in the slicing of the space-time sheet around wormhole throat to light-like 3-surfaces labeled by the points of string. Hamilton-Jacobi coordinates [1] suggest that the M^4 projections of these curves light-like so that the curves would be space-like.
2. For string like objects obtained as deformations of cosmic strings $X^2 \times Y^2 \subset M^4 \times CP_2$ one can assign Kähler magnetic flux flowing along the stringy curves. These curves should define a special class of stringy curves.
3. If the basin for the slicing by light-like 3-surfaces for a given wormhole throat has an outer boundary at which induced Kähler form vanishes (it is not obvious that this can be the case), one can ask whether stringy curves effectively end at the boundary of the basin or what happens? Magnetic flux conservation does not allow to assign magnetic flux to the stringy curves now. The analogy with field lines gravitational scalar potential suggests a possible answer. All wormhole throats would act as sources for these lines identifiable as field lines of a gradient vector field. Basins would not actually have any boundaries since the extrema of

the potential would consist in the generic case of a discrete set of points. Whether stringy curves really have something to do with field lines of a gradient of gravitational potential must be however left an open question.

4. Despite the emergence of stringy picture, string model as such does not seem to help much since the graviton emission vertex is completely different from that in string models.

0.1.2 What one really means with gravitons?

One can also ask what one really means with graviton. The identification of graviton is indeed far from obvious.

1. Wormhole throats and contacts allow $J = 2$ states but they couple only to states which corresponds to $d \geq 2$ monomials of theta so that couplings to the fermions are absent.
2. TGD predicts a hierarchy of string like objects of all possible sizes and these are good candidates for graviton like states. The hierarchy of Planck constants and the huge values of gravitational Planck constant suggests that gigantic gravitons identifiable as stringy curves connecting particles at astrophysical distances are possible. The emission of dark graviton would be bi-local process in astrophysical length scales and would look locally like an emission of gauge boson.
3. One can of course argue it is not clear whether stringy gravitons represent hadron like objects responsible for strong gravitation below relevant p-adic length scale rather than genuine gravitons. For instance, the identification of elementary particles in terms of CP_2 type extremals forces to ask whether gravitons could correspond to pieces of CP_2 type extremals connecting positive and negative energy space-time sheets with a wormhole contact having two pairs of wormhole throats so that spin two states would become possible. If this generalization is accepted, one must also accept the possibility of wormhole contacts with arbitrary number of throat pairs. One can also wonder what is the origin of Planck length which is roughly 10^4 times shorter than CP_2 length. For instance, could it have purely geometric interaction characterizing the distance between these wormhole contacts?

With this identification graviton emission at elementary particle level could be seen as a creation of a virtual wormhole throat pair inside wormhole contact formed by fermion and anti-fermion and making possible emission of graviton. One can also consider a distribution of wormhole throat pairs inside wormhole created in this manner in which case $1/G_N$ would characterize the probability for the appearance of wormhole throat pair.

4. Graviton must be generalized to a super-field and bi-locality suggests that this field is a bi-local composite of super gauge fields in some sense. Ordinary graviton would be only single component of this field.

To sum up, it is far from clear what graviton precisely is and gauge-theory-gravitation correspondence suggests that there is a rich spectrum of graviton like states. Despite this one can characterize rather precisely what the description of gravitational interaction at QFT limit must be by using general symmetry principles and basic structure of quantum TGD.

0.1.3 Could bi-local QFT allow to describe gravitation as a square of gauge interactions?

The key question is whether one can generalize the formalism of QFT limit to describe also gravitational interactions. The first guess is that in some sense gravitation is a square of YM interactions. This statement has a precise content in some string theories. Also the scattering amplitudes of

$N = 8$ super-gravity allow a construction in terms of $N = 4$ SYM amplitudes. In the recent case gravitation as a square of YM theory would mean that graviton propagator emerges from vector super-field propagators assignable at the ends of the gravitonic string. Vector propagators would in turn emerge from chiral super-field propagators.

The bi-local character of the basic process suggests that a bi-local generalization of QFT limit is needed to describe gravitation. In fact, at the long length scale limit of the theory the appearance of second derivatives in the curvature scalar could be seen as a signature of bi-locality at fundamental level. Bi-locality brings in the notion of distance and the metric description of gravitation indeed assumes that distances are dynamical. Note that also the typical experimental arrangements for detecting gravitons are bi-local (typically the variation of the distance between the ends of a metal bar is measured).

1. Bi-locality would suggest that one has a pairing of the chiral actions to a bi-local action. Whether the vector bosons at the ends of graviton string move collinearly or not is a non-trivial question. Experimentation with the candidates for the bilinear gravitational action shows that the simplest theory results when collinearity assumption is given up. It is also far from clear whether collinearity assumption allows any internally consistent mathematical realization: the problem is that by collinearity graviton propagator becomes proportional to $1/p^4$ and one should somehow eliminate one $1/p^2$ factor. If one gives up collinearity, one obtains a bosonic loop integral with vector boson momenta $p - k$ and k . Graviton kinetic term emerges from a loop of two bosons and is therefore dimensionless so that IR cutoff L is necessary in order to obtain $p^2 L^2$ type kinetic term and finiteness. The IR cutoff comes naturally as the size scale L of the largest CD involved and appears also as scaling factor of the action by purely dimensional reasons and disappears naturally from the interaction vertices.
2. Graviton would correspond to a bi-local composite of super gauge fields acting as operators $V(\theta_i, \partial_{\theta_i})$, $i = 1, 2$, on the chiral super-fields at the ends of the string and graviton propagation should reduce to vector boson propagation just as vector boson propagation reduces to fermion pair propagation. General gauge invariance at the level of space-time sheet is not a problem. At the level of M^4 , whose coordinates label the positions for the tips of CD the possibility to choose preferred M^4 coordinates guarantees general coordinate invariance trivially. The elimination of non-physical graviton polarizations for massless gravitons is achieved by the ordinary gauge invariance. In this conceptual framework elimination of non-physical graviton polarization does not have obvious connection with general coordinate invariance. The properties of the slicings by light-like 3-surfaces suggest this connection.
3. At the point like limit the emission of gravitons is described by an interaction term of form $T^{\alpha\beta} \delta g_{\alpha\beta}$. This expression should have a bi-local gauge invariant generalization. The energy momentum tensor for Dirac action suggests the following remarkably simple expression for the interaction action L_{gr} in super space.

$$L_{gr} = K \bar{\Psi} D^A \Psi \times \bar{\Psi} D_A \Psi . \quad (1)$$

A summation over the contracted index pairs is understood in the formula. The theta parameters associated with the two actions are regarded as independent Grassmann variables.

4. If the vector boson momenta at the ends of graviton string vary freely apart from the constraint that they sum up to the momentum of the virtual graviton, K must be of form $K = k L^2$ to compensate the dimension $1/L^2$ coming from the two D_A s. L naturally corresponds to IR cutoff defined by the size of the largest CD involved. The bosonic loop giving

graviton propagator at the IR limit is dimensionless so that the resulting propagator must be proportional to $1/(p^2 L^2)$ so that the powers of L cancel each other in the propagators. $D_A = p_A + Q_A + V_A$ is the covariant derivative corresponding to a particular momentum component. Note that also color charge (color hyper charge or isospin) is included and is present for massive particles. Since only covariant derivatives appear, the expression is manifestly super gauge invariant.

5. The integration over the theta parameters gives factors $D = \hat{\Gamma}^A D_A / M$ for each integrated pair of theta parameters. Here M is a parameter with dimensions of mass to make D dimensionless and CP_2 is the most natural guess for its value. The resulting action for graviton has the following form

$$\begin{aligned}
L_{gr} &= \frac{K}{M^2} \bar{\Psi} O^A \Psi \times \bar{\Psi} O_A \Psi , \\
O^A &= \frac{D^{\rightarrow} D^{A\rightarrow} - D^{\leftarrow} D^{A\leftarrow}}{M} , \\
D^{\leftarrow} &= \frac{D_A^{\leftarrow} \hat{\Gamma}^A}{M} , \quad D^{\rightarrow} = \frac{\hat{\Gamma}^A D_A^{\rightarrow}}{M} , \quad D = \frac{\hat{\Gamma}^A D_A}{M} .
\end{aligned} \tag{2}$$

The $1/p^2 L^2$ from the IR cutoff for the loop integral defining the emergent graviton propagator given by a dimensionless bosonic loop cancels L^2 from factor kL^2/M^2 and kM^2 should be proportional to G_N .

6. The tensor structure of the graviton vertex resulting from DD^A in the lowest order seems to be correct. $\hat{\Gamma}^A D^{B\rightarrow}$ *resp.* $\hat{\Gamma}^A D^{B\leftarrow}$ is the analog of energy momentum tensor and in the lowest order gives rise to the desired proportionality of the gravitational coupling to momentum. Since graviton is emitted by a pair of particles the proportionality to the momenta of both particles is natural. Note that only the momenta associated with the vector bosons defining the emitted graviton-like particle are collinear, not the momenta of the emitting particles at the ends of the string. The bilinear $D_B \otimes D_C$ is the counterpart of $\delta g_{\alpha\beta}$ and polarization tensor of graviton. Both D_B and D_C are contracted with the analog of the energy momentum tensor.
7. Ordinary graviton must correspond to electro-weak $U(1)$ for which coupling is to fermion number. The mixing of $U(1)_Y$ and $U(1) \subset SU(2)$ should be completely absent for gravitons. In other words, the corresponding value of Weinberg angle must vanish: $\sin^2(\theta_{W,gr}) = 0$ implying $m_Z = m_W$ in gravitonic propagation. The graviton analogs formed from massless gluons would have a finite interaction range by confinement and weak gravitons would be massive so that no dramatic new effects are predicted.

When one feeds the information about space-time surface into the theory additional complications arise since the modified gamma matrices $\hat{\Gamma}^\alpha(x) = \Gamma^k \partial L_K / \partial_\alpha h^k$ would replace the $M^4 \times S^1$ gamma matrices and one must integrate over the points x . As found, the condition that weighting scheme depends on zero modes only (is symplectic invariant at the level of WCW) fixes it uniquely to a weighting by magnetic flux at the intersections of light-like wormhole throats with the light-like boundaries of CD relevant for the p-adic length scale defined by the virtual momentum squared.

1. Bi-locality suggests that both ends of string correspond to their own partonic 2-surfaces so that both ends involve weighting by the Kähler magnetic flux $J\sqrt{g}/g_K$. $J = J^{\alpha\beta} \epsilon_{\alpha\beta}$. Since J vanishes for vacuum regions and since also its sign varies, this is expected to bring in four identical reduction factors -call them x - to the kinetic term of graviton.

2. The defining property of the emergence is that the variation of the scale of $\hat{\Gamma}^A$ is compensated by the variation of the scale of the propagator so that the proportionality of $\hat{\Gamma}^A$ to $1/g_K^2$ is not seen in scattering amplitudes.
3. Again one must decide whether the weighting is performed for the calculation of the propagator or whether one uses the bosonic propagators already calculated with corresponding weightings at the ends of lines. Only the latter option conforms with the idea about gravitation as square of gauge interactions predicting α_K^2 -proportionality for the graviton propagator. From the general proportionality of bosonic propagators to $g_K^2/x^2 \propto \alpha_K$ one has the order of magnitude estimate

$$16\pi G_N \sim \frac{k g_K^4}{x^4 M^2} \sim \frac{k \alpha_K^2}{M^2} . \quad (3)$$

$16\pi G$ comes from the fact that it appears in the linearized Einstein's equations as the coefficient of energy momentum tensor. If k does not depend on \hbar then $\alpha_K \propto 1/\hbar$ and $M \propto \hbar/R$ correctly predicts that G_N does not depend on \hbar . Using $\alpha_K \simeq 1/137$ and $M = m(CP_2) = .2437 \times 10^{-3} m_{Pl}$ [2] one obtains the very rough estimate $k = (m(CP_2)/\alpha_K m_{Pl})^2 = .056$.

4. Note that the solutions of field equations in the static limit when the situation resembles formally electrostatics, gravitational coupling strength is estimated classically to be of order CP_2 length squared [1]. Since the value of CP_2 mass (and thus length) is firmly fixed by elementary particle mass calculations [2], this results could be seen as a serious objection against TGD. One could say that the weighting provides a "screening mechanism" reducing the naive value of the gravitational coupling strength.

References

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