Emergent gravity and dark Universe

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Abstract

Eric Verlinde has published article with title *Emergent Gravity and the Dark Universe*. The article represents his recent view about gravitational force as thermodynamical force described earlier in and suggests an explanation for the constant velocity spectrum of distant stars around galaxies and for the recently reported correlation between the real acceleration of distant stars with corresponding acceleration caused by baryonic matter. In the following I discuss Verlinde's argument and compare the physical picture with that provided by TGD. I have already earlier discussed Verlinde's entropic gravity from TGD view point.

Before continuing it is good to recall the basic argument against the identification of gravity as entropic force. The point is that neutron diffraction experiments suggests that gravitational potential appears in the Schrödinger equation. This cannot be the case if gravitational potential has thermodynamic origin and therefore follows from statistical predictions of quantum theory: to my opinion Verlinde mixes apples with oranges.

1 Verlinden's argument

Consider now Verlinde's argument.

1. Verlinde wants to explain the recent empirical finding that the observed correlation between the acceleration of distant stars around galaxy with that of baryonic matter [E2] (see `http://tinyurl.com/jd2m9ll`) in terms of apparent dark energy assigned with entanglement entropy proportional to volume rather than horizon area as in Bekenstein-Hawking formula. This means giving up the standard holography and introducing entropy proportional to volume.

   To achieve this he replaces anti-de-Sitter space (AdS) to which AdS/CFT duality is usually assigned with de-Sitter space(dS) space with cosmic horizon expressible in terms of Hubble constant and assign it with long range entanglement since in AdS only short range entanglement is believed to be present (area law for entanglement entropy). This would give rise to an additional entropy proportional to the volume rather than area. Dark energy or matter would corresponds to a thermal energy assignable to this long range entanglement. One can of course criticize this assumption as ad hoc hypothesis.

2. Besides this Verlinde introduces tensor nets as justification for the emergence of gravitation: this is just a belief. All arguments that I have seen about this are circular (one introduces 2-D surfaces and thus also 3-space from beginning) and also Verlinde uses dS space. What is to my opinion alarming that there is no fundamental approach really explaining how space-time and gravity emerges. Emergence of space-time should lead also to the emergence of spinor structure of space-time and this seems to me something impossible if one really starts from mere Hilbert space.

3. Verlinde introduces also analogy with the thermodynamics of glass involving both short range crystal structure and amorphous long range behaviour that would correspond to entanglement entropy in long scales long range structure. Above the horizon size the contribution proportional to volume would begin to dominate in entropy. Also analogy with elasticity is introduced. Below Hubble scale the microscopic states do not thermalize below the horizon

and display memory effects. Dark gravitational force would be analogous to elastic response due to what he calls entropy displacement.

4. Verlinde admits that this approach does not say much about cosmology or cosmic expansion, and even less about inflation.

2 TGD view about the situation

2.1 The long range correlations of Verlinde correspond to hierarchy of Planck constants in TGD framework

The physical picture has analogies with my own approach [L2] to the explanation of the correlation between baryonic acceleration with observed acceleration of distant stars. In particular, long range entanglement has the identification of dark matter in terms of phases labelled by the hierarchy of Planck constants as TGD counterpart.

1. Concerning the emergence of space and gravitation TGD leads to a different view. It is not 3-space but the experience about 3-space - proprioception -, which would emerge via tensor nets realized in TGD in terms of magnetic flux tubes emerging from 3-surfaces defining the nodes of the tensor net [L1]. This picture leads to a rather attractive view about quantum biology (see for instance `http://tinyurl.com/q4jyoc5`).

2. Twistor lift of TGD has rapidly become a physically convincing formulation of TGD [K8] (see `http://tinyurl.com/zjgmax6`). One replaces space-time surfaces in $M^4 \times CP_2$ with the 12-D product $T(M^4 \times CP_2)$ of the twistor spaces $T(M^4)$ and $T(CP_2)$ and Kähler action with its 6-D variant. This requires that $T(M^4)$ and $T(CP_2)$ have Kähler structure. This is true but only for M^4 (and its variants E^4 and S^4) and CP_2. Hence TGD is completely unique also mathematically and physically (providing a unique explanation for the standard model symmetries). The preferred extremal property for Kähler action could reduce to the property that the 6-D surface as an extremal of 6-D Kähler action is twistor space of space-time surface and thus has the structure of S^2 bundle. That this is indeed the case for the preferred extremals of dimensionally reduced 4-D action expressible as a sum of Kähler action and volume term remains to be rigorously proven.

3. Long range entanglement even in cosmic scales would be crucial and give the volume term in entropy breaking the holography in the usual sense. In TGD framework hierarchy of Planck constants $h_{eff} = n \times h$ satisfying the additional condition $h_{eff} = h_{gr}$, where $h_{gr} = GMm/v_0$ (M and m are masses and v_0 is a parameter with dimensions of velocity) is the gravitational Planck constant introduced originally by Nottale [E1], and assignable to magnetic flux tubes mediating gravitational interaction makes [K4, K3, K6]. This makes possible quantum entanglement even in astrophysical and cosmological long length scales since h_{gr} can be extremely large [K6, K7]. In TGD however most of the the galactic dark matter and energy is associated with cosmic strings having galaxies along it (like pearls in necklace) [K5, K1]. Baryonic dark matter could correspond to the ordinary matter which has resulted in the decay of cosmic strings taking the role of inflaton field in very early cosmology. This gives automatically a logarithmic potential giving rise to constant spectrum velocity spectrum modified slightly by baryonic matter and a nice explanation for the correlation, which served as the motivation of Verlinde. In particular, the only parameter of the model is string tension and TGD allows to estimate also this and the value is completely fixed for the ideal cosmic strings and reduces as they thicken.

4. Also glass analogy has TGD counterpart. Kähler action has 4-D spin glass degeneracy giving rise to 4-D spin-glass degeneracy. In twistor lift of TGD cosmological term appears and reduces the degeneracy by allowing only minimal surfaces rather than all vacuum extremals. This removes the non-determinism. Cosmological constant is however extremely small implying non-perturbative behavior in the sense that the volume term for the action is extremely small and depends very weakly on the preferred extremal. This suggests that spin glass in

3-D sense remains as Kähler action with varying sign is added: the space-time regions dominated by electric or magnetic fields give contributions with different sign and one can obtain the characteristic fractal spin glass energy landscape with valleys inside valleys.

5. The mere Kähler action for the Minkowskian (at least) regions of the preferred extremals reduces to a Chern-Simons terms at light-like 3-surfaces at which the signature of the induced metric of the space-time surface changes from Minkowskian to Euclidian. The interpretation could be that TGD is almost topological quantum field theory. Also the interpretation in terms of holography can be considered.

   Volume term proportional to cosmological constant given by the twistorial lift of TGD [K8] (see `http://tinyurl.com/zjgmax6`) could mean a small breaking of holography in the sense that it cannot be reduced to a 3-D surface term. One must however be very cautious here because TGD strongly suggests strong form of holography meaning that data at string world sheets and partonic 2-surfaces (or possibly at their metrically 2-D light-like orbits for which only conformal equivalence class matters) fix the 4-D dynamics.

   Certainly volume term means a slight breaking of the flatness of the 3-space in cosmology since 3-D curvature scalar cannot vanish for Robertson-Walker cosmology imbeddable as a minimal surface except at the limit of infinitely large causal diamond (CD) implying that cosmological constant, which is proportional to the inverse of the p-adic length scale squared, vanishes at this limit. Note that the dependence $\Lambda \propto 1/p$, p p-adic prime, allows to solve the problem caused by the large value of cosmological constant in very early cosmology. Quite generally, volume term would describe finite volume effects analogous to those encountered in thermodynamics.

2.2 The argument against gravitation as entropic force can be circumvented in zero energy ontology

Could TGD allow to resolve the basic objection against gravitation as entropic force or generalize this notion?

1. In Zero Energy Ontology (ZEO) quantum theory can be interpreted as "complex square root of thermodynamics". Vacuum functional is an exponent of the action determining preferred extremals - Kähler action plus volume term present for twistor lift. This brings in gravitational constant G and cosmological Λ constant as fundamental constants besides CP_2 size scale R and Kähler coupling strength α_K [K8]. Vacuum functional would be analogous to an exponent of $E_c/2$, where E_c would be complexified energy. I have also considered the possibility that vacuum functional is analogous to the exponent of free energy but following argument favors the interpretation as exponent of energy.

2. The variation of Kähler action would give rise to a 4-D analog of TdS term and the variation of cosmological constant term to the analog of $-pdV$ term in $dE = TdS - pdV$. Both T and p would be complex and would receive contributions from both Minkowskian and Euclidian regions. The contributions of Minkowskian and Euclidian regions to the action would differ by a multiplication with imaginary unit and it is possible that Kähler coupling strength is complex as suggested in [K2].

   If the inverse of the Kähler coupling is strength is proportional to the zero of Riemann zeta at critical line, it is complex, and the coefficient of the volume term must have the same phase: otherwise space-time surfaces are extremals of Kähler action and minimal surfaces simultaneously. In fact, the known non-vacuum extremals of Kähler action are surfaces of this kind, and one cannot exclude the possibility that preferred extremals have quite generally this property. The physical picture below does not favor this idea.

   Note: One can consider also the possibility that the values of Kähler coupling strength correspond to the imaginary part for the zero of Riemann zeta.

3. Suppose that both terms in the action are proportional to the same phase factor. The part of the variation of the Kähler action with respect to the imbedding space coordinates giving the analog of TdS term would give the analog of entropic force. Since the variation of the

entire action vanishes, the variation of Kähler action would be equal to the negative of the variation of the volume term with respect to the induced metric given by $-pdV$. Since the variations of Kähler action and volume term cancel each other, the entropic force would be non-vanishing only for the extremals for which Kähler action density is non-vanishing. The variation of Kähler action contains variation with respect to the induced metric and induced Kähler form so that the sum of gravitational and U(1) force would be equal to the analog of entropic force and Verlinde's proposal would not generalize as such.

The variation of the volume term gives rise to a term proportional to the trace of the second fundamental form, which is 4-D generalization of ordinary force and vanishes for the vacuum extremals of Kähler action in which case one has analog of geodesic line. More generally, Kähler action gives rise to the generalization of U(1) force on particle so that the field equations give a 4-D generalization of equations of motion for a point like particle in U(1) force having also interpretation as a generalization of entropic force.

4. In Zero Energy Ontology (ZEO) TGD predicts a dimensional hierarchy of basic objects analogous to the brane hierarchy in M-theory: space-time surfaces as 4-D objects, 3-D light-like orbits of partonic 2-surfaces as boundaries of Minkowskian and Euclidian regions plus space-like 3-surfaces defining the ends of space-time surface at the opposite boundaries of CD, 2-D partonic surfaces and string world sheets, and 1-D boundaries of string world sheets. The natural idea is to identify the dynamics D-dimensional objects in terms of action consisting of D-dimensional volume in induced metric and D-dimensional analog of Kähler action. The surfaces at the ends of space-time should be freely choosable apart from the conditions related to to super-symplectic algebra realizing strong form of holography since they correspond to initial values.

   For the light-like orbits of partonic 2-surfaces 3-volume vanishes and one has only Chern-Simons type topological term. For string world sheets one has area term and magnetic flux, which is topological term reducing to a mere boundary term so that minimal surface equations are obtained. For the dynamical boundaries of string world sheets one obtains 1-D volume term as the length of string world line and the boundary term from string world sheet. This gives 1-D equation of motion in U(1) force just like in Maxwell's theory but with induced Kähler form defining the U(1) gauge field identifiable as the counterpart of classical U(1) field of standard model. Induced spinor fields couple at boundaries only to the induced em gauge potential since induced classical W-boson gauge fields vanish at string world sheets in order to achieve a well-defined and conserved spinorial em charge (here the absolutely minimal option would be that the W and Z gauge potentials vanish only at the time-like boundaries of string world sheet). Should world-line geometry couple to the induced em gauge field instead of induced Kähler form? The only logical option is however that geometry couples to the U(1) charge perhaps identifiable in terms of fermion number.

5. There however an objection against this picture. All known extremals of Kähler action are minimal surfaces and there are excellent number theoretical arguments suggesting that all preferred extremals of Kähler action are also minimal surfaces so that the original picture would be surprisingly near to the truth. The separate vanishing of variation implies that the solutions do not depend at all on coupling parameters as suggested by number theoretical universality and universality of the dynamics at quantum criticality. The discrete coupling constant evolution makes it however visible via boundary conditions classically. This would however predicts that the analogs to TdS and pdV vanish identically in space-time interior.

   The variations however involve also boundary terms, which need not vanish separately since the actions in Euclidian and Minkowskian regions differ by multiplication with $\sqrt{-1}$! The variations reduce to terms proportional to the normal component of the canonical momentum current contracted with the deformation at light-like 3-surfaces bounding Euclidian and Minkowskian space-time regions. These must vanish. If Kähler coupling strength is real, this implies decoupling of the dynamics due to the volume term and Kähler action also at light-like 3-surfaces and therefore also exchange of charges - in particular four-momentum - becomes impossible. This would be a catastrophe.

   If α_K is complex as quantum TGD as a square root of thermodynamics and the proposal that the spectrum of $1/\alpha_K$ corresponds to the spectrum of zeros of zeta require [K2], the normal component of the canonical momentum current for Kähler action equals to that for the volume term at the other side of the bounding surface. The analog of $dE = TdS - pdV = 0$ would hold true in the non-trivial sense at light-like 3-surfaces and thermodynamical analogy holds true (note that energy is replaced with action). The reduction of variations to boundary terms would also conform with holography. Strong form of holography would even suggest that the 3-D boundary term in turn reduces to 2-D boundary terms.

A possible problem is caused by the variation of volume term: $\sqrt{g_4}$ vanishes at the boundary and g^{nn} diverges. The overall result should be finite and should be achieved by proper boundary conditions. What I have called weak form of electric-magnetic duality [**?**]llows to avoid similar problems for Kähler action, and implies self-duality of the induced Kähler form at the boundary. Both conditions require the finiteness of the limit of $g^{nn}\sqrt{g_4}$ at both Minkowskian and Euclidian sides of the horizon. The condition that g_{nn} and g_{tt} approach to zero in the same manner guarantees this.

Physically this picture is very attractive and makes cosmological constant term emerging from the twistorial lift rather compelling. What is nice that this picture follows from the field equations of TGD rather than from mere heuristic arguments without underlying mathematical theory.

REFERENCES

Theoretical Physics

Cosmology and Astro-Physics

[E1] Nottale L Da Rocha D. Gravitational Structure Formation in Scale Relativity. Available at: `http://arxiv.org/abs/astro-ph/0310036`, 2003.

[E2] Lelli F McGaugh SS and Schombert JM. The radial acceleration relation in rotationally supported galaxies. Available at:`https://arxiv.org/pdf/1609.05917v1.pdf`, 2016.

Books related to TGD

[K1] Pitkänen M. Cosmic Strings. In *Physics in Many-Sheeted Space-Time*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdclass/tgdclass.html#cstrings`, 2006.

[K2] Pitkänen M. Does Riemann Zeta Code for Generic Coupling Constant Evolution? In *Towards M-Matrix*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdquantum/tgdquantum.html#fermizeta`, 2006.

[K3] Pitkänen M. Quantum Astrophysics. In *Physics in Many-Sheeted Space-Time*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdclass/tgdclass.html#qastro`, 2006.

[K4] Pitkänen M. TGD and Astrophysics. In *Physics in Many-Sheeted Space-Time*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdclass/tgdclass.html#astro`, 2006.

[K5] Pitkänen M. TGD and Cosmology. In *Physics in Many-Sheeted Space-Time*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdclass/tgdclass.html#cosmo`, 2006.

[K6] Pitkänen M. Criticality and dark matter. In *Hyper-finite Factors and Dark Matter Hierarchy*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/neuplanck/neuplanck.html#qcritdark`, 2014.

[K7] Pitkänen M. Quantum gravity, dark matter, and prebiotic evolution. In *Genes and Memes*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/genememe/genememe.html#hgrprebio`, 2014.

[K8] Pitkänen M. From Principles to Diagrams. Onlinebook.Available at: http://tgdtheory.fi/public_html/tgdquantum/tgdquantum.html#diagrams, 2016.

Articles about TGD

[L1] Pitkänen M. Holography and Quantum Error Correcting Codes: TGD View. Available at: http://tgdtheory.fi/public_html/articles/tensornet.pdf, 2016.

[L2] Pitkänen M. TGD interpretation for the new discovery about galactic dark matter. Available at: http://tgdtheory.fi/public_html/articles/darknew.pdf, 2016.