Graviton as a phonon and dark energy problem

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Roger Penrose: "It is not dark and it is not an energy..."



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Classical explanation of the problem of dark energy



- add **cosmological constant** to Einstein equations
- introduce a new field: scalar field (phantom, quintom, quintessence)
- modification of gravity:
 - modify the law of gravity at large distances
 - build the models of gravity from the higher-dimensional models

Quantum gravity and accelerated expansion

- causal set approach (with cosmological constant)
- Ø discrete approaches to QG (with cosmological constant)
- metastring theory (with cosmological constant)
- group field theory (with phantom matter)
- string gas cosmology (with phantom matter)
- theory based on non-commutative geometry (with new dark energy particle mitron)
- causal dynamical triangulations (with cosmological constant)
- bolographic dark energy
- asymptotic safety program (without dark energy)
- entropic gravity (without dark energy)

We suppose in quantum gravity that the relation

$\Delta \Lambda \Delta V \sim \hbar$

holds, where $\Delta \Lambda$ is a fluctuation in cosmological constant in given volume *V*. The central result:

$$\Delta\Lambda\sim rac{1}{\sqrt{V}}$$

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The standard cosmological argument:

$$V \sim (H^{-1})^4 = H^{-4} \Rightarrow \Lambda \sim rac{1}{\sqrt{V}} \sim H^2 \sim
ho_{crit}$$

It implies that Λ will be everpresent at least in 3 + 1 dimensions, arXiv: 1903.11544.

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Loop quantum gravity and other discrete approaches

- consider microscopic structure of spacetime and its interaction with matter
- discreteness of geometry and Lorentz invariance at low energies is a key aspect of QG
- massive fields are the natural candidates for probes of spacetime discreteness

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The 'friction-like' force must be proportional to **R** (**Ricci scalar**), mass *m*, **4-velocity** u^{μ} , **spin of the particle** s^{μ} and **time-like unit vector** ξ^{μ} specifying the local frame defined by the matter that curves spacetime. The formula is the following:

$$u^{\mu}
abla_{\mu} u^{
u} = lpha rac{m}{m_{
ho}^2} \mathrm{sign}(s \cdot \xi) \mathbf{R} \; s^{
u},$$

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where α is a dimensionless coupling, arXiv: 1711.05183.

The **avoidance of singularities in SGC** entails certain costs: the **null energy conditions** is violated in the earliest stages; It is an open question in string theory whether it allows the null energy condition violations, even of the "effective"type, when the full non-perturbative theory is taken into account. However, it is clear that the era of null energy condition must be very brief, it must come to an end and it should be replaced by the inflationary era, arXiv:hep-th/0502209.

Asymptotic safety program

Swiss cheese model, which combines globally the homogeneous and isotropic Universe and locally a Schwarzschild black hole:

$$ds^{2} = -dt^{2} + a^{2}(t)[\frac{dr^{2}}{1 - \kappa r^{2}} + r^{2}(d\theta^{2} + \sin^{2}(\theta)d\phi^{2})],$$

where κ has values -1,0 or 1. We define further a radius r_{Σ} , where r_{Σ} is a constant. The spacetime will be described for $r \leq r_{\Sigma}$ by a static spherically symmetric metric given in Schwarzschild-like coordinates by

$$ds^2 = -J(R)F(R)dT^2 + rac{dR^2}{F(R)} + R^2[d heta^2 + \sin^2(heta)darphi^2],$$

where J and F is bigger than 0, arXiv:1806.10580.

'In any case, it seems to me that the alternative continuum-discontinuum is a genuine alternative; i.e. there is no compromise here. In theory there cannot be space and time, only numbers. It will be especially difficult to elicit something like a spatio-temporal quasi-order from such a schema. I can not picture to myself how the axiomatic framework of such a physics could look. But I hold it as altogether possible that developments will lead there.' [Albert Einstein]

Ring Paradigm

The usual picture about the gravitational interaction was that some quantum (graviton) is exchanging between every particle in the Universe. We suggest a different scheme in RP.





We substitute the picture of the gravitons carrying the initial impulse by the creation of a gravitational ring, which tightens the objects in Planck time.



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Unchanged particle sector

The elementary particles of the standard model could move only around gravitational rings.



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Variational principle

The ring has the shortest length from all possible configurations in space, which means a variational principle must be applied in the derivation of the field equations of RP.



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Processes with rings



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Graviton as a phonon

The creation of rings in Planck time effectively gives rise to springs between the galaxies. We quantize their longitudinal vibrations and obtain the graviton-phonons, which mediate the Newtonian force.



$$H = \sum_{i=1}^{2} \frac{1}{2m} P_i^2 + \sum_{i,j=1}^{2} V_{ij} Q_i Q_j,$$

where

$$V = \begin{pmatrix} \frac{1}{2}k + \frac{1}{2}k_3 & -\frac{1}{2}k_3 \\ -\frac{1}{2}k_3 & \frac{1}{2}k + \frac{1}{2}k_3 \end{pmatrix},$$

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 $k, k_3 > 0.$

Graviton-phonon

The wave equation is derived

$$\nabla^2 \psi - \frac{1}{c^2} \frac{\partial^2 \psi}{\partial t^2} = 0.$$

The most important observation is that photons are the field particles for electromagnetic interaction, which we describe by Maxwell equations containing the Coulomb law, $\vec{F}_{Q_1Q_2} = \frac{1}{4\pi\epsilon_0} \frac{Q_1Q_2}{L^2}$. It has exactly the similar form to the formula for the Newtonian force, $F_{m_1m_2} = G\frac{m_1m_2}{L^2}$. **Graviton-phonons** are the correct "mediators" of the **Newtonian force**!

Let's stress the result: RP could give an explanation for two facts in classical physics. We know from experiments that gravitational waves are traveling by velocity c_{aw} , which is very close to the velocity of light c with an amazing precision, $|c - c_{aw}| < 10^{-15}$. But c_{aw} should be exactly *c* according to RP (it was supposed in GR that $c_{aw} = c$, but there had been no reason for that). Further, the similarity of the formulas for the Coulomb and Newton laws is not accidental, but it is necessary for building the parallelism between photons and graviton-phonons. As we will see later, these are only the first little surprises that RP brings us.

Accelerated expansion of the Universe

The classical description is that the gravitational rings are effectively made from some material, which has an inner dependence on the deformation due to the stress. The "gravitational"material breaks at *Mpc* distances, which causes accelerated expansion in the Universe.



Modification of gravity

$$\mathscr{R}_{\mu\nu} - \frac{1}{2}\mathscr{R}\mathscr{G}_{\mu\nu} + \Lambda_r \mathscr{G}_{\mu\nu} = \frac{8\pi G \mathscr{T}_{\mu\nu}}{c_g^4}, \qquad (1)$$

where $\mathscr{G}_{\mu\nu}$ is the metric and also all the other quantities have an analogous meaning as in GR. The cosmological constant Λ_r could be computed from QFT. We neglect the RHS with respect to the LHS, so

$$\mathscr{R}_{\mu\nu} - \frac{1}{2}\mathscr{R}\mathscr{G}_{\mu\nu} + \Lambda_r \mathscr{G}_{\mu\nu} = 0. \tag{2}$$

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$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$
(3)

A new cosmological constant term Λ appeared approximately 8 billion years after Big Bang due to the QG phenomenon (actually $\Lambda = \Lambda_b$ in our previous notation):

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$
(4)

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Application of the paradigm

- singularity theorems
- 2 cyclic universes
- Is black hole information paradox
- dimensional reduction
- Survature of the universe
- EPR-paradox
- determinism of physical theories

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RP is a highly non-local theory, and the rings are sticking out of the horizon for any black hole. It means that the information could travel at superluminal speed from the interior of the black hole. This gives us a full solution of the information paradox on the non-perturbative QG level.





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RP is built on the postulate that the elementary particles move only at the pre-prepared lanes. This could have serious consequences for the determinism of physical theories.



The gravitational rings are mediating gravity by a velocity $c_g > c$. It is equal to the maximal allowed velocity, how information can actually be transmitted according to QG.



Generalization of transformations

$$t' = \frac{t - \frac{x}{v} \frac{v^2}{c^2} \epsilon - \frac{x}{v} \frac{v^2}{c_g^2}}{\sqrt{1 - \frac{v^2}{c^2} \epsilon - \frac{v^2}{c_g^2}}},$$
$$x' = \frac{x - tv}{\sqrt{1 - \frac{v^2}{c^2} \epsilon - \frac{v^2}{c_g^2}}},$$

where $\epsilon = \epsilon(v)$ denotes some step function defined by the prescription

$$\epsilon(\mathbf{v}) = \begin{cases} 1 & \text{for } \mathbf{v} \le \mathbf{c}, \\ 0 & \text{for } \mathbf{v} > \mathbf{c}. \end{cases}$$

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Work for future

- scalar field in classical cosmology
- Lorentz violating theories
- conformal field theory in 2 dimension

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Albert Schweitzer: "Example is not the main thing in influencing others, it is the only thing."



Mnemonic rule: (st)ring theory

Thank You for paying attention! (Some pictures were taken from the web and some were created by myself.) jan.novak@johnynewman.com

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