Graviton as a phonon and dark energy problem

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Dark 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
 - 2 build the models of gravity from 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)

- 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:

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

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where α is a dimensionless coupling, arXiv: 1711.05183.

An approach based on non-commutative geometry

It is possible to formulate a different approach to QG based on the ideas of **non-commutative geometry**, arXiv: 1911.01955. Universe is made of **atoms of space-time-matter** (STM) according to this approach. Dark energy consists of about 10^{122} STM atoms and each have an associated **mass** of $10^{-33}eV/c^2$. We call this particle **mitron** and it is a quantum gravitational entity.

Group field theory and phantom energy

The energy density ρ_{ψ} satisfies the conservation equation

$$\dot{
ho}_{\psi} + 3H(1+w)
ho_{\psi} = 0,$$

where $H = \frac{V}{3V}$ and we take $V = a^3$ for scale factor *a*. Then it is possible to rewrite the equation as

$$\frac{d\rho_{\psi}}{dV} + \frac{1+w}{V}\rho_{\psi} = 0.$$

We get a solution for constant w

$$\rho_{\psi} = \frac{\rho_{\psi_0}}{V^{1+w}}.$$

The key result of GFT is that phantom energy could model dark energy, 2105.03751.

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.

Phantom cosmologies based on AdS/CFT correspondence

The pressure composes from two parts, which correspond to the **de Sitter universe and some matter ingredient**:

 $p = p_{dS} + p_{\psi}$

We could rewrite it as following:

$$\boldsymbol{p} = -\rho_{dS} + \boldsymbol{w}_{\psi}\rho_{\psi}$$

It is important that it is only for non-constant *w* that a Big Smash can be averted. The **superposition of the two fluids**, when each of them have constant but different *w*, does not have itself the constant *w*, JHEP 0208:029.

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

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

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

Entropic gravity

- our universe contains a large amount of quantum information in extremely long range correlations of the underlying microscopic degrees of freedom
- the present local laws of physics are not capable of detecting or describing these delocalized states.
- De Sitter space behaves as a glassy system with a very high information density that is slowly being manipulated by the microscopic dynamics

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Details are in arXiv:1611.02269.

'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



Postulate

All particles and fields in Nature are attached to some ring. They could move only on these rings, which are non-local objects.





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Limits



we quantize longitudinally vibrating rings and we obtain graviton as a phonon; particle sector is not changed

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the second limit is general relativity

Old concept of interaction in gravity sector



Graviton as a phonon



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Model of dark energy in ring paradigm



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Mathematical problem: we have a finite collection of N rings S^1 in R^3 , which could not touch; Give a **complete characterization of all non-homeomorphic structures**, which could be constructed from this finite collection of rings. Every two rings could be linked only once, they could not be knotted or twisted (in the case we have differentiable structure). We do not consider any Brunnian type of link in 3 and more rings.

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Definition

A **plabic graph** is an undirected planar graph G, which we draw inside a disk (considered modulo homotopy) with n boundary vertices on the boundary of the disk, labeled 1, ..., n in clockwise order, as well as some colored internal vertices. These internal vertices are strictly inside the disk and are each colored either black or white. Each boundary vertex i in G is incident to a single edge. If a boundary vertex is adjacent to a leaf (vertex of degree 1), we refer to that leaf as a lollipop.

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Toy model



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Hamiltonian is equal to

$$\hat{H} = \sum_{i=1}^{2} \frac{1}{2m} \hat{P}_{i}^{2} + \sum_{i=1}^{2} V_{ij} \hat{Q}_{i} \hat{Q}_{j},$$

where

$$V_{ij} = egin{pmatrix} rac{1}{2}k + rac{1}{2}k_3 & -rac{1}{2}k \ -rac{1}{2}k & rac{1}{2}k + rac{1}{2}k_3 \end{pmatrix},$$

and we will compute eigenvalues of the Hamiltonian:

$$w_1 = \sqrt{\frac{k}{m}}, w_2 = \sqrt{\frac{k}{m} + 2\frac{k_3}{m}}.$$

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The key observation is that the supermassive black holes are vibrating with temperature T_G .

The next step is to construct the partition function Z and the average energy of the system

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$${\sf E} = \sum_{lpha} {\sf E}_{lpha} {\sf P}_{lpha},$$

where $P_{\alpha} = \frac{\exp(-\beta E_{\alpha})}{Z}$ and $\beta = \frac{1}{k_B T_G}$. The result is

$$E = \hbar \frac{e^{-2\beta\hbar(w_1+w_2)}}{(1-e^{-\beta\hbar w_1})^2(1-e^{-\beta\hbar w_2})^2} \left[\frac{w_1}{(1-e^{-\beta\hbar w_1}} + \frac{w_2}{1-e^{-\beta\hbar w_2}}\right]$$

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Open questions

- We know that general relativity is perturbatively non-renormalizable. Will be the results of computation for interaction of graviton (phonon) with other particles finite?
- How will change the Ring paradigm early Universe cosmology? The singularities in black holes disappeared, because we define the theory on a grid, which is ever-present.
- Observe that the serveral of the serveral

Conclusion

- it is possible that the problem of dark energy is solvable only in quantum gravity
- we suggested a new approach (ring paradigm), which has advantages in cosmology

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 ring paradigm is connected with very nice mathematics (algebraic geometry and topology) 'It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with an experiment, it's wrong.' [Richard P. Feynman]



Some pictures were taken from web, some were created by software Inkscape.

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