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Explaining the Universe with gravitation dependent quantum vacuum

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Recent experimental hints for the equivalence principle violation point to an effective vacuum polarization in gravitational fields. This will change vacuum properties altering magnitudes of the physical constants. Here I discuss how a variable Planck constant and light speed, modified by gravity, can explain the main cosmological observations without invoking the space expansion. The obtained results are suggesting a simplified Universe without the Big-Bang, Dark Energy or Dark Matter, pointing to gravitationally excited quantum vacuum as the source of the Cosmic Microwave Background.

INTRODUCTION

Currently accepted theories are describing physical interactions mediated either by virtual particles in the case of electroweak and nuclear forces or by spacetime deformations in the case of gravitation[1]. The empty space or vacuum is also an inevitable counterpart of any interaction specified by zero-point energy (a.k.a. vacuum fluctuations) in the Standard Model and cosmological constant in General Relativity [1]. According to quantum physics, the vacuum properties can be modified by fields and particles. This materializes by vacuum polarization when the fields or particles interact with the vacuum constituent virtual counterparts [2]. The induced polarization, in turn, will affect propagation of other fields and particles through such modified vacuum. Calculations [3, 4] show that applied electromagnetic fields will build up vacuum fluctuations, slowing down the light propagation while a background gravitational field or a parallel plates' boundary condition (Cazimir vacuum) will reduce vacuum density, thus, increasing the light speed c [5]. A thin vacuum will, apart from speeding up the light, also enhance the elementary electric charge e because of reduced screening by virtual electron-positron pairs. Hence, the vacuum density depends on imposed fields or conditions and defines values of physical constants such as the light speed and the elementary charge. Likewise the magnitude of Planck constant h could be altered in a possibly more complicated way, since, as a spin related quantity, it will be affected by Quantum Chromodynamics (QCD) chiral vacuum on top of the Quantum Electrodynamics (QED) symmetric zero-point fluctuations [1]. Although a dynamic nature of physical constants, shaped by quantum interactions, has been mentioned by Paul Dirac as early as in 1937 [6], direct observations of the constants' changes are still experimentally unreachable. For example, the most investigated constant's, light speed, variations in electromagnetic and gravitational fields achievable at laboratory, are below $10^{-12} m/s$ for the electromagnetic and $10^{-32} m/s$ for the gravity respectively [5, 7].

[1] A theoretical (mathematical) connection between virtual particle and spacetime deformation could be the Rosetta Stone of Quantum Gravity.

Gravitational polarization of vacuum is possible only with a broken equivalence when different components of the vacuum can sense gravity differently. That is the main reason for the weakness of gravity's influence on the vacuum compared to other interactions. The mentioned vacuum polarization in a conventional gravitational field becomes sizable only when the space curvature radius is approaching the Compton wavelength – the path-length of a virtual electron-positron pair [7, 8]. Only then gravity will attract the pair's components differently. Such violation of the gravitational interaction equivalence, however, is a manifestation of a usual tidal effect.

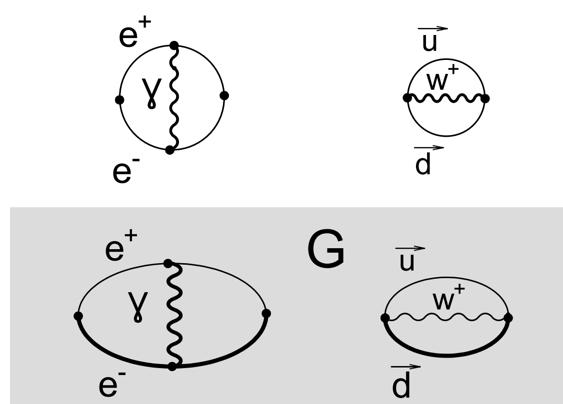

FIG. 1. Vacuum electron-positron and quarks loop components depicted in a style of Feynman diagrams. Upper row: pure vacuum without background fields; Lower row: vacuum in an asymmetric gravitational field. Particle line widths are drawn proportional to a possible violent (charge, spin) gravitational interaction intensity. Left column: QED vacuum; Right column: QCD chiral vacuum. Arrows denote correlated spins.

The situation will change for an asymmetric gravity, depending on e.g. electrical charge or spin of the attracted particles. A schematic view of QED and QCD vacuum gravitational polarizations is shown in Fig. 1. In gravitational fields, symmetry violations of different types are foreseen since from the electroweak and strong interactions we have learned that weaker forces are less symmetric and, gravitation is the weakest force. That is confirmed by recently reported experimental hints for space and charge parity gravitational violations [9, 10]. These equivalence principle breaking phenomena suggest that influence of a gravitational field on the vacuum, and hence on the physical constants, could be stronger than it is assumed.

As pointed above, the laboratory experiments' sensitivity is not sufficient for detecting fundamental constants' changes even inside the strong electromagnetic fields. Astronomical observations, on the other hand, can explore gravitational fields variations over cosmological distances to access possible changes of the physical constants. In this way, using astrophysical spectroscopic measurements, several constants' possible changes have been tightly bounded [11], among them the proton-electron mass ratio μ, and the fine structure constant

$$\alpha = \frac{e^2}{2\epsilon_0 hc}, \tag{1}$$

where the ϵ_0 is the electric constant. Hence, relying also on the dimensionless nature of μ and α, we will assume them to be vacuum and gravity independent, "true" constants. The dimensional constituents in Eq.(1), however, would be affected through the described vacuum polarization induced by the equivalence violating gravitation. Thus, with invariant fine structure constant α, and gravitation dependent fundamental constants $\epsilon_0, c, h, e,$ one can try to explain the main astronomical observations, cornerstone phenomena of the current cosmology model ΛCDM:

– redshifts of the galaxies

– anomalous dimness of supernova Ia events

– cosmic microwave background (CMB)

– non-luminous gravitating masses

The first three phenomena are enhancing with distance and the ΛCDM model interprets these effects as evidences for the space Big-Bang with accelerated expansion, inevitably introducing unphysical singularity, energy-momentum violation and mysterious Dark-energy [1]. The proposed variable constant's model, in contrast, can explain all observations within a single phenomenon – gravitational modification of vacuum, with static gravitational field spatial-cosmological distribution as the responsible for the mentioned distance dependence. Within the variable constant's model we interpret the quoted cosmological observations as following.

REDSHIFTS OF THE GALAXIES

More than 99% of the observed galaxies exhibit a common pattern of red-shifted spectra [12]. Redshifts' correlation with distance, discovered by Hubble [13], is currently treated as a result of the space expansion with moving apart galaxies. Distance dependent redshifts, however, can naturally be attributed to spatially different gravitational vacuum as the background for static galaxies. Assuming an unaltered fine structure constant, from the redshift definition

$$z = \frac{\lambda}{\lambda_z} - 1, \tag{2}$$

and the Rydberg constant, I obtain a relation

$$\frac{c_z}{h_z} = \frac{c}{h}(1+z), \tag{3}$$

for the fundamental constants h and c which is sufficient to explain the cosmological redshift effect. In the formulas the index z denotes the corresponding values at the redshift (distance) z while the λ is the atoms' radiation wavelength measured at laboratory. Eq.(3) directly follows from the expression of the wavelengths' ratio in Eq.(2) by the Rydberg constants' ratio at the laboratory, R_∞, and at a redshift z, $R_{\infty z}$; $\lambda / \lambda_z = R_{\infty z}/R_\infty$. The constants $\epsilon_0, e, \epsilon_{0z}, e_z$ cancel out from equations and do not contribute to the observed redshift pattern.

ANOMALOUS DIMNESS OF SUPERNOVA IA EVENTS

Supernovae Ia standardized magnitudes' distribution versus their redshift shows an anomalous decay [14] which is interpreted as the space expansion acceleration within the ΛCDM model. Meanwhile, the gravitationally modified Planck constant h_z and light speed c_z at the redshift z could explain the observed supernovae decay, provided

$$\frac{c_z}{c} < \frac{h_z^3}{h^3}. \tag{4}$$

This relation is derived from the well established model of light sources of the supernova type Ia [15, 16]. According to the model, a supernova's main luminous power is maintained by weak interaction – radioactive decays of ^{56}Ni and ^{56}Co. Therefore, for a gravitation dependent weak interaction, intensifying with distance (redshift), the distant supernova Ia explosions will burn-out rapidly becoming dimmer with distance. Such growing intensity of the weak interaction could be expressed through Fermi constant G_F, recalling its dimension

$$[G_F] = \Big[\frac{h^3}{M^2 c}\Big]. \tag{5}$$

Assuming a distance (gravitation) invariant defining mass M, for the Fermi constant at a redshift z one obtains

$$G_{Fz} = G_F \frac{ch_z^3}{c_z h^3}, \qquad (6)$$

which directly transforms to relation (4) in order to provide $G_{Fz} > G_F$. Thus, the condition (4) qualitatively explains the supernovae Ia anomaly within the gravitationally modified vacuum model without introducing space acceleration and Dark energy concepts.

COSMIC MICROWAVE BACKGROUND (CMB)

One of the major observational proofs for the Big-Bang cosmology is considered to be the CMB radiation [17, 18] which is interpreted as the remnant light from the Big-Bang explosion [1]. Yet, within the static universe and variable constants model the CMB radiation would rather originate from vacuum decay induced by the background gravitational field. The vacuum decay becomes possible in case of the gravitational energy-matter or boson-fermion equivalence violation. Indeed, for different strengths of gravitational interaction with photon and electron, one of the legs of the virtual photon in Fig. 1 could be broken to produce an on-shell, real photon with energy-momentum taken from and proportional to the gravitational field. In order to investigate matter-energy difference in gravity, causing the vacuum decay, I recall the unusual refractivity for gamma-quanta, observed in a laboratory Compton scattering [19] experiment, which could readily be reinterpreted as a photon-electron asymmetry of the gravitational interaction. For quantifying such asymmetry let's assume a gravitational constant G_e for the electrons, retaining the usual constant G for the photons. This will modify the electron's momentum P and energy $\mathcal{E}$ relation in a gravitational field with a Newtonian potential U as

$$c\frac{P}{\mathcal{E}} = \frac{v}{c} - \frac{2}{c^2}\Big(U + \Delta U\Big), \qquad (7)$$

where v is the speed of the electron and $\Delta U = U\Delta G/G$, with $\Delta G = G_e - G$. A similar relation for the photon with $v = c$, $\Delta U = 0$ will modify Compton scattering energy-momentum conservation and change the scattered photon's nominal maximal energy (Compton edge) ω_{max} with a relative shift proportional to ΔU

$$\frac{\Delta\omega_{max}}{\omega_{max}} = 4\Delta U\gamma^2\frac{2-x}{(1+x)^2}, \qquad (8)$$

where γ is the electron's Lorentz factor and x is the Compton scattering kinematic factor. The applied approximations and assignments are detailed in ref. [10] with a quite similar calculation. Substituting the observed Compton edge shift at HERA [19] $\Delta\omega_{max}/\omega_{max} = 0.046 \pm 0.01$, in Eq(8), I obtain $\Delta U = (1.64 \pm 0.45)\cdot 10^{-11}$ with the sign indicating a stronger gravitational coupling to matter (electron) relative to energy (photon). The same result (with opposite sign) is obtained when reverting the initial condition assuming gravitational nominal (G) and an anomalous coupling for the electron and the photon respectively. Thus, the Compton edge is shifting depending on the electron and photon coupling difference to the gravitational field. The same effect, detected at SLC [19] implies $\Delta U = (1.41 \pm 0.02)\cdot 10^{-12}$ – one order of magnitude lower than the HERA outcome. Here, however, more important is the same sign of both results indicating a suppression of the vacuum gravitational-electromagnetic decay by energy-momentum conservation (the relative electron-photon gravitational refractivity is lower for the photon). The radiation from vacuum decay, however, prohibited for the case of gravitational energy-matter violation, can be present in the processes with parity violating chiral QCD or with asymmetrically interacting matter-antimatter. The broken symmetries in gravity with preliminary quantified magnitudes are listed in Table I for analysis of candidate processes and numerical estimations. For extracting $\Delta G/G$ factors from the quoted above and in Refs. [9, 10] measured ΔU values, the potential of the Virgo Super-Cluster, $U/c^2 = 3\cdot 10^{-5}$, has been used.

TABLE I. Discrete symmetry violations in gravitational fields estimated with laboratory (preliminary) measurements. One σ standard deviation errors are listed in parentheses.

Violation by Gravity	Symmetry (Parity) Left-Right P (Spin)	Matter-Antimatter C (Charge)	Matter-Energy (Spin statistics)
ΔU	$1.7(0.2)\cdot 10^{-14}$	$< 1.3(0.3)\cdot 10^{-11}$	$1.4\cdot 10^{-12}$
$\Delta G/G$	$5.7(0.6)\cdot 10^{-10}$	$< 4(1)\cdot 10^{-7}$	$4.7\cdot 10^{-8}$

A plausible explanation for CMB is a spin radiation from decay of the lowest order QCD chiral vacuum component involving W boson (shown on Fig. 1). A gravitational energy $\Delta U_P M_{Wud}/2$, associated with two opposite spins of virtual u and d quarks in parity violating gravity, can convert to a real photon as it diagrammed in Fig. 2. Here the index P stands for parity, the $M_{Wud} \approx M_W$ is the total mass of this vacuum component with W boson mass M_W. Assuming Planck spectrum for $G(udW) \to \gamma$ decay photons (vacuum is a perfect black body for temperatures $T \to 0$), with the magnitude and error of ΔU_P from Table I, one can successfully describe CMB measurements [20, 21] (fit is presented on Fig. 2).

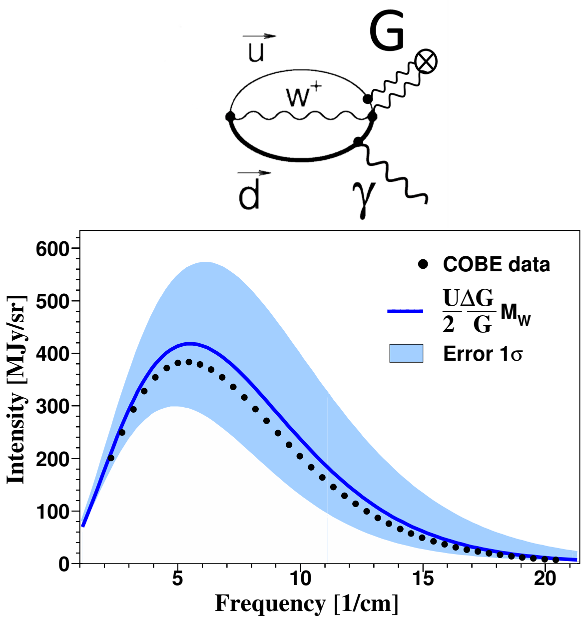

FIG. 2. Diagram of QCD vacuum decay process (upper part) induced by chiral gravitation. Gravitational parity violation measurement fitted to the Cosmic Microwave Background spectrum (lower part).

NON-LUMINOUS GRAVITATING MASSES

Astronomically measured missing masses at galactic and larger scales are currently attributed to the Cold Dark Matter (CDM) (see Ref. [22] and The Dark Matter - Sec. 26 of Ref. [1]). Considerable theoretical and experimental efforts have been invested and are currently underway for searching Dark Matter constituent particle(s) [23]. Meanwhile, the CDM observations can be explained by polarization of quantum vacuum as it suggested in Ref.[24]. According to the model, the polarized vacuum, consisting of virtual particle-antiparticle dipoles, will gravitate itself adding to the polarizing gravitational field. The numerical estimates in Ref.[24], however, rely on anti-gravity for the antiparticles which is ruled-out by Ref. [9] observations. An accurate calculation should substitude the gravitational dipole moment Md, introduced in Ref.[24] for the particle and anti-gravitating antiparticle with mass M at a distance d, by $0.5Md\Delta G/G$. This replacement corresponds to the gravitational symmetry breaking by an amount $\Delta G/G$ (for anti-gravity $\Delta G/G$=2). Then, a summation over all vacuum constituent gravitational (reduced) dipoles and possible multipoles for different $\Delta G_i/G$ asymmetries (see Table I) have to be done in order to fit the observed Dark Matter effects.

CONCLUSIONS

In order to discuss the obtained results, ΛCDM theory explanations of the major astronomical observations are collected in Table II against the newly suggested cosmological solutions. Apparently, the gravitation dependent vacuum model is simpler in its unified explanations within conventional quantum physics, compared to largely exotic and complex, Big-Bang theory with known deficiencies. One can simplify the suggested model even further by taking into consideration the recent investigations [25–29], which challenge the results of the supernovae Ia anomalous z-dependence. Eliminating the "Accelerating Space Expansion" from Table II removes the constraint on fundamental constants imposed by Eq.(4), leaving only Eq.(3) limitation. Then, any one of the z-dependent Planck constant or light speed alone can lead to the red-shifted galaxies. Preserving constancy of the light speed, $c_z = c$, with gravitationally modified quantum constant, $h_z = h/(1+z)$, one can possibly save Einstein's General Relativity [30], extending it with a minimal assumption of the cosmological constant dependence on spin, charge and spin statistics. In any case, more laboratory (experimental) and astronomical (observational) efforts are necessary to understand and describe the quantum vacuum and gravitation interplay.

TABLE II. Explanations of the astronomical discoveries within current cosmological theory and the suggested GRAvitationally Modified empty Space (abbreviated as GRAM blank S) model.

Observation	Cosmological interpretation	
	ΛCDM	GRAM S
Redshifts of the galaxies	Space Expansion (SE)	Variable constants $c_z/h_z = (1+z)c/h$
Anomalous dimness of supernovae Ia	Accelerating SE, Dark Energy	$G_{Fz} > G_F$ $c_z/c < h_z^3/h^3$
Cosmic microwave background	Big-Bang remnants	Vacuum decay products
Non-luminous gravitating masses	Dark Matter	Polarized quantum vacuum

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