Localized gravitons as essence of dark energy: Implications for accelerated cosmic expansion

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Abstract. A theory of Emerging Quantum Mechanics (EQM) has been developed \cite{1} contributing to the understanding of the measurement problem by assigning a quantum dynamical process to collapse within Schrödinger’s theory.

EQM treats cosmological problems in a quantum field theory in high dimensional spacetime (11D) including matter and the gravitational field. Gravity is quantized in the weak interaction limit. The EQM Lagrangian contains terms up to fourth order in the gravitational field. Second and fourth order terms are associated with repulsive dark energy and third order terms with attractive dark matter effects. Gravonon-gravonon repulsion, i.e. dark energy in EQM, modifies the structure of the gravitational field and leads to accelerated expansion of the universe.

Quantum diffusion of the matter particles in three dimensional space is suggested as the mechanism of the expansion of the universe. The rate of expansion is given by the frequency of the soft gravitational modes. A lower limit of the deceleration parameter for the expansion of the universe, derived in EQM, is in the range between -0.6 and -0.8, an observed value of -0.55 has been reported.

1. Introduction: Some unexplained experimental observations
The measurement problem is the most prominent unresolved problem of standard quantum mechanics. Observations unexplained by standard quantum mechanics range from atomic to cosmological scales, some of them are summarized in table 1. The collapse process is not the result of any well defined quantum dynamics in four dimensional spacetime. Furthermore in cosmology the physical nature of dark energy and dark matter, needed to reproduce numerous cosmological observations, is not clarified. The coincidence problem presents a further difficulty for quantum cosmology.

In a recent publication a quantum field theory was presented \cite{1}, called Emerging Quantum Mechanics (EQM), which uses high dimensional spacetime and quantizes gravity in the weak interaction limit, leading to the solution of the measurement problem \cite{2}. The idea in EQM is that the entanglement with gravonons, i.e. localized gravitons, leads to the localization of quantum particles as beables. This happens if and only if the coupling is weak and nearly degenerate with a continuum of states of high density. This is a kind of dimensionality effect warranted only by the continuum of gravonons which, in addition to our three dimensional space, live in...


Table 1. Summary of some experimental observations and their understanding within standard quantum mechanics

| Experiment                                      | Experimental result                                      | Prediction by standard quantum mechanics                  | Judgement                                      |
|-------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|------------------------------------------------|
| expansion of universe                          | small value of dark energy                               | extremely large value of cosmological constant            | quantum theory fails by 123 orders of magnitude |
| diffraction of mesoscopic molecules            | wave → particle transition                               | collapse, measurement problem                            | heuristic postulate instead of a theory         |
| sticking of gas atoms at $T \to 0K$            | everything is stuck at $T \to 0K$                        | nothing is stuck at $T \to 0K$                            | quantum theory fails by an infinite order of magnitude |
| $Xe$ atom localization                         | $Xe$ atom on a metal surface does not move for days and weeks | $Xe$ atom wave packet decays within $10^{-10}$ s          | theory fails by twenty orders of magnitude     |
| hydrogen diffusion on metal surfaces           | diffusion rate depends strongly on experimental setup    | no explanation                                           | theory fails by nine orders of magnitude       |

hidden high spacial dimensions. A beabling condition must be fulfilled which is a requirement for the magnitude of the coupling strength between the quantum particle and the gravonons [5]. Because of the weakness of the coupling, particle localization and beabling via gravonons is effective on the energy shell defined by the incident wave packet. Therefore the site of particle localization, e.g. on the detector surface in the double slit experiment, is determined by the presence of gravonons, degenerate with the initial state of the incident particle wave. Schrödinger’s equation leads deterministically to the chosen site of particle localization if the initial state is known.

We use the EQM approach to solve the cosmological problems of the nature and the effects of dark energy and dark matter, which emerge in the theory (section 2). Quantum diffusion of hydrogen atoms in a crystal in intergalactic space is the mechanism of the expansion of the universe in EQM [5]. The accelerated expansion of the universe is due to gravonon-gravonon repulsive interactions resulting in a range of values for the deceleration parameter of the order of the experimentally determined value [3] (section 4.1).

2. Features of EQM. Emerging dark energy and dark matter.

Inspired by string theory in EQM we assume 11 dimensional spacetime, with the additional spacial dimensions being hidden and compactified. A three dimensional brane exists and is embedded in 10 dimensional space. The size of the compactified hidden dimensions is stabilized by the presence of branes. It is of the order of $10^3 \sim 10^4$ bohr and is determined by comparison with the experimental rate of adsorbate quantum diffusion on solid surfaces [1]. Gravitons, the quanta of the gravitational field, are the only particles living in all spacial dimensions. All other particles (fields) live only on the three dimensional brane.

The mathematical implications of the features of EQM refer to:

- Localization of particles out of delocalized wave functionals.
- Telegraph-like transitions between localized particles states.
- Transitions between localized and delocalized particle states (tiny bursts).
“Strong” gravitational force on the molecular scale.
- Existence of localized graviton states (gravonons).
- Reproduction of the experimental facts in table 1.
- Single world wave functional, which is a superposition of delocalized and localized configurations, and develops with time via Schrödinger’s equation.

As it is derived in ref. [1], the gravitational field is quantized in the limit of weak gravity. In the non-relativistic limit new particles emerge named gravonons, which represent local versions of the gravitons.

2.1. Objects in EQM

New objects are defined:
- Gravonons are linear combinations of gravitons of various wave lengths. They are localized over a region encompassing a molecule or a micro-, meso- or macroscopic piece of matter.
- Beables: matter fields entangled to gravonons constitute beables. A matter particle loosing entanglement to gravonons can escape into plane waves and then be recaptured on a localized place.
- Limbo state is any solution of Schrödinger’s equation in 4 dimensional spacetime in tensor product with gravitational configurations in 10 spacial dimensions, out of which 7 are hidden. In the limbo state matter particles are not accessible in experiment.
- Limbo-beable transition is a change of the wave functional with time, from a dominating tensor product of 4 dimensional components times gravitational components, to a wave functional, for which linear combination of such tensor products has essential physical consequences.

The world wave functional $|\Psi(t)\rangle$ is a solution of Schrödinger’s equation:

$$|\Psi(t)\rangle = \sum_{\text{limbo}} C_{\text{limbo}}(t) |\text{limbo}\rangle.$$  \hspace{1cm} (1)

It is a superposition of many-particle states where $|\text{limbo}\rangle$ is a four dimensional solution of Schrödinger’s equation, not involving gravitational interaction, in tensor product with a state describing gravitons and/or gravonons.

Equation (1) is a sum of tensor products, which is not a tensor product itself. If this superposition is dominated by a sum of components, which describe a matter particle in tensor product with gravonons, then this is a beable where the matter particle is entangled with the gravonons. If the world wave functional is dominated by a single tensor product of a single particle state and gravonons, it corresponds to an independent particle and gravonon continuum, hence there is no entanglement between them. This state we call the limbo state.

2.2. Interaction Lagrangian. Dark energy and dark matter emerge in EQM.

Einstein’s field equation describes classical physics where particles move along trajectories (geodesics):

$$E_{\mu\nu} = 8\pi G(T_{\mu\nu} + \Lambda g_{\mu\nu}).$$ \hspace{1cm} (2)

$E_{\mu\nu}$: Einstein’s tensor; $G$: Newton’s constant; $T_{\mu\nu}$: energy-momentum tensor ($T_{00}$ contains the density of classical particles); $\Lambda$: the cosmological constant, which together with the metric $g_{\mu\nu}$
represents the so-called dark energy term.

In the weak gravitational limit the Euler-Lagrange equation in EQM [1] is the analogue of Einstein’s field equation and reads for the 00-component:

\[ \partial^2 h_{00} = -8\pi G(N)(T_{00} + \frac{1}{2} T_{00} h_{00}) \] (3)

\[ T_{00} = m\psi^+\psi + \frac{1}{2} m\psi^+\psi h_{00} \] (4)

\[ \partial^2 h_{00} = -8\pi G(N)(m\psi^+\psi + m\psi^+\psi h_{00}) = -8\pi G(N)(\rho_{\text{matter}} + \rho_{\text{matter}} h_{00}). \] (5)

This is the equation of motion of the gravitational field \( h_{00} \). (\( G(N) \): gravitational constant in \( N \)-dimensional space.) Because of the existence of additional hidden dimensions the term proportional to \( h_{00} \) becomes only significant for short separations between matter particles.

The (negative) interaction Lagrangian in EQM is derived from the Einstein-Hilbert action:

\[ \frac{1}{2} h_{00} T^{00} \left( 1 - \frac{1}{2} h_{00} \right) \approx \frac{1}{2} m^2 \psi^+\psi \left( h_{00} + \xi^\dagger_00 \xi_00 + \frac{1}{4} \xi^\dagger_00 \xi_00 h_{00} + \frac{3}{8} (\xi^\dagger_00 \xi_00)^2 \right). \] (6)

The graviton field \( h_{00} \) is defined in the non-relativistic limit with the graviton operators \( \xi^\dagger_00, \xi \) as: \( h_{00}(x) = e^{-ikc t} \xi_00(x), h^{00}(x) = e^{ikc t} \xi^\dagger_00(x) \). The first term in eq. (6) is Newton’s gravity for mass \( m \) with density distribution \( \psi^+\psi \), corresponding to the first term on the r.h.s of eq. (2). Terms of second, third, and fourth order in the gravitational field emerge. The second and the fourth order terms in the gravitational field are repulsive terms. They are associated with dark energy. The attractive term in eq. (6) is due to third order terms in the graviton field and it is associated with dark matter effects.

### 2.3. Cosmological constant problem solved in EQM

The analogy with Einstein’s field equation allows to associate the dark energy term in eq. (2) with:

\[ \Lambda g_{00} \to \frac{1}{2} \rho_{\text{matter}} \left( \xi^\dagger_00 \xi_00 + \frac{3}{8} (\xi^\dagger_00 \xi_00)^2 \right) \] (7)

hence \( \Lambda \) is an operator:

\[ \Lambda \to \frac{1}{2} \rho_{\text{matter}} \left( \xi^\dagger_00 + \frac{3}{8} (\xi^\dagger_00)^2 \xi_00 \right) \] (8)

involving the density of matter \( \rho_{\text{matter}} \), which is not a constant in space and in time. The "cosmological coincidence" \( \Lambda \propto \rho_{\text{matter}} \) comes out of EQM. Our quantum gravity explains the value of \( \Lambda \) which is proportional to the density of observable matter for all cosmological times.

The cosmological term eq. (8) is a product of three operators and has enormous consequence for the solution of Schrödinger’s equation, for instance it leads to the accelerated expansion of the universe. The cosmological constant paradox does not exist within EQM, no fit to anything is needed. This is in contrast with standard QFT, where the cosmological constant has a value \( 10^{123} \) times the experimental value and has the meaning of the vacuum energy. In EQM, also a QFT theory, which includes gravity as a quantum field, a cosmological constant with the correct value emerges.
3. The model universe in EQM

The model universe in EQM is a collection of hydrogen-atom lattices in free space and is described in detail in ref. [5]. A fraction of a hydrogen atom lattice is shown in fig. 1. In article [5] on cosmic expansion it is shown that the interactions are Newton-like, leading to soft gravonon modes with frequency $\omega_{\text{Newton mode}}$. Beabling via the Newton gravonons is only possible for a hydrogen-atom crystal with approximately $10^6$ atoms on the lattice sites and lattice constant of the order of 10 m in interaction with the photon field. The gravonon mode of the crystal is only negligibly influenced by the atom vibrations induced by the optical field but the strength of gravitational interaction in this light-atom-lattice (LAL) is enhanced so that the beabling condition is fulfilled.

4. Accelerated expansion of the universe in EQM

In order to study accelerated expansion one has to study interpenetrating LALs, where the separation between the hydrogen atoms might become smaller than the compactification radius. Then the higher order terms in eq. (5) become effective, i.e. dark energy emerges and modifies the unperturbed expansion of the universe as described in ref. [5]. This is symbolically illustrated in the upper panel of fig. 2 where the two mattresses represent now two LALs, i.e. the circles represent now single hydrogen atoms, in contrast to fig. 1.

In EQM the accelerated expansion of the universe is due to gravonon-gravonon repulsion between intergalactic hydrogen-atom crystals (dark energy repulsion). According to the $\gamma - \eta$ theory [6] this leads to the generation of harder gravonon modes of the Newton crystal $\omega_{\text{Newton mode}}$ and hence to acceleration of the expansion of the universe.

4.1. Deceleration parameter in EQM. $\gamma - \eta$ theory.

Accelerated expansion of the universe in EQM is due to dark energy repulsion, i.e. gravonon-gravonon repulsion between hydrogen-atom lattices (fig. 2, upper panel). These are the terms of second and fourth order in the gravitational field in the (negative) interaction Lagrangian of EQM (eq. 6).
Gravonon-gravonon interaction between intergalactic clusters

Figure 2. Upper panel: fractions of a two hydrogen atom crystals $L1$ and $L2$. One selected atom $q_{L1}$ in $L1$ interacts directly with one atom $q_{L2}$ in $L2$, which is involved in the Newton gravonon mode and couples to its neighbours $\{q_{L2_i}\}$ via gravonon-gravonon interactions. Lower panel: variation of the frequency of a soft (dashes, blue curve) and hard Newton gravonon modes (dots, red curve) in $L2$, resulting as a solution of eq. (9). This is the effect of the direct gravonon interaction between the two hydrogen atoms in the two intergalactic hydrogen-atom lattices, shown in the upper panel, and the gravonon-gravonon interactions induced by atom $q_{L1}$ among the neighbours $\{q_{L2_i}\}$ of atom $q_{L2}$ in the second lattice. The deceleration parameter $q(\eta)$ resulting from the faster expansion of $L2$ due to the gravonon-gravonon repulsion induced among its atoms, is plotted with the full green curve which may serve as a lower bound for the experimental value of $q$. 
The Hamiltonian is that of the $\gamma - \eta$ theory [6], reformulated for a cosmological model of two intergalactic clusters ($\omega_{\text{Newton}} = \omega_{\text{Newton mode}}$ in ref. [5]):

$$H = H_o + V = H_o - \gamma \sqrt{\frac{m_{L2}}{m_{L1}}} \omega_{\text{Newton}}^2 q_{L1} q_{L2} + \frac{\eta}{2} \gamma \omega_{\text{Newton}}^2 q_{L2}^2 + \frac{1 - \eta}{K} \gamma \omega_{\text{Newton}}^2 q_{L2} \sum_n q_{L2,n}$$

$$- \frac{1 - \eta}{2K} \omega_{\text{Newton}}^2 \sum_n q_{L2,n}^2$$

$$= H_o - \omega_{\text{Newton}}^2 q_{L1} q_{L2} + \frac{\eta}{2} \omega_{\text{Newton}}^2 q_{L2}^2 + \frac{1 - \eta}{K} \omega_{\text{Newton}}^2 q_{L2} \sum_n q_{L2,n}$$

$$- \frac{1 - \eta}{2K} \omega_{\text{Newton}}^2 \sum_n q_{L2,n}^2.$$  \hspace{1cm} (9)

$\gamma = 1$, because it is the ratio of the force constants of the harmonic oscillators $q_{L2}$ and $q_{L1}$, which are equal ($\omega_{L1} = \omega_{L2}$ and $m_{L1} = m_{L2}$). $\eta$ is a measure of the many-body character of the interactions in lattice $L_2$. $\eta = 0$ means extreme many-body character, $\eta = 1$ refers to a spring model. The many-body interactions in $L_2$ are perturbed by the presence of the intergalactic lattice $L_1$ and new vibrational modes are generated: a softer and a harder one compared to the non-perturbed Newton vibrational mode of a single hydrogen-atom lattice.

The result of the solution is the generation of a softer and a harder vibration modes compared to the Newton mode for a single lattice (fig. 2, lower panel). The softer vibration (blue curve, dashes) is not important for expansion because it is just an in-phase vibration of the atoms in lattice $L_2$. The harder vibration (red curve, dots) is the counter-phase vibration of the hydrogen atoms in $L_2$ and leads to a faster beable-limbo transition, hence to accelerated expansion of the lattice. Varying the weight of the many-body character of the interactions within lattice $L_2$ changes the frequency of the hard vibration and as a consequence the Hubble time changes.

A pure spring model of the gravonon-gravonon interactions in $L_2$ yields harder Newton-like vibration than a vibration resulting from many-body interactions because in the first case the whole interaction force is concentrated between each pair of interacting atoms in $L_2$, whereas in the latter case it is distributed among the surrounding atoms.

If just a single atom of one lattice interacts with a single atom of the second lattice, then nothing will change. Only if the two lattices penetrate into each other there will be an effect. But this is the extreme situation of strongest gravonon-gravonon repulsion and it yields a lower limit for the value of the deceleration parameter:

$$q = 2 \frac{t - t_o}{t_o},$$

$t_o$ being the Hubble time. The deceleration parameter $q(\eta)$ varies with $\eta$ in the range from -0.6 to -0.8 (full green curve in fig. 2). It can be compared to the value of -0.55 based on Planck spacecraft data [3]. The comparison of our result with the Planck data assumes that (nearly) every hydrogen atom in crystal $L_1$ interacts with another hydrogen atom in crystal $L_2$ in the way indicated in the upper panel of fig. 2. In fact it requires that every LAL in a Newton-mode-lattice penetrates a LAL in a different Newton-mode-lattice. Because this will hardly be realized in the intergalactic matter it is clear that the theoretical values of $q$ are lower limits for the experimental Planck data.

Choosing one value for the frequency of the vibrational mode $\omega_{\text{Newton}} = 8.64 \times 10^{-35}$ a.u.$^{-1}$ of the interacting lattices yields, solving Scrödinger's equation, a faster transition beable-limbo,
Figure 3. Development with time of the weight of the beable of a single hydrogen atom in one crystal entangled with non-perturbed gravonons of frequency of the order of $5.68 \times 10^{-35}$ a.u.$^{-1}$, i.e. $t_o = 4.25 \times 10^{17}$ seconds, typical for a single crystal (red full curve). The weight of the beable due to entanglement of a hydrogen atom with the modified harder gravonons of frequency $\omega_{\text{Newton}} = 8.64 \times 10^{-35}$ a.u.$^{-1}$, i.e. $t = 2.80 \times 10^{17}$ s, one typical value for a modified Newton mode of the hydrogen atom crystals due to interaction with a second hydrogen atom crystal, is plotted with the blue dotted curve.

hence faster expansion of the interacting hydrogen-atom lattices (fig. 3).

The $\gamma - \eta$ model applies only if the distance between atoms on the different clusters are smaller than the compactification radius.

5. Conclusion

Terms associated with dark matter attraction and dark energy repulsion emerge in the Lagrangian of the quantum field theory EQM, starting from Einstein-Hilbert action in high dimensional spacetime. New particles, called gravonons, emerge in the non-relativistic limit. Gravonon-gravonon interactions are the physical background of dark matter and dark energy. Non-adiabatic effects due to interaction between gravonons and the Newton vibrational mode in the hydrogen atom crystal and gravonon-gravonon repulsive interaction are the physical reason for the accelerated expansion of the universe.

In EQM there is no cosmological coincidence problem, the cosmological "constant" being an operator, defined by the gravonon creation and destruction operators and the matter density. They differ in space and time.

Some typical problems of standard quantum mechanics, collected in table 1, have been resolved.
within the present theory and the reader can find the solutions in refs. [1, 2, 7]. Within EQM experimental observations in a range of time scales of $10^{-3}$ seconds to $10^{10}$ years and in a range of distances from atomic to cosmological scales are reproduced and explained.

References

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