Decay (Expansion) of the Universe and Stability of the Solar System in a Fundamental Quantum Description

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Abstract

The expanding (decaying) universe is discussed in the framework of a local quantum field theory, based on a Lagrangian, in which all fermion operators are coupled to bosons. In this formalism the initial phase of the universe has been explained by creation of particles out of the vacuum, accumulation of a system of large mass and immense radius dominated by (e^-p^+) and (e^+p^-) pairs, followed by a chirally triggered collapse and annihilation of all (e^+p^-) pairs (antimatter).
The resulting annihilation photons led to strong heating and disintegration of the remaining (e^-p^+) pairs (matter) during the "Big Bang", resulting in exponentially increasing velocities of the decay fragments towards large radii (accelerated expansion). A good description of velocity-distance data from supernovae Ia observation is obtained by adjusting the position of the Solar system to a radius of the universe of ~ 1200 Mpc. Of importance, at this radius the repulsive and attractive forces compensate each other. Combined with a calculation of its mass, this yields surprising evidence for a stable Solar system and most likely also other cosmic systems, which do not follow the general expansion of the universe.
The accelerated expansion - interpreted in cosmological models as due to unknown dark energy - is understood by the strong radial fall-off of the gravitational potential generated in the early universe.

Keywords: Fundamental quantum description of gravity, accelerated expansion of the universe, stable bound states.

Introduction

To understand the origin and evolution of the universe is one of the biggest challenges of mankind. So far, this problem has been discussed mainly in cosmological models [1] based on Einstein's theory of general relativity [2], in which it is assumed that the universe developed from a singularity (Big Bang), followed by rapid inflation and expansion. Inflation [3] is usually believed to be responsible for the smooth properties of isotropy and homogeneity, Euklidean geometry and the absence of magnetic monopoles. Although the universe has been discussed as static or oscillatory structure, presently it is believed to be ever expanding, even with accelerated speed. This result has been obtained from the outstanding projects of supernovae observation [4, 5], which showed that SNe Ia can be used as standard candles for distance measurements up to 1000 Mpc.
These data as well as the majority of all sky observations have been interpreted in cosmological models, see also ref. [6]. However, this is not really satisfactory, because on one hand the basic physics is not understood, as the mechanisms, which led to the generation of mass and the observed breaking of the matter-antimatter symmetry (in the universe essentially matter is found only, but in the generation of mass equal amounts of matter and antimatter are created). On the other hand, evidence for dominant dark matter and dark energy has been obtained, but these contributions could neither be experimentally detected nor be logically explained.
These problems may be caused by the description using a global theory, in which parameters, as expansion, curvature, cosmological constant etc., have been fitted to experimental data. One cannot explain, why the universe is expanding and not oscillating, because this depends just on the needed fitting parameters. Therefore, a (more) fundamental theory has to exist, in which this property can be understood from first principles. This is most likely a quantum theory. Indeed, only in such a formalism the constancy of the coupling G_N in Newton's gravitational law could be understood [7].
Such a quantum theory has been developed [8, 9, 10] during the last decade, in which all fundamental interactions - including gravitation - can be treated in a unified way by local interactions between basic particles. This theory

couples to the vacuum and can explain the creation of particles out of the vacuum [8]. Further, the mass of particle bound states is entirely given by binding and kinetic energies. Of crucial importance, **all** parameters of the theory are determined by severe boundary conditions.
Of special interest, in composite gravitational systems a dynamical structure is found due to an acceleration term in the formalism [10], which can lead to a collapse. In particular, a gigantic gravitational system built mainly of (e^-p^+) and (e^+p^-) pairs must have been accumulated in the initial phase of the universe [10]. These lepton-hadron pairs could arise from decay of simple fermion-antifermion bound states created out of the vacuum, with a homogeneous and isotropic distribution in the system. By chiral separation of (e^-p^+) pairs (matter) and (e^+p^-) (antimatter), all accumulated (e^+p^-) pairs were drawn to small radii, collapsed and annihilated, before the (e^-p^+) pairs at larger radii could undergo a similar process (complete annihilation of $(e^\pm p^\mp)$ pairs is possible in the present formalism, because $e^\pm$ and $p^\mp$ are of $(q^+q^-)^n q^\pm$ and $(q^+q^-)^n q^\mp$ structure, respectively, where q denotes massless fermions, "quantons").
In the present paper the decay (expansion) of the remaining (matter) universe is discussed, after heating and disintegration by the produced annihilation photons during the "Big Bang". Since this theory is free of external parameters, the complete dynamics of the system has to be included in the properties of the bound state. This has already been verified in the description of galaxy rotation [7]. An important aspect of the present study is the possible existence of bound states in the universe. Galactic and solar systems are bound by rotation, but it is important to see, whether there are more specific boundary conditions for stability of such cosmic objects in the universe.

2. Theoretical aspects and radial features of bound systems

For a closed system, momentum and energy-momentum must be conserved; this has to be valid also for fundamental systems composed of elementary fermions and bosons. However, in most current theories of fundamental forces these basic conservation laws are not incorporated; instead phenomenological parameters are used, which are fitted to experimental data. This may be the reason, why a unified description of all elementary forces had not been possible. These basic conservation laws can be verified only in a quantum field theory, in which fermion and boson momentum and energy-momentum is conserved explicitly. This requires a Lagrangian, in which the fermion operators are coupled to bosons, see ref. [8, 9]

$$\mathcal{L} = \frac{1}{\tilde{m}^2}\bar{\Psi}\ i\gamma_\mu D^\mu D_\nu D^\nu \Psi\ -\ \frac{1}{4}F_{\mu\nu}F^{\mu\nu}\ , \qquad (1)$$

where $\tilde{m}$ is a mass parameter and Ψ in general a two-component fermion field $\Psi = (\Psi^+\ \Psi^o)$ and $\bar{\Psi} = (\Psi^-\ \bar{\Psi}^o)$ with charged and neutral part. Vector boson fields A_μ with charge coupling g are contained in the covariant derivatives $D_\mu = \partial_\mu - igA_\mu$ and the Abelian field strength tensor $F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$.
This third-order Lagrangian is not renormalizable and has therefore no relativistic solution. But more important, by going to three dimensions (3-momentum or separating space and time degree of freedom) finite bound state solutions can be found [8, 9] with a structure consistent with the size of hadrons and other particles. In this way bound states of all fundamental forces have been generated.
If we consider gravitation, which is given by magnetic binding of lepton-hadron pairs [7, 9], there is a basic (lepton-hadron)^2 state of very small energy[1], but also large gravitational systems [10] with a dynamical structure due to an acceleration term. In particular, one can assume that all features of the decay of the large gravitational system accumulated in the early universe can be described in the present formalism.
We can define global matrix elements in the form

$$M_{ng} = \psi(r)\ V_{ng}(r)\ \psi(r)\ , \qquad (2)$$

with two potentials $V_{2g}(r)$ and $V_{3g}(r)$ given by

$$V_{2g}(r) = \frac{\alpha^2(2s+1)(\hbar c)^2}{8\tilde{m}}\ \Big(\frac{d^2 w_s(r)}{dr^2} + \frac{2}{r}\frac{dw_s(r)}{dr}\Big)\frac{1}{w_s(r)} + E_o\ , \qquad (3)$$

with s=0 for scalar and s=1 for vector states, and

$$V_{3g}(r) = \frac{\alpha^2(\hbar c)}{\tilde{m}}\int dr'\ w_{s,v}(r')\ v_v(r-r')\ w_{s,v}(r')\ , \qquad (4)$$

with boson wave functions $w_{s,v}(r)$ (for scalar and vector coupling) and an interaction $v_v(r) \sim -\alpha(\hbar c)\ w_v(r)$. Importantly, to fulfill energy-momentum conservation the constant E_o has to be 0, which indicates a coupling of the theory to the vacuum [8].

[1] and a first-order equivalent coupling constant in agreement with Newton's gravitational constant G_N.

There are geometric boundary conditions $\psi_{s,v}(r) \sim w_{s,v}(r)$ and $|V^v_{3g}(r)| \sim c\ w^2_s(r)$, which can be satisfied by boson wave functions of the form [8, 9]

$$w_s(r) = w_{s_o}\ exp\{-(r/b)^\kappa\} \tag{5}$$

and

$$w_v(r) = w_{v_o}\ [w_s(r) + \beta R\ \frac{dw_s(r)}{dr}]\ , \tag{6}$$

with the normalization factors obtained from $2\pi \int rdr\ w^2_{s,v}(r) = 1$ and $\beta R = -\int r^2 dr\ w_s(r)/\int r^2 dr\ [dw_s(r)/dr]$.

Of large importance, for a fixed shape parameter κ the relative features of these potentials do not depend on the used parameters. This has been verified for very different systems, hadrons, leptons, atoms and gravitational bound states. In the application to composite systems, as gravitation, it should be realized that the distribution of the constituents in the wave functions $\psi_{s,v}(r)$ and $w_{s,v}(r)$ is homogeneous, in the scalar wave functions $\psi_s(r)$ and $w_s(r)$ also isotropic. However, in the decay of a system, which had been strongly heated up by annihilation photons, a certain granularity of the emitted matter is expected.

By considering only the radial degree of freedom (compression and following dilatation), we can start from the gravitational potential density $V\rho(r) \sim (|V_{2g}(r)| + |V_{3g}(r)|)\ \psi^2_s(r)$. The dynamical potential strength $(V\rho)_{dyn}(r)$ for radii smaller than $< r^2_s >^{1/2}$ can be derived from the normalization of the wave function $norm = 4\pi \int r^2 dr\ \psi_s(r)^2$, which leads to a strong increase for small radii $\sim 1/r$. In addition, (e^-p^+) (matter) and (e^+p^-) pairs (antimatter) separate and compress, the latter going to a collapse. This is taken into account by an additional $1/r$ factor for antimatter.

In the above potentials and wave functions the full information on the bound state system has to be included, also that on the decay of the system. Specially for the radial degree of freedom the global velocities can be defined only in two ways, one given by $(v/c)(r) = \sqrt{2E_{kin}(r)/M_{tot}}$, the other by $(v/c)(r) = \sqrt{M_{tot}/2E_{kin}(r)}$. The first form leads to a radial velocity for attraction

$$(v/c)_{att}(r) = (2\ |V_{2g}(r) + V_{3g}(r)|\ \psi^2_s(r)/M_{tot})^{1/2}\ , \tag{7}$$

which increases for $r \to 0$. The second form has to be valid for decay of the system

$$(v/c)_{rep}(r) = -N\ (2|V_{2g}(r) + V_{3g}(r)|\ \psi^2_s(r)/M_{tot})^{-1/2}\ . \tag{8}$$

N is a normalization factor, which has to be fixed by bound state properties, as discussed below. To include the full relativistics, the velocities $(v/c)_{att/rep}(r)$ should be interpreted as redshift $z_{att/rep}(r)$ $(z = \sqrt{(1 + v/c)/(1 - v/c)} - 1)$. Then, the relativistic velocities are given by $(v/c)_{att/rep}(r) = (z_{att/rep}(r) + 1)^2 - 1/[(z_{att/rep}(r) + 1)^2 + 1]$. For radii smaller than $< r^2_s >^{1/2}$ the dynamics yields an additional factor $1/r$ for eq. (7) and r for eq. (8).

The global acceleration of the system may be given by the derivatives of the velocities

$$\Delta(v/c)(r) \sim \frac{d(v/c)(r)}{dr} \tag{9}$$

with corresponding $1/r$ and r factors for radii smaller than $< r^2_s >^{1/2}$.

3. Comparison of the results with supernovae data

In the present formalism the relative bound state properties do not depend on the radius of the system (for a fixed shape parameter κ). Therefore, potentials, velocities and acceleration components have been calculated by using the parameters κ=1.35 and α=2.14 (as before [7, 8, 9]) and $\tilde{m}$=0.45 and slope parameter b=0.6. This yields a root mean square radius $< r^2_s >^{1/2}$= 1 and a mass $M_{tot} = M_{2g} + M_{3g} = 0.9$ (in arbitrary units with the dimensions $[r, M]$ related by $[r] \cdot [M] = \hbar c$). If this solution should be used for a specific system, a calibration of the radius is needed. In this way the accumulated large gravitational system of the early universe can be described, but also any other bound state, as the Solar system discussed below.

The dynamical potential strength $(V\rho)_{dyn}(r)$ is shown in the upper part of fig. 1 by solid line; for r smaller $< r^2_s >^{1/2}$ it increases strongly $\sim 1/r^2$, whereas for larger radii it follows the fall-off of the gravitational potential. The behavior at small radii is consistent with a compression of matter and antimatter (as explained in ref. [10]) and shall be discussed in detail elsewhere together with the corresponding densities.

In the second part, both velocity components (7) and (8) are given by dot-dashed and solid lines. The latter is multiplied with $N = 6.5\ 10^{-18}$, which is needed to get the correct boundary condition for the Solar system, see below. These curves are strongly nonlinear and show a complementary behavior: whereas for attraction the velocity follows

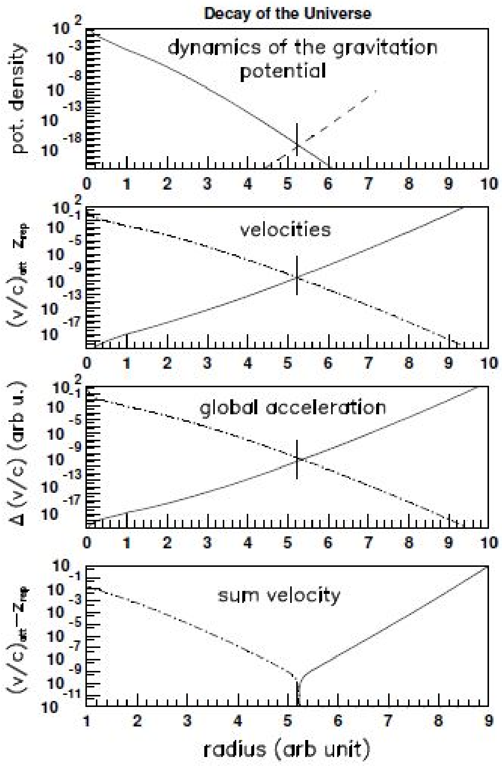

Figure 1: Properties of the gravitational bound state as a function of radius. Upper part: Attractive and repulsive dynamical potential strength (solid and dashed lines, respectively). Middle parts: Velocities and global accelerations for repulsive decay (solid lines) and gravitational attraction (dot-dashed line). Lower part: Sum velocity, which shows a profound cusp for $(v/c)_{att}(r) + (v/c)_{rej}(r) = 0$. The velocities given by dot-dashed lines in the lower three parts have been multiplied with -1.

the dynamics of the gravitational potential and increases for $r \to 0$, the deduced velocity of repulsion is strongly suppressed at small radii by the strong binding. Only at radii several times larger than the root mean square radius the attractive potential has fallen off appreciably, allowing for an exponential speeding up of the velocity of expansion, which is quite different from the linear distance dependence of the empirical Hubble law.

The decay velocity at large radii has been compared with data on velocity-distances from supernovae Ia observation [4, 5, 11]. By adjusting the radial scale, shown in the upper part of fig. 2, by a relation between the distance from the Solar system to the radius of the universe: $distance\ (m - M) \simeq (radius - R_s) * 12.6\ [mag]$, a reasonable account of the supernovae data [4] is obtained, as shown by the dashed line in the lower part of fig. 2. The extracted radius $R_s = 5.2$ (arb. units) multiplied with the scale factor 12.6 as well as $(m - M)_{LMC} \sim 18.3$ (mag)[2] indicates that the Solar system has (presently) a distance from the center of the universe R_{sol} of about 1200 Mpc.

Here it should be stressed that from the same supernovae data a strong dark energy component has been deduced from cosmological model studies [6], which amounts to about 70 % of the total mass/energy of the universe. Such a larger source of unknown energy is difficult to understand. Indeed, in the present analysis a dark energy component is not needed. The observed accelerating expansion of the universe is entirely due to the gravitational potential (4), which falls off strongly towards large radii, leading to an exponential increase of the decay velocity.

4. Striking evidence for a bound state structure of the Solar system

An important and quite surprising result is that at the radius R_s both global velocity curves for decay and attraction cross each other (indicated in the figs. by vertical lines), with a sum velocity $(v/c)_{rep}(R_s) + (v/c)_{att}(R_s) = 0$. In

[2]for distance ladders the distance to the Large Magallanic Cloud (LMC) is taken as zero point.

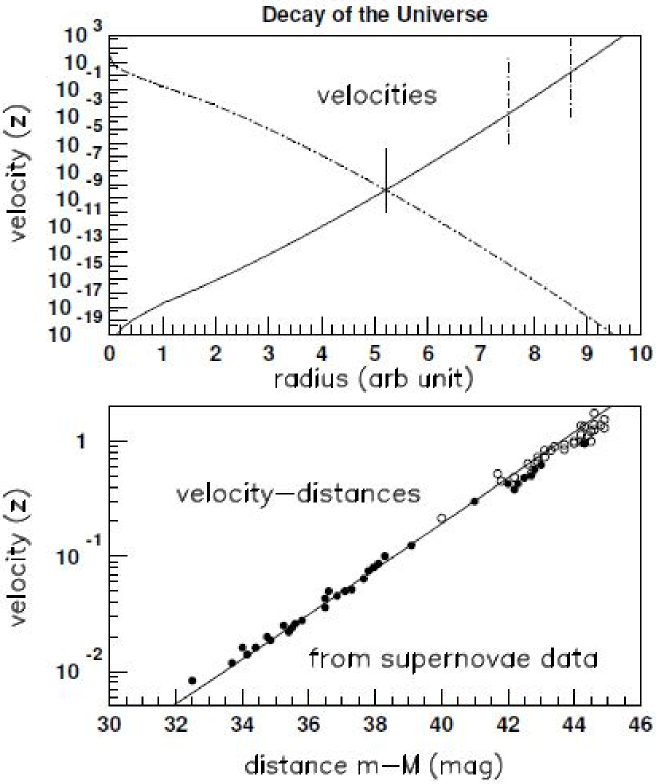

Figure 2: Upper part: Velocities for repulsive decay (solid line) and attraction (dot-dashed line) as a function of radius (in arbitrary units). Lower part: Calculated decay velocities as a function of distance in comparison with velocity-distances from supernovae observation [4]. New data at high redshift from ref. [11] are given by open points. The radii corresponding to the data limits of 30 and 46 mag are indicated in the upper part by vertical dot-dashed lines.

addition, the normalization factor N of the decay velocity matches the fall-off of the attractive gravitational potential. These two facts can be considered as an important boundary condition for a radially stabilized state in the gravitational field of the universe. Fig. 1 shows that this effect is observed in the potential densities (the repulsive potential density $(V\rho)_{rep}(r) = N^2[(|V_{2g}(r)| + |V_{3g}(r)|)\ \psi_s^2(r)]^{-1}$ is given in the upper part by dashed line) as well as in the acceleration terms (third part). The sum velocity in the lower part shows a pronounced cusp at 5.2 (arb. u.), which can be considered as a steep barrier for a system, for which appropriate boundary conditions are fulfilled.
Of large importance, the mass of such a bound state can be calculated from the absolute height of the gravitational potential in fig. 1. Using the relation $M = M_{tot}N^{-1}f_{con}$, where $M_{tot} = 0.9$ GeV/c^2, $N = 6.5\ 10^{-18}$ (consistent with the fall-off of the attractive potential) and f_{con} is the conversion factor from 1200 Mpc $\rightarrow$ 5.2 fm, a mass M in quantitative agreement with the Solar mass ($M_{sol} = 1.11574\ 10^{57}$ GeV/c^2) is obtained.
The slope of the fit in the lower part of fig. 2 is somewhat steeper than in the supernovae data. Since the supernovae data are taken from earth, a slightly better description can be obtained by inserting a smaller mass $M \sim M_{sol}/77$, $R_s = 4.8$ and a scale factor of 14.15 (instead of 12.6), leading to a radius $R_{sol} \sim 1240$ Mpc.
Also the acceleration term is canceled at a radius close to R_s (shown in fig. 1). Therefore, the Solar system can be considered as a very stable bound state, whereas other cosmic objects continue acceleration by loosing their complete binding energy.
Bound state conditions for systems of different masses are possible, even for galaxies of $M \sim 10^{12}\ M_{sol}$. However, one should realize that in a quantum theory the bound state spectrum should be discrete (see the structure of hadrons, leptons and atoms). This may explain why the observed supernovae (with masses not very different from the Solar system) are not stabilized in radius.
One might argue that at the time of expansion to large distances the attractive gravitational potential may not exist any more. However, the same potential $V_{2g}(r) + V_{3g}(r)$ is responsible for compression and subsequent decay. This

indicates that the gravitational field of the universe is extremely stable and can decay only after all constituents have left the system. But due to the above bound state conditions this possibility is prevented.

5. Conclusion

Within a fundamental bound state formalism of all elementary forces a consistent description of the development of the universe is obtained, in which the generation of mass and the matter-antimatter breaking is well understood.

The main results are:
1. The deduced decay velocity gives a good account of velocity-distance data deduced from supernovae Ia observations, by adjusting the distance of the Solar system to the center of the universe to $R_{sol} \sim 1200$ Mpc. A large attractive gravitational potential (as obtained here) is not included in cosmological models; therefore, to describe the correct decay velocities a large dark energy component had to be introduced artificially.

2. At $R_{sol} \sim 1200$ Mpc the attractive and repulsive forces cancel each other, giving rise to a boundary condition for a radially stabilized system. This is strongly supported by the deduced bound state mass, which is consistent with that of the Solar system. Similarly, other stars and galaxies may be regarded also as gravitational bound states.

3. Although it is well known that the Solar system is highly stabilized (with an enormous compactification into sun and high density planets, which have strongly cooled down during the last 10^9 years), it is nevertheless surprising that this property is predicted in the present quantum description of the universe. This system is definitively very different from non-stable systems, for which their binding energies decrease permanently until they disintegrate completely.
As a positive outlook, in spite of the expansion and escape of a large part of the universe to empty space, it is not unrealistic to assume that the Solar system is so well stabilized that live can continue its development for millions (billions) of years, until the fusion energy of the sun is ceasing.

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