Mass of the Universe from a Fundamental Quantum Description

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Abstract

Within a quantum theory, in which gravitation is described by magnetic binding of hadron-lepton pairs, the mechanisms responsible to the development of the universe are well understood. The Solar system has been found to be a stable bound state with a present distance from the center of the universe of about 1200 Mpc. Using this result, the effective radius of the universe, which comprises essentially all matter, is estimated to be about 1800 Mpc. The total mass is given by the accumulated mass, before the early gravitational system became destabilized by CP-violating processes. Consistent with the known energy-density of the universe of 5.31 GeV/m^3 a mass of about 4 10^{78} GeV/c^2 ($\sim$ 4 10^{21} Solar masses) is obtained.

Further, from the present temperature of the cosmic microwave background (CMB) of 2.73 K the annihilation radius is estimated to be in the sub-mm region. Combining average energy-density and CMB temperature, a maximum energy density of about 3 10^{91} GeV/m^3 is obtained.

Keywords: Fundamental Quantum Description of Gravity, Effective Radius And Mass of The Universe, Annihilation Radius And Maximum Energy Density.

Introduction

It has been always a big dream of mankind to understand the universe with its enormous size and mass, which hosts billions of stars and galaxies. Detailed star observations have been already made by the old high cultures in Mesopotamia, Egypt, and China, and in the middle ages, culminating in Newton's gravitational law. Significant progress in the understanding of the universe has been made only during the last century by intense astronomical and astrophysical research with modern techniques. One of the most exciting facts is that the universe has a dynamic structure; it has developed from a very small size during the Big Bang to the presently gigantic system of stars, galaxies, and intergalactic matter. A surprising result deduced from supernovae Ia observations [1, 2, 3] is that the expansion of the universe is accelerating, a big puzzle for cosmological interpretations.

Concerning the mechanisms responsible for the evolution of the universe, we can assume that elementary fermion-antifermion pairs emerged out of the vacuum (of fluctuating photons) and have been bound by fundamental forces to simple particles [4, 5]. By creation of these particles over long periods of time a huge mass has been accumulated, which decayed into protons, electrons and their antiparticles. By gravitation, (p^+e^-) pairs gave rise to matter contributions, whereas (p^-e^+) pairs resulted in antimatter. The generation of particles is matter-antimatter symmetric, but in the universe essentially matter is found only.

The breaking of the matter-antimatter symmetry has been explained as due to the chiral structure of gravitationally bound systems [5, 6]. Due to PC-violating processes matter could separate from antimatter[1]. Then antimatter was drawn to small radii, collapsed and annihilated to photon pairs (complete annihilation of $(p^\pm e^\mp)$ is possible in the present formalism [6], because $p^\pm$ and $e^\mp$ are composite particles of $(q^+q^-)^n q^\pm$ and $(q^+q^-)^n q^\mp$ structure,

[1] Originally one thought, that the matter/antimatter symmetry must be broken by PC-violation on the level of hadrons or leptons, but these effects are many orders of magnitude too small.

respectively, where q denotes a massless elementary fermion, "quanton"). Matter was first pushed to larger radii, but by changing rotation it has been also drawn to the center. During the Big Bang the annihilation photons (resulting from the collapse of antimatter) gave rise to a strong impact of the surrounding matter, resulting in strong heating, disintegration and decay (or expansion) to free space. At small radii the attractive gravitational field allowed only a slow decay velocity, but due to a decreasing attraction at larger distances this velocity could speed up drastically (this accelerating expansion has been verified in supernovae observations [1, 2] and is not understood by cosmological models, in which the gravitational field of the early universe has not been taken into consideration). In the above interpretation the observed photons in the universe in form of a cosmic microwave background (CMB) are due to annihilation photons, whose energy has been damped by multiple collisions with matter.

For a realistic understanding of these mechanisms a theoretical description is needed, in which the generation of mass, the breaking of the matter-antimatter symmetry, an explication of the Big Bang with subsequent decay of the universe, but also Newton's gravitational constant G_N can be understood. Such a framework has been developed during the last decade in form of a local quantum theory [4, 5, 6, 7], in which hadrons, leptons, atoms and gravitational systems are described in a consistent way as systems bound by electromagnetic forces. This theory couples to the vacuum and can explain the creation of particles out of the vacuum. The mass of all particle bound states is entirely given by binding and kinetic energies; further, **all** parameters of the theory are determined by severe boundary conditions, based on geometry, momentum and energy-momentum conservation. Of crucial importance, an acceleration term is found in this formalism [5], which gives rise to a natural description of the dynamics of gravitation.

In the present paper estimates of radii and the total mass of the universe are presented. These may be considered as a severe test of the mechanisms responsible for different states of development.

2. Relevant radius and total mass

An estimate of the effective radius of the universe can be obtained from the analysis [8] of velocity-distance data of supernovae observations [1, 2, 3] together with the fact that the Solar system can be considered as bound state with a present distance to the center of the universe of about 1200 Mpc. The bound state condition is given by the balance of the velocities of repulsion and attraction $(v/c)_{rep}(R_s) + (v/c)_{att}(R_s) = 0$. However, the dynamics of the decay gives rise to a velocity increase with time $\Delta(v/c)_{rep}$ - related also to a slightly larger distance $R_s + \Delta R$ from the center, but without effecting the bound state characteristics.

Within a similar picture the mass of the early universe can be estimated also from a bound state calculation with arbitrary slope parameter b, as discussed in refs. [5, 8]. This yields

$$M_{tot} = \frac{M_o\, f_{CP}}{f_{red}^3(R_{eff})} \ , \tag{1}$$

where M_o is the bound state mass and $f_{red}(R_{eff})$ the reduction of the potential density between $R = 0$ and the effective radius R_{eff}. In addition, we assume that the accumulation of mass was limited by CP-violating processes (which led to destabilization of the gravitational potential by chiral separation of matter and antimatter [5]). Therefore, in eq. (1) a CP-suppression factor f_{CP} is included.

CP-violating $K_2^o \to \pi^+\pi^-$ decay has been observed with a branching ratio B_r of 0.2±0.4 %. The factor f_{CP} may be given by $f_{CP} = f_{K_2^o}\ B_r\ f_{pe}$, where $f_{K_2^o}$ is the probability of $2(p^\pm e^\mp) \to K_2^o \bar{K}_2^o$ and f_{pe} the probability to get back from $\pi^\pm\pi^\mp \to p^\mp e^\pm$. Using for $f_{K_2^o}$ and f_{pe} probabilities of $\sim 10^{-3}$, this leads to $f_{CP} \sim 4\ 10^{-9}$. Further, CP-violating processes have been found in B-decays [9]. However, the corresponding branching ratios as well as creation and decay probabilities are much smaller, each by factors of 10 or more, indicating that their effect in the present mass estimate is negligible.

Using calculations with the same parameters as in ref. [8] (with $\tilde{m}$= 0.45, slope parameter b=0.6, κ=1.35, α=2.14) and f_{CP}= 4 10^{-9} yields a radial dependence of M_{tot} (in units of Solar masses, $M_{sol} = 1.11574\ 10^{57}$ GeV/c^2) given by the dot-dashed line in the upper part of fig. 1. There may be significant errors in the above estimate of f_{CP}. However, by assuming values of f_{CP} larger or smaller by a factor 10, only small changes of the radius of ±20 Mpc are found.

2.1 Mass estimate from the average energy density of the universe

A second mass estimate can be obtained from the energy density

$$M'_{tot} = \frac{4\pi}{3}\ \frac{(E\rho)^{av}}{c^2}\ R_{eff}^3\ . \tag{2}$$

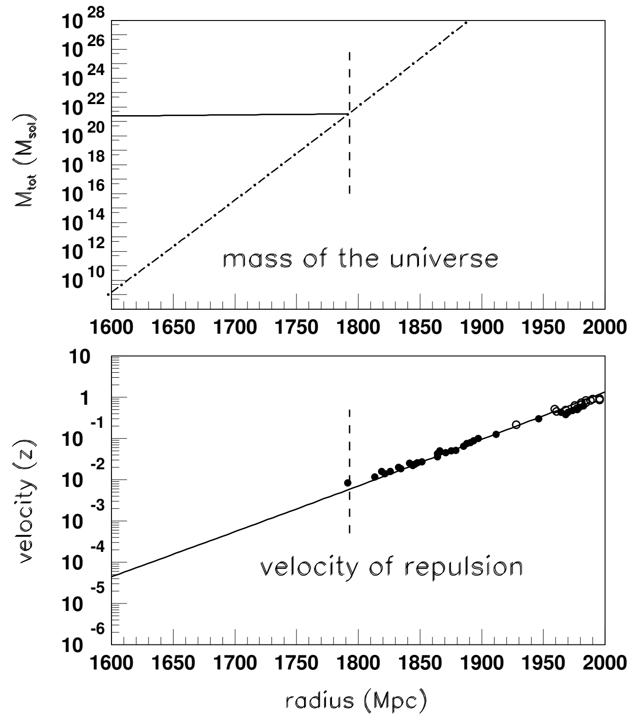

Figure 1: Upper part: Radius dependence of the calculated mass of the universe, assuming a CP-suppression factor $f_{CP} = 4\ 10^{-9}$ (dot-dashed line) in comparison with the mass deduced from the known energy density (solid line). Lower part: Radius dependence of the decay velocities in comparison with velocity-distance data from supernovae observation [1, 2]. The vertical lines indicate the effective radius R_{eff} at which the calculated gravitational mass matches that deduced from the energy density.

Using the known energy density $(E\rho)^{av} = 9.47\ 10^{-27}$ kg/ m^3, a total mass (again in units of Solar masses) is obtained as given by the solid line in the upper part of fig. 1. One can see that both mass estimates match for a radius of 1790 Mpc, given by the vertical dot-dashed lines. This yields a total mass of 3.8 10^{78} GeV/c^2 (corresponding to 3.4 10^{21} Solar masses).

Interestingly, at this radius the velocity of repulsion $(v/c)_{rep}$ is $< 10^{-2}$, which can be seen in the lower part of fig. 1 (taken from the analysis [8] of supernovae data). This shows that the total mass is dominated by matter of rather small kinetic energy (and not by large velocity components observed in the supernovae data), which may indicate that an appreciable fraction of the mass of the universe is due to bound states with limited kinetic energy, in agreement with the conclusions drawn in ref. [8]. This is supported by the fact that above 1800 Mpc a bound state condition $(v/c)_{rep} + (v/c)_{att} = 0$ may not be possible any more; the corresponding system would have a mass $> 10^{12} M_{sol}$, which exceeds the mass of observed galaxies. In addition, the estimated mass due to matter at high speed is more than a factor 10^{18} times smaller than the mass discussed above.

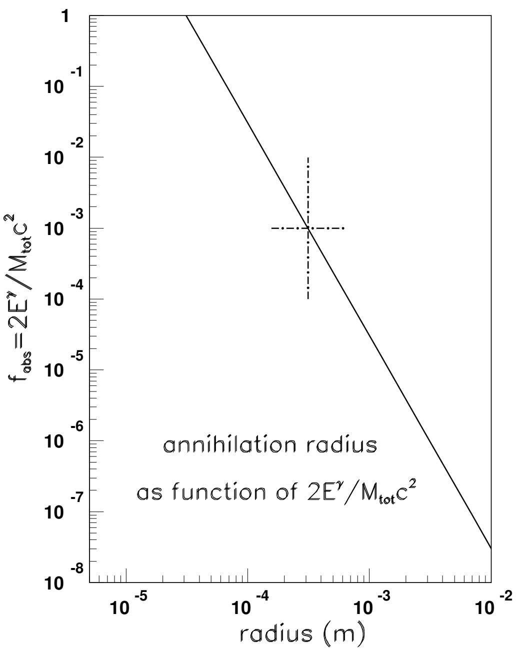

Figure 2: Photon radius R_{ann}, given by solid line as a function of the fraction of the total annihilation energy absorbed in the universe. The dot-dashed crossed lines indicate a radius of 3.16 10^{-4} m at $2E^{\gamma}/M_{tot}c^2 = 10^{-3}$.

3. Annihilation radius

One expects that at the time of annihilation of antimatter the radius of the collapsed antimatter had been very small. This radius can be deduced from the radius and mass, if in addition the cosmic microwave background radiation (CMB) is taken into account, for which a temperature of 2.73 K has been measured. The annihilation process yields two photons with an isotropic distribution, as confirmed experimentally. Using a kinetic energy given by $E_k = 3/2\ k_B\ T$, this yields $E_k = 3.53\ 10^{-4}$ eV.

The photon energy may be given by $E^{\gamma} = E_k\ S_{ann}^3$, where $S_{ann} = R_{eff}/R_{ann}$ and R_{ann} is the annihilation radius. This leads to

$$R_{ann} = R_{eff}\ [\frac{E_k}{E^{\gamma}}]^{1/3}\ . \tag{3}$$

By replacing E^{γ} by the fraction of the photon energy $f_{abs} = 2E^{\gamma}/M_{tot}c^2$, this relation is shown by the solid line in fig. 2, which indicates that from the onset of annihilation (of antimatter) - which could be a factor of 10 larger than the minimum of R_{ann} - the energy E^{γ} increases up to $\frac{1}{2}M_{tot}c^2$. For $f_{abs} = 1$ a minimum annihilation radius of 3.16 10^{-5} m is obtained. The corresponding energy density is given by

$$(E\rho)_{ann} = M_{tot}c^2/(\frac{4\pi}{3}\ R_{ann}^3)\ , \tag{4}$$

which yields a maximum value of $(E\rho)_{ann} = 2.9\ 10^{91}$ GeV/m^3.

As an interesting consequence, this result allows a new (and more realistic) estimate of the electron radius, which is known to be unmeasurably small. In the $e^-e^+ \rightarrow 2\gamma$ reaction the annihilation energy is 1.02 MeV. Assuming for this system the same energy density for annihilation $E\rho = 3E_{2\gamma}/(4\pi\ R_{2e}^3)$ of 2.9 10^{91} GeV/m^3 (where R_{2e} is the root mean square radius of the e^-e^+ pair), we obtain $R_{2e} \sim 2\ 10^{-17}$ fm. If the critical energy density for annihilation would be a factor 10^3 smaller, $R_{2e} \sim 2\ 10^{-16}$ fm is obtained. With both estimates the root mean square radius is well below $\sim 4\ 10^{-10}$ fm assumed before [6].

4. Energy density from annihilation and gravitational matter, error estimates

One can formulate another relation for the energy density

$$(E\rho)'_{ann} = (E\rho)_{av}\ (\frac{R_{eff}}{R_{ann}})^3\ . \tag{5}$$

In this expression annihilation is related only to the average density of the universe, connecting experimental information from CMB temperature and mean density. The maximum value of $(E\rho)'_{ann}$ of 2.9 10^{91} GeV is the same as extracted from eq. (4), showing again the close relationship between mass and radius of the universe and the radius of annihilation.

Concerning the uncertainties of the different quantities, errors in the known mean energy density and the CMB temperature are small and have not been considered. For the mass estimate, we relied on the fact that the radial coordinate is very well tuned by the description of supernovae data, see ref. [8], in which the distance equal to zero is related to the bound state radius of the Solar system in the universe. Since in the present formalism the bound state is given entirely by its mass and radius (the mass is known), a radius of 1200 Mpc with a very small error of $\sim \pm 40$ Mpc is estimated. This yields $\delta R_1 \sim \pm 60$ Mpc at 1800 Mpc and an error δM_{tot} of about ± 10 %. A further radius error δR_2 of ± 20 Mpc is due to uncertainties in the CP-violation factor f_{CP} (see sect. 2). However, in the mass estimate this uncertainty is compensated to a large extent by the matching of M_{tot} in eqs. (1) and (2), adding not more than ± 4 % to δM_{tot}.

Interestingly, the errors in R_{ann} cancel each other essentially, leading to $\delta(E\rho)_{ann} \sim \delta M_{tot} \leq \pm 15$ %. This indicates that the order of magnitude of the deduced quantities is well extracted.

5. Summary

From a fundamental bound state description an estimate of the mass of the universe is presented, assuming that in the early phase of the universe a gigantic gravitational potential has been accumulated, which destabilized by CP-violating processes. The agreement with the known energy density confirms the validity of the assumed mechanisms.

For this mass estimate an effective radius of about 1800 Mpc is used, at which the decay velocity is still rather small, $(v/c)_{rep} < 10^{-2}$. This could indicate that an appreciable fraction of matter exists in form of bound states with rather limited kinetic energies. The radial limit of 1800 Mpc may indicate a break down of the boundary condition for stable bound states (this is supported by the fact that galaxies with masses larger than 10^{12} Solar masses are not found).

Finally, by taking the cosmic microwave background (CMB) radiation into account, a tiny annihilation radius in the sub-mm range is obtained. The comparison with $e^+e^- \rightarrow 2\gamma$ annihilation shows that a similar energy density of annihilation is needed. This is expected and reveals the strong links between macroscopic and microscopic systems in the present formalism.

The author thanks B. Loiseau for discussions and the reading of the manuscript.

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