A Possible Solution to Cosmic Baryon Excess Problem in the Universe

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Abstract. Here, it is shown that curvature induced riccions and riccinos being very heavy decayed to spinless mesons and nucleons respectively in the early universe. Due to this phenomenon baryons over-powered, as anti-baryons were not produced. Thus, it provides a solution to baryon excess problem.

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1. Introduction :

Our universe observes abundance of matter over anti-matter. The ratio of anti-matter and matter, in cosmic rays, is 10^{-4} . Presence of X-rays, which could have occurred due to annihilation of matter and anti-matter, is not observed in the universe. Moreover, existence of stars, planets, gas clouds and galaxies show that our universe is made of matter and not of anti-matter. Barring dark energy, dark matter and radiation, the rest of cosmic matter is made up of baryons. So, the problem of excess of visible matter in the universe is the problem to find out the source of baryon excess.

According to the standard cosmological scenario, particles and their anti-particles were produced in equal number at the epoch of big-bang. This raises a natural question "Why do we observe baryon-anti-baryon asymmetry in the universe upto the extent that anti-matter is almost extinct ?". It compels cosmologists to think for some source of matter other than the big-bang. From time to time, such attempts have been made in the past in the context of grand unified and other theories, but without producing a satisfactory solution.

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Space-time curvature has a crucial role in cosmic evolution. So, it is reasonable to think that possibly curvature, itself, might have caused this asymmetry in the early universe. In what follows, a solution to this problem is probed in the context of this possibility.

During last few years, higher-dimensional gravity appeared as a popular theory in the context of string / M-theory, inspired brane-gravity as it provides a solution to the hierarchy problem, lowering down the fundamental scale from Planck level [1]. Before advent of brane-gravity, Kaluza-Klein type of higher-dimensional gravity, with compact extra space, had been a strong candidate. Moreover, higher-derivative gravity also became important in the context of renormalization of gravity, though it faces unitarity problem if gravitons given by metric tensor components are quantized. Here, quantization aspect is not considered and at classical level, it is found that singularity problem does not arise if coupling constants in the higher-dimensional higher- derivative gravity are taken properly as first noted in [2]. In what follows, it is obtained that higher-derivative gravity, in higher dimensional space time can provide a possible answer to baryon-antibaryon asymmetry in the universe.

2. Main Results :

Like [3], here Kaluza. Klein type higher-dimensional theory is used having topology of space-time, given by $M^4 \otimes T^D$, with M^4 being 4-dimensional curved space-time and T^D being D-dimensional torus (extra compact manifold). So, the (4+D)-dimensional space-time is given as

$$ds^2_{(4+D)} = g_{\mu\nu}dx^\mu dx^\nu - \rho_1^2 d\theta_1^2 - \rho_2^2 d\theta_2^2 - \cdots - \rho_D^2 d\theta_D^2 \qquad (1)$$

where $\rho_1, \rho_2, \ldots, \rho_D$ are radii of different circles making T^D as $T^D = S^1 \otimes S^2 \otimes \ldots D$ times, $0 \leq \theta_1 \ldots \theta_D \leq 2\pi$, greek letters $\mu, \nu = , 1, 2, 3, \ldots, m, n = 0, 1, 2, 3, \ldots, (3+D)$, and $g_{\mu\nu}$ are metric tensor components in M^4. Here natural units ($h = c = k_B = 1$, with symbols having their standard meaning) are used with GeV being the fundamental unit. The gravitational action is taken as

$$S = \int d^4x d^D y \sqrt{|g(4+D)|} \left[\frac{R_{(4+D)}}{16\pi G_{(4+D)}} + \bar{\alpha} R^2_{(4+D)} + \bar{\beta} \Box_{(4+D)} R_{(4+D)} \right] \qquad (2)$$

where $R_{(4+D)} = R + R_D = R$ as $R_D = 0$ for T^D with R being the Ricci scalar in $M^4, \bar{\alpha} = \alpha/(2\pi)^D \rho_1 \ldots \rho_D$ and, $\beta = /(2\pi)^D \rho_1 \ldots \rho_D$ are coupling constants with mass

dimension D as well as

$$G_{(4+D)} = (2\pi)^D \rho_1 \ldots \rho_D G_N \tag{3}$$

with $G_N = M_P^{-2}$ and $M_P = 10^{19} GeV$.

Moreover

$$\Box_{(4+D)} = \frac{1}{\sqrt{|g(4+D)|}} \left[\sqrt{|g(4+D)|} g^{mn} \frac{\partial}{\partial x^n} \right], \tag{4}$$

Invariance of S, with respect to $g_{mn} \to g_{mn} + \delta g_{mn}$ yield gravitational field equations:

$$\frac{R_{(4+D)}}{16\pi G_{(4+D)}} \left[R_{mn} - \frac{1}{2} g_{mn} R_{(4+D)} \right]$$

$$+ \bar{\alpha} \left[2R_{(4+D);mn} - 2g_{mn} \Box_{(4+d)} R(4+D) - \frac{1}{2} g_{mn} R_{(4+D)}^2 + 2R_{mn} R_{(4+D)} \right]$$

$$+ \bar{\beta} \left[\Box_{(4+D)} R_{(4+D)} - \frac{1}{2} g_{mn} \Box(4+D) R_{(4+D)} \right] = 0 \tag{5}$$

Taking trace of equations (5) and using $R_{(4+D)} = R$ (given above), it is obtained that

$$\Box R + \lambda R^2 + m^2 R = 0, \tag{6a}$$

where $\Box$ is the operator defined in M^4 as,

$$\Box = \frac{1}{\sqrt{|-g_4|}} \frac{\partial}{\partial x^\mu} \left[\sqrt{|-g_4|} g^{\mu\nu} \frac{\partial}{\partial x^\nu} \right], \tag{6b}$$

$$\lambda = \frac{D\alpha}{[4(D+3)\alpha + (D+2)\beta]}, \tag{6c}$$

$$and \qquad m = \left\{ \frac{(D+2)M_p^2}{16\pi[4(D+3)\alpha + (D+2)\beta]} \right\}^{1/2}. \tag{6d}$$

For dimensional correction (6a) is multiplied by η being a constant with $(\text{mass})^{-1}$ dimension and ηR is recognized as $\tilde{R}$ namely riccion [4]. Thus, (6a) is re-written as

$$\Box \tilde{R} + \lambda R \tilde{R} + m^2 \tilde{R} = 0, \tag{7}$$

showing that $\tilde{R}$ behaves like a spinless physical field satisfying Klein-Gordon equation with non-minimal coupling λ and mass m given by (6c) and (6d) respectively.

At this stage, to avoid a confusion in reader's mind, it is important to remark that riccion is different from (scalar mode of graviton), as for graviton $\lambda = 0 = m^2$, but for riccion $m^2 \neq 0$ with λ vanishing as well as non-vanishing.

In case $\lambda = \frac{1}{4}$ i.e $(D+2) = -12\alpha/\beta$ giving $D = 6$ for $= -\frac{3}{2}$ and $D = 1$ for $= -4$ taking $\alpha = 1$ without harming the theory, (7) is factorized as [3, for details]

$$\bar{\Psi}[\gamma^\mu \nabla_\mu - im][\gamma^\nu \nabla_\mu + im]\Psi = 0 \tag{8}$$

(with $i = \sqrt{-1}$) provided that

$$\nabla_\mu \nabla_\nu \bar{\Psi} \gamma^\mu \gamma^\nu \Psi = 0. \tag{9}$$

Here the scalar $\tilde{R}$ is envisaged as $\bar{\Psi}\Psi$ (with Ψ being the dirac spinor, $\bar{\Psi} = \Psi^\dagger \gamma^0$ and $\Psi^\dagger$ being hermitan conjugate of Ψ). Dirac matrices γ^μ, in curved space-time M^4, obey the condition

$$\{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}$$

where $\gamma^\mu = e_a^\mu \bar{\gamma}^a$ with $\{\tilde{\gamma}^a, \tilde{\gamma}^b\} = 2\eta^{ab}$, $g^{\mu\nu} = e_a^\nu e_b^\nu \eta^{ab}$ and η^{ab} being 4 dimensional Minkowskian metric components.

Moreover

$$\nabla_\mu = \partial_\mu + \frac{1}{4} \left(\partial_\mu e_a^\rho + \Gamma^\rho_{\sigma\mu} e_a^\sigma \right) g_{\nu\rho} e_b^\nu \tilde{\gamma}^{\,b} \tilde{\gamma}^{\,a} \tag{10}$$

The condition (9) can be expressed as

$$\nabla_\mu \nabla_\nu \bar{\Psi}_L \gamma^\mu \gamma^\nu \Psi_R = -\nabla_\mu \nabla_\nu \bar{\Psi}_R \gamma^\mu \gamma^\nu \Psi_L \tag{11}$$

with $\Psi_{L,R} = [(1 \pm \tilde{\gamma}^{\,5})/2]\Psi$ and $\tilde{\gamma}^{\,5} = i\tilde{\gamma}^{\,0}\tilde{\gamma}^{\,1}\tilde{\gamma}^{\,2}\tilde{\gamma}^{\,3}$, (11) shows breaking of left-right symmetry. Here Ψ is called riccino as in [3,4]. Thus, is it obtained that, in case $\lambda = \frac{1}{4}$ and parity is voilated, higher-dimensional higher-derivative gravity gives riccinos, which are electrically neutral spin $-\frac{1}{2}$ particles like riccions. So, their anti-particles are same as particles like photons and anti-photons, neutrons and anti-neutrons and others. Having equal mass, riccions and riccinos are super-partners.

As superstrings support 10-dimensional space-time, here $D = 6$ is taken. So, from (6c),

$$m = 8.14 \times 10^{17} GeV. \tag{12}$$

It shows that riccions and riccinos are very heavy particles produced, from the gravitational sector, in the early universe, where curvature was high enough and cosmic evolution was fast. These exotic particles could not be stable below temperature $10^{17} GeV$. Moreover, for $T < 10^{17} GeV$, number of these particles decrease by the factor $\tilde{e}^{m/T}$ being non-relativistic [5]. A strong possibility for decrease of number of these particles is decay of these to known particles, being very light comparative to these particles.

3. Concluding Remarks :

It is reasonable to think that spinless riccions decayed to spinless mesons and riccions decayed as

$$\Psi \longrightarrow n(neutron) + \gamma(photon). \tag{13}$$

$$\Psi \longrightarrow p(proton) + \bar{e}(electron) + \gamma(photon). \tag{14}$$

Reverse of these reactions are not possible as riccinos are not in thermal equilibrium with these particles below $10^{17}GeV$. When temperature came down below $10^{-3}GeV$, evolution of universe continued like standard big-bang theory with recently observed acceleration in the late universe [6]. Also we conclude that one riccino can yield $\sim 10^{17}$ protons or neutrons as these have mass $\sim 1GeV$. This scenario is different in the sense that it shows heavy production of baryons in the early universe. So, it provides a possible solution to baryon excess problem emerging from gravitation itself, if this phenomenon is true which can be decided by experiments.

References

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