Matter Creation from Dynamical Dark Energy

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The 'quantum/classical connection', a set of equations found in an analysis of dynamical vacuum energy, maps: the age of the universe at the onset of inflation onto the GUT scale, the age at nucleosynthesis onto the mass scale of light nuclei, the age at the onset of recombination onto the mass of the electron and the age at the onset of the accelerating expansion of the universe onto a mass scale of 7 keV—the mass of a dark matter candidate. The analysis suggests that as the universe expands and the vacuum (dark) energy density reduces, a particle emerges from the vacuum when the Hubble radius surpasses the length scale that maps onto the mass of the particle. When the Hubble radius maps onto, in turn, the weak, QCD, electromagnetic and 7 keV scales, the value of the dark energy density takes specific values that have a binary basis.

1. Introduction

In the Planck Model, the dark energy density is a dynamic quantity of equal numerical value (in Planck units: ħ = c = G = 1) to the zero-point energy in an $AdS_5 \times S^5$ spacetime [1]. As the universe expands, the dark energy density scales in inverse proportion to the increasing volume of the S^5. As time has progressed since t = 0 the dark energy density has reduced by 123 orders of magnitude. Its present value suggests that the current radius of the S^5 closely approximates to the Bohr radius. At the same time, the dark energy density closely approximates to the inverse square of the radius of the observable universe [2]. The *quantum/classical connection*, a set of equations that correlate quantum and classical scales, generalises the correspondence between the Bohr radius and the radius of the observable universe, mapping 'quantum' length and mass/energy scales onto 'classical' length and mass/energy scales, and vice versa [3, 4, 5, 6, 7, 8, 9].

The quantum/classical connection will be used to calculate the mass scale corresponding to the age of the universe when, in turn, inflation, nucleosynthesis, recombination and the acceleration of expansion occurred.

Values, in Planck units, of the dynamical dark energy density will be calculated from the age of the universe corresponding, through the quantum/classical connection, to key mass/energy scales.

2. The Quantum/Classical Connection

First, the present value of dark energy density ρ_Λ will be calculated.

In the Λ-CDM model of cosmology, ρ_Λ for a flat universe is given by

$$\rho_\Lambda = \Omega_\Lambda \cdot \frac{3{H_0}^2}{8\pi G} \tag{1}$$

where Ω_Λ is the dark energy density parameter and H_0 is the Hubble constant. Results from the Planck mission (Ω_Λ = 0.692 ± 12, H_0 = 67.8 ± 0.9 km s^{-1} Mpc^{-1} [10]) suggest that ρ_Λ= 1.16 ± 0.03 × 10^{-123} Planck units. A larger value of H_0 (73.24 ± 1.74 km s^{-1} Mpc^{-1}) has been found by Riess et al from HST observations of Cepheid variables and the measurement of redshifts and distances [11]. This second value of H_0, together with Ω_Λ = 0.692 ± 0.012, suggests that ρ_Λ= 1.35 ± 0.5 × 10^{-123} Planck units.

In the Planck Model, ρ_Λ is calculated in two ways. In an $AdS_5 \times S^5$ spacetime, the zero-point energy density immediately before the Big Bang was ½ in Planck units, there being radiation of Planck wavelength alone. As the universe has expanded, the vacuum energy density has decreased in inverse proportion to the volume of the S^5. At the scale of the Bohr radius a_0 = 0.529 × 10^{-10} m, the dark energy density $\rho_\Lambda = {a_0}^{-5}/2$ has the value 1.33 × 10^{-123} Planck units. In four dimensions, at the scale of the radius r_{OU} = 14.3 Gpc of the observable universe [12], one finds that ${r_{OU}}^{-2}$ = 1.34 × 10^{-123} Planck units. We see that, numerically,

$$2{a_0}^5 = {r_{OU}}^2 \tag{2}$$

Generalising, the quantum/classical connection correlates 'quantum' length scales l_Q and mass/energy scales m_Q $(= 1/l_Q)$ with 'classical' length scales l_C and mass/energy scales m_C $(> m_P)$:

$$2{l_Q}^5 = {l_C}^2 \tag{3}$$

$$2{m_Q}^{-5} = {l_C}^2 \tag{4}$$

$$2{l_Q}^5 = {m_C}^2 \tag{5}$$

$$2{m_Q}^{-5} = {m_C}^2 \tag{6}$$

In (3), with $l_Q = a_0$, we have found that $l_C = r_{OU}$. Since $a_0 = (\pi/2)^{125}\, l_P$ [13], it follows that $r_{OU} = [2.(\pi/2)^{625}]^{½}\, l_P$, which is of value 14.36 Gpc. Integer powers of $(\pi/2)^{25}$ occur repeatedly in the Planck Model [14]. Integer powers of 2^{25} occur in this work.

Equations (5) and (6) have been used in the analysis of astrophysical objects [5, 6, 8, 9].

3. Mass/Energy Scales of the Expanding Universe

We now calculate mass/energy scales corresponding, through the quantum/classical connection, to the Hubble radius at stages during the expansion of the universe. We assume that the Hubble radius c/H = ct, where H is the Hubble parameter and t is the age of the universe. The mass/energy scales calculated from (4) for four stages during the expansion of the universe are shown in Table 1.

Stage	Age of the Universe	Mass/energy scale calculated from the quantum/classical connection
Inflation	~10^{-36} s	2×10^{16} GeV; ~GUT scale
Nucleosynthesis	~10 – 100 s	4 – 10 GeV; mass scales of light nuclei
Recombination	~250 kyr	0.5 MeV; ~electron mass
Accelerating expansion	~9.8 Gyr	7 keV; ~mass of a dark matter candidate [15, 16]

Table 1: Mass/energy scales correlated, through the quantum/classical connection, with the age of the universe at which various processes occurred

Recombination, in which ions and electrons combine, occurred when the Hubble radius surpassed the length scale that maps onto the mass of the electron.

Like the fundamental particles, and astrophysical objects, nuclei occupy the mass levels of the Planck sequences [17]. The era of nucleosynthesis occurred when the Hubble radius surpassed the length scales that map onto the mass scales of light nuclei.

Inflation occurred when the Hubble radius surpassed the length scale that maps onto the GUT scale of 2×10^{16} GeV.

Accelerating expansion occurred when the Hubble radius surpassed the length scale that maps onto the mass scale of 7 keV. This is the mass of a particle—a dark matter candidate—that could explain the 3.5 keV line in inner-galactic X-ray spectra [15, 16].

4. The Dynamical Dark Energy Density

We have seen that, in Planck units, the dark energy density closely approximates to the inverse square of the radius of the observable universe:

$$\rho_\Lambda \sim r_{OU}^{-2} \tag{7}$$

At present, the radius of the observable universe (14.3 Gpc) is ~ 3.4 times the Hubble radius, r_H, of the model (13.8 Glyr). Noting that $(4\pi)^{½}$ ~ 3.5, we write

$$\left(\frac{r_{OU}}{r_H}\right)^2 \sim 4\pi \tag{8}$$

From (7) and (8),

$$\rho_\Lambda \sim (4\pi r_H^2)^{-1} \tag{9}$$

and therefore

$$\rho_\Lambda \sim A_H^{-1} \tag{10}$$

where A_H is the area of the Hubble sphere. We see that the dark energy density is encoded on the surface of the Hubble sphere in a manifestation of the holographic conjecture. This result suggests that (8) is always valid.

From (9), since the cosmological constant $\Lambda = 8\pi\rho_\Lambda$, we can write

$$\Lambda \sim \frac{2}{r_H^2} \tag{11}$$

and therefore

$$\Lambda \sim \frac{2}{t^2} \tag{12}$$

where t is the age of the universe.[1] We can infer the relationship between the mass m_V of a particle and the value of the dark energy density when the particle was created from the vacuum. From (4), with $l_C = r_H$,

$$2m_V^{-5} = r_H^2 \tag{13}$$

From (9) and (13),

$$m_V^5 = 8\pi\rho_\Lambda \tag{14}$$

and therefore

$$m_V^5 = \Lambda \tag{15}$$

[1] $r_H = t$ in Planck units

5. The Hubble Sphere and the Mass/Energy Scales of Physics

Motivated by the results of work on Bekenstein-Hawking entropy [18, 19], here we hypothesise that the area of the Hubble sphere takes values $k.2^N$, where k is a constant and N is an integer, when the Hubble radius maps, by way of the quantum/classical connection, onto key mass/energy scales m_S. It is expedient to work with the dual equations:

$$m_S{}^{-5} = 2\pi.2^N \qquad (16)$$

$$r_H{}^2 = 4\pi.2^N \qquad (17)$$

where m_S maps onto r_H, as in (4).

Consider the weak scale (taken to be the Higgs field vacuum expectation value of 246 GeV), the QCD scale (200–250 MeV; taken to be 225 MeV), the electromagnetic scale of 6.8 eV (equal to the electron-positron (positronium) ground state binding energy) and a hypothetical dark matter scale of 7 keV.

Values of N calculated from (16) for the above scales are shown in Table 2. Each value of N is a multiple of 25.

Scale	Value	N
Weak	246 GeV	274.7
QCD	225 MeV	325.1
Dark Matter	7 keV	400.0
Electromagnetic	6.8 eV	450.0

Table 2: Values of N calculated from (16) for key scales

New physics may be associated with a scale of 7.5 TeV, for which N = 250.0.

From (16) and (17), we see that key scales are correlated with specific values of $r_H{}^2$ and therefore with the area, $A_H = 4\pi r_H{}^2$, of the Hubble sphere. From (17), when the Hubble radius maps onto key mass/energy scales,

$$A_H = 16\pi^2.2^N \qquad (18)$$

where N is a multiple of 25.

At present, in a universe 13.799 ± 0.021 Gyr old [10], N = 401.008 ± 0.003. The area of the Hubble sphere has doubled since the conjectured 7 keV particle was created and the accelerating phase of expansion initiated.

6. Discussion

By way of the quantum/classical connection, the masses of light nuclei map onto the Hubble radius at the time of nucleosynthesis and the mass of the electron maps onto the Hubble radius at the time recombination initiated. It seems that the 'era of nucleosynthesis' coincided with the emergence from the vacuum of nuclei, and the process of recombination took place following the emergence from the vacuum of the electron. On this basis, the quantum/classical connection between the GUT scale and the time at which inflation occurred suggests that inflation followed the creation of a GUT-scale particle: the inflaton. Similarly, an accelerating phase of expansion followed the creation of a 7 keV particle.

The results suggest that a particle is created when the Hubble radius surpasses the length that maps onto the mass, m_V, of the particle. This occurs when the dynamic vacuum energy density, ρ_Λ, falls below $m_V{}^5/8\pi$ (and Λ falls below $m_V{}^5$). Since particle masses depend on the geometry of the higher-dimensional spacetime and on symmetry [14], the particle essentially awaits its emergence from the vacuum until the vacuum energy density has fallen sufficiently.

The surface area of the Hubble sphere—a store of information—has a binary basis. The area has been found to take specific values ($16\pi^2.2^N$, where N is a multiple of 25) when the Hubble radius maps onto key mass/energy scales.

7. References

1. B. F. Riley, The cosmological constant from $AdS_5 \times S^5$, viXra:1307.0107
2. B. F. Riley, The cosmological constant from a distant boundary, viXra:1502.0017
3. B. F. Riley, 10D/4D correspondence and the Big Bang, viXra:1503.0104
4. B. F. Riley, Dark energy, dark matter and the accelerating expansion of space, viXra:1503.0185
5. B. F. Riley, The black hole as a trans-Planckian particle, viXra:1505.0084
6. B. F. Riley, Planets and their moons as trans-Planckian bodies, viXra:1508.0167
7. B. F. Riley, Atomic, nuclear and gravitational binding energy in a unified model, viXra:1509.0001
8. B. F. Riley, Particles as the analogues of black holes, viXra:1511.0127
9. B. F. Riley, The correlation between stellar radii and the masses of stable atomic nuclei, viXra:1704.0049
10. Planck Collaboration, Planck 2015 Results. XIII. Cosmological Parameters, arXiv:1502.01589; Astronomy & Astrophysics 594, A13 (2016)
11. A. G. Riess et al, A 2.4% Determination of the Local Value of the Hubble Constant, arXiv:1604.01424
12. J. R. Gott III et al, A Map of the Universe, arXiv:astro-ph/0310571; Astrophys. J. 624:463, 2005
13. B. F. Riley, The scales of atomic and particle physics in relation to Planck scale, viXra:1305.0061
14. B. F. Riley, The Planck Model, viXra:1311.0053
15. E. Bulbul et al, Detection of an unidentified emission line in the stacked X-ray spectrum of galaxy clusters, arXiv:1402.2301v1
16. A. Boyarsky et al, An unidentified line in X-ray spectra of the Andromeda galaxy and Perseus galaxy cluster, arXiv:1402.4119v1
17. B. F. Riley, Particle mass levels, viXra:0909.0006
18. B. F. Riley, Bekenstein-Hawking entropy from holography, viXra:1602.0305
19. B. F. Riley, The dual nature of Bekenstein-Hawking entropy, viXra:1607.0379