

The Origin of Wave-particle Duality

ABSTRACT

We present a basic model for the formation of a stress-free Universe, which shows that its formation gives rise to a wave and particle mass, which together characterize the Universe. In this model a decaying exponential expansion rate is responsible for the particle mass (M_P) and a growing exponential expansion rate is responsible for the wave mass (M_W). The evolution of the Universe is governed by the ratio ($\alpha = M_P/M_W$) in which $\alpha = K_0/c$ where K_0 is the initial expansion rate and c is the velocity of light. In a stress-free expansion process, $0 \leq \alpha \leq 1/2$, the mass ratio, $M_P/M_W = \alpha$. The mass of the Universe, $M = M_W + M_P$, in which it is found from the exponential model that $M_W = m_0 c T / \ln(1/\alpha)$ where T is the age of the Universe and $m_0 = c^2/G$ where G is the universal gravitational constant. Observations of the mass and age of the Universe, yield, $\alpha = 0.235$, and hence $M_P / M = 0.19$. This ratio is very close to the ratio of ordinary matter to dark matter of 0.18 in [4]. Hence, the wave mass, M_W , can be interpreted as the dark matter remaining after the formation of the particle matter. The analysis also shows that on time scales (t_0) much less than the age of the Universe (T), $M_P(t_0) / M_W(t_0) \rightarrow 1$, which is an exact wave-particle duality.

Keywords: *net-zero stress, evolution of the Universe, wave-particle duality.*

1. INTRODUCTION

The concept of wave-particle duality is a central topic in modern theoretical physics, which was originated by endeavours to obtain an understanding of the properties of light [1]. In this paper, we place the concept directly in a cosmological framework on the time scale of the Universe, rather than the Nano-scale of particle physics, and show theoretically how duality is at the centre of an understanding of the Universe.

The governing process in the expansion of the Universe is the formation of ordinary matter from dark matter. This process is not just conceptual, but rather it can be precisely expressed through an analysis based on Newtonian physics, which leads to theoretical predictions, which can be tested by observational data.

The application of the theoretical model, which makes use of observational data for the age and mass of the Universe to predict the radius of the Universe, is based on a stress-free dynamical model of the astrophysics. The results follow on from work in four previous papers, [2],[3],[4] and [5], which have focused on the properties of the stress-free model.

In section 2, we present the theoretical results while section 3 reviews the data on the age and mass of the Universe. This section shows that the results of the theoretical model are consistent with a stress-free expansion process for the Universe. It predicts the radius of the Universe to be $4.7 \cdot 10^{26}$ km, which is similar to observational estimates.

In addition, wave-particle duality is the main property of the analysis, which predicts that the ratio of the particle mass to the wave mass in the Universe is 0.235. On time scales much less than that of the Universe, however, the theoretical analysis predicts that an exact wave-particle duality occurs.

Finally, section 4 concludes our discussion by presenting the results of the study in a wider context, in particular with regard to the ratio of ordinary matter to dark matter.

2. THE MASS OF THE EVOLVING UNIVERSE

2.1 The Growing Exponential Expansion Rate

In a stress-free model of the Universe, the evolving Universe expands at the homogeneous rate,

$$dR/dt_R = K(t_0), \quad 0 \leq t_0 \leq \infty \quad (1)$$

where $K(t_0)$ is the homogenous expansion rate [5] in which t_0 is the absolute time, and t_R is the local time at the radius (R). We investigate the solution of (1) for a *growing* exponential rate,

$$K(t_0) = K_0 \exp(\lambda t_0) \quad (2)$$

where $\lambda > 0$, and K_0 is the expansion rate at the origin of time ($t_0 = 0$). On expressing the local time (t_R) which occurs in a Universe of radius (R), in terms of the absolute time (t_0) using the fundamental time relation,

$$t_R = t_0 + R/c \quad (3)$$

where c is the velocity of light, we obtain for a growing exponential rate, as in Equation 5 for a decaying exponential rate,

$$dR/dt_0 = K_0 \exp(\lambda t_0) / (1 - \alpha) \quad (4)$$

where $\alpha = K_0/c$. Thus, on differentiating the defining relation for mass, $M_W = m_0 R$ where M_W is the wavemass of the expanding Universe, and $m_0 = c^2/G$, in which G is the universal gravitational constant [4]. Integrating Equation 4 with respect to and on t_0 assuming that $R = 0$ at $t_0 = 0$, we obtain,

$$M_W(t_0) = m_0 K_0 (\exp \lambda t_0 - 1) / [\lambda (1 - \alpha)], 0 \leq t_0 \leq t_1 \quad (5)$$

At the radius ($R_1 \equiv R(t_1)$), $t_0 = t_1$ the ratio of the expansion rate ($K(t_1)$) to the velocity of light (c) is unity, from which on evaluating (5) at $t_0 = t_1$, using (2), we have $\exp(\lambda t_1) - 1 = (1 - \alpha)/\alpha$, and hence,

$$R_1 = c / \lambda \quad (6)$$

and,

$$T = \lambda^{-1} \ln(1/\alpha) \quad (7)$$

in which $T \equiv t_1$ is the age of the Universe, and from (7), the wavemass of the Universe, is,

$$M_W = m_0 c T / \ln(1/\alpha) \quad (8)$$

where $M_W \equiv M_W(t_1)$, which is independent of λ .

2.2 The Decaying Exponential Expansion Rate

The model in Section 2.1 is only half the story. The other half of the story was originally investigated in Equation 5, in which instead of a growing exponential rate at $t_0 \geq 0$, the decaying exponential rate,

$$K(t_0) = K_0 \exp(-\lambda t_0) \quad (9)$$

where $\lambda > 0$ was assumed. The two relations in equations 5 and 9 can be used to model the production and dispersal of material in the Universe. On making use of the results in Section 2.1, the solution of Equation 1 for the decaying exponential rate in Equation 9 is easily obtained.

On substituting (9) in (1), and integrating w.r.t. t_0 , assuming that $R = 0$ at $t_0 = 0$, and using (6), we obtain,

$$M_P(t_0) = m_0 K_0 (1 - \exp(-\lambda t_0)) / [\lambda(1 - \alpha)], \quad 0 \leq t_0 \leq t_1 \quad (10)$$

and on evaluating Equation 10 at $t_0 = T$, using Equation 7, we find that the particle mass of the Universe,

$$M_P = m_0 \alpha c T / \ln(1/\alpha) \quad (11)$$

where $M_P \equiv M_P(t_1)$. Hence, from Equation 8,

$$M_P / M_W = \alpha \quad (12)$$

in which, from Equation 7,

$$\alpha = \exp(-\lambda T) \quad (13)$$

and also by conservation of mass, the mass (M) of the Universe is the sum of the wave mass (M_W) and the particle mass (M_P),

$$M = M_P + M_W \quad (14)$$

which, from Equations 8 and 11,

$$M = (1 + \alpha) m_0 c T / \ln(1/\alpha) \quad (15)$$

Hence, from Equations 6 and 8 we have,

$$M = (1 + \alpha) m_0 R_1 \quad (16)$$

An alternative expression, in terms of the particle mass, is,

$$M = \alpha m_0 R_2 \quad (17)$$

where R_2 is the radius of the Universe. On equating the two expressions for mass Equations 16 and 17, we obtain,

$$R_2 / R_1 = (1 + \alpha) / \alpha \quad (18)$$

and hence from Equation 18, the radius of the Universe becomes,

$$R_2 = F(\alpha) c T \quad (19)$$

where $F(\alpha) = (1 + \alpha) / (\alpha \ln 1/\alpha)$.

3. DUALITY

Observations indicate that the mass of the Universe, $M = 1.5 \cdot 10^{53}$ kg [6] and the age of the Universe, $T = 13.8 \cdot 10^9$ yr [7] ; and $c = 3 \cdot 10^8$ m s⁻¹ and $G = 6.674$ kg⁻¹ m⁻² s⁻³, from which $m_o = 1.35 \cdot 10^{27}$ kg m⁻¹[4], and hence $M / (m_o c T) = 0.85$. On substituting this ratio in Equation 8 and using Equation 12, we obtain $\alpha = 0.235$ which is well within the allowable range ($0 \leq \alpha \leq \frac{1}{2}$) for a stress-free expansion mechanism for the Universe [5].

For $\alpha = 0.235$, Equation 6 predicts that $R_1 = 0.9 \cdot 10^{26}$ km. Thus from Equation 18, the radius of the Universe, $R_2 = 4.7 \cdot 10^{26}$ km, which is similar to observational estimates of $4.4 \cdot 10^{26}$ km. From Equation 12, $M_P / M_W = 0.235$ which indicates that on the time scale of the Universe the wave mass is about four times greater than the particle mass.

On the time scale (t_o) much less than that of the Universe (T), (5) and (10) show respectively that, $M_W(t_o) = M_P(t_o) = m_o c t_o \alpha / (1 - \alpha)$, and hence,

$$M_P(t_o) / M_W(t_o) = 1, t_o/T \rightarrow 0. \quad (20)$$

which is an exact wave-particle duality.

4. CONCLUSION

The particle mass (M_P) and the mass (M), arguably can be equated respectively with the ordinary matter mass (M_P) and the dark matter mass (M_D) in [4]. In this study, the mass ratio, $M_P / M = 0.19$, which is very close to the mass ratio of ordinary matter to dark matter, $M_P / M_D = 0.18$. This concurrence indicates that the wave mass (M_W) is the dark matter remaining after the formation of the particle mass (M_P).

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