Original Research Article

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 $\alpha = K_o/c$ where K_o is the initial expansion rate and c is the velocity of light. In a stress-free expansion process, $0 \leq \alpha \leq ½$, 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 $M_W = m_o c T / \ln (1/\alpha)$ *where T is the age of the Universe and $m_o = c^2/G$ 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], and 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_o) much less than the age of the Universe (T), $M_P(t_o) / M_W(t_o) \rightarrow 1$, which is an exact wave-particle duality.*

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

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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.

The theoretical results are presented in Section 2.

In Section 3, the data on the age and mass of the Universe are accessed, and it is shown that the results of the theoretical model are consistent with a stress-free expansion process for the Universe, and also that the predicted radius of the Universe is $4.7\ 10^{26}$ km, which is similar to observational estimates. 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.

Section 4 is a Conclusion which discusses the results of the study in a wider context, in particular with regard to the ratio of ordinary matter to dark matter.

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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,

$$dR/dt_R = K(t_o)\ , \qquad 0 \le t_o \le \infty \qquad (1)$$

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

$$K(t_o) = K_o \exp(\lambda\, t_o) \qquad (2)$$

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

$$t_R = t_o + R/c \qquad (3)$$

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

$$dR/dt_o = K_o \exp(\lambda t_o)/(1 - \alpha) \tag{4}$$

where $\alpha = K_o/c$. Hence, on differentiating the defining relation for mass, $M_W = m_oR$ where M_W is the wave mass of the expanding Universe, and $m_o = c^2/G$, in which G is the universal gravitational constant [4], and on integrating (4) w.r.t t_o assuming that $R = 0$ at $t_o = 0$, we obtain,

$$M_W(t_o) = m_o K_o (\exp \lambda t_o - 1) / [\lambda (1 - \alpha)], \qquad 0 \leq t_o \leq t_1 \tag{5}$$

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

$$R_1 = c/\lambda \tag{6}$$

and,

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

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

$$M_W = m_o c T/\ln(1/\alpha) \tag{8}$$

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 [5], in which instead of a growing exponential rate at $t_o \geq 0$, the decaying exponential rate,

$$K(t_o) = K_o \exp(-\lambda t_o) \tag{9}$$

where $\lambda > 0$ was assumed. The two relations (2) and (9) model the production and dispersal of material in the Universe. On making use of the results in Section 2.1, the solution of (1) for the decaying exponential rate (9) is easily obtained.

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

$$M_P(t_o) = m_o K_o (1 - \exp(-\lambda t_o))/[\lambda(1 - \alpha)] \quad , \quad 0 \leq t_o \leq t_1 \tag{10}$$

and on evaluating (10) at $t_o = T$, using (7), we find that the particle mass of the Universe ,

$$M_P = m_o \alpha c T / \ln(1/\alpha) \tag{11}$$

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

$$M_P / M_W = \alpha \tag{12}$$

in which, from (7),

$$\alpha = \exp(-\lambda T) \tag{13}$$

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),

$$M = M_P + M_W \tag{14}$$

which, from (8) and (11), is,

$$M = (1 + \alpha) m_o cT / \ln(1/\alpha) \tag{15}$$

Hence, from (6) and (7),

$$M = (1 + \alpha) m_o R_1 \tag{16}$$

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

$$M = \alpha m_o R_2 \tag{17}$$

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

$$R_2/R_1 = (1 + \alpha) / \alpha \tag{18}$$

and hence from (18), on using (6) and (7), the radius of the Universe,

$$R_2 = F(\alpha) c T \tag{19}$$

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

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3. DUALITY

Observations indicate that the mass of the Universe, $M = 1.5\ 10^{53}$ kg [6] and the age of the Universe, $T = 13.8\ 10^{9}$ yr [7] ; and $c = 3\ 10^{8}$ m s^{-1} and $G = 6.674$ kg^{-1} m^{-2} s^{-3}, from which $m_o = 1.35\ 10^{27}$ kg m^{-1} [4], and hence $M/(m_o c T) = 0.85$. On substituting this ratio in (8) using (12), we obtain $\alpha = 0.235$ which is well within the allowable range ($0 \leq \alpha \leq ½$) for a stress-free expansion mechanism for the Universe [5].

For $\alpha = 0.235$, (6) predicts, using (7), that $R_1 = 0.9\ 10^{26}$ km, and hence from (18), the radius of the Universe, $R_2 = 4.7\ 10^{26}$ km, which is similar to observational estimates of $4.4\ 10^{26}$ km [6], and also from (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,

$$M_P(t_o) / M_W(t_o) = 1, \qquad t_o/T \to 0. \tag{20}$$

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, $M_P/M_D = 0.18$ in [4]. 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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