

3 **The Origin of Wave-particle Duality**5 **ABSTRACT**

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

20 **Keywords:** *net-zero stress, evolution of the universe, wave-particle duality*

21 **1. INTRODUCTION**

22 The concept of wave-particle duality is a central topic in modern theoretical physics, and it
23 arose from efforts to comprehend the properties of light [1]. In this research, we place the
24 concept directly in a cosmological framework on the temporal scale of the universe, rather than
25 the nanoscale of particle physics, and explain theoretically how duality lies at the heart of an
26 understanding of the universe. The production of ordinary matter from dark matter is the
27 governing process in the expansion of the universe. This process is not merely theoretical; it
28 can be explicitly defined through an analysis based on Newtonian physics, which leads to
29 theoretical predictions, which can be tested by observational data. The theoretical model,

30 which uses observational data for the age and mass of the universe to forecast the radius of the
31 cosmos, is based on an astrophysical stress-free dynamical model. The results build on
32 previous research in four papers, [2 - 5] that focused on the features of the stress-free model.

33 Section 2 presents the theoretical results. In section 3 data on the age and mass of the universe
34 are accessed, and it is demonstrated that the results of the model are consistent with a stress-
35 free expansion process for the universe, as well as that the predicted radius of the universe is
36 $4.7 \cdot 10^{26}$ km, which is similar to observational estimates.

37 The main property of the study is wave-particle duality. The theoretical model predicts that the
38 ratio of the particle mass to the wave mass in the universe is 0.235, and suggests that an exact
39 wave-particle duality occurs on temporal scales much smaller than those of the cosmos.

40 Section 4 is a conclusion that puts the findings of the study in a broader framework,
41 specifically the ratio of ordinary matter to dark matter.

42

43 **2. THE MASS OF THE EVOLVING UNIVERSE**

44 **2.1 The Growing Exponential Expansion Rate**

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

$$46 \quad dR/dt_R = K(t_0) , \quad 0 \leq t_0 \leq \infty \quad (1)$$

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

$$50 \quad K(t_0) = K_0 \exp (\lambda t_0) \quad (2)$$

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

$$54 \quad t_R = t_0 + R/c \quad (3)$$

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

57
$$dR/dt_0 = K_0 \exp (\lambda t_0) / (1 - \alpha) \quad (4)$$

58 where $\alpha = K_0/c$. Thus, on differentiating the defining relation for mass, $M_W = m_0 R$ where M_W
 59 is the wave mass of the expanding universe, and $m_0 = c^2/G$, in which G is the universal
 60 gravitational constant [4], and integrating equation 4 with respect to t_0 assuming that $R = 0$ at t_0
 61 $= 0$, we obtain,

62
$$M_W(t_0) = m_0 K_0 (\exp \lambda t_0 - 1) / [\lambda (1 - \alpha)], \quad 0 \leq t_0 \leq t_1 \quad (5)$$

63 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
 64 (c) is unity, from which on evaluating equation 5 at $t_0 = t_1$, using equation 2, we have $\exp (\lambda$
 65 $t_1) - 1 = (1 - \alpha)/\alpha$, and hence,

66
$$R_1 = c / \lambda \quad (6)$$

67 and,

68
$$T = \lambda^{-1} \ln(1/\alpha) \quad (7)$$

69 in which $T \equiv t_1$ is the age of the universe, and from equation 7, the wave mass of the universe,
 70 is,

71
$$M_W = m_0 c T / \ln (1/\alpha) \quad (8)$$

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

73 2.2 The Decaying Exponential Expansion Rate

74 The model in section 2.1 is only half the story. The other half of the story was originally
 75 investigated in [5], in which instead of a growing exponential rate at $t_0 \geq 0$, the decaying
 76 exponential rate,

77
$$K(t_0) = K_0 \exp (-\lambda t_0) \quad (9)$$

78 where $\lambda > 0$ was assumed. The two relations (2) and (9) can be used to model the production
 79 and dispersal of material in the universe. On making use of the results in section 2.1, the
 80 solution of equation 1 for the decaying exponential rate in equation 9 is easily obtained.

81 On substituting equation 9 in equation 1, and integrating with respect to t_0 , assuming that $R =$
 82 0 at $t_0 = 0$, and using equation 6, we obtain,

83
$$M_P(t_0) = m_0 K_0 (1 - \exp(-\lambda t_0)) / [\lambda(1 - \alpha)] \quad , \quad 0 \leq t_0 \leq t_1 \quad (10)$$

84 and on evaluating equation 10 at $t_0 = T$, using equation 7, we find that the particle mass of the
85 universe ,

86
$$M_P = m_0 \alpha c T / \ln(1/\alpha) \quad (11)$$

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

88
$$M_P / M_W = \alpha \quad (12)$$

89 in which, from equation 7,

90
$$\alpha = \exp(-\lambda T) \quad (13)$$

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

93
$$M = M_P + M_W \quad (14)$$

94 which, from equations 8 and 11, is,

95
$$M = (1 + \alpha) m_0 c T / \ln(1/\alpha) \quad (15)$$

96 Hence, from equations 6 and 8,

97
$$M = (1 + \alpha) m_0 R_1 \quad (16)$$

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

99
$$M = \alpha m_0 R_2 \quad (17)$$

100 where R_2 is the radius of the universe. On equating the two expressions for mass, equations 16
101 and 17, we obtain,

102
$$R_2 / R_1 = (1 + \alpha) / \alpha \quad (18)$$

103 and hence from equation 18, the radius of the universe becomes,

104
$$R_2 = F(\alpha) c T \quad (19)$$

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

106

107 3. DUALITY

108

109 Observations indicate that the mass of the universe, $M = 1.5 \cdot 10^{53}$ kg [6] and the age of the
110 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 $m_o =$
111 $1.35 \cdot 10^{27}$ kg m⁻¹ [4], and hence $M / (m_o c T) = 0.85$. On substituting this ratio in equation 8
112 using equation 12, we obtain $\alpha = 0.235$ which is well within the allowable range ($0 \leq \alpha \leq \frac{1}{2}$)
113 for a stress-free expansion mechanism for the universe [5].

114 For $\alpha = 0.235$, equation 6 predicts that $R_1 = 0.9 \cdot 10^{26}$ km. Thus from equation 18, the radius of
115 the universe, $R_2 = 4.7 \cdot 10^{26}$ km, which is similar to observational estimates of $4.4 \cdot 10^{26}$ km [6],
116 and also from equation 12, $M_P / M_W = 0.235$ which indicates that on the temporal scale of the
117 universe the wave mass is about four times greater than the particle mass.

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

$$120 \quad M_P(t_o) / M_W(t_o) = 1, \quad t_o / T \rightarrow 0. \quad (20)$$

121 which is an exact wave-particle duality..

122

123 4. CONCLUSION

124 The particle mass (M_P) and the mass (M), arguably can be equated respectively with the
125 ordinary matter mass (M_P) and the dark matter mass (M_D) in [4]. In this study, the mass ratio,
126 $M_P / M = 0.19$, which is very close to the mass ratio of ordinary matter to dark matter,
127 $M_P / M_D = 0.18$ in [4]. This concurrence indicates that the wave mass (M_W) is the dark matter
128 remaining after the formation of the particle mass (M_P). In particular, equation 20 shows
129 that the masses of ordinary matter and wave matter (which is dark matter) are equal in light

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134 COMPETING INTERESTS

135 Author has declared that no competing interests exist.

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