A simple alternative explanation for dark matter in physical cosmology

Jo. Ke.

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Abstract

We show that neither dark matter nor dark energy is needed for physical cosmology. We use our previous conjecture that, for a distribution of normal baryonic matter, the dynamical mass can be different from the baryonic mass. This simple idea enables us to explain the main results of physical cosmology: the expansion of the Universe; the cosmic microwave background (CMB); the acoustic peaks in the CMB power spectrum; the formation of structure; the apparent accelerated expansion. We suggest the Universe is not accelerating but rather moving from one decelerating track with a low Hubble parameter to its current decelerating track with a higher Hubble parameter. This also provides us with a solution to the Hubble tension. Our explanations make no use of cold dark matter (CDM) and no use of the cosmological constant (Λ), and we conclude neither exists.

1 Introduction

Physical cosmology is described well by the Wikipedia article "Physical cosmology" and the peer-reviewed references cited therein. It uses a theoretical model to explain the observed properties of the Universe, and these include: the expansion of the Universe; the cosmic microwave background (CMB); the formation of structure; the apparent acceleration in the expansion. The currently accepted model is the ΛCDM model of cosmology, which uses general relativity, a cosmological constant (Λ) and cold dark matter (CDM). The ΛCDM model is described well by the Wikipedia article "Lambda-CDM model" and the peer-reviewed references cited therein.

Astronomy & cosmology have problems in explaining a number of observations in both the current Universe and the early Universe. Many of these involve gravity, usually a discrepancy between the amount of matter observed (the so-called baryonic mass) and the amount of matter required to explain the observations (the so-called dynamical mass). The ΛCDM model solves these by introducing both a cosmological constant (Λ) into the equations of General Relativity (GR) and a hypothetical form of mass, cold dark matter (CDM). Dark matter is described well by the Wikipedia article "Dark matter" and the peer-reviewed references cited therein. The observations where dark matter is invoked are described well in the book "The Dark Matter Problem" (Sanders, 2010). Overall the ΛCDM model is very successful to the extent that most astronomers & physicists believe some form of dark matter must exist. One serious problem for dark matter is that, despite decades of searching, no dark matter particle has ever been detected in any experiment.

The problem areas where dark matter is needed can be split into two categories:

(A) the current Universe with difficulties explaining:
- (1) the flat rotation curves of disk galaxies,
- (2) the high velocities of galaxies in clusters,
- (3) gravitational lensing.

(B) the early Universe with difficulties explaining:
- (4) the acoustic peaks in the power spectrum of the cosmic microwave background (CMB),
- (5) the formation of structure.

The problem areas where dark energy is needed can be put into a third category:

(C) other cosmological difficulties explaining:
- (6) the flatness of the Universe,
- (7) the accelerating expansion of the Universe.

Our solution to the Category A problems is set out in viXra paper 2311.0041 ("A simple alternative explanation for dark matter"). For that we show that the observations reveal the existence of a weighting function that allows the dynamical mass to be derived from the observed baryonic mass. This weighting function follows a linear relationship that is common to both disk galaxies and galaxy clusters. So, without any dark matter, we can explain the flat rotation curves of disk galaxies, the velocities of galaxies in cluster, and (separately) gravitational lensing. The linear relationship is not something we have imposed on the galaxies or the galaxy clusters; it is something that drops out of the observations, and was completely unexpected at the time.

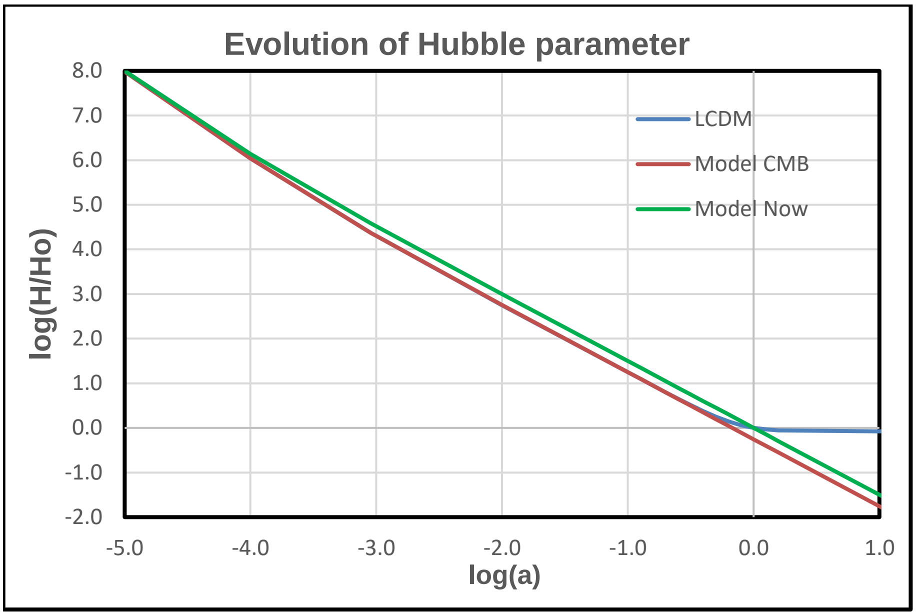


Figure 1. Evolution of the Hubble parameter. The horizontal axis is the scale factor, a, expressed as log(a); the vertical axis is the Hubble parameter, H, expressed as log(H/H_0). The current epoch is at log(a)=0.0; the CMB epoch is at log(a)=-3.04. The blue curve is the ΛCDM model. The green curve is our model with our weighting function γ=20.8; it agrees with the ΛCDM model at the current epoch. The red curve is our model with γ=6.46; it agrees with the ΛCDM model at the CMB epoch.

Our solution to the category B problems is to extend our concept of a weighting function to physical cosmology where, again, we determine the dynamical mass from the baryonic mass. Figure 1 above shows how our concept of a weighting function affects the Friedmann equation and evolution of the Hubble parameter. The horizontal axis is the scale factor, a. The current epoch is a=1.0 (i.e. log(a)=0.0); the CMB epoch is at a≈1/1080 (i.e. z=1079, log(a)=-3.04). The blue curve is the ΛCDM model. The green curve is our model with our weighting function γ=20.8; it agrees with the ΛCDM model at the current epoch. The red curve is our model with γ=6.46; it agrees with the ΛCDM model at the CMB epoch. All models agree at very early times (i.e. small-scale factor, a, or large redshift, z), when the Universe was radiation dominated. This is all explained in later sections of this paper.

In section 2 "A weighting function for disk galaxies" we revisit our justification for the existence of a weighting function for disk galaxies and galaxy clusters. In section 3 "Baryonic mass and dynamical mass" we look at what baryonic mass and dynamical mass mean in the context of physical cosmology. Section 4 "Friedmann equation" looks at how the Friedmann equation is modified to accommodate our conjecture. Section 5 "Two epochs" looks at the data for the current epoch and the epoch of the cosmic microwave background (CMB). Section 6 "Expansion of the Universe" shows how our modified Friedmann equation explains the expansion of the Universe. Section 7 "Cosmic microwave background" looks at how our conjecture explains the CMB, and section 8 "Acoustic peaks" looks at how we explain the acoustic peaks of the CMB power spectrum. Section 9 "Structure formation" shows how our conjecture explains the formation of large structures at early times, despite there being no dark matter. In section 10 "The accelerating expansion of the Universe", we show how we can explain the apparent acceleration in the expansion of the Universe. Finally in section 11 "Hubble tension" we suggest how we can explain the difference in the determinations of the Hubble constant between distance-ladder measurements and CMB measurements.

For our explanation of physical cosmology we are not starting from scratch; far from it. We adopt most of the assumptions of the ΛCDM model including:

(a) Einstein's general theory of relativity describes the dynamics of the Universe,

(b) Friedmann's equation is the solution of general relativity that applies to the Universe,

(c) the Universe contains radiation and baryonic matter.

Where we differ from the ΛCDM model is in our twin assumptions:

(d) there is no dark matter,

(e) there is no cosmological constant.

Some of the material presented here was previously presented in viXra paper 2007.0017 ("Variation of the energy scale: an alternative to dark matter"). In particular, we made a number of testable predictions that follow from our concept of a weighting function.

2 A weighting function for disk galaxies

In this section we revisit the existence of a weighting function that generates the dynamical mass from the baryonic mass. The evidence was presented in full in viXra article viXra:2311.0041 ("A simple alternative explanation for dark matter"), and was based on the observed data for disk galaxies. The possible existence of such a weighting function is the main driver for using it to explain physical cosmology without either dark matter or dark energy.

Newton's law of gravity gives the gravitational acceleration ***g(r)*** at ***r*** arising from mass ***M*** at ***O*** as

$$g(r) = -\frac{G}{r^2}\ M \tag{1}$$

where ***r*** is the distance and ***G*** the gravitational constant.

We modify this by introducing a weighting function ξ to give

$$g(r) = -\frac{G}{r^2}\ M\left\{\frac{\xi(0)}{\xi(r)}\right\} \tag{2}$$

where $\xi(0)$ is the value of the weighting function for mass ***M*** at ***O*** ; $\xi(r)$ is the value of the weighting function at ***r*** .

In this context, the baryonic mass is

$$M_{\text{bar}} = M \tag{3}$$

and the dynamical mass is

$$M_{\text{dyn}} = M\left\{\frac{\xi(0)}{\xi(r)}\right\} \tag{4}$$

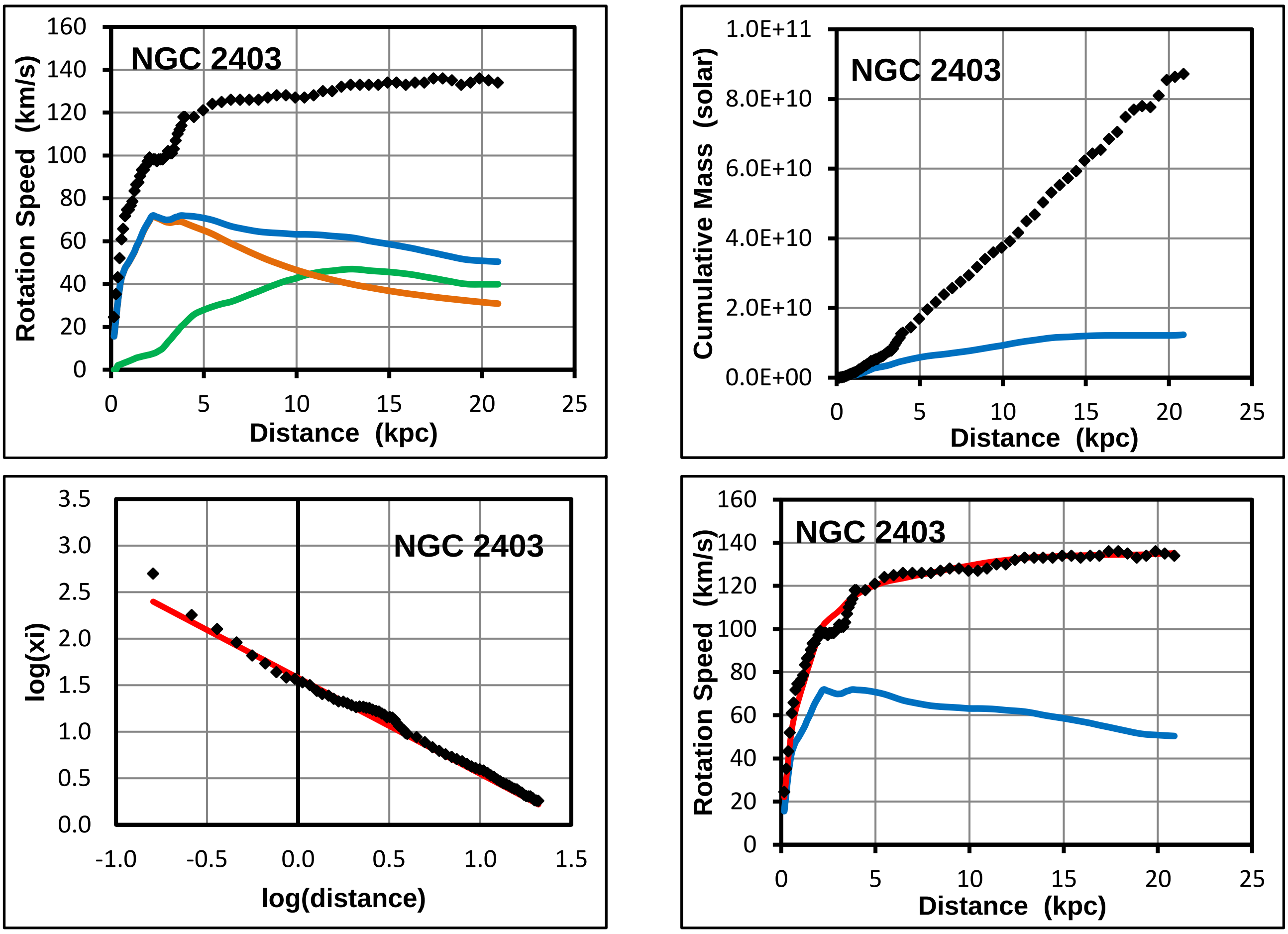
So, the weighting function operates on the baryonic mass to give the dynamical mass.

When we apply this idea to the rotation curve of a disk galaxy, we find that the rotational velocity, ***v(r)*** , at distance ***r*** is given by (JoKe, 2023).

$$v(r)^2 = \frac{G}{r\ \xi(r)}\int_0^r \xi(x)\, dM_{\text{bar}}(x) \tag{5}$$

where $\xi(r)$ is the value of the weighting function at ***r*** ; $\xi(x)$ is the value of the ξ-function at ***X***; $dM_{\text{bar}}(x)$ is the baryonic mass of the incremental shell at ***X***. So each incremental shell is weighted by the local value of ξ, and the whole integral is then divided by the value of ξ at ***r*** .

The SPARC catalog of disk galaxies (Lelli et al, 2016) provides both the baryonic mass distribution and the rotational velocities for 175 disk galaxies. This data enables us to solve equation (5) for our weighting function $\xi(r)$. This is illustrated below for spiral galaxy NGC 2403.



Figures 2. Upper-left panel, the black dots are the observed rotation curve, the lines are the contributions from stars & gas. Upper-right panel, the blue line is the cumulative baryonic mass, the black dots are the cumulative dynamical mass. Lower-left panel, the derived weighting function ξ. Lower-right panel, the red line is our fit to the observed rotation curve (black dots) based on the baryonic mass and our weighting function.

The upper-left panel shows the rotation curves using the observed data of Lelli et al (2016). The black diamonds are observed velocities. The orange curve is the contribution to the velocity from the disk of stars; the green curve from the gas. The blue curve is the expected velocity given by aggregating the components.

The upper-right panel shows the cumulative mass distribution corresponding to the velocities in the top left panel. The black diamonds give the cumulative "dynamical mass" corresponding to the black diamonds in the upper-left panel. The blue line gives the cumulative "baryonic mass" corresponding to the blue line in the upper-left panel. It is clear that the total baryonic mass (blue line) has converged by 15 kpc, whereas the total dynamical mass (black diamonds) continues to increase.

The lower-left panel is a logarithmic plot of our weighting function, ξ , against the radial distance. The black diamonds are the values of the weighting function and are based solely on the observed dynamical and baryonic masses. The near linear relationship away from the galaxy centre is very clear. The red line is a straight line fit to the data, ignoring the first few data points.

The lower-right panel shows the rotation curve again. The black diamonds are the same observed velocities as in the upper-left panel. Similarly, the blue line is the same expected velocities as in the upper-left panel. The red line is the fitted rotation curve derived by applying the red line from the lower-left panel for the weighting function to the blue line from the upper-right panel.

A linear relationship to that shown in the lower-left panel is seen for all disk galaxies; the lines have slopes varying from -0.5 to -1.5. A similar linear relationship is also seen in the observed data for galaxy clusters (JoKe, 2023). This observational result gives strong support to our conjecture of a weighting function linking the baryonic mass to the dynamical mass.

3 Baryonic mass and dynamical mass

The concepts of baryonic mass and dynamical mass were discussed previously in JoKe 2023 (viXra:2311.0041 "A simple alternative explanation for dark matter"). For our examination of physical cosmology, we need to work with baryonic mass and dynamical mass in a slightly different way to that used for disk galaxies and galaxy clusters.

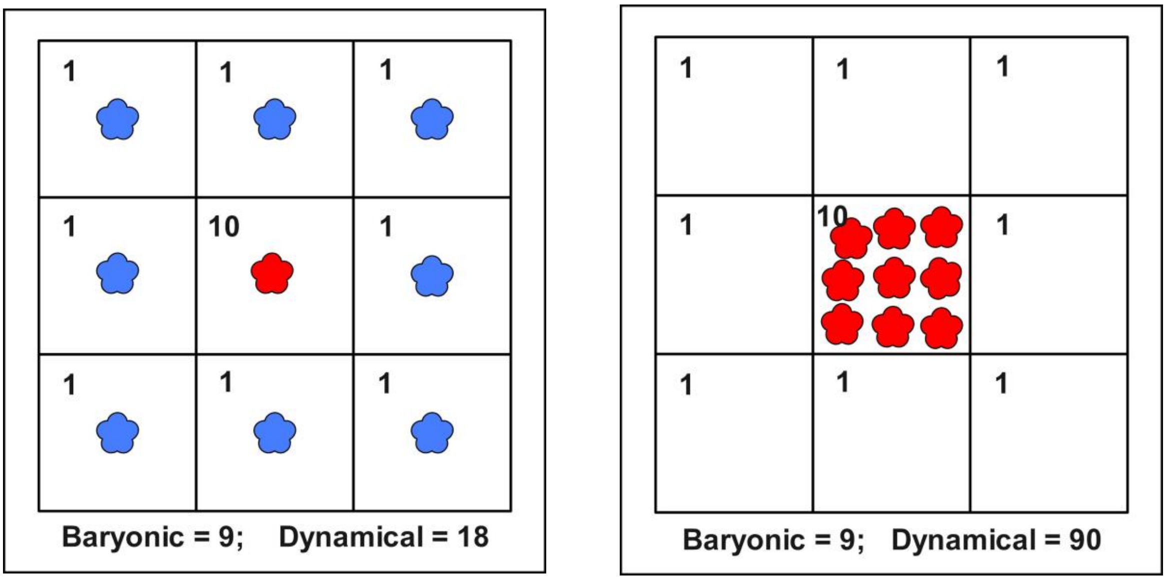


Figure 3. The left-hand panel shows a 3x3 grid with each cell containing a single mass. The red blobs represent masses with a high weighting function; the blue blobs represent masses with a low weighting function. The weight of each cell is the number in the upper left corner. The right-hand panel shows the same grid after gravity has pulled all the masses into the central cell.

Consider the following hypothetical situation as illustrated in Figure 3 above. We have a 3×3 grid of 9 cells. Each cell has a different value for our weighting function, as given by the number in each cell; the outer cells have a weight of 1, the central cell has a weight of 10. We start with the left-hand panel with a single unit mass in each cell.
The total baryonic mass is 9, as it is simply the sum of the individual masses.
The dynamical mass is the baryonic mass multiplied by the weight. The total dynamical mass is 18: the central cell contributes 10 (mass 1 × weight 10), the surrounding 8 cells contribute 1 each (mass 1 × weight 1).
A remote observer measures the dynamical mass to be twice the baryonic mass.

We now let gravity concentrate all the masses into the central cell, which now contains all 9 masses. This is shown in right-hand panel above.
The total baryonic mass is still 9, as we still have 9 lumps of mass 1.
However, the total dynamical mass has increased to 90; 9 lumps of mass 1 × weight 10.
The remote observer now measures the dynamical mass as ten times the baryonic mass.

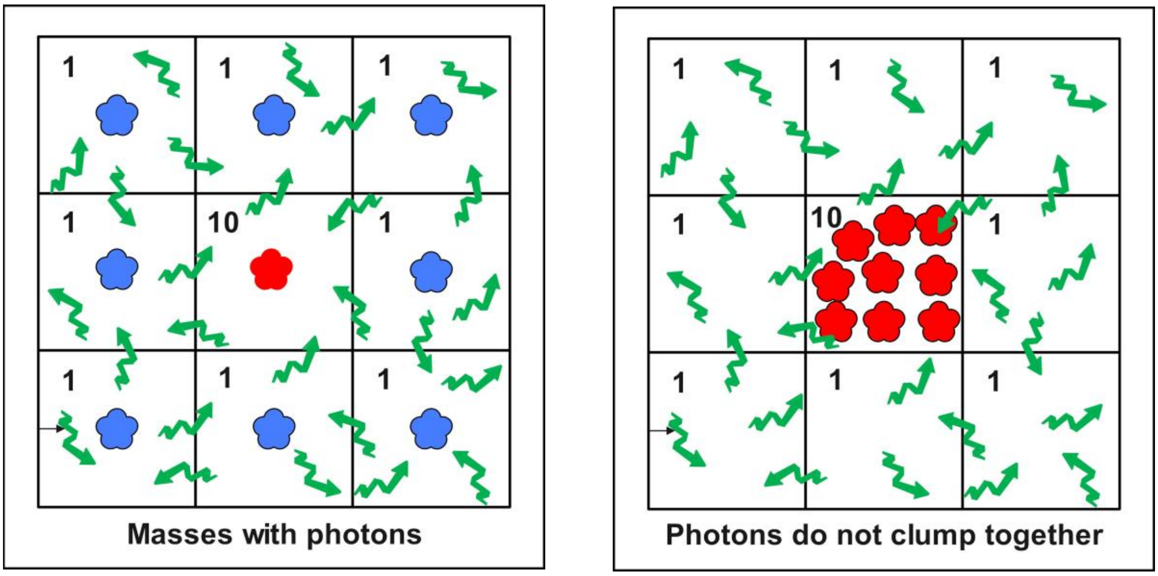


Figure 4. Left-hand panel is the same as in Figure 3 but with added photons (green squiggles). Right-hand panel is the same as Figure 3; although the masses clump together in the central cell, the photons remain scattered throughout the cells.

Lastly, we consider what happens to photons as illustrated in Figure 4 above. In the left-hand panel the masses and photons (green squiggles) are distributed amongst all the cells. In the right-hand panel the masses have clumped into the central cell, but the photons continue to travel through all the cells. Gravity does not suck the photons into the central cell; they are free to travel everywhere, although there will be a tiny gravitational shift as they travel in & out of the central cell.

We can draw a number of conclusions from this hypothetical situation:

(a) the dynamical mass can be larger than the baryonic mass,

(b) if the baryonic masses clump together, in a region with a high weighting function, then the dynamical mass increases,

(c) over time gravity causes the observed dynamical mass of a region to increase,

(d) photons are unaffected; the dynamical energy of the photons remains essentially unchanged.

These conclusions are important in the next section where we come to discuss the Friedman Equation.

From what we have discussed above, and for a Universe containing only matter and radiation, the dynamical energy density is given by

$$\boldsymbol{\varepsilon_{dyn}} = \boldsymbol{\varepsilon_r} + \boldsymbol{\gamma}\ \boldsymbol{\varepsilon_b} \tag{6}$$

where $\boldsymbol{\varepsilon_{dyn}}$ is the dynamical energy density; $\boldsymbol{\varepsilon_r}$ the energy density of radiation (photons & neutrinos); $\boldsymbol{\varepsilon_b}$ the energy density of baryons (normal matter); $\boldsymbol{\gamma}$ is our weighting function. This expression is what we will be using in the Friedmann equation.

4 Friedmann equation

The Friedmann equation is a solution to Einstein's general theory of relativity; it describes the behaviour of a homogeneous & isotropic Universe. The best model we have for explaining such a Universe is the ΛCDM model (Λ=cosmological constant, CDM=cold dark matter). This assumes the Universe is made up of four components:

a) radiation (photons and neutrinos),
b) baryonic matter,
c) cold dark matter (CDM),
d) cosmological constant (Λ).

It also assumes the Universe is flat, which means the energy density is the critical energy density.

Friedmann's first equation for such a Universe can be written as (Ryden, 2017)

$$\boldsymbol{H^2 = \left\{\frac{\dot{a}}{a}\right\}^2 = \frac{8\,\pi\,G}{3\,c^2}\,\{\varepsilon_r + (\varepsilon_b + \varepsilon_d) + \varepsilon_\Lambda\} = \frac{8\,\pi\,G}{3\,c^2}\,\varepsilon_c} \tag{7}$$

where

$$\boldsymbol{\varepsilon_b + \varepsilon_d = \varepsilon_m} \tag{8}$$

and where $\boldsymbol{H}$ is the Hubble parameter; $\boldsymbol{a}$ the scale factor; $\boldsymbol{\varepsilon_r}$ the energy density of radiation; $\boldsymbol{\varepsilon_b}$ the energy density of baryonic matter; $\boldsymbol{\varepsilon_d}$ the energy density of dark matter; $\boldsymbol{\varepsilon_\Lambda}$ the energy density of a cosmological constant; $\boldsymbol{\varepsilon_m}$ the energy density of matter; $\boldsymbol{\varepsilon_c}$ the critical energy density. All the terms (apart from the cosmological constant) are functions of time and vary as the Universe evolves.

For the present epoch we can write the Friedmann equation as

$$\boldsymbol{H_0^2 = \frac{8\,\pi\,G}{3\,c^2}\,\left\{\varepsilon_{r,0} + \left(\varepsilon_{b,0} + \varepsilon_{d,0}\right) + \varepsilon_{\Lambda,0}\right\} = \frac{8\,\pi\,G}{3\,c^2}\,\varepsilon_{c,0}} \tag{9}$$

where the $\boldsymbol{_0}$ subscript denotes the current epoch.

The Friedmann equation can also be written in terms of the density parameter, $\boldsymbol{\Omega}$, (Ryden, 2017)

$$\boldsymbol{H^2 = \left\{\frac{\dot{a}}{a}\right\}^2 = \frac{8\,\pi\,G}{3\,c^2}\,\{\Omega_r + (\Omega_b + \Omega_d) + \Omega_\Lambda\}\,\varepsilon_c} \tag{10}$$

where

$$\boldsymbol{\Omega_r = \frac{\varepsilon_r}{\varepsilon_c}} \tag{11}$$

similarly for the other components. It follows that

$$\boldsymbol{\Omega_r + \Omega_b + \Omega_d + \Omega_\Lambda = 1} \tag{12}$$

It is also known how the energy densities change with the scale factor, $\boldsymbol{a}$, (Ryden, 2017).
For radiation we have

$$\varepsilon_r = \frac{\varepsilon_{r,0}}{a^4} \tag{13}$$

And for matter (both baryonic and dark) we have

$$\varepsilon_m = \frac{\varepsilon_{m,0}}{a^3} \tag{14}$$

where the ***0*** subscript denotes current epoch.

Using equations (13) & (14), we can write the Friedmann equation in terms of the density parameter

$$\left\{\frac{H(a)}{H_0}\right\}^2 = \frac{\Omega_{r,0}}{a^4} + \frac{(\Omega_{b,0} + \Omega_{d,0})}{a^3} + \Omega_\Lambda \tag{15}$$

where ***H(a)*** is the value of the Hubble parameter for scale factor ***a*** .

We now look at how the above equations change for our conjecture of

(a) no dark matter

(b) no dark energy

(c) a weighting function, ***γ*** , that affects only the baryonic matter. The photons are unaffected, as explained in the previous section.

The Friedmann equation becomes, using equation (6)

$$H^2 = \left\{\frac{\dot{a}}{a}\right\}^2 = \frac{8\,\pi\,G}{3\,c^2}\,\{\varepsilon_r + \gamma(a)\,\varepsilon_b\} = \frac{8\,\pi\,G}{3\,c^2}\,\varepsilon_c \tag{16}$$

where ***γ(a)*** is the value of our weighting function for scale factor ***a*** .
For the present epoch this is

$$H_0^2 = \frac{8\,\pi\,G}{3\,c^2}\,\{\varepsilon_{r,0} + \gamma_0\,\varepsilon_{b,0}\} = \frac{8\,\pi\,G}{3\,c^2}\,\varepsilon_{c,0} \tag{17}$$

In terms of the density parameters, equation (15) becomes

$$\left\{\frac{H(a)}{H_0}\right\}^2 = \frac{\Omega_{r,0}}{a^4} + \gamma(a)\frac{\Omega_{b,0}}{a^3} \tag{18}$$

Comparing equations (7) and (16) we have for the energy densities, ***ε***

$$\varepsilon_r + (\varepsilon_b + \varepsilon_d) + \varepsilon_\Lambda = \varepsilon_r + \gamma(a)\varepsilon_b = \varepsilon_c \tag{19}$$

leading to

$$\gamma(a) = \frac{(\varepsilon_b + \varepsilon_d) + \varepsilon_\Lambda}{\varepsilon_b} = \frac{(\varepsilon_c - \varepsilon_r)}{\varepsilon_b} \tag{20}$$

This means that if our weighting function, $\boldsymbol{\gamma}$, follows equation (20), then our model will agree exactly with the ΛCDM model.

And comparing equations (15) and (18) we have density parameters, $\boldsymbol{\Omega}$

$$\frac{\Omega_{r,0}}{a^4} + \frac{(\Omega_{b,0} + \Omega_{d,0})}{a^3} + \Omega_\Lambda = \frac{\Omega_{r,0}}{a^4} + \gamma(a)\frac{\Omega_{b,0}}{a^3} \tag{21}$$

leading to

$$\gamma(a)\ \frac{\Omega_{b,0}}{a^3} = \frac{(\Omega_{b,0} + \Omega_{d,0})}{a^3} + \Omega_\Lambda \tag{22}$$

This means that if our weighting function, $\boldsymbol{\gamma}$, follows equation (22), then our model will agree exactly with the ΛCDM model.

Alternatively, equation (12) simply becomes

$$\Omega_r + \gamma(a)\ \Omega_b = 1 \tag{23}$$

or

$$\gamma(a) = \frac{(1 - \Omega_r)}{\Omega_b} \tag{24}$$

5 Two epochs

In physical cosmology there are only two epochs where we have observational data to pin down the values of the variables in the Friedmann equation

(a) current epoch: $\boldsymbol{a}$ = 1.0; $\boldsymbol{z}$ =0.0.

(b) epoch of the cosmic microwave background (CMB): $\boldsymbol{a}$ = 1/1090; $\boldsymbol{z}$ = 1089.

For the ΛCDM model we could argue that dark matter is introduced to make the Friedmann equation work at the epoch of the CMB, and that dark energy is introduced to make the Friedmann equation work at the current epoch.

For the current epoch, the radiation energy density is insignificant, and equation (20) leads to our weighting factor being

$$\boldsymbol{\gamma_0} = \frac{\boldsymbol{\varepsilon_{c,0}}}{\boldsymbol{\varepsilon_{b,0}}} = \mathbf{20.8} \tag{25}$$

using the values in Table 1.

For the CMB epoch, the cosmological constant factor is insignificant, and equation (20) leads to

$$\boldsymbol{\gamma}_{\mathbf{CMB}} = \frac{(\boldsymbol{\varepsilon_b} + \boldsymbol{\varepsilon_d})}{\boldsymbol{\varepsilon_b}} = \frac{\left(\boldsymbol{\varepsilon_{b,0}} + \boldsymbol{\varepsilon_{d,0}}\right)}{\boldsymbol{\varepsilon_{b,0}}} = \mathbf{6.46} \tag{26}$$

using the values in Table 2

This is just the ratio of normal matter to total matter (i.e. matter + dark matter) in the ΛCDM theory. Of course, no additional matter or dark matter are created during the evolution of the Universe (after the Big Bang), and so the ratio must be a constant in the ΛCDM model. In our hypothesis we have the concept of a weighting function and so the dynamical mass can be very different from the baryonic mass. This accounts for the different value of $\boldsymbol{\gamma}$ in equations (25) and (26).

So our weighting factor has increased by around a factor of three from the epoch of the CMB to the present time. This is consistent with what we mentioned earlier in section 3 (Baryonic mass and dynamical mass), where we expect the weighting factor to increase as matter coalesces together to form galaxies and galaxy clusters.

The following two tables give the values of the variables based on data taken from Ryden (2017). The "ΛCDM" column is based on equations (9) through (15); the "Our model" column is based on equations (16) through (18).

Table 5.1 Current epoch

$a = 1.0$; $z = 0.0$

Quantity	ΛCDM	Our model
Energy density		
$\varepsilon_{r,o}$	**4.38E5 eV m^{-3}**	**4.38E5 eV m^{-3}**
$\varepsilon_{b,0}$	**2.34E8 eV m^{-3}**	**2.34E8 eV m^{-3}**
γ_0	-	20.8
$\gamma_0 \times \varepsilon_{b,0}$		**4.87E9 eV m^{-3}**
$\varepsilon_{d,0}$	**1.28E9 eV m^{-3}**	-
$\varepsilon_{m,0}$	1.51E9 eV m^{-3}	-
$\varepsilon_{\Lambda,0}$	**3.36E9 eV m^{-3}**	-
$\Sigma\varepsilon_{\alpha,0} = \varepsilon_{c,0}$	**4.87E9 eV m^{-3}**	**4.87E9 eV m^{-3}**
Density parameter		
$\Omega_{r,0}$	**9.00E-5**	**9.00E-5**
$\Omega_{b,0}$	**0.048**	0.048
γ_0	-	20.8
$\gamma_0 \times \Omega_{b,0}$	-	**1.000**
$\Omega_{d,0}$	**0.262**	-
$\Omega_{m,0}$	0.310	-
$\Omega_{\Lambda,0}$	**0.690**	-
$\Sigma\ \Omega_{\alpha,0} = \Omega_0$	**1.000**	**1.000**

Cosmological parameters for the current epoch. The values for the ΛCDM model are from Ryden (2017). The green values are the sum of the yellow values. The green values for our model agree with those for the ΛCDM model.

Table 5.2 Epoch of CMB

a = 1/1090; ***z*** = 1089

Quantity	**ΛCDM**	**Our model**
Energy density		
ε_r	**6.21E17 eV m^{-3}**	**6.21E17 eV m^{-3}**
ε_b	**3.04E17 eV m^{-3}**	3.04E17 eV m^{-3}
γ	-	6.46
$\gamma \times \varepsilon_{b,}$		**1.96E18 eV m^{-3}**
ε_d	**1.66E18 eV m^{-3}**	-
ε_m	1.96E18 eV m^{-3}	-
ε_Λ	**3.36E9 eV m^{-3}**	-
$\Sigma\varepsilon_\alpha = \varepsilon_c$	**2.58E18 eV m^{-3}**	**2.58E18 eV m^{-3}**
Density parameter		
Ω_r	**0.240**	**0.241**
Ω_b	**0.118**	0.118
γ	-	6.46
$\gamma \times \Omega_b$	-	**0.759**
Ω_d	**0.642**	-
Ω_m	0.760	-
Ω_Λ	**0.000**	-
$\Sigma\, \Omega_\alpha = \Omega$	**1.000**	**1.000**

Cosmological parameters for the epoch of the cosmic microwave background (CMB). The values for the ΛCDM model are from Ryden (2017). The green values are the sum of the yellow values. The green values for our model agree with those for the ΛCDM model.

6 Expansion of the Universe

As mentioned in the introduction, our starting point is that the Friedmann equation is the solution to Einstein's general theory of relativity that describes the Universe, and that the Universe contains only baryonic matter and radiation. Our conjecture is that there is no dark matter and no cosmological constant, and that the Universe is made up of only radiation (photons & neutrinos) and matter (normal baryonic matter). This means the Friedmann equation (16) takes the form:

$$\boldsymbol{H^2 = \left\{\frac{\dot{a}}{a}\right\}^2 = \frac{8\,\pi\,G}{3\,c^2}\,\{\,\varepsilon_r + \gamma\,\varepsilon_b\} = \frac{8\,\pi\,G}{3\,c^2}\,\varepsilon_c} \qquad (27)$$

where $\boldsymbol{H}$ is the Hubble parameter; $\boldsymbol{a}$ the scale factor; $\boldsymbol{\varepsilon_r}$ the energy density of radiation; $\boldsymbol{\varepsilon_b}$ the energy density of baryonic matter; $\boldsymbol{\varepsilon_c}$ the critical energy density; $\boldsymbol{\gamma}$ is the value of our weighting function.

The right-hand side of equation (27) is positive, which means that the rate of change of the scale factor, $\boldsymbol{\dot{a}}$, is either positive or negative. We, naturally, take the positive square root to give us an expanding Universe. So, by replacing the amount of dark matter and the cosmological constant by our weighting factor, we still have an expanding Universe.

Equation (27) contains no curvature term, so we also have a flat Universe; a Universe where the energy density is always the critical energy density. For this to hold, it means there must be some physical mechanism in place that adjusts our weighting factor to keep the Universe flat and expanding at the critical rate.

The expansion of the Universe in our model progresses in exactly the same way as for the ΛCDM model. This should be clear from the parameter values presented in Tables 1 & 2. So the cosmic microwave background (CMB) happens after 370,000 years at a redshift of z=1090. And that for the current epoch the age of the Universe is around 13.8 years and the Hubble constant is around 68 km/sec/Mpc.

7 Cosmic microwave background

With our conjecture of a weighting function that defines the dynamical mass from the baryonic mass, there is no difference in the early history of the Universe between our model and the ΛCDM model. The cosmic microwave background (CMB) formed when the plasma cooled to a temperature where the protons and electrons could combine to form stable neutral atoms of atomic hydrogen.

The early Universe was dominated by matter and radiation (the cosmological constant played no part) and the Friedmann equation for the ΛCDM model, equation (7), was essentially identical to that for our conjecture, equation (16). The parameters describing the expansion for both models are set out in Table 2. In both models everything happens in exactly the same way. The Universe expands and cools until it eventually reaches the temperature where the electrons & protons combine to form neutral atoms. For both models this recombination happens at a redshift of z=1380, a temperature of 3760K, and an age of around 250,000 years (Ryden, 2017). The photons that make up the CMB come from the slightly later time of last-scattering, at a redshift of z=1090, a temperature of 2970K, and an age of around 370,000 years (Ryden, 2017).

So, our model explains the CMB in exactly the same way as the ΛCDM model.

8 Acoustic peaks

The power spectrum of the cosmic microwave background (CMB) shows a set of peaks and troughs. These are interpreted as arising from the oscillations of the photon-baryon fluid that existed during the early Universe. The cause of the peaks is summarised well by Lyth & Liddle (2009, section 8.6)

> *"Until photon decoupling, the baryons and photons form a tightly coupled fluid, supporting a standing-wave acoustic oscillation. The photons then travel freely, but imprinted on their distribution is a snapshot of the oscillation as it existed just before decoupling. This gives rise to the peak structure in the CMB anisotropy."*

The first peak is relatively straightforward to understand. At the end of inflation, ripples in the baryon-photon fluid would have emanated from regions of high density, pressure & temperature. These ripples would have travelled outwards at the speed of sound of the fluid, until recombination when the photons decoupled from the electrons, the ionised plasma became neutral, and the rippled stopped. So the first peak corresponds to the distance a sound wave can travel up to the time of the CMB, around an age of 370,000 years (Ryden, 2017). This corresponds to an angular size of around 0.7 degrees, which agrees with the position of the first peak.

The physics and mathematics, behind the acoustic peaks of the CMB, are quite complicated and involve both the density, $\boldsymbol{\rho}$, and the density parameter, $\boldsymbol{\Omega}$. The relevant equations are set out in many texts including Weinberg (2008), Lyth & Liddle (2009). We need to show how these equations should be modified away from the ΛCDM model to our conjecture. This can be achieved by imposing the following two rules.

Rule 1: In all those equations where local physics applies, we use the baryonic density as is

$$\boldsymbol{\rho_b} \rightarrow \boldsymbol{\rho_b} \tag{28}$$

$$\boldsymbol{\Omega_b} \rightarrow \boldsymbol{\Omega_b} \tag{29}$$

where the → symbol stands for "is replaced by".

For example, this applies to the baryon-to-photon ratio of big bang nucleosynthesis (BBN). Neither dark matter nor dark energy appear in these equations.

Rule 2: In all those equations where the Friedmann Equation is used or the matter density is needed we use the baryonic density multiplied by our $\boldsymbol{\gamma}$ factor

$$\boldsymbol{\rho_m} \rightarrow \boldsymbol{\gamma} \; \boldsymbol{\rho_b} \tag{30}$$

$$\boldsymbol{\Omega_m} \rightarrow \boldsymbol{\gamma} \; \boldsymbol{\Omega_b} \tag{31}$$

where the → symbol stands for "is replaced by". And should they occur, we also set any dark energy terms to zero.

For example, many of the equations in chapter 7 "Anisotropies in the Microwave Sky" (Weinberg, 2008) are based on the Friedmann Equation and should lead to the same results if equations (30) and (31) are employed.

With our substitutions the equations that define the physics behind the peaks in the CMB power spectrum are essentially unchanged. We are replacing the additive dark matter terms with our multiplicative weighting factor. The end results are all exactly the same. As a consequence, we expect the CMB peaks to lie in exactly the same locations and have exactly the same relative heights.

9 Structure formation

Up to the time of the cosmic microwave background (CMB), around 370,000 years after the Big Bang, the electrons & protons were tightly coupled with the photons, which prevented any structures from forming. After the CMB, neutral atoms formed, which were not coupled to the photons, and so could collapse under gravity to form stars & galaxies. With only baryons present, structures form very slowly and cannot account for the current existence of stars, galaxies, clusters and super-clusters. Some additional source of gravity is required to form the structures at early enough times.

In the ΛCDM model, most of the mass is in the form of dark matter. This does not interact with the photons and can start collapsing under gravity to from structures immediately after the Big Bang. By the time of the CMB, dark matter has already formed a hierarchy of structures of different sizes. These act as gravitational wells and kick-start the collapse of the neutral atoms into forming stars & galaxies. Computer simulations of Universes containing dark matter demonstrate that the ΛCDM model can account for the observed distribution of stars, galaxies and clusters.

How can we account for the growth of structure in our Universe of only baryonic matter and photons? This is where our weighting function comes to our rescue. In our Universe there are regions where the weighting function is higher than in other regions. The baryonic matter in these regions has a higher dynamical mass than average and they act as gravitational wells that suck in matter from nearby regions. Our high weighting function regions act in exactly the same manner as the dark matter potential wells, and so have the ability to explain the early formation of structures.

We have run a simple computer model to demonstrate how our weighting function speeds up the formation of structure. The model consists of 250 equal mass particles distributed randomly within a square grid and with small random motions. There is a central mass of 10. In one case we have a weighting function with a Gaussian distribution; in the other case we have gravity alone. The results of one such run is shown below. The left-hand images show the development of structure with our weighting function. The right-hand images show the same starting configuration but with no weighting function. It is clear that our weighting function speeds up the formation of structure.

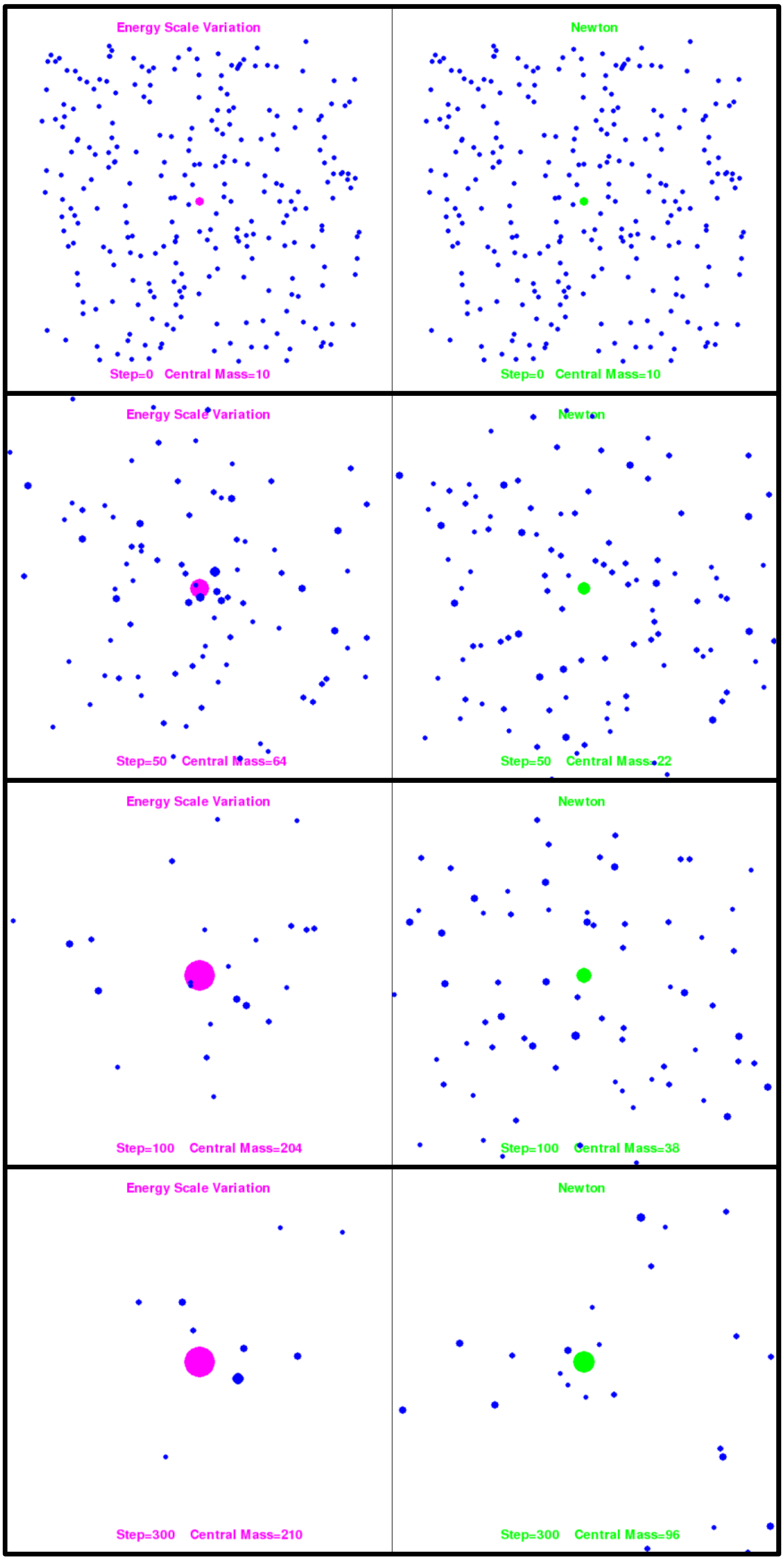


Figure 5. Evolution of 250 randomly placed masses with random speeds. Right side is simple Newtonian gravity; left side includes our weighting function.

Figure 6 shows the growth of the central mass for 10 separate runs. It is clear that our weighting function leads to a much faster growth rate. This leads us to conclude that with our model we expect large structures, such as galaxies and galaxy clusters, to form very early on in the history of the Universe.

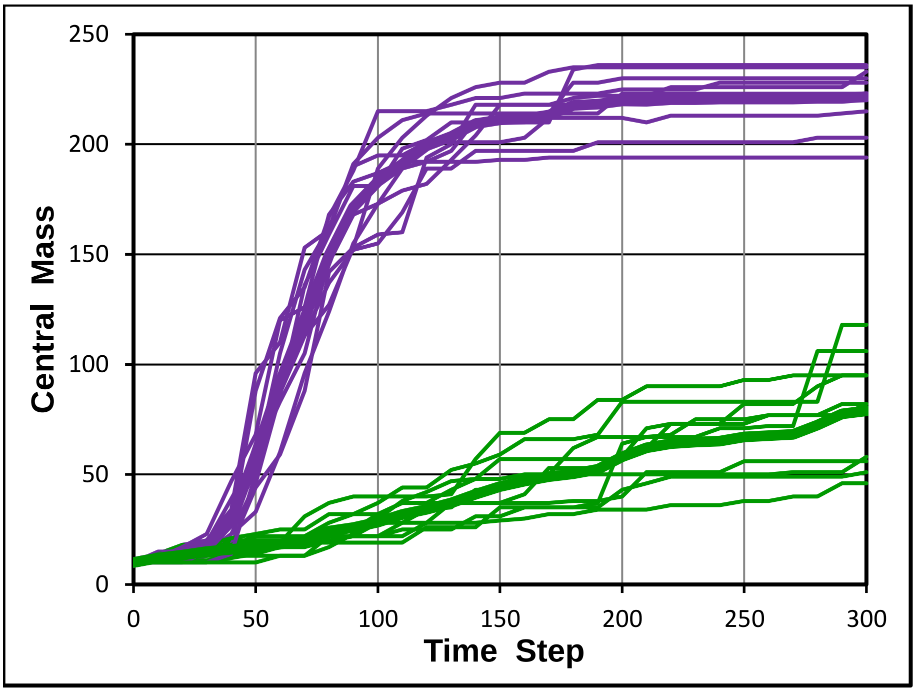


Figure 6. Growth of the central mass for 10 runs of the numerical simulation. The green lines are for Newtonian gravitational; the purple lines are for Newtonian gravity plus our weighting function. The thick lines are the averages of the runs. It is clear that the weighting function gives rise to structure formation on a faster time scale.

10 The accelerating expansion of the universe

Observations of type Ia supernovae out to a redshift of around z=1.0 show that they are dimmer than expected (Ryden, 2017). For the ΛCDM model, this is interpreted as an acceleration in the expansion of the Universe. So rather than the Universe slowing down it is in fact speeding up. At the present epoch only matter and the cosmological constant are significant (see Table 2), and the Friedmann equation for the ΛCDM model, equation (7), can be written as

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\,\pi\,G}{3\,c^2}\left\{\frac{\varepsilon_{m,0}}{a^3} + \varepsilon_\Lambda\right\} \tag{32}$$

This can be differentiated to give the acceleration of the scale factor

$$\left(\frac{\ddot{a}}{a}\right) = \frac{8\,\pi\,G}{3\,c^2}\left\{\varepsilon_\Lambda - \frac{\varepsilon_{m,0}}{2\,a^2}\right\} \tag{33}$$

From Table 2 it is clear that, for the ΛCDM model, the cosmological constant dominates the matter energy density. This means the bracketed term in equation (33) is positive and the Universe is accelerating, in agreement with observations.

We have to show how our conjecture, of no dark matter and no dark energy, also leads to a Universe that appears to be accelerating. Table 2 shows that, for the current epoch, only baryonic matter is important for the Friedmann equation, which becomes

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\,\pi\,G}{3\,c^2}\,\gamma(a)\,\varepsilon_b = \frac{8\,\pi\,G}{3\,c^2}\,\gamma(a)\,\frac{\varepsilon_{b,0}}{a^3} \tag{34}$$

where ***γ(a)*** is the value of our weighting function for scale factor ***a*** .
Differentiating this equation leads to

$$\left(\frac{\ddot{a}}{a}\right) = \frac{1}{2}\left(\frac{\dot{a}}{a}\right)\left(\frac{\dot{\gamma}}{\gamma} - \frac{\dot{a}}{a}\right) \tag{35}$$

So, by suitable choice of $\dot{\gamma}/\gamma$ the acceleration of the scale factor, $\ddot{a}/a$, can be positive, which gives us an accelerating Universe.

However, we have a different way of looking at the accelerating Universe. If our weighting factor ***γ*** is a constant, then equation (34) can be written as

$$\left(\frac{\dot{a}}{a}\right) = \sqrt{\frac{8\,\pi\,G\,\varepsilon_{b,0}}{3\,c^2}}\,\sqrt{\gamma}\;(a)^{-3/2} \;\propto\; (a)^{-3/2} \tag{36}$$

This means our Universe evolves down the decelerating track defined by our fixed value of the weighting function ***γ***. If ***γ*** changes to a higher value, then the Universe moves to a new decelerating track but with a higher value of the Hubble parameter, $\dot{a}/a$. While the Universe moves from a low speed track to a high speed track, it can appear to be accelerating.

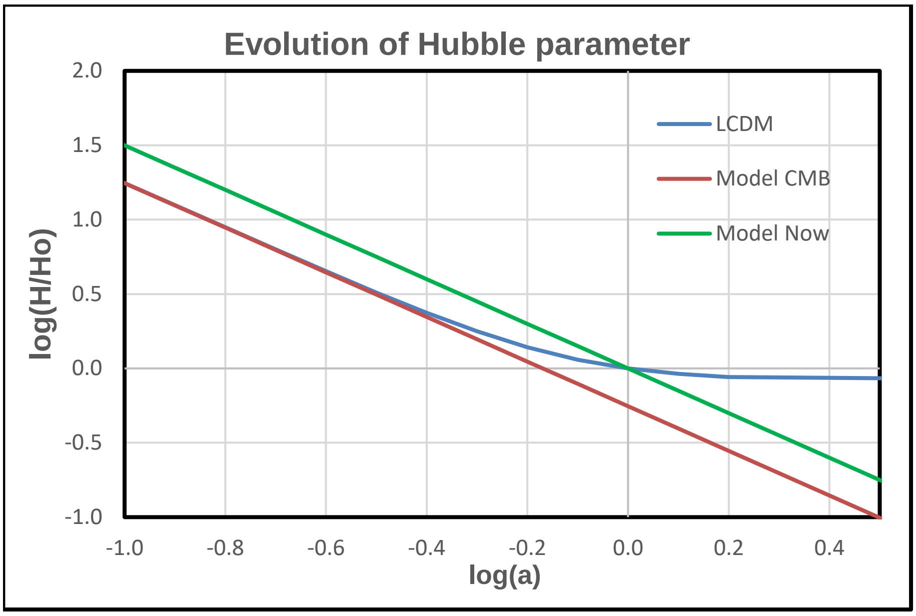


Figure 7. Evolution of the Hubble parameter. The horizontal axis is the scale factor, a, expressed as log(a); the vertical axis is the Hubble parameter, H, expressed as log(H/H_0). The point (0.0, 0.0) is the current epoch (scale factor a=1.0; Hubble parameter = Hubble constant, $H=H_0$). The blue curve is the ΛCDM model. The green curve is our model with γ=20.8; it agrees with the ΛCDM model at the current epoch. The red curve is our model with γ=6.46; it agrees with the ΛCDM model at the CMB epoch.

This is illustrated in Figure 7, which is an enlarged region of Figure 1. The current epoch, now, is the point (0.0,0.0). The blue track is the ΛCDM model; the green track is our model with ***γ***=20.8 which agrees with the ΛCDM model at the current epoch; the red track is our model with ***γ***=6.46 which agrees with the ΛCDM model at the CMB epoch.

It is clear that by varying the value of our weighting function, ***γ*** , we can get our model to follow the track of the ΛCDM model. This leads us to suggest that the long term future of the Universe is not one of accelerated expansion but of a steady slowing down of the expansion speed, and that at the present epoch the Universe is simply moving between decelerating tracks.

As mentioned at the beginning of this section, distant type Ia supernovae appear fainter than expected, which means they are further away than expected. Ryden (2017) gives the luminosity distance, $\boldsymbol{d_L}$, as

$$d_L \approx \frac{c}{H_0} z \left(1 + \frac{1 - q_0}{2} z\right) \tag{37}$$

where $\boldsymbol{q_0}$ is the deceleration parameter. In moving from one of our tracks to another we are essentially changing the value of the Hubble constant, $\boldsymbol{H_0}$. So, when we move from the current epoch track with H_0=70 km/s/Mpc to an earlier track with a smaller H_0, then the luminosity distance increases and the object appears fainter.

So, with our model, we can explain the faintness of distant type Ia supernovae without resorting to an accelerating Universe.

11 Hubble tension

The Hubble parameter, H, is defined in the Friedmann equation, equation (7); it does not have a fixed value and varies with the age of the Universe. Its value at the present epoch, $\boldsymbol{H_0}$, is known as the Hubble constant and it has a value around 70 km/s/Mpc. Physical cosmology is often phrased in terms of the Hubble constant rather than the Hubble parameter through equations similar to equation (15).

The value of the Hubble constant has to be determined through observations and can be done in essentially two ways

(a) using the distance-ladder technique of observing objects close to the current epoch out to a redshift of around z=1.0. This method gives a value $\boldsymbol{H_0} = 73 \pm 0.5$ km/s/Mpc.

(b) fitting the ΛCDM model to observations of the CMB. This method gives a lower value $\boldsymbol{H_0} = 68 \pm 0.5$ km/s/Mpc.

The so-called Hubble tension is the fact that these two independent methods of measuring the Hubble constant given different values, not covered by the error bars.
The Hubble tension is explained well in the Wikipedia article on "Hubble's law" and the peer-reviewed articles contained therein.

Our resolution of the Hubble tension comes from fitting the CMB observations, not with the ΛCDM model as defined by equation (15), but with our weighting function model as defined by equation (18). This gives rise to a different value of the Hubble constant, H_0. Figure 7 shows that our evolutionary track that fits the CMB (red line) lies below the track that fits the current epoch. This means we expect a lower value for the Hubble constant as defined by CMB observations than for the Hubble constant as defined by current observations. This is the Hubble tension with the CMB based value of 68 km/sec/Mpc being lower than the current based value of 73 km/sec/Mpc.

Simply put, our weighting function, γ, varies with time and this leads to different values of the Hubble constant at different epochs. We expect it to have a higher value now than at the CMB epoch, exactly as indicated by the Hubble tension.

12 Discussion

In Jo.Ke. (2023, "A simple alternative explanation for dark matter") we introduced our conjecture of a weighting function that defines the dynamical mass from the baryonic mass. We showed how this explains the observations of disk galaxies, clusters of galaxies, and gravitational lensing. In this paper we have extended our conjecture to cover physical cosmology and put forward explanations for the expansion of the Universe, the cosmic microwave background (CMB), the acoustic peaks, structure formation, the accelerated expansion, and the Hubble tension. In these two papers we have put forward a conjecture that provides a single explanation for all the observations where dark matter is invoked. And in this paper, we have provided an alternative explanation for dark energy.

However, no doubt you have noticed that our alternative explanations are somewhat thin on hard calculations. We have provided an alternative form for the Friedmann equation, but we have not derived values for our alternative parameters by fitting the Planck satellite data of the CMB, nor have we fitted our parameters against the acoustic peaks of the CMB power spectrum. Hopefully, such calculations will become possible in the reasonably near future. What we have provided in this paper is the outline of how our explanations are expected to work in replacing dark matter and dark energy as well.

In Jo.Ke. (2023, "A simple alternative explanation for dark matter") we made a number of predictions and tests. However, in this paper we are not (yet) in a position to make any predictions for physical cosmology that can be tested readily. We do not have a killer test that will put an end to the hypotheses of dark matter and dark energy. Perhaps the best we can do at the moment is the following:

Our conjecture of a weighting function implies that this varies in value across the Universe from the time of the Big Bang up to the present epoch. This means the Universe would have started with a non-uniform dynamical density distribution even though the underlying baryonic density distribution was uniform. So we predict that observations of the Universe at very early times will show it to be clumpy and with large structures appearing early on.

Currently, we do not have a proper theory for our weighting function. We are simply stating that if it exists, then we have an alternative to dark matter and dark energy. As mentioned in JoKe (2023) our weighting function clearly constitutes a scalar field, in that it has a single scalar value at every point of space. As such it should then be amenable to the physics of scalar fields, which then takes us into the area of potential theory including items such as Gauss's Theorem and Poisson's Equation. These ideas are beyond the scope of this paper but one suggestion as to why the weighting function proposed here might actually exist is that the Higgs field (which determines the masses of the fundamental particles) is already known to be a scalar field.

Overall we are replacing the dual hypotheses of dark matter and dark energy with the single hypothesis of a weighting function that gives the dynamical mass from the baryonic mass. One key driver for adopting this hypothesis is the failure to detect any dark matter particles, which is becoming more of problematic as time goes on.

13 Executive Summary

We can summarize our conjecture as follows

(a) there is no dark matter,

(b) there is no dark energy, or alternatively the cosmological constant is zero,

(c) the dynamical mass can be different from the baryonic mass,

(d) there exists a weighting function that determines the dynamical mass from the baryonic mass,

(e) for galaxies and galaxy clusters, Newton's law of gravitation is replaced with

$$\boldsymbol{g(r) = -\frac{G}{r^2}\; M \left\{\frac{\xi(0)}{\xi(r)}\right\}} \tag{38}$$

where $\boldsymbol{\xi(0)}$ is the value of the weighting function for the mass $\boldsymbol{M}$ at $\boldsymbol{O}$; $\boldsymbol{\xi(r)}$ is the value of the weighting function at $\boldsymbol{r}$.

(f) for physical cosmology, Friedmann's first equation is replaced with

$$\boldsymbol{H^2 \;=\; \left\{\frac{\dot{a}}{a}\right\}^2 \;=\; \frac{8\,\pi\,G}{3\,c^2}\;\{\,\varepsilon_r + \gamma(a)\,\varepsilon_b\}\;=\;\frac{8\,\pi\,G}{3\,c^2}\;\varepsilon_c} \tag{39}$$

where $\boldsymbol{\gamma(a)}$ is the value of our weighting function; $\boldsymbol{H}$ is the Hubble parameter; $\boldsymbol{a}$ the scale factor; $\boldsymbol{\varepsilon_r}$ the energy density of radiation; $\boldsymbol{\varepsilon_b}$ the energy density of baryonic matter; $\boldsymbol{\varepsilon_c}$ the critical energy density.

(g) We are not introducing any new particles.

(h) We are not changing the laws of gravity (Newton, Einstein).

(i) Instead, we are changing the way mass behaves, by using its dynamical mass rather than its baryonic mass.

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