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Dark Matter and Dark Energy as Radiating Media Accounts for the Cosmological Density Parameters

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Abstract

We present the possibility that dark matter and dark energy behave analogously to accelerating electric charges but emitting dark radiation and reacting to that radiation. Classical electromagnetic radiation-reaction is governed by the Lorentz-Dirac equation for a charged particle with length scale given by the classical electron radius. Changing to a cosmological length scale, $l \equiv \lambda R_0$, where R_0 is the Hubble radius, we couple the Lorentz-Dirac equation with the Friedmann equations utilizing the two equation of state parameters, $w = 0$ for dark and baryonic matter and $w = -1$ for dark energy. Solving the three resulting cosmological Lorentz-Dirac equations for the three types of matter yields the remarkable solutions for characteristic length scale, $\lambda = 1/15$: $\Omega_{DE} = 3/4$, $\Omega_{DM} = 1/5$ and $\Omega_{BM} = 1/20$, where Ω is the mass density normalized by the critical density. These match the observed WMAP parameters to within a few percent.

Keywords

Cosmology, Dark Matter, Dark Energy, Dark Radiation

1. Introduction

Dirac [1] derived the covariant generalization of the Abraham-Lorentz equation describing the self-forces on a point electron arising from its emission of radiation and its reaction to an external electric force. This is the Lorentz-Dirac (LD) equation. Radiation reaction (RR) theory following the LD equation is nicely summarized and applied in Barut [2]. The LD equation governs the dynamical effects of radiation emission along the particle path resulting from an "external force". Indeed, it has been shown by Ringermacher [3] that the precise covariant form of the LD equation for an external "Minkowski force" is demanded by the Frenet-Serret equations, alone, of a curve in a 4-space and is thus a universal, covariant result, independent of the nature of the physics, except for the Minkowski force requirement—that the force is orthogonal to the four-velocity. Thus, the LD equation should hold as well for cosmological forces as it does for electrodynamics. Application to electrodynamics permits the identification of two constant coefficients, the mass and classical electron radius as the length scale on the curve. Application to cosmology will result in a new cosmological length scale. In the present work we will apply the LD equation to the dynamics of a co-moving cosmology. Classical electromagnetic (EM) forces acting on classical charges will be replaced by dark forces acting on dark matter (DM), dark energy (DE) and baryonic matter (BM), resulting in an acceleration and consequent emission of dark radiation.

Modeling of dark EM and dark matter is not new and has been done using a gauge field and plasma approach [4]. Dark radiation has also been proposed [5]-[11] acting through the standard model. Indeed, Buckley [5] shows that dark radiative loss can still permit DM halos in galaxies. But no classical approach has been attempted, for example as in Jackson's "Classical Electrodynamics" [12] where radiation and radiation reaction are included. We will take a more global approach to provide some insight arising from radiation using the LD equation. Applying the cosmological scale LD equation and using the Friedmann equations as a first-order dynamics approximation for the dark material is described in the sections below. This is not intended as a complete theory, but rather provides a foundation including aspects of radiation theory and forces not included in general relativity, but relate to the unusual nature of the dark sector. We are allowing Minkowski forces and a LD formalism because we observe apparent real universe acceleration over a sufficiently large scale while we deal with a locally comoving Friedmann geometry.

2. The Cosmological Lorentz-Dirac Equation

The standard form of the electrodynamic LD equation for an external force, F, with radiation reaction forces is, for metric signature (−2):

$$F^{\mu} = m\dot{v}^{\mu} - \frac{2}{3}e^{2}\left[\ddot{v}^{\mu} + v^{\mu}\left(\dot{v}^{\alpha}\dot{v}_{\alpha}\right)\right], \tag{1}$$

$$v^{\mu} = \dot{x}^{\mu} = \frac{\mathrm{d}x^{\mu}}{\mathrm{d}\tau}, \quad v^{\mu}v_{\mu} = 1$$

The terms in the bracket of Equation (1) are the covariant radiation reaction force [2] [6]. e is the electron charge. We will couple the Friedmann equations (below) to the LD Equation (1). We use the FRW metric for the Friedmann equations to extract the behavior of the scale factor $a(t)$:

$$\mathrm{d}\tau^{2} = c^{2}\mathrm{d}t^{2} - R^{2}(t)\left(\frac{\mathrm{d}x^{2}}{1-kx^{2}} + x^{2}\mathrm{d}\theta^{2} + x^{2}\sin^{2}\theta\mathrm{d}\varphi^{2}\right) \tag{2}$$

We take $k = 0$ for the space curvature. $x = r/R_0$ and

$$R(t)=a(t)R_0,\quad R_0=c/H_0\,,\tag{2a}$$

where $R(t)$ is the expanding radius of the Hubble sphere, $a(t)$ is the scale factor and R_0 is the Hubble radius at present as defined from the Hubble constant H_0. Moving to a frame of reference with free-falling matter in an expanding space allows us to use a Lorentzian metric for the LD equation:

$$\mathrm{d}\tau^2=c^2\mathrm{d}t^2-\mathrm{d}R^2\tag{2b}$$

Ringermacher's [3] generalized LD equation is shown in Equation (3). It is a relativistic generalization of Newton's laws governing all possible motions along a general path and is strictly geometric, thus allowing for length scales other than the electron radius.

$$F^\mu=\sigma_1\dot{v}^\mu+\sigma_2\left[\ddot{v}^\mu+v^\mu\left(\dot{v}^\alpha\dot{v}_\alpha\right)\right]+\sigma_3\left[\dddot{v}^\mu+3v^\mu\left(\dot{v}^\alpha\ddot{v}_\alpha\right)\right]\tag{3}$$

For EM we see, from Equation (1), that $\sigma_1=m$ and $\sigma_2=-2/3e^2$. The third term in Equation (3) plays no known role in EM so we set $\sigma_3=0$. Let us rewrite Equation (1) in the form of total acceleration, α^μ:

$$\alpha^\mu=\dot{v}^\mu-\frac{2}{3}l\left[\ddot{v}^\mu+v^\mu\left(\dot{v}^\alpha\dot{v}_\alpha\right)\right],\tag{4}$$

where l is a length scale to be determined replacing the classical electron radius. α^μ is the acceleration arising from an external force, F^μ. We have maintained the EM form of the LD equation changing only the length scale. The motion we are going to track for the trajectory of the LD equation is the radial expansion of the universe. The Hubble expansion in physical radial coordinates is described by:

$$\frac{\dot{R}}{R}=\frac{\dot{a}}{a}=H(t)\equiv H\,,\tag{5}$$

where $a(t)$ is the scale factor. Time and distance are normalized to the Hubble time and Hubble radius so that at the present time $a(t_0)=a(1)=1$ and $\dot{a}(1)=1$. The Hubble constant, $H_0=H(t_0)$, is taken as 73 km/s/Mpc. The metric (2b) is used for the remaining LD calculations.

Confining the motion to line of sight (constant θ,φ) on the hypersphere, defining $\dot{v}^1=\ddot{R}$ and taking the non-relativistic limit of Equation (4) yields

$$\alpha=\alpha_N-\frac{2}{3}l\left[\frac{\dddot{R}}{c}-\frac{\dot{R}\left(\alpha_N^2\right)}{c^3}\right],\tag{6}$$

where we have defined the Newtonian acceleration $\alpha_N=\dot{v}=\ddot{R}$. The over-dot is a time derivative from here on. Equation (6) is the LD equation for a massive universe over Hubble-flow distances in co-moving coordinates. Its dynamics will describe the universe's response to an external Minkowski force spanning the Hubble sphere. The acceleration allows for the emission of dark radiation and a reaction force. In order to address this equation, consider the Hubble expansion in the FRW formalism. Our equation of state is $p=w\rho c^2$, where ρc^2 is the energy density of the medium being addressed. The Friedmann equations for flat space are:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho \tag{7a}$$

$$\frac{\ddot{a}}{a} = \frac{-4\pi G\rho}{3}(1+3w) \tag{7b}$$

The continuity equation, for convenience, is:

$$\dot{\rho} = -3H\rho(1+w). \tag{7c}$$

In order to evaluate the acceleration, Equation (6), we will need to calculate the various time derivatives of *R*. From Equation (5) we have:

$$\frac{\dot{R}}{R} = H \tag{8}$$

Differentiating Equation (7b) and using Equation (7c) together with Equation (5), yields:

$$\frac{\dddot{R}}{\ddot{R}} = -H(2+3w) \tag{9}$$

The general LD acceleration becomes, using Equations (6), (8) and (9):

$$\alpha = \alpha_N\left[1+\frac{2}{3}\frac{lH}{c}(2+3w)\right]+\frac{2lHR}{3c^3}\left(\alpha_N^2\right) \tag{10}$$

This can be simplified and referenced to the present time:

$$\alpha = \alpha_N\left[1+\frac{2}{3}\lambda(2+3w)\right]+\frac{2}{3}\lambda\left(\frac{\alpha_N^2}{\alpha_0}\right), \tag{11}$$

where,

$$\alpha_0 \equiv cH_0,\quad l \equiv \lambda R_0 \quad \text{and} \quad R_0 \equiv \frac{c}{H_0} \tag{11a}$$

Equation (11) is the cosmological LD equation describing the acceleration of matter, given its equation of state, subject to an external dark force. If we measure all accelerations in terms of α_0, in Equation (11), by dividing through by α_0, then we can think of it as the "critical acceleration". If the force is constant and attractive (negative) for a given volume, we can then express the energy density (which can be negative) of the accelerated medium from Newton's laws as

$$\frac{\rho}{\rho_c} \equiv \frac{-\alpha_0}{\alpha}, \tag{12}$$

where $\rho_c \equiv 3H_0^2/8\pi G$ is the critical mass density. The constant force density is

$$F_0 = -\alpha_0\rho_c = \frac{-c^4}{2G\left(\frac{4}{3}\pi R_0^3\right)}. \tag{13}$$

Thus, the constant force is:

$$F_0 = -\frac{c^4}{2G} \tag{14}$$

This is, in fact, the black hole force binding a universe of the Hubble mass with the event horizon at the Hubble radius. This suggests the dark force involved is gravitational.

Equation (11) can be converted into a mass density using (12):

$$\frac{\rho}{\rho_c} = \frac{-1}{\frac{\alpha_N}{\alpha_0}\left[1+\frac{2}{3}\lambda(2+3w)\right]+\frac{2}{3}\lambda\left(\frac{\alpha_N^2}{\alpha_0^2}\right)} \tag{15}$$

Mass density is now measured in units of the critical density while the Newtonian acceleration is measured in units of the critical acceleration. From Equation (11), if we take the baryonic matter (BM) only to be subject to the Newtonian acceleration (the case when $l = 0$) then $\alpha_N = \alpha_{BM}$. We can then rewrite Equation (15) as the general density for the various phases of media, using (12).

$$\Omega = \frac{1}{\frac{1}{\Omega_{BM}}\left[1+\frac{2}{3}\lambda(2+3w)\right]-\frac{2}{3}\lambda\left(\frac{1}{\Omega_{BM}^2}\right)} \tag{16}$$

Equation (16) points to BM as the reacting medium. The external force then acts upon the various media. Choosing the medium subject to an external force to be DE, we set $w = -1$ in Equation (16):

$$\Omega_{DE} = \frac{1}{\frac{1}{\Omega_{BM}}\left[1-\frac{2}{3}\lambda\right]-\frac{2}{3}\lambda\left(\frac{1}{\Omega_{BM}^2}\right)} \tag{17}$$

We need to be careful for the case $w = 0$ since this includes both DM and BM so we must sum both densities:

$$\Omega_{DM} + \Omega_{BM} = \frac{1}{\frac{1}{\Omega_{BM}}\left[1+\frac{4}{3}\lambda\right]-\frac{2}{3}\lambda\left(\frac{1}{\Omega_{BM}^2}\right)} \tag{18}$$

We also know:

$$\Omega_{DE} + \Omega_{DM} + \Omega_{BM} = 1 \tag{19}$$

Equations (17)-(19) comprise three density equations for the three media, DE, DM and BM, but four unknowns including λ.

3. Solutions of the Cosmological Lorentz-Dirac Equations and Choice of Length Scale

We chose the cosmological scale, Equation (11a), as $l = \lambda R_0$. We are not aware of a way to relate λ to the matter densities to provide a fourth equation unless we postulate a conversion of one form of matter into another. However, it is fair to assume $0 < \lambda < 1$. We also require for each density $1 > \Omega_x > 0$. There are many solutions that do not qualify or do not approach known parameter data. There is, however, a single remarkable LD solution that fits all three parameters within a few percent and is also in rational form for the scale $\lambda = 1/15$, or about 300 Mpc:

$$\Omega_{DE} = 0.750, \quad \Omega_{DM} = 0.200, \quad \Omega_{BM} = 0.050 \tag{20}$$

The LD solution (Equation (20)) is compared to observed energy density parameters from WMAP, Planck and CMB. for Hubble constant $h = 0.73$ in **Table 1**.

Table 1. A comparison of LD, WMAP, Planck and CMB density parameters for $h = 0.73$.

	LD	WMAP	Planck	CMB
Ω_{DE}	0.750	0.721	0.703	0.69
Ω_{DM}	0.200	0.233	0.220	0.225
Ω_{BM}	0.050	0.047	0.042	0.042

Choices of $1/14 > \lambda > 1/17$ match the data well also but are not as unique as the solutions for 1/15 resulting in all, near correct, rational values. Greater or smaller values of λ are significantly different from observed values or produce negative or imaginary results.

4. Power Radiated by Dark Matter and Dark Energy

Since we have an exact match between the EM LD equation and the Cosmological LD equation, we can extract and apply the EM power radiated for an accelerating charge to power radiated by DM and DE very easily. The power radiated by a Classical EM charge is the second term in the bracket from Equation (1):

$$\frac{\mathrm{d}p^{\mu}}{\mathrm{d}t} = -\frac{2}{3}\frac{e^2}{c^3}v^{\mu}\left(\dot{v}^{\alpha}\dot{v}_{\alpha}\right), \tag{21}$$

where the 4-momentum is

$$p^{\mu} = m_0 c\, v^{\mu} = \left(\gamma, \gamma\,\beta\right) m_0 c = \left(\frac{E}{c}, \frac{p^i}{c}\right). \tag{22}$$

Thus the power radiated by a non-relativistic EM charge is:

$$\frac{\mathrm{d}E}{c\,\mathrm{d}t} = \frac{2}{3}\frac{e^2}{c^2}\frac{\dot{v}^2}{c^2} \tag{23}$$

Dividing by the mass defines the EM length scale $R_e = e^2/m c^2$ which we then convert immediately to the chosen cosmological scale $l = \lambda R_0$:

$$\frac{\mathrm{d}E}{m c\,\mathrm{d}t} = \frac{2}{3}\frac{e^2}{m c^2}\left(\frac{\dot{v}^2}{c^2}\right) \to \frac{2}{3}\lambda R_0\left(\frac{\dot{v}^2}{c^2}\right) \tag{24}$$

The power radiated must refer to that radiated from DM and DE. Since the sum of these densities is 95% of the critical density, then the acceleration must be approximately α_0. Thus, the power radiated by a mass m of DM and DE over the distance scale $l = \lambda R_0$ is:

$$\frac{\mathrm{d}E}{\mathrm{d}t} = \frac{2}{3}m\,\lambda R_0\left(\frac{\alpha_0^2}{c}\right) = \frac{2}{3}m c^2 \lambda H_0, \tag{25}$$

where $H_0 = 2.3\times10^{-18}\,\mathrm{s}^{-1}$. α_0 is approximately $7\times10^{-10}\,\mathrm{m\cdot s^{-2}}$ which, in fact, is the actual expansion acceleration of the universe over cosmological distances on the order of 300 Mpc.

The fractional energy radiated per second is:

$$\frac{1}{mc^2}\frac{dE}{dt} = \frac{2}{3}\lambda H_0 = \frac{2}{45}H_0 \tag{26}$$

The fractional energy radiated over one Hubble time is about 4%. This result is only intended to describe the analogous power radiated methodology, but does not consider the actual time dependence of the solutions, out of the scope of the present work.

5. Temperature of Dark Matter

Knowing the power radiated by DM from Equation (25), we can use the Stefan-Boltzmann law to extract the temperature. Over the Hubble sphere, the radiated power is given by:

$$\frac{dE}{dt} = 4\pi R_0^2 \sigma T^4, \tag{27}$$

where σ is the Stefan-Boltzmann constant, $5.67\times10^{-8}\ \mathrm{W\cdot m^{-2}\cdot K^{-4}}$. Equating this to (25) yields:

$$4\pi R_0^2 \sigma T^4 = \frac{2}{3}\left(\Omega_{DM}\,\rho_c \frac{4\pi R_0^3}{3}\right)\frac{\lambda c}{R_0}, \tag{28}$$

where we have converted the DM mass to critical energy density. This yields the temperature:

$$\sigma T^4 = \frac{2}{9}\lambda \Omega_{DM}\,\rho_c\, c$$

or, $T = 10.9\ \mathrm{K}$.

6. Conclusion

The LD equation describes the radiation reaction of radiating charged particles subject to an external EM force. The EM length scale is the classical electron radius. However, Ringermacher [3] has shown that the LD equation is strictly a geometric equation for the trajectory of a general curve in 4-space and therefore may support alternative physics as well. We attempt to apply this equation to the trajectory of an expanding space, at cosmological scale, governed by the Friedmann equations. This then postulates that DM and DE must radiate (dark radiation) and together with BM provides the inertia resulting in radiation-reaction. With these assumptions we are able to generate three LD equations in the three unknown matter densities fixed by a choice of length scale $l = \lambda R_0$. For $\lambda = 1/15$, the solutions to the three LD equations are: $\Omega_{DE} = 3/4$, $\Omega_{DM} = 1/5$, $\Omega_{BM} = 1/20$. These match the WMAP, Planck and CMP parameters to within a few percent. This reinforces the possibility that DM and DE are radiative components of a type of matter subject to a dark force. The force appears to be an external gravitational-like force (note the minus sign in Equation (12)) acting on matter in our universe inducing emission of dark radiation analogous to that from an accelerating electric charge. We do not know the significance of this particular length scale other than defining an inhomogeneous radiating region of space. There is room for one more equation defining a unique scale factor that could be related to one form of matter converting to another.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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