Journal of High Energy Physics, Gravitation and Cosmology, 2026, 12(2), 1131-1141
https://www.scirp.org/journal/jhepgc
ISSN Online: 2380-4335
ISSN Print: 2380-4327

A Dark Energy Hypothesis X

—The ΛCDM Theory and a DEH: Comparison and Contrast

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How to cite this paper: Togeas, J. (2026) A Dark Energy Hypothesis X. *Journal of High Energy Physics, Gravitation and Cosmology*, **12**, 1131-1141.
https://doi.org/10.4236/jhepgc.2026.122058

Received: February 9, 2026
Accepted: April 21, 2026
Published: April 24, 2026

Abstract

A major difference from the standard ΛCDM theory is the dark matter/dark energy dynamic of a DEH, which produces energy conservation, two testable predictions, and the increase of information and order with increasing entropy in the early universe. A comparison of solutions of the Friedmann-Lemaître equation reveals that the two models complement each other in the early universe but are otherwise incompatible making them essentially different.

Keywords

Dark Matter, Dark Energy, Cosmological Predictions, Cosmological Information

1. Introduction

The purpose of this article is to compare and contrast the ΛCDM theory and a Dark Energy Hypothesis, which is an alternative cosmology. The touchstone is the nature of dark energy. In the former, which of course is the standard cosmology, it is Einstein's cosmological constant, Λ. In the latter, it is a parameter that decreases monotonically with time, $\Lambda = 1/\eta^2 a^2$, where "a" is the scale factor and the conformal time: $a d\eta = c dt$. Hence in the ΛCDM theory, dark energy density is constant in time but in a DEH it decreases: $\Lambda = \kappa \epsilon_\lambda$, where κ is the Einstein gravitational constant, $\kappa = 8\pi G/c^4 = 2.076 \times 10^{-43}\ \mathrm{m \cdot J^{-1}}$.

2. The Dark Matter/Dark Energy Dynamic

Overview. This is one of the most striking differences between a DEH and the ΛCDM theory. Dynamic means that in a DEH dark matter continuously transforms into dark energy over a period of about 22.5 Gyr, whence it disappears [1].

This dynamic has three principal consequences: total energy is conserved in a DEH in contrast to the ΛCDM theory; the dynamic leads to two testable predictions; and it leads to the introduction of information theory into cosmology. Each of the three is described in turn.

Conservation of energy. Total energy U is conserved as long as dark energy remains in existence.

$$U = U_\lambda + F(dm) + F(b) = \Gamma/\kappa \tag{1}$$

The first term in the trio is dark energy, followed by the Helmholtz free energies of dark matter and baryonic matter. Γ on the right is the conserved scale length of the cosmos and κ the Einstein gravitational constant. Dark energy is

$$U_\lambda = \frac{a}{\kappa\eta^2}$$

By Hubble's Law, the scale factor will always increase in hyperbolic space, and hence dark energy must always increase. As in the ΛCDM theory, baryonic matter is conserved, $F(b) = 0.05\Gamma/\kappa$, so Equation (1) becomes

$$U - F(b) = U_\lambda + F(dm) = 0.95\Gamma/\kappa \tag{2a}$$

Since the sum of dark energy and dark matter is a constant, and since dark energy must always increase, then the dark matter free energy must always decrease, which is their dynamic. Equation (2a) can be written in the simplified form

$$\lambda + \chi(dm) = 0.95 \tag{2b}$$

where λ is the dark energy parameter:

$$\lambda = (\cosh(\eta) - 1)/6\eta^2 \tag{3}$$

and $\chi(dm)$ is the dark matter parameter. Hence, the dynamic is

$$d\lambda = -d\chi(dm) > 0$$

The details are implicit in Equation (7) and explicit in the reference.

By contrast total energy is not conserved in the ΛCDM theory. The total energy is

$$U = U_\lambda + F(dm) + F(b)$$

The two free energy terms are constants because the dark matter and baryonic masses are constant. The dark energy density is constant because of the constancy of the Einstein cosmological constant: $\Lambda = \kappa\varepsilon_\lambda$. Then the dark energy is $U_\lambda = \varepsilon_\lambda a^3$, which grows without limit. Hence, the total energy is not constant.

Two testable predictions. Given that dark matter continuously transforms into dark energy, then the dark matter to dark energy ratio, $\chi(dm)/\lambda$, should increase with redshift on the backward lightcone, which is the first prediction. It is testable because in July 2023 the European Space Agency launched the Euclid probe to survey dark matter and dark energy among other cosmological parameters, so the data collected should verify or invalidate it. It is easily quantified.

Using Equation (7) the cosmological redshift is

$$z=\frac{a_0-a}{a}=\frac{\cosh(\eta_0)-1}{\cosh(\eta)-1}-1=\frac{130.35}{\cosh(\eta)-1}-1$$

The conformal time for the current epoch is η_0 = 5.571 as shown in §4, which gives the right-hand term. Then the conformal time corresponding to the redshift is

$$\eta=\cosh^{-1}\left[1+\frac{130.35}{z+1}\right]$$

Combining this with Equations (2b) and (3) gives

$$\frac{\chi(dm)}{\lambda}=\frac{5.70\eta^2}{\cosh(\eta)-1}-1 \tag{4}$$

The procedure is to choose a redshift, find η, and calculate the ratio from Equation (4).

A range of small values of z = 0 - 1, Δz = 0.1, gives an excellent fit to a straight line as Figure 1 shows. Linear regression gives

$$\frac{\chi(dm)}{\lambda}=0.3768+0.7275z \qquad \text{with} \quad r=0.9989$$

Larger values of z can be conveniently fit to a semilog plot. As $z\to\infty$, $\eta\to 0$, and the ratio approaches a limiting value as Figure 2 shows. In a DEH IX this is

$$\frac{\chi(dm)}{\lambda}=\frac{13/15}{1/12}=10.4$$

In Equation (4) $\cosh(\eta)-1\to\eta^2/2$, so

$$\frac{\chi(dm)}{\lambda}=11.4-1=10.4$$

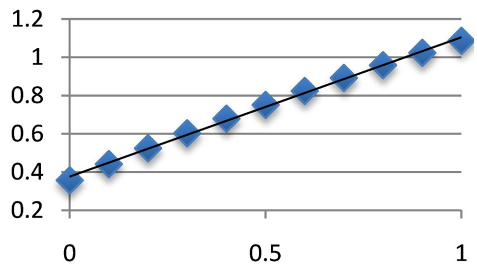

Figure 1. Dark matter/dark energy ratio vs. redshift z.

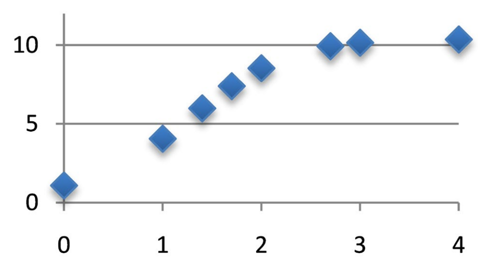

Figure 2. Dark matter/dark energy ratio vs. $\log_{10}z$.

Data from Euclid will lead to a measured value of the deceleration parameter, which is expected to be $q_0 \sim -1$ corresponding to the acceleration of the expansion. In contrast the expansion decelerates in a DEH leading to the second prediction:

$$q_0 = 1/\left(1+\cosh(5.571)\right) = 0.00756$$

<u>Information theory</u>. The question to be answered is the relationship between the change in information and the change in entropy: what is the correct sign?

$$\pm k_B \Delta I = \Delta S > 0$$

The entropy is the cosmological entropy given in DEH VIII-IX; the Boltzmann constant is required because information is a dimensionless quantity. The following short summary defines notation [2].

The bit is the unit of information with a value of 0 or 1 assigned to dark matter or dark energy. Let Ω be a set of cells with one bit of information in each cell; let the total number of bits for dark energy and dark matter be ω_λ & ω_χ, resp., so that $\Omega = \omega_\lambda + \omega_\chi$. Shannon's measure of information is.

$$i = -\left[f(\lambda)\ln f(\lambda) + f(\chi)\ln f(\chi)\right]$$

where f is the fraction of that parameter in the model: $f(\lambda) + f(\chi) = 1$. In information theory $f = \omega/\Omega$ for each parameter whereas in a DEH $f(\lambda) = \lambda/0.95$ and $f(\chi) = \chi(dm)/0.95$ from Equation (2b). Shannon's measure is the average information per parameter. Hence, $I = \Omega i$. The maximum value of Shannon's measure is for $f(\lambda) = f(\chi) = 1/2$ giving $i_{\max} = \ln(2) = 1$ bit.

Figure 3 illustrates the dynamic with

$$i = -\left[(1-x)\ln(1-x) + x\ln x\right]$$

If x is dark energy, then the early universe where dark matter dominates is to the left of the maximum and evolution occurs left to right. If x is dark matter, then the early universe is to the right of the maximum and evolution occurs right to left.

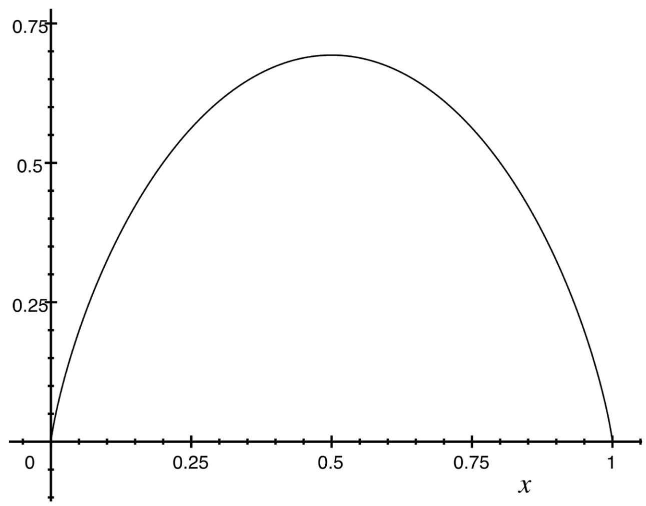

Figure 3. Shannon's measure of information.

In what follows let $\eta_2 > \eta_1$, so that $\Delta I = I_2 - I_1$ and $\Delta S = S_2 - S_1 > 0$. The answer to the question is simple since $\Delta I = \Omega(i_2 - i_1)$ and the sign will be positive for the early universe and negative for the late no matter which graphing is chosen.

In the realm of dark matter dominance, $f(\chi) > f(\lambda)$, $\Delta i > 0$, so $k_B \Delta I = \Delta S > 0$;

In the realm of dark energy dominance, $f(\chi) < f(\lambda)$, $\Delta i < 0$, so $-k_B \Delta I = \Delta S > 0$.

Hence, information appears in the early universe and disappears in the late. In the realist's perspective, dark matter produces information and dark energy destroys it; the positivist would say there's a correlation.

In a sense this should not surprise since structure emerges from a uniform medium in any evolutionary cosmology, but here in the dark matter/dark energy dynamic with information theory it appears explicity, not implicitly. That increasing entropy correlates to loss of information and of order is correct only half of the time on the cosmological scale. In our epoch of dark energy dominance, dark matter is the gravitational cohesive of cosmological structure, but in the epochs when it is dominant, it produces structure. Dark matter is the ordering parameter.

3. Tools for Further Comparisons and Contrasts

The Friedmann-Lemaître equation governs the evolution of the universe:

$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{kc^2}{a^2} = \frac{8\pi G\rho}{3} + \frac{\Lambda c^2}{3} \tag{5a}$$

It can also be written as an algebraic equation:

$$1 = \Omega_r + \Omega_m + \Omega_\lambda - \Omega_k \tag{5b}$$

where r, m, λ and k refer to radiation, matter (both dark and baryonic), dark energy, and curvature. The dimensionless Ω parameters are relative energy densities as shown in **Appendix**. In the ΛCDM theory space is flat, $k = 0$, but in a DEH it is hyperbolic, negatively curved, $k = -1$.

Three works are sources for the ΛCDM theory. Two of them are landmark studies: the Nobel prize winning study of Type Ia supernovae as standard candles for Hubble's Law [3]; and the Planck collaboration of 2018 in which the temperature fluctuations in the cosmic microwave radiation (CMR) were fit to a six-parameter ΛCDM model to produce a Hubble constant $H_0 = 67.4\ \text{km}\cdot\text{s}^{-1}\cdot\text{Mpc}^{-1} = 2.18 \times 10^{-18}\ \text{s}^{-1}$ and other results [4]. The third is the Benchmark Model based on the Friedmann-Lemaître equation [5].

The principal source for a DEH is the ninth paper in the DEH series, which is a summary of the first eight.

The first step is to specify numbers. 1) The Hubble constant will be the reciprocal of the Hubble time: $t_H = 14.4\ \text{Gly}$ giving $H_0 = 2.20 \times 10^{-18}\ \text{s}^{-1}$. There is no general agreement on the value of the Hubble constant, but the range of possible values is narrow. This is the value used in the DEH papers; evidently there would be little change in the numerical results if, for example, the Planck collaboration value were used. 2) The proportions of dark energy and matter will be that of Perlmutter *et al.*: $\Omega_\lambda = 0.70$ and $\Omega_m = 0.30$.

4. Integration of the Friedmann-Lemaître Equation

For the ΛCDM theory use the Benchmark model in which $k = 0$ and Λ is constant. As shown in [6] the exact result is

$$a = \alpha^{1/3}\left(\sinh\left(3\gamma t/2\right)\right)^{2/3} \tag{6}$$

where $\alpha = \kappa M c^2/\Lambda$ and $\gamma = c\sqrt{\Lambda/3}$.

As shown in [7] integration for a DEH gives

$$a = \frac{\Gamma}{6}\left(\cosh\left(\eta\right)-1\right) \quad \& \quad ct = \frac{\Gamma}{6}\left(\sinh\left(\eta\right)-\eta\right) \tag{7}$$

Equation (7) incorporates energy conservation. The quantity Γ is the conserved characteristic scale length of the cosmos as stated in Section 1, whose total conserved energy then is $U = \Gamma/\kappa$.

Numerical values for the parameters in Equations (2) and (5) must be found in order for them to be useful. That is the reason for the next step.

5. The Hubble Parameter

In the Benchmark Model

$$H = \frac{\mathrm{d}\ln\left(a\right)}{\mathrm{d}t} = \gamma\coth\left(3\gamma t/2\right) \tag{8}$$

With t_0 = 13.74 Gyr (Ryden, p. 92) and the above Hubble constant, γ = 0.05761 Gyr^{-1}, giving $\Lambda = 1.11 \times 10^{-52}\ \text{m}^{-2}$, which is time-invariant.

In a DEH,

$$H = \frac{\mathrm{d}\eta}{\mathrm{d}t}\frac{\mathrm{d}\ln\left(a\right)}{\mathrm{d}\eta} = \frac{6c\sinh\eta}{\Gamma\left[\cosh\eta-1\right]^2} \tag{9}$$

Given that the cosmos is 70% dark energy at the present epoch, then the dimensionless dark energy parameter of a DEH is

$$\lambda_0 = 7/10 = \left[\cosh\eta_0 - 1\right]/6\eta_0^2$$

giving $\eta_0 = 5.571$. With the above value of the Hubble constant, $\Gamma = 6.320 \times 10^{24}$ m. Then the scale factor in the present epoch is $a_0 = 1.373 \times 10^{26}$ m.

6. Mass Energy in the ΛCDM Theory

This is the final step in making Equation (6) useful for numerical work. The method of finding Mc^2 is a curious one of taking the ΛCDM theory and a DEH into the early universe and comparing them. In the early universe, Equation (6) becomes

$$a = \alpha^{1/3}\left(3\gamma t/2\right)^{2/3}$$

while Equation (7) becomes

$$a = \frac{\Gamma \eta^2}{12} \quad \& \quad ct = \frac{\Gamma \eta^3}{36}$$

giving

$$a = \left(\frac{3\Gamma}{4}\right)^{1/3} (ct)^{2/3}$$

Since $a^3 \propto t^2$ in both cases, equate the two and solve for the total mass energy, which gives the simple result

$$Mc^2 = \frac{\Gamma}{\kappa} = 3.068 \times 10^{67}\ \text{J} \tag{10}$$

The mass energy in the Benchmark Model is the total energy in a DEH. Since both are conserved quantities, then if they are equal in the early universe they must be equal in the current epoch. The goal is thus realized.

$$\alpha^{1/3} = 3.84 \times 10^{25}\ \text{m}$$

7. Transformation of Metrics

The ΛCDM and DEH metrics can be transformed into one another, a mathematical manipulation that has been long known [7]. The euclidean space of the former has a Minkowski metric, here expressed in spherical polar coordinates.

$$ds^2 = c^2 dt^2 - dR^2 - R^2 d\Omega^2 \tag{11a}$$

Setting $ct = c\tau \cosh(\chi)$ and $R = c\tau \sinh(\chi)$ gives

$$ds^2 = c^2 d\tau^2 - a^2 \left[d\chi^2 + \sinh^2(\chi) d\Omega^2 \right] \tag{11b}$$

with $a = c\tau$. This is the metric for hyperbolic space, which is that of a DEH. Given this transformation and the close relationship of the two models as revealed in Section 6, the temptation is to say that they are really two representations of the same cosmology, but that's erroneous.

8. Two Incompatibilities

1) Equation of state for dark energy. This is a relationship between the pressure exerted by dark energy and its energy density: $p = w\varepsilon$, where w is a constant.

The universe expands adiabatically because the cosmological temperature is uniform, which precludes heat transport: $dU + pdV = 0$. With $U = \varepsilon V$, the first law of thermodynamics becomes

$$\varepsilon a^{3(1+w)} = \text{constant} \tag{12}$$

In the ΛCDM theory, $\varepsilon = \Lambda/\kappa$ is constant, meaning that $w = -1$: dark energy exerts a pressure that is the negative of its energy density; $w_0 = -1.03 \pm 0.03$ according to the Planck collaboration, consistent with a constant dark energy density. In a DEH $\varepsilon a^3 = U_\lambda$, the total dark energy. Hence $w = 0$ meaning that dark energy is pressureless.

2) Evolution. For a specific example, how does the cosmos evolve into a state where $\Omega_{\lambda,0} = 7/10$ and $\Omega_{m,0} = 3/10$?

Benchmark model. Equation (6) can be rewritten

$$\varepsilon_\lambda = \varepsilon_m \left[\sinh\left(3\gamma t/2\right)\right]^2 = \Lambda/\kappa$$

The two energy densities will be equal when the hyperbolic sign term is unity, which occurs for t = 10.2 Gyr. Since $\Omega_\lambda = \Omega_m = 1/2$ at this time, evolution will have to continue to a later time with the matter density decreasing until the required state is reached at t_0 = 13.74 Gyr.

DEH. In the early universe, the dimensionless dark energy parameter $\lambda = \left(\cosh(\eta)-1\right)/6\eta^2 = 1/12$ for $\eta \to 0$. From here it must evolve to λ = 7/10. However, if space is spherical λ can only decrease and if it's flat it can't evolve at all; space must be hyperbolic to evolve to the required state, which occurs at t_0 = 14.0 Gyr by Equation (7). In other words, only hyperbolic space is compatible with dark energy dominance in the present epoch.

9. Distribution of Dark Energy, Matter, and Radiation

The fractional contribution of each in the present epoch is a relative energy density. The numerical work that produces the fourth column in the following Table 1 is in **Appendix**.

Table 1. Cosmological parameters in three models.

Component	Perlmutter	Planck	DEH
$-\Omega_k$	0	−0.0007 ± 0.0019	0.9558
Ω_λ	0.70	0.685	0.0308
Ω_m	0.30	0.315	0.0132
Ω_r	0	<0.01%	0.0002

The parameters sum to unity as required by Equation (5b). Curvature dominates the dynamics of a DEH in this epoch. The three entries agree that the contribution of radiation is negligible, which is why it has been ignored throughout this article. On the relative contributions of dark energy and matter in a DEH, note that 0.0308/0.0132 = 2.33 ~ 7/3 in the fourth column.

The fourth column suggests that the DEH universe is emptier than that of the ΛCDM, which is confirmed by the following simple calculation. From the data given in §5, the mass density of the latter in the current epoch is $\rho_0 = 2.72 \times 10^{-27}$ kg·m^{-3}. The critical mass density is $\rho_{cr,0} = 3H_0^2/8\pi G = 8.7\times10^{-27}\ \mathrm{kg\cdot m^{-3}}$ corresponding to $\Omega_{m,0} = 1$; then 2.7/8.7 = 0.31 with a nice consistency. Dark matter in a DEH continuously changes into dark energy, meaning that the total mass decreases with time. By the DEH formalism, the total mass at this epoch is $M = 0.3\Gamma/\kappa c^2 = 1.016 \times 10^{50}$ kg, giving $\rho_0 = 3.93 \times 10^{-29}$ kg·m^{-3}, which is about two orders of magnitude smaller.

10. The Late Universe

"Late universe parameters"—this is a phrase from the Planck collaboration paper.

Its meaning here will be that the argument x is sufficiently large that $\cosh(x) = \sinh(x) = \exp(x)/2$, and $\coth(x) = 1$ with negligible error. This is certainly true for the conformal time for the current epoch $\eta_0 = 5.571$ in a DEH.

"Late universe" in the ΛCDM Theory. Equation (6) becomes

$$a = (\alpha/4)^{1/3} \exp(\gamma t)$$

meaning that the universe has entered a de Sitter state of continuous acceleration. The deceleration parameter is

$$q = -\frac{a\ddot{a}}{\dot{a}^2} = -1$$

The Hubble parameter is simply $H = \gamma = 1.82 \times 10^{-18}\ \text{s}^{-1} = \text{constant}$.

"Late universe" in a DEH. Equation (7) becomes

$$a = ct \quad \text{giving} \quad H = \frac{1}{t}$$

The formula for the Hubble parameter is the signature of Milne's kinematic relativity, where Hubble's law is

$$v = \dot{a} = Ha = \frac{a}{t} = \text{constant}$$

Since the recession is unaccelerated for a given galaxy, in dramatic contrast to the previous section, the deceleration parameter $q \equiv 0$, corresponding to $q = 1/(1+\cosh(\eta)) \to 0$ in a DEH. In Milne's cosmology $\Lambda = 0$, which corresponds to $\Lambda \to 0$ here. Hence, instead of entering a de Sitter state, the universe enters a Milne-like state.

11. Dark Energy in the Two Cosmologies

As shown in Section 1, total energy in the ΛCDM theory must increase without limit given the constancy of Λ; it's a curious feature that the dark energy density is invariant amid the evanescence of other parameters. As is well-known, Einstein who invented the cosmological constant later repudiated it, even writing to Lemaître that he found it "ugly", that "I am unable to believe that such an ugly thing should be realized in nature." Its ugliness lay in its simple addition to his gravitational law [8]. By contrast, the cosmological parameter of a DEH is not part of the gravitational law, but rather a deduction from the law that has no cosmological constant.

The Russian theoretician Matvei Bronstein (1906-1938) proposed that the cosmological "constant" increases with time [9]. His motivation was the time symmetry of the Friedmann-Lemaître equation, which is consistent with either the increase or decrease of the scale factor; supposedly, its observed increase was due to boundary conditions, a statement that he deemed unsatisfactory. (The reason that it's increasing today is that it was increasing yesterday, and was increasing the day before that, etc.). An increasing value meant that Λ functions like an entropy increase that drives the expansion. It also means that the expansion is no longer adiabatic with the consequence that energy is dissipated, that the first law is no longer a law, whose equation would become

$$dU + pdV = -\frac{Vd\Lambda}{\kappa} < 0 \quad \text{because} \quad d\Lambda > 0$$

He was encouraged to discount energy conservation by the BKS conjecture of his day (Bohr, Kramers, Slater) that energy isn't conserved in individual atomic events but is only a constant statistically, a short-lived view of the first law.

Peebles and Ratra [10] have written that dark energy may be evolutionary, "allowing the arguably appealing picture that the dark energy density is evolving to its natural value, zero, and is small now because the expanding universe is old." The cosmological parameter of a DEH is a "late universe parameter" whose numerical value is evolving towards zero, its value in the current epoch being, with numbers from §4,

$$\Lambda_0 = \frac{1}{\eta_0^2 a_0^2} = 1.71 \times 10^{-54}\ \text{m}^{-2}$$

which is nearly two orders of magnitude smaller than the cosmological constant of the ΛDCM theory.

The relationship of a DEH to the Bronstein proposal seems straightforward. The former conserves total energy, the latter does not. The dark energy density in a DEH decreases with time, $d\Lambda < 0$, but the total dark energy increases, $dU_\lambda > 0$, which leads to a cosmological entropy increasing in time. Given a realist perspective on DEH, the driving force for expansion is the conversion of dark matter into dark energy, and the increase in entropy is a by-product of the conversion. However, if Bronstein's proposed increase in the cosmological constant solved the time symmetry problem, then the conversion of dark matter into dark energy should be the equivalent solution in a DEH.

Finally, if the cosmological parameter of a DEH is "better-behaved" than the cosmological constant in a ΛCDM, would it make sense to replace the latter Λ with the former? That's an easy question to answer: No, it wouldn't make any sense at all; the comparison and contrast clearly shows that. There are too many implications of the cosmological parameter that are foreign to the ΛCDM theory. ΛCDM and DEH are distinct cosmologies, not proposals with interchangeable parts: one has to choose one or the other; one can't have both.

Conflicts of Interest

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

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Appendix

These are the energy densities required to calculate the cosmological parameters in **Table A1**: $\eta_0 = 5.571$; $a_0 = 1.373 \times 10^{26}$ m; $\sigma = 7.565 \times 10^{-16}$ Pa·K^{-4}; $T_0 = 2.7255$ K.

Table A1. Energy densities for cosmological parameters.

Energy density	Numerical (Pa)
$\varepsilon_k = 1/\kappa a_0^2$	2.555×10^{-10}
$\varepsilon_\lambda = \varepsilon_k/\eta_0^2$	8.233×10^{-12}
$\varepsilon_m = 3\varepsilon_\lambda/7$	3.522×10^{-12}
$\varepsilon_r = \sigma T_0^4$	4.174×10^{-14}
Σ	2.673×10^{-10}