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Hubble Parameter Evolution in the 4DEU Framework: No Need for Dark Energy and Implications for the Hubble Tension

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Abstract

The apparent late-time acceleration of cosmic expansion can be consistently explained without invoking a dark energy component when interpreted within the Four-Dimensional Electromagnetic Universe (4DEU) framework. Specifically, we investigate the redshift evolution of the Hubble parameter and demonstrate that observational data can be reproduced without introducing any additional energy component. In this scenario, the universe is described as a real four-dimensional hypersphere expanding uniformly at the rate c along a privileged radial coordinate T. We live, and perform our observations, within the three-dimensional hyperspherical section of this real four-dimensional universe. The observed variation of the Hubble parameter $H(z)$ naturally emerges as a geometric projection effect, rather than as evidence for new physics. Using a model-independent compilation of type Ia supernovae and cosmic chronometers, we show that the linear 4DEU prediction $H(z) = H_0(1+z)$ reproduces the data with robust statistical agreement, and that the consistency is markedly higher, with a likelihood ratio of roughly 219:1, for $H_0 \approx 67$ km·s^{-1}·Mpc^{-1} (Planck-CMB) than for $H_0 \approx 73$ km·s^{-1}·Mpc^{-1} (local distance ladder). The likelihood analysis indicates that the lower value is favored by the data by more than two orders of magnitude, strongly disfavoring the higher local determination. While extended gravity theories have been proposed to address the dark-energy problem (as reviewed by Capozziello & Francaviglia), the 4DEU framework offers a purely geometric resolution without additional fields or free parameters. Recent theoretical developments by Maglione provide the foundations of this approach, which consistently interprets cosmic expansion as the projection of a uniform 4D universe evolution onto its 3D portion where we live, eliminating the need to hypothesize dark energy and strongly suggesting that the resolution of the Hubble tension lies in the Planck-

CMB value of H_0.

Keywords

Dark Energy Problem, Four-Dimensional Electromagnetic Universe (4DEU), Cosmic Expansion, Hubble Parameter, Geometric Projection, Hubble Tension

1. Introduction

In the standard ΛCDM model, the observed acceleration is attributed to a dark-energy component; alternative explanations have been explored within extended-gravity approaches (review in [1]), whereas the present work, developed within the framework of the Four-Dimensional Electromagnetic Universe (4DEU) [2]-[5], strongly suggests that the cosmic acceleration is only apparent, arising from the geometric projection of a uniform four-dimensional expansion onto the three-dimensional hypersurface we inhabit, thereby removing the need for dark energy, quintessence, or any additional cosmological parameter. The following sections briefly summarize the ΛCDM interpretation of cosmic acceleration, review the main alternative approaches to the dark-energy problem, and outline the theoretical foundations of the 4DEU framework on which the present analysis is based.

1.1. The Accelerating Universe in the ΛCDM Model

The discovery that the universe's expansion is accelerating represents one of the most significant achievements of modern observational cosmology. The evidence emerged in the late 1990s from type Ia supernova (SNe Ia) measurements, which showed that distant events appeared dimmer than expected in a uniformly expanding universe [6] [7].

This result implied that the Hubble parameter, expressed as a function of redshift $H(z)$, decreases less rapidly at low redshifts ($z \lesssim 0.5$) than predicted by a matter-dominated model, indicating a phase of accelerated expansion.

In the standard ΛCDM cosmology, the expansion rate of the universe at cosmic time t is given by

$$H(t) = \frac{1}{a(t)} \cdot \frac{\mathrm{d}a}{\mathrm{d}t}$$

where $a(t)$ is the scale factor of the universe and t denotes cosmic time.

To account for the supernovae evidence, as well as other cosmological probes such as the cosmic microwave background (CMB) anisotropies [8] [9] and baryon acoustic oscillations [10] [11], the ΛCDM model introduces a dominant dark energy component, commonly identified with Einstein's cosmological constant Λ. In this framework, the present-day energy density of the universe is dominated by dark energy ($\Omega_\Lambda \simeq 0.69$) and cold dark matter ($\Omega_m \simeq 0.31$), according to the most recent Planck results [9]. The accelerated expansion is thus explained by a vacuum energy term with negative pressure, corresponding to an equation-of-state parameter $w = p/\rho \simeq -1$.

1.2. Alternative Approaches to the Dark Energy Problem

While the ΛCDM model explains the observed acceleration by introducing the cosmological constant Λ, its physical origin remains unknown. This has motivated a broad range of theoretical attempts to account for the phenomenon without postulating an unexplained vacuum energy. Two main strategies can be distinguished: 1) introducing new dynamical components, and 2) modifying the theory of gravity itself.

A first class of alternatives considers dynamical dark energy, in which the acceleration is driven by scalar fields evolving over cosmic time. Quintessence models describe a slowly rolling scalar field with a potential that produces negative pressure [12] [13]. Variants such as k-essence and phantom energy explore different kinetic terms or equations of state with $w < -1$ [14] [15]. While these models can reproduce the late-time acceleration, they require fine-tuning of initial conditions and potentials, raising concerns about predictivity.

A second class of proposals focuses on modifications of gravity at cosmological scales. Extended gravity theories generalize Einstein's General Relativity by altering the gravitational Lagrangian. One of the most studied examples is *f(R)* gravity, where the Einstein-Hilbert action is replaced by a more general function of the Ricci scalar R [16] [18] [19]. These models can produce self-acceleration without invoking a cosmological constant and have been extensively investigated for their cosmological and astrophysical implications [1] [17]. Other frameworks include scalar-tensor theories, such as Brans-Dicke gravity [20], Horndeski theories [21] [33], and Gauss-Bonnet extensions.

More recently, massive gravity and bimetric theories have been explored as possible explanations for cosmic acceleration [22]. These approaches modify the graviton's properties or introduce additional metrics, leading to an effective late-time repulsive effect. Similarly, higher-dimensional frameworks such as braneworld cosmologies [23] generate acceleration from modifications of gravity in extra dimensions.

Despite their diversity, all these alternative frameworks share the goal of addressing the dark energy problem without invoking a pure cosmological constant. However, they typically come at the cost of introducing new dynamical fields, parameters, or degrees of freedom. Furthermore, they are strongly constrained by both cosmological observations and local gravity tests, which often limit the allowed parameter space [24] [25]. Ultimately, their viability depends on the ability to distinguish them from General Relativity through precise experimental tests, such as the interferometric detection of gravitational waves [26].

The aim of the following section is to briefly review the foundations of the Four-Dimensional Electromagnetic Universe (4DEU) framework, so as to provide the necessary background for the subsequent analysis. **Table 1** summarizes the main alternative theoretical approaches to the dark energy problem.

Table 1. Alternative theoretical approaches to the dark energy problem.

(i) Introducing new dynamical components		
Category	**Brief description**	**References**
Quintessence and scalar fields	A slowly evolving scalar field with a potential that generates negative pressure.	[12] [13]
K-essence/Phantom energy	Variants with non-standard kinetic terms or equation of state w < −1.	[14] [15]
(ii) Modifying the theory of gravity itself		
f(R) gravity	Generalization of the Einstein-Hilbert action by replacing R with a function f(R).	[16] [18] [19]
Scalar-tensor theories	Scalar field coupled to gravity, generalization of General Relativity.	[20] [21] [33]
Extended gravity theories	General extensions of GR, designed to reproduce cosmic acceleration.	[1] [17]
Massive gravity and bimetric theories	Modified gravity introducing a graviton mass or additional metrics.	[22]
Braneworld cosmologies	Universe as a brane embedded in extra dimensions; acceleration from extra-dimensional effects.	[23]
General reviews and comparisons	Critical reviews and comparative analyses of different modified gravity models.	[24] [25]

1.3. Foundations of the Four-Dimensional Electromagnetic Universe (4DEU) Framework

The aim of this section is to briefly review the foundations of the Four-Dimensional Electromagnetic Universe (4DEU) framework, so as to provide the necessary background for the subsequent analysis.

The Four-Dimensional Electromagnetic Universe (4DEU) framework postulates that the cosmos is not a (3 + 1)-dimensional spacetime with time as an abstract coordinate, but a real four-dimensional Euclidean hypersphere. Within this framework, space is postulated to be quantized, with the Planck length representing the fundamental minimum unit [3]. In this picture, the three ordinary spatial-dimensions correspond to the curved 3D hypersurface where we live, while the fourth real spatial dimension is perceived by observers as time. The universe expands uniformly at rate c along this fourth dimension, denoted T, which acts as a privileged temporal coordinate. In the 4DEU framework, c does not represent a velocity in the conventional sense; rather, it should be regarded as the expansion rate of time real dimension and, more fundamentally, as a universal conversion factor between the units historically used to measure spatial and temporal intervals.

Accordingly, in the 4DEU framework the so-called Big Bang corresponds to the center of the 4D universe, while the temporal dimension represents its radius. From this postulate also follows the existence of a privileged reference frame centered on the Big Bang event. This is analogous to the use of cosmic time in the standard cosmological model, where the cosmic microwave background (CMB) provides the universal reference frame in which the universe appears isotropic.

Consequently, every entity moving with respect to the Big Bang must also possess a temporal velocity component of fixed magnitude c, corresponding to the constant expansion rate that governs everything in the 3D portion of the 4D universe. For example, electromagnetic waves, including light, have a four-velocity composed of a spatial component in 3D and a temporal component of constant value c [2] [3].

Two further key postulates underlie the 4DEU framework.

The second postulate is the Restricted Holographic Principle (RHP), which establishes that any phenomenon occurring along the fourth spatial dimension is not directly accessible, but manifests in the 3D portion of the 4D universe, where we live, in a qualitatively different yet quantitatively proportional way.

The third postulate defines the Temporal Waves (TWs), stationary electromagnetic waves confined exclusively to the fourth spatial dimension, with a wavelength equal to four times the radius of the 4D universe. As a consequence of the Restricted Holographic Principle, properties such as mass, energy, and charge are interpreted as emergent effects of these TWs. TWs are at the very origin of the universe: at the onset of cosmic expansion, from the ever-existing quantum vacuum, four orthogonal TWs of opposite phases were generated, ensuring isotropy and overall charge neutrality. These waves are stable at all times, including the very beginning, and their properties evolve coherently with the growth of the 4D hypersphere [4] [5].

TWs exert a negative radiation pressure directed outward, perpendicular to the 3D hypersurface where observers reside. This radiation pressure drives the uniform expansion of the 4D universe at rate c, playing in 4DEU the same role attributed to dark energy in the ΛCDM model.

The Restricted Holographic Principle explains how physical quantities such as time, mass, electric and magnetic charge, and gravity emerge as projections of TW dynamics.

The main consequences of the RHP are summarized in **Table 2**.

Implications

From these postulates, the 4DEU framework leads to several major conclusions:

- The measurements of the cosmic microwave background (CMB) temperature at redshifts 0.89, 3.025, and 6.34 are in full agreement with the 4DEU relation:

$$T(z) = T_0(1+z)$$

where T_0 denotes the present-day temperature of the CMB. In this framework, such a dependence follows directly from the 4D geometry without requiring any additional assumptions, thus finding direct confirmation in the observational data [4] [5].

- In the full 4D universe, mass, charge, and similar quantities do not exist intrinsically; they are only 3D projections of TW properties [2].
- Since gravity is confined to the 3D section of the 4D universe, and mass—as a manifestation of TW energy—exists only within that 3D portion, it cannot influence or slow down the expansion along the temporal dimension. In this framework, the 3D portion of the universe can be regarded as a massive

Table 2. Restricted Holographic Principle: 4D Sources and Their 3D Observational Manifestations.

4D Source[1]	How 4D Source is observed in the 3D part of the 4D universe	
	Qualitatively	Quantitatively
Expansion along the 4th spatial dimension	Time; flow of time	$dt = dS/c$
Energy of TWs	Mass	$E = mc^2$
TW Phase (two options shifted by π)	Phase 0˚ = Positive electric charge and north magnetic pole Phase π = Negative electric charge and south magnetic pole	$E_{TW(x,R_t)} = \pm E_{0[tw(R_t)]} \sin\left(\frac{\pi x}{2R_t}\right)$ (a)
Density of TWs	Gravity	$ds_{3D}^2 = \frac{dr^2}{1-\frac{2GM}{c^2 r}} + r^2 d\Omega_2^2$ (b)

[1]"4D Source" indicates the fundamental physical cause acting along the fourth spatial dimension of the real four-dimensional universe (the 4D hypersphere). Its effect appears in 3D as the corresponding observable manifestation. (a) Eq. 115 in [5]. The equivalent cosine representation is given in Eq. 80 of [3]. Here x indicates a point along the time dimension, ranging from the privileged coordinates $-R_t$ to $+R_t$, $E_{tw(x,R_t)}$ indicate the intensity of the electric field of a TW at point x (along the radius at time T (R_t) of the 4D universe), and $E_{0[tw(R_t)]}$ the maximum absolute amplitude of the electric field. (b) Eq. 2.23 in [4].

hyperspherical shell of the 4D universe which, because it does not exert gravitational attraction on itself, cannot decelerate the expansion of the 4D universe [2].

- Gravity arises solely from 3D spatial curvature, at least as demonstrated in the weak-field regime, reproducing the classical tests of General Relativity [4].
- The dual nature of light is naturally explained in terms of energy partition: its wave-like behavior arises from the energy associated with the 3D spatial component of its four-momentum, while its particle-like behavior originates from the energy associated with the temporal component (which, according to the RHP, appears to us as mass) [5].
- Recently, observations with the Hubble Space Telescope and, more importantly, with JWST have revealed several galaxies at very high redshifts ($z > 10$), specifically GN-Z11, GN-Z12, and GN-Z14-0. These systems already appear well developed, exhibiting properties they should not possess if their ages were those predicted by ΛCDM. Within the 4DEU framework, however, the inferred ages of such galaxies are approximately three times greater than in ΛCDM, thereby naturally reconciling their observed degree of evolution with the cosmic epoch at which they are detected [4] [5].
- Antimatter is confined to the antipodal 3D section of the 4D hypersphere, consistent with the symmetry of TWs (see **Figure 1** below, reproduced from [5]).
- Thermodynamic analysis indicates that the total energy of the 4D universe has

been exactly zero since the beginning, remains zero at the present epoch, and will continue to be zero at any future time [3].

- The dark matter component of ΛCDM is reinterpreted as 3D spatial curvature generated by the Gravitational Constraint that locally halts cosmic Expansion, described entirely through the 3D Ricci scalar ${}^{(3)}R$ (manuscript in preparation).

Building on these foundations, we next apply the 4DEU framework to the evolution of the Hubble parameter and directly compare its predictions with model-independent observational data.

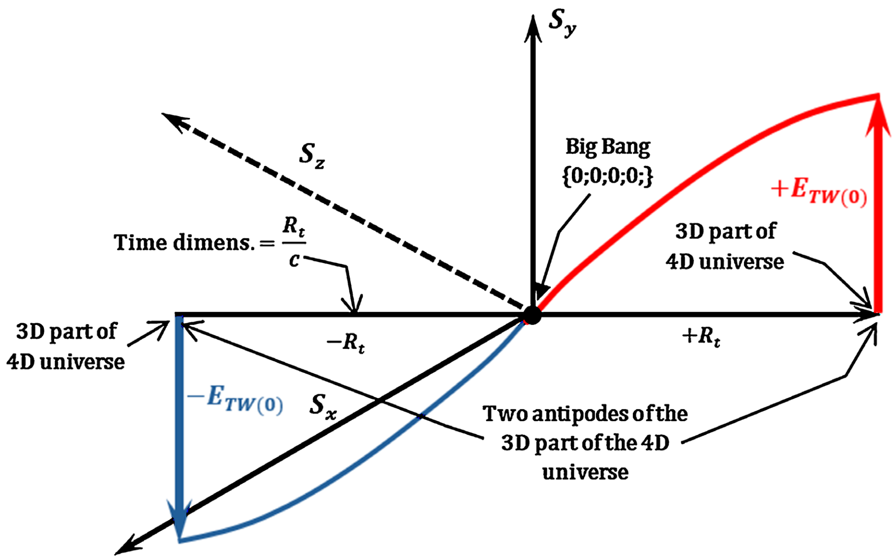

Figure 1. Schematic representation of electric fields of a single TW. The TW is represented as a symmetric stationary wave extending along the real-time dimension, from $-R_t$ to $+R_t$, with electric field values reaching $\pm E_{TW(0)}$ at the antipodes and vanishing at the Big Bang. The red and blue segments correspond to opposite electric polarities. The 3D parts of the 4D universe are located at the temporal boundaries, where the TW manifests as localized electric charge. Reproduced from [5].

2. Results

Application of the Four-Dimensional Electromagnetic Universe (4DEU) Framework to Cosmic Expansion

In this work, we propose an alternative geometric interpretation within the Four-Dimensional Electromagnetic Universe (4DEU) framework. In this scenario, the universe is conceived as a real 4D hypersphere expanding uniformly at rate c along a privileged radial coordinate T. The 3D part of the 4D universe, where we observers reside and measurements are performed, corresponds to a curved 3D spatial hypersurface of this 4D real universe.

Within this framework, the variation of the Hubble parameter with redshift arises from the projection of uniform expansion of the 4D universe into its 3D portion. This leads to the following linear relation (Eq. 274a in [5]). For its full derivation, see also Appendix:

$$H_z = H_0(1+z) \tag{1}$$

Equation (1) reflects the uniform expansion along the fourth spatial dimension, with no physical acceleration required. The apparent cosmic acceleration thus emerges as a projection effect, eliminating the need for a dark energy component.

In contrast, the standard cosmological model (ΛCDM) interprets the variation of the Hubble parameter $H(z)$ as evidence for an accelerating expansion, leading to the postulation of a dark energy term. In ΛCDM, the Hubble parameter is fundamentally defined as a function of cosmic time t through the scale factor:

$$H(t) = \frac{1}{a(t)} \cdot \frac{\mathrm{d}a}{\mathrm{d}t} \tag{2}$$

where $a(t)$ is the scale factor, while t denotes cosmic time. Observationally, an apparent increase in H_z at low redshifts ($z \lesssim 0.5$) is interpreted within ΛCDM as evidence of cosmic acceleration driven by dark energy.

By contrast, the 4DEU relation (Equation (1)) arises directly from the geometric link between redshift and the expansion radius of the 4D hyperspherical universe. The apparent acceleration is therefore a geometric artifact, emerging from the projection of four-dimensional geodesics onto the curved three-dimensional section inhabited by observers (*i.e.*, us).

To test the validity of this prediction, the theoretical values of $H(z)$ were computed from Equation (1) using the Planck-CMB derived value H_0 = 67.4 ± 0.5 km/s/Mpc [9], and compared with observational data from type Ia supernovae and cosmic chronometers. The results, summarized in **Table 3**, show excellent statistical agreement. A fundamental criterion in selecting the observational dataset is that only experimental measurements—either direct or indirect—are considered, provided they are obtained without imposing ΛCDM or other models as a prior in their derivation. This ensures that the resulting values remain model-independent and can be interpreted within alternative theoretical frameworks without bias.

Moreover, when adopting the more recent local estimate H_0 = 73.0 ± 1.0 km/s/Mpc inferred from Cepheid-calibrated type Ia supernovae [31], similar results have been obtained (see **Table 4**).

This strongly supports the interpretation that the observed acceleration is a geometric projection effect rather than evidence for a dark energy component.

Furthermore, to quantitatively evaluate how well the 4DEU predictions reproduce the observational data, a total chi-squared test was performed for both reference values of the Hubble constant. For each redshift point, the squared difference between the observed and predicted H_z values was divided by the sum of the squared observational and theoretical uncertainties, and the contributions from all points were summed to obtain the total chi-squared,

$$\chi^2_{tot} = \sum_i \frac{\left(H_{obs,i} - H_{pr,i}\right)^2}{\sigma^2_{obs,i} + \sigma^2_{pr,i}} \tag{3}$$

Table 3. Comparison between observed and 4DEU-Predicted Hubble parameters using $H_0 = 67.4 \pm 0.5$ km/s/Mpc.

Z	Predicted H_z by 4DEU (Km/s/MPC)	Observed H_z (Km/s/MPC)	Reference	σ^*	Statistical Compatibility**
0.07	72.1 ± 0.54	69.0 ± 19.6	[27]	0.158	Consistent
0.12	75.5 ± 0.56	68.6 ± 26.2	[27]	0.263	Consistent
0.20	80.9 ± 0.60	72.9 ± 29.6	[27]	0.270	Consistent
0.28	86.3 ± 0.64	88.8 ± 36.6	[27]	0.068	Consistent
0.35	91.0 ± 0.68	88 ± 16$	[28]	0.187	Consistent
0.43	96.4 ± 0.72	91.8 ± 5.3	[29]	0.860	Consistent
0.48	99.8 ± 0.74	97.0 ± 62.0	[30]	0.045	Consistent
0.75	118.0 ± 0.88	98.8 ± 33.6	[31]	0.571	Consistent
0.78	120.0 ± 0.89	88 ± 11$	[28]	2.900	Not Consistent
0.875	126.4 ± 0.94	124 ± 17$	[28]	0.141	Consistent
1.30	155.0 ± 1.15	168.0 ± 17.0	[32]	0.763	Consistent
1.43	163.8 ± 1.22	177.0 ± 18.0	[32]	0.732	Consistent
1.75	185.4 ± 1.38	202.0 ± 40.0	[32]	0.415	Consistent

* $\sigma = \frac{|\Delta H|}{\sqrt{\delta H_{obs}^2 + \delta H_{4DEU}^2}}$; **The statistical consistency between theoretical and observed values is assessed by computing the deviation in units of the standard deviation (σ), assuming Gaussian and independent uncertainties on both quantities. Values with $\sigma < 1$ are considered fully consistent; values in the range $1 < \sigma < 2$ indicate marginal consistency. $Data from MaStro models provided by [28].

Table 4. Comparison Between Observed and 4DEU-Predicted Hubble Parameters using $H_0 = 73.0 \pm 1.0$ km/s/Mpc.

Z	Predicted H_z by 4DEU (Km/s/MPC)	Observed H_z (Km/s/MPC)	Reference	σ^*	Statistical Compatibility**
0.07	78.1 ± 1.07	69.0 ± 19.6	[27]	0.464	Consistent
0.12	81.8 ± 1.12	68.6 ± 26.2	[27]	0.503	Consistent
0.20	87.6 ± 1.20	72.9 ± 29.6	[27]	0.496	Consistent
0.28	93.4 ± 1.28	88.8 ± 36.6	[27]	0.126	Consistent
0.35	98.6 ± 1.35	88 ± 16$	[28]	0.660	Consistent
0.43	104.4 ± 1.43	91.8 ± 5.3	[29]	2.295	Tension
0.48	108.0 ± 1.48	97.0 ± 62.0	[30]	0.177	Consistent
0.75	127.8 ± 1.75	98.8 ± 33.6	[31]	0.862	Consistent
0.78	129.9 ± 1.78	88 ± 11$	[28]	3.760	Tension

Continued

0.875	136.9 ± 1.88	124 ± 17[$]	[28]	0.754	Consistent
1.30	167.9 ± 2.30	168.0 ± 17.0	[32]	0.006	Consistent
1.43	177.4 ± 2.43	177.0 ± 18.0	[32]	0.022	Consistent
1.75	200.8 ± 2.75	202.0 ± 40.0	[32]	0.030	Consistent

* $\sigma = \frac{|\Delta H|}{\sqrt{\delta H_{obs}^2 + \delta H_{4DEU}^2}}$; **The statistical consistency between theoretical and observed values is assessed by computing the deviation in units of the standard deviation (σ), assuming Gaussian and independent uncertainties on both quantities. Values with $\sigma < 1$ are considered fully consistent; values in the range $1 < \sigma < 2$ indicate marginal consistency; values; values in the range $2 < \sigma < 4$ are interpreted as tension; and values with $\sigma > 4$ are interpreted as strong tension. [$]Data from MaStro models provided by [28].

where $H_{obs,i}$ is the observed Hubble parameter at redshift z_i, $H_{pr,i}$ is the predicted value from the 4DEU model, $\sigma_{obs,i}$ is the observational uncertainty, and $\sigma_{pr,i} = (1+z)\sigma_{H_0}$ is the propagated theoretical uncertainty from the error on H_0 (σ_{H_0}).

The resulting χ^2_{tot} value, together with the number of degrees of freedom (*dof*), was used to compute the reduced χ^2_{red} and the corresponding p-value, thus providing a global measure of the statistical compatibility between theory and observations. The number of data points is $N = 13$, and since no free parameters are fitted, the number of degrees of freedom is also $dof = 13$.

For H_0 = 67.4± 0.5 km/s/Mpc (Planck-CMB) the results are:

$$\chi^2_{tot} = 11.142, \quad dof = 13, \quad \chi^2_{red} \approx 0.857, \quad p \approx 0.599 \tag{4}$$

This indicates a very high statistical compatibility between the model and the data, with deviations significantly smaller than expected from the quoted uncertainties.

For H_0 = 73.0 ± 1.0 km/s/Mpc (Cepheid-calibrated SN Ia) the results are:

$$\chi^2_{tot} = 21.918, \quad dof = 13, \quad \chi^2_{red} \approx 1.686, \quad p \approx 0.057 \tag{5}$$

This still indicates overall statistical compatibility, but with a noticeably lower probability than in the $H_0 = 67.4$ case.

The comparison of the two χ^2_{tot} analyses shows that the Planck-CMB value of H_0 yields a much closer match to the observational data in the 4DEU framework than the local Cepheid-based value.

Moreover, this higher statistical significance holds precisely because the value H_0 = 67.4 ± 0.5 km/s/Mpc, derived from the Planck-CMB data. This comparison shows that, within the 4DEU framework, the statistical agreement with model-independent data is markedly stronger for the Planck-CMB value $H_0 = 67.4 \pm 0.5$ km/s/Mpc than for the local Cepheid-based determination ($H_0 \approx 73$ km/s/Mpc). This suggests that the true expansion rate is closer to the CMB estimate, while the higher local values may be affected by not yet fully identified systematic effects not yet fully understood. In this way, the 4DEU framework removes the need to postulate dark energy and avoids the inconsistency between early and late universe determinations that defines the so-called Hubble tension. This reinforces the interpretation that the expansion rate inferred from CMB observations provides the most consistent and physically meaningful description of the data within the 4DEU framework.

To quantitatively assess whether the Four-Dimensional Electromagnetic Universe (4DEU) framework provides a better description of model-independent H_z measurements when adopting H_0 values from Planck-CMB or SH0ES determinations, we performed a global chi-squared analysis.

We compared two cases: 1) Planck-CMB determination with $H_0 = 67.4 \pm 0.5$ km·s^{-1}·Mpc^{-1}, and 2) SH0ES local distance ladder with $H_0 = 73.0 \pm 1.0$ km·s^{-1}·Mpc^{-1}. We use the data already computed above, specifically:

For the Planck-CMB case, and the SH0ES case we use data from Eq.4 and Eq.5, respectively.

When the data are Gaussian and independent (as in the case of the H_z measurements with quoted uncertainties), the likelihood (LR) is:

$$\mathrm{LR} \propto \exp\left(-\frac{\Delta\chi^2_{tot}}{2}\right) \tag{6}$$

Note that the likelihood is generally defined up to a normalization constant, hence the proportionality in Equation (6). However, when comparing two models with the same number of data points and identical normalization, normalization constants cancels out, and the likelihood ratio can be written explicitly as in Equation (8).

The difference,

$$\Delta\chi^2_{tot} = 21.918 - 11.142 = 10.776 \tag{7}$$

corresponds to a likelihood ratio of:

$$\mathrm{LR} = \exp\left(-\frac{\Delta\chi^2_{tot}}{2}\right) = \exp(-5.388) \approx 4.57 \times 10^{-3} \tag{8}$$

Thus, $\mathrm{LR} \approx 4.57 \times 10^{-3}$ means that, given the data, the likelihood of the model with $H_0 = 73.0$ is only about 0.457% of that of model with $H_0 = 67.4$. This corresponds to a statistical support of approximately 219:1 in favor of the Planck-CMB determination. Such a pronounced difference cannot be attributed to random fluctuations alone: it reflects a robust preference of the data for the lower Hubble constant value and provides strong evidence that the linear 4DEU prediction is more consistent with model-independent measurements.

These results show that within the 4DEU framework the linear prediction $H(z) = H_0(1+z)$ is statistically favored when adopting the Planck-CMB value of H_0, while the SH0ES determination yields a substantially poorer fit to the data. This quantitative comparison confirms that the physically meaningful expansion rate, as constrained by model-independent measurements, lies closer to ≃67 km·s^{-1}·Mpc^{-1}, and that the so-called Hubble tension is naturally alleviated in 4DEU as a geometric projection effect rather than evidence for dark energy component.

3. Conclusions and Discussion

In most alternative frameworks, the dark energy problem is addressed either by introducing new dynamical components, such as scalar fields [12] [13], or by modifying gravity on cosmological scales [1] [17]. These approaches can reproduce the observed late-time acceleration and are generally constructed to remain consistent with the wealth of cosmological observations [9], but they do so at the cost of introducing additional fields, free parameters, or degrees of freedom. Their viability ultimately depends on the possibility of distinguishing them from General Relativity through high-precision experimental tests—for example, the interferometric detection of gravitational waves, which provides a direct empirical discriminator between GR and alternative gravity theories [26].

By contrast, the 4DEU framework explains the apparent acceleration without invoking new dynamical entities or altering the Einstein-Hilbert action. Its only conceptual difference with respect to General Relativity is an additional simplification: in 4DEU, time is treated as a privileged linear coordinate rather than a curved one. In this context, we denote by t_{rel} the relative time, *i.e.*, the time that an observer assigns to a clock located in another reference frame, either in a different gravitational potential or in relative motion. This quantity corresponds to the coordinate time in Special and General Relativity and, in most cases, coincides with the proper time τ. By contrast, the privileged time T coincides with the locally measured proper time of each observer, advancing identically for all regardless of motion or gravity [4] [5]. The relation between T and t_{rel} is given by the standard expressions:

in a gravitational field,

$$t_{rel} = T\sqrt{\frac{1-\frac{2GM}{r'c^2}}{1-\frac{2GM}{rc^2}}}$$

and in inertial relative motion,

$$t_{rel} = \frac{T}{\sqrt{1-\frac{v^2}{c^2}}}$$

As a consequence, the 4DEU reproduces the same weak-field results as GR, including gravitational redshift, light deflection, Shapiro delay, and the perihelion precession of Mercury [4] [5].

The results presented here show that the linear 4DEU prediction (Eq.1) for the Hubble parameter $H(z)$ matches model-independent datasets of type Ia supernovae and cosmic chronometers with high level of statistical significance. In particular, the statistical consistency is markedly higher when adopting the Planck-CMB value of the Hubble constant ($H_0 = 67.4 \pm 0.5$ km/s/Mpc) than when using the local distance-ladder estimate ($H_0 \approx 73$ km/s/Mpc). This behavior indicates that the value near 67 km/s/Mpc should be regarded as the physically meaningful one, while the higher local values may be influenced by systematics that are not yet fully understood.

Crucially, within the 4DEU framework, the observed late-time acceleration no longer requires the introduction of a dark energy component: it emerges naturally as a geometric projection effect of uniform 4D expansion. By Occam's razor, the combination of stronger statistical agreement with independent datasets and the conceptual simplicity resulting from eliminating an otherwise unknown form of energy strongly favors the solution with $H_0 \approx 67$ solution.

Moreover, other observational puzzles—such as the CMB temperature-redshift relation, the unexpectedly advanced ages of galaxies detected by JWST at $z \gtrsim 10$, and the thermodynamic balance of the Universe—are also consistent with the 4DEU framework, as discussed in previous works by Maglione [2]-[5]. Taken together with the present analysis of the Hubble parameter, these results indicate that a broad set of independent astronomical datasets is already in good agreement with the predictions of the 4DEU framework. Further systematic analyses across a broader range of cosmological probes will be necessary, but the current evidence suggests that 4DEU represents a viable alternative to more complex dark-energy or extended-gravity models, without introducing extra degrees of freedom, additional parameters, new fields, or exotic energy components.

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Conflicts of Interest

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

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Appendix. Derivation of Equation (1) in the 4DEU Framework

For completeness, we derive Equation (1) within the 4DEU framework in a self-contained way.

Starting from the definition of the expansion rate:

$$H(t)=\frac{1}{a(t)}\frac{\mathrm{d}a}{\mathrm{d}t}=\frac{1}{R_t}\frac{\mathrm{d}R_t}{\mathrm{d}t} \tag{A1}$$

where $a(t)$ denotes the scale factor; $H(t)$, the Hubble parameter at cosmic time t; R_t, the 4D radius at time t.

The uniform expansion along the time dimension in 4DEU Theory is described by Eq.1 in [3]:

$$\frac{\mathrm{d}R_t}{\mathrm{d}t}=c \tag{A2}$$

Combining (A1) with (A2) gives:

$$H(t)=\frac{c}{R_t} \tag{A3}$$

Equivalently, derived here,

$$R_t=\frac{c}{H(t)} \tag{A4}$$

Denoting R_z as the 4D radius of the universe at redshift z and $H(z)$ as the Hubble parameter at redshift z, Eq. (A4) becomes:

$$R_z=\frac{c}{H(z)} \tag{A4a}$$

At the present epoch the scale factor equals unity, $a_0 \equiv a(t_0)=1$, and the red-shift-radius relation in 4DEU framework is Eq.B.5 in [3]:

$$1+z=\frac{R_0}{R_z} \tag{A5}$$

where z indicates redshift and R_0 represents the present day radius of 4D universe.

Isolating R_z from (A5) we have:

$$R_z=\frac{R_0}{1+z} \tag{A6}$$

Here R_z denotes the 4D radius at redshift z. For example, at the present epoch ($z_0=0$), $R_{z_0}=R_0$.

Evaluating (A4a) at the present epoch ($z_0=0$) yields the present-day radius in terms of the Hubble parameter,

$$R_0=\frac{c}{H_0} \tag{A6a}$$

where H_0 is the Hubble parameter today, that is at $z=0$.

Finally, combining (A4a), (A6) and (A6a), we have:

$$\frac{c}{H(z)} = \frac{R_0}{1+z} = \frac{c}{H_0}\frac{1}{1+z} \tag{A7}$$

which yields Equation (1) of the main text:

$$H(z) = H_0(1+z)$$