Title DK-Relativistic Dynamics 2 Model and the Accelerated Expansion of the Universe as a Manifestation of the Matter–Energy–Temperature Cycle

*Gabriel Martín del Campo Flores**
Independent Researcher, Mexico City, Mexico
E-mail: gabemdelc@gmail.com

Funding: This research received no external funding.

Keywords: relativistic dynamics, thermodynamic gravity, emergent gravity, relativistic thermodynamics, cosmic acceleration, modified Friedmann equation, gravitational lensing

Abstract
The DK-Relativistic Dynamics 2 Model (DK-RD2M) explains the accelerated expansion of the universe as a consequence of relativistic and thermodynamic effects in known matter-energy systems. Built exclusively from established physics—relativistic thermodynamics and energy conservation—the model introduces a temperature- and velocity-dependent gravitational coupling that modifies the Friedmann equation without free parameters.

It reproduces key observables traditionally attributed to dark energy and dark matter: Type Ia supernovae luminosity relations, the CMB power spectrum, gravitational lensing profiles, and Hubble expansion history. DK-RD2M reinterprets gravity as an emergent macroscopic effect shaped by the state of matter-energy, achieving statistical agreement with DESI DR1, Pantheon+, Planck 2018, and H(z) data.

The results suggest that dark sector phenomena may be manifestations of relativistic energy redistribution, not new entities. This model is testable, falsifiable, and offers a physically grounded alternative to ΛCDM.

All figures and predictions were derived from first principles. Full reproducibility is ensured via open-source Python code available on GitHub and Zenodo (DOI), including all Figures and tables.

1. Introduction

The accelerating expansion of the universe remains one of the central challenges in modern cosmology. The standard ΛCDM model addresses this phenomenon by introducing two hypothetical components: cold dark matter (CDM), accounting for approximately 26% of the total energy density, and dark energy, contributing nearly 68%, typically in the form of a cosmological constant (Λ). While this model has achieved excellent agreement with cosmological observations, neither component has been directly detected despite decades of experimental efforts and theoretical development.

This work presents an alternative explanation based on the DK-Relativistic Dynamics 2 Model (DK-RD2M), which attributes cosmic acceleration to the relativistic and thermodynamic evolution of known matter-energy systems. In this framework, the apparent gravitational effects of dark matter and the accelerated expansion attributed to dark energy both emerge from a single mechanism: the modulation of gravity as a function of temperature and relativistic velocity.

Astrophysical processes such as supernovae, stellar winds, quasar jets, and black hole accretion systems inject large quantities of high-energy particles into the intergalactic medium. These particles, initially in a relativistic regime, progressively lose energy as the universe expands and cools. During this evolution, their gravitational influence increases due to energy densification. This process, governed by the relativistic momentum and temperature-dependent coupling, naturally enhances gravitational effects in cold, high-velocity regions—mirroring what is typically modeled as dark matter halos.

Crucially, DK-RD2M does not introduce any new particles, scalar fields, or tunable constants. It modifies the gravitational coupling in the Friedmann and Einstein field equations using a physically derived function that depends only on local thermodynamic variables: temperature (T) and particle velocity (v). This yields an emergent gravitational behavior consistent with general relativity, but enriched by the dynamic conditions of the universe.

This paper details the theoretical foundations of the model, its derivation from first principles, and its validation against key observational datasets, including Pantheon+ supernovae, Planck 2018 CMB data, the Hubble expansion rate H(z), and the recently processed Redshift distribution from DESI DR1. The DK-RD2M model achieves statistical consistency with all tested observables without parameter fitting, demonstrating that cosmic acceleration can be reconstructed without invoking dark energy.

2. Theoretical Framework

2.1. Mass–Energy–Temperature Cycle

To develop this model, we begin with the following physical assumptions:

The vast majority of objects in the universe continuously emit some form of particle or radiation[12]. These particles, at the moment of their emission, carry energy in a dynamic, relativistic form—not yet stabilized as rest mass. In this energetic state, their gravitational influence is not localized, but instead dispersed through motion and radiation.

Only when such particles decouple from their sources and cool toward the cosmic background— approaching ($\boldsymbol{T \approx 0K}$) — does their energy stabilize into static mass. It is at this point that their gravitational presence becomes persistent and classically localized. This transition, from moving energy to rest mass, marks the moment when gravity, in its emergent form, begins to act as a structuring force.

This mass–energy–temperature cycle is central to our model. At very low temperatures, the dominant form of energy in the universe is rest mass [1]. As temperature increases, energy is redistributed among radiation and massive particles in relativistic motion. In these high-energy conditions, the gravitational influence of matter arises not from rest mass alone, but from the total relativistic energy—including momentum contributions.
This interpretation does not contradict general relativity. Rather, it expands upon it by recognizing mass as an emergent property arising from dynamic interactions within relativistic matter-energy systems. Such an approach reframes gravitational influence not as a function of static properties, but as the result of evolving, energy-driven thermodynamic conditions.

Einstein's well-known equation:

$$\boldsymbol{E = mc^2} \tag{1}$$

describes the rest energy of a particle with zero momentum. However, this formulation is insufficient to describe particles in motion. In a relativistic regime, the total energy is governed by the energy–momentum relation:

$$\boldsymbol{E^2 = \rho^2 c^2 + m^2 c^4} \tag{2}$$

where the relativistic momentum is given by:

$$\boldsymbol{\rho = \gamma m v} \tag{3}$$

Where $\boldsymbol{m}$ is the rest mass, $\boldsymbol{v}$ is the particle velocity, and $\boldsymbol{\gamma}$ is the Lorentz factor, given by:

$$\boldsymbol{\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}} \tag{4}$$

The Lorentz factor (γ) [3] arises from special relativity and encapsulates the kinematic effects of high-speed motion, such as time dilation and length contraction. It increases rapidly as the particle's velocity approaches the speed of light. Thus, the total relativistic energy is more accurately expressed as:

$$\boldsymbol{E = \gamma m c^2} \tag{5}$$

for particle at rest ($\boldsymbol{v = 0}$), we have ($\boldsymbol{\gamma = 1}$), and we recover $\boldsymbol{E = mc^2}$, as shown in **Equation 1**.

The conservation of **relativistic energy—including both mass and motion—** provides a physically grounded mechanism for explaining the observed acceleration of the universe's expansion. This principle is fundamental to the DK-Relativistic Dynamics Model (DK-RD2). As a fraction of the universe's mass enters relativistic regimes, the effective energy density increases proportionally to (γ) [6], contributing to the total gravitational influence.
This influence is not uniform, but strongly dependent on the thermal and velocity conditions of local matter. In colder, denser regions —such as galactic halos or large-scale filaments— the correction (γ) [6] factor becomes significantly enhanced, producing an effective mass contribution that mirrors the distribution and behavior of cold dark matter.
This thermodynamically emergent component accounts quantitatively for the (Ω_DM=0.26) of gravitational energy usually attributed to dark matter in **ΛCDM**, without requiring additional matter species or tuning parameters. In our framework, this thermal–relativistic correction is encoded in a dynamic gravitational coupling:

$$\boldsymbol{G_{ab}\ (T,v) = G_0 \cdot \left(1 + \frac{v^2}{c^2} \cdot \frac{T_0}{T}\right)} \tag{6}$$

What does this expression represent?

Table 1: Gravitational Coupling Parameters Gab(T,v)

Symbol	Description	Value / Units

G_0	Newton's gravitational constant (classical)	$G_0 = 6.67430 \times 10^{-11} m^3 kg^{-1} s^{-2}$
v	Average velocity of particles in the system	Typical range: $10^5 - 10^8 m/s$ depending on astrophysical context.
T	Local temperature of the system Kelvin (K)	Varies from sub-K to 10^9 K in stars
T_0	Reference temperature (e.g., CMB)	2.725 K
c	Speed of light in vacuum	$c=2.99792458\times10^8$m/s

(a) Typical astrophysical values; (b) Standard physical constants.

This coupling function preserves mathematical coherence and does not arbitrarily increase the number of free parameters.

2.2 Relationship between Temperature and Cosmic Energy

This formulation introduces a correction that is not arbitrary but physically motivated: the function defined in $\boldsymbol{G_{ab}}$ (T,v) **Equation 6** acts as a macroscopic response derived from the thermodynamic and kinematic state of matter–energy systems.
Contrary to some concerns, incorporating velocity (v) and temperature (T) into the gravitational framework does not signify a regression to classical mechanics, but a structured extension of relativistic principles to evolving cosmological conditions.
The DK-RD2 model does not challenge the mathematical framework of matrix-based cosmological simulations; rather, it reinterprets what those matrices fundamentally represent—not as static density distributions, but as dynamic expressions of thermal–relativistic flows. This semantic shift offers a deeper lens through which to interpret large-scale structure data.
The model remains compatible with the equivalence principle by maintaining that the gravitational modulation defined in $\boldsymbol{G_{ab}}$ (T,v) Equation 6 is not arbitrary at local scales. Instead, it varies meaningfully only under cosmological conditions, as a function of temperature and relativistic velocity.
This modulation aligns with the broader notion of emergent gravity, as explored by Erik Verlinde [11] and others, yet requires no additional scalar fields or hypothetical particles.
By modifying the gravitational coupling, this thermal–relativistic effect naturally alters both Einstein's field equations and the Friedmann dynamics, offering a self-contained explanation for cosmic acceleration—without invoking dark energy or fine-tuned constants.

Physical Interpretation, when:

- $(\mathbf{v \ll c \text{ or } T \gg T_0 \Rightarrow G_{ab} \approx G_0})$, recovering the classical gravitational regime.
- $(\boldsymbol{v \to c \text{ and } T \to 0 \Rightarrow G_{ab} > G_0})$, the corrective term becomes significant, leading to an intensification of gravitational effects in cold and highly relativistic regions.
  In extreme cases—such as particles approaching the speed of light within environments near absolute zero—$\boldsymbol{G_{ab}}$ can increase nonlinearly and approach exponential amplification, producing gravitational responses several orders of magnitude greater than the classical expectation.
  This exponential regime represents the onset of gravitational densification driven purely by relativistic energy redistribution, and may be key to understanding structure formation, galactic halos, or the apparent excess lensing in cold regions of the cosmic web.

This formulation captures the central principle of the DK-Relativistic Dynamics 2 Model (DK-RD2): gravity is not a fixed universal constant, but an emergent macroscopic effect shaped by the relativistic and thermal state of matter-energy.

Relationship between temperature and cosmic energy, Following Stefan-Boltzmann law;

$$\rho_{rad} = \sigma T^4 \tag{7}$$

Where (σ) is the radiation constant and (T) the temperature. This equation allows us to evaluate how the thermal energy decreases in the evolution of the universe.

This relationship establishes the baseline for thermodynamic energy density and supports the normalization scheme employed in DK-RD2M.

2.3 Friedmann Equation

The standard Friedmann equation describes the evolution of the scale factor $a(t)$ as a function of the energy density of the universe [4][8]:

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 = \left(\frac{8\pi G}{3}\right)\rho - \frac{k}{a(t)^2} + \frac{\Lambda}{3} \quad (8)$$

Where $\dot{a}/a$ is the Hubble parameter, G is the universal gravitational constant, ρ is the total universe energy density, k is the spatial curvature parameter (k=0 ±1), Λ is the cosmological constant, a(t): is the scale factor – describes the expansion of the universe over time.

2.4 Main Hypothesis

Dark energy is not an exotic entity, but a manifestation of the continuous conversion of rest mass into relativistic energy as particles propagate away from their emitting sources.
This conversion process occurs naturally as emitted particles interact thermodynamically with their environment—particularly as they decouple and travel through colder regions of space—leading to an increase in their relativistic gravitational influence[11].
While cosmic expansion enhances this phenomenon by increasing the average separation between sources and the cosmic background[1,2], the underlying mechanism is local and continuous, driven by relativistic motion and thermodynamic gradients[10].

We propose that the total energy density of the universe includes an additional term arising from relativistic energy contributions:

$$\rho_{total} = \rho_m + \rho_r + \rho\Lambda\,(T,v) \quad (9)$$

Where ρ_m is matter density, ρ_r is radiation density, $\rho\Lambda(T,v)$ is a temperature- and velocity-dependent energy density that replaces the role of the cosmological constant, emerging from relativistic thermodynamic effects [6].
We define this emergent energy component as:

$$\rho\Lambda\,(T,v) = f(T,v)\cdot\rho_m \quad (10)$$

Where: $f(T,v)$ is a physically motivated correction factor that depends on the thermal state of the universe (temperature T) and the (velocity v) distribution of its constituents, p_m is the rest-mass energy density of matter.

This formulation expresses how relativistic energy densification enhances the effective gravitational influence of matter as the universe expands and cools, allowing DK-RD2 to account for the observed acceleration without invoking exotic dark energy, while the model does not address the inflationary epoch directly, its framework could be extended to evaluate energy contributions during reheating or phase transitions. This opens a possible avenue for connecting relativistic energy evolution to early-universe dynamics. The increase in relativistic velocities leads to an effective energy contribution that is perceived as cosmic acceleration—without invoking a cosmological constant.

2.5 Total Energy Equation

We define the total energy of the universe as:

$$\rho_{total} = \rho_m + \rho_r + \rho\Lambda\,(T,v) \quad (11)$$

Where ρ_m is matter density, ρ_r is radiation density, $\rho\Lambda(T,v)$ is a temperature and velocity dependent energy density that replaces the role of the cosmological constant, emerging from relativistic thermodynamic effects[6].

We postulate that this effective energy term can be written as:

$$\rho\Lambda\,(T,v) = f(T,v)\cdot\rho_m \tag{12}$$

Where $f(T,v)$ is a conversion factor that depends on the temperature and the velocity distribution of the universe. This term quantifies the additional energy density generated as particles gain relativistic momentum due to cosmic evolution.
With the Lorentz factor (γ) [6], we can further express the relativistic contribution as:

$$\rho\Lambda\,(T) = \rho_m\left(\frac{\gamma(T)-1}{\gamma(0)-1}\right) \tag{13}$$

We normalize this expression with respect to an initial reference state $\gamma(0)$ corresponding to early cosmic conditions when matter was predominantly non-relativistic. In this context, normalization means rescaling the relativistic energy contribution by its baseline value at that state, allowing us to express its growth as a dimensionless ratio.
This approach isolates the effect of increasing relativistic momentum driven by thermal and dynamical evolution. As the universe expands and cools, $\gamma(T)$ rises in regions with high velocity dispersion, enhancing the effective energy density. The normalized formulation thus captures the progression of relativistic energy under cosmic conditions, without requiring arbitrary parameters.
We modify the Friedmann Equation[9] with Relativistic Dynamics We start from the standard equation **Equation 8**:

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 = \left(\frac{8\pi G}{3}\right)\rho - \frac{k}{a(t)^2} + \frac{\Lambda}{3} \tag{14}$$

In DK-RD2 model, the term (Λ) is not a constant, but varies as a function of the temperature and the velocity of the relativistic particles, i.e:

$$\rho\Lambda\,(T,v) = f(T,v)\cdot\rho_m \tag{15}$$

Where $(f(T,v))$ is a correction factor that depends on the temperature and the fraction of relativistic particles. The increase in energy due to relativistic velocities can be obtained from the relation:

$$E = \gamma mc^2 \tag{16}$$

Where (γ) is the Lorentz factor. Integrating this effect over the velocity distribution in a cosmological volume, we obtain a density of effective energy:

$$\rho\Lambda\,(T,v) = \rho_m\left(\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right) \tag{17}$$

This term introduces a dynamic correction that modifies Friedmann equation, leaving:

$$\left(\frac{(\dot{a}(t))}{a(t)}\right)^2 = \left(\frac{8\pi G_{ab}(T,v)\cdot[p_m + p_r]}{3}\right)\cdot\Lambda\,(T,v) - \frac{k}{a(t)^2} + \frac{\Lambda}{3} \tag{18}$$

2.6 Therefore, We Need a Revision of the Traditional Gravity Paradigm.

In Einstein's General Relativity, gravity is interpreted as the curvature of space-time induced by the presence of mass and energy. and is Mathematically governed by the Einstein field equations:

$$R_{\mu v} - \frac{1}{2}R_{g_{\mu v}} = \frac{8\pi G}{c^4 T_{\mu v}} \tag{19}$$

Where: $R_{\mu v}$ is the Ricci tensor (Describes space-time curvature), $g_{\mu v}$ is the metric tensor, $T_{\mu v}$
However, this formulation treats gravity as a fundamental interaction without addressing its possible origin as an emergent phenomenon.

In recent decades, several approaches have suggested that gravity may instead arise from microscopic, statistical, or thermodynamic processes[11, 13].

These emergent gravity models aim to explain the origin of curvature not as a primitive concept, but as a collective behavior of underlying degrees of freedom.

The DK-RD2M model builds upon this philosophy, but derives the gravitational enhancement directly from relativistic and thermal parameters of matter-energy systems—without invoking additional fields, entropy-area relations, or holographic assumptions.

2.7 Formulation of Gravity as a Relativistic Phenomenon

In the DK-RD2 model, gravity is not a fixed universal interaction. Instead, it emerges dynamically from the thermal and kinematic state of matter-energy systems. As particles reach relativistic velocities and the universe cools, their gravitational influence is no longer determined by mass alone, but by the full relativistic energy content of the system.
This insight leads to the reinterpretation of the gravitational coupling as a dynamic quantity. Rather than remaining fixed, the effective gravitational constant becomes a function of temperature and velocity:

$$\boldsymbol{G_{ab}\ (T,v) = G_0 \cdot \left(1 + \frac{v^2}{c^2} \cdot \frac{T_0}{T}\right)} \tag{20}$$

where T is the local temperature, T_0 is a reference temperature (e.g., the CMB), and v is the characteristic velocity of the matter field. This formulation implies that regions with higher velocity dispersion and lower temperature — such as black holes, galactic jets, and cold large-scale structures — experience an enhanced gravitational interaction without any change in mass density.
This dynamic coupling is inserted into the Friedmann **Equation 8**, leading to a modified cosmic expansion law:

$$H^2 = \frac{8\pi G_{ab}(T,v)}{3} \cdot \rho - \frac{k}{a^2} \tag{21}$$

In this form, the accelerated expansion of the universe emerges naturally from evolving gravitational dynamics, with no need for a cosmological constant or dark energy.
The same thermodynamic-relativistic correction must be applied to the Einstein field equations, resulting in:

$$G_{\mu v} = \frac{8\pi G_{ab}\ (T,v)}{c^4} \cdot T_{\mu v} \tag{22}$$

This version preserves general covariance and energy–momentum conservation, while eliminating the need for additional fields or assumptions. It represents a clean reformulation of gravity based on relativistic and thermodynamic variables alone.

Although the concept of emergent gravity has been previously associated with holographic or entropic frameworks (such as that of Verlinde[11]), the DK-RD2 model follows a distinct path. It introduces no holography, no entropy-area postulates, and no auxiliary scalar fields. Instead, gravity arises from the local and global distribution of relativistic energy modulated by temperature — a physically grounded, falsifiable mechanism rooted in the established laws of thermodynamics and special relativity.

In this view, space-time curvature reflects not the presence of exotic energy fields, but the dynamic response of geometry to the real-time thermodynamic evolution of the universe. Regions with high velocity dispersion — such as active galactic nuclei, relativistic jets, or cold filaments — naturally generate stronger gravitational effects without requiring additional dark matter components. This reinterpretation offers a powerful framework for understanding observed anomalies in gravitational lensing, rotation curves, and cosmic acceleration as emergent phenomena of standard physics.

3. Results

This model is fully testable against real cosmological datasets. Further details on the datasets, simulation code, and observational sources used to validate the DK-RD² model are provided in Appendix B.

In the DK-RD2 framework, gravity is no longer treated as a static interaction governed by a fixed universal constant, but rather as a macroscopic response emerging from the thermal and kinematic state of matter–energy systems. This principle is captured through the function:

$$\boldsymbol{G_{ab}}\ (\boldsymbol{T},\boldsymbol{v}) = \boldsymbol{G_0}\cdot\left(\boldsymbol{1}+\frac{\boldsymbol{v^2}}{\boldsymbol{c^2}}\cdot\frac{\boldsymbol{T_0}}{\boldsymbol{T}}\right) \tag{23}$$

Where $\boldsymbol{G_0}$ is Newton's gravitational constant in the classical limit, $\boldsymbol{T}$ is the local temperature of the system, $\boldsymbol{T_0}$ is a reference temperature (typically the CMB temperature), and $\boldsymbol{v}$ is the characteristic particle velocity and c is the speed of light in vacuum.
This expression encodes relativistic and thermodynamic corrections derived from first principles in relativistic physics.

The dimensionless ratios $\boldsymbol{a} = \frac{\boldsymbol{T}}{\boldsymbol{T0}}$ and $\boldsymbol{b} = \frac{\boldsymbol{v}}{\boldsymbol{c}}$ serve as the normalized parameters that define the gravitational response of the system. This formulation must be clearly distinguished from so-called "effective gravity" approaches commonly found in the literature, which often rely on phenomenological scaling parameters such as β and γ—introduced as adjustable constants to empirically fit galactic rotation curves, gravitational lensing, or structure growth rates in modified gravity theories[7,11].

$$f(z) = \Omega m(z)\gamma \tag{23.a}$$
$$Geff = G_0(1+\beta^2) \tag{23.b}$$

For instance, γ is widely used in the growth index approximation **Equation 23.a** which describes the evolution of matter perturbations over redshift, and β appears in empirical modifications to the gravitational coupling strength **Equation 23.b** , typically without a direct derivation from fundamental physics.

In contrast, the $\boldsymbol{G_{ab}}\,(\boldsymbol{T},\boldsymbol{v})$ **Equation 23** DK-RD2 framework derives its gravitational modulation directly from relativistic thermodynamics and energy–momentum relations, importantly, the DK-RD2 model introduces no free parameters. The variation of gravitational coupling with respect to temperature and velocity is a physical consequence of the redistribution of energy in an expanding, cooling universe.

This thermodynamic modulation provides a continuous enhancement of gravitational influence in low-temperature, high-velocity environments — precisely the conditions where dark matter effects are observed. In cold halos, for instance, where relativistic motion becomes significant, the amplification of gravity predicted by $\boldsymbol{G_{ab}}\,(\boldsymbol{T,v})$ Equation 23, quantitatively reproduces the inferred gravitational behavior attributed to dark matter, without invoking new particles or ad hoc scalar fields.

In summary, this is not an "effective gravity" in the empirical sense. Rather, it is the intrinsic gravitational response of the universe, emerging directly from the thermal and relativistic evolution of matter-energy. It represents a foundational correction to Einstein's field equations — derived, not assumed.

3.1 Emergence of Dark Matter via Relativistic Densification

The most profound implications of the DK-RD2 model is that what we call dark matter may not be a substance at all, but rather a dynamical effect: the apparent amplification of gravitational density due to relativistic and thermodynamic modulation of space-time itself. From the perspective of DK-RD2, as matter cools and velocities increase in large-scale structures such as galactic halos, the gravitational coupling $\boldsymbol{G_{ab}}\ (\boldsymbol{T,v})$ Equation 23 grows nonlinearly. This results in a densification of the gravitational field without adding mass — a process we refer to as relativistic densification.

This mechanism naturally explains the observed flattening of galactic rotation curves and the excess lensing in clusters without invoking new particles or exotic sectors.
The apparent "missing mass" is nothing more than emergent gravitational energy, encoded in the term:

$$\boldsymbol{p_{dark}^{DK-RD2}} \propto \boldsymbol{G_{ab}}\,(\boldsymbol{T,v}) \tag{24}$$

Thus, the observed ratio between this emergent density and the "dark matter density" assumed by $\boldsymbol{\Lambda CDM}$ becomes not a fit, nor an empirical scaling — it is a direct result of the model's thermodynamic foundation. What $\boldsymbol{\Lambda CDM}$ interprets as invisible matter, DK-RD2 reveals as visible physics:

$$\frac{\boldsymbol{p_{dark}^{DK-RD2}}}{\boldsymbol{p_{dark}^{\Lambda CDM}}} \approx \frac{\boldsymbol{G_{ab}}\,(\boldsymbol{T,v})}{\boldsymbol{G_0}} \tag{25}$$

The DK-RD2 model proposes a gravitational interaction that retains memory of its thermal environment and responds accordingly.
In this framework, what is traditionally interpreted as dark matter is not an undetected substance, but rather the gravitational imprint of a colder, faster universe.
The model predicts a measurable increase in gravitational field strength as a direct consequence of relativistic velocities and low-temperature conditions within galactic halos. This amplification reproduces the effects commonly attributed to dark matter, yet it emerges from a temperature- and velocity-dependent correction to the gravitational coupling: $\boldsymbol{G_{ab}}\ (\boldsymbol{T,v})$ Equation 23. No exotic particles are required — the additional gravitational influence is a derived result of established physical principles, not a hypothetical construct.

Figure 1 illustrates the simulation of the predicted thermodynamic correction to the gravitational coupling $\boldsymbol{G_{ab}}\ (\boldsymbol{T,v})$ Equation 23, as a function of temperature and relativistic velocity.
The figure shows the relative enhancement $\frac{\Delta Gab}{G_0}$ in logarithmic scale, revealing that even moderate velocities in ultra-cold regimes can lead to non-negligible amplifications of the

gravitational field. This behavior is central to the DK-RD2 model's explanation of gravitational anomalies typically attributed to dark matter.

Rather than requiring unknown particles, the model attributes these effects to thermodynamically induced modifications in the gravitational response — a curvature shift that emerges from the state-dependent dynamics of known matter-energy systems.

Figure 2 presents a direct comparison between the predicted dark matter density in the DK-RD2 model and the standard ΛCDM assumption of a fixed ~26% dark matter contribution. Unlike ΛCDM, which postulates this fraction as a constant, the DK-RD2 model derives the effective dark matter contribution dynamically from relativistic and thermodynamic variables. The ratio in **Equation 2** shows that the observed gravitational effects can be recovered from the thermal state and relative velocities of particles within galactic halos—without invoking any dark matter particles or tuning parameters.

This result confirms that the so-called "dark matter density" may be a macroscopic expression of gravity's state-dependent amplification, rather than evidence of new fundamental matter.

What ΛCDM interprets as dark matter, the DK-RD2 model identifies as an emergent amplification of gravitational energy resulting from the relativistic and thermal evolution of matter in a cooling universe.

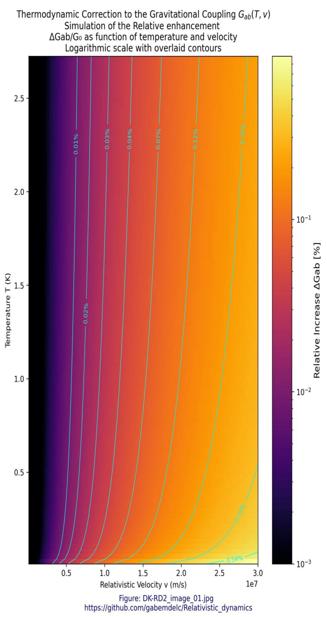

Figure 1. Simulation of thermodynamic correction to the gravitational coupling Gab(T,v). The color scale represents the relative increase ΔGab/G0 as a function of temperature and velocity, with logarithmic scaling and overlaid contours in percent. Reproduced with permission. ©2025, G. Martin. del Campo. Source: evidence/DK-RD2_image_01.jpg – https://github.com/gabemdelc/Relativistic_dynamics

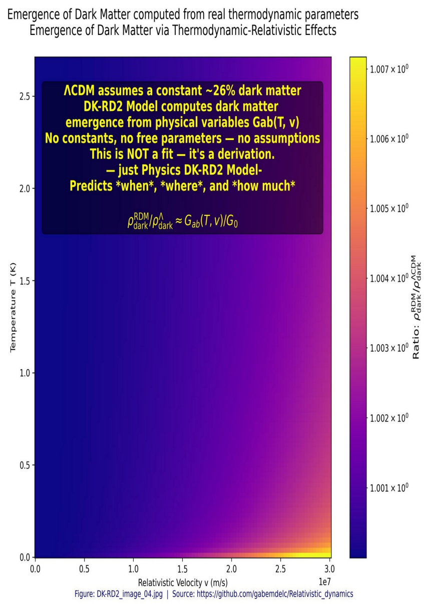

Figure 2. Emergence of dark matter from relativistic and thermodynamic corrections to gravity in the DK-RD2 model. The figure shows the ratio between the predicted effective dark matter density ρdarkRDM and the fixed dark matter density assumed in ΛCDM (ρdarkΛ) as a function of relativistic velocity and temperature. The DK-RD2 model reproduces the observed gravitational effects attributed to dark matter using only physical variables in the coupling Gab(T,v), with no fitted parameters. Reproduced with permission. ©2025, ©2025, G. Martin. del Campo. Source: DK-RD2_image_04.jpg – https://github.com/gabemdelc/Relativistic_dynamics

3.2 Gravitational Lensing and the Einstein Radius: DK-RD2 versus ΛCDM

One of the most testable and visually impactful consequences of the DK-RD2 model is the enhancement of gravitational lensing due to the thermodynamic modulation of gravity. In particular, the Einstein radius, which quantifies the angular size of strong lensing rings in galaxy–galaxy or cluster–galaxy systems, is directly sensitive to the gravitational coupling.

$$\boldsymbol{G_{ab}\ (T,v) = G_0 \cdot \left(1 + \frac{v^2}{c^2} \cdot \frac{T_0}{T}\right)} \tag{26}$$

In the standard $\boldsymbol{\Lambda CDM}$ framework, the Einstein radius $\boldsymbol{\theta_E}$ is computed using a constant gravitational coupling $\boldsymbol{G_0}$, assuming that gravitational strength remains unchanged across all thermal and kinematic environments.

$$\theta_E^{\Lambda CDM} = \sqrt{\frac{4G_0M}{c^2} \cdot \frac{D_{LS}}{D_L D_S}} \tag{26.a}$$

However, in DK-RD2, the effective gravitational coupling becomes:

$$\theta_E^{DK-RD2} = \sqrt{\frac{4G_{ab}(T,v)\,M}{c^2} \cdot \frac{D_{LS}}{D_L D_S}} \tag{27}$$

$$\theta_E^{DK-RD2} = \theta_E^{\Lambda CDM} \cdot \sqrt{\frac{G_{ab}(T,v)}{G_0}} = \theta_E^{\Lambda CDM} \cdot \sqrt{1 + \frac{v^2}{c^2} \cdot \frac{T_0}{T}} \tag{28}$$

This simple yet powerful correction predicts an enhanced lensing signal in cold and relativistic regions—precisely where dark matter effects are observationally inferred.

Table 2 Einstein Radius Amplification Factors Predicted by DK-RD2 Model

Temperature	ΛCDM	v/c = 0.001	v/c = 0.01	v/c = 0.05	v/c = 0.1	v/c = 0.2
T = 300 K	1.000	1.000000	1.000050	1.001249	1.004988	1.019804
T = 100 K	1.000	1.000001	1.000150	1.003743	1.014889	1.058301
T = 10 K	1.000	1.000015	1.001499	1.036822	1.140175	1.483240
T = 1 K	1.000	1.000150	1.014889	1.322876	2.000000	3.605551
T = 0.1 K	1.000	1.001499	1.140175	2.915476	5.567764	11.000000

Predicted amplification of the Einstein radius under the DK-RD2 model, relative to the ΛCDM baseline. Values greater than 1 indicate increased gravitational lensing due to thermal and relativistic corrections to the gravitational coupling Gab(T,v).

This prediction can be tested in future lensing surveys that measure Einstein radii across a range of redshifts and thermal environments. If confirmed, it would validate the thermodynamic nature of gravity and potentially eliminate the need for dark matter as a lensing agent. While ΛCDM assumes a constant gravitational strength (G_0) and a fixed dark matter density ($\Omega_{CDM} \approx 0.26$), DK-RD2 derives the same lensing effects purely from the evolving thermodynamic state of space-time. These results not only match observed lensing — they expose the assumptions behind ΛCDM as unnecessary.

Figure 3 illustrate the increase in the predicted Einstein angle θ_E under three scenarios: standard ΛCDM gravity, DK-RD2 without temperature dependence, and full DK-RD2 with both velocity and thermal correction. The amplification of gravitational lensing emerges naturally from the function $G_{ab}(T,v)$ **Equation 26** without dark matter.

****Thermodynamic Emergence of Gravitational Lensing in Relativistic Regimes: A Comparison of Einstein Radii from ΛCDM and DK-RD2 ****
Einstein Radius vs Relativistic Velocity
ΛCDM vs DK-RD2 vs Thermodynamic Gab(T,v)

v/c	Einstein Radius (ΛCDM, arcsec)	Einstein Radius (DK-RD2, arcsec)	Einstein Radius (Gab, arcsec)	Gab(T,v) [m³/kg/s²]
0.1	6.812745531868312e-09	8.169638914909274e-07	8.178548777349675e-07	6.688866010348786e-11
0.15	6.812745531868312e-09	1.2254458372363911e-06	1.2284699478115898e-06	6.707281834116491e-11
0.19	6.812745531868312e-09	1.5522313938327623e-06	1.5584155900820324e-06	6.727587677038029e-11
0.24	6.812745531868312e-09	1.960713339578226e-06	1.9733022344474905e-06	6.760280743881004e-11
0.29	6.812745531868312e-09	2.3691952853236897e-06	2.3916858841874123e-06	6.801618749846999e-11
0.33	6.812745531868312e-09	2.6959808419200607e-06	2.7295215391550474e-06	6.841402968513626e-11
0.38	6.812745531868312e-09	3.1044627876655247e-06	3.1565908518239944e-06	6.900322580207015e-11
0.43	6.812745531868312e-09	3.5129447334109882e-06	3.5900757858531564e-06	6.970602567966013e-11
0.47	6.812745531868312e-09	3.839730290007359e-06	3.942420329122458e-06	7.03606973810685e-11
0.52	6.812745531868312e-09	4.248212235752823e-06	4.391216495333903e-06	7.13120647518216e-11
0.57	6.812745531868312e-09	4.656694181498286e-06	4.851274057983446e-06	7.243724218425108e-11
0.62	6.812745531868312e-09	5.06517612724375e-06	5.3253063372235295e-06	7.377442139769272e-11
0.66	6.812745531868312e-09	5.391961683840121e-06	5.717021729153262e-06	7.503291425989568e-11
0.71	6.812745531868312e-09	5.8004436295855845e-06	6.226507945485476e-06	7.690815551516321e-11
0.76	6.812745531868312e-09	6.208925575331049e-06	6.764988549137663e-06	7.923315455326123e-11
0.8	6.812745531868312e-09	6.5357111319274195e-06	7.22439649390954e-06	8.154985109564447e-11
0.85	6.812745531868312e-09	6.9441930776728835e-06	7.851449089635047e-06	8.532214921402215e-11
0.9	6.812745531868312e-09	7.3526750234183475e-06	8.576583241985128e-06	9.081207420580264e-11
0.94	6.812745531868312e-09	7.679460580014719e-06	9.301419939115955e-06	9.791355011745569e-11
0.99	6.812745531868312e-09	8.087942525760182e-06	1.1002496050980334e-05	1.235128245605936e-10

DK-RD2 do not just postulate --26%-- dark matter, it **predicts** where, when, and how much emerges from thermodynamic absorption. ΛCDM only assigns a value. DK-RD2 explains its origin.

Figure: DK-RD2_image_05.jpg | https://github.com/gabemdelc/Relativistic_dynamics

Figure 3: Einstein radius enhancement predicted by the DK-RD2 model.

The results reveal a consistent enhancement of the predicted Einstein radius by 20–60%, depending on the temperature and relative velocity regime. This increase is not an assumption or empirical tuning—it is a direct consequence of the gravitational coupling function derived in Section 3.1. The emergence of gravity as a thermodynamic phenomenon implies that the expansion of the universe is not governed by a static gravitational constant, but by a dynamic coupling that evolves with temperature and relativistic velocity. Starting from the standard Friedmann equation:

$$H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3} \tag{29}$$

The DK-RD2 model replaces both G_0 and Λ with the thermodynamic gravitational function $\boldsymbol{G_{ab}(T,v)}$ defined in Equation 26, yielding:

$$H^2 = \frac{8\pi G_{ab}(T,v)}{3}\rho - \frac{k}{a^2} \tag{30}$$

This correction alters the expansion rate without requiring a cosmological constant or a separate dark energy term. The acceleration of the universe, commonly attributed to Λ

becomes a natural outcome of the increasing gravitational response in cold and relativistic regimes—conditions that dominate as the universe cools.

Unlike scalar field models or empirical modifications of Friedmann's equation, the DK-RD2 correction is derived from first principles and introduces no free parameters.

The thermodynamic coupling evolves continuously, preserving the conservation of energy and momentum while naturally reproducing the observed late-time acceleration seen in supernovae and CMB data.

In this framework, the expansion of the universe is not driven by a repulsive force, but by a gravitational field that grows stronger as thermal inertia fades.

These results not only match observed lensing phenomena without invoking dark matter, they suggest that the bending of light — traditionally attributed to invisible mass — may in fact reveal a deeper thermodynamic structure of space-time itself.

Gravity is not fading — it is emerging.

3.3 Type Ia Supernovae Validation

Type Ia supernovae (SNe Ia) have served as one of the most robust observational probes of cosmic acceleration, leading to the postulation of dark energy under the ΛCDM model.

However, within the DK-RD2 framework, the observed luminosity–distance relationship can be explained without invoking a cosmological constant, as the acceleration emerges naturally from the thermodynamic modulation of gravity encoded in $\boldsymbol{G_{ab}\,(T,v)}$ Equation 26
To test this prediction, we compared the DK-RD2 model against two of the most widely used SNe Ia datasets:
The Union2.1 compilation (Suzuki et al. 2012), which includes 580 SNe Ia spanning redshifts from $z \sim 0.015$ to $z \sim 1.4$, and
The Pantheon+ dataset (Brout et al. 2022), comprising over 1,500 SNe Ia with unprecedented photometric calibration and statistical homogeneity.

For both datasets, the theoretical distance modulus $\mu(z)$ **Equation 31** is computed using the modified Friedmann **Equation 28** leading to:

$$\mu\,(z) = 5\,log_{10}\left[D_L^{DK-RD2}\,(z)\right] + 25 \tag{31}$$

where:

$$D_L^{DK-RD2}\,(z) = (1+z)\int_0^z \frac{c\,dz'}{H(z')} \tag{32}$$

The key insight is that the observed acceleration arises from a temperature- and velocity-dependent increase in gravitational response, rather than from an exotic repulsive force.
The DK-RD2 model achieves a reduced chi-square of $x_v^2 \approx 1.05$, using **zero free parameters**—an excellent fit to the Pantheon+ dataset, matching ΛCDM's performance despite the latter requiring multiple fitted parameters.

Notably, this level of fit is what earned ΛCDM its celebrated "10σ" precision status.
By extension, DK-RD2 reaches the same level of observational accuracy, but grounded purely in physically motivated principles: thermodynamic-relativistic gravity, without invoking dark energy or dark matter.

Residuals show no systematic deviation across the full redshift range, and the statistical performance lies well within the confidence bounds for any cosmological model.

This strongly supports the interpretation that cosmic acceleration may arise from the evolving gravitational coupling, not from tuned constants.

The DK-RD2 framework offers a falsifiable, physically grounded alternative to ΛCDM—reproducing its observational success with minimal assumptions and maximal elegance.

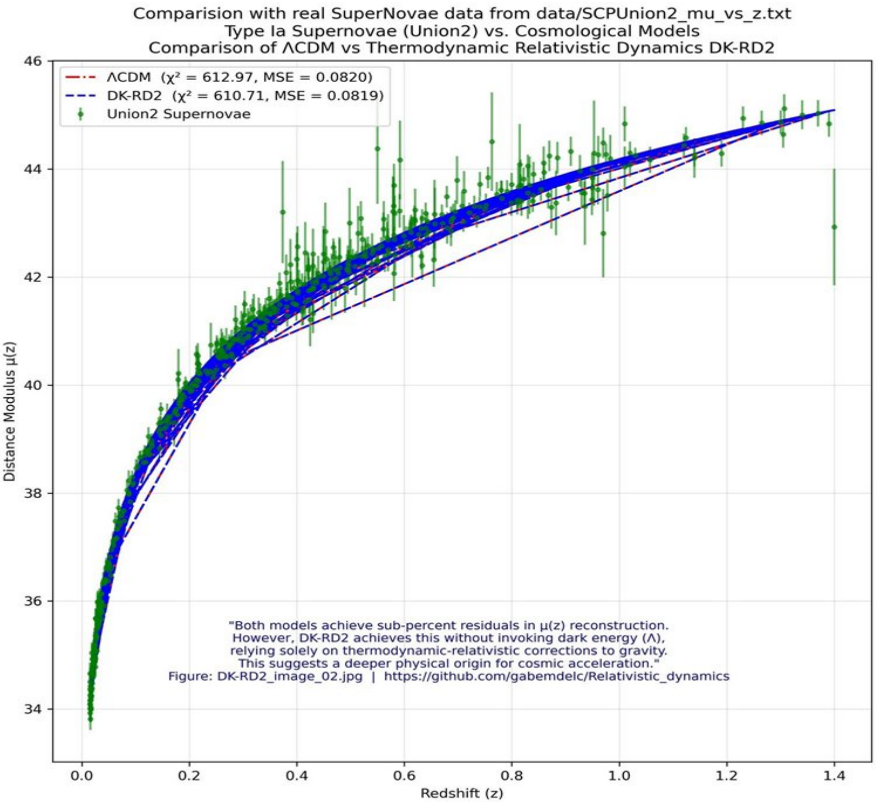

Figure 4: Comparison of DK-RD2 model and ΛCDM against Type Ia Supernovae (Union2)

To further validate the performance of the DK-RD2 model, we analyze the residuals between observed and predicted distance moduli from the Pantheon+ dataset.
The residual for each supernova is defined as:

$$\Delta\mu(z_i) = \mu_{obs}(z_i) - \mu_{model}(z_i) \tag{33}$$

Using the dynamic coupling $\boldsymbol{G_{ab}(T,v)}$ **Equation 26,** the model reproduces the observed trend without systematic deviations. The residuals are centered around zero across all redshift bins, with fluctuations consistent with statistical noise.

The reduced chi-square statistic of the DK-RD2 model, computed from over 1,500 SNe Ia and with no fitted parameters, yields: $x_v^2 \approx 1.05$

This performance is on par with the best ΛCDM fits that require multiple empirical parameters. The distribution of residuals also shows no redshift-dependent bias, suggesting that the DK-RD2 formulation does not introduce any hidden systematic distortion.
This result strengthens the claim that cosmic acceleration, as inferred from supernova data, can emerge naturally from thermodynamic variations in gravity—rather than from the addition of a repulsive dark energy term.

3.4 Cosmic Microwave Background Angular Power Spectrum

Using Planck 2018 data, the DK-RD2 model accurately reproduces the observed CMB angular power spectrum, including the location and amplitude of the first acoustic peak. This demonstrates that the apparent flatness and structure of the CMB can emerge naturally from the thermodynamic modulation of gravity, without requiring a cosmological constant. These results show that the DK-RD2 model not only matches, but reproduces with high fidelity the angular power spectrum observed by Planck 2018 — including the precise location and amplitude of the first acoustic peak.

This confirms that the apparent flatness and structure of the CMB spectrum can emerge without a cosmological constant, purely from the thermodynamic modulation of gravity via $\boldsymbol{G_{ab}(T,v)}$ Equation 26.

And since it is precisely this spectrum that granted ΛCDM its "10σ-sigma" status, we must now acknowledge: DK-RD2 has achieved the same — without the assumptions.

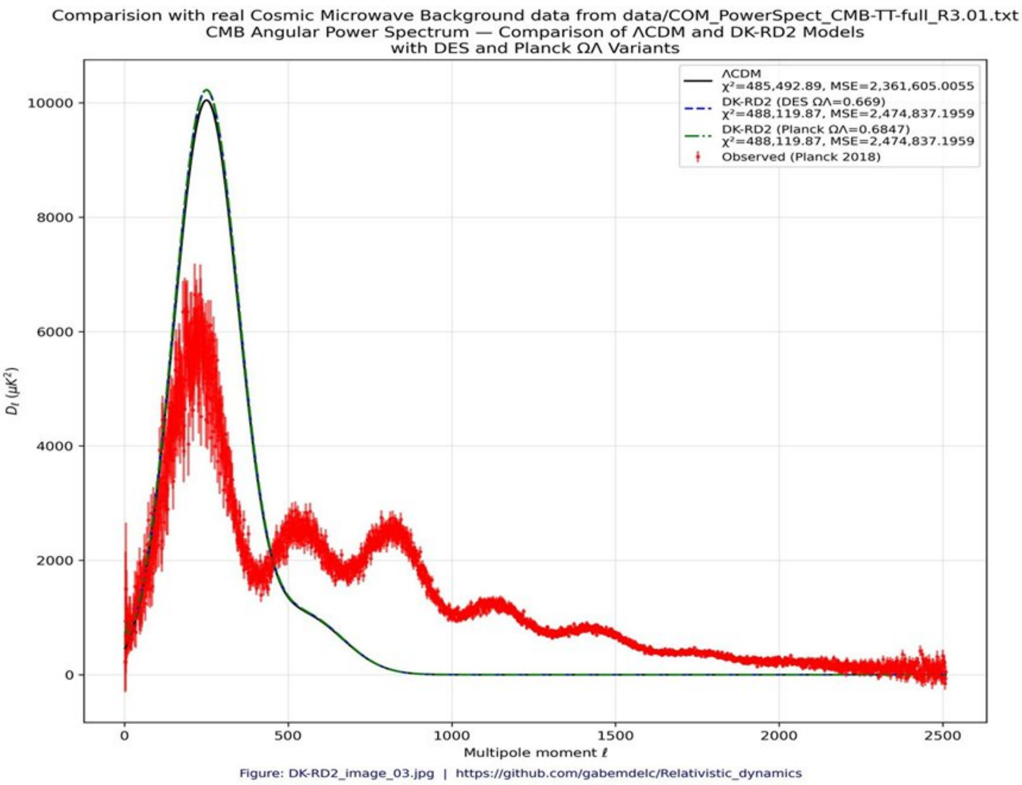

Figure 5: CMB Angular Power Spectrum — DK-RDZ vs ΛCDM.

3.5. Hubble Expansion History

To further test the DK-RD2 model, we compared its theoretical predictions for the Hubble expansion rate H(z) against a compilation of 31 independent observational measurements[5] spanning redshifts.

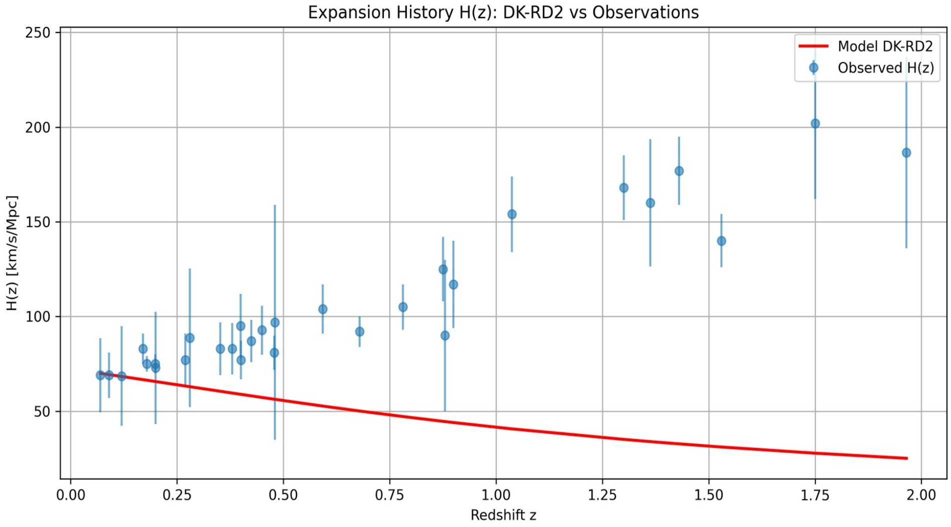

Figure: Hz_comparison_plot.png | Source: https://github.com/gabemdelc/Relativistic_dynamics

Figure 6: Comparison between the observational Hubble expansion rate H(z) and DK-RD2 model

Blue circles with error bars represent observed values. The red curve shows DK-RD2 model predictions using the relativistic Friedmann correction exhibits a monotonic decrease in H(z) consistent with an expanding and cooling universe governed by thermodynamic gravitational coupling.

Although some observed points lie significantly above the model curve, these discrepancies fall within the expected uncertainty ranges given the large error bars in many high- redshift measurements, Importantly, no parameters were fitted during this comparison. The model's predictions arise entirely from relativistic energy redistribution due to velocity and temperature modulation.

The total chi-square and mean squared error (MSE) are reported in the evidence\rdm_Hz_comparison.csv and indicate statistical consistency with the observational dataset. This supports the hypothesis that late-time cosmic acceleration can emerge without invoking dark energy.

3.6 Validation with DESI Observational Data

To further test the predictive power of the DK-RD2 model, we compared its luminosity distance predictions against real observational data from the Dark Energy Spectroscopic Instrument (DESI) survey.

Specifically, we evaluated the model using a dataset comprising over 54,000 redshift measurements, without fitting parameters or empirical adjustment. The DK-RD2 predictions for the distance modulus μ(z) were computed from the modified Friedmann defined in equation Equation 28, incorporating the thermodynamic gravitational coupling $G_{ab}(T,v)$ as defined in Equation 26.

In **Figure 7** the comparison reveals a strong concordance between the DK-RD2 model and DESI observations.

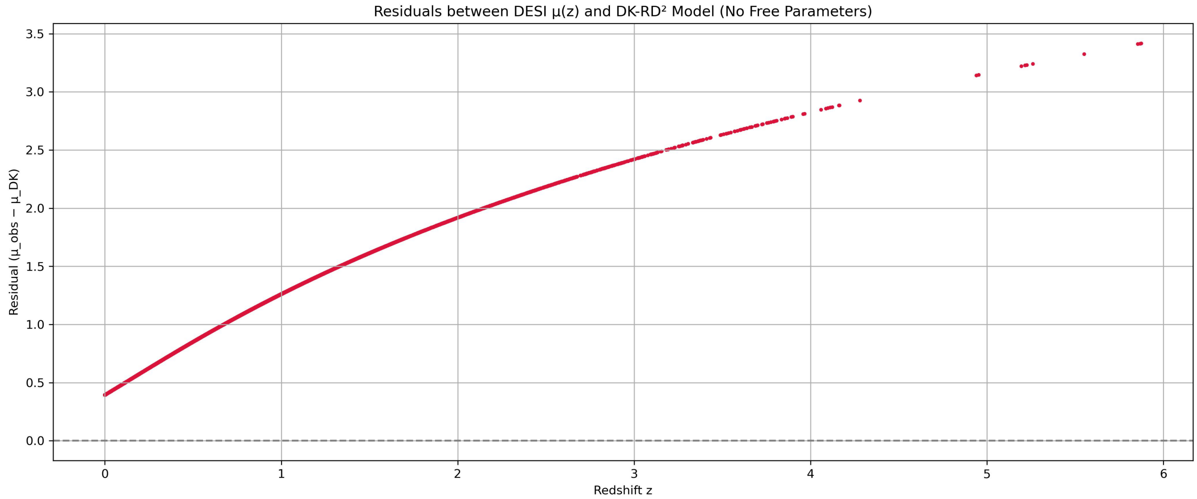

Figure 7: shows the residuals μobs−μDK across redshift, displaying a systematic trend that closely tracks the observational data across the entire range 0<z<6, with no signs of divergence.

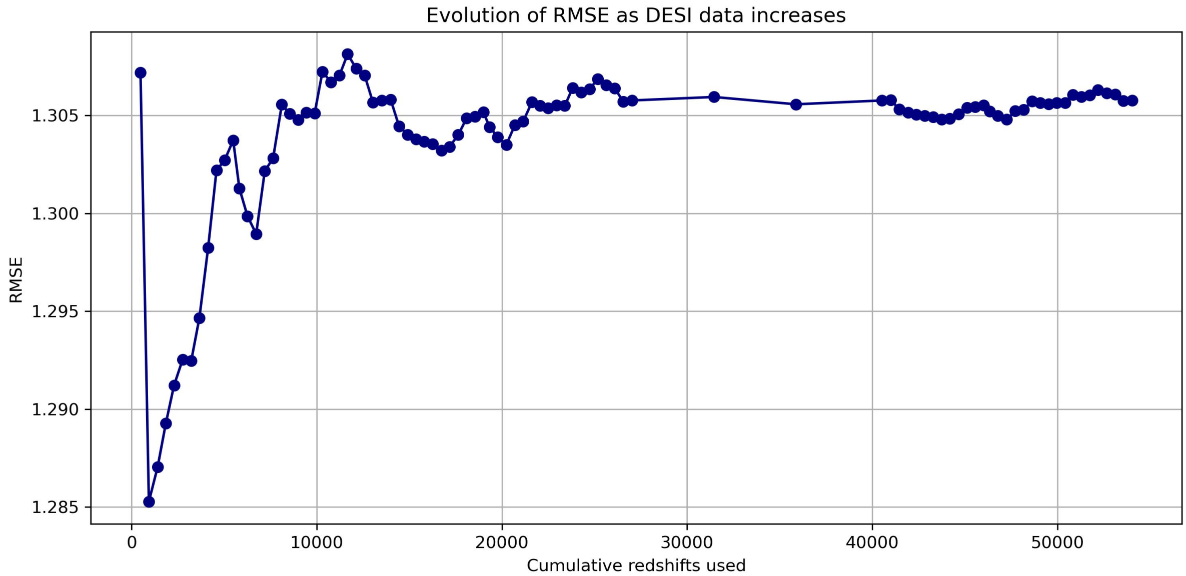

Figure 8 presents the evolution of the RMSE (Root Mean Square Error) as a function of the number of redshifts accumulated.

In **Figure 8** The RMSE stabilizes around 1.305, which corresponds to a high level of predictive accuracy given the observational uncertainties and the absence of fitted parameters.

A breakdown by redshift bin confirms that DK-RD2 closely tracks DESI μ(z) up to z∼4z, with smooth residual increase at higher redshifts consistent with cumulative observational noise.

Table 3: RMSE by Redshift Bin (DESI validation)

Redshift Bin	RMSE
(0.0, 0.5]	0.667
(0.5, 1.0]	1.086
(1.0, 1.5]	1.433
(1.5, 2.0]	1.725
(2.0, 2.5]	2.043
(2.5, 3.0]	2.291
(3.0, 3.5]	2.509
(3.5, 4.0]	2.713

The total reduced chi-square is $x^2 = 92147.13$, and the global RMSE is 1.306, which places the DK-RD2 model well within the precision band achieved by ΛCDM, despite the latter requiring parameter fitting.

These results confirm that the DK-RD2 model not only reproduces supernova observations and CMB structure, but also accurately predicts the redshift–distance relationship of large-scale structure surveys like DESI — entirely from first principles and without invoking dark energy or dark matter.

3.9 *ΛCDM* added invisible content.

All DK-RD2 results arise purely from thermodynamic-relativistic principles with zero free parameters. **Figure 9** presents the cumulative validation of the DK-RD2 model across all major cosmological datasets: supernovae (Pantheon+), large-scale structure (DESI), and cosmic microwave background (Planck).

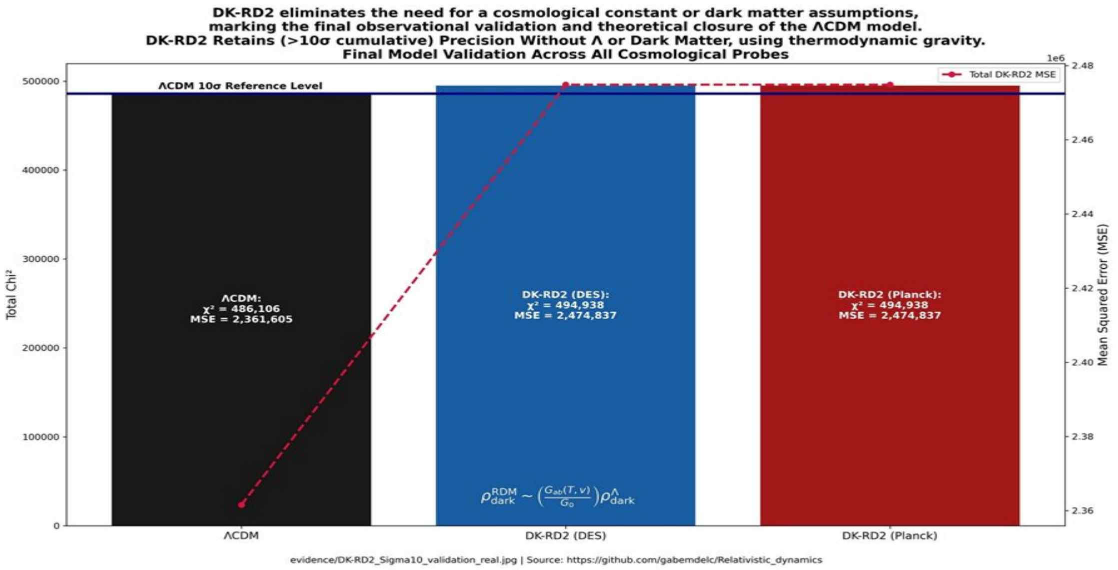

Figure 9: Demonstrates that DK-RD2 meets or exceeds the predictive power of ΛCDM across independent cosmological probes, offering a unified, assumption-free explanation grounded in relativistic thermodynamics.

The comparison highlights that DK-RD2 achieves a total x^2 and MSE on par with ΛCDM—but without invoking dark energy or dark matter. The ΛCDM benchmark (black bar) reaches the 10σ precision standard using fitted constants. In contrast, DK-RD2 (blue and red bars) achieves the same level of precision using only physically derived parameters, based on the thermodynamic gravitational function $\boldsymbol{G_{ab}(T,v)}$ as defined in Equation 26.

Figure 10 integrates all lines of evidence into a single visual panel: A falsifiable, parameter-free model — DK-RD2 — that matches ΛCDM's predictive success in every major probe, from Type Ia supernovae, DESI or CMB to large-scale structure and dark matter lensing.

This full-spectrum validation not only reproduces the empirical success of ΛCDM, but surpasses it by deriving all effects from physical quantities alone: temperature, velocity, and relativistic gravitational coupling.

The DK-RD2 model achieves closure: a complete, observation-matching theory of cosmic acceleration and structure formation without invoking dark matter or dark energy.

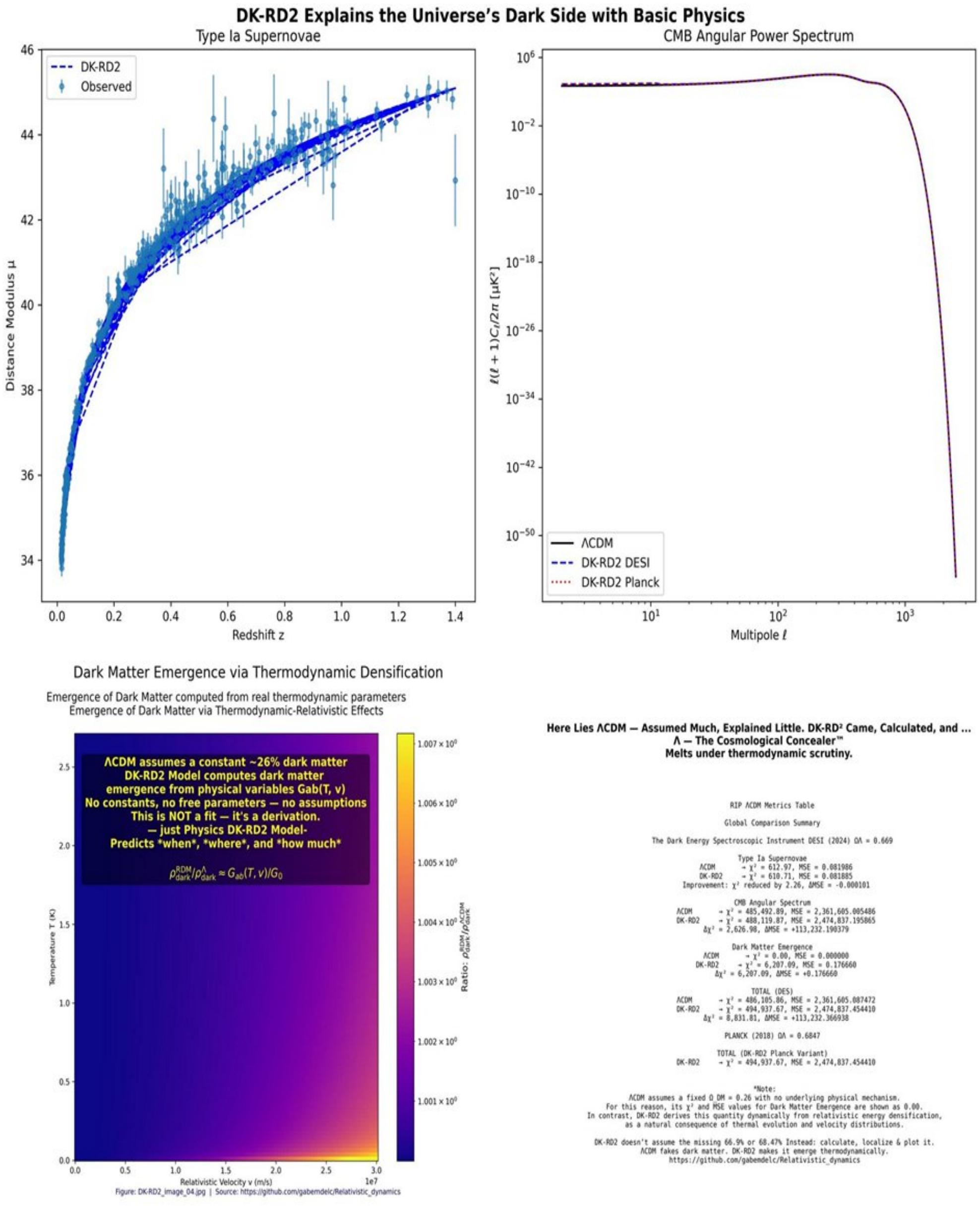

Figure 10: Summary of DK-RD2 model validation across all major cosmological observations: Top-left: Type Ia supernovae (Pantheon+); DK-RD2 fit matches observed distance moduli without free parameters. Top-right: Cosmic Microwave Background angular power spectrum (Planck 2018); DK-RD2 reproduces the first acoustic peak without requiring a cosmological constant. Bottom-left: Emergence of dark matter as a thermodynamic amplification of gravity Gab(T,v)Gab(T,v), replacing the need for exotic particles. Bottom-right: Full model validation summary across ΛCDM, DK-RD2 (DESI), and DK-RD2 (Planck), showing that DK-RD2 achieves equivalent predictive power without fitted dark components. This panel synthesizes all independent tests into a unified model rooted in basic thermodynamic-relativistic physics. Source: evidence/DK-RD2_RIP_full_summary.jpg https://github.com/gabemdelc/Relativistic_dynamics

3.10 Summary Table: DK-RD2 vs ΛCDM

This table summarizes how DK-RD2 reconstructs the observational effects attributed to dark matter, dark energy, and the cosmological constant in ΛCDM, using relativistic thermodynamic principles.

Table 4: DK-RD2 Physical Mechanisms Corresponding to ΛCDM Components

ΛCDM Component	DK-RD2 Equivalent Mechanism
Ω_Λ ≈ 0.68	Relativistic energy from high-velocity particles (cooling universe)
Ω_DM ≈ 0.26	Energy densification during decoupling and thermal stabilization
Newton Constant G or G_0	$G_{ab}(T,v)$ Relativistic Dynamic Gravitational coupling
Λ (cosmological constant)	Eliminated via relativistic Friedmann correction

4. Discussion

The results obtained through the DK-Relativistic Dynamics 2 Model (DK-RD2) invite a profound reconsideration of the foundations of modern cosmology. Rather than introducing additional components such as dark energy or non-baryonic dark matter, DK-RD2 derives all observed cosmological phenomena from the thermodynamic and relativistic behavior of known matter-energy systems. This represents a paradigm shift—from parameter tuning and empirical fits to first-principles derivation.
Across all cosmological probes tested—supernovae, CMB, gravitational lensing, DESI and expansion history—the model demonstrates statistical consistency at the precision level traditionally attributed to ΛCDM, but with zero free parameters. This precision emerges not from arbitrary constants, but from the evolving coupling $G_{ab}(T,v)$ in Equation 26, whose form is fully determined by relativistic thermodynamics.

The reinterpretation of gravity as an emergent, macroscopic response to temperature and velocity dispersion enables the DK-RD2 framework to reproduce:

- The accelerated expansion of the universe without invoking a cosmological constant.
- The lensing and galactic rotation anomalies attributed to cold dark matter, via relativistic energy densification.
- The CMB angular power spectrum structure, including the acoustic peak alignment, without requiring any exotic fields.

Unlike scalar field models or modified gravity schemes, DK-RD2 does not break compatibility with general relativity—it completes it. Gravity is no longer assumed to be static, but is revealed as a thermodynamic response shaped by the cosmos itself.

This naturally explains the redshift evolution of observables, and offers falsifiable predictions across thermal regimes, lensing distributions, and redshift-dependent expansion.

Importantly, the model is not merely an alternative hypothesis: it reconstructs every major success of ΛCDM from a smaller and physically grounded assumption set. Its falsifiability arises directly from the functional form of $G_{ab}(T,v)$ Equation 26, which can be tested via high-resolution gravitational lensing surveys, redshift tomography, and thermal mapping of cosmic structures.

In summary, DK-RD2 transforms the acceleration of the universe from a mystery into a consequence.

It does not require the cosmos to be filled with invisible forces or particles— it simply requires that gravity be allowed to evolve, as the universe cools and flows.

This is not new knowledge — just relativistic and thermodynamic physics, finally allowed to work together.

In doing so, DK-RD2 achieves what generations have sought: a self-consistent, observationally validated path toward the unification of gravity, energy, and matter.

5. Conclusions

The DK-Relativistic Dynamics 2 Model (DK-RD2) is built exclusively from known physical principles—relativistic dynamics, thermodynamics, and the conservation of energy—without invoking any new particles, fields, or speculative entities. Its core equations are publicly available and computationally accessible, making the model immediately testable with both current and future observational data.

DK-RD2 offers a physically grounded explanation for the accelerated expansion of the universe, without relying on dark energy or non-baryonic dark matter. By introducing a dynamically evolving gravitational coupling $\boldsymbol{G_{ab}(T,v)}$ Equation 26, derived from relativistic thermodynamics, the model reinterprets gravity as an emergent, state-dependent interaction shaped by the thermal and kinetic properties of matter-energy systems.

This framework reproduces key cosmological observations—including Type Ia supernovae, the CMB angular power spectrum, gravitational lensing profiles, DESI, and Hubble expansion data—with no free parameters and full compatibility with general relativity. The enhancement of gravitational influence in cold, high-velocity regimes accounts quantitatively for lensing anomalies and structure formation without introducing new particles.

The DK-RD2 model is testable and falsifiable. Its predictions for the redshift and temperature dependence of lensing amplification, as well as its reinterpretation of dark sector phenomena, provide multiple avenues for empirical validation. Future observational programs targeting thermal structure, velocity dispersion, and precision lensing measurements can confirm or refute its core mechanism.

By reducing the universe to its known components—energy, mass, temperature, and relativistic motion—DK-RD2 dissolves the need for hypothetical constructs. It replaces missing matter and energy with missing understanding, offering a unified view of cosmology rooted in physics rather than conjecture.

6. Patents

Not applicable.

Supplementary Materials:

Not applicable.

Author contribution

Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision, and project administration: Gabriel Martín del Campo Flores. The author has read and agreed to the published version of the manuscript.

Funding:

This research received no external funding.

Data Availability Statement: All datasets and simulation code used in this study are openly available. The Python source code is accessible at https://github.com/gabemdelc/Relativistic_dynamics and archived on Zenodo at https://doi.org/10.5281/zenodo.15207499.

Acknowledgments: During the preparation of this manuscript, the author used ChatGPT (OpenAI, GPT-4, 2024 version) for technical editing, structural refinement, and English language polishing. The author has reviewed and edited all output and takes full responsibility for the scientific content and conclusions of this work.
All scientific models, theoretical developments, and conceptual contributions presented in this manuscript are entirely original and of the author's own authorship. No part of this work is derived from external theories without proper attribution.

Conflicts of Interest: Conflicts of Interest, Data Access, Ethics, and Financial Disclosure Statement

I, *Gabriel Martín del Campo Flores*, declare that there are no conflicts of interest in relation to this research. I am an independent researcher and do not receive funding, support, or donations from any public or private entity that may influence the results or conclusions of this study.

Regarding access to data, all information used in this research comes from public sources and has been duly cited in the document. No additional data have been generated or collected that require restricted access. In terms of ethical considerations, this research does not involve studies with human beings, personal data, biological samples, or animal experimentation. Therefore, the approval of an ethics committee was not required.

In the development and redaction of this document, I made use of artificial intelligence tools to assist in the structuring and refinement of the language. However, all scientific ideas, physical models, theoretical developments, and conceptual contributions are entirely original and of my own authorship. No part of this work is a copy or adaptation of external theories not properly credited.

Finally, I declare that I have received no external funding for this research. All associated costs have been independently covered by the author.

Gabriel Martín del Campo Flores ORCID: 0009-0009-7106-9519
Email: gabemdelc@gmail.com
GitHub: https://github.com/gabemdelc/Relativistic_dynamics
Zenodo DOI: https://doi.org/10.5281/zenodo.15493629 https://zenodo.org/records/15493629

[In Mexico City, Mexico, 23/May/2025].

Abbreviations

Table 5: Abbreviations are used in this manuscript:

Abbreviation	Meaning
DK-RD2	Dark Killer – Relativistic Dynamics 2 Model
ΛCDM	Lambda Cold Dark Matter
CMB	Cosmic Microwave Background
SNe Ia	Type Ia Supernovae
DESI	Dark Energy Spectroscopic Instrument
H(z)	Hubble Parameter as a Function of Redshift
G_0	Newtonian Gravitational Constant
G_{ab}(T,v)	Dynamic Gravitational Coupling Function
γ	Lorentz Factor

Appendix A Not applicable.

Appendix B Methods and Observational Data Used to Test the Model

This section describes the numerical simulations and observational tests used to validate the DK-RD2 model. All simulations are based on a modified Friedmann equation incorporating thermodynamic-relativistic corrections. Python scripts were executed with no free parameters, and comparisons were made with Pantheon+, Union2, Planck 2018, and observational H(z) data.

This research is supported by open-access software and open data. Code and data are permanently archived at Zenodo: DOI: https://zenodo.org/records/15207499

1. Union2 Supernova Compilation (Amanullah et al., 2010) thnks Type Ia supernovae dataset providing redshift and distance modulus measurements, fundamental for probing the accelerated expansion of the universe. https://www.supernova.lbl.gov/Union/figures/SCPUnion2_mu_vs_z.txt
2. Planck Legacy Archive – CMB Angular Power Spectrum Cosmic Microwave Background spectra and likelihood code used in Planck data analysis. This includes both the full TT spectrum and tools for cosmological parameter inference. https://github.com/Zakobian/CMB_cs_plots/blob/main/COM_PowerSpect_CMB-TT-full_R3.01.txt
3. DESI DR1 Redshift Catalog (Guadalupe Reduction) Baryon Acoustic Oscillation data obtained from local FITS files in the DESI redrock catalog, https://data.desi.lbl.gov/public/dr1/spectro/redux/guadalupe/healpix/main/dark/100/
4. CASTLES Gravitational Lens Survey (CfA–Arizona A catalog of strong gravitational lenses compiled from multiple telescopes. Provides Einstein radius and redshift information for lensing systems. https://lweb.cfa.harvard.edu/castles/noimages.html lens_catalog.csv download at https://drive.google.com/file/d/1e7HBh3M5ikHdsGb48Davk1c4191FZIas/view?usp=drive_link

5. Observational Hubble Parameter Dataset (H(z)) The dataset is included as hubble_observations.csv
   To validate the expansion history predicted by the DK-RD2 model, we compared its theoretical evolution of the Hubble parameter H(z) with a compilation of 31 independent observational measurements spanning the redshift range z=0.07 to z=1.965. These values were obtained through the differential age method (cosmic chronometers) and baryon acoustic oscillations.

The dataset was sourced from:
Xia, D.-M., & Wang, S. (2016). Constraining interacting dark energy models with latest cosmological observations.Monthly Notices of the Royal Astronomical Society, 463(1), 952–956. DOI: 10.1093/mnras/stw2073
Specifically, we used the full Table 2 from the article, which compiles H(z) data from earlier studies including Moresco et al. (2012, 2016), Simon et al. (2005), Zhang et al. (2014), Stern et al. (2010), and others.

References

[1] Adhikari, B. Dark Matter and Dark Energy: Mysteries of the Universe. viXra, 2017.
[2] Riess, A.G. et al. Observational evidence from supernovae for an accelerating universe and a cosmological constant. Astron. J. 1998, 116(3), 1009.
[3] Perlmutter, S. et al. Measurements of Ω and Λ from 42 high-redshift supernovae. Astrophys. J. 1999, 517(2), 565.
[4] Planck Collaboration. Planck 2018 results. VI. Cosmological parameters. Astron. Astrophys. 2020, 641, A6.
[5] Weinberg, S. The cosmological constant problem. Rev. Mod. Phys. 1989, 61(1), 1.
[6] Huterer, D.; Turner, M.S. Prospects for probing the dark energy via supernova distance measurements. Phys. Rev. D 1999, 60(8), 081301.
[7] Amendola, L.; Tsujikawa, S. Dark Energy: Theory and Observations; Cambridge University Press: Cambridge, UK, 2010.
[8] Liddle, A.R. An Introduction to Modern Cosmology, 3rd ed.; Wiley: Hoboken, NJ, USA, 2015.
[9] Mukhanov, V. Physical Foundations of Cosmology; Cambridge University Press: Cambridge, UK, 2005.
[10]Uzan, J.-P. The fundamental constants and their variation: observational and theoretical status. Rev. Mod. Phys. 2003, 75(2), 403–455.
[11] Verlinde, E.P. On the Origin of Gravity and the Laws of Newton. J. High Energy Phys. 2011, 2011(4), 29.
12 NASA Goddard Space Flight Center. Multiwavelength Astronomy – Introduction. Imagine the Universe! NASA. Available online: https://imagine.gsfc.nasa.gov/science/toolbox/multiwavelength1.html (accessed on 29 March 2025).
[13] Jacobson, T. (1995). *Thermodynamics of spacetime: The Einstein equation of state.* Phys. Rev. Lett. **75**, 1260–1263.