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Physics Renaissance (I) Thermodynamic Solution to the Expansion of the Universe – Elimination of Dark Energy

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Physics Renaissance (I) Thermodynamic Solution to the Expansion of the Universe—Elimination of Dark Energy

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Abstract

This study constructs a gravitational-entropy dynamic equilibrium model by coupling general relativity and thermodynamics, demonstrating that cosmic expansion can be driven by the natural competition between gravitational potential and entropy increase—without introducing dark energy. The model derives a Hubble constant of 67.3 km/s/Mpc, which is in high agreement with observations from the *Planck* satellite [7]. It also defines two critical scales: a global scale (513 Mpc) and a local scale (160 Mpc), matching the observational characteristics of the Coma Supercluster [9]and Laniakea Supercluster [8], respectively. The results show that the *dark energy* hypothesis is redundant at both mathematical and physical levels [10], and cosmic evolution can be uniformly described by fundamental physical laws, consistent with Occam's Razor principle.

Keywords: expansion of the universe; dark energy; gravitational - entropy equilibrium; hubble constant; critical scale

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1. Introduction

As the core hypothesis to explain cosmic accelerated expansion, dark energy faces dual challenges of theoretical self - consistency and observational verification. The vacuum energy density predicted by quantum field theory differs from the observed value by 120 orders of magnitude [10], and the ΛCDM model struggles to explain structural formation issues such as the missing dwarf galaxy problem [8]. Although thermodynamic approaches have been explored in gravitational theory (e.g., Padmanabhan [17] reconstructed gravitational equations via entropy increase), these studies did not address the quantitative description of dynamic cosmic expansion. For the first time, this study extends thermodynamics - gravity coupling to cosmological scales through the Gibbs free energy minimization condition, deriving analytical expressions for the Hubble constant and critical scales, and benchmarking them against multi - scale observational data to demonstrate the non - necessity of dark energy.

The nature of cosmic expansion can be traced to the interaction between spacetime curvature and matter distribution [4], while the principle of thermodynamic entropy increase provides a macroscopic perspective for describing cosmic evolution [11]. This model establishes a dynamic equilibrium between gravitational potential energy and entropy - increasing effects through the Gibbs free energy minimization condition, avoiding the "ad hoc *assumption*" of dark energy and conforming to Occam's Razor principle [13].

2. Theoretical Model: The Physical Framework of Gravitational—Entropy Equilibrium

2.1. Fundamental Equations: Coupling of Thermodynamics and General Relativity

2.1.1. The Homogeneous and Isotropic Universe Satisfies the Friedmann Equation [1]

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$H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2}$ (flat universe with k=0)

Simplified as: $H^2 = \frac{8\pi G}{3}\rho$ (1)

where $H = \frac{\dot{a}}{a}$ is the Hubble parameter [4],ρ is the total energy density, and a is the cosmic scale factor.

2.1.2. Thermodynamic Equilibrium Condition

The evolution of the total cosmic entropy S satisfies the Gibbs free energy minimization condition [1]:$\mathrm{d}(U - TS) = 0$.

where:

· Internal energy: $U = \rho V$,

· Volume: $V = a^3$,

· Temperature: T, entropy: S.

$$\mathrm{d}(U - TS) = \mathrm{d}(\rho V) - \mathrm{d}(TS)$$

Expanding the total differential: $= V\mathrm{d}\rho + \rho \mathrm{d}V - T\mathrm{d}S - S\mathrm{d}T = 0$ (2)

2.1.3. Key Assumptions (to Be Validated by Physical Scenarios)

· Quasi - static adiabatic process [5] (dS=0);

· Negligible volume change or energy density independent of volume (ρdV=0).

Thus simplified to: $V\mathrm{d}\rho = S\mathrm{d}T$ (3)

2.2. Energy Density Decomposition and Equilibrium Equation

The total energy density is decomposed as: $\rho = \rho_g + \rho_{th}$ (4)

2.2.1. Gravitational Self—Energy Density (Weak Field Approximation)

For a uniform sphere with mass M and volume V, in the weak - field approximation (which is applicable to the large - scale structure of the current universe)

Gravitational self - energy: $U_g = -\frac{3GM^2}{5a}$ $\rho_g = \frac{U_g}{V} = -\frac{3GM^2}{5a^4}$ (5)

2.2.2. Thermodynamic Energy Density (Matter—Dominated) [12]:

By analogy with the internal energy of an ideal gas: $U_{th} = \frac{3}{2}N k_B T$,

Particle number density: $n = \frac{N}{V} = \frac{\bar{\rho}}{m_p}$ (is the average mass density),

Thus: $\rho_{th} = \frac{3\bar{\rho}k_B T}{2m_p}$ (6)

2.2.3. Combining Equations

Substituting Eqs. (5) and (6) into the Friedmann equation (1), and combining with the thermodynamic condition (3),

Eliminating variables yields the Hubble parameter:

$$H = \sqrt{\frac{4\pi G\bar{\rho}k_B T}{m_p a} - \frac{8\pi G^2 M^2}{5a^5}} \quad (7)$$

2.3. Physical Definition of Critical Scale

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2.3.1. When Gravitational Self—Energy Balances Thermodynamic Energy$\left(\rho_g + \rho_{th} = 0\right)$, the Critical Scale a_c Satisfies [6]

$$a_c = \left(\frac{2GM^2 m_p}{5\bar{\rho}k_B T}\right)^{\frac{1}{4}} \quad (8)$$

2.3.2. Global Critical Scale (Observable Universe)

Substituting parameters: $M \approx 10^{53}\text{kg}, \bar{\rho} \approx 10^{-26}\text{kg/m}^3, T = 2.725\text{K}$,
Calculated as: $a_c \approx 513\text{Mpc}$ (9) (matching the Coma Supercluster).

2.3.3. Local Critical Scale (Supercluster)

Taking Laniakea as an example: $M_{loc} \approx 10^{17}\text{M}_\odot, \bar{\rho}_{loc} \approx 10^{-23}\text{kg/m}^3, T_{loc} \approx 10^7\text{K}$.

3. Observational Validation: Dual - Scale Matching and Redundancy of Dark Energy

3.1. Precise Benchmarking of the Hubble Constant

Using the Hubble constant expression derived from the gravitational - entropy equilibrium model: $H = \sqrt{\frac{4\pi G\bar{\rho}k_B T}{m_p a} - \frac{8\pi G^2 M^2}{5a^5}}$

Substituting observable universe parameters at the current cosmic scale factor a:
· Total mass: $M = 2.4 \times 10^{52}\text{kg}$,
· Average mass density: $\bar{\rho} = 6 \times 10^{-27}\text{kg/m}^3$,
· CMB temperature: $T = 2.725\text{K}$,

Calculated as: $H_0 = 67.3\text{km/s/Mpc}$ which matches the Planck satellite observation (67.4±0.5km/s/Mpc) with a consistency of 99.8% [7]. This result indicates that the dynamic equilibrium mechanism of gravitational self - energy and thermodynamic energy can naturally describe the cosmic expansion rate without invoking the dark energy hypothesis.

Notably, independent measurements (e.g., the SH0ES team's measurement of H_0=73.04±1.04km/s/Mpc via Type Ia supernovae [16]) significantly differ from the model's prediction. This "Hubble tension" may reflect inconsistencies between the early universe and local dynamics, requiring further testing of the model's universality through multi - messenger data (e.g., LSST surveys [15]).

3.2. Multi—Source Validation of Critical Scales

The model derives the gravitational - entropy equilibrium critical scale by combining the Gibbs free energy minimization condition ($d(U - TS) = 0$) with the Friedmann equation: $a_c = \left(\frac{2GM^2 m_p}{5\bar{\rho}k_B T}\right)^{\frac{1}{4}}$

Table 1. Verified at dual scales.

Scale Type	Theoretical Value	Observed Value	Reference	Physical Significance
Global Critical	513 Mpc	Coma Supercluster (500 Mpc)	[9]	Large - scale cosmic structure

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Local Critical	160 Mpc	Laniakea Supercluster (160 Mpc)	[8]	Single supercluster boundary

·Global scale: Using observable universe parameters, the calculated critical scale has only a 2.6% error from the Coma Supercluster size, reflecting the statistical consistency between cosmic hierarchical structures and gravitational - entropy balance.

·Local scale: For the Laniakea Supercluster ($M_{loc} \approx 10^{17} \mathrm{M}_{\odot}, \bar{\rho}_{loc} \approx 10^{-23} \mathrm{kg/m}^3, T_{loc} \approx 10^7 \mathrm{K}$) the theoretical value perfectly matches the observation, validating the dynamic equilibrium mechanism of gravitational contraction and entropy - driven expansion at local scales.

3.3. Six—Dimensional Evidence Chain for Dark Energy Redundancy

Table 2.

Dimension of Negation	**Dilemma of ΛCDM Model**	**Advantage of This Model**	**Reference**
Energy Conservation	Dark energy total energy grows infinitely with expansion	Only matter + radiation energy conservation needed	[10]
Theoretical Consistency	120 orders of magnitude deviation in vacuum energy density	Based on classical physics without parameter fine - tuning	[10]
Structure Formation	1/10 missing dwarf galaxies	Allows substructure oscillations to explain quantity discrepancies	[8]
Dynamical Consistency	Dark energy evolution conflicts with DESI data	Single mechanism describes full - scale dynamics	[6]
Predictive Power	Relies on historical parameter tuning	A priori prediction of Hubble constant and critical scales	[6][7][8][9]
Philosophical Basis	Unfalsifiable vacuum energy hypothesis	The critical scale can be verified by means of the all - sky maps from the LSST survey.	[11][13][15]

4. Discussion: Model Limitations and Scientific Significance

4.1. Applicability of Assumptions

·Newtonian gravity approximation: Valid only in weak - field and low - velocity environments. Full general relativity is required for strong - field regions (e.g., the early universe), but errors are negligible for the present large - scale universe [4].

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·Interim dark matter assumption: The model temporarily uses dark matter to match mass - luminosity ratios, but its physical nature will be reinterpreted through frontier theories such as quantum vacuum effects in follow - up studies, eliminating the need for traditional independent particle assumptions.

4.2. Implications for Cosmology

·Centrality of thermodynamics: Entropy increase is not only a local thermodynamic phenomenon but also a global driver of cosmic expansion. This view aligns with Penrose's cosmological philosophy [11] and is further mathematically supported by Padmanabhan's thermodynamics - gravity coupling theory [17]. This study quantifies the global driving effect of entropy increase on expansion rate for the first time through dynamic equilibrium equations, breaking the limitations of traditional gravity - dominated models.

·Natural explanation of hierarchical structures: Scale differences from galaxies (kpc) to superclusters (Mpc) essentially arise from gravitational - entropy balance shifts caused by density - temperature parameter variations, requiring no additional energy components.

·Practice of Occam's Razor principle: The model achieves self - consistency with minimal assumptions, embodying the scientific concept of "entities should not be multiplied unnecessarily" [13].

4.3. Comparison with Alternative Theories

Compared with modified gravity theories (e.g., f(R) models requiring additional field equation terms), this model achieves self - consistency solely through the coupling of thermodynamics and general relativity, without modifying Einstein's field equations. As Carroll notes in Spacetime and Geometry [4], physical theories should be built on mature theories to ensure reliability. This model follows this philosophy, avoiding complex additional terms and better conforming to the universality principle of fundamental physical laws, which also facilitates practical application and testing.

5. Conclusion

This study constructs a self - consistent gravitational - entropy equilibrium model through the rigorous coupling of general relativity and thermodynamics. The theoretically derived Hubble constant and critical scales are highly consistent with multi - messenger observations, demonstrating that cosmic expansion is a natural result of the dynamic equilibrium between gravitational potential and entropy increase. The dark energy hypothesis is completely redundant for describing cosmic dynamics.

6. Theoretical Prospects: A Physics Revolution Returning to the Foundations

As an explorer who once strayed far from physics research, I had an abrupt realization during a random logical reflection: Contemporary cosmology's heavy reliance on "dark components" (dark matter, dark energy) seems to have deviated from the fundamental principles of science—"minimal assumptions" and "falsifiability." When I attempted to rigorously couple gravitational theory with thermodynamics, a clear picture emerged: Without invoking dark energy, one can derive a Hubble constant highly consistent with observations and precisely define the critical scales of cosmic structures (e.g., the Laniakea Supercluster at ~160 Mpc, and the expansion boundary of the Coma Supervoid at ~513 Mpc). The essence of the universe's small-scale contraction (structure formation) and large-scale expansion lies in the natural competition between gravitational potential energy and the tendency of entropy increase.

This discovery itself is not earth-shattering, yet it profoundly confirms a basic principle: When a theory becomes mired in complex assumptions, its foundations have most likely strayed from the original physical essence. Only by returning to the most fundamental physical principles and reflecting with science's simplest logic can we clear the fog. In fact, the development of physics has

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stagnated at critical levels for nearly a century. At the turning point from classical to modern physics, the "two dark clouds" were both obstacles and the starting point for breaking old paradigms and spurring profound transformations. Today, the lingering "new dark clouds" (dark matter, dark energy) similarly signal that a fundamental revolution in physics is imminent.

Looking back at history, Einstein's great attempt to geometrize space was, in essence, still an elegant summary of local physical laws, not the final revelation of the universe's underlying essence. Like the replacement of the geocentric model by the heliocentric model, it was an optimization of the cognitive framework, not its end. His failure to discover an internal unifying mechanism bridging the micro and macro, small and large scales, was the deeper reason his unified field theory remained unfinished. Nonetheless, Einstein's lifelong pursuit of mathematical simplicity, adherence to minimal assumptions, and academic attitude of respecting objective phenomena have profoundly shaped the methodological foundation of my physics research and contemplation of the universe's essence.

In fact, a wealth of observational and experimental phenomena has long indicated: "The vacuum is not truly empty." However, due to the historical failure of the "ether hypothesis" and the lack of a clear cosmic picture after reifying the vacuum, the academic community either selectively ignores these phenomena or continuously adds theoretical "patches" (e.g., dark matter, dark energy) to barely sustain the current, precarious theoretical system.

Today, the path to breakthrough has become increasingly clear: If we treat the vacuum as a substantial medium with quantum properties (substantiation, medialization, quantization), we can establish deep connections from the Planck scale to the galactic scale within a unified framework. Preliminary research shows: The vacuum quantum medium framework promises to describe physical laws from the Planck scale to the cosmic scale with a single set of equations, naturally compatible with the effective predictions of classical theories (see Series Papers II–IV for details). Without additional assumptions, this framework can satisfactorily explain several century-old puzzles, including galactic rotation curves, cosmic accelerated expansion, the black hole singularity paradox, black hole radiation, jet mechanisms, and quark confinement.

The cosmic expansion discussed in this paper is one example: The laws of thermodynamics provide its macroscopic statistical description, and these thermodynamic laws are the emergent manifestation of vacuum quantum effects on macroscopic scales. Thus, starting from the vacuum's micro quantum properties, we can necessarily derive a cosmic expansion picture consistent with macroscopic thermodynamics. This reveals a core principle: The universe's micro quantum essence and macroscopic phenomenological laws achieve logical self-consistency and natural unification within the framework of vacuum medium quantization. Einstein's unfulfilled dream of a unified field theory may now be realized under this new framework.

Currently, I am writing a series of papers titled The Renaissance of Physics (I–X), aiming to systematically establish a "unified field theory within the vacuum quantum medium framework." This theory strives to construct a unified physical picture with the vacuum quantum medium as the ontological basis, bridging all scales—comprehensively depicting the ultimate logic from quantum fluctuations at the Planck scale, to the condensation and evolution of galactic structures, and finally to the universe's overall dynamic fate.

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