95% of the universe is geometry: ΛCDM as the effective limit of an elastic medium

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Abstract

The **Λ**CDM model describes the observed cosmology with six parameters and remarkable precision, yet it leaves 95 % of the energy content of the universe unexplained: dark matter and dark energy enter as quantities fitted to the data whose nature it does not account for. This work proposes that this silence is resolved by reading **Λ**CDM as the effective limit of a substrate theory, and tests the proposal in the cosmological sector. The theory is PIU-**Ψ**, which treats the vacuum as a real elastic medium —the Plenum— described by a complex scalar field $\boldsymbol{\Psi = S\, e^{i\theta}}$ and governed by a single Lagrangian whose coefficients are pure numbers of the geometry of the medium, with no fitted parameters other than one declared scale calibration. From the same medium follow gravity, quantum mechanics, and the constants of nature. The relation between the two descriptions is that of statistical mechanics to thermodynamics: **Λ**CDM emerges as the linear limit of the background dynamics of the Plenum, exact at its two observational anchors —the present epoch and last scattering— and with deviations, at the edges of that limit, that account for the live tensions of cosmology: in the Hubble and DESI tensions PIU derives the sign of the deviation from first principles, and in structure growth it contributes a momentum coupling between matter and dark energy whose effect —suppression— runs in the observed direction. In the dark sector the contrast is greatest: the ratio of dark to baryonic matter is derived as $\boldsymbol{\sqrt{3}\,\pi}$ from the geometry of the lattice. A supplementary script recomputes each of these numbers from the structural definitions of the medium and confirms that no value in the body rests on a hidden fit. **Λ**CDM is not displaced, but grounded.

Keywords: cosmology, **Λ**CDM, emergent gravity, elastic substrate, Hubble tension, dark energy, dark matter, Planck scale

1 Introduction

The Standard Model of particle physics and the ΛCDM model of cosmology are, between them, extraordinarily precise and at the same time incomplete: they contain of order twenty numerical constants that are not predicted but measured, inserted by hand, and used as inputs. On the cosmological side, the incompleteness is even more marked. ΛCDM fits an enormous body of observations—the cosmic microwave background, baryon acoustic oscillations, type Ia supernovae, large-scale structure—with only six parameters, and does so with an economy and a reach that place it among the most successful descriptions in physics. Yet of the three components that make up the density of the universe, two are of unknown origin. Dark matter ($\approx 27\,\%$) is added because galaxies rotate and clusters stay bound as if there were invisible mass; dark energy ($\approx 68\,\%$) is added because the expansion accelerates. Together they constitute $95\,\%$ of the energy content, quantified but not explained.

Any proposal that aspires to contribute to the understanding of the cosmos must start from the recognition of these successes. Established physics is not wrong in the regimes where it has been validated, and a theory that aspires to be more basic is obliged to recover it as an effective limit in those regimes—otherwise it would contradict the evidence and be refuted at once. Recovering known physics is not a concession or a redundancy: it is a requirement of admissibility. What a foundational framework adds on top of that requirement is an underlying ontology from which the effective descriptions emerge, and an explanation of why each one works in its domain.

This work makes a precise claim about ΛCDM: **it is the effective limit of PIU-Ψ.** ΛCDM is derived from the first principles of PIU as the linear regime of a deeper dynamics; it works with precision because that limit is exact at its two observational anchors—the present epoch and last scattering—where the nonlinear corrections vanish; and it fails, when it fails, exactly at the edges of that regime, where the observational tensions that today occupy cosmology [5] appear not as causeless anomalies, but as the expected signature of an effective description used beyond its domain of validity. The whole claim fits, in fact, in a single background equation (§7): the dynamics of the medium collapses to the Friedmann equation of ΛCDM in the limit where its kinetics switches off, and departs from it—as tensions—exactly where that limit breaks.

The strength of this claim rests on a fact about PIU worth fixing at the outset: it is not a theory of cosmology. It is a program that derives fundamental physics—gravity, quantum mechanics, the gauge sector of the Standard Model, the constants of nature—from one and the same medium and one and the same Lagrangian, and for which cosmology, including the dark sector, is one of its consequences. Newton's and Planck's constants come from the same substrate that dark energy comes from; the fractional electric charges of the quarks, from the same one that dark matter comes from. That breadth is what gives literal content to the relation with ΛCDM: no substitute for the dark sector is proposed, but the fundamental theory of which the whole of ΛCDM is the macroscopic limit.

The exposition follows the arc of that claim in three stretches. The first fixes the substrate: the conceptual framework (§2) situates the relation as a grounding, not a competition; the medium and its Lagrangian (§3) define what PIU is and what it derives; the cosmology of the medium (§4) establishes the readings—no expansion, redshift as stretch, H_0 as the reading of a clock—that the tensions will require; and the cosmological components (§5) are identified as modulations of that medium. The second stretch establishes the correspondence: the principle that governs the mapping (§6), the reason ΛCDM succeeds as a linear limit (§7), the term-by-term comparison of the two descriptions (§8), and the reason it fails at four edges (§9). The third deepens and closes: the dark sector as the example of most leverage (§10), the confrontation with the live tensions and the declaration of the open ends (§11), and the conclusion (§12). A verification script that recomposes every derived quantity from the structural definitions of the medium, and confirms the internal numerical consistency of the body and the absence of hidden fitting, accompanies the work as supplementary material.

2 The framework: ΛCDM is to PIU as thermodynamics is to statistical mechanics

The relation between ΛCDM and PIU has an exact precedent in the history of physics. Thermodynamics was built in the nineteenth century from macroscopic observations—Carnot, Clausius, Kelvin—with no knowledge of atoms, and it worked: it predicted the efficiency of engines, the direction of processes, the behavior of gases. When Boltzmann and Gibbs developed statistical mechanics, they did not refute thermodynamics. They derived it: they showed that its laws are the macroscopic limit of the dynamics of an enormous number of constituents, that entropy is the logarithm of the number of microstates, and that thermodynamics fails exactly where fluctuations matter, in small systems or near critical points—the regimes where the macroscopic average ceases to be a good description.

PIU's relation to ΛCDM is of the same kind:

ΛCDM : PIU :: thermodynamics : statistical mechanics.

The correspondence operates at the level of structure, not illustration. Statistical mechanics did not explain only thermodynamics: the same theory of microscopic constituents accounted for matter, states of aggregation, phase transitions, and radiation, and thermodynamics was one of its applications. PIU stands in that position with respect to cosmology. It derives gravity, quantum mechanics, and the particle sector from the same medium, and ΛCDM is its linear limit in the cosmological sector. PIU does not refute ΛCDM: it derives it, explains why it works with the precision it does, and bounds its domain of validity by showing where and with what sign it must fail. The tensions of ΛCDM are, in this analogy, the equivalent of the fluctuations that thermodynamics cannot capture: not defects of the universe, but the edges where the effective description runs out.

3 What PIU is: the medium and its Lagrangian

So that the rest of the argument has content, this section fixes what PIU is: the medium, its mathematical description, its dynamics, and what emerges from it.

The Pleno. The physical vacuum is taken to be a real elastic medium with internal structure, a continuum that fills all of space, called *the Pleno.* It is not a field on a background spacetime: it is the substrate from which spacetime itself emerges. Its local state is described by a complex scalar field,

$$\Psi(x) = S(x)\, e^{i\theta(x)}, \tag{1}$$

where the **modulus** S measures the local deformation of the medium relative to its ground state, and the **phase** θ is a compact $U(1)$ angle. The field Ψ is the mathematical description of the substrate, not the substrate itself; the dimensionless numbers that follow are read off the geometry of its internal structure—angular averages over its cell, mode counts, invariants of its arrangement—so that they are properties of a physical thing, not artifacts of the algebra that describes it. This inversion of the usual order of explanation—the medium is primary, and space, time, and the constants are readings of it—is what gives the program its force: if the medium is primary, its native description is in its own ratios, and the dimensional constants are derived readings, not inputs.

The medium carries two substantive properties and one causal structure: a stiffness density ρ_P, which sets the energy scale of the deformations; a coherence length ℓ_P, the structural grain below which the flexural rigidity suppresses short-wavelength excitations; and the causal structure c, which is not an adjustable property but the statement that space and time are directions of a single causal cone. The substantive freedom of the medium is the pair (ρ_P, ℓ_P). Both coincide numerically with the Planck density and length, but as the result of a single act of calibration, not by definition.

The Lagrangian. The dynamics of the medium is governed by a single Lagrangian density, constructed—not postulated—as the most general effective field theory compatible with the symmetries of the medium [16]. Written entirely in the medium's own properties, with no derived constant inside, it has four terms:

$$\mathcal{L} = \tfrac{1}{2}\rho_P c^2 \ell_P^2\, \partial_\mu \Psi^* \partial^\mu \Psi \;-\; V(S) \;-\; \frac{\rho_P c^2 \ell_P^4}{40} (\Box S)^2 \;-\; \frac{3}{8}\frac{\rho_P c^2}{S^2}. \tag{2}$$

In order: a relativistic kinetic term weighted by the elastic modulus $\rho_P c^2 \ell_P^2$, whose dimension is that of c^4/G; a potential $V(S)$ depending only on the modulus—hence automatically $U(1)$ invariant—which fixes the ground state; a flexural term quadratic in the d'Alembertian, the curvature penalty of the discrete medium, whose coefficient $\rho_P c^2 \ell_P^4/40 = \hbar c/40$ is the spectral average of the discrete Laplacian over the Brillouin zone of the diamond lattice—the same $1/40$ that, scaling as $1/Z^2$, fixes the coordination $Z = 4$ (§5); and an affine (Klauder) term [14] that enforces the strict positivity $S > 0$ by diverging as $S \to 0$, with coefficient $3/8$ fixed by affine quantization on the half-line $S \geq 0$, with no ordering freedom. No coefficient contains a derived constant: each is a pure number—$\frac{1}{2}$, $\frac{1}{40}$, $\frac{3}{8}$—read off the geometry of the structure, multiplying a monomial in (ρ_P, c, ℓ_P). The claim that $F1$ has no free parameters is exact, and its limit is stated in the same breath: every coefficient of the Lagrangian is a fixed geometric number, none fitted to a datum, and the single number the theory calibrates is not in the Lagrangian but in the overall scale of the pair (ρ_P, ℓ_P), entered once and declared openly (§11).

The axioms. Six axioms fix the properties of the medium: A1 establishes the existence of the Pleno with its lattice structure; A2 imposes a quantum wall in the infrared, a floor below which the modulus does not fall; A3 fixes the causal structure of the medium—a single velocity cone c, common to all its modes, from which Lorentz covariance follows as an effective property; A4 introduces the ultraviolet regulation at the Planck scale; A5 establishes the conservation of the $U(1)$ current of the phase; A6 imposes a hard deformation bound, a maximum density. From them, the modulus inherits a floor $S_{\min}$ (from A2) and a ceiling $S_{\max}$ (from A6), and its excursion between the two organizes all of cosmology. Both are pure ratios of the lattice geometry: $S_{\min} = 12(\pi^2 - 4)/\pi^4 \approx 0.7231$ and $S^2_{\max,\text{geom}} = (8/3)\sqrt{2/3} \approx 2.1773$, derived with no free parameter.

What emerges. From the same Lagrangian, with no added ingredients, follows the fundamental physics that today is gathered in separate theories. Solving the modulus sector by two independent routes—classical linear response and Sakharov's one-loop induced action [6–8]—gives the gravitational identity; quantizing the phase rotor gives the action identity:

$$G = \frac{c^2}{\rho_P\, \ell_P^2}, \qquad \hbar = \rho_P\, c\, \ell_P^4. \tag{3}$$

They are two distinct pure numbers—a compliance and an angular inertia—derived in ratios before any unit is introduced. Evaluated with the Pleno's properties, the two identities give $G = 6.674 \times 10^{-11}$ m^{3}kg^{-1}s^{-2} and $\hbar = 1.0546 \times 10^{-34}$ J·s, against the CODATA values [19] $G_{\text{obs}} = 6.6743 \times 10^{-11}$ and $\hbar_{\text{obs}} = 1.0546 \times 10^{-34}$: the agreement is better than 0.1 % with no parameter fitted, and the residue is due only to rounding (ρ_P, c, ℓ_P) to four figures. The comparison is especially demanding for $\hbar$, and notable for G, the fundamental constant measured with the least experimental precision (of order 10^{-4}). Eliminating ρ_P between the two identities further recovers the Planck relation $\ell_P = \sqrt{\hbar G/c^3}$ as an algebraic consequence. From the same medium follow the full Einstein equations in the macroscopic limit—not just their Newtonian form—; Maxwell electrodynamics as the dynamics of the phase sector, with the photon as a massless phase mode by Goldstone's theorem; quantum mechanics as the statistics of the medium's configurations under perturbation, with the Born rule $|\psi|^2$ read off the behavior of the solitons; special relativity as the stiffening of the medium as c is approached; and the particles as localized, stable configurations, whose fermionic or bosonic statistics follow from the topology of their configuration space and whose fractional charges $\pm 1/3$, $\pm 2/3$ emerge from the modular arithmetic of the lattice. The three gauge structures of the Standard Model—$U(1)$, $SU(2)$, $SU(3)$—are a single mechanism, the circulation of the phase, according to whether it commutes or not.

A material medium with a rest state faces an immediate objection: a substrate with a preferred frame generally breaks Lorentz invariance, and the experimental bounds on that breaking are among the strictest in physics. In PIU the invariance is not postulated to dodge the objection; it emerges, and with a falsifiable signature. The structural reason is that all propagation modes of the medium—the phase mode identified with the photon and the transverse tensor mode identified with gravity—are excitations of the same Pleno and therefore share a single velocity c in the infrared regime, that of the A3 causal cone. That universality, which does not hold in an ordinary solid (longitudinal and transverse modes travel at different speeds), is here a property of the medium, and it is what special relativity encodes as invariance. The equality $v_\gamma = v_{\mathrm{GW}}$ that follows from it is measured: the temporal coincidence of GW170817 and its electromagnetic counterpart confirms it to one part in 10^{15}. The emergence further leaves a residue that makes it falsifiable: the same flexural term that regulates the lattice imprints an ultraviolet correction on the dispersion, $\omega^2 = c^2k^2[1 + (k\ell_P)^2/20 + \mathcal{O}((k\ell_P)^4)]$, with derived coefficient; today it lies tens of orders of magnitude below the bounds from high-energy astrophysical propagation, but it is a departure from exact relativity with fixed sign and magnitude, not a free parameter [DERIVED].

That a single medium with two properties reproduces quantities from sectors that share no scale—gravitational, quantum, particle—is not reasonably attributed to chance. Quantified in the program's Bayesian analysis, the improbability of that coincidence gives a Bayes factor against the numerological-coincidence hypothesis of $K_c \approx 6.7 \times 10^5$, a decisive category on the Jeffreys scale [18], rising to $\sim 10^{11}$ when G and $\hbar$ are included (corpus [20], §V.2.6).

Each result that follows carries a visible epistemic tag: [DERIVED] for a complete proof, [STRONG DEDUCTION] for a strong structural deduction without conceptual gap, [CALIBRATED] for a value anchored to a datum, [HYPOTHESIS] for a motivated conjecture. The derived *form* of each quantity is never confused with the calibrated *value* of what is read off the state of the universe.

4 The cosmology of the medium: no expansion, a clock, a frozen floor

From this ontology follows a consequence that changes the meaning of quantities ΛCDM takes for granted. In PIU there is no expansion of space. The Pleno is a preexisting continuous medium whose microstructure, once crystallized, is a lattice of a fixed number of cells; what ΛCDM describes as expansion is the stretch of that medium's deformation map. Redshift is not the growth of a stage, but the ratio between the stretch at emission and at reception, $1 + z = L(\tau_0)/L(\tau_e)$. The Hubble constant, consequently, is not an expansion rate but the reading of a clock: the state factor $\sqrt{\Theta(t)}$ that measures where the medium is along its trajectory.

The background radial modulus is frozen at its floor $S_{\min}$ since crystallization. That floor is not a void or an absence: it is the ground state of the Pleno, the level of minimal deformation below which the medium does not fall (Klauder wall, axiom A2). The Pleno exists at $S_{\min}$ as the full, relaxed substrate on top of which everything else happens; there is no late dynamical source pushing an expansion, only a medium at rest whose phase modulations evolve on top of it.

These readings—stretch instead of expansion, clock instead of rate, relaxed floor instead of void—are the idiom in which the cosmological tensions are resolved later, and every calculation is done in the medium's variables: the modulus S, the stretch

L, and the time τ as accumulated change, without the scale factor $a(t)$ as a primitive object.

5 What the cosmological components are: space, matter, and the dark sector as modulations of the medium

The substrate of all cosmology is the Pleno in its relaxed state, the vacuum at the floor $S_{\min}$—what the program calls the sea of $S_{\min}$. That sea is the continuous elastic medium itself, and its microstructure, once crystallized, is an ordered lattice. On top of that preexisting sea live the two modulations that ΛCDM records as separate components—matter and dark energy—, and the sea itself, with its structure, is what we call space. The three are not distinct substances put together, but the same medium: the sea and its two undulations.

The event that fixes this structure is crystallization. In PIU's cosmological history there is no singular Big Bang: the hard bound A6 prevents the medium from compressing to infinite density, so a prior collapse bounces before reaching the ceiling. During that cycle the Pleno transits between two packings—the compact one ($Z = 12$) at maximal compression and the diamond lattice ($Z = 4$) upon relaxing—, and that recrystallization $Z = 12 \to Z = 4$ is what imprints the primordial spectrum, on top of a persistent background that survives the transition and is identified with dark energy.

Space is the continuous elastic solid itself. Its microstructure is not a postulate: it is what that solid adopts upon saturating, the arrangement that minimizes its flexural energy. That this microstructure is the diamond lattice—tetrahedral coordination $Z = 4$—is a derived consequence, and the whole geometry of the dark sector (§10) rests on it. The coordination $Z = 4$ is forced by the isotropy of the medium: four unit bond vectors with isotropic second-moment matrix and vanishing sum satisfy $\sum_{i<j} \mathbf{v}_i \cdot \mathbf{v}_j = -2$, so that each pair forms the angle $\arccos(-\frac{1}{3}) = 109.47°$; the only four points on the sphere with that property are the vertices of the regular tetrahedron (the four-point spherical 2-design [13]). The cubic stacking—which distinguishes the diamond lattice from wurtzite, both tetrahedral—follows from the flexural term of $F1$: the cubic modulation cancels the fourth-order curvature anisotropy, whereas every non-cubic polytype carries an irreducible anisotropy of positive flexural cost, and the medium relaxes to the modulation that concentrates no curvature. A third route converges on the same result: the flexural coefficient $1/40$ of the Lagrangian scales as $1/Z^2$, so the observed value fixes $Z = 4$ uniquely among isotropic coordinations (the alternatives $Z = 6, 8, 12$ would give $1/90, 1/160, 1/360$). The diamond lattice is thus derived, not postulated.

Matter is the modulus mode δS: a perturbation of the modulus on top of the sea, massive by the curvature of the potential V''_{eff}, localized at the topological defects that crystallization leaves frozen. They are the particles, stable configurations whose topological charge cannot be undone without violating $U(1)$ conservation, and whose density dilutes as a^{-3} as the medium stretches.

Dark energy is the phase sector of the sea in its state of rest. It has two parts: the homogeneous component—the Telón, the background phase θ_0 at rest, at the floor $S_{\min}$, which constitutes the bulk—and, on top of it, the waves $\delta\theta$. The homogeneous component has density $\rho_{\rm DE} = \rho_P c^2\, S_{\min}^2$, structurally constant because both the anchor and the floor are fixed; since the background phase is at rest, its energy-momentum tensor is proportional to the metric, $T_{\mu\nu} \propto g_{\mu\nu}$, giving an equation of state $w = -1$ exactly—not fitted, but forced by the symmetry of the ground state [DERIVED].

At linear order the two modulations decouple: the phase kinetic term of $F1$ gives $|\partial\Psi|^2 = (\partial\delta S)^2 + S_{\min}^2(\partial\delta\theta)^2 + \mathcal{O}(\delta^3)$, so that the modulus mode (matter) and the phase mode (the wave, massless, propagating at c) do not mix. That separation is what makes an observer see independent fluid components, and their coupling—which will deviate structure growth (§9)—is necessarily a second-order effect. Matter and dark energy are not two substances that interact: they are two undulations of the same medium sharing substance, the Pleno modulated on top of the sea of $S_{\min}$.

6 The correspondence principle: geometric ratio times state factor

A structural principle governs the whole mapping between the two descriptions, and from it follows what PIU derives and what it reads off the present position of the medium. Every cosmological magnitude factorizes in the form

$$\text{magnitude} = (\text{fixed geometric ratio}) \times (\text{unit anchor}) \times (\text{state factor}), \tag{4}$$

where the geometric ratio is an invariant of the diamond lattice, derivable with no datum; the anchor carries the units and is fixed by the two scales of the medium; and the state factor encodes where the Pleno is along the trajectory of its single dynamical background variable, the average modulus $\bar{S}(t)$. The curve $\bar{S}(t)$ is theory; the point on it at which the universe finds itself today is an observational datum, of the kind of the time a clock reads.

From this follows the epistemic status of each magnitude. A magnitude is **geometric**—derived from first principles—if it depends only on the fixed endpoints $\{S_{\min}, S_{\max,\text{geom}}\}$ of the excursion. It is **positional**—read off the present state, not derivable as a timeless number—if it depends on the instantaneous value $\bar{S}(t)$ or its rate $\dot{\bar{S}}(t)$. There are two distinct varieties of positional: those of **type A** depend on the value of $\bar{S}$ today—the Hubble constant and the dark-energy fraction—, and those of **type B** depend on the rate $\dot{\bar{S}}$—the spectral index and the apparent equation of state.

ΛCDM collapses the three pieces into a single fitted number, anchored at $z \approx 1089$, and there its fragility is born: it does not distinguish the geometric from the positional. The principle reframes the boundary between theory and datum uniformly: PIU does not derive the numerical value of H_0; it derives the form of the relation and the class of the object, and reads the value off the present state of the medium.

7 Why ΛCDM works: Friedmann as the linear limit of the medium

With the medium and its components defined, the comparison with ΛCDM begins. Its first result is the most basic: why ΛCDM is right. ΛCDM works because it is the linear limit of PIU's background dynamics near the floor of the potential, and the derivation is explicit: the background equation of motion, its kinetic constraint, and how it reproduces the form of Friedmann.

The background equation. On a homogeneous and isotropic background, the dynamical variable is the stretch of the medium, e, with $L = e^e$ the deformation map, and the average modulus $\bar{S}$ that accompanies it. The kinetic energy of the isotropic deformation and the effective potential of the Pleno are

$$T = \tfrac{1}{2}\rho_P \ell_P^2 \cdot 3\dot{e}^2 = \tfrac{3}{2}\rho_P \ell_P^2 \dot{e}^2, \qquad V = V_{\text{eff}}(\bar{S}), \tag{5}$$

where the factor 3 is the three directions of the stretch and V_{eff} is the complete potential of the medium (the Klauder wall of axiom A2 plus the Gent bound [15] of axiom A6), with minimum at $S_{\min} = 0.7231$. The mean modulus and the stretch are not independent: the density of the medium is $\rho_{\text{medium}} = \rho_P \bar{S}^2$ and dilutes as $L^{-3} = e^{-3e}$ under stretching, so that $\bar{S}^2 \propto e^{-3e}$; expressing the dynamics in $\bar{S}$ rather than e introduces, through this change of variable, a factor $\propto \bar{S}^{-2}$ in the kinetic metric of configuration space. The Euler–Lagrange equation for the modulus, $\frac{d}{dt}\left(\frac{\partial \mathcal{L}}{\partial \dot{\bar{S}}}\right) - \frac{\partial \mathcal{L}}{\partial \bar{S}} = 0$ with $\mathcal{L} = T - V_{\text{eff}}$, then gives the background equation, in units $c = \ell_P = \rho_P = 1$:

$$\ddot{\bar{S}} = \frac{\dot{\bar{S}}^2}{\bar{S}} - \tfrac{3}{4}\,\bar{S}^2\, V'_{\text{eff}}(\bar{S}). \tag{6}$$

It is a **second-order** equation—that of a nonlinear oscillator against a hard wall—to which the viscous damping $-\gamma\dot{\bar{S}}$ derived from the flexural sector is added. The infrared Klauder wall makes the bounce a structural fact, and the viscosity settles the modulus at $S_{\min}$, the state of the Telón.

The kinetic constraint and the form of Friedmann. The density and pressure of the background are

$$\rho_{\text{Pleno}} = \tfrac{1}{2}\rho_P \ell_P^2 \dot{\bar{S}}^2 + V_{\text{eff}}(\bar{S}), \qquad p_{\text{Pleno}} = \tfrac{1}{2}\rho_P \ell_P^2 \dot{\bar{S}}^2 - V_{\text{eff}}(\bar{S}). \tag{7}$$

The Friedmann constraint is not imposed: it arises from the invariance of the action under time reparametrization. Writing the background action with a lapse function N that fixes the pace of proper time, $dt \to N\,d\tau$,

$$\mathcal{S} = \int d\tau\, N \left[\frac{1}{N^2}\,\tfrac{3}{2}\rho_P \ell_P^2 \left(\frac{de}{d\tau}\right)^2 - V_{\text{eff}}\right], \tag{8}$$

the variation with respect to the lapse, $\delta\mathcal{S}/\delta N = 0$, gives the Hamiltonian constraint—the vanishing of the Hamiltonian density, $\mathcal{H} = 0$—which is the energy constraint of the system:

$$\mathcal{H} \propto \rho_P \ell_P^2 \, H^2 - \rho_e = 0 \implies H^2 \propto \frac{\rho_e}{\rho_P \ell_P^2} = \frac{G}{c^2}\,\rho_e, \tag{9}$$

with $H \equiv \dot{L}/L$ the stretch rate and where the last equality uses the native identity $G = c^2/(\rho_P \ell_P^2)$. The constraint thus fixes the *structure* $H^2 \propto (G/c^2)\rho_e$; the numerical prefactor is the canonical one of the Einstein equations that PIU recovers from the same medium. That prefactor is not a fit: Sakharov's induced action identifies the gravitational rigidity with the kinetic coefficient of $F1$ when the coefficient b of the induced Einstein–Hilbert term satisfies $b = 8\pi^2$, and this equality is structural, not a number to be determined. It is equivalent to $b/16\pi^2 = \frac{1}{2}$, whose two factors are already fixed: $16\pi^2 = (4\pi)^2$ is the four-dimensional phase-space volume of the heat kernel—universal to the method—and $\frac{1}{2}$ is the kinetic coefficient of $F1$ in its normalization $\frac{1}{2}\rho_P c^2 \ell_P^2 \, \partial_\mu \Psi^* \partial^\mu \Psi$. The coincidence of the two routes to the same G—induced gravity and the direct reading of that normalization—is therefore an identity between the structure of the method and the normalization of the Lagrangian, with falsifiable content: a substrate with a scalar gravitational mode or additional polarizations would give $b \neq 8\pi^2$. Hence the canonical factor $8\pi/3$, so that

$$H^2 = \frac{8\pi}{3}\frac{G}{c^2}\,\rho_e. \tag{10}$$

The constraint $\mathcal{H} = 0$ is exactly the mechanism by which general relativity produces the Friedmann constraint; here it arises in the same way, from the temporal invariance of the medium's action, and the same $8\pi/3$ reappears on reading $H_0^2 = \frac{8\pi}{3}\,\Theta\,(c/\ell_P)^2$ with Θ the state of the stretch today.

The kinetic structure is well defined over the reals and preserves unitarity: the kinetic energy $T = \frac{3}{2}\rho_P \ell_P^2 \dot{e}^2$ is a manifestly non-negative quadratic form in $\dot{e}$, with no fractional powers or signs that could introduce complex roots, so the Hamiltonian is real and bounded below by the potential. The physical source is

$$\rho_e = \rho_{m,0}\, L^{-3} + \rho_{\mathrm{DE}}, \tag{11}$$

with matter (the solitons) diluting as L^{-3} as the medium stretches and the background phase condensate constant ($w = -1$). Gathering the complete source with the constraint of the medium, the background dynamics of PIU condenses into a single equation,

$$H^2 = \frac{8\pi}{3}\frac{1}{\rho_P \ell_P^2}\left[\underbrace{\rho_{m,0}\, L^{-3}}_{\text{matter}} + \underbrace{\tfrac{1}{2}\rho_P \ell_P^2 \dot{\bar{S}}^2}_{\text{kinetic, modulus}} + \underbrace{V_{\mathrm{eff}}(\bar{S})}_{\text{potential with its two walls}}\right] = \frac{8\pi}{3}\frac{G}{c^2}[\,\cdots\,], \tag{12}$$

where the primary form is written entirely in the properties of the medium (ρ_P, ℓ_P, c), and the second equality is only its conventional reading: $G/c^2 = 1/(\rho_P \ell_P^2)$ is the native identity (§3), so that G enters not as an external constant but as the name of the inverse rigidity of the medium. Matter is the solitonic excitations; the kinetic term of the modulus together with the complete potential are the dynamics of the background—all of it, matter and background, configurations of the single medium.

The same equation, made dimensionless by the scales of the medium, exhibits what H measures. Writing $V_{\text{eff}} = \rho_P c^2\, v(\bar{S})$ and $\rho_{m,0} = \rho_P c^2\, \mu$ with v and μ pure numbers, and factoring $\rho_P c^2$ out of the bracket,

$$H^2 = \frac{8\pi}{3}\left(\frac{c}{\ell_P}\right)^2 \left[\mu\, L^{-3} + \tfrac{1}{2}\,\tau_P^2\,\dot{\bar{S}}^2 + v(\bar{S})\right], \qquad \tau_P = \frac{\ell_P}{c}, \tag{13}$$

with the whole bracket dimensionless and the only scale in the prefactor $(c/\ell_P)^2$, the squared frequency of the Planck tick. In this form the ontology of the clock can be read off: H is a rate measured in Planck ticks, and the Hubble constant is not a constant of nature but the number of ticks the medium has run—the same c/ℓ_P that reappears in $H_0 = \sqrt{8\pi/3}\,(c/\ell_P)\sqrt{\Theta}$ (§8).

From the master equation ΛCDM follows with nothing added: near the floor the modulus settles ($\dot{\bar{S}} \to 0$) and the walls of V_{eff} are negligible, so that $V_{\text{eff}}(\bar{S}) \to V(S_{\min}) = \rho_P c^2 S_{\min}^2 = \rho_{\text{DE}}$ and only the diluted matter and the constant floor survive; consequently,

$$H^2(z) = H_0^2\big[\Omega_m(1+z)^3 + \Omega_\Lambda\big], \qquad \Omega_\Lambda = f_c, \quad \Omega_m = 1 - f_c, \tag{14}$$

which is the Friedmann equation of ΛCDM, with the identification $\Omega_\Lambda = f_c$ of the condensate fraction —derived separately, in §10.4, not a consequence of (12)—. The two terms that ΛCDM inscribes as independent substances—matter and Λ—are, in (12), two readings of the same medium: matter as its solitons, Λ as the value of its potential at the floor. The kinetic term, negligible today, is the one that governs the edges where ΛCDM fails.

Why it is exact at the anchors, and why it fails away from them. The limit that takes (12) to Friedmann is exact only where its two conditions hold. Near the floor of the potential, where the modulus is relaxed, the nonlinear term $\frac{3}{4}\bar{S}^2 V'_{\text{eff}}$ and the damping are negligible, and the second-order equation reduces to the first-order Friedmann constraint. That reduction is exact at the two observational anchors of ΛCDM—the present epoch and last scattering—because at both the medium is near the floor and the wall corrections vanish. The divergence with ΛCDM lives in the nonlinear regime of the walls: the origin of the universe (where the Gent wall turns the singularity into a bounce) and the edges where the wall corrections cease to be negligible. There is where ΛCDM fails, and it is the content of the next section. A single equation thus explains both things: it collapses to ΛCDM when the kinetics switches off and the walls recede, and departs from it—as tensions—exactly when either of those two conditions ceases to hold.

Two further features complete the reason for ΛCDM's success. First, its **fluid components are modes of the Pleno that decouple at linear order**: on linearizing $F1$ around the relaxed vacuum, the modulus (matter) and the phase (light, dark energy) do not mix at first order, so an observer measuring the background plus linear perturbations sees independent components behaving as separate fluids—ΛCDM's inventory. It works because "one fluid per mode" is the correct bookkeeping to that order; the unification into a single medium becomes visible only at nonlinear order. Second, $w = -1$ **works because it is the real floor of the potential**: ΛCDM postulates it and gets it right, and PIU explains why the floor is exactly -1 (the symmetry of the ground state, §8.3).

8 The term-by-term comparison: how each parameter corresponds, and why

The background equation (12) already contains the entire correspondence in integrated form: every symbol of the Friedmann equation of ΛCDM has, within it, an object of the medium that produces it. What follows breaks that correspondence down parameter by parameter. Each parameter of ΛCDM occupies a place within PIU, and that place explains why ΛCDM works and why it fails. The mapping that follows takes the six-parameter structure of ΛCDM and gives, for each one, what object of PIU corresponds to it, with what algebra, and what fitting freedom is lost in the translation. The dark sector (§10) is the example where the comparison has most leverage.

8.1 The principle of the comparison: three pieces collapsed into one

The fragility of ΛCDM relative to PIU has a precise root. Every cosmological magnitude, in PIU, factorizes into three pieces (§6): a fixed geometric ratio, a unit anchor, and a positional state factor. ΛCDM collapses the three into a single number fitted to the data and anchored to the epoch of last scattering ($z \approx 1089$). In doing so, it does not distinguish what is structure—derivable from first principles—from what is position—a reading of the state of the universe today. The parameter-by-parameter comparison is, at bottom, the operation of un-collapsing each ΛCDM number into its three pieces and seeing which dominates.

8.2 The background sector: PIU's two structural parameters

The cosmological sector of PIU is described by two structural parameters, neither freely fitted. The first is gravitational; the second, dynamical.

The **gravitational coupling** κ is the coefficient that Sakharov's induced action [6] identifies with the Einstein–Hilbert term—the gravitational rigidity of the medium read off the Hamiltonian of $F1$:

$$\kappa \equiv \tfrac{1}{2}\rho_P c^2 \ell_P^2 = \frac{c^4}{2G} \approx 6.05 \times 10^{43}\ \mathrm{N}, \tag{15}$$

where the second equality is the reading of κ in terms of the derived constant $G = c^2/(\rho_P \ell_P^2)$, not its definition: the primary form is the rigidity of the medium $\frac{1}{2}\rho_P c^2 \ell_P^2$, and $c^4/2G$ is its expression in the conventional language. Its value follows from the primary properties (ρ_P, ℓ_P, c) with no fit, and coincides with the kinetic coefficient of the $F1$ term: the same rigidity that weights the deformations of the medium fixes the gravitational coupling constant.

The **dynamical parameter** δ is the ratio, at each instant, between the kinetic and the potential contribution of the background Pleno:

$$\delta(t) \equiv \frac{\frac{1}{2}\rho_P \ell_P^2 \,\dot{\bar{S}}(t)^2}{V(\bar{S}(t))}, \qquad \delta(t) \geq 0. \tag{16}$$

Substituting into the density and pressure of the sector, the equation of state takes the closed form. The density and pressure are $\rho = \frac{1}{2}\rho_P \ell_P^2 \dot{\bar{S}}^2 + V$ and $p = \frac{1}{2}\rho_P \ell_P^2 \dot{\bar{S}}^2 - V$ (§7); their ratio, dividing numerator and denominator by V and introducing δ, gives

$$w(t) = \frac{p}{\rho} = \frac{\frac{1}{2}\rho_P \ell_P^2 \dot{\bar{S}}^2 - V}{\frac{1}{2}\rho_P \ell_P^2 \dot{\bar{S}}^2 + V} = \frac{\delta(t) - 1}{\delta(t) + 1}. \tag{17}$$

These two parameters govern the whole cosmological background, and their contrast with the six of ΛCDM is the content of the comparison.

8.3 The mapping, parameter by parameter

The Hubble constant H_0. In ΛCDM it is a constant of nature, measured. In PIU it is the positional state factor of type A—the reading of a clock—,

$$H_0 = \sqrt{\tfrac{8\pi}{3}}\,\frac{c}{\ell_P}\sqrt{\Theta}, \tag{18}$$

with Θ the state of the stretch of the medium today. The form of the relation is derived; the value is positional, not a constant derivable as a timeless number. Redshift as a whole is reinterpreted with the same logic: $1 + z = L(\tau_0)/L(\tau_e)$, the stretch ratio of the medium, not the growth of a stage. The number does not change relative to ΛCDM; its ontological status does.

The dark-energy equation of state w. ΛCDM postulates it equal to -1 (the cosmological constant) and gets it right. PIU derives it: the late sector is the phase condensate in its ground state, at rest at $S_{\min}$ with $\dot{\theta}_0 = 0$, so the kinetic density vanishes, $\delta = 0$, and

$$w = \left.\frac{\delta - 1}{\delta + 1}\right|_{\delta=0} = -1 \quad \text{exact.} \tag{19}$$

It is not an approximate asymptotic limit, but the symmetry of the ground state: with the kinetic vanishing, the energy-momentum tensor is $T_{\mu\nu} \propto g_{\mu\nu}$, the rest four-vector disappears, and $p = -\rho$. Here is the essential difference from a quintessence model, which answers the natural objection that $w + 1 \geq 0$ is generic to any canonical scalar field. It is—indeed, $\delta \geq 0$ gives $w \geq -1$ for any scalar sector—but in quintessence the potential $V(S)$ is postulated with freedom to fit the trajectory $w(z)$, whereas in PIU the effective potential is derived with fixed parameters and the ground state is rest at $S_{\min}$. What distinguishes PIU is not the bound $w \geq -1$, but that the same floor $S_{\min}$

that fixes $w = -1$ also fixes the dark-matter ratio $\sqrt{3}\,\pi$ and the dark-energy fraction f_c (§10): a quintessence model does not tie its equation of state to the proportion of the dark sector; PIU does, because the three quantities come from the same potential on the same diamond lattice (§5).

The dynamical dark-energy parameters w_0, w_a. The extension of ΛCDM that fits the DESI data [2, 3] introduces two free parameters to let w evolve. In PIU there are not two freedoms: the background has $\delta = 0$ structural, and the sole freedom of the sector is the initial condition of the bounce that fixes where the modulus ended up along its relaxation trajectory. The two parameters of ΛCDM collapse to one, and that one is positional, not a dynamical equation of state. The veto of a dynamical $\delta > 0$ in the background is derived: a condensate gaining physical density with time would have $w + 1 = -\frac{1}{3}\,d\ln\rho/dN < 0$, that is $w < -1$ phantom—the sign opposite to the observed and forbidden by the positivity of the kinetic—, and a phase mode that rolled ($\dot{\theta}_0 \neq 0$) would dilute as dust, $\rho \propto L^{-3}$, incompatible with a $w = -1$ component. The late sector has $\delta = 0$ structural, not $\delta > 0$ small.

The densities Ω_Λ and Ω_m. In ΛCDM they are two parameters tied by flatness ($\Omega_\Lambda + \Omega_m = 1$). In PIU they are the condensate fraction f_c and its complement: $\Omega_\Lambda = f_c$, $\Omega_m = 1 - f_c$, with $f_c = S^2_{\mathrm{max,eff}}/S^2_{\mathrm{max,geom}} \approx 0.6869$ (derived in §10.4), at $0.30\,\sigma$ and $0.27\,\sigma$ of Planck respectively. The structure of the ratio is derived; the numerator is positional. There are not two freedoms, but a derived structure plus a state reading—a weaker agreement than that of $\sqrt{3}\,\pi$, because its target shares the model dependence of Ω_Λ, as detailed in §10.4.

The dark-matter density $\omega_c = \Omega_c h^2$. In ΛCDM it is a parameter independent of the baryon density ω_b. In PIU it is not independent: it is derived from ω_b by the geometric ratio

$$\omega_c = \sqrt{3}\,\pi \cdot \omega_b \quad \text{(full derivation in §10.2)}, \tag{20}$$

with $\sqrt{3}\,\pi = 5.4414$, confronted with the Planck 2018 value $\Omega_{\mathrm{dm}}/\Omega_b = 5.375 \pm 0.077$ at $0.86\,\sigma$—a 98.8 % agreement with zero free parameters and zero observational input. The contrast with ΛCDM is direct: where ΛCDM has two independently fitted parameters whose ratio it does not predict, PIU fixes the proportion of the dark sector by the geometry of the lattice. And the comparison is robust, not inherited from the model: the ratio cancels the factor h^2, so it is confronted against physical densities read off the heights of the acoustic peaks, which ΛCDM cannot choose to match PIU.

The acoustic scale θ_*, the spectral index n_s, and the amplitude A_s. The acoustic scale $\theta_* = r_s/D_M$ is a ratio of distances over the expansion function $E(z)$; in PIU, $E(z)$ is forced by the potential $v(S)$ of the background, so the form of θ_* is derived although its value incorporates the state. The spectral index n_s and the scalar amplitude A_s are the two descriptors—tilt and normalization—of the same primordial spectrum, which in PIU is not postulated but imprinted at the packing crossover $Z = 12 \to Z = 4$ of the bounce (§5): the tilt n_s is of type B—it depends on the rate $\dot{S}$ of the crossover—, with its zeroth-order value derived from the bounce spectrum and a positional correction; the amplitude A_s is likewise positional, fixed by the freeze-out rate of the transition, not an independent parameter but the normalization of the same spectrum whose tilt gives n_s. Where ΛCDM fits n_s and A_s as two free numbers of the initial spectrum, PIU ties them to the single event that imprints them.

Reionization τ_{reio}. It is astrophysics of the formation of the first stars, outside the background sector in both ΛCDM and PIU; neither framework derives it. Its presence in ΛCDM's list of six reveals that the list mixes background parameters with astrophysics: τ_{reio} is the only one with no geometric ratio beneath it.

8.4 The balance of the comparison

Gathering the mapping, the correspondences fall into four classes, and the comparison of freedom is the central result:

ΛCDM parameter	Object in PIU	Class of correspondence
The six base parameters of Λ*CDM*		
ω_b	baryon density	positional anchor
ω_c	$\sqrt{3}\,\pi\,\omega_b$	**derived from** ω_b (geometry)
θ_*	r_s/D_M over $E(z)$ forced by $v(S)$	derived form
n_s	tilt of the bounce spectrum	derived at order 0 + positional (type B)
A_s	normalization of the same spectrum	positional (freeze-out rate)
τ_{reio}	reionization	astrophysics (outside the background, both frameworks)
Derived parameters and extensions		
Ω_Λ	f_c	derived structure + positional value
Ω_m	$1 - f_c$	derived
H_0	$\sqrt{8\pi/3}\,(c/\ell_P)\sqrt{\Theta}$	positional (clock reading, type A)
w	$(\delta-1)/(\delta+1)$, $\delta = 0$	**derived** ($w = -1$ exact)
w_0, w_a	initial condition of the bounce	**a single freedom** (collapsed 2→1)

The classes are: **collapsed**, where PIU derives one parameter from another and has less freedom than ΛCDM (ω_c via $\sqrt{3}\,\pi$; w_0, w_a reduced to an initial condition; Ω_Λ, Ω_m via f_c); **reclassified**, where what ΛCDM postulates PIU derives ($w = -1$); **reinterpreted without changing the number**, where the value coincides but the ontology changes (H_0 as clock reading, redshift as stretch); and **outside the background in both frameworks** (τ_{reio}). The parameter count is not the aim of the work—the derivation of ΛCDM and of its failures is—, but the table shows the structural result of the comparison: where ΛCDM has independent parameters, PIU frequently has a single geometric or positional quantity behind them, and that reduction of freedom is what gives falsifiable content to the relation.

9 Why ΛCDM fails: the four edges of its domain

The failures of ΛCDM are the edges of the linear regime. There are four, and in three of them the sign and location of the deviation are derived from the substrate, which turns the observational tensions from unexplained anomalies into predictions of PIU.

9.1 The singularity becomes a bounce (edge: saturation density)

ΛCDM extrapolates its linear limit to infinite density: the singular Big Bang. PIU cannot make that extrapolation because axiom A6 imposes a hard deformation bound—the Gent wall in the potential, which diverges as $S \to S_{\max}$—: before reaching it, the response of the medium stiffens and the collapse bounces.

The calculation quantifies why the local self-gravity of matter does not suffice to bring the medium to the wall. The effective potential of the modulus has a derived closed form, with its three contributions—the hyperelastic response of the saturable medium, the logarithmic Gent wall (axiom A6), and the quantum Klauder wall (axiom A2)—,

$$V_{\text{eff}}(S) = \frac{E_0}{2}\frac{S^4}{(S_{\max}^2 - S^2)^2} - \frac{\rho_P c^2}{2}\ln\left(1 - \frac{S^2}{S_{\max}^2}\right) + \frac{3}{8}\frac{\rho_P c^2}{S^2}, \tag{21}$$

with E_0 fixed with no freedom by the condition that the minimum of the total potential fall at the spectral floor: $V'_{\text{eff}}(S_{\min}) = 0$ is a single algebraic equation with E_0 as the only unknown, whose solution gives $E_0 = 4.2546\,\rho_P c^2$ evaluated at $S_{\min} = 0.7231$ and $S_{\max}^2 = (8/3)\sqrt{2/3} = 2.1773$ (§10.4). The number is not fitted: it is the one that makes the spectral position of the minimum consistent with the dynamics of the potential, and the supplementary script recomputes it. Its minimum thus falls exactly at the floor $S_{\min} = 0.7231$ (Fig. 1), and the excess energy of an overdensity over the background is $\Delta\varepsilon(S) = V_{\text{eff}}(S) - V_{\text{eff}}(S_{\min})$. Integrating the background equation with the gravitational force of that overdensity, the restoring force dV_{eff}/dS overcomes gravity near the floor and the system settles just above the background, at $S \approx 0.743$. The energy balance is explicit, evaluating V_{eff} at the two extremes. The excess that local self-gravity can supply, up to $S \approx 0.74$, is

$$\Delta\varepsilon(0.74) \approx 2.8 \times 10^{-3}\,\rho_P c^2, \tag{22}$$

whereas bringing the modulus to the region of the wall ($S \approx 1.45$, where the Gent term already diverges) requires

$$\Delta\varepsilon(1.45) \approx 1.68 \times 10^{3}\,\rho_P c^2, \tag{23}$$

so that the ratio between required and available is

$$\frac{\Delta\varepsilon(1.45)}{\Delta\varepsilon(0.74)} \approx \frac{1.68 \times 10^3}{2.8 \times 10^{-3}} \approx 6 \times 10^5. \tag{24}$$

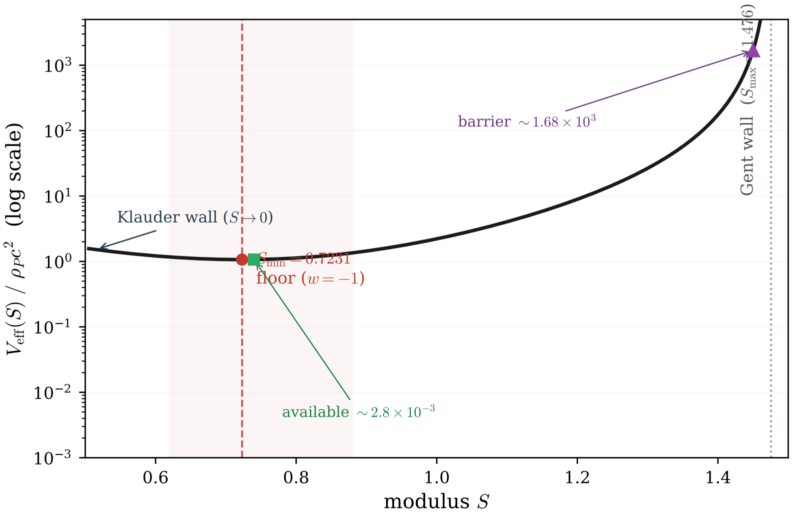

Fig. 1 Effective potential of the modulus, $V_{\text{eff}}(S)$, on a logarithmic scale, with its three derived contributions. The full excursion of the modulus is shown between its two walls: the floor $S_{\min} = 0.7231$ (the Telón, with $w = -1$), with the Klauder wall (axiom A2) diverging to its left as $S \to 0$, and the Gent wall (axiom A6) as $S \to S_{\max} = 1.476$. The logarithmic scale makes both the relaxed well and the barrier that turns the singularity into a bounce visible in a single panel: the energy required to reach the Gent wall ($\sim 1.68 \times 10^3\, \rho_P c^2$) exceeds by nearly six orders of magnitude what local self-gravity can supply ($\sim 2.8 \times 10^{-3}\, \rho_P c^2$).

Local self-gravity is therefore insufficient by nearly six orders of magnitude to compress the Pleno to the Gent wall on its own: the compression to the bounce requires the global cosmological forcing of the collapse—the Friedmann contraction, which by $\rho_{\text{medium}} = \rho_P S^2$ and $\rho \propto 1/a^3$ gives $S^2 \propto 1/a^3$ and compresses the modulus toward $S_{\max}$ [DERIVED]. The bounce is structural, and with it the singularity that ΛCDM inherits from general relativity without resolving disappears.

9.2 The dynamical dark-energy signal of DESI (edge: nonlinear regime)

The DESI analyses (2024–2025) [2, 3], fitting the expansion with a dynamical dark-energy parametrization, infer $w_0 > -1$ today. In PIU the background has $w = -1$ exact (§5), so this signal cannot be a physical deviation from $w = -1$: it is the artifact of forcing a medium with $w = -1$ into a parametric mold that does not fit it. The sign of the artifact is derived. The density and pressure of the background sector are read off the energy–momentum tensor of the modulus field (§7):

$$\rho = \tfrac{1}{2}\rho_P \ell_P^2 \dot{S}^2 + V_{\text{eff}}, \qquad p = \tfrac{1}{2}\rho_P \ell_P^2 \dot{S}^2 - V_{\text{eff}}, \tag{25}$$

whence the equation of state $w \equiv p/\rho$ satisfies

$$w+1=\frac{p+\rho}{\rho}=\frac{\rho_P\ell_P^2\dot{S}^2}{\frac{1}{2}\rho_P\ell_P^2\dot{S}^2+V_{\rm eff}}=\frac{2\delta}{\delta+1}\geq 0,\qquad \delta\equiv\frac{\frac{1}{2}\rho_P\ell_P^2\dot{S}^2}{V_{\rm eff}},\tag{26}$$

where $\delta \geq 0$ is the ratio of the modulus's kinetic to potential energy. Equivalently $w = (\delta-1)/(\delta+1)$, which at the floor ($\delta = 0$, $\dot{S} = 0$) gives $w = -1$ exact and for any excitation ($\delta > 0$) gives $w > -1$. By the positivity of the canonical kinetic, any residue pushes the inferred w above -1 (toward quintessence), never below (toward the phantom region) [DERIVED]. That is exactly the direction DESI reports. The prediction is falsifiable: the signal must dissolve in raw observables (the D_H/r_d pattern, the unprocessed acoustic angle); if it consolidated at $w_0 < -1$, the phantom region the kinetic vetoes, PIU would be refuted.

9.3 The Hubble tension (edge: a state factor read as a constant)

ΛCDM treats H_0 as a constant and measures it by two routes—the cosmic microwave background ($\approx$67) [1] and the local distance ladder ($\approx$73) [4]—which disagree by more than 5σ. In PIU, $H_0 = \sqrt{\Theta}$ is the reading of a clock, a positional state factor of type A (§6), not a constant. The discrepancy is then read with two distinct statements.

First, the local value (73) is not valid as a background value. The age of the universe follows from the master equation by integrating $H = \dot{a}/a$: since $dt = da/(aH)$,

$$t_0=\int_0^1\frac{da}{a\,H(a)},\qquad H(a)=H_0\sqrt{\Omega_m a^{-3}+\Omega_\Lambda},\tag{27}$$

so that the dimensionless product $A \equiv H_0 t_0$ depends only on Ω_m (with $\Omega_\Lambda = 1-\Omega_m$):

$$A(\Omega_m)=\int_0^1\frac{da}{a\sqrt{\Omega_m a^{-3}+\Omega_\Lambda}}=\frac{2}{3\sqrt{1-\Omega_m}}\ \text{arcsinh}\sqrt{\frac{1-\Omega_m}{\Omega_m}}.\tag{28}$$

With the matter density derived by the program, $\Omega_m = 1 - f_c = 0.3131$ (§10), this gives the ceiling $A(w{=}-1) = 0.9526$ [DERIVED]. The ceiling is conditional on its two inputs—the matter density Ω_m and the equation of state $w = -1$, both derived in the same sector—, and $A(\Omega_m)$ is monotone: a larger Ω_m lowers it, a smaller one raises it, and only a $w < -1$ would push it above unity. A background with the observed age of the universe ($t_0 \approx 13.8\,\text{Gyr}$) and $H_0 = 73$ would instead require $A = H_0t_0 \approx 1.030$, above the ceiling; reaching it would require $\Omega_m < 0$ or $w < -1$—the phantom region vetoed by the kinetic positivity of the previous edge. The value $H_0 = 67.4$ gives $A = 0.951$, below the ceiling and therefore allowed. Thus 73 is correct as a reading of the local ladder, but is excluded as the background value of the clock [DERIVED].

Second: since PIU and ΛCDM coincide to linear order (§7), the gap between 67 and 73 cannot be expansion physics. PIU's nonlinear correction to the primordial background is of hundredths of a percent ($\approx$0.02 %), not the 8 % that would separate 67 from 73. This is not a failure of PIU: it is the evidence for the claim. If the two descriptions coincide where ΛCDM anchors its 67, the gap with 73 has to be an artifact of reading a state factor as if it were a constant. The prediction is that the tension attenuates or dissolves in model-independent observables.

9.4 Structure growth (edge: ponderomotive phase drag)

The fourth edge touches the growth of structure, quantified by $f\sigma_8(z)$. PIU predicts here an effect that ΛCDM does not contain: a drag force on matter, mediated by the phase waves of the Telón (§5), whose form derives from the kinetic term of $F1$.

The kinetic term weights the phase by the modulus, $\mathcal{L}_{\rm cin} = \frac{1}{2}\rho_P c^2 \ell_P^2 \big[(\partial S)^2 + S^2(\partial\theta)^2\big]$, and it is that factor S^2 that couples the two sectors. Substituting the perturbation of the relaxed vacuum, $\Psi = (S_{\min} + \delta S)\, e^{i(\theta_0+\delta\theta)}$, and retaining to second order, the phase term gives

$$S^2(\partial\delta\theta)^2 = \underbrace{S_{\min}^2(\partial\delta\theta)^2}_{\text{free wave}} + \underbrace{2S_{\min}\,\delta S\,(\partial\delta\theta)^2}_{\text{wave–matter coupling}} + \mathcal{O}(\delta^3), \tag{29}$$

whose cross term ties the modulus perturbation (matter, δS) to the energy of the phase wave. It is not an added ingredient: it is the second order of the same kinetic term that, at first order, gives the free equations of the modulus and the phase. Averaging over the fast phase oscillations, the drag force per unit matter density follows by variation with respect to δS:

$$\mathbf{F}_{\rm drag} = -\rho_P c^2 \ell_P^2\, S_{\min}\, \nabla\langle(\partial\delta\theta)^2\rangle \quad [\text{DERIVED}]. \tag{30}$$

The force is ponderomotive, and three properties are read off its form. A uniform wave does not drag: the effect requires amplitude modulation, $\nabla\langle(\partial\theta)^2\rangle \neq 0$. The wave, massless, travels at c and outruns matter, which follows it partially. The sign $\mathbf{F} = -\nabla\langle\cdots\rangle$ pulls matter toward the minima of phase agitation. From this a local consequence with a definite sign follows: an *anti-correlation* between the phase agitation of dark energy and the matter overdensity —matter settles where the phase is quiet—, distinguishable in principle from the structure produced by the emergent curvature alone [STRONG DEDUCTION]. The *net* effect on the growth rate, by contrast, is not read off the local force in isolation: it results from the coupled modulus–phase dynamics, resolved below by the class to which the coupling belongs.

In cosmological language, the drag is an effective dark-energy–matter coupling, a fifth force mediated by the phase waves that adds to the emergent curvature of the Pleno. Its structure is that of a *momentum coupling* between the dark-energy sector (the phase θ of the Telón) and matter (the modulus δS): the same kinetic term ties the gradient of the phase to the perturbation of the modulus, and it does so with no coupling at the background level—the drag is purely perturbative, present over the homogeneous Telón whatever its equation of state. That signature —coupling in the perturbations but not in the background— is exactly the one defining the class of pure momentum-transfer models between dark matter and dark energy studied by Pourtsidou, Skordis and Copeland [21] (their Type 3 model) and by Pourtsidou and Tram [22]. For that class the effect on growth is established: the momentum coupling imparts to matter an additional peculiar flow that competes with gravitational collapse in the continuity equation and *suppresses* the growth of structure, a result that Chamings, Avgoustidis, Copeland, Green and Pourtsidou [23] show to be generic for couplings of this type. The ponderomotive drag of PIU physically realizes that momentum coupling —the force $\mathbf{F} = -\nabla\langle(\partial\delta\theta)^2\rangle$ is its explicit form—, so that its effect on $f\sigma_8$ inherits the sign of the class: **it suppresses the growth of structure relative to ΛCDM**, in the direction of the observed S_8 tension.

The temporal location of the effect is likewise determined: it gains relative weight toward the present ($z \to 0$), by the same structural mechanism by which dark energy grows in relative weight while its physical density decreases—matter dilutes as a^{-3} and the phase agitation, a massless radiation-type mode, as a^{-4}, so the drag gains importance against motive gravity as the universe ages [STRONG DEDUCTION]. What is robust is the sign of the relative growth, not its exact exponent.

The legitimate observable to confront is not the "S_8 tension"—a ΛCDM-dependent quantity, since σ_8 is an output of the six-parameter fit—but $f\sigma_8(z)$ measured raw (redshift-space distortions, cosmic shear). The drag is a perturbative effect of the $\delta\theta$ waves, independent of whether the background has $w = -1$ exactly: its signature lives in the growth of structure, not in the equation of state of the background nor in the w_0–w_a signal of DESI. Thus the mechanism (the wave–matter coupling) is **derived** from the second order of $F1$; its class (momentum transfer with no background coupling), and with it the sign of the effect (*suppression* of growth), are fixed by the correspondence with the momentum-coupling literature [21–23]; and its temporal location ($z \to 0$) is [STRONG DEDUCTION]. The only piece that remains is the *magnitude* [CALIBRATED]—an order-unity efficiency coefficient that fixes how much of the phase agitation is transferred to late-time growth, awaiting the full perturbative computation or a simulation of the medium. The S_8 sector thus aligns with the other three edges: PIU supplies a derived mechanism and a sign —in the observed direction—, with the magnitude declared as an open end.

10 The dark sector: quantitative derivation of the 95%

The dark sector is where the ignorance of ΛCDM is greatest and the derivational power of PIU is most complete, and so it is the ground where the comparison between the two descriptions has most leverage. In ΛCDM, dark matter and dark energy are two parameters of unknown origin: the model fits their densities to the data, but offers no mechanism for their existence, no explanation of their nature, no reason for their proportion. In PIU there are not two dark substances to postulate, but a medium modulated in two ways, and the two quantities are derived in detail with explicit algebra: the dark-to-baryonic matter ratio, $\sqrt{3}\,\pi$, and the dark-energy fraction, f_c.

10.1 Dark matter: nature and transparency

Dark matter, in PIU, is Q-ball-type configurations of the modulus [17]: solitons with no topological winding charge, whose stability rests on a global Noether charge—the internal phase rotates, $\dot{\theta} \neq 0$, and that rotation *is* its $U(1)$ charge (axiom A5)—not a gauge charge coupled to the photon. Ordinary matter, by contrast, is solitons with topological baryonic charge $B = 1$: the configuration winds in $\pi_3(SU(2)) = \mathbb{Z}$, with the integer B the winding number, and that charge cannot be undone without unwinding the configuration.

From this distinction follows, derived, the transparency of dark matter. Coupling to the photon—the gauge phase mode $U(1)_{\rm em}$ that emerges over the A/B bipartition of the lattice—requires gauge charge, distinct from both the baryon number B and the global Noether charge of the Q-ball. The Q-ball carries no such gauge charge: its phase rotation is global, not the local holonomy that couples to the photon. It does not emit, absorb, or reflect light; it is gravitationally active—it curves the emergent metric like any configuration with mass—but electromagnetically inert. Where ΛCDM notes that dark matter does not interact with light, PIU derives the reason from the classification of the defect.

10.2 The ratio $\Omega_{MO}/\Omega_M = \sqrt{3}\,\pi$: derivation

The cosmological ratio between dark and baryonic matter is not a fitted parameter. It is obtained from the ratio of the semiclassical partition functions of the two soliton classes, evaluated in the saturated regime after crystallization. For each class $i \in \{M, MO\}$, the partition function expands into five factors,

$$\mathcal{Z}_i = \underbrace{e^{-S_E[\Psi_i^*]/\hbar}}_{(\alpha)\text{ classical action}} \cdot \underbrace{\mathcal{N}_i}_{(\beta)\text{ norm.}} \cdot \underbrace{\mathcal{V}_i^{\rm moduli}}_{(\gamma)\text{ moduli}} \cdot \underbrace{\det{}'_{\rm surf}}_{(\delta)\text{ surface}} \cdot \underbrace{\chi_{\rm FR}^{(i)}}_{(\varepsilon)\text{ statistics}}, \tag{31}$$

and the weight of each sector is $W_i = \mathcal{Z}_i$. The sought ratio emerges from the controlled cancellation of these factors, not from a heuristic product of constants.

Pillar 1 — the boundary areas and why the weight is linear in the area. The scaling of the weight with the area is a fact of *classical* energy, not of quantum fluctuation, and it is worth establishing with care because the correct route is not the naive one. In the saturated regime the hard Gent bound of axiom A6 makes the curvature of the potential diverge inside the defect, $V''_{\rm eff}(S) \propto (S_{\max} - S)^{-2}$, and with it the cost of every internal deformation of the modulus: the fluctuations are confined to a boundary shell of thickness $\xi \to 0$. That suppression has an exact and verifiable consequence on the modulus fluctuation determinant, $\det'(-K\nabla^2 + V''_{\rm eff})$: its *volume* term—the Seeley–DeWitt coefficient a_0, proportional to $\int_\Omega d^3x$—is common to both classes (same saturated floor, same bulk V'') and *cancels identically in the ratio*; a Gelfand–Yaglom integration of the radial profile confirms it numerically (the volume part of the renormalized log-determinant is independent of the defect size, $d(\log\det_{\rm ren})/dL \to 0$). What survives the ratio is the first boundary-sensitive invariant, the edge coefficient a_1, strictly proportional to the area with a universal coefficient (identical for sphere and tetrahedron).

Now, that Gaussian determinant contributes to the weight as $\exp(-\frac{1}{2}\log\det) \sim \exp(-\sigma A_i)$: it is *exponential* in the area, not linear, and on its own would give a ratio $\exp[-\sigma(A_S - A_T)]$, not the sought area ratio. The linearity in the area—the one that produces A_S/A_T—does not come from the determinant, but from the *effective mass* of the soliton, which is classical wall energy. The contribution of the boundary shell is a domain wall of the modulus between the interior of the defect and the $S_{\min}$ sea, with surface tension

$$\Sigma = \int \sqrt{2\,V_{\text{eff}}(S)}\,dS \qquad \text{(BPS wall)}, \tag{32}$$

so the soliton mass is $m_i = \Sigma\, A_i$. The tension Σ depends *only* on the potential V_{eff}, which is the same for both classes: Σ is therefore universal and cancels in the mass ratio, leaving $m_{MO}/m_M = A_S/A_T$ exact and linear. It is this classical reading—mass equals universal tension times area—that fixes the linear dependence; the surface determinant only guarantees, through the cancellation of its volume term, that no bulk contribution contaminates the ratio. The partition factor (δ) is thus understood precisely: it is not the origin of the linearity, but the control that the bulk does not break it. The area each class occupies is forced by its topology.

For dark matter (Q-ball, $B = 0$), the phase does not wind and the boundary is free to relax. The surface energy the Lagrangian assigns it is the gradient term $\frac{1}{2}\rho_P c^2 \ell_P^2 |\nabla S|^2$, manifestly isotropic. At fixed volume, that functional is minimized by the sphere (isoperimetric theorem), so the spherical geometry is not postulated but is the minimum of the functional:

$$A_S = 4\pi R^2. \tag{33}$$

For ordinary matter (soliton, $B = 1$), the phase winds, and that winding anchors the defect to the lattice: it cannot slide or round off without unwinding the charge, which topological conservation forbids. The boundary stays pinned to the nodes, and the minimal region containing a node with its tetrahedral coordination $Z = 4$ is its Voronoi cell, a tetrahedron. Its area follows from the geometry of that cell: a regular tetrahedron with circumradius R has edge $a = R\sqrt{8/3}$ and total area $\sqrt{3}\,a^2$, so that

$$A_T = \sqrt{3}\left(R\sqrt{8/3}\right)^2 = \sqrt{3}\cdot\frac{8}{3}R^2 = \frac{8\sqrt{3}}{3}R^2. \tag{34}$$

Pillar 2 — the spinorial factor (factor γ). The two moduli groups project differently to observables. Ordinary matter is fermionic: its skyrmion-type soliton lives in $SU(2) \cong S^3$, with fermionic statistics mandatory for odd B (2π rotation with factor $(-1)^B$ [12], Finkelstein–Rubinstein theorem [11]). Dark matter is scalar and lives in $SO(3)$. The ratio of the invariant volumes is exact,

$$\frac{\text{Vol}(SO(3))}{\text{Vol}(SU(2))} = \frac{\pi^2}{2\pi^2} = \frac{1}{2} \qquad (SO(3) \cong SU(2)/\mathbb{Z}_2), \tag{35}$$

so ordinary matter undergoes a $\frac{1}{2}$ reduction on projecting from $SU(2)$ to the $SO(3)$ observables, and dark matter does not.

The factors that cancel. The other three factors do not contribute to the ratio. The classical action (α) cancels because both sectors stabilize at the same saturation floor, with equal actions. The normalization (β) cancels because the asymptotic boundary conditions, and with them the asymptotic symmetry groups, are identical. The Finkelstein–Rubinstein statistics (ε) distinguishes the quantum interpretation of each class (fermionic matter, bosonic dark matter), but not the mean densities, for which $|\chi_{\rm FR}|^2 = 1$ intervenes in both.

The bridge to energy densities. There remains the step that connects the ratio of masses with the ratio of cosmological densities. The energy density of each class is $\rho_i = n_i\, m_i$, with n_i the number density and $m_i = \Sigma A_i$ the surface mass (32). The density ratio inherits the area ratio by two structural facts of the medium, each with a declared refinement front.

The first is the **equality of number densities at crystallization**, $n_{MO}/n_M = 1$. Both classes nucleate on the same Pleno floor with the same surface density of states, so that crystallization deposits the same number of defects per class; the subsequent dilution is common to both ($n_i \propto L^{-3}$, non-relativistic matter) and cancels in the ratio [DERIVED]. The pending refinement—whether Kibble–Zurek nucleation [9, 10] introduces a class-dependent density correction—is a low-severity calculation over an already-derived result, not a gap in it [OPEN END: CLASS NUCLEATION].

The second is the **dominance of wall energy**: the excess energy of each soliton over the sea is its surface wall ΣA_i, with the internal fluctuations suppressed by the Gent divergence $V'' \propto (S_{\max} - S)^{-2}$ that confines the modulus to a shell of vanishing thickness. This fixes $m_i \propto A_i$ [DERIVED]. That the Noether charge energy ωQ of the Q-ball does not alter the ratio—its accounting being common over the same floor—closes completely with the mass of the saturated Q-ball from $F1$, a declared low-severity front [OPEN END: WALL VS. CHARGE REGIME]. With this,

$$\frac{\rho_{MO}}{\rho_M} = \frac{n_{MO}\, m_{MO}}{n_M\, m_M} = \frac{n_{MO}}{n_M} \cdot \frac{\Sigma A_{MO}\, g_{MO}}{\Sigma A_M\, g_M} = \frac{A_{MO}\, g_{MO}}{A_M\, g_M}, \tag{36}$$

where g_i is the moduli projection factor of Pillar 2 (the spinorial $\frac{1}{2}$ reduction of the fermionic class) and the universal tension Σ cancels. The number ratio is unity and the common dilution cancels, so that the ratio of energy densities in the late regime is fixed by the geometry of the boundaries and the moduli factor, with no further ingredients.

Assembly. Gathering the factors that do not cancel:

$$\frac{\Omega_{MO}}{\Omega_M} = \frac{W_{MO}}{W_M} = \frac{A_S \cdot 1}{A_T \cdot \frac{1}{2}} = \frac{2A_S}{A_T} = \frac{2 \cdot 4\pi R^2}{(8\sqrt{3}/3)R^2} = \frac{8\pi}{8\sqrt{3}/3} = \frac{3\pi}{\sqrt{3}} = \sqrt{3}\,\pi. \tag{37}$$

Numerically, $\sqrt{3}\,\pi = 1.7321 \times 3.1416 = 5.4414$. The Planck 2018 value is $\Omega_{\rm dm}/\Omega_b = 5.375 \pm 0.077$ [1], so the agreement is $0.86\,\sigma$, with zero free parameters and zero observational input.

The chain is a complete derivation [DERIVED]: each link—the geometry of the two boundaries, the isoperimetric minimum and the Voronoi anchoring, the $\frac{1}{2}$ Peter–Weyl factor, the cancellation of the volume term of the determinant, and the surface mass with universal tension—follows from $F1$ with no fitted number. The two refinement fronts of the bridge do not alter that status: they operate on already-derived links and are of low severity, in the same way that the higher-order correction of a computed quantity does not lower the order that is already established.

Two features accompany this result. First, it is robust against model dependence: the ratio $\Omega_{MO}/\Omega_M = \omega_{\rm dm}/\omega_b$ cancels the h^2 factor, so it is compared against physical densities read directly off the heights of the acoustic peaks, not against parameters that would inherit ΛCDM assumptions; the peak heights fix the target with little freedom, so ΛCDM cannot choose it to coincide with PIU. Second, the input geometry admits a test that it is not a search coincidence. Fixing a set of atoms ($\{1, 2, 3, 4, \pi, e\}$) and of operations (addition, subtraction, product, quotient, root, logarithm, square), the space of algebraic expressions up to complexity five has of order four thousand distinct elements; the fraction of that space falling within the two-sigma window around the observed value of $\Omega_{\rm dm}/\Omega_b$ is of order 10^{-2}, and that of Ω_Λ of the same order, so the probability that two expressions reproduce *both* quantities at once is $\sim 10^{-4}$. That number is a property of the declared set of atoms and operations, not a universal constant, and the supplementary script recomputes it with those assumptions in view, so that anyone can vary the set and see how it changes. Its reading is bounded: it does not prove the theory, but rules out that reproducing $\sqrt{3}\,\pi$ from simple geometry is generic. [CALIBRATED]

The program develops, separately, a Bayes factor that additionally weights the quality of the fit at each anchor and places the evidence against the coincidence hypothesis in the decisive category of the Jeffreys scale [18]. That computation is not reproduced in this work—it depends on the full Bayesian construction of the corpus [20], not on the enumeration above, and chaining the two would mix quantities from distinct computations—; the corpus is referred to for reproducing it, not as an authority but as open code the reader can run.

10.3 Dark energy: what it is, and its equation of state

Dark energy is the Telón: the phase condensate of the Pleno in its minimally excited state, at the floor $S_{\rm min}$, with the background phase at rest ($\dot{\theta}_0 = 0$). In that state the rest four-vector of the sector disappears and the energy-momentum tensor is proportional to the metric,

$$T_{\mu\nu} \propto g_{\mu\nu} \implies p = -\rho \implies w = -1 \text{ exact.} \tag{38}$$

The density is $\rho_{\rm DE} = \rho_P c^2 S_{\rm min}^2$—the value of the modulus potential $V(S) = \rho_P c^2 S^2$ evaluated at the floor, without the wall contributions that act only far from it—, structurally constant because both the anchor and the floor are fixed; what grows with cosmic time is only the relative weight $\Omega_{\rm DE}$, because matter dilutes while the density of the Telón remains. That this $w = -1$ is derived and not postulated, and why that distinguishes PIU from a quintessence model, was treated in the mapping of the parameter w (§8.3). The same floor $S_{\rm min}$ that fixes $w = -1$ also fixes the two geometric quantities of this section, $\sqrt{3}\,\pi$ and f_c.

10.4 The dark-energy fraction f_c: derived structure, positional value

The dark-energy fraction is written as the ratio of two bounds of the modulus,

$$f_c \equiv \frac{S^2_{\max,\text{eff}}}{S^2_{\max,\text{geom}}}, \tag{39}$$

and here the fixed-geometry $\times$ position pattern is seen transparently, in a precise epistemic gradation. The **denominator** $S^2_{\max,\text{geom}}$ is derived from first principles: it is the maximum capacity of the coherent mode, fixed by the packing of the lattice. The hard bound of axiom A6 corresponds to the maximum packing density (Kepler-Hales) relative to the structural density of the diamond lattice, and that ratio has a closed form,

$$S^2_{\max,\text{geom}} = \frac{n^{\max}_{\text{FCC}}}{n_{\text{diamond}}} = \frac{\sqrt{2}/\ell_P^3}{3\sqrt{3}/(8\ell_P^3)} = \frac{8\sqrt{2}}{3\sqrt{3}} = \frac{8}{3}\sqrt{\frac{2}{3}} \approx 2.1773, \tag{40}$$

pure geometry of the lattice, with no free parameter. The **numerator** $S^2_{\max,\text{eff}}$ is positional: it measures the effective occupation of the coherent mode in the present, that is, at what point of its relaxation trajectory the modulus of the universe ended up, fixed by the initial condition of the bounce. Its present value, $S^2_{\max,\text{eff}} \approx 1.4956$, is not a derivable timeless constant, but a state quantity, on the same footing as the Hubble constant—a clock reading.

The ratio then gives

$$f_c = \frac{S^2_{\max,\text{eff}}}{S^2_{\max,\text{geom}}} = \frac{1.4956}{2.1773} \approx 0.6869, \tag{41}$$

which coincides with observed Ω_Λ at $0.30\,\sigma$, and $\Omega_m = 1 - f_c \approx 0.3131$ at $0.27\,\sigma$ of Planck. The status of this result is weaker than that of $\sqrt{3}\,\pi$: the structure of the ratio is derived with zero cosmological fitting parameters—nothing is fitted against the observed value of Ω_{DE}, and that is why the prediction is not circular—but the numerator is calibrated to the physics of the present regime, not derived as a closed number. PIU explains *what* dark energy is and *why* it has $w = -1$, and places its exact amount in the same category as the reading of the cosmic clock: a reading of the state of the universe, not a derivable constant.

It is worth making precise the relation between this $\Omega_m = 1 - f_c \approx 0.3131$ and the "Ω_m tension" between probes —which BAO geometry and the DESI full-shape analysis place near 0.296, and the CMB near 0.315— to forestall a misreading. The two numbers are not the same object and do not compete. The 0.3131 here is a *positional* quantity, inherited from the calibrated numerator $S^2_{\max,\text{eff}}$; it is not a rigid prediction of the program, but a state reading with the same model dependence as its target Ω_Λ, which is why its agreement is declared weaker. The 0.296, by contrast, is the value that fits the CMB-independent BAO *distances*. The quantity PIU does fix without freedom in this sector is neither Ω_m, but the ratio of *physical* densities

$\omega_{\rm dm}/\omega_b = \sqrt{3}\,\pi$, which cancels h^2 and lives in the robust layer —the one the Ω_m tension does not touch—, where the agreement is $0.86\,\sigma$. The Ω_m tension is a dispute over the partition $\Omega_m = \omega_m/h^2$ of a common physical density, i.e. over the split (Ω_m, h), not over the robust density the program predicts; the companion work on the DESI sector [24] develops this reading in detail. PIU's closed prediction therefore does not pick a side of that tension: it sidesteps it, by sitting in the layer where the observable does not depend on the split.

10.5 The contrast, and why it is not a local fit

ΛCDM describes 95 % of the universe with two parameters whose nature it leaves open. PIU does not have that 95 % of ignorance: the existence and nature of both components follow from the Lagrangian, the mutual proportion is derived from pure geometry, and the dark-energy fraction factorizes into a derived geometric part and a positional one. ΛCDM gets right the quantification of two components it cannot explain; PIU explains what they are, why they exist, and why in that proportion, and recovers the same numbers.

The strength of these results lies not in the dark sector taken apart, but in that the same scales (ρ_P, ℓ_P) that give G and $\hbar$, and the same lattice geometry that gives the charges of the particles, also fix $\sqrt{3}\,\pi$ and f_c. They are not local fits of a dark-energy model, but consequences of a substrate already constrained by gravity and quantum mechanics. The cosmological-constant problem illustrates it: the question of why the vacuum density is some 120 orders of magnitude smaller than the Planck density—the worst fine-tuning of the standard model—does not even arise in ΛCDM as solvable. In PIU it is reframed: that number is not a tiny density to explain, but the positional reading of an old universe measured in Planck ticks. The partition reduces to the order-one fraction $f_c \approx 0.69$, and the absolute scale to the inverse square of the age in ticks; there is no exponent to explain, but to count how many ticks the clock has run, and that is an age, not a tuned parameter.

11 Confrontation, falsifiability, and declared open ends

A grounding theory is judged by two things: that its classification of the known anomalies be coherent, and that it declare with precision what it does not yet close.

A third, more basic requirement precedes those two: that its numbers be reproducible without faith. Every quantity derived in this work—the floor $S_{\rm min} = 12(\pi^2 - 4)/\pi^4$, the bound $S^2_{\rm max,geom} = (8/3)\sqrt{2/3}$, the dark-sector ratio $\sqrt{3}\,\pi$, the fraction f_c, the coordination $Z = 4$ fixed by the $1/Z^2$ scaling, the minimum of the effective potential and the nearly-six-order barrier that turns the singularity into a bounce—is recomposed from the structural definitions of the medium, with no fitted value, in a single-run verification script accompanying this work. What the script establishes is bounded and exact: that each number in the body follows from the geometric definitions with no hidden fit, that the three forms of the master equation are identical term by term, that $\sqrt{3}\,\pi$ is dimensionless—the scales ρ_P, c, ℓ_P cancel—, and that the wall tension cancels in the ratio of the dark sector. The Planck data enter only as a yardstick for confrontation, declared external. The script does not prove the theory—it verifies the internal consistency of the body and aborts on any discrepancy outside tolerance—, and that is exactly its function: to guarantee that no result rests on a number put in by hand.

The three numbers the sector fixes—$\sqrt{3}\,\pi$, f_c, and the coordination $Z = 4$—coincide with already-measured quantities, and that coincidence is a retrodiction, not an a priori prediction: the apparatus reproduces a value the observation had already established. The distinction matters for reading the weight of the evidence with precision. A retrodiction is weak when the observed value entered as an input of the computation—then the coincidence is tautological—and strong when it did not. Here it did not: the geometry of the diamond lattice fixes $\sqrt{3}\,\pi$ with not a single fitted cosmological parameter, and the script confirms that the scales of the medium cancel identically in the ratio. A number derived by an independent route that falls within $0.86\,\sigma$ of a well-constrained density is an improbable coincidence under the hypothesis that the input geometry were arbitrary; reaching the correct value by an independent path does not question it, but offers another way of seeing the same fact. The probative force lies precisely in that the computation could have given any other number and gave the measured one.

Confronted with the list of live tensions of the standard model, each one falls into a positional factor read as a constant or into a modulation of the medium not contained in ΛCDM: the Hubble tension and the DESI signal as state factors (type A and type B respectively), the deviation of $f\sigma_8$ as the ponderomotive phase-drag force. As a negative control, the curvature Ω_K—which in PIU is geometric, not positional—should show no positional tension, and indeed it dissolves on combining data, just as predicted. That the live tensions be positional and the geometric control not is evidence in favor of the reading.

Falsifiability is explicit and multiple. The program breaks if the Hubble tension persists in model-independent observables instead of dissolving; if the DESI signal consolidates in the phantom region $w_0 < -1$ that the kinetic vetoes, or persists as $w_0 > -1$ in raw observables; if the nonlinear correction of the expansion yields a sign incompatible with the unprocessed acoustic oscillations; or if raw structure growth demands a large deviation of non-astrophysical origin that phase drag cannot produce. Each tension is, at once, a prediction with a sign and a route to refutation.

The status of the program is thereby situated between conjecture and established theory, and it is worth naming with precision. It is falsifiable: each tension declares the measurement that would break it. It is partially confirmed, but only in the precise sense that its already-testable necessary consequences have passed their tests—the structural equality $v_\gamma = v_{\mathrm{GW}}$, required by the uniqueness of the causal cone, verified by GW170817 to one part in 10^{15}; the recovery of G and $\hbar$ within $0.1\,\%$—none of which is yet discriminating against general relativity or ΛCDM. What would decide the status remains pending: the predictions that *only* PIU makes—the sign of the DESI deviation in raw observables, the suppression of $f\sigma_8$, the ultraviolet correction of dispersion—are blind predictions on quantities not yet measured to the required precision. The program does not, therefore, claim to be established physics; it claims to be a falsifiable framework whose retrodictions are numerous and whose discriminating confirmation awaits the data.

Four open ends remain in the treated sector. The first is the magnitude of the ponderomotive drag on $f\sigma_8$: the coupling and the form of the force are derived from the second order of $F1$, and the sign of the effect —suppression of growth— is fixed by the momentum-coupling class to which it belongs, but the magnitude depends on the amplitude of the phase perturbations, which is not fixed without additional input, and remains calibrated—the closed computation requires full perturbative analysis or a simulation of the medium. The second is the fine nonlinear correction of $H(z)$ introduced by the Gent and Klauder walls at accessible redshifts, and whether it is measurable in raw BAO D_H/r_d; on it depends the exact value of the ceiling $A(w{=}-1)$ of the Hubble argument. The remaining two concern the derivation of $\sqrt{3}\,\pi$ (§10.2) and touch neither the input geometry —derived— nor the numerical result —robust at $0.86\,\sigma$—, but two regime refinements of the bridge to densities, each over an already-derived link: the equality of number densities at crystallization, $n_{MO}/n_M = 1$, whose possible class-dependent adjustment by Kibble–Zurek nucleation remains to be computed; and the accounting of the Q-ball charge energy, which closes with the mass of the saturated soliton from $F1$. None of the four affects the central claims; all four mark the next research front.

12 Conclusion

This work has derived the whole of ΛCDM as the linear limit of the background dynamics of a single medium—the Pleno—, and has shown that its relation to PIU-Ψ is the one thermodynamics bears to statistical mechanics: not a rival theory, but the theory of the substrate that gives it content and marks its limits. ΛCDM works with the precision it does because its linear limit is exact at the two observational anchors—the present epoch and last scattering—, and fails, where it fails, exactly at the edges where that limit runs out.

There lies the reading that unifies the three tensions that today occupy cosmology. Hubble, the dynamical dark-energy signal of DESI, and the deviation of structure growth are neither new physics nor causeless anomalies: they are the signature—of an effective description analyzed under static assumptions and with parameters that are outputs of the very fit one seeks to transcend—of a linear regime used past its edge. In two of them, Hubble and DESI, PIU derives the sign of the deviation from first principles and declares it falsifiable on raw observables, independent of ΛCDM. In the third, structure growth, the ponderomotive phase drag realizes a momentum coupling between matter and dark energy —of the class studied by Pourtsidou, Skordis and Copeland [21–23], whose signature is to couple in the perturbations but not in the background—, and its effect on growth is suppression, in the direction of the observed tension. Each is falsifiable: if the Hubble tension persists rather than dissolving, if the DESI signal consolidates in the phantom region that the kinetics vetoes, or if raw growth demanded an *increase* of growth that a momentum coupling cannot produce, the program is refuted.

The dark sector is where the reading has most leverage, and where the title of this work is borne out. The 95% of the universe that ΛCDM quantifies without explaining ceases to be a parametrized ignorance: dark matter and dark energy are two modulations of a single medium, with their nature derived—why dark matter is transparent to light, why dark energy has $w = -1$ exactly—and their proportion fixed by the geometry of the lattice. The dark-to-baryonic matter ratio is $\sqrt{3}\,\pi$, a pure number of the defect areas; the dark-energy fraction factorizes into a derived geometric capacity and a positional reading of the state of the universe. The dark 95 % is, in the part the theory fixes, geometry of the substrate; in the part it does not, the reading of the cosmic clock—not a constant to explain, but a state to read.

That cosmology receives this reading is not a local result, and therein lies its weight. The same ρ_P and ℓ_P that give G and $\hbar$ fix the cosmological proportions; the same lattice geometry that gives the fractional quark charges gives the dark-to-baryonic matter ratio. A single substrate reproduces at once gravitational, quantum, and cosmological scales, and that coherence—not a fortunate fit of the dark sector—is what sustains the reading of ΛCDM as an effective limit and what distinguishes PIU from one more dark-energy model. ΛCDM is not refuted: it is grounded, with its domain of validity derived and its edges explained.

Four open ends remain in the treated sector—the magnitude of the ponderomotive drag on $f\sigma_8$, the fine nonlinear correction of $H(z)$ in raw BAO, and two regime refinements of the bridge to densities of the dark sector—, none of which affects the central claims; all mark the next front. The cosmological sector is, moreover, one part of a broader program that applies the same medium and the same Lagrangian to the Einstein equations, to the Standard Model, and to the topological origin of spin, with the derivations, verification scripts, and complete compendium deposited openly on Zenodo [20] and reviewed at piuniversal.com. The invitation is not to believe these results, but to reproduce them and to try to break them: each tension of ΛCDM is at once a signed prediction of the substrate and a route by which the program can fall. If the Pleno is correct, its signature is in the raw observables, waiting to be read.

Data and code availability

The complete PIU-Ψ V5.0 corpus, with all derivations and the mathematical compendium, is deposited openly on Zenodo (DOI 10.5281/zenodo.21205881). The numerical verification script that recomposes from the structural definitions of the medium every derived quantity of this work, and confirms its internal consistency, accompanies the article as supplementary material. The observational data used for confrontation are from Planck 2018 [1] and DESI [2, 3], publicly available.

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