

# Dark Energy as a Coherent Condensate Fraction: Reformulating the 123-Order Cosmological Constant Problem

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## Abstract

We identify the cosmological dark-energy fraction with the Bogoliubov–Yukalov condensed fraction of a coherent macroscopic quantum state occupying the cosmological *Pleno*-ground (the continuous hyperelastic scalar substrate postulated by PIU). By shifting the ontological paradigm from a QFT vacuum of diverging zero-point modes to a saturated Bose–Einstein-type continuous substrate, the historical 123-order-of-magnitude multiplicative fine-tuning problem is structurally *reformulated* as an  $\mathcal{O}(1)$  pure geometric ratio. We are explicit that this is a *reformulation*, not a derivation of the absolute vacuum-energy density: the absolute value of  $\rho_{\text{crit}}$  remains an open program. The theoretical identification yields  $\Omega_{\Lambda} \equiv f_c = S_{\text{max,eff}}^2/S_{\text{max,geom}}^2$ , with the upper bound  $S_{\text{max,geom}}^2 = (8/3)\sqrt{2/3}$  [derived] from Kepler–Hales close-packing, and the lower bound  $S_{\text{max,eff}}^2 \approx 1.4956$  [calibrated] convergently from three independent non-cosmological observables (renormalisation group, Q-balls, Pleno cosmology). The resulting structural value is  $\Omega_{\Lambda}^{\text{PIU}} \approx 0.6869$ , in agreement with Planck 2018 ( $0.6847 \pm 0.0073$ ) at  $0.30\sigma$ , with zero additional cosmological free parameters. We also incorporate the V31.10 *EO-Curtain* ontological reformulation, under which dark energy is the permanent structural state of the Pleno-ground rather than a dynamical component.

## 1. Introduction

The cosmological constant problem remains the most severe quantitative mismatch between theory and observation in the history of physics. Standard Quantum Field Theory (QFT) predicts that the vacuum energy, arising from the sum of zero-point fluctuations of all fundamental fields up to the Planck scale, should manifest as a cosmological constant  $\Lambda$ . Yet this theoretical prediction exceeds the observed value of dark-energy density by approximately 123 orders of magnitude [1].

In standard cosmology, dark energy is introduced ad hoc to explain the accelerated expansion of the universe, contributing roughly 68.5% to the total cosmic energy budget [2]. Resolving the immense discrepancy requires fine-tuning the bare cosmological constant to an extraordinary degree to cancel the QFT vacuum contributions.

The *Principle of Universal Integrity* (PIU) framework approaches this crisis through an ontological shift. In PIU [9], the universe is modelled as a continuous hyperelastic substrate (the *Pleno*) that structurally bounds ultraviolet contributions. Dark energy is not the divergent sum of localised vacuum modes; rather, it is the residual structural tension of the Pleno acting as a coherent macroscopic Bose–Einstein-like condensate.

**A precise statement of what is reformulated.** A central commitment of the present paper is epistemic honesty about what is achieved. We do *not* claim to derive the absolute value of  $\rho_{\text{vac}}$  from first principles, nor to resolve the dimensional formulation  $\rho_P/\rho_{\text{crit}} \sim 10^{122}$  in absolute terms. What we do claim is a *translation* of the question: PIU recasts the cosmological-constant problem into a dimensionless geometric

question—the condensed fraction  $f_c$ —which *does* admit an  $\mathcal{O}(1)$  prediction with zero additional cosmological free parameters [9]. The absolute critical density  $\rho_{\text{crit}}$  remains within an open program (F-cosmo-1, V31.8).

## 2. The Pleno as a coherent condensate

The PIU framework governs the Pleno via a tripartite complex scalar Lagrangian  $\mathcal{L}_{F1}$ , in which the field amplitude  $S$  encodes the local substrate density and the phase  $\theta$  encodes its hydrodynamic flow. At the cosmological scale, the universe is not an empty geometrical void but a filled substrate characterised by a minimal structural ground-state density  $S_{\text{min}}$  [9].

A formal structural correspondence between the non-relativistic limit of  $\mathcal{L}_{F1}$  and the Gross-Pitaevskii equation [3, 4] establishes the Pleno as a macroscopic self-interacting condensate (V31.10 §4.bis.bis, status [DLF] pending fully closed algebraic derivation). In the thermalised post-cascade regime of the cosmos, the total available “quanta” of the Pleno are partitioned between the coherent macroscopic ground state and the depleted localised excitations (topological baryons and scalar dark matter).

Under Bogoliubov’s theory of interacting Bose gases [5] and Yukalov’s formulation of quantum depletion [6], the total macroscopic state exhibits a characteristic condensed fraction  $f_c$ . Because the amplitude squared  $S^2$  in the PIU formalism maps to the relative particle density  $n/n_0$  under the Bogoliubov–Josephson identification [9], the density parameters are dimensionless geometric ratios rather than absolute energy densities. This is the structural reason the cosmological-constant problem can be reformulated as a packing problem.

**Dark energy under the EO-Curtain reading (V31.10).** The V31.10 corpus introduces the *EO-Curtain* ontological reformulation (§14.quater of [9]): dark energy is the permanent structural state of the Pleno-ground ( $S \equiv S_{\text{min}}$ ), not a dynamical component subject to gravitational accretion. Three convergent arguments support this reading. Empirically, if dark energy were attractable, one would observe “dark-energy wells” around supermassive black holes,

with local correlation between  $\rho_{\text{EO}}$  and gravitational potential; none is detected. Structurally, V31.10 F6 states  $\rho_{\text{matter}} = \rho_P[S^2 - S_{\text{min}}^2]$ , so matter is the perturbation over the structural background. Dynamically, the equation of state  $w = -1$  with  $T_{\mu\nu} \propto g_{\mu\nu}$  is consistent with a homogeneous structural property. The quantitative prediction  $\Omega_{\text{EO}} = f_c$  is preserved; what changes is its interpretation:  $\Omega_{\text{EO}}$  is no longer “the fraction of energy carried by a cosmological component” but “the structural ratio between the gravitational effect of the background and the total gravitational effect”. The two readings are observationally equivalent under conventional coordinate analysis.

## 3. Derivation of the dark-energy fraction

In standard  $\Lambda$ CDM the energy budget satisfies  $\Omega_\Lambda + \Omega_m = 1$ . In the PIU framework, the total cosmic budget corresponds to the maximum saturation capacity of the Pleno lattice. Dark energy ( $\Omega_{\text{EO}}$ ) corresponds uniquely to the coherent undisrupted background state, while all localised matter (dark and baryonic) constitutes the depleted excited modes.

The fraction of dark energy is therefore ontologically identified with the quantum condensed fraction:

$$\Omega_\Lambda \equiv f_c = \frac{S_{\text{max,eff}}^2}{S_{\text{max,geom}}^2} \quad (1)$$

### 3.1. Geometric upper bound: Kepler–Hales

The Pleno maps locally to a discrete bipartite diamond lattice ( $Z = 4$ ) in its saturation regime (Manuel-V31 hypothesis of the geometric support, [9] §0.bis.4). The maximum absolute saturation limit is the Kepler–Hales close-packing bound for interlocking polyhedra [7]:

$$S_{\text{max,geom}}^2 = \frac{8}{3} \sqrt{\frac{2}{3}} \approx 2.1773. \quad (2)$$

**Epistemic status:** Eq. (2) is [derived] in V31.7 of the corpus via Kepler–Hales geometry applied to the saturated Pleno under the Bogoliubov–Josephson identification [9].

### 3.2. Effective upper bound: $S_{\text{max,eff}}^2$

Physical substrates undergoing extreme quantum coherent states cannot reach perfect geometric packing because of quantum pressure (Klauder affine wall  $V_q$ ) and structural frustration. The *effective* saturation, set by the topological stabilisation potential  $V_{\text{topo}}$  of the F1 Lagrangian, has corpus-canonical value

$$S_{\text{max,eff}}^2 = 1.4956 \pm 3.9 \times 10^{-5}. \quad (3)$$

**Epistemic status:** Eq. (3) is [calibrated] in V31.7–V31.10 of the corpus [9]. The calibration is convergent across three independent non-cosmological channels: (i) renormalisation-group analysis of the Gent potential (Appendix K corrected); (ii) Q-ball mass scale  $M_Q$  (Appendix QQ); (iii) Pleno cosmology equations of state F6, F12. The numerical agreement across three independent channels is what permits us to claim “zero *additional cosmological* free parameters”: the value is fixed by non-cosmological physics and only *evaluated* against cosmological data here.

### 3.3. The structural prediction

Substituting (3) and (2) into (1) yields

$$\Omega_{\Lambda}^{\text{PIU}} = \frac{1.4956}{2.1773} \approx 0.6869 \pm 2 \times 10^{-5} \quad (4)$$

where the uncertainty is propagated from the calibration error on  $S_{\text{max,eff}}^2$ .

## 4. Observational agreement and the $10^{123}$ problem

### 4.1. Comparison with Planck 2018

The Planck Collaboration reports the dark-energy fraction from cosmic-microwave-background anisotropies [2]:

$$\Omega_{\Lambda}^{\text{obs}} = 0.6847 \pm 0.0073. \quad (5)$$

The PIU structural prediction (4) differs from the Planck central value by  $0.30\sigma$ . This is a sub- $\sigma$  agreement from the purely structural mechanics of the Bogoliubov–Yukalov condensate ratio, with no additional cosmological fit.

### 4.2. Bayesian context (V31.10 closure of C-meta-1)

A natural objection to a single-number prediction is sophisticated numerology: with enough free choice of algebraic combinations, one can match any one observable by accident. V31.10 [9] closes this objection quantitatively (Block G). The space of elementary algebraic formulas on the alphabet  $\{1, 2, 3, 4, \pi, e\}$  with operators  $\{+, -, \times, \div, \sqrt{\cdot}, \ln, (\cdot)^2\}$  is enumerated computationally up to Kolmogorov complexity  $N = 5$  (3778 distinct expressions). For each of the two cosmological structural predictions of the corpus ( $\Omega_{\text{MO}}/\Omega_{\text{M}} = \sqrt{3}\pi$  and  $\Omega_{\text{EO}} = f_c$ ), the probability under the null hypothesis  $H_0$  (chance numerological coincidence) of falling within the  $2\sigma$  observational window is bounded:

$$P(D_1, D_2 | H_0) < 3 \times 10^{-4}.$$

The corresponding cosmological Bayes factor is

$$K_c = \frac{P(D_1, D_2 | H_{\text{PIU}})}{P(D_1, D_2 | H_0)} \approx 6.7 \times 10^5,$$

stable in  $\log_{10} K_c \in [5.40, 5.94]$  for  $N \in \{3, 4, 5\}$ . On the Jeffreys (1961) scale,  $\log_{10} K_c \approx 5.83$  corresponds to *decisive* evidence by approximately four orders of magnitude over the critical threshold (cosmological sector alone). Even a sceptical prior  $P(H_{\text{PIU}}) = 10^{-6}$  updates rationally to  $\sim 40\%$  posterior on the cosmological sector alone.

### 4.3. Resolution of the multiplicative fine-tuning

The  $10^{123}$  discrepancy in QFT arises from assuming that the vacuum is an infinite reservoir of additive zero-point fluctuation modes defined over an empty metric spacetime. In PIU, the ultraviolet modes are strictly truncated by the finite rigidity of the substrate (Axiom A4,  $\kappa_{\text{max}} = 1/\ell_P$ ) and the hard density bound  $S_{\text{max,geom}}^2$  [9]. The macroscopic energy density of the universe is not the sum of microscopic fluctuations but the global cohesive tension of the coherent Pleno-ground.

The colossal multiplicative factor is therefore *not summed*: it is structurally absent. The problem is translated from an ultraviolet momentum integral to a macroscopic packing problem governed by an  $\mathcal{O}(1)$  ratio,  $1.4956/2.1773$ .

**Epistemic status:** What this paper claims — and does not claim. We claim: (i) a *reformulation* of the cosmological-constant problem from a divergent multiplicative integral into an  $\mathcal{O}(1)$  structural geometric ratio; (ii) a structural *prediction*  $\Omega_\Lambda = 0.6869$  in  $0.30\sigma$  agreement with Planck 2018, with *no additional cosmological free parameters* (the parameter  $S_{\max, \text{eff}}^2$  being calibrated convergently from three independent non-cosmological observables). We do not claim: (a) a derivation of the absolute value of the vacuum-energy density  $\rho_{\text{vac}}$  from first principles; (b) a resolution of the dimensional ratio  $\rho_P/\rho_{\text{crit}} \sim 10^{122}$  in its raw form. These remain within an open programme (F-cosmo-1, V31.8) and are explicitly outside the scope of the present paper.

## 5. Epistemic ledger

Result	PIU corpus status
$\Omega_\Lambda \equiv f_c$ identification, Eq. (1)	[derived] (Block F.1, V31.9; composition of F1-a V31.6, Theorem M2 V31.3, F6 V31.8)
$S_{\max, \text{geom}}^2 = (8/3)\sqrt{2/3}$ , Eq. (2)	[derived] (V31.7, Kepler–Hales on saturated Pleno)
$S_{\max, \text{eff}}^2 = 1.4956 \pm 3.9 \times 10^{-5}$ , Eq. (3)	[calibrated] (RG, Q-ball $M_Q$ , Pleno cosmology)
$\Omega_\Lambda^{\text{PIU}} = 0.6869$ , Eq. (4)	[derived] from above, no additional cosmological fit
Bayesian closure C-meta-1, $K_c \approx 6.7 \times 10^5$	[derived] (V31.10 Block G)
EO-Curtain ontological reading	[articulated] consequence of F6 V31.8 (V31.10 Block J)

## 6. Conclusion

By identifying the dark-energy component of the universe with the macroscopic Bogoliubov–Yukalov condensed fraction of the Pleno-ground, the PIU framework *reformulates* the long-standing cosmological-constant problem from a multiplicative fine-tuning of  $10^{123}$  into an  $\mathcal{O}(1)$  geometric packing question. The reformulation yields a structural prediction  $\Omega_\Lambda^{\text{PIU}} \approx 0.6869$ , in  $0.30\sigma$  agreement with Planck 2018, with zero *additional cosmological* free parameters. The corpus V31.10 closes the natural “sophisticated numerology” objection with a Bayes factor  $K_c \approx 6.7 \times 10^5$

(decisive on the Jeffreys scale).

We have been deliberate about the difference between *reformulation* and *absolute resolution*: the absolute value of  $\rho_{\text{vac}}$  remains an open programme. What this paper provides is a structural redefinition of the question into a form that admits a single-number prediction matching observation, paired with the V31.10 EO-Curtain ontological reading under which dark energy is a permanent structural state of the Pleno-ground rather than a dynamical fluid.

## References

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