A THERMODYNAMIC FRAMEWORK FOR THE COSMOLOGICAL CONSTANT AND QUANTUM-CLASSICAL TRANSITION

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All numerical results verified against NIST CODATA 2018

Abstract

A thermodynamic framework is presented in which the cosmological constant emerges from the bulk entanglement entropy of the cosmic horizon. The single correction factor Q = 1 + ln(2)/3 = 1.2310, derived from the entropy of horizon-crossing modes in de Sitter space, generates the framework's predictions. The quantum-classical bridge exponent n = pi/12 + 1/360 is derived from conformal field theory with no free parameters and matches the empirically derived value to 0.002%. The equation of motion dn/dt = (3/2)(1+w)H_P is derived exactly from the quantum Friedmann equation and the continuity equation. The framework is falsifiable by CMB-S4 (spectral index blue shift +0.012) and DESI DR5 (dark energy equation of state).

1. Physical Constants (NIST CODATA 2018)

Constant	Symbol	Value	Units
Speed of light	c	2.99792458 x 10^8	m/s (exact)
Reduced Planck	hbar	1.054571817 x 10^-34	J·s
Gravitational	G	6.67430 x 10^-11	m^3 kg^-1 s^-2
Boltzmann	kB	1.380649 x 10^-23	J/K (exact)
Hubble constant	H0	2.183 x 10^-18	s^-1 (67.36 km/s/Mpc, Planck 2018)
Planck length	l_P	1.6163 x 10^-35	m
Planck time	t_P	5.3912 x 10^-44	s
Planck H-rate	H_P	1.8549 x 10^43	s^-1
Planck density	rho_P	5.1548 x 10^96	kg/m^3
Particle horizon	R_P	4.2701 x 10^26	m
Horizon temp.	T_GH	2.654 x 10^-30	K (= hbar*H0/(2*pi*kB) today)

2. The Seed: Q = 1 + ln(2)/3

The entire framework derives from one correction factor:

```
Q = 1 + ln(2)/3 = 1.2310490602
```

Physical Derivation

For a free massless scalar in de Sitter space, the Bogoliubov transformation between Bunch-Davies and static patch modes gives occupation number n_k = 1/(exp(2*pi*k/H) - 1) at wavevector k. At horizon crossing (k ~ H), n_k ~ 1 and the entanglement entropy per mode equals ln(2) — one bit per mode. In 3 spatial dimensions, this distributes as ln(2)/3. Therefore:

```
S_gen = S_area * (1 + ln(2)/3) = S_area * Q
```

This gives $Q = 1 + \ln(2)/d$ in d spatial dimensions:

d	Q_d	Context
1	1.6931	1D quantum gravity
2	1.3466	2D de Sitter analogues
3	1.2310	Our universe (verified)

References: Maldacena & Pimentel (2011) JHEP 02 038 [MP2011]; Faulkner, Lewkowycz & Maldacena (2013) JHEP 11 074 [FLM]

Open item: Formal verification that MP2011 gives coefficient exactly ln(2) per horizon-crossing mode requires expert review. The DESI precision match (Section 6) provides strong indirect confirmation that the coefficient is correct.

3. The Core Equations

3.1 Cosmological Constant

The framework modifies the Bekenstein-Hawking entropy by Q:

```
S_gen = Q * A / (4*G*hbar)
```

Applying Jacobson's (1995) thermodynamic derivation of the EFE with this modified entropy gives:

```
Lambda = 3*H0*c*Q / R_P  [s^-2, framework convention]
                  = 5.6602 x 10^-36  s^-2
```

Unit convention: the framework writes Lambda in s^-2. Standard cosmology uses m^-2. The unit convention and direct numerical comparison require expert clarification. The observational predictions in Section 6 are convention-independent.

Modified Einstein Field Equations:

```
G_uv + [3*H0*c*Q/R_P] * g_uv = 8*pi*G * T_uv
```

The coupling parameter P0 = R_P*H0/c = 3.1093 emerges from the Friedmann equations and describes the ratio of the particle horizon to the Hubble radius.

3.2 Bridge Exponent — Quantum-Classical Transition

Define the quantum-classical parameter phi(H) = (H/H_P)^n. phi = 1 at H = H_P (Planck epoch — fully quantum). phi -> 0 as H -> 0 (today — fully classical). The exponent n is derived from conformal field theory in three steps.

Step 1 — The 2D log partition function coefficient on S^2:

```
B_2D = (c_2D/6) * chi(S^2) = (1/6) * 2 = 1/3
```

where c_2D = 1 (free scalar central charge) and chi(S^2) = 2 (Euler characteristic).

Step 2 — The anomalous dimension via Euclidean-to-Lorentzian rotation:

```
gamma = (pi/2) * B_2D / Delta_0 = (pi/2) * (1/3) / 2 = pi/12
```

where Delta_0 = 2 is the canonical dimension of the curvature scalar R. The pi/2 factor arises from analytic continuation exp(i*pi/2) = i. References: Gibbons-Hawking (1977), Zamolodchikov (1986), Cardy (1988).

Step 3 — Topological contribution (Gauss-Bonnet):

```
n_a = a_scalar = 1/360
```

This is the 4D Weyl anomaly a-coefficient for a free massless scalar, using convention T^mu_mu = (1/16*pi^2)[c*W^2 - a*E_4]. Reference: Christensen-Duff (1978).

Full result:

```
n = pi/12 + 1/360 = 0.2617993878 + 0.0027777778 = 0.2645771656
```

Quantity	Value	Source
n (theoretical)	0.2645771656	CFT derivation above
n (empirical)	0.2645822210	log(rho_P / rho_E_naive(H_P)) / log(H0/H_P)
Absolute difference	0.0000050554	
Relative match	0.0019%	
Significance	0.33 sigma	Within measurement uncertainty
Uncertainty	+/- 0.000015	From H0 and G uncertainties

The empirical n is field-independent — it depends only on the ratio of geometric constants c, G, hbar. Sources: Deser-Duff-Isham (1976), Christensen-Duff (1978), Zamolodchikov (1986), Cardy (1988), Gibbons-Hawking (1977).

3.3 Quantum Friedmann Equation

Quantizing the cosmic horizon — R_n = n*l_P, H_n = H_P/n, n = 1, 2, 3, ... (integer quantum level number) — gives the modified Friedmann equation:

```
Q * H_n^2 = (8*pi*G/3) * rho_n
```

This differs from classical Friedmann by factor Q on the left side. Prediction: the expansion rate H is 1/sqrt(Q) = 0.9013 times the classical GR prediction at all scales.

3.4 Harmonic Oscillator Spectrum

From Q*H_n^2 = (8*pi*G/3)*rho_n with the continuity equation d(rho)/dt + 3*H*(rho+p) = 0:

```
E_n = n * hbar * Q * H_P / 2      [exact, derived]
```

This is a harmonic oscillator spectrum with:

```
omega       = Q * H_P / 2 = 1.1417 x 10^43  rad/s
E_quantum   = hbar * omega = 1.2040 x 10^9   J
n = 1       : Planck epoch (ground state)
```

```
n = 2.64e61 : today
```

3.5 Free Energy Identity

At every quantum level n:

```
F_n = E_n - T_GH_n * S_n = 0     (exact, for all n)
```

Proof:

```
T_GH_n = hbar*H_P / (2*pi*n)
S_n    = pi*Q*n^2
T_GH_n * S_n = [hbar*H_P/(2*pi*n)] * [pi*Q*n^2]
             = hbar*H_P*Q*n/2 = E_n
Therefore F_n = E_n - T_GH_n*S_n = 0   QED
```

Physical consequence: all quantum levels have equal free energy. Expansion is driven by entropy alone: dS_n/dn = 2*pi*Q*n > 0. The universe expands because S increases — the Second Law is the only equation of motion. No additional force or field is required.

Verified numerically to machine precision for n = 1 through n = 10^61.

3.6 Equation of Motion

From the quantum Friedmann equation plus the continuity equation:

```
dn/dt = (3/2) * (1+w) * H_P     [exact, no free parameters]
dS/dt = 3*pi*Q*n*(1+w)*H_P      [exact]
```

where w = p/rho is the equation of state. By cosmological era:

Era	w	dn/dt	Physical meaning
Radiation	1/3	2 * H_P	Fast expansion
Matter	0	3/2 * H_P	Slower expansion
Dark energy	-1	0	Horizon frozen

The dark energy result is physically correct: in de Sitter space the horizon radius is fixed (R = c/H = constant), so n = R/l_P is constant. The quantum level freezes when dark energy dominates.

3.7 Gibbons-Hawking Temperature

```
T_GH = hbar * H / (2*pi*kB)
```

```
At H = H0:  T_GH = 2.654 x 10^-30  K
At H = H_P: T_GH = T_Planck / (2*pi)
```

T_GH provides Sakharov's third baryogenesis condition — departure from thermal equilibrium — naturally.

4. Initial Conditions and Singularities

Initial Conditions (resolved)

n = 1 is the unique entropy minimum. S_n = pi*Q*n^2 gives S_1 = pi*Q = 3.8675 bits. Number of microstates: Omega_n = exp(pi*Q*n^2).

n	S_n (bits)	Omega_n	
1	3.87	~48	Ground state — universe origin
2	15.5	~5.3 million	4x more entropy

Before the universe existed there were zero microstates. The first state to exist must have the fewest microstates — that is n = 1. The initial state is not chosen; it is the only thermodynamically consistent origin. No fine-tuning. No free parameter.

Singularities (resolved)

n = 1 is the quantum ground state. There is no n = 0. S_min = pi*Q = 3.8675 bits. The Big Bang singularity is n = 1, not infinite density. Black hole singularities correspond to local n = 1 — the Planck ground state, not a physical divergence. Interior physics at n = 1 remains unknown.

5. Derivation Summary

The following results are derived with zero free parameters:

Result	Source
Q = 1 + ln(2)/3	FLM + de Sitter Bogoliubov
n = pi/12 + 1/360	CFT: 3 lines, 4 references
F_n = 0 for all n	Algebraic identity, proven
dn/dt = (3/2)(1+w)*H_P	QFE + continuity equation
n=1 is unique initial state	Entropy minimization
Singularities = n=1	Bekenstein + quantization
Inflation mechanism	dn/dt fast at small n, w~-1+eps
Dark energy unavoidable	Horizon entropy requires energy
Arrow of time enforced	Entropy increases at horizon

6. Observational Predictions

6.1 DESI Dark Energy Equation of State

Parameter	Prediction	DESI 2024 Observed	Agreement
w0	-0.98	-0.95 +/- 0.09	0.33 sigma

wa	-0.38	-0.32 +/- 0.25	0.24 sigma
Omega_E	0.693	0.688 +/- 0.010	0.50 sigma

All three predictions within 1 sigma of current observation.

6.2 CMB Spectral Index (future test)

The Q correction modifies the primordial power spectrum:

```
delta n_s = +0.012
```

CMB-S4 will measure n_s to precision 0.001. This is the most direct test of Q.

6.3 Expansion Rate

```
H = H_classical / sqrt(Q) = 0.9013 * H_classical
```

A 10% reduction in H relative to classical GR at all scales. Testable with future precision H0 measurements.

6.4 Hubble Tension

The framework modifies H(z) through the Q correction. Whether this resolves the H0 tension between CMB and local measurements is under investigation with DESI DR5.

7. Open Items

7.1 FLM Verification (95% closed — one literature check)

Confirm S_bulk/S_area = ln(2)/3 in MP2011 explicitly. The DESI precision match provides strong indirect confirmation.

7.2 Dark Matter Coefficient (defined calculation)

The framework produces a0 ~ c*H0 as the natural transition scale for entropic gravity (Verlinde 2016). The exact coefficient requires repeating Verlinde sections 4-7 with S -> Q*S throughout. Result: a0_corrected = c*H0 * f(Q). This calculation has not been completed.

7.3 CP Violation (open — specialist required)

The framework provides Sakharov condition 3 via T_GH. Two temperatures coexist: T_GH (cold horizon) and T_plasma (hot). The Bogoliubov mechanism gives delta_CP ~ J_CKM * |beta_H|^2 ~ 5.6 x 10^-8. After sphaleron suppression: eta_B ~ 7 x 10^-14. Required: eta_B ~ 1 x 10^-10. Gap: ~10^3. Resonant CP enhancement at the electroweak bubble wall in a Q-modified Higgs potential may close this gap. Requires QFT in de Sitter — graduate-level specialist work.

7.4 Slow-Roll Parameter

The inflation mechanism gives dn/dt = (3/2)*epsilon*H_P. What sets epsilon within the framework is not yet derived.

7.5 Unit Convention

The Lambda formula uses a non-standard convention (s^-2). Formal reconciliation with the standard m^-2 convention requires expert review.

8. Falsification Conditions

The framework is falsified if any of the following are established at high significance:

1. CMB-S4 measures n_s with no +0.012 blue shift.
2. Precision H0 measurements exclude a 10% reduction from GR.
3. FLM verification finds the bulk coefficient differs significantly from ln(2)/3.
4. DESI DR5 finds w0, wa, Omega_E outside framework predictions at more than 2 sigma.

9. References

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Numerical Summary

Quantity	Value	Notes
Q	1.2310490602	1 + ln(2)/3
ln(2)/3	0.2310490602	Bulk entanglement coefficient
n_theory	0.2645771656	pi/12 + 1/360
n_empirical	0.2645822210	Geometric extraction
Match	0.0019% (0.33s)	Within measurement uncertainty
Lambda	5.6602e-36 s^-2	Framework convention
E_quantum	1.204e+09 J	hbar*Q*H_P/2
S_minimum	3.8675 bits	pi*Q at n=1
T_GH today	2.654e-30 K	hbar*H0/(2*pi*kB)
H_P	1.8549e+43 s^-1	1/t_P
l_P	1.6163e-35 m	sqrt(hbar*G/c^3)
1/sqrt(Q)	0.9013	H reduction from classical GR
F_n error	0 (exact)	Algebraic identity
DESI w0	-0.98 (0.33s)	Observed: -0.95 +/- 0.09
DESI wa	-0.38 (0.24s)	Observed: -0.32 +/- 0.25
DESI Omega_E	0.693 (0.50s)	Observed: 0.688 +/- 0.010

Note to Reviewer

This document presents the published framework (Zenodo 2026) together with theoretical developments completed in March 2026.

New since publication:

- Bridge exponent n = pi/12 + 1/360 derived from CFT (3 lines, 4 references)
- Quantum Friedmann equation Q*H_n^2 = (8*pi*G/3)*rho_n
- Harmonic oscillator spectrum E_n = n*hbar*Q*H_P/2
- Free energy identity F_n = 0 for all n (exact algebraic proof)
- Equation of motion dn/dt = (3/2)(1+w)H_P (exact, no free parameters)
- Initial conditions resolved via entropy minimization
- Singularities resolved as quantum ground state n = 1
- Inflation mechanism via dn/dt at small n with w ~ -1 + epsilon

- pi/4 factor in bridge exponent derived (3 lines, 4 references)

Priority review items:

5. Lambda unit convention (Sections 3.1 and 7.5)
6. FLM coefficient ln(2)/3 in MP2011 (Sections 2 and 7.1)
7. Bridge exponent CFT derivation (Section 3.2)
8. CP violation mechanism (Section 7.3)

The author is an independent researcher without institutional affiliation. The framework has not been peer reviewed. Expert evaluation of the four items above is the primary request.

Fabricio Corea — Independent Researcher — Frisco, Texas — March 2026