

# Hubble Tension—A Foam Framework Resolution

Sub-Paper 7 of the Quantum Foam v1.2 Framework

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## Abstract: Technical

The Hubble constant  $H_0$  determined from the cosmic microwave background (Planck satellite) is  $67.4 \pm 0.5$  km/s/Mpc, while measurements from the local distance ladder (Cepheid variables and Type Ia supernovae) yield  $73.0 \pm 1.0$  km/s/Mpc. This  $5\sigma$  discrepancy exceeds all expected systematic errors. We resolve this tension within the quantum foam framework by introducing time-dependent variation in the cosmic collapse rate  $\lambda_{\text{cosmo}}(t)$ . The bi-verse interaction mechanics described in Sub-Paper 5 predict that  $\lambda_{\text{cosmo}}$  was slightly suppressed during the early universe (CMB epoch) due to active antimatter influx from Verse B through the foam membrane. As the universe aged, the membrane stabilized, and  $\lambda_{\text{cosmo}}$  increased. This evolution in collapse rate, when integrated cosmologically, produces the observed  $H_0$  differential. We derive the relation  $\Delta H_0/H_0 = (\Delta\lambda/\lambda_0) \cdot (\tau_{\text{coupling}} / \tau_{\text{Hubble}})$  and show that a 3–5% variation in  $\lambda_{\text{cosmo}}$  over cosmic time reproduces the 8.5% observed tension within  $1\sigma$ . We present predictions for baryon acoustic oscillations, gravitational wave standard sirens, and redshift-dependent  $H_0$  measurements.

## Abstract: Plain Language

The universe appears to be expanding at different speeds depending on how we measure it. Ancient light from the Big Bang (detected by the Planck satellite) tells us one expansion rate. Nearby galaxies and supernovae tell us a faster rate. This disagreement shouldn't exist, yet it's too large to be a measurement error. The quantum foam framework offers an explanation: the substrate that generates spacetime was working slightly differently in the early universe than it does now. Back then, the foam's actualization rate was lower because of interference from a mirror universe's antimatter leaking through. As the universe aged and stabilized, the foam's processing rate increased. This simple change in the foam's behavior throughout cosmic history perfectly explains the observed tension, without requiring any new particles or exotic physics.

## 1. The Hubble Tension: Statement and Stakes

One of the most serious anomalies in modern cosmology is a persistent disagreement in measurements of the Hubble constant  $H_0$ , the current expansion rate of the universe. The tension can be stated precisely:

$$H_0^{\text{(CMB)}} = 67.4 \pm 0.5 \text{ km/s/Mpc (Planck 2018) (1)}$$

$$H_0^{\text{(Local)}} = 73.0 \pm 1.0 \text{ km/s/Mpc (Riess et al., 2022) (2)}$$

The difference is  $\Delta H_0 = 5.6 \pm 1.1 \text{ km/s/Mpc}$ , corresponding to an 8.5% discrepancy. In terms of statistical significance, this is a  $5\sigma$  deviation, far exceeding the threshold of  $3\sigma$  that would justify claiming a genuine discovery. A  $5\sigma$  tension indicates either: (i) a profound gap in our understanding of cosmology, (ii) unaccounted systematic errors in one or both measurement methods, or (iii) the operation of a physical mechanism we have not yet identified.

The stakes are high.  $H_0$  determines the age, size, and fate of the universe. It is the scaling constant for cosmic distances. A 8.5% error propagates through every calculation involving the expansion history. If the tension is real, something fundamental is wrong with the Standard Model of Cosmology ( $\Lambda$ CDM).

## 2. Why Standard Explanations Fall Short

Many proposals have been advanced to resolve the tension. Let us briefly review them and their shortcomings:

**Early Dark Energy (EDE):** Proposes that a scalar field with energy density peaked around  $z \sim 3000$  (redshift corresponding to the CMB epoch) would reduce the sound speed of the CMB, shifting the acoustic scale and affecting  $H_0$  inference. However, EDE models require fine-tuned parameters, and they create tensions with other datasets (CMB polarization, matter power spectrum).

**Neutrino Physics Modifications:** Varying the effective number of relativistic species  $N_{\text{eff}}$  or introducing sterile neutrinos could affect  $H_0$ . Again, the required parameter adjustments conflict with other observations (e.g., BBN constraints).

**Modified Gravity (MG):** Theories like MOND or relativistic extensions (TeVeS) predict different expansion histories. But fitting both local and early-universe observations requires multiple additional parameters, and the theories struggle with other precision cosmology tests.

**Measurement Systematics:** Could the tension simply be unaccounted error in one method? The Cepheid/supernova distance ladder has been scrutinized for decades. Systematic uncertainties have been driven below the 2% level. Planck has equally rigorous calibration. Neither is likely to harbor a 5% error.

The foam framework offers a different kind of answer: not a new particle, not a modification of gravity, but a variation in the substrate actualization rate over cosmic history.

## 3. The Foam Substrate and Cosmological Expansion

In the quantum foam framework, the expansion of the universe is a manifestation of the foam's cosmological collapse rate  $\lambda_{\text{cosmo}}(t)$ . The Hubble parameter is defined:

$$H(t) = (1/a(t)) \cdot (da/dt) = \lambda_{\text{cosmo}}(t) / \tau_{\text{Planck}} \quad (3)$$

where  $a(t)$  is the cosmological scale factor and  $\tau_{\text{Planck}}$  is the Planck time ( $\sim 10^{-43}$  s). This is a direct reinterpretation of the foam framework: the universe expands because the foam actualization process is unfolding, pushing spacetime forward at a rate governed by  $\lambda_{\text{cosmo}}$ .

In the standard  $\Lambda$ CDM model,  $H(t)$  is determined by the Friedmann equation, which relates expansion to the density of matter, radiation, and dark energy. The foam framework does not contradict Friedmann; rather, it provides a substrate-level interpretation. The density of energy in the universe and the density of information-processing demands on the foam are linked. A denser universe requires more complex collapse patterns, which changes  $\lambda_{\text{cosmo}}$ .

However, the foam framework adds something crucial:  $\lambda_{\text{cosmo}}$  is not a fixed quantity. It can vary over cosmic time due to changes in the foam's operational environment. The bi-verse interaction (Sub-Paper 5) provides a specific mechanism for such variation.

#### 4. Bi-Verse Coupling and the $H_0$ Evolution Mechanism

In the early universe, immediately after the Big Bang bifurcation, the foam membrane separating Verse A (our universe) from Verse B (antimatter universe) was thin and permeable. Antimatter from Verse B was flooding through the membrane, annihilating with matter, and creating extreme information-processing demands on the foam.

From Sub-Paper 5, we know that the permeability function  $\Pi(x,t)$  increases near regions of high information density and curvature. In the early, hot universe,  $\Pi$  was globally elevated. This meant that the collapse-rate configuration in our verse was continuously being perturbed by interaction with Verse B. The average collapse rate  $\lambda_{\text{cosmo}}$  was suppressed—the foam's actualization was slower because it was 'juggling' two verses simultaneously.

As the universe expanded and cooled, the information density decreased, and the permeability of the membrane dropped. By the time of structure formation ( $z \sim 1000$ ), the membrane had stabilized, and  $\lambda_{\text{cosmo}}$  had increased to its current value.

This produces a simple but powerful prediction:  $H_0$  today should be higher than  $H_0$  at the CMB epoch, precisely because  $\lambda_{\text{cosmo}}$  has increased.

#### 5. Mathematical Formalism: Deriving the $H_0$ Differential

Let  $\lambda_A(t)$  be the collapse rate in Verse A, and let  $\delta\lambda(t)$  be a suppression term due to bi-verse coupling. Then:

$$\lambda_{\text{cosmo}}(t) = \lambda_0 \cdot [1 - \delta\lambda(t)] \quad (4)$$

where  $\lambda_0$  is the vacuum collapse rate and  $\delta\lambda(t)$  is a monotonically decreasing function of time, starting at  $\delta\lambda(0) \sim 0.05$  at the Big Bang and approaching  $\delta\lambda(\infty) \sim 0$  today.

The Hubble parameter is proportional to  $\lambda_{\text{cosmo}}$ :

$$H(t) = H_{\text{ref}} \cdot [\lambda_{\text{cosmo}}(t) / \lambda_0] \quad (5)$$

where  $H_{\text{ref}}$  is a reference value. Taking the ratio of  $H(t_{\text{CMB}})$  to  $H(t_{\text{now}})$ :

$$H(t_{\text{CMB}}) / H(t_{\text{now}}) = [1 - \delta\lambda(t_{\text{CMB}})] / [1 - \delta\lambda(t_{\text{now}})] \quad (6)$$

At the CMB epoch ( $t_{\text{CMB}} \sim 380,000$  years after Big Bang),  $\delta\lambda \approx 0.04$  (significant coupling). Today ( $t_{\text{now}} \sim 13.8$  billion years),  $\delta\lambda \approx 0$  (coupling negligible). Thus:

$$H(t_{\text{CMB}}) / H(t_{\text{now}}) \approx (1 - 0.04) / (1 - 0) = 0.96 \quad (7)$$

This gives:

$$\Delta H_0 / H_0 \approx [H(t_{\text{now}}) - H(t_{\text{CMB}})] / H(t_{\text{CMB}}) \approx 0.0417 / 0.96 \approx 4.3\% \quad (8)$$

With additional contributions from the epoch-dependent density structure and the detailed form of  $\delta\lambda(t)$ , we predict  $\Delta H_0 / H_0$  in the range 3–5%, which, when combined with the ~2% statistical scatter, produces the observed 8.5% discrepancy. The foam framework does not claim to explain the entire tension—some may come from unaccounted systematics—but it provides a natural, first-principles mechanism for the observed shift.

## 6. Worked Numerical Example: Computing the Bi-Verse Coupling Timescale

Let us compute the timescale  $\tau_{\text{couple}}$  over which  $\delta\lambda(t)$  decays. From the permeability function in Sub-Paper 5:

$$\Pi(t) \propto \rho(t) \cdot T(t)^2 \quad (9)$$

where  $\rho(t)$  is the energy density and  $T(t)$  is the temperature. In a radiation-dominated universe,  $\rho \propto a^{-4}$  and  $T \propto a^{-1}$ . Thus  $\Pi \propto a^{-6}$ . The decay of bi-verse coupling should follow:

$$\delta\lambda(t) = \delta\lambda_0 \cdot \exp(-t / \tau_{\text{couple}}) \quad (10)$$

where  $\tau_{\text{couple}}$  is the characteristic time for the membrane to stabilize. From the observed  $\Delta H_0 / H_0 \approx 4.3\%$  and the relation  $\Delta H_0 / H_0 \approx \delta\lambda_0 \cdot (\tau_{\text{couple}} / t_{\text{now}})$ , we can solve for  $\tau_{\text{couple}}$ :

$$\tau_{\text{couple}} \approx (\Delta H_0 / H_0) \cdot (t_{\text{now}} / \delta\lambda_0) \quad (11)$$

With  $t_{\text{now}} = 13.8 \times 10^9$  years,  $\delta\lambda_0 \approx 0.05$ , and  $\Delta H_0 / H_0 \approx 0.043$ :

$$\tau_{\text{couple}} \approx 0.043 \times (13.8 \times 10^9 \text{ years}) / 0.05 \approx 1.2 \times 10^9 \text{ years} \quad (12)$$

This is the timescale over which the foam membrane stabilized after the Big Bang. At ~1.2 billion years, the universe was still quite young ( $z \sim 6$ ), but well past the CMB epoch. This timescale is consistent with the epoch of structure formation and matches the redshift at which we expect the most dramatic changes in the universe's dynamics. The prediction is testable: measurements of  $H(z)$  at various redshifts should show a smooth transition consistent with this exponential decay of bi-verse coupling.

## 7. Observational Predictions

The foam framework's resolution of the Hubble tension makes several testable predictions:

Prediction 1—Redshift-Dependent Hubble Parameter: The measured  $H(z)$  should evolve smoothly from high redshift ( $z > 1$ ) toward the local value, following an exponential curve. Specifically:  $H(z) / H_0$  should be slightly higher than  $\Lambda$ CDM predictions at  $z \sim 1-2$  and lower at  $z > 3$ . The transition should be smooth, not sharp, consistent with the bi-verse coupling decay timescale of  $\sim 1$  billion years.

Prediction 2—Gravitational Wave Standard Sirens: Binary neutron star mergers and binary black hole mergers at intermediate redshifts ( $z \sim 0.5-2$ ) should yield  $H_0$  estimates that lie between the CMB value (67.4 km/s/Mpc) and the local value (73 km/s/Mpc). Initial data from LIGO/Virgo gravitational wave events are already consistent with this trend.

Prediction 3—Baryon Acoustic Oscillations Asymmetry: The baryon acoustic oscillation (BAO) scale should show subtle redshift-dependent shifts. In standard  $\Lambda$ CDM, the BAO scale is constant. In the foam framework, the effective sound speed varies slightly with epoch due to collapse-rate evolution. The predicted shift is  $\Delta(\text{BAO scale})/\text{BAO} \approx 0.5-1\%$  between  $z = 2$  and  $z = 0.5$ .

Prediction 4—CMB Power Spectrum Anomalies: The CMB power spectrum should show subtle oscillations in the acoustic peaks that encode information about the collapse-rate evolution. The amplitude of these oscillations is predicted to be at the percent level, potentially detectable by future missions like the Simons Observatory.

## 8. Connection to Sub-Paper 5: The Bifurcated Universe

This resolution to the Hubble tension is not an isolated patch to the theory; it is a direct consequence of the bi-verse cosmology described in Sub-Paper 5. The matter-antimatter asymmetry requires a bifurcation of the foam at the Big Bang. This bifurcation creates a membrane between verses. The membrane's permeability evolves over cosmic time, gradually diminishing as the universe cools and its energy density drops. This evolution in membrane permeability naturally predicts a time-varying collapse rate  $\lambda_{\text{cosmo}}$ , which in turn predicts the observed  $H_0$  tension.

The two papers are deeply interwoven. Sub-Paper 5 explains why there is a foam membrane. This paper explains what the membrane's evolution does to cosmological expansion. Together, they provide a unified account of two major anomalies in modern cosmology: the matter-antimatter imbalance and the Hubble tension.

## 9. Falsifiability and Competing Hypotheses

The foam framework's predictions are falsifiable. If the proposed evolution in  $H(z)$  is not observed—if instead the transition from CMB-epoch to local  $H_0$  is sharp or inconsistent with the exponential decay predicted by the coupling timescale—then the hypothesis is ruled out. Current data from gravitational wave standard sirens and BAO measurements already provide constraints. Future observations from the Vera C. Rubin Observatory (formerly LSST), the James Webb Space Telescope (JWST), and next-generation gravitational wave detectors will provide precise tests.

It is important to note that the foam framework does not claim to have the unique solution. Early dark energy models, neutrino physics extensions, and modified gravity theories all make predictions for  $H(z)$ . A comprehensive observational program comparing these predictions against data will be necessary to determine which (if any) is correct.

## 10. Discussion: Implications and Limitations

The Hubble tension has exposed a gap in the Standard Model of Cosmology. Whether that gap is filled by new physics or by a better understanding of measurement systematics remains an open question. The quantum foam framework offers a distinctive perspective: the universe is not expanding because of the inventory of matter and energy (the  $\Lambda$ CDM view) but because the substrate that generates spacetime is actuating at a particular rate. That rate has evolved over cosmic history due to the operation of bi-verse coupling.

This perspective does not contradict  $\Lambda$ CDM; rather, it provides a substrate-level reinterpretation. The observed energy density, the expansion rate, and the large-scale structure all remain consistent with  $\Lambda$ CDM predictions to the percent level. The foam framework explains why  $\Lambda$ CDM parameters have the values they do and why a particular systematic shift in  $H_0$  arises when measuring from different epochs.

The framework is testable and falsifiable. It makes specific predictions for the redshift evolution of  $H(z)$ , the behavior of BAO scales, and the distribution of gravitational wave standard siren measurements. These predictions are now beginning to be constrained by data. Within the next 3–5 years, with improved observations from JWST, Rubin Observatory, and next-generation gravitational wave detectors, the hypothesis should either be strongly supported or clearly falsified.

## 11. References

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