Sonoluminescence as Lattice Compression Event

A Quantitative Supplement to The Computable Universe

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Sound squeezes a bubble hard enough to make light.

Nobody fully agrees on why. We think we know.

Abstract

The Computable Universe framework (2026) predicts that the electromagnetic propagation lattice — the graded network of computable paths through spacetime along which electromagnetic interactions can occur — densifies under gravitational compression and thins under expansion. This supplement applies that prediction to sonoluminescence: the emission of light from violently collapsing bubbles in liquid. We argue that the extreme compression during single-bubble sonoluminescence temporarily forces the local electromagnetic lattice dense enough that matter normally between the threads is squeezed onto computable paths, producing a brief window of anomalous electromagnetic accessibility. The observed flash includes a lattice transition component: energy released as previously dark stress-energy becomes momentarily visible.

The key physical insight is that the relevant variable is not absolute energy density — which at sonoluminescence scales is 100 orders of magnitude below the Planck scale — but the *rate of compression*: the spacetime curvature gradient. Sonoluminescence achieves extraordinary compression gradients through resonant acoustic driving, with a million-fold volume change occurring in nanoseconds. We develop the mathematics of gradient-driven lattice densification, show that the energy budget closes with a modest lattice perturbation of 0.6–6%, and derive five observable predictions that distinguish the lattice model from standard thermal explanations. A specific experimental test — broadband electromagnetic monitoring phase-locked to the acoustic driving frequency — is proposed as a decisive discriminator. Convergence with recent analog gravity treatments of sonoluminescence (Karmakar and Maity, 2024) and with observations of sub-Poissonian photon statistics (Rezaee et al., 2022) provides additional structural support.

1. The Connection

In *The Computable Universe*, we established that if physical law is constrained to computable operations, electromagnetic interactions are limited to a graded lattice of propagation paths through spacetime. The lattice is dense where spacetime is compressed and sparse where spacetime is diffuse. This produces the dark matter fraction: gravity couples to all matter, electromagnetism couples only to matter on the threads, and the difference is what we've been calling dark matter for fifty years.

A central prediction of that framework is that the dark matter fraction is not constant. It varies with environment. Under extreme compression, the lattice saturates and more matter becomes electromagnetically accessible. The dark-to-visible ratio shrinks. This is the mechanism behind the JWST prediction: early galaxies appear anomalously bright not because they formed stars more efficiently, but because more of their matter was visible when the universe was younger and more compressed.

Sonoluminescence is that same prediction at laboratory scale.

A gas bubble in liquid, driven by an acoustic standing wave, undergoes periodic collapse. During collapse, the bubble's volume compresses by more than a millionfold in microseconds. Pressures reach tens of thousands of atmospheres. Temperatures inside the bubble are estimated at 10,000 to 50,000 kelvin. At the moment of maximum compression, a flash of light is emitted — a burst of photons lasting 50–300 picoseconds. The flash is remarkably repeatable: stable single-bubble sonoluminescence can produce millions of identical flashes per second.

The mechanism of this flash has been debated since the phenomenon was first observed in 1934 (Frenzel and Schultes). Nine decades later, there is still no consensus. Hypotheses include thermal bremsstrahlung from ionized gas (Jarman, 1960), the dynamic Casimir effect from a moving dielectric boundary (Schwinger, 1992; Liberati et al., 1998), collision-induced radiation, and quantum vacuum photon production through analog gravity (Karmakar and Maity, 2024). The thermal model accounts for much of the observed spectrum, but persistent discrepancies remain: the effective blackbody temperature is higher than adiabatic compression models predict, the UV component is stronger than expected, and a 2022 study from the University of Ottawa (Rezaee et al.) found sub-Poissonian photon statistics — a quantum signature that purely thermal models do not naturally produce.

The lattice framework doesn't discard the thermal mechanism. It augments it. When the bubble collapses, the extreme local compression does two things simultaneously: it heats the gas (producing thermal photons through standard mechanisms), and it densifies the electromagnetic propagation lattice (forcing previously dark matter onto computable paths). The second process releases energy that the first process doesn't account for. The flash has two components, and we've only been modeling one.

2. Why Absolute Energy Density Is the Wrong Variable

An immediate objection arises. The Planck energy density is approximately 4.6×10^{113} J/m³. The energy density at sonoluminescence collapse is roughly 10^9–10^{12} J/m³. That's 100 orders of magnitude below the Planck scale. If the lattice filling fraction φ depends on the ratio ρ/ρ_{Planck}, then the lattice response at sonoluminescence energies is of order 10^{-100}. Negligible. Sonoluminescence would need to be explained entirely by conventional physics.

But the framework does not say the lattice responds to absolute energy density. The framework says the lattice densifies under *compression* — meaning it responds to changes in the geometry of spacetime, not to a static energy density threshold. The natural variable is not ρ but the spacetime curvature gradient: how rapidly the geometry is deforming.

This is the key physical claim: the lattice is a dynamical structure that responds to geometric deformation rate, not to static geometry. A region of high but constant energy density (the core of a neutron star) has a dense lattice because it was compressed to that state — the compression event densified the lattice and the high density maintains it. But a region of moderate energy density undergoing rapid compression can transiently achieve lattice densification beyond what its static energy density would predict, because the compression itself is doing work on the lattice.

The analogy is rocking a van. You don't tip a van over with a single push. You rock it — each cycle builds on the last, and a rhythm of modest pushes produces a peak displacement that no single push could achieve. The acoustic driving frequency (25 kHz) is not the frequency that matters. What matters is the effective compression frequency at the bubble wall during the final collapse.

The bubble dynamics are governed by the Rayleigh-Plesset equation, and its nonlinearity is the key: the acoustic drive at 25 kHz produces a collapse whose final stage has an effective compression frequency orders of magnitude higher. The system is a frequency upconverter. The wall velocity at minimum radius reaches 1,000–4,000 m/s. The compression rate — the fractional rate of volume decrease — reaches approximately 2.4×10^{10} s^{-1} at peak compression. That's a compression rate of roughly 24 GHz. The energy density changes by a factor of 10^6 in a few nanoseconds. There is nothing else in laboratory physics that achieves this combination of compression ratio and compression speed at these length scales.

3. The Lattice Response Function

The Computable Universe framework establishes four boundary conditions for the electromagnetic lattice filling fraction φ(ρ) — the fraction of spacetime coordinates that are electromagnetically addressable. The ambient cosmological average is $\varphi_0 \approx 1/6 \approx 0.167$ (producing the observed 5.5:1 dark-to-visible ratio). At infinite compression, φ saturates to 1 (all matter visible). At zero density, φ goes to 0 (the lattice thins to nothing). And φ is non-decreasing in energy density.

These constraints are not sufficient to fix φ(ρ) uniquely. We propose a decomposition into static and dynamic components:

φ(ρ, d𝓡/dt) = φ_static(ρ) + φ_dynamic(d𝓡/dt)

The **static component** is the equilibrium lattice density at a given energy density: φ_static(ρ) = 1 − (1 − $φ_0$)exp(−ρ/ρ*), where ρ* is the characteristic density where the lattice begins to appreciably densify. Given that the lattice is nearly saturated at Big Bang nucleosynthesis energy densities (~10^{25} J/m^3), we estimate ρ* ~ 10^{24}–10^{26} J/m^3. At sonoluminescence densities, the static component contributes a lattice enhancement of approximately 10^{-14}. Completely negligible. The static lattice does not respond at laboratory energy densities.

The **dynamic component** is the transient lattice response to rapid compression: φ_dynamic(d𝓡/dt) = α · (|d𝓡/dt| / d𝓡_c/dt)^β for sub-critical curvature rates, saturating at α for curvature rates above the critical threshold. Here α is the maximum transient lattice enhancement (dimensionless, α ≪ 1 for laboratory conditions), β is the response exponent, and d𝓡_c/dt is the critical curvature rate above which the dynamic response saturates.

The physical motivation: rapid compression creates a transient in the spacetime geometry. During this transient, the manifold is deforming faster than the lattice can adapt. The deformation itself forces matter at near-lattice coordinates onto the lattice — the grooves widen momentarily, then snap back. The effect is proportional to the compression rate, not the compression level.

3.1 Coherent Amplification: The Van-Rocking Mechanism

A single compression event produces a curvature transient. The lattice response to a single transient is proportional to the integrated curvature impulse. For a single bubble collapse, this impulse is finite but small. However, single-bubble sonoluminescence operates at resonance. The bubble undergoes millions of collapse-expansion cycles per second, each producing a curvature impulse. If the lattice has a relaxation time τ_L — a characteristic timescale over which it returns to equilibrium after perturbation — then successive compressions can accumulate.

The accumulation factor is A(f, τ_L) = 1/(1 − exp(−1/(f · τ_L))). When the driving frequency is much faster than lattice relaxation (f · τ_L ≫ 1), the accumulation factor grows linearly: A ≈ f · τ_L. Each acoustic cycle adds a curvature impulse before the previous one has fully relaxed. The effective lattice perturbation builds up to φ_eff = A(f, τ_L) · φ_single.

This is the van-rocking mechanism in equations. You don't need one enormous push. You need a rhythm. The acoustic driving frequency, tuned to be fast relative to lattice relaxation, builds up the lattice perturbation over many cycles until the cumulative effect is measurable.

For substantial resonant accumulation, we need $f \cdot \tau_L \geq 1$, which requires $\tau_L \geq 1/f \approx 40$ μs. This is a strong and testable claim: the lattice relaxation time at the scale of a sonoluminescence bubble is at least ~40 μs. The flash intensity should depend on driving frequency in a specific way that directly measures τ_L.

4. Energy Budget

The total energy of the gas inside the bubble at minimum radius is approximately 1–100 nJ. The observed flash energy is approximately 1 pJ — roughly 10^{-3} to 10^{-5} of the total bubble energy.

Under the lattice model, the flash energy from the lattice transition component is:

$$E_{flash} = [\varphi_{eff}(\rho, d\mathscr{R}/dt) - \varphi_0] \cdot E_{thermal} \cdot \varepsilon_{rad}$$

where ε_{rad} is the radiative efficiency — the fraction of newly-visible thermal energy actually radiated during the brief compression window. For a blackbody at $T \approx 10^4$ K with the size of the bubble at minimum radius, the thermal radiation timescale is approximately 0.6 μs. The flash duration is 50–300 ps. So $\varepsilon_{rad} \approx 100$ ps / 0.6 μs $\approx 1.7 \times 10^{-4}$.

Matching the observed ratio $E_{flash}/E_{bubble} \approx 10^{-3}$–$10^{-5}$ requires a lattice enhancement of $\Delta\varphi \approx 0.6$–6%. That's the lattice going from $\varphi_0 \approx 16.7\%$ to roughly 17.3–22.7% at peak compression. The dark matter fraction locally decreases from ~83% to ~77–83%.

Is this physically reasonable? The total dynamic range of the lattice is from $\varphi_0 \approx 1/6$ to $\varphi = 1$ (full saturation). We're asking for 0.6–6% of the remaining dynamic range. Less than one-tenth. We're not asking the lattice to do anything dramatic. We're asking for a slight, transient compression of the thread structure, just enough to momentarily light up a tiny fraction of the dark matter in a region half a micron across for a hundred picoseconds.

The energy budget closes.

5. Convergence with Analog Gravity

The lattice interpretation has a striking parallel in recent formal work. Karmakar and Maity (2024), published in Physical Review D, model sonoluminescence using analog gravity: they treat the collapsing bubble as a time-dependent analog geometry and show that non-minimal coupling of the electromagnetic field to this geometry produces photon production through parametric resonance from the quantum vacuum. Their framework explicitly uses the bubble's curvature — the Ricci scalar of the analog metric — as the mechanism driving photon emission.

The parallel is not superficial. Their model says: the geometry of the collapsing bubble changes the way the electromagnetic field behaves in that region, producing photons that the field alone wouldn't generate. Our model says: the geometry of compressed spacetime changes which electromagnetic paths are computable, temporarily making dark matter visible. Both locate the mechanism in the relationship between geometry and electromagnetic accessibility. Both predict photon production exceeding what thermal models explain. Both treat bubble collapse as fundamentally a geometric event with electromagnetic consequences.

Additionally, Rezaee et al. (2022) found that photon statistics in single-bubble sonoluminescence are sub-Poissonian — meaning the photons arrive in a pattern that is more ordered than random thermal emission would produce. Purely thermal models predict Poissonian or super-Poissonian statistics. The sub-Poissonian result is a quantum signature. The lattice model provides a natural explanation: the transition from dark to visible is a geometric, coherent process governed by the lattice structure, not a stochastic thermal process. The photon statistics should reflect that coherence.

This is the same pattern of convergence we noted in the main paper regarding quantum gravity. Independent routes — analog gravity, quantum photon statistics, and the computability axiom — arriving at overlapping conclusions about the non-thermal nature of sonoluminescence.

6. Five Predictions That Distinguish the Lattice Model

6.1 Spectrum Shape

Thermal model: The flash spectrum should be a blackbody at some effective temperature, modified by opacity effects.

Lattice model: The flash includes radiation from matter appearing on the electromagnetic lattice. This matter has been gravitationally thermalized but electromagnetically silent. Its first electromagnetic act is to radiate. The spectrum should be broadband (the newly-visible matter has a thermal kinetic energy distribution from gravitational coupling) but *not precisely blackbody* (the emitting matter has not equilibrated electromagnetically — it has had zero electromagnetic history). Specifically, the model predicts a Wien-like spectrum with systematic deviations from Planck at low frequencies, because the newly-visible matter has not had time to establish the long-wavelength tail.

Observed: The SBSL spectrum is approximately blackbody at $T \approx 10^4$–10^5 K, but with persistent deviations that have resisted clean thermal fitting. The UV emission is consistently stronger than blackbody models predict. This is qualitatively consistent with the lattice model.

6.2 Flash Duration

Thermal model: The flash decays as the plasma cools, with approximately exponential decay.

Lattice model: The flash cuts off when the compression reverses and the lattice perturbation relaxes. The cutoff is not governed by cooling but by the inverse of the compression rate: the threads snap back as the curvature gradient reverses. The flash duration should be *shorter* than the thermal cooling time of a plasma at the inferred blackbody temperature and density. For $T \approx 10^4$ K and compressed noble gas densities, the bremsstrahlung cooling time is approximately 1–10 ns. The observed flash duration is 50–300 ps — 3 to 200 times shorter.

Observed: SBSL flash durations are indeed anomalously short relative to plasma cooling timescales. This is one of the outstanding puzzles of SBSL. The lattice model resolves it naturally: the flash is controlled by the compression timescale, not the cooling timescale.

6.3 Driving Frequency Dependence

Thermal model: Flash intensity depends on driving frequency only through its effect on minimum bubble radius. No direct frequency dependence at constant R_{min}.

Lattice model: If the lattice has a characteristic relaxation time τ_L, the flash intensity should show resonance structure as a function of driving frequency. The accumulation factor $A(f, \tau_L)$ produces flash intensity that increases with driving frequency (at fixed minimum radius) until saturation. If R_{min} can be held constant while varying f, the lattice model predicts a monotonic increase following the accumulation curve. The shape of this curve directly measures τ_L. At frequencies where $f \cdot \tau_L \approx 1$, the intensity increases steeply. Above this, it saturates.

6.4 Noble Gas Dependence

Thermal model: Flash properties track ionization energy and thermal conductivity. Spectral characteristics should shift systematically with ionization energy (He: 24.6 eV, Ne: 21.6 eV, Ar: 15.8 eV, Kr: 14.0 eV, Xe: 12.1 eV).

Lattice model: Flash properties track compressibility — how efficiently the gas transmits acoustic compression to a change in spacetime curvature. The spectrum should NOT track ionization energy. The peak frequency should correlate with the compression rate achieved at minimum radius, which depends on equation-of-state properties (atomic polarizability and van der Waals volume) rather than electronic structure.

6.5 The Decisive Test: Broadband Electromagnetic Monitoring

Thermal model: All emission is thermal optical/UV photons from hot, dense plasma. No correlated emission outside the optical/UV during the collapse event.

Lattice model: Matter appearing on the lattice couples to *all* electromagnetic frequencies simultaneously, because the lattice enhancement is a geometric property, not a frequency-specific one. The sonoluminescence flash should be accompanied by a broadband electromagnetic pulse extending from radio through microwave, infrared, optical, UV, and potentially soft X-ray. The pulse should be simultaneous with the optical flash (to within the light-crossing time of the bubble, ~1.7 fs), temporally correlated across all frequency bands, and broadband in a way that does not match any single-temperature blackbody.

The expected radio power per flash is extraordinarily small. But SBSL produces ~25,000 flashes per second, and phase-locked detection can integrate over millions of cycles. A microwave detector (10–100 GHz, where the Rayleigh-Jeans emission is 10^2–10^4 times stronger than at radio frequencies) phase-locked to the acoustic driving frequency is the proposed decisive test.

7. Experimental Protocol

The proposed experiment combines a standard SBSL setup with broadband electromagnetic monitoring.

SBSL system: Spherical flask, piezoelectric driver at 25 kHz, noble gas bubble (Ar, Kr, or Xe in degassed water). Standard optical detection chain (PMT, fast oscilloscope) for timing reference.

Broadband EM monitoring: Radio (1–10 GHz) via horn antenna and low-noise amplifier, microwave (10–100 GHz) via waveguide receiver, infrared (1–100 μm) via FTIR spectrometer with fast MCT detector, and UV/soft X-ray (10–100 nm) via windowless vacuum UV spectrometer. All channels phase-locked to the acoustic driving frequency and phase-averaged over millions of cycles.

Signal discrimination: The thermal model predicts zero lock-in signal in radio/microwave bands (or signal accounted for by driver interference). The lattice model predicts a nonzero lock-in signal correlated with the optical flash phase.

Control experiments: (1) Driver-only control — acoustic driver with no bubble, establishing the interference baseline. (2) Noble gas series — He, Ne, Ar, Kr, Xe under identical acoustic conditions; the lattice model predicts EM emission tracking compressibility while the thermal model predicts emission tracking ionization energy. (3) Frequency sweep — varying driving frequency with amplitude compensation to maintain constant R_{min}; the lattice model predicts intensity following the accumulation curve while the thermal model predicts no frequency dependence. (4) Multi-bubble comparison — MBSL has lower peak compression; the lattice model predicts fainter individual flashes with specific dependence on bubble size distribution.

Most predictions in fundamental physics require billion-dollar detectors. The basic sonoluminescence apparatus is a flask of water, a piezoelectric transducer, and an acoustic driver. Single-bubble sonoluminescence has been achieved in university teaching labs. The framework that explains why 85% of the universe is invisible may be testable with sound, water, and light.

8. Free Parameters and Honest Assessment

The model introduces three genuinely new parameters: the coupling strength α (how strongly the lattice responds to curvature rate, constrained by flash energy), the relaxation time τ_L (how fast the lattice returns to equilibrium, constrained by frequency dependence and flash duration), and the response exponent β (how the response scales with curvature rate, constrained by compression-rate dependence across SBSL regimes). This is the same number of free parameters as standard thermal SBSL models, which require effective temperature, opacity model, and emission volume. The lattice model does not add degrees of freedom. It replaces them with different ones that make different predictions.

Several important limitations apply. This supplement has not computed the expected lattice transition energy for a given compression profile from first principles. Without that computation, we predict qualitative existence and scaling behavior, not specific magnitudes. Existing thermal models already explain most of the observed spectrum; the non-thermal excess would need to be extracted from small residuals subject to systematic uncertainties. The connection between local bubble compression and the cosmological electromagnetic lattice is an extrapolation — we assume self-similarity across scales because the computability axiom applies at all scales, but this is an assumption, not a derivation. And the calorimetric prediction may be unmeasurably small at accessible compression levels.

We state these limitations because a framework that tells you where it's weak is more useful than one that pretends it isn't. The framework survives a null result by retreating to the position that the lattice responds only to absolute compression (the static component), which produces negligible effects at laboratory energy densities. This is an honest retreat, not a dodge — it reduces the framework's scope but does not kill it.

9. Relationship to the Main Framework

Of the thirteen predictions in The Computable Universe (Section 8), sonoluminescence most directly tests two.

Prediction 7 (Environment-dependent dark matter fraction): If the dark matter fraction varies with local compression, then sonoluminescence creates a transient region of reduced dark matter fraction inside the bubble. The flash is the observational signature of that reduction. A positive result would demonstrate environment-dependent lattice density at human-accessible scales.

Prediction 3 (JWST early galaxy brightness): Sonoluminescence and the JWST anomaly are the same phenomenon at different scales. The early universe was a permanent, universe-scale compression event. Sonoluminescence is a transient, micrometer-scale one. If the lattice model explains both, the same parameters (α, τ_L, β) must be consistent across 20+ orders of magnitude in scale.

The pattern is the same. Squeeze the fabric hard enough, and what was dark becomes light. The universe does this at cosmological scale over billions of years. A bubble does it at laboratory scale in picoseconds. One axiom, applied consistently, from the largest scales to the smallest.

10. Conclusion

Sonoluminescence is either the most boring thing in this framework or the most important. The mathematical analysis establishes five results. (1) The relevant variable is compression gradient, not absolute energy density — the static lattice does not respond at laboratory energies. (2) Resonant acoustic driving acts as a coherent amplifier, building up lattice perturbation over many cycles. (3) The energy budget closes — a lattice enhancement of $\Delta\varphi \approx 0.6$–$6\%$ reproduces the observed flash energy. (4) Five predictions distinguish the lattice model from thermal models:

non-blackbody spectrum, anomalously short flash duration, driving-frequency dependence, compressibility-tracking noble gas dependence, and broadband electromagnetic emission. (5) A specific experimental test is proposed: broadband EM monitoring phase-locked to the acoustic driving frequency.

The math works. The energy budget closes. The predictions are specific. Now someone needs to point a microwave detector at a singing bubble.

11. Acknowledgments

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