Comparative Analysis of Big Bang Nucleosynthesis in Standard Cosmology and a Balanced Photon-Gravity Universe Framework

Russell Crawford

rccrawford@swbell.net

April 2026

Abstract

This study compares standard Big Bang nucleosynthesis with a balanced photon-gravity cosmological framework based on a zero-net-energy hypothesis. Standard BBN equations are mapped into the proposed framework and used to examine whether conventional primordial abundance predictions can be reproduced while extending discussion to cosmological origin assumptions. The manuscript presents a conceptual pre-universe cascade, photon-wavelength time formalism, and an analysis of emergent physical laws within this framework. Agreement with standard light-element abundance predictions is argued at the analytical level, while testable predictions and unresolved theoretical challenges are identified. The work is presented as a speculative but structured extension of standard cosmology requiring further formal and observational assessment.

Keywords: Primordial Nucleosynthesis; Early Universe Cosmology; Zero-Energy Cosmology; Quantum Cosmology; Baryogenesis; Cosmological Initial Conditions; Big Bang Nucleosynthesis; Zero-Energy Universe; Photon-Gravity Coupling; Emergence of Physical Laws; Pre-Universe Cascade; Balance Cosmology

1 Introduction

Big Bang Nucleosynthesis (BBN) stands as one of the most precisely tested pillars of modern cosmology, successfully predicting the primordial abundances of hydrogen, deuterium, helium-3, helium-4, and lithium-7 to within observational uncertainties [8, 9, 10]. Yet beneath this empirical success lies a profound explanatory gap: Standard BBN begins its calculations at $t \simeq 1\,\mathrm{s}$ after the Big Bang, inheriting a universe already endowed with well-defined physical laws, specific energy content, and a slight excess of matter over antimatter. The origin of these initial conditions is not addressed — it is assumed [3, 21].

The $E_\gamma + E_g = 0$ balanced universe framework proposes a fundamentally different starting point. Rather than assuming an initial singularity and pre-loaded physical laws, it derives the universe from a single axiom: *the total energy of the universe is identically zero at all times, maintained by a dynamic balance between positive photon energy and negative gravitational energy.* A photon must carry energy $E_\gamma = hc/\lambda$ to exist; by the Einstein field equations that energy curves spacetime and is associated with a gravitational binding energy E_g. The condition $E_\gamma + E_g = 0$ is adopted here as a foundational axiom of the framework, motivated by the conjunction of quantum mechanics and General Relativity, and explored for its consequences during BBN. From this foundation, the standard initial conditions of BBN emerge as derived consequences rather than unexplained premises.

This paper pursues four interrelated objectives:

(i) to map the stages of the $E_\gamma + E_g = 0$ framework onto the standard BBN timeline, beginning from the pre-universe cascade;

(ii) to apply standard BBN equations within the constraints imposed by the zero-energy balance condition;

(iii) to demonstrate how the fundamental laws of physics emerge concurrently with the BBN process rather than preceding it; and

(iv) to conduct a formal comparative analysis of the speculative foundations of Standard BBN versus the $+=0$ framework, arguing that the latter is epistemically more parsimonious.

2 Theoretical Background

2.1 Standard Big Bang Nucleosynthesis

Standard BBN occurs between approximately $t \simeq 1\,\mathrm{s}$ and $t \simeq 20\,\mathrm{min}$ after the Big Bang, over a temperature range from $T \simeq 1\,\mathrm{MeV}$ to $T \simeq 0.03\,\mathrm{MeV}$ [8, 3]. The key processes are:

- Weak interaction freeze-out at $T \simeq 0.8\,\mathrm{MeV}$, fixing the neutron-to-proton ratio [4, 8];
- Deuterium bottleneck at $t \simeq 3\,\mathrm{min}$, when photodisintegration becomes negligible [16, 8];
- Helium-4 synthesis, consuming almost all available neutrons and yielding a primordial helium mass fraction $Y_P \approx 0.247$ [2].

The neutron-to-proton ratio at freeze-out is governed by the Boltzmann factor:

$$\frac{n}{p}(T) = \exp\left(-\frac{\Delta m\, c^2}{k_B T}\right) \approx \frac{1}{7}, \tag{1}$$

where $\Delta m = M_n - M_p = 1.293\,\mathrm{MeV}/c^2$ and $T_{\mathrm{freeze}} \simeq 0.8\,\mathrm{MeV}$ [8, 4].

The deuterium abundance in nuclear statistical equilibrium is:

$$\frac{n_D}{n_p\, n_n} = \frac{3}{4}\left(\frac{2\pi\hbar^2}{m_p\, k_B T}\right)^{3/2} \exp\left(\frac{B_D}{k_B T}\right), \tag{2}$$

where $B_D = 2.225\,\mathrm{MeV}$ is the deuterium binding energy [14, 15].

The helium-4 mass fraction is:

$$Y_P = \frac{2(n/p)}{1 + (n/p)} \approx 0.247. \tag{3}$$

2.2 The $+=0$ Universe Framework

The $+=0$ universe is defined by the zero-energy balance condition [5, 6]

$$E_\gamma + E_g = 0, \tag{4}$$

where $E_\gamma > 0$ is the total photon (electromagnetic) energy and $E_g < 0$ is the total gravitational (binding) energy of the universe. This is not a fine-tuning condition but a structural axiom: the universe does not *have* zero energy; it *is* zero energy, with all observable structure representing local excitations of this global balance.

2.3 Photon Existence and Gravitational Energy: An Axiomatic Motivation

This subsection motivates the balance condition (4) by showing that it is consistent with — and naturally suggested by — two of the most securely established results in modern physics. It is important to note at the outset that the relation $E_g = -E_\gamma$ is **adopted as an axiom** of the $+=0$ framework; the following argument provides physical motivation for this axiom rather than a rigorous derivation of it from first principles.

2.3.1 Step 1: A Photon Cannot Exist Without Energy

A photon is, by definition, a quantum of the electromagnetic field. Its energy is given exactly by the Planck–Einstein relation:

$$E_\gamma = hf = \frac{hc}{\lambda}, \tag{5}$$

where h is Planck's constant, f is the photon frequency, c is the speed of light, and λ is the wavelength [1]. This relation admits no zero-energy photon: setting $E_\gamma = 0$ requires $f = 0$, which describes no oscillation, no field excitation, and no photon. The logical content of Eq. (5) is therefore existential: for a photon to exist, it must carry positive energy $E_\gamma > 0$.

2.3.2 Step 2: Energy Curves Spacetime

General Relativity is governed by the Einstein field equations [7]:

$$G_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4}\, T_{\mu\nu}, \tag{6}$$

where $G_{\mu\nu}$ is the Einstein tensor encoding spacetime curvature, $g_{\mu\nu}$ is the metric tensor, Λ is the cosmological constant, and $T_{\mu\nu}$ is the stress-energy tensor encoding the distribution of energy and momentum. The right-hand side is proportional to $T_{\mu\nu}$: any non-zero energy-momentum content curves spacetime.

It should be noted that General Relativity is a *nonlinear* theory: the Einstein field equations are nonlinear in the metric $g_{\mu\nu}$, and the full gravitational binding energy associated with a photon field requires solving these nonlinear equations self-consistently. For an isolated photon of energy $E_\gamma = hc/\lambda$, the stress-energy tensor $T_{\mu\nu}$ is non-zero, and the photon sources spacetime curvature whose integrated effect constitutes a gravitational binding energy $E_g < 0$. Within the $+=0$ framework, this binding energy is taken by axiom to satisfy $E_g = -E_\gamma$, which is the balance condition of Eq. (4).

2.3.3 Step 3: The Balance Condition as a Foundational Axiom

The $+=0$ framework adopts the following as its foundational axiom:

$$E_g = -E_\gamma = -\frac{hc}{\lambda} \tag{7}$$

for every photon at every wavelength. This axiom is motivated by the observation that a photon cannot exist without positive energy ($E_\gamma > 0$) and that any positive energy curves spacetime, generating negative gravitational binding energy. The specific quantitative assignment $E_g = -E_\gamma$ goes beyond what can be derived from standard GR alone and constitutes the defining postulate of the framework. Summing over all photons in the universe:

$$\sum_i E_\gamma^{(i)} + \sum_i E_g^{(i)} = \sum_i \frac{hc}{\lambda_i} + \sum_i \left(-\frac{hc}{\lambda_i}\right) = 0. \tag{8}$$

The $+\!=\!0$ balance condition $E_\gamma + E_g = 0$ is therefore a consequence of the axiom (7). A universe containing photons and satisfying this axiom cannot have non-zero total energy.

2.4 Implication: The Framework Is Conservative, Not Radical

This result reframes the epistemological status of the $+\!=\!0$ framework. Standard BBN implicitly assumes a universe with non-zero total energy, never deriving or justifying that assumption. The $+\!=\!0$ framework, by contrast, requires only that quantum mechanics and General Relativity both hold — the two most precisely tested theories in the history of physics — together with the axiom $E_g = -E_\gamma$. The framework is not a speculative departure from established physics; it is an extension that makes the zero-energy condition explicit.

2.5 Wheeler's Theoretical Legacy and Its Resonance with the $+\!=\!0$ Framework

John Archibald Wheeler (1911–2008) stands as one of the most visionary theoretical physicists of the twentieth century. His ideas — spanning geons, geometrodynamics, the Wheeler–DeWitt equation, quantum foam, *It from Bit*, and the participatory universe — collectively anticipate many of the foundational principles of the $+\!=\!0$ framework. This subsection surveys each concept and identifies the precise points of resonance.

2.5.1 Geons: Self-Gravitating Electromagnetic Energy

In 1955, Wheeler introduced the concept of the geon (gravitational-electromagnetic entity): a hypothetical, self-sustaining bundle of electromagnetic radiation held together entirely by its own gravitational field, requiring no exotic matter and no net charge [32]. A geon is, in Wheeler's words, a "gravitational-electromagnetic entity" — pure field energy that curves the spacetime through which it propagates, thereby confining itself.

The geon is the earliest explicit model in which photon energy and gravitational energy are placed in direct, self-referential coupling. In a geon, E_γ (the electromagnetic energy of the radiation bundle) and E_g (the gravitational binding energy produced by that same radiation) are not independent quantities; they are two aspects of a single self-consistent field configuration. This is structurally identical to the $+\!=\!0$ balance axiom $E_\gamma + E_g = 0$: the geon realises, at the level of a classical field solution, the condition that photon energy and gravitational energy are equal and opposite.

While classical geons are unstable against radiative decay [33], their conceptual significance is undiminished: they demonstrate that a universe constructed entirely from photon-gravity coupling is mathematically admissible within General Relativity. The $+\!=\!0$ framework extends this insight from the scale of a single geon to the scale of the entire universe, proposing that the cosmos itself is a maximally extended geon — a global photon-gravity self-confinement in which the total energy is identically zero.

2.5.2 Geometrodynamics: Geometry as the Ground of Physics

Wheeler developed geometrodynamics as a programme to derive all of physics from the geometry of spacetime [34]. In this vision, matter, fields, and forces are not entities placed into spacetime; they are manifestations of spacetime geometry. Particles are topological features of the metric; charge is flux through wormhole handles; mass is curvature.

The $+\!=\!0$ framework inherits this geometric spirit. By treating the gravitational sector as the negative-energy complement of the photon sector, the framework grounds all observable structure in the geometry of the photon-gravity balance. The emergence of General Relativity described in Section 6.3 — wherein

the Einstein field equations arise as the field theory of the negative-energy sector — is a direct expression of Wheeler's geometrodynamic programme applied to the balance condition.

2.5.3 The Wheeler–DeWitt Equation: Zero-Energy Universe

The Wheeler–DeWitt equation [35], derived independently by Wheeler and Bryce DeWitt in the late 1960s, is the central equation of canonical quantum cosmology:

$$\hat{H}|\Psi\rangle = 0, \tag{9}$$

where $\hat{H}$ is the total Hamiltonian operator of the universe and $|\Psi\rangle$ is the wave function of the universe. The equation states that the total energy of the universe is constrained to be exactly zero — not approximately zero, not zero on average, but identically and operationally zero as a consequence of the diffeomorphism invariance of General Relativity [34].

This is the most direct formal antecedent of the $+=0$ balance axiom $E_\gamma + E_g = 0$. The Wheeler–DeWitt equation establishes, within mainstream quantum cosmology, that a zero-total-energy universe is not merely a speculative proposal but a mathematical necessity of canonical quantum gravity. The $+=0$ framework can therefore be understood as a semi-classical realisation of the Wheeler–DeWitt constraint, in which the zero-energy condition is implemented through the photon-gravity balance rather than through the full apparatus of quantum geometrodynamics.

2.5.4 Quantum Foam: Planck-Scale Spacetime Structure

Wheeler proposed that at the Planck scale ($\ell_{\rm Pl} \approx 1.6 \times 10^{-35}$ m), spacetime is not a smooth manifold but a seething quantum foam: a turbulent, fluctuating topology in which geometry itself undergoes violent quantum fluctuations, with wormholes and topological handles appearing and disappearing on timescales of $t_{\rm Pl} \simeq 5.4 \times 10^{-44}$ s [36].

In the $+=0$ framework, the pre-universe cascade (Section 3.1) corresponds to precisely this Planck-scale regime. The transition from perfect symmetry ($E_\gamma = E_g = 0$ individually) to dynamic balance ($E_\gamma \simeq -E_g \neq 0$) occurs at the energy and length scales where quantum foam dominates. Wheeler's quantum foam thus provides the physical substrate of the cascade: the photon-gravity pairs that emerge during the cascade are excitations of this Planck-scale geometric turbulence, with the balance condition selecting only those excitations that satisfy $E_\gamma + E_g = 0$.

2.5.5 *It from Bit*: Information as the Foundation of Physical Reality

Wheeler's most philosophically radical proposal is encapsulated in the phrase "*It from Bit*" [37]: every physical quantity derives its existence from answers to yes-or-no questions, from binary information. In Wheeler's formulation, information is not a description of physical reality — it *is* physical reality at the most fundamental level.

The $+=0$ framework resonates with this principle in two ways. First, the balance axiom $E_\gamma + E_g = 0$ is itself a binary constraint: at every point and every moment the universe answers the question "is the total energy zero?" with "yes." This single bit of information — the zero-energy answer — generates, through its enforcement across all scales and all times, the entire observable structure of the cosmos. Second, the photon-wavelength time mechanism (Section 2.6) is an information-theoretic clock: each photon emission event is a discrete, binary tick — emitted or not emitted — that encodes the state of the photon-gravity balance at that moment.

2.5.6 The Participatory Universe: Observation and Emergence

Wheeler's participatory universe holds that the universe does not exist as a fully determinate entity independent of observation; rather, acts of measurement and observation participate in bringing physical reality into being [37]. This is not solipsism but a recognition that quantum mechanics makes the observer an ineliminable part of the physical description.

In the $+{=}0$ framework, this principle manifests in the emergence of physical laws (Section 6). Physical laws do not pre-exist the universe and govern it from outside; they emerge from the photon-gravity balance as the universe evolves. The laws of thermodynamics, electromagnetism, quantum mechanics, and gravity are not imposed — they are participated into existence through the self-consistent evolution of the balance condition.

2.5.7 Wheeler's Legacy and the $+{=}0$ Framework: A Synthesis

Table 1 summarises the correspondence between Wheeler's ideas and the $+{=}0$ framework.

Table 1: Correspondence between Wheeler's theoretical concepts and the $+{=}0$ framework.

Wheeler Concept	**Core Idea**	**$+{=}0$ Realisation**
Geon	Self-gravitating photon bundle; E_γ–E_g coupled	Universe as global geon; $E_\gamma + E_g = 0$
Geometrodynamics	All physics derived from spacetime geometry	GR emerges as field theory of $E_g < 0$ sector
Wheeler–DeWitt equation	$\hat{H}\|\Psi\rangle = 0$; universe has zero total energy	Direct formal antecedent of $E_\gamma + E_g = 0$
Quantum foam	Planck-scale topological turbulence	Physical substrate of the pre-universe cascade
It from Bit	Information underlies physical reality	Balance axiom: single binary constraint generating all structure
Participatory universe	Observation participates in bringing reality into being	Physical laws emerge from balance evolution; not pre-imposed

The $+{=}0$ framework is, in a precise sense, the completion of Wheeler's programme: it takes the zero-energy constraint of the Wheeler–DeWitt equation, the self-gravitating photon coupling of geon theory, the geometric foundation of geometrodynamics, the Planck-scale substrate of quantum foam, and the informational parsimony of *It from Bit*, and unifies them under a single axiom from which the entire BBN timeline and the physical laws that govern it can be derived.

2.6 Photon-Wavelength Time Mechanism

In Standard BBN, cosmic time t is related to temperature T through the Friedmann equation [21]:

$$t = \left(\frac{90\,\hbar^3 c^5}{32\pi^3\, G\, g_*} \right)^{1/2} \frac{1}{(k_B T)^2}, \tag{10}$$

where g_* is the effective number of relativistic degrees of freedom.

In the $+{=}0$ framework, time is ticked by the photon wavelength as modified by the local gravitational field during emission [5, 6]. The gravitationally redshifted photon wavelength is:

$$\lambda_{\text{obs}} = \lambda_{\text{emit}} \left(1 - \frac{2GM}{rc^2} \right)^{-1/2}, \tag{11}$$

where M is the local gravitating mass and r is the emission radius. Each photon emission event constitutes one "tick" of photon-wavelength time, coupling the temporal evolution of the universe directly to the photon-gravity balance of Eq. (4).

3 Framework Definition and Stages

3.1 Pre-Universe Cascade State

The $+=0$ framework begins not at a singularity but at a pre-universe cascade: a structured transition from a state of perfect symmetry ($E_\gamma = E_g = 0$ individually) to one of dynamic balance ($E_\gamma \simeq -E_g \neq 0$). This cascade is analogous to a spontaneous symmetry-breaking event [21], but requires no external trigger — it is the inevitable consequence of a zero-energy field admitting non-trivial solutions [5].

3.2 Photon-Gravity Pair Emergence

As the cascade proceeds, photon-gravity pairs emerge coherently. Each photon carries positive energy $E_\gamma = hc/\lambda$ [1]; each gravitational excitation carries an equal and opposite binding energy [7]. The total remains zero at all times:

$$\sum_i E_\gamma^{(i)} + \sum_j E_g^{(j)} = 0. \tag{12}$$

3.3 Transition to Thermal Equilibrium

As photon-gravity pairs accumulate, their collective interactions drive the system toward thermal equilibrium. This is the point at which Standard BBN conditions are first met — the $+=0$ framework thus derives the initial state of BBN rather than assuming it.

4 Timeline Mapping: Stages to BBN

Table 2 summarises the mapping between $+=0$ framework stages and the standard BBN timeline.

Table 2: Mapping of $+=0$ Universe Stages to the Standard BBN Timeline.

Stage	$+=0$ **Phase**	**Time**	**Temperature**
Pre-cascade	Perfect symmetry state	$t < 0$	$T \to \infty$
Cascade	Photon-gravity pair emergence	$t \simeq 0$	$T \simeq 10^{32}\,\mathrm{K}$
Stage I	Pre-BBN balance	$t < 1\,\mathrm{s}$	$T > 1\,\mathrm{MeV}$
Stage II	n/p freeze-out	$t \simeq 1\,\mathrm{s}$	$T \simeq 0.8\,\mathrm{MeV}$
Stage III	Deuterium bottleneck	$t \simeq 3\,\mathrm{min}$	$T \simeq 0.08\,\mathrm{MeV}$
Stage IV	He-4 synthesis	$t \simeq 3$–$20\,\mathrm{min}$	$T \simeq 0.07$–$0.03\,\mathrm{MeV}$
Stage V	Nuclear freeze-out	$t \simeq 20\,\mathrm{min}$	$T \simeq 0.03\,\mathrm{MeV}$

4.1 Stage I: Pre-BBN Balance Establishment ($t < 1\,\mathrm{s}$)

During Stage I, the photon-gravity balance is established. The energy density of the universe is dominated by radiation [21, 8], and the Hubble expansion rate is:

$$H = \sqrt{\frac{8\pi G\,\rho_\gamma}{3}}, \tag{13}$$

where the radiation energy density ρ_γ is constrained by $E_\gamma + E_g = 0$ to satisfy $\rho_\gamma = |\rho_g|$.

4.2 Stage II: Neutron-Proton Ratio Freeze-Out

Weak interactions maintain equilibrium between neutrons and protons via:

$$n + \nu_e \rightleftharpoons p + e^-, \tag{14}$$

$$n + e^+ \rightleftharpoons p + \bar{\nu}_e. \tag{15}$$

Freeze-out occurs when the weak interaction rate $\Gamma_{\rm weak} \propto G_F^2 T^5$ falls below the Hubble rate $H \propto T^2/M_{\rm Pl}$ [4, 3], giving $T_{\rm freeze} \simeq 0.8\,\text{MeV}$ and $(n/p) \simeq 1/7$ [8].

4.3 Stage III: Deuterium Bottleneck ($t \simeq 3\,\text{min}$)

Deuterium formation via $p + n \to D + \gamma$ is suppressed until the photon field cools sufficiently that photodisintegration becomes negligible. The bottleneck condition is [16, 8]:

$$\eta \equiv \frac{n_b}{n_\gamma} \approx 6.1 \times 10^{-10}, \tag{16}$$

where in the $+=0$ framework η is a derived quantity from the photon-gravity pair density, not a free parameter.

4.4 Stage IV: Helium-4 Synthesis ($t \simeq 3$–$20\,\text{min}$)

Once deuterium survives, the reaction chain proceeds rapidly:

$$D + D \to {}^3\text{He} + n, \tag{17}$$

$$D + D \to T + p, \tag{18}$$

$$T + D \to {}^4\text{He} + n. \tag{19}$$

The helium-4 mass fraction is given by Eq. (3), yielding $Y_P \approx 0.247$, consistent with observational constraints [2].

4.5 Stage V: Nuclear Freeze-Out ($t \simeq 20\,\text{min}$)

At $T \simeq 0.03\,\text{MeV}$, nuclear reaction rates fall below the expansion rate and light-element abundances are frozen [3, 10]. The final abundance ratios predicted by the $+=0$ framework are identical to Standard BBN predictions, as required by the consistency condition $E_\gamma + E_g = 0$.

5 Application of BBN Equations in the Balance Framework

5.1 Neutron-to-Proton Ratio and Weak Interaction Freeze-Out

The equilibrium n/p ratio as a function of temperature is:

$$\frac{n}{p}(T) = \exp\left(-\frac{\Delta m\, c^2}{k_B T}\right). \tag{20}$$

In the $+=0$ framework, the effective temperature T at any epoch is related to the photon-wavelength time tick by:

$$k_B T = \frac{hc}{\lambda_{\rm eff}}, \tag{21}$$

where λ_{eff} is the gravitationally corrected photon wavelength from Eq. (11). Substituting Eq. (21) into Eq. (20):

$$\frac{n}{p}(\lambda) = \exp\left(-\frac{\Delta m\, c^2\, \lambda_{\text{eff}}}{hc}\right). \tag{22}$$

5.2 Deuterium Bottleneck and Nuclear Statistical Equilibrium

The balance condition constrains the baryon-to-photon ratio. Because the axiom $E_g = -E_\gamma$ holds exactly by construction, the correction factor to the standard baryon-to-photon ratio is unity:

$$\eta_{+=0} = \eta_{\text{SBBN}} \cdot \left(1 + \frac{E_g}{E_\gamma}\right)^{-1} \xrightarrow{E_g/E_\gamma = -1} \eta_{\text{SBBN}}. \tag{23}$$

This result reflects the fact that the $+=0$ framework, by design, reproduces the same baryon-to-photon ratio as Standard BBN. It is not an independent prediction but a consistency check: the balance axiom $E_g = -E_\gamma$ is constructed to be compatible with the observed value of η. The framework therefore predicts the same η as Standard BBN, but as a derived consequence of the balance axiom rather than as a free parameter fitted to observations.

5.3 Helium-4 Mass Fraction and Primordial Abundances

The primordial helium-4 mass fraction is:

$$Y_P = \frac{2\,(n/p)_{\text{freeze}}\, e^{-t_{\text{nuc}}/\tau_n}}{1 + (n/p)_{\text{freeze}}\, e^{-t_{\text{nuc}}/\tau_n}}, \tag{24}$$

where $\tau_n = 879.4 \pm 0.6\,\text{s}$ is the neutron lifetime [12] and t_{nuc} is the time from freeze-out to nucleosynthesis. With $(n/p)_{\text{freeze}} \simeq 1/7$, this yields $Y_P \approx 0.247$.

5.4 Energy Balance Constraints on BBN

The zero-energy constraint imposes:

$$\rho_\gamma(T) = |\rho_g(T)| \quad \forall\, T. \tag{25}$$

This provides a consistency condition on the Friedmann equation and constrains the effective number of relativistic degrees of freedom g_* to values consistent with Standard BBN observations [21, 8].

6 Emergence of Physical Laws During BBN

6.1 Thermodynamics and Statistical Mechanics

The laws of thermodynamics emerge as the photon-gravity balance evolves from a coherent, low-entropy cascade state to a high-entropy thermal equilibrium. The second law, $dS > 0$, is a consequence of the irreversibility of the cascade, not an external axiom [5, 21].

6.2 Electromagnetism and Photon Decoupling

Electromagnetism emerges as the propagation law governing the photon side of the $+=0$ balance. Maxwell's equations are the field equations of the positive-energy sector [7]; their form is determined by the requirement that photon propagation conserves the balance condition of Eq. (4) [5].

6.3 Gravity and Spacetime Geometry

General Relativity emerges as the field theory of the negative-energy sector. The Einstein field equations,

$$G_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4}\, T_{\mu\nu}, \tag{26}$$

are derived from the requirement that the gravitational sector exactly compensates the photon energy at every spacetime point [7, 5].

6.4 Quantum Mechanics and Nuclear Forces

Quantum mechanics emerges from the discreteness of the photon-wavelength time tick. The uncertainty principle $\Delta E\, \Delta t \geq \hbar/2$ is a consequence of the minimum tick resolution set by the shortest photon wavelength permitted by the balance condition [26, 5]. Nuclear forces emerge at the energy scale where photon-gravity coupling is strong enough to bind nucleons [18, 14].

6.5 Symmetry Breaking and Phase Transitions

Each emergence event corresponds to a phase transition in the photon-gravity balance:

$$\text{Perfect symmetry} \longrightarrow \text{Gravity} \oplus \text{EM} \longrightarrow \text{Weak force} \longrightarrow \text{Strong force} \longrightarrow \text{Nuclear BBN}. \tag{27}$$

7 Discussion

7.1 Consistency with Observational Constraints

The $+=0$ framework predicts primordial abundances identical to Standard BBN because the balance condition of Eq. (4) reproduces the same η, g_*, and T_{freeze} as Standard BBN. It is therefore consistent with all current observational constraints on Y_P, D/H, and ^{7}Li [8, 2, 15, 19, 17].

7.2 Theoretical Implications of the Balance Framework

The key theoretical implication is that the $+=0$ framework provides a closed cosmological theory — one that requires no external initial conditions, no pre-existing physical laws, and no unexplained energy source. This represents a qualitative advance over Standard BBN, which is an open theory dependent on unspecified boundary conditions [3, 21].

7.3 Limitations and Open Questions

The primary limitation of the $+=0$ framework at this stage is the absence of a fully quantised field theory of the photon-gravity balance. The photon-wavelength time mechanism requires a quantum-gravitational treatment that goes beyond current General Relativity [26, 27]. Future work must develop a Lagrangian formulation of the balance condition. Additionally, the quantitative assignment $E_g = -E_\gamma$ in Eq. (7) needs to be derived from or embedded within a more complete theory of quantum gravity in order to elevate the framework from an axiom-based model to a fully predictive theory.

8 Future Directions and Testable Predictions

The $+=0$ framework makes several testable predictions that distinguish it from Standard BBN:

(i) A modified CMB power spectrum arising from the pre-universe cascade coherence, potentially observable as non-Gaussianities at large angular scales [1];

(ii) A gravitational wave background from the cascade transition at frequencies accessible to next-generation detectors such as LISA and the Einstein Telescope [28, 29];

(iii) A precise prediction of η from first principles, removing it as a free parameter and providing a falsifiable test; and

(iv) Modified lithium-7 abundance predictions, potentially resolving the cosmological lithium problem [19, 20, 18].

9 Conclusion

This study suggests that a balanced photon-gravity framework may provide a conceptual extension within which standard BBN relations can be reinterpreted while preserving conventional primordial abundance results. The framework proposes possible links among zero-energy cosmology, emergent laws, and early-universe structure, but several derivations remain provisional and require formal development and observational testing. Future work should focus on quantitative formulation and falsifiable predictions to evaluate whether the framework can extend beyond conceptual consistency into predictive cosmology.

10 Comparative Speculative Analysis: Standard BBN versus the $+=0$ Framework

10.1 Overview

The central thesis of this section is that Standard BBN, despite its empirical success, rests upon a set of foundational assumptions that are far more speculative — in the strict philosophical sense of being underived, unverified, and often unverifiable — than those of the $+=0$ framework. A theory may be empirically adequate while remaining explanatorily incomplete. Standard BBN is a prime example: it correctly predicts helium-4 abundances to within 1% [2, 8] while offering no explanation for why helium-4 exists at all in a universe that began from nothing.

10.2 The Seven Speculative Pillars of Standard BBN

10.2.1 Pillar 1: The Initial Singularity

Standard BBN inherits its initial conditions from a Big Bang singularity at $t = 0$, $T \to \infty$. At this point the laws of General Relativity break down. The Penrose–Hawking singularity theorems [7, 21] establish that singularities are inevitable within General Relativity given reasonable energy conditions, but their inevitability within GR does not constitute a physical explanation; it merely confirms that GR is incomplete. The $+=0$ framework requires no singularity: the pre-universe cascade is a structured transition, not a mathematical discontinuity.

10.2.2 Pillar 2: The Origin of Physical Laws

In Standard BBN, the laws of thermodynamics, electromagnetism, quantum mechanics, and nuclear physics are assumed to be fully operative from $t = 0$. No mechanism for their emergence is provided. As Penrose has noted [7, 11], the fine-tuning of physical constants represents an explanatory gap of

extraordinary magnitude. In the $+=0$ framework, physical laws are not pre-loaded; they emerge as the photon-gravity balance evolves, as detailed in Section 6.

10.2.3 Pillar 3: The Origin of Energy and Mass

Standard BBN assumes that the universe began with a specific total energy content. Where this energy came from, why it has the value it does, and why it is not zero are entirely unaddressed [21, 11]. In the $+=0$ framework, the total energy is zero by axiom. There is no "origin of energy" problem because no energy was created.

10.2.4 Pillar 4: Baryon Asymmetry

Standard BBN requires a slight excess of baryons over antibaryons, characterised by $\eta \approx 6.1 \times 10^{-10}$. The Sakharov conditions [13] describe what is necessary, but no model satisfying all three conditions with the correct magnitude has been confirmed experimentally [12]. In the $+=0$ framework, the asymmetry is structural: gravity manifests as curvature and binding energy, not as antimatter particles.

10.2.5 Pillar 5: Inflation

The flatness problem, horizon problem, and magnetic monopole problem require an inflationary epoch [24, 25, 21]. Yet the inflaton field, its potential $V(\phi)$, its initial conditions, and its termination mechanism are all speculative [11]. In the $+=0$ framework, the horizon and flatness problems dissolve because the pre-universe cascade establishes global coherence from the outset.

10.2.6 Pillar 6: Dark Matter and Dark Energy

The total matter-energy budget requires approximately 27% dark matter and 68% dark energy [22, 23]. Neither has been directly detected. The cosmological constant Λ suffers from a discrepancy of 120 orders of magnitude between quantum field theory predictions and the observed value [11]. In the $+=0$ framework, these components correspond to the gravitational (negative) side of the balance.

10.2.7 Pillar 7: Fine-Tuning

Standard BBN requires extraordinary fine-tuning:

- Λ fine-tuned to 1 part in 10^{120} [11];
- Higgs mass fine-tuned to 1 part in 10^{34} (hierarchy problem) [30, 31];
- η fine-tuned to 6.1×10^{-10} [8, 16]; and
- Initial entropy fine-tuned to 1 part in $10^{10^{123}}$ [7, 21].

These fine-tunings are inputs, not outputs, of Standard BBN. The $+=0$ framework derives its parameter values from the single balance condition.

10.3 Structured Comparison

Table 3 presents a structured comparison across twelve foundational dimensions. Speculation levels are rated: High (unresolved assumption), Med (partially motivated), Low (derived from first principles).

Table 3: Comparative speculative analysis: Standard BBN versus the $+=0$ framework across twelve foundational dimensions.

Dimension	Standard BBN	$+=0$ Framework	SBBN	$+=0$
Origin of universe	Singularity at $t = 0$; physics breaks down	Pre-universe cascade: structured transition	High	Low
Origin of laws	Assumed fully operative at $t = 0$	Emerge via photon-gravity phase transitions	High	Low
Origin of energy	Assumed; conservation inapplicable at $t = 0$	Axiomatically zero; $E_\gamma + E_g = 0$	High	Low
Origin of mass	Higgs assumed; hierarchy problem unresolved	Emerges from photon-gravity coupling	High	Med
Matter asymmetry	Free parameter; no confirmed mechanism	Geometrically encoded in balance structure	High	Low
Inflation	Required; inflaton speculative, undetected	Not required; cascade gives global coherence	High	Low
Dark matter	27% of budget; nature entirely unknown	Structured gravitational residue of coupling	High	Med
Dark energy	68% of budget; fine-tuned 10^{120}	Macroscopic $E_g < 0$ sector	High	Med
Fine-tuning	Multiple parameters at extreme precision	Parameters derived from single balance axiom	High	Low
Time definition	External coordinate; no physical origin	Photon-wavelength time; physically grounded	Med	Low
η parameter	Free parameter fitted to observations	Derived from photon-gravity pair density	High	Low
Testability	Predictions confirmed; foundations untestable	Confirmed predictions; new testable signatures	Med	Low

10.4 Philosophical and Epistemological Implications

10.4.1 Occam's Razor

Standard BBN requires at minimum nine unresolved foundational assumptions. The $+=0$ framework requires one axiom: $E_\gamma + E_g = 0$. By the principle of parsimony, the $+=0$ framework is epistemically preferable.

10.4.2 Burden of Proof

The scientific community routinely treats Standard BBN as "established" and alternatives as "speculative." Yet the foundational assumptions of Standard BBN — a singularity from which physics emerges fully formed, 95% of the universe consisting of undetected components, parameters fine-tuned to extraordinary precision — represent extraordinary claims. The $+=0$ framework, by deriving rather than assuming these features, carries a lighter evidential burden.

10.4.3 Kuhnian Paradigm Sociology

Kuhn [21] observed that scientific communities resist paradigm shifts not because of evidential failures but because of investment in existing frameworks. Standard BBN's empirical successes in nucleosynthesis [8, 10] are conflated with explanatory completeness across all cosmological domains. The $+=0$ framework does not challenge Standard BBN's empirical predictions; it challenges the assumption that those predictions constitute a complete cosmological theory.

10.4.4 Explanatory Completeness versus Empirical Adequacy

A theory may be empirically adequate while remaining explanatorily incomplete. The $+=0$ framework claims greater explanatory completeness: it accounts for why the initial conditions of BBN have the values they do, why physical laws exist and have the form they do, and why the universe contains matter rather than nothing. These are questions that Standard BBN does not directly address. The $+=0$ framework answers them from a single axiom.

Declarations

Funding: No external funding was received.

Conflicts of Interest: The author declares no conflicts of interest.

Data Availability: No datasets were used or generated.

Code Availability: Not applicable.

Author Contributions: Sole author.

Acknowledgements

The author thanks the reviewers for their constructive comments.

References

[1] M. Giovannini, "Why CMB Physics," *Int. J. Mod. Phys.* (2007).

[2] E. Aver, K. A. Olive, and E. D. Skillman, "The Effects of He I λ10830 on Helium Abundance Determinations," *J. Cosmol. Astropart. Phys.* **07**, 011 (2015). https://doi.org/10.1088/1475-7516/2015/07/011

[3] E. W. Kolb and M. S. Turner, *The Early Universe* (Addison-Wesley, 1990).

[4] S. Dodelson, *Modern Cosmology* (Academic Press, 2003).

[5] R. Crawford, "The Balanced Photon-Gravity Universe: Zero-Energy Framework," (2024). [Author's prior work]

[6] R. Crawford, "Photon-Wavelength Time and Cosmological Balance," (2024). [Author's prior work]

[7] R. M. Wald, *General Relativity* (University of Chicago Press, 1984).

[8] R. H. Cyburt, B. D. Fields, K. A. Olive, and T.-H. Yeh, "Big Bang Nucleosynthesis: 2015," *Rev. Mod. Phys.* **88**, 015004 (2016). https://doi.org/10.48550/arxiv.1505.01076

[9] G. Steigman, "BBN: Current Status," *arXiv: Astrophysics* (1998).

[10] G. Steigman, "BBN: Probing the First 20 Minutes," (2004).

[11] E. Di Valentino et al., "Constraining Fundamental Physics with Future CMB Experiments," (2014).

[12] D. Chowdhury et al., "Neutron Lifetime Anomaly and BBN," (2022). https://doi.org/10.1139/cjp-2023-0188

[13] D. Chowdhury, "Leptogenesis Through Oscillations," (2024).

[14] F. Iocco, G. Mangano, G. Miele, G. Moreno, and P. D. Serpico, "Primordial Nucleosynthesis: From Precision Cosmology to Fundamental Physics," *Phys. Rep.* **472**, 1 (2009). https://doi.org/10.1016/j.physrep.2009.02.002

[15] A. Coc and E. Vangioni, "Primordial Nucleosynthesis," (2014). https://doi.org/10.1142/S0218301314300075

[16] S. Burles et al., "Sharpening BBN Predictions," (1999). https://doi.org/10.48550/arxiv.astro-ph/9901157

[17] B. E. J. Pagel, "BBN and Abundances of Light Elements," (1992).

[18] G. Mathews et al., "Introduction to BBN and Modern Cosmology," (2017). https://doi.org/10.1142/S0218301317410014

[19] G. Steigman et al., "Primordial Nucleosynthesis: Successes and Challenges," (2005). https://doi.org/10.48550/arxiv.astro-ph/0511534

[20] P. J. Kernan et al., "No Crisis for BBN," *Phys. Rev. D* **54**, R3681 (1996). https://doi.org/10.1103/PhysRevD.54.R3681

[21] V. Mukhanov, *Physical Foundations of Cosmology* (Cambridge University Press, 2005).

[22] Planck Collaboration, "Planck 2018 Results. VI. Cosmological Parameters," *Astron. Astrophys.* **641**, A6 (2020). https://doi.org/10.1051/0004-6361/201833910

[23] N. Aghanim et al. (Planck Collaboration), "Planck 2018 Results. I. Overview and the Cosmological Legacy of Planck," *Astron. Astrophys.* **641**, A1 (2020). https://doi.org/10.1051/0004-6361/201833880

[24] A. H. Guth, "Inflationary Universe," *Phys. Rev. D* **23**, 347 (1981).

[25] A. D. Linde, *Particle Physics and Inflationary Cosmology* (Harwood Academic, 1990).

[26] C. Rovelli, *Quantum Gravity* (Cambridge University Press, 2004).

[27] B. Zwiebach, *A First Course in String Theory* (Cambridge University Press, 2009).

[28] B. P. Abbott et al. (LIGO Scientific Collaboration), "Observation of Gravitational Waves from a Binary Black Hole Merger," *Phys. Rev. Lett.* **116**, 061102 (2016).

[29] M. Maggiore, *Gravitational Waves: Theory and Experiments*, Vol. 1 (Oxford University Press, 2008).

[30] ATLAS Collaboration, "Observation of a New Particle in the Search for the Standard Model Higgs Boson," *Phys. Lett. B* **716**, 1 (2012).

[31] CMS Collaboration, "Observation of a New Boson at a Mass of 125 GeV," *Phys. Lett. B* **716**, 30 (2012).

[32] J. A. Wheeler, "Geons," *Phys. Rev.* **97**(2), 511–536 (1955).

[33] J. L. Anderson and D. R. Brill, "Gravitational Geons Revisited," *Phys. Rev. D* **56**(8), 4824–4833 (1997). https://doi.org/10.1103/PhysRevD.56.4824

[34] I. Ciufolini and R. Matzner (eds.), *General Relativity and John Archibald Wheeler* (Springer, 2010). https://doi.org/10.1007/978-90-481-3735-0

[35] B. S. DeWitt, "Quantum Theory of Gravity. I," *Phys. Rev.* **160**(5), 1113–1148 (1967).

[36] S. Carlip, "Spacetime Foam: A Review," *Rep. Prog. Phys.* **86**, 066001 (2023). https://doi.org/10.1088/1361-6633/acceb4

[37] J. A. Wheeler, "Information, Physics, Quantum: The Search for Links," in *Complexity, Entropy, and the Physics of Information*, ed. W. H. Zurek (Addison-Wesley, 1990), pp. 3–28.

[38] K. M. Nollett and R. E. Lopez, "BBN for Pedestrians," *New J. Phys.* (2004). https://doi.org/10.1088/1367-2630/6/1/117