Zero-field Spectral Cosmology. Theory

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Abstract

A hypothesis is proposed that physical space-time and interactions emerge from a more fundamental probabilistic field existing at zero entropy level. In this state, there are no space or time, only amplitudes and probabilistic fields representing potential configurations of all possible energies and interactions. Basic postulates are formulated, preliminary mathematical relations are provided, and a research plan is outlined to align this model with known physical laws and constants.

1 Introductory Intuition and ZFSC Postulates

1.1 Postulate 1: Zero Entropy Level

The existence of a fundamental pre-geometric level is assumed, where classical distances, spatial and temporal dimensions are absent, and entropy approaches zero:

$$S \to 0.$$

Formally, the initial state is represented by a pure quantum state ρ on a probabilistic-amplitude structure $\mathcal{H}$ with zero entropy:

$$S(\rho) = -\mathrm{Tr}\,(\rho \ln \rho) = 0.$$

At this level, the Universe is described by a pure probabilistic field of amplitudes:

$$\Psi = \sum_i a_i |i\rangle,$$

where $\{|i\rangle\}$ are potential configurations (space, energy, interactions), and $a_i \in \mathbb{C}$ are their amplitudes.

- Denote the Hilbert space of "potential states" as $\mathcal{H}$.
- On $\mathcal{H}$, a **self-adjoint operator** (observable) is defined:

$$\boxed{\Lambda = L + M} \tag{1}$$

  where L is the "intra-sector" part (local connections), and M is the "inter-sector" connections (mixing).

Physical Meaning. The spectrum $\{\lambda_k^{\mathrm{eff}}\}$ of the operator Λ encodes potential "frequencies" $\tilde{\omega}_k$ of elementary **modes**, from which particles, fields, and geometry later emerge.

1.2 Eigenmodes and Basic Formulas

$$\Lambda \mathbf{v}_k = \lambda_k^{\mathrm{eff}} \mathbf{v}_k, \qquad \tilde{\omega}_k \equiv \sqrt{\lambda_k^{\mathrm{eff}}} \ (\geq 0). \tag{2}$$

- $\mathbf{v}_k$ — eigenvector (form of the "mode").
- $\lambda_k^{\mathrm{eff}} \geq 0$ — eigenvalue (square of the "frequency").
- $\tilde{\omega}_k$ — effective "frequency" of the mode.

Particle Masses.

$$\boxed{m_k = \frac{\hbar}{c^2}\tilde{\omega}_k = \frac{\hbar}{c^2}\sqrt{\lambda_k^{\mathrm{eff}}}} \tag{3}$$

- $\hbar$ — reduced Planck constant.
- c — speed of light in vacuum.

Mixing (PMNS/CKM).

$$\boxed{U_{\alpha i} \sim \langle \alpha | \mathbf{v}_i \rangle} \tag{4}$$

- $|\alpha\rangle$ — basis of "flavors/sectors" (electronic, muonic, etc.).
- Overlaps of eigenvectors yield **mixing angles** and **CP phase**.

2 Emergent Geometry: How Time and Space "Arise"

2.1 Spectral Transition (ZFST): "Great Unfolding"

Transition Hypothesis. The "Big Bang" is replaced by a **zero-field spectral transition (ZFST)** — a rapid regime of increasing connectivity and the emergence of non-zero entropy S.

Introduce "proto-time" τ — a parameter of spectrum evolution under the influence of a **gradient flow** (minimization of "spectral action"):

$$\frac{d\Lambda}{d\tau} = -\frac{\delta \mathcal{S}_{\mathrm{spec}}}{\delta \Lambda}, \qquad \mathcal{S}_{\mathrm{spec}} = \mathrm{Tr}\, f\left(\frac{\Lambda}{\Lambda_*}\right). \tag{5}$$

- f — a positive decaying function (e.g., a smoothed spectrum cutoff).
- Λ_* — cutoff scale (Planck order).
- **Meaning:** The system "decomposes" high and low modes into a structure with minimal "spectral action".

Emergent Physical Time.

$$\boxed{t(\tau) = \int^{\tau} \zeta\big(S(\tau')\big)\, d\tau', \quad \zeta' > 0} \tag{6}$$

- $\zeta(S)$ — monotonic "clock speed": while $S \approx 0$, physical time "almost stands still"; as S grows, clocks "turn on".

2.2 Spectral Gap and Scale Factor

Define the **first non-zero gap**:

$$\lambda_1(\tau) = \min\{\lambda_k^{\text{eff}}(\tau) > 0\}, \qquad \xi(\tau) \sim \frac{1}{\sqrt{\lambda_1(\tau)}}. \tag{7}$$

- ξ — correlation length (size of coherence regions).
- **Assumption:** Scale factor $a \propto \xi$:

$$\boxed{a(\tau) \propto \frac{1}{\sqrt{\lambda_1(\tau)}}} \;\Rightarrow\; H \equiv \frac{\dot{a}}{a} = -\frac{1}{2}\frac{\dot{\lambda}_1}{\lambda_1}. \tag{8}$$

If during the ZFST phase $\lambda_1(\tau)$ decreases **exponentially**,

$$\lambda_1(t) = \lambda_1(0)\, e^{-2Ht} \;\Rightarrow\; a(t) \propto e^{Ht}, \tag{9}$$

we obtain **inflation without an inflaton**: accelerated expansion is pure spectral dynamics.

2.3 Vacuum Energy and Entropic Suppression

Effective "vacuum" density from the zero-point energies of modes (with entropic weighting):

$$\boxed{\rho_{\text{vac}}(S, a) = \frac{\hbar}{2V(a)} \sum_k \tilde{\omega}_k\, F\big(\tilde{\omega}_k, S\big)\, \Theta\big(k_c(a) - k\big)} \tag{10}$$

- $V(a) \propto a^3$ — volume;
- $\frac{\hbar}{2}\tilde{\omega}_k$ — zero-point energy of the mode;
- $F(\tilde{\omega}, S) \in [0, 1]$ — **entropic suppression factor** for high frequencies as S grows;
- Θ — window function with a "sliding" cutoff $k_c(a)$ (cosmological co-moving scale).

Physics: As long as the sum changes weakly $\Rightarrow w = p/\rho \approx -1$, inflation proceeds; as suppression factors "turn off," inflation stops, and energy redistributes into **localized modes** (reheating).

2.4 Spectral Dimension and Phased Unfolding 1D → 3D

Spectral dimension d_s is introduced via the heat trace:

$$K(s) = \operatorname{Tr} e^{-s\Lambda} \;\sim\; \frac{1}{(4\pi s)^{d_s/2}} \quad (s \to 0^+). \tag{11}$$

- During ZFST, a stage with $d_s \simeq 1$ (quasi-linear connection chains) is possible, then through the flow (5), the network gains **three equivalent "directions"** of connectivity $\Rightarrow d_s \to 3$.

Why exactly 3D + time? (Minimality Hypothesis.) Configurations with $d_s = 1$ are unstable (too small correlation volumes), while $d_s \geq 4$ are spectrally "expensive" (many high modes without sufficient suppression). The minimum "spectral action" is achieved with **three** nearly equal orthogonal connections — i.e., 3D.

Where do other dimensions "reside"? In blocks of Λ with **large gaps** ($\lambda_{\text{compact}} \gg \lambda_1$) — their correlation lengths are microscopic, remaining **compactified**. Their contribution to ρ_{vac} is suppressed by $F(\tilde{\omega}, S)$, but they:

- shift gauge constants (through integration of high modes),
- introduce small corrections to masses/mixing,
- may produce weak "hidden" interactions.

3 Masses, Generations, and Mixing

3.1 "Generation Ladder"

Empirically, each family exhibits three hierarchical levels. ZFSC models this as a "ladder":

$$\boxed{\mu = \{0, \varepsilon, c\varepsilon\}, \qquad m_i^2 \propto \lambda_0 + \mu_i} \tag{12}$$

- $\lambda_0 \geq 0$ — base level shift (common "background" of the sector);
- $\varepsilon > 0$ — step;
- $c > 1$ — **hierarchy ratio** (key characteristic of the family).

From two masses $\to c$. For example, for leptons (order $e \to \mu \to \tau$):

$$c_\ell = \frac{m_\tau^2 - m_e^2}{m_\mu^2 - m_e^2} \approx 2.828 \times 10^2. \tag{13}$$

For neutrinos (in terms of differences): $c_\nu = \frac{\Delta m_{31}^2}{\Delta m_{21}^2} \approx 34.$

3.2 Micro-model of "Generations": Matrix $B(\delta, r, \dots)$

Minimal 3×3 version:

$$\boxed{B(\delta, r; g_L) = \begin{pmatrix} 0 & g_L & 0 \\ g_L & \delta & r \\ 0 & r & 0 \end{pmatrix}, \quad \operatorname{spec}(B) = \left\{ 0, \ \frac{\delta \pm \sqrt{\delta^2 + 4(g_L^2 + r^2)}}{2} \right\}} \tag{14}$$

- δ — "central shift" (asymmetry of the central node);
- r — right "shoulder" connection channel; g_L — left channel.

For sorted levels ($\lambda_{\min} < \lambda_{\text{mid}} < \lambda_{\max}$) and $\lambda_{\text{mid}} = 0$ (as in (14)), the "ladder" ratio is:

$$\boxed{c = \frac{\lambda_{\max} - \lambda_{\min}}{\lambda_{\text{mid}} - \lambda_{\min}} = \frac{2\sqrt{\delta^2 + 4(g_L^2 + r^2)}}{\sqrt{\delta^2 + 4(g_L^2 + r^2)} - \delta}} \tag{15}$$

and in the large δ regime:

$$\boxed{c \approx \frac{\delta^2}{g_L^2 + r^2} + 2} \quad (\delta^2 \gg g_L^2 + r^2). \tag{16}$$

Meaning: Large hierarchies c naturally arise with a large central shift δ and a narrow "bottleneck" of connections (small g_L, r).

6×6 and Asymmetries. In practice, we use an extended 6×6 matrix with edges g_L, g_R and asymmetries $h_{1,2,3}$, which allows:

- supporting different hierarchies in sectors (ν, ℓ, u, d);
- introducing **common parameters** (unification) and testing predictiveness.

3.3 Prediction of Light Mass from Two Heavy Ones

If the ladder is $\{0, 1, c\}$ and we identify $\mu \to 1$, $\tau \to c$, then:

$$s^2 = \frac{m_\tau^2 - m_\mu^2}{c - 1}, \qquad \boxed{m_{\text{light}}^2 = m_\mu^2 - s^2} \tag{17}$$

- s^2 — overall "scale" of the sector;
- **Important:** Here, c is **predicted** by the model (from the spectrum of B), not calculated from three masses (otherwise, it is an identity, not a prediction).

4 Gravity and Curvature from the Spectrum

4.1 Heuristic for G

The total "stiffness" of the vacuum, composed of all modes:

$$\boxed{\frac{1}{G_{\text{eff}}} \sim \sum_k \hbar \tilde{\omega}_k W_k} \tag{18}$$

- W_k — weight depending on the structure of modes and suppression (analogous to "spectral action").

Idea: The more high-frequency modes are involved (considering $F(\tilde{\omega}, S)$), the greater the "elasticity" of the geometry (smaller G).

4.2 Contribution of a Single Mode to Curvature

In the linear regime:

$$\boxed{\delta R_{\mu\nu}^{(k)} \simeq \frac{8\pi G}{c^4} T_{\mu\nu}^{(k)}, \qquad T_{\mu\nu}^{(k)} \propto m_k u_\mu u_\nu} \tag{19}$$

- u_μ — 4-velocity of the mode carrier;
- m_k from (3); collectively, $\sum_k \delta R_{\mu\nu}^{(k)}$ forms the observed curvature.

This links **masses** and **curvature** as two sides of the same spectral "mechanism" Λ.

5 Dark Energy and "Why It Is Small"

5.1 Vacuum Formula and Suppression

Returning to (10): a small ρ_Λ is ensured by:

- suppression of $F(\tilde{\omega}, S)$ for "compact" high modes (blocks with large λ);
- a "sliding" cutoff $k_c(a)$, reducing the ultraviolet contribution as a grows.

Effective Equation of State.

$$w + 1 \simeq -\frac{d \ln \rho_{\text{vac}}}{d \ln a} \simeq -\frac{d \ln F}{d \ln a} \quad \text{(small)}. \tag{20}$$

A $w \approx -1$ with a tiny drift is expected — a cosmologically testable trace.

6 Why 1D → 3D, Not Other Dimensions, and "Where They Reside"

1. **1D Stage.** At the onset of ZFST, the connection network is "thin," the spectral gap λ_1 is large, $d_s \approx 1$. The scale $a \propto 1/\sqrt{\lambda_1}$ grows exponentially (9).
2. **Transition to 3D.** The minimum of $\mathcal{S}_{\text{spec}}$ is achieved with three nearly equivalent "directions" of connectivity (entropic efficiency): $d_s \to 3$.
3. **Why not 4D?** For $d_s \geq 4$, the characteristic spectrum $\rho(\lambda)$ produces too strong an ultraviolet contribution without sufficient suppression by F, making ρ_{vac} unstable/too large (heuristically: "expensive" in spectral action).
4. **Other dimensions** remain in "compact" blocks of Λ with large gaps λ_{compact}:
   - correlation length $\xi_{\text{compact}} \sim 1/\sqrt{\lambda_{\text{compact}}}$ is microscopic;
   - their contribution to observable dynamics occurs through **renormalization of constants**, small shifts in masses/mixing, and ρ_Λ.

7 Computational Program and Testable Consequences

7.1 Generation Matrices and Coefficient c

We use matrices $B(\delta, r; g_L, g_R, h_{1,2,3})$ of size 3, 4, or 6. In the simplest 3×3 case, c is given by (15)–(16); in 6×6 — numerically based on three **fixed levels** (it is important not to select the triplet for a target, otherwise hidden fitting occurs).

Practical Rule (Fairness):

- Choose one triplet rule (e.g., "three lowest levels") and **do not change it** across sectors;
- In unification regimes, c is **predicted**, not fitted.

7.2 Prediction of Light Masses

For leptons:

$$m_e^{\text{pred}} = \sqrt{m_\mu^2 - \frac{m_\tau^2 - m_\mu^2}{c_\ell^{\text{pred}} - 1}}, \tag{21}$$

where c_ℓ^{pred} is extracted from the spectrum of B in the same **unification regime** as for neutrinos, quarks, etc. Similarly, predictions for light quarks (u, d) can be constructed from (c, s, t) or (d, s, b).

7.3 Toolkit

- **Regimes:** `independent_all`, `shared_r_all`, `shared_delta_all`, `full_unify_all`, `grand_unify_all`, `grand_unify_all_scaled`.
- **Breakthrough Criteria:** In strict regimes (`full_unify_all`), simultaneously:
  - $z_\nu \lesssim 2\sigma$ (for c_ν),
  - $z_e \lesssim 2\sigma$ (for m_e^{pred} with 1% model σ),
  - and global $z \lesssim 2\sigma$.
- **Technical Notes:**
  - Do not use c_ℓ^{exp} during optimization if the goal is to **predict** m_e;
  - The choice of level triplet is **fixed** (e.g., "three lowest");
  - Quark masses should be compared at a fixed $\overline{\text{MS}}$-scale.

8 ZFSC Equation Set (Minimal "System" with Comments)

1. **Eigenmodes:** $\Lambda \mathbf{v}_k = \lambda_k^{\text{eff}} \mathbf{v}_k$.
2. **Mode Mass:** $m_k = \frac{\hbar}{c^2}\sqrt{\lambda_k^{\text{eff}}}$.
3. **Mixing:** $U_{\alpha i} \sim \langle \alpha | \mathbf{v}_i \rangle$.
4. **Ladder:** $\mu = \{0, \varepsilon, c\varepsilon\}$, $m_i^2 \propto \lambda_0 + \mu_i$.
5. **Hierarchy Coefficient (3×3):** $c = \frac{2\sqrt{\delta^2 + 4(g_L^2 + r^2)}}{\sqrt{\delta^2 + 4(g_L^2 + r^2)} - \delta} \simeq \frac{\delta^2}{g_L^2 + r^2} + 2$.
6. **Light Mass Prediction:** $m_{\text{light}}^2 = m_\mu^2 - (m_\tau^2 - m_\mu^2)/(c-1)$.
7. **Entropic Dynamics:** $\frac{d\Lambda}{d\tau} = -\frac{\delta \mathcal{S}_{\text{spec}}}{\delta \Lambda}$, $t(\tau) = \int \zeta(S)\, d\tau$.
8. **Gap–Scale Factor:** $a \propto 1/\sqrt{\lambda_1}$, $H = -\frac{1}{2}\frac{\dot{\lambda}_1}{\lambda_1}$.
9. **Vacuum Energy:** $\rho_{\text{vac}} = \frac{\hbar}{2V}\sum_k \tilde{\omega}_k F(\tilde{\omega}_k, S)\Theta(k_c - k)$.
10. **Gravitational "Stiffness":** $G_{\text{eff}}^{-1} \sim \sum \hbar \tilde{\omega}_k W_k$.

11. **Linear Gravity of a Mode:** $\delta R^{(k)}_{\mu\nu} \simeq \frac{8\pi G}{c^4} T^{(k)}_{\mu\nu}$.
12. **Spectral Dimension:** $K(s) = \mathrm{Tr}\, e^{-s\Lambda} \sim (4\pi s)^{-d_s/2}$.

Each coefficient:

- $\hbar, c$ — fundamental constants (scale the "frequency $\to$ mass" connection).
- $\delta, r, g_L, g_R, h_{1,2,3}$ — **connection geometry** in the pre-geometric network (determine the spectrum shape and, consequently, c, masses, and mixing).
- ε, λ_0 — "step" and base shift in the ladder approximation of levels.
- $F(\tilde{\omega}, S)$, $k_c(a)$ — phenomenological suppressions of UV contributions (entropy and scale), subject to calibration.
- W_k — weight of mode contribution to the "stiffness" of geometry (depends on spectral action normalization).

9 Observable Consequences and Tests

1. **Neutrino Hierarchies:** c_ν is large (~ 34), robust to details; range of $m_{\beta\beta}$ for $0\nu\beta\beta$ (small, $\sim$ meV).
2. **Leptons:** Prediction of m_e from (μ, τ) with **common** parameters B with neutrinos (via shared regimes).
3. **Gauge Constants:** Through substructures of Λ — possibility to relate phenomenological constants to the "average connectivity" of subgraphs (general spectral action logic).
4. **Inflation:** Small tensor signal r and weak running, expressed through $d \ln \lambda_1/dt$.
5. **Dark Energy:** $w \approx -1$ with a micro-drift $w + 1 \sim -d \ln F/d \ln a$.
6. **Unseen Dimensions:** The absence of unfolding of other dimensions manifests as **small but collective** corrections to masses and constants.

10 Research Roadmap

- **(A)** Fix the architecture of B (small number of parameters) and **one rule** for triplet selection.
- **(B)** Calibrate **minimally** (e.g., Δm^2 for ν and μ, τ for ℓ), **predict** the rest (m_e, $m_{\beta\beta}$, PMNS/CKM angles, m_W/m_Z).
- **(C)** Compute χ^2, **z-scores** for independent observables, **Global z** accounting for the number of parameters.
- **(D)** Check stability against variations in ranges/grids (without "hidden triplet fitting").
- **(E)** If necessary, add **one** new handle (e.g., weak asymmetry) — and retest predictiveness.

11 Conclusion

ZFSC offers a unified picture where a **single spectrum** $\Lambda = L+M$ on a zero-probabilistic field sequentially generates:

- **masses** (through $\sqrt{\lambda_k^{\text{eff}}}$),
- **mixing** (through eigenvectors),
- **gravity** (through the total "stiffness" of modes),
- **inflation** (through the exponential fall of the spectral gap),
- **small dark energy** (entropic suppression of zero modes),
- **3D space** + **time** (from spectral minimality),
- and leaves "other dimensions" in compact blocks of Λ, where they subtly influence constants.

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