A Non-Singular Cyclic Contracting Cosmology: From Operational Scale Covariance to Born–Infeld Bounce Dynamics

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Abstract

We present a unified, non-singular cyclic cosmological framework that bridges low-energy observational scale covariance with high-energy non-linear electrodynamic bounce dynamics. In the macroscopic regime, the global spacetime scale undergoes an exponential contraction derived variationally from General Relativity coupled to a stationary scalar field. By defining cosmological observables operationally via dimensionless ratios relative to conformally co-evolving atomic standards, the model naturally reproduces positive cosmological redshift, Type Ia supernova luminosity distances without dark energy, baryon acoustic oscillation (BAO) scaling, and a strictly negative Sandage–Loeb redshift drift ($\dot{z} = -C(1+z)$). As contraction progresses toward extreme energy densities, magnetohydrodynamic (MHD) induction triggers exponential electron-positron pair production via the Schwinger mechanism, driving a Golden Ratio-scaled Born–Infeld electromagnetic field toward saturation. The resulting asymptotically negative electromagnetic pressure, stabilized by a holographic entropic backreaction, prevents the Big Bang singularity and executes a smooth mechanical bounce at a non-zero minimum radius ($a_{\min}$). Localized energy configurations are preserved across the bounce as invariant topological skyrmions, while higher-order Euler–Heisenberg vacuum corrections generate non-inflationary primordial B-mode polarization signatures and fractal multipolar resonances testable in forthcoming CMB surveys.

Keywords: contracting cosmology; cyclic bounce; operational redshift; Born–Infeld electrodynamics; Schwinger effect; topological skyrmions; redshift drift

1 Introduction

Standard ΛCDM cosmology faces persistent foundational challenges, including the initial Big Bang singularity, the horizon problem, the physical nature of dark energy, and emerging parameter tensions [1, 2, 3]. While alternative bouncing and cyclic frameworks—such as Loop Quantum Cosmology (LQC) or conformal cyclic models—attempt to resolve the initial singularity, they typically rely exclusively on Planck-scale gravitational modifications and often lack a unified operational treatment of low-redshift observables.

In this work, we unify two complementary dynamical regimes within a single covariant framework. First, in the low-energy macroscopic regime, we establish a variationally derived contracting background where local physical standards (rulers and clocks) co-evolve conformally with the scale factor, similar to variable-mass frameworks [4]. Second, in the asymptotic high-energy regime approaching collapse, we introduce non-linear Born–Infeld electrodynamics [5], Schwinger vacuum polarization [6], and holographic topological constraints to halt gravitational collapse and generate a smooth, singularity-free bounce.

2 Unified Variational Framework

We formulate the complete cosmic dynamics from a single covariant action within General Relativity coupled to a scalar scale degree of freedom ϕ and a non-linear electromagnetic sector:

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G}R - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi) + \mathcal{L}_{\rm EM}(\mathcal{F},\mathcal{G},\Phi)\right] \tag{1}$$

where R is the Ricci scalar, $V(\phi)$ is the scalar potential, and $\mathcal{L}_{\rm EM}$ represents the non-linear electromagnetic Lagrangian scaled by algebraic resonances of the Golden Ratio $\Phi = (1+\sqrt{5})/2$. To ensure a physical mechanism for the co-evolution of local standards, matter fields are minimally coupled in the Jordan frame via a conformal metric $g_{\mu\nu}^{\rm atomic} = \Omega^2(\phi)g_{\mu\nu}$.

Varying the action with respect to the metric $g^{\mu\nu}$ yields the coupled Einstein field equations:

$$G_{\mu\nu} = 8\pi G\left(T_{\mu\nu}^{(\phi)} + T_{\mu\nu}^{(\rm EM)} + T_{\mu\nu}^{(\rm ent)}\right) \tag{2}$$

where $T_{\mu\nu}^{(\phi)} = \partial_\mu\phi\partial_\nu\phi - \frac{1}{2}g_{\mu\nu}(\partial\phi)^2 - g_{\mu\nu}V(\phi)$, $T_{\mu\nu}^{(\rm EM)}$ is the non-linear electromagnetic stress–energy tensor, and $T_{\mu\nu}^{(\rm ent)}$ accounts for holographic entropic backreaction at extreme densities. Adopting a spatially flat ($k=0$) homogeneous and isotropic FLRW metric,

$$ds^2 = -\frac{c^2}{n^2(t)}dt^2 + a^2(t)\gamma_{ij}dx^i dx^j \tag{3}$$

where $n(t)$ denotes the effective cosmic refractive index of the active magneto-dielectric cosmic web medium ($n(t)\simeq 1$ in the dilute macroscopic limit).

3 Macroscopic Regime: Exponential Contraction and Operational Observables

3.1 Background Solution and Scale Covariance

In the dilute, low-energy regime far from the bounce ($a \gg a_{\rm min}$), electromagnetic backreaction is negligible ($T_{\mu\nu}^{(\rm EM)} \simeq 0$, $n(t)\simeq 1$) and the scalar field sits stationary at an extremum of its potential:

$$\phi(t) = \phi_0, \quad \dot\phi = 0, \quad \left.\frac{dV}{d\phi}\right|_{\phi_0} = 0, \quad V(\phi_0) = V_0 > 0 \tag{4}$$

The Friedmann equations reduce to $H^2 = \frac{8\pi G}{3}V_0 \equiv C^2$ and $\dot H = 0$. Selecting the contracting branch ($H = -C$) yields the exact exponential contraction law:

$$\frac{\dot a}{a} = -C \implies a(t) = a_0 e^{-Ct} \tag{5}$$

In this conformal frame, effective elementary particle masses scale inversely with the background factor, $m(t) \propto a^{-1}(t)$, causing the local Bohr radius and atomic reference wavelengths to shrink synchronously with propagating photon wavelengths: $\lambda_\gamma(t) \propto a(t)$ and $\lambda_{\rm at}(t) \propto a(t)$. Defining the measured redshift operationally via dimensionless ratios yields:

$$1 + z_{\rm meas} \equiv \frac{\lambda_\gamma(t_0)/\lambda_{\rm at}(t_0)}{\lambda_\gamma(t_e)/\lambda_{\rm at}(t_e)} = \frac{a(t_e)}{a(t_0)} = e^{C(t_0-t_e)} \tag{6}$$

This renders global contraction locally unobservable while producing a positive cosmological redshift across cosmic time.

3.2 Supernova Distances, BAO, and Redshift Drift

For small look-back times ($\Delta t \ll C^{-1}$), Eq. (6) recovers the linear Hubble law $z_{\rm meas} \simeq \frac{C}{c} d$ with $H_{\rm eff} \equiv C$. Evaluating the comoving radial integral $\chi = \int_{t_e}^{t_0} \frac{dt}{a(t)}$ relative to co-evolving atomic energy standards ($E_{\rm at}(t) \propto a^{-1}(t)$) yields the closed-form luminosity distance:

$$d_L(z) = \frac{c}{C}(1 + z_{\rm meas}) \ln(1 + z_{\rm meas}) \tag{7}$$

This logarithmic relation accounts for the dimming of distant Type Ia supernovae without dark energy [2, 3]. Similarly, co-evolving BAO resonance scales ($\lambda_{\rm BAO}(t) = \lambda_{\rm BAO,0} a(t)$) provide a distinct high-redshift geometric test [7].

Crucially, differentiating Eq. (6) with respect to the observer's proper time t_0 yields the Sandage–Loeb redshift drift [8, 9]:

$$\dot{z}_{\rm meas} \equiv \frac{dz_{\rm meas}}{dt_0} = -C(1 + z_{\rm meas}) \tag{8}$$

This strictly negative drift ($\dot{z}_{\rm meas} < 0$) sharply distinguishes our contracting framework from ΛCDM, where dark energy induces a positive drift at low-to-moderate redshifts.

4 High-Energy Regime: Born–Infeld Saturation and Non-Singular Bounce

4.1 Schwinger Pair Production and Born–Infeld Repulsion

As contraction continues toward extreme densities ($a \to a_{\rm min}$), plasma motion through cosmic web filaments induces macroscopic electric fields $\vec{E}_{\rm MHD} = -\frac{1}{\sigma}\nabla \times \vec{B} + \beta \dot{a}(t) \vec{B}(t)$. When the field intensity $\mathcal{E}^2(t) = E^2(t) + c^2 B^2(t)$ approaches the critical threshold E_c, vacuum breakdown triggers exponential electron-positron pair production via the Schwinger mechanism [6]:

$$\frac{d\rho_m}{dt} + 3\left(\frac{\dot{a}}{a}\right)\rho_m = \frac{e^2 \mathcal{E}^2(t)}{4\pi^3 \hbar^2} \exp\left(-\pi \frac{E_c}{\|\vec{E}_{\rm MHD}\|}\right) \cdot c^2 \tag{9}$$

To prevent a singularity, the electromagnetic sector transitions into the non-linear Born–Infeld regime [5] scaled by the algebraic Golden Ratio factor $f(\Phi) = \cosh(\ln \Phi) = \frac{\sqrt{5}}{2}$:

$$\mathcal{L}_{\rm BI} = b^2 f(\Phi) \left(1 - \sqrt{1 - \frac{E^2 - c^2 B^2}{b^2 f(\Phi)} - \frac{(\vec{E} \cdot \vec{B})^2}{b^4 f^2(\Phi)}}\right) \tag{10}$$

As $\mathcal{E}^2 \to b^2 f(\Phi)$, the effective electromagnetic pressure becomes asymptotically negative:

$$P_{\rm BI} = b^2 - \frac{b^2}{\sqrt{1 - \frac{E^2 + c^2 B^2}{b^2}}} \cdot (1 + \gamma) \xrightarrow[\mathcal{E}^2 \to b^2 f(\Phi)]{} -\infty \tag{11}$$

Incorporating this saturation alongside a holographic entropic backreaction derived from Verlinde's entropic gravity framework yields the full Friedmann bounce equation:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\left[\rho_m(a) + \frac{\sqrt{5}}{2} b^2 \left(\frac{1}{\mathcal{D}(a)} - 1\right)\right] - \frac{c^2 \ell_P^2}{a^4}\left(\frac{dS_{\rm VN}}{d\Omega}\right) \max \tag{12}$$

where $\mathcal{D}(a) = \sqrt{1 - \frac{\mathcal{E}^2(a)}{b^2 \cosh^2(\ln \Phi)}}$ is the damping factor and ℓ_P is the Planck length. At $a = a\min$, the negative pressure and entropic deceleration balance gravitational collapse ($\dot{a} = 0, \ddot{a} > 0$), executing a smooth bounce governed locally by $a(t) \simeq a_{\rm min}\left[1 + \frac{8\pi G \rho_c}{3} t^2\right]$.

4.2 Topological Skyrmions and Holographic Bounds

Localized electromagnetic energy configurations survive the bounce as topologically protected cosmic skyrmions carrying an invariant integer charge:

$$Q = \frac{1}{4\pi} \int \vec{n} \cdot \left(\frac{\partial \vec{n}}{\partial x} \times \frac{\partial \vec{n}}{\partial y} \right) dxdy \in \mathbb{Z} \implies \frac{dQ}{dt} = 0 \tag{13}$$

At the bounce surface ($t = 0$), total von Neumann entropy $S_{\rm VN}$ obeys the Holographic Principle:

$$S_{\rm VN}(t=0) = \sum_{\rm nodes} Q_i \cdot \ln(\Phi) \leq \frac{\pi a_{\rm min}^2}{\ell_P^2} \tag{14}$$

ensuring unitarity and information preservation across cosmic cycles.

5 Primordial B-Mode Signatures and Observational Tests

In the post-bounce transition, higher-order Euler–Heisenberg vacuum loop corrections [10],

$$\mathcal{L}{\rm EH} = \mathcal{L}{\rm Maxwell} + \frac{2\alpha^2\hbar^3}{45 m_e^4 c^5} \left[4 \left(\frac{E^2 - c^2 B^2}{2} \right)^2 + 7c^2 (\vec{E} \cdot \vec{B})^2 \right] \tag{15}$$

induce quantum plasma forces $\vec{F}{\rm EH}$ that generate primordial B-mode polarization ($C\ell^{BB} = \int dt, \dot{\phi}{\rm EH}^2(t) C\ell^{EE}(t)$) without requiring standard inflation. Simultaneously, extreme vacuum polarization induces anomalous dispersion ($\omega(\partial n/\partial\omega) < -n(\omega)$) and negative group delay ($v_g < 0$) [11], providing an optical boost to the apparent Hubble parameter $H_{\rm apparent} = -\frac{\dot{a}}{a} - \frac{\dot{n}}{n}$ during early post-bounce phases. To test these signatures in CMB residual data, we define a fractal Fibonacci Filter scanning multipoles ℓ for Φ^n-scaled resonances:

$$S_F(n) = \sum_{\ell=\ell_{\rm min}}^{\ell_{\rm max}} \left[C_\ell - C_\ell^{\Lambda{\rm CDM}} \right] \cdot \cos\left(2\pi \cdot \frac{\ell}{\Phi^n} \right) \tag{16}$$

This filter, combined with upcoming ELT-ANDES spectroscopic measurements of the negative redshift drift ($\dot{z} = -C(1+z)$), offers a decisive experimental pathway to validate or falsify the unified contracting cycle.

6 Conclusions

We have formulated a complete, non-singular cyclic cosmological model that unifies operational scale covariance in the low-energy contracting universe with non-linear Born–Infeld electrodynamics at the bounce. By anchoring local atomic standards to a conformally coupled scalar field, the model reproduces positive redshift and supernova luminosity distances without dark energy, while predicting a strictly negative Sandage–Loeb redshift drift. At extreme densities, Schwinger pair production, Born–Infeld negative pressure, and holographic skyrmion conservation eliminate the initial singularity at a finite radius $a_{\rm min}$ and imprint testable primordial B-mode signatures.

Compliance with Ethical Standards

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References

[1] Planck Collaboration. Planck 2018 results. VI. Cosmological parameters. *Astron. Astrophys.* **2020**, *641*, A6.

[2] Riess, A.G.; et al. Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant. *Astron. J.* **1998**, *116*, 1009–1038.

[3] Perlmutter, S.; et al. Measurements of Ω and Λ from 42 High-Redshift Supernovae. *Astrophys. J.* **1999**, *517*, 565–586.

[4] Wetterich, C. A Universe without expansion. *Phys. Dark Univ.* **2013**, *2*, 184–196.

[5] Born, M.; Infeld, L. Foundations of the New Field Theory. *Proc. R. Soc. A* **1934**, *144*, 425–451.

[6] Schwinger, J. On Gauge Invariance and Vacuum Polarization. *Phys. Rev.* **1951**, *82*, 664.

[7] Eisenstein, D.J.; et al. Detection of the Baryon Acoustic Peak in the Large-Scale Correlation Function of SDSS Luminous Red Galaxies. *Astrophys. J.* **2005**, *633*, 560–574.

[8] Sandage, A. The Change of Redshift and Apparent Luminosity of Galaxies with Time. *Astrophys. J.* **1962**, *136*, 319–333.

[9] Loeb, A. Direct Measurement of Cosmological Parameters from the Redshift Drift of Distant Sources. *Astrophys. J. Lett.* **1998**, *499*, L111–L114.

[10] Heisenberg, W.; Euler, H. Folgerungen aus der Diracschen Theorie des Positrons. *Z. Phys.* **1936**, *98*, 714.

[11] Angulo, D.; Sinclair, J.; Steinberg, A.M. Measuring Negative Time Spent by Photons in an Atomic Medium. *PRX Quantum* **2024**, *5*, 010314.