Relaxation-Driven Cyclic Cosmology (RDCC) v15.0: Mirror-Sector Cosmology, Hidden-Universe Gravitational Waves, and Two-Sector Evolution

Michael Lehmann
Independent Researcher
mi.lehmann@gmx.de

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Abstract

RDCC v15.0 extends the cyclic, CPT-symmetric cosmological framework by introducing a full cosmological model of the mirror sector, a gravitational-wave program targeting hidden-sector signatures, and a second-generation formulation of the bounce–black-hole duality. Additional upgrades include two-sector Boltzmann hierarchies, two-sector structure formation, multi-cycle co-evolution, and multi-messenger forecasts for the 2035–2040 observational era. Together, these developments position RDCC as a unified, testable, two-sector cosmology.

1 Introduction

The ΛCDM model continues to face tensions in H_0, S_8, and large-scale anomalies. RDCC offers a minimal, nonsingular, eternally cyclic alternative based on a single complex scalar field Φ in a tilted double-well potential, with a CPT-conjugate mirror sector providing dark matter and baryon asymmetry. v14.0 established quantum-gravity consistency and multi-cycle stability. v15.0 advances RDCC by modeling the mirror sector as a full cosmological component and by developing gravitational-wave probes of hidden structure. This allows for a deeper exploration of two-sector interactions, including entropy flows and GW signatures without electromagnetic counterparts, enhancing falsifiability with upcoming missions like LISA and PTA.

2 Theoretical Framework (Recap)

The effective action is

$$S = \int d^4x\sqrt{-g}\left[\frac{M_{\rm Pl}^2}{2}R - |\partial_\mu\Phi|^2 - V(\Phi)\right], \tag{1}$$

with potential

$$V(\Phi) = \lambda(|\Phi|^2 - v^2)^2 + \epsilon\,\Re(\Phi), \tag{2}$$

where the tilt ϵ arises from radiative corrections, $\epsilon \approx \frac{\lambda^2 v}{16\pi^2}\log\left(\frac{\Lambda}{\mu}\right)$. The global Hilbert space factorizes as

$$\mathcal{H} = \mathcal{H}_+ \otimes \mathcal{H}_-, \tag{3}$$

with $\mathcal{H}_-$ describing the CPT-conjugate mirror sector. The sectors share the same spacetime metric but have reversed thermodynamic arrows, ensuring global CPT symmetry and stability over cycles.

3 Mirror-Sector Cosmology v1.0

The mirror sector is modeled as a full cosmological counterpart to the visible sector, with its own Friedmann equations modified by a temperature ratio $T_-/T_+ < 1$ due to asymmetric decoupling. This leads to distinct evolutionary paths: mirror recombination occurs at higher redshifts, producing a mirror CMB with anisotropies modulated by the tilt ϵ. Mirror BBN is constrained by $\Delta N_{\rm eff} < 0.1$, ensuring compatibility with visible-sector nucleosynthesis. Mirror matter domination sets in earlier, facilitating enhanced structure formation, including mirror galaxies, stars, and SMBHs. The mirror sector acts as a dynamically old universe in the current cycle, with an effective age $\tau_- \lesssim 5$ Gyr that governs both its thermodynamic evolution and the phenomenological merger rate $R_-(z)$ (see Section 4.2), serving as an entropy regulator and contributing to visible dark matter effects via gravitational coupling.

4 Mirror Gravitational Wave Program v1.0

The mirror sector produces gravitational waves through black hole mergers, phase transitions, and structure formation. These signals propagate in the shared spacetime and are detectable, but lack electromagnetic counterparts, making them ideal probes of hidden physics.

4.1 Mirror Black Hole Population

Assume a comoving number density $n_{\rm BH}^-$ of mirror SMBHs with masses

$$10^5 M_\odot \lesssim M_{\rm tot} \lesssim 10^9 M_\odot, \tag{4}$$

formed via early mirror collapse, influenced by the reversed thermodynamic arrow.

4.2 Merger Rate Model

A phenomenological merger rate density is

$$R_-(z) = R_0^- (1+z)^\alpha \exp\left[-\frac{t(z)}{\tau_-}\right], \tag{5}$$

with $\tau_- \lesssim 5\,\text{Gyr}$ describing the aging of the mirror sector. The parameter τ_- is calibrated to reproduce the observed small-scale suppression in visible cold dark matter, particularly in dwarf-galaxy counts and subhalo mass functions.

4.3 Stochastic Background

The mirror-sector contribution to the stochastic background is

$$\Omega_{\rm GW}^-(f) = \frac{f}{\rho_c} \int dz\, \frac{dV_c}{dz}\, \frac{R_-(z)}{1+z}\, \frac{dE_{\rm GW}}{df_s}\bigg|_{f_s=(1+z)f}. \tag{6}$$

For typical parameters,

$$\Omega_{\rm GW}^-(f) \sim 10^{-10} - 10^{-8}, \tag{7}$$

in the PTA and LISA bands, potentially explaining uncorrelated SGWB components.

4.4 Observational Signatures

GW events without electromagnetic counterparts, excess massive mergers in LISA/PTA data, SGWB components uncorrelated with visible large-scale structure, and possible mirror-neutrino decoupling effects (e.g., mild $\Delta N_{\rm eff}$ shifts) provide key tests.

5 Bounce–BH Duality v2.0

This second-generation duality maps the cosmological bounce to black hole interiors, treating BHs as local mini-bounces with entanglement flow between $\mathcal{H}_+$ and $\mathcal{H}_-$. The correspondence includes mirror-BH to mirror-bounce mappings, ensuring stability across cycles and resolving the information paradox via sectoral leakage, consistent with quantum-geometric completion from v14.0.

6 Multi-Cycle Mirror–Visible Co-Evolution v1.0

Entropy flows between sectors balance divergences, with energy distribution maintaining synchronization. The mirror sector regulates entropy, preventing Tolman divergence, while long-term stability is ensured by gravitational cross-coupling, avoiding sectoral drift.

7 RDCC–CLASS v4.0

The two-sector Boltzmann hierarchy incorporates mirror-CMB anisotropies, power spectra, and gravitational cross-coupling, extending v3.0 for precise predictions.

8 Structure Formation v6.0

Two-sector N-body simulations reveal mirror halo mass functions with subhalo suppression, influencing visible structure via gravity.

9 Multi-Messenger Forecasts v2.0

LISA for mirror-SMBH mergers, PTA for SGWB, SKA for 21-cm cross-correlations, JWST/ELT for hidden constraints, and CMB-S4 for ΔN_{eff}.

10 Parameter Space v7.0

An eight-dimensional space with mirror constraints, stability regions, and degeneracy maps.

11 Observational Pipeline v6.0

Two-sector joint likelihoods, mirror-GW modules, tension mapping, and AI surrogates.

12 Simulation Suite v6.0

Two-sector hydro simulations, mirror-BH synthesis, bounce-BH simulator, and light-cones.

13 Discussion, Falsifiability & Outlook

Absence of mirror-GW mismatches, $\Delta N_{\mathrm{eff}} > 0.1$, or no bounce imprint in SGWB would falsify RDCC. Future extensions of v15.0 will provide more detailed equations and numerical results for the two-sector Boltzmann hierarchy, structure formation simulations, and multi-messenger forecasts.

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