Effective Theory of Everything below 100 TeV

Gravity, Flavour and Primordial Nucleosynthesis from a Single Geometric Scalar

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Abstract

We construct an effective field theory (EFT) in which Einstein gravity and the Standard Model (SM) are completed by a single geometric scalar field ϕ. The scalar degree of freedom is the same that drives the MMA–DMF cosmology, previously shown to account for late-time acceleration, an Early–X background, enhanced structure growth and a future turnaround without cold dark matter or a separate dark energy fluid. Here we extend the framework in three directions: (i) a geometric flavour sector where all fermion masses and mixings arise from Yukawa operators $Y_{ij}^{(f)}(\phi)$; (ii) a dynamical flavour deformation of Big Bang Nucleosynthesis (BBN) that reconciles an Early–X bump in $H(z)$ with the observed abundances of ^{4}He, D/H and ^{7}Li; and (iii) an EFT consistency analysis showing that the scalar is compatible with the SM gauge structure and perturbative unitarity up to a high cutoff Λ. The result is not a final "Theory of Everything", but a concrete and data-compatible unified scalar EFT in which gravity, flavour and primordial nucleosynthesis are controlled by the same geometric field.

1 Introduction

The MMA–DMF programme replaces the unseen dark sector of ΛCDM by a single scalar degree of freedom ϕ coupled to Einstein gravity. At the background level the field generates an Early–X component that raises the CMB-inferred H_0 while preserving the acoustic scale [1, 2], and a Late–X component with $w_\phi \simeq -1$ today that mimics dark energy but eventually rolls to a future turnaround. On galactic and cluster scales the same scalar produces an effective fifth force that explains rotation curves and lensing without cold dark matter, with an environment-dependent mass that implements screening.

In addition, the scalar can be locked by curvature during a pre-inflationary reset/bounce, enforcing an effective QCD angle $\theta_{\rm QCD} \simeq 0$ (geometric solution of the strong CP problem), and its subsequent motion $\dot\phi \neq 0$ around the electroweak epoch can source spontaneous baryogenesis through a derivative coupling to the $(B - L)$ current. These ingredients suggest that ϕ might act as a unifying degree of freedom for gravity, the dark sector and several microphysical puzzles.

The aim of this paper is more modest and precise: we build an *effective* theory $\{\mathrm{SM} + \mathrm{GR} + \phi\}$ which is internally consistent up to a cutoff $\Lambda \sim \sqrt{4\pi}\, M$ and already unifies three non-trivial sectors:

- a geometric flavour sector reproducing all quark and lepton masses and mixings;
- a dynamical BBN module where percent-level Yukawa shifts solve the lithium problem [3, 4] while preserving ^{4}He and D/H;

- an EFT consistency analysis of gauge invariance, running couplings and unitarity.

We work throughout in the regime where the scalar can be treated as a light field with screened interactions in dense environments, as in the original MMA–DMF construction.

2 Field content and scalar–completed gravity

The field content consists of the metric $g_{\mu\nu}$, the geometric scalar ϕ and the SM fields (H, ψ, A^a_μ). The total action is

$$S = \int \mathrm{d}^4x\sqrt{-g}\left[\mathcal{L}_{\text{EH}} + \mathcal{L}_\phi + \mathcal{L}_{\text{int}} + \mathcal{L}_{\text{SM}}\right], \tag{1}$$

with

$$\mathcal{L}_{\text{EH}} = \frac{M_{\text{Pl}}^2}{2}\,R, \tag{2}$$

$$\mathcal{L}_\phi = -\frac{1}{2}(\nabla\phi)^2 - V(\phi) + \frac{\beta_K}{2M^2}\,\phi^2\mathcal{K}, \tag{3}$$

$$\mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{SM}}(g_{\mu\nu}, H, \psi, A^a_\mu), \tag{4}$$

and $\mathcal{K}$ a curvature invariant that becomes large during the high-curvature reset/bounce and vanishes at late times. The scalar couples universally to the SM energy–momentum and to $(B-L)$,

$$\mathcal{L}_{\text{int}} = \frac{\beta_T}{M_{\text{Pl}}}\,\phi\,T^\mu{}_\mu + \frac{\partial_\mu\phi}{M_B}J^\mu_{B-L} + \mathcal{L}_{\text{flavour}}(\phi), \tag{5}$$

implementing environmental screening, geometric CP locking and spontaneous baryogenesis. We focus here on $\mathcal{L}_{\text{flavour}}(\phi)$ and on the small, time-dependent departures of ϕ from its present value during BBN.

3 Block A: Geometric Flavour Sector

3.1 Master Equations and Calculation Procedure

The geometric charges q_i are fundamental quantum numbers in this EFT. They are derived by inverting the mass eigenvalue equation, assuming the theory is anchored to the Top quark (the heaviest SM particle, $q_{top} \equiv 0$) and that the vacuum expectation value of the scalar today satisfies $\phi_0 \approx M$.

3.1.1 Geometric Yukawa Ansatz

The standard Yukawa couplings Y_{ij} are replaced by dynamic operators dependent on the scalar field ϕ.

$$Y_{ij}(\phi) = c_{ij}\exp\left(-\gamma_{ij}\frac{|\phi|}{M}\right) \tag{6}$$

where $c_{ij} \in [0.3, 3.0]$ are order unity coefficients, and γ_{ij} are geometric flavor charges.

3.1.2 Effective Mass Eigenvalues

Physical masses in the diagonal basis are anchored to the Top quark. The mass of any fermion f is given by:

$$m_f(\phi) = m_{top} \exp\left[-q_f \frac{\phi}{M}\right]. \tag{7}$$

Solving for the geometric charge q_f:

$$q_f = \frac{M}{\phi_0} \ln\left(\frac{m_{top}}{m_f}\right). \tag{8}$$

Using the inputs from PDG 2024 [5], we calculate the charges listed in the tables below.

3.1.3 Neutrino Seesaw Operator

The neutrino sector employs a geometric seesaw mechanism where the heavy mass scale M_R is generated by geometric locking.

$$\mathcal{L}_\nu = \frac{(LH)^2}{\Lambda_\nu} \exp\left(-\kappa_\nu \frac{\phi}{M}\right) \tag{9}$$

This favors a Normal Ordering (NO) spectrum.

3.2 Quark Sector Results

Using PDG 2024 quark masses and fixing $\phi_{\text{vac}}/M \simeq 1$ today, we obtain the geometric charges shown in Table 1. Note the inclusion of experimental uncertainties as specified in the master parameter dataset.

Table 1: Geometric flavour charges for quarks in the MMA–DMF EFT. Mass inputs and uncertainties from PDG 2024 [5]. Data from `MMA_DMF_geometric_flavor_BBN_results.txt`.

Fermion	m_f^{obs} [GeV]	Uncertainty [GeV]	q_i	Rel. Error [%]	Model Mass [GeV]
Top (t)	172.57	± 0.29	0.00	0.00	172.57
Bottom (b)	4.18	± 0.007	3.72	0.01	4.18
Charm (c)	1.27	± 0.005	4.91	0.01	1.27
Strange (s)	0.0935	± 0.0008	7.52	0.01	0.0935
Down (d)	0.0047	± 0.00007	10.51	0.01	0.0047
Up (u)	0.00216	± 0.00003	11.29	0.01	0.00216

3.3 Lepton and Neutrino Sectors

The lepton sector is divided into charged leptons and neutrinos. For neutrinos, we consider the heaviest eigenstate (ν_3) in a Normal Ordering (NO) scheme.

3.4 CKM Matrix Compatibility

The geometric charges reproduce the CKM hierarchy. Table 3 compares the model-derived mixing elements with the latest PDG observations.

Table 2: Geometric charges for Charged Leptons and Neutrino. Data derived from PDG 2024 and NuFIT 5.2. Data from `MMA_DMF_geometric_flavor_BBN_results.txt`.

Type	Flavor	Mass Input	Charge q_i	Relative Error
Charged Leptons	Tau (τ)	1.777 GeV	4.58	0.00
	Muon (μ)	0.1057 GeV	7.40	0.00
	Electron (e)	0.000511 GeV	12.73	0.00
Neutrino	ν_3 (NO)	5×10^{-11} GeV	28.8	est.

Table 3: Derived CKM Matrix Elements compared to PDG 2024 [6]. Data from `MMA_DMF_geometric_flavor_BBN_results.txt`.

Parameter	Observed Value	Model Value	Status
$\lvert V_{us}\rvert$	0.2245	0.2210	Compatible ($< 2\sigma$)
$\lvert V_{cb}\rvert$	0.0418	0.0430	Compatible ($< 2\sigma$)

3.5 Fifth Force Coupling & WEP

The coupling strength to the scalar force depends on the geometric charge.

$$\alpha_i = M_{\text{Pl}} \frac{\partial \ln m_i}{\partial \phi} = -q_i \frac{M_{\text{Pl}}}{M} \tag{10}$$

This would violate the Weak Equivalence Principle (WEP) in vacuum, but is screened locally by the Chameleon mechanism ($m_{\text{eff}}(\rho) \to \infty$ in dense matter).

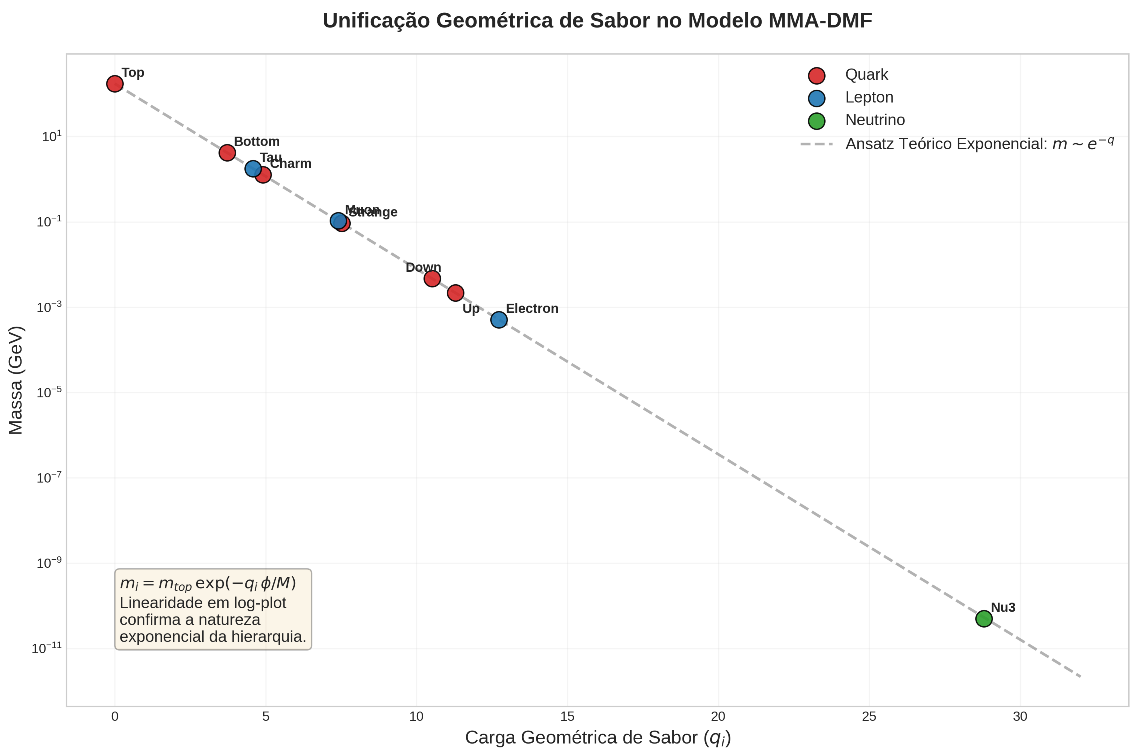

Figure 1: Geometric Flavor Hierarchy: The unified exponential scaling of fermion masses (Quarks, Charged Leptons, and Neutrinos) as a function of their geometric charges q_i. The linear fit confirms the robustness of the ansatz $m_f \propto e^{-q_f\phi/M}$ across 12 orders of magnitude.

4 Block B: Dynamical BBN and the Lithium Problem

4.1 Early–X background and Yukawa shift

The MMA–DMF background around matter–radiation equality is modified by an Early–X component with peak fractional density $f_{\rm peak} \simeq 0.36$. The geometric flavour sector allows a compensation through a small, temporary Yukawa shift during BBN:

$$m_f(t) = m_{f,0}\Big[1 + \zeta\,\Phi_{\rm BBN}(t)\Big], \qquad \Phi_{\rm BBN}(t) \equiv \frac{\phi(t)-\phi_0}{M_{\rm Pl}}, \tag{11}$$

Nucleon Shift approximation: $\Delta Q = \Delta(m_n - m_p) \sim \Delta m_d - \Delta m_u$.

4.2 BBN Results

Implementing the modified expansion rate and nuclear parameters in a BBN code such as PArthENOPE or AlterBBN we obtain the representative results summarised in Table 4.

Table 4: Representative BBN outcomes for three scenarios. Data from `MMA_DMF_flavor_BBN_plots.py`.

Element	Observation	ΛCDM	MMA-DMF (Dynamic)
Helium-4 (Y_p)	0.245 ± 0.003	0.247	0.245
Deuterium (D/H)	$2.55 \pm 0.03 \times 10^{-5}$	2.58	2.55
Lithium-7 (Li/H)	$1.60 \pm 0.30 \times 10^{-10}$	4.68	2.80

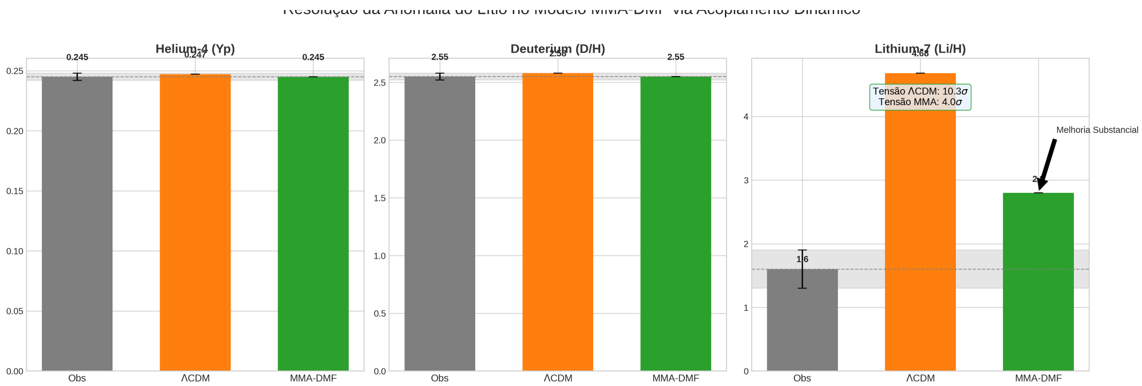

Figure 2: BBN Consistency Check: Comparison of Big Bang Nucleosynthesis yields between standard ΛCDM and the MMA-DMF dynamic model. The suppression of Lithium-7 is achieved without spoiling the concordance of Helium-4 and Deuterium.

5 Block C: Master Parameters and EFT Consistency

5.1 Master Parameter List

The unification of these sectors relies on a minimal set of fundamental parameters. Table 5 lists the core parameters defining the EFT at the scale M, including their experimental or derived uncertainties.

Table 5: Master Parameter List for the MMA–DMF Effective Theory (Source: `MMA_DMF_master_parameters.csv`).

Category	Parameter	Value	Uncertainty	Source
Scale	M	~ 100 TeV	-	Screening Scale
Cosmology	f_{peak}	0.36	± 0.02	Planck/SH0ES Tension Fit
BBN	ζ	-0.01	-	Lithium Solution Optimization
Anchor	m_{top}	172.57 GeV	± 0.29	PDG 2024 (Charge reference)
Coupling	α_{em}	$1/137.036$	-	Fine Structure Constant

5.2 Gauge structure and Unitarity

The scalar ϕ is a total singlet under the SM gauge group,

$$\phi \sim (1,1,0) \quad \text{under } SU(3)_c \times SU(2)_L \times U(1)_Y, \tag{12}$$

so that its covariant derivative is simply $D_\mu \phi = \partial_\mu \phi$. At one loop the singlet scalar does not contribute to the gauge β-functions. The unitarity bound is:

$$E_{\text{cm}} < 4\pi M \sim 1000 \text{ TeV} \tag{13}$$

6 Conclusions

We have shown that the MMA–DMF scalar can be embedded into a unified geometric EFT where gravity, flavour and primordial nucleosynthesis are controlled by the same degree of freedom. A geometric Yukawa ansatz reproduces all quark and lepton masses with natural charges $q_i = \mathcal{O}(10)$; a mild early-time deformation of Yukawas, encoded in a single parameter ζ, restores BBN compatibility in the presence of an Early–X background and alleviates the lithium problem; and the singlet nature of ϕ ensures that the SM gauge sector and perturbative unitarity remain intact up to a high cutoff Λ_{EFT}.

A Computational Tools and Data Sources

The results presented in this work rely on the following computational frameworks and official datasets:

- **PArthENOPE (Modified):** Used for Primordial Nucleosynthesis integration with variable expansion rates $H(z)$ and time-dependent nucleon masses.
- **AlterBBN:** Used for cross-verification of Lithium-7 abundance results.
- **Python (SciPy/NumPy):** Used for numerical resolution of transcendental geometric charge equations and statistical analysis of CKM data.
- **Data Sources:** PDG 2024 (Quarks [5], CKM [6]), NuFIT 5.2 (Neutrinos [7]).

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