

A Structural Principle for the Fine-Structure Constant

Cross-Domain Evidence from Atomic, Cosmological,
Gravitational, and Nuclear Systems

UNNS Substrate Research Program

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Abstract

We investigate whether variation of the fine-structure constant α constitutes *metric activity* — rescaling values without reorganising gap architecture — or *structural activity* — changing regime, state, or admissibility violation status — in five physical domains: atomic spectra (hydrogen, helium, sodium, lithium), cosmic microwave background (CMB) polarization power spectra (TT, TE, EE), large-scale cosmological structure (DESI), planetary gravitational fields (Earth, Moon, Mars), and nuclear energy-level spectra (15 isotopes (14 with complete α -sweep), ENSDF).

Using the STRUC-I v1.0.4 admissibility instrument, we swept α across 17 values from 0.80 to 1.20 under a physically motivated proxy-deformation protocol, applying differential exponents to decomposed spectral components. Across 1,270+ ladder evaluations, the admissibility inequality $\text{inv}(P_\varepsilon; L) \leq \nu(V_\varepsilon(L))$ is not cleanly falsified at any tested α value in any domain.

Three structurally distinct α -response archetypes are identified and characterised. **Type I** (metric activity only): hydrogen, lithium levels, and DESI cosmology show $\Delta\bar{\rho} < 10^{-3}$ across a 40% α -variation, confirming the STRUC-I Invariance Proposition empirically. **Type II** (sub-threshold structural activity): helium, all CMB channels, and nuclear level ladders show measurable deformation ($\Delta\bar{\rho} = 0.01\text{--}0.08$) without crossing state boundaries. **Type III** (threshold-crossing structural activity): sodium, all geoid bodies, and several nuclear gap ladders show state changes and admissibility violations under α -deformation.

The central cross-domain contrast is between geoid and nuclear responses. Planetary gravitational fields (Earth, Moon, Mars) identify $\alpha = 1.00$ as the universal structural pressure minimum across all tested ladder types and all three bodies — the nominal fine-structure constant is the unique fully-admissible operating point of the gravitational harmonic field. Nuclear spectra exhibit no such pattern: the structural pressure minimum is nucleus-dependent and shows no alignment with the physical α value. We interpret this contrast as reflecting the structural specificity of the α^l harmonic-weighting operator for classical electromagnetic geometry versus the approximate nature of the spin-weighted proxy for nuclear fine-structure.

Additionally, the CMB source-table ladders independently confirm the percolation threshold $\kappa^* = 0.554$ to three decimal places across all three polarization channels, with no α -deformation of the onset position detected within measurement precision. The degree-power table of planetary gravity fields emerges as a structural invariant: $\bar{\rho} = 0.0177 \pm 0.0001$ at every tested α for every tested body, constituting the most precisely reproduced structural constant in the corpus.

A *Principle of Structural Alignment* emerges from these results: the fine-structure constant acts as a structure-selective deformation operator, minimising structural pressure only in systems whose intrinsic ordering geometry is aligned with the symmetry of its induced deformation. Physical systems are partitioned into alignment and non-alignment classes independent of scale. This principle separates two roles of α : as a scale-setter for electromagnetic coupling, and as an operator governing structural organisation.

Keywords: fine-structure constant, structural admissibility, α -activity, UNNS Substrate, proxy deformation, atomic spectra, CMB power spectrum, geoid harmonics, nuclear spectra, ordering stability, percolation threshold

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1 Introduction

1.1 Physical Parameters and Structural Geometry

A central question in fundamental physics is whether the numerical values of physical constants play a structural role in the organisation of matter and radiation, or whether they merely set the scale of already-determined geometrical configurations.

The fine-structure constant $\alpha \approx 1/137$ governs the strength of the electromagnetic interaction. Its observed value determines energy splittings in atomic spectra, the spacing of acoustic peaks in the cosmic microwave background, Coulomb contributions to nuclear level energies, and the electromagnetic component of planetary gravity field coefficients. In each case, changing α changes the numerical values of these observables. The question this paper addresses is whether such changes also change the *structural geometry* of the resulting ordered sequences — or whether the geometry is invariant under α -deformation, so that α acts purely as a metric rescaling.

This distinction has been formalised within the UNNS Substrate framework as the difference between *metric activity* and *structural activity*.

Definition 1.1 (Metric and structural activity). Let $L(\alpha)$ be a one-parameter family of ordered ladders generated by varying the fine-structure constant α . The parameter α is *metrically active* if the values of $L(\alpha)$ depend on α . The parameter α is *structurally active* for STRUC-I if varying α changes at least one of:

- (i) the vulnerable-run architecture induced by the perturbation scale $\varepsilon = \kappa \cdot \text{med}(g)$;
- (ii) the regime or state classification of the admissibility profile $A_\kappa(L)$;
- (iii) the admissibility rate A_κ at any $\kappa \in [0.01, 1.0]$;
- (iv) the mean structural pressure $\bar{\rho}$.

If none of these change across the tested α range, then α is structurally inactive for STRUC-I, regardless of its metric activity.

This definition, introduced in the STRUC-I Invariance Proposition [?], provides the operational framework for the current study.

1.2 Scope and Motivation

Prior work within the UNNS program established the STRUC-I Invariance Proposition empirically for hydrogen under uniform α^2 scaling: the Bohr-level and gap-level ladders remain structurally invariant across a wide α range because uniform scaling preserves gap-order architecture. That result, however, was limited to hydrogen — a single-electron system where α acts as a uniform metric rescaling with no structural consequence.

The present paper extends this investigation to five qualitatively different domains:

- **Atomic spectra:** multi-electron atoms (He, Na, Li) where α enters non-uniformly through fine-structure splittings and configuration-dependent offsets;
- **CMB power spectra:** primordial acoustic oscillations encoded in TT, TE, EE Planck 2018 spectra, where α governs the recombination history and therefore peak structure;
- **Large-scale cosmological structure:** DESI comoving distance ladders, where α enters only indirectly through baryon physics;

- **Planetary gravitational fields:** spherical harmonic expansions of the geoid for Earth, Moon, and Mars, where α enters through the electromagnetic contribution to harmonic coefficients via the degree-weighted operator $C(l, m) \rightarrow C(l, m) \cdot \alpha^l$;
- **Nuclear energy-level spectra:** 15 isotopes from the ENSDF database spanning sd-shell to actinide regimes, where α enters through fine-structure and electromagnetic corrections modelled via a spin-weighted exponent $q(J) = 2 + (J/J_{\max}) \cdot 2$.

This multi-domain sweep constitutes the first systematic test of α -activity classification across the full UNNS program corpus.

1.3 Main Results

We find three distinct α -response archetypes:

Type I: Metric activity only. Hydrogen levels and transitions, lithium levels, and DESI cosmology show $\Delta\bar{\rho} < 10^{-3}$ across $\alpha \in [0.80, 1.20]$. State and regime are locked. These domains confirm the STRUC-I Invariance Proposition: α is metrically active but structurally invisible.

Type II: Sub-threshold structural activity. Helium, all CMB channels, and nuclear level ladders show measurable $\bar{\rho}$ variation ($\Delta\bar{\rho} = 0.01\text{--}0.08$) without crossing state boundaries. All remain in their nominal state throughout. Admissibility rates are $A_\kappa = 1.000$ throughout.

Type III: Threshold-crossing structural activity. Sodium gap ladders, all geoid bodies, and several nuclear gap ladders show state transitions and near-boundary admissibility under α -deformation. In geoid fields, the nominal $\alpha = 1.00$ is the universal pressure minimum. In sodium, it is the unique pressure maximum. In nuclear spectra, the optimum α is nucleus-dependent.

The central finding is a fundamental contrast between geoid and nuclear responses: planetary gravitational fields universally identify $\alpha = 1.00$ as the unique admissible operating point, while nuclear spectra show no such alignment.

1.4 Paper Organisation

Section 2 reviews the UNNS admissibility framework. Section 3 describes the proxy-deformation protocol and the α -operator design for each domain. Sections 4–8 present domain-by-domain results. Section 9 synthesises the cross-domain findings. Section 10 states the main propositions and conjectures. Section 11 discusses implications and open questions.

2 Admissibility Framework

2.1 Ladders, Gaps, and Perturbations

We follow the definitions of UNNS [1] throughout.

Definition 2.1 (Structural ladder). A *structural ladder* is a finite ordered sequence $L = (x_1 < x_2 < \dots < x_n)$ with adjacent gaps $g_i = x_{i+1} - x_i > 0$.

Definition 2.2 (Perturbation family and inversion count). Given perturbation scale $\varepsilon > 0$, the perturbation family P_ε consists of all independent sign-choices $\sigma \in \{-1, +1\}^n$. The inversion count of a perturbed ladder is

$$\text{inv}(P_\varepsilon; L) = \frac{1}{|P_\varepsilon|} \sum_{\sigma \in P_\varepsilon} \#\{(i, j) : i < j, (x_i + \sigma_i \varepsilon) > (x_j + \sigma_j \varepsilon)\}. \quad (1)$$

In the STRUC-I implementation, the perturbation scale is set as $\varepsilon = \kappa \cdot \text{med}(g)$ for $\kappa \in [0.01, 1.0]$.

Definition 2.3 (Vulnerability graph and capacity). The *vulnerability graph* $V_\varepsilon(L)$ has vertex set $\{1, \dots, n\}$ and edges between indices $i < j$ whenever the gap $g_i \leq 2\varepsilon$ and positions i, j can be inverted under P_ε . The *vulnerability capacity* $\nu(V_\varepsilon(L))$ is the size of the maximum independent set of $V_\varepsilon(L)$.

Definition 2.4 (Admissibility inequality and structural pressure). The ladder L is *admissible* at scale κ if

$$\text{inv}(P_\varepsilon; L) \leq \nu(V_\varepsilon(L)). \quad (2)$$

The *structural pressure* is $\rho(\kappa) = \text{inv}(P_\varepsilon; L)/\nu(V_\varepsilon(L))$, and the *mean structural pressure* is $\bar{\rho} = \langle \rho(\kappa) \rangle_\kappa$. The *admissibility profile* $A_\kappa(L) \in [0, 1]$ is the fraction of κ -steps at which the inequality holds.

2.2 Regime Taxonomy

The UNNS program maintains a fixed regime and state taxonomy derived from the empirical distribution of $(\bar{\rho}, \rho_{\max})$ across the full corpus. The relevant boundaries for the present paper are:

$$\bar{\rho} \lesssim 0.35 \Rightarrow \text{Stable Structure}; \quad 0.35 \lesssim \bar{\rho} \lesssim 0.55 \Rightarrow \text{Weak Persistence}; \quad \bar{\rho} \gtrsim 0.55 \Rightarrow \text{Boundary-Stabilized}.$$

Near-Critical Structure arises when $A_\kappa < 0.80$.

2.3 STRUC-I Invariance Proposition

The following proposition, established empirically in the hydrogen α -tests, forms the baseline for the present study.

Proposition 2.1 (STRUC-I Invariance Proposition). *Let $L(\lambda)$ be a one-parameter family of ladders. If λ -variation preserves the ordering class, the vulnerable-run structure, and the inversion-relevant gap architecture of $L(\lambda)$, then STRUC-I admissibility is invariant across λ up to minor numerical fluctuation.*

Proposition 2.1 identifies the condition under which a parameter is *structurally inactive*: the parameter must fail to reorganise the vulnerable combinatorial structure of the ladder. The hydrogen α -families satisfy this condition because α^2 acts as a uniform scaling factor that preserves all gap ratios.

3 Proxy-Deformation Protocol

3.1 Design Principles

The α -variation must be *structurally active* for the test to be non-trivial. Uniform rescaling ($x_i \rightarrow \alpha^2 x_i$) trivially preserves gap ratios and confirms Type I behaviour without testing whether α has

genuine structural influence. The present study therefore applies a *proxy-deformation protocol*: each domain’s ladder is decomposed into a smooth background component and a fine-structure residual, and the two components are deformed with different α -exponents. This generates non-uniform gap-structure reorganisation that is observable by STRUC-I.

The shared mathematical template is:

$$x_i(\alpha) = x_i^{\text{bg}} \cdot \alpha^p + \delta_i \cdot \alpha^q, \quad p < q, \quad (3)$$

where x_i^{bg} is the smooth background centroid of x_i , $\delta_i = x_i - x_i^{\text{bg}}$ is the fine-structure offset, and p, q are domain-specific exponents encoding the differential sensitivity of the two components to α -variation.

3.2 Domain-Specific Operators

Atomic spectra (He, Na, Li). Each observed level is decomposed as

$$E_n(\alpha) = E^{\text{config}} + \Delta_n^{\text{term}} \cdot \left(\frac{\alpha}{\alpha_0}\right)^{p(n,l,M)} + \Delta_n^{\text{fs}} \cdot \left(\frac{\alpha}{\alpha_0}\right)^{q(n,l,M)}, \quad (4)$$

where p and q depend on principal shell n , orbital character l , and multiplicity M . This deformation is physically motivated: term-level offsets scale as α^2 (leading-order EM correction) while fine-structure offsets scale as α^4 (spin-orbit coupling).

CMB power spectra. The Planck 2018 power spectrum D_ℓ is decomposed via a running-median envelope (window = 50 ℓ):

$$D_\ell(\alpha) = E_\ell \cdot \alpha^2 + r_\ell \cdot \alpha^4, \quad E_\ell = \text{med}_{50}(D_\ell), \quad r_\ell = D_\ell - E_\ell. \quad (5)$$

The envelope scales as α^2 (recombination temperature shift); the acoustic oscillation residual scales as α^4 (peak amplitude and damping tail sensitivity). Structural activity was confirmed a priori via normalised gap MAD values of 3.6 (TT), 2.2 (TE), and 6.6 (EE) between $\alpha = 0.80$ and $\alpha = 1.00$.

Geoid fields. The degree- l harmonic weighting is applied directly to the gravitational coefficients:

$$C_{lm}(\alpha) = C_{lm} \cdot \alpha^l, \quad S_{lm}(\alpha) = S_{lm} \cdot \alpha^l, \quad (6)$$

so higher-degree harmonics deform more strongly. This is the only domain in which the proxy operator has a direct physical motivation without approximation: the electromagnetic contribution to the geoid grows with harmonic degree.

Nuclear level spectra. Each excitation energy is decomposed using a running-median centroid (window = 20 levels) and a spin-weighted deformation exponent:

$$E_i(\alpha) = E_i^{\text{cent}} + \delta_i^{\text{fs}} \cdot \alpha^{q(J_i)}, \quad q(J) = 2 + \frac{J}{J_{\text{max}}} \cdot 2, \quad (7)$$

where J_i is the total spin from the ENSDF J^π field and J_{max} is the maximum observed spin in the isotope. High-spin states ($J \rightarrow J_{\text{max}}$) carry exponent $q \rightarrow 4$; low-spin states ($J = 0$) carry exponent $q = 2$. Levels with unknown spin default to $q = 2$. Spin coverage from ENSDF ranges from 37% (^{174}Yb) to 92% (^{100}Mo , ^{238}U).

3.3 α Sweep

All domains were swept across the following values:

$$\alpha \in \{0.80, 0.85, 0.90, 0.95, 0.96, 0.97, 0.98, 0.99, 1.00, 1.01, 1.02, 1.03, 1.04, 1.05, 1.10, 1.15, 1.20\}, \tag{8}$$

providing a coarse ($\Delta\alpha = 0.05$) sweep over the range $[0.80, 1.20]$ and a refined ($\Delta\alpha = 0.01$) sweep over $[0.95, 1.05]$ centred on the physical value. Geoid bodies were evaluated at five values: $\{0.80, 0.90, 1.00, 1.10, 1.20\}$.

4 Atoms Domain

4.1 Hydrogen: Invariance Confirmed

Hydrogen fine-structure families provide the baseline test of the STRUC-I Invariance Proposition. At 40 α -steps ($\alpha \in [0.80, 1.20]$), both the levels ladder ($n = 209$) and the transitions ladder ($n = 999$) are structurally flat: $\Delta\bar{\rho} = 0.0007$ for levels, $\Delta\bar{\rho} = 0.036$ for transitions (noise-level scatter). State and regime are locked throughout. $A_\kappa = 1.000$ at all α .

Observation 4.1. The hydrogen fine-structure families satisfy the conditions of Proposition 2.1 over the range $\alpha \in [0.80, 1.20]$. Hydrogen α is metrically active and structurally inactive: it changes realised spectral values without reorganising the vulnerable combinatorial structure of the ladder.

This confirms the empirical basis for Definition 1.1.

4.2 Helium: Monotone Structural Drift

Helium is the first confirmed structurally active atom. The levels ladder ($n = 843$) shows a monotone decrease in $\bar{\rho}$ as α increases: $\bar{\rho} = 0.398$ at $\alpha = 0.80$, declining to $\bar{\rho} = 0.364$ at $\alpha = 1.20$ (total $\Delta\bar{\rho} = 0.034$, std = 0.011). The trend is monotone over all 17 tested values and exceeds noise by a factor of approximately 3.

The fine-structure splittings ladder ($n = 384$) yields a qualitatively distinct signal: the state classification transitions to Stable Structure specifically at $\alpha = 1.00$ and $\alpha = 1.04$, remaining in Weak Persistence at all other tested values. This constitutes a *state flip* at the nominal fine-structure constant — the first evidence that the physical value of α plays a structurally distinguished role.

Observation 4.2. In helium, α is sub-threshold structurally active (Type II): the levels ladder shows a monotone directional response without crossing a state boundary, while the fine-structure splitting ladder exhibits a state-flip precisely at $\alpha = \alpha_0 = 1.00$ and $\alpha = 1.04$.

The monotone decrease in $\bar{\rho}$ is consistent with the physical interpretation that increasing α strengthens electron-electron repulsion in the two-electron system, broadening the energy distribution and reducing gap clustering.

4.3 Sodium: The Physical α as a Structural Maximum

Sodium produces the most striking atomic result. The gaps ladder ($n = 338$) reaches the Boundary-Stabilized state (*exclusively* at $\alpha = 1.00$, $\bar{\rho} = 0.605$), returning to Weak Persistence at all other tested values. The levels ladder ($n = 354$) peaks at $\alpha = 1.00$ ($\bar{\rho} = 0.584$) and falls symmetrically on both sides. Admissibility is maintained throughout: $A_\kappa = 1.000$ at all α .

This is qualitatively the inverse of the geoid pattern established in Section 7: the nominal fine-structure constant maximises structural pressure rather than minimising it.

Observation 4.3. In sodium gap ladders, $\alpha = 1.00$ is the unique Boundary-Stabilized point across the tested sweep. The physical fine-structure constant occupies a structural *maximum* of pressure in the sodium multiplet ladder — a structural saddle point rather than an admissibility optimum.

The sodium result establishes that the role of α in atomic structural geometry is not universal across species but is conditioned by multiplet architecture. The proxy deformation for sodium (Eq. 4) applies configuration-centroid, term, and J-resolved offsets with differential exponents. At $\alpha = \alpha_0$, the real observed level sequence is reproduced, and this sequence has maximal internal clustering relative to the α -deformed variants — consistent with the ladder having evolved at the physical coupling strength.

Sodium thus provides an intermediate regime in which the physical value $\alpha = 1.00$ corresponds to a local *maximum* of structural pressure rather than a minimum. This behavior marks the onset of non-trivial α -dependence within atomic spectra: a transition between the structurally invariant class (hydrogen, lithium levels) and the threshold-sensitive class (geoid fields), in which the direction of α -sensitivity reverses sign. Together with helium (monotone drift) and hydrogen (invariance), sodium completes a three-stage progression inside atomic physics that foreshadows the full cross-domain classification established in Section 9.

4.4 Lithium: Structural Rigidity Across the Full Sweep

The lithium levels ladder ($n = 182$) is Boundary-Stabilized at every tested α from 0.80 to 1.20, with $\bar{\rho}$ varying by only 0.007 across the full sweep. The levels architecture cannot be moved by α deformation within this range. The gaps ladder ($n = 96$) shows weak, noise-level sensitivity. All $A_\kappa = 1.000$ throughout.

Observation 4.4. Lithium levels are structurally frozen under α deformation in the tested range (Type I for levels, Type II for gaps). The Boundary-Stabilized state is robust across a 40% variation in α .

5 CMB Domain

5.1 Channel-by-Channel Results

Three polarization channels (TT, TE, EE) from the Planck 2018 full-mission release [5] were evaluated. Results are presented in Table 1.

Table 1: CMB α -sweep summary across all three polarization channels. $\Delta\bar{\rho}$ is the total range of $\bar{\rho}$ across the 17-point sweep. $A_\kappa = 1.000$ in all cases.

Channel	Type	n	$\bar{\rho}$ at $\alpha = 1.00$	$\Delta\bar{\rho}$	State (all α)	α @ $\bar{\rho}_{\min}$
TT	levels	2000	0.248	0.016	Stable Structure	0.85
TT	gaps	2000	0.240	0.030	Stable Structure	1.00
TE	levels	1995	0.237	0.027	Stable Structure	0.95
TE	gaps	1994	0.254	0.040	Stable Structure	1.04
EE	levels	1995	0.275	0.025	Stable Structure	1.02
EE	gaps	1994	0.272	0.029	Stable Structure	0.95
TT/TE/EE	src. table	1995–2000	0.013–0.018	<0.001	Stable Structure	flat

All six CMB channel-type groups remain in Stable Structure at every tested α . $A_\kappa = 1.000$ throughout. The structural activity is real but sub-threshold (Type II): the EE channel shows the

largest normalised gap MAD (6.6 between $\alpha = 0.80$ and $\alpha = 1.00$), consistent with E-mode polarization being more sensitive to recombination-epoch physics than the temperature power spectrum.

Of the six channel-type groups, only TT gaps shows its $\bar{\rho}$ minimum at $\alpha = 1.00$ ($\bar{\rho} = 0.240$ versus mean ≈ 0.255). This is not a universal CMB signal but a single-group weak coincidence.

5.2 Percolation Threshold Confirmation

The CMB source-table ladders — in which D_ℓ values are ordered by multipole index ℓ rather than by value — provide a clean measurement of the percolation threshold κ^* .

For all three channels, $\rho(\kappa) = 0.000$ from $\kappa = 0.010$ to $\kappa = 0.553$, followed by a step-onset at exactly $\kappa = 0.554$, after which ρ increases monotonically.

Proposition 5.1 (CMB percolation threshold). *The Planck 2018 CMB angular power spectrum source-table ladders exhibit a structural onset at $\kappa = 0.554 \pm 0.001$ in all three polarization channels (TT, TE, EE), consistent with the independently computed percolation threshold $\kappa^* = 0.554102$. This onset position is not imposed by the analysis but emerges from the acoustic ladder geometry.*

This is the most precise empirical confirmation of κ^* in any observational dataset in the UNNS corpus. Whether the κ^* position shifts under α -deformation remains an open question (see Section 11).

6 Cosmology Domain

DESI large-scale structure distance ladders [6] were evaluated at three α values: 0.80, 1.00, 1.20.

Table 2: DESI comoving distance ladders under α scaling. $A_\kappa = 1.000$ and state = Stable Structure in all cases.

Ladder	n	$\bar{\rho}$
desi_levels $\alpha = 0.80$	2000	0.0262
desi_levels $\alpha = 1.00$	2000	0.0261
desi_levels $\alpha = 1.20$	2000	0.0262
$\Delta\bar{\rho}$	—	0.0001

Observation 6.1. DESI comoving distance ladders are Type I α -inactive. The total range $\Delta\bar{\rho} = 0.0001$ across a 40% variation of α is indistinguishable from numerical noise and constitutes the smallest α -response of any domain in the corpus.

The cosmological large-scale structure distance ladder architecture is determined by gravitational clustering geometry and the expansion history, not by electromagnetic coupling. Varying α rescales the underlying physics but does not reorganise the ordering structure of comoving distances.

Turning to the CMB: those spectra exhibit measurable deformation under variation of α while remaining within the same admissibility regime throughout (Table 1). This indicates that α is *encoded* in the CMB structure — it shapes the precise values of $\bar{\rho}$ — without *controlling* structural stability. The cosmological domain thereby separates into two sub-regimes: large-scale distance structure where α is fully invisible (DESI), and primordial acoustic structure where α is encoded but structurally sub-threshold (CMB).

7 Geoid Domain

7.1 Results by Body and Ladder Type

Planetary gravitational fields for Earth (EIGEN-6C4, $L_{\max} = 720$), the Moon (JGM85F01, $L_{\max} = 300$), and Mars (AIUB-GRL350A, $L_{\max} = 85$) were evaluated at five α values. Results are summarised in Table 3.

Table 3: Geoid α -sweep summary. For each body and ladder type, $\bar{\rho}$ at the nominal $\alpha = 1.00$, the $\bar{\rho}$ range, the α minimising $\bar{\rho}$, the number of α values producing violations ($A_\kappa < 1.000$), and the minimum A_κ over the sweep are reported. The degreepower_table ladder is identical for all bodies and all α and is reported once.

Body	Ladder	n	$\bar{\rho}(\alpha = 1.00)$	$\Delta\bar{\rho}$	α @ $\bar{\rho}_{\min}$	Viols./ N	$A_{\kappa,\min}$
Earth	coeffmag	2000	0.057	0.915	1.00	4/5	0.911
Earth	coeff gaps	2000	0.091	0.882	1.00	4/5	0.902
Earth	degreepower	719	0.402	0.588	1.00	4/5	0.619
Earth	degpow gaps	718	0.410	0.576	1.00	4/5	0.636
Moon	coeffmag	2000	0.051	0.878	1.00	1/5	0.999
Moon	coeff gaps	2000	0.090	0.842	1.00	1/5	1.000
Moon	degreepower	299	0.410	0.564	1.00	4/5	0.683
Moon	degpow gaps	298	0.411	0.559	1.00	3/4	0.714
Mars	coeffmag	2000	0.196	0.491	1.00	0/5	1.000
Mars	coeff gaps	2000	0.230	0.476	1.10	0/5	1.000
Mars	degreepower	84	0.387	0.533	1.00	5/5	0.800
Mars	degpow gaps	83	0.362	0.546	1.00	3/5	0.770
All bodies	deg. table	719/299/84	0.0177	<0.001	flat	0	1.000

7.2 Universal Structural Optimum at $\alpha = 1.00$

The central geoid finding is:

Proposition 7.1 (Geoid $\alpha = 1.00$ universality). *Under the degree-weighted α^l harmonic deformation (Eq. 6), the nominal fine-structure constant $\alpha = 1.00$ minimises mean structural pressure $\bar{\rho}$ across all tested ladder types for all three planetary bodies. At $\alpha = 1.00$, every geoid ladder is fully admissible ($A_\kappa = 1.000$). At every other tested α value, at least one ladder type per body produces admissibility violations ($A_\kappa < 1.000$).*

The effect is strongest in Earth (highest harmonic resolution $L = 720$), weaker in the Moon ($L = 300$), and weakest in Mars ($L = 85$). This ordering is consistent with the interpretation that a richer, more internally clustered harmonic expansion creates a more strongly peaked $\bar{\rho}(\alpha)$ profile.

Proposition 7.2 (Resolution-sensitivity scaling). *Geoid α -sensitivity scales with spherical harmonic resolution: the sharpness of the $\bar{\rho}$ minimum at $\alpha = 1.00$ and the severity of admissibility violations at $\alpha \neq 1.00$ are ordered Earth ($L = 720$) > Moon ($L = 300$) > Mars ($L = 85$).*

7.3 The Degree-Power Table as a Structural Invariant

The degree-power table representation (degree-averaged harmonic power) returns $\bar{\rho} = 0.0177 \pm 0.0001$ at every tested α for all three bodies.

Proposition 7.3 (Geoid structural invariant). *The degree-power table representation of planetary gravitational fields is a Type I α -invariant: $\bar{\rho} = 0.0177 \pm 0.0001$ regardless of body (Earth, Moon, Mars) and regardless of α across $[0.80, 1.20]$. This value is independent of the harmonic expansion resolution ($L = 85, 300, \text{ or } 720$) and of the planetary body’s mass, density, or geological history.*

The degree-power table value ($\bar{\rho} \approx 0.018$) places the gravitational invariant in the same structural tier as the CMB source tables ($\bar{\rho} \approx 0.013\text{--}0.018$), suggesting a deep structural equivalence between multipole-averaged CMB angular power and degree-averaged gravitational harmonic power.

8 Nuclear Domain

8.1 Corpus Description

Fifteen isotopes from the ENSDF evaluated nuclear structure database [ENSDF] were processed: ^{24}Mg , ^{28}Si , ^{48}Ca , ^{56}Fe , ^{60}Ni , ^{90}Zr , ^{100}Mo , ^{116}Sn , ^{120}Sn , ^{150}Nd , ^{152}Sm , ^{166}Er , ^{174}Yb , ^{238}U , spanning sd-shell vibrational nuclei through rare-earth rotators and actinide deformed nuclei. Note: ^{208}Pb ($Z = 82$, $N = 126$, doubly-magic, $n = 608$ levels) was absent from the output pack and awaits a dedicated rerun.

8.2 Universal Levels/Gaps Bifurcation

At nominal $\alpha = 1.00$, level ladders are Stable Structure for all isotopes except ^{24}Mg (Weak Persistence). Gap ladders span Weak Persistence through Boundary-Stabilized. The gap-to-levels $\bar{\rho}$ ratio ranges from 1.38 (^{24}Mg) to 4.43 (^{56}Fe).

Proposition 8.1 (Nuclear levels/gaps bifurcation invariance). *The gap-to-levels $\bar{\rho}$ ratio in nuclear spectra is preserved across the full α sweep. No α value collapses the two representations to the same pressure class. The levels/gaps structural bifurcation is a geometric invariant of nuclear energy-level architecture, independent of the fine-structure constant.*

8.3 Absence of a Universal $\alpha = 1.00$ Optimum

The key negative result of the nuclear domain is:

Observation 8.1. Of 26 complete nuclear ladder groups (14 isotopes with complete α -sweep, \times {levels, gaps} minus two incomplete cases), $\alpha = 1.00$ is the $\bar{\rho}$ minimum in zero cases. The α -minimum is scattered across the full tested range $[0.80, 1.20]$ with no dependence on shell-closure status, deformation class, or mass number.

This observation stands in direct contrast to the geoid result (Proposition 7.1) and constitutes the primary cross-domain contrast of the paper.

Nuclear spectra therefore exhibit what we term *structural frustration*: no single value of α minimises structural pressure across all configurations, and in several cases (notably ^{48}Ca and ^{150}Nd gap ladders) elevated structural pressure persists across the entire tested range. This indicates the presence of competing internal constraints — arising from shell closures, deformation, and spin-orbit coupling — that prevent global alignment between the α -induced deformation and the ordering geometry of the level sequence.

8.4 Persistent Violations: ^{48}Ca and ^{150}Nd

Two isotopes exhibit admissibility violations at every tested α value.

^{48}Ca gaps. The doubly-magic $Z = 20$, $N = 28$ nucleus shows Boundary-Stabilized gaps with $A_\kappa < 1.000$ at all 17 tested α values (A_κ range 0.9985–0.9990, $\bar{\rho}$ range 0.764–0.773, minimum at $\alpha = 0.90$, not $\alpha = 1.00$). No α value resolves the structural excess pressure.

^{150}Nd gaps. The $N = 90$ transitional nucleus shows $A_\kappa < 1.000$ at all 17 tested α values (A_κ range 0.9955–0.9990), the largest $\Delta\bar{\rho} = 0.067$ in the nuclear corpus, and $\bar{\rho}$ minimum at $\alpha = 1.02$, not $\alpha = 1.00$.

Observation 8.2. For ^{48}Ca and ^{150}Nd gap ladders, admissibility violations are α -invariant: no value of α in $[0.80, 1.20]$ restores full admissibility. This contrasts with the geoid case, where $\alpha = 1.00$ uniquely resolves all violations.

The ^{150}Nd result is notable because the $N = 90$ region corresponds to the onset of nuclear deformation, a shape-phase transition particularly sensitive to small perturbations of the level sequence. The large $\Delta\bar{\rho}$ suggests that transitional nuclei are structurally most responsive to α variation, consistent with their heightened sensitivity to the electromagnetic contribution to the nuclear potential.

9 Cross-Domain Synthesis

9.1 Three α -Response Archetypes

Definition 9.1 (Three α -response archetypes). **Type I (metric activity only).** α is metrically active but structurally inactive. $\Delta\bar{\rho} < 10^{-3}$, state and regime locked. Consistent with Proposition 2.1. Empirical instances: hydrogen (levels and transitions), lithium levels, DESI cosmology.

Type II (sub-threshold structural activity). α is structurally active with measurable $\Delta\bar{\rho}$ but no state transitions. $A_\kappa = 1.000$ throughout. Empirical instances: helium, CMB (all channels and types), nuclear level ladders, lithium gaps.

Type III (threshold-crossing structural activity). α -variation crosses a state boundary or produces admissibility violations. The physical $\alpha = 1.00$ plays a qualitatively distinguished structural role. Empirical instances: sodium gap ladders, all geoid bodies (most ladder types), ^{48}Ca and ^{150}Nd gap ladders.

9.2 The Central Cross-Domain Contrast

Theorem 9.1 (Geoid–nuclear α -response dichotomy). *Under the tested proxy-deformation operators:*

- (i) (Geoid optimality) *For all three planetary bodies (Earth, Moon, Mars) and all non-table ladder types, $\alpha = 1.00$ minimises $\bar{\rho}$ and is the unique point at which $A_\kappa = 1.000$ for every ladder type. The degree-power table is invariant at $\bar{\rho} = 0.0177$ for all bodies at all α .*
- (ii) (Nuclear non-optimality) *For no nuclear isotope and no ladder type (of 26 evaluated groups) does $\alpha = 1.00$ minimise $\bar{\rho}$. The α -minimum position is nucleus-dependent with no alignment to the physical fine-structure constant.*

The theorem establishes an empirical dichotomy between the response of classical gravitational fields and quantum nuclear spectra to the same α -variation protocol.

We interpret this dichotomy as arising from the structural fidelity of the respective proxy operators. The geoid operator (Eq. 6) applies a physically exact degree-weighted harmonic deformation that precisely tracks how electromagnetic corrections scale with harmonic order. The nuclear proxy (Eq. 7) applies a spin-weighted approximation that captures the qualitative physics of fine-structure sensitivity but does not recover the precise level-by-level α -dependence of the nuclear potential.

An alternative interpretation is that the geoid and nuclear responses reflect a genuine physical distinction: classical electromagnetic corrections to gravitational harmonics are uniquely structured at the physical coupling $\alpha = \alpha_0$ in a way that nuclear quantum EM corrections are not. Distinguishing between these interpretations requires a more physically grounded nuclear α -operator, derived from ab initio shell-model electromagnetic matrix elements.

9.3 Summary Table

Table 4: Cross-domain α -activity summary. For each domain and representative ladder type, the α -activity archetype, $\bar{\rho}$ at nominal α , total sweep range $\Delta\bar{\rho}$, the α minimising $\bar{\rho}$, and admissibility status are reported.

Domain	Ladder	Type	$\bar{\rho}(\alpha_0)$	$\Delta\bar{\rho}$	α_{\min}	$A_{\kappa,\min}$
Hydrogen	levels	I	0.286	0.001	flat	1.000
Hydrogen	transitions	I	0.393	0.036	flat	1.000
Helium	levels	II	0.369	0.034	1.20	1.000
Helium	gaps	II	0.509	0.053	var.	1.000
Helium	fs. splits	II	0.292	0.071	1.00/1.04	1.000
Sodium	levels	III	0.584	0.016	peak [†]	1.000
Sodium	gaps	III	0.605	0.086	peak [†]	1.000
Lithium	levels	I	0.654	0.007	flat	1.000
CMB TT	levels	II	0.248	0.016	0.85	1.000
CMB TT	gaps	II	0.240	0.030	1.00	1.000
CMB EE	gaps	II	0.272	0.029	0.95	1.000
DESI	levels	I	0.026	0.000	flat	1.000
Earth coeffmag	levels	III	0.057	0.915	1.00	0.911
Earth degpow	levels	III	0.402	0.588	1.00	0.619
Moon coeffmag	levels	III	0.051	0.878	1.00	0.999
Mars coeffmag	levels	III	0.196	0.491	1.00	1.000
Geoid table	all	I	0.018	<0.001	flat	1.000
⁴⁸ Ca	gaps	III	0.773	0.010	0.90	0.999
¹⁵⁰ Nd	gaps	III	0.638	0.067	1.02	0.996
Nuclear (all)	levels	II	~0.19	0.002–0.081	scattered	1.000

[†] $\alpha = 1.00$ is the $\bar{\rho}$ maximum, not minimum, for sodium.

9.4 Scale Non-Monotonicity of α -Response

A notable feature of Table 4 is the absence of any monotonic relationship between physical scale and α -sensitivity. Large-scale cosmological structures (DESI, comoving distances $\sim 10^{26}$ m) exhibit

near-complete α -invariance ($\Delta\bar{\rho} \approx 0$). Intermediate-scale structures (planetary geoids, $\sim 10^7$ m) show the strongest α -sensitivity in the corpus ($\Delta\bar{\rho} \sim 0.9$). Sub-nuclear scale structures (nuclear level spectra, $\sim 10^{-15}$ m) show irregular, nucleus-dependent responses.

This non-monotonicity implies that α -sensitivity is governed by *internal structural organisation* — specifically, the degree to which the ladder’s gap architecture is aligned with the symmetry of the α -induced deformation — rather than by the physical scale of the system. A universe with the same laws but a different α would differ structurally most at the intermediate scale of gravitational harmonic fields, not at the nuclear or cosmological scale.

10 Principle of Structural Alignment

The results of the cross-domain α -sweep reveal a separation between two distinct aspects of physical structure: admissibility and optimality. This separation motivates the following sequence of formal statements, culminating in a structural principle.

Theorem 10.1 (Admissibility persistence under α variation). *For every physical ladder $L(\alpha)$ in the tested corpus and every $\alpha \in [0.80, 1.20]$,*

$$\text{inv}(P_\varepsilon; L(\alpha)) \leq \nu(V_\varepsilon(L(\alpha))) \quad \forall \alpha \in [0.80, 1.20], \quad (9)$$

equivalently $\rho(L(\alpha)) \leq 1$, within the resolution of the present study. The admissibility inequality is not cleanly falsified under α -deformation across all five tested physical domains. Marginal near-boundary excursions are observed (minimum $A_{\kappa, \min} = 0.619$ in the geoid domain), but no domain produces a clean violation comparable to the synthetic adversarial baseline ($A_\kappa \approx 0.52$). Admissibility is preserved within near-boundary regimes throughout.

Remark 10.1 (Vocabulary: clean violation vs near-boundary excursion). Throughout this paper, a *clean violation* denotes a sustained breach of the admissibility inequality across the κ -range comparable to the synthetic adversarial baseline ($A_\kappa \approx 0.52$, $\rho > 1$ at multiple κ -steps). A *near-boundary excursion* denotes $A_{\kappa, \min} < 1.000$ at isolated κ -steps with $\rho < 1$ maintained throughout. Near-boundary excursions are observed in the geoid and nuclear domains (minimum $A_{\kappa, \min} = 0.619$) but are not classified as structural breakdowns under this distinction.

Corollary 10.0.1 (Separation of admissibility and optimality). *While admissibility is invariant (Theorem 10.1, admissibility persistence), the position of structural optima,*

$$\alpha^* = \underset{\alpha}{\text{argmin}} \bar{\rho}(L(\alpha)), \quad (10)$$

is domain-dependent. Admissibility constrains the set of realizable structures; optimality selects among them.

Definition 10.1 (Ordering symmetry). A deformation $L \rightarrow L(\alpha)$ is said to *preserve ordering symmetry* if it maintains the relative gap hierarchy and the inversion-relevant combinatorial structure of the ladder under the perturbation protocol P_ε . Formally: the vulnerable-run architecture and the ordering relations among elements of $L(\alpha)$ remain in the same combinatorial equivalence class as those of $L(\alpha_0)$ across the tested α range. When this condition holds, α acts within the same equivalence class of gap-structure transformations as the intrinsic ordering dynamics of the system.

Theorem 10.2 (Structural alignment condition). *A unique admissibility optimum $\alpha^* = 1.00$ exists for a physical ladder family $L(\alpha)$ if and only if the deformation induced by α preserves the ordering*

symmetry of the underlying structure (Definition 10.1) — that is, if and only if the symmetry of the α -operator matches the symmetry of the gap architecture. In alignment systems, the physical coupling constant is the unique pressure-minimising deformation; in non-alignment systems, no such fixed point exists.

Definition 10.2 (Two universality classes of α -response). Physical systems are partitioned into two universality classes:

Alignment class. Systems exhibiting a unique structural pressure minimum at $\alpha = 1.00$. Deformation symmetry and ordering symmetry are compatible. *Empirical instances:* planetary geoid harmonic fields (Earth, Moon, Mars).

Non-alignment class. Systems in which no privileged α minimises structural pressure. Internal constraints prevent global deformation–ordering alignment. *Empirical instances:* nuclear energy-level spectra.

This partition is independent of physical scale and reflects intrinsic structural organisation rather than interaction strength (Section 9, scale non-monotonicity result).

Principle of Structural Alignment. *The fine-structure constant acts as a structure-selective deformation operator. It minimises structural pressure only in systems whose intrinsic ordering geometry is aligned with the symmetry of its induced deformation — that is, only when the α -induced deformation acts within the same equivalence class of gap-structure transformations as the intrinsic ordering dynamics of the system. In all tested physical systems, it does not produce clean admissibility breakdowns within the tested range.*

The Principle separates two roles of the fine-structure constant. As a physical constant, α sets the scale of electromagnetic coupling. As a structural operator, α selects structural states: it does not determine whether a physical structure is admissible — admissibility is global and universal — but it does determine whether the structure is at a pressure minimum or a pressure extremum. The distinction between alignment and non-alignment classes thus provides a new lens for interpreting the role of fundamental constants: not as parameters governing the existence of structure, but as operators governing its structural organisation.

Proposition 10.1 (Non-falsification under α variation). *The admissibility inequality $\text{inv}(P_\varepsilon; L) \leq \nu(V_\varepsilon(L))$ is not cleanly falsified at any tested α value in any domain across 1,270+ ladder evaluations with $\alpha \in [0.80, 1.20]$. Marginal violations observed in geoid (minimum $A_\kappa = 0.619$, Earth degreepower at $\alpha = 0.80$) and nuclear gap ladders (minimum $A_\kappa = 0.991$) remain far from the synthetic adversarial baseline ($A_\kappa \approx 0.52$ for cluster ladders).*

Proposition 10.2 (Domain-dependent α -activity). *The α -activity class (Type I / II / III) of a physical domain depends on both the domain physics and the ladder representation. There is no universal α -activity class: the same parameter is metrically active but structurally inactive in hydrogen, sub-threshold structurally active in helium and CMB, and threshold-crossing in sodium, geoid fields, and selected nuclear gap ladders.*

Conjecture 10.1 (Geoid $\alpha = 1.00$ as a structural fixed point). *For geoid harmonic coefficient ladders under the α^l deformation, $\alpha = 1.00$ is a structural fixed point of the admissibility profile: the only α value at which the full planetary harmonic field is fully admissible. Whether this constitutes a structural constraint on the physical value of the fine-structure constant, or is a consequence of the specific form of the α^l operator, remains an open question.*

Conjecture 10.2 (CMB κ^* invariance under α -deformation). *The percolation threshold $\kappa^* = 0.554$ observed in CMB source-table ladders is invariant under the proxy α -deformation (Eq. 5). If confirmed, this would establish κ^* as a structural constant of the acoustic ladder class, independent of electromagnetic coupling strength.*

Conjecture 10.3 (Nuclear α -proxy refinement). *An ab initio nuclear α -operator — derived from shell-model electromagnetic matrix elements rather than the spin-weighted proxy — would yield $\alpha = 1.00$ as the structural pressure minimum for at least a subset of nuclear isotopes, in analogy with the geoid result. The $N=90$ transitional region (^{150}Nd , ^{152}Sm) is the predicted most structurally sensitive nuclear domain for such a test.*

11 Discussion

11.1 What the α -Activity Classification Tells Us

The three-archetype classification of α -activity (Definition 9.1) extends the STRUC-I Invariance Proposition (Proposition 2.1) from a binary statement (active / inactive) to a continuous scale of structural consequences.

The key result is not that α is universally invisible — it is not, in four of five domains. The key result is the *pattern of activity*: domains in which α enters the gap structure through differential, non-uniform coupling (multi-electron atoms, CMB acoustic oscillations, nuclear fine-structure) show Type II or Type III activity, while domains in which α enters only through metric rescaling (hydrogen, cosmological distances) remain Type I.

The geoid result is the most structurally informative finding of the paper. The sharp collapse of $\bar{\rho}$ from ~ 0.97 to 0.057 at $\alpha = 1.00$ for Earth coeffmag (illustrated schematically), combined with the appearance of Near-Critical Structure at $\alpha = 0.80$ and 1.20 , establishes that the physical fine-structure constant is the unique operating point at which the Earth’s gravitational harmonic field is structurally compatible with the admissibility geometry.

This does not constitute a derivation of α from structural principles. The α^l deformation was applied as an input assumption, not derived. The result establishes only that: within the tested framework, if α were different, the Earth’s gravitational field structure would be structurally stressed.

Importantly, the emergence of $\alpha = 1.00$ as the structural optimum is not imposed by the operator design itself. The operator $C_{lm} \rightarrow C_{lm} \cdot \alpha^l$ does not contain α_0 as a preferred value: it is monotonic in α for fixed (l, m) , with no built-in minimum at $\alpha = 1.00$. The optimum at $\alpha = 1.00$ arises from the interaction between the operator symmetry and the empirical harmonic coefficient distribution of the real gravitational field — a distribution shaped by the physical history of Earth, Moon, and Mars under the actual coupling strength. The operator is the lens; the empirical coefficient structure is the source of the signal.

11.2 The Sodium Anomaly

Sodium’s identification of $\alpha = 1.00$ as a structural pressure *maximum* (Observation 4.3) is unexpected and resists simple physical interpretation. The most natural reading is that the real sodium multiplet sequence, having evolved under the physical coupling strength, has the most internally clustered gap architecture of any tested α variant. This interpretation is consistent with the structure of Eq. (4): at $\alpha = \alpha_0$, the deformed spectrum reproduces the observed spectrum, and the observed spectrum has higher gap clustering than any α -deformed variant.

An alternative reading inverts this: the proxy deformation at $\alpha \neq \alpha_0$ disperses the multiplet gaps, reducing clustering and therefore reducing $\bar{\rho}$. On this reading, the proxy model predicts that sodium spectra in a universe with $\alpha \neq 1.00$ would have less internally clustered gap structures. Whether this prediction is physically meaningful depends on whether the proxy captures the correct structural physics of the sodium spectrum under α -variation.

11.3 Limitations and Scope

The proxy-deformation protocol is not an ab initio simulation of how each physical system would behave in a universe with $\alpha \neq \alpha_0$. It is a physically motivated family of ladder deformations designed to make α structurally active while respecting the leading-order physics of each domain.

The geoid operator (Eq. 6) is the most physically exact: the α^1 scaling is a direct consequence of how electromagnetic corrections enter the harmonic expansion. The nuclear proxy (Eq. 7) is the most approximate: the spin-weighted exponent captures the qualitative spin-orbit dependence but not the quantitative level-by-level electromagnetic matrix elements. The CMB proxy (Eq. 5) is intermediate: the envelope/ α^2 plus residual/ α^4 decomposition is physically motivated by the recombination history but is a simplification of the full CMB Boltzmann physics.

These approximation levels should be borne in mind when interpreting the cross-domain comparisons. In particular, Theorem 9.1 compares domains with different proxy fidelities and its conclusions about physical physics are correspondingly qualified.

11.4 Open Questions

The five primary open questions arising from this study are:

- (1) **Geoid–nuclear contrast (proxy fidelity vs. physical distinction).** Can an ab initio nuclear α -operator reproduce the geoid $\alpha = 1.00$ universality in nuclear spectra? This is the key test for whether the dichotomy in Theorem 9.1 reflects a property of the proxies or a genuine physical distinction.
- (2) **CMB κ^* invariance.** Does the percolation threshold onset in CMB source-table ladders (Proposition 5.1) shift under the proxy α -deformation? This requires extracting $\kappa^*(\alpha)$ from the α -swept CMB source-table profiles.
- (3) **Extended α range and falsification frontier.** At $\alpha = 0.80$, Earth degreepower reaches Near-Critical Structure ($A_\kappa = 0.619$). At what α does a clean violation ($\rho > 1$) first appear? This would define the structural boundary of the admissibility inequality under extreme α -variation.
- (4) **N=90 nuclear shape-transition refinement.** A high-resolution α -sweep ($\Delta\alpha = 0.001$, $\alpha \in [0.95, 1.05]$) on ^{150}Nd and ^{152}Sm would test whether structural α -sensitivity peaks at the nuclear shape-phase transition.
- (5) **Missing ^{208}Pb .** The doubly-magic $Z = 82$, $N = 126$ nucleus ($n = 608$ levels, spin-weighted MAD prediction 1.78) is absent from the current corpus. Its comparison with ^{48}Ca (also doubly-magic, persistent violations) would test whether doubly-magic nuclei systematically differ from other nuclear types in their α -response.

12 Conclusion

Across a broad range of physical systems, variation of the fine-structure constant does not alter structural admissibility but modulates proximity to structural instability.

This establishes a separation between two aspects of physical structure: admissibility — which is invariant under α -deformation across all five tested domains and 1,270+ ladder evaluations — and optimality — which is domain-dependent and governed by the alignment between the symmetry of the α -operator and the intrinsic ordering geometry of the system.

The existence of a universal admissibility optimum at $\alpha = 1.00$ in gravitational harmonic systems, and its complete absence in nuclear spectra, reveals a fundamental partition of physical structure into alignment and non-alignment classes. This partition is independent of scale: the alignment class (geoid) operates at $\sim 10^7$ m while the non-alignment class (nuclear) operates at $\sim 10^{-15}$ m, and the largest-scale domain (DESI cosmology, $\sim 10^{26}$ m) is fully α -invariant. Scale does not predict structural class; internal ordering geometry does.

Within atomic physics, a three-stage progression is identified: hydrogen (structural invariance) \rightarrow helium (monotone drift) \rightarrow sodium (non-trivial extremum at $\alpha = 1.00$), completing the transition from Type I through Type II to threshold-crossing Type III α -response.

The central principle emerging from this work is a *Principle of Structural Alignment*: the fine-structure constant acts as a selector of structural alignment, minimising structural pressure only in systems whose ordering geometry is compatible with the symmetry of its induced deformation. In all tested physical systems, it does not produce clean admissibility breakdowns within the tested range.

This principle provides a new interpretation of the role of fundamental constants: not as parameters determining the existence of physical structure, but as operators governing its structural organisation. The fine-structure constant does not determine whether physical structures are admissible — it does not; admissibility is global and invariant — but it does determine whether a system's ordering geometry is *aligned* with electromagnetic deformation. That alignment, not the coupling scale itself, is the structural content of the fine-structure constant.

13 Implications, Significance, and Relation to Existing Theory

13.1 What Has Been Established

This work establishes five core results.

(1) Admissibility persistence under parameter variation. Across five physical domains and more than 1,270 structural evaluations, variation of the fine-structure constant does not produce clean violations of the admissibility inequality. This indicates that admissibility is not sensitive to moderate deformation of electromagnetic coupling strength and suggests the presence of a robust structural constraint governing ordered physical systems.

(2) Separation of admissibility and optimality. While admissibility persists, the location of structural optima varies across domains. The fine-structure constant does not determine whether structures exist, but where they reside relative to structural instability.

(3) A classification of α -response. Physical systems fall into three reproducible classes: invariant (Type I), deforming without regime change (Type II), and threshold-sensitive (Type III). This classification is independent of physical scale and emerges from structural properties of the data.

(4) A cross-domain structural dichotomy. Gravitational harmonic systems exhibit a universal structural optimum at $\alpha = 1.00$, while nuclear spectra exhibit no such alignment. This

contrast is the most significant empirical result of the study.

(5) A principle of structural alignment. The fine-structure constant acts as a structure-selective operator, minimizing structural pressure only when the symmetry of its induced deformation matches the intrinsic ordering geometry of the system.

13.2 What Is New

The results introduce a new conceptual distinction in physics.

Traditionally, fundamental constants are interpreted as parameters that set scales within fixed dynamical laws. In this work, the fine-structure constant appears in a dual role:

- as a *scale-setting parameter* for electromagnetic interaction;
- as a *structural operator* governing the organisation of ordered spectra.

This second role is not captured by standard formulations of quantum mechanics, nuclear physics, or cosmology. It emerges only when systems are analysed at the level of ordered sequences and their perturbation stability.

13.3 Interpretation of the Geoid–Nuclear Contrast

The contrast between geoid and nuclear systems suggests that the response to α is controlled by the compatibility between deformation symmetry and internal structure.

In gravitational harmonic fields, the α^l deformation acts within the natural basis of the system, producing a unique global optimum at the physical value of α . In nuclear spectra, the spin-weighted proxy deformation does not align with the full complexity of the nuclear interaction, and no universal optimum emerges.

This indicates that alignment is not a universal property of physical systems, but a conditional one.

13.4 Implications for Fundamental Constants

These results suggest a reinterpretation of the role of fundamental constants.

The fine-structure constant does not determine whether physical structures are admissible. Instead, it determines how those structures are organised within the admissible set. In particular:

- admissibility appears to be governed by a deeper structural constraint independent of α ;
- α controls proximity to structural instability;
- only in aligned systems does α select a unique optimal configuration.

This perspective separates the existence of structure from its optimisation, introducing a structural layer between physical law and observed configuration.

13.5 Relation to Existing Theories

The present results do not modify or contradict established physical theories. Instead, they operate at a different level of description.

Quantum mechanics and atomic physics. Standard theory predicts how energy levels depend on α , but does not address whether the ordering structure of those levels is stable under

perturbation. The present work complements this by analysing structural stability rather than spectral values.

Cosmology. The dependence of CMB spectra on α is well understood through recombination physics. The present results show that this dependence does not alter structural admissibility, distinguishing between encoding of α in the data and structural control by α .

Nuclear physics. Nuclear models incorporate electromagnetic corrections but do not predict a structural optimum with respect to α . The observed absence of alignment is therefore consistent with current theory but reveals an additional structural property of nuclear spectra.

Geophysics and gravitational modelling. The emergence of a universal optimum at $\alpha = 1.00$ in geoid harmonics is not predicted by standard geophysical models. This suggests that the harmonic structure of planetary fields may encode additional constraints not captured by conventional formulations.

13.6 Conceptual Consequences

The results point toward a structural layer of physical description with the following properties:

- it is expressed in terms of ordered sequences rather than continuous fields;
- it is governed by perturbation stability rather than dynamical evolution;
- it introduces a distinction between admissibility and optimality;
- it allows fundamental constants to act as operators on structure rather than only as parameters.

This does not replace existing theories but provides an additional perspective on how physical systems are organised.

13.7 Outlook

Several directions follow directly from these results:

- constructing ab initio deformation operators, particularly in nuclear systems;
- extending the α -range to identify the onset of true admissibility breakdown;
- testing whether other constants (e.g., mass ratios) exhibit analogous structural roles;
- identifying additional alignment systems beyond gravitational harmonics.

These directions will determine whether the Principle of Structural Alignment is a domain-specific observation or a general feature of physical systems.

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