Apeiron: The Universal Carrier Hypothesis and a Programme for Its Physical Realization

Foundations, an explicit effective theory, and tests

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Foundations paper, version 2.0 — 23 September 2026

Abstract

Apeiron proposes one universal fundamental dynamical carrier whose differently organized states may underlie observable matter, dark-sector phenomena and effective causal geometry. We place this hypothesis at the centre of a research programme that requires explicit dynamics, controlled bridges to physical sectors and discriminating observable relations. The original geometry, reconversion, entropy and conditional quantum branches are stated with their physical commitments. Each proposed realization must specify its assumptions and failure conditions; additional structure creates a new accountable version rather than turning a failed prediction into confirmation. As a concrete mathematical foundation for this programme, we retain an explicitly defined local three-field scalar effective theory, its parameter benchmark and its checked equations. Its derivative-dependent tilt fixes the phase kinetic normalization. Within the admissible timelike-gradient domain, the phase characteristic is positive and no faster than the metric cone. The same action satisfies the null energy condition there and excludes a nonsingular spatially flat bounce under minimal Einstein coupling. A previously checked local spectrum supplies a numerical benchmark, and a conditional characteristic relation identifies the inputs needed for a physical test. These results establish consequences of a specified effective sector. Deriving that sector and observed physical structures from the universal carrier is the central remaining task. The paper thus presents a foundational hypothesis, a constrained programme for its realization and a retained mathematical core on which that programme can be critically developed.

1 Motivation and scope

The Apeiron hypothesis asks whether the physical diversity of the universe can arise from different organizations of one fundamental dynamical carrier. Matter, dark-sector phenomena and causal geometry would then require a common physical account. The ambition is explanatory: a successful realization must derive restrictive relationships among these manifestations and recover their observed behaviour. Unity as a description is insufficient unless the proposed dynamics makes it consequential.

This paper gives that ambition a definite starting point. It first states the original universal-carrier hypothesis and the physical roles of its principal branches. It then formulates a research programme whose individual realizations can succeed, fail or remain unresolved under stated criteria. The second part retains the already checked local scalar theory, including its equations, parameters, corrected kinetic normalization and negative cosmological consequence. This order makes the intended theory visible while keeping its mathematical support inspectable.

The source is the original Apeiron preprint v1.6, its retained canonical specification v1.5, and the recovered internal scalar-EFT record [1, 2]. Sections 4–6 and Appendix A reproduce the

mathematical core of the preceding local-theory paper without altering its text. This version adds the foundational account and programme, rather than a new physical calculation. The companion change note and source matrix distinguish recovered source commitments from the proposed programme discipline.

An effective theory is a suitable first controlled component of a foundational programme because it makes equations and consequences explicit. Its status is also precise: an internally assessable sector does not derive the entire ontology. The outstanding bridges are substantive research questions, identified below with the outputs and failures that would decide particular realizations.

2 The universal fundamental carrier hypothesis

2.1 The physical proposal

Apeiron postulates one universal fundamental dynamical carrier, whose differently organized states may underlie observable matter, dark-sector phenomena and effective causal geometry. This is the organizing hypothesis of the programme. Its aim is a common physical account of apparently different sectors through their states, organization and dynamics. A successful realization would have to explain their differences as well as their common origin.

The terms have definite roles. *Universal* states the intended reach across physical sectors. *Fundamental* places the carrier beneath the effective descriptions used for those sectors. *Carrier* names the proposed physical basis whose organization supports them; it does not identify a particular observed particle or fix a microscopic state space. The original formulation does not select a constituent lattice, an additional canonical scalar, or a unique pre-geometric dynamics. Those choices would be substantive theoretical commitments, to be specified and tested in a realization. The source for this interpretation is the original single-carrier statement in preprint v1.6, section 3.4, with its causal-geometry development in sections 11.1–11.4 [1].

In that proposal, ordinary baryonic matter is an organized manifestation of the same carrier. Dark-matter-like gravitational effects and dark-energy-like large-scale behaviour are possible manifestations or dynamical states, rather than independently postulated fundamental substances. This is a proposed explanatory relation, not an identification already supplied by the scalar action below. The Higgs/QCD branch similarly asks whether known structures can arise as organized low-energy manifestations, while retaining the established Standard Model structures and the QCD $SU(3)$ framework. A useful derivation must recover their content; changing their names would explain nothing.

Additional particles are compatible with a one-carrier ontology in principle. Their existence alone would therefore neither refute nor confirm it. A particular Apeiron realization must instead provide a dynamical account of their properties and an independently checkable relation. Section 3 imposes this requirement on extensions, including dark-sector proposals.

2.2 Why an effective theory is part of the programme

The hypothesis motivates a progression from an underlying physical account to controlled descriptions and then to observations. Effective fields label degrees of freedom useful in a stated regime. Their number need not equal the number of fundamental constituents. The three variables σ, θ, χ in the retained model are therefore not three fundamental substances, and none is automatically identical to the complete universal carrier. The radial/order-parameter-like and phase-like descriptions are effective interpretations; they do not establish a fundamental canonical complex field.

The local scalar model supplies something concrete: an action, a chosen parameter point, field equations, an admissible domain and consequences that can be checked. The logical connection runs from the specified action to those consequences. Deriving that action from the universal

carrier, or deriving observed matter from its modes, requires further maps and dynamics. We retain this distinction because it identifies the next theoretical work, rather than because it diminishes the intended scope of the hypothesis.

The noncanonical pressure belongs to the established k-essence framework [3]. The contribution here is the source-faithful formulation of the particular Apeiron sector and its place in a wider programme. The programme does not claim priority for that general mathematical framework.

2.3 Geometry and a common causal limit

The original causal proposal is that a stable observable phase of the carrier supports a single effective geometry for light, matter and gravity. Its schematic organization can be written

$$\mathcal{A} \longrightarrow G_{\mu\nu}[\mathcal{A}] \longrightarrow \{\text{light, matter, gravity}\}. \tag{1}$$

Here $\mathcal{A}$ is a collective descriptor of the proposed carrier and $G_{\mu\nu}[\mathcal{A}]$ denotes the intended effective geometry. Neither a carrier action nor the indicated map is specified by this schematic expression. In particular, $G_{\mu\nu}[\mathcal{A}]$ here is not the Einstein tensor $G_{\mu\nu}$ used later in the conventional gravity equations. We retain the source's schematic notation only in (1).

The target is a common finite limiting speed in the observable phase. The source does not require a separate universal microscopic speed c_A, a hidden ordinary proper time for photons, or a classical refractive substance that slows light from a larger ordinary speed. A proposed deeper development parameter is not yet a derived physical clock. The origin of Lorentz symmetry and universal coupling to one metric remain theoretical tasks. Nor does this proposal determine the numerical SI value assigned to c.

The retained action later gives a precise, narrower result: its canonical fields have the metric principal cone, and its phase sector has a controlled characteristic cone in the stated domain, coinciding with the metric cone at zero gradient. This supplies a consistency property of that effective sector. Universal light–matter–gravity coupling on physical backgrounds requires a separate derivation.

2.4 Organization, reconversion and entropy

Extreme curvature motivates a second source branch: organized matter-like manifestations may de-organize toward more fundamental Apeiron states. The original post-freeze reconversion extension uses an organization variable s, a transport field u^μ and a curvature-response variable, denoted here $\mathcal{R}$ to distinguish it from the scalar kinetic coefficient $K(z)$. Its proposed relations are

$$0 \le s \le 1, \qquad u^\mu \nabla_\mu s = -\Gamma_{\text{rec}}\, C(\mathcal{R})\, s, \qquad \Gamma_{\text{rec}} \ge 0, \quad 0 \le C < 1, \tag{2}$$

$$\tau_{\mathcal{R}} u^\mu \nabla_\mu \mathcal{R} = W - \mathcal{R}, \qquad W \ge 0, \tag{3}$$

$$\nabla_\mu T^{\mu\nu}_{\text{AP}} = 0. \tag{4}$$

The endpoints $s = 1$ and $s = 0$ label organized matter-like and more fundamental carrier states, respectively. The latter is not nothingness or an additional identified field. These relations reproduce the form of the separate extension in preprint section 10.5; its response variable and relaxation time have merely been renamed together. No identification $s = \sigma$ or $\mathcal{R} = K(z)$ is implied.

The original branch reports structural feasibility for directed de-organization, total stress conservation and compatible causal evolution. Equations (2)–(4) alone do not close that system. Constitutive functions, a total stress tensor and couplings to the scalar sector are required before a complete evolution or hyperbolicity claim can be assessed. They are not additions to the action in section 4.

The accompanying information/entropy proposal assumes transformation or re-encoding within one physical system, rather than destruction of information. Information preservation is distinct from constant entropy. Entropy may be produced, transferred or redistributed, and a newly formed observable low-entropy phase would need to be accounted for within a larger entropy budget. The original Genesis/cyclic motivation is retained at this level of assumptions. A quantitative total entropy balance and a generalized-second-law test are still required. Local covariant stress conservation in (4) also does not supply a globally conserved cosmological energy number by itself [1, sections 10.5–10.6].

2.5 The conditional quantum branch

The source's entanglement extension is conditional: *if* the carrier is quantum and supports nonseparable states, separated manifestations can be described as parts of a common quantum state. Standard quantum state and measurement rules are assumed. The proposal neither derives the Born rule nor replaces those rules with a Bell-local classical hidden-variable model. Bell's result constrains the latter class under its stated assumptions [4]. Quantum nonseparability does not permit a controllable faster-than-light signal under the standard measurement rules [5, sections 2.4–2.5]. The carrier interpretation presently supplies no distinct entanglement prediction beyond that framework [1, section 11A].

These branches articulate the original physical ambition. Their joint realization requires explicit bridges among carrier dynamics, effective variables, geometry, quantum states and organization. The next section turns those missing bridges into a finite programme of accountable tasks.

3 A programme of constrained realizations

3.1 What counts as progress

The universal-carrier hypothesis provides an organizing proposal; a *realization* makes restricted choices of states, dynamics and observable relations. This paper fixes one local scalar sector, denoted here the retained effective realization. The wider research programme is to construct and test the bridges that would give that sector, and eventually other sectors, a common physical basis.

Four evidential categories will be used. A *hypothesis* states a proposed physical relation. A *derived result* follows from specified equations and assumptions. A *retained benchmark* records an existing numerical choice or output with its provenance. An *open task* requires a missing derivation, input or test. Agreement inside one category cannot silently establish another. In particular, mathematical consistency is necessary work toward a physical theory, while empirical support requires an observable comparison.

The programme is ordered by dependencies. A concrete realization must identify its degrees of freedom and regime; supply the dynamics and matching maps; demonstrate internal control; and only then compare calibrated observables with data. Some branches can develop in parallel, but they cannot borrow a missing premise from the existence of another branch. Each version must freeze its target, assumptions, allowed parameter freedom or estimation rule, validity domain, predicted relations, error treatment and decision criteria before its decisive mathematical, numerical or observational evaluation.

3.2 Stage I: carrier states and effective matching

The first foundational task is to specify a carrier state space and dynamics, together with a coarse-graining or matching construction that yields an effective sector. For the scalar route, the output must identify the roles of σ, θ, χ and recover the action's coefficient functions and

domain, or state a new version if they differ. A mere reinterpretation of the three symbols would leave the explanatory gap unchanged.

The mathematical test is whether the proposed map actually produces the declared dynamics with controlled residual terms over a nonempty regime. Failure to recover its advertised effective equations, an inconsistent state space, or uncontrolled omitted terms rules out that claimed realization in that regime. An absent map leaves the task open. Success establishes that bridge; it does not yet identify the sector with observed particles.

3.3 Stage II: physical sectors and universal geometry

A matter-sector bridge must recover the relevant symmetries, degrees of freedom, interactions and measured relationships within stated tolerances. In the Higgs/QCD route, established Standard Model and QCD structures are constraints on the construction. A dark-sector route must specify which gravitational or cosmological observables arise from which carrier states and with what parameter dependence. A particle discovered elsewhere can only be incorporated through an explicit dynamical extension with independently testable content.

For causal geometry, the output is a derivation of the shared effective metric and couplings for the physical sectors in the claimed phase, with a controlled account of corrections and stability. The scalar principal-cone result in section 6 is one local input, not this complete derivation. A fixed realization fails if its predicted physical propagation or coupling relations conflict with appropriately calibrated observations beyond its declared uncertainties. Persistent internal incompatibility among its sectors also defeats that realization. Where a sector or error budget is unspecified, the result is incomplete rather than experimentally confirmed.

These requirements give universality physical content: one mechanism must constrain several sectors. Independent adjustable descriptions that can fit each sector without a cross-sector relation would not yet accomplish that aim.

3.4 Stage III: controlled evolution and extreme regimes

The current scalar sector must be given consistent initial data, a controlled range of backgrounds and an estimate of truncation errors for the proposed application. A local vacuum spectrum cannot certify long-time evolution. The quadratic χ truncation supplies no bounded endpoint in a tachyonic region; any stabilizing interaction is a new specified ingredient whose consequences must be checked. A quantum cosmological route also needs a state, renormalization choices and a controlled response construction.

The reconversion route must close (2)–(4), establish its coupling to organized matter and geometry, and track the full entropy budget through the proposed transition. A completed version is rejected in an advertised regime if it violates its required conservation, causal well-posedness or entropy conditions. An unclosed stress tensor or unknown entropy flow cannot be counted as a successful transition.

One constraint is already available. For the retained scalar action, positive P_X implies the null energy condition, and minimal Einstein gravity in spatially flat FRW implies $\dot{H} \leq 0$. A nonsingular bounce requiring $\dot{H} > 0$ at $H = 0$ is therefore unavailable while those assumptions hold. A Genesis or cyclic realization that needs such a bounce must explicitly change or leave at least one assumption and establish the resulting theory's validity. Merely invoking the carrier interpretation does not remove the obstruction. Proposition 1 gives the retained proof.

3.5 Stage IV: a discriminating observable programme

A physical test requires a forward map from theory and calibrated background to a detector observable. Section 7 supplies a conditional phase-characteristic relation from the present action and lists the missing inputs. A useful implementation must show that the measurement isolates

that relation in a nonempty frequency window, with independent calibration and controlled model and instrument errors. Fitting a combination of parameters is not the same as identifying all of them.

Before a test, its version record should state the allowed parameter region, nuisance/calibration treatment, alternative explanations, comparison statistic and decision thresholds appropriate to that measurement. No numerical threshold or statistical confidence is claimed here without an actual protocol. Data outside the validity range cannot decide the advertised prediction; data inside it can reject a fixed realization when the predeclared relation fails. Agreement supports the tested relation to the extent that alternatives and uncertainties have been resolved. It is not a unique demonstration of the universal ontology.

3.6 How the programme can fail

Each stage must return one of three outcomes for its stated target: *established within the declared scope*, *failed*, or *unresolved*. A mathematical contradiction or a controlled failed observable prediction is a failure of the version that made it. Missing inputs and insufficient precision are unresolved outcomes, not successes. A new interaction, a changed background, a new carrier state space or a widened calibration freedom creates a new version. The failed version and the reason for changing it remain in the record; a repaired version must yield a further checkable consequence. Its prospective check or independent constraint must not be chosen from the same information used to motivate or tune the repair; agreement with that information is retrospective.

The unrestricted statement that everything has one carrier does not, by itself, choose a discriminating observation. The programme therefore commits to evaluating restricted realizations, not treating every conceivable outcome as support for the same completed theory. If no controlled bridge or discriminating relation can be constructed, the programme has not achieved its physical aim. Repeated fitting through unconstrained additions would be evidence of that failure of explanatory progress. The present paper supplies a concrete effective sector and a versioned agenda; its fundamental claim remains a hypothesis whose scientific value depends on completing those tasks.

4 One specified model

4.1 Source identity and conventions

The source pairing is preprint v1.6 (21 September 2026), its retained canonical specification v1.5 (20 September 2026), and the recovered S06 internal matter terms. The specification retains an older opening version heading; its file version and section identify the source. The selected matter action is reconstructed from the explicit covariant scalar terms in the recovered original internal sources and the frozen global functions used by their spectrum and cosmological runtime. Identifying that covariant matter theory with the operational homogeneous Apeiron proposal is a declared, source-based model postulate; the homogeneous preprint does not uniquely derive a covariant completion. We adopt the global quartic potential and screened portal benchmark throughout. The companion source matrix identifies the original messages, runtime definitions, preprint versions and existing independent checks [1, 2, 6]. General multi-field perturbation theory also shows why a homogeneous specification should not be assumed to fix every perturbative property [7].

We work in four dimensions with metric signature $(-,+,+,+)$ and units $\hbar = c = 1$. The reduced Planck mass is $M_{\rm Pl}$. The real fields σ, θ, χ have mass dimension one. Define

$$z = \frac{\sigma}{f_\sigma}, \qquad z_c = \frac{2}{\sqrt{3}}, \qquad X = -\frac{1}{2} g^{\mu\nu} \nabla_\mu \theta \nabla_\nu \theta. \tag{5}$$

Thus X has mass dimension four. The coordinate θ is a real local phase coordinate, not a globally identified periodic field: the full potential contains a linear tilt and a polynomial, despite the periodic portal. The suggested parametrization $(v+\sigma)e^{i\theta/f_{\rm phase}}$ does not derive this action from a canonical complex scalar.

Use $\Box = g^{\mu\nu}\nabla_\mu\nabla_\nu$ and $T_{\mu\nu} = -2(-g)^{-1/2}\delta S_{\rm m}/\delta g^{\mu\nu}$. On a homogeneous spatially flat Friedmann–Robertson–Walker (FRW) background, $\Box\theta = -\ddot{\theta} - 3H\dot{\theta}$. Variations have compact support, or compatible boundary data and the required gravitational boundary terms are understood.

4.2 Action and exact coefficient functions

The matter postulate is

$$S_{\rm m} = \int \mathrm{d}^4x\sqrt{-g}\,\mathcal{L}_{\rm m}, \qquad \mathcal{L}_{\rm m} = -\frac{1}{2}(\nabla\sigma)^2 + P(X,\sigma,\theta) - \frac{1}{2}(\nabla\chi)^2 - \frac{1}{2}m_\chi^2(\sigma,\theta)\chi^2, \tag{6}$$

with

$$F(z;b) = \frac{1}{4}z^4 - \frac{1}{2}z^2 + bz, \tag{7}$$

$$b_\theta(\theta) = b_* + b_1\frac{\theta}{M_{\rm Pl}}, \tag{8}$$

$$b(X,\theta) = b_\theta(\theta) - \frac{5X}{\Lambda^4}, \tag{9}$$

$$m_\chi^2 = m_{\chi0}^2 + 2\lambda(v+\sigma)^2\cos\left(\frac{2\theta}{f_{\rm phase}}\right), \tag{10}$$

$$P = X + \frac{5(z-z_c)^2}{3\Lambda^4}X^2 - E_cF\big(z;b(X,\theta)\big) - V_s(\theta). \tag{11}$$

The exact equivalent form is

$$P = K(z)X + a(z)X^2 - U(\sigma,\theta), \tag{12}$$

$$K(z) = 1 + \frac{5E_cz}{\Lambda^4}, \qquad a(z) = \frac{5(z-z_c)^2}{3\Lambda^4}, \tag{13}$$

$$U = E_c\left[\frac{1}{4}z^4 - \frac{1}{2}z^2 + b_\theta(\theta)z\right] + V_s(\theta). \tag{14}$$

The contribution $5E_cz/\Lambda^4$ in K follows from the original X-dependent tilt. Omitting it changes the theory and its canonical normalization. The symbol $K(z)$ denotes a coefficient function, not the full kinetic matrix on every background. The function $a(z)$ is unrelated to an FRW scale factor.

The portal is quadratic in χ and has exact $\chi \mapsto -\chi$ symmetry. This finite truncation specifies neither a nonlinear saturation mechanism in a tachyonic region nor a quantum-complete portal theory.

4.3 Parameters and the retained benchmark

The dimension-one parameters are $\Lambda, f_\sigma, f_{\rm phase}, v, m_{\chi0}$ and the reference normalization H_*. The parameters E_c, V_s have dimension four, a dimension minus four, and K, b_*, b_1, λ are dimensionless. Apart from the prescribed functional forms, parameters are model inputs. The following retained numerical point is an archival benchmark, not a determination from measured uncertainties.

Quantity	Selected value
$\Lambda/M_{\rm Pl}$	0.0023
$f_\sigma/M_{\rm Pl}$	0.025
$H_*/M_{\rm Pl}$	2×10^{-6}
$E_c/M_{\rm Pl}^4$	$4.8\times10^{-13}=0.04\times3(H_*/M_{\rm Pl})^2$
$b_*,\ b_1$	$0.35,\ -0.0478$
$f_{\rm phase}/M_{\rm Pl}$	0.8549468502440697
$v/M_{\rm Pl}$	0.03272387838931097
λ	$1.6740193604000272\times10^{-5}$
$m_{\chi0}/M_{\rm Pl}$	$9.817951142008693\times10^{-5}$

Write $\vartheta=\theta/M_{\rm Pl}$ and

$$V_s(\theta)=M_{\rm Pl}^4\sum_{j=0}^{4}d_j\vartheta^j. \tag{15}$$

The frozen coefficients are

$$\begin{aligned} d_0&=1.1971212004620583\times10^{-11}, & d_1&=9.87022611239063\times10^{-14},\\ d_2&=-1.0336424891583054\times10^{-13}, & d_3&=1.189490499106138\times10^{-10},\\ d_4&=1.2236365189926054\times10^{-10}. \end{aligned}$$

Printed digits retain the source point; they do not express experimental precision. H_* fixes this normalization and is not the Hubble rate of the static background below. The source label screened denotes the archived portal parameter choice, not an all-orders radiative-protection result. The generic portal defaults of the archived `Params` class describe a different benchmark and are not used here.

5 Dynamics, constraints and local validity

5.1 Matter and optional gravitational equations

Partial derivatives of $P(X,\sigma,\theta)$ hold the other listed arguments fixed. Variation of (6) gives

$$\Box\sigma+P_\sigma-\tfrac{1}{2}(\partial_\sigma m_\chi^2)\chi^2=0, \tag{16}$$

$$\nabla_\mu(P_X\nabla^\mu\theta)+P_\theta-\tfrac{1}{2}(\partial_\theta m_\chi^2)\chi^2=0, \tag{17}$$

$$\Box\chi-m_\chi^2\chi=0. \tag{18}$$

For the selected theory,

$$P_X=K+2aX, \qquad P_{XX}=2a, \tag{19}$$

$$P_\sigma=K_{,\sigma}X+a_{,\sigma}X^2-U_{,\sigma}, \qquad P_\theta=-U_{,\theta}, \tag{20}$$

$$P_{X\sigma}=K_{,\sigma}+2a_{,\sigma}X, \qquad P_{X\theta}=0. \tag{21}$$

The stress tensor is

$$T_{\mu\nu}=\nabla_\mu\sigma\nabla_\nu\sigma+P_X\nabla_\mu\theta\nabla_\nu\theta+\nabla_\mu\chi\nabla_\nu\chi+g_{\mu\nu}\mathcal{L}_{\rm m}. \tag{22}$$

For a fixed metric these are matter equations. If gravity is dynamical, the additional postulate is minimal Einstein coupling,

$$S_{\rm g}=\int{\rm d}^4x\sqrt{-g}\,\frac{M_{\rm Pl}^2}{2}R, \qquad M_{\rm Pl}^2G_{\mu\nu}=T_{\mu\nu}, \tag{23}$$

with curvature convention $G_{00} = 3H^2$ in flat FRW. This matches the archived FRW convention and does not derive spacetime or Einstein gravity from the scalar fields. On the matter equations, diffeomorphism invariance gives $\nabla_\mu T^{\mu\nu} = 0$.

In flat FRW with homogeneous fields, $X = \dot{\theta}^2/2$ and

$$\rho = \tfrac{1}{2}\dot{\sigma}^2 + 2XP_X - P + \tfrac{1}{2}\dot{\chi}^2 + \tfrac{1}{2}m_\chi^2\chi^2, \tag{24}$$

$$p = \tfrac{1}{2}\dot{\sigma}^2 + P + \tfrac{1}{2}\dot{\chi}^2 - \tfrac{1}{2}m_\chi^2\chi^2, \tag{25}$$

$$3M_{\rm Pl}^2H^2 = \rho, \qquad -2M_{\rm Pl}^2\dot{H} = \rho + p, \qquad \dot{\rho} + 3H(\rho + p) = 0. \tag{26}$$

The P-sector energy-density identity is standard in k-essence [8]; the canonical sectors and portal here are retained explicitly. The field equations reduce to

$$\ddot{\sigma} + 3H\dot{\sigma} - P_\sigma + \tfrac{1}{2}(\partial_\sigma m_\chi^2)\chi^2 = 0, \tag{27}$$

$$D\ddot{\theta} + 3HP_X\dot{\theta} + P_{X\sigma}\dot{\sigma}\dot{\theta} - P_\theta + \tfrac{1}{2}(\partial_\theta m_\chi^2)\chi^2 = 0, \tag{28}$$

$$\ddot{\chi} + 3H\dot{\chi} + m_\chi^2\chi = 0, \tag{29}$$

where $D = P_X + 2XP_{XX} = K + 6aX$. The mixed term in (28) is required by the σ dependence of the phase kinetic coefficient. The Friedmann equation constrains the initial data; it is not an independent freely assignable initial Hubble rate. These classical homogeneous equations are not the complete operational quantum map, in which renormalized χ mode expectations supply separate source terms.

5.2 Domain and initial data

The adopted scope is a local classical theory at tree level, about a specified smooth background. The scale Λ labels an operator coefficient. It does not establish a sharp physical cutoff, a bound on every omitted operator, or a controlled quantum expansion. A quantum use would require a state, renormalization prescriptions and additional counteroperators.

For timelike or zero $\nabla\theta$, impose

$$X \geq 0, \qquad P_X = K + 2aX > 0, \qquad D = K + 6aX > 0. \tag{30}$$

These give positive phase kinetic and spatial-gradient coefficients in the timelike rest frame. Since $a \geq 0$, $K > 0$ is a sufficient restriction for all such X; it is not necessary at every nonzero X. For nonzero null or spacelike gradients the full principal symbol and a common Cauchy hypersurface must be checked instead. The timelike formula below cannot be extended to that class by assertion.

Near the selected constant vacuum we additionally require $m_\chi^2 > 0$, a positive canonically normalized σ–θ Hessian and sufficiently small fluctuations that remain inside this patch. These local conditions do not prove stability of every interacting or gravitational perturbation. At $m_\chi^2 < 0$, the quadratic χ sector diagnoses a tachyonic onset but provides no bounded nonlinear endpoint. The unrestricted field space is not claimed healthy: K can also change sign at sufficiently negative z.

An initial-value problem must specify the fields and normal derivatives on a common spacelike hypersurface, compatible spatial boundary conditions, and, when the metric is dynamical, geometry and extrinsic data satisfying the gravitational constraints. Equations (6)–(15) do not select a unique cosmological trajectory or quantum state. No new historical cosmological evolution is computed here.

6 Consequences of the selected action

6.1 Characteristic cone and energy condition

The characteristic construction is standard for noncanonical scalars [9]. Linearizing the highest-derivative part of (17) gives

$$\mathcal{G}_\theta^{\mu\nu} = P_X g^{\mu\nu} - P_{XX}\nabla^\mu\theta\nabla^\nu\theta. \tag{31}$$

The canonical σ and χ equations have the metric principal cone. Their couplings to θ introduce lower-derivative mixing but no off-diagonal second-derivative terms in this formulation.

Proposition 1 (Local cone and a flat-FRW restriction)**.** *On a timelike-gradient background satisfying* (30)*, the phase characteristic speed in its local rest frame is*

$$c_\theta^2 = \frac{P_X}{D} = \frac{K+2aX}{K+6aX}, \qquad 0 < c_\theta^2 \le 1. \tag{32}$$

At zero gradient the same expression gives the metric cone provided $K > 0$. Throughout a region with $P_X > 0$, the matter stress satisfies the metric null energy condition. Consequently, a spatially flat FRW solution with the Einstein coupling (23) *cannot undergo a nonsingular bounce requiring $\dot{H} > 0$ at $H = 0$ while remaining in that domain.*

Proof. In the timelike rest frame, (31) has coefficients $(-D, P_X, P_X, P_X)$. Its characteristic equation therefore yields (32). Positivity follows from (30); the upper bound follows from $D - P_X = 4aX \ge 0$. Equality occurs at $aX = 0$. At zero gradient the symbol is $Kg^{\mu\nu}$. For any metric-null vector n^μ, (22) gives

$$T_{\mu\nu}n^\mu n^\nu = (n\cdot\nabla\sigma)^2 + P_X(n\cdot\nabla\theta)^2 + (n\cdot\nabla\chi)^2 \ge 0. \tag{33}$$

In homogeneous FRW, $\rho + p = \dot{\sigma}^2 + 2XP_X + \dot{\chi}^2 \ge 0$, hence (26) implies $\dot{H} \le 0$. This contradicts the stated bounce condition inside that domain. □

This is a characteristic statement about the displayed local equations, not a frequency-independent group velocity for every massive mixed normal mode. It also differs from a low-frequency sound speed after other fields have been integrated out; controlled heavy-mode elimination has separate assumptions [10]. Its physical use needs a frequency range below a justified EFT cutoff and above masses, relevant mixing rates and background-variation scales. No such nonempty physical window is established by the formal principal symbol alone. It does not derive the measured value of c, a shared cone for unspecified matter, global causal completeness, or the exact ultraviolet front velocity of a completed theory. The bounce restriction assumes spatial flatness, minimal Einstein coupling and the healthy domain; it does not exclude constructions that change those assumptions.

6.2 Constant matter background and retained spectrum

At $X = \chi = 0$, the stationary matter equations are

$$z_0^3 - z_0 + b_\theta(\theta_0) = 0, \qquad E_c z_0 \frac{b_1}{M_{\rm Pl}} + V_s'(\theta_0) = 0. \tag{34}$$

The existing negative-z source solution is

$$\sigma_0/M_{\rm Pl} \simeq -0.02886751345948129, \tag{35}$$

$$\theta_0/M_{\rm Pl} \simeq -0.7301292774006391, \qquad z_0 \simeq -1.1547005383792515. \tag{36}$$

This is distinct from the positive-z cosmological initial branch. It supplies no trajectory connecting the two.

With $q = (\delta\sigma, \delta\theta)^T$, define

$$\mathcal{K}_0 = \mathrm{diag}(1, K_0), \quad K_0 = 1 + \frac{5E_c z_0}{\Lambda^4} \simeq 0.9009694329240460, \tag{37}$$

and the potential Hessian

$$\mathcal{H}_0 = \begin{pmatrix} E_c(3z_0^2 - 1)/f_\sigma^2 & E_c b_1/(f_\sigma M_{\rm Pl}) \\ E_c b_1/(f_\sigma M_{\rm Pl}) & V_s''(\theta_0) \end{pmatrix}. \tag{38}$$

The quadratic local matter Lagrangian is

$$\mathcal{L}_{\rm m}^{(2)} = -\tfrac{1}{2}\nabla q^T \mathcal{K}_0 \nabla q - \tfrac{1}{2} q^T \mathcal{H}_0 q - \tfrac{1}{2}(\nabla\delta\chi)^2 - \tfrac{1}{2} m_{\chi,\rm vac}^2 (\delta\chi)^2. \tag{39}$$

The eigenvalues of $\mathcal{K}_0^{-1/2}\mathcal{H}_0\mathcal{K}_0^{-1/2}$ are the two canonically normalized squared masses. Existing S06 calculations and their independent checks [6] give

$$\frac{m_1^2}{M_{\rm Pl}^2} \simeq 2.90211845795\times10^{-10}, \quad \frac{m_2^2}{M_{\rm Pl}^2} \simeq 2.30400046423\times10^{-9}, \quad \frac{m_{\chi,\rm vac}^2}{M_{\rm Pl}^2} \simeq 9.57111\times10^{-9}. \tag{40}$$

These numbers are reused from the checked record, not presented as newly computed trajectories or experimental masses. Positive curvature does not imply an asymptotically stable particle: the original interaction analysis permits $\phi_2 \to \phi_1\phi_1$. The local fixed-metric expansion is also not an assertion of an exact Minkowski solution of dynamical gravity. The value of $U(\sigma_0, \theta_0)$ must enter Einstein's equations; near-zero cancellation with printed coefficients is not an exact vacuum-energy identity.

The earlier preprint/specification statement [1] $P_X(0) = 1$ is corrected to $P_X(0) = K_0$. Nevertheless, $D = K_0$ at $X = 0$, so $c_\theta^2 = 1$ survives. Correcting normalization is essential for the mass matrix and interactions even when that ratio is unchanged.

7 A concrete conditional test perspective

A test must bind an observable to the fields and background of this action. Consider a region with a calibrated timelike phase gradient and a resolved local rest frame. Independent inputs would be the background z, X, the parameters entering K, a, the reference metric propagation speed, a detector coupling that selects the phase perturbation, and a frequency window in which the principal approximation and EFT truncation both apply. Equation (32) then predicts its characteristic cone. A measured characteristic inconsistent with that relation, after jointly controlled calibration and model errors, would reject this fixed model in that specified regime.

For the sufficient subdomain $K > 0$, let $q_X = aX/K \geq 0$. The same relation reads

$$c_\theta^2 = \frac{1 + 2q_X}{1 + 6q_X}, \qquad q_X = \frac{1 - c_\theta^2}{6c_\theta^2 - 2} \qquad (\tfrac{1}{3} < c_\theta^2 \leq 1). \tag{41}$$

The inverse supplies only the combination q_X; a speed measurement alone cannot determine all action parameters or the background. The lower limiting value is approached as q_X grows and is not a license to take arbitrarily large X outside a controlled EFT regime. This additional range uses $K > 0$, not just the more general conditions (30).

No detector coupling, accessible experimental system or justified measurement-error budget is derived here. Thus this is a specified falsification relation and an input list for a future test, not an immediately executable laboratory proposal or empirical validation. A cosmological application would additionally need constrained initial data, a quantum state where relevant, transfer functions and controlled backreaction/omitted-operator errors. The benchmark in (40) gives another conditional forward target once a physical identification is supplied; assigning its modes to observed particles is presently unsupported.

8 Relationship to the existing inverse-theory study

The separate P01 study, *Identifiability and calibration limits of a single dispersion branch in a two-field effective theory*, [11] provides a useful methodological comparison: specifying a forward model, identifying its parameters from exact observations, and obtaining a reliable inference with finite errors are different tasks. That study uses its own fixed-metric action and rolling background. Its exact reconstruction results and classical matching example therefore cannot be imported into the action of this paper without an explicit map of fields, coefficients, background and observation protocol.

Its retrospective plasmon-polariton application likewise does not validate Apeiron. In that application the unobserved upper gap is not independently certified, calibration freedom remains relevant, and deterministic compatibility thresholds are not experimental confidence intervals. We retain the existing P01 publication and reproduction record as supporting material, without recalculating its historical fits or reinterpreting its dataset as a test of the present core. The local companion's reproduction index gives the exact source paths and checksums.

9 Present status and unresolved theoretical work

9.1 The established scope

The present contribution has three linked parts: a source-faithful statement of the universal-carrier hypothesis, a disciplined programme for its physical realization, and a fully specified effective sector. The retained action, equations, domain, characteristic result, energy-condition restriction and canonical mass recipe belong to the same mathematical model. The frozen numerical point is a retained benchmark with previously checked outputs. None is an observed identification of the carrier.

The broader historical record remains in its original status. Preprint v1.6 reports a stored v7.13 protocol `HARD-PASS`, while also reporting that a later clean-room comparison did not reproduce that classification and that independent-map reproduction level V4 remained open [1, p. 2]. This paper neither reruns that map nor substitutes a classical homogeneous χ evolution for its renormalized mode-source closure. The local scalar checks and the historical cosmological protocol are different evidence. A revision of exposition cannot close an unresolved reproduction gate.

9.2 Limits that direct the next work

The global quartic phase potential and screened portal benchmark define the retained version. A local reconstructed potential, generic unscreened portal defaults or a stabilizing χ^4 term would define different choices requiring an explicit new analysis. The positive-z cosmological initial branch and negative-z local vacuum are distinct backgrounds; no connecting trajectory is supplied. Positive local masses also do not establish an asymptotically stable particle spectrum, as the permitted decay in section 6.2 illustrates.

The optional heavy scalar with source $J = g_0(z - z_c)X$ is a conditional completion ansatz. Saturating the displayed aX^2 coefficient fixes $g_0^2/(2M_S^2) = 5/(3\Lambda^4)$, not an absolute mediator mass. Such an exchange must replace the saturated operator rather than double-count it. A four-field contact coefficient is not the complete massive coupled-channel scattering amplitude, and a massless half-bound diagnostic is not a certified physical cutoff. General analyticity/positivity arguments require their own scattering assumptions [12]. A constant determinant for a pure Gaussian heavy-field integral does not show that full mixed heavy/light one-loop matching vanishes. These distinctions remain part of the retained theory's interpretation.

The next foundational work is therefore specific: define carrier dynamics and matching; recover physical matter and universal geometry; close nonlinear and quantum response sectors;

and construct a calibrated observable test. The reconversion and entropy branches require constitutive and thermodynamic closure. The quantum branch requires an explicit physical realization beyond the conditional use of standard quantum rules. The present source does not settle the microscopic ontology by choosing one of these tasks in advance.

10 Conclusion

Apeiron's central proposal is one universal fundamental dynamical carrier. Its scientific development requires restricted realizations that connect this hypothesis to known physical structures and measurable relationships. The retained scalar effective theory supplies an explicit starting component: its normalization is corrected, its local characteristic relation is derived, its existing spectrum is identified and its healthy flat-FRW bounce obstruction is retained. The research programme makes the missing connections and the consequences of failure explicit. Its next achievement must be a controlled physical bridge or a discriminating test, with the result recorded for the version that made the claim.

Author, support and preparation

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A Explicit derivatives and variational checks

For direct implementation of the field equations,

$$K_{,\sigma} = \frac{5E_c}{f_\sigma \Lambda^4}, \qquad a_{,\sigma} = \frac{10(z - z_c)}{3 f_\sigma \Lambda^4}, \tag{42}$$

$$U_{,\sigma} = \frac{E_c}{f_\sigma}(z^3 - z + b_\theta), \qquad U_{,\theta} = \frac{E_c b_1 z}{M_{\rm Pl}} + V_s'(\theta), \tag{43}$$

$$(\partial_\sigma m_\chi^2) = 4\lambda(v+\sigma)\cos\left(\frac{2\theta}{f_{\rm phase}}\right), \qquad (\partial_\theta m_\chi^2) = -\frac{4\lambda(v+\sigma)^2}{f_{\rm phase}}\sin\left(\frac{2\theta}{f_{\rm phase}}\right). \tag{44}$$

Writing $\delta X = -\nabla^\mu\theta\nabla_\mu\delta\theta$ in the action and integrating once by parts yields (17). Expanding its first term gives

$$\nabla_\mu(P_X\nabla^\mu\theta) = \mathcal{G}_\theta^{\mu\nu}\nabla_\mu\nabla_\nu\theta + P_{X\sigma}\nabla_\mu\sigma\nabla^\mu\theta + P_{X\theta}\nabla_\mu\theta\nabla^\mu\theta. \tag{45}$$

The final term vanishes for this model. Evaluating the middle term on a homogeneous background supplies the mixed term in (28) after multiplication by minus one. Metric variation supplies (22); contraction with a null vector removes its $g_{\mu\nu}\mathcal{L}_{\rm m}$ term and yields (33).

B Evidence, versioning and reproduction scope

The companion claim/source matrix binds the foundational claims to preprint v1.6, especially sections 3.4, 10.5–10.6, 11.1–11.4 and 11A. Its exact original hash and physical page locators are recorded. The effective-core matrix and reproduction index identify the recovered internal

action, numerical sources and prior checks. Existing sources and the entire v1 delivery remain unchanged. File hashes verify the exact retained core and derivative appendix.

The publication package distinguishes document production from scientific reproduction. This revision rebuilds and visually checks the new English paper, presentation and German reading versions. It performs no new historical trajectory, spectrum, loop or cosmological-map calculation. The prior bounded convention check covers 14 exact rational-polynomial identities and an explicitly labelled floating-point illustration; it is not a new vacuum search. Retaining those results does not broaden their scope.

The English main paper is the publication-preparation version. A complete German technical reading version and a separate German plain-language account are supplied for personal reading, each bound to the final English files. A short English presentation summarizes the same status distinctions. The previous local-theory package is included as historical v1 evidence. The README identifies the v2 entry points and the remaining administrative decisions.

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