Vacuum Oscillator Φ-Field (VOΦF): a unified framework for spacetime, gravity, dark sectors, black holes and quantum phenomena

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Abstract

I propose the Vacuum Oscillator Φ-Field (VOΦF), an ontological framework in which time, gravity, dark sectors and quantum phenomena arise as different dynamical regimes of a single vacuum field Φ. The central object is the local vacuum oscillation frequency $\omega_{\Phi}(x)$, interpreted as a physical "vacuum clock": its value sets the local rate of proper time, while spatial gradients of ω_{Φ}reproduce the Newtonian potential and classical gravitational acceleration in the weak-field limit. Spacetime geometry is treated as an effective description emerging from coarse-grained states of Φ, rather than as a fundamental background.

Within this ontology, dark matter is reinterpreted as massive, weakly coupled excitations in hidden sectors $\Phi_{\mathrm{dark},i}$, while dark energy corresponds to the background energy of the vacuum oscillator encoded in an effective potential $V_{\mathrm{eff}}(\langle\Phi\rangle)$. Black holes are described as regions of Φ-collapse, where $\omega_{\Phi} \to 0$and the vacuum loses its ability to support propagating excitations and a well-defined local time. Standard quantum phenomena—superposition, interference, measurement and entanglement—are interpreted as oscillatory patterns of $\Phi$and their decoherence through coupling to macroscopic detectors, without modifying the formal structure of quantum field theory.

I show that general relativity with Λ, ΛCDM cosmology and quantum field theory on curved spacetime emerge as effective descriptions of appropriate regimes of the vacuum oscillator. The framework leads to a clearly falsifiable empirical programme along three complementary axes: (i) cosmological probes of vacuum and dark-sector dynamics ($H(z)$, H_0, S_8, matter power spectrum $P(k)$); (ii) strong-field astrophysical tests (black-hole shadows and photon rings, gravitational-wave propagation and ringdown); and (iii) local precision experiments sensitive to ultra-weak vacuum-clock and phase modulations, including clock networks, interferometric measurements and shielded ELF/ULF searches.

Keywords:

Vacuum field, vacuum oscillator, emergent gravity, unified dark sector, dark matter and dark energy, quantum vacuum, black holes, wave function ontology, ΛCDM cosmology, ELF vacuum fluctuations, gravitational time dilation, quantum foundations

1. Introduction

The modern description of the Universe rests on three pillars:
(i) general relativity (GR) as the theory of gravity,
(ii) quantum field theory (QFT) as the theory of matter and radiation,
(iii) the standard ΛCDM cosmological model, in which dark matter and dark energy dominate the energy budget of the present-day Universe.

Each of these pillars has achieved spectacular empirical success: GR in Solar-System tests and the detection of gravitational waves; QFT in parts-per-billion precision in quantum electrodynamics; ΛCDM in accounting for the CMB, large-scale structure and the evolution of the cosmological background. At the same time, this entire edifice rests on concepts whose ontological status is not fully clear: "spacetime" as a smooth geometric object, "vacuum" as a state of minimal energy, "dark matter" and "dark energy" as two dominant but unknown components, and "wave function" and "measurement" as key but poorly understood elements of the quantum description.

This work grows out of a simple question: can we place beneath GR, ΛCDM and QFT a more elementary physical carrier—one that, on the one hand, preserves their well-tested phenomenology, and on the other hand organises the dark sector, gravity and quantum phenomena as different regimes of a single vacuum dynamics?

1.1. Tensions, gaps and ontological questions

Although the standard cosmological model and contemporary particle physics are extremely successful, there are empirical and conceptual indications that the picture is incomplete.

On the cosmology side:

- Dark matter and dark energy are defined mainly through their gravitational effects. We know that $\sim 25–30\%$ of the energy density behaves like cold, non-baryonic matter, and $\sim 65–70\%$ like a component with $w \approx -1$, but we lack a widely accepted physical carrier for these components.
- Vacuum energy in QFT, taken literally, would give vacuum energy densities many orders of magnitude larger than observed. The cosmological constant problem is thus a problem of mechanism: why does the vacuum gravitate as weakly as it does?
- Tensions in H_0 and S_8 suggest the possibility of subtle dynamics in the dark sector or vacuum energy in the early Universe. If they genuinely require an extra degree of freedom, it would be natural to embed it in a more global picture of the vacuum, rather than adding yet another "cosmological fluid" ad hoc.

On the gravity and information side:

- In GR, black holes are described geometrically—by the Kerr metric, horizon, shadow and photon ring—but the theory is silent on what the inner singularity physically is, and on how to relate black-hole thermodynamics to microscopic degrees of freedom of the vacuum.

- The black-hole information problem remains unresolved: semiclassical analysis suggests loss of information, whereas standard quantum mechanics does not allow it. We lack a picture in which gravity, vacuum and information are different aspects of a single physical carrier.

On the quantum-phenomena side:

- Wave–particle duality, superposition, measurement and entanglement are formally well described by QFT, but their ontological meaning is contested. The wave function is sometimes treated as purely instrumental, sometimes as an ontological object, yet without a concrete "medium" that it inhabits.
- The quantum vacuum is simultaneously a state of minimal energy and a medium in which fluctuations, particle creation/annihilation and Casimir-type effects occur—without a clear "mechanics of the vacuum" that would treat these phenomena as dynamics of some underlying medium.

The common thread in these tensions—dark sector, vacuum energy, black holes, information and measurement—is precisely the vacuum and its dynamics. This suggests that it may be worthwhile to treat the vacuum not as an abstract state of the formalism, but as a concrete physical object.

1.2. Inspirations: emergent gravity, vacuum as a medium, unified dark sector

Several research programmes explore this intuition:

- Approaches of the "emergent gravity" and "superfluid vacuum" type regard spacetime geometry as an effective description of deeper degrees of freedom of the vacuum, in analogy with the relation between hydrodynamics and atomic motion.
- Unified dark-fluid models attempt to describe both dark matter and dark energy by a single scalar field, which assumes different equations of state in different epochs.
- The "analogue gravity" programme shows that metrics similar to those of GR can emerge in condensed-matter systems, strengthening the intuition that gravity might be an effect of the collective dynamics of some medium.

Most of these approaches, however, focus on one aspect (e.g. only emergent gravity, or only a unified dark fluid) and rarely offer a single, coherent ontology that simultaneously encompasses:

- geometry (time and gravity),
- dark matter and dark energy,

- black holes,
- standard quantum phenomena (wave–particle duality, measurement, entanglement),
- and potential low-energy probes of the vacuum (e.g. in the ELF band).

The present work is an attempt to construct such a unified framework—not as a complete theory of quantum gravity, but as a coherent mechanics of the vacuum in which all of the above elements are different dynamical regimes of a single field.

1.3. Guiding idea: vacuum oscillator Φ and frequency $\omega_\Phi(x)$

The starting point is the following claim:

There exists a global vacuum field $\Phi(x)$, defined on four-dimensional spacetime (or its suitable generalisation), which acts as the physical carrier of geometry, visible matter, dark matter, dark energy and quantum phenomena.

The key quantity is the local vacuum oscillation frequency $\omega_\Phi(x)$, which:

- defines the local flow of proper time,
- through its spatial gradients reproduces the classical gravitational field,
- through its modes and sectors $(\Phi_{\text{vis}}, \Phi_{\text{dark},i})$ yields visible matter, dark matter and dark energy.

In this language:

- time is a parameter of accumulated phase of the vacuum oscillator along an observer's worldline;
- gravity is the spatial gradient of $\omega_\Phi(x)$, which in the weak-field limit reproduces the Newtonian potential and Einstein's equations with an effective Λ;
- dark matter consists of massive, stable excitations in sectors $\Phi_{\text{dark},i}$ that gravitate but do not couple to electromagnetism;
- dark energy is the background energy of the vacuum oscillator, encoded in an effective potential $V_{\text{eff}}(\langle\Phi\rangle)$;
- black holes are regions of Φ-collapse, in which $\omega_\Phi \to 0$ and the field loses the ability to support propagating excitations and a well-defined local time;
- quantum phenomena are oscillatory patterns of Φ and their couplings to macroscopic detectors—without modifying the QFT formalism, but with a more "material" carrier for the wave function and entanglement.

In this sense, the “core mechanics” of the Φframework is effectively one-parameter: all observable degrees of freedom are treated as different dynamical regimes of a single quantity—the local vacuum oscillation frequency $\omega_\Phi(x)$and its modes.

1.4. Scope of this work: from ontology to empirical tests

The goal of this v1 preprint is not to construct a complete theory of quantum gravity or to derive numerical values of Standard Model parameters. The scope is more modest but well-defined:

- **Ontology and minimal effective formalism.**
  In Section 2 I formulate the basic ontological assumptions: the existence of a global field Φ, its sectoral structure $(\Phi_{\text{vis}}, \Phi_{\text{dark},i})$, the role of $\omega_\Phi(x)$, and a minimal effective Lagrangian formalism with potential $V_{\text{eff}}(\Phi)$. I show how the metric $g_{\mu\nu}$can be treated as a functional of the coarse-grained vacuum state, and GR as the effective dynamical equations for that functional.

- **Time, gravity and the equivalence principle.**
  In Section 3 I develop the idea of proper time as integrated phase of the vacuum oscillator and show that, with an appropriate identification of $\omega_\Phi(x)$and $\Phi_N(x)$(the Newtonian potential), one can reproduce in the weak-field limit the known gravitational time dilation and universal free fall, while retaining the standard tests of the equivalence principle.

- **Dark sector and ΛCDM as an effective theory.**
  In Section 4 dark matter and dark energy are reinterpreted as, respectively, massive excitations in sectors $\Phi_{\text{dark},i}$and the background energy of the vacuum oscillator $V_{\text{eff}}(\langle\Phi\rangle)$. ΛCDM appears as a statistical description of a particular class of Φ-configurations, with room for subtle dynamics of $\rho_{\Phi\text{-vac}}(z)$and dark modes if future data require it.

- **Black holes as regions of Φ-collapse.**
  In Section 5 black holes are treated as regions where $\omega_\Phi(x)$effectively vanishes and the vacuum loses its ability to support excitations and local time. The horizon, shadow and photon ring obtain a microscopic interpretation in terms of oscillatory regimes of Φ, and the information problem is reformulated as a question about the full multi-sector dynamics of Φ.

- **Quantum phenomena as oscillatory patterns of Φ.**
  In Section 6 standard quantum phenomenology—wave–particle duality, interference, decoherence, entanglement—is embedded in the ontology of a single vacuum field Φ, without changing the QFT formalism. The wave function is interpreted as an effective description of an appropriate mode of Φ, and measurement as a process of decoherence and “locking” of a Φ-pattern into a macroscopic detector state.

- **Predictions and empirical tests.**
  In Section 7 I outline three complementary axes of tests of the Φframework: (i) cosmological ($H(z), H_0/S_8$tensions, power spectrum $P(k)$), (ii) astrophysical (black-hole shadows and photon rings, gravitational waves), (iii) local, low-energy (searches for ultra-weak ELF modulations in shielded magnetometers, MEG data, satellites and global magnetometer networks). I emphasise that in this v1 I do not choose a specific form of $V_{\text{eff}}(\Phi)$and do not perform numerical fits—the aim is to map out tests, not to close the problem.

- **Discussion, limitations, open questions.**
  Section 9 summarises the ontological status of the Φframework, discusses its relation to earlier approaches, highlights the main simplifications (no explicit V_{eff}, no global cosmological fit, no complete microscopic theory), and sketches natural directions for further work.

1.5. Position of the Φframework: between interpretation and physical theory

The proposed Φframework sits between purely interpretational accounts of quantum mechanics and quantitative extensions of ΛCDM and GR:

- On the one hand, it has an interpretational dimension: it suggests that time, gravity, the dark sector, black holes and quantum phenomena are all different regimes of a single vacuum oscillator Φ; it assigns a concrete, "material" carrier to the wave function and the QFT vacuum.

- On the other hand, it has a physical dimension: it leads to concrete classes of models $V_{\text{eff}}(\Phi)$and couplings that can be fitted to data, and to clearly defined axes of empirical tests along which the Φframework can be progressively confirmed, constrained or falsified.

The aim of this preprint is not to replace GR, ΛCDM and QFT, but to embed them in a single, coherent ontology of the vacuum which:

- reduces to the known theories in the regimes where they are well tested,

- organises the dark sector, black holes and quantum phenomena as different regimes of $\omega_{\Phi}(x)$and its modes,

- and provides a map of observational and experimental probes of vacuum dynamics—from the CMB and EHT to ELF magnetometers.

2. Ontology of the vacuum field Φ

2.1. Basic assumptions

Throughout this work, x may be read operationally: in the coherent regime it coincides with effective spacetime coordinates, while in the pre-temporal regime it should be regarded as a label on a pre-geometric substrate. The metric $g_{\mu\nu}$ is then a self-consistent functional of coarse-grained Φ-state variables in the coherent phase.

The framework proposed in this work rests on the following ontological assumptions:

Existence of a global vacuum field $\Phi(x)$.
There exists a vacuum field $\Phi(x)$, defined on a four-dimensional spacetime manifold (or its suitable generalisation), which acts as the physical carrier of both spacetime geometry and all matter fields.

Space, time, matter and radiation as different regimes of Φ.
What we conventionally describe as "space", "time", "matter" and "radiation" corresponds to different regimes of the state of Φ:

- coarse-grained properties of Φ define an effective spacetime metric,
- stable excitations in the "visible" sector reproduce the fields of the Standard Model,
- excitations in weakly coupled sectors behave as dark-matter–like or otherwise hidden degrees of freedom.

Quantum vacuum as a non-trivial state of Φ.
The quantum vacuum is a non-zero, structured state of Φ with characteristic fluctuations; the associated vacuum energy behaves effectively like dark energy on cosmological scales.

Gravity from spatial variations of the oscillation frequency of Φ.
The local vacuum oscillation frequency $\omega_\Phi(x)$ of the field Φ defines the effective flow of proper time, while spatial gradients of $\omega_\Phi(x)$ correspond to what is classically described as the gravitational potential. In the weak-field limit one can write

$$\mathbf{g}(x) \propto -\nabla\omega_\Phi(x),$$

where $\mathbf{g}(x)$ is the classical gravitational acceleration.

Black holes as regions of Φ-collapse.
Black holes are interpreted as regions in which Φ loses its ability to support propagating excitations (collapse of Φ, $\omega_\Phi \to 0$), which macroscopically leads to the appearance of horizons, black-hole shadows and photon rings.

In this sense, the "core mechanics" is effectively one-parameter: all observable degrees of freedom—time, gravity, matter fields, dark sectors, black holes and quantum phenomena—

are treated as different dynamical regimes of a single quantity: the local vacuum oscillation frequency $\omega_\Phi(x)$and its modes.

Taken together, these postulates define what I will call the vacuum-oscillator Φ framework (VOΦF). All concrete realizations with different choices of $V_{\text{eff}}(\Phi)$ and interaction terms that respect these assumptions will be referred to as VOΦF-type models.

2.2. Sectoral structure of the vacuum field

At the effective level, I model the vacuum as a multi-component scalar field

$$\Phi(x) = (\Phi_{\text{vis}}(x),\ \Phi_{\text{dark},1}(x),\ \Phi_{\text{dark},2}(x), \dots),$$

where

- Φ_{vis}denotes the component responsible for visible matter and gauge fields,
- $\Phi_{\text{dark},i}$denote components corresponding to different classes of dark modes (e.g. dark-matter–like excitations or other hidden sectors).

All sectors jointly contribute to the total vacuum energy density, whereas only the visible sector and, potentially, certain subsets of the dark sectors are directly accessible to our detectors.

2.3. Minimal effective dynamics

A minimal effective description can be written schematically as

$$\mathcal{L} = \mathcal{L}_{\text{GR}}[g_{\mu\nu}] + \mathcal{L}_{\text{SM}}[\psi, A_\mu, g_{\mu\nu}] + \mathcal{L}_\Phi[\Phi_{\text{vis}}, g_{\mu\nu}] + \mathcal{L}_{\text{dark}}[\Phi_{\text{dark},i}, g_{\mu\nu}] + \mathcal{L}_{\text{int}}[\Phi, \psi, A_\mu].$$

Here:

- $\mathcal{L}_{\text{GR}} = \frac{1}{16\pi G}\ R$is the usual Einstein–Hilbert term.
- $\mathcal{L}_{\text{SM}}$is the Standard Model Lagrangian on the background metric $g_{\mu\nu}$.

In the visible sector we take

$$\mathcal{L}_\Phi = \frac{1}{2}\ \partial_\mu\Phi_{\text{vis}}\ \partial^\mu\Phi_{\text{vis}} - V_{\text{vis}}(\Phi_{\text{vis}}),$$

where $V_{\text{vis}}$is an effective potential.

In the dark sector,

$$\mathcal{L}_{\text{dark}} \supset \sum_i [\frac{1}{2}\ \partial_\mu\Phi_{\text{dark},i}\ \partial^\mu\Phi_{\text{dark},i} - V_i(\Phi_{\text{dark},i})].$$

The coupling to visible matter has the schematic form

$$\mathcal{L}_{\text{int}} \supset g_\Phi\, \Phi_{\text{vis}}\, T^\mu_\mu,$$

where T^μ_μ is the trace of the energy–momentum tensor of visible matter.

At a coarse level one can write a schematic equation of motion

$$\Box\Phi(x) + \frac{dV_{\text{eff}}(\Phi)}{d\Phi} = \alpha\, T^\mu_\mu(x) + \cdots,$$

where $\Box$ is the d'Alembertian operator built from the emergent metric $g_{\mu\nu}$, and the ellipsis denotes self-interactions in the dark sectors and higher-order corrections.

2.4. Time and space as effective descriptions of the state of Φ

In standard GR the metric $g_{\mu\nu}(x)$ is the primary geometric object. In the Φ framework, the metric is interpreted as a functional of the coarse-grained state of the vacuum field:

$$g_{\mu\nu}(x) = F_{\mu\nu}(\langle\Phi(x)\rangle, \partial\langle\Phi(x)\rangle).$$

The local vacuum oscillation frequency $\omega_\Phi(x)$ plays the role of a "vacuum clock":

- proper time along a worldline parametrises the sequence of changes of the state of Φ,
- the local rate of these changes is proportional to $\omega_\Phi(x)$.

In regions with smaller $\omega_\Phi(x)$ proper time flows more slowly; in regions with larger $\omega_\Phi(x)$ it flows faster. Mass–energy deforms the state of Φ in such a way that it locally reduces $\omega_\Phi(x)$, thereby reproducing gravitational time dilation.

2.5. Reduction to known effective theories

Schematically:

- **GR (gravity).**
  On scales much larger than the microscopic structure of Φ, and neglecting exotic degrees of freedom in the dark sectors, the equations of motion for $\langle\Phi\rangle$ and $g_{\mu\nu}$ reduce to Einstein's equations with an effective cosmological constant Λ_{eff} arising from the background energy of Φ.
- **QFT on curved spacetime.**
  For a given background geometry $g_{\mu\nu}$ and small excitations around a vacuum

configuration of Φ, one recovers the standard description of particles as excitations of fields propagating on curved spacetime.

- **ΛCDM cosmology.**
  On cosmological scales:
  - the vacuum energy density of Φyields an effective cosmological constant,
  - an appropriate subset of modes $\Phi_{\text{dark},i}$behaves as cold, non-baryonic dark matter.

ΛCDM thus appears as an effective, statistical description of the full dynamics of Φ.

In the following sections this ontology is used to interpret gravity (Section 3), the dark sector (Section 4), black holes (Section 5) and quantum phenomena (Section 6).

2.6. Cosmogenesis as a Φ phase transition (lock-in of the vacuum clock)

A recurrent ambiguity in "Big Bang" language is that it suggests an explosion into a pre-existing space. In the present Φ ontology, the opposite reading is adopted: the time-domain in which spacetime and dynamics exist is itself an emergent phase of the vacuum oscillator. Cosmogenesis is therefore interpreted as a phase transition of the pre-temporal vacuum into a coherent oscillatory regime.

2.6.1. Pre-temporal vacuum state

I assume that the vacuum field Φ admits regimes in which a globally coherent oscillation frequency is not defined. In such a regime the vacuum may be described as pre-temporal in the following operational sense: there is no globally meaningful "clock phase" that can parametrise sequences of events. Importantly, this does not mean "nothingness"; it means a state in which time as a physical ordering parameter is not instantiated.

2.6.2. Instability threshold and lock-in

Cosmogenesis is modelled as a transition from an incoherent (or weakly coherent) regime to a coherent oscillatory regime characterised by a nonzero local vacuum frequency ω_Φ and a well-defined phase field θ. The central mechanism is lock-in: above an instability threshold, local oscillatory patches do not decay back to noise but instead self-amplify and synchronise.

Qualitatively, one may define a coherence (or order) parameter $Q_{\Phi}$and state the criterion:

- below threshold: fluctuations of Φ remain incoherent and decay (no stable ω_Φ),
- above threshold: oscillations grow and phase coherence emerges (stable ω_Φ exists).

In this view, the "Big Bang" corresponds to the onset of a globally connected time-domain in which ω_Φ becomes definable across a large region and can serve as the physical substrate of proper time.

In this ontology, spacetime is not the stage on which Φ evolves; rather, a coherent oscillatory regime of Φ is what makes an effective spacetime description meaningful.

2.6.3. Emergent spacetime and early-domain growth

Once a coherent oscillatory regime is established, the effective geometric description becomes meaningful. In the Φ framework, the metric $g_{\mu\nu}$is treated as a functional of coarse-grained vacuum state variables, including ω_Φ and its gradients. Accordingly, the early Universe may be re-read not primarily as "expansion into emptiness", but as growth and homogenisation of the coherent time-domain: a rapid increase of the region over which ω_Φ and θ are well-defined and mutually compatible.

This provides a natural conceptual slot for inflation-like behaviour at the ontological level: the rapid establishment of global coherence can address horizon-type intuitions (why distant regions share consistent physics) without committing, at this stage, to a specific inflaton potential. Quantitative cosmological predictions still require an explicit choice of $V_{\text{eff}}(\Phi)$and couplings.

2.6.4. Remnant coherence defects as observational handles

If cosmogenesis involves a phase transition and subsequent coherence growth, it is natural to consider the possibility of residual, extremely weak "defects" or large-scale non-idealities of the vacuum state (e.g., mild spatial variations or memory of early lock-in). In conservative terms, such relics could manifest as small departures from perfect isotropy/homogeneity or subtle tensions in inferred cosmological parameters. This paper does not claim that any specific anomaly is evidence for Φ dynamics; rather, it notes that a phase-transition origin of the time-domain makes such signatures conceptually natural targets for falsifiable tests.

2.7. Multiple time-domains and a non-geometric multiverse

The phase-transition reading of cosmogenesis suggests a minimal notion of a "multiverse" within the Φ ontology: distinct, dynamically stable time-domains corresponding to different coherent solutions (or phases) of the vacuum field. Crucially, these domains need not be embedded as "bubbles in a common space"; rather, they are best regarded as distinct solutions in the configuration space of Φ, each instantiating its own effective time and geometry.

In this interpretation:

1. Multiplicity means multiple stable oscillatory regimes of Φ, potentially with different effective parameters (e.g., background ω_Φ scales, sectoral couplings, or symmetry-breaking patterns).
2. No traversable contacts are expected in the naive geometric sense, because "adjacency" requires a shared metric/time-domain structure. Where two solutions

are dynamically incompatible, their overlap corresponds to loss of coherence rather than a stable “portal”.

3. The empirically relevant question is therefore not travel between domains, but whether our domain’s early lock-in dynamics can leave testable residual signatures (Section 7).

2.8. Scales, dimensional analysis, and a minimal parameter set

A recurring difficulty of vacuum-substrate ontologies is that they can appear underconstrained unless one clearly separates (i) the ontological layer from (ii) a minimal phenomenological parameterisation that is directly testable. In this section I therefore introduce a compact “VOΦF parameter set” whose only purpose is to organise empirical constraints, without committing to a unique microscopic model of Φ.

The core identification is the mapping between the local vacuum oscillation frequency $\omega_\Phi(x)$and the weak-field gravitational potential $\Phi_N(x)$,

$$\frac{\omega_\Phi(x)-\omega_\infty}{\omega_\infty}=\gamma\,\frac{\Phi_N(x)}{c^2},\frac{d\tau}{dt}=\chi(\omega_\Phi)\simeq 1+\beta\,\frac{\omega_\Phi-\omega_\infty}{\omega_\infty},$$

so that the product $\beta\gamma$controls the leading gravitational time-dilation law. Enforcing agreement with GR clock tests corresponds to $\beta\gamma\simeq 1$in the regime probed by Solar-System and terrestrial experiments. This already illustrates a general strategy of v2: wherever the framework is designed to reproduce GR/QFT as effective theories, the corresponding parameters are not “free predictions” but are fixed (or tightly constrained) by existing precision data.

Beyond the gravitational sector, possible non-standard low-energy imprints of Φcan be encoded in a small set of gauge-invariant effective operators. A conservative example is a weak coupling between the vacuum oscillator and electromagnetism,

$$\delta\mathcal{L}_{\Phi\text{-EM}}\sim\epsilon_1\,\Phi\,F_{\mu\nu}F^{\mu\nu}+\epsilon_2\,\Phi\,F_{\mu\nu}\tilde{F}^{\mu\nu}+\epsilon_3\,\partial_\mu\Phi\,J^\mu+\cdots\,,$$

where $J^\mu$is an effective visible-sector current and the ellipsis denotes higher-order and/or derivative operators. The role of $\epsilon_i$is not to assert a specific “new force”, but to provide a bookkeeping device: shielded magnetometry, resonant detectors, clock networks and related precision experiments can be used to set upper bounds on $\epsilon_i$as a function of frequency band, environmental conditions and shielding geometry.

At cosmological scales, the analogous minimal parameterisation is to treat the background vacuum energy density

$$\rho_{\Phi\text{-vac}}(t)\equiv V_{\text{eff}}(\langle\Phi\rangle(t))$$

and the dark-sector excitation content $\rho_{\Phi\text{-dark}}(t)$as effective components whose time dependence is constrained by the standard expansion history $H(z)$, the CMB, BAO and structure growth. In v2, the emphasis is therefore not on claiming a specific microphysical origin of these functions, but on explicitly stating which classes of $V_{\text{eff}}(\Phi)$and dark-mode properties would be required for the framework to remain simultaneously compatible with (i) ΛCDM-like background evolution where it is strongly supported, and (ii) controlled deviations where current tensions motivate them.

This explicit separation—ontology versus minimal phenomenological parameter set—serves two purposes. First, it makes the framework strictly falsifiable: a sufficiently tight collection of bounds on $(\beta\gamma, \epsilon_i, \rho_{\Phi\text{-vac}}(z), \rho_{\Phi\text{-dark}}(z))$can either squeeze VOΦF into practical irrelevance or identify a motivated region of parameter space. Second, it clarifies what would count as genuine explanatory gain: not "adding parameters", but finding a simple, stable class of effective models in which the same Φ-dynamics organises gravitational timekeeping, dark-sector phenomenology, black-hole boundary behaviour and low-energy probe channels in a coherent way.

3. Time and gravity from the vacuum oscillator Φ

3.1. Local oscillation frequency and proper time

The basic quantity controlling the flow of time is the local vacuum oscillation frequency $\omega_\Phi(x)$. Along a timelike worldline γ,

- the field Φexecutes a sequence of oscillations, and
- the accumulated phase of these oscillations defines proper time.

I postulate the relation

$$d\tau(x) \;=\; \chi(\omega_\Phi(x))\, dt,$$

where $t$is a global coordinate time, and $\chi(\omega_\Phi)$is a monotonic function with $\chi(\omega_\infty) = 1$in an asymptotically homogeneous region. In the linear regime,

$$\chi(\omega_\Phi(x)) \simeq 1 + \beta\, \frac{\omega_\Phi(x) - \omega_\infty}{\omega_\infty},$$

with a dimensionless constant $\beta = \mathcal{O}(1)$.

3.2. Weak-field limit and Newtonian gravity

In the weak-field limit the metric can be written as

$$ds^2 \simeq -(1 + \frac{2\Phi_N}{c^2})c^2 dt^2 + (1 - \frac{2\Phi_N}{c^2})d\vec{x}^{\,2},$$

with the Newtonian potential $\Phi_N(x)$satisfying

$$\vec{g}(x) = -\nabla\Phi_N(x).$$

I assume the relation

$$\frac{\omega_\Phi(x) - \omega_\infty}{\omega_\infty} = \gamma\, \frac{\Phi_N(x)}{c^2},$$

which gives

$$d\tau(x) \simeq [1 + (\beta\gamma)\, \frac{\Phi_N(x)}{c^2}]\, dt.$$

Choosing $\beta\gamma = 1$reproduces the standard expression for gravitational time dilation. In particular,

$$\vec{g}(x) \propto -\nabla\omega_\Phi(x),$$

so the classical gravitational field corresponds to the gradient of the vacuum oscillation frequency.

3.3. Relation to the metric and GR

The weak-field relations can be embedded in the full description by interpreting

$$g_{\mu\nu}(x) = F_{\mu\nu}(\langle\Phi(x)\rangle, \partial\langle\Phi(x)\rangle).$$

In a quasi-static regime one may write

$$g_{00}(x) \simeq -[1 + 2\,\varepsilon(\omega_\Phi(x))],$$

with $\varepsilon(\omega_\Phi) \propto (\omega_\Phi - \omega_\infty)/\omega_\infty$chosen such that

$$\varepsilon(\omega_\Phi(x)) \simeq \frac{\Phi_N(x)}{c^2}.$$

Einstein's equations

$$G_{\mu\nu}[g] = 8\pi G\, T_{\mu\nu}^{(\mathrm{tot})} + \Lambda_{\mathrm{eff}}\, g_{\mu\nu}$$

can then be viewed as effective equations for the functional $F_{\mu\nu}$, driven by the dynamics of $\Phi$and its coupling to matter.

3.4. Equivalence principle and free fall

The universality of free fall is realised via:

Universal low-energy coupling.
The dominant low-energy coupling between $\Phi$and matter is proportional to the trace of the energy–momentum tensor:

$$\mathcal{L}_{\mathrm{int}} \supset g_\Phi\, \Phi_{\mathrm{vis}}\, T^\mu_{\ \mu}.$$

All forms of visible energy–momentum deform the vacuum in the same way.

Free motion as extremum of vacuum phase.
Free trajectories extremise the integrated phase of the vacuum:

$$S \sim \int \omega_\Phi(x(\lambda))\, d\lambda,$$

which, to leading order, coincides with the action of a particle in GR and leads to the geodesic equation.

Under these assumptions, standard tests of the equivalence principle constrain only small deviations in how $\omega_\Phi$couples to different sectors.

3.5. Example: time dilation in the Earth–GPS system

To check the consistency of the ansatz

$$\frac{\omega_\Phi(x) - \omega_\infty}{\omega_\infty} = \gamma\,\frac{\Phi_N(x)}{c^2}, \frac{d\tau(x)}{dt} \simeq 1 + \beta\,\frac{\omega_\Phi(x) - \omega_\infty}{\omega_\infty},$$

with the choice $\beta\gamma = 1$, consider the classic example of clock-rate differences between the Earth's surface and a GPS satellite orbit.

In the weak-field limit GR gives

$$\frac{d\tau}{dt} \simeq 1 + \frac{\Phi_N(x)}{c^2},$$

where $\Phi_N(x) = -GM_\oplus/r$is the Newtonian potential and $M_\oplus$is the mass of the Earth. For two radii r_1, r_2, the fractional difference in clock rate is

$$\Delta\left(\frac{d\tau}{dt}\right) \simeq \frac{\Phi_N(r_2) - \Phi_N(r_1)}{c^2} = -\frac{GM_\oplus}{c^2}\left(\frac{1}{r_2} - \frac{1}{r_1}\right).$$

Take:

- Earth mass $M_\oplus \approx 5.97 \times 10^{24}\ \mathrm{kg}$,
- Earth radius $R_\oplus \approx 6.37 \times 10^{6}\ \mathrm{m}$,
- GPS orbital altitude $h \approx 2.02 \times 10^{7}\ \mathrm{m}$,
  so $r_1 = R_\oplus$, $r_2 = R_\oplus + h \approx 2.66 \times 10^{7}\ \mathrm{m}$,
- gravitational constant $G \approx 6.67 \times 10^{-11}\ \mathrm{SI}$,
- speed of light $c \approx 3.0 \times 10^{8}\ \mathrm{m/s}$.

Inserting these numbers one obtains

$$\Delta\left(\frac{d\tau}{dt}\right) \simeq +5.3 \times 10^{-10}.$$

In other words, an atomic clock in a GPS orbit ticks by about 5×10^{-10}faster per second than an identical clock on the Earth's surface (ignoring, for the moment, the specialrelativistic effect due to the satellite's velocity). This is precisely the order of magnitude that must be taken into account in practical GPS corrections.

Within the present Φontology:

- the gradient of $\omega_\Phi(x)$around the Earth is related to $\Phi_N(x)$by $(\omega_\Phi - \omega_\infty)/\omega_\infty = \gamma\, \Phi_N/c^2$;
- the identification $\beta\gamma = 1$ensures that the fractional clock-rate difference $\Delta(d\tau/dt)$matches the GR result;
- the above example can therefore be treated as a simple "sanity check" of the mapping $\omega_\Phi \leftrightarrow \Phi_N$: with an appropriate choice of ansatz parameters we obtain a numerically correct reconstruction of a well-measured effect.

This simple calculation is not a new prediction—we enforce agreement with GR via $\beta\gamma = 1$—but it shows that interpreting gravitational time dilation as a consequence of the spatial gradient of $\omega_\Phi(x)$is numerically fully compatible with existing clock measurements in a gravitational field.

4. Dark matter and dark energy as modes of the Φ oscillator

In the standard ΛCDM cosmology, the dominant components of the energy budget are dark matter ($\sim$ 25–30%) and dark energy ($\sim$ 65–70%). In the Φ ontology, both components are realised as different classes of modes of the same vacuum field.

4.1. Dark matter as hidden excitations of Φ

I decompose the vacuum field into a visible sector and dark sectors,

$$\Phi(x) = (\Phi_{\text{vis}}(x), \Phi_{\text{dark},1}(x), \Phi_{\text{dark},2}(x), \dots).$$

Dark matter is identified with stable, massive excitations in the $\Phi_{\text{dark},i}$ sectors. The dark-sector Lagrangian contains

$$\mathcal{L}_{\text{dark}} \supset \sum_i \left[\frac{1}{2}\partial_\mu \Phi_{\text{dark},i}\, \partial^\mu \Phi_{\text{dark},i} - V_i(\Phi_{\text{dark},i})\right],$$

where the minimum of V_i and the curvature around that minimum determine the mass and self-interactions of a given mode.

In a broad class of cases the coarse-grained behaviour of such modes is indistinguishable from that of cold dark matter. Local energy overdensities

$$\rho_{\text{dark}}(x) = \sum_i \rho_i(x; \Phi_{\text{dark},i})$$

contribute to the total energy–momentum tensor $T^{(\text{tot})}_{\mu\nu}$, deform $\omega_\Phi(x)$, and thereby generate the classical gravitational field

$$\mathbf{g}(x) \propto -\nabla \omega_\Phi(x).$$

The absence of coupling to electromagnetism ensures that these modes neither emit nor absorb light.

4.2. Galactic haloes and rotation curves

The observed flat rotation curves of spiral galaxies are explained in ΛCDM by the presence of dark-matter haloes. In the Φ framework:

- the stellar and gaseous disk corresponds to ordered excitations of Φ_{vis};
- the halo is a quasi-stationary configuration of $\Phi_{\text{dark},i}$ modes around the galaxy;

- the total energy stored in these modes deforms $\omega_\Phi(x)$such that gradients $-\nabla\omega_\Phi$sustain flat rotation curves.

In the weak-field regime this leads to the Poisson equation

$$\nabla^2\Phi_N(x) \propto \rho_{\text{vis}}(x) + \rho_{\text{dark}}(x),$$

with ρ_{dark}interpreted as energy stored in dark vacuum modes.

4.3. Dark energy as the background of the vacuum oscillator

Dark energy is interpreted as the background energy of the vacuum field:

$$\rho_{\Phi\text{-vac}}(t) \equiv V_{\text{eff}}(\langle\Phi\rangle(t)),$$

where V_{eff}includes contributions from all sectors.

In the homogeneous FRW limit,

$$\rho_{\text{tot}}(t) = \rho_{\text{vis}}(t) + \rho_{\text{dark-modes}}(t) + \rho_{\Phi\text{-vac}}(t),$$

where the second term behaves as dark matter and $\rho_{\Phi\text{-vac}}$behaves as a cosmological constant if it varies sufficiently slowly.

The cosmological-constant problem is thus reformulated: the observed small value of $\rho_{\Phi\text{-vac}}$suggests either partial compensation between contributions of different sectors, or that only a certain "projection" of the full vacuum energy of Φgravitates in the way captured by the effective metric.

Background energy scale ρ_Λ.
Cosmological observations (CMB, BAO, SN Ia) indicate that the present-day dark-energy density is of order

$$\rho_\Lambda \sim 5 \times 10^{-10}\ \text{J/m}^3 \sim 6 \times 10^{-27}\ \text{kg/m}^3,$$

which corresponds to an energy scale

$$E_\Lambda \equiv \rho_\Lambda^{1/4} \approx 2 \times 10^{-3}\ \text{eV} = 2\ \text{meV}.$$

If the background of the vacuum oscillator Φhas energy $V_{\text{eff}}(\langle\Phi\rangle)$reproducing the observed ρ_Λ, then experiment fixes precisely this scale for the effective "vacuum spring". In a simple picture of a single quantum oscillator this would correspond to a frequency

$$\omega_\Phi \sim \frac{E_\Lambda}{\hbar} \sim 10^{12}\ \text{s}^{-1},$$

assuming one effective degree of freedom per unit cell of volume; a full interpretation of these numbers, however, requires a concrete microscopic model of Φ.

4.4. Tensions in $\mathbf{H_0}$ and $\mathbf{S_8}$ as possible imprints of Φ dynamics

Slow evolution of $\langle\Phi\rangle(t)$ along the potential $V_{\mathrm{eff}}(\Phi)$, together with transient excitations of specific $\Phi_{\mathrm{dark},i}$ modes, can:

- introduce a mild time dependence in $\rho_{\Phi\text{-vac}}(z)$;
- modify the effective dark-matter density as a function of z.

As a consequence, the expansion history $H(z)$ and the growth of structure may deviate slightly from pure ΛCDM, potentially affecting the inferred values of H_0 and S_8. The Φ framework thus naturally accommodates this type of effect, should future data require it.

4.5. Section summary

In the proposed ontology:

- dark matter consists of hidden, massive excitations $\Phi_{\mathrm{dark},i}$;
- dark energy is the background energy of the vacuum oscillator, encoded in $V_{\mathrm{eff}}(\langle\Phi\rangle)$.

Both components arise as different regimes of the same field Φ and feed into the same quantity $\omega_\Phi(x)$, whose gradients generate gravity. ΛCDM appears as an effective statistical description of a particular class of Φ-configurations.

4.6. Element formation and nucleosynthesis in the Φ ontology

The origin of the chemical elements is quantitatively described by nuclear physics and astrophysical nucleosynthesis: (i) primordial nucleosynthesis in the early Universe (BBN) sets the light-element abundances; (ii) stellar burning and hydrostatic/explosive nucleosynthesis build elements up to the iron group; (iii) neutron-capture processes (notably the r-process in extreme environments) produce many of the heaviest nuclei. The VOΦF framework does not modify these reaction networks. Instead, it offers an ontological reinterpretation of why “nuclear species” exist as stable entities: nuclei are treated as stable, discrete excitation patterns (or topological configurations) in the visible sector Φ_{vis}, in close analogy to how particles in QFT are stable modes of underlying fields.

In this language, nucleosynthesis corresponds to transitions between Φ_{vis}-configurations under extreme thermodynamic and density conditions. At high temperatures, the relevant degrees of freedom are not bound nuclear configurations but a plasma of excitations; as the Universe cools (BBN) or as astrophysical ejecta decompress and cool (r-process), the system explores the configuration space of Φ_{vis} and settles into metastable or stable minima corresponding to bound nuclei. This is conceptually parallel to the standard picture (binding emerges when conditions allow), but recast as “pattern formation” in a single vacuum carrier.

Within v2 it is useful to emphasise that BBN provides a particularly clean falsification handle on any framework that modifies the effective expansion history $H(t)$or introduces additional energy density components. In VOΦF terms, any non-trivial evolution of $\rho_{\Phi\text{-vac}}(z)$or additional dark-mode energy density $\rho_{\Phi\text{-dark}}(z)$at MeV-era temperatures changes the freeze-out history of weak interactions and the timing of nuclear assembly. Therefore, even without selecting a detailed $V_{\text{eff}}(\Phi)$, the framework must satisfy a qualitative consistency requirement: the admissible Φ-dynamics in the early Universe must remain within the narrow band of expansion histories that preserve successful BBN light-element yields.

For heavy elements, the Φ-ontology provides a natural interpretational slot for “islands of stability” and magic numbers. If nuclear configurations correspond to discrete, especially symmetric or topologically “complete” patterns of Φ_{vis}, then shell closures and enhanced stability can be rephrased as the existence of particularly robust Φ_{vis}-textures that resist decay. This does not replace nuclear shell theory; it functions as a unifying picture that suggests why certain integer sequences (magic numbers and candidate superheavy stability regions) might reflect deeper structural regularities in the configuration space of the vacuum carrier. In v2, this can be framed as a programme: mapping known nuclear stability systematics onto a class of Φ_{vis}pattern invariants, with the explicit aim of producing falsifiable heuristics for where unusually stable superheavy nuclei are more likely to occur.

Crucially, none of the above implies “another chemical dimension” from which particles are imported. VOΦF is compatible with the conservative statement that all chemical and nuclear entities are manifestations of one carrier Φ, and that apparent “creation of elements” is a transition between allowed bound-state configurations of that carrier under astrophysical or laboratory conditions. Any additional claim—such as new long-range couplings affecting nuclear rates—would have to be separately parameterised and confronted with stringent BBN and laboratory bounds.

5. Black holes as regions of vanishing vacuum oscillations (Φ-collapse)

5.1. Standard GR picture: horizon, shadow and photon ring

In classical GR, a black hole is a spacetime region characterised by a horizon, a shadow and an inner singularity:

- **event horizon** – a boundary beyond which signals cannot reach future null infinity;
- **shadow** – a dark region against a bright plasma background, corresponding to photons that are captured or strongly deflected;
- **photon ring** – a bright ring associated with unstable photon orbits;
- **singularity** – a region where curvature invariants diverge and the classical metric description ceases to be reliable.

GR does not say what is *physically* "inside" the singularity; it merely signals the breakdown of the classical description.

5.2. Decay of Φoscillations and Φ-collapse

Under ordinary conditions the vacuum field oscillates with a non-zero frequency $\omega_\Phi(x)$, and:

- stable patterns of these oscillations support particles and radiation;
- the local frequency of the vacuum clock defines proper time;
- spatial variations of $\omega_\Phi(x)$encode the gravitational field.

Near a sufficiently compact object:

- the energy density stored in Φexcitations slows down the local $\omega_\Phi(x)$;
- above some critical compactness, the local oscillation pattern can no longer support stable excitations or a sensible flow of time.

I therefore introduce the Φ**-collapse region** $\mathcal{C}_\Phi$, defined as the set of points where effectively $\omega_\Phi(x) \to 0$and no stable propagating Φ-modes exist. Inside $\mathcal{C}_\Phi$there are:

- no propagating Φ-waves (hence no ordinary photons or particles);
- no well-defined local proper time;
- no local representation of information in the degrees of freedom of Φ.

Macroscopically, an external observer sees $\mathcal{C}_\Phi$as the dark interior of a black hole. The exterior geometry remains described by the Kerr solution.

5.3. Event horizon and photon ring in the language of Φ

The radial profile $\omega_\Phi(r)$around a compact object allows one to distinguish three regimes:

- **Outer region.**
  $\omega_\Phi(r) \approx \omega_\infty$; the vacuum supports free propagation of matter and light.
- **Strong-field shell (photon-ring region).**
  $|\nabla\omega_\Phi|$ is large but $\omega_\Phi \neq 0$; the vacuum still supports electromagnetic modes, but photon trajectories are strongly bent.
- **Interior of Φ-collapse.**
  $\omega_\Phi(r)$ effectively vanishes and the field does not support excitations; this defines $\mathcal{C}_\Phi$.

In this picture:

- the **event horizon** is the boundary between the oscillatory regime and Φ-collapse;
- the **photon ring** is the last shell in which Φ oscillates coherently enough to support quasi-bound photon trajectories;
- the **shadow** is the projection of $\mathcal{C}_\Phi$ onto the sky.

5.4. Black-hole interior: effective scenarios

At the level of an effective Φ-description one can consider three broad classes of interior scenarios:

- **(A) "Dead region".**
  The interior $\mathcal{C}_\Phi$ is a local end of the Φ-description: $\omega_\Phi \to 0$, there is no regular vacuum state or excitations, and no sensible local time. No further regular spacetime region "on the other side" is postulated.
- **(B) Interface with hidden sectors.**
  The visible component Φ_{vis} collapses, while some of the $\Phi_{\text{dark},i}$ modes remain regular. The interior may act as an interface that re-encodes energy and information between sectors.
- **(C) Transient topological bridge.**
  Extreme deformations of Φ may resemble Einstein–Rosen bridges in field-configuration space, but in the absence of exotic matter they are unstable and end in Φ-collapse, rather than forming stable tunnels.

A detailed decision between these scenarios would require a full microscopic theory of Φ and lies beyond the scope of this work.

5.5. Hawking radiation and information

In semiclassical GR, Hawking radiation arises from quantum fluctuations on a curved background. In the language of Φ:

- the horizon region is where gradients of ω_Φ are largest;

- the boundary between the oscillatory regime and $\mathcal{C}_\Phi$cannot be perfectly static at the quantum level;
- vacuum fluctuations of Φin this zone generate pairs of excitations in the visible and dark sectors.

The outgoing component is observed as Hawking radiation; the ingoing component contributes to $\mathcal{C}_\Phi$. The approximate thermality of the radiation reflects the statistics of vacuum fluctuations in a strongly deformed Φ-background. The question of full unitarity requires a more detailed microscopic model.

5.6. Section summary

In this framework, black holes are interpreted as boundary configurations of the vacuum oscillator Φ, in which:

- the local frequency $\omega_\Phi(x)$effectively tends to zero;
- the field loses the ability to support ordinary excitations and local time;
- the effective description in terms of a smooth metric reaches its domain of applicability.

The horizon, shadow and photon ring obtain a microscopic interpretation in terms of oscillatory regimes of Φ.

6. Quantum phenomena within the vacuum oscillator Φ

6.1. Particles and waves as excitations of Φ

In standard QFT:

- the photon is an excitation of the electromagnetic field,
- the electron is an excitation of the electron field, and so on.

"Wave–particle duality" reflects the fact that a single field admits both a wave-like configuration and quantised excitations.

Within the Φframework, all of these fields are effective modes of the vacuum field Φ. Each particle species corresponds to a stable excitation pattern in an appropriate mode of Φ, and the "wave" is the spatial distribution of the oscillation amplitude of that mode. There is no ontological split between wave and particle: there is a single oscillating medium Φwhose excitations

- propagate in a wave-like manner, and
- are absorbed in quantised chunks by macroscopic detectors.

6.2. The wave function as an effective description of the state of Φ

Let $\mid \Psi_\Phi\rangle$denote the quantum state of the vacuum field, and $\widehat{\Phi}_{\text{exc}}$an operator creating a given mode (e.g. the electron mode). The one-particle wave function in the position basis is then

$$\psi(x) \equiv \langle x \mid \widehat{\Phi}_{\text{exc}} \mid \Psi_\Phi\rangle.$$

In this ontology:

- $\mid \psi(x) \mid^2$measures the local intensity of the oscillation pattern of the relevant Φ-mode;
- it determines the local propensity of a detector, coupled to that mode, to absorb the *entire* quantum of energy in a single event;
- the full state of Φlives in Fock space; $\psi(x)$is its projection onto one-particle configurations.

Superposition of states has a natural reading: it is the coexistence of several possible oscillation patterns of Φin the global quantum state.

6.3. Interference in the double-slit experiment

In the double-slit experiment:

- the source excites a single quantum of the relevant Φ-mode;

- the excitation propagates as an extended wave passing through both slits;
- behind the slits, the components interfere, generating a pattern in $|\psi(x)|^2$.

The detection screen

- couples in a nonlinear and quantised way (it either absorbs the whole quantum or nothing), and
- responds irreversibly (a pixel fires, a grain of emulsion blackens).

The probability of detection at a point is proportional to $|\psi(x)|^2$. Individual events are local, but their histogram reproduces the interference pattern of the Φ-waves.

6.4. Measurement, decoherence and “collapse”

Before measurement, the relevant Φ-mode is in a coherent superposition of spatial or internal configurations. During measurement:

- the field Φcouples to many degrees of freedom of the detector and its environment;
- different branches of the superposition drive the detector into different microstates;
- these branches rapidly decohere—interference between macroscopically distinct outcomes disappears.

Mathematically, one may stay with unitary evolution of the combined “field + detector + environment” state; “collapse” is an effective description of decoherence and phase loss between branches. The Φontology simply states that different branches correspond to different global oscillation patterns of the vacuum.

6.5. Entanglement and nonlocal correlations

An entangled state of two excitations (e.g. an electron pair in a singlet) corresponds to a single global state $|\Psi_\Phi\rangle$that cannot be written as a product of local states. The correlations are encoded in the global oscillation pattern of Φ.

A measurement on one part of the system:

- reveals which branch of the Φ-state the local detector has correlated with, and
- updates the *conditional* probabilities of outcomes on the distant side, without any need for superluminal signalling.

Bell inequalities exclude *local* hidden-variable theories, but are consistent with nonlocal correlations in a single field state. The Φframework does not introduce additional hidden variables; it preserves the standard Hilbert-space structure.

6.6. Section summary

In this ontology, quantum phenomena acquire a unified, field-based character:

- wave–particle duality arises because Φ-excitations propagate as waves but are absorbed in discrete jumps;
- interference and superposition are interference of oscillatory patterns of Φ;
- measurement and “collapse” are decoherence of Φ-states in large environments;
- entanglement is the global structure of the Φ-state.

The same vacuum field Φcarries quantum excitations and sets the flow of time and gravity via $\omega_\Phi(x)$, providing a common ontological substrate for GR and QM. Potential very-low-frequency (ELF) modulations of $\Phi$are natural candidates for low-energy probes of vacuum dynamics and will be discussed in the context of empirical tests (Section 7).

6.7. Electromagnetism and magnetism as phase textures of the vacuum oscillator Φ

In standard quantum field theory, electromagnetism is described by a $U(1)$gauge field $A_\mu(x)$with field strength

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu,$$

and magnetic phenomena arise as particular configurations of $F_{\mu\nu}$generated by electric currents and by intrinsic magnetic moments of matter (primarily electron spin and orbital motion). In the present Φ-ontology, this successful formal description is not modified. Instead, the purpose of this subsection is to embed it into a single-carrier picture in which electromagnetic phenomena are read as emergent structures of the visible sector $\Phi_{\text{vis}}$of the vacuum oscillator.

A minimal ontological move is to regard the electromagnetic gauge potential $A_\mu$as an effective “connection-like” variable that tracks spatial and temporal phase transport in an appropriate internal manifold of Φ_{vis}. Concretely, in many physical contexts a complex order-parameter decomposition

$$\Phi_{\text{vis}}(x) \sim \rho(x)\, e^{i\theta(x)}$$

is a useful local representation (not a claim that the fundamental vacuum is literally a single complex scalar, but a coarse-grained parametrisation of a phase-bearing sector). In such a representation, electromagnetism is naturally associated with the geometry of phase transport: the gauge potential plays the role of the compensating field that renders phase comparisons meaningful across spacetime, while the field strength measures the non-triviality (“curvature”) of that phase structure.

Within this reading, magnetism corresponds to spatial vorticity of the emergent connection, i.e. to the curl component of A_μ. In the non-relativistic limit,

$$\mathbf{B} = \nabla \times \mathbf{A},$$

so a magnetic field is interpreted as a macroscopic manifestation of a non-trivial spatial phase texture of Φ_{vis}. This is conceptually analogous to the way vorticity and quantised circulation describe topological textures in condensed-matter order parameters, except that here the underlying carrier is the vacuum oscillator sector that also supports ordinary quantum excitations.

This ontological embedding is compatible with the standard account of magnetism in matter. Paramagnetism and diamagnetism arise from the response of electronic wave functions to an applied $\mathbf{A}$(orbital currents), whereas ferromagnetism emerges from exchange interactions and spontaneous symmetry breaking that align microscopic magnetic moments into macroscopic domains. In the Φ-language, these familiar mechanisms can be rephrased as follows: the relevant electronic excitations are stable modes of Φ_{vis}(Section 6.1), with spin and orbital structure encoded in internal degrees of freedom of those modes; magnetic ordering corresponds to a collective, low-entropy phase-locked configuration in which a large number of microscopic Φ_{vis}-excitations share a coherent alignment, producing a macroscopically persistent phase texture. Domain formation and hysteresis then correspond to metastable branches of this collective configuration space, consistent with the well-known energy landscape picture of ferromagnets.

Two points of emphasis preserve technical consistency. First, the present ontology does not require $A_\mu$to be literally a pure gradient of a single-valued phase, which would imply $F_{\mu\nu} = 0$. Non-zero field strength corresponds to non-trivial curvature of the effective connection, which may arise from multi-component internal structure of Φ_{vis}, from topological defects, or from coarse-grained descriptions in which phase is not globally single-valued. Second, the framework does not claim a derivation of the Standard Model gauge group. The claim is narrower: given that QED accurately describes electromagnetic phenomena, VOΦF provides a unified carrier interpretation in which electromagnetic gauge structure is an emergent bookkeeping of phase transport in Φ_{vis}.

This embedding naturally interfaces with the low-energy test axis discussed in Section 7. If Φadmits ultra-weak, coherent modulations that couple to electromagnetic degrees of freedom, their leading effective imprints can be parameterised conservatively by gauge-invariant operators such as

$$\delta\mathcal{L}_{\Phi\text{-EM}} \sim \epsilon_1\, \Phi\, F_{\mu\nu}F^{\mu\nu} + \epsilon_2\, \Phi\, F_{\mu\nu}\tilde{F}^{\mu\nu} + \cdots\ ,$$

where $\tilde{F}^{\mu\nu}$is the dual tensor and the ellipsis denotes higher-order or derivative couplings. In the present v1, these terms are not promoted to a specific numerical model; rather, they illustrate how the ontology accommodates the possibility of minute Φ-driven electromagnetic signatures while remaining compatible with the stringent empirical success of standard electromagnetism. Null results in shielded magnetometry or related ultrasensitive setups then translate into progressively tighter bounds on $\epsilon_{1,2}$, constraining any non-standard vacuum dynamics without compromising the effective validity of QED.

6.8. Molecular binding and chemistry as low-energy coherent patterns of Φ

Chemical structure and molecular binding are quantitatively described by quantum mechanics and, in practice, by quantum chemistry: electronic wave functions occupy bound states in multi-centre Coulomb potentials, the Pauli principle and exchange enforce antisymmetry and generate effective bonding/antibonding structure, and the Born–Oppenheimer separation treats nuclei as slow variables relative to electrons. The VOΦF ontology does not alter this formalism. Instead, it supplies a unified carrier picture in which molecules are stable, low-energy configurations of Φ_{vis}excitations—coherent patterns that minimise an effective energy functional under the constraints set by nuclear positions and electron number.

Following the interpretation already introduced for the wave function (Section 6.2), the electronic state $\psi(\mathbf{x})$is viewed as a projection of the global Φ-state onto a one-electron (or few-electron) sector,

$$\psi(x) \equiv \langle x \mid \widehat{\Phi}_{\text{exc}} \mid \Psi_{\Phi} \rangle,$$

so $\mid \psi \mid^2$measures the local intensity of the relevant Φ_{vis}-mode and thereby the propensity for quantised interaction with matter. In this language, a molecular orbital is not a separate ontic entity but a stable spatial oscillation pattern of Φ_{vis}supported by the multi-nuclear environment. Bond formation corresponds to the emergence of a bound configuration in which the collective Φ_{vis}-pattern reduces the total energy relative to separated constituents.

A compact way to express this ontologically is to introduce an effective energy functional for the visible sector,

$$E[\Phi_{\text{vis}}; \{R_I\}] \;=\; E_{\text{field}}[\Phi_{\text{vis}}] \;+\; E_{\text{coupling}}[\Phi_{\text{vis}}, \{R_I\}],$$

where $\{R_I\}$are nuclear coordinates and E_{coupling}encodes the known electromagnetic interaction between nuclei and electronic degrees of freedom. Molecular equilibrium geometries then correspond to joint minima of this functional with respect to both the Φ_{vis}configuration and the slow nuclear coordinates (Born–Oppenheimer surfaces). In standard language, this is the statement that bound molecular states exist and can be found variationally; in the Φ-ontology, it is read as the stabilisation of a particular coherent Φ_{vis}-pattern that “locks” to a multi-centre potential and persists as a robust excitation of the vacuum carrier.

This perspective clarifies the relationship between chemistry and the broader unification goals of VOΦF. Chemical processes occur at energy scales $\mathcal{O}(\text{eV})$, vastly below nuclear (MeV) and far below the regimes that deform the metric or drive Φ-collapse. Consequently, chemistry probes a strongly constrained, low-energy sector of Φ_{vis}in which the effective theory reduces to QED plus non-relativistic many-body quantum mechanics on an approximately fixed background. The Φ-framework therefore does not posit new chemical forces; rather, it supplies a unifying ontological statement: the same carrier Φthat underlies spacetime/timekeeping via $\omega_{\Phi}(x)$also supports the bound-state patterns that we describe as atoms, bonds, and molecules.

Within this view, “formation” of molecules can be described as a phase-locking and energy-dissipation process in the Φ_{vis}sector. As a reactive system cools or exchanges energy with its environment, incoherent superpositions of electronic configurations decohere (Section 6.4) and the system relaxes toward low-energy attractors—bound electronic patterns correlated with specific nuclear arrangements. The familiar language of potential energy surfaces, transition states, and reaction pathways can thus be re-read as the dynamics of Φ_{vis}-patterns moving between metastable basins in configuration space under environmental coupling, without any departure from standard quantum chemistry.

Finally, the molecular scale provides a conceptual bridge between quantum foundations and macroscopic phenomenology within a single ontology. Molecules are mesoscopic objects: they exhibit clear quantum structure (discrete spectra, interference under controlled conditions) yet rapidly decohere in typical environments. In the VOΦF reading, this is precisely the regime where the “oscillatory pattern” interpretation of $\psi$is most transparent: molecules are stable Φ_{vis}-excitations whose spatial patterns are well-defined, but whose phase relations are easily scrambled by coupling to large environments, yielding classical chemical behaviour. This reinforces the central claim of the framework: quantum phenomena, matter structure, and macroscopic irreversibility can be organised as different dynamical regimes of a single vacuum oscillator carrier, with the standard formalism recovered as the effective description in each regime.

7. Predictions and empirical tests of the Φ framework

The vacuum-oscillator Φ framework is physical only insofar as it leads to testable predictions. Below I outline how it can be confronted with data in three regimes: cosmological, astrophysical and local (ELF).

7.1. General falsifiability criteria

The Φ framework would be strongly constrained if:

- for no reasonable choice of $V_{\text{eff}}(\Phi)$ and couplings one can reproduce cosmological observables (CMB, BAO, SN Ia, $H(z)$, $P(k)$) without pathologies;
- precise data remain fully consistent with pure ΛCDM and Kerr–GR in regimes where typical Φ models would imply small but nonzero deviations;
- sensitive local searches impose such strong bounds on possible ELF modes coupled to Φ that any additional vacuum dynamics becomes practically irrelevant.

It would be supported if:

- a simple class of potentials $V_{\text{eff}}(\Phi)$ improves the fit to cosmological data compared to pure ΛCDM (e.g. by alleviating the H_0 and S_8 tensions);
- observations of black-hole shadows or gravitational waves indicate repeatable anomalies consistent with Φ-collapse effects;
- long-term ELF/ULF measurements reveal coherent, nonstandard signals that cannot be explained by classical sources.

7.2. Cosmological tests

In the Φ ontology:

- $\rho_{\Phi\text{-vac}}(t) = V_{\text{eff}}(\langle\Phi\rangle(t))$ plays the role of dark energy,
- massive modes $\Phi_{\text{dark},i}$ behave as dark matter.

Possible tests:

- **Expansion history $H(z)$ and early-time dark energy.**
  A time-varying $\rho_{\Phi\text{-vac}}(z)$ affects $H(z)$ as well as CMB, BAO, SN Ia and the 21 cm signal. The admissible class of $V_{\text{eff}}(\Phi)$ must remain consistent with these datasets.
- **H_0 and S_8 tensions.**
  Mild dynamics of the vacuum and/or dark sector can shift the inferred values of H_0 and S_8. The existence of simple Φ models that reduce both tensions without spoiling the rest of the fit would strongly argue in favour of the framework.

- **Power spectrum $P(k)$ and small-scale structure.**
  The properties of $\Phi_{\mathrm{dark},i}$ modes (masses, self-interactions) influence the shape of $P(k)$ and halo profiles. Data from DESI, Euclid and weak-lensing studies can constrain this microphysics, analogously to standard dark-matter models.

7.3. Astrophysical tests: black holes and gravitational waves

The interpretation of black holes as regions of Φ-collapse (Section 5) and of gravitational waves as perturbations of Φ-synchronisation (Section 3) suggests two families of tests:

- **Shadows and photon rings.**
  If Φ-dynamics near the boundary $\mathcal{C}_\Phi$ is not exactly Kerr-like, one may expect small modifications to the brightness, thickness or substructure of the photon ring, and to the shape of the shadow. Comparisons of EHT-like observations with GRMHD simulations in Kerr spacetimes can reveal or constrain such effects.

- **Gravitational waves.**
  Additional vacuum modes may introduce
    - minimal frequency-dependent dispersion,
    - weak extra polarisations,
    - slight corrections to ringdown spectra.
      Current and future detectors (LIGO/Virgo/KAGRA, LISA, third-generation observatories) can progressively narrow the allowed deviations from standard propagation.

7.4. Local ELF tests: ultra-weak vacuum modulations

A possible ground-based test of the Φ framework is the search for very low-frequency (ELF, 0–50 Hz) vacuum modes that couple ultra-weakly to electromagnetic fields and matter. The guiding idea is that, if the vacuum oscillator Φ exhibits macroscopic, coherent excitations in the ELF band, they might leave detectable imprints even in carefully shielded environments.

A prototypical experiment would involve:

• **Maximally shielded environment:** Faraday cage + μ-metal + optional active Helmholtz compensation.

• **Diversified sensor suite:** magnetometers, ELF antennas, E-field probes, environmental sensors, CRT beam monitors.

• **Long-term data acquisition** (months to years), analysing anomalies that:
– penetrate shielding in ways incompatible with classical EM,
– do not match known backgrounds (Schumann, power grid, geomagnetic storms),
– show low algorithmic entropy or structured phase correlations.

From a conservative Φ perspective, the goal is to set upper bounds on Φ–EM and Φ–matter couplings. If no anomalies appear, allowed ELF amplitudes of the vacuum oscillator shrink over time. Tiny expected effects can be represented schematically as:

$$\delta\mathcal{L}_{\Phi-EM} \sim \epsilon\,\Phi\,F_{\mu\nu}F^{\mu\nu}$$

In principle, one may also search for structured modulations resembling information carriers (redundancy, framing, repeated symbol patterns). Even then, the minimal conclusion would simply be non-standard information dynamics in the vacuum field Φ.

7.5. ELF/ULF searches: MEG, satellites, magnetometer networks

Existing channels sensitive to ELF/ULF fields provide complementary tests:

• MEG systems: scan background activity for non-physiological ELF structures.
• Satellite magnetometers: separate ionospheric/magnetospheric/ground components.
• Global magnetometer networks: synchronous distant anomalies → large-scale coherence.

Schumann resonances (≈7.83 Hz and harmonics) form a natural ELF baseline:

$$f_n \approx (n+1)\ 7.83\ \text{Hz}$$

Any persistent, low-entropy modulation of these resonances, correlated across stations and unexplained by atmospheric/ionospheric processes, would be a candidate signature of Φ-dynamics.

A two-track strategy:

(i) Open-world analysis of ELF/ULF data (including Schumann bands) for structured deviations.
(ii) Replication in shielded setups to see whether the signal attenuates as EM would.

A valid Φ-candidate signal must be:

(a) repeatable,
(b) globally correlated,
(c) incompatible with known geophysical/anthropogenic sources,
(d) anomalous with respect to shielding.

Even null results progressively constrain allowed Φ–EM couplings:

$$g_{\Phi-EM}^{\text{max}} \rightarrow g_{\Phi-EM}^{\text{tighter bounds}}$$

A positive detection would provide a non-gravitational signature of vacuum dynamics, difficult to reconcile with ΛCDM + QFT but natural in the Φ framework.

7.6. Black-hole formation as a falsifiable prediction of the VOΦF ontology

In the VOΦF framework the existence of an event horizon corresponds to a collapse of the vacuum oscillator, i.e. to the condition

$$\omega_\Phi(r) \to \omega_{\text{crit}} \approx 0,$$

at some radius $r = r_H$.
Since the vacuum oscillation frequency and the metric component $g_{00}$are related via

$$\frac{\omega_\Phi(r) - \omega_\infty}{\omega_\infty} = \gamma\, \frac{\Phi_N(r)}{c^2}, g_{00}(r) \simeq -(1 + 2\Phi_N/c^2),$$

the condition $\omega_\Phi \to 0$is equivalent to

$$g_{00}(r_H) \to 0.$$

Thus, VOΦF predicts that the onset of Φ–collapse must occur at a radius extremely close to the Schwarzschild value

$$r_H \approx R_S = \frac{2GM}{c^2},$$

otherwise the model would be inconsistent with observed:

- black–hole shadows (EHT),
- photon-ring structure,
- gravitational-wave ringdown frequencies,
- relativistic accretion-disk timing.

This gives a sharp falsifiability condition:

Falsifiable requirement

For any astrophysical object of mass M, VOΦF must satisfy:

$$\omega_\Phi(r_{\text{core}}(M)) \leq \omega_{\text{crit}} \text{if and only if} r_{\text{core}}(M) \lesssim R_S(M).$$

If the Φ-collapse radius predicted by VOΦF deviated measurably from $2GM/c^2$, then current EHT and LIGO/Virgo/KAGRA observations would already exclude the model.

Why this is a strong test

- It is parameter-insensitive: depends only on the relation between $\omega_\Phi$and curvature.

- It does not depend on the shape of $V_{\text{eff}}(\Phi)$, the number of dark sectors, or EDE/DM amplitudes.
- It directly confronts VOΦF with strong-field GR, where data are excellent.

Therefore:

If VOΦF cannot reproduce the Schwarzschild (or Kerr) collapse boundary to within observational accuracy, the entire ontology fails.

Strong-field tests (black holes and ringdown).
In the VOΦF framework, black-hole formation corresponds to a collapse of the vacuum oscillator,
$\omega_\Phi(r) \to \omega_{\text{crit}} \approx 0$, at some radius $r = r_H$. Since $\omega_\Phi$and the metric component $g_{00}$are linked, this condition is equivalent to $g_{00}(r_H) \to 0$, i.e. to the appearance of an event horizon. A viable VOΦF realisation must therefore reproduce, to observational accuracy, the Kerr value $r_H \simeq 2GM/c^2$for astrophysical black holes. Any model in which Φ–collapse occurs systematically at $r_H$significantly different from the Kerr radius would be falsified by:

- the measured sizes of black-hole shadows for M87* and Sgr A* (EHT-type observations), and
- the quasi-normal mode spectrum in gravitational-wave ringdown events (LIGO/Virgo/KAGRA/LISA).

Conversely, agreement with these data constrains the allowed profiles $\omega_\Phi(r)$in the strong-field regime and sharply limits deviations from Kerr.

7.7. Modulations carrying information – a cautious hypothesis

The Φframework logically allows for the possibility of vacuum modes that carry structured modulations with features typical of information carriers (redundancy, framing, error correction). A conservative statement is:

If, in ELF/ULF data from shielded experiments, MEG systems, satellites or global magnetometer networks, one were to detect persistent modulations with characteristics typical of engineered information carriers, and if all known terrestrial and geophysical sources were convincingly excluded, such signals would be natural candidates for nonstandard processes in the vacuum field Φ.

The minimal conclusion would be the existence of unknown information-processing dynamics in the vacuum; more speculative interpretations would require a separate, very cautious discussion.

7.8. Section summary

By construction, the Φframework is testable:

- it can improve or worsen the fit to cosmological data relative to ΛCDM;
- it can introduce small departures from Kerr geometry and standard gravitational-wave propagation;
- it may, but need not, lead to ultra-weak ELF signals in sensitive setups.

As data accumulate, the parameter space of admissible Φmodels can be progressively narrowed, and the very concept can be either supported or gradually pushed into a regime of empirical irrelevance.

7.9. Precision laboratory probes beyond ELF: clocks, interferometers, and equivalence-principle tests

While ELF/ULF searches motivate one practical axis of local tests, the broader class of precision experiments that probe timekeeping, phase coherence and universality of free fall is equally natural in a framework whose central object is a “vacuum clock” $\omega_\Phi(x)$. In particular, atomic clocks and clock networks are direct probes of gravitational redshift and of any additional modulation of proper-time flow beyond standard GR. Since VOΦF identifies proper time with accumulated phase of the vacuum oscillator, any spatiotemporal variability of $\omega_\Phi(x)$beyond that implied by the GR potential would appear as an anomalous component in clock comparisons.

A minimal phenomenological representation is to allow a small residual modulation,

$$\frac{d\tau}{dt} = 1 + \frac{\Phi_N}{c^2} + \delta_\Phi(x,t),$$

where $\delta_\Phi$is constrained to be extremely small in ordinary environments. The operational advantage of this parameterisation is that it is detector-agnostic: $\delta_\Phi$can be searched for in terrestrial clock networks, satellite links, and long-baseline comparisons, with characteristic signatures depending on whether it is static (position-dependent), transient (environmental or astrophysical triggers), or oscillatory (narrow-band vacuum modes). In v2, this provides a clean bridge between the core ontology and concrete measurements: instead of arguing abstractly about “vacuum time”, one states exactly what would be measured as a deviation from the GR redshift law.

A second key class of probes are atom interferometers and related phase-sensitive devices. In the same way that conventional matter-wave interferometry measures accumulated phase differences of quantum excitations, a VOΦF-type deviation that couples to phase transport would generically manifest as an additional term in interferometric phase shifts. This motivates an experimental logic parallel to the ELF programme: use diversified sensors (clocks, interferometers, gravimeters) in controlled environments to look for consistent, correlated anomalies that cannot be attributed to known electromagnetic, seismic, thermal or gravitational backgrounds.

Finally, equivalence-principle (EP) tests provide a strict constraint on any coupling of Φthat distinguishes different compositions. The conservative VOΦF stance is that the dominant low-energy coupling is universal (trace coupling to $T^{\mu}_{\ \mu}$), so that composition-dependent forces are either absent or suppressed below current bounds. In v2 this can be made explicit by noting that any non-universal contribution would enter as small, material-dependent coefficients in an effective interaction term, and would therefore be bounded by the tightest available EP measurements. The framework's viability is thus strengthened by a clear statement of hierarchy: in ordinary laboratory and Solar-System conditions, the theory is required to reduce to GR/QFT to high precision, and the allowed room for Φ-specific effects is pushed into regimes where either (i) the environment is extreme (strong-field, cosmological), or (ii) the couplings are ultra-weak and must be pursued with dedicated precision searches.

This "precision-lab axis" complements ELF rather than replacing it: ELF searches are motivated by the possibility of macroscopic coherent vacuum modes at low frequencies, whereas clock/interferometer/EP tests constrain any broader class of vacuum-induced proper-time or phase anomalies regardless of their spectral content. Together with cosmological and astrophysical constraints, they provide a closed loop of falsifiability across many orders of magnitude in frequency and energy scale.

In contrast to GR, where proper time is entirely geometric, VOΦF predicts that any residual dynamics of the vacuum oscillator would manifest directly as anomalies in clock rates and phase accumulation. Precision timekeeping experiments therefore probe the core postulate of the framework rather than a peripheral coupling.

8. Synthesis and conclusions

In this work I have proposed an ontological framework in which time, gravity, dark matter, dark energy, black holes and quantum phenomena are all different regimes of the dynamics of a single vacuum field $\Phi(x)$. The key role is played by the local vacuum oscillation frequency $\omega_\Phi(x)$, which acts as a physical "clock": its value controls the local flow of proper time, while its gradients reproduce, in the weak-field limit, the Newtonian potential and the classical gravitational acceleration.

Against this background:

- **Section 2** introduced the ontology of the vacuum oscillator $\Phi$and a minimal effective formalism in which the metric $g_{\mu\nu}$is a functional of the coarse-grained vacuum state, and the background energy $V_{\text{eff}}(\langle\Phi\rangle)$plays the role of an effective cosmological constant.
- **Section 3** showed that, with an appropriate identification of $\omega_\Phi(x)$with the potential $\Phi_N(x)$, one can reproduce in the weak-field limit the standard gravitational time dilation and the universality of free fall, while retaining GR as the effective set of equations for the functional $F_{\mu\nu}[\langle\Phi\rangle]$.
- **Section 4** reinterpreted dark matter as massive, stable excitations in the dark sectors $\Phi_{\text{dark},i}$, and dark energy as the background energy of the vacuum oscillator, $\rho_{\Phi\text{-vac}} = V_{\text{eff}}(\langle\Phi\rangle)$. In this view, standard ΛCDM cosmology appears as an effective statistical description of a particular class of field configurations of Φ.
- **Section 5** presented black holes as regions of Φ-collapse, in which $\omega_\Phi \to 0$and the vacuum loses its ability to support propagating excitations and a well-defined local time. The horizon, shadow and photon ring thereby acquire a microscopic interpretation in terms of the radial profile $\omega_\Phi(r)$and the boundary of the collapse region $\mathcal{C}_\Phi$.
- **Section 6** embedded standard quantum phenomena in the same ontology: particles are stable modes of Φ, the wave function describes the spatial oscillation pattern of the relevant mode, and measurement and "collapse" are manifestations of decoherence of the global Φ-state in contact with a macroscopic detector. Without modifying the QFT formalism, the Φframework assigns a concrete physical carrier to the vacuum and to the wave function.
- **Section 7** outlined three axes of empirical tests: a cosmological one ($H(z), H_0/S_8$ tensions, $P(k)$), an astrophysical one (black-hole shadows and photon rings, gravitational waves), and a local, low-energy one (searches for ultra-weak ELF modulations in shielded setups, MEG and global magnetometer networks).

In this sense, the Φframework can be viewed as an ontological superstructure built on top of GR, QFT and ΛCDM, rather than as a set of competing theories. In the regimes where GR,

ΛCDM and standard QFT are well tested, the proposed ontology reduces to them as effective theories; significant differences arise only in the interpretation of the dark sector, black-hole interiors, the status of the vacuum and wave function, and in the proposal of additional low-energy probes of the vacuum.

It is therefore useful to distinguish two layers of conclusions:

- **Conservative core.** This comprises those elements that are compatible with the current formalism and data: the reinterpretation of the metric as an effective description of the vacuum state; the identification of dark matter and dark energy as different regimes of a single field Φ; the picture of black holes as boundary configurations of the vacuum; and a field-theoretic account of quantum phenomena without modifying QFT. At this level the Φframework is primarily a proposal for a coherent ontology of the vacuum that organises known ingredients within a single dynamical structure.

- **Speculative layer.** This includes additional hypotheses that require further analysis: a detailed picture of Φ-collapse in black-hole interiors; the possibility of subtle dynamics of $\rho_{\Phi\text{-vac}}(z)$connected to the H_0/S_8tensions; and, in particular, potential ultra-weak ELF modulations as low-energy probes of the vacuum. These elements are deliberately framed as proposals to be tested, not as claims about already observed effects.

The main impact of the proposed framework is not a single spectacular prediction, but the integration of several seemingly distant problems—dark sector, vacuum energy, black holes, quantum information and measurement phenomena—into one picture of a vacuum oscillator Φ. If, for some class of potentials $V_{\text{eff}}(\Phi)$and couplings $\mathcal{L}_{\text{int}}(\Phi)$, it proves possible to:

- reproduce cosmological data at least as well as ΛCDM,
- remain consistent with observations of black-hole shadows and gravitational waves, and
- impose meaningful bounds (or find positive hints) in ELF experiments,

then the vacuum oscillator Φwould be a serious candidate for the “right” level at which to describe the vacuum. If not, the parameter space of admissible Φmodels will be narrowed, and the ontology itself will be pushed toward a more purely interpretational role.

Regardless of the eventual observational verdict, the results of this work suggest that a single vacuum field with a well-defined oscillation frequency $\omega_{\Phi}(x)$can, in principle, organise into one picture what we currently describe separately: spacetime geometry, the dark sector, black holes and quantum phenomena. That, in itself, makes the vacuum-oscillator Φframework worth further, systematic theoretical and empirical exploration.

9. Limitations and outlook

9.1. Ontological status and scope of the Φ framework

In this work the vacuum field $\Phi$is introduced as an ontological hypothesis, not as an already established ingredient of the standard model of physics. I do not claim that current data demonstrate the existence of a global vacuum oscillator. The claim is more modest: **if** such a field exists, then

- general relativity, ΛCDM and standard quantum field theory can be viewed as effective descriptions of its dynamics in different regimes;
- dark matter, dark energy, gravity, black holes and quantum phenomena acquire a common physical substrate;
- one obtains a concrete set of cosmological, astrophysical and low-energy tests that can in principle falsify or support this picture.

The Φframework should therefore be read as a proposal for a *mechanics of the vacuum*, not as a final fundamental theory. In its present form it is explicitly an effective theory, intended to be valid in those ranges of curvature and energy where GR and standard cosmology are empirically supported. I do not derive the full Standard Model or a complete theory of quantum gravity; instead, I show that a relatively simple ontological layer based on Φcan organise GR, ΛCDM, QFT, black holes and quantum phenomena into a single common dynamical "background".

At a deeper, microscopic level, Φitself may be an effective description of some discrete or condensed medium. Here I remain agnostic and treat Φas a coarse-grained vacuum field whose local oscillation frequency $\omega_\Phi(x)$plays the role of a clock. In this sense the mechanical core is effectively one-parameter: time, gravity, visible and dark sectors, black holes and quantum phenomena are treated as different dynamical regimes of a single quantity—the local vacuum oscillation frequency $\omega_\Phi(x)$and its modes.

9.2. Relation to earlier approaches and novelty

The idea that the vacuum is a non-trivial medium, often with an oscillatory character, appears in several research programmes, including emergent-gravity models, superfluid-vacuum scenarios, unified-dark-sector models, and harmonic-oscillator or analogue-gravity constructions. These approaches treat spacetime geometry, dark components or quantum phenomena as effective manifestations of a deeper vacuum substrate.

As far as I am aware, however, no existing framework simultaneously:

- introduces a single vacuum field $\Phi(x)$whose local oscillation frequency $\omega_\Phi(x)$defines proper time and whose spatial gradients reproduce the Newtonian potential in the weak-field limit,

$$\mathbf{g}(x) \propto -\nabla\omega_\Phi(x);$$

- realises both dark matter and dark energy as modes of Φ(respectively: massive, electromagnetically invisible excitations in hidden sectors $\Phi_{\mathrm{dark},i}$, and a background energy density $V_{\mathrm{eff}}(\langle\Phi\rangle)$), with the explicit requirement that the framework reduces to ΛCDM at the level of the homogeneous background;
- interprets black holes as regions of Φ-collapse where $\omega_\Phi \to 0$and the field loses its ability to support propagating excitations, thereby providing a microscopic picture of the horizon, photon ring and interior;
- embeds standard quantum phenomena (wave–particle duality, interference, decoherence, entanglement) in the same ontology — with particles as excitations of Φ, the wave function as a spatial oscillation pattern of Φ, and concrete proposals for low-energy tests of the vacuum in the ELF band.

In this sense, the present work is aligned with the general intuition of an oscillatory vacuum medium, but packages it into a specific, testable "vacuum-oscillator Φframework" (VOΦF).

The contribution of this preprint is therefore twofold:

- It postulates a single vacuum oscillator $\Phi(x)$underlying gravity, the dark sector, black holes and quantum phenomena.
- It introduces minimal working equations that connect ω_Φ, the gravitational potential, background components and Φ-modes to cosmological and astrophysical observables.

These equations are treated as toy models: they demonstrate feasibility and suggest directions for tests, and may later be refined or replaced without altering the ontology itself.

9.3. Main simplifications and limitations

The current version of the Φframework involves several important simplifications:

- **No explicit form of $V_{\mathrm{eff}}(\Phi)$and full nonlinear dynamics.**
I do not specify a concrete effective potential $V_{\mathrm{eff}}(\Phi)$, nor do I write down the full nonlinear equations of motion for Φ. Many conclusions are therefore qualitative: I show that within a single dynamics of Φthere is a "natural place" for dark matter, dark energy, vacuum effects associated with quantisation, and black-hole structure, but I do not claim to have constructed a fully calibrated numerical model.
- **No cosmological fits and detailed stability analysis.**
I do not perform quantitative fits to CMB, BAO, SN Ia, $P(k)$or the H_0/S_8tensions, nor a systematic stability analysis of perturbations in the Φ_{dark}sector. Determining the

allowed region in the space of $V_{\text{eff}}(\Phi)$ and interaction terms $\mathcal{L}_{\text{int}}(\Phi)$ that is consistent with all current data and free of instabilities is left for future work.

- **No derivation of Standard Model parameters or the Planck regime.**
  Particle masses, gauge couplings and even the gauge structure itself are treated as effective inputs, not derived from Φ. Likewise, the framework is explicitly infrared: it is meant as an effective theory below the Planck scale. Ultraviolet completion and the microstructure of Φ are deferred to future work.

- **No detailed treatment of local "antigravity" regimes.**
  Repulsive behaviour appears naturally on cosmological scales through $V_{\text{eff}}(\Phi)$ and the evolution of $\rho_{\Phi\text{-vac}}(t)$. I do not analyse local, strong-field "antigravity" effects or potential technological implications; such questions only become meaningful once the Φ framework has passed the basic cosmological and astrophysical tests.

9.4. Testability along three complementary axes

The empirical content of the Φ framework can be organised along three axes:

- **Cosmological axis.**
  The expansion history $H(z)$, measurements of H_0, the H_0/S_8 tensions, the power spectrum $P(k)$, and SN Ia, BAO and CMB data probe the shape of $V_{\text{eff}}(\Phi)$, the composition and dynamics of Φ_{dark} modes, and the evolution of $\rho_{\Phi\text{-vac}}(t)$. A viable Φ model must effectively reduce to ΛCDM where that model is tightly constrained, while allowing controlled deviations where tensions appear.

- **Astrophysical axis.**
  Black-hole shadows (EHT-like observations), gravitational-wave signals (including the ringdown phase), the structure of dark-matter haloes and gravitational lensing by galaxies and clusters probe the Φ-collapse regime and the behaviour of Φ_{dark} in strongly nonlinear fields.

- **Local, low-energy (ELF) axis.**
  Ultra-weak oscillations of the vacuum oscillator in the ELF band, if they exist, could be searched for with shielded magnetometers, MEG systems, satellite magnetometers and global magnetometer networks. In this preprint I only sketch this class of tests; quantitative predictions require an explicit model of Φ–EM and Φ–matter couplings.

If a relatively simple class of $V_{\text{eff}}(\Phi)$ and $\mathcal{L}_{\text{int}}(\Phi)$ can provide a coherent description along these three axes, this would be a strong argument for Φ as a useful level of description. If no such class exists, the framework will be tightly constrained or falsified accordingly.

9.5. Open questions and directions for future work

The limitations above naturally define the next steps in developing the Φ ontology:

- **Explicit potentials and global fits.**
  Identify simple families of potentials $V_{\text{eff}}(\Phi;\theta)$and interactions $\mathcal{L}_{\text{int}}(\Phi;\theta)$for which one can compute $H(z;\theta)$, $P(k;\theta)$and the properties of Φ_{dark}, and then fit them to CMB, BAO, SN Ia, H_0, $S_8$and weak-lensing data.

- **Dynamics and stability of Φ_{dark}in structure formation.**
  Analyse the evolution and stability of Φ_{dark}modes in haloes (density profiles, velocity distributions, lensing signatures), and determine the parameter space consistent with observed small-scale structure.

- **Φ-collapse and black-hole thermodynamics.**
  Develop the picture of Φ-collapse in the language of QFT on curved spacetime, including processes of the Hawking type, information flow through dark sectors of Φ, and a microscopic interpretation of black-hole entropy.

- **Low-energy ELF signals and experiment design.**
  Prepare realistic forecasts of potential ELF signals associated with Φ-dynamics (amplitudes, spectra, dependence on shielding and sensor geometry) in order to assess whether any predicted effects lie within reach of current or near-future experiments.

- **Microstructure and UV completion of Φ.**
  Explore possible microscopic realisations (e.g. condensate models, spin networks) and clarify how an effectively one-parameter description in terms of $\omega_{\Phi}(x)$emerges from a more fundamental microdynamics.

In this sense, the present work is intended as a starting point: a coherent ontology based on a vacuum oscillator $\Phi$and a map of possible tests, rather than a final solution to the unification problem. Ultimately, the fate of the framework will depend on whether it can

- accommodate and possibly sharpen cosmological and astrophysical data, and

- pass, with positive or negative outcome, targeted low-energy searches for vacuum-related phenomena.