Quantum Theory of Chronovibrational Time: Quantization of $\psi(t)$, Possible Experiments, and Observable Predictions

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Abstract

This work proposes a deeper development of chronovibrational theory by introducing the quantization of the temporal field $\psi(t)$, which is promoted to a quantum operator $\hat{\psi}(t)$ defined over a Hilbert space. Time is thus interpreted as a dynamic and quantizable physical variable, subject to observable residual fluctuations. This approach allows us to model the residual quantum imperfections of chronovibration — a decaying "cosmic beat" originating from the Big Bang — and provides a coherent framework for the emergence of time within a harmonic and dissipative cosmology.

The aim is to predict measurable effects, including post-merger gravitational echoes, metrological instabilities, and interference phenomena induced by coupling with external fields. A chronovibrational transfer matrix is introduced, along with a set of experimental protocols — both passive (e.g., LIGO, atomic clocks) and active (e.g., ITER, modulated RF fields) — capable of falsifying or confirming the model. Energy dynamics are rendered conservative through a second scalar field $\Psi(t)$, acting as a vibrational memory and regulator of phase transitions.

Overall, this model represents a first testable theoretical proposal for a quantum reformulation of time, unifying aspects of canonical quantum gravity, scalar–tensor theories, and emergent cosmology into a single observable harmonic structure. It does not claim to be exhaustive in any way.

Keywords: quantum time, chronovibration, time operator, scalar field quantization, gravitational wave echoes, Hilbert space, canonical quantization, Wheeler–DeWitt equation, electromagnetic coupling, time metrology, emergent time, RF modulation, experimental quantum gravity, ITER

Foreword

This work aims to represent a significant step forward with respect to the previous formulation of chronovibrational theory[1], by introducing a hypothesis of quantum structure for the chronovibrational field $\hat{\psi}(t)$ and outlining a clearer path toward its potential experimental realization. The goal is not only to formalize a new temporal dynamics, but to propose a theoretical framework susceptible to falsification or confirmation through observational protocols and concrete physical measurements. This work does not aim to provide definitive answers but seeks to serve as a starting point and an open proposal, with the hope of fostering constructive scientific discussion.

Conceptual Motivation The underlying idea of the chronovibrational theory is that

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time — although locally relative as predicted by general relativity — may emerge from a universal absolute origin: a primordial cosmic vibration initiated at the Big Bang, defining an underlying "universal beat." This beat, referred to as *chronovibration*, is not directly observable as a coordinate parameter but can be modeled as a global scalar field whose dynamics represent the evolution of time itself. In this view, time is not a passive entity or mere label of causal ordering, but a physical manifestation, subject to decay, propagation, and interaction, and thus observable in its "errors." The aim of this work is to build a theoretical model that translates this intuition into physically quantifiable and, in principle, verifiable terms.

The field $\psi(t)$, initially conceived as a global classical scalar field describing cosmic temporal evolution, is here promoted to a quantum operator $\hat{\psi}(t)$, defined over a Hilbert space. This quantization is neither arbitrary nor decorative but responds to a precise physical and conceptual necessity: *to rigorously and measurably model the local deviations from the ideal chronovibration.* Since the perfect harmonic beat of time — postulated as a universal cosmic structure — is not directly observable, only its residual imperfections, i.e., local deviations from the ideal configuration, are experimentally accessible. These deviations, being neither deterministic nor systematic, require *a sound probabilistic treatment.* This is where the structure of quantum mechanics emerges as the *only coherent formalization*: promoting $\psi(t)$ to a quantum operator $\hat{\psi}(t)$ allows us to describe these fluctuations as observable quantities, endowed with well-defined statistical distributions in Hilbert space.

Furthermore, two additional physical motivations reinforce this choice: (i) similar to homogeneous scalar fields used in inflation and quintessence models, $\psi(t)$ represents a dynamic degree of freedom associated with vacuum geometry and the evolution of the cosmological background; (ii) its operator interpretation naturally fits within canonical quantum gravity, where time is not an external parameter but an emergent internal variable — for instance in the generalization of the Wheeler–DeWitt equation.

From this perspective, dark matter is not interpreted as an ontologically distinct component of the universe, but as one of the harmonic modes of the field $\psi(t)$, which in turn represents a coherent fluctuation of the dynamic vacuum. The distinction between visible matter, dark matter, and dark energy thus does not derive from a substantial difference between physical entities, but from a difference in modal parameters — frequency Ω_i, phase Φ_i, and damping rate Λ_i — of the same fundamental degree of freedom associated with chronovibration. As such, dark matter and dark energy are seen as specific manifestations of the harmonic structure of time, fully compatible with the quantum interpretation of the field $\hat{\psi}(t)$ and the formalism of canonical gravity.

Time is therefore no longer a passive or ordering variable, but becomes an observable datum, derived from a primitive quantum field, subject to fluctuations and interactions. This allows us to overcome the historical dichotomy between absolute and emergent time, providing a theoretical framework consistent with the symmetries of general relativity and capable of generating testable predictions.

Starting from a classical model of a damped harmonic oscillator, a canonical quantization of the system is developed, defining operators and commutators, and deriving the quantum equation of motion. The associated Hilbert space, the temporal evolution of quantum states, and the residual field fluctuations — expressed as the expectation value $\langle \delta\psi^2(t) \rangle$ — are analyzed, representing one of the key predictions of the model.

The resulting formalism also allows for the description of couplings between $\hat{\psi}(t)$ and known physical fields, such as electromagnetism and gravity, via a dedicated interaction Lagrangian. From this, scattering cross sections, amplitudes, and observable parameters are derived, with particular attention to harmonic modulation effects on the propagation of gravitational waves — including post-merger echoes and metric interference — described through a chronovibrational transfer matrix.

The model is also accompanied by a detailed experimental framework, which includes both passive tests — such as with LIGO–Virgo interferometers or ultrastable atomic clocks — and active experiments, such as the interaction with modulated RF fields in high-intensity magnetic environments (e.g., ITER). Each protocol is accompanied by concrete quantitative predictions, useful for validating or falsifying the model.

In summary, this work proposes a qualitative leap in chronovibrational theory, grounding its structure on solid theoretical bases and a necessary quantum formalization to treat temporal fluctuations in a physical, measurable, and experimentally accessible manner. The result is a unified vision that connects quantum gravity, harmonic cosmology, and time metrology, opening new conceptual and technological perspectives.

Introduction

The core idea of this work is that time can be described not merely as an external parameter or coordinate, but as a physical degree of freedom endowed with its own dynamics. In this perspective, time takes the form of a global scalar field $\psi(t)$, whose harmonic evolution on cosmological scales is at the heart of what we call chronovibration.

The aim is not to propose a metaphysical entity, but to construct a physical formalism that allows time to be treated as a quantizable field, subject to interactions and fluctuations, on par with the other fundamental sectors of physics. The promotion of $\psi(t)$ to a quantum operator $\hat{\psi}(t)$ represents, in this context, the necessary step to describe such fluctuations and to formulate predictions compatible with quantum mechanics and canonical gravity.

Throughout the text, it will be shown how this construction fits coherently within various known theoretical frameworks — including the Wheeler–DeWitt equation, scalar–tensor models, and dynamically conformal geometries — and how it allows us to derive observable effects such as harmonic metric modulations, gravitational echoes, and drifts in temporal measurement systems.

This work is not merely speculative: it aims to provide a formal basis for computing quantum observables of the temporal field, introducing operators, equations of motion, numerical methods, and experimental protocols capable of guiding future research toward possible validation (or falsification) of the theory.

On the Philosophical Reasons for Retaining the Non-Spiral Chronovibrational Model

A reflection is currently underway regarding the fundamental mathematical structure of the Chronovibration model. This reflection is primarily motivated by a philosophical reconsideration of the nature of time. In this perspective, time would be better represented not as a simple oscillation—an alternating movement around a fixed point—but rather as a continuous circular evolution, a rotational phenomenon with a decaying amplitude.

Following this philosophical view, the scalar field $\psi(t)$, originally described as a damped harmonic oscillator:

$$\psi(t) = Ae^{-\Lambda t} \cos(\Omega t + \Phi) \tag{1}$$

could be extended to a *damped spiral motion*:

$$\psi(t) = Ae^{-\Lambda t} e^{i(\Omega t + \Phi)} \tag{2}$$

where A is the initial amplitude, Λ is the damping coefficient, Ω is the angular frequency, and Φ is the initial phase.

In this formulation, $\psi(t)$ becomes a complex-valued function whose modulus $|\psi(t)| = Ae^{-\Lambda t}$ decays exponentially, while the phase $\Omega t + \Phi$ rotates continuously. This structure would reflect a more "dynamic" and "evolving" concept of time, embedding a continuous transformation rather than a mere to-and-fro oscillation.

However, from a **practical physical standpoint**, this philosophical refinement does not alter the main predictions of the theory. In both formulations, the key dynamical feature—the exponential damping of the field—remains unchanged. Observable consequences, such as the modulation of spacetime metrics and the emergence of energetic sectors, are governed by the decay rate and amplitude evolution, which are unaffected by whether $\psi(t)$ oscillates or spirals.

Importantly, however, to preserve the foundational principle of chronovibrational theory—the existence of a universal, synchronized cosmic time—it is necessary that the field $\psi(t)$ remains strictly homogeneous in space. Although a spiral evolution in time is conceptually admissible, any nontrivial spatial dependence of the phase or amplitude would introduce variations across different regions of the universe, thereby breaking the fundamental postulate of global uniformity. A spatially varying spiral field would necessitate a model in which the decay rate or phase evolution depends on position, undermining the universality of the chronovibrational background and leading to a relativization of temporal flow—an outcome fundamentally incompatible with the intended structure of the theory.

Mathematically, the field is assumed to be of the form:

$$\Psi(x,y,z,t) = \psi(t) + \epsilon\,\delta\psi(x,y,z,t), \quad \epsilon \ll 1, \tag{3}$$

where $\delta\psi(x,y,z,t)$ represents small localized deviations (imperfections) and ϵ is a small perturbative parameter. The dominant behavior is governed by $\psi(t)$, ensuring the maintenance of a global cosmic time, while $\delta\psi$ captures the small spatial fluctuations we seek to detect experimentally.

Therefore, **at the current stage**, we prioritize the original damped harmonic oscillator model, where ψ depends solely on cosmic time t, ensuring the preservation of a universal, homogeneous temporal evolution. The search for small spatial variations $\delta\psi(x,y,z,t)$—manifested as experimental imperfections—does not invalidate the theory; on the contrary, it provides a potential avenue to confirm its deeper structure and the existence of quantized residual chronovibrational phenomena.

PART I: Theoretical Structure

1 Quantum Formalism of the Field $\psi(t)$

1.1 Quantization and Dominance of the Temporal Mode

In our approach, the chronovibrational field $\psi(t)$ is initially conceived as a homogeneous scalar field, depending solely on cosmic time, similar to the models of inflation and quintessence. However, chronovibration, as a primordial manifestation of the universe's temporal dynamics, is not directly observable in its ideal harmonic modes, but only through the residual fluctuations caused by cosmic dissipation. This motivates the promotion of the field from a classical object to a quantum operator $\hat{\psi}(t)$, defined over a Hilbert space. The chronovibrational field $\hat{\psi}(t)$ thus emerges as a fundamental degree of freedom through three physical principles:

1. **Temporal Uncertainty.**
   Analogous to $\Delta E\,\Delta t \geq \hbar/2$, the field $\hat{\psi}(t)$ satisfies:
   $$\Delta\psi\,\Delta\pi \geq \frac{\hbar}{2}e^{-\Lambda t}$$
   where Λ measures the cosmological damping.

2. **Inflationary Analogy.**
   Just as the inflaton ϕ generates fluctuations in the CMB, $\hat{\psi}(t)$ would also induce potentially observable instabilities on cosmological scales.

3. **Quantum Backreaction.**
   Interaction with the gravitational vacuum imposes:
   $$\hat{\psi}(x^\mu) = \hat{\psi}(t) + \delta\hat{\psi}(\vec{x},t)$$
   where $\delta\hat{\psi}$ represents residual spatiotemporal fluctuations.

To maintain compatibility with quantum field theory in curved spacetime, the field is thus generalized into this form, where $\hat{\psi}(t)$ represents the dominant global mode (zero-mode), and $\delta\hat{\psi}(\vec{x},t)$ introduces spatial fluctuations that can be treated perturbatively. In the limit of a sufficiently homogeneous cosmological background, $\delta\hat{\psi}$ may be neglected, reducing the dynamics to the sole quantized temporal component.

1.2 Operators and Commutators

We thus promote $\psi(t)$ to a canonical quantum operator:

$$\psi(t) \to \hat{\psi}(t) \tag{4}$$

The corresponding conjugate momentum is defined as:

$$\hat{\pi}(t) = \frac{\partial \mathcal{L}}{\partial \dot{\hat{\psi}}(t)} \tag{5}$$

with the canonical commutation relations (in natural units $\hbar = 1$):

$$[\hat{\psi}(t), \hat{\pi}(t')] = i\delta(t - t') \tag{6}$$

Here, $\hat{\pi}(t)$ represents the conjugate momentum of the quantum degree of freedom $\hat{\psi}(t)$, not of time itself. This distinction is crucial to avoid conceptual misunderstandings regarding the role of time in covariant quantum theories.

Canonical quantization then follows from the effective Lagrangian:

$$\mathcal{L} = \frac{1}{2}(\partial_t \hat{\psi})^2 - V(\hat{\psi}) + \mathcal{L}_{\text{int}}(\hat{\psi}, g_{\mu\nu}) \tag{7}$$

with conjugate momentum:

$$\hat{\pi}(t) = \frac{\partial \mathcal{L}}{\partial \dot{\hat{\psi}}} = \dot{\hat{\psi}} + \frac{\lambda}{3!}\hat{\psi}^3 \tag{8}$$

The non-canonical commutation relations (due to cosmological damping) are:

$$[\hat{\psi}(t), \hat{\pi}(t')] = i\hbar e^{-\Lambda|t-t'|}\delta(t - t') \tag{9}$$

1.3 Quantized Field Equation

The classical equation of motion for the field in a dissipative background is:

$$\frac{d^2\psi}{dt^2} + 2\Lambda\frac{d\psi}{dt} + \Omega^2\psi = 0 \tag{10}$$

which, under canonical quantization, becomes:

$$\frac{d^2\hat{\psi}}{dt^2} + 2\Lambda\frac{d\hat{\psi}}{dt} + \Omega^2\hat{\psi} = 0 \tag{11}$$

This equation is formally analogous to that of a damped harmonic oscillator interacting with an environment (Caldeira–Leggett-type models).

The complete equation includes nonlinear effects and quantum noise:

$$\begin{gathered}\frac{d^2\hat{\psi}}{dt^2} + 2\Lambda\frac{d\hat{\psi}}{dt} \\ +\Omega^2\hat{\psi} + \underbrace{\frac{\lambda}{4!}}_{\text{Self-interaction}}\hat{\psi}^3 + \underbrace{\hat{\xi}(t)}_{\text{Vacuum noise}} = 0\end{gathered} \tag{12}$$

where $\langle\hat{\xi}(t)\hat{\xi}(t')\rangle = \hbar\Lambda\delta(t - t')$ describes the coupling with the cosmological thermal bath.

The dissipation term Λ accounts for the coupling of the quantized field to the expanding background. The resulting evolution is non-unitary, reflecting the effective openness of the system and justifying the use of mixed states and density operators in advanced treatments.

1.4 Quantum states and damped Hamiltonian

We still define the coherent classical background as

$$\psi_0(t) = A\,e^{-\Lambda t}\cos(\Omega t), \qquad \hat{\psi}(t)\;|0\rangle = \psi_0(t)\;|0\rangle\,.$$

For a damped harmonic oscillator the correct Hermitian generator is the *Caldirola–Kanai* Hamiltonian[2]:

$$\boxed{\hat{H}_{\text{CK}}(t) = \frac{1}{2}\,e^{-2\Lambda t}\,\hat{\pi}^2 + \frac{1}{2}\,\Omega^2\,e^{2\Lambda t}\,\hat{\psi}^2 + \frac{\lambda}{4!}\,\hat{\psi}^4} \tag{13}$$

with canonical momentum $\hat{\pi} = e^{\Lambda t}\,\dot{\hat{\psi}}$, so that $[\hat{\psi}(t), \hat{\pi}(t)] = i\hbar$.

The Heisenberg equations derived from (13) give $\ddot{\hat{\psi}} + 2\Lambda\dot{\hat{\psi}} + \Omega^2\hat{\psi} = 0$, i.e. the required damped dynamics.

Perturbative ground state. At each instant t we can regard $\hat{H}_{\text{CK}}(t)$ as an *instantaneous* Hamiltonian. To first order in the self-coupling λ the field operator reads

$$\hat{\psi}(t)\;|0\rangle = \left[A\,e^{-\Lambda t}\cos(\Omega t) + \mathcal{O}(\lambda)\right]|0\rangle\,. \tag{14}$$

Mode expansion with damping. Using the damped eigenfunctions $u_\omega(t) =$

[2]See G. Caldirola, Il Nuovo Cimento **18**, 393 (1941); H. Kanai, Prog. Theor. Phys. **3**, 440 (1948).

$\dfrac{e^{-\Lambda t}}{\sqrt{2\tilde{\omega}}}\, e^{-i\tilde{\omega} t}$, $\tilde{\omega} = \sqrt{\omega^2 - \Lambda^2}$, the quantum fluctuations decompose as

$$\hat{\psi}(t) = \psi_0(t) + \int_0^\infty d\omega \Big[u_\omega(t)\, \hat{b}_\omega + u^*_\omega(t)\, \hat{b}^\dagger_\omega\Big], \tag{15}$$

with standard commutators $[\hat{b}_\omega, \hat{b}^\dagger_{\omega'}] = \delta(\omega - \omega')$.

The explicit time dependence of $\hat{H}_{\mathrm{CK}}(t)$ encodes the loss of mechanical energy due to cosmological damping, while the quantization remains internally consistent.

This state does not coincide with the Fock vacuum built from the simple harmonic modes $e^{\pm i\omega t}$, but rather with a displaced vacuum centered on a damped coherent trajectory. Excitations with respect to this vacuum are described by the following mode decomposition, where the field is expanded in terms of damped harmonic eigenmodes:

$$\hat{\psi}(t) = \psi_0(t) + \int_0^\infty d\omega \left[u_\omega(t)\, \hat{b}_\omega + u^*_\omega(t)\, \hat{b}^\dagger_\omega\right] \tag{16}$$

Here, the mode functions $u_\omega(t)$ are given by

$$u_\omega(t) = \frac{e^{-\Lambda t}}{\sqrt{2\tilde{\omega}}}\, e^{-i\tilde{\omega} t}, \quad \text{with} \quad \tilde{\omega} = \sqrt{\omega^2 - \Lambda^2}. \tag{17}$$

The operators $\hat{b}_\omega$ and $\hat{b}^\dagger_\omega$ satisfy the canonical commutation relations

$$[\hat{b}_\omega, \hat{b}^\dagger_{\omega'}] = \delta(\omega - \omega'), \qquad [\hat{b}_\omega, \hat{b}_{\omega'}] = 0, \tag{18}$$

thus ensuring a consistent quantization scheme even in the presence of cosmological damping.

The operators $\hat{a}_\omega$ and $\hat{a}^\dagger_\omega$ satisfy the standard bosonic commutation relations:

$$[\hat{a}_\omega, \hat{a}^\dagger_{\omega'}] = \delta(\omega - \omega')$$

This structure ensures formal consistency with QFT, while maintaining the 0+1D approximation.

1.5 Notes on Covariance and the 4D Extension

The restriction to cosmic time alone should be understood as a homogeneous limit valid on cosmological scales. In a fully covariant version, the field equation would be:

$$(\Box + V''(\psi))\, \hat{\psi}(x^\mu) = 0 \tag{19}$$

but by neglecting $\delta\hat{\psi}$, one recovers the purely temporal dynamics described above. This reduction is compatible with current cosmological observations and serves as a foundation for a future extension to $3+1$ dimensions.

The full 4D extension indeed requires the following form:

$$\left(\Box + m^2 + \frac{\lambda}{2}\hat{\psi}^2\right) \hat{\psi}(x^\mu) = \hat{J}(x^\mu) \tag{20}$$

where $\hat{J}(x^\mu)$ represents quantum sources. In the homogeneous limit:

$$m^2 = \Omega^2 - \Lambda^2 + \mathcal{O}(\hbar\lambda) \tag{21}$$

This parameter m^2 coincides, in the classical limit, with the effective mass of the field in the regime of damped harmonic oscillation. When $\psi(t)$ exactly satisfies the harmonic equation $\ddot{\psi} + \Omega^2\psi = 0$, the system is in a state of maximal coherence: in this case, the harmonic coherence function defined as

$$F[\psi(t)] = \exp\left(-\left|\ddot{\psi} + \Omega^2\psi\right|\right) \tag{22}$$

reaches its maximum value $F[\psi(t)] \to 1$, which represents the chronovibrational analogue of the unit coefficient in Lorentz transformations. In this limit, the geometric factor — already discussed in Chapter 2 of the previous work and revisited later — is given by:

$$\Gamma_{\text{harm}}(t) = \frac{1}{\sqrt{1 - F[\psi(t)]}} \tag{23}$$

As extensively explained, this does not indicate a physical pathology but rather connects to what was described in Section 1.4 and in equations 11, 12, and 13.

Conceptual Note. This limiting state, in which $\psi(t)$ exactly satisfies the harmonic equation $\ddot{\psi} + \Omega^2\psi = 0$, represents a *state of absolute dynamical coherence.* In this regime:

- The quantized field $\hat{\psi}(t)$ coincides with its damped classical trajectory $\psi_0(t)$, and the fluctuation $\langle \delta\hat{\psi}^2(t)\rangle \to 0$;
- The expectation value $\psi(t)$ constitutes a perfectly coherent *non-Fockian* chronovibrational vacuum;

- Simultaneously, the harmonic coherence function $F[\psi(t)] \to 1$, and the metric factor $\Gamma_{\text{harm}}(t) \to \infty$, formally diverging and recovering the unit coefficient of Lorentz transformations.

In this sense, the "0" initial state of chronovibration and the "1" value of the relativistic function represent two aspects of the same fundamental state of the model, which serves both as a metric origin and a universal harmonic reference. Time thus emerges as a quantized field in perfect coherence with the spacetime metric, and only subsequent misalignments (fluctuations, damping) introduce observable dynamics.

Table 1: Comparison with cosmological observables

Observable	Prediction
CMB fluctuations	$\Delta T/T \sim 10^{-5} \cdot \delta\psi/\psi_0$
Clock drifts	$\Delta\nu/\nu \sim 10^{-18} e^{-\Lambda t}$
Gravitational waves	$\delta h \sim 10^{-23}\sqrt{\hbar\Omega}$

2 Coupling with Quantum Gravity

2.1 Modified Wheeler–DeWitt Equation

In the framework of canonical quantum gravity, the field $\hat{\psi}(t)$ is treated as an additional degree of freedom whose dynamics modulate the internal "flow" of time. We therefore propose a generalization of the Wheeler–DeWitt equation:

$$\left(\hat{H}_{\text{grav}} + \hat{H}_{\psi}\right)|\Psi\rangle = 0 \tag{24}$$

where $\hat{H}_{\text{grav}}$ is the geometric Hamiltonian (e.g., FLRW) and $\hat{H}_{\psi}$ is the Hamiltonian associated with $\hat{\psi}(t)$. In this formalism, time is not external to the universe but emerges as an internal quantized degree of freedom.

Unlike the standard interpretation, where time is absent from the Wheeler–DeWitt equation, in this model the presence of $\hat{\psi}(t)$ reintroduces a notion of **internal absolute time** that modulates the global quantum state $|\Psi\rangle$. This field acts as a "cosmic harmonic basis" onto which all dynamics are projected, allowing the equation to be interpreted not as "timeless" but as **constrained by an emergent temporal dynamics**.

In other words, the equation $\hat{H}\Psi = 0$ is here reinterpreted as compatible with a physical absolute time, provided that such time is described by a quantizable scalar field $\hat{\psi}(t)$, internal to the system and not an external coordinate.

2.2 Derivation of the Quantized Metric

The field $\hat{\psi}(t)$ acts as a harmonic modulator of the metric. In analogy with semiclassical gravity, we introduce the quantized metric:

$$\hat{g}_{\mu\nu}(t) = \eta_{\mu\nu}\left(1 + \epsilon\hat{\psi}(t)\right) \tag{25}$$

where ϵ is a small dimensionful parameter. In the semiclassical average, setting $\psi(t) = \langle\hat{\psi}(t)\rangle$, we recover the metric deformation consistent with the equivalence principle:

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G}R + \frac{1}{2}\partial_\mu\psi\partial^\mu\psi - V(\psi)\right] \tag{26}$$

In the FRW regime, $\partial_\mu\psi\partial^\mu\psi = (\dot{\psi})^2$, and the deformation is effectively temporal. The presence of the term $\epsilon\hat{\psi}(t)$ in the metric introduces harmonic instabilities, gravitational echoes, and observable shifts in metric phenomena, consistent with the predictions of the model.

This structure shows how time, if interpreted as a quantum field, can directly affect the spacetime metric, reconciling quantized geometry with observable temporal dynamics.

2.3 Consistency with Existing Models

This proposal naturally aligns with:

- inflationary theories that treat quantized scalar fields on curved backgrounds;
- models of quantum backreaction in semiclassical gravity (e.g., Sakharov gravity);

- mini-superspace formulations of the Wheeler–DeWitt equation;
- dynamical metric theories (e.g., $f(R)$, bimetric, Brans–Dicke models).

What distinguishes the present approach is the interpretation of the field $\hat{\psi}(t)$ not as a new form of matter, but as the quantization of time itself. Its fluctuations define a structural "imprecision" of time, manifesting metrically as gravitational echoes, shifts in clock systems, or modulations in the propagation of gravitational waves.

The model does not strictly preserve classical Lorentz symmetry, but reformulates it as a temporally harmonic symmetry modulated by the field $\psi(t)$. As already discussed in Chapter 2 of the previously published work, the traditional unit coefficient in Lorentz transformations is replaced by a dynamic function $\Gamma_{\text{harm}}(t)$, defined as:

$$\Gamma_{\text{harm}}(t) = \frac{1}{\sqrt{1 - F[\psi(t)]}}, \tag{27}$$

which reflects the degree of chronovibrational coherence of the vacuum. This deformation, although it modifies the metric in a non-trivial way, respects causality and preserves the weak equivalence principle. It therefore represents a consistent generalization of special relativity, in which the constancy of the speed of light emerges as a static limit for $\psi(t) \to 1$.

It is specified that the function $F[\psi(t)]$ in the definition of $\Gamma_{\text{harm}}(t)$ is to be understood as depending on the expectation value of the quantum field, that is:

$$\psi(t) \equiv \langle \hat{\psi}(t) \rangle, \tag{28}$$

in line with the semiclassical approximation adopted for the metric deformation. This approach allows the residual quantum effects of time to be directly embedded into the geometric structure of spacetime, while remaining compatible with the effective action and perturbative analysis on cosmological scales.

3 Quantum Formalism and Hilbert Space Structure of the Field $\hat{\psi}(t)$

Before examining in detail the possible experimental manifestations of the chronovibrational field $\hat{\psi}(t)$ — either in passive conditions (invariant harmony) or under active disturbance (as in the proposed ITER experiments) — it is essential to clarify the theoretical formalism that makes such quantum behaviors possible.

In particular, all predictions — from the presence of residual quantum fluctuations to phase transitions, and harmonic interference phenomena — derive from the fact that the field $\psi(t)$ is not treated as a classical function, but as a quantum operator acting on a Hilbert space, analogous to operators in standard quantum mechanics.

This section therefore provides the formal foundation necessary to correctly interpret the proposed observables: it introduces the mathematical structure of the state space, the construction of the density matrix, and the representation of operators in a harmonic basis. These tools are essential for modeling any coherent, measurable, or stochastic evolution of the field $\hat{\psi}(t)$, and for computing quantities such as correlations, fluctuation spectra, and transition probabilities.

3.1 Basis of Temporal States

The Hilbert space $\mathcal{H}_\psi$ associated with the chronovibrational field is generated by the temporal eigenstates:

$$\hat{\psi}(t) \left| n \right\rangle = \psi_n(t) \left| n \right\rangle, \quad n \in \mathbb{N} \tag{29}$$

The states $\{|n\rangle\}$ form an orthonormal basis:

$$\langle m|n|m|n \rangle = \delta_{mn}, \quad \sum_{n=0}^{\infty} \left| n \right\rangle \left\langle n \right| = \mathbb{I} \tag{30}$$

These states represent the discrete harmonic modes of the field $\hat{\psi}(t)$, each of which may contribute, in quantum superposition, to the observable behavior of the field.

3.2 Temporal Density Matrix

To describe mixed or non-purely coherent states of the field, we use the density matrix:

$$\rho(t) = \sum_{n,m} p_{nm}(t) |n\rangle \langle m| \quad (31)$$

Its matrix elements in the temporal basis are:

$$\rho_{nm}(t) = \langle n| \hat{\psi}(t) |m\rangle = \psi_n(t)\psi_m^*(t) \quad (32)$$

The density matrix enables the calculation of observables such as the temporal mean of the field, vibrational entropy, and correlations between modes.

3.3 Operators in the Basis

Finally, we introduce the creation and annihilation operators in the frequency modes of the field, which satisfy the canonical commutation relations:

$$[\hat{a}_\omega, \hat{a}^\dagger_{\omega'}] = \delta(\omega - \omega') \quad (33)$$

Their matrix representation in the harmonic basis is:

$$\hat{a}_\omega = \begin{pmatrix} 0 & \sqrt{1} & 0 & \cdots \\ 0 & 0 & \sqrt{2} & \cdots \\ 0 & 0 & 0 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}, \quad \hat{a}^\dagger_\omega = (\hat{a}_\omega)^\dagger \quad (34)$$

These operators are used to model the quantized temporal evolution of the field, the generation of excited states, and transitions induced by external interactions (such as RF fields in the experimental contexts considered).

4 Fractal–Wavelet Bases and Quantisation of Deviations in the Chronovibrational Field

4.1 Physical motivation

The "chronovibrational deviations" that arise when the scalar field $\hat{\psi}(t)$ drifts away from its ideal harmonic motion are governed by high–frequency fluctuations and strongly localised structures. To capture *temporal localisation* and *self–similar structure* at once we adopt an *orthonormal wavelet basis* whose mother function has a fractal support. The construction follows the multiresolution– analysis (MRA) scheme of Strichartz [1] and Jorgensen–Pedersen [2].

4.2 Fractal multiresolution analysis

Let $\mu_{\mathcal{F}}$ be the self–similar measure associated, e.g., with the Cantor dust[3]. There exist discrete filters $h[\ell]$, $g[\ell] \in \mathbb{R}$ that generate an MRA $\{V_J\}_{J\in\mathbb{Z}}$ with the properties [3]:

$$V_J \subset V_{J+1}, \qquad \bigcap_{J\in\mathbb{Z}} V_J = \{0\}, \quad \overline{\bigcup_{J\in\mathbb{Z}} V_J} = L^2(\mathbb{R}, \mu_{\mathcal{F}}).$$

The *scaling function* $\varphi(t)$ and the *mother wavelet* $\psi(t)$ are defined as solutions of the refinement equations $\varphi(t) = \sqrt{2}\sum_\ell h[\ell]\,\varphi(2t-\ell)$ (and similarly for ψ).

From the MRA we obtain the orthonormal family

$$\psi_{J,k}(t) = \; 2^{\frac{J}{2}}\,\psi(2^J t - k), \qquad J, k \in \mathbb{Z},$$

which forms a **Hilbert basis** of $L^2(\mathbb{R}, \mu_{\mathcal{F}})$ and, via periodic extension, of $L^2([0,1])$.

4.3 Expansion of $\hat{\psi}(t)$

Let $\mathcal{B} = \{\psi_{J,k}\}_{J,k}$ be the fractal wavelet basis. At a fixed time the field $\hat{\psi}(t)$ admits the expansion

$$\hat{\psi}(t) = \sum_{J\in\mathbb{Z}} \sum_{k\in\mathbb{Z}} c_{J,k}\,\psi_{J,k}(t), \qquad c_{J,k} = \langle \psi_{J,k} \mid \hat{\psi}\rangle. \quad (35)$$

Because the basis is orthonormal, $\sum_{J,k} |c_{J,k}|^2 = \|\hat{\psi}\|^2$.

4.4 Normalisation errors

The *global normalisation error* is defined as

$$\varepsilon_{\text{norm}}(t) = \Big| \sum_{J,k} |c_{J,k}(t)|^2 - 1 \Big|. \quad (36)$$

To quantify the energy that hides beyond a given scale we introduce

$$P_{>J}(t) = \sum_{n>J} \sum_k |c_{n,k}(t)|^2, \quad (37)$$

which measures the share of the norm associated with structures finer than 2^{-J}. If $P_{>J}(t) \ll 1$ the dynamics is "almost harmonic" down to the scale 2^{-J}.

[3] We use the Cantor dust only as a pedagogical example; the procedure is identical for the Sierpiński gasket, the Menger carpet, and other classic fractals.

4.5 Chronovibrational deviation operators

Let $\hat{L}_{\text{ideal}}$ denote the unperturbed Lorentz operator and $\hat{L}_{\text{mod}}(t)$ its chronovibrationally modified counterpart. We set

$$\Delta\hat{L}(t) = \hat{L}_{\text{mod}}(t) - \hat{L}_{\text{ideal}}. \tag{38}$$

The *mean deviation* is

$$\langle \Delta L \rangle_t = \text{Tr}\big[\rho(t)\, \Delta\hat{L}(t)\big], \tag{39}$$

with $\rho(t) = |\hat{\psi}(t)\rangle\langle\hat{\psi}(t)|$ (or the mixed–state density matrix, if required).

4.6 Illustrative example

Assume an external pulse shifts part of the norm from the band $|J| \leq J_0$ to coefficients with $J > J_0$. If after the evolution $P_{>J_0}(t_{\text{f}}) = 0.07$ then $7\,\%$ of the chronovibrational energy resides in structures finer than 2^{-J_0}. To first order, $\langle \Delta L \rangle$ increases proportionally to $P_{>J_0}$.

4.7 Experimental implications

- **Observational experiments** — the statistical distribution of $\{c_{J,k}(t)\}$ for undisturbed states provides direct information on the multifractal structure of the chronovibrational vacuum.
- **Perturbative experiments** — RF/laser sequences can induce controlled scale jumps ($J \to J \pm 1$); by measuring $\varepsilon_{\text{norm}}$, $P_{>J}$ one obtains quantitative tests of the theory.

References

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[2] P. E. T. Jorgensen & S. Pedersen, *Harmonic analysis of fractal measures*, J. Funct. Anal. **160** (1998) 181–206.

[3] J. C. Lagarias & Y. Wang, *Integral self-affine tiles in* $\mathbb{R}^n$, J. London Math. Soc. **54** (1996) 161–179.

[4] Douglas Ruffini, *Electron Approach Theory Fractal Extension*, 2025.

5 Computation of Quantum Fluctuations

After defining the structure of the Hilbert space and the operatorial representation of the chronovibrational field, we can now proceed with the analysis of one of the model's most significant quantities: the quantum fluctuations of the field relative to its ground state.

Such fluctuations are the source of all observable anomalies in the model, from the generation of stochastic noise in gravitational wave detectors to temporal variations in metrological signals. In other words, the quantity $\langle \delta\psi^2(t) \rangle$ describes how much the quantized field $\hat{\psi}(t)$ deviates from its average harmonic configuration $\psi_0(t)$ due to intrinsically quantum effects.

5.1 Vacuum Expectation Value

As a first step, we compute the mean value of the field in the ground state $|0\rangle$, which represents the minimum energy configuration compatible with the quantum conditions imposed by the model:

$$\langle 0|\, \hat{\psi}(t)\, |0\rangle = \psi_0(t) \tag{40}$$

This value, already defined in the formalism as $\psi_0(t) = Ae^{-\Lambda t}\cos(\Omega t)$, represents the classical time evolution of the field in the absence of excitations.

5.2 Quadratic Fluctuations

From the ground state, we can now calculate the variance of the field, i.e., the mean squared deviation of the quantized field from the classical value. This quantity describes the presence of residual quantum noise even in the vacuum state:

$$\langle \delta\psi^2(t) \rangle = \langle 0|\, [\hat{\psi}(t) - \psi_0(t)]^2\, |0\rangle \tag{41}$$

$$= \sum_{n=1}^{\infty} |\, \langle n|\, \hat{\psi}(t)\, |0\rangle\, |^2 \tag{42}$$

$$= \frac{\hbar}{2\Omega} e^{-2\Lambda t} \tag{43}$$

This result shows that, even in the quantum vacuum, the field oscillates with a non-zero amplitude that decreases over time. This behavior is a direct consequence of the damped harmonic formalism used to quantize $\psi(t)$, and it is responsible for all residual fluctuations observable in experiments, such as those described in Sections 4 and 5.

5.3 Temporal Correlation Matrix

To fully model the evolution of the field, it is useful to calculate the two-time correlation function, which describes the coherence of fluctuations at two distinct instants t and t'. The complete correlation matrix includes both symmetric and conjugate operator combinations:

$$G(t,t') = \begin{pmatrix} \langle 0|\,\hat{\psi}(t)\hat{\psi}(t')\,|0\rangle & \langle 0|\,\hat{\psi}(t)\hat{\psi}^\dagger(t')\,|0\rangle \\ \langle 0|\,\hat{\psi}^\dagger(t)\hat{\psi}(t')\,|0\rangle & \langle 0|\,\hat{\psi}^\dagger(t)\hat{\psi}^\dagger(t')\,|0\rangle \end{pmatrix} \tag{44}$$

In particular, the element $G_{11}(t,t')$, which represents the direct temporal correlation of the field in the vacuum, takes the form:

$$G_{11}(t,t') = \frac{\hbar}{2\Omega} e^{-\Lambda(t+t')} \cos[\Omega(t-t')] \tag{45}$$

This result is essential to predict harmonic interference, decoherence, and resonant coupling phenomena in real experimental systems. The presence of the cosine term indicates that the field maintains temporal coherence over short time intervals relative to Λ^{-1}, suggesting a finite and potentially observable correlation scale.

6 Coupling with the Electromagnetic Field

One of the most significant aspects of chronovibrational theory is the possibility that the quantum field of time $\hat{\psi}(t)$, homogeneous and scalar, may interact directly with known fundamental fields, in particular with the electromagnetic field. This interaction is central both for the **experimental falsifiability of the model**, and for its possible **astrophysical and metrological implications**.

In the context of the experiment proposed in the second part of this work, such as at the ITER reactor, the coupling between $\hat{\psi}(t)$ and radiofrequency (RF) waves plays a crucial role. The coherent modulation of the RF field in a vacuum and high static magnetic field environment could act as an *external harmonic stimulus* to activate chronovibrational fluctuations, generating measurable signals via precision instruments.

6.1 Interaction Lagrangian – Extended Derivation and Constraint Analysis

The interaction between the quantized chronovibrational field $\hat{\psi}(t)$ and the classical electromagnetic field can be modeled through a modification of the variational action, introducing a time-dependent coupling that reflects the global influence of the quantum background field on the vacuum response.

We assume that the field $\hat{\psi}(t)$ is a homogeneous scalar operator quantized on cosmological scales, and that in the semiclassical regime its effects result in an effective modulation:

$$f(t) = 1 + \lambda\langle\hat{\psi}(t)\rangle \tag{46}$$

where λ is a coupling parameter with inverse dimensions relative to $\hat{\psi}(t)$, and $\langle\hat{\psi}(t)\rangle$ is its expectation value in the physical vacuum. This modulation can be interpreted as a variation in the effective permittivity of the vacuum.

The modified action is therefore:

$$S = -\frac{1}{4}\int d^4x\, f(t) F_{\mu\nu}F^{\mu\nu} \tag{47}$$

where:

- $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ is the classical electromagnetic tensor;
- $f(t) \in C^1(\mathbb{R})$ is a time-dependent function reflecting the dynamics of $\hat{\psi}(t)$.

Equations of motion. Varying the action with respect to A_μ, we obtain:

$$\boxed{\partial_\mu\left[f(t)F^{\mu\nu}\right] = 0} \tag{48}$$

which generalizes Maxwell's equations to a dynamic vacuum. The homogeneous equations $\partial_{[\lambda}F_{\mu\nu]} = 0$ remain unchanged.

Physical interpretation. The function $f(t)$ can be seen as a **time-modulated effective vacuum permittivity**. Even in the absence of sources, the electromagnetic field evolves in a dynamic background, giving rise to **quantum harmonic modulations** of the vacuum. In metrological contexts (e.g., optical clocks, superconducting resonators), a variation in $f(t)$ implies an observable frequency shift:

$$\frac{\Delta\nu}{\nu} \sim \lambda \frac{d}{dt}\langle\hat{\psi}(t)\rangle \tag{49}$$

For $\lambda \sim 10^{-15}$ and harmonic oscillations of $\hat{\psi}(t)$ of order unity, we estimate $\Delta\nu/\nu \sim 10^{-12}$, a value at the current limit of metrological sensitivity.

Rapid variation regimes. If $f(t)$ exhibits rapid variations (as in active experiments with RF sources), it is possible to trigger resonance phenomena, quantum interference, or nonlinear absorption, potentially observable as anomalies in spectral peaks or quality factors of resonators.

6.2 Analysis of Gauge Symmetry – Soft Breaking and Hamiltonian Formalism

The introduction of $f(t)$ formally breaks gauge invariance $A_\mu \to A_\mu + \partial_\mu\Lambda(x)$, but since the dependence is purely temporal, the breaking is **soft** and can be treated in a controlled way.

The Lagrangian density becomes:

$$\mathcal{L} = \frac{1}{2} f(t)(\mathbf{E}^2 - \mathbf{B}^2)$$

The conjugate momentum is:

$$\Pi^i = \frac{\partial\mathcal{L}}{\partial\dot{A}_i} = f(t)E^i, \qquad \Pi^0 = 0$$

The primary constraint $\Pi^0 = 0$ is preserved, and the Hamiltonian density is:

$$\mathcal{H} = \frac{1}{2f(t)}\Pi^i\Pi^i + \frac{1}{2}f(t)\mathbf{B}^2 + A^0(\partial_i\Pi^i)$$

From this, we obtain the **modified Gauss constraint** $\partial_i\Pi^i = 0$. As long as $f(t) \in C^1$, its conservation is guaranteed, and the evolution of the system is constrained and coherent. No ghosts or dynamical instabilities arise.

6.3 Charge Conservation and Dynamical Coherence

Despite the gauge breaking, the global temporal symmetry of the action is preserved. The associated Noether current is:

$$J^\nu = \partial_\mu\left[f(t)F^{\mu\nu}\right] \tag{50}$$

Integrating over space:

$$\frac{d}{dt}\int d^3x\, J^0 = 0$$

we obtain **total charge conservation**, a necessary condition for quantum consistency.

6.4 Classical Limit and Possible Extensions

In the limit $\hat{\psi}(t) \to 0$, we have $f(t) \to 1$, and the classical equations are recovered:

$$\partial_\mu F^{\mu\nu} = 0$$

This approach is compatible with low-energy limits and the symmetries of standard QED. In future extensions, local couplings (e.g., $\hat{\psi}(t)J^\mu A_\mu$) may be considered, which could arise from loop effects or spontaneous symmetry breaking, or be relevant in astrophysical contexts (e.g., FRBs, anisotropic CMB).

6.5 Conclusion

This formulation describes in a dynamically consistent way the interaction between the chronovibrational field $\hat{\psi}(t)$ and the electromagnetic field, ensuring:

- charge conservation;
- absence of instabilities and ghosts;
- compatibility with high-precision metrology;
- experimental testability in controlled environments (ITER, resonators, atomic clocks);
- consistency with a harmonic extension of gauge symmetry.

Science does not require every symmetry to be sacred; it requires that every violation be motivated, controlled, and verifiable.

7 Quantum Scattering Amplitudes and Temporal Superposition

One of the most relevant consequences of the coupling between the quantum field of time $\hat{\psi}(t)$ and electromagnetic radiation is the possibility of observing a process of *quantum vibrational scattering*, in which a photon interacts with the field $\hat{\psi}(t)$, inducing a harmonic fluctuation observable in the energy or temporal domain.

Formally, we consider the process:

$$\gamma \to \gamma + \psi$$

where ψ represents a component of the chronovibrational field, which may be real (emission of a fluctuation) or virtual (effective modulation of propagation). This mechanism opens the door to transitions between photonic states capable of probing the existence and quantum dynamics of time.

7.1 Transition Matrix and Interaction Mechanism

The process is described, within perturbative formalism, by an effective matrix connecting the initial photonic state with the final photon–field coupled state:

$$\mathcal{M} = \begin{pmatrix} \langle\gamma| \mathcal{L}_{\text{int}} |\gamma\rangle & \langle\gamma\psi| \mathcal{L}_{\text{int}} |0\rangle \\ \langle 0| \mathcal{L}_{\text{int}} |\gamma\psi\rangle & 0 \end{pmatrix}$$

This structure encodes the transition from purely photonic states to hybrid states that incorporate the dynamical activation of the field $\hat{\psi}(t)$, which acts as a harmonic modulator of propagation.

7.2 Cross Section and Temporal Dependence

The differential cross section of the process is given by:

$$\sigma(E_\gamma, t) = \frac{\lambda^2}{16\pi} \cdot \frac{E_\gamma^2}{\Omega^2} \cdot e^{-2\Lambda t}$$

where:

- λ is the harmonic coupling coefficient,
- E_γ is the energy of the incoming photon,
- Ω is the characteristic frequency of the excited vibrational component,
- Λ represents the decay rate of the field.

The expression shows that the process is favored at high energies (gamma rays) and at early cosmological times (small t), due to the exponential effect of vibrational decay.

7.3 Comparison with the Quantum Time Flip

A relevant experimental analogy is represented by the *quantum time flip*, recently realized by Strömberg et al.[4]. In this experiment, a single photon passes through an optical configuration in which its temporal evolution is placed in coherent superposition between the *forward* and *backward* directions using waveplates and balanced interferometers.

Physically, the photon's state evolves as:

$$|\psi\rangle_T |+\rangle_C \to \frac{1}{\sqrt{2}}\Big((UV^T) |\psi\rangle_T |+\rangle_C + (U^T V) |\psi\rangle_T |-\rangle_C \Big) \quad (51)$$

where the temporal direction of evolution is encoded in a coherent *control state*.

In our formalism, the interaction $\gamma \to \gamma + \psi$ can be interpreted as a dynamical generalization of this effect: the quantized field $\hat{\psi}(t)$, subject to harmonic decay, modulates the temporal evolution probability of the photon, introducing a *vibrational misalignment* analogous to the directional superposition experienced in the time flip.

This reinterpretation provides a conceptual bridge between:

- controlled superposed evolution (experiment);
- and the **dynamic harmonic modulation** (chronovibrational model), which acts as a "quantum vibrational environment" responsible for the photon's phase transition in time.

[4] T. Strömberg et al., *Experimental superposition of a quantum evolution with its time reverse*, arXiv:2211.01283v3 (2024).

Observable and Astrophysical Implications

The phenomenological implications are manifold:

1. **Controlled scattering in RF cavities**, e.g., at ITER, where harmonic modulation can be tested via excitation of the field $\hat{\psi}(t)$ with electromagnetic waves at resonant frequency;

2. **Selective attenuation of cosmic gamma photons**, potentially observable as anomalies in the high-energy spectra of blazars or GRBs, detectable by FERMI or INTEGRAL;

3. **Optical experimentation**, where superposition between temporal directions may be reinterpreted as interference between vibrational modes induced by $\hat{\psi}(t)$, offering a potential testbed in quantum photonics.

In conclusion, the connection between the process $\gamma \to \gamma + \psi$ and the *quantum time flip* suggests that the emergence of alternative or superposed temporal directions can ultimately be described as an observable manifestation of the harmonic time field. Our model thus provides a quantifiable physical basis for effects previously considered purely informational, embedding temporal vibration as a dynamic and testable element.

8 Chronovibrational Effects on Gravitational Wave Propagation

After analyzing the experimental behavior of the field $\hat{\psi}(t)$ in electromagnetic contexts (ITER) and temporal systems (atomic clocks), a fundamental question arises: how does the chronovibrational field interact with gravity, and in particular with gravitational waves?

In the proposed model, the classical gravitational wave, represented by a perturbation $h_{\mu\nu}$ of the flat metric, no longer propagates on a simple Minkowski background, but on a metric modified by the harmonic presence of the field $\psi(t)$. This implies a deformed propagation dynamic and the emergence of new phenomena such as echoes, interference, and spectral instabilities.

8.1 Vibrationally Modified Metric

The spacetime metric, in the simultaneous presence of a gravitational wave and the chronovibrational field, takes the form:

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} + \epsilon\psi(t)\,\eta_{\mu\nu} \tag{52}$$

The term $\epsilon\psi(t)$ represents a global modulation of the metric structure, with cumulative effects over time.

8.2 Deformed Gravitational Wave Equation

Substituting this metric into the perturbative formalism yields a modified equation for the evolution of the gravitational signal:

$$\Box h_{\mu\nu} = -16\pi G\left(T_{\mu\nu} - \frac{1}{2}\epsilon\,\psi(t)\,T\,\eta_{\mu\nu}\right) \tag{53}$$

This equation reveals a direct coupling between the energy–momentum density $T_{\mu\nu}$ and the chronovibrational field, mediated by $\psi(t)$. This term introduces harmonic instabilities and dynamic metric distortions in the propagation of the wave.

8.3 Chronovibrational Transfer Matrix

When a gravitational wave passes through a region of spacetime where $\psi(t) \neq 0$, its evolution can be formally described by a harmonic transfer matrix:

$$\begin{pmatrix} h_+ \\ h_\times \\ \psi \end{pmatrix}_{\text{out}} = \begin{pmatrix} 1-\alpha & 0 & \beta \\ 0 & 1-\alpha & \beta \\ \gamma & \gamma & 1-\delta \end{pmatrix} \begin{pmatrix} h_+ \\ h_\times \\ \psi \end{pmatrix}_{\text{in}} \tag{54}$$

where the coefficients depend on the crossing time:

$$\alpha = \frac{\epsilon^2\Omega^2}{4}t^2, \quad \beta = \epsilon\Omega t, \tag{55}$$

$$\gamma = \frac{\epsilon\Lambda}{2}t, \quad \delta = \Lambda t \tag{56}$$

This formalism implies that part of the gravitational signal can be converted into a chronovibrational component, and vice versa.

Physical Interpretation: the Graviton as a Messenger in a Harmonic Background

Although not generated by $\psi(t)$, the graviton — the quantized excitation of the gravitational field — moves in a background deformed by chronovibration. This implies:

- An effective temporal variation of the metric;
- Harmonic-dependent propagation;
- A concrete possibility of detecting such distortions through experiments like LIGO/Virgo, especially in black hole post-mergers.

Connection with Experiments (Second Part)

This section closes the theoretical loop, connecting the two main experimental branches:

- Forced harmonic transitions (RF experiments like ITER);
- Passive signal propagation (astrophysical experiments on gravitational waves and the CMB).

Both contexts can be explored using already existing instruments. If the field $\hat{\psi}(t)$ actually modulates the metric, even subtly, then global temporal fluctuations will leave detectable imprints in the gravitational waveforms.

This is the core challenge of the theory: to transform an abstract harmonic model into measurable and thus falsifiable predictions.

8.4 Fractal Chronovibrational Basis and Emergent Mass Effects

In this work, we have introduced the construction of a Hilbert space for the temporal field $\psi(t)$ based on a discrete fractal numerical basis, generated through recursive decompositions of prime numbers. This framework is proposed as a foundational structure for the quantization of the chronovibrational field. Within this formalism, each quantum state of the field corresponds to a node on a fractal graph, with transitions between these states governed by structured probabilities rather than stochastic randomness. This structured fractal approach allows for precise quantification and prediction of errors in the chronovibrational field, thereby opening new avenues for experimental verification.

Specifically, as detailed in the chronovibrational quantization model, transitions among states in the fractal Hilbert space are described by predictive transition matrices , whose elements represent the probabilities of transitioning from state to state . These matrices are informed by the density and recurrence of prime decompositions and enable quantifiable predictions of local deviations (errors) from ideal harmonic evolution. The emergence of mass in this context is interpreted naturally as arising from these localized coherence deviations induced by fractal transitions, a view that aligns coherently with recent ideas proposed by Valamontes concerning emergent graviton mass from coherence geometry.[5].

In fact, Valamontes introduces a broader conceptual framework where mass and spin, traditionally considered fundamental properties of elementary particles, are instead emergent from underlying coherence-based vacuum geometry. Within this coherence geometry, termed the Superluminal Graviton Condensate Vacuum (SGCV), mass is identified as a curvature-induced projection resulting from localized disruptions in the coherence tensor . Explicitly, Valamontes defines the emergent graviton mass as:

$$m_g^2(x) \sim \frac{\delta^2 C_{\mu\nu}(x)}{\delta R_{\alpha\beta}, \delta x^\lambda}, \tag{57}$$

highlighting the deep interplay between coherence, curvature, and mass.

Analogously, in the fractal chronovibrational model, we define an effective mass emerging from deviations in local harmonic coherence as:

$$m_{\text{eff}}^2(x^\mu) \sim \Delta\mathcal{C}(x^\mu), \tag{58}$$

where quantitatively represents the local coherence errors within the fractal Hilbert space. These coherence errors are directly computable via the predictive transition matrices and can thus be empirically verified through precision

[5] A. Valamontes, "Emergent Graviton Mass from Coherence Geometry", 2025.

metrology, gravitational wave observations, or specifically designed RF modulation experiments (e.g., ITER).

Crucially, this model naturally explains why gravitational waves (and consequently gravitons) remain massless despite coherence-induced mass effects in other quantum fields. As Valamontes emphasizes, the graviton is identified as the minimal coherence-preserving mode (spin-2) propagating through vacuum geometry without local coherence deviations [**?**]. In the fractal chronovibrational formulation, the graviton remains strictly massless precisely because its propagation through spacetime corresponds to pathways within the fractal Hilbert space that preserve perfect global harmonic coherence, free from fractal-induced coherence errors.

In summary, within this combined theoretical framework:

- **Massive particles** arise naturally as localized coherence defects, quantifiable as errors in transitions between fractal Hilbert-space nodes;
- **The graviton** remains massless, representing the pure and error-free propagation of global harmonic coherence across the fractal vacuum geometry.

This theoretical integration not only provides a coherent and predictive mechanism for mass emergence but also remains fully compatible with current observational data confirming the massless nature of gravitational waves.

9 Numerical Methods for the Chronovibrational Field

We now propose an approach to address the computational problem associated with its dynamic evolution. In particular, we consider the discrete evolution of the field as described by an effective Hamiltonian matrix, truncated to finite dimension, to obtain a quantized spectrum of vibrational frequencies and transitions between states.

9.1 Foundations for Numerical Modeling: Fractal Bases and Predictive Error Structures

As a necessary preamble to the formal computational methods presented below, it is useful to briefly anticipate the logical foundation that will guide the numerical modeling of the chronovibrational field.

Specifically, we introduce the concept that the discrete structure of the chronovibrational field can be effectively represented through a fractal numerical basis, inspired by recursive prime decompositions as proposed in recent theoretical developments. In this framework, each temporal eigenstate of the field corresponds to a node in a recursive prime graph, and the dynamic transitions between states are governed by structured probabilities, rather than uniform randomness.

The predictive utility of this fractal structure lies in its ability to encode, probabilistically, the likelihood of deviations (errors) from ideal harmonic evolution. This becomes particularly relevant when analyzing the modified Lorentz constant $\hat{L}_{\text{mod}}(t)$ under both observational and perturbative experimental conditions.

For each pair of discrete temporal states (p_i, p_j), we can associate a transition probability matrix M_{ij}, constructed based on the local density and the recurrence frequency of prime decompositions. These matrices act as predictive maps for possible spontaneous or induced deviations in the chronovibrational evolution.

Thus, error quantization can be formalized by evaluating the deviation operator:

$$\Delta L = \|\hat{L}_{\text{mod}}(t) - \hat{L}_{\text{ideal}}(t)\|,$$

and computing its expectation value over the evolving field state:

$$\langle \Delta L \rangle_t = \text{Tr}(\rho(t)\Delta\hat{L}).$$

This formalism will allow, in future sections, the construction of both theoretical forecasts and experimental benchmarks to validate the chronovibrational field behavior.

In conclusion, the numerical methods described below (Hamiltonian diagonalization, spectrum extraction, operator computation) must be understood as the technical machinery to realize these theoretical insights: providing concrete, computable quantities that will later be matched against fractal-based predictions of error distributions, both in equilibrium and perturbed conditions.

9.2 Hilbert Matrix Diagonalization

The quantum dynamics of the chronovibrational field $\hat{\psi}(t)$ is formalized through a tridiagonal Hamiltonian matrix, which represents the harmonic coupling between different quantized states of the field. This matrix takes the form:

$$H = \begin{pmatrix} \Omega & g & 0 & \cdots & 0 \\ g & 2\Omega & \sqrt{2}g & \cdots & 0 \\ 0 & \sqrt{2}g & 3\Omega & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & N\Omega \end{pmatrix} \tag{59}$$

where:

- Ω is the fundamental frequency of the chronovibrational system;
- g is the coupling constant between consecutive states;
- N is the finite dimension, chosen to ensure both numerical convergence and physical representativeness.

9.3 Explicit Computational Algorithm

To determine the chronovibrational energy spectrum and related physical observables, rigorous numerical steps are applied according to the following detailed methodology:

1. Matrix Truncation The Hamiltonian matrix H is truncated to dimension $N \times N$. The choice of N must strike the right balance between numerical precision and computational feasibility. Typically, values $N \sim 10^2 \boldsymbol{\nabla} \cdot 10^4$ are sufficient to achieve spectral convergence.

2. Lanczos Algorithm The diagonalization is performed using the Lanczos algorithm, which is particularly efficient for large sparse symmetric matrices. The algorithm proceeds as follows:

1. A normalized random initial vector q_1 is chosen;
2. Iteratively, new vectors q_{k+1} are generated and orthogonalized with respect to the previous ones using the recurrence relation:

$$\beta_{k+1} q_{k+1} = H q_k - \alpha_k q_k - \beta_k q_{k-1} \tag{60}$$

with coefficients defined by:

$$\alpha_k = q_k^T H q_k, \quad \beta_{k+1} = \|H q_k - \alpha_k q_k - \beta_k q_{k-1}\| \tag{61}$$

3. A reduced tridiagonal matrix is constructed, which is easily diagonalizable:

$$T_k = \begin{pmatrix} \alpha_1 & \beta_2 & 0 & \cdots \\ \beta_2 & \alpha_2 & \beta_3 & \cdots \\ 0 & \beta_3 & \alpha_3 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix} \tag{62}$$

Example: Construction of a Predictive Transition Matrix M_{ij}

To illustrate the application of the fractal basis to numerical modeling, we consider a simple case where the temporal Hilbert space is spanned by three prime states $|p_1\rangle = |11\rangle$, $|p_2\rangle = |17\rangle$, and $|p_3\rangle = |23\rangle$.

Based on the recursive prime structure, the transition probabilities between these states can be estimated by the local connectivity and density of the prime graph. For instance, transitions between $|11\rangle$ and $|17\rangle$ are favored due to frequent prime decompositions, while transitions involving $|23\rangle$ are less probable.

Thus, the predictive transition matrix M can be schematically written as:

$$M = \begin{pmatrix} 1-\epsilon & \epsilon & 0 \\ \epsilon & 1-2\epsilon & \epsilon \\ 0 & \epsilon & 1-\epsilon \end{pmatrix} \tag{63}$$

where $\epsilon \ll 1$ represents the small probability of a transition induced either by spontaneous fluctuation or external perturbation.

The matrix M is stochastic (the sum of each row equals one) and approximately symmetric under the assumption of near-reversible transitions.

This construction exemplifies how the recursive fractal architecture translates into concrete numerical tools, usable in the Hamiltonian evolution and in the quantization of chronovibrational deviations. In full-scale simulations, larger matrices derived from deeper levels of the fractal graph will be employed.

3. Extraction of Eigenvalues and Eigenvectors From the reduced matrix T_k, using standard methods (e.g., QR decomposition), the eigenvalues E_n and eigenvectors $|n\rangle$ are extracted. These eigenvalues represent the energy spectrum of the chronovibrational field, while the eigenvectors provide the state basis used for computing observables.

4. Computation of Operator Matrix Elements Using the eigenvectors $|n\rangle$, the matrix elements of relevant physical operators, such as the field operator $\hat{\psi}(t)$ or its conjugate momentum $\hat{\pi}(t)$, are computed as:

$$\langle m| \hat{O} |n\rangle = \sum_{i,j} c_{mi} O_{ij} c_{nj} \tag{64}$$

where c_{mi} and c_{nj} are the components of the eigenvectors in the chosen original basis, and O_{ij} is the matrix representation of the physical operator.

9.4 Interpretation of Results

The final outcome of the numerical diagonalization allows a quantitative interpretation of:

- The characteristic frequencies of the system;
- The amplitude of quantum fluctuations under vacuum conditions;
- The transition probabilities between different quantum states, which are crucial for the design and interpretation of the proposed experiments (such as ITER and LIGO/Virgo data analyses).

This detailed analysis, supported by the numerical approach just described, constitutes a fundamental step toward the experimental validation and understanding of the possible outcomes of the experiments.

PART II: Observational Proposals

10 Observable Predictions

10.1 Types of Experiments

This section proposes a number of experiments, both observational and active, aimed at testing or potentially falsifying the chronovibrational theory as formulated in its quantum extension.

The proposed experiments are divided into two conceptually distinct categories, depending on the global vibrational state of the environment in which they are conducted:

10.1.1 Experiments in a State of Invariant Harmony

This category includes passive or observational measurements carried out under conditions of apparent equilibrium. According to the theory, even in a macroscopically stable harmonic state, the chronovibrational field $\psi(t)$ is subject to residual quantum fluctuations. This is reflected in a function $F[\psi(t)]$ that, while asymptotically approaching one, exhibits small local deviations:

$$F[\psi(t)] \approx 1 - \eta\, |\delta\psi(t)|, \tag{65}$$

where $\delta\psi(t)$ represents the harmonic stochastic component, intrinsically predicted by the Hilbert-space quantization model. Since no physical system is ever in perfect equilibrium, such fluctuations could manifest as anomalous drifts or low-frequency oscillations in atomic clocks, stochastic signals in gravitational wave detectors, or periodic instabilities in precision spectroscopy.

10.1.2 Experiments in a State of Disturbed Harmony

This category includes active experiments in which the environment is deliberately perturbed by coherent external sources, in order to stress the field $\psi(t)$ and induce measurable variations. In such configurations, the dynamics of $\psi(t)$ may depart from the equilibrium harmonic regime and enter a state of forced response, similar to a system in parametric resonance.

This includes experiments at the ITER reactor, where the high intensity of the static magnetic field and the possibility of coherent radiofrequency (RF) modulation provide an ideal testbed for harmonic coupling between the electromagnetic field and the chronovibrational field.

This theoretical distinction between states of invariant harmony and disturbed harmony provides a fundamental interpretative guide for the design of experiments and subsequent data analysis. In both cases, the central prediction of the model is that the field $\psi(t)$, while globally coherent, can undergo quantifiable local and temporal variations, whose physical consequences — if detectable — would form the basis for experimental validation of the entire theory.

10.2 Data Processing and Residual Noise Analysis

In order to rigorously test the chronovibrational model against experimental data, it is crucial to implement a systematic methodology for isolating genuine chronovibrational signals from instrumental and environmental noise.

The recorded arrival times of photons, or any time-sensitive observables, are inevitably affected by a combination of thermal noise, electronic readout noise, and systematic machine errors. To discriminate between ordinary statistical fluctuations and potential chronovibrational effects, we adopt the following noise modeling and residual analysis protocol:

- **Noise Characterization:** Prior to active measurements, a calibration phase is conducted where no signal is deliberately injected. This provides a reference dataset of pure instrumental noise, assumed to follow a Gaussian distribution with measurable mean μ_{noise} and variance σ^2_{noise}.

- **Experimental Data Acquisition:** Experimental data are collected under the desired operational conditions, resulting in a measured distribution $P_{\text{measured}}(\Delta t)$ of arrival time deviations or equivalent observables.

- **Statistical Noise Subtraction:** Assuming linear superposition, the measured distribution is modeled as the sum of noise and potential signal:

$$P_{\text{measured}}(\Delta t) = P_{\text{noise}}(\Delta t) + P_{\text{signal}}(\Delta t). \tag{66}$$

  The noise contribution $P_{\text{noise}}(\Delta t)$ is subtracted statistically, either by deconvolution techniques or by baseline removal using the previously characterized noise model.

- **Residual Analysis:** The residual distribution $P_{\text{signal}}(\Delta t)$ is analyzed through normality tests (such as Shapiro-Wilk, Anderson-Darling, or Kolmogorov-Smirnov) to verify if it significantly deviates from Gaussianity.

- **Spectral and Temporal Analysis:** In case of non-Gaussian residuals, spectral analysis (e.g., Fourier Transform) and temporal correlation studies are performed to identify potential harmonic patterns or periodic structures compatible with chronovibrational dynamics.

This methodology ensures that any claimed deviations from standard noise statistics are substantiated by a robust data-driven process, minimizing false positives and enhancing the credibility of potential chronovibrational signatures. By applying these residual analysis techniques, the experimental results can be rigorously compared with the theoretical predictions of the model, offering a solid basis for its validation or falsification.

11 Experiments in a State of Invariant Harmony (Passive)

11.1 Experiment 1: Chronovibrational Gravitational Noise Analysis

Experimental Objective This pilot experiment aims to identify anomalous stochastic signals in gravitational waves attributable to fluctuations of the quantum chronovibrational field $\hat{\psi}(t)$. The goal is to clearly distinguish chronovibrational noise from standard background noise in gravitational detector data.

Suggested Experimental Apparatus The use of publicly available data from the LIGO and Virgo gravitational interferometers is proposed. These data can be accessed through the LIGO-Virgo-KAGRA (LVK) collaboration upon registration and approval of a scientific project. The current sensitivity of the interferometers (on the order of $10^{-23}\,\mathrm{Hz}^{-1/2}$ for strain) is theoretically compatible with the predicted fluctuation scale of the model.

Theoretical Assumptions and Interpolation Models According to the quantum chronovibrational model, fluctuations of the field $\hat{\psi}(t)$ induce quantum metric variations via:

$$\hat{g}_{\mu\nu}(t) = \eta_{\mu\nu}(1 + \epsilon\hat{\psi}(t)),$$

from which an effective gravitational strain perturbation arises:

$$\delta h(t) = \epsilon \cdot \delta\psi(t).$$

Assuming $\langle \delta\psi^2(t)\rangle = \frac{\hbar}{2\Omega}e^{-2\Lambda t}$, the predicted spectral amplitude of the signal is:

$$S_h(f) \approx \frac{\epsilon^2\hbar}{2\Omega}e^{-2\Lambda t} \cdot \delta(f - f_\psi),$$

where $f_\psi = \Omega/2\pi$ represents the dominant frequency of the field. It is assumed that $\Omega \sim 10^{13}\,\mathrm{Hz}$, with $\epsilon \sim 10^{-4}$ as a weak coupling factor.

Methodology and Measurement Duration

- Acquisition of O3/O4 datasets for at least 6 months.
- Calculation of the power spectral density $S_h(f)$ via FFT on sliding windows.
- Cross-correlation analysis between multiple interferometers.
- Gaussian or exponential fit on the residual relative to the theoretical background $S_{\text{noise}}(f)$.

Detection Threshold and Expected Values The theoretical minimum detection threshold is:

$$\delta h \gtrsim 3\sigma_{\text{noise}} \sim 3 \cdot 10^{-23},$$

with a standard deviation σ_{noise} estimated from the instrumental band. A positive signal would be indicated by an isolated component with:

$$\frac{S_h(f)}{S_{\text{noise}}(f)} \gtrsim 5,$$

on a timescale $t > 10^4\,\mathrm{s}$.

Data Analysis and Experimental Uncertainty The total uncertainty Δh is given by the quadrature sum:

$$\Delta h = \sqrt{\Delta h^2_{\text{instrument}} + \Delta h^2_{\text{model}}},$$

where $\Delta h_{\text{instrument}}$ can be estimated from calibration signals and Δh_{model} from uncertainty propagation on ϵ and Λ.

11.2 Experiment 2: Optical Drift in Ultra-Stable Atomic Clocks

Experimental Objective This pilot experiment aims to detect possible chronovibrational anomalies through drifts or shifts in the frequency of optical atomic clocks, caused by the quantum dynamics of the field $\hat{\psi}(t)$.

Suggested Experimental Apparatus Two ultra-stable optical clocks (e.g., Sr or Yb), located in different facilities (e.g., INRIM and PTB), connected via a stabilized optical link or GNSS synchronization. The experiment may leverage existing datasets collected in networks such as the ITOC project (International Timescales with Optical Clocks).

Theoretical Assumptions and Interpolation Models The field $\hat{\psi}(t)$ modifies the local metric, altering the perceived passage of time by the clocks. The observed frequency is therefore:

$$\nu(t) = \nu_0 \cdot \sqrt{1 + \epsilon\hat{\psi}(t)} \approx \nu_0\left(1 + \frac{\epsilon}{2}\hat{\psi}(t)\right).$$

The relative fluctuations are thus:

$$\frac{\delta\nu(t)}{\nu_0} = \frac{\epsilon}{2}\delta\psi(t),$$

and the expected standard deviation is:

$$\left(\frac{\delta\nu}{\nu}\right)_{\text{rms}} = \frac{\epsilon}{2}\sqrt{\langle\delta\psi^2(t)\rangle} \sim \frac{\epsilon}{2}\cdot\sqrt{\frac{\hbar}{2\Omega}e^{-2\Lambda t}}.$$

Measurement Methodology and Duration

- Continuous monitoring over ~ 1 year with $\Delta t < 1\,\text{s}$.
- Computation of the autocorrelation function to detect periodic patterns.
- Fit using exponential regression:

  $$\frac{\delta\nu(t)}{\nu_0} \approx A_0 e^{-\Lambda t}\cos(\Omega t + \phi),$$

  where $A_0 \propto \epsilon/\sqrt{\Omega}$.

Detection Threshold and Expected Values With optical clocks operating at 10^{-18} precision, the signal is detectable if:

$$\left(\frac{\delta\nu}{\nu}\right)_{\text{obs}} > 3\sigma_{\text{clock}} \sim 3\cdot 10^{-18},$$

which implies that $\epsilon\sqrt{\hbar/\Omega} \gtrsim 10^{-17}$.

Data Analysis and Experimental Uncertainty The total uncertainty $\Delta(\delta\nu/\nu)$ includes contributions from:

- Intrinsic clock stability (Allan deviation);
- Environmental noise (vibrations, EM interference, temperature);
- Systematic uncertainty in the values of Ω and Λ.

Data may be extracted from existing campaigns under EURAMET, PTB, NIST, or via direct access to differential GNSS datasets.

Connection with Recent Advances in Optical Quantum Communication Recent experimental breakthroughs have demonstrated the ability to transmit quantum-coherent optical signals over distances exceeding 250 km using existing commercial fiber infrastructures[6].

This achievement shows that quantum states with extremely low decoherence rates can be preserved over macroscopic distances without requiring specialized cryogenic conditions.

In this context, the chronovibrational model predicts that small deviations induced by the field $\hat{\psi}(t)$ could manifest not only as direct clock drifts but also as tiny, statistically coherent phase shifts or coherence losses along stabilized optical links.

Such effects, though minute, could become detectable through advanced autocorrelation analysis or phase noise measurements, leveraging the same techniques employed in modern long-distance quantum communication protocols.

Therefore, the growing maturity of quantum optical infrastructures opens a realistic experimental pathway for the future detection of chronovibrational deviations via long-baseline optical networks.

[6] M. Pittaluga et al., "Long-distance coherent quantum communications in deployed telecom networks," *Nature*, vol. 640, pp. 911–917, 2025. DOI: 10.1038/s41586-025-08801-w.

11.3 Further Proposed Experiments for Theoretical Extension

Additional Hypothetical Experiments to Develop

1. **Photon–$\psi(t)$ Field Scattering:** Quantum interaction between high-energy photons and the chronovibrational field. Cross section:

$$\sigma(E_\gamma) = \frac{\lambda^2 E_\gamma^2}{16\pi\Omega^2} e^{-\Lambda t}$$

$\rightarrow$ selective attenuation in the gamma spectrum (FERMI, INTEGRAL).

2. **Oscillations or Harmonic Variations of α_{EM}:** Local modulation detectable via ultra-fine spectroscopy or clock comparisons.

3. **Gravitational Echoes and Post-Merger GW Instabilities:** Transitions in $\psi(t)$ during collapse produce secondary signals ("echoes") in gravitational wave post-processing.

4. **Anomalies in GPS Signals and Satellite Metrology:** Harmonic deviations in signal propagation times detectable by IGS, Galileo, BeiDou.

5. **Chronovibrational Effects in Astrophysical Neutrinos:** Flavor misalignments in transient high-energy events (e.g., SN, GRBs).

All require formal modeling and development of predictive thresholds, which will be addressed in future updates of this work.

12 Experiments in a State of Altered Harmony (Active)

12.1 ITER Experiment

Modern facilities for controlled nuclear fusion, such as the experimental ITER reactor, use superconducting magnets capable of generating extremely intense magnetic fields, on the order of 13 Tesla. These conditions represent some of the most extreme physical environments achievable on Earth and are ideal candidates for experimentally testing unconventional physical models.
The chronovibrational theory, which posits the existence of a global harmonic field $\psi(t)$ capable of locally modulating spacetime dynamics, predicts that this field may be weakly but measurably influenced by external configurations characterized by high magnetic coherence. In particular, it is hypothesized that static high-intensity structures, such as those present in ITER, may represent a possible passive coupling with $\psi(t)$, acting as local harmonic perturbators.
However, to detect an active response of the field $\psi(t)$, coherent temporal modulation is required, which is not achievable with static configurations.
Within the framework of the theory, even minimal modulation of $\psi(t)$ may result in observable variations in the function $F[\psi(t)]$, which in the model locally replaces the Lorentz factor in relativistic transformations. Although such variations are extremely small, it is proposed that they may emerge as anomalies in precision instrumentation signals — traditionally attributed to experimental noise, environmental fluctuations, or systematic effects.

12.2 Chronovibrational Predictions and Observable Parameters

Chronovibrational theory postulates that the global scalar field $\psi(t)$, characterized by intrinsic harmonic dynamics, can be locally perturbed by intense magnetic fields through a quantum-mediated coupling mechanism. In particular, a strong magnetic field $\mathbf{B}$ could indirectly interact with $\psi(t)$ via its induced effect on the local spacetime structure, manifesting as minimal but measurable metric perturbations.

To clarify the hypothesized physical mechanism, we assume that the interaction occurs through a local curvature variation produced by the energy–momentum tensor of the intense electromagnetic field:

$$T_{\mu\nu}^{EM} = \frac{1}{\mu_0}\left(F_{\mu\alpha}F_{\nu}{}^{\alpha} - \frac{1}{4}g_{\mu\nu}F^{\alpha\beta}F_{\alpha\beta}\right), \quad (67)$$

where $F_{\mu\nu}$ is the electromagnetic field tensor and μ_0 the vacuum magnetic permeability.

This local electromagnetic energy and momentum density could, according to the chronovibrational model, slightly deform the local metric $g_{\mu\nu}$, thereby modulating the field $\psi(t)$ via an effective connection of the form:

$$\Gamma_{\mu}^{(\psi)} \propto \xi\, T_{\mu\nu}^{EM}\nabla^{\nu}\psi(t), \quad (68)$$

with ξ a phenomenological coefficient quantifying the strength of the chronovibrational–electromagnetic coupling.

The predicted variation in the function $F[\psi(t)]$, which in the model replaces the Lorentz factor, is:

$$F[\psi(t)] \approx 1 - \eta\left|\frac{d^2\psi}{dt^2} + \omega^2\psi(t)\right|, \quad (69)$$

with η proportional to ξ and to the magnetic field intensity $\mathbf{B}$.

Expected Observable Effects

- Micro-variations in ultra-stable atomic clock frequencies: $\Delta f/f \sim 10^{-18}$;
- Phase shifts in laser interferometers;
- Variations in apparent gravitational field (quantum gravimetry);
- Anomalies in inertial mass (atomic interferometry);
- Variations in atomic transitions sensitive to α.

All effects depend on the spatial gradient and intensity of the magnetic field, suggesting a concrete experimental strategy, but one that requires stringent systematic controls.

12.3 Experiment at ITER

The proposed experiment exploits the magnetic and geometric configuration of ITER to test the sensitivity of the field $\psi(t)$ to external harmonic perturbations.

Experiment Phases

1. Use of intense static magnetic fields ($B \approx 13\,\mathrm{T}$);
2. Integration of dynamic modulation via RF (ECRH: 170 GHz, ICRH: 40˘55 MHz);
3. Identification of three measurement zones:
   - **Zone A (Field Center)** – maximum B intensity;
   - **Zone B (Field Gradient)** – spatial variation of the field;
   - **Zone C (Control)** – shielded outer zone for differential comparison.

Involved Instruments

- Ultra-stable atomic clocks;
- Optical interferometers (Michelson / Fabry–Pérot);
- Cold atom quantum gravimeters;
- Atomic interferometers.

Measurements will be synchronized and statistically processed using advanced techniques (matched filtering, multichannel coherence, spectral analysis).

12.4 Vacuum Harmonic RF Experiment

To amplify the interaction, we propose performing the experiment in the absence of plasma, keeping the ITER toroidal vessel in vacuum conditions. The RF sources (ECRH and ICRH) can generate a coherently modulated harmonic field, stimulating a controlled dynamic response of $\psi(t)$.

12.5 Theoretical Basis of the RF–$\psi(t)$ Coupling

Equation of the Forced System

$$\ddot{\psi}(t) + 2\Lambda\dot{\psi}(t) + \omega_0^2\psi(t) = \varepsilon\cos(\omega_{\mathrm{RF}}t) \quad (70)$$

Solution in the Steady-State Regime

$$\psi(t) = \frac{\varepsilon \cos(\omega_{\mathrm{RF}} t + \phi)}{\sqrt{(\omega_0^2 - \omega_{\mathrm{RF}}^2)^2 + 4\Lambda^2 \omega_{\mathrm{RF}}^2}},$$
$$\phi = \arctan\left(\frac{2\Lambda\omega_{\mathrm{RF}}}{\omega_0^2 - \omega_{\mathrm{RF}}^2}\right) \tag{71}$$

12.6 Resonance Conditions and Expected Observables

When $\omega_{\mathrm{RF}} \approx \omega_0$, the amplitude of $\psi(t)$ is maximal. Measurable effects include:

- Frequency shifts in atomic clocks: $\Delta f/f \sim 10^{-18}$;
- Optical phase shifts detectable with interferometers;
- Apparent metric fluctuations (gravimetry);
- Inertial anomalies (atomic interferometry).

12.7 Detailed Experimental Methodology

1. Systematic RF frequency scan around ECRH/ICRH ranges;
2. Simultaneous measurements in zones A, B, C;
3. Advanced statistical analysis of signals (coherence, matched filtering);
4. Pre-calibration of instruments in controlled environments.

12.8 Managing Experimental Limitations

Given the complexity of the ITER environment, the experiment is considered exploratory. Preliminary tests are proposed in shielded RF cavities or isolated laboratory environments to:

- Validate measurement protocols;
- Optimize instrument sensitivity;
- Rule out environmental noise and false positives.

13 Preliminary Laboratory Experiments

As mentioned above, before proceeding with large-scale tests in high-energy environments like ITER, it is advisable and desirable to conduct **controlled preliminary experiments in the laboratory**, aimed at verifying the sensitivity of the chronovibrational field $\psi(t)$ to external harmonic stimuli under less extreme yet scientifically meaningful conditions. While these experiments cannot replicate the field intensities of a fusion facility, they allow us to **test methodology, calibrate instruments, reduce systematic uncertainties**, and, if successful, **provide empirical justification** for the use of more complex facilities.

13.1 Objective

To verify whether, in the presence of *harmonically modulated magnetic fields* generated by RF sources in a shielded and vacuum environment, it is possible to observe *micro-variations in physical parameters sensitive to the field* $\psi(t)$, analogous to those predicted for ITER, but on a reduced scale.

13.2 Reduced Experimental Configuration

1. Static and Modulated Magnetic Field A solenoid or Helmholtz pair is used to generate a static field between 0.5 T and 2 T, integrated with an RF source to produce a *coherent harmonic modulation* (e.g., 100 MHz to 1 GHz), simulating the ECRH/ICRH effect on a smaller scale.

2. Vacuum Environment The magnetic cavity is placed in a controlled vacuum chamber (pressure $< 10^{-5}$ mbar) to *eliminate nonlinear couplings* due to ionized gases or thermal effects.

3. Three-Dimensional Measurement Zones Three zones are defined, analogous to those proposed for ITER:

- **Zone A**: field center (maximum intensity);

- **Zone B**: field gradient;
- **Zone C**: control zone (outside the field, shielded).

13.3 Involved Instrumentation

- Portable atomic clocks (chip-scale, rubidium, cesium);
- Fiber optic interferometers (miniaturized Michelson);
- Bench-top gravimeters (atomic or optomechanical);
- Tabletop atomic interferometers.

13.4 Forcing Equation in Reduced Conditions

The response of the field $\psi(t)$ under harmonic stimulation is described by the same forced differential equation:

$$\ddot{\psi}(t) + 2\Lambda\dot{\psi}(t) + \omega_0^2\psi(t) = \varepsilon\cos(\omega_{\mathrm{RF}}t), \quad (72)$$

with ω_{RF} values in the MHz or GHz range, depending on the available sources.

13.5 Expected Predictions and Observables

Under resonance conditions ($\omega_{\mathrm{RF}} \approx \omega_0$), the maximum field response is hypothesized:

- Frequency shift in atomic clocks: $\Delta f/f \sim 10^{-17}\boldsymbol{\nabla}\cdot 10^{-18}$;
- Microvariations in interferometric phase: $\Delta\phi \sim 10^{-4}\,\mathrm{rad}$;
- Apparent gravitational fluctuations: $\Delta g \sim 10^{-10}\,\mathrm{m/s^2}$.

These signals may be *negligible in conventional experiments*, but are *coherent in time and spectrum*, making them identifiable via *matched filtering*, phase coherence, or statistical stacking over multiple cycles.

13.6 Measurement Methodology and Control

1. Continuous scan of RF frequencies around the value of ω_0;
2. Simultaneous measurements in zones A, B, and C;
3. Thermal, magnetic, and acoustic isolation of the apparatus;
4. Signal analysis using correlation techniques and adaptive filtering;
5. Validation of "false zero" via phase inversion and modulation deactivation.

13.7 Strategic Value of a Positive Outcome

A positive (even partial) laboratory result would:

- Validate the hypothesis of weak harmonic coupling between $\psi(t)$ and $T_{\mu\nu}^{EM}$;
- Strengthen the plausibility of measurable effects in more energetic environments like ITER;
- Provide preliminary data to calibrate models and numerical simulations;
- Establish an experimental precedent to request beam time on large-scale infrastructures.

Conclusion

The proposal for this tabletop experiment represents a fundamental phase in the strategy of active testing under harmony disturbance for the chronovibrational theory. Even in the absence of conclusive confirmations, it would provide the opportunity to fine-tune the methodology, evaluate the signal-to-noise ratio, and establish a concrete experimental foundation for more advanced studies. Should plausible confirmations of the theory already emerge from this first experimental phase, it would provide a scientifically stronger motivation for deploying more complex and energetically costly structures such as ITER.

Common-Sense Objection: Why Haven't These Effects Been Detected, Despite Valid Scientists Testing and Measuring Daily?

Although the chronovibrational model predicts potentially observable effects — such as stochastic gravitational fluctuations or atomic clock drifts — these have not yet been experimentally confirmed. This may be surprising but can be explained by several factors:

- **Lack of a predictive model:** Until now, no coherent theory indicated *what* to look for, *where*, and *in what form*. In the absence of a structured theoretical framework, the hypothesized signals are often ignored or classified as instrumental noise.
- **Automatic filtering of weak signals:** In gravitational detectors and metrological networks, fluctuations of extremely small amplitude ($\sim 10^{-18} \boldsymbol{\nabla} \cdot 10^{-23}$) are typically considered environmental errors or systematic disturbances. As a result, they may be eliminated by standard data analysis pipelines.
- **Bandwidth or sensitivity limitations:** For example, LIGO/Virgo interferometers are sensitive up to tens of kHz, but the natural frequency of the $\psi(t)$ field may lie well above this range. In other cases, the signal may be present but buried in high-noise regions.
- **Lack of multiple correlations:** Some signals, if present, may appear anomalous until they emerge through cross-analysis across multiple observatories (e.g., LIGO+Virgo or INRIM+PTB). Lack of statistical replication hinders their consideration.

Therefore, the absence of observations to date does not constitute a refutation of the model, but reflects the fact that no one has yet looked *specifically* for these effects using the proper interpretative and analytical tools. This work proposes precisely such a theoretical structure to guide those searches in a falsifiable manner.

Conclusions

This work represents a conceptual and formal extension of the chronovibrational theory originally proposed in its theoretical form[7], outlining a quantization pathway for the temporal field $\hat{\psi}(t)$ consistent with the principles of quantum mechanics, general relativity, and canonical quantum gravity.

Through the introduction of a Hilbert space structure, the rigorous definition of operators and commutators, the construction of a damped quantum equation of motion, and the analysis of residual fluctuations, a theoretical framework has been provided that yields physically falsifiable predictions. The formalism also allows for modeling the coupling between $\hat{\psi}(t)$ and known fundamental fields, such as the electromagnetic and gravitational fields, offering the possibility of concrete experimental connections through measurements with atomic clocks, gravitational detectors, and coherent RF fields.

Methodologically, the work proposed an explicit diagonalization of the chronovibrational Hamiltonian using stable numerical algorithms, paving the way for large-scale computational simulations and the identification of quantum spectral signatures.

However, this treatment does not claim to be a complete or definitive model. On the contrary, it aims to be a first structured attempt to define time as an observable, harmonic, and dynamic quantum field. The model includes simplifying assumptions — such as global temporal homogeneity, linear harmonic coupling, and the neglect of spatial fluctuations — that must be overcome in more complete future studies.

Most importantly, the theory is formulated with a spirit of critical openness: it does not claim to offer definitive answers, but rather to pose formally precise and experimentally testable questions. The scientific community is therefore invited to consider this framework as a point of theoretical and empirical dialogue, contributing with observations, critiques, extensions, or refutations. In this spirit, quantum chronovibration is not to be seen as a new isolated ontology, but as a coherent extension of the physical theories currently recognized as shared scientific knowledge. It seeks to explore a new theoretical frontier, in which the observable reality is one of the possible harmonic representations of the universe. This approach opens the door to alternative hypotheses on the nature of time and spacetime, formulated in mathematically rigorous terms and designed to be verifiable or falsifiable through experiment.

«Hypotheses non fingo, sed experientia demonstranda sunt.»

[7] Paolo Giordana, *Chronovibration Theory and Warp Propulsion: Vibrational Unification of Cosmic Components and Metric Implications*, Zenodo (2025). `https://zenodo.org/records/15240876`

Appendix A: Experimental Predictions and Numerical Justifications

This appendix presents a structured summary of the observable predictions of the chronovibrational model and an explicit discussion of the numerical parameters and algorithms used.

1. Fundamental Parameters Used for Predictions

Table 2: Reference values for quantitative estimates

Parameter	Value	Notes
Ω	$10^{13}\,\mathrm{Hz}$	Harmonic frequency of the $\psi(t)$ field
Λ	$10^{-3}\,\mathrm{s}^{-1}$	Chronovibrational damping
ϵ	10^{-4}	Metric–field coupling
λ	$10^{-15}\,\mathrm{s}$	Electromagnetic–chronovibrational coupling
$\hbar$	$1.05 \times 10^{-34}\,\mathrm{J}\cdot\mathrm{s}$	Reduced Planck constant

2. Justification of Numerical Parameters and Algorithms

The main parameters involved in the model are:

- Ω: natural frequency of chronovibration. Chosen in the range $10^{12} - 10^{14}$ Hz for compatibility with Compton scales and quantum vacuum energy density.
- Λ: damping coefficient, related to the decoupling scale of the field. In some models, it is parametrized as $\Lambda \sim H_0\sqrt{c/L_{\mathrm{Pl}}}$.
- g: coupling parameter in the bilinear term of the Hamiltonian (Section 10), chosen in analogy with weakly coupled oscillators. Calibrated to reproduce energies on the order of $\sim 10^{-12} - 10^{-6}$ eV.

Lanczos Algorithm. The Lanczos algorithm is used for the diagonalization of the harmonic chronovibrational Hamiltonian (Section 10). The numerical data obtained represent:

- The eigenvalues of the residual vibrational energy after damping;
- The modal amplitudes of the field $\hat{\psi}(t)$ and its projection onto the ground state;
- The dominant frequencies emerging at $\omega \approx \Omega$ and $\omega \approx 0$, as predicted by the dissipative formalism.

These data can be mapped to experimental observables according to the scheme:

$$\text{Modal amplitude} \longrightarrow \Delta\nu_{\text{clocks}}, \tag{73}$$
$$\text{Vibrational eigenvalue} \longrightarrow E_{\text{residual}}, \tag{74}$$
$$\text{Frequencies} \longrightarrow \delta h(t) \text{ in LIGO spectrum} \tag{75}$$

3. Distinction from Noise and Falsifiable Predictions

The theory predicts coherent harmonic signals, not stochastic, characterized by:

- Recurring peaks in the spectrum;
- Constant relative phase between independent detectors;
- Harmonic modulation in the presence of exponential damping.

These characteristics distinguish it from:

- Thermal noise (white or 1/f);
- Instrumental quantum noise (shot noise);
- Random walk drifts in clocks.

Falsifiability criterion. In the absence of signals compatible with predictions (e.g., $\delta h \sim 10^{-23}$ at $f \sim 10^{13}$ Hz, or clock drifts $\gtrsim 10^{-18}$), over an observation period of at least 1 year and with inter-instrument coherence above 95

Appendix B: Comparison with Alternative Theories

Here we summarize the main alternative models currently available and highlight the key differences with the chronovibrational approach.

B.1 Main Competing Theories

- **Classical Dark Matter and Dark Energy:** postulate invisible components with gravitational interaction but do not explain their origin or provide a unified description. Chronovibration instead proposes a common vibrational origin for all sectors.
- **Modifications of General Relativity (f(R), MOND, Brans–Dicke):** act on the geometric side of the field equations, often with phenomenological motivations. Our model introduces a quantized scalar field that harmonically modulates the metric, derived from an effective action while preserving a Lagrangian structure.
- **Quantum theories of time (Page–Wootters, timeless decoherence):** offer formal treatments of time as an emergent entity, but do not predict direct observable effects. Our approach, by contrast, links the time field to quantifiable laboratory predictions (e.g., clocks, LIGO).
- **Instrumental and thermal noise:** described by stochastic statistical models, showing no phase coherence or persistent harmonic dependence. Chronovibration predicts a harmonic signal with constant phase detectable in multiple decoupled instruments.

B.2 Conceptual Advantages of the Chronovibrational Model

- Unifies gravity, visible matter, dark matter, and dark energy as vibrational modes of a single scalar field;
- Formally integrates quantized time into a canonical structure compatible with the Wheeler–DeWitt equation;
- Provides verifiable and falsifiable predictions, distinguishable from noise and other models;
- Allows for natural extension to gauge interactions, metric–field coupling, and non-stationary dynamics.

B.3 Limitations and Complementarity

- The chronovibrational model does not exclude the existence of dark matter or dark energy, but proposes a reinterpretation as different vibrational states of the field $\psi(t)$;
- It can be seen as a harmonic extension of f(R) and Brans–Dicke theories, where the field potential includes dissipative and quantum components absent in other models;
- It can coexist with standard theories such as the Standard Model or General Relativity, acting as a background field in analogy with inflation.

In conclusion, the chronovibrational model does not present itself as an antithesis to existing theories, but as a unifying extension with predictive content and a formally coherent theoretical basis. Its validity, like any physical theory, depends on its ability to be tested and, if necessary, falsified.

Appendix C: Fractal Bases and Predictive Matrices in Chronovibrational Quantization

Motivation for the Fractal Choice

In the present model, the use of a fractal numerical basis derived from recursive prime decompositions is not an arbitrary aesthetic choice but a motivated strategy to discretize the Hilbert space $\mathcal{H}_\psi$ associated with the quantized temporal field $\hat{\psi}(t)$.

The prime fractal structure introduced by Ruffini [1] offers a naturally non-Euclidean, recursive, and scale-invariant topology. Such characteristics are particularly suited to model the expected hierarchical and fluctuating nature of temporal deviations in the chronovibrational framework.

Unlike uniform bases (e.g., standard Fock bases) that assume isotropy and homogeneity, a fractal basis allows encoding non-trivial internal correlations and structured transition pathways between temporal eigenstates.

Comparison with Ruffini's Work

While Ruffini's work introduced the concept of recursive prime decompositions to describe fundamental structures, our chronovibrational model extends and operationalizes this idea in a quantum physical context.

Specifically, we:

- Interpret each prime triplet decomposition $\Phi(p) = (p_n, b, c)$ as a basis element $|p\rangle$ in $\mathcal{H}_\psi$.
- Construct a transition matrix M_{ij} based on the connectivity of the fractal graph.
- Use these matrices to predict and quantify deviations (chronovibrational errors) in both observational and perturbative experimental scenarios.

Thus, Ruffini's fractal primes are not just a mathematical curiosity but become dynamic and predictive structures within a full physical model.

.1 Predictive Transition Matrices: Extended Example

As a concrete illustration, consider a basis composed of five prime states:

$$|p_1\rangle = |3\rangle\,, \quad |p_2\rangle = |5\rangle\,, \quad |p_3\rangle = |7\rangle\,, \quad |p_4\rangle = |11\rangle\,, \quad |p_5\rangle = |17\rangle\,.$$

Based on the recursive prime structure, the estimated transition probabilities might yield a matrix:

$$M = \begin{pmatrix} 1-2\epsilon & \epsilon & \epsilon & 0 & 0 \\ \epsilon & 1-3\epsilon & \epsilon & \epsilon & 0 \\ \epsilon & \epsilon & 1-3\epsilon & \epsilon & \epsilon \\ 0 & \epsilon & \epsilon & 1-2\epsilon & \epsilon \\ 0 & 0 & \epsilon & \epsilon & 1-2\epsilon \end{pmatrix} \tag{76}$$

where $\epsilon \ll 1$ represents a small transition probability.

Properties of this matrix:

- It is approximately symmetric.
- Each row sums to 1 (stochastic matrix).
- Neighboring primes are more strongly coupled (direct decompositions).

Such a structure reflects the fractal connectivity: transitions are easier along frequent decompositions and suppressed otherwise.

Physical and Computational Relevance

These predictive matrices serve two complementary roles:

1. **Physical role**: Modeling the spontaneous or induced evolution of the field $\hat{\psi}(t)$ through probabilistic pathways.

2. **Computational role**: Providing structured input for the numerical diagonalization of the Hamiltonian, stability analysis, and simulation of experimental scenarios.

In large-scale simulations, extended matrices derived from deeper layers of the prime graph will be constructed, enabling a more realistic modeling of quantum chronovibrational dynamics.

Suggested Numerical Parameters for Initial Simulations

For practical implementation of the initial computational models, the following reference parameters are suggested:

Parameter	**Value**	**Notes**
Fundamental Frequency Ω	10^{13} Hz	Chronovibrational base frequency
Damping Coefficient Λ	$10^{-3}\,\mathrm{s}^{-1}$	Cosmological damping rate
Transition Probability ϵ	10^{-4}	Inter-state transition weight
Matrix Dimension N	100	Truncated Hilbert space size
Coupling Constant g	10^{-6} eV	Hamiltonian coupling between states

Table 3: Reference numerical parameters for chronovibrational field simulations.

References

[1] Douglas Ruffini,
Electron Approach Theory Fractal Extension, 2025.