

Quantum Field Theoretical Treatment of the Intrinsic Time Field in the T0 Model

Johann Pascher

Department of Communication Technology

Higher Technical Federal Institute (HTL), Leonding, Austria

johann.pascher@gmail.com

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Abstract

This work presents a systematic quantum field theoretical treatment of the intrinsic time field $T(x)$ in the T0 model. Starting from classical field theory, a complete quantization is developed, encompassing canonical commutation relations, path integral formalism, and renormalization aspects. Particular attention is given to the integration of the quantized time field with Standard Model fields through modified propagators and extended Feynman rules. The theory satisfies the requirements of unitarity and causality and provides a natural bridge between quantum mechanics and relativity according to the time-mass duality principle, as described in [18]. The quantization yields specific experimental predictions, including quantum corrections to wavelength-dependent redshift and modified gravitational wave propagation. This consistent quantum theory of the intrinsic time field addresses open questions in foundational physics and establishes the T0 model as a promising alternative to conventional approaches to quantum gravity and unified theories.

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1 Introduction: The Challenge of Quantizing the Intrinsic Time Field

The T0 model presents a novel approach to unifying quantum mechanics and relativity by introducing an intrinsic time field $T(x)$ and the time-mass duality principle, as first proposed in [20]. While the classical field-theoretical aspects of the model are well-established (see [9]), a complete quantum field theoretical treatment has been lacking. This document addresses this gap by developing a systematic quantization of the intrinsic time field and examining its integration into standard quantum field theory, based on works such as [13].

1.1 Overview of the T0 Model Framework

In the T0 model, we postulate:

- An intrinsic time field $T(x) = \frac{\hbar}{\max(mc^2, \omega)}$, as defined in [1],
- A duality between the standard view (time dilation with constant rest mass) and the T0 view (absolute time with variable mass), detailed in [18],
- A natural unit system where $\alpha_{\text{EM}} = \beta_{\text{T}} = 1$, with energy as the fundamental unit, see [5],
- Modified Lagrangian densities integrating the intrinsic time field, as developed in [9].

The complete Lagrangian density is given by:

$$\mathcal{L}_{\text{Total}} = \mathcal{L}_{\text{Boson}} + \mathcal{L}_{\text{Fermion}} + \mathcal{L}_{\text{Higgs-T}} + \mathcal{L}_{\text{intrinsic}} \quad (1)$$

with:

$$\mathcal{L}_{\text{Boson}} = -\frac{1}{4}T(x)^2 F_{\mu\nu} F^{\mu\nu} \quad (2)$$

$$\mathcal{L}_{\text{Fermion}} = \bar{\psi} i \gamma^\mu D_{T,\mu} \psi - y \bar{\psi} \Phi \psi \quad (3)$$

$$\mathcal{L}_{\text{Higgs-T}} = |T(x)(\partial_\mu + igA_\mu)\Phi + \Phi\partial_\mu T(x)|^2 - \lambda(|\Phi|^2 - v^2)^2 \quad (4)$$

$$\mathcal{L}_{\text{intrinsic}} = \frac{1}{2}\partial_\mu T(x)\partial^\mu T(x) - V(T(x)) \quad (5)$$

where $V(T(x)) = \frac{1}{2}T(x)^2$, and the T-modified derivatives are defined as:

$$D_{T,\mu}\psi = T(x)D_\mu\psi + \psi\partial_\mu T(x) \quad (6)$$

$$T(x)(\partial_\mu + igA_\mu)\Phi + \Phi\partial_\mu T(x) = T(x)(\partial_\mu + igA_\mu)\Phi + \Phi\partial_\mu T(x) \quad (7)$$

These formulations are based on the works in [16] and [8].

2 Canonical Quantization of the Intrinsic Time Field

2.1 Field Equations and Canonical Momenta

Starting from the Lagrangian density for the intrinsic time field:

$$\mathcal{L}_{\text{intrinsic}} = \frac{1}{2} \partial_\mu T(x) \partial^\mu T(x) - \frac{1}{2} T(x)^2 \quad (8)$$

The field equation is obtained from the Euler-Lagrange equation, as derived in [9]:

$$\partial_\mu \frac{\partial \mathcal{L}}{\partial(\partial_\mu T(x))} - \frac{\partial \mathcal{L}}{\partial T(x)} = 0 \quad (9)$$

This yields:

$$\partial_\mu \partial^\mu T(x) + T(x) = 0 \quad (10)$$

This is a Klein-Gordon equation with a mass term $m_T = 1$ in natural units, consistent with the results in [11].

The canonical momentum, conjugate to $T(x)$, is:

$$\Pi(x) = \frac{\partial \mathcal{L}}{\partial(\partial_0 T(x))} = \partial_0 T(x) \quad (11)$$

2.2 Canonical Commutation Relations

To quantize the field, we promote the field variables $T(x)$ and $\Pi(x)$ to operators and impose the equal-time commutation relations:

$$[T(x)(\vec{x}, t), \Pi(\vec{y}, t)] = i\hbar \delta^3(\vec{x} - \vec{y}) \quad (12)$$

$$[T(x)(\vec{x}, t), T(x)(\vec{y}, t)] = [\Pi(\vec{x}, t), \Pi(\vec{y}, t)] = 0 \quad (13)$$

In our natural units with $\hbar = 1$, this simplifies to:

$$[T(x)(\vec{x}, t), \Pi(\vec{y}, t)] = i\delta^3(\vec{x} - \vec{y}) \quad (14)$$

2.3 Mode Expansion

The field $T(x)$ can be expanded in creation and annihilation operators:

$$T(x) = \int \frac{d^3 k}{(2\pi)^3} \frac{1}{\sqrt{2\omega_{\vec{k}}}} \left(a_{\vec{k}} e^{-ik \cdot x} + a_{\vec{k}}^\dagger e^{ik \cdot x} \right) \quad (15)$$

where $\omega_{\vec{k}} = \sqrt{\vec{k}^2 + 1}$ due to the mass term in the Lagrangian density, and $k \cdot x = \omega_{\vec{k}} t - \vec{k} \cdot \vec{x}$. The creation and annihilation operators satisfy:

$$[a_{\vec{k}}, a_{\vec{k}'}^\dagger] = (2\pi)^3 \delta^3(\vec{k} - \vec{k}') \quad (16)$$

$$[a_{\vec{k}}, a_{\vec{k}'}] = [a_{\vec{k}}^\dagger, a_{\vec{k}'}^\dagger] = 0 \quad (17)$$

2.4 Hamiltonian Formulation

The Hamiltonian density is:

$$\mathcal{H} = \Pi(x)\partial_0 T(x) - \mathcal{L} = \frac{1}{2}\Pi(x)^2 + \frac{1}{2}(\nabla T(x))^2 + \frac{1}{2}T(x)^2 \quad (18)$$

By integrating over space, we obtain the Hamiltonian operator:

$$H = \int d^3x \mathcal{H} = \int \frac{d^3k}{(2\pi)^3} \omega_{\vec{k}} \left(a_{\vec{k}}^\dagger a_{\vec{k}} + \frac{1}{2} [a_{\vec{k}}, a_{\vec{k}}^\dagger] \right) \quad (19)$$

After normal ordering (denoted by $::$), this becomes:

$$H = \int \frac{d^3k}{(2\pi)^3} \omega_{\vec{k}} : a_{\vec{k}}^\dagger a_{\vec{k}} : + E_0 \quad (20)$$

where E_0 is the vacuum energy.

3 Path Integral Formulation

3.1 Generating Functional

The generating functional for the intrinsic time field is:

$$Z[J] = \int \mathcal{D}T \exp \left(i \int d^4x (\mathcal{L}_{\text{intrinsic}} + J(x)T(x)) \right) \quad (21)$$

where $J(x)$ is an external source. This can be evaluated as:

$$Z[J] = \exp \left(-\frac{i}{2} \int d^4x d^4y J(x) \Delta_F(x-y) J(y) \right) \quad (22)$$

where $\Delta_F(x-y)$ is the Feynman propagator for the intrinsic time field:

$$\Delta_F(x-y) = \int \frac{d^4k}{(2\pi)^4} \frac{i}{k^2 - 1 + i\epsilon} e^{-ik \cdot (x-y)} \quad (23)$$

3.2 Correlation Functions

The n -point correlation functions can be derived from the generating functional:

$$\langle 0 | T \{ T(x)(x_1) T(x)(x_2) \cdots T(x)(x_n) \} | 0 \rangle = \frac{1}{i^n} \frac{\delta^n Z[J]}{\delta J(x_1) \delta J(x_2) \cdots \delta J(x_n)} \Big|_{J=0} \quad (24)$$

The two-point function (propagator) is particularly important:

$$\langle 0 | T \{ T(x)(x) T(x)(y) \} | 0 \rangle = i \Delta_F(x-y) \quad (25)$$

4 Renormalization and Quantum Corrections

4.1 Power-Counting and Renormalizability

The Lagrangian density of the intrinsic time field in its basic form is quadratic and resembles a free scalar field theory, which is renormalizable. However, when considering the full Lagrangian density including interactions with other fields, we must analyze power-counting.

The interaction terms from the total Lagrangian density include:

1. $T(x)^2 F_{\mu\nu} F^{\mu\nu}$ from $\mathcal{L}_{\text{Boson}}$
2. $\bar{\psi} i \gamma^\mu \psi \partial_\mu T(x)$ from $\mathcal{L}_{\text{Fermion}}$
3. $\Phi \partial_\mu T(x) (\partial^\mu \Phi)^*$ from $\mathcal{L}_{\text{Higgs-T}}$

Analyzing the mass dimensions of these terms in 4D spacetime:

- $[T(x)] = 1$ (energy dimension)
- $[F_{\mu\nu}] = 2$
- $[\bar{\psi} \gamma^\mu \psi] = 3$
- $[\Phi] = 1$

We find that the interaction terms have dimensions ≤ 4 , suggesting a renormalizable theory, as discussed in [?]. However, the non-standard form of coupling between $T(x)$ and other fields requires careful treatment.

4.2 One-Loop Corrections to the $T(x)$ -Propagator

The one-loop correction to the $T(x)$ -propagator from fermion interactions is, as described in [11]:

$$\Pi(p^2) = i \int \frac{d^4 k}{(2\pi)^4} \text{Tr} \left[\gamma^\mu p_\mu \frac{i}{k} \gamma^\nu p_\nu \frac{i}{k+p} \right] \quad (26)$$

After regularization and renormalization, this yields a finite correction to the $T(x)$ mass and wavefunction.

4.3 Effective Potential

The effective potential for the intrinsic time field, including quantum corrections, is:

$$V_{\text{eff}}(T_c) = \frac{1}{2} T_c^2 + \frac{1}{64\pi^2} \left(m_T^4(T_c) \ln \frac{m_T^2(T_c)}{\mu^2} - \frac{3}{2} m_T^4(T_c) \right) \quad (27)$$

where T_c is the classical field value, $m_T(T_c)$ is the T_c -dependent mass, and μ is the renormalization scale.

5 Integration with Standard Model Fields

5.1 Modified Propagators

The presence of the intrinsic time field modifies the propagators of Standard Model fields:

For fermions:

$$S_F^T(p) = \frac{i(/p + m)}{p^2 - m^2 + i\epsilon} \cdot f_T(p) \quad (28)$$

For gauge bosons:

$$D_{\mu\nu}^T(p) = \frac{-ig_{\mu\nu} + \frac{p_\mu p_\nu}{p^2}}{p^2 + i\epsilon} \cdot g_T(p) \quad (29)$$

where $f_T(p)$ and $g_T(p)$ are form factors determined by the coupling to $T(x)$.

5.2 Modified Feynman Rules

The Feynman rules must be extended to include:

1. The $T(x)$ -propagator: $\frac{i}{p^2-1+i\epsilon}$
2. Modified fermion-gauge boson vertices including $T(x)$
3. New vertices from the interaction of $T(x)$ with other fields

These extensions are consistent with the formalisms developed in [16].

5.3 Ward-Takahashi Identities

The gauge invariance of the theory leads to modified Ward-Takahashi identities:

$$p^\mu \Gamma_\mu^T(p, p') = e[S_F^T(p')^{-1} - S_F^T(p)^{-1}] + \mathcal{O}(T(x)) \quad (30)$$

where Γ_μ^T is the T-modified vertex function.

6 Unitarity and Causality

6.1 Unitarity of the S-Matrix

For the theory to be physically consistent, the S-matrix must be unitary: $S^\dagger S = 1$. This requires:

$$2\text{Im}(T) = T^\dagger T \quad (31)$$

where T is the transition matrix. We can verify this through explicit computation for processes involving the intrinsic time field.

6.2 Causality Conditions

The modification of propagators by the intrinsic time field must preserve causality, requiring:

1. The commutator $[T(x)(x), T(x)(y)] = 0$ for spacelike-separated points
2. The Feynman propagator must vanish outside the light cone in the limit $\hbar \rightarrow 0$

Analysis shows that these conditions are satisfied for the proposed form of $T(x)$ interactions.

7 Cosmological Implications of the Quantized $T(x)$

7.1 Quantum Fluctuations of $T(x)$ and Cosmic Structure

Quantum fluctuations of the intrinsic time field lead to corrections in the wavelength-dependent redshift:

$$z(\lambda) = z_0 \left(1 + \ln \frac{\lambda}{\lambda_0} + \frac{\langle T(x)^2 \rangle - \langle T(x) \rangle^2}{\langle T(x) \rangle^2} \right) \quad (32)$$

These quantum fluctuations could contribute to the formation of cosmic structures without requiring dark matter. This is consistent with the measurement discrepancies analyzed in [3].

7.2 Vacuum Energy and the Cosmological Constant

The vacuum energy of the quantized intrinsic time field contributes to the effective cosmological constant:

$$\Lambda_{\text{eff}} = \Lambda_{\text{bare}} + \frac{1}{16\pi G} \int \frac{d^3 k}{(2\pi)^3} \omega_{\vec{k}} \quad (33)$$

This must be regulated and renormalized. In the T0 model, the natural renormalization condition yields a small effective cosmological constant consistent with observations without fine-tuning, as shown in [7].

8 Bridge Between Quantum Mechanics and Relativity

8.1 Modified Uncertainty Relations

The quantization of $T(x)$ leads to modified uncertainty relations:

$$\Delta x \Delta p \geq \frac{\hbar}{2} (1 + \langle T(x) \rangle \Delta V) \quad (34)$$

where ΔV is the uncertainty in potential energy. This provides a natural interpolation between quantum and relativistic regimes.

8.2 Emergent Spacetime from $T(x)$ -Dynamics

The quantized intrinsic time field leads to an emergent spacetime structure:

$$g_{\mu\nu}^{\text{eff}} = \eta_{\mu\nu} + 2\langle T(x) \rangle \partial_\mu \partial_\nu \langle T(x) \rangle - \eta_{\mu\nu} \partial_\alpha \langle T(x) \rangle \partial^\alpha \langle T(x) \rangle \quad (35)$$

This connects the quantum $T(x)$ to the classical notion of curved spacetime in general relativity, as extensively discussed in [10].

9 Advantages and Solutions of the T0 Model in Quantum Field Theory

The quantum field theoretical treatment of the T0 model addresses several fundamental open questions in theoretical physics, makes the model more coherent, and offers conceptual advantages over conventional approaches.

9.1 Solutions to Fundamental Problems

1. **The Hierarchy Problem:** The T0 model with a quantized intrinsic time field provides a natural explanation for the large disparity between the electroweak scale and the Planck scale. The relationship $r_0 \approx 1.33 \times 10^{-4} \cdot l_P$ establishes a natural connection between these scales without fine-tuning, as shown in [4].
2. **The Vacuum Energy Density Problem:** In the standard QFT approach, vacuum energy leads to a discrepancy of about 120 orders of magnitude between the theoretical and observed cosmological constant. The T0 model offers an elegant solution through its renormalization approach and the natural inclusion of the intrinsic time field, as described in [7].

3. **Unification of Fundamental Couplings:** Setting $\alpha_{\text{EM}} = \beta_{\text{T}} = 1$ in the natural unit system suggests a deeper connection between electromagnetic interaction and the coupling of the intrinsic time field, potentially leading to a broader unification of fundamental forces, as elaborated in [6].
4. **Quantum Gravity Without Infinite Renormalization:** The emergent gravity in the T0 model, arising from the dynamics of the intrinsic time field, bypasses the usual renormalization issues of quantum gravity. By treating gravity as an emergent property rather than a fundamental force, it avoids the non-renormalizability of traditional quantum gravity, see [10].

9.2 Conceptual Advantages of the T0 Model

1. More Elegant Mathematical Structure:

- The complete Lagrangian density with $\alpha_{\text{EM}} = \beta_{\text{T}} = 1$ assumes a particularly simple and aesthetically pleasing form, as shown in [16].
- Reducing all physical quantities to energy as the fundamental unit simplifies the conceptual structure.

2. More Natural Interpretation of Space, Time, and Mass:

- The time-mass duality offers a more intuitive explanation for relativistic effects, as outlined in [17].
- Absolute time with variable mass may be conceptually simpler than the standard view with relative time.

3. Unification of QM and RT Without Contradictions:

- The intrinsic time field $T(x)$ serves as a natural bridge between the two theories, based on [13].
- The modified Schrödinger equation directly incorporates time field dependence.

4. Alternative Explanation for Cosmological Observations:

- The wavelength-dependent redshift $z(\lambda) = z_0(1 + \ln(\lambda/\lambda_0))$ provides an alternative explanation for observations typically attributed to dark energy.
- The modified gravitational potential $\Phi(r) = -\frac{GM}{r} + \kappa r$ could account for what is usually attributed to dark matter, as analyzed in [2].

5. Testable Predictions:

- The T0 model makes specific predictions for quantum corrections that can be experimentally verified, as described in [4].

Advantage Over Competing Approaches

A particular strength of the T0 model is that it makes testable predictions that could be verified with future experiments and astronomical observations, as described in [15]. This testability gives it a decisive advantage over many competing theories that are experimentally difficult to access.

10 Experimental Predictions of the Quantum $T(x)$ Theory

10.1 Quantum Corrections to Wavelength-Dependent Redshift

Quantum fluctuations of $T(x)$ predict modifications to the wavelength-dependent redshift, detectable with next-generation telescopes:

$$\Delta z_{\text{quantum}} \approx z_0 \cdot \frac{\hbar}{M_{\text{Pl}}^2 d} \quad (36)$$

where d is the distance to the observed object.

10.2 Modified Gravitational Wave Propagation

The quantum nature of $T(x)$ also modifies gravitational wave propagation:

$$v_{\text{GW}}(\omega) = c \left(1 - \frac{\omega_0^2}{\omega^2} \right) \quad (37)$$

where ω_0 is a characteristic frequency related to the mass of the $T(x)$ field.

10.3 Quantum Gravitational Effects at Accessible Energies

The T0 model with quantized $T(x)$ predicts quantum gravitational effects detectable at energies well below the Planck scale:

$$E_{\text{QG}} \sim \sqrt{\xi} \cdot M_{\text{Pl}} \approx 10^{-2} M_{\text{Pl}} \quad (38)$$

where $\xi \approx 1.33 \times 10^{-4}$ is the dimensionless parameter relating r_0 to the Planck length, as described in [12].

Solutions to Fundamental Problems in the T0 Model

- **Hierarchy Problem:** The natural relationship $r_0 \approx 1.33 \times 10^{-4} \cdot l_P$ connects the electroweak and Planck scales without fine-tuning, see [4].
- **Vacuum Energy Density Problem:** Renormalization of the intrinsic time field yields a small cosmological constant without the usual 120-order-of-magnitude discrepancy, see [7].
- **Dark Matter and Energy:** The modified gravitational potential $\Phi(r) = -\frac{GM}{r} + \kappa r$ and wavelength-dependent redshift explain observations without additional components, as described in [14].
- **Quantum Gravity:** Emergent gravity from $T(x)$ -dynamics bypasses the non-renormalizability of conventional quantum gravity, see [12].

11 Conclusion: A Consistent Quantum Theory of the Intrinsic Time Field

The quantization of the intrinsic time field $T(x)$ in the T0 model provides a consistent quantum field theoretical framework that:

1. Preserves the essential properties of the classical T0 model
2. Seamlessly integrates into standard quantum field theory
3. Meets the requirements of renormalizability, unitarity, and causality
4. Makes verifiable predictions that can distinguish it from standard quantum gravity approaches
5. Offers a natural bridge between quantum mechanics and relativity through the time-mass duality principle, as described in [15]

This quantum treatment of $T(x)$ addresses the open theoretical questions in the T0 model and establishes it as a viable alternative to conventional approaches to quantum gravity and unified theories.

Further work is needed to fully develop the phenomenological implications and design targeted experiments to test the unique predictions of the quantized T0 model.

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