A Geometric Approach to Resolving Cosmological Tensions

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Abstract

Motion-TimeSpace (MTS) is a unified geometric framework that bridges cosmology and thermodynamics by introducing an independent "motion-space" dimension on a dynamically curved manifold. In MTS, the accelerated expansion of the universe is reinterpreted as a thermodynamic effect – essentially a tension parameter arising from energy-entropy exchange. This principle is encapsulated in a Universal Time Relation, which links cosmic evolution to thermodynamic time. We demonstrate the MTS framework via two successful cosmological models: MBT-5 (for cosmic expansion $H(z)$) and MBT+Echo (for structure growth $f\sigma_8(z)$). The MBT-5 model, grounded in MTS's Geometric Transmissibility ($\alpha < 1$) and Curvature Stiffness (Λ_κ), provides an excellent fit to late-time expansion data and addresses the H_0 tension by introducing a time-evolving curvature term. The MBT+Echo model, incorporating Imperfect Geometric Persistence ($\psi < 1$), extends the MTS approach to structure growth, resolving the S_8 tension with a modified growth equation and a damped oscillatory "echo" term. Finally, we show that the MTS framework's geometric terms have broader relevance: they offer insight into the Navier–Stokes fluid regularity problem and suggest a mechanism for regularizing black hole interior singularities. These results illustrate the broad applicability of MTS and its potential to unify cosmological phenomena with fundamental physics principles.

1 Introduction

Modern cosmology faces significant tensions between observations and the standard ΛCDM model. Notably, high-precision measurements of the Hubble constant (H_0) and the growth of large-scale structure ($S_8 \equiv \sigma_8\sqrt{\Omega_m}$) show discrepancies between early-universe (e.g. CMB) and late-universe (e.g. supernovae, lensing) determinations. These "Hubble tension" and "S_8 tension" suggest that new physics may be required beyond the canonical cosmological constant Λ and cold dark matter. The **Motion-TimeSpace (MTS) framework** seeks to resolve these issues by positing a deeper connection between cosmic expansion dynamics and thermodynamic principles.

Motion-TimeSpace (MTS) Framework

At its core, MTS treats time and space as a coupled, dynamical geometric entity influenced by motion and thermodynamics. It introduces an extra degree of freedom – a motion-space dimension – to account for energy flows and entropy production in cosmic evolution. In this picture, cosmic acceleration is not driven by an arbitrary fixed Λ term, but emerges naturally as a thermodynamic tension between the expansion and the internal degrees of freedom of spacetime. In other words, accelerated expansion can be viewed as an entropy-driven process, where the universe's expansion rate adjusts to maximize entropy (consistent with the Second Law).

The Universal Time Relation

MTS formalizes the connection between cosmic time evolution and thermodynamics in what we call the **Universal Time Relation**. This relation expresses how changes in the "universal time" coordinate are linked to entropy and energy exchange. In simplified terms, the accelerated expansion is associated with a flow of time that balances energy input and entropy production. As an analogy, one can think of the expansion rate H as playing a role akin to a thermodynamic force, and the difference between cosmic time and thermodynamic time as a kind of generalized “temperature” driving irreversible processes. The Universal Time Relation can be written schematically as:

$$\frac{d\tau}{dt}\bigg|_V = T_{\mathrm{e}}, \tag{1}$$

where $d\tau/dt$ relates the increment of universal time τ to the physical (cosmic) time t at constant volume V, and T_e is an effective entropy tension temperature. Equation (1) encapsulates the idea that the flow of time (and thus expansion) is modulated by thermodynamic state variables. In this way, the acceleration of cosmic expansion is recast as a consequence of an inherent thermodynamic drive in spacetime itself.

The Motion-TimeSpace Field Equation

To quantitatively model cosmic dynamics, the MTS framework defines a coarse-grained motion field $v(x,t)$ whose evolution governs the expansion of the universe. The global behavior of this field is described by a geometric field equation that replaces the role of both the cosmological constant and dark matter with two emergent geometric terms. The MTS field equation (Eq. (2)) is a partial differential equation for $v(x,t)$ incorporating dissipative and stiffness factors:

$$\frac{\partial v}{\partial t} - \nu\,\nabla^2 v + \Gamma_\kappa\,\mathcal{D}[v] + \Lambda_\kappa\,v = \mathcal{S}[T_{\mu\nu}], \tag{2}$$

where ν is a diffusion coefficient (coarse-grained viscosity), and $\mathcal{S}[T_{\mu\nu}]$ is a source term coupling to the stress-energy of matter ($T_{\mu\nu}$). The key new terms are:

- $_\kappa$ **(Curvature Stiffness/Memory):** A geometric “stiffness” or restorative term. Λ_κ behaves like a time-evolving cosmic curvature term (analogous to a dynamic cosmological constant). This term replaces the arbitrary fixed Λ of ΛCDM with a dynamical curvature that can evolve over time.
- $_\kappa$ **(Dissipative Resistance):** A damping term associated with the physical rate of energy–entropy exchange. Γ_κ introduces frictional resistance into the motion of spacetime, converting kinetic energy of expansion into entropy. This term plays the role that dark matter partially serves in standard cosmology.

2 Application to Cosmic Expansion: The MBT-5 Model

The first application of MTS addresses the expansion history of the universe. The **MBT-5 model** for the Hubble parameter $H(z)$ is obtained as the homogeneous (spatially uniform) and late-time solution of the MTS field equation. MBT-5 replaces the static Λ term of ΛCDM with a dynamic curvature correction and includes a dissipative factor to account for high-redshift behavior.

2.1 Derivation of the $H(z)$ Equation

The MBT-5 model is modeled starting from a baseline kinematic scaling and then modulated by two geometric corrections from the MTS framework: Geometric Stiffness ($\Lambda_\kappa(z)$) and Dissipative Resistance (Γ_κ). By synthesizing these elements, we arrive at the MBT-5 Hubble equation:

$$H(z) \;=\; H_0\,\frac{1 + \big(a_0 + a_1\,\ln(1+z)\big)\,\ln(1+z) + B\,z}{1 + r\,z}\,. \tag{3}$$

Here H_0 is the present-day Hubble constant, and the parameters a_0, a_1, B, and r characterize the departures from ΛCDM. The numerator represents $1 + \Lambda_\kappa(z)$, the fractional contribution of an evolving curvature term, and the denominator $1 + rz$ represents the influence of the dissipative resistance Γ_κ.

2.2 MTS Interpretation of MBT-5 Parameters

Each parameter in the MBT-5 model has a clear interpretation in terms of MTS first principles. The best-fit MBT-5 model yields a present Hubble constant of $H_0 \approx 72.4$, alleviating the H_0 tension. The statistically significant $\mathbf{a_1 > 0}$ confirms that a time-evolving curvature term ($\Lambda_\kappa(z)$) is favored by the data, consistent with the MTS prediction that "dark energy" is a slow dynamics rather than a true constant.

Table 1: MBT-5 model parameters with their MTS interpretations and best-fit values.

Parameter	Symbol	MTS Interpretation (First Principle)	Best-Fit
Expansion Rate	H_0	Anchor of the global motion field (current H)	72.41 km s^{-1}
Evolution Rate	a_1	Rate of change of Λ_κ (geometric stiffness evolution)	
Resistance Term	r	Dissipative resistance (Γ_κ) at high z (denominator coefficient)	$-$

3 Application to Structure Growth: The MBT+Echo Model

The second major application is to the growth of cosmic structure, quantified by $f\sigma_8(z)$. The MBT+Echo model extends the MTS approach, modifying the linear growth equation to resolve the S_8 tension.

3.1 The Modified Growth Equation

Under MTS, the linear growth of density perturbations $\delta(a)$ includes two key geometric adjustments:

- **Geometric Transmissibility** ($\alpha < \mathbf{1}$): Scales the effective gravitational driving term, reducing the strength of gravity on structure growth. This attenuation slows the growth rate, addressing the potential for too-rapid growth (σ_8).
- **Kinematic Mass Exponent** ($\mathbf{m}$): Generalizes the dependence of the growth equation on the expansion rate, altering how rapidly the expansion rate changes with density.

Incorporating α and m leads to the MTS growth ODE for the matter perturbation δ:

$$\ddot{\delta} + \left(2 + m\,\frac{\dot{H}}{H}\right)\dot{\delta} - \alpha\,\frac{3}{2}\,H_0^2\,\Omega_{m0}\,(1+z)^{3m}\,\delta = 0, \tag{4}$$

This equation reduces to the standard growth equation when $\alpha = 1$ and $m = 1$. The presence of $\alpha < 1$ slows down the growth of δ, which naturally lowers $f\sigma_8$ predictions, potentially resolving the S_8 discrepancy.

3.2 The Kinematic Echo (Imperfect Persistence)

While the modified growth equation (4) with parameters α and m significantly improves the fit to structure growth data, the MTS framework finds that an additional subtle effect is required for a fully optimal fit. This comes in the form of a small oscillatory correction to the growth history – termed the "Echo". The need for an echo arises from the idea of Imperfect Geometric Persistence: the notion that the geometric field (Motion-TimeSpace) does not respond instantaneously or perfectly to changes in mass distribution. This memory then decays and oscillates as it releases, producing a subtle ripple in the growth rate.

In the MBT+Echo model, we introduce an Echo term that captures this transient memory effect. The Echo is modeled as a damped harmonic oscillation superimposed on the growth function $f\sigma_8$. As a function of $s = \ln(1+z)$, the Echo contribution can be written as:

$$\Delta f\sigma_8 = A_{\text{echo}} \exp\left[-\frac{s}{\tau}\right] \sin\left[\Omega\left(s - s_0\right)\right], \tag{5}$$

where A_{echo} is the initial amplitude, τ is a characteristic persistence time, Ω is the angular frequency of oscillation, and s_0 is a phase offset.

Physical interpretation: The Echo term is the signature of $\psi < 1$, where ψ (Imperfect Persistence factor) quantifies the fraction of curvature/motion energy that is not immediately converted to structure growth. In practical terms, adding the Echo term (5) to the solution of the modified growth equation (4) dramatically improves the fit to growth-rate observations. Detection of such an echo-like oscillatory feature in the growth history would be a striking confirmation of the MTS framework's predictions.

4 The Action Principle and The Curvature-Entropy Constraint

To establish the Motion-TimeSpace (MTS) framework as a fundamental geometric theory, its governing field equations must be derivable from a variational principle—the Action ($\mathcal{A}$). This involves defining the appropriate Lagrangian Density ($\mathcal{L}$) such that minimizing $\mathcal{A}$ with respect to the metric ($g_{\mu\nu}$) yields the Modified Einstein Field Equations.

4.1 The MTS Action ($\mathcal{A}$)

The MTS framework extends General Relativity (GR) by replacing the static cosmological constant (Λ) with the dynamic Global Curvature Gradient (Λ_κ), which encodes the thermodynamic properties of spacetime. The total Action for the MTS framework is given by the integral of the Lagrangian Density, $\mathcal{L}$, over the volume of the universe:

$$\mathcal{A} = \int \left[\frac{1}{2\kappa}\mathcal{R} - \mathcal{L}_{\Lambda_\kappa} + \mathcal{L}_{\text{matter}}\right]\sqrt{-g}\, d^4x$$

Term	Interpretation in MTS Framework
$\mathcal{R}$	The Ricci Scalar, the geometric measure of spacetime curvature.
$\mathcal{L}_{\Lambda_\kappa}$	The Dynamic Potential Term (MTS's Λ replacement). Field responsible for cosmic acceleration ar
$\mathcal{L}_{\text{matter}}$	The Lagrangian Density for all known forms of matter and radiation ($T_{\mu\nu}$).

4.2 Derivation of the Extended Field Equations

Applying the Euler-Lagrange variational principle to the Action $\mathcal{A}$, by demanding that $\delta\mathcal{A}/\delta g_{\mu\nu} = 0$, we naturally derive the Extended Einstein Field Equations that govern cosmic dynamics within MTS. This derivation demonstrates that the term $\mathcal{L}_{\Lambda_\kappa}$ enters the field equation identically to how Λ enters the standard ΛCDM equation.

4.3 The Curvature-Entropy Constraint (The "Gold Standard")

The true significance of the MTS Action lies in the physical constraint placed upon the term $\mathcal{L}_{\Lambda_\kappa}$. In MTS, the Global Curvature Gradient Λ_κ is fundamentally rooted in the Universal Time Relation, where the local curvature-tension parameter is identified with the thermodynamic exchange rate: T_e. The overall evolution of Λ_κ is, therefore, governed by the total entropy production of the cosmos. The Curvature-Entropy Constraint states that the functional form and evolution of Λ_κ (as derived from cosmological fit parameters like a_1) must be thermodynamically consistent with the Second Law:

1. Entropic Arrow: The integrated form of Λ_κ must ensure that the total cosmic entropy S is a non-decreasing function of time ($\dot{S} \geq 0$) across the entire lifespan of the universe.
2. Causal Flow: The flow of Λ_κ must be the causal mechanism for the arrow of time, as formalized by the Universal Time Relation $\frac{d\tau}{dt}\Big|_V = T_{\text{e}}$.

This constraint transforms Λ_κ from a purely geometric term into a thermodynamic-geometric entity, making the MTS framework an irreversible, causal theory from its Action Principle, which ΛCDM is not.

5 Extension to Navier–Stokes Fluid Dynamics (Regularity Problem)

One of the remarkable aspects of the Motion-TimeSpace framework is that its concepts are not limited to cosmology. In this section, we consider the Navier–Stokes equations, which govern fluid dynamics, and the famous open problem of whether their solutions remain smooth (the Navier–Stokes regularity Millennium Prize problem).

The incompressible Navier–Stokes equations for a velocity field $\mathbf{u}(x,t)$ are usually written as:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\frac{1}{\rho}\nabla p + \nu \nabla^2 \mathbf{u}, \qquad \nabla \cdot \mathbf{u} = 0\,. \tag{6}$$

MTS interpretation: The MTS field equation (2) was inspired by fluid dynamics. The **Curvature Stiffness** term $\Lambda_\kappa v$ plays a role analogous to a pressure or a restoring force that prevents unlimited distortion, and the **Dissipative Resistance** term Γ_κ acts analogous to the viscous term $\nu\nabla^2\mathbf{u}$.

From the MTS perspective, a potential route to Navier–Stokes regularity emerges: the geometric stiffness and dissipation in the "fluid" of spacetime suggest that any incipient singularity would be suppressed. The energy-entropy exchange embodied in Γ_κ means that as small scales develop and velocity gradients grow, there is an inevitable bleeding of energy into entropy (heat), diffusing it before a singularity can form.

In practical terms, applying MTS to Navier–Stokes suggests augmenting the NS equations with terms akin to Λ_κ and Γ_κ. Doing so would guarantee smoothness by construction. This line of reasoning offers a physically motivated argument: Nature might prohibit true finite-time singularities in fluids because any attempt to create one inevitably triggers new physics (geometric damping or stiffness) that intervenes.

6 Extension to Black Hole Interiors (Singularity Regularization)

Another domain where the MTS framework shows promise is in addressing the singularity at the core of black holes. In general relativity, classical black hole solutions contain a central singularity where curvature invariants diverge and the theory breaks down. MTS offers a novel geometric mechanism for black hole interior regularization by leveraging its dynamic curvature stiffness.

In the context of a black hole, Λ_κ can be thought of as an internal curvature pressure that opposes unlimited collapse. As curvature grows near the singularity, the **Curvature Stiffness** term $\Lambda_\kappa(t)$ correspondingly increases, acting as a repulsive term in the MTS field equation. This could manifest as a bounce or an asymptotic halt to collapse before true singularity formation. The black hole interior might then be a region of extremely high but finite curvature, supported by the MTS stiffness in a state analogous to a highly compressed but finite-density core.

Meanwhile, the **Dissipative Resistance** Γ_κ channels some of the energy from infalling matter into entropy. This continual conversion acts to remove kinetic energy, thermalizing the core.

In practical terms, the MTS framework implies that time itself is altered inside the black hole. The motion-time dimension can stretch in such a way that, from the infalling matter's perspective, reaching $r = 0$ might take an infinite amount of the internal "universal time" τ. This is a speculative but intriguing consequence of the Universal Time Relation (1) applied under extreme conditions.

7 Structure Growth and the S_8 Tension: The MBT+Echo Model

The S_8 tension measures the disagreement between the amplitude of matter density fluctuations predicted by early-universe observations (CMB by Planck) and those measured in the late universe via weak gravitational lensing. The MTS framework offers a dynamic and geometric solution to this tension via the MBT+Echo model.

7.1 The Geometric Suppression of Structure

The S_8 tension indicates that the universe's matter structure did not grow as vigorously as standard CDM predicts. MTS addresses this by modifying the growth rate (f) through two related geometric principles:

1. Reduced Gravitational Coupling: In the MTS framework, the effective strength of gravity (G_{eff}) is slightly reduced due to the continuous energy exchange with the Λ_κ field. This is analogous to introducing a dimensionless coupling factor, α, derived from the long-range geometric resistance: $\alpha \equiv 1 - \Gamma_\kappa$. This small reduction directly suppresses the growth of density perturbations δ at late times, as $\ddot{\delta} \propto \alpha G_{\text{eff}} \rho \delta$.

2. Modified Expansion Impact: The geometric acceleration term, Λ_κ, acts as a dynamically evolving counter-pressure. Its presence modifies the Hubble friction term in the growth equation, effectively reducing the overall impact of expansion on structure formation, further contributing to a suppressed S_8 value.

7.2 The Signature of Geometric Imperfection: The Echo Effect

The core of the MBT+Echo model is the unique prediction of a subtle, dampened oscillatory correction to the structure growth history. The continuous exchange of curvature information, which defines time in MTS, is not perfectly smooth; this imperfect geometric persistence manifests as an **Echo** in the growth rate $f\sigma_8(z)$. The correction to the standard growth factor, $\Delta f\sigma_8(s)$, takes the form of a damped sine wave:

$$\Delta f\sigma_8(s) = A_{\text{echo}} \exp\left(-\frac{s}{\tau}\right) \sin\left(\Omega\left(s - s_0\right)\right)$$

The existence of the Echo effect is a distinctive and testable prediction of MTS. Future high-precision surveys will be able to search for this subtle damped oscillatory signature.

7.3 Resolution of the S_8 Tension

The combined effects of the reduced effective coupling (α) and the modified expansion impact (Λ_κ) suppress the overall amplitude of the matter power spectrum at small scales, where the S_8 parameter is primarily measured. The MTS framework achieves a correlated resolution:

- H_0 Resolution: MBT-5 increases the low-redshift expansion rate via Λ_κ to meet the local H_0 value.
- S_8 Resolution: The same dynamic Λ_κ simultaneously introduces a suppression mechanism (α and Λ_κ) to curb structure growth, reconciling the early- and late-time measurements of S_8.

8 Conclusion

We have presented the **Motion-TimeSpace (MTS) framework** as a unifying geometric theory that connects cosmology with thermodynamics and offers solutions to pressing problems in both arenas. By introducing the concept of a dynamic motion-space dimension and the Universal Time Relation, MTS reframes cosmic acceleration as an entropy-driven process rather than a cosmological constant of unknown origin. Within this framework, we derived the **MBT-5 model** for cosmic expansion, which naturally incorporates a time-evolving curvature term (replacing Λ) and a dissipative factor (mimicking dark matter effects). The MBT-5 model fits observational data successfully, providing a high H_0 consistent with local measurements and statistically requiring an evolving "stiffness" of spacetime – a notable departure from ΛCDM that could resolve the Hubble tension.

For the growth of structure, the **MBT+Echo model** emerged from the same MTS principles, introducing a reduced gravitational coupling (α) and modified expansion impact (m) to resolve the S_8 tension, and predicting a subtle damped oscillatory correction – the Echo – as a signature of imperfect geometric persistence. The existence of this echo effect is a distinctive prediction of MTS that can be tested with future data, potentially serving as a critical validation of the framework.

Beyond cosmology, we explored how the geometric terms of MTS – Curvature Stiffness Λ_κ and Dissipative Resistance Γ_κ – imply deeper principles that could address unresolved issues in physics. In fluid dynamics, these terms suggest an inherent regularization mechanism that may guarantee smooth solutions for the Navier–Stokes equations by preventing unchecked cascades of energy to singular scales. In gravitational physics, they provide a plausible mechanism for avoiding black hole singularities, essentially by introducing a repulsive curvature feedback and entropy production that halt infinite collapse.

The Motion-TimeSpace framework is still in development, and many details remain to be fleshed out. For instance, a more rigorous mathematical formulation of the Universal Time Relation and a detailed derivation of the field equation from first principles (e.g. an action principle or a fundamental Lagrangian) are important next steps. On the phenomenological side, applying MTS to early-universe cosmology (inflation or alternatives) and other astrophysical phenomena (e.g. cosmic void dynamics, galaxy rotation curves without dark matter) will further test its scope and consistency. Each success of MTS in these domains would reinforce the central idea: that the evolution of the universe, the flow of time, and the production of entropy are inextricably linked through geometry.

In conclusion, Motion-TimeSpace offers a compelling new paradigm that not only addresses current cosmological tensions but also hints at a deeper unity between the laws of cosmic expansion and fundamental physics. It replaces fixed unexplained parameters with dynamic, interpretable quantities rooted in thermodynamic and geometric principles. As observational cosmology and theoretical physics advance, MTS provides a fertile ground for formulating hypotheses and driving the next generation of discoveries about the nature of time, space, and motion in our universe.