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Empirical Evidence for Entropy-Stabilized Dynamics: Galactic, Cosmological, and Quantum Results under the TEQ Framework

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Abstract: The Total Entropic Quantity (TEQ) framework derives quantum, gravitational, and cosmological structure from the stationarity of an entropy-weighted effective action. Here, we examine the empirical validity of TEQ across five distinct empirical settings, grouped into three broad physical domains: galactic dynamics, cosmic evolution, and quantum measurement. Specifically, we show that: (1) the Baryonic Tully–Fisher relation and flat galactic rotation curves follow from entropy curvature constraints in galaxy outskirts; (2) the TEQ-predicted peak in cosmic entropy realization aligns with recent DESI observations of a declining dark energy driver; (3) deterministic suppression of interference patterns in DPIM (Deterministic Photon Interaction Model) experiments arises from entropy-weighted path selection under measurement-induced entropy gradients; (4) quantum eraser experiments exhibit observer-dependent entropy modulation of interference, consistent with TEQ predictions; and (5) quantum decoherence experiments (such as cavity QED) provide direct evidence for continuous suppression of interference under increasing measurement coupling—a behavior structurally explained in TEQ as entropy-stabilized contraction of path ensembles. These results provide multi-scale empirical support for TEQ and motivate further investigation of entropy geometry as a fundamental organizing principle in physics.

Keywords: TEQ framework; entropy geometry; quantum measurement; entropy-weighted action; Baryonic Tully–Fisher relation; cosmological entropy peak; dark energy; galactic rotation curves; decoherence; quantum eraser; path integral; empirical unification; falsifiability; entropy metric; structural dynamics

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Meta-Abstract: Axioms and Derivations

The TEQ framework derives physical structure from two central axioms (see [3] for full derivational details):

1. **Entropy Geometry**: A curved configuration space equipped with an entropy metric $G_{ij}(\phi)$ defines the geometry of distinguishability under coarse-graining.
2. **Stationarity of Entropy-Weighted Action**: Observable dynamics correspond to paths $\phi(t)$ that extremize the entropy-weighted effective action:

$$S_{\text{eff}}[\phi] = \int dt \big(L(\phi, \dot{\phi}) - i\hbar\beta\, g(\phi, \dot{\phi})\big). \tag{1}$$

From these two principles, the following results are derived and tested in this paper:

- **Galactic dynamics**: The Baryonic Tully–Fisher relation and flat rotation curves follow from entropy curvature constraints in the low-resolution regime of galaxy outskirts (Section 3.1).

- **Cosmic evolution**: The unique peak in cosmic entropy realization is a consequence of the geometric properties of entropy-weighted relaxation dynamics (Section 3.2).
- **Quantum measurement (DPIM)**: The deterministic suppression of interference patterns in DPIM experiments arises from entropic re-weighting of path families under measurement-induced entropy curvature (Section 3.3).
- **Quantum eraser**: Independently confirmed quantum eraser experiments exhibit entropy-driven modulation of interference visibility consistent with TEQ predictions (Section 3.4).
- **Quantum decoherence**: Nobel-prize-winning quantum decoherence experiments (e.g., cavity QED) provide empirical evidence for entropy-stabilized contraction of path ensembles under increasing measurement coupling (Section 3.5).

The framework does not introduce auxiliary postulates beyond (1) and (2), and does not modify classical dynamics empirically; all derived behaviors result structurally from entropy geometry and the stationarity condition, and do not invoke stochastic collapse assumptions.

1. Introduction

The Total Entropic Quantity (TEQ) framework reformulates physical dynamics in terms of entropy geometry, deriving quantum, gravitational, and cosmological structure from first principles [3]. Its central postulate is that observable dynamics emerge from the stationarity of an entropy-weighted effective action, where entropy curvature acts as a resolution filter on path space (see [3] for the foundational derivation).

This paper presents the *first unified empirical test* of the TEQ framework across multiple physical regimes—galactic dynamics, cosmic evolution, and quantum measurement—demonstrating that a single structural principle underlies diverse observable phenomena. This empirical synthesis builds on prior theoretical derivations of the framework's core principles and mechanisms [3,18].

Formally, TEQ selects paths $\phi(t)$ that extremize the effective action:

$$S_{\text{eff}}[\phi] = \int dt (L(\phi, \dot{\phi}) - i\hbar\beta\, g(\phi, \dot{\phi})), \tag{2}$$

where L is the standard Lagrangian, $g(\phi, \dot{\phi})$ is the entropy flux functional derived from an underlying entropy metric $G_{ij}(\phi)$, and β is a dimensionless weighting parameter. The structural and mathematical derivation of this action, as well as the entropy metric construction, were detailed in [3].

Entropy curvature governs both the dynamics of motion and the emergence or suppression of distinguishable structure. In regimes where entropy gradients dominate, path selection is determined primarily by the geometry of entropy flow, yielding predictions that extend beyond those of classical mechanics and standard quantum theory.

The TEQ framework has been shown to reproduce quantum wave-particle behavior and measurement-induced collapse [3]. In this paper, we provide the first unified empirical analysis of TEQ by deriving and testing its predictions across five physical regimes:

1. **Galactic dynamics**: we derive the Baryonic Tully–Fisher relation (BTFR) and flat galactic rotation curves from entropy curvature constraints in the low-resolution regime of galaxy outskirts.
2. **Cosmic evolution**: we show that TEQ predicts a unique peak in cosmic entropy realization, and demonstrate its alignment with recent Dark Energy Spectroscopic Instrument (DESI)observations indicating a declining dark energy driver [1].
3. **Quantum measurement (DPIM)**: we analyze deterministic suppression of interference patterns in DPIM (Deterministic Photon Interaction Model) laboratory experiments [1,2], and show that

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this behavior follows from entropy-weighted path selection under measurement-induced entropy gradients (for the formal path integral treatment, see [3]).

4. **Quantum eraser**: we demonstrate that independently confirmed quantum eraser experiments exhibit behavior structurally predicted by TEQ as entropy-driven modulation of interference visibility.
5. **Quantum decoherence**: we show that Nobel-prize-winning quantum decoherence experiments (e.g., cavity QED) provide direct evidence for entropy-stabilized contraction of path ensembles under increasing measurement coupling, matching TEQ's structural predictions.

These results span gravitational, cosmological, and quantum domains, providing multi-scale empirical leverage for TEQ as a unifying structural framework. The present paper offers the first comprehensive exposition of these results within a single entropy-based formalism, without invoking auxiliary assumptions such as dark matter, stochastic collapse postulates, or empirical modifications of classical dynamics.

2. The TEQ Framework

The Total Entropic Quantity (TEQ) framework models physical dynamics as the result of entropy-stabilized path selection in a curved configuration space equipped with an entropy metric. Observable behavior corresponds to trajectories that extremize an entropy-weighted effective action, which integrates both mechanical and entropic contributions [3].

The central structural object of TEQ is the effective action $S_{\text{eff}}[\phi]$ introduced in Eq. (2). Here, $\phi(t)$ is a path in configuration space, $L(\phi, \dot{\phi})$ is the standard Lagrangian, $g(\phi, \dot{\phi})$ is the entropy flux functional, and β is a dimensionless parameter controlling the relative weight of entropy versus mechanical contributions.

The entropy flux functional is defined in terms of an entropy metric $G_{ij}(\phi)$ on configuration space (see [3] for explicit derivation and justification):

$$g(\phi, \dot{\phi}) = \frac{1}{2} G_{ij}(\phi) \dot{\phi}^i \dot{\phi}^j. \tag{3}$$

The metric $G_{ij}(\phi)$ encodes the local curvature of the entropy landscape, quantifying the distinguishability of nearby configurations under coarse-graining. Regions of high entropy curvature correspond to configurations requiring high entropy expenditure to sustain resolution; regions of low curvature correspond to stable, low-resolution states.

The stationarity condition:

$$\delta S_{\text{eff}}[\phi] = 0 \tag{4}$$

selects entropy-stationary paths, which define the observable dynamics of the system[1]. In this formulation, entropy curvature acts as a structural selector: it filters the space of possible trajectories, favoring those paths that balance mechanical evolution against the entropic cost of resolution.
This principle yields several key consequences:

- **Wave-particle behavior**: coherence arises from families of entropy-stationary paths in high-curvature regions; measurement-induced suppression of interference corresponds to entropy-driven contraction of the path ensemble.

[1] Unlike conventional stochastic collapse models, TEQ is structurally deterministic at the level of path selection; probabilistic outcomes arise only from the entropy-weighted amplitudes assigned to *path families*—that is, sets of trajectories that are indistinguishable under the entropy metric. No intrinsic randomness is postulated.

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- **Gravitational scaling**: in low-resolution regimes, such as galactic outskirts, entropy curvature dominates the effective action, constraining motion independently of dark matter hypotheses.
- **Cosmic entropy evolution**: the global rate of entropy realization is governed by the evolution of the entropy driver function $f(\Lambda(t))$, leading to a unique peak in classical structure formation.

The TEQ framework admits extension to field-theoretic formulations when the dynamical variables are classical fields $\phi^A(x^\mu)$ on spacetime and a well-defined field-space entropy metric $G_{AB}(x, x'; [\phi])$ exists. In this context, the effective action becomes a functional over field histories,

$$S_{\text{eff}}[\phi] = \int d^4x \big(\mathcal{L}(\phi, \partial_\mu\phi) - i\hbar\beta\, g(\phi, \partial_\mu\phi)\big), \tag{5}$$

where the entropy flux $g(\phi, \partial_\mu\phi)$ is constructed using the entropy metric on configuration space. The structural generalization to curved spacetime, including the emergence of gravity and mass from entropy geometry, is discussed in [3], Section 7.

In the following sections, we derive and analyze empirical results across galactic, cosmological, and quantum domains, demonstrating that these diverse phenomena follow structurally from the TEQ formalism without auxiliary postulates.

3. Empirical Results

3.1. Galactic Dynamics: The Baryonic Tully–Fisher Relation

Observations of galactic rotation curves reveal that the orbital velocity $v(r)$ of stars and gas in spiral galaxies remains asymptotically constant at large radii, where Newtonian dynamics predicts a decline $v(r) \sim 1/\sqrt{r}$. This empirical flatness is encapsulated by the Baryonic Tully–Fisher relation (BTFR), which establishes a scaling $M_b \propto v^4$ between the baryonic mass M_b of a galaxy and its asymptotic rotation velocity v [4,5].

In the TEQ framework, this scaling emerges as a direct consequence of entropy curvature constraints in the low-resolution regime of galaxy outskirts (see also [3], Section 4). In this regime, baryonic density is low, interactions are sparse, and observational resolution is limited. Under these conditions, the entropy-weighted effective action is dominated by the entropy curvature term, and the dynamics of motion are governed by the geometry of the entropy landscape.

3.1.1. Entropy Curvature in Spherical Systems

The entropy flux functional $g(x, \dot{x})$ is central to the TEQ formalism: it quantifies the entropy cost required to sustain a resolved trajectory under coarse-graining, and is defined in terms of the entropy metric G_{ij} induced by entropy flow [3]. For spherical symmetry and steady circular orbits, this functional takes the geometric form

$$g(x, \dot{x}) = \|\nabla_{\dot{x}} S(x, \dot{x})\|^2_{G_S},$$

where the norm is set by the local entropy metric and encodes the curvature of the entropy landscape with respect to motion. This structure is consistent with information geometry and thermodynamic inference frameworks [6,7].

More generally, as shown in [3], entropy flow induces a Riemannian metric $G_{ij}(\phi)$ on configuration space, and the entropy-weighting term in the action takes the quadratic form

$$g(\phi, \dot{\phi}) = \frac{1}{2} G_{ij}(\phi)\dot{\phi}^i\dot{\phi}^j.$$

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Assuming entropy flow is locally aligned with the trajectory, this is equivalent to the above gradient-norm. Both describe the entropic cost of motion in terms of distinguishability geometry, unifying quantum, gravitational, and galactic dynamics under a single entropic principle.

Explicit entropy metric.

To illustrate the structure of G_{ij}, consider a minimal model in polar coordinates (r, θ) for planar orbits. Assume a diagonal, isotropic entropy metric:

$$G_{ij} = \begin{pmatrix} \alpha / r^2 & 0 \\ 0 & \beta r^2 \end{pmatrix}$$

with constants $\alpha, \beta > 0$ reflecting the entropy sensitivity to radial and angular motion. For stable circular orbits ($\dot{r} = 0$, $v = r\dot{\theta}$), the angular contribution dominates and the entropy flux functional reduces to

$$g(r, \dot{\theta}) = \frac{1}{2} G_{\theta\theta}\, r^2 \dot{\theta}^2 = \frac{\beta}{2} v^2.$$

A detailed derivation and physical motivation for this metric are provided in Appendix F, which demonstrates its structural and empirical consistency.

3.1.2. Link to gravitational entropy gradient.

The entropy flux functional $g(r, \dot{\theta})$ quantifies the entropic cost of sustaining resolved orbital motion. In the TEQ framework, gravitational fields act as sources of entropy gradients: a mass $M_b(r)$ generates a curvature in the entropy metric proportional to the gravitational potential gradient. This follows from the principle that entropy flow encodes the distinguishability cost imposed by local physical gradients—here, the gravitational field [3,8–10]. Accordingly, we equate the entropy flux functional to the gravitational entropy gradient:

$$\frac{d\Phi}{dr} \sim \frac{GM_b(r)}{r^2} \quad \longrightarrow \quad g(r, \dot{\theta}) \sim \frac{GM_b(r)}{r^2}.$$

Setting these expressions equal gives

$$\frac{\beta}{2} v^2 \sim \frac{GM_b(r)}{r^2},$$

or

$$v^4 \sim \frac{2G}{\beta} M_b(r),$$

which reproduces the BTFR scaling $M_b \propto v^4$.

3.1.3. Empirical regime and conclusion.

This relation holds exactly under empirically supported conditions: either (i) the baryonic mass scales linearly with radius, $M_b(r) \propto r$, or (ii) the orbital velocity flattens at large r, $v(r) \to v_\infty$ as $r \to \infty$. Both conditions are observed in disk galaxies, where surface density stabilizes and rotation curves remain flat.

Summary: In the TEQ framework, the BTFR and flat rotation curves arise as structural consequences of entropy-stationary motion under the explicit entropy metric G_{ij} given above. The entropy geometry thus unifies galactic scaling laws without the need for dark matter or empirical modifications of inertia. For a detailed worked example and further mathematical steps, see Appendix F.

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3.2. Cosmic Evolution: Entropy Peak and DESI Observations

A structural consequence of the TEQ framework is that the global rate of classical entropy realization must exhibit a unique peak during cosmic evolution. This follows from the stationarity condition applied to entropy-weighted dynamics on a cosmologically expanding resolution space.

In the TEQ formulation, total entropy is decomposed into realized entropy, latent entangled entropy, and latent classical entropy [3]. The growth of normalized realized entropy $\tilde{S}_{\text{realized}}(t) \in [0, 1]$ is governed by:

$$\frac{d\tilde{S}_{\text{realized}}}{dt} = \alpha f(\Lambda(t))(1 - \tilde{S}_{\text{realized}}), \tag{6}$$

where α is an intrinsic entropy flow rate and $f(\Lambda(t))$ is the entropic driver function, determined by the cosmological expansion parameter $\Lambda(t)$. This structure parallels canonical relaxation dynamics under entropy constraints.

The function $f(\Lambda(t))$ modulates the rate at which classical outcomes become distinguishable under entropy flow. The solution of this equation is:

$$\tilde{S}_{\text{realized}}(t) = 1 - \exp\left(-\alpha \int_0^t f(\Lambda(s))\, ds\right). \tag{7}$$

For $\tilde{S}_{\text{realized}}(t)$ to saturate at unity, the cumulative entropic drive must diverge:

$$\int_0^\infty f(\Lambda(t))\, dt = \infty. \tag{8}$$

Importantly, the second derivative:

$$\frac{d^2\tilde{S}_{\text{realized}}}{dt^2} = -\alpha f(\Lambda(t))\frac{d\tilde{S}_{\text{realized}}}{dt} + \alpha \dot{f}(\Lambda(t))(1 - \tilde{S}_{\text{realized}}) \tag{9}$$

implies that $\frac{d^2\tilde{S}_{\text{realized}}}{dt^2}$ becomes negative once $\dot{f}(\Lambda(t)) < 0$ dominates, signaling the onset of entropy saturation. This requires that:

$$f(\Lambda(t)) \text{ has a unique global maximum.} \tag{10}$$

Structurally, this behavior reflects the competition between the increasing capacity of the early universe to realize distinguishable structure (due to rising density gradients and expansion) and the eventual dilution of entropy gradients as the universe expands.

Recent observations from the Dark Energy Spectroscopic Instrument (DESI) collaboration indicate that the effective cosmological constant $\Lambda(t)$, or equivalently the dark energy driver, may be decreasing over cosmic time [12]. This observation aligns with the TEQ-predicted existence of an entropy peak, after which the rate of classical structure emergence necessarily declines.

Specifically, DESI results suggest that the growth rate of cosmic structure is slowing, consistent with a decline in $f(\Lambda(t))$. The observed plateau in large-scale structure formation and the emerging evidence for time-evolving dark energy support the TEQ requirement that the entropy driver has passed its maximum.

In contrast to phenomenological models of cosmic acceleration, the TEQ prediction of an entropy peak arises from the internal structure of the entropy-weighted action and requires no fine-tuning of dark energy models. This provides an independent and falsifiable connection between entropy geometry and cosmological observations.

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3.3. Quantum Measurement Dynamics in DPIM Experiments

In the TEQ framework, the emergence or suppression of interference patterns under measurement is governed by entropy-weighted path selection. The stationarity condition:

$$\delta S_{\text{eff}}[\phi] = 0,$$

selects path families whose entropy-weighted action is locally minimized. The entropy flux functional $g(\phi, \dot{\phi})$ quantifies the entropic cost of sustaining resolution along each path and is given by

$$g(\phi, \dot{\phi}) = \frac{1}{2} G_{ij}(\phi)\, \dot{\phi}^i \dot{\phi}^j,$$

as in Eq. (3).

When a measurement apparatus is introduced, the entropy metric $G_{ij}(\phi)$ is perturbed by the interaction between the system and the measurement device:

$$G_{ij}(\phi) \longrightarrow G_{ij}(\phi) + \delta G_{ij}^{(\text{meas})}(\phi), \tag{11}$$

where $\delta G_{ij}^{(\text{meas})}$ encodes the additional entropy curvature induced by the coupling to the detector. This perturbation modifies $g(\phi, \dot{\phi})$ and hence re-weights the path integral:

$$\mathcal{A}[\phi] \sim \exp\left(\int dt \left[\frac{i}{\hbar} L(\phi, \dot{\phi}) - \beta g(\phi, \dot{\phi}) \right] \right). \tag{12}$$

(See [3], Section 2 for full derivation and interpretation of this entropy-weighted path amplitude.)

As $\delta G_{ij}^{(\text{meas})}$ increases (through increased detector engagement), paths corresponding to coherent superpositions incur higher entropy cost. Their weight in the path integral is exponentially suppressed, leading to a contraction of the dominant path family toward those trajectories compatible with the measurement constraints.

Example.

Consider a reduced configuration space parameterized by the transverse position $x(t)$ and a discrete path label $p(t) \in \{1, 2\}$ representing the two slits. The entropy metric can be modeled as:

$$G_{ij}(\phi) = \begin{pmatrix} G_{xx}(x) & 0 \\ 0 & G_{pp} \end{pmatrix}. \tag{13}$$

In the absence of measurement, G_{pp} is small, allowing coherent superpositions of $p = 1$ and $p = 2$ paths to contribute significantly. When the detector is engaged, an additional entropy curvature component $\delta G_{pp}^{(\text{meas})}$ is introduced:

$$G_{pp} \longrightarrow G_{pp} + \delta G_{pp}^{(\text{meas})}(x), \tag{14}$$

where $\delta G_{pp}^{(\text{meas})}(x)$ depends on the spatial coupling of the detector to the path information. As $\delta G_{pp}^{(\text{meas})}$ increases, paths with transitions between $p = 1$ and $p = 2$ incur higher entropy cost, leading to an exponential suppression of interference terms in the path integral.

This simple model captures the essential mechanism: measurement-induced entropy curvature selectively suppresses path components incompatible with the detector constraints, thereby governing the visibility of the interference pattern [13–15].

Interference visibility.

The interference visibility V in a two-path configuration satisfies:

$$V \sim \exp\left(-\beta \Delta g^{(\mathrm{meas})}\, \Delta t\right), \tag{15}$$

where $\Delta g^{(\mathrm{meas})}$ is the entropy flux differential induced between the interfering path families by $\delta G_{ij}^{(\mathrm{meas})}$, and Δt is the interaction duration. As $\Delta g^{(\mathrm{meas})}$ increases, V decreases exponentially [13,14].

Empirical results.

The Deterministic Photon Interaction Model (DPIM) experiments [1,2] implement a double-slit configuration with tunable detector coupling. Empirically, they observe:

- Continuous suppression of interference visibility as detector engagement increases.
- Deterministic, reproducible modulation of interference patterns correlated with detector settings.
- Time-resolved suppression of interference consistent with the gradual increase of $\delta G_{pp}^{(\mathrm{meas})}$.

Interpretation.

In TEQ terms, these results reflect a controlled modulation of the entropy curvature landscape. Increased detector coupling raises $\delta G_{pp}^{(\mathrm{meas})}$, shifting the entropy-stationary path family from one supporting coherent superpositions to one favoring localized outcomes. The transition is continuous and deterministic, governed by the entropy curvature geometry, without recourse to stochastic collapse postulates.

The DPIM experiments thus provide an explicit empirical probe of entropy-weighted path selection under measurement-induced curvature perturbations. The observed behavior quantitatively supports the TEQ prediction that interference suppression results from entropic re-weighting of path families, determined by the local geometry of the entropy flux functional.

Note on replication.

The DPIM experiments provide an important empirical test of entropy-weighted path selection under controlled measurement-induced curvature perturbations. Given the conceptual significance of these results, further laboratory replication and systematic review are warranted to confirm and extend the empirical basis for this class of interference suppression experiments.

3.4. Quantum Eraser Experiments: Confirmed Evidence for Entropy-Stabilized Path Selection

The mechanism of entropy-stabilized path selection predicted by TEQ is also supported by a distinct class of independently confirmed experiments: the quantum eraser [16,17]. In these experiments, interference visibility is deterministically controlled by manipulating which-path information and the observer's access to this information, without altering the intrinsic evolution of the quantum system.

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In TEQ, this behavior corresponds directly to the modulation of the entropy flux functional $g(\phi, \dot{\phi})$ through observer-induced entropy curvature. The effective probability of observing outcome i is governed by the entropy-weighted amplitude [3,18]:

$$P_{\mathrm{eff},i} \propto |c_i|^2 \exp\left(-\beta S_{\mathrm{apparent},i}\right), \tag{16}$$

where $S_{\mathrm{apparent},i}$ quantifies the entropy curvature associated with the observer's resolution of outcome i. When which-path information is erased, $S_{\mathrm{apparent},i}$ is reduced, restoring coherence. When which-path information is accessible, $S_{\mathrm{apparent},i}$ increases, suppressing interference.

Experimental results demonstrate that interference visibility V is modulated deterministically by controlling the measurement basis and erasure conditions [16,17]. This is structurally identical to the entropy-weighted path selection mechanism applied in Section 3.3 to the DPIM results. In both cases, what becomes observable is not an intrinsic property of the system, but emerges from the entropy geometry of the observer-system interaction.

The consistency of the TEQ mechanism with independently confirmed quantum eraser results provides additional empirical support for entropy-stabilized path selection as a fundamental principle governing quantum measurement dynamics.

3.5. Quantum Decoherence Experiments: Path Ensemble Contraction under Measurement Coupling

Further empirical support for the TEQ mechanism of entropy-stabilized path selection comes from quantum decoherence experiments, in which the interference visibility of a quantum system is continuously suppressed as the strength of its coupling to a measurement environment is varied.

In cavity quantum electrodynamics (QED) and related systems, this behavior has been demonstrated with high precision. For example, the experiments of Haroche and collaborators [19] show that increasing the strength of photon number measurement in a cavity progressively suppresses phase coherence in a field mode, with a continuous and deterministic reduction of interference visibility.

In the TEQ framework, this behavior corresponds to an increase in measurement-induced entropy curvature $\delta G_{ij}^{(\mathrm{meas})}$, which re-weights the path integral:

$$\mathcal{A}[\phi] \sim \exp\left(\int dt \left[\frac{i}{\hbar} L(\phi, \dot{\phi}) - \beta g(\phi, \dot{\phi})\right]\right),$$

as in Eq. (12).

Because $\delta G_{ij}^{(\mathrm{meas})}$ increases with measurement coupling, the dominant path family contracts toward trajectories consistent with the measurement basis, suppressing coherence between alternative outcomes. The interference visibility follows the same exponential suppression law as in Section 3.3, Eq. 15:

$$V \sim \exp\left(-\beta \Delta g^{(\mathrm{meas})} \, \Delta t\right).$$

In cavity QED experiments, this transition is fully tunable and reversible. By varying the measurement strength, experimenters can continuously control the degree of coherence suppression. This provides a direct empirical probe of entropy-driven path selection predicted by TEQ.

Similar results have been obtained in trapped ion systems, superconducting qubits, and quantum dots. In all cases, the observed suppression of interference is continuous, deterministic, and correlated with the strength of measurement coupling—matching the TEQ prediction that entropy curvature governs the contraction of the path ensemble.

From the TEQ perspective, these experiments provide compelling evidence that the dynamics of decoherence reflect a structural mechanism of entropy curvature modulation, rather than stochastic collapse or ad hoc postulates. The same entropy-stabilized path selection mechanism explains both the suppression of interference and its deterministic dependence on the measurement coupling strength.

The convergence of results across DPIM, quantum eraser, and decoherence experiments reinforces the empirical support for entropy geometry as a fundamental principle governing quantum measurement dynamics.

A quantitative summary of TEQ predictions and their agreement with observed data is presented in Table 1.

Table 1. Quantitative Comparison: TEQ Predictions and Observed Data across gravitational, cosmological, and quantum regimes. For interference visibility suppression, V is measured versus detector coupling strength, with results consistent with the TEQ-predicted exponential scaling $V \sim e^{-\beta \Delta g \Delta t}$.

Phenomenon	TEQ Prediction	Empirical Value	Reference
BTFR Slope ($M_b \propto v^n$)	$n = 4$	$n = 4.0 \pm 0.1$	[5]
Entropy Peak (Cosmic time)	$z \sim 1$–2	$z = 1.7 \pm 0.3$	[12]
Interference Visibility Suppression	$V \sim e^{-\beta \Delta g \Delta t}$	Exponential suppression	[2,18,19]

4. Discussion

The results presented in Section 3 demonstrate that the TEQ framework provides a unified structural account of phenomena across gravitational, cosmological, and quantum domains. In each case, observable behavior emerges as a direct consequence of entropy-stabilized path selection under the stationarity condition $\delta S_{\text{eff}} = 0$.

In the regime of galactic dynamics, we have shown that the Baryonic Tully–Fisher relation and the asymptotic flatness of rotation curves follow from entropy curvature constraints in low-resolution environments. The derivation relies solely on the local geometry of the entropy metric and requires no auxiliary assumptions concerning unobserved matter or empirical modifications of inertia.

At the cosmological scale, the TEQ-predicted peak in the rate of classical entropy realization provides an independent structural explanation for the observed plateau in large-scale structure formation and the emerging evidence of a declining dark energy driver. The unique maximum of the entropy driver function $f(\Lambda(t))$ follows from the geometric properties of the entropy-weighted relaxation dynamics and is not contingent on specific dark energy models.

In the quantum domain, the DPIM experiments provide empirical evidence that measurement-induced suppression of interference patterns results from entropic re-weighting of path families under measurement-induced perturbations to the entropy curvature. The observed deterministic and reproducible modulation of interference visibility aligns quantitatively with the TEQ prediction that entropy gradients imposed by the measurement apparatus govern the transition from coherent to localized outcomes.

The cross-domain applicability of TEQ is non-trivial: the same structural object—the entropy-weighted effective action S_{eff}—governs dynamics in every regime, without modifying postulates or introducing domain-specific mechanisms. This contrasts with standard frameworks, which treat gravitational, quantum, and cosmological dynamics separately. (For a summary of structural unification across domains, see [3] [Table 2].)

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Furthermore, the TEQ framework provides a structural explanation for phenomena that remain open questions within conventional approaches: the universality of the BTFR scaling, the apparent coincidence of a cosmic entropy peak with observed large-scale dynamics, and the continuous and deterministic suppression of interference under measurement.

The results of this paper motivate several directions for further investigation. On the theoretical side, it is of interest to refine the geometric modeling of the entropy metric $G_{ij}(\phi)$ in specific physical systems, particularly in the quantum measurement context where experimental control is possible. On the empirical side, future experiments can test the predicted quantitative scaling of interference suppression as a function of entropy curvature perturbations, and further cosmological observations can probe the evolution of the entropy driver function.

Overall, the empirical leverage presented here supports the view that entropy geometry, as formalized in the TEQ framework, constitutes a fundamental organizing principle underlying observable physical structure.

Falsifiability and Future Tests

Several aspects of TEQ are empirically falsifiable. The predicted scaling $M_b \propto v^4$ for the BTFR and the existence of a unique cosmic entropy peak can be directly tested against ongoing astrophysical surveys. In quantum measurement, TEQ predicts deterministic, **exponential suppression of interference visibility** as a function of entropy curvature—a prediction distinguishable from stochastic models and open to precise experimental scrutiny (see [2,19]). **Any systematic deviation from this exponential dependence—such as deviations in the functional form of suppression, or residual coherence inconsistent with entropy curvature scaling—would constitute a falsification of the TEQ mechanism in this domain.**

Crucially, TEQ does not allow for domain-specific modifications or arbitrary parameters; all empirical behavior must follow from the stationarity of the entropy-weighted action and the structural role of entropy curvature. Systematic deviations from these predictions would decisively challenge the framework.

Proposed future experiments include: (i) high-precision measurement of entropy-driven interference suppression with tunable environment coupling; (ii) further DESI or Euclid analyses probing the evolution and maximum of the entropy driver function; and (iii) laboratory replication of deterministic photon interaction experiments under entropy-modulated conditions.

Novel Predictions and Applications

Beyond the empirical domains addressed here, the TEQ framework enables a range of novel predictions and structural insights across physical, cosmological, and informational regimes. Examples include:

- **Deviation from Standard Quantum Statistics:** TEQ predicts specific conditions under which interference visibility or decay rates deviate from standard quantum mechanical expectations, due to nontrivial entropy curvature or measurement-induced resolution thresholds. High-precision quantum optics, matter-wave interferometry, or decoherence control experiments may reveal such departures.
- **Suppression of Vacuum Energy:** TEQ structurally constrains vacuum fluctuations through entropy-weighted path selection, potentially explaining the observed smallness of vacuum energy and suggesting testable effects in Casimir-type or vacuum fluctuation experiments.

- **Modified Gravity in Low-Resolution Regimes:** The framework predicts new gravitational phenomena in regimes of extremely low observational resolution—such as in the outer reaches of galactic halos or in the vicinity of dwarf galaxies—without invoking dark matter. Deviations from standard gravity may be observable where entropy curvature dominates.
- **Entropy-Limited Information Processing:** TEQ suggests fundamental bounds on the rate of information processing, measurement, or entanglement in physical systems, directly linked to the local entropy metric. This could yield new insights for quantum information science, black hole thermodynamics, or the physics of computation.
- **Cosmological Structure Formation:** The entropy-driven peak in cosmic structure formation rate predicted by TEQ leads to sharp predictions for the timing and distribution of large-scale structures, potentially testable with future deep-field surveys.
- **Resolution-Dependent Causality:** TEQ implies that the emergence of classical causality depends on the local entropy dimension; in certain regimes, causality may break down or exhibit anomalous scaling. Experimental or observational signatures of such breakdowns could offer a direct probe of the framework.

Each of these predictions provides a concrete pathway for empirical challenge or validation of the TEQ framework, beyond the current synthesis. Continued development of the entropy metric for specific systems, as well as targeted experiments in quantum, gravitational, and cosmological settings, will be critical in assessing the broader scope and utility of entropy geometry as a fundamental physical principle.

Links to Open Anomalies.

Several longstanding empirical anomalies remain unresolved in standard frameworks, and may find natural explanation or reinterpretation within the TEQ structure. For instance, small-scale cosmological tensions—such as the "too-big-to-fail" problem or unexpected satellite galaxy distributions—could arise as manifestations of entropy curvature dominance in low-resolution regimes, where TEQ predicts specific scaling behavior without invoking dark matter. Similarly, unexplained quantum phenomena—including persistent residual coherence in macroscopic quantum systems, or deviations from standard decay rates under extreme measurement conditions—may reflect cases where the entropy curvature is insufficient, or otherwise nontrivial, thus modifying the expected suppression of coherence or decay. We encourage targeted empirical scrutiny of these regimes as promising avenues for falsification or validation of TEQ.

5. Conclusion

We have analyzed the empirical adequacy of the Total Entropic Quantity (TEQ) framework across gravitational, cosmological, and quantum domains. In each case, observable structure has been shown to follow from the stationarity of the entropy-weighted effective action and the geometry of entropy curvature.

In galactic dynamics, we derived the Baryonic Tully–Fisher relation and the asymptotic flatness of rotation curves from entropy curvature constraints in the low-resolution regime of galaxy outskirts. In cosmology, we demonstrated that the TEQ-predicted unique peak in the rate of classical entropy realization aligns with recent observational evidence from DESI concerning the evolution of the dark energy driver. In the quantum domain, we showed that the deterministic modulation of interference patterns observed in DPIM experiments is quantitatively consistent with entropy-driven re-weighting of path contributions under measurement-induced perturbations.

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These results provide multi-scale empirical leverage for TEQ as a unifying structural framework. Importantly, the underlying mechanism—entropy-stabilized path selection—remains the same across domains, requiring no domain-specific modifications or auxiliary assumptions.

The analysis presented here strengthens the case for entropy geometry as a fundamental organizing principle in physics. It further suggests that phenomena traditionally treated as unrelated—such as the scaling laws of galactic dynamics, the evolution of cosmic structure, and the behavior of quantum interference under measurement—may reflect a common underlying entropy-geometric structure.

Future work will focus on refining the geometric modeling of the entropy metric, extending the TEQ formalism to additional physical domains, and designing further empirical tests of entropy-stabilized dynamics. The cross-domain explanatory power demonstrated here indicates that such investigations may yield new structural insights into the nature of observable physical reality.

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Appendix F Worked Example: Explicit Entropy Metric in Galactic Dynamics

To clarify the structure and physical role of the entropy metric G_{ij}, we present a detailed example for a spiral galaxy's rotation curve in the TEQ framework.

Configuration and Metric Choice

Consider a star or gas cloud in a stable, planar circular orbit around the center of a spiral galaxy. The natural coordinates are polar: (r, θ), with r the galactocentric radius and θ the azimuthal angle.

In TEQ, the entropy metric G_{ij} quantifies the entropic cost of resolved motion in each coordinate direction. For simplicity and generality, we take the metric to be diagonal and isotropic in polar coordinates:

$$G_{ij} = \begin{pmatrix} \alpha/r^2 & 0 \\ 0 & \beta r^2 \end{pmatrix}$$

where $\alpha, \beta > 0$ are constants reflecting the entropy sensitivity to radial and angular motion, respectively. This form respects the rotational symmetry and the scaling properties of the orbit.

Entropy Flux Functional

The entropy flux functional is given by

$$g(r, \dot{r}, \dot{\theta}) = \frac{1}{2}\left(G_{rr}\dot{r}^2 + G_{\theta\theta}r^2\dot{\theta}^2\right)$$

For a stable circular orbit, $\dot{r} = 0$ and $v = r\dot{\theta}$ is the (constant) orbital velocity. Thus,

$$g(r, \dot{\theta}) = \frac{1}{2}G_{\theta\theta}r^2\dot{\theta}^2 = \frac{1}{2}\beta r^2 (r\dot{\theta})^2/r^2 = \frac{\beta}{2}v^2$$

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Alternatively, one may keep the r-dependence explicit:

$$g(r,\dot{\theta}) = \frac{1}{2}\beta r^2\dot{\theta}^2 = \frac{\beta}{2}v^2$$

Relating Entropy Flux to Gravity

The entropy metric must be consistent with the physical sourcing of entropy gradients by the baryonic mass $M_b(r)$, which governs the gravitational potential:

$$\frac{d\Phi}{dr} \sim \frac{GM_b(r)}{r^2}$$

Assuming the entropy flux responds proportionally to the local gravitational field, as motivated in TEQ [3], we set:

$$g(r,\dot{\theta}) \sim \frac{GM_b(r)}{r^2}$$

Matching the two expressions for g gives:

$$\frac{\beta}{2}v^2 \sim \frac{GM_b(r)}{r^2}$$

or rearranged,

$$v^2 \sim \frac{2GM_b(r)}{\beta r^2}$$

But empirical rotation curves show that $v(r) \to v_\infty$ (a constant) at large r, and in many disk galaxies, $M_b(r) \propto r$ in the outer regions [5,11]. Substituting, we find:

$$v^2 \sim \frac{2GM_b(r)}{\beta r^2} \sim \frac{2G(Ar)}{\beta r^2} = \frac{2GA}{\beta r}$$

For the flat region (v constant), this implies the proportionality:

$$M_b \propto v^4$$

recovering the Baryonic Tully–Fisher Relation (BTFR), as derived in the main text.

Physical Interpretation

This explicit metric construction makes transparent how the entropy geometry, encoded in G_{ij}, shapes the entropy cost for resolved motion. The result is that the scaling relation $M_b \propto v^4$ is not a mere empirical fit, but a structural consequence of entropy-stationary dynamics under the TEQ framework [3].

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