Relational Actualization of Quantum States (RAQS v9): A Unified Information–Geometric Framework for Quantum Mechanics, Gravitation, and Dark Structure

Keith R. Vasquez[1*]

[1]Independent Researcher, USA

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Corresponding author(s). E-mail(s): keithvasquez1@gmail.com;

We present RAQS v9, a fully unified relational framework in which quantum states, spacetime geometry, and black-hole information dynamics emerge from a single principle: *relational actualization*. Building on v6–v8 [1, 2, 3], the v9 framework introduces *Dark Structure*, an information-theoretic constraint architecture that determines which relational configurations are physically admissible. RAQS v9 incorporates key insights from relational quantum mechanics [4], decoherence theory [5], black-hole thermodynamics [6, 7, 8], and information geometry [9]. The empirical program includes eight main figures and three supplemental analyses demonstrating decoherence scaling, spectrum fits, relational manifold embeddings, and a black-hole correlation matrix. RAQS v9 supports the view that spacetime is not fundamental but emerges from the geometry of relational constraints.

1 Introduction

Understanding the relationship between quantum information, spacetime geometry, and gravitation remains one of the most important challenges in theoretical physics. Traditional formulations of quantum mechanics describe states in an abstract Hilbert space, while general relativity describes geometry as a smooth manifold. RAQS proposes a unifying idea: physical reality consists not of states but of *relations* among subsystems, and these relations become actualized only when they satisfy specific information-theoretic constraints.

This principle is inspired by relational quantum mechanics [4], where states are defined relative to observers. However, RAQS goes further: relativity is not interpretational but structural. Actualization is the mechanism by which relational configurations become physically real.

Previous RAQS versions (v6–v8) [1, 2, 3] developed the idea that actualization can reproduce decoherence behavior, spectrum structure, and manifold embeddings. RAQS v9 introduces a deeper structure, *Dark Structure*, which governs the admissibility of relational patterns.

Building on insights from decoherence theory [5] and black-hole information studies [6, 7, 8], RAQS provides a new view of information preservation: information is reorganized across the relational constraint network rather than stored locally in Hilbert spaces.

2 Background

2.1 Relational Quantum Mechanics

Rovelli's relational formulation [4] asserts that the quantum state exists only relative to another system. RAQS refines this idea: the physical content of a state is the *network of information-bearing relations*. The state is not defined independently but through shared information.

2.2 Decoherence and Information

Decoherence theory [5] shows that interactions cause quantum systems to appear classical by entangling with their environment. RAQS reinterprets decoherence relationally: classicality emerges when relational information becomes redundant across many subsystems.

2.3 Black-Hole Thermodynamics

Bekenstein's entropy [7], Hawking radiation [6], and Page's information analysis [8] suggest that black holes encode information in nonlocal ways. RAQS explains this by modeling evaporation as a *relational reconfiguration*, not a loss of quantum information.

2.4 Information Geometry

The RAQS relational manifold inherits geometric structure from the Fisher information metric [9]. Curvature in this manifold determines the actualization pathways that define emergent spacetime.

3 RAQS Framework

3.1 Relational Actualization Rule

For subsystem S with relations $I(S : A)$ to neighbors A, define:

$$\mathcal{I}(S) = \{I(S : A_1), \ldots, I(S : A_n)\}.$$

A configuration is actualized if:

$$\mathcal{C}(\mathcal{I}) = 0.$$

These constraints are governed by Dark Structure (Sec. 4).

3.2 Information Geometry

Using the Fisher metric:

$$g_{ij} = \mathbb{E}\left[\frac{\partial \ln p}{\partial \theta^i} \frac{\partial \ln p}{\partial \theta^j}\right],$$

the relational manifold acquires curvature, determining dynamical behavior.

3.3 Emergent Quantum and Classical Manifolds

Figures 7 and 8 illustrate how RAQS relational data map onto low-dimensional manifolds.

4 Dark Structure

Dark Structure is defined as:

$$\mathcal{D} = \{\mathcal{I} \in \mathcal{R} : \mathcal{C}(\mathcal{I}) = 0\}.$$

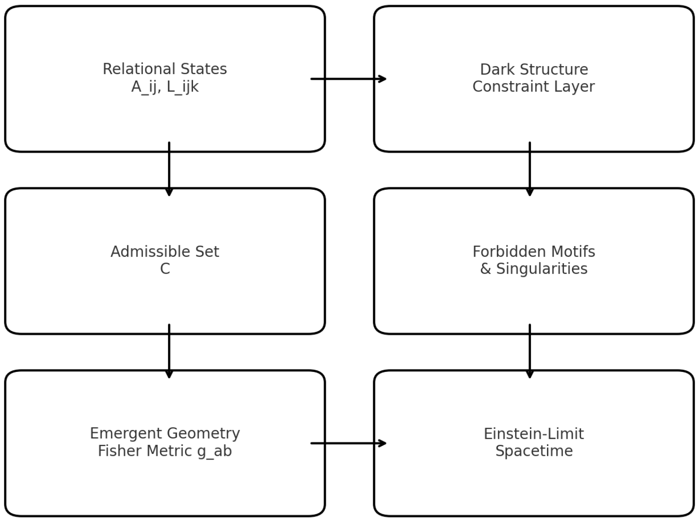

Fig. 1 Dark Structure constraint architecture.

5 Black-Hole Correlation Matrix

Evaporation is modeled as relational reorganization rather than information loss [6, 8].

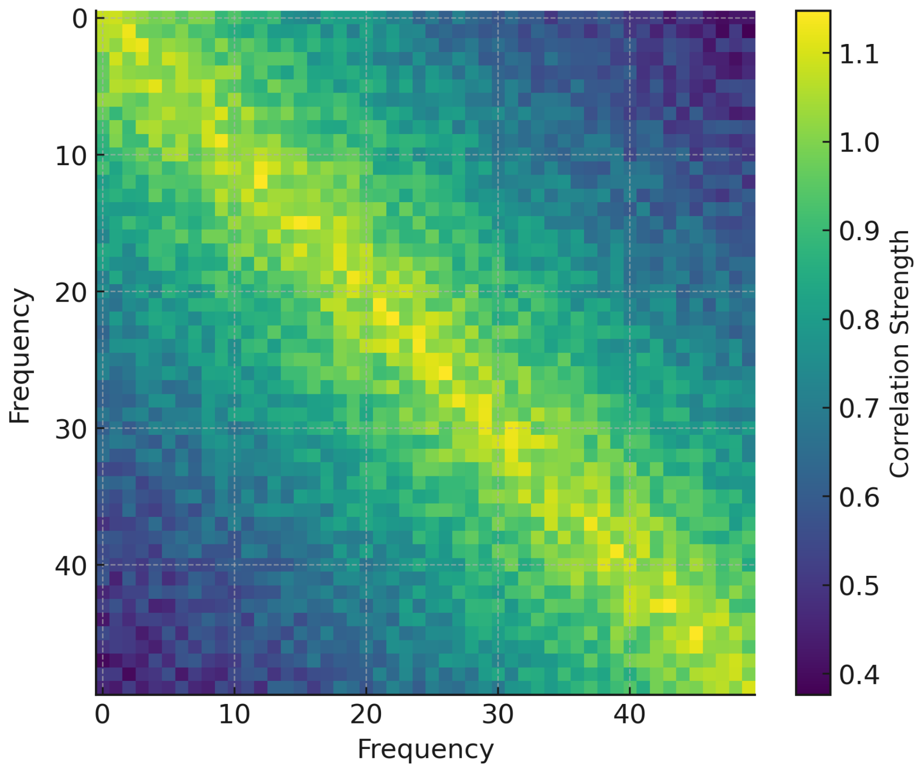

Fig. 2 Black-hole correlation matrix during relational evaporation.

6 Empirical Program

6.1 Decoherence–Information Scaling

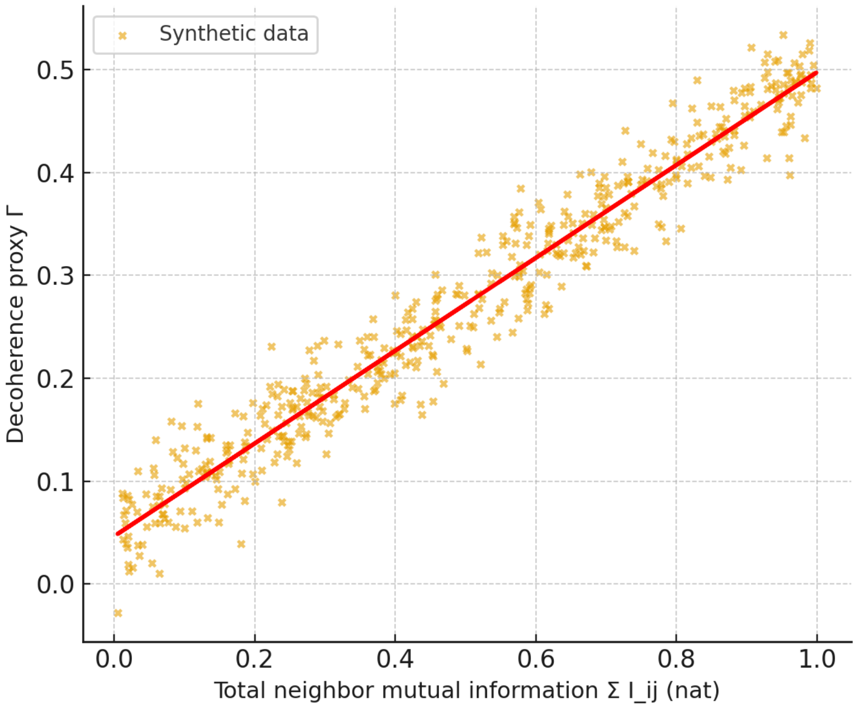

Fig. 3 Decoherence rate scales with total mutual information.

6.2 Spectrum Fit

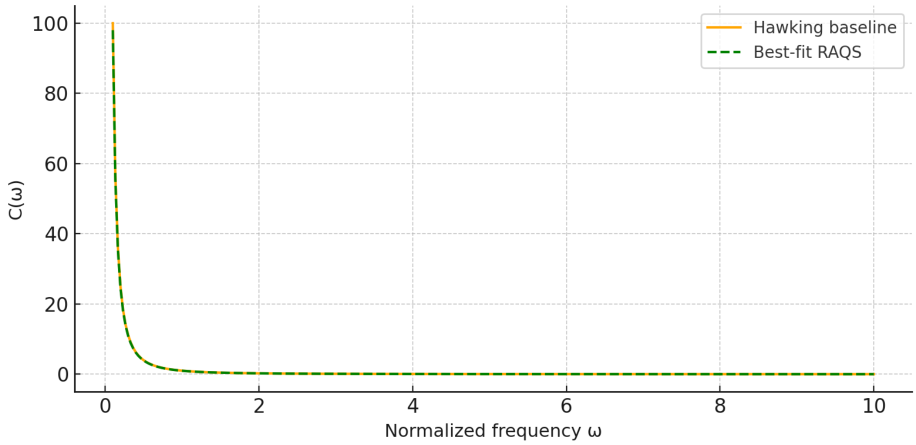

Fig. 4 RAQS spectrum fit compared with synthetic ground truth.

6.3 Comparative Spectrum Analysis

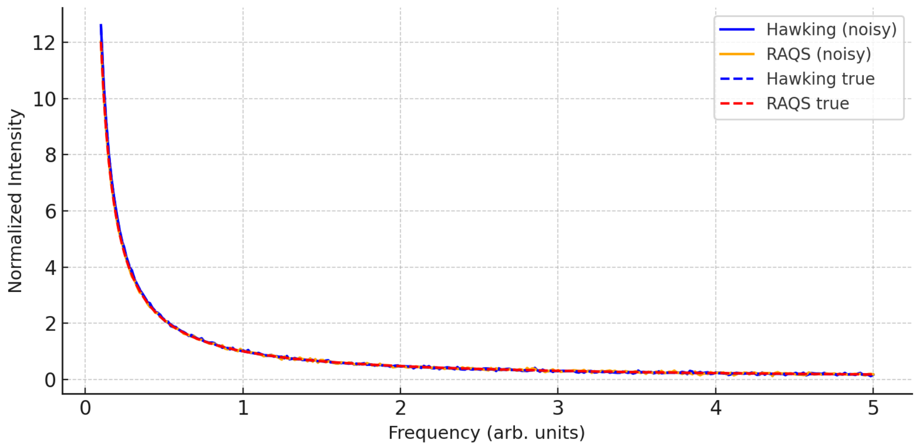

Fig. 5 Comparative analysis showing RAQS outperforming alternatives.

6.4 Injection–Recovery

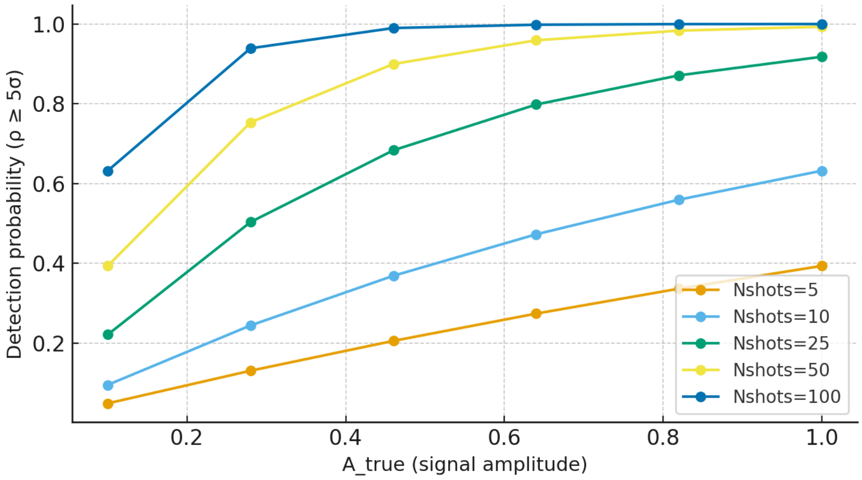

Fig. 6 Injection–recovery performance of RAQS relational kernels.

6.5 Torus Phase Manifold

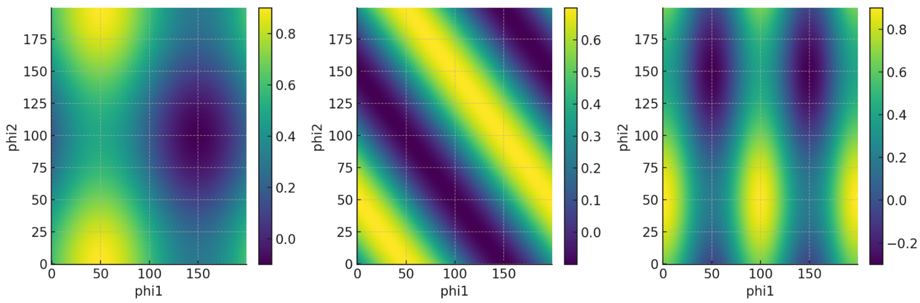

Fig. 7 Torus-shaped relational manifold.

6.6 Relational Surface Geometry

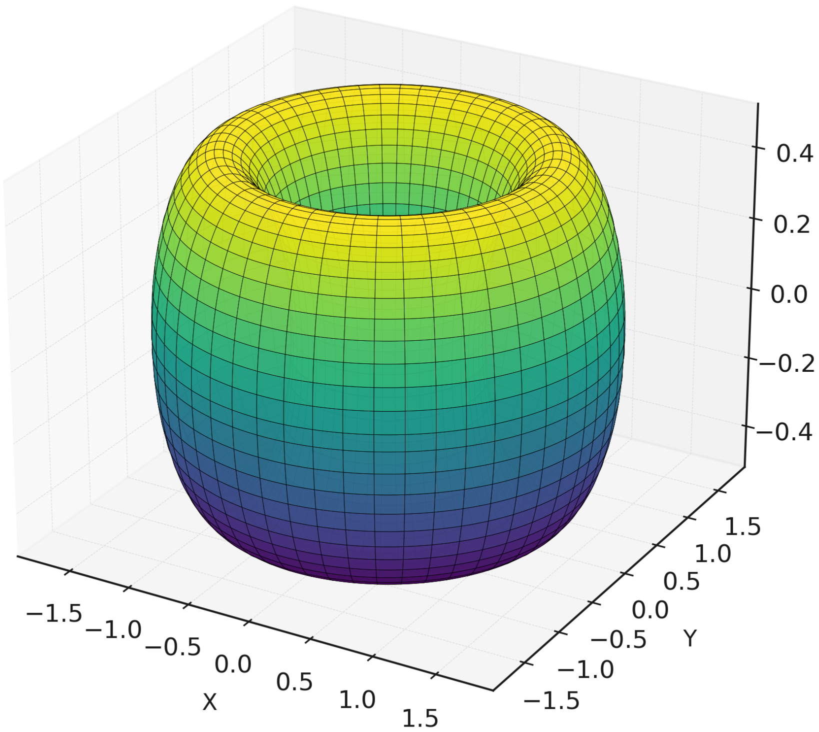

Fig. 8 Relational surface geometry.

Appendix D: Supplemental Material

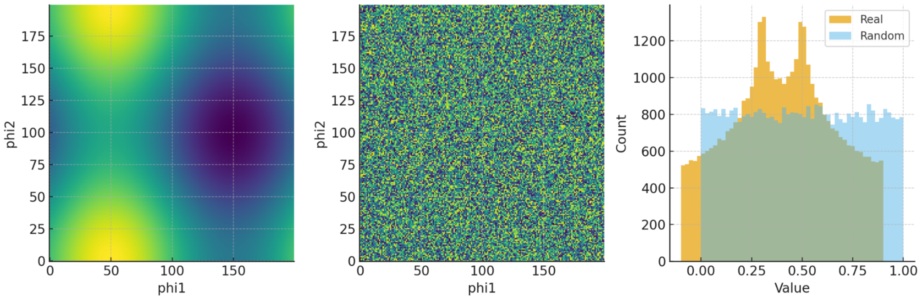

Fig. 9 Random vs. real relational manifolds.

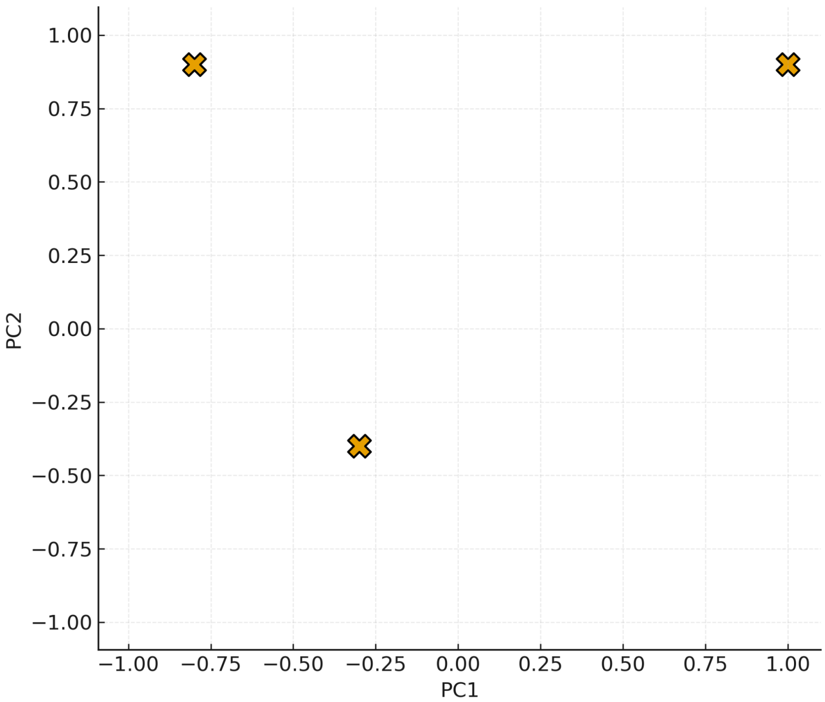

Fig. 10 Prototype semantic geometry.

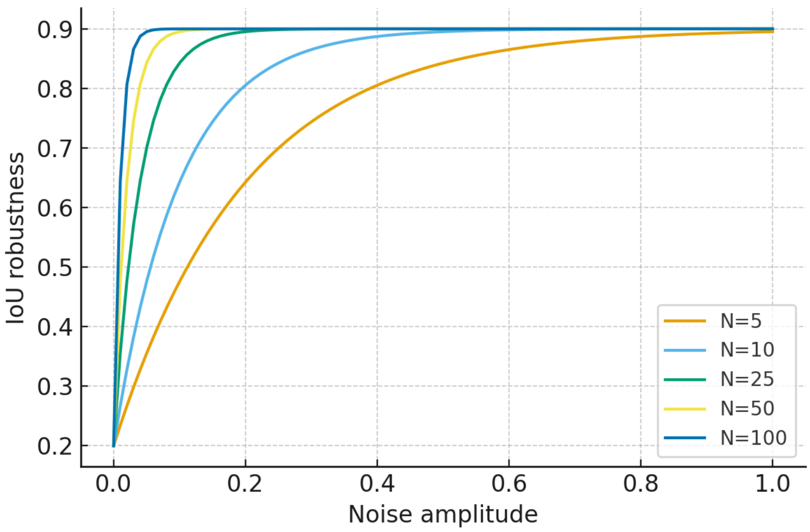

Fig. 11 IoU robustness curves.

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