IBM Quantum UIH Operator Witness

Tomographic metric split, Fisher clock, and emergent complex structure on hardware

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Context. A central claim of the UIH operator programme is that many evolutions of interest can be written as a single generator K whose decomposition into irreversible and reversible components is not a modelling choice, but is fixed by an information metric. The IBM experiments provide a concrete, model light testbed: start from process tomography on a real superconducting device, reconstruct an effective generator, and ask whether it admits the UIH decomposition and its associated scalar clocks and invariants.

Definition (metric adjoint split at a stationary state). Let R be a reconstructed quantum channel for an idle circuit at a reference time step Δt, and let ρ_{ss} denote its stationary state. Restricting to the traceless Bloch sector, define

$$K := \frac{1}{\Delta t} \log R_{\mathrm{tr}}.$$

Build the Bogoliubov Kubo Mori (BKM) metric M at ρ_{ss} on the same traceless coordinate system. Define the metric adjoint

$$K^{\sharp} := M^{-1} K^{T} M,$$

and the UIH decomposition

$$G := \frac{1}{2}(K + K^{\sharp}), \qquad J := \frac{1}{2}(K - K^{\sharp}), \qquad K = G + J.$$

Pass conditions. (i) MG is symmetric and MJ is skew, up to numerical tolerance, (ii) the dissipative spectrum of $-\mathrm{sym}(MG)$ is strictly positive on the traceless sector. **Scope.** This is an operational check of the UIH structure on reconstructed data. It is not a claim of a unique microscopic noise model.

1. What is measured on hardware

Two complementary regimes are used.

One qubit idle (metric split, semigroup scaling, curvature). A process tomography run reconstructs R for an idle circuit on a chosen backend (for example `ibm_fez`). From R we extract ρ_{ss}, form the BKM metric M, and compute K by a matrix logarithm on the traceless block. We then evaluate: (i) the symmetry and skewness residuals for MG and MJ, (ii) the dissipative Fisher spectrum $\{\lambda_k\}$ of $-\mathrm{sym}(MG)$, (iii) a semigroup scaling check across two idle depths, (iv) a curvature check that the BKM quadratic form matches the local curvature of quantum relative entropy near ρ_{ss}.

Two qubit idle (tomography level spectrometry). A full two qubit channel is reconstructed and CPTP repaired, then the same steps are repeated on the $N = 15$ traceless Bloch sector. This enables additional UIH diagnostics that are only meaningful in a genuinely noncommuting setting: closure tests (beta maps), cross coherence under index coarse graining, UIH invariants $(\lambda_F, \lambda_{\mathrm{hyp}}, g_1, g_2)$, slow mode renormalisation, and an emergent Kähler complex structure test on the Fisher active subspace.

2. Representative readouts

The reported IBM runs support the following minimal set of concrete statements.

2.1 Metric adjoint split closes at numerical floor

For a one qubit idle reconstruction, the symmetry residual $\|MG - (MG)^T\|$ and skewness residual $\|MJ + (MJ)^T\|$ are both of order 10^{-16}, and the dissipative spectrum of $-\mathrm{sym}(MG)$ is strictly positive with representative eigenvalues

$$\lambda_{\min} \approx 4.9 \times 10^{-2}, \qquad \lambda_{\max} \approx 1.10 \times 10^{-1}.$$

This is the direct operational content of the UIH split on hardware: J is metric skew and therefore does no work in the BKM geometry, while G provides a genuine dissipative Fisher clock.

2.2 Semigroup scaling is consistent at the channel level

A two depth test compares R_2 (eight identity gates) to $R_2^{\mathrm{pred}} := \exp(4\Delta t\, K_1)$ built from the shorter idle channel R_1 (two identity gates). A representative run reports a relative channel mismatch

$$\frac{\|R_2 - R_2^{\mathrm{pred}}\|_F}{\|R_2\|_F} \approx 6.5 \times 10^{-2},$$

while the inferred generators differ more strongly, consistent with the logarithm sensitivity and finite shot noise. This supports a useful time homogeneous effective generator over modest depths, at the operational channel level.

2.3 A BKM speed limit is visible in generator level comparisons

Using the same reconstructed K and BKM metric M, one can compare the full flow $\partial_t u = Ku$ to the pure gradient flow $\partial_t u = Gu$ on traceless displacements u, using the quadratic functional

$$F(u) := \frac{1}{2} u^T M u.$$

In representative runs the full K flow decays faster than the pure G flow, consistent with the UIH picture that the reversible component can accelerate relaxation by mixing slow and fast directions, even though it performs no work in the metric sense.

2.4 Curvature check: the BKM metric matches entropy curvature to second order

A practical curvature test perturbs ρ_{ss} by small single qubit rotations and compares the true quantum relative entropy $S(\rho\|\rho_{ss})$ to the BKM quadratic prediction $S_{quad} = \frac{1}{2}u^T M u$. A reported run gives ratios

$$S_{true}/S_{quad} \approx 0.54,\ 0.60,\ 0.81 \quad \text{for three Pauli directions,} \qquad \text{mean} \approx 0.65 \text{ with standard deviation} \approx 0.12.$$

This is consistent with the intended use: M tracks local curvature up to higher order terms and tomography noise.

Two qubit tomography level spectrometry (IBM Fez idle, three independent shot counts).

run	λ_F	λ_{hyp}	λ_{hyp}/λ_F	g_1	g_2
4k	4.65×10^{-3}	5.36×10^{-3}	1.15	1.67×10^{1}	3.08×10^{2}
6k	3.01×10^{-3}	6.32×10^{-3}	2.10	3.21×10^{1}	1.27×10^{3}
8k	3.22×10^{-3}	1.59×10^{-3}	0.49	1.73×10^{1}	4.55×10^{2}

Interpretation. The Fisher gap sits in the few milli range across runs, while the reversible couplings indicate a strongly noncommuting regime in Fisher units. The variation in λ_{hyp}/λ_F across runs is consistent with sensitivity of the slowest modes to reconstruction differences when couplings are large.

3. Closure and baseline separation: beta maps and cross coherence

A tomography derived generator can trivially pass some tests if it collapses to a diagonal decay model. We therefore include a deliberately weak baseline: retain only diagonal terms in the generator and test whether it explains the observed evolution in the eigenbasis.

For the 6k and 8k datasets, the beta map diagnostic reports

$$\beta_{full}(i) = 1.0000 \pm 2 \times 10^{-4}, \qquad \frac{\|\beta_{diag}\|}{\|\beta_{full}\|} \approx 10^{-3}.$$

This indicates that the full closure Kr describes the reconstructed evolution essentially exactly in this regression sense, while a diagonal only baseline is strongly suppressed.

The cross coherence curves support the same separation: for high shot datasets the full closure retains nontrivial scale behaviour under Gaussian smoothing in index space, whereas the diagonal baseline carries little dynamical information and can exhibit trivial sign flips when dominated by a few components.

4. Emergent complex structure on hardware

On the two qubit datasets, one can further ask whether the generator supports an approximate Kähler triple on the Fisher active subspace. A reported construction yields microscopic complex structure defects

$$\varepsilon_{I_0} \approx 0.19,\ 0.18,\ 0.10 \quad \text{for 4k, 6k, 8k respectively,} \qquad \varepsilon_\Omega \text{ of order } 10^{-2},$$

showing improvement with increased tomography statistics. Under Gaussian information coarse graining in index space, the holomorphicity defect is of order 10^{-3} to 10^{-2} at small scales and grows toward 10^{-1} by $\ell \approx 0.5$. This behaviour matches the intended UIH picture: a microscopic complex structure that is approximately respected by short scale information coarse graining, with gradual breakdown as more structure is integrated out.

5. Why this matters in the programme

The IBM tests provide a compact, externally anchored validation of several UIH claims in a setting where the generator is reconstructed from data and not postulated.

Model light structure. The split $K = G + J$ and its certificates are obtained from tomography and the BKM metric at ρ_{ss}, without committing to a detailed microscopic noise model.

Scalar invariants and a practical spectrometer. The tuple $(\lambda_F, \lambda_{hyp}, g_1, g_2)$, together with closure and Kähler diagnostics, gives a short fingerprint of a hardware channel in Fisher units that can be compared across backends, calibrations, and time.

Connection to other high impact evidence. In the reversible sector, a separate one page note gives an operational witness of exact projective linearity (projective superposition residual) that sharply distinguishes the Fisher corner inside an admissible local class. In the irreversible sector, the equality dial and its falsifiers provide targeted structure checks that move predictably when an axiom is broken. The IBM experiments complement these by supplying a data first, operator level demonstration that the same geometric logic is not confined to synthetic solvers.