QATNU Phase-0 Negative Controls

A First Result for the Spin-2 Emergence Test

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Status. This paper reports a Phase-0 exact-simulation result and provides hardware-ready circuits for real quantum processors. It does not report a successful spin-2 derivation. The result is deliberately negative: the small graph controls tested here are rejected as gravitational substrates while still producing measurable scalar and bond observables.

Abstract

The QATNU spin-2 program requires a severe first check: the diagnostic must say no on substrates that cannot support an infrared transverse-traceless tensor sector. This paper reports that check for a hardware-readable qubit encoding of the QATNU/SRQID Hamiltonian. Matter degrees of freedom are assigned to graph vertices and one bond qubit is assigned to each graph edge, corresponding to a bond cutoff $\chi_{\max} = 2$. The implemented Hamiltonian contains a matter clock driver, diagonal bond energy, nearest-neighbor $Z_i Z_j$ matter coupling, and frustration-controlled bond promotion. Four small negative-control graph families are tested by exact statevector evolution: a path, a cycle, a star, and a diamond plaquette.

The results are as intended. All four graph families return `FAIL_EXPECTED_NEGATIVE_CONTROL` for the spin-2 test. This is not a failure of the program; it is the first evidence that the proposed exam is not automatically positive. The same runs show nonzero bond occupation and scalar load, so the code is not merely inert. The path and star exhibit nonzero scalar-load contrast, while the symmetric cycle and diamond have uniform scalar load under the chosen initial condition. None of these graphs has the dimensionality, low-momentum continuum window, or transverse-traceless helicity structure needed for the real spin-2 target.

The paper also supplies OpenQASM 2 circuits and Python runners for IBM Quantum and Quafu/BAQIS. These circuits allow the same Phase-0 controls to be submitted to real superconducting quantum processors. The hardware goal is not to discover gravity on a small chip. It is to verify that the measured observables and the negative-control logic survive noise, compilation, and finite shots.

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1 Purpose

The previous target for QATNU was methodological: a candidate substrate must generate a spin-2 sector rather than inserting one by projection. The immediate next step is a result. The smallest honest result is not a positive claim. It is a negative control.

A path graph, a small cycle, a star graph, and a single plaquette cannot produce a genuine long-wavelength helicity-2 gravitational sector. They have no three-dimensional infrared continuum, no stable low-k tensor dispersion, and no protected transverse-traceless mode count. A valid diagnostic should therefore reject them.

This paper reports exactly that test. It answers a narrow question:

> Can the QATNU Phase-0 code measure scalar and bond observables while refusing to label small inadmissible graphs as spin-2 substrates?

The answer is yes for the four exact-simulation controls reported here.

2 Hardware-readable QATNU encoding

Let $G = (V, E)$ be a finite graph. Each vertex $i \in V$ carries one matter qubit. Each edge $e = \langle i, j\rangle \in E$ carries one bond qubit. This is the smallest hardware-readable version of the QATNU bond ladder and corresponds to $\chi_{\max} = 2$.

The Hilbert space is

$$\mathcal{H} = \bigotimes_{i\in V} \mathbb{C}_i^2 \otimes \bigotimes_{e\in E} \mathbb{C}_e^2, \tag{1}$$

with dimension

$$\dim \mathcal{H} = 2^{|V|+|E|}. \tag{2}$$

The Phase-0 Hamiltonian is

$$H = H_{\text{mat}} + H_{ZZ} + H_{\text{bond}} + H_{\text{prom}}, \tag{3}$$

where

$$H_{\text{mat}} = \frac{\omega}{2} \sum_{i\in V} X_i, \tag{4}$$

$$H_{ZZ} = J_0 \sum_{\langle i,j\rangle\in E} Z_i Z_j, \tag{5}$$

$$H_{\text{bond}} = \Delta_B \sum_{e\in E} n_e, \tag{6}$$

$$H_{\text{prom}} = \lambda \sum_{e=\langle i,j\rangle} F_{ij} X_e. \tag{7}$$

Here

$$n_e = \frac{I - Z_e}{2}, \qquad F_{ij} = \frac{1 - Z_i Z_j}{2}. \tag{8}$$

Thus a frustrated matter edge promotes or demotes the corresponding bond qubit.

The parameter values used in this run are

$$\omega = 1.0, \quad J_0 = 0.12, \quad \Delta_B = 0.55, \quad \lambda = 0.35, \tag{9}$$

with evolution time $T = 2.0$ in dimensionless units. The initial state is

$$|\psi_0\rangle = |+\rangle^{\otimes|V|} \otimes |0\rangle^{\otimes|E|}. \tag{10}$$

3 Measured observables

The bond occupation on edge e is

$$\langle n_e \rangle = \langle \psi(T) | n_e | \psi(T) \rangle. \tag{11}$$

The scalar load at vertex i is

$$\Lambda_i = \sum_{e \ni i} \log\left(1 + \langle n_e \rangle\right). \tag{12}$$

The load spread is

$$\Delta\Lambda = \max_i \Lambda_i - \min_i \Lambda_i. \tag{13}$$

For embedded graphs we also compute a raw anisotropy diagnostic,

$$M_{ab} = \sum_e q_e \left(\hat{t}_{e,a} \hat{t}_{e,b} - \frac{1}{2} \delta_{ab} \right), \qquad q_e = \langle n_e \rangle - \frac{1}{|E|} \sum_f \langle n_f \rangle. \tag{14}$$

This object is not a spin-2 derivation. It is a debugging diagnostic: it checks whether the bond occupations carry any centered directional anisotropy in the assigned two-dimensional chart.

4 Negative-control criteria

Each graph is marked inadmissible for the infrared spin-2 test for a structural reason:

- **Path.** One-dimensional; no transverse-traceless helicity-2 sector.
- **Cycle.** Finite ring; useful scalar control but no three-dimensional infrared tensor limit.
- **Star.** Hub-dominated spectrum; no smooth low-k continuum.
- **Diamond.** Single plaquette; no low-k scaling window.

The required Phase-0 spin-2 outcome is therefore

$$\texttt{FAIL_EXPECTED_NEGATIVE_CONTROL}. \tag{15}$$

A positive spin-2 claim from these graphs would be a warning sign: it would mean the diagnostic is hallucinating tensor gravity where none can exist.

5 Exact-simulation results

Table 1 gives the exact statevector results for the four negative controls.

Graph	Matter	Edges	Qubits	$\langle n_e \rangle$	$\Delta\Lambda$	Gap	Spin-2 result
Path	4	3	7	0.1288	0.1228	0.6491	fail expected
Cycle	4	4	8	0.1301	0.0000	0.5485	fail expected
Star	4	3	7	0.1305	0.2453	0.6279	fail expected
Diamond	4	4	8	0.1301	0.0000	0.5485	fail expected

Table 1: Phase-0 exact-simulation results. The graphs show nonzero bond occupation and scalar load, but none is admissible as an infrared spin-2 substrate. The reported gap is the lowest many-body spectral gap of the qubit-encoded Hamiltonian.

The important feature is not the precise value of the bond occupation. It is the combination of two facts: the scalar/bond sector is active, and the spin-2 test remains negative.

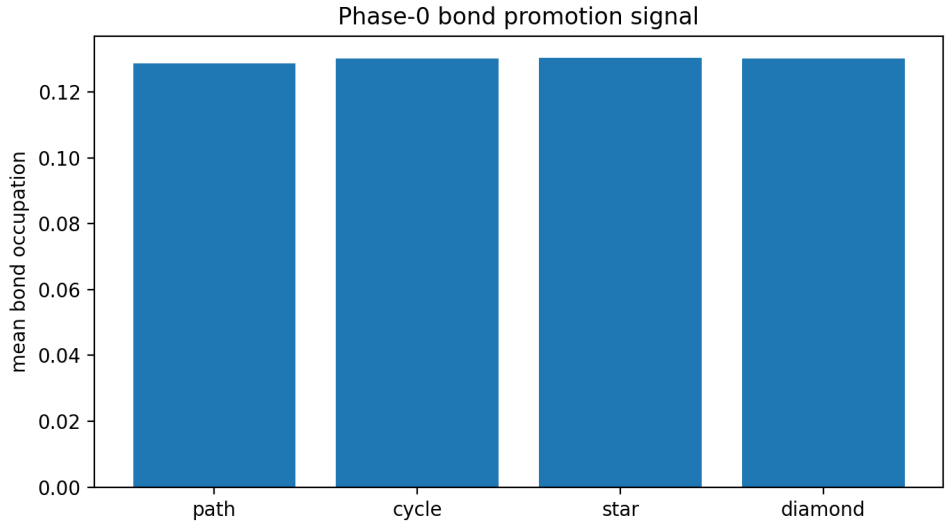

Figure 1: Mean bond occupation after evolution from $|+\rangle^{\otimes|V|} \otimes |0\rangle^{\otimes|E|}$. All tested graphs show nonzero promotion signal.

6 Interpretation

This is a result paper in the modest Phase-0 sense. It does not claim that QATNU has produced gravity. It establishes the first necessary control: the diagnostic can reject graph families that should not pass.

The result has three implications.

1. The scalar observable pipeline is live. Bond occupation and scalar load are measurable in the qubit-encoded Hamiltonian.
2. The spin-2 exam is not automatically positive. Small graphs are rejected for structural reasons.
3. The next admissible search must move to graph families with an approximate continuum limit, an assigned local chart, enough angular structure to define tensor observables, and finite-size scaling across increasing system sizes.

7 Real-QPU deployment

The code package emits OpenQASM 2 circuits for each Phase-0 graph. These circuits are hardware-readable because the bond ladder has been reduced to one qubit per edge and the Hamiltonian is Trotterized into standard rotations and CNOTs.

The package provides two hardware runners:

- `run_ibm_qpu.py`: submits QASM circuits to IBM Quantum through Qiskit Runtime.
- `run_quafu_qpu.py`: submits QASM circuits to Quafu/BAQIS through PyQuafu.

The real-QPU experiment should begin with the 7-qubit path circuit:

$$\texttt{qasm/qatnu_phase0_path_N4.qasm}. \tag{16}$$

A successful hardware reproduction does not require a perfect match to the exact simulation. It

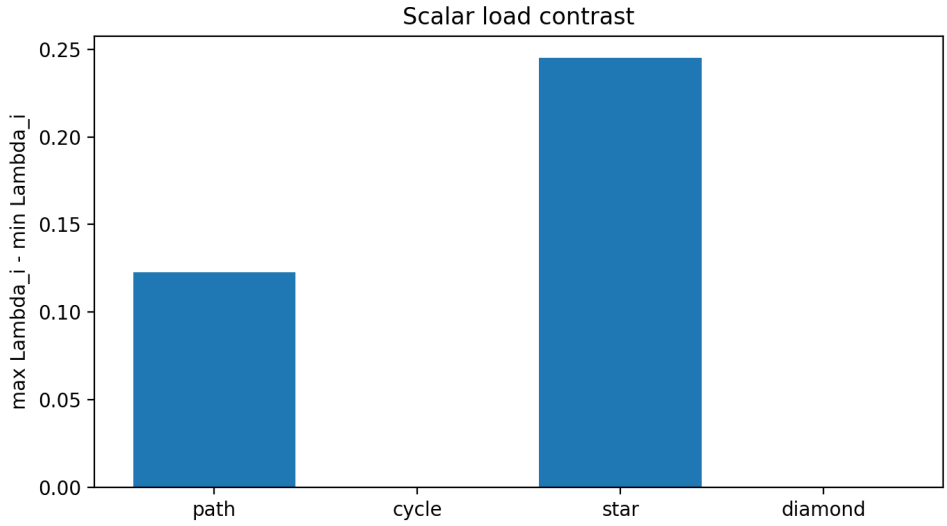

Figure 2: Scalar load contrast. The path and star produce nonuniform scalar load. The symmetric cycle and diamond are uniform under the chosen initial state and parameters.

requires the same qualitative conclusion after finite-shot and noise effects:

$$\text{nonzero scalar/bond signal} + \text{inadmissible spin-2 geometry}. \tag{17}$$

8 Reproducibility

To reproduce the local result:

```
cd qatnu_phase0_qpu
python src/run_phase0_exact.py
python src/generate_plots.py
```

To analyze hardware counts:

```
python src/analyze_counts.py --counts path_counts.json --topology path --N 4
```

The expected output field is

```
"spin2_phase0_result": "FAIL_EXPECTED_NEGATIVE_CONTROL"
```

9 Conclusion

The QATNU spin-2 program now has its first result: negative controls fail. The tested small graphs show measurable bond promotion and scalar loads, but they do not meet the structural requirements for an infrared transverse-traceless tensor sector. This is exactly what should happen.

The next stage is not another framework paper. It is a finite-size scaling study on admissible embedded graph families, followed by the extraction of a genuine tensor structure factor. The Phase-0 result reported here is the gatekeeper: before asking whether QATNU can generate spin-2 gravity, the protocol first proves it can say no.

A Hardware run prompt

Run the QATNU Phase-0 negative-control experiment. First reproduce the exact statevector results with `python src/run_phase0_exact.py`. Then submit the smallest OpenQASM circuit, `qasm/qatnu_phase0_path_N4.qasm`, to a real QPU using either IBM Quantum or Quafu. Save raw bitstring counts as JSON. Analyze counts with `src/analyze_counts.py`. Report bond occupations, scalar loads, raw anisotropy, backend name, job id, shots, and whether the graph is admissible for an infrared spin-2 test. The expected scientific result is `FAIL_EXPECTED_NEGATIVE_CONTROL`.

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