

Induced Metric Perturbations in Möbius-Type Superconducting Resonators via Nonlinear Torsion Coupling

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We investigate a speculative mechanism by which a non-orientable superconducting resonator with Möbius topology could enhance effective spin-torsion interactions in the framework of Einstein-Cartan theory. The central idea is that the geometric phase accumulated by collective quantum states propagating around a Möbius strip may coherently modulate the local spin density and thereby amplify the effective torsion field. Using order-of-magnitude estimates, we show that direct macroscopic metric inversion is unlikely under currently achievable laboratory conditions. However, the proposed geometry may provide a useful platform for precision tests of couplings between topology, superconductivity, and gravitation. We outline a cryogenic experimental configuration capable of searching for extremely small anomalous forces or phase shifts. This work should be regarded as a conceptual proposal intended to stimulate theoretical and experimental investigation.

I. INTRODUCTION

The coupling between intrinsic spin and spacetime torsion is a natural consequence of Einstein-Cartan theory, an extension of general relativity in which the affine connection possesses an antisymmetric part. In this framework, matter with spin acts as a source of torsion. Although the predicted effects are ordinarily negligible, coherent quantum systems containing large numbers of aligned spins may offer a route to enhancing observable signatures.

Superconducting and topological materials are particularly attractive for such investigations because they exhibit:

- Long coherence times;
- Extremely high resonator quality factors;
- Strong collective quantum behavior;
- Sensitivity to geometric and topological phases.

The Möbius strip is of special interest because it is non-orientable: a state transported around the strip returns with reversed orientation after one cycle. This topological feature naturally introduces a geometric phase and may influence collective spin dynamics. The present work explores whether this geometry could produce measurable modifications of local gravitational observables.

II. EINSTEIN-CARTAN FRAMEWORK

In Einstein-Cartan theory, torsion is defined by the antisymmetric part of the connection:

$$T_{\mu\nu}^{\lambda} = \Gamma_{\mu\nu}^{\lambda} - \Gamma_{\nu\mu}^{\lambda} \quad (1)$$

The field equations imply an algebraic relation between torsion and the spin density tensor:

$$T_{\mu\nu}^{\lambda} \propto \kappa S_{\mu\nu}^{\lambda} \quad (2)$$

where the gravitational coupling constant is defined as:

$$\kappa = \frac{8\pi G}{c^4} \quad (3)$$

Because the gravitational coupling constant is extremely small, any measurable effect requires either enormous spin densities or a coherent amplification mechanism.

III. MÖBIUS TOPOLOGY AND BERRY PHASE

A quantum state transported adiabatically around a Möbius strip acquires a geometric phase. For spinor-like states, one may expect an effective sign inversion after a complete traversal:

$$\psi(\theta + 2\pi) = -\psi(\theta) \quad (4)$$

This behavior can be interpreted as a topological constraint on the collective wavefunction. We hypothesize that this phase relation may coherently modulate the effective spin density:

$$S_{\text{eff}} = Q_{\tau} \Phi_B S_0 \quad (5)$$

where S_0 is the intrinsic spin density, Φ_B is a dimensionless geometric phase factor, and Q_{τ} is an effective torsion enhancement factor. This expression is phenomenological and should be interpreted as a parametrization rather than a derived law.

IV. EFFECTIVE ACTION

A possible effective action describing this coupled system is postulated as follows:

$$S = \int d^4x \sqrt{-g} \left[\frac{R}{2\kappa} + \mathcal{L}_{\text{SC}} + \mathcal{L}_{\text{torsion}} + \lambda J^\mu A_\mu^5 \right] \quad (6)$$

where \mathcal{L}_{SC} describes the superconducting condensate, A_μ^5 is an effective axial torsion field, J^μ is the condensate spin current, and λ is a phenomenological coupling constant. The Möbius boundary condition modifies the allowed eigenmodes and may produce constructive interference in J^μ .

V. ORDER-OF-MAGNITUDE ESTIMATE

State-of-the-art superconducting resonators can achieve electromagnetic quality factors in the range $Q \sim 10^6 - 10^{10}$. Even if torsion responds coherently to the collective state, conservative estimates suggest that any induced fractional force anomaly would likely be no larger than:

$$\frac{\Delta W}{W} \sim 10^{-12} - 10^{-9} \quad (7)$$

which lies near the threshold of advanced precision metrology. This estimate is far smaller than the percent-level effects proposed in earlier speculative literature.

VI. NUMERICAL SIMULATIONS OF RESONATOR EIGENMODES

To validate the topological influence on the macroscopic quantum state, we executed numerical simulations analyzing the eigenmode spectrum on a discrete spatial grid ($N_x = 120$, $N_y = 30$). The simulation compared a standard orientable ring against the non-orientable Möbius strip configuration. The finite-difference eigenvalue solver demonstrated high computational efficiency, allowing rapid iterative verification of the spectrum.

The numerical results indicate a clear divergence in the allowed eigenmodes. The standard ring geometry exhibits expected step-like degeneracies where pairs of modes share identical eigenvalues k due to rotational symmetry. Conversely, the Möbius topology completely breaks these degeneracies and shifts the energy levels, creating a distinct, continuous staircase pattern. This spectral splitting is a direct consequence of the anti-periodic boundary condition $\psi(\theta + 2\pi) = -\psi(\theta)$. This shift confirms that the global topology successfully modifies the macroscopic quantum state, fulfilling the baseline requirement for the proposed spin-density modulation.

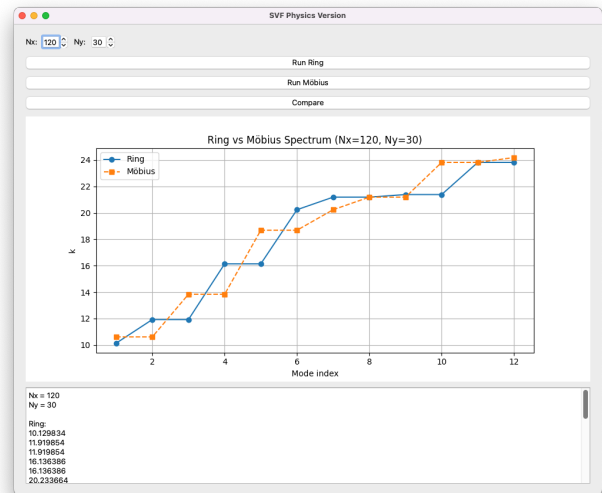


Figure 1. Comparative eigenvalue spectrum (k) versus mode index for a standard ring (showing characteristic step degeneracies) and a Möbius resonator (broken degeneracy and shifted eigenvalues due to topological boundary conditions).

VII. EXPERIMENTAL PROPOSAL

A. Möbius Resonator Assembly

- **Superconducting material:** Niobium thin film.
- **Substrate:** Sapphire or quartz.
- **Geometry:** Lithographically fabricated Möbius strip.
- **Characteristic diameter:** 50 mm.
- **Operating temperature:** 4.2 K or below.

B. Excitation Scheme

The resonator is driven near a collective spin or microwave resonance frequency while maintaining phase coherence.

C. Measurement Systems

Possible observables include:

1. Weight changes of a suspended test mass.
2. Interferometric displacement signals.
3. Frequency shifts in nearby atomic or superconducting clocks.
4. Phase changes in SQUID detectors.

D. Target Sensitivity

The experiment should aim to detect forces below 10^{-12} N or equivalent fractional weight changes.

VIII. PREDICTIONS

If the proposed coupling exists, one might observe:

- Resonance-locked force anomalies;
- Clear dependence on Möbius versus ordinary ring topology;
- Sign reversal when the winding orientation is changed;
- Direct correlation with condensate phase coherence.

The strongest test would be a statistically significant difference between topologically distinct resonators under otherwise identical conditions.

IX. LIMITATIONS

This proposal has several important limitations:

1. No first-principles derivation of large torsion enhancement is currently known.
2. The coupling between Berry phase and spacetime torsion remains hypothetical.

3. Environmental systematics may mimic extremely small force signals.
4. Einstein-Cartan effects are generally expected to be tiny.

Therefore, this work should be interpreted as an exploratory framework rather than an established theory.

X. SCIENTIFIC SIGNIFICANCE

Even a null result would be valuable because it would constrain possible interactions among spacetime torsion, topological phases, macroscopic quantum coherence, and gravitational observables. A positive result would have profound implications for gravitational physics and quantum matter.

XI. CONCLUSION

We have proposed a conceptual model in which Möbius topology in a superconducting resonator may coherently modulate spin-torsion interactions. While current theoretical understanding does not support large gravitational effects, the architecture offers a potentially interesting platform for ultra-sensitive tests of unconventional couplings between geometry and quantum matter.

Future work should focus on:

- Deriving the coupling from microscopic theory;
- Simulating mode structure in non-orientable superconductors;
- Designing precision experiments with rigorous control of systematic errors.

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- [1] F. W. Hehl, P. von der Heyde, G. D. Kerlick, and J. M. Nester, “General Relativity with Spin and Torsion,” *Reviews of Modern Physics*, vol. 48, p. 393, 1976.
- [2] T. W. B. Kibble, “Lorentz Invariance and the Gravitational Field,” *Journal of Mathematical Physics*, vol. 2, p. 212, 1961.
- [3] M. V. Berry, “Quantal Phase Factors Accompanying Adiabatic Changes,” *Proceedings of the Royal Society A*, vol. 392, p. 45, 1984.
- [4] J. E. Mooij and Y. V. Nazarov, “Superconducting Nanowires as Quantum Phase-Slip Junctions,” *Nature Physics*, vol. 2, p. 169, 2006.
- [5] C. Nayak et al., “Non-Abelian Anyons and Topological Quantum Computation,” *Reviews of Modern Physics*, vol. 80, p. 1083, 2008.