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The rich topological tapestry embedded in entangled states

Topology has emerged as a fundamental feature across diverse physical systems, from cosmology and condensed matter to high-energy physics and wave dynamics. Yet, despite its broad relevance, topological studies have largely been confined to low-dimensional classical systems. Here, using entangled quantum states, we uncover a vast landscape of diverse topological maps derived from high dimensional entangled states. By engineering our quantum states to mimic a non-Abelian field in SU(d) Yang-Mills theory, we predict multiple topological structures as mappings between a reference 2-sphere and multiple submanifolds embedded within the high dimensional manifold yielding a topological spectrum of invariants which scales with the dimension of the states. Notably, partitioning this spectrum into trivial and non-trivial components enables simultaneous robustness against perturbations while also serving as a probe for them, achieved by detecting emergent signatures in the initially trivial partition. While the results and analysis are presented using the orbital angular momentum of photonic quantum states as an example the theoretical framework provided is broadly applicable to any particle type, dimension, or degree of freedom. This work opens exciting prospects for quantum sensing and communication through topology.

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