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Classical Simulation of Quantum Error Correction in a Fibonacci Anyon Code

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arxiv:1506.03815

Classically simulating the dynamics of anyonic excitations in two-dimensional quantum systems is likely intractable in general because such dynamics are sufficient to implement universal quantum computation. However, processes of interest for the study of quantum error correction in anyon systems are typically drawn from a restricted class that displays significant structure over a wide range of system parameters. We exploit this structure to classically simulate, and thereby demonstrate the success of, an error-correction protocol for a quantum memory based on the universal Fibonacci anyon model. We numerically simulate a phenomenological model of the system and noise processes on lattice sizes of up to 128x128 sites, and find a lower bound on the error-correction threshold of approximately 12.5

Parafermionic phases with symmetry-breaking and topological order

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arxivp:1506.03455

Parafermions are the simplest generalizations of Majorana fermions that realize topological order. We propose a less restrictive notion of topological order in 1D open chains, which generalizes the seminal work by Fendley [J. Stat. Mech., P11020 (2012)]. The first essential property is that the groundstates are mutually indistinguishable by local, symmetric probes, and the second is a generalized notion of zero edge modes which cyclically permute the groundstates. These two properties are shown to be topologically robust, and applicable to a wider family of topologically-ordered Hamiltonians than has been previously considered. An an application of these edge modes, we formulate a new notion of twisted boundary conditions on a closed chain, which guarantees that the closed-chain groundstate is topological, i.e., it originates from the topological manifold of degenerate states on the open chain. Finally, we generalize these ideas to describe symmetry-breaking phases with a parafermionic order parameter. These exotic phases are condensates of parafermion multiplets, which generalizes Cooper pairing in superconductors. The stability of these condensates are investigated on both open and closed chains.

Locality of temperature in spin chains

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arxiv:1506.04060

In traditional thermodynamics, temperature is a local quantity: a subsystem of a large thermal system is in a thermal state at the same temperature as the original system. For strongly interacting systems, however, the locality of temperature breaks down. We study the possibility of associating an effective thermal state to subsystems of infinite chains of interacting spin particles of arbitrary finite dimension. We study the effect of correlations and criticality in the definition of this effective thermal state and discuss the possible implications for the classical simulation of thermal quantum systems.

Mean-field ansatz for topological phases with string tension

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arxiv:1506.03259

We propose a simple mean-field ansatz to study phase transitions from a topological phase to a trivial phase. We probe the efficiency of this approach by considering the string-net model in the presence of a string tension for any anyon theory. Such a perturbation is known to be responsible for a deconfinement-confinement phase transition which is well described by the present variational setup. We argue that mean-field results become exact in the limit of large total quantum dimension.

Constructions and Noise Threshold of Hyperbolic Surface Codes

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arxiv:1506.04029

We show how to obtain concrete constructions of homological quantum codes based on tilings of 2D surfaces with constant negative curvature (hyperbolic surfaces). This construction results in two-dimensional quantum codes whose tradeoff of encoding rate versus protection is more favorable than for the surface code. These surface codes would require variable length connections between qubits, as determined by the hyperbolic geometry. We provide numerical estimates of the value of the noise threshold and logical error probability of these codes against independent X or Z noise, assuming noise-free error correction.

Reexamination of the evidence for entanglement in the D-Wave processor

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arxiv:1506.03539

A recent experiment [Lanting et al., PRX, (2014)] claimed to provide evidence of up to 8-qubit entanglement in a D-Wave quantum annealing device. However, entanglement was measured using qubit tunneling spectroscopy, a technique that provides indirect access to the state of the system at intermediate times during the anneal by performing measurements at the end of the anneal with a probe qubit. Because the state is effectively classical at the end of the anneal, it is important to test whether a classical or semiclassical description of the device can somehow reproduce the experimental signature. To check this, we consider a recently proposed classical rotor model with classical Monte Carlo updates, which has been successfully employed in describing features of earlier experiments involving the device. We also consider simulated quantum annealing with quantum Monte Carlo updates, a semiclassical algorithm that samples from the instantaneous Gibbs state of the device Hamiltonian. As our quantum model, we use an adiabatic master equation, which cannot be efficiently simulated classically and which has previously been used to successfully capture the open system quantum dynamics of the device. We find that only the master equation is able to reproduce the features of the tunneling spectroscopy experiment, while both the classical rotor model and simulated quantum annealing fail to reproduce the experimental results. This bolsters the evidence for the reported entanglement.

Topological Superconductivity and High Chern Numbers in 2D Ferromagnetic Shiba Lattices
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Phys. Rev. Lett. 114, 236803

Inspired by the recent experimental observation of topological superconductivity in ferromagnetic chains, we consider a dilute 2D lattice of magnetic atoms deposited on top of a superconducting surface with a Rashba spin-orbit coupling. We show that the studied system supports a generalization of $p_x + ip_y$ superconductivity and that its topological phase diagram contains Chern numbers higher than $\xi/a(1)$, where ξ is the superconducting coherence length and a is the distance between the magnetic atoms. The signatures of nontrivial topology can be observed by STM spectroscopy in finite-size islands.

Formation of Quantum Phase Slip Pairs in Superconducting Nanowires
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Phys. Rev. X 5, 021023

Macroscopic quantum tunneling is a fundamental phenomenon of quantum mechanics related to the actively debated topic of quantum-to-classical transition. The ability to realize macroscopic quantum tunneling affects implementation of qubit-based quantum computing schemes and their protection against decoherence. Decoherence in qubits can be reduced by means of topological protection, e.g., by exploiting various parity effects. In particular, paired phase slips can provide such protection for superconducting qubits. Here, we report on the direct observation of quantum paired phase slips in thin-wire superconducting loops. We show that in addition to conventional single phase slips that change the superconducting order parameter phase by 2π, there are quantum transitions that change the phase by 4π. Quantum paired phase slips represent a synchronized occurrence of two macroscopic quantum tunneling events, i.e., cotunneling. We demonstrate the existence of a remarkable regime in which paired phase slips are exponentially more probable than single ones.

Decoherence of nuclear spins in the frozen core of an electron spin
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Phys. Rev. B 91, 214303

Hybrid qubit systems combining electronic spins with nearby (proximate) nuclear spin registers offer a promising avenue towards quantum information processing, with even multispin error-correction protocols recently demonstrated in diamond. However, for the important platform offered by spins of donor atoms in cryogenically cooled silicon, decoherence mechanisms of Si29 proximate nuclear spins are not yet well understood. The reason is partly because proximate spins lie within a so-called frozen core region where the donor electronic hyperfine interaction strongly suppresses nuclear dynamics. We investigate the decoherence of a central proximate nuclear qubit arising from quantum spin baths outside, as well as inside, the frozen core around the donor electron. We consider the effect of a very large nuclear spin bath comprising many (108) weakly contributing pairs outside the frozen core (the far bath). We also propose that there may be an important contribution from a few (of order 100) symmetrically sited nuclear spin pairs (equivalent pairs), which were not previously considered because their effect is negligible outside the frozen core. If equivalent pairs represent a measurable source of decoherence, nuclear coherence decays could provide sensitive probes of the symmetries of electronic wave functions. For the phosphorus donor system, we obtain T2n values of order 1 second for both the far-bath and equivalent-pair models, confirming the suitability of proximate nuclei in silicon as very-long-lived spin qubits.