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Statistical mechanics of multipartite entanglement in Hadamard qubits states

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We investigate the thermodynamic properties of the uniform real-phased submanifold in n-qubit systems, called Hadamard states, represented as a classical ensemble of 2^n spins subject to a potential encoding the multipartite entanglement. For small system sizes (n<6 qubits), we perform an exact enumeration, enabling a complete statistical characterization of the energy landscape and associated thermodynamic observables. For larger systems (n = 6 and 7 qubits), where exact methods become computationally prohibitive, we employ a stochastic annealing approach to efficiently sample the high-dimensional state space. This method accurately reproduces known benchmarks and captures key features of the system's thermodynamic behavior. Our analysis reveals intricate entropic structures arising from the interplay between entanglement constraints and the underlying combinatorial geometry of quantum state spaces. These findings provide new insights into the statistical mechanics of constrained quantum systems and highlight the utility of thermodynamic tools in characterizing complex entangled states.

Author: SCARAFILE, Paolo (Napoli)

Co-authors: MAGNIFICO, Giuseppe (Istituto Nazionale di Fisica Nucleare); FACCHI, Paolo (Istituto Nazionale di Fisica Nucleare); PASCAZIO, Saverio (Istituto Nazionale di Fisica Nucleare); Dr TROTTA, giorgia (Napoli)

Presenter: SCARAFILE, Paolo (Napoli)

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