Understanding strongly correlated quantum systems is one of the greatest challenges of modern physics. The correlation effects are particularly important in one and two spatial dimensions resulting in exotic states of matter whose applications range from the high-temperature superconductivity to the topological quantum computers. They are very hard to solve by analytical or numerical methods, especially in two dimensions, where the analytical methods often boil down to different variants of the mean field theory whose reliability is problematic in the most interesting applications, variational wave-functions arbitrarily bias the class of possible solutions, and the celebrated unbiased quantum Monte Carlo suffers form the sign problem caused by frustration or Fermi statistics. These days quantum tensor networks emerge as the most promising candidate to make a major breakthrough. They are a refined numerical method derived from the theory of quantum information. They provided the best approximations to the ground states of the $t-J$ and Hubbard models, i.e., the paradigmatic models of the high-temperature superconductivity. Since they do not suffer from the sign problem, they may prove to be a competitive tool to study most ground states with a relatively weak quantum entanglement. However, when the entanglement is too large even for tensor networks, then the method of last resort are adiabatic quantum simulators. They are controllable quantum systems/devices that can be employed to make a fully quantum simulation of other quantum systems without any limitation on quantum entanglement. The most famous quantum simulator is the D-Wave purchased by Google.

The general objective of this project is development and application of quantum tensor networks to strongly correlated systems just as well as a better understanding of adiabatic quantum simulators thanks to, among other things, their numerical simulation with tensor networks and direct experiments on the D-Wave machine.

Encouraged by the success of tensor networks in unravelling the nature of ground states of strongly correlated systems, we proposed a tensor network to simulate their quantum states at finite temperature. This network will be applied to a wide class of frustrated spin systems and models of strongly interacting electrons. The algorithm will be developed further in order to meet even the greatest challenges like, e.g., charactering phase diagrams of high-temperature superconductors.

Another goal is development of a new tensor network algorithm to study topological order in the ground state of strongly interacting particles. Topologically ordered ground states possess excitations with an exotic anyonic statistics that is neither fermionic nor bosonic. These excitations can be employed for quantum computations that, by their very topological nature, are robust against environmental decoherence. Our topological tensor network will make possible a systematic search for topologically ordered systems that could be used for a physical implementation of the topological quantum computer.

An adiabatic quantum simulator must be able to evolve its Hamiltonian slowly enough to remain in its ground state. It is very difficult to achieve near a quantum critical point where the ground state undergoes a fundamental change and is very susceptible to both environmental disturbances and imperfections of the physical implementation. The aim of this project is to construct a comprehensive theory describing their influence on the adiabaticity of the quantum simulator's operation. The theory will be tested with the D-Wave simulator and it may contribute to its improvement.