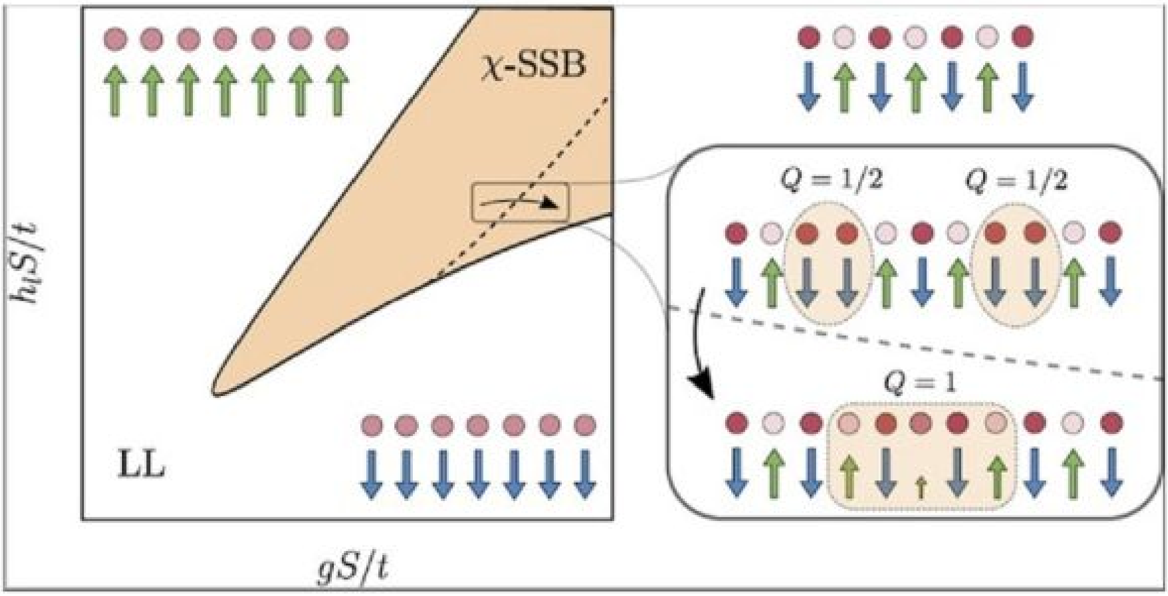

# Ultra cold atoms to understand confinement-deconfinement of quarks

## An international team of researchers reports in Physical Review X Quantum on a novel approach that uses ultra-cold atoms as quantum simulators to understand the behavior of quarks in very extreme conditions.

January 14, 2021

According to the Standard Model of particle physics, quarks are confined into groups forming more complex objects, such as protons and neutrons. Immediately after the Big Bang occurred, the universe was at extremely high temperatures and filled with a hot and very dense matter known as baryonic matter. Right before it eventually cooled down and quarks became confined forming these atomic elements we know and have heard about frequently, these quarks were deconfined and independent, forming a so-called quark-gluon plasma. Such matter is still being created in the present universe in the final stage of stellar objects, such as in gamma-ray bursts or Type-II supernovae (core-collapse) or still can be found permanently in the core of neutron stars. A quark-gluon plasma is approximately 100,000 times hotter than the center of the sun.

Now, studies have been conducted to understand the nature of this confinement-deconfinement phase transition, but it is still an open problem to be solved in high-energy physics, stemming from the complexity of solving the corresponding non-Abelian gauge theories describing such nonperturbative processes using standard analytical or numerical techniques.

Thus, quantum simulators are proving to being capable in approaching this and related questions and search for a proper solution in a more efficient way. In a recent study published in Physical Review X Quantum, ICFO researchers Daniel Gonzalez-Cuadra, Alexandre Dauphin, led by ICREA Prof. at ICFO Maciej Lewenstein, in collaboration with M. Aidelsburger from Ludwig-Maximilians-Universitat and A. Bermudez, from the Universidad Complutense de Madrid, report on a novel approach that could solve simplified cases of this issue, by using cold-atomic systems.

In particular, they show how a Bose-Fermi atomic mixture in an optical lattice can be described at low energies by a quantum field theory that, although much simpler, shares many qualitative features with quantum chromodynamics, the sector of the Standard Model describing quarks. They are able to find a confinement-deconfinement transition between fractionally charged quasiparticles, and show how it could be investigated using state-of-the-art experimental resources. Other similarities with quark physics include dynamical mass generation and chiral symmetry restoration. Despite the microscopic differences, such a near-term simulator can help to understand universal features about confinement that could foster further progress in particle physics.

This results obtained in this study suggest alternative paths to study high-energy phenomena where, instead of simulating the full problem at hand, the flexibility of these ultra-cold atomic systems is employed to design simplified models that can provide information about the problem at large.