Heavy Quarks and the Big Bang

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Abstract:
Quantum Chromodynamics (QCD) is the well-established theory of the strong nuclear force, with quarks and gluons as the elementary degrees of freedom. However, the emergence of its most prominent phenomena, i.e., the quark confinement into hadrons and the generation of hadronic mass, remains under intense investigation. Over the last two decades, another remarkable phenomenon has been discovered, namely the quark-gluon plasma (QGP), with transport properties that are often referred to as the ``most perfect liquid", close to conjectured limits set by quantum mechanics. The QGP last existed in the early universe, in the first few microseconds after the Big Bang. It is truly fascinating that this matter can be recreated 14 billion years later in laboratory experiments on Earth, by colliding heavy atomic nuclei at high energies. After an introduction to QCD and its phase diagram, the focus will be on the use of the heavy charm and bottom quarks to probe the QGP's properties. We will introduce a quantum many-body approach to the QGP that provides a basis for transport simulations aimed at describing heavy-flavor observables in heavy-ion collisions. A critical role in constraining the interactions in the QGP, which occur in the non-perturbative regime of QCD, is played by first-principles computations of the QCD, or "lattice QCD". We will highlight progress over the last decade in applications to heavy-flavor observables in heavy-ion collisions, where it appears that remnants of the confining force in the QGP are at the origin of its extraordinary transport properties. We also make the case for dedicated inter-institutional theory efforts to convert the experimental findings into robust knowledge of the QGP and its conversion into hadrons, as it happened in the Big Bang.