Neutron Stars, Quark-Gluon Plasma, and the Early Universe: Uncovering the Phases of of the Strong Interaction in High-Energy Nuclear Collisions

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What is matter made of, and how does it behave under the most extreme conditions in the Universe? In this talk, we'll explore how the strong interaction—one of nature's fundamental forces, described by Quantum Chromodynamics (QCD)—shapes the structure of everything from atomic nuclei to stars.

To understand how matter behaves at extreme temperatures and densities, scientists recreate these conditions in the lab using high-energy nuclear collisions. In such experiments, ordinary matter can melt into an exotic state known as the quark-gluon plasma (QGP)—a hot, dense "soup" where the building blocks of protons and neutrons, quarks and gluons, are free to move. This state of matter existed just microseconds after the Big Bang.

As the QGP cools, it transforms back into familiar particles in a smooth transition called a crossover. But at very high densities—like those found in the core of neutron stars—the transition is predicted to be much more dramatic, like water suddenly boiling into steam. The point where these two types of transitions meet is called the QCD critical point, a key missing piece in our understanding of the Universe and a major goal in modern nuclear physics.

In this colloquium, we'll look at how cutting-edge experiments are helping us map the QCD phase diagram, revealing how matter behaves under these extreme conditions. We'll discuss recent findings on how matter expands in collisions, how certain quantum properties fluctuate, and what the production of rare particles like hypernuclei tells us about the inner structure of neutron stars. Finally, we'll look ahead to the next generation of experiments, made possible by powerful new research facilities currently under construction around the world.