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Equation of State of Strongly Interacting Matter from Physics-Informed Neural Networks

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Understanding the properties of strongly interacting matter is one of the central challenges in high-energy physics. In heavy-ion collisions, nuclei are smashed together at relativistic speeds to recreate extreme conditions of temperature and density, briefly producing a state of matter known as the quark-gluon plasma. This hot, dense matter behaves as a nearly perfect liquid — flowing with remarkably low viscosity — and is best described by relativistic hydrodynamics, whose key input is the equation of state encoding the system's thermodynamic properties.

The underlying theory, quantum chromodynamics, cannot yet be solved from first principles across the full phase diagram. Lattice QCD is reliable only at low baryon chemical potential, while the hadron resonance gas model holds only at low particle densities. Between them lies a critical gap — one that coincides precisely with the region being probed by next-generation experiments such as RHIC BES, FAIR, and CBM.

In this talk, I present a neural-network approach to bridging this gap. The network is trained to reproduce lattice QCD and hadron resonance gas thermodynamics in their regimes of validity, while extrapolating into the uncharted high-baryon-density region in a manner that remains thermodynamically consistent — enforced through convexity-preserving architecture and derivative constraints, in the spirit of physics-informed neural networks. The result is a four-dimensional equation of state, $P(T, {}_B, {}_Q, {}_S)$, spanning the full phase space relevant to heavy-ion collisions. I will conclude by showing how this equation of state is implemented within a full relativistic hydrodynamic simulation framework.

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