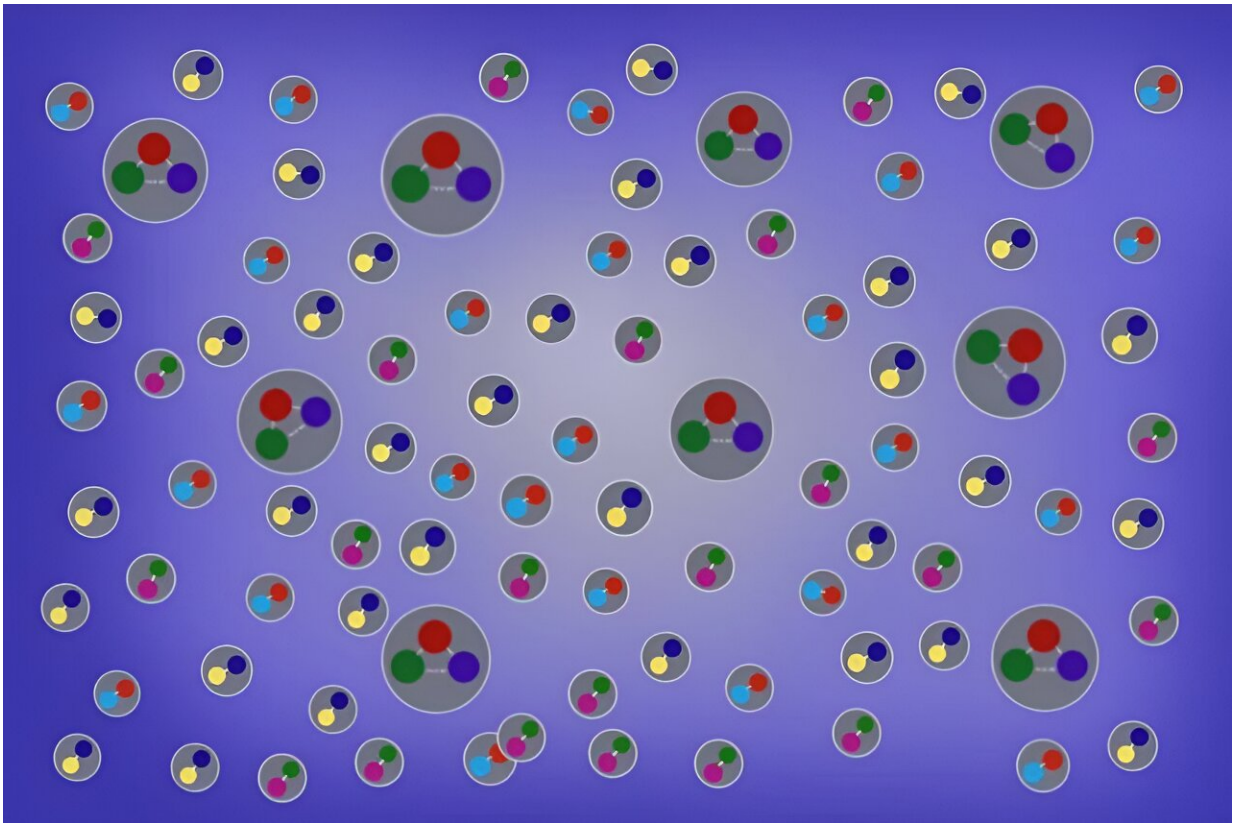


# How do quark-gluon-plasma fireballs explode into hadrons?

December 20 2023

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A cartoon of free-streaming hadrons emerging from quark-gluon plasma. Credit: Maneesha Sushama Pradeep

Quark gluon plasma (QGP) is an exciting state of matter that scientists create in a laboratory by colliding two heavy nuclei. These collisions

produce a QGP fireball. The fireball expands and cools following the laws of hydrodynamics, which govern how fluids behave in various conditions. Eventually, subatomic particles (protons, pions, and other hadrons, or particles made up of two or more quarks) emerge and are observed and counted by detectors surrounding the collision.

Fluctuations in the number of these particles from [collision](#) to collision carry important information about the QGP. However, extracting this information from what scientists can observe is a difficult task. An approach called the maximum entropy principle provides a crucial connection between these experimental observations and the hydrodynamics of the QGP [fireball](#).

The approach is [described](#) in the journal *Physical Review Letters*.

As a QGP fireball expands and cools, it eventually becomes too diluted to be described by hydrodynamics. At this stage the QGP has "hadronized." This means its energy and other quantum properties are carried by hadrons. These are [subatomic particles](#) such as protons, neutrons, and pions that are made up of quarks. The hadrons "freeze out"—they freeze information about the final hydrodynamic state of the QGP fireball, allowing the particles streaming from the collision to carry this information to the detectors in an experiment.

The research provides a tool for using simulations to compute observable [fluctuations](#) in the QGP. This has allowed the researchers, from the University of Illinois, Chicago, to use freeze-out to identify hints of a [critical point](#) between a QGP fireball and a gaseous hadronized state. This critical point is one of scientists' unresolved questions about [quantum chromodynamics](#), the theory of the strong gluon-driven interactions between quarks.

Fluctuations in the QGP carry information about the region of the QCD

phase diagram where the collisions "freeze out." This makes connecting fluctuations in hydrodynamics to fluctuations of the observed hadrons a crucial step in translating experimental measurements into the map of the QCD phase diagram. Large event-by-event fluctuations are telltale experimental signatures of the critical point.

Data from the Run-I Beam Energy Scan (BES) program at the Relativistic Heavy-Ion Collider (RHIC) hint at the presence of the critical point. To follow this hint, the researchers proposed a novel and universal approach to converting hydrodynamic fluctuations into fluctuations of hadron multiplicities.

The approach elegantly overcomes challenges faced by previous attempts to solve this problem. Crucially, the new approach based on the maximum-entropy principle preserves all the information about the fluctuations of conserved quantities described by hydrodynamics. The novel freeze-out procedure will find applications in the theoretical calculations of event-by-event fluctuations and correlations observed in experiments such as the Beam Energy Scan program at RHIC aimed at mapping the QCD phase diagram.

**More information:** Maneesha Sushama Pradeep et al, Maximum Entropy Freeze-Out of Hydrodynamic Fluctuations, *Physical Review Letters* (2023). [DOI: 10.1103/PhysRevLett.130.162301](https://doi.org/10.1103/PhysRevLett.130.162301)

Provided by US Department of Energy

Citation: How do quark-gluon-plasma fireballs explode into hadrons? (2023, December 20) retrieved 28 April 2024 from <https://phys.org/news/2023-12-quark-gluon-plasma-fireballs-hadrons.html>

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