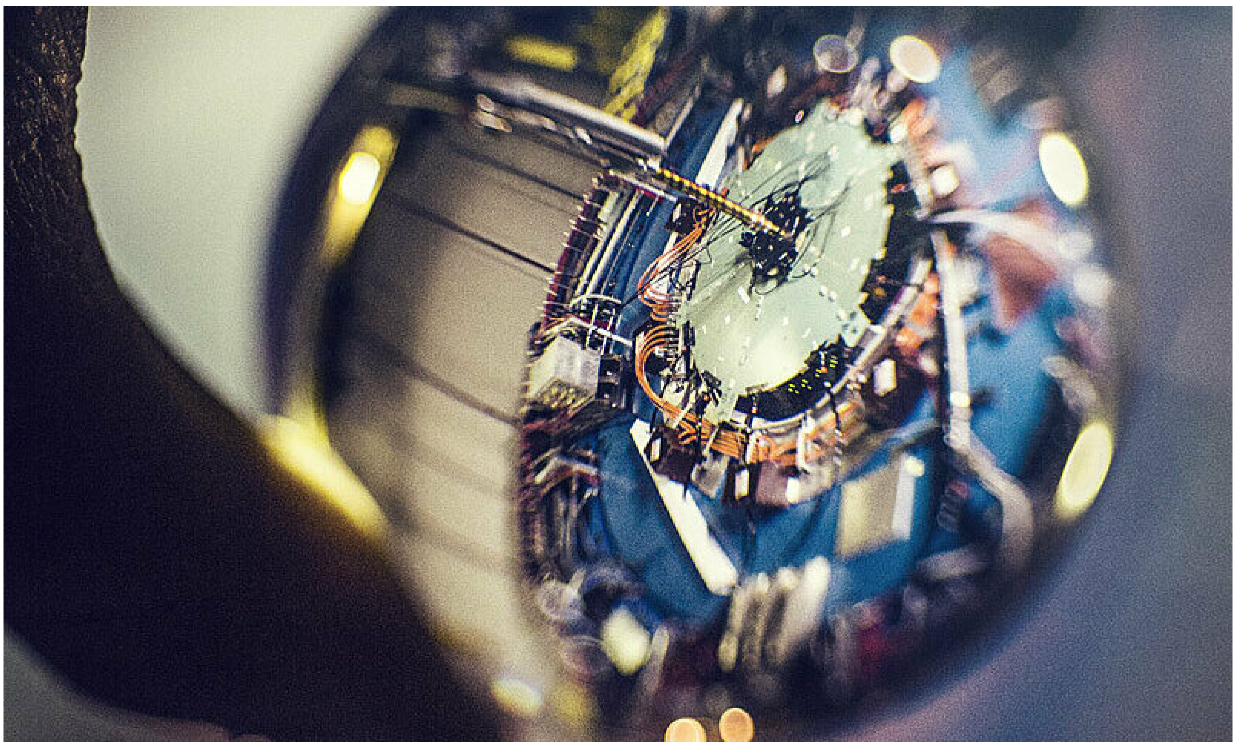
Big Bang query: Mapping how a mysterious liquid became all matter

January 14 2019



A new perspective of the STAR detector at RHIC, seen through crystal ball refraction photography.The photo was a finalist for Brookhaven National Laboratory's Photowalk in 2018. Credit: Joe Caggiano

The leading theory about how the universe began is the Big Bang, which says that 14 billion years ago the universe existed as a singularity, a one-dimensional point, with a vast array of fundamental particles contained within it. Extremely high heat and energy caused it to inflate and then expand into the cosmos as we know it—and, the expansion continues to this day.

The initial result of the Big Bang was an intensely hot and energetic liquid that existed for mere microseconds that was around 10 billion degrees Fahrenheit (5.5 billion Celsius). This liquid contained nothing less than the building blocks of all matter. As the universe cooled, the particles decayed or combined giving rise to... well, everything.

Quark-gluon plasma (QGP) is the name for this mysterious substance so called because it was made up of quarks—the fundamental particles—and gluons, which physicist Rosi J. Reed describes as "what quarks use to talk to each other."

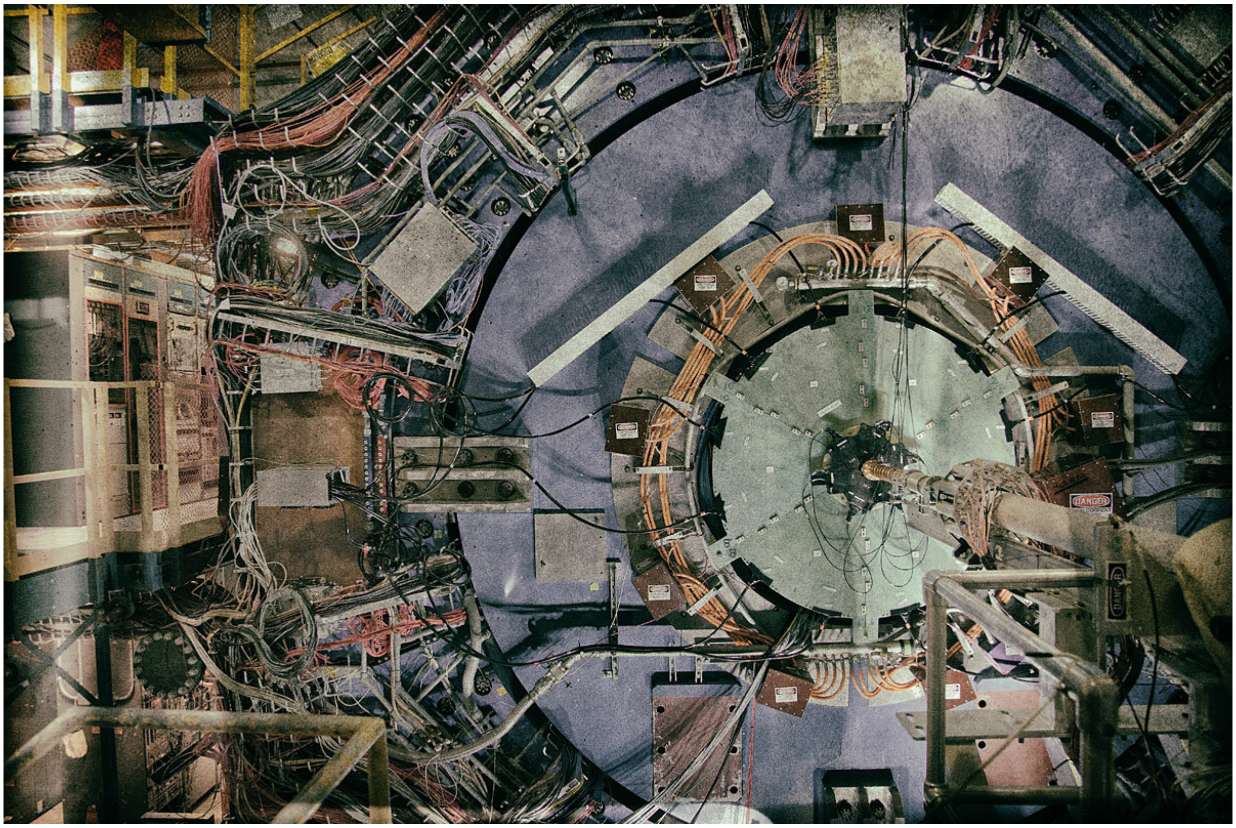
Scientists like Reed, an assistant professor in Lehigh University's Department of Physics whose research includes experimental high-energy physics, cannot go back in time to study how the Universe began. So they re-create the circumstances, by colliding heavy ions, such as Gold, at nearly the speed of light, generating an environment that is 100,000 times hotter than the interior of the sun. The collision mimics how quark-gluon plasma became matter after the Big Bang, but in reverse: the heat melts the ions' protons and neutrons, releasing the quarks and gluons hidden inside them.

There are currently only two operational accelerators in the world capable of colliding heavy ions—and only one in the U.S.: Brookhaven National Lab's Relativistic Heavy Ion Collider (RHIC). It is about a three-hour drive from Lehigh, in Long Island, New York.

Reed is part of the STAR Collaboration , an international group of scientists and engineers running experiments on the Solenoidal Tracker at RHIC (STAR). The STAR detector is massive and is actually made up of many detectors. It is as large as a house and weighs 1,200 tons. STAR's specialty is tracking the thousands of particles produced by each ion collision at RHIC in search of the signatures of quark-gluon plasma.

"When running experiments there are two 'knobs' we can change: the species—such as gold on gold or proton on proton—and the collision energy," says Reed. "We can accelerate the ions differently to achieve different energy-to-mass ratio."

Using the various STAR detectors, the team collides ions at different collision energies. The goal is to map quark-gluon plasma's phase diagram, or the different points of transition as the material changes under varying pressure and temperature conditions. Mapping quark-gluon plasma's phase diagram is also mapping the nuclear strong force, otherwise known as Quantum Chromodynamics (QCD), which is the force that holds positively charged protons together.



The photo was a winner in Brookhaven National Laboratory's 2018 Photowalk . Credit: Steven Schreiber

"There are a bunch of protons and neutrons in the center of an ion," explains Reed. "These are positively charged and should repel, but there's a 'strong force' that keeps them together? strong enough to overcome their tendency to come apart."

Understanding quark-gluon plasma's phase diagram, and the location and existence of the phase transition between the plasma and normal matter is of fundamental importance, says Reed.

"It's a unique opportunity to learn how one of the four fundamental forces of nature operates at temperature and energy densities similar to those that existed only microseconds after the Big Bang," says Reed.

Upgrading the RHIC detectors to better map the "strong force"

The STAR team uses a Beam Energy Scan (BES) to do the phase transition mapping. During the first part of the project, known as BES-I, the team collected observable evidence with "intriguing results." Reed presented these results at the 5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan in Hawaii in October 2018 in a talk titled: "Testing the quark-gluon plasma limits with energy and species scans at RHIC."

However, limited statistics, acceptance, and poor event plane resolution did not allow firm conclusions for a discovery. The second phase of the project, known as BES-II, is going forward and includes an improvement that Reed is working on with STAR team members: an upgrade of the Event Plane Detector. Collaborators include scientists at Brookhaven as well as at Ohio State University.

The STAR team plans to continue to run experiments and collect data in 2019 and 2020, using the new Event Plane Detector. According to Reed, the new detector is designed to precisely locate where the collision happens and will help characterize the collision, specifically how "head on" it is.

"It will also help improve the measurement capabilities of all the other detectors," says Reed.

The STAR collaboration expects to run their next experiments at RHIC in March 2019.

Provided by Lehigh University