Table-top supernova: Amplification of cosmic magnetic fields replicated (w/ Video)

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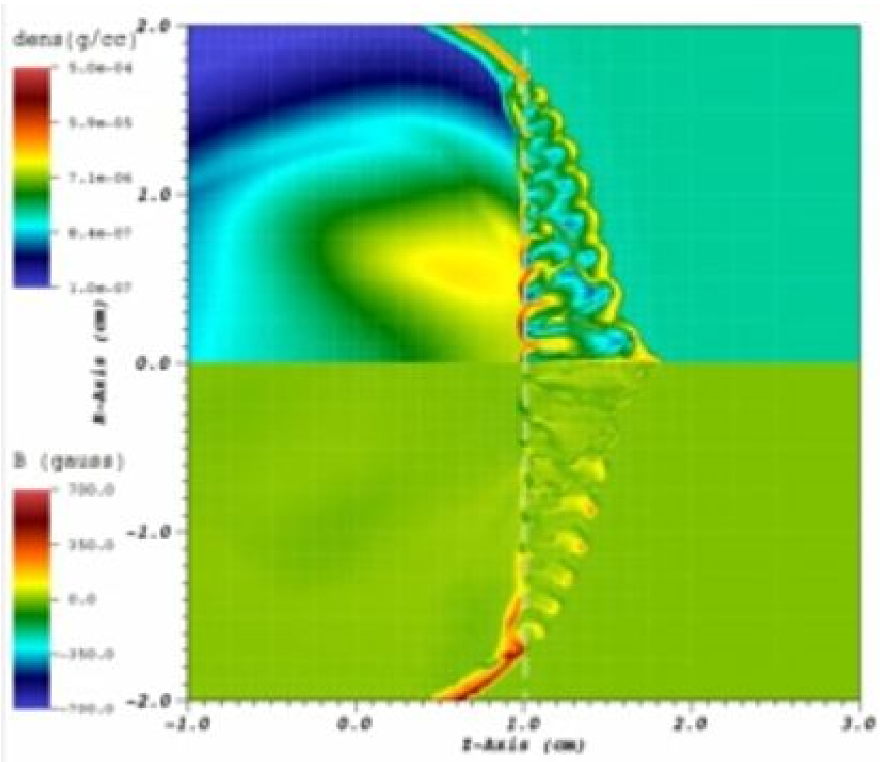

Astrophysicists have established that cosmic turbulence could have amplified magnetic fields to the strengths observed in interstellar space.

"Magnetic fields are ubiquitous in the universe," said Don Lamb, the Robert A. Millikan Distinguished Service Professor in Astronomy &

Astrophysics at the University of Chicago. "We're pretty sure that the fields didn't exist at the beginning, at the Big Bang. So there's this fundamental question: how did magnetic fields arise?"

Helping to answer that question, which is of fundamental importance to understanding the universe, were millions of hours of supercomputer simulations at Argonne National Laboratory. Lamb and his collaborators, led by scientists at the University of Oxford, report their findings in an article published in the June 1 issue of *Nature Physics*.

The paper describes experiments at the Vulcan laser facility of the United Kingdom's Rutherford Appleton Laboratory that recreates a supernova (exploding star) with beams 60,000 billion times more powerful than a laser pointer. The research was inspired by the detection of magnetic fields in Cassiopeia A, a supernova remnant, which are approximately 100 times stronger than those in adjacent interstellar space.

Physics at multiple scales

"It may sound surprising that a tabletop laboratory experiment that fits inside an average room can be used to study astrophysical objects that are light years across," said Gianluca Gregori, professor of physics at Oxford. "In reality, the laws of physics are the same everywhere, and physical processes can be scaled from one to the other in the same way that waves in a bucket are comparable to waves in the ocean. So our experiments can complement observations of events such as the Cassiopeia A supernova."

Making the advance possible was the extraordinarily close cooperation between Lamb's team at UChicago's Flash Center for Computational Science and Gregori's team of experimentalists.

"Because of the complexity of what's going on here, the simulations were absolutely vital to inferring exactly what's going on and therefore confirming that these mechanisms are happening and that they are behaving in the way that theory predicts," said Jena Meinecke, graduate student in physics at Oxford and lead author of the *Nature Physics* paper.

Magnetic fields range from quadrillionths of a gauss in the cosmic voids of the universe, to several microgauss in galaxies and galaxy clusters (ordinary refrigerator magnets have magnetic fields of approximately 50 gauss). Stars like the sun measure thousands of gauss. Neutron stars, which are the extremely compact, burned out cores of dead stars, exhibit the largest magnetic fields of all, ones exceeding quadrillions of gauss.

In 2012, Gregori's team successfully created small magnetic fields, called "seed fields," in the laboratory via an often-invoked effect called the Biermann battery mechanism. But how could seed fields grow to gigantic sizes in interstellar space? Building on their earlier findings, Gregori and his collaborators at 11 institutions worldwide now have demonstrated the amplification of magnetic fields by turbulence.

In their experiment, the scientists focused laser beams onto a small carbon rod sitting in a chamber filled with a low-density gas. The lasers, generating temperatures of a few million degrees, caused the rod to explode, creating a blast that expanded throughout the gas.

"The experiment demonstrated that as the blast of the explosion passes through the grid it becomes irregular and turbulent, just like the images from Cassiopeia," Gregori said.

Experimental variables

"The experimentalists knew all the physical variables at a given point. They knew exactly the temperature, the density, the velocities," said

UChicago research scientist Petros Tzeferacos, a study co-author. Tzeferacos and his colleagues incorporated that data into their FLASH simulations.

"This allows us to benchmark the code against something that we can see," Tzeferacos said. Such benchmarking—called validation—shows that the simulations can reproduce the experimental data. The simulations consumed 20 million processing hours on both the Mira and Intrepid supercomputers at Argonne. Mira, which can perform 10 quadrillion calculations per second, is 20 times faster than Intrepid.

With validation in hand, all members of the collaboration could return repeatedly to the simulations to get answers to new questions regarding the physics they saw. "We could look at the velocity instead of the density of the magnetic field, or we might look at the pressure," Lamb said. "This simulation is a treasure trove of information about what's really going on. It's actually critical to understanding correctly what's really happening."

More information: "Turbulent amplification of magnetic fields in laboratory laser-produced shock waves," by J. Meinecke and 26 others, *Nature Physics*, June 1, 2014. DOI: 10.1038/nphys2978

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