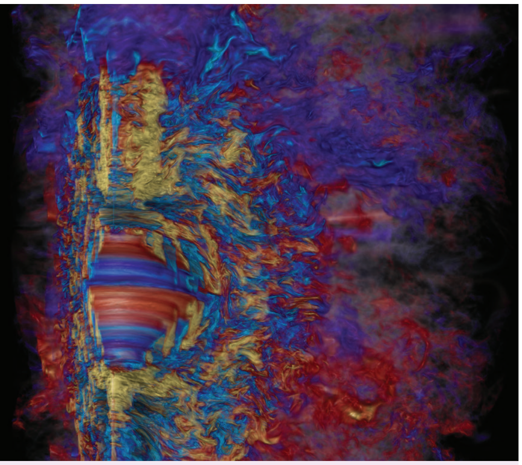
Building Powerful Magnetic Fields



A visualization of the strong, ordered magnetic field built up by dynamo action in the core of a rapidly rotating, collapsed star.

When certain massive stars use up all of their fuel and collapse onto their cores, explosions 10 to 100 times brighter than the average supernova occur. Astrophysicists from Caltech, UC Berkeley, the Albert Einstein Institute, and the Perimeter Institute for Theoretical Physics have used the National Science Foundation's Blue Waters supercomputer to perform three-dimensional computer simulations to fill in an important missing piece of our understanding of what drives these blasts.

In the past, scientists have simulated the evolution of massive stars from their collapse to jet-driven explosions by factoring unrealistically large magnetic fields into their models—without explaining how they could be generated in the first place.

"That's what we were trying to understand with this study," says Luke Roberts, a NASA Einstein Fellow at Caltech and a coauthor on a paper reporting the team's findings in the journal *Nature*. "How can you start with the magnetic field you might expect in a massive star that is about to collapse—or at least an initial magnetic field that is much weaker than the field required to power these explosions—and build it up to the strength that you need to collimate a jet and drive a jet-driven supernova?"

For more than 20 years, theory has suggested that the magnetic field of the innermost regions of a massive star that has collapsed, also known as a proto-neutron star, could be amplified by an instability in the flow of its plasma if the core is rapidly rotating, causing its outer edge to rotate faster than its center. However, no previous models could prove this process could strengthen a magnetic field to the extent needed to collimate a jet, largely because these simulations lacked the resolution to resolve where the flow becomes unstable.

Lead author on the paper Philipp Mösta—who started the work while a postdoctoral scholar at Caltech and is now a NASA Einstein Fellow at UC Berkeley—and his colleagues developed a simulation of a rapidly rotating collapsed stellar core and scaled it so that it could run on the Blue Waters supercomputer, known for its ability to provide sustained high-performance computing for problems that produce large amounts of information. The team's highest-resolution simulation took 18 days of around-the-clock computing by about 130,000 computer processors to simulate just 10 milliseconds of the core's evolution.

In the end, the researchers were able to simulate the so-called magnetorotational instability responsible for the amplification of the magnetic field. As theory predicted, they saw that the instability creates small patches of an intense magnetic field distributed throughout the core of the collapsed star. They found that a dynamo process connects those patches and generates currents that amplify the magnetic fields, turning them into the kind needed to power jets. —*KF*