Tied in knots: New insights into plasma behavior focus on twists and turns

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Physicist Christopher Smiet. Credit: Elle Starkman / PPPL Office of Communications

Whether zipping through a star or a fusion device on Earth, the electrically charged particles that make up the fourth state of matter better known as plasma are bound to magnetic field lines like beads on a string. Unfortunately for plasma physicists who study this phenomenon, the magnetic field lines often lack simple shapes that equations can easily model. Often they twist and knot like pretzels. Sometimes, when the lines become particularly twisted, they snap apart and join back together, ejecting blobs of plasma and tremendous amounts of energy.

Now, findings from an international team of scientists led by the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) show that the twisted magnetic fields can evolve in only so many ways, with the plasma inside following a general rule. As long as there is high pressure on the outside of the plasma pressing inward, the plasma will spontaneously take on a doughnut, or torus, shape and balloon out in a horizontal direction. However, the outward expansion is constrained by the average amount of twisting in the plasma, a quality known as "helicity."

"The helicity prevents the configuration from blowing apart and forces it to evolve into this self-organized, twisted structure," says Christopher Smiet, a physicist at PPPL and lead author of the paper reporting the results in the *Journal of Plasma Physics*.

The findings apply to the entire gamut of plasma phenomena and can provide insight into the behavior of magnetic clouds, huge masses of plasma emitted from the sun that can expand and collide with the Earth's own magnetic field. In mild form, the collisions cause the northern lights. If powerful enough, these collisions can disrupt the operations of satellites and interfere with cell phones, global positioning systems, and radio and television signals.

"Since the effects are in part caused by topological properties like linking and twisting that are not affected by shape or size, the results apply both to outer space plasma plumes thousands of light years long and centimeter-long structures in Earth-bound fusion facilities," Smiet says.

Moreover, "by studying the magnetic field in this more general framework, we can learn new things about the self-organizing processes within tokamaks and the instabilities that interfere with them," Smiet says.

Smiet's future research plans involve investigating changes in the linking and connections of field lines in tokamaks during two types of plasma instabilities that can hinder fusion reactions. "It's fascinating what you can learn when you study how knots unravel," Smiet says.

The research team included scientists from Leiden

University, the Dutch Institute for Fundamental Energy Research, and the University of California-Santa Barbara. This research was supported by the U.S. Department of Energy (Fusion Energy Sciences) and the Rubicon program that is partly funded by the Netherlands Organization for Scientific Research.

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