Space Magnetism May Hold Secret to Fusion Power

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New discoveries about magnetic field lines and the first-ever direct observation of their reconnection in space are offering hope that scientists will learn how to unlock fusion power as an energy source in the future.

"The reconnection processes in the [Earth's] magnetosphere and in fusion devices are the same animal," said James Drake, a University of Maryland physicist.

Space contains magnetic fields that direct the flow of plasma, an energetic fourth state of matter consisting of positive ions and electrons. The plasma particles normally follow the paths of the magnetic field lines like streams of cars following highways.

Magnetic reconnection can release that stored energy when two magnetic field lines bend towards each other and fuse to create new field lines. The effect is not unlike an earthquake forcibly realigning parallel highways into perpendicular routes and channeling cars along the newly created paths. Although some released plasma energy travels in a straight line — called a super-Alfvenic electron jet — other plasma particles fan out as though escaping the opening of a trumpet.

The effect not only fascinates astrophysicists but also frustrates efforts on Earth to create sustained energy sources through fusion. Experimental fusion reactors force atomic particles to fuse together and release energy as plasma. The plasma is contained within a "magnetic bottle," or a cage of magnetic field lines, so that the high plasma temperatures can maintain the fusion reaction.

However, magnetic reconnection can break the magnetic bottle and allow plasma to reach the colder walls of the reactor where fusion will not sustain itself.

Drake became interested in the topic when he looked at early fusion studies and realized how many theories at the time were "dead wrong" about magnetic reconnection. To learn more about the phenomenon, he had to look beyond Earth.

"I started realizing some of the best magnetic reconnection data is in space," Drake said.

During a sabbatical at the University of California-Berkeley, the theoretical physicist happened to work in the same office as Tai Phan, an observational physicist who was looking at magnetic field data from the European Space Agency's Cluster satellites.

"I was doing theory, Tai was doing data and we suddenly saw this correspondence," Drake marveled. "It was purely accidental."

The four Cluster satellites crossed through a turbulent plasma region just outside Earth's magnetic field in January 2003, when they happened to run into an area where magnetic reconnection had occurred. Physicists thought such areas, known as electron diffusion regions, were just over six miles long and so spacecraft would probably miss them in the vastness of space.

Instead, a new look at the Cluster data showed that the electron diffusion region measured 1,864 miles long — 300 times longer than early theoretical expectations and still four times longer than seen in the latest astrophysics simulations. That also marked the first ever direct observations of magnetic reconnection in space.

Although the basic physics behind magnetic reconnection remain a mystery, Cluster promises that future missions have a good chance of further examining the phenomenon. One example is NASA's Magnetospheric Multiscale mission, which will consist of four spacecraft that study why the plasma particles can become "unfrozen" or unstuck from the magnetic field lines they normally travel along. Magnetic reconnection is simply the most "dramatic" example of this, Drake said.

Such an energy release amounts to a conversion of magnetic energy into particle energy, which can occur in black hole jets and drives solar flares. Drake hopes to someday create a computer model that can accurately describe the conversion process — and if scientists can also apply some understanding towards improving fusion reactors, so much the better.

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