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Reconnecting with a magnetic mystery

MAGNETIC RECONNECTION MAKES THINGS explode. It operates anywhere magnetic fields pervade space—which is to say almost everywhere. On the Sun, magnetic reconnection causes solar flares as powerful as a billion atomic bombs. In Earth's atmosphere, it fuels magnetic storms and auroras. In laboratories, it can cause big problems in fusion reactors.

However, scientists cannot explain it.

The basics are clear enough. Magnetic lines of force cross, cancel and reconnect, and an explosion results. Magnetic energy is unleashed in the form of heat and charged-particle kinetic energy.

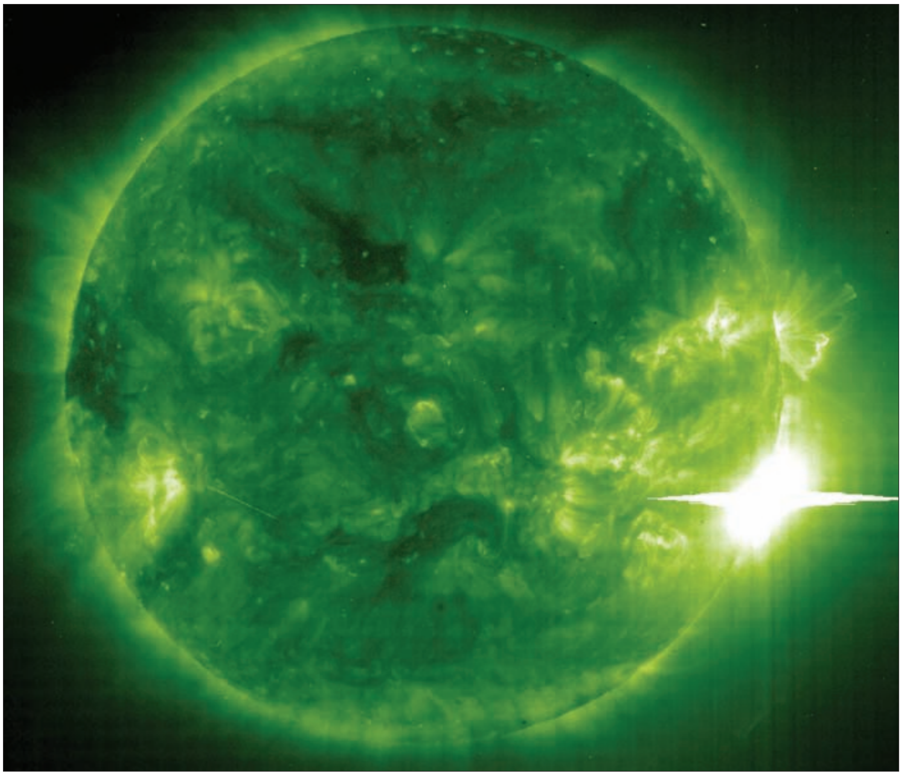
Researchers are trying to understand why the simple act of crisscrossing magnetic field lines triggers such a ferocious explosion. "Something very interesting and fundamental is going on that we do not really understand—not from lab experiments or from simulations," says Melvyn Goldstein, chief of the Geospace Physics Laboratory at NASA Goddard.

NASA is going to launch a mission to try to get to the bottom of the mystery, through the Magnetospheric MultiScale or MMS mission. MMS consists of four identical satellites that will fly in a tetrahedron formation through Earth's magnetosphere to discover how magnetic reconnection works.

When magnetic fields become tangled, as they often do in the magnetosphere, they can merge, which creates an explosive release of energy whereby magnetic energy is converted directly into heat and charged-particle kinetic energy. Magnetic reconnection sparks solar flares and powers auroras; it even pops up in nuclear fusion chambers (tokamaks) on Earth. It is the ultimate driver of space weather, impacting human technologies such as communications, navigation and power grids.

MMS will seek to solve the mystery of the small-scale physics of reconnection. It will also investigate how the energy conversion that occurs during the process accelerates particles to high energies, and what role plasma turbulence plays in reconnection events.

The Sun unleashed a powerful flare on November 4, 2003, that could be the most powerful ever witnessed and probably as strong as anything detected since satellites were able to record these events in the mid-1970s. It was captured by instruments aboard the SOHO satellite.



A natural laboratory

These processes—magnetic reconnection, particle acceleration and turbulence—occur in all astrophysical plasma systems but can be studied in situ only in our solar system, and most efficiently only in Earth's magnetosphere, where they control the dynamics of the geospace environment and play an important role in phenomena known as space weather.

The MMS science investigation is called SMART—solving magnetospheric acceleration, reconnection and turbulence. Principal investigator James L. Burch of Southwest Research Institute (SwRI) in San Antonio will head the SMART team, comprising a group of researchers from several U.S. and foreign institutions.

The mission passed its preliminary design review in May 2009 and was approved for implementation the following month. Engineers can now start building the spacecraft.

"Earth's magnetosphere is a wonderful natural laboratory for studying reconnection," Burch points out. "It is big and roomy, and reconnection is taking place there almost nonstop."

In its outer layer, where Earth's magnetic field meets the solar wind, reconnection events create temporary magnetic "portals" connecting the Earth to the Sun. Inside the magnetosphere, in a long drawn-out structure called the magnetotail, reconnection propels high-energy plasma clouds toward Earth, triggering the Northern Lights when they hit. There are many other examples, and MMS will explore them all.

The spacecraft and instruments

NASA Goddard will build all four spacecraft and integrate four sets of instruments into the four MMS observatories. "Each observatory is shaped like a giant hockey puck, about 12 ft in diameter and 4 ft in height," says Karen Halterman, MMS project manager at Goddard.

Goddard scientists will conduct environmental testing and support launch vehicle integration and operations. Goddard is also developing the Mission Operations Center that will monitor and control the satellites and provide all the flight dynamics support for the extensive maneuvering and orbit raising required for the mission. Scientists and engineers at Goddard are also building the Fast Plasma Investigation, which is part of the instrument suite.

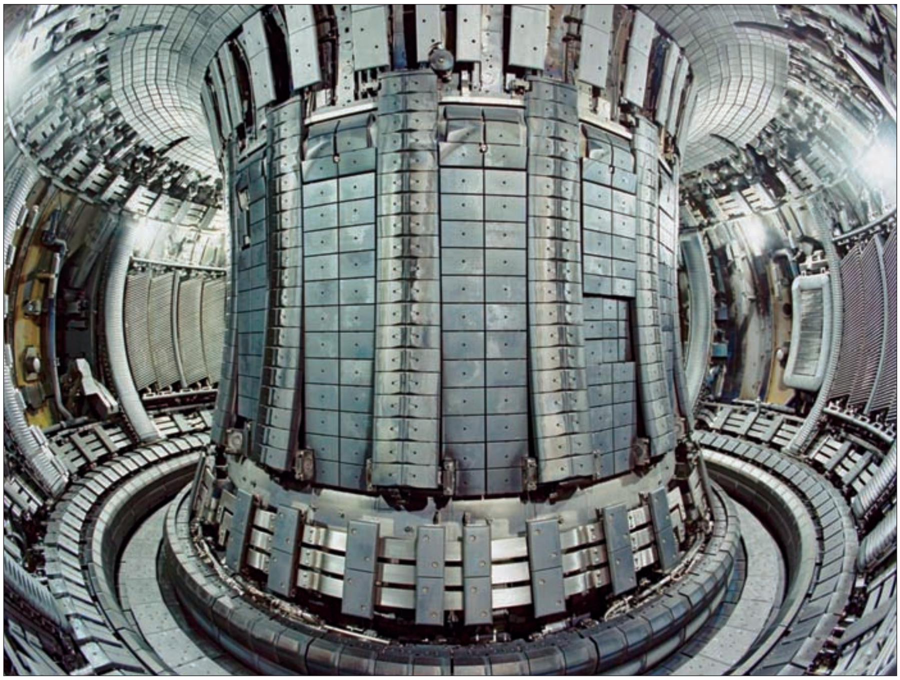
Engineers at SwRI will provide the MMS instruments as a suite. Under contract to Goddard, SwRI is responsible for the mission science, development of the instruments for the four observatories, science operations, data analysis, theory and modeling, education and public outreach.

The mission's sensors will monitor electromagnetic fields and charged particles. The sensors are being built at a number of universities and labs around the country, led by scientists at SwRI. When the instruments are completed, they will be integrated into the spacecraft frames at Goddard. Launch is scheduled for 2014 onboard an Atlas V rocket.

Improving on tokamaks

Any new physics that MMS learns could ultimately help alleviate the energy crisis on Earth.

"For many years, researchers have looked to fusion as a clean and abundant source of energy for our planet," notes Burch. "One approach, magnetic confinement fusion, has yielded very promising results with devices such as tokamaks. But there have been problems keeping the plasma [hot ionized gas] contained in the chamber.



Inside a tokamak, magnetic reconnection can cause a sawtooth crash.

"One of the main problems is magnetic reconnection," he adds. "A spectacular and even dangerous result of reconnection is known as the sawtooth crash: As the heat in the tokamak builds up, the electron temperature reaches a peak and then 'crashes' to a lower value, and some of the hot plasma escapes. This is caused by reconnection of the containment field."

In light of this, one might suppose that tokamaks would be a good place to study reconnection. But no, says Burch—reconnection in a tokamak happens in such a tiny volume, only a few millimeters wide, that it is very difficult to study. It is practically impossible to build sensors small enough to probe the reconnection zone.

Earth's magnetosphere is much better. In the expansive magnetic bubble that surrounds our planet, the process plays out over volumes as large as tens of kilometers across. "We can fly spacecraft in and around it and get a good look at what's going on," he says.

The MMS spacecraft will fly directly into the reconnection zone. They are sturdy enough to withstand the energy released by the reconnection events known to occur in Earth's magnetosphere. There is nothing standing in the way of a full two-year discovery mission.

Program structure

Science team members and instrument development for the MMS mission are provided by the Universities of California-Los Angeles, Colorado, Iowa, and New Hampshire; Johns Hopkins University Applied Physics Laboratory; Rice University; NASA Goddard; Lockheed Martin Advanced Technology Center; and the Aerospace Corporation. International contributions to the MMS instrument suite are provided by the Austrian Academy of Sciences, Sweden's Royal Institute of Technology and Institute of Space Physics; France's Plasma Physics Laboratory and Toulouse Space Center; and Japan's Institute of Space and Astronautical Science.

MMS is a NASA Science Mission Directorate Heliophysics mission in the Solar Terrestrial Probes Program. Goddard manages the effort, and Kennedy Space Center is providing launch services.

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