Several NASA spacecraft track energy through space

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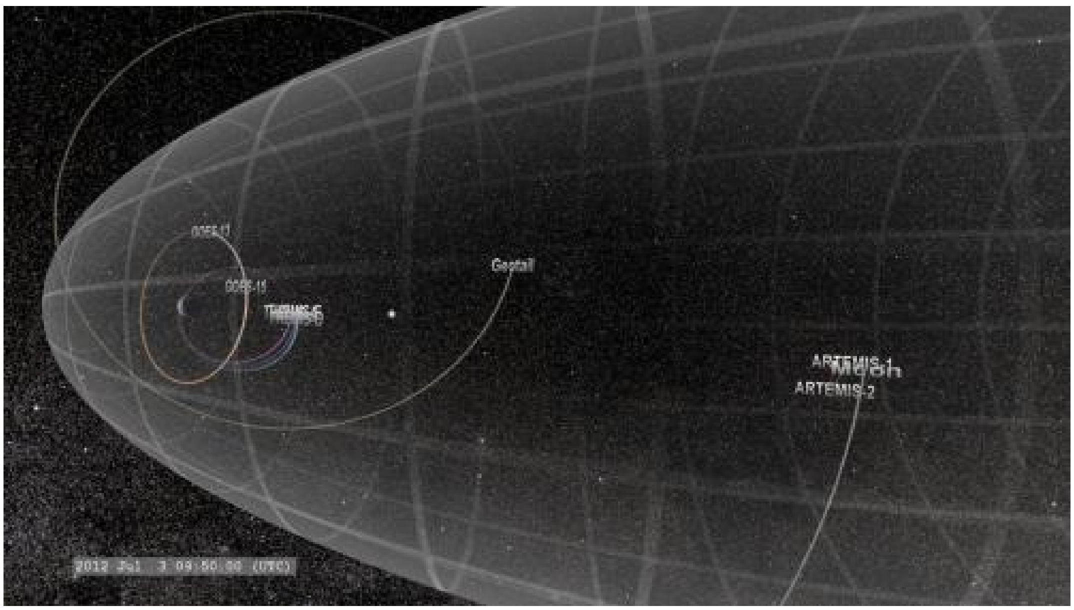

On July 3, 2012, eight spacecraft were lined up on the night side of Earth, enabling scientists to track how magnetic energy from the sun moved around Earth, reconnected at a point about half way to the moon, and then spread through the back end of Earth's magnetic environment, the magnetotail. Credit: NASA/SVS

(Phys.org) —Scientists have provided the most comprehensive details yet of the journey energy from the sun takes as it hurtles around Earth's magnetosphere. Understanding the changes energy from the sun undergoes as it travels away and out into space is crucial for scientists to achieve their goal of some day predicting the onset of space weather that creates effects such as the shimmering lights of the aurora or interruptions in radio communications at Earth.

Taking advantage of an unprecedented alignment of eight satellites through the vast magnetic environment that surrounds Earth in space, including NASA's ARTEMIS and THEMIS, scientists now have comprehensive details of the energy's journey through a process that forms the aurora, called a substorm. Their results, published in the journal *Science* on Sept. 27, 2013, showed that small events unfolding over the course of a millisecond can result in energy flows that last up to half an hour and cover an area 10 times larger than Earth.

"One of the unique features of our research field is that microscopic things can sometimes run the whole show," says David Sibeck, the project scientist for ARTEMIS and THEMIS at NASA's Goddard Space Flight Center in Greenbelt, Md. "The tiniest causes may have global consequences. That's not typical in terrestrial weather where you don't have to look at a tiny spot on a weather map to understand a whole hurricane."

Trying to understand how gigantic explosions on the sun can create space weather effects involves tracking energy from the original event all the way to Earth. It's not unlike keeping tabs on a character in a play with many costume changes, because the energy changes form frequently along its journey: magnetic energy causes eruptions that lead to kinetic energy as particles hurtle away, or thermal energy as the particles heat up. Near Earth, the energy can change through all these various forms once again.

Most of the large and small features of substorms take place largely in the portion of Earth's magnetic environment called the magnetotail. Earth sits inside a large magnetic bubble called the magnetosphere. As Earth orbits around the sun, the solar wind from the sun streams past the bubble, stretching it outward into a teardrop. The magnetotail is the long point of the teardrop trailing out to more than 1 million miles on the night side of Earth. The moon orbits Earth much closer, some 240,000 miles away, crossing in and out of the magnetotail.

Tracking how such small events can have large-scale space weather effects requires observatories located throughout the whole system. To help with this endeavor, in July 2011, two of the five THEMIS (Time History of Events and Macroscale Interactions during Substorms) spacecraft moved into place around the moon for a different vantage point on the magnetotail, through which the moon travels once a month. NASA renamed these two spacecraft the ARTEMIS mission for Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun. Once per year, all the orbits of the THEMIS and ARTEMIS spacecraft line up in the magnetotail together. On the most recent conjunction, in July 2012, a substorm occurred. During the same period, the joint Japan Aerospace Exploration Agency/NASA mission Geotail and the National Oceanic and Atmospheric Administration's GOES 13 and GOES 15 were also in the magnetotail.

With eight spacecraft making observations at once, the scientists had a comprehensive view of how the energy in any given region moved around and transformed into other kinds of energy.

"It's a meticulous accounting job," says Vassilis Angelopoulos, the principle investigator of ARTEMIS and THEMIS at the University of California in Los Angeles and the first author on the *Science* paper. "With all these spacecraft measuring what's going on continuously throughout the system, we can track the total energy and see where and when it's converted into different kinds of energy. And the effort paid off handsomely!"

Scientists have observed much of the energy's journey through a substorm before. When the solar wind streams off the sun it can connect with the front of Earth's magnetosphere. As the two sets of magnetic fields come together, a process called magnetic reconnection turns the energy of the forward-moving solar wind into an explosion that sends particles and magnetic fields moving around the planet to the far side of Earth. Here, the fields reconnect again creating a burst that turns magnetic energy into acceleration of particles and heating. Just where and how this energy converted to particle movement, however, has been unclear.

The details of what happened next required observations from many spacecraft simultaneously. While the magnetic reconnection event itself happened in a specific place somewhere halfway between Earth and moon's orbit in a region just a couple hundreds of miles across, this is not the main place where the energy was converted. Regions, labeled as "reconnection fronts" in the paper, surged away from the original reconnection point—one propagated toward Earth and one moved away, past the moon and down the magnetotail. These fronts are like sheets of current, a wall hurtling in each direction, continuing to convert energy for up to 30 minutes afterward. The energy moving in toward Earth helps to create the aurora and it also funnels into the giant donuts of radiation around Earth called the radiation belts.

"The amount of power being converted is comparable to the electric power generation on Earth from all sources at any moment in time. And it happens over 30 minutes," says Angelopoulos. "The amount of energy released is equivalent to a 7.1 Richter scale earthquake."

The fact that this energy can move around so dramatically is not in and of itself surprising. Scientists have certainly previously suggested such things based on computer models. But it is only with a fleet of spacecraft that scientists can confirm the location and exact nature of the process, not to mention learning something new such as how continuous and long term the energy conversion process is after the initial magnetic reconnection event.

In late 2014, NASA will add a new mission to their Heliophysics fleet. The Magnetospheric Multiscale or MMS mission will put spacecraft directly in the magnetic reconnection areas on both the day- and night-sides of Earth.

"Understanding where to look for the energy conversion, opens up a new window for research," says Sibeck. "MMS will be focusing on tracking just this kind of observation."

Work like this lays the groundwork for a full mapping of the transfer of energy from sun to Earth. Once MMS launches there will be even more opportunities to add observations to the yearly ARTEMIS and THEMIS spacecraft conjunctions along with other space assets in orbit, forming a veritable global space weather station network. These will be able to observe and study the constantly changing solar energy along its journey through Earth's near space environment, in the upcoming solar maximum. This knowledge is critical for improving future modeling and prediction of space weather fronts as meteorologists do now for weather fronts on Earth.

More information: "Electromagnetic Energy Conversion at Reconnection Fronts," by V. Angelopoulos et al. *Science*, 2013.

Provided by NASA's Goddard Space Flight Center