Lunar orbiters discover source of space weather near Earth

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Credit: NASA

(Phys.org) —Solar storms—powerful eruptions of solar material and magnetic fields into interplanetary space—can cause what is known as "space weather" near Earth, resulting in hazards that range from interference with communications systems and GPS errors to extensive power blackouts and the complete failure of critical satellites.

New research published today increases our understanding of Earth's space environment and how space weather develops.

Some of the energy emitted by the sun during solar storms is temporarily stored in Earth's stretched and compressed magnetic field. Eventually, that solar energy is explosively released, powering Earth's radiation belts and lighting up the polar skies with brilliant auroras. And while it is possible to observe solar storms from afar with cameras, the invisible process that unleashes the stored magnetic energy near Earth had defied observation for decades.

In the Sept. 27 issue of the journal *Science*, researchers from the UCLA College of Letters and Science, the Austrian Space Research Institute (IWF Graz) and the Japan Aerospace Exploration Agency (JAXA) report that they finally have measured the release of this magnetic energy close up using an unprecedented alignment of six Earth-orbiting spacecraft and NASA's first dual lunar orbiter mission, ARTEMIS.

Space weather begins to develop inside Earth's magnetosphere, the giant magnetic bubble that shields the planet from the supersonic flow of magnetized gas emitted by the sun. During solar storms, some solar energy enters the magnetosphere, stretching the bubble out into a long, teardrop-shaped tail that extends more than a million miles into space.

The stored magnetic energy is then released by a process called "magnetic reconnection." This event can be detected only when fast flows of energized particles pass by a spacecraft positioned at exactly the right place at the right time.

Luckily, this happened in 2008, when NASA's five Earth-orbiting THEMIS satellites discovered that magnetic reconnection was the trigger for near-Earth substorms, the fundamental building blocks of space weather. However, there was still a piece of the space weather puzzle missing: There did not appear to be enough energy in the reconnection flows to account for the total amount of energy released for typical substorms.

In 2011, in an attempt to survey a wider area of the Earth's magnetosphere, the THEMIS team repositioned two of its five spacecraft into lunar orbits, creating a new mission dubbed ARTEMIS after the Greek goddess of the hunt and the moon. From afar, these two spacecraft provided a unique global perspective of energy storage and release near Earth.

Similar to a pebble creating expanding ripples in a pond, magnetic reconnection generates expanding fronts of electricity, converting the stored magnetic energy into particle energy. Previous spacecraft observations could detect these energy-converting reconnection fronts for a split second as the fronts went by, but they could not assess the fronts' global effects because data were collected at only a single point.

By the summer of 2012, however, an alignment among THEMIS, ARTEMIS, the Japanese Space Agency's Geotail satellite and the U.S. National Oceanic and Atmospheric Administration's GOES satellite was finally able to capture data accounting for the total amount of energy that drives space weather near Earth.

During this event, reported in the current *Science* paper, a tremendous amount of energy was released.

"The amount of power converted was comparable to the electric power generation from all power plants on Earth—and it went on for over 30 minutes," said Vassilis Angelopoulos, a professor in the UCLA Department of Earth, Planetary and Space Sciences, principal investigator for ARTEMIS and THEMIS, and lead author of the research in Science. "The amount of energy released was equivalent to a 7.1 Richter-scale earthquake."

Trying to understand how gigantic explosions on the sun can have effects near Earth involves tracking energy from the original solar event all the way to Earth. It is like keeping tabs on a character in a play who undergoes many costume changes, researchers say, because the energy changes frequently along its journey: Magnetic energy causes solar eruptions that lead to flow energy as particles hurtle away, or to thermal energy as the particles heat up.

Near Earth, that energy can go through all the various changes in form once again. Understanding the details of each step in the process is crucial for scientists to achieve their goal of someday predicting the onset and intensity of space weather.

Using ARTEMIS, a clear picture emerged of the total energy stored, and the entire fleet of satellites tracked the energy fronts at high time resolution, Angelopoulos said.

The spacecraft and satellites observed two expanding energy fronts launched symmetrically on either side of the magnetic reconnection site, one moving toward Earth and the other away from it, past the moon. The magnetic energy was transformed into particle and wave energy during its quarter-million–mile journey from its origin within a narrow region only a few dozen miles across.

This, the researchers said, explains why single-satellite measurements in the past did not make much of the energy release. The multiple satellite fleet, however, showed that the energy conversion continued for up to 30 minutes after the onset of reconnection.

"We have finally found what powers Earth's aurora and radiation belts," Angelopoulos said. "It took many years of mission planning and patience to capture this phenomenon on multiple satellites, but it has certainly paid off. We were able to track the total energy and see where and when it is converted into different kinds of energy."

With the full, global picture of energy storage and transfer in the magnetosphere, scientists can now focus their attention on the physics of the energy conversion and its eventual dissipation in order to improve space weather forecasts.

What scientists learn on Earth can also inform our knowledge elsewhere in our solar system. The sun's eruptions are also controlled largely by magnetic reconnection, and intense auroras at Jupiter create the most powerful electromagnetic emissions in the solar system besides the sun, Angelopoulos said.

Similar emissions from planets orbiting other stars may one day reveal the interior structure of distant worlds. Since the sun's surface and very distant planets cannot yet be visited, there is no place better than Earth's own space environment to study energy transformation on large and small scales with a coordinated fleet of highly capable satellites, he said.

NASA is currently building the Heliophysics System Observatory, which combines existing and future satellite resources in space, including THEMIS, ARTEMIS, the recently launched twin Van Allen Radiation Belt Probes, and the four Magnetospheric MultiScale satellites, which will be launched in 2014 (and which have involved UCLA scientific and hardware participation).

"It is a very exciting time ahead," said David Sibeck, THEMIS/ARTEMIS project scientist at NASA's Goddard Space Flight Center. "Never before did we have the possibility for so many high-quality observatories lining up."

ARTEMIS stands for Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun. THEMIS (Time History of Events and Macroscale Interactions during Substorms) was launched Feb. 17, 2007, from Cape Canaveral, Fla., to impartially resolve the trigger mechanism of substorms. Themis was the blindfolded Greek goddess of order and justice.

Provided by University of California, Los Angeles

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