Plasma Bullets Spark Northern Lights

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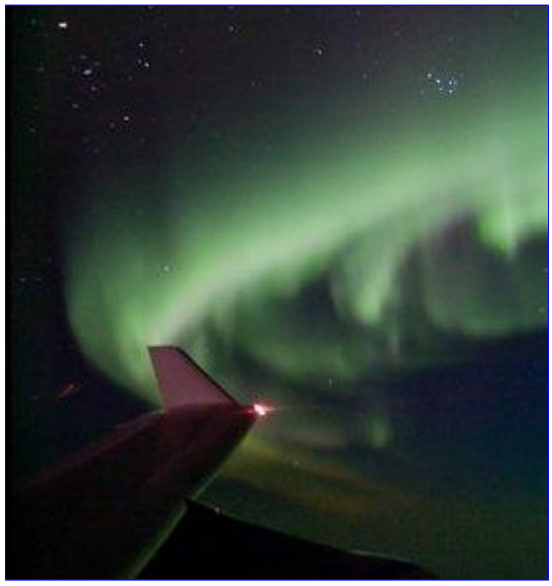
July 24, 2008: Duck! Plasma bullets are zinging past Earth.

That's the conclusion of researchers studying data from NASA's five THEMIS spacecraft. The gigantic bullets, they say, are launched by explosions 1/3rd of the way to the Moon and when they hit Earth—wow. The impacts spark colorful outbursts of Northern Lights called "substorms."



Right: A substorm of Northern Lights photographed from the window of an airplane over Hudson Bay, Canada, on Feb 27, 2008. Credit: Jeff Hapeman. [more]

"We have discovered what makes the Northern Lights dance," declares UCLA physicist Vassilis Angelopoulos, principal investigator of the THEMIS mission. The findings appear online in the July 24 issue of *Science Express* and in print August 14 in the journal *Science*.

The THEMIS fleet was launched in February 2007 to unravel the mystery of substorms, which have long puzzled observers with their unpredictable eruptions of light and color. The spacecraft wouldn't merely observe substorms from afar; they would actually plunge into the tempest using onboard sensors to measure particles and fields. Mission scientists hoped this *in situ* approach would allow them to figure out what caused substorms--and they were right.

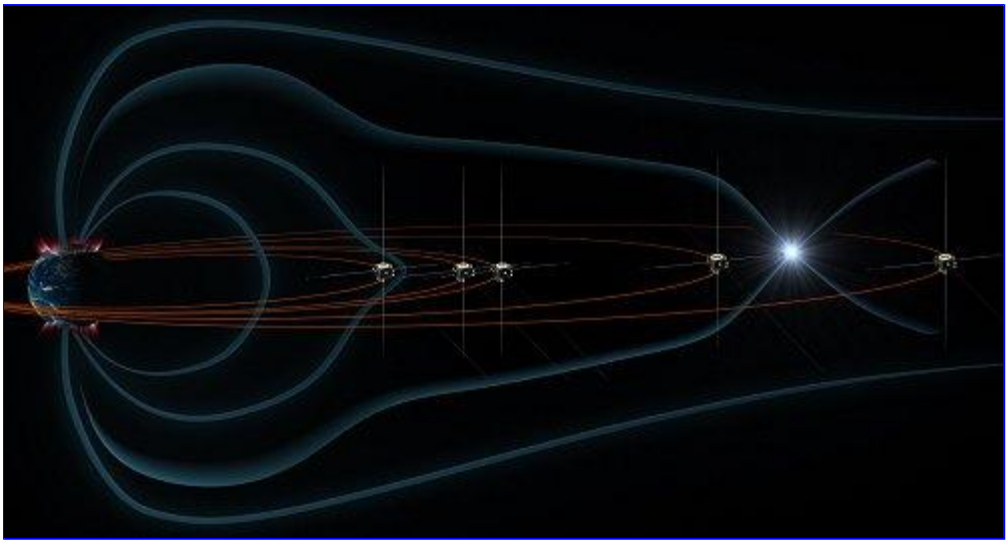
The discovery came on what began as a quiet day, Feb 26, 2008. Arctic skies were dark and Earth's magnetic field was still. High above the planet, the five THEMIS satellites had just arranged themselves in a line down the middle of Earth's magnetotail—a million kilometer long tail of magnetism pulled into space by the action of the solar wind.

That's when the explosion occurred.

A little more than midway up the THEMIS line, magnetic fields erupted, "releasing about 10^{15} Joules of energy," says Angelopoulos. "For comparison, that's about as much energy as a magnitude 5 earthquake."

Although the explosion happened inside Earth's magnetic field, it was actually a release of energy from the sun. When the solar wind stretches Earth's magnetic field, it stores energy there, in much the same way energy is stored in a rubber band when you stretch it between thumb and forefinger. Bend your forefinger and—crack!—the rubber band snaps back on your thumb. Something similar happened inside the magnetotail on Feb. 26, 2008. Over-stretched magnetic fields snapped back, producing a powerful explosion. This process is called "magnetic reconnection" and it is thought to be common in stellar and planetary magnetic fields.

The blast launched two "plasma bullets," gigantic clouds of protons and electrons, one toward Earth and one away from Earth. The Earth-directed cloud crashed into the planet below, sparking vivid auroras observed by some 20 THEMIS ground stations in Canada and Alaska. The opposite cloud shot harmlessly into space, and may still be going for all researchers know.



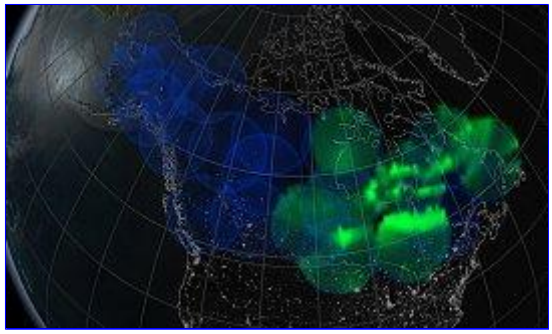
Above: An artist's concept of the THEMIS satellites lined up inside Earth's magnetotail with an explosion between the 4th and 5th satellites. [Larger image]

The THEMIS satellites were perfectly positioned to catch the shot.

"We had bulls-eyes on our solar panels," says THEMIS project scientist David Sibeck of NASA's Goddard Space Flight Center. "Four of the satellites were hit by the Earth-directed cloud, while the opposite cloud hit the fifth satellite." Simple geometry pinpointed the site of the blast between the 4th and 5th satellite or "about 1/3rd of the way to the Moon."

No damage was done to the satellites. Plasma bullets are vast, gossamer structures less dense than the gentlest wisp of Earth's upper atmosphere. They whoosh past, allowing THEMIS instruments to sample the cloud's internal particles and fields without truly buffeting the satellite.

This peaceful encounter on the small scale of a spacecraft, however, belies the energy deposited on the large scale of a planet. The bullet-shaped clouds are half as wide as Earth and 10 times as long, traveling hundreds of km/s. When such a bullet strikes the planet, brilliant auroras and geomagnetic storms ensue.



Right: A collection of ground-based All-Sky Imagers (ASI) captures the aurora brightening caused by a substorm. Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio. [animation]

"For the first time, THEMIS has shown us the whole process in action—from magnetic reconnection to aurora borealis," says Sibeck. "We are finally solving the puzzle of

substorms."

The THEMIS mission is scheduled to continue for more than another year, and during that time Angelopoulos expects to catch lots more substorms--"dozens of them," he says. "This will give us a chance to study plasma bullets in greater detail and learn how they can help us predict space weather."

"THEMIS is not finished making discoveries," believes Sibeck. "The best may be yet to come."