Multipoint satellite observations provide insight into the origins of substorms

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The nature of substorms in the magnetosphere, the magnetic-field region that surrounds the Earth, has long been a topic of research. A substorm results from the interaction between the Sun and Earth. The sun's outer atmosphere is constantly expanding into space producing the solar wind. When the solar wind interacts with the Earth's magnetic field, it couples energy into the magnetosphere through magnetic reconnection. A research team, including Geoffrey Reeves (Intelligence & Space Research, ISR-DO) has investigated observations from multiple satellites to develop a more comprehensive picture of substorm interactions with the Earth's magnetosphere. The *Journal of Geophysical Research: Space Physics* published their findings.

Magnetic reconnection happens between the Sun's magnetic field (carried by the solar wind) and the Earth's. The reconnection happens on the sunward side (the day side) of the Earth where the two systems interact. After dayside reconnection, one end of the field line remains connected to the Earth while the solar wind carries the other end to the night side of the Earth. This action stretches and compresses the magnetic field on the night side forming a magnetotail. When sufficient magnetic energy builds up, reconnection starts between the field lines attached to Earth in the northern and southern hemispheres. Reconnection in the magnetotail has two effects. It produces a magnetic "bubble" that pops off back into the solar wind and it creates a slingshot of magnetic field lines that return toward Earth. The result is a substorm, a type of space weather. See a NASA animation detailing a magnetospheric substorm.

Substorms drive huge electrical currents and energize the protons and electrons in the magnetotail. One of the signatures of substorm activity is the sudden Earthward transport of tens to hundreds of keV electrons and/or ions throughout the near-Earth plasma sheet and into the inner magnetosphere, a phenomenon called energetic particle injection. Often the energetic particles appear near geosynchronous orbit, the area where most large satellites operate including some that carry Los Alamos-developed sensors used to monitor the Nuclear Test Ban Treaty. With satellite use becoming increasingly pervasive for missions including expanded communications and Internet access, Earth imaging, and more, scientists seek to understand how and why substorms occur. These space weather effects can disrupt satellites via the buildup of electrical charge on the surface of a satellite damaging its electronics. Researchers aim to predict when substorms are likely and how severe their effects might be. Better data about space weather could enable satellites design to better address the specific radiation conditions they will encounter. Click here for Reeves discussing the potential catastrophic effects of space weather on satellites.

Los Alamos has been studying substorms and substorm injections since the 1970s. Lab researchers have flown energetic particle instruments on over a dozen different satellites in geosynchronous orbit (35,786 km above Earth's equator). As a result, most of what the scientific community knew about substorm injections until recently was based on geosynchronous measurements. The Laboratory's work continues today with the Space and Atmospheric Burst Reporting System (SABRS) payload, part of the United States Nuclear Detonation Detection System (USNDS) program.

In this new study, the team capitalized on recent observations during a conjunction between NASA's Magnetospheric Multiscale Mission (primarily measures the region outside geosynchronous orbit) and Van Allen Radiation Belt Storm Probes mission (measures inside geosynchronous) that occurred on 7 April 2016. With complementary data from Time History of Events and Macroscale Interactions during Substorms, Geotail, and Los Alamos National Laboratory spacecraft in geosynchronous orbit (16 spacecraft in total), this is the first research to use data from all of these satellite systems to examine the complex dynamics of charged particles in substorm injections. The event occurred during generally quiet magnetospheric activity under steady, below-average solar wind conditions. The investigators aimed to develop a more comprehensive global picture of injections and the injection region and to gain insight on the nature of substorms and reconnection in Earth's magnetotail.

The data resulted in a more comprehensive picture of substorm injections. Previous studies could only look at two points: geosynchronous orbit+inward or geosynchronous orbit+outward but not both simultaneously. In this study the team analyzed the three regions (outside, inside, and at geosynchronous) and confirmed that the observed injections moved Earthward. The analysis revealed that at least five electron injections, which were localized in magnetic local time, preceded a larger injection of both electrons and ions across nearly the entire nightside of the magnetosphere near geosynchronous orbit. The discrepancy between the number, penetration depth, and complexity of electron versus ion injections presents challenges to the current conceptual models of energetic particle injections.

The Los Alamos team and their collaborators now have two years of overlapping data from the collection of satellites. They will continue looking at similar events and collecting new data to produce a more comprehensive and complete analysis of these space weather events.

Reference: "Multipoint Observations of Energetic Particle Injections and Substorm Activity during a Conjunction between Magnetospheric Multiscale (MMS) and Van Allen Probes," *Journal of Geophysical Research: Space Physics* *122*, 11,481 (2017). Authors: D. L. Turner, J. F. Fennell, J. B. Blake, S. G. Claudepierre, and J. H. Clemmons (The Aerospace Corporation); A. N. Jaynes, T. Leonard, and D. N. Baker (University of Colorado – Boulder); I. J. Cohen, M. Gkioulidou, A. Y. Ukhorskiy, and B. H. Mauk (Johns Hopkins University); C. Gabrielse, V. Angelopoulos, and R. J. Strangeway (University of California – Los Angeles); C. A. Kletzing (University of Iowa); O. Le Contel (CNRS/Ecole Polytechnique/UPMC Université Paris Université Paris-Sud/Observatoire de Paris); H. E. Spence and R. B. Torbert (University of New Hampshire); R. B. Torbert and J. L. Burch (Southwest Research Institute); and G. D. Reeves (Intelligence & Space Research, ISR-DO).

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