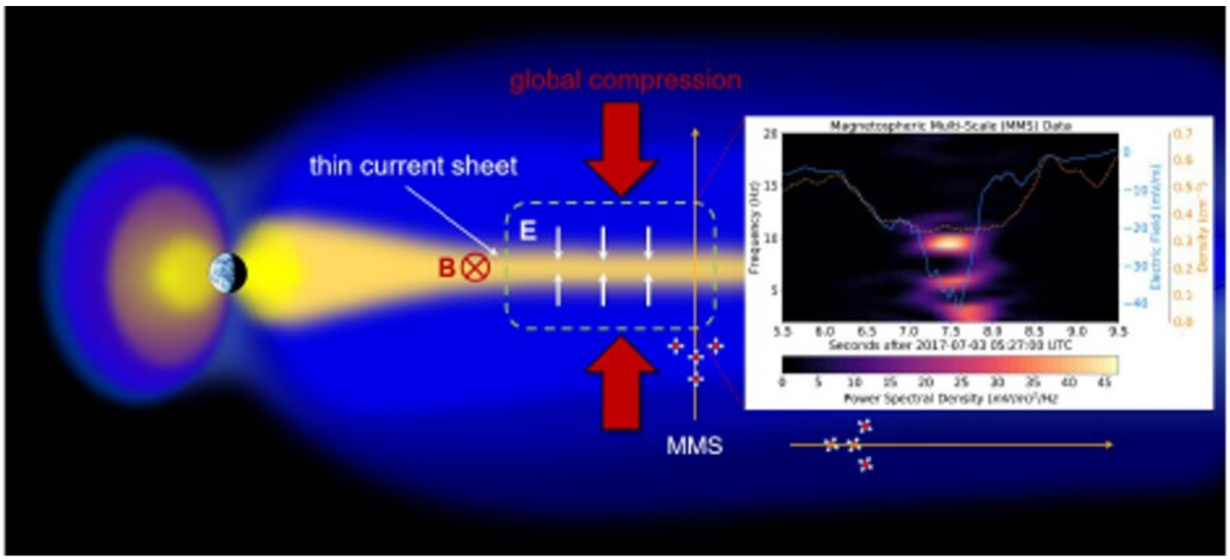
Micro-scale current sheets unleash macro-scale space weather

November 8 2021



The Earth's magnetosphere can undergo global compression due to solar wind. This compression creates thin and non-ideal current sheets in the magnetotail. NASA's MMS spacecraft fly through this compressed, thin current sheet, and reveal that a small-scale electric field forms (blue line on plot) which generates a highly sheared electron flow that drives lower hybrid waves (bright spots in plot) while the plasma density is relatively flat (orange dashed line on plot). Understanding the formation of these current sheets and the small-scale structures and dynamics within is important because they are thought to be important in the processes that initiate magnetic reconnection, which can drive intense space weather in the Earth's magnetosphere. Credit: Dr. Bill Amatucci, NRL

While movies show Earth as existing in a calm, pristine corner of the universe, in reality the near-Earth space environment is dangerous and dynamic. On any given day, hot charged particles and blobs of plasma, called the solar wind, travel from the sun and are deflected by the Earth's magnetic field, causing beautiful aurora around north and south poles. During solar storms, however, the solar wind can compress the Earth's magnetic field, causing the magnetic field lines to rearrange and reconnect (also known as magnetic reconnection), shooting hot, dense plasma back toward the Earth. Processes like these are commonly referred to as space weather. Because of the effect that these space-based disruptions can have on key elements of our modern society, such as telecommunication systems and power grids, obtaining a good understanding of these processes is just as essential as understanding ground-based weather.

A major challenge in understanding magnetic reconnection in the Earth's magnetosphere has been the difficulty in resolving the smaller kinetic-scale processes in satellite observations. NASA's Magnetospheric Multi-Scale (MMS) spacecraft, however, recently made it possible to make detailed studies of this previously unseen micro-scale physics.

Scientists at the U.S. Naval Research Laboratory (NRL) in Washington, D.C. have been using MMS data to study the micro-scale physics that occurs in the Earth's magnetotail, a thin portion of the magnetosphere that is illustrated in Figure 1. The magnetotail is formed when the Earth's magnetosphere is compressed by the solar wind into a thin current sheet, creating an ideal location to study magnetic reconnection.

NRL scientists recently made the first observation of plasma waves driven by highly sheared electron flows (velocity shear) in one of these compressed current sheets. The velocity shear is created in the current sheet when a localized electric field oriented perpendicular to the background magnetic field arises as the current sheet is compressed.

These waves are a rich source of local enhanced diffusivities, which can trigger the magnetic reconnection process.

NRL scientists also used these observations to discover a key component missing from existing theoretical models of thin current sheets and magnetic reconnection—an ambipolar electric field that forms perpendicular to the current sheet and intensifies as the current sheet undergoes strong compression. A new theoretical model has since been developed and indicates that the ambipolar electric field can self-consistently develop in response to global compression of the plasma. This in turn produces the velocity shear that can drive the waves observed in the spacecraft data. The current driven by the electron flow also changes the magnetic field profiles and allows for the formation of current sheets that are both thin and non-ideal, features which cannot simultaneously be explained by the standard models. The theoretical model results shine a new light on the key connection between the micro-scale and macro-scale physics.

These findings challenge the existing understanding of the physics of thin current sheets, and the identification of the shear-driven plasma waves also establishes the significance of the localized ambipolar electric field and the highly inhomogeneous conditions that drive the physics. This deeper understanding of the physics at small scales, when combined with the larger scale models, will lead to a more complete knowledge of the global dynamics and especially the energy flux in the heliosphere from the sun into the Earth's immediate neighborhood that affects near-Earth space weather.

More information: Abstract: GI01.00002. Structure and Dynamics of a Compressed Current Sheet in the Earth's Magnetotail

Provided by American Physical Society