National Aeronautics and Space Administration

magnetospheric multiscale

A SOLAR TERRESTRIAL PROBE

The Magnetospheric Multiscale mission resolves the basic physics of Magnetic Reconnection – a fundamental process that converts magnetic energy to high speed flows, thermal energy, and energetic particles in plasmas throughout the Universe.

MMS SCIENCE OBJECTIVES

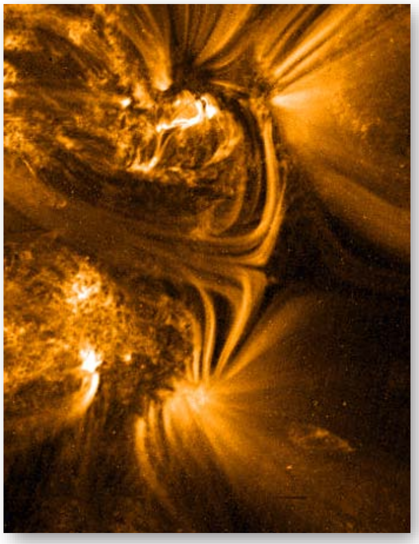
Three science objectives have been identified for the MMS mission. In priority order, these objectives are to:

- Determine the role played by electron inertial effects and turbulent dissipation in driving reconnection in the electron diffusion region;
- Determine the rate of magnetic reconnection and the parameters that control it; and
- Determine the role played by ion inertial effects in the physics of reconnection.

INTRODUCTION TO RECONNECTION

Throughout the universe, when magnetic fields in adjacent regions have significantly different directions, they often become interconnected, and plasmas move rapidly across the otherwise impenetrable boundary between the regions. This process is called magnetic reconnection. Magnetic reconnection is especially important because it explosively converts magnetic energy to heat and kinetic energy of charged particles, producing hazardous radiation particles and other intense phenomena such as our brilliant auroras.

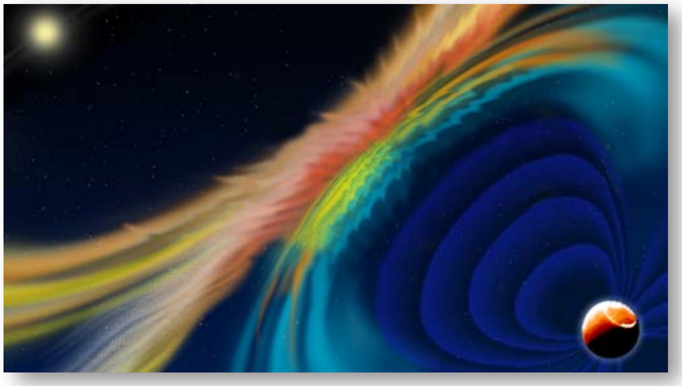
The best laboratory for studying reconnection is the Earth's magnetosphere, the most accessible place where this process occurs regularly enough to be studied in situ. Previous studies of the process have provided some insight, most importantly that the critical physics takes place on electron spatial scales, which are too small to be resolved in laboratory investigations, but large enough in space to be probed by a closely-packed group of small spacecraft.



Reconnection in Solar Flares

STRATEGIC IMPORTANCE

It is important to understand reconnection because it is the universal process by which magnetic energy is transferred to material particles in plasmas. Reconnection enables a magnetized plasma to convert magnetic energy into high-speed flows, thermal energy and energetic particles. Examples where magnetic reconnection is the driver of important phenomena in nature are numerous. Its broad importance in nearly all plasma systems, ranging from laboratory experiments to the Earth's magnetosphere, the solar corona and the astrophysical environment, render it one of the premier scientific topics in plasma physics.



Jets of electrically charged particles are regularly created in space via the process of "magnetic reconnection". The jets, which are powered by reconnecting magnetic fields, are the result of natural particle accelerators. Reconnection-powered jets occur in Earth's magnetic shield and within the solar wind, producing severe magnetic storms.

In the solar corona, magnetic reconnection is responsible for driving flares and it produces the change in magnetic topology required for coronal mass ejections. The The heating of the solar corona may arise from micro-flares driven by magnetic reconnection. Therefore, magnetic reconnection is a major driver of space weather throughout the heliosphere. Nearer to home, the structure and dynamics of the Earth's magnetosphere is largely controlled by magnetic reconnection. The erosion of magnetic flux on the dayside magnetosphere due to the reconnection of the Earth's magnetic field with that of the interplanetary field ejected from the Sun leads to a cycle of magnetic energy storage and release, which powers the aurora and populates the inner magnetosphere with energetic particles.

There is increasing recognition that magnetic fields also play a central role in many astrophysical systems, including accretion disks, jets and supernova shocks and in producing high-energy cosmic rays, which make interplanetary space travel hazardous. The generation of the magnetic field in astrophysical systems is through a dynamo process in which plasma flows twist and amplify seed magnetic fields. Reconnection provides a fundamental dissipation process for the magnetic energy that balances the dynamo generation. Understanding both the generation and dissipation mechanism for magnetic field energy is required to predict and understand the role of the magnetic field in astrophysical systems.

In the case of fusion experiments, magnetic reconnection phenomena play a critical role in virtually every configuration that is being explored to confine high-temperature plasmas. Fundamentally, magnetic reconnection destroys symmetries in the fields that are required to confine high-temperature plasma. As a consequence, the formation of “magnetic islands” degrades energy confinement, and reconnection driven "disruptions" can lead to a complete loss of containment.

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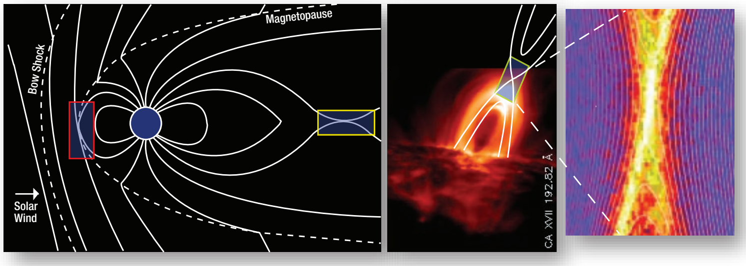
BACKGROUND

The study of magnetic reconnection has a long history, dating back to the 1950's when the basic ideas were laid out to try to explain the near-explosive release of energy observed in solar flares. In spite of the large number of papers addressing the issue, there is no accepted first-principles model that can explain the central observations: sudden onset, explosive release of magnetic energy and the production of large numbers of energetic particles. The absence of a consensus model is a consequence of the complexity and richness of the problem.



Magnetic reconnection is important in the Earth's magnetosphere, in the solar corona (solar flares and CMEs), to the science of controlled nuclear fusion, and throughout the universe (high energy particle acceleration).

The topological change in the magnetic field and release of magnetic energy requires dissipation at small spatial scales in a narrow boundary layer known as the "diffusion region." Classical dissipation processes such as resistivity are too weak to explain observations in the nearly collisionless systems, so the dissipation is thought to be intrinsically kinetic. Observations further indicate that the boundary layer is typically turbulent and that the dynamics are strongly nonlinear, which is consistent with the production of energetic particles.

Important but competing theories have been advanced on the magnetic reconnection problem over the past several years. The prime mission of MMS is to discriminate among these competing theories, experimentally advance their predictions, and understand the universality of the processes and mechanisms at work. The MMS mission provides the combination of measurements to discriminate between these competing theories: the most important elements of this combination are ultra-high time resolution plasma and fields measurements, sensitive measurements of the full three-dimensional electric field, and the capability for making simultaneous measurements of all of these parameters within and surrounding reconnection sites.

MEASUREMENT STRATEGY

Because reconnection is a 3-D process involving the rapid inflow and outflow of charged particles, a cluster of four spacecraft with carefully selected separations and instruments are needed for a definitive experiment. Conducting this experiment in space requires being able to transform measurements into a reference frame moving with the reconnection region. To do this, two critical parameters must be determined: the orientation and the velocity of the reconnecting current sheet. Measurements from two or three spacecraft can provide important information about current sheet orientation and velocity, but data from four separate points are required to conclusively specify these characteristics and to measure unambiguously the plasma current, independent of orientation assumptions. For full success, the MMS mission design thus requires a tetrahedral formation of four spacecraft. Magnetic field measurements are the primary basis for the determination of current sheet orientation and velocity, so magnetic field measurements from multiple spacecraft are critical for mission success.

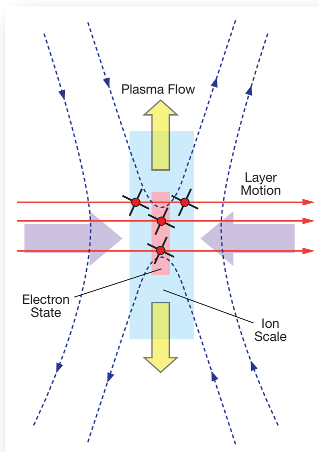
ORBIT STRATEGY

Because reconnection manifests itself in the Earth's magnetosphere at two locations with differing scale sizes and magnetic field orientations, a two-phase orbit strategy has been developed to test the universality of the mechanisms at work and to better understand how it controls planetary space weather. Phase 1 will probe reconnection sites at the mid-latitude dayside magnetopause, while Phase 2 focuses on reconnection sites that occur within the nightside magnetic neutral sheet.

SUMMARY

The NASA Magnetospheric Multiscale (MMS) mission, scheduled for launch in 2014, will obtain the measurements needed to test the prevailing theories as to how reconnection is enabled and how it progresses.

- Experiments on four spacecraft deployed in a tetrahedral constellation with separations as small as 10 km will reveal the three-dimensional structure of the diffusion region on scales as small as the electron inertial length (tens of kilometers).
- Plasma measurements in the few eV to tens of keV range will determine the properties of electrons and ions that flow into and out of the reconnection region and participate in the reconnection processes.
- Time resolutions for the electron measurements will be 30 milliseconds, as compared to the best previous satellite measurements, which have cadences of a few seconds.
- 3-D electric and magnetic field measurements will be used to search the diffusion region for the "smoking gun" of reconnection – an electric current and an electric field that are parallel to each other which provides the dissipation needed to "break" magnetic field lines.
- Mass spectrometers allow specific tests of the effects of heavy ions on reconnection dynamics and rates.
- Energetic particle detectors will remotely sense the regions where reconnection occurs and to determine how reconnection processes produce such large numbers of energetic particles.



Spacecraft formations and separations allow the payload to sample the two inflow regions and two outflow regions. To determine processes driving reconnection, the closest separations place spacecraft within the diffusion region.

MMS OVERVIEW

SCIENCE OBJECTIVES

Discover the fundamental plasma physics process of reconnection in the Earth's magnetosphere

- Temporal scales of milliseconds to seconds
- Spatial scales of 10s to 100s of km

MISSION TEAM

- NASA SMD
- Southwest Research Institute
  - Science Leadership
  - Instrument Suite
  - Science Operations Center
  - Science Data Processing
- NASA GSFC
  - Project Management
  - Mission Systems Engineering
  - Spacecraft
  - Mission Operations Center
- NASA KSC
  - Launch Services

MISSION DESCRIPTION

- 4 identical satellites
- Formation flying in a tetrahedron
- 2-year operational mission

ORBITS

- Elliptical Earth orbits in 2 phases:
  - Phase 1 day side of magnetic field 1.2 R_E by 12 R_E
  - Phase 2 night side of magnetic field 1.2 R_E by 25 R_E
- Significant orbit adjust and formation maintenance

INSTRUMENTS

- Identical in situ instruments on each satellite measure:
  - Electric and magnetic fields
  - Fast plasma
  - Energetic particles
  - Hot plasma composition

SPACECRAFT

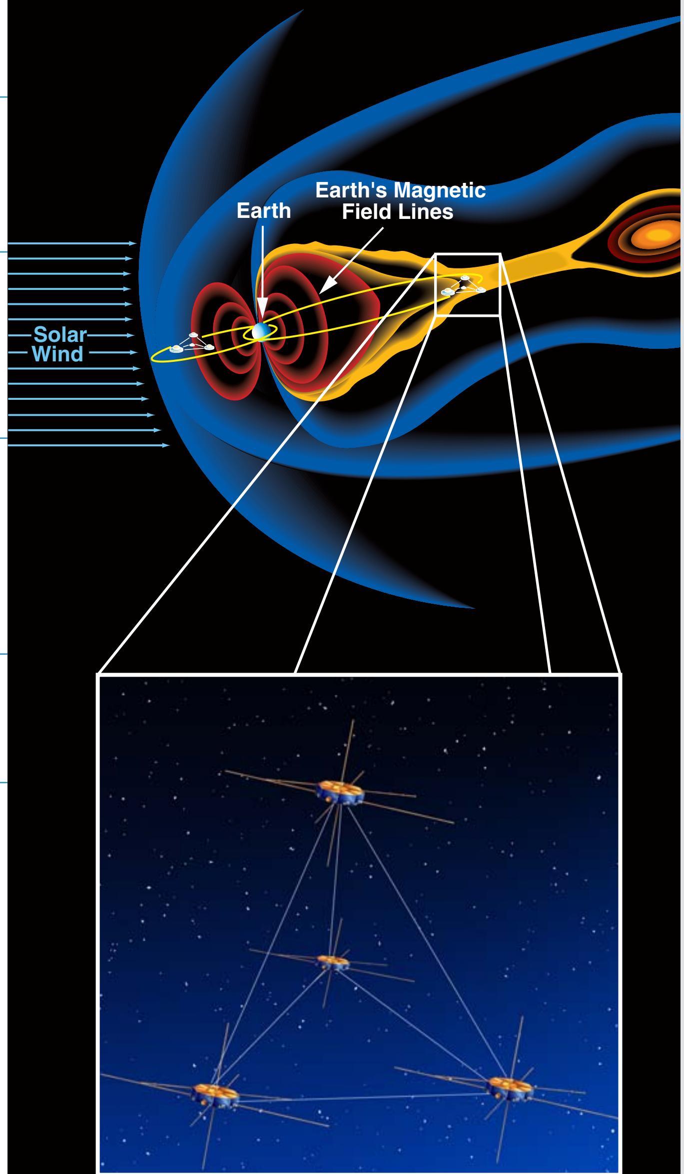
- Spin stabilized at 3 RPM
- Intersatellite ranging system

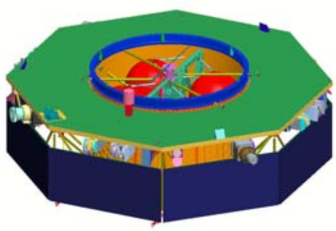
LAUNCH VEHICLE

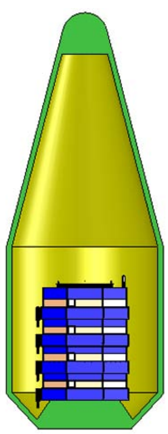
- 4 satellites launched together in one Evolved Expendable Launch Vehicle (EELV)

MISSION STATUS

- Currently in formulation
- Launch in 2014







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