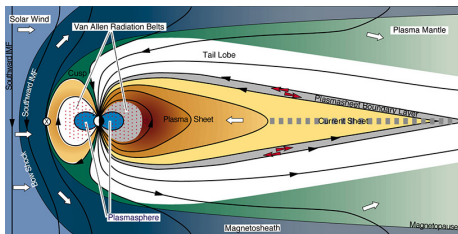


Space Weather

Lecture 6: Interaction between the Earth's and Interplanetary Magnetic Fields. Reconnection.

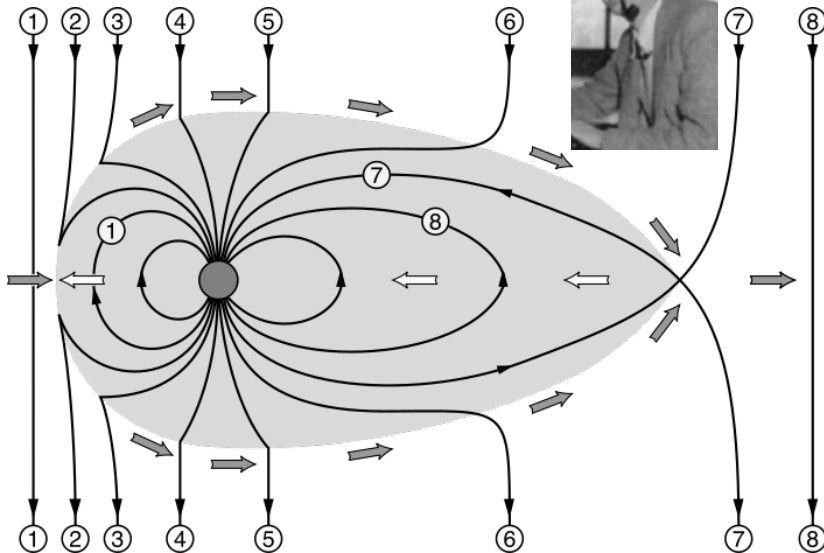


Elena Kronberg (Room 442)
elena.kronberg@lmu.de

IMF southward: Dungey Cycle

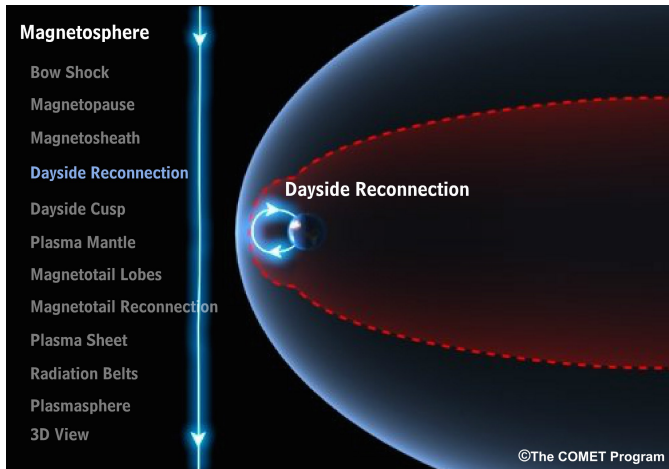


James Dungey, British physicist, 1923–2015 proposed the theory in 1961

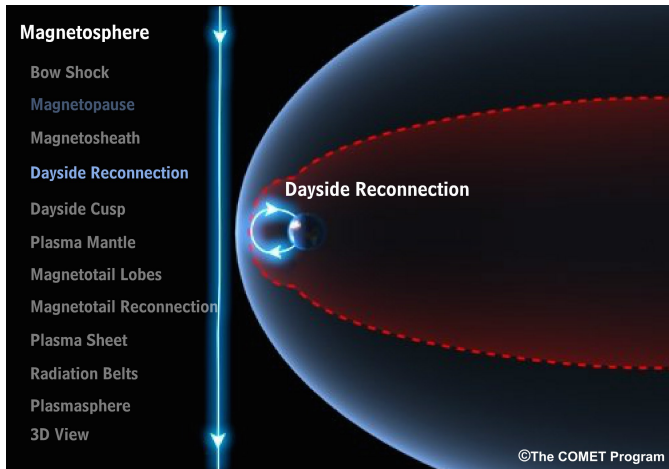


Baumjohann & Treumann

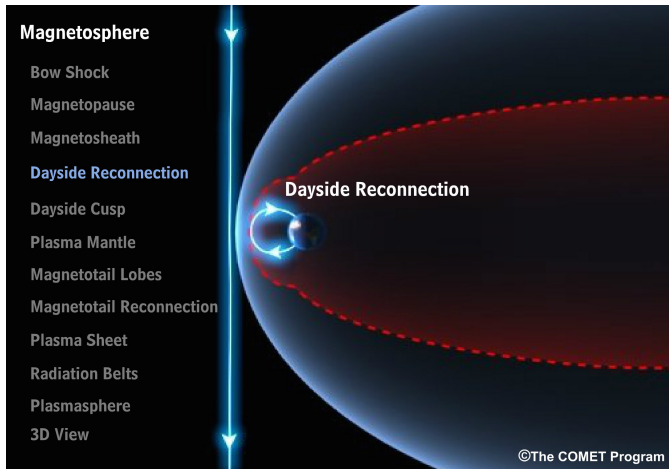
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms

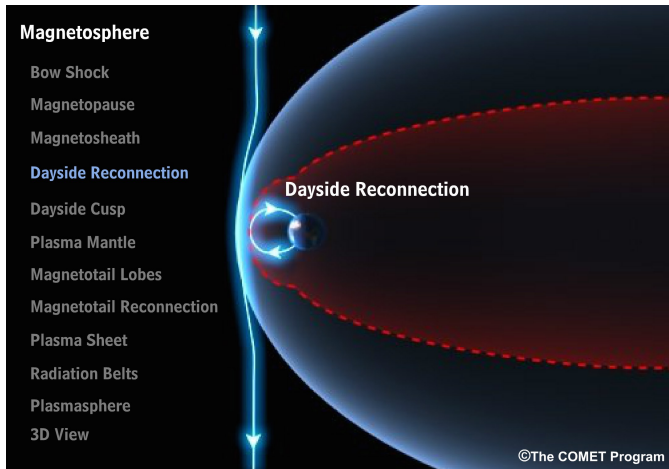


- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms

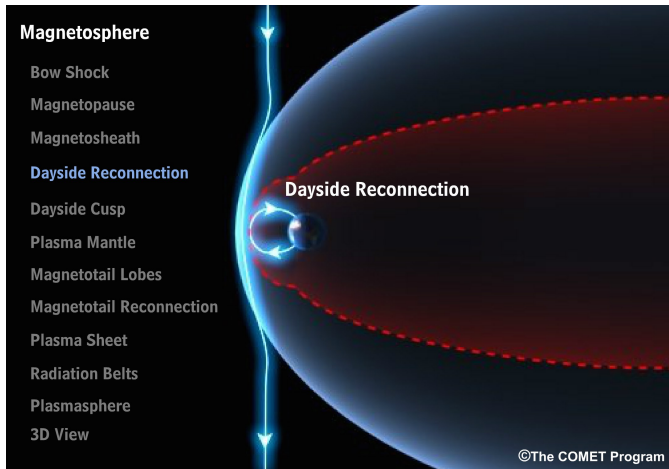


-
- The diagram illustrates the structure of Earth's magnetosphere. A vertical blue line with arrows at both ends represents the interplanetary magnetic field. The Earth's surface is shown as a dark sphere. The magnetosphere is depicted as a blue, elongated region extending away from the Earth. The bow shock is shown as a curved line in front of the magnetosphere. The magnetopause is the boundary between the magnetosphere and the solar wind. The magnetosheath is the region between the bow shock and the magnetopause. Dayside reconnection is shown as a process where magnetic field lines from the solar wind and the magnetosphere connect. The dayside cusp is the region where the solar wind enters the magnetosphere. The plasma mantle is the region between the cusp and the magnetopause. The magnetotail lobes are the regions of low plasma density in the magnetotail. Magnetotail reconnection is shown as a process where magnetic field lines in the magnetotail reconnect. The plasma sheet is the region of high plasma density in the magnetotail. The radiation belts are the regions of high-energy particles in the magnetosphere. The plasmasphere is the region of low-energy plasma in the magnetosphere. The 3D view shows the magnetosphere as a blue, elongated region.
- Magnetosphere**
- Bow Shock
 - Magnetopause
 - Magnetosheath
 - Dayside Reconnection**
 - Dayside Cusp
 - Plasma Mantle
 - Magnetotail Lobes
 - Magnetotail Reconnection
 - Plasma Sheet
 - Radiation Belts
 - Plasmasphere
 - 3D View
- Dayside Reconnection**
- ©The COMET Program

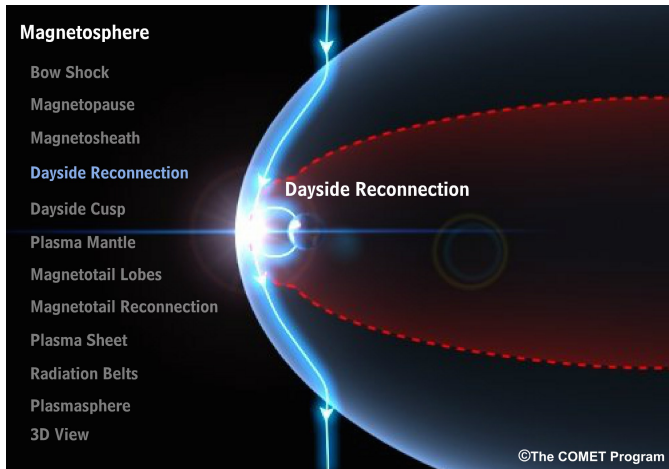
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



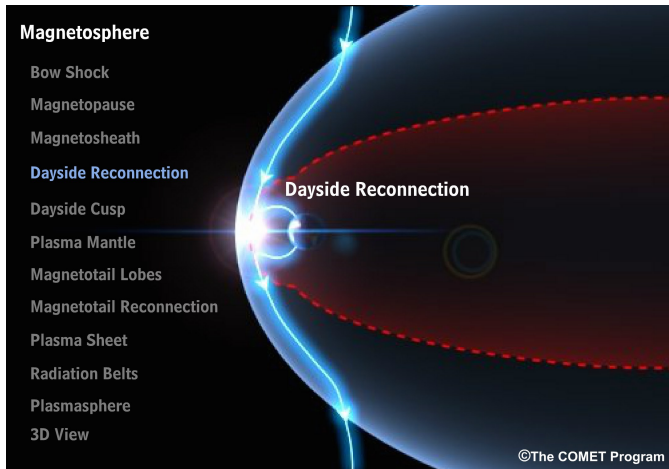
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



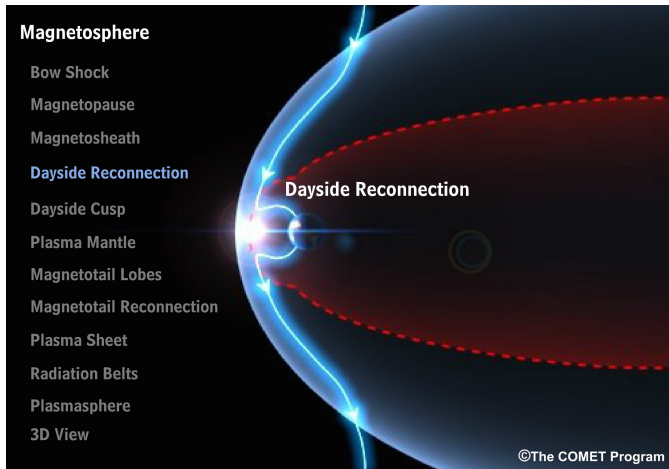
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



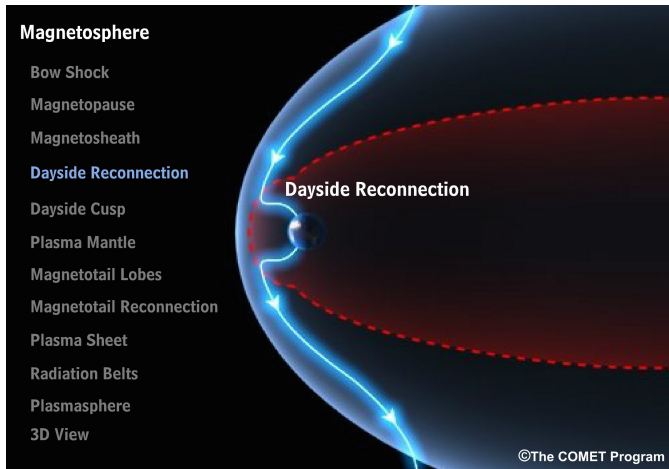
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



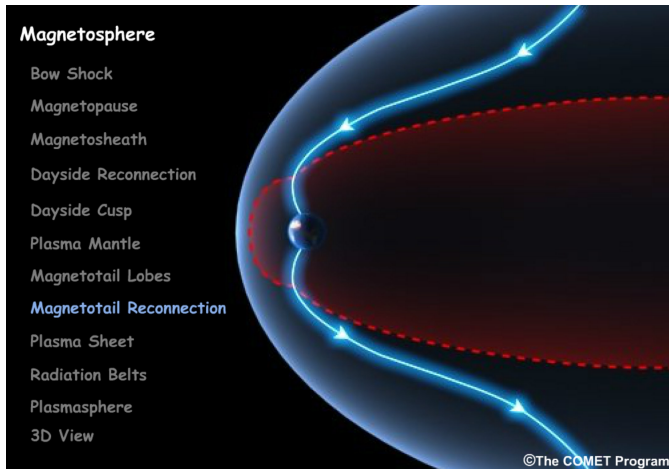
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



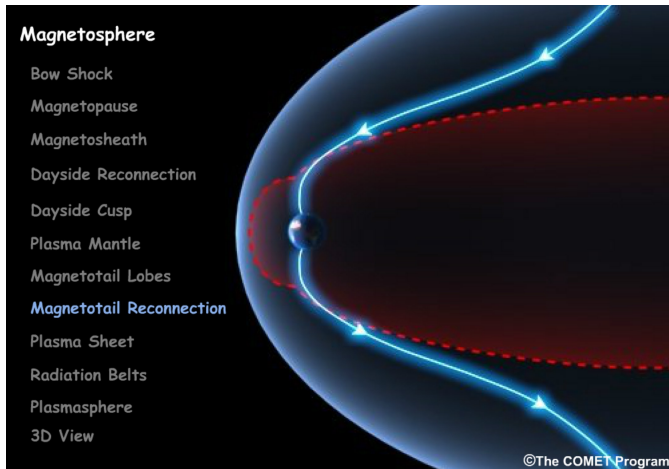
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



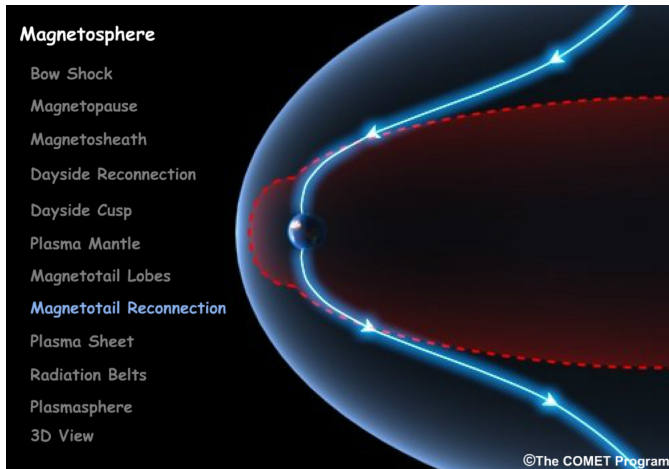
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



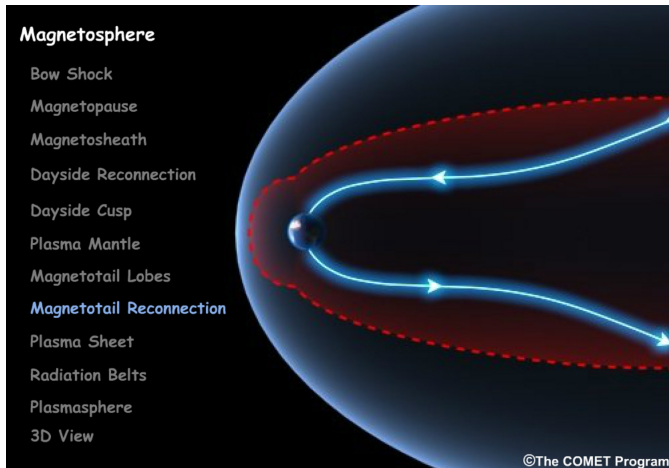
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



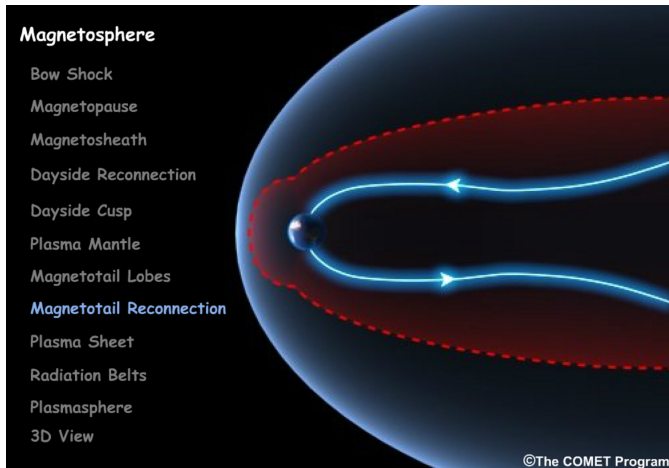
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



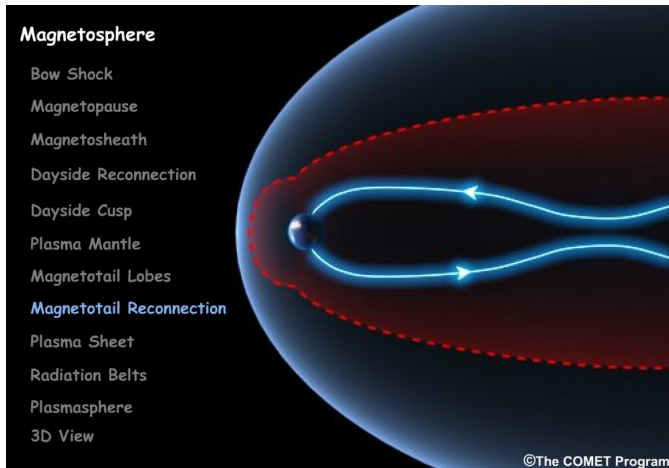
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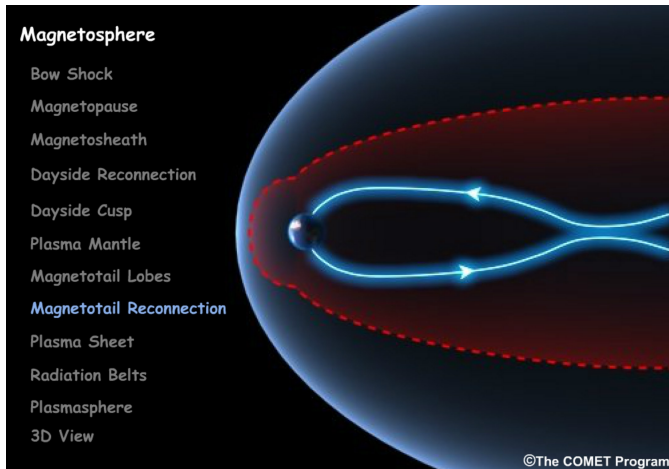
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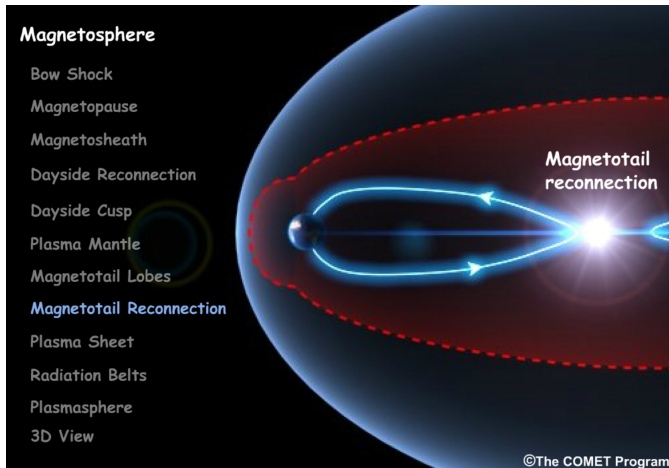
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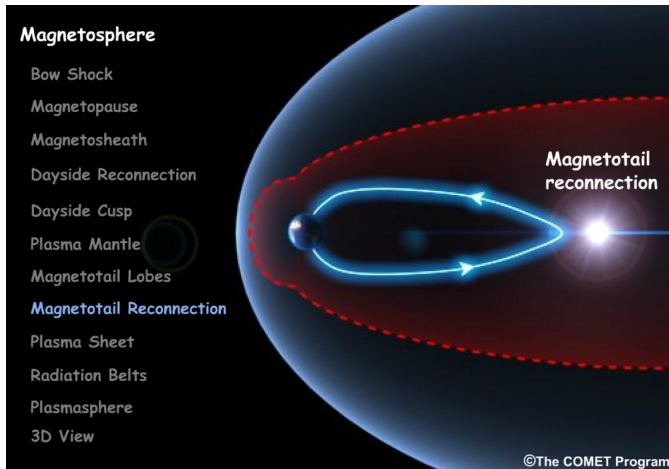
- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



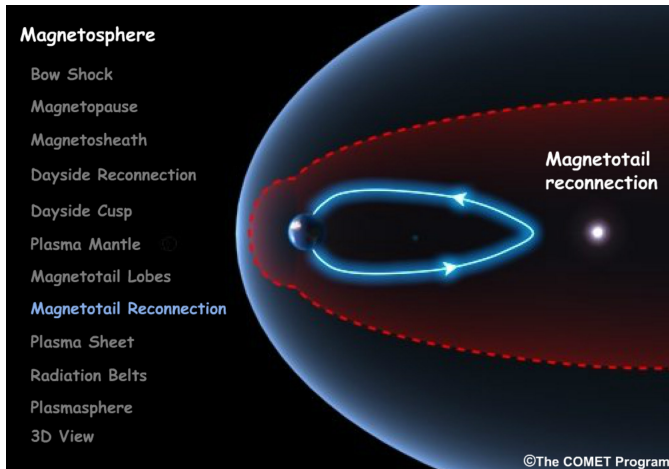
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- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms

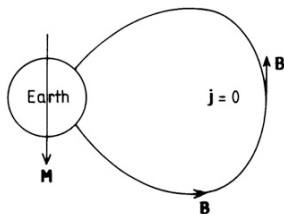


- IMF $B_z < 0$ drives the magnetospheric convection: storms/substorms



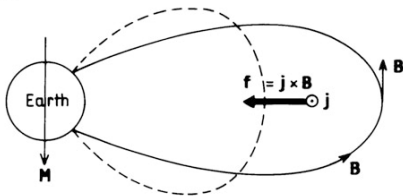
Reconnection in the magnetotail

a)



DIPOLE MAGNETIC FIELD $\mathbf{j} = \frac{1}{\mu_0} \nabla \times \mathbf{B} = 0$

b)

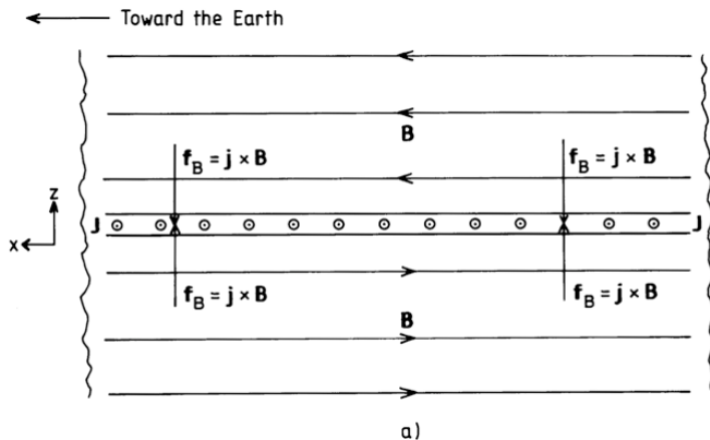


DISTORTED DIPOLE FIELD $\mathbf{j} = \frac{1}{\mu_0} \nabla \times \mathbf{B} \neq 0$

Brekke 2013

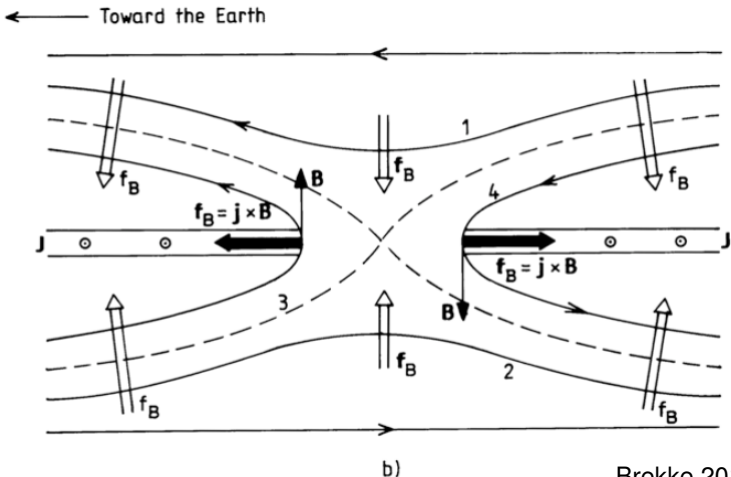
Reconnection

Brekke 2013



Reconnection

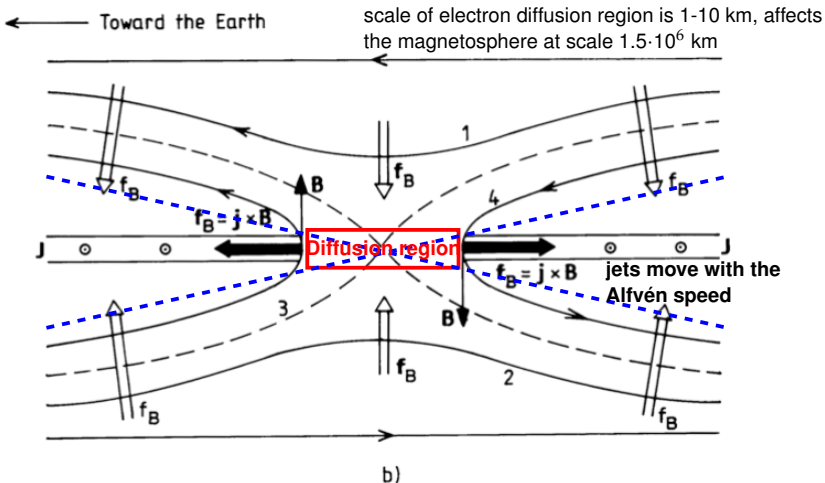
- Magnetic reconnection converts, often explosively, stored magnetic energy to particle energy (Hesse&Cassak, 2019)



Brekke 2013

Challenge: how to get it fast?

Brekke 2013



Sweet-Parker theory (1956-1958): reconnection occurs in the diffusion region via small-scale physics (resistive 2D MHD), slower than in space plasmas which are collisionless

Petschek theory (1964): diffusion region has shrunk to a dot, nobody managed to simulate the ideal case

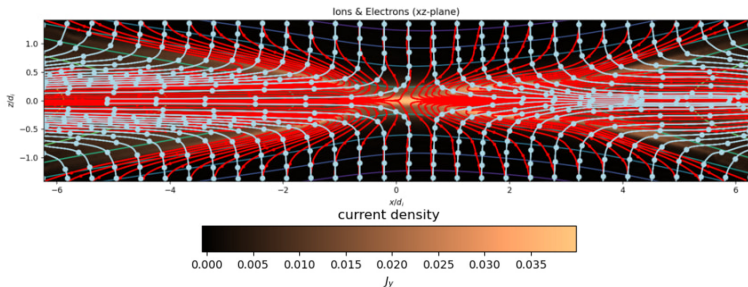
Elena Kronberg: Space Weather Lecture 6: Interaction between the Earth's and Interplanetary Magnetic Fields. Reconnection.

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Challenge: What physics can produce necessary electric fields to accelerate plasma?

One event can release $\sim 10^{12}$ W (Stern 1984),
1 year energy consume of a village

Visualization by Tom Bridgman



- Sonnerup (1979) has proposed generation of the out-of-plane magnetic field with quadrupolar structure
- This is due to the difference in e and ion behavior (Hall effect)
- Leads to generation of the Hall electric field, $\mathbf{E} = \frac{1}{ne} \mathbf{j} \times \mathbf{B}$.

Challenge: What physics can produce necessary electric fields to accelerate plasma?

Vasyliunas 1975

Generalized Ohm's law for electron fluid

$$\vec{E} = -\vec{v}_e \times \vec{B} - \frac{1}{en_e} \nabla \cdot \vec{P}_e - \frac{m_e}{e} \left(\frac{\partial \vec{v}_e}{\partial t} + \vec{v}_e \cdot \nabla \vec{v}_e \right)$$

convection
term

vanishes
because

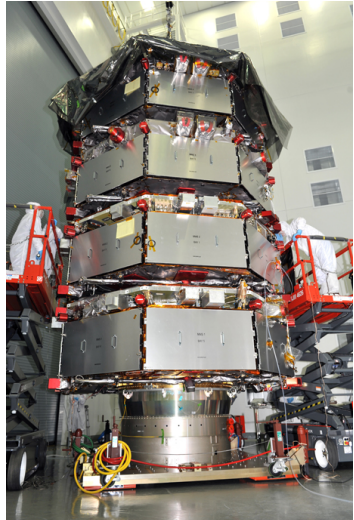
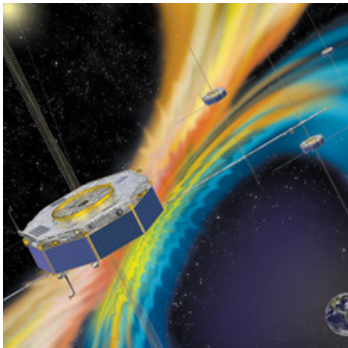
$B \sim 0$

divergence
of the e

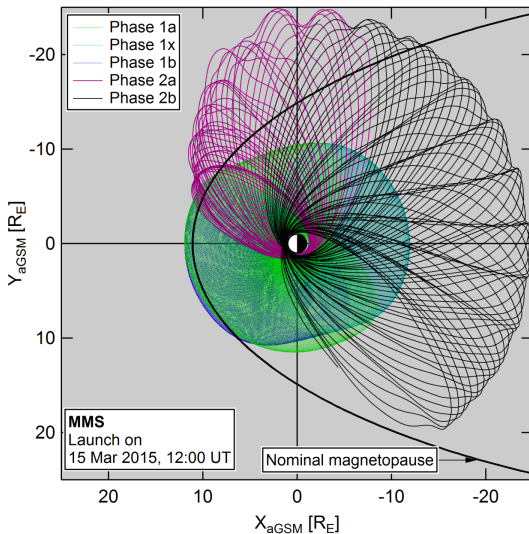
pressure
tensor

electron
inertia term

Observations by Magnetospheric Multiscale (MMS) mission

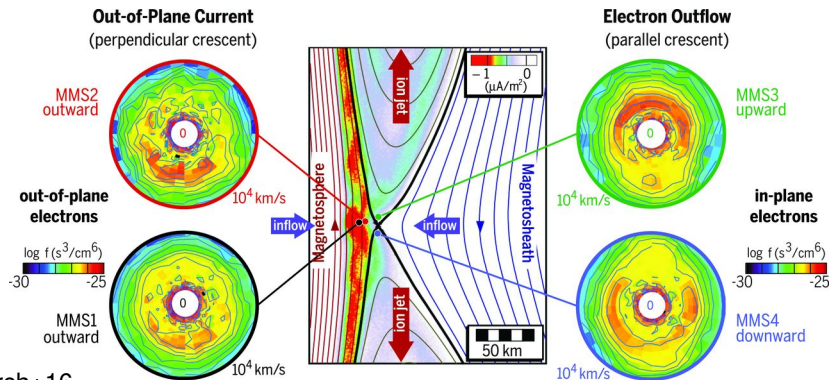


MMS trajectories: separation between spacecraft 10 km



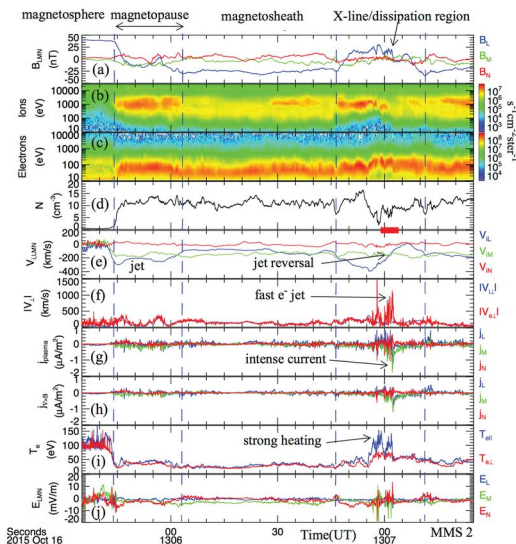
Electron-scale measurements of magnetic reconnection

- Left side: electrons with velocities from 0 to 10^4 km/s carrying current out of the drawing plane
- Right side: electrons flowing upward and downward along the reconnected magnetic field



Burch+16

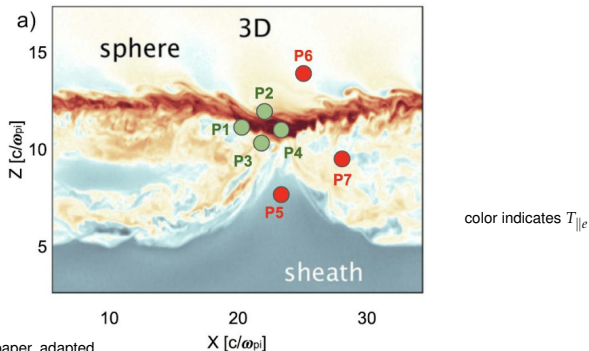
Two magnetopause crossings of MMS2



Burch+16

Lessons learned from MMS and outlook

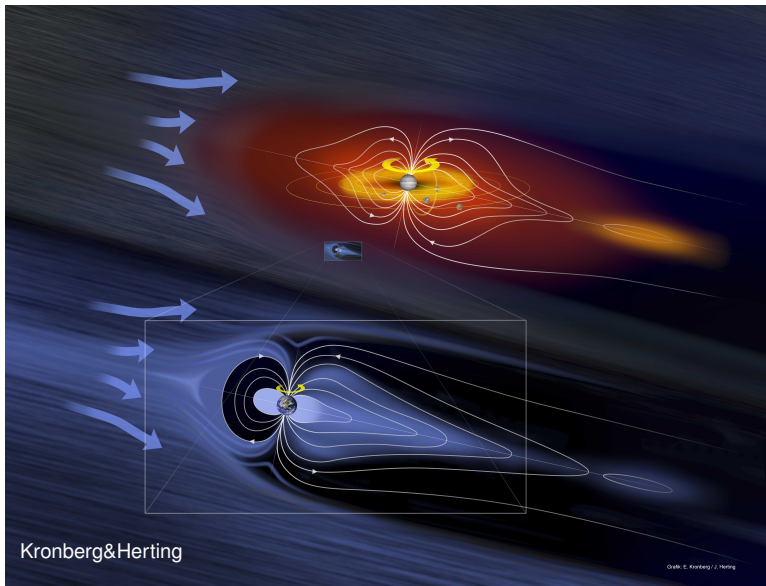
- Magnetic reconnection facilitates the transport and conversion of energy on huge spatial scales through processes that are localised on comparatively tiny kinetic scales.
- Research into how precisely the tiny diffusion region couples to the large scales, and how this multiscale interaction occurs so effectively is of prime importance.



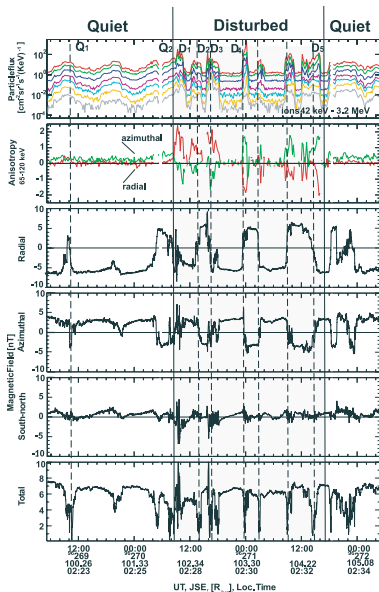
from Plasma Observatory white paper, adapted

from Le et al., 2016

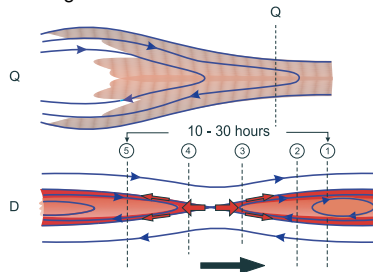
Reconnection in the magnetotail: Earth and Jupiter



X-line formation

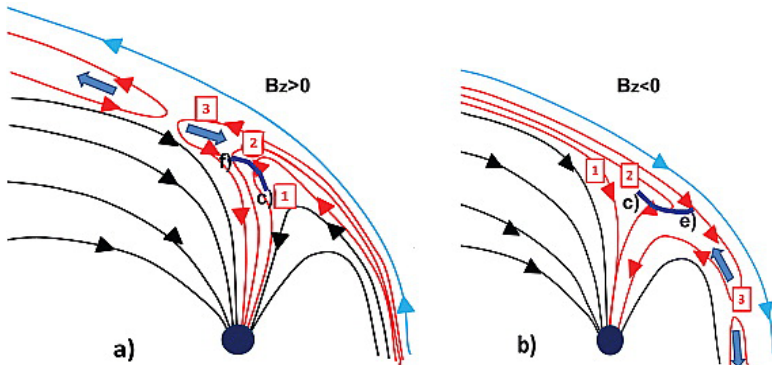


Kronberg+05



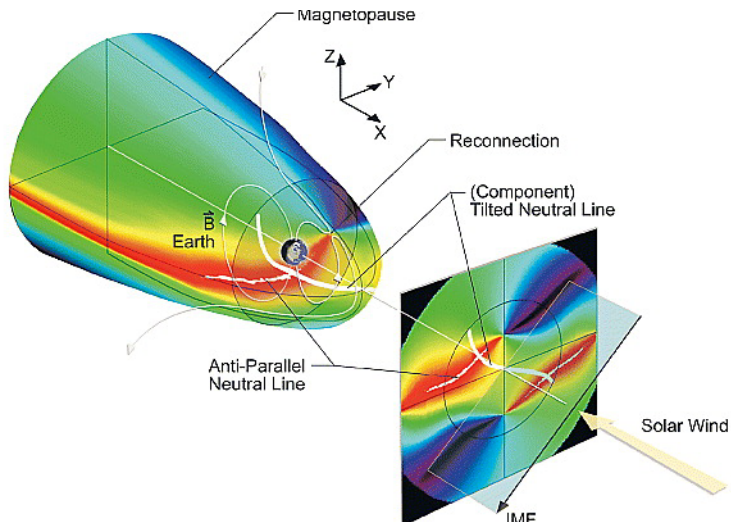
- X-line formation is one of the key signatures of the reconnection
- A change of the flow direction is often observed during the energy release phase

IMF northward: Reconnection at high latitudes



Nykyri+11

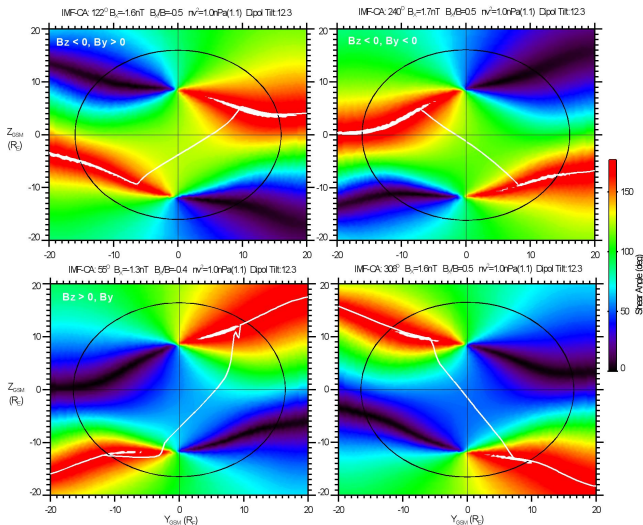
Reconnection: IMF with dawn-dusk component



Trattner+07

Reconnection: IMF with dawn-dusk component

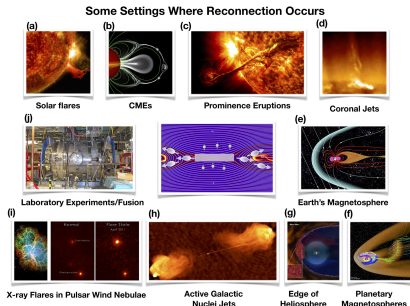
Location of the reconnection at different IMF directions



Luo+2017

Summary

- The IMF strongly influences the dynamics of the magnetosphere.
- Reconnection is a commonplace transformation process of magnetic energy to particle energy in plasmas.
- It changes the magnetic field topology and accelerates particles.
- It can be observed at the Sun, in the solar wind, in the magnetospheres of various planets, pulsars, in Tokamaks. . .
- It leads to spectacular phenomena such as solar flares, CMEs, auroras. . .



Hesse&Cassak, 2019

- M. Hesse and P. Cassak, Magnetic Reconnection in the Space Sciences: Past, Present, and Future, JGR, 2019
- W. Baumjohann and R. Treumann, Basic Space Plasma Physics, 1996
- A. Brekke, Physics of the Upper Polar Atmosphere, 2013
- K. Nykyri, et al., Cluster observations of a cusp diamagnetic cavity: Structure, size, and dynamics, JGR, 2011
- J. Burch, Electron-scale measurements of magnetic reconnection, Science, 2016
- E. Kronberg, Mass release at Jupiter: Substorm-like processes in the Jovian magnetotail. JGR, 2005