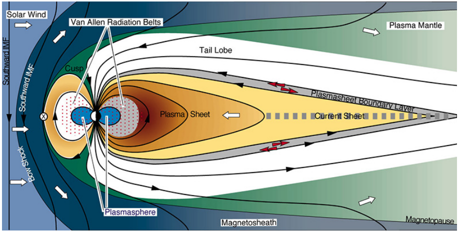
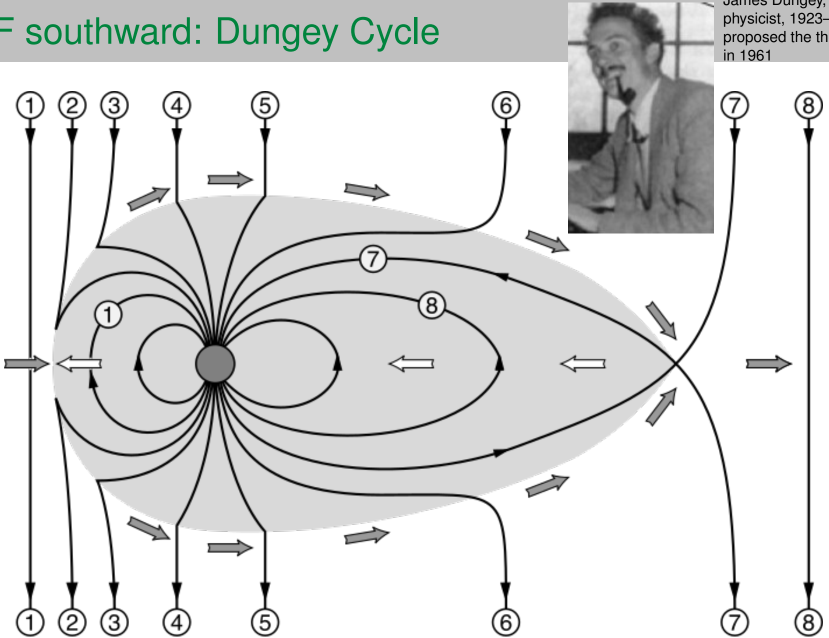
Space Weather
Lecture 6: Interaction between the Earth's and Interplanetary Magnetic Fields. Reconnection.



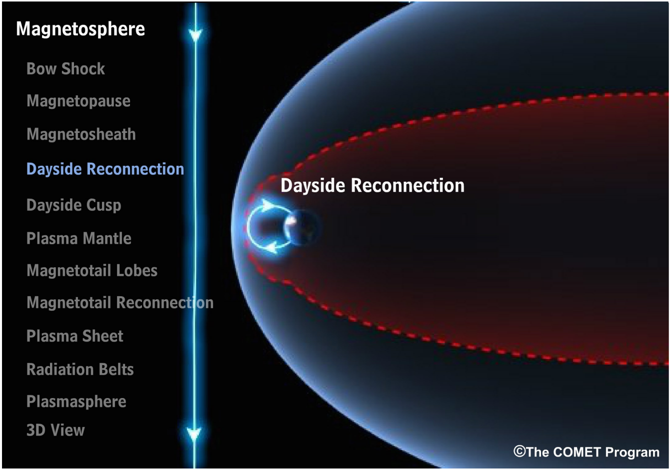
Elena Kronberg (Room 442)
elena.kronberg@lmu.de

IMF southward: Dungey Cycle



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

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



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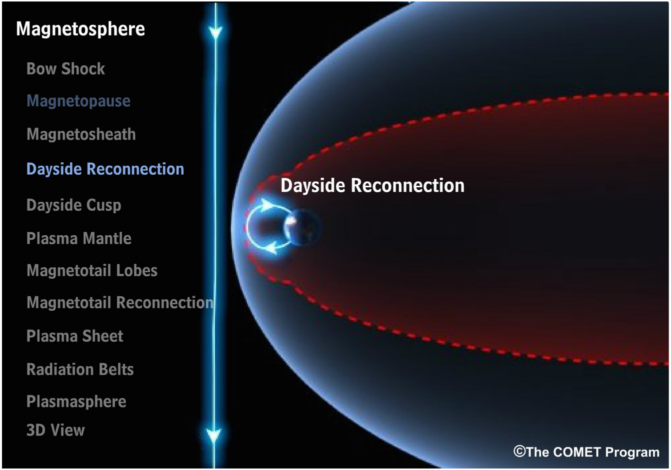

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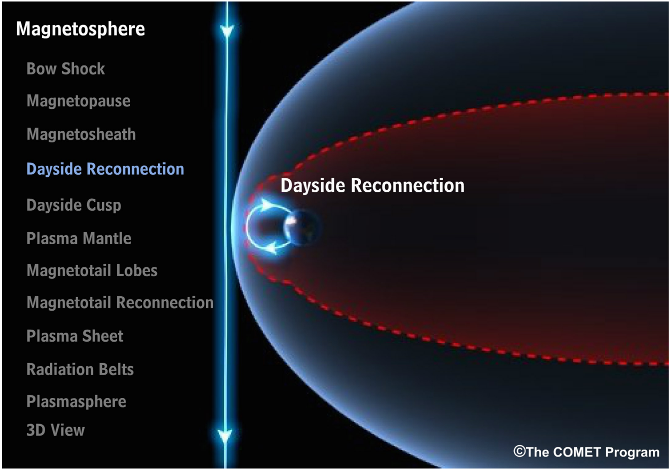

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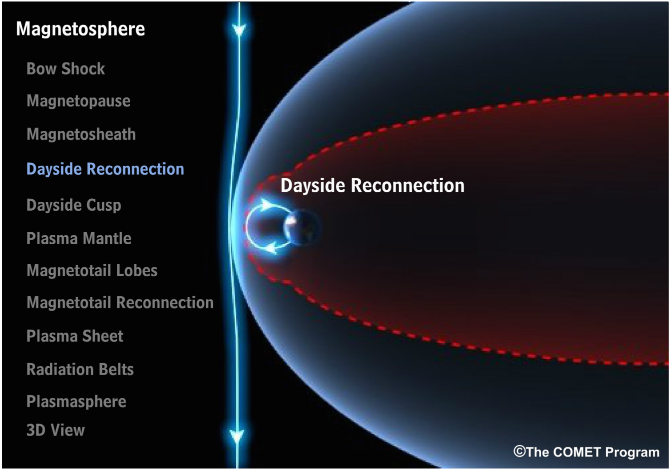

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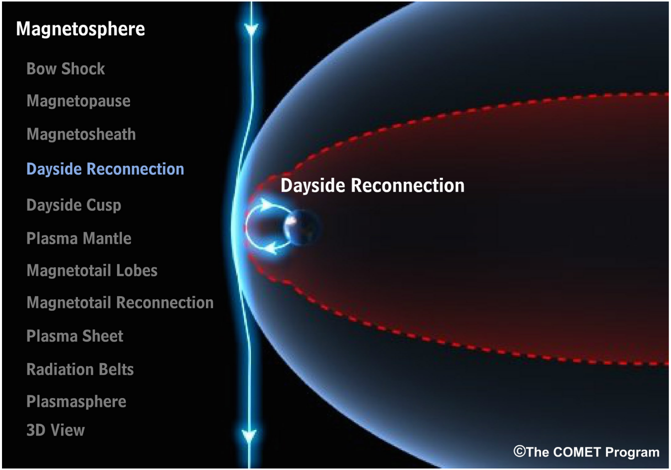

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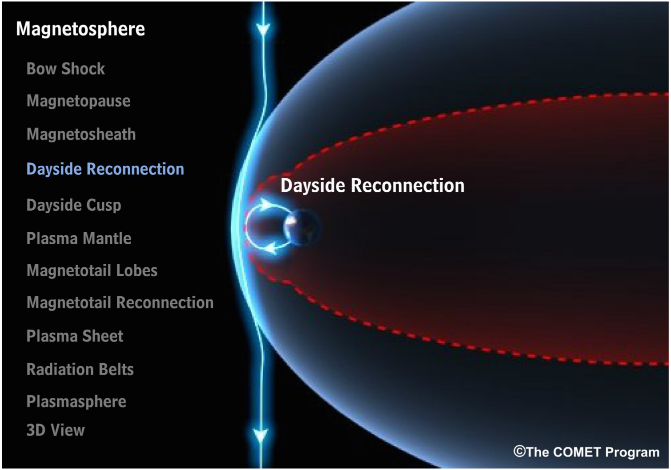

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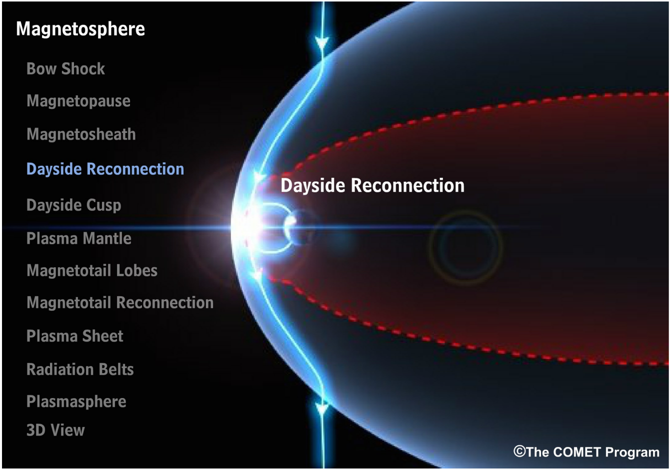

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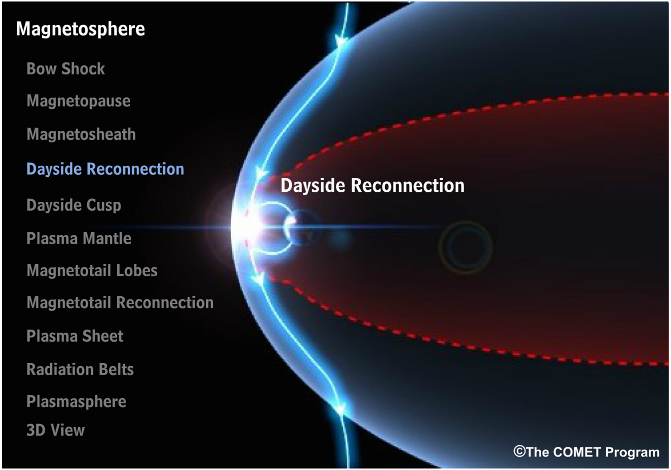

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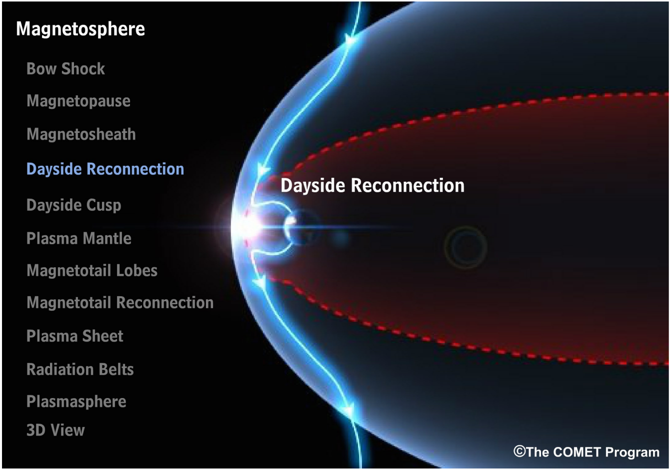

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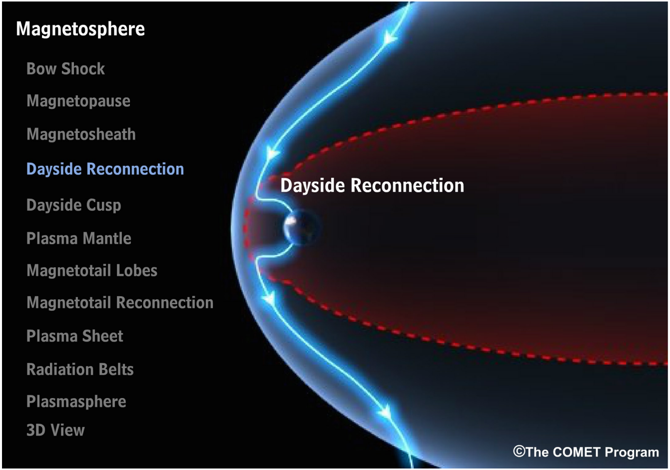

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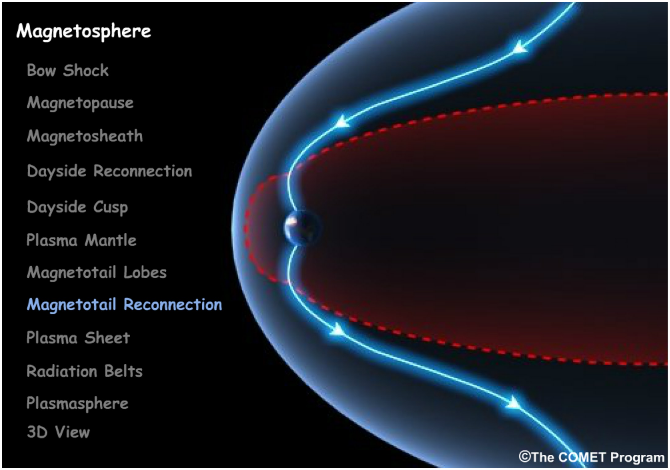

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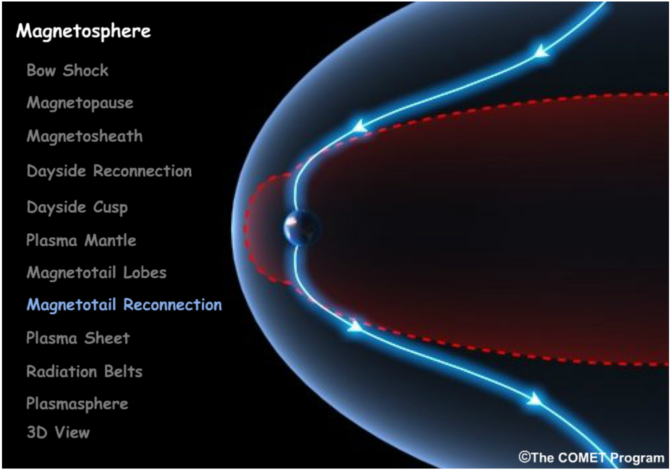

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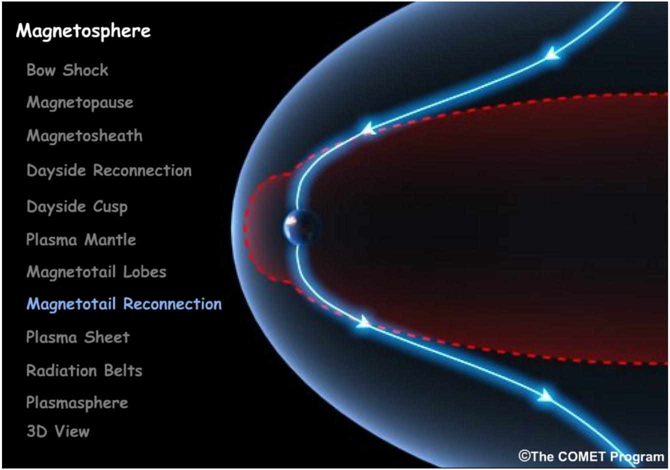

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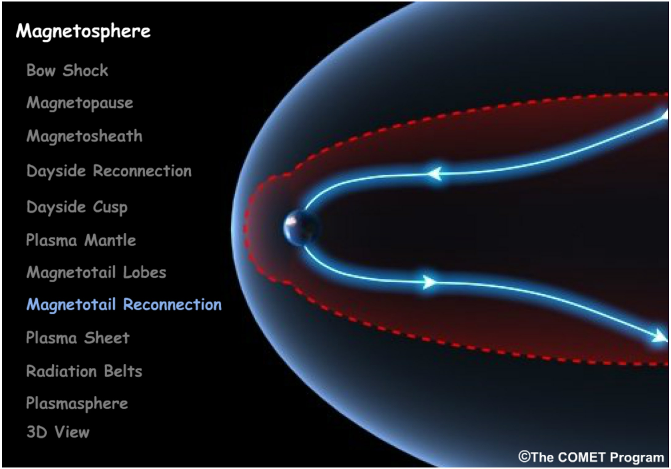

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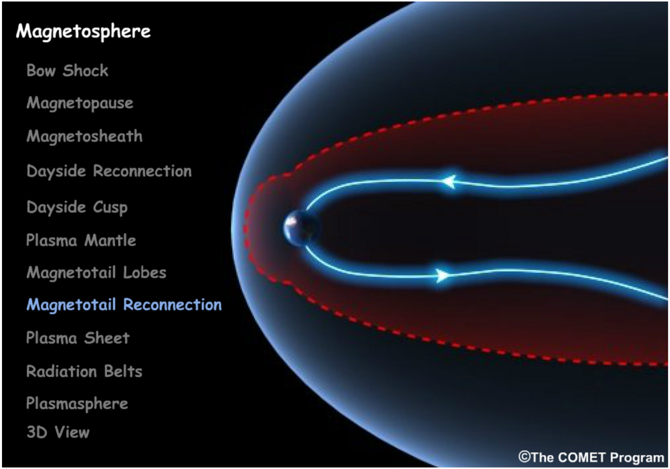

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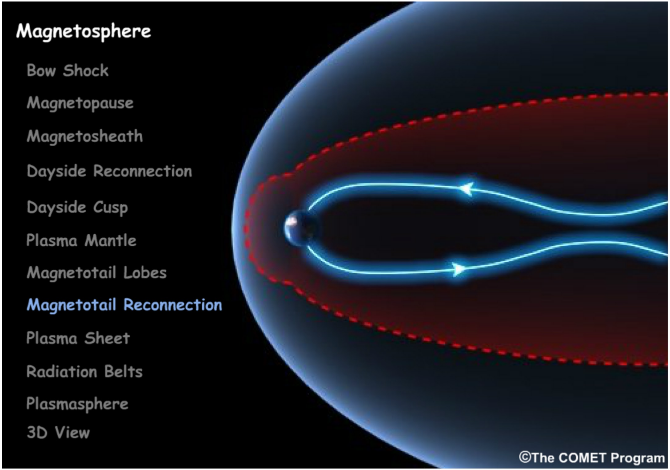

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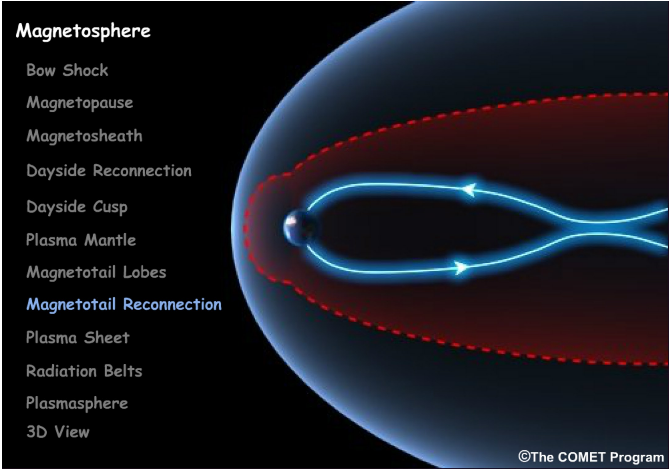

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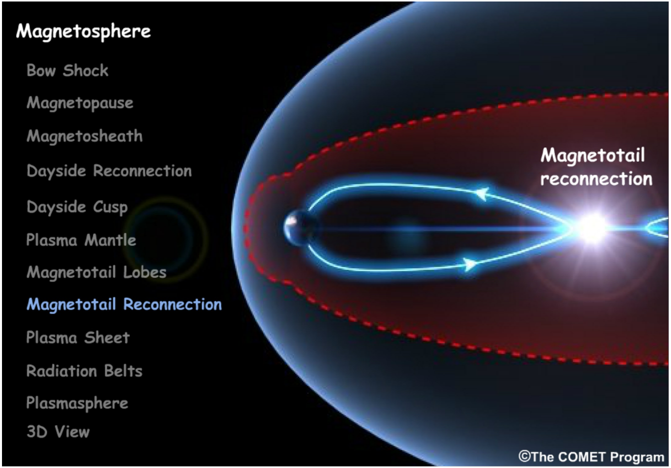

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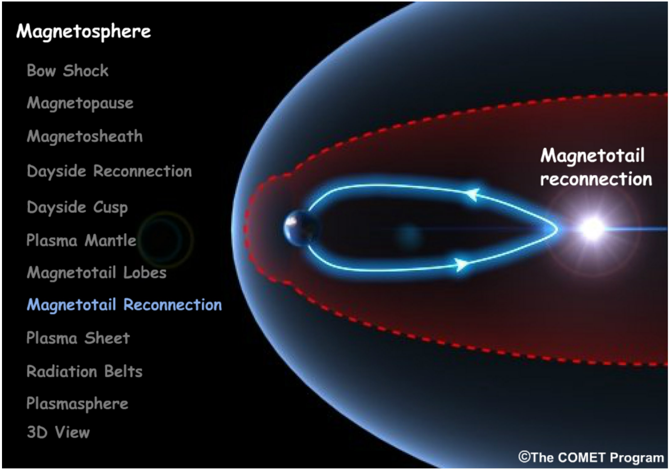

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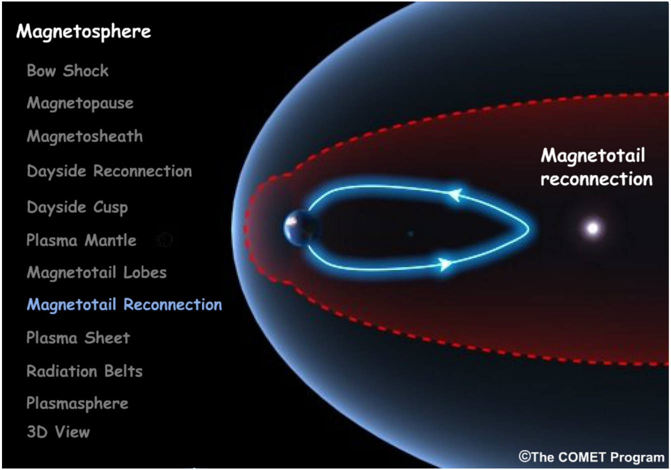
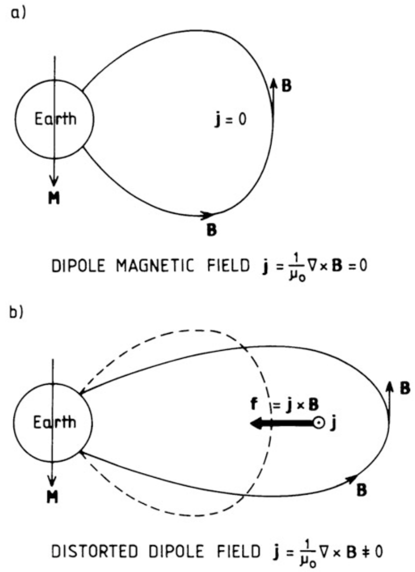


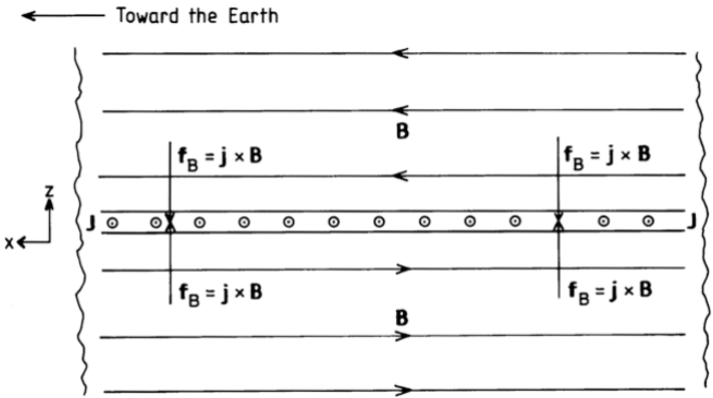
Reconnection in the magnetotail



Brekke 2013

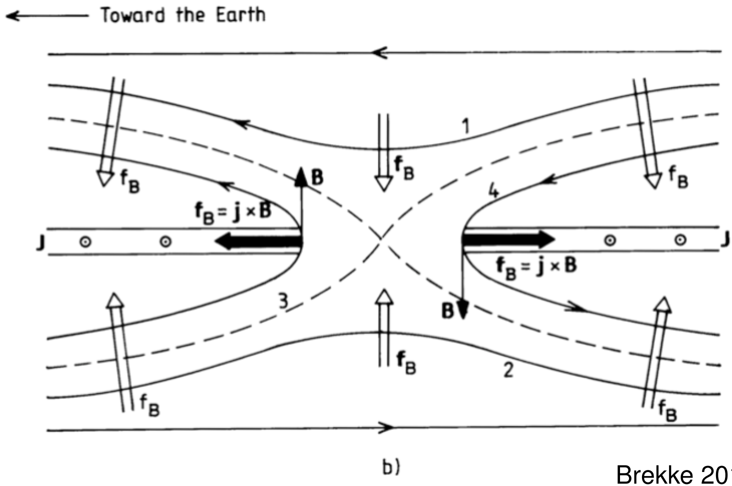
Reconnection

Brekke 2013



a)

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

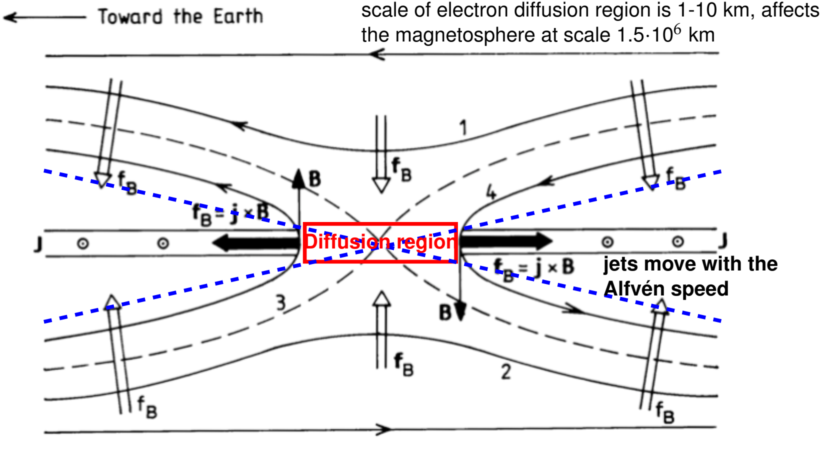


Brekke 2013

Challenge: how to get it fast?

Brekke 2013

scale of electron diffusion region is 1-10 km, affects the magnetosphere at scale $1.5 \cdot 10^6$ km



b)

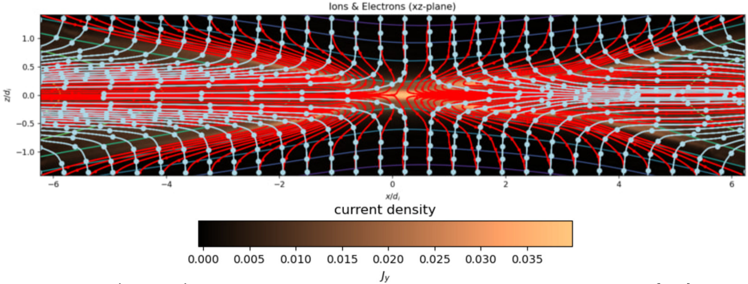
Sweet-Parker theory (1956-1958): reconnection occurs in the diffusion region via small-scale physics (resistive 2D MHD), slower than in space plasmas which are collisionless

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

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?

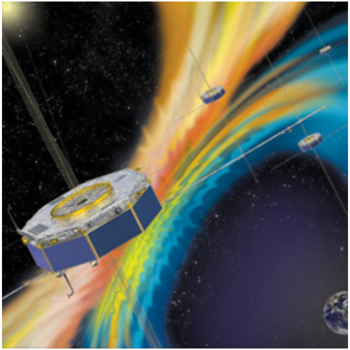
Vasyliunas 1975

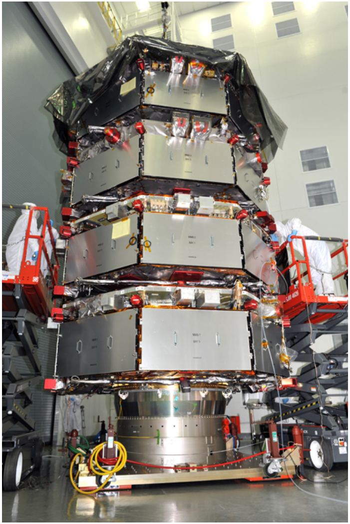
Generalized Ohm's law for electron fluid

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

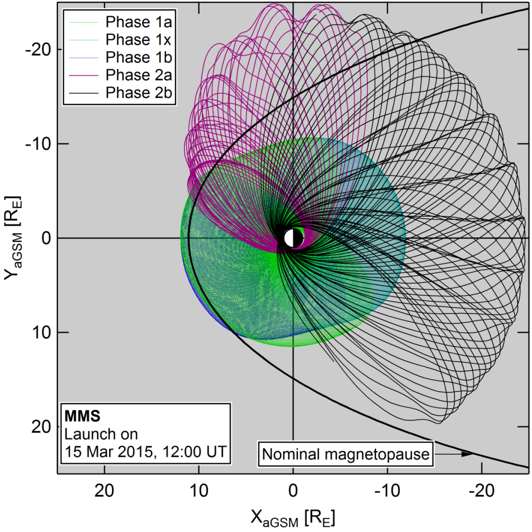
convection term vanishes because $B \sim 0$	divergence of the e pressure tensor	electron inertia term

Observations by Magnetospheric Multiscale (MMS) mission



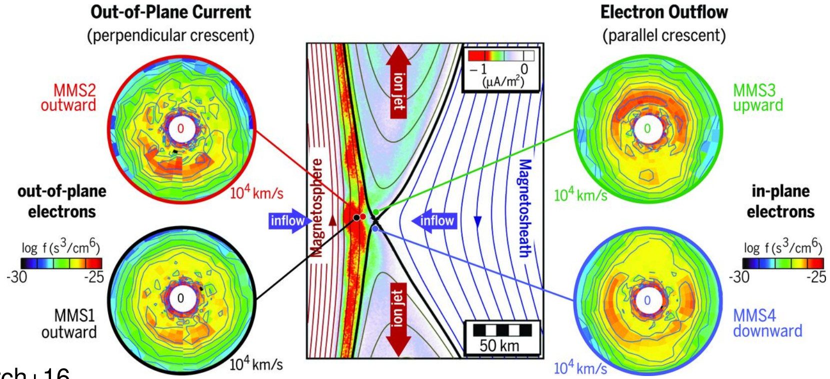


MMS trajectories: separation between spacecraft 10 km



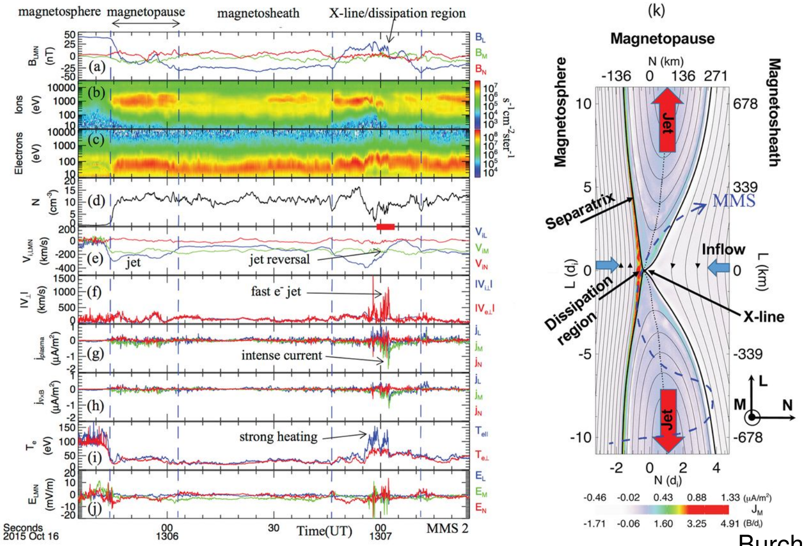
Electron-scale measurements of magnetic reconnection

- 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

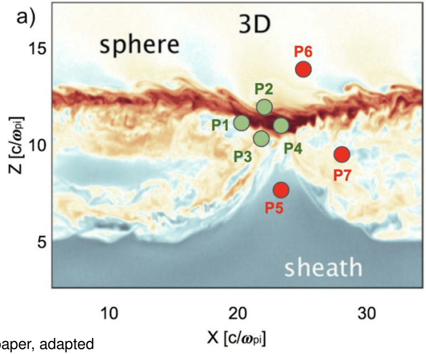
Two magnetopause crossings of MMS2



Burch+16

Lessons learned from MMS and outlook

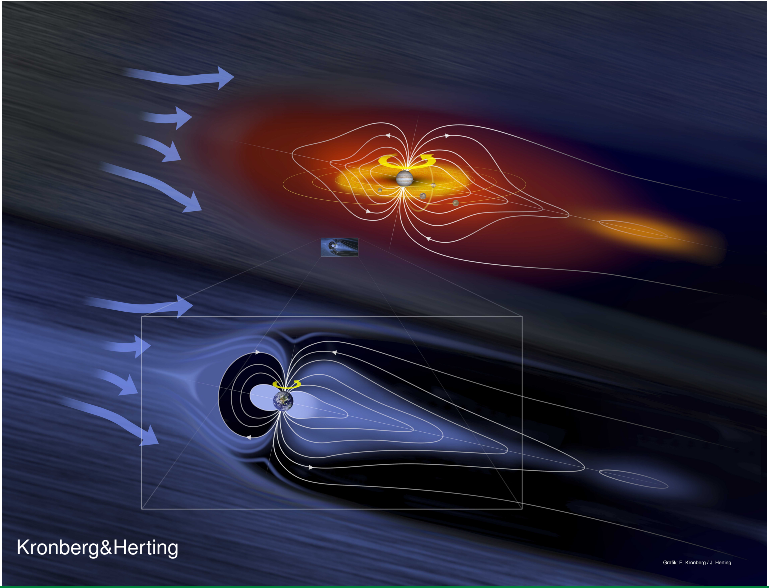
- Magnetic reconnection facilitates the transport and conversion of energy on huge spatial scales through processes that are localised on comparatively tiny kinetic scales.
- Research into how precisely the tiny diffusion region couples to the large scales, and how this multiscale interaction occurs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



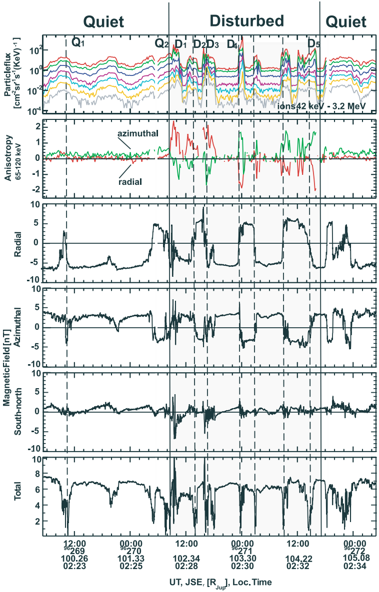
color indicates $T_{\parallel e}$

from Plasma Observatory white paper, adapted from Le et al., 2018

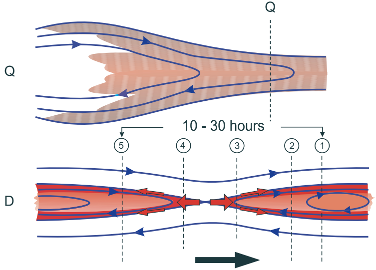
Reconnection in the magnetotail: Earth and Jupiter



X-line formation

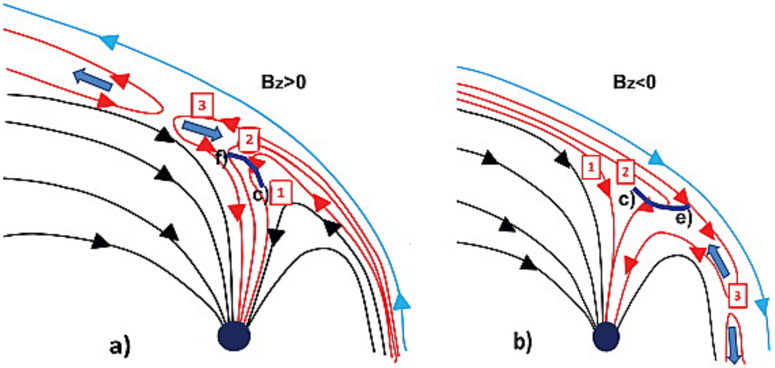


Kronberg+05



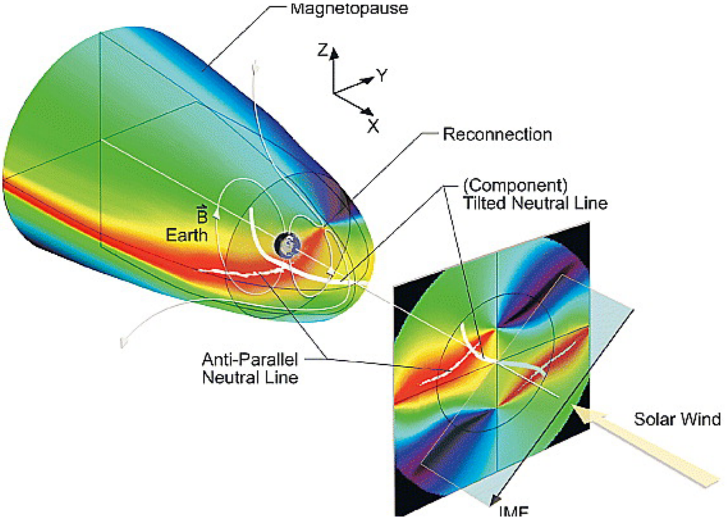
- X-line formation is one of the key signatures of the reconnection
- A change of the flow direction is often observed during the energy release phase

IMF northward: Reconnection at high latitudes



Nykyri+11

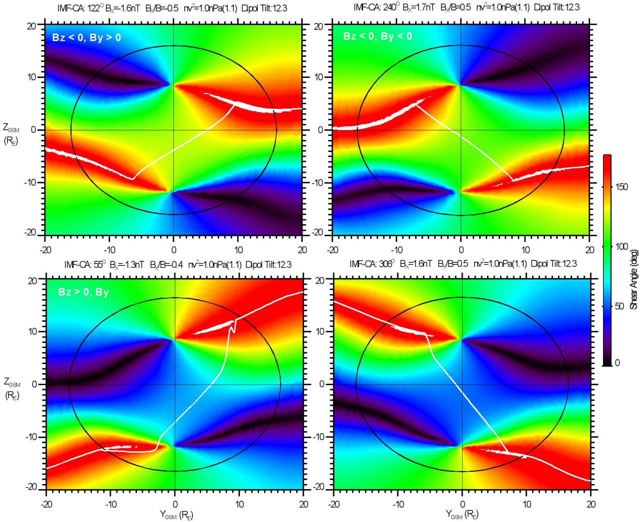
Reconnection: IMF with dawn-dusk component



Trattner+07

Reconnection: IMF with dawn-dusk component

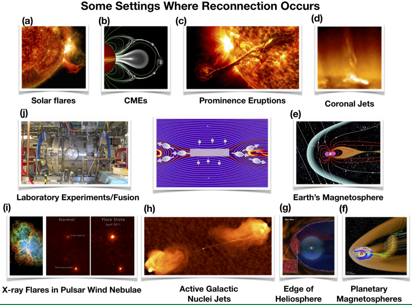
Location of the reconnection at different IMF directions



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

Literature

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