

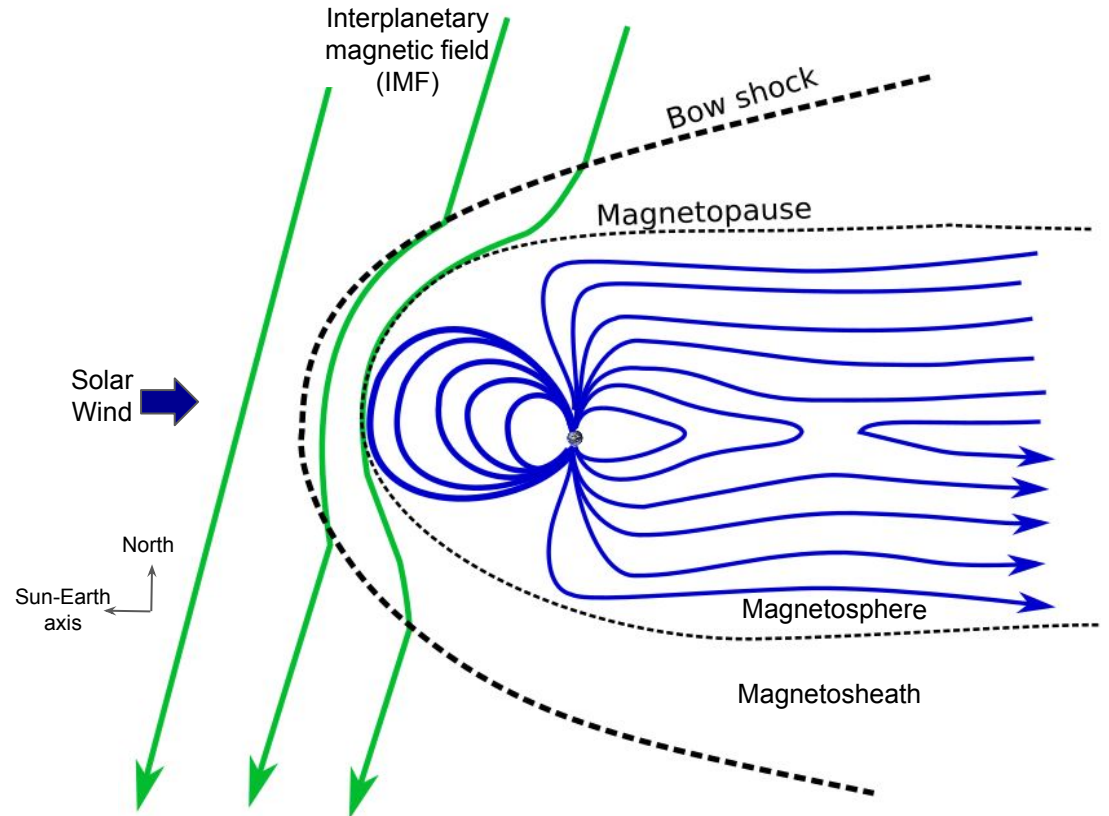
Modeling the Earth's plasma environment and magnetic reconnection at the magnetopause

Bayane Michotte de Welle, Nicolas Aunai,
Benoit Lavraud, Vincent Génot, Roch Smets

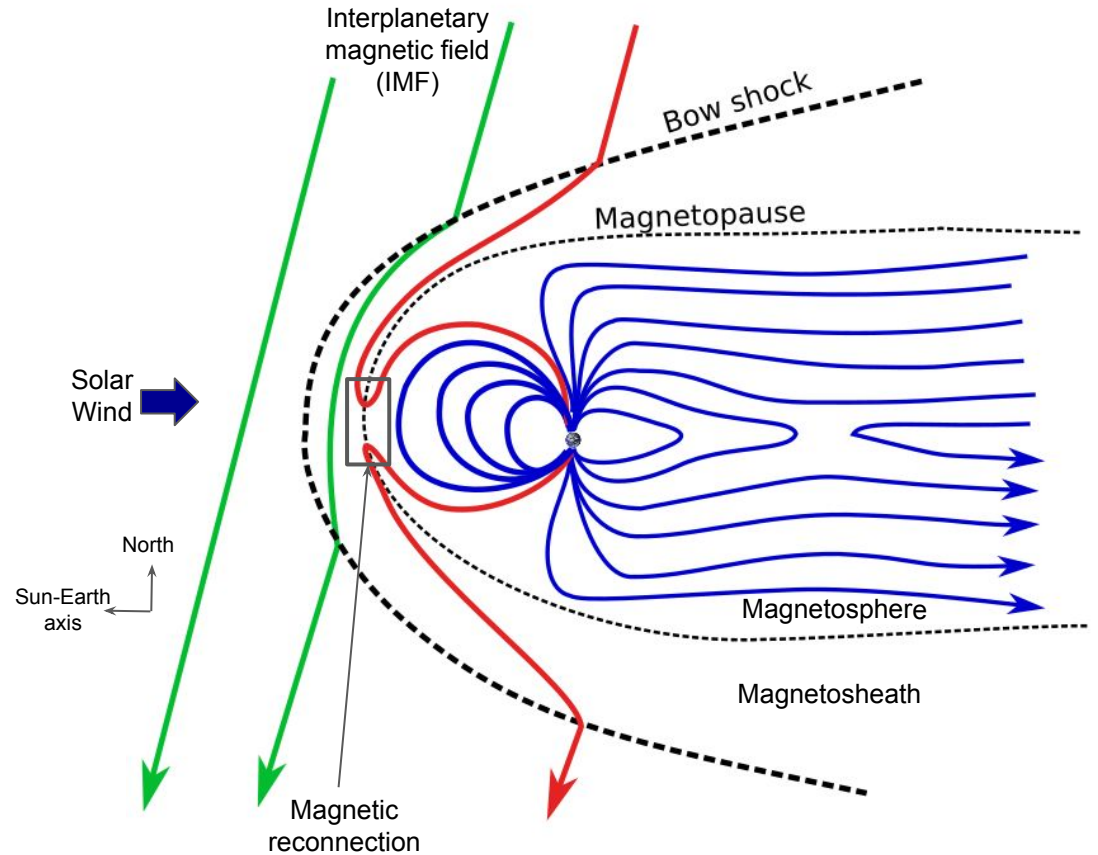
Laboratoire de Physique des Plasmas
École Polytechnique, France



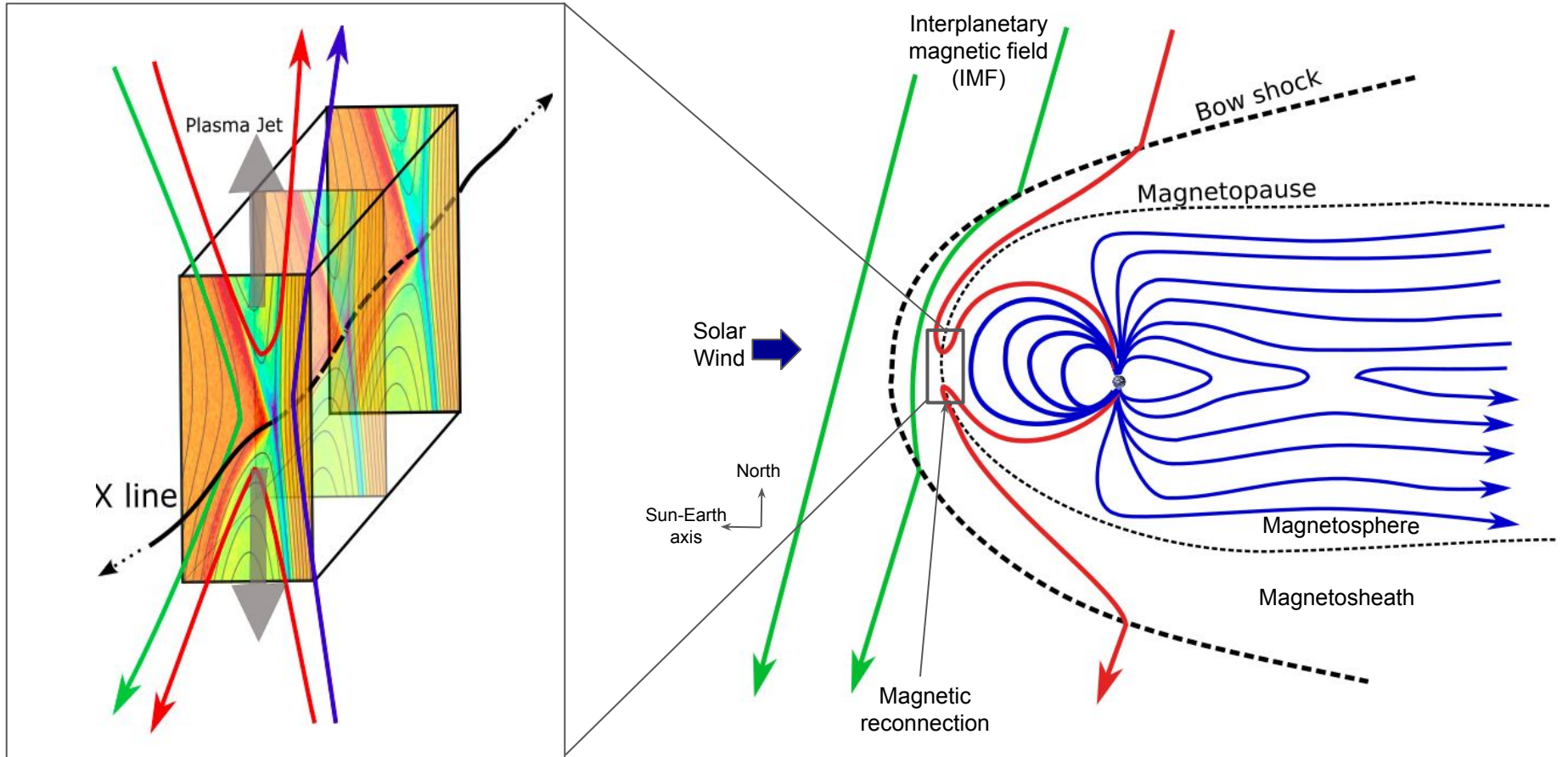
Where is the reconnection line ?



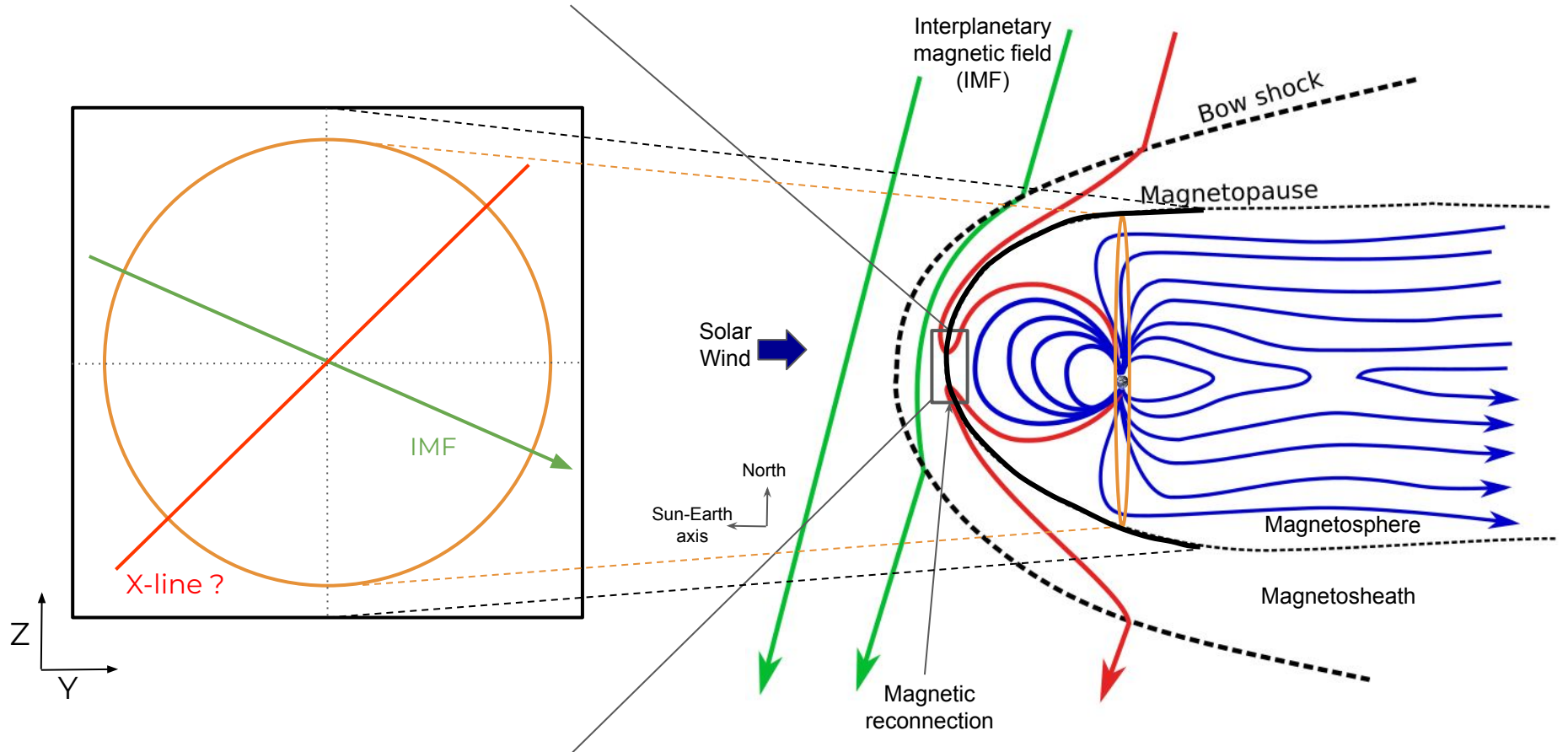
Where is the reconnection line ?



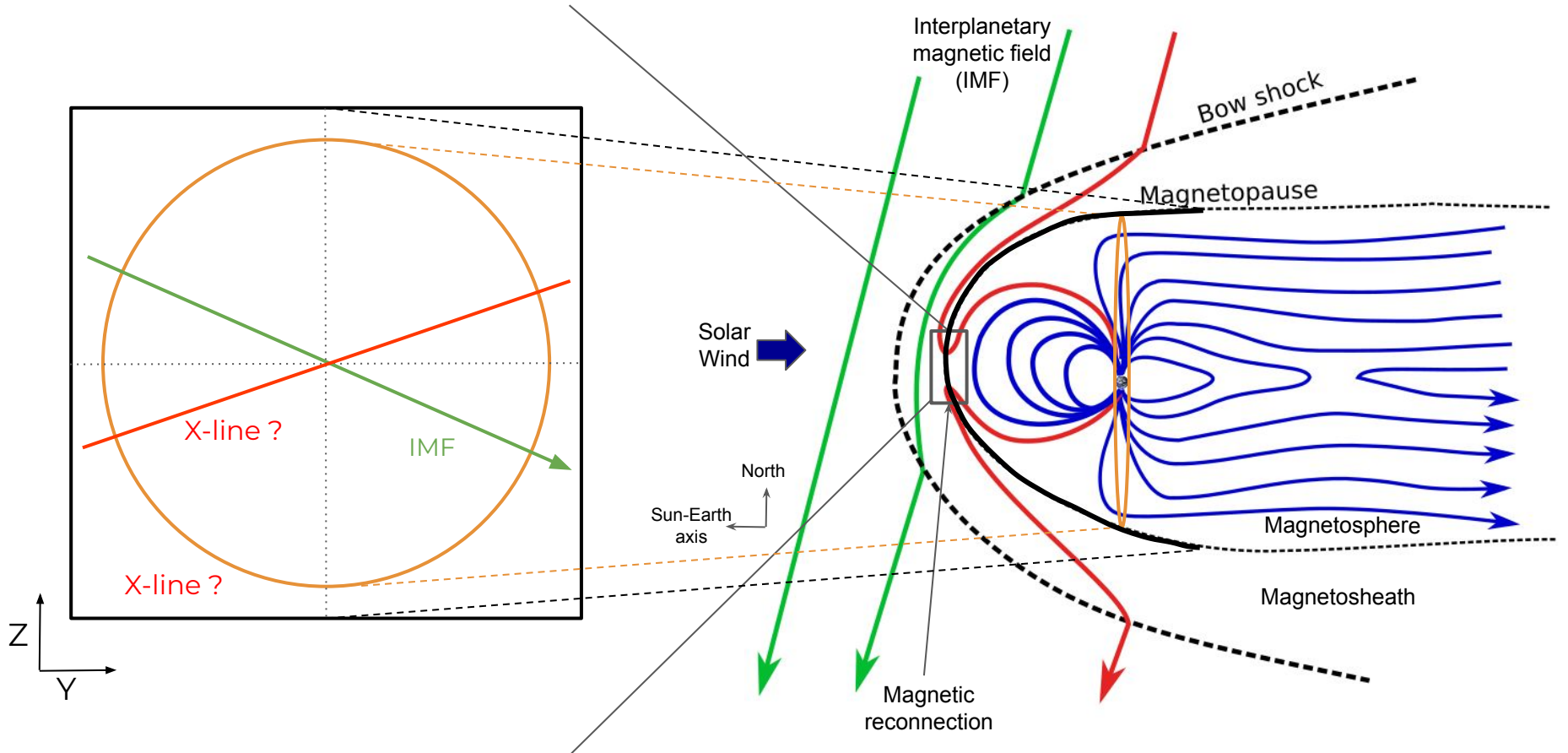
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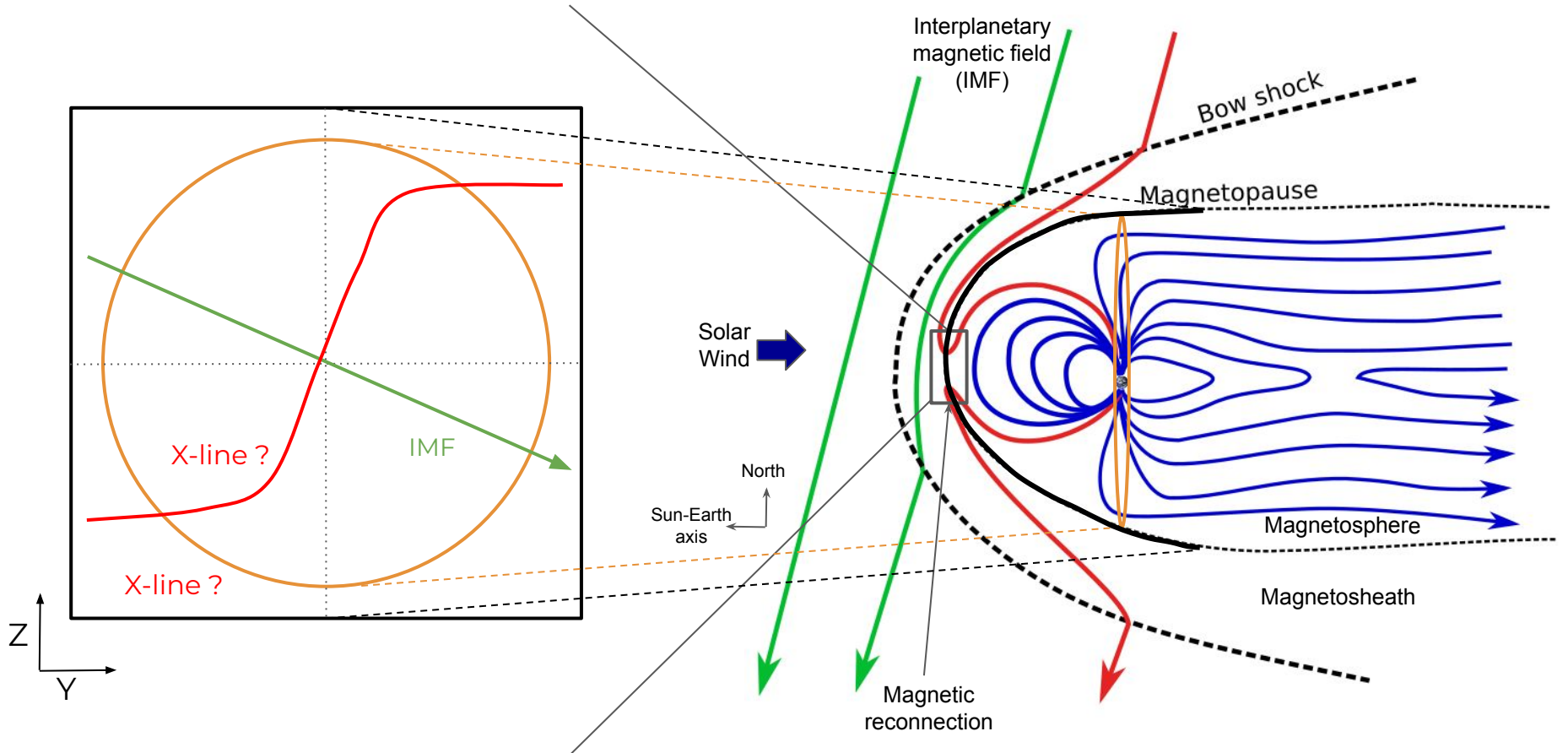
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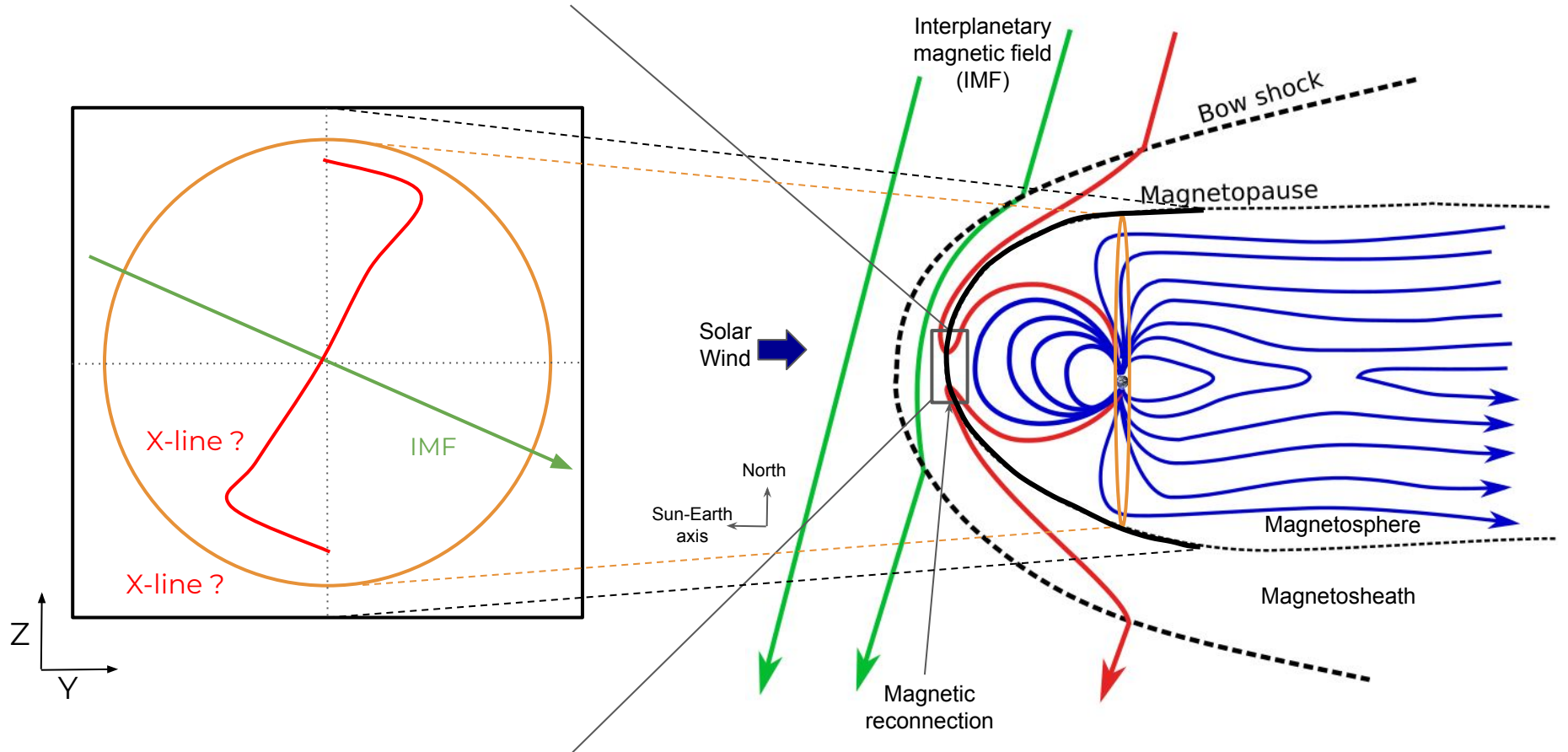
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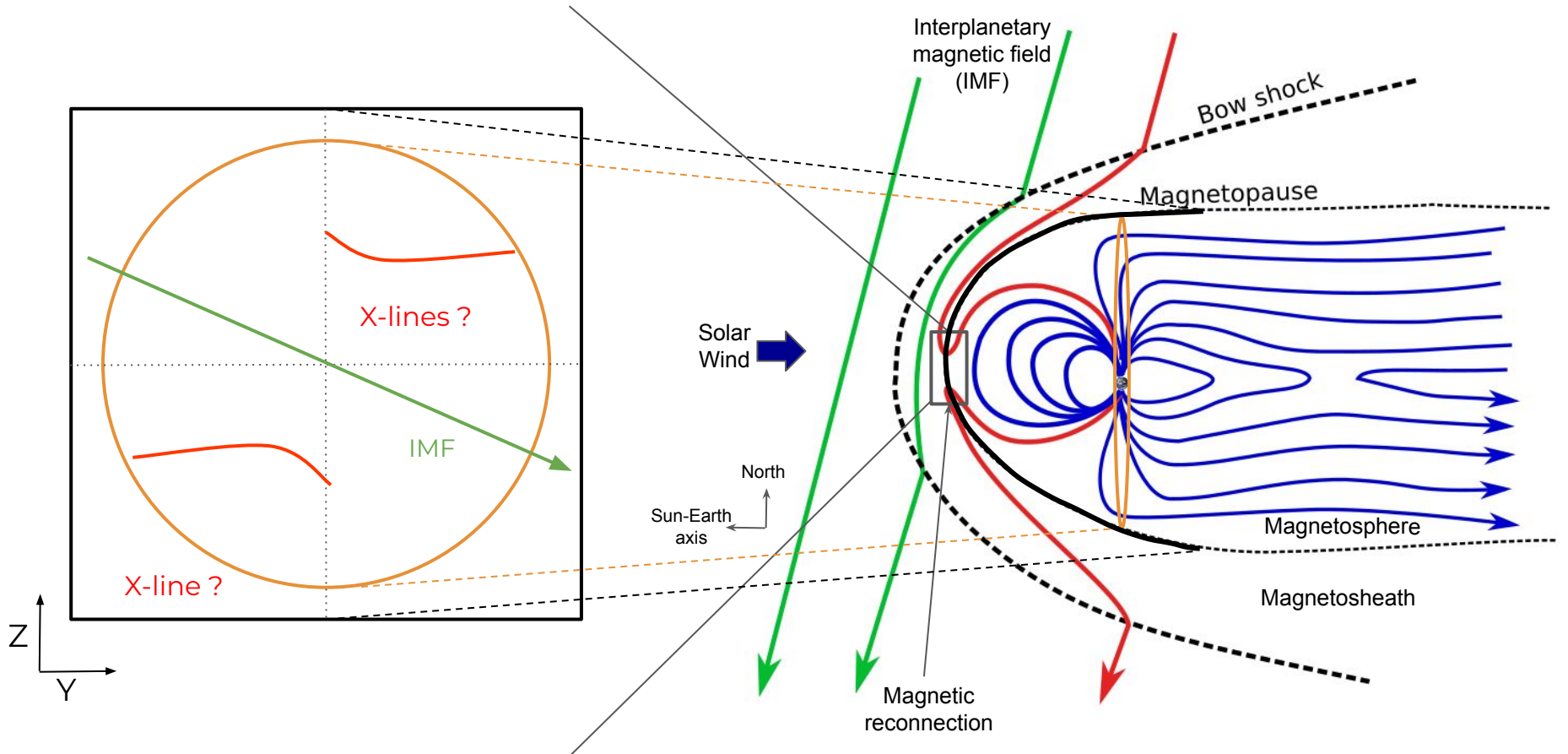
Where is the reconnection line ?



Where is the reconnection line ?



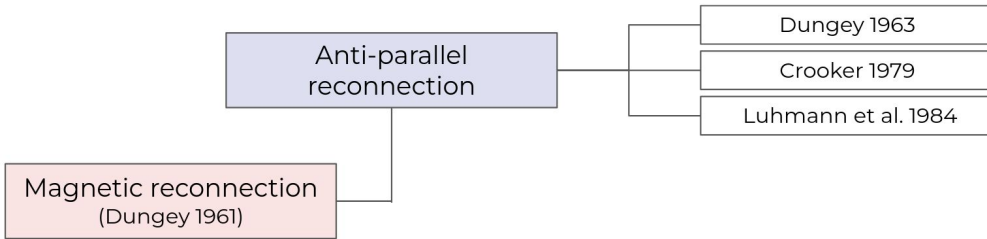
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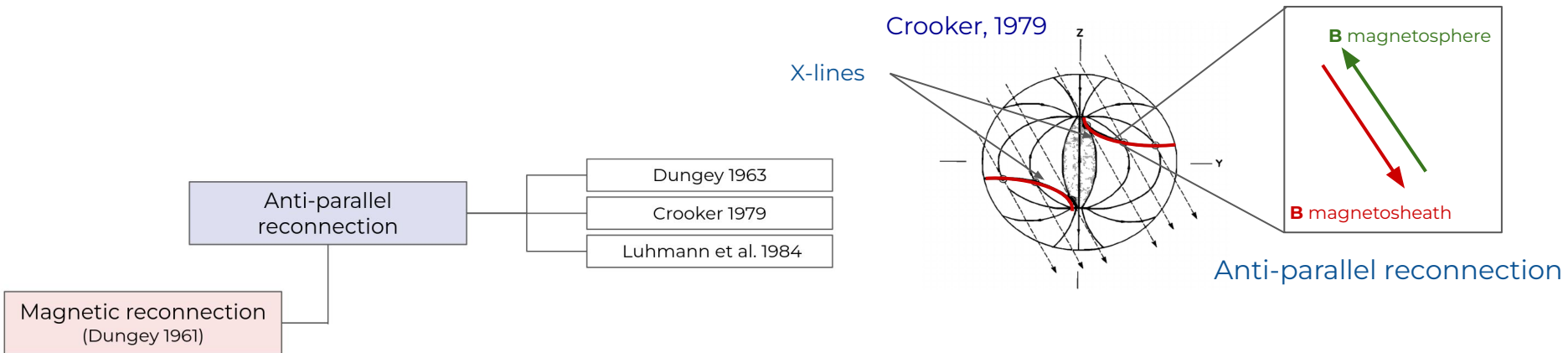
Two paradigms : anti-parallel and component reconnection

Magnetic reconnection
(Dungey 1961)

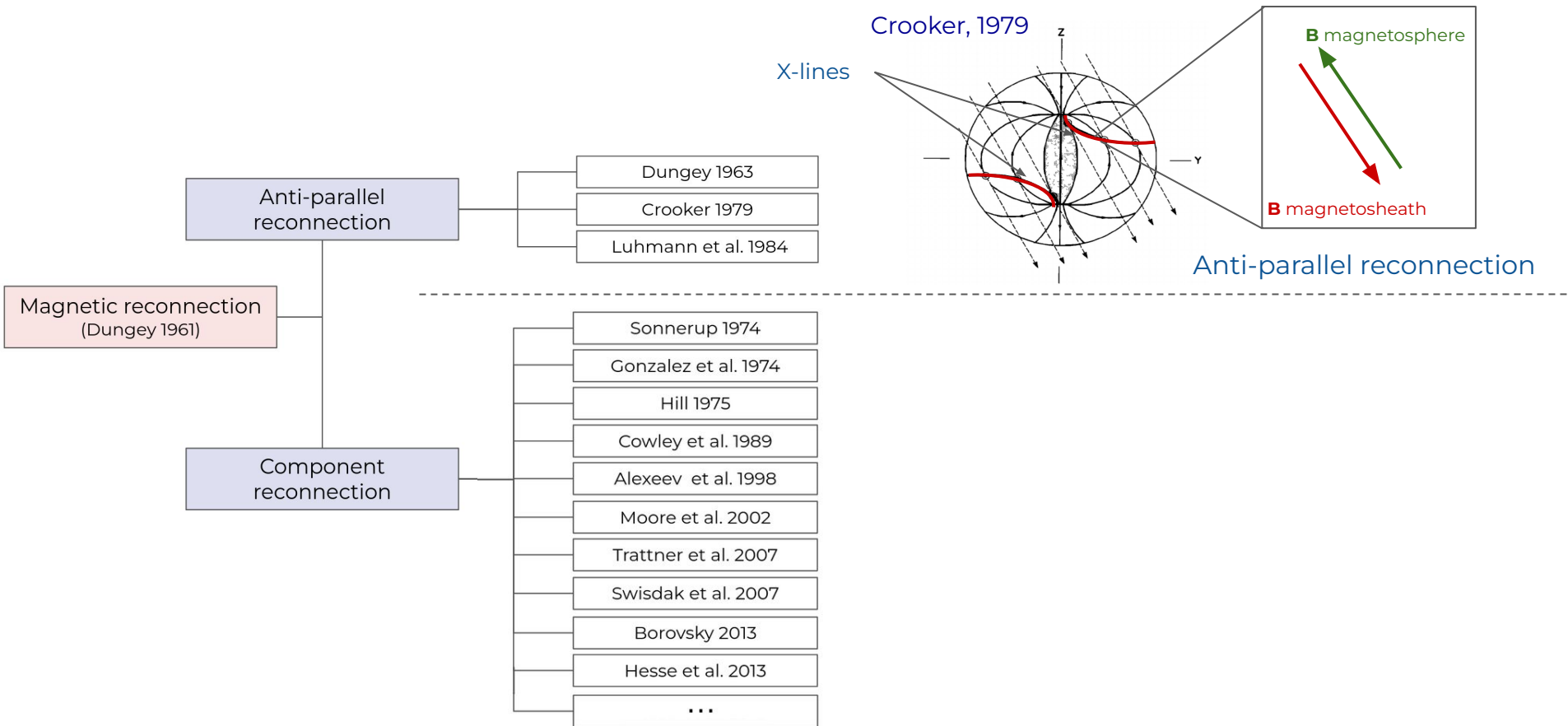
Two paradigms : anti-parallel and component reconnection



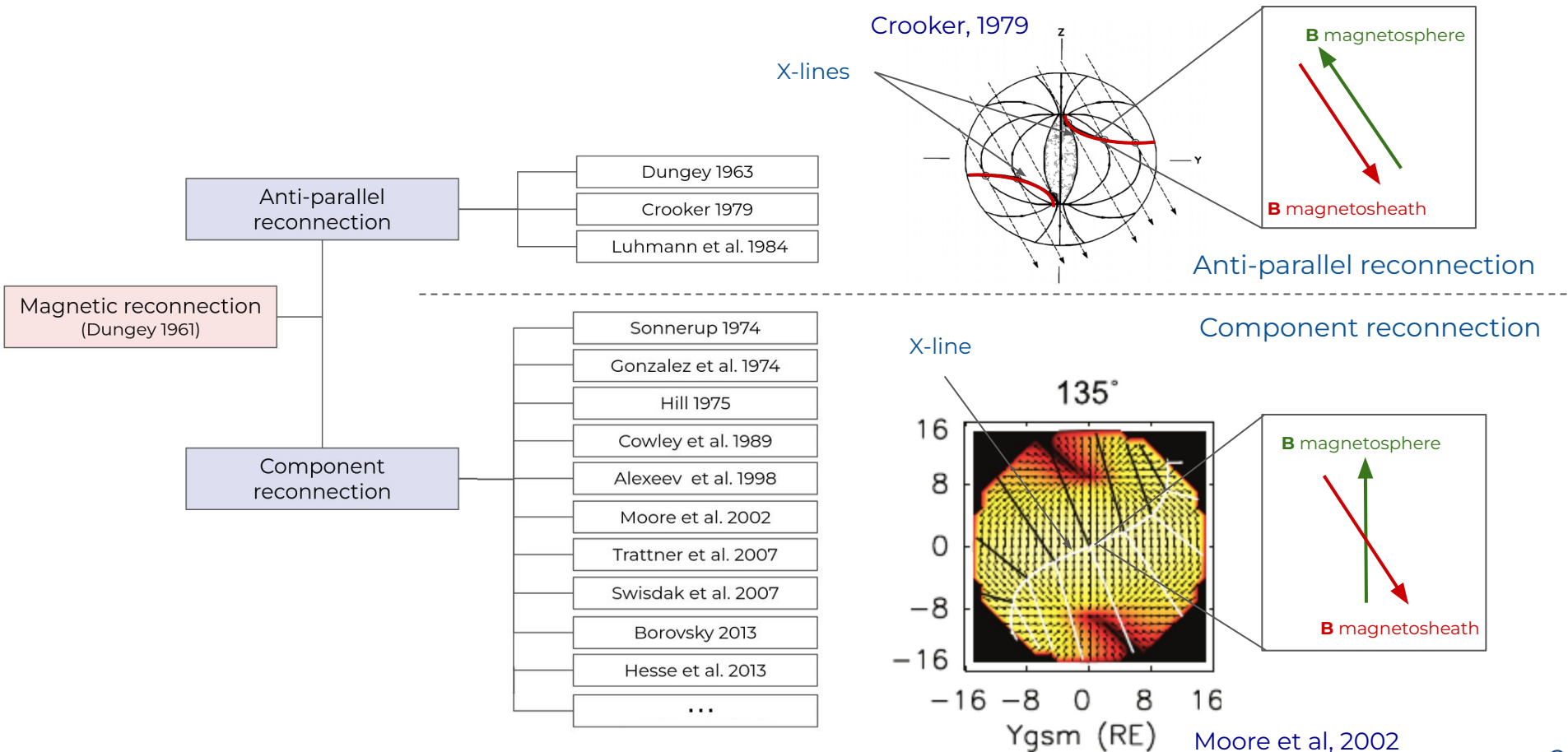
Two paradigms : anti-parallel and component reconnection



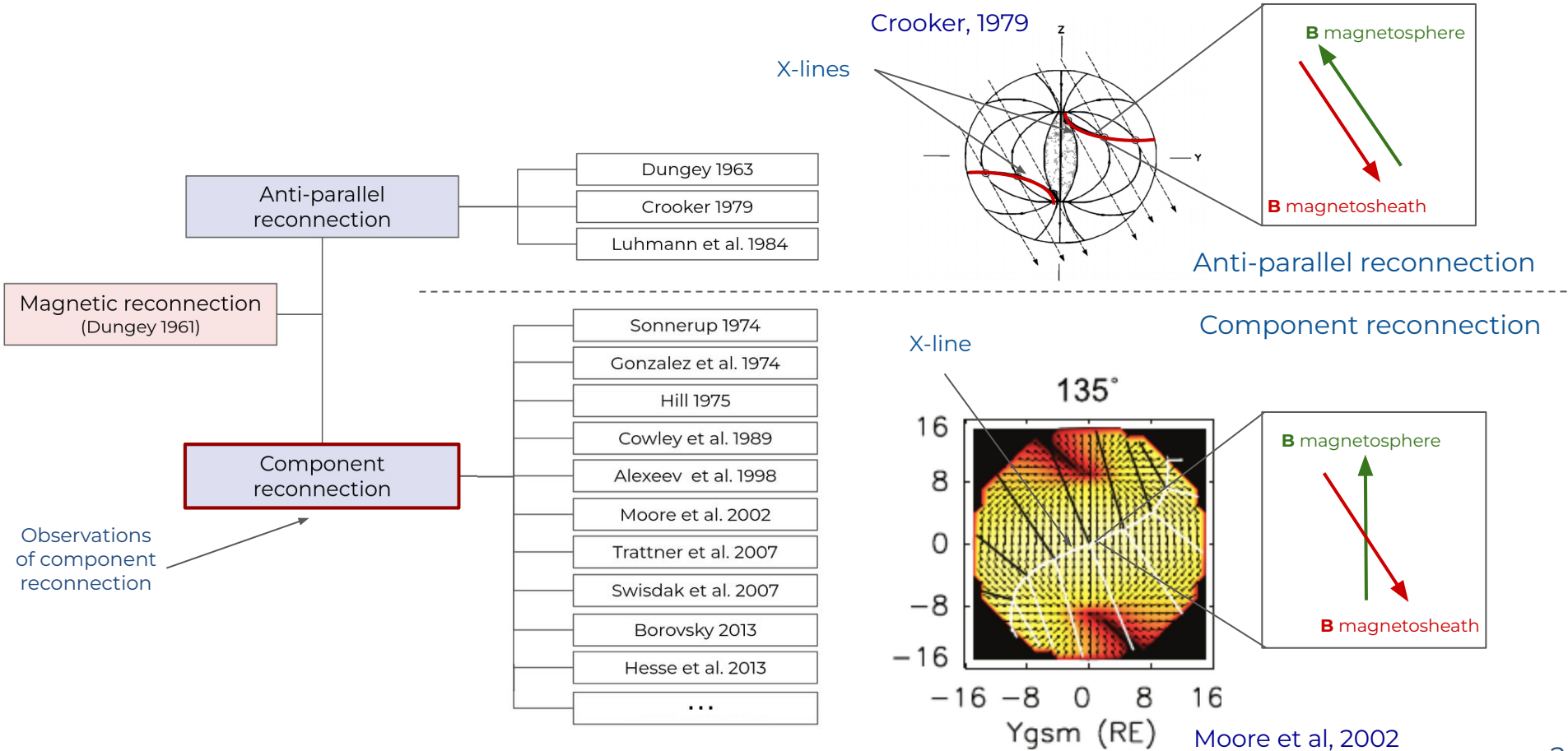
Two paradigms : anti-parallel and component reconnection



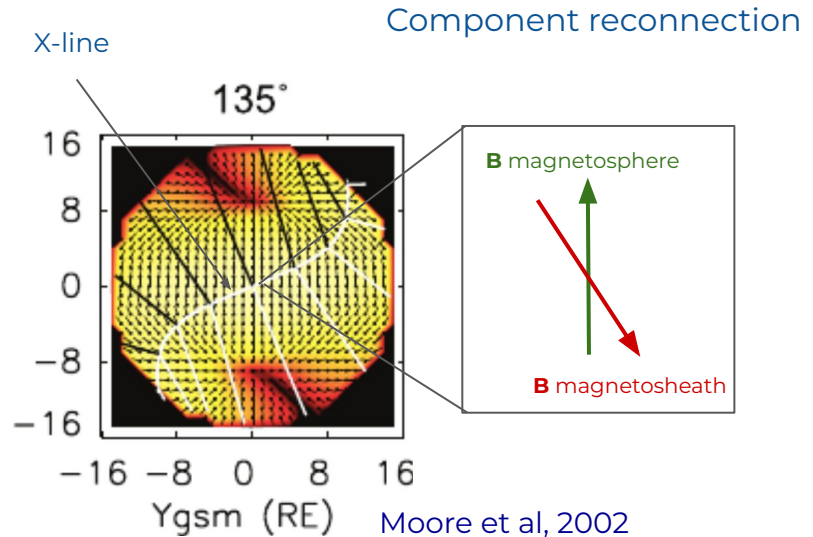
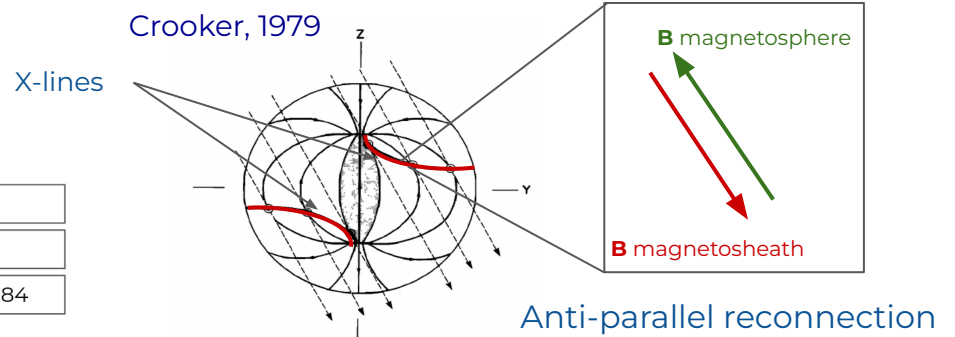
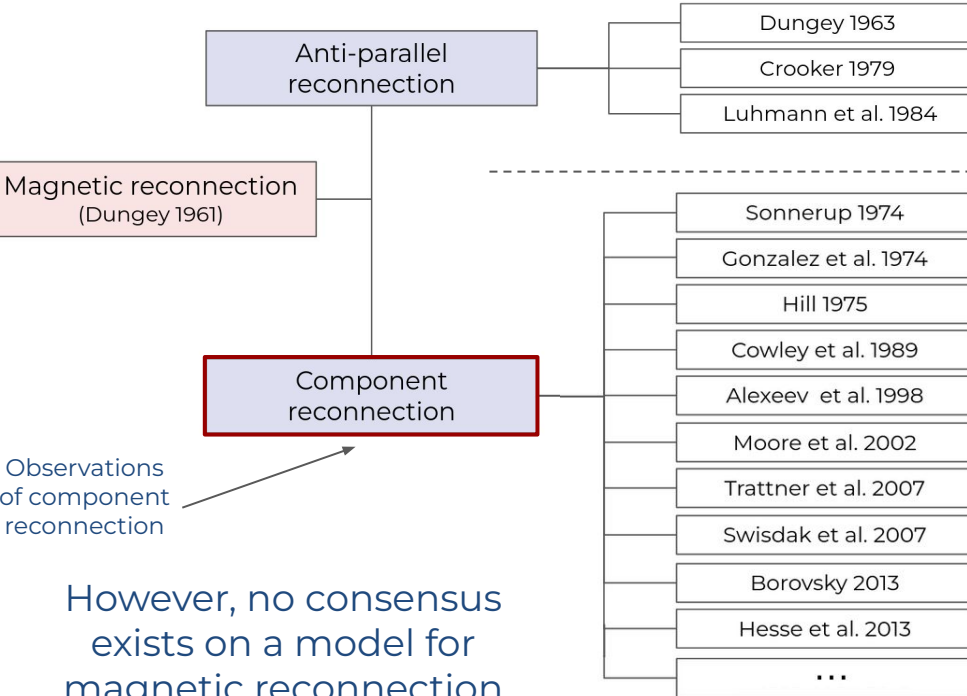
Two paradigms : anti-parallel and component reconnection



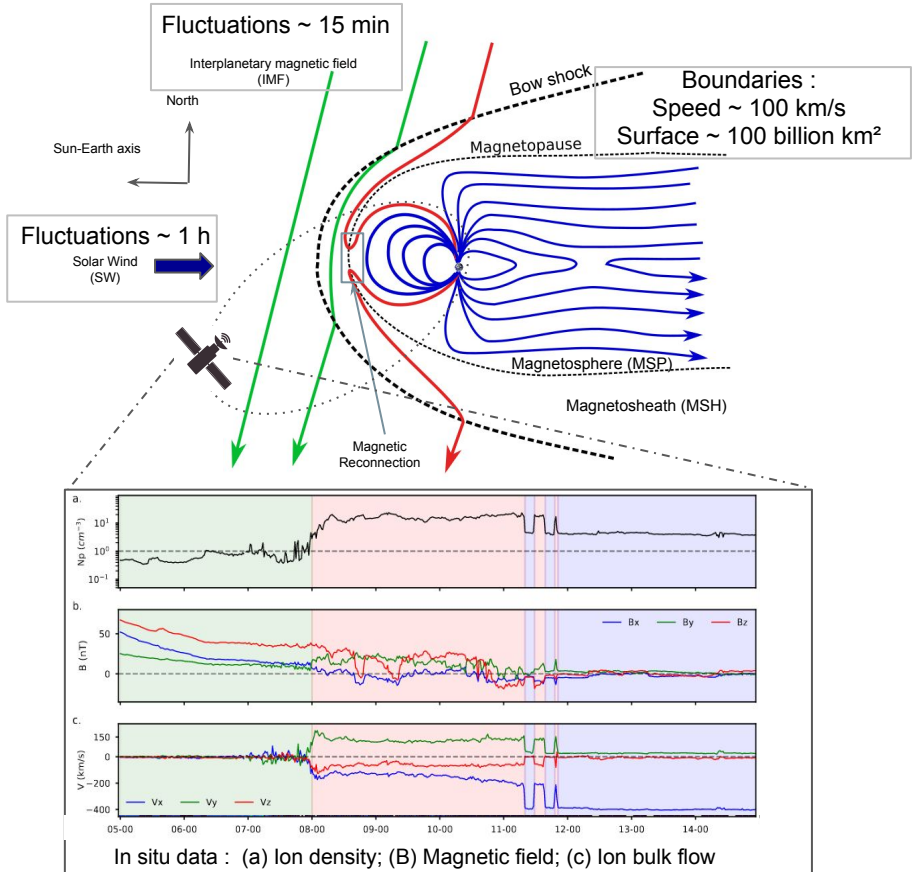
Two paradigms : anti-parallel and component reconnection



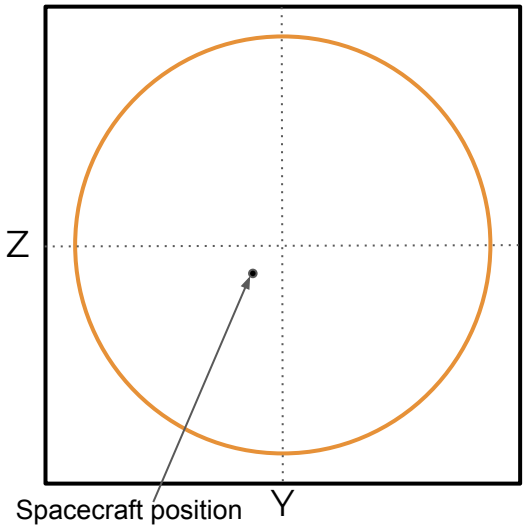
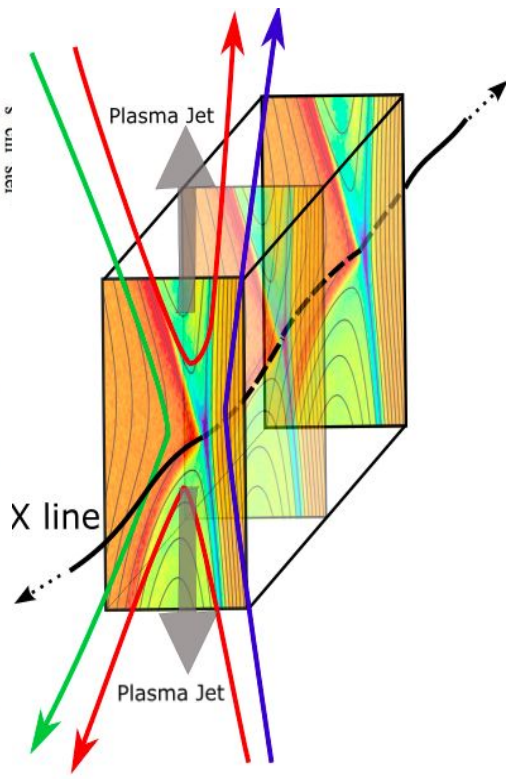
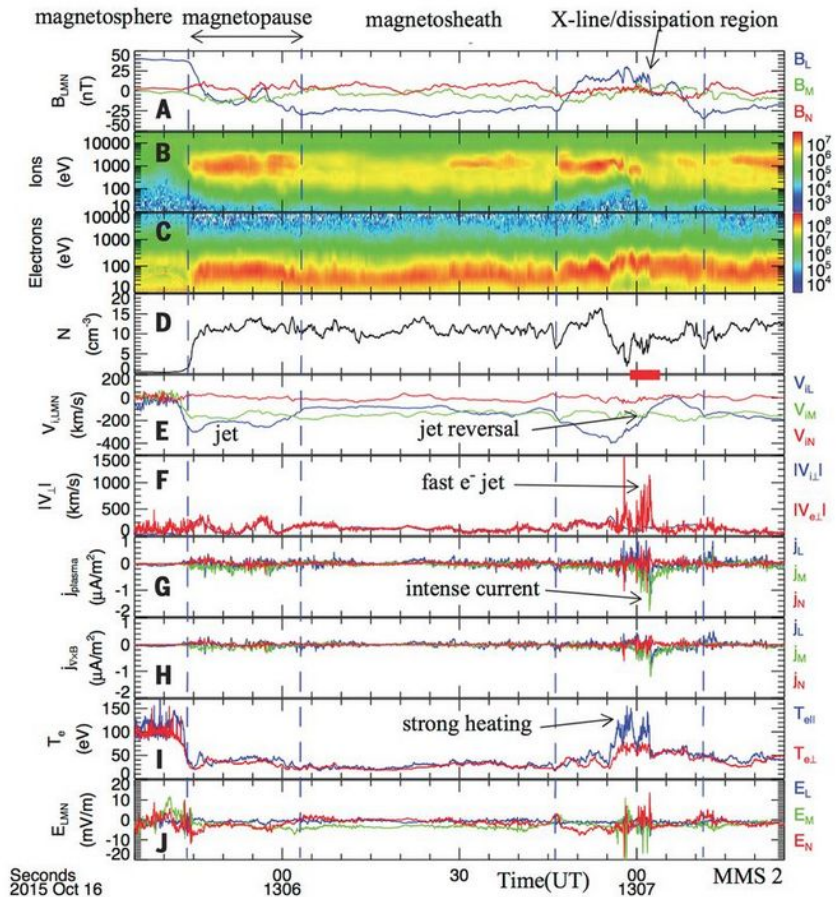
Two paradigms : anti-parallel and component reconnection



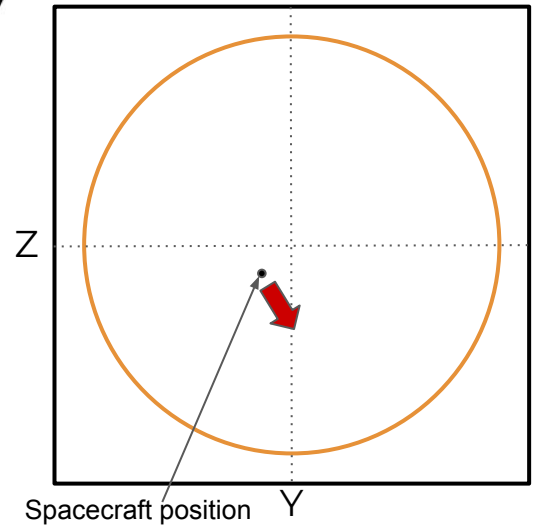
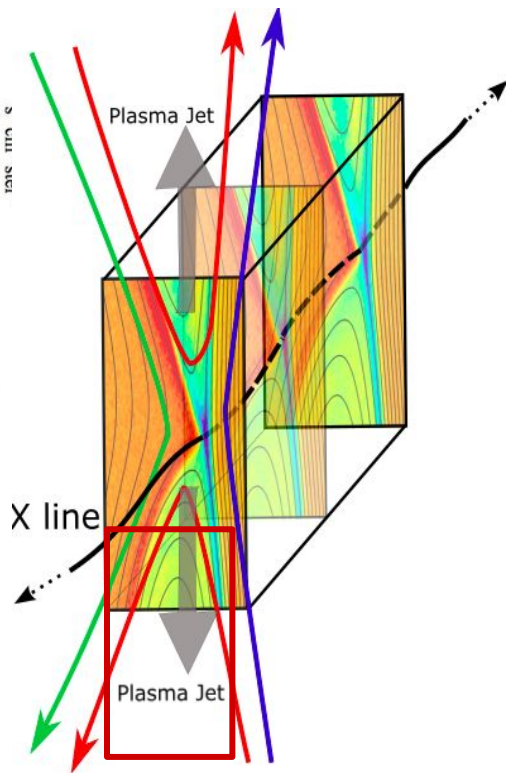
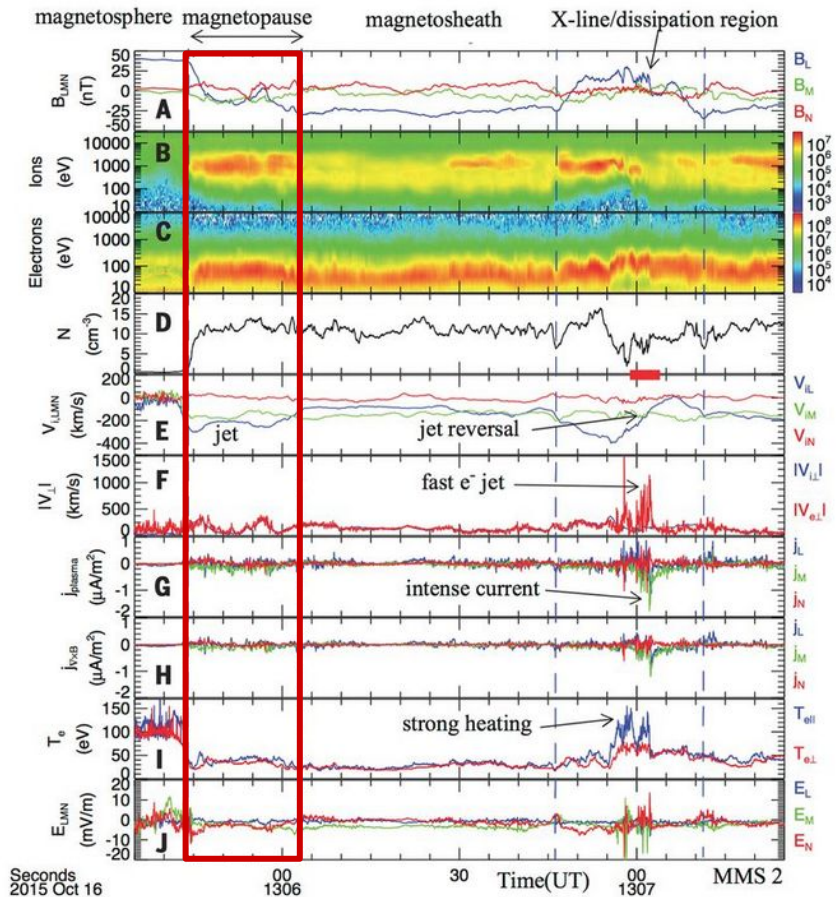
Highly dynamic system / complex and multi-scale phenomenon



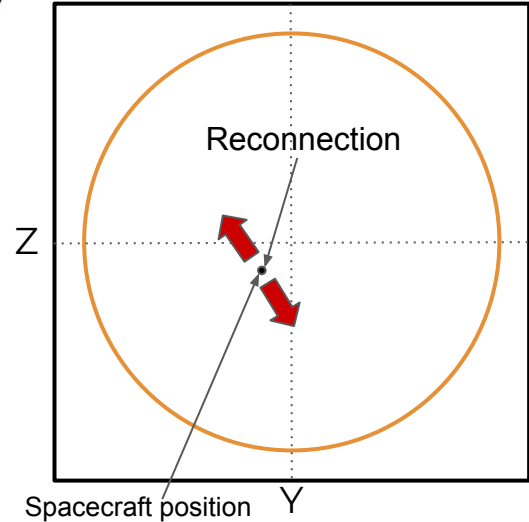
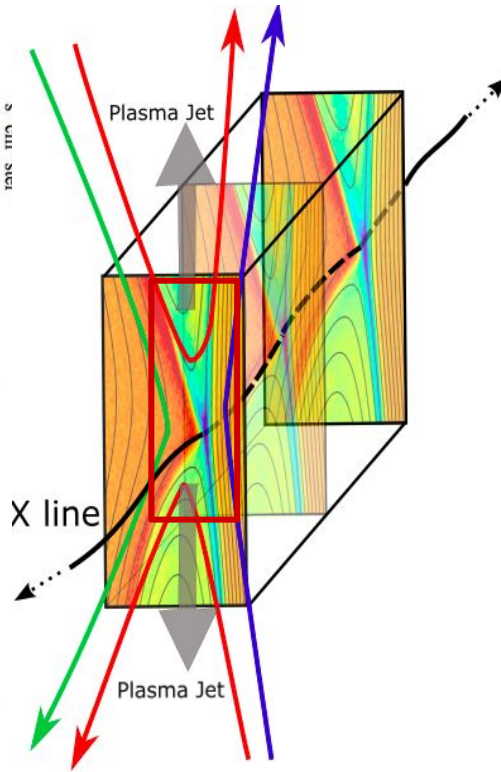
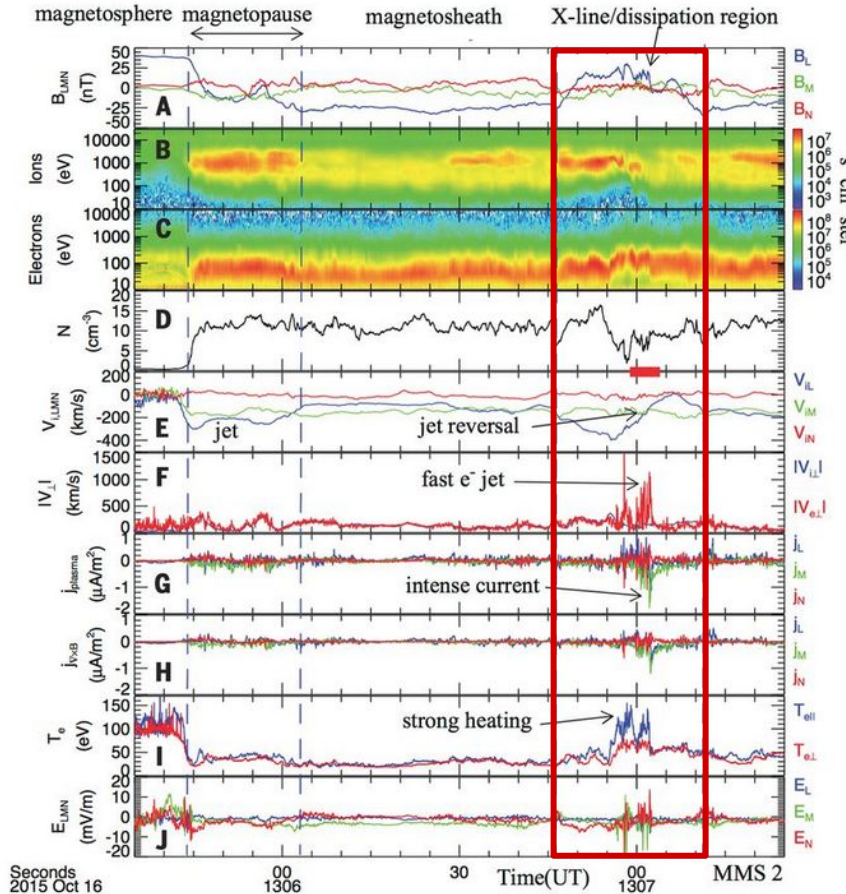
In-situ observation of magnetic reconnection



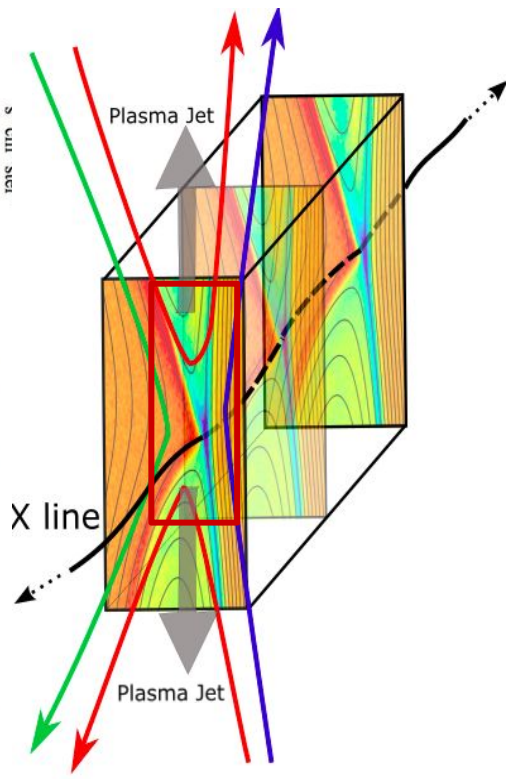
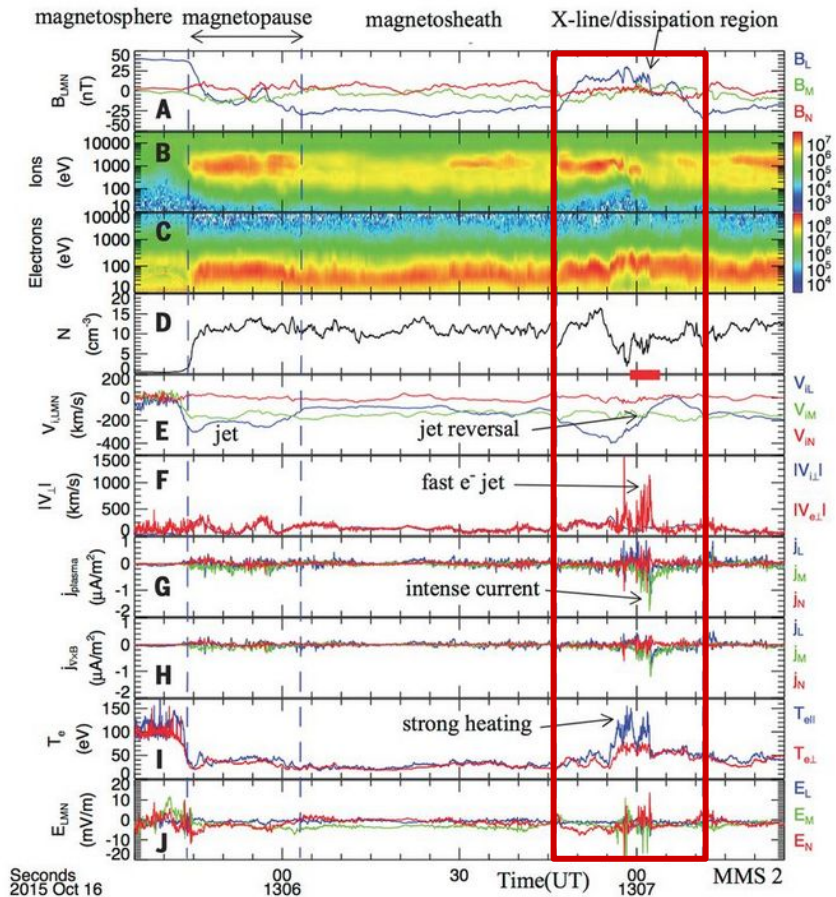
In-situ observation of magnetic reconnection



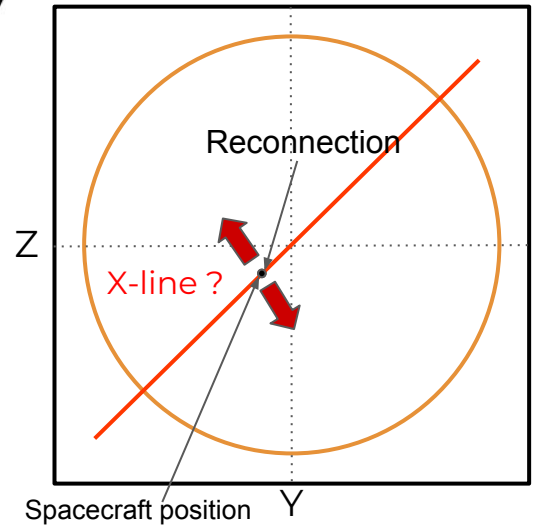
In-situ observation of magnetic reconnection



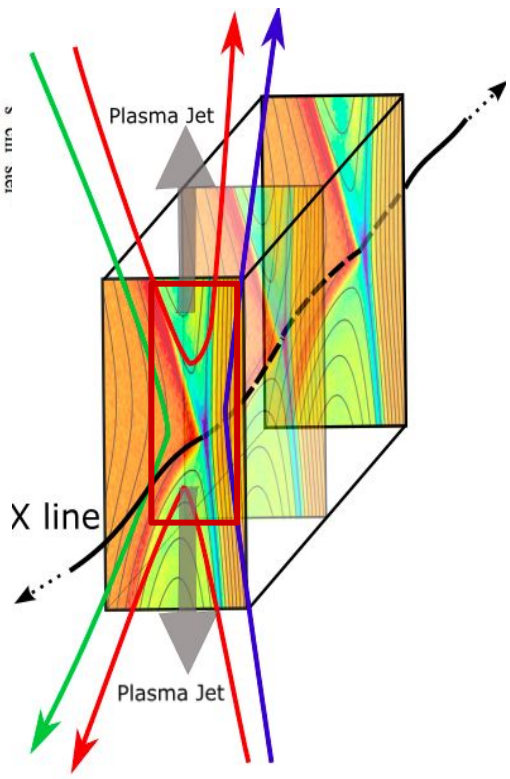
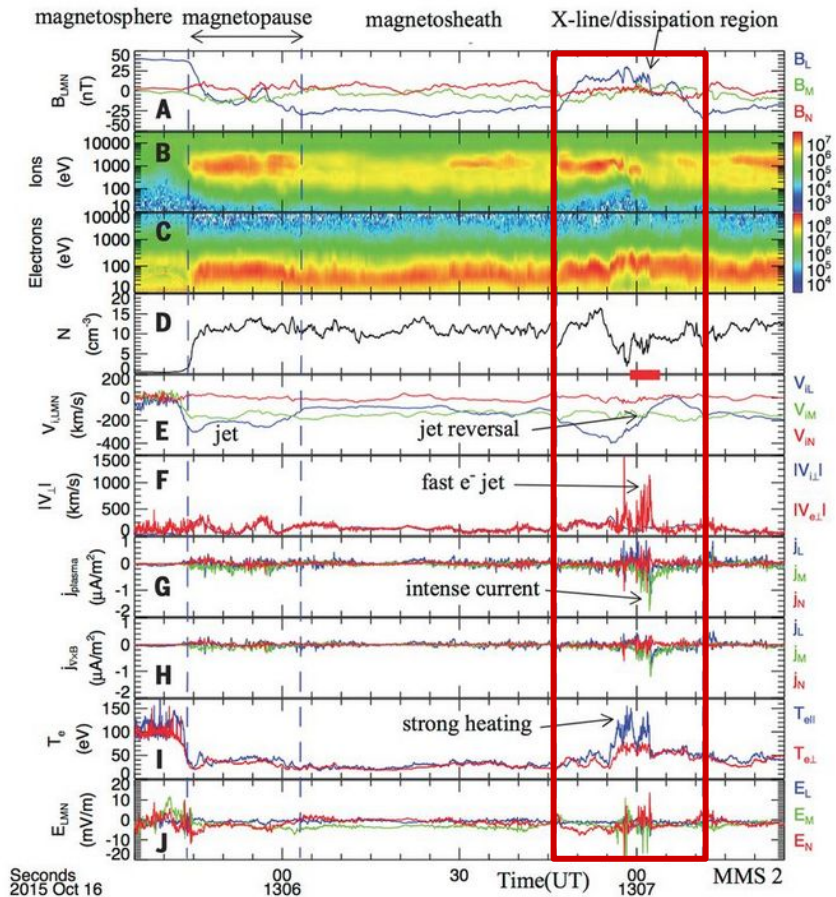
In-situ observation of magnetic reconnection



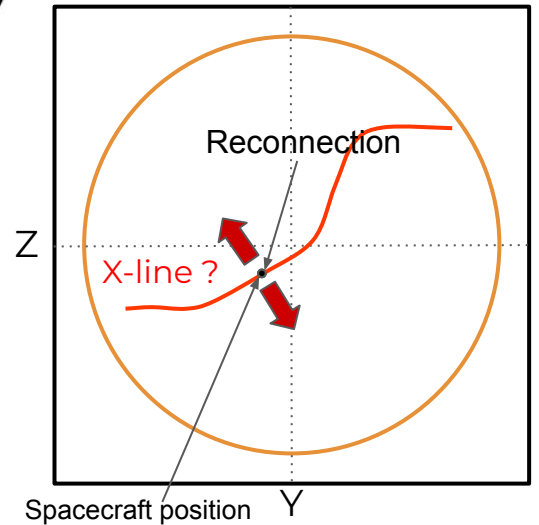
Local observation on a huge and highly dynamic system



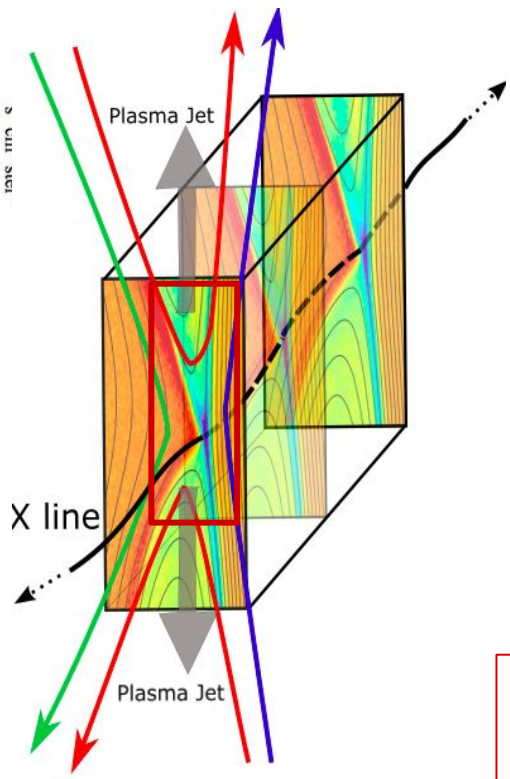
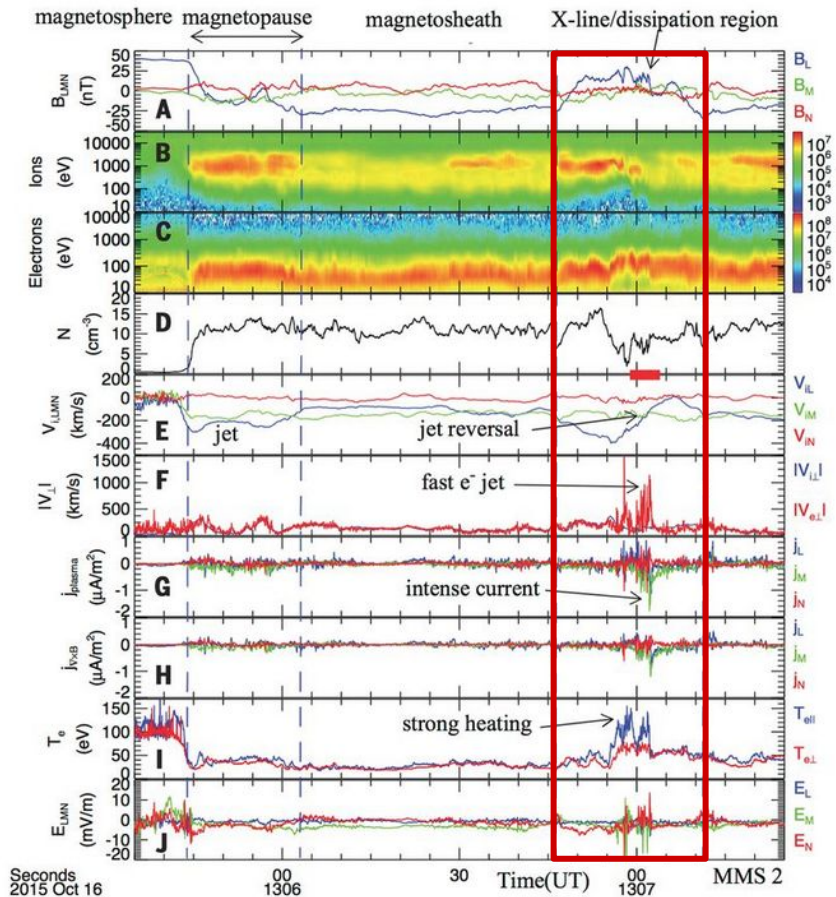
In-situ observation of magnetic reconnection



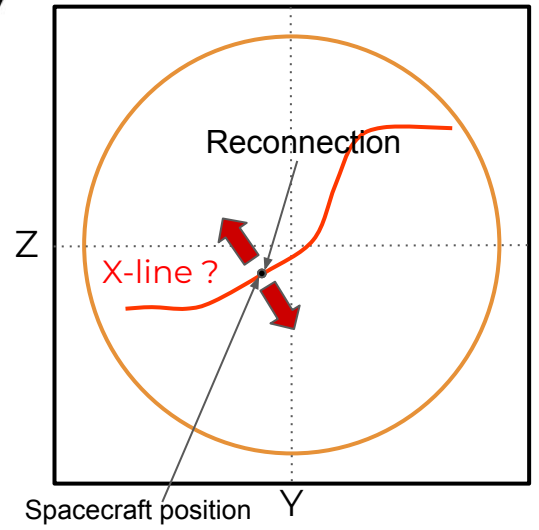
Local observation on a huge and highly dynamic system



In-situ observation of magnetic reconnection

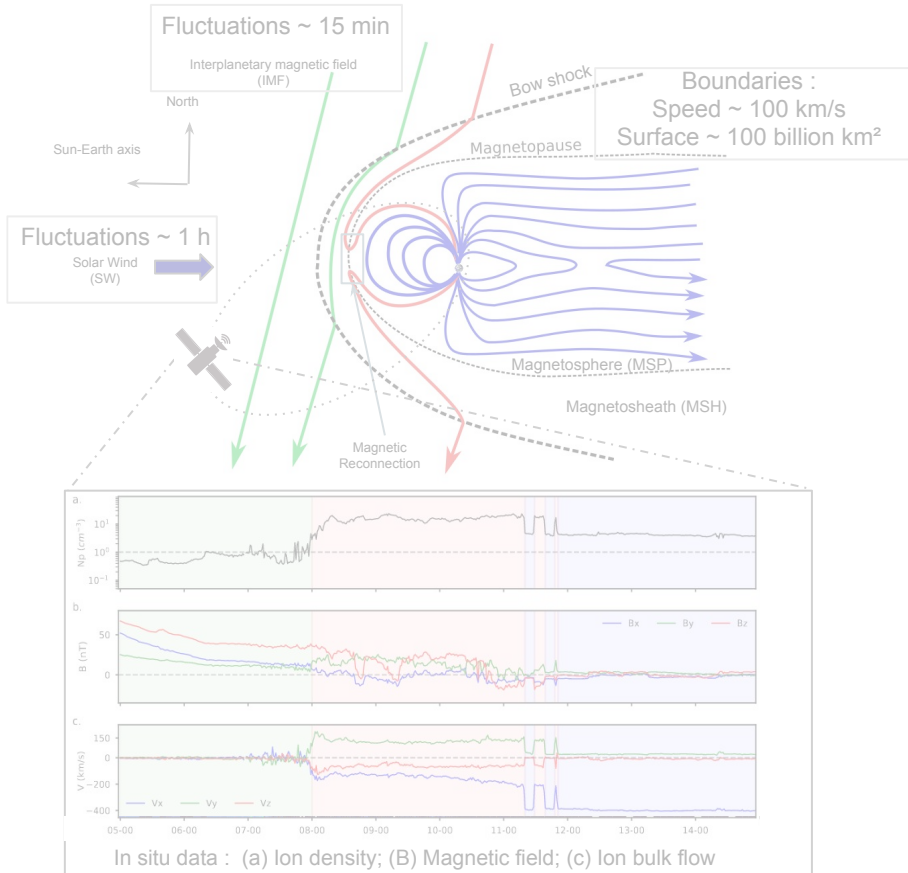


Local observation on a huge and highly dynamic system

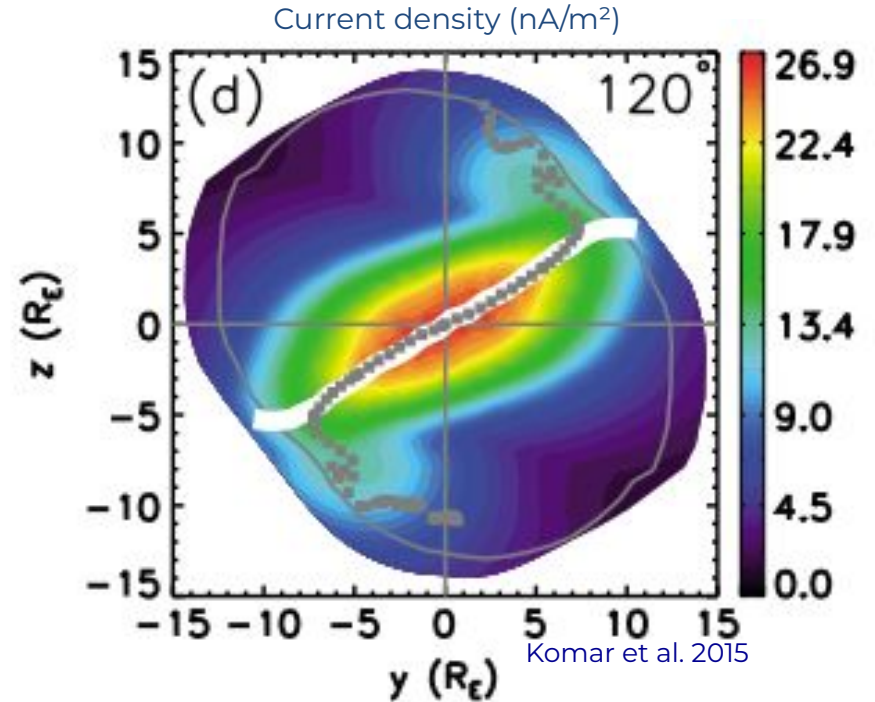


Need to better understand the global constraints on magnetic reconnection

Highly dynamic system / complex and multi-scale phenomenon

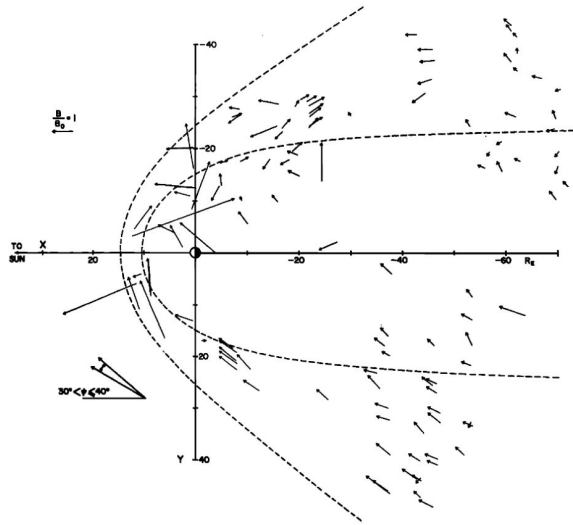


Studying magnetic reconnection in MHD simulations:



Paradigm shift in the use of in-situ measurements

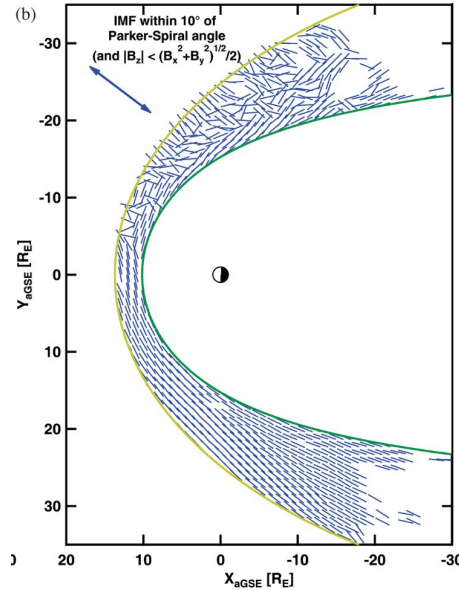
Magnetic field in the magnetosheath from in-situ data



Behannon et al. 1969

Missions :

- Explorers



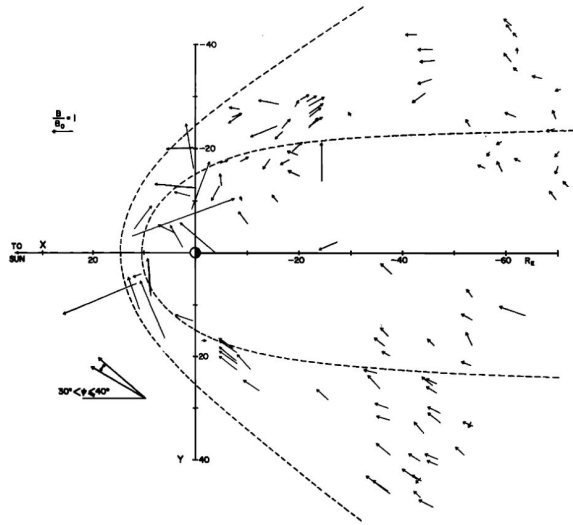
Petrinec 2012

Mission :

- THEMIS

Paradigm shift in the use of in-situ measurements

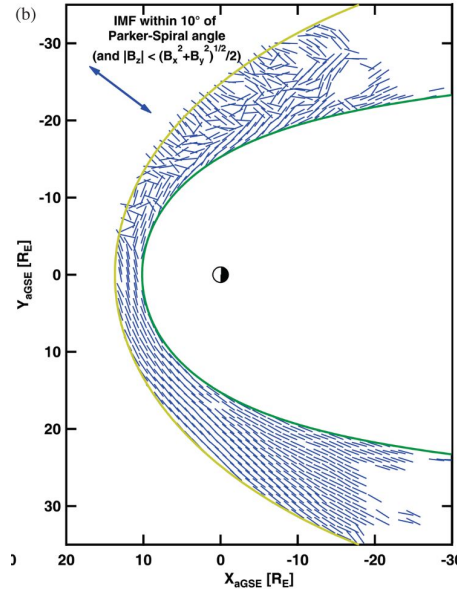
Magnetic field in the magnetosheath from in-situ data



Behannon et al. 1969

Missions :

- Explorers

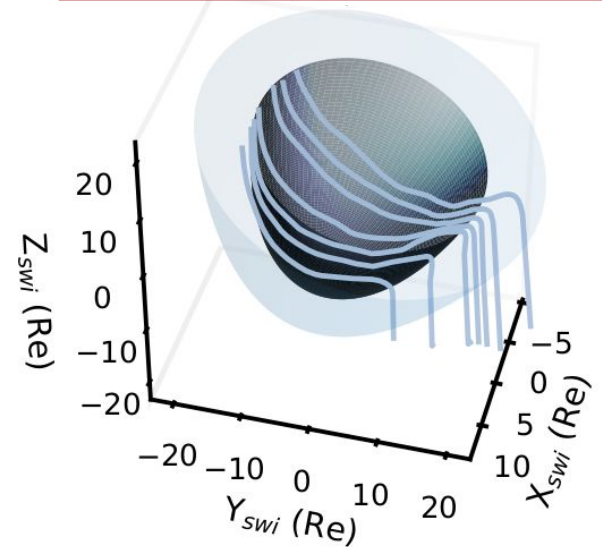


Petrinec 2012

Mission :

- THEMIS

Machine learning:
Massive data extraction



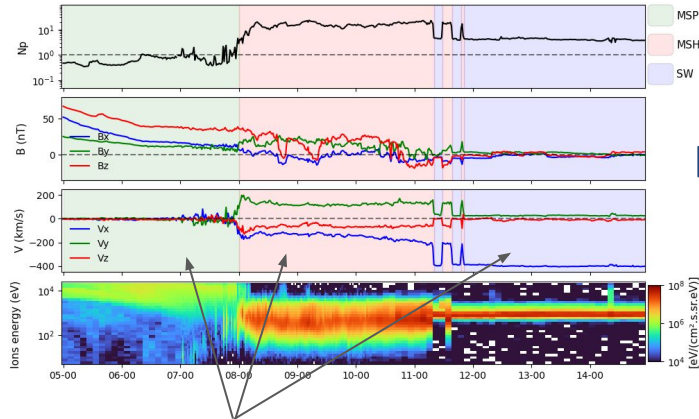
Michotte de Welle et al. 2022

Missions :

- Cluster
- DoubleStar
- THEMIS
- MMS

From in-situ data to global 3D maps

In-situ data : intrinsically local
in both time and space



Automatic detection of Earth's
plasma environment on 4 missions:

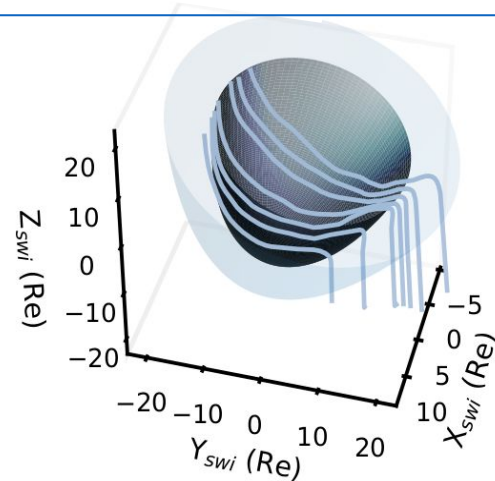
- Cluster
- DoubleStar
- THEMIS
- MMS

Pipeline

- Region detection
- Association with SW/IMF
params
- Normalization between
MP/BS
- kNN / field line integration

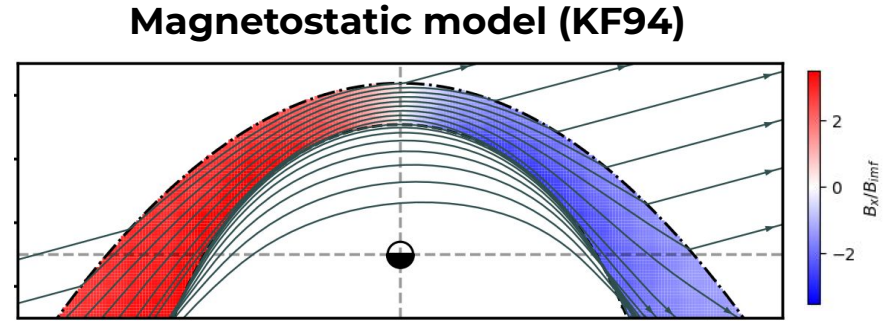
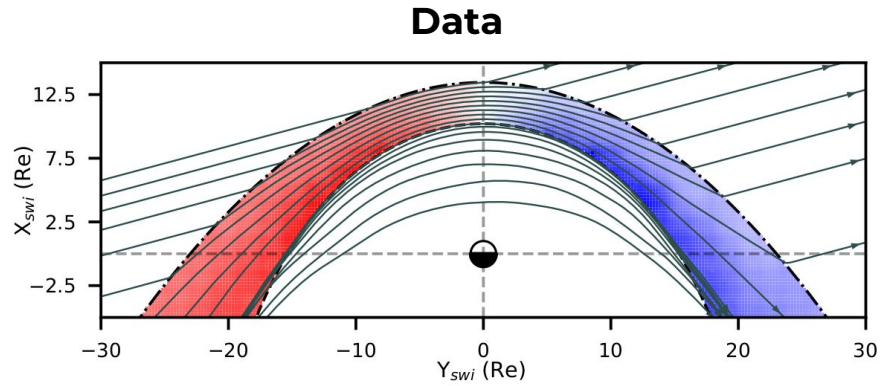
~ 45 millions magnetosheath
and
~ 55 millions magnetosphere
data points

Stationary and 3D
representation

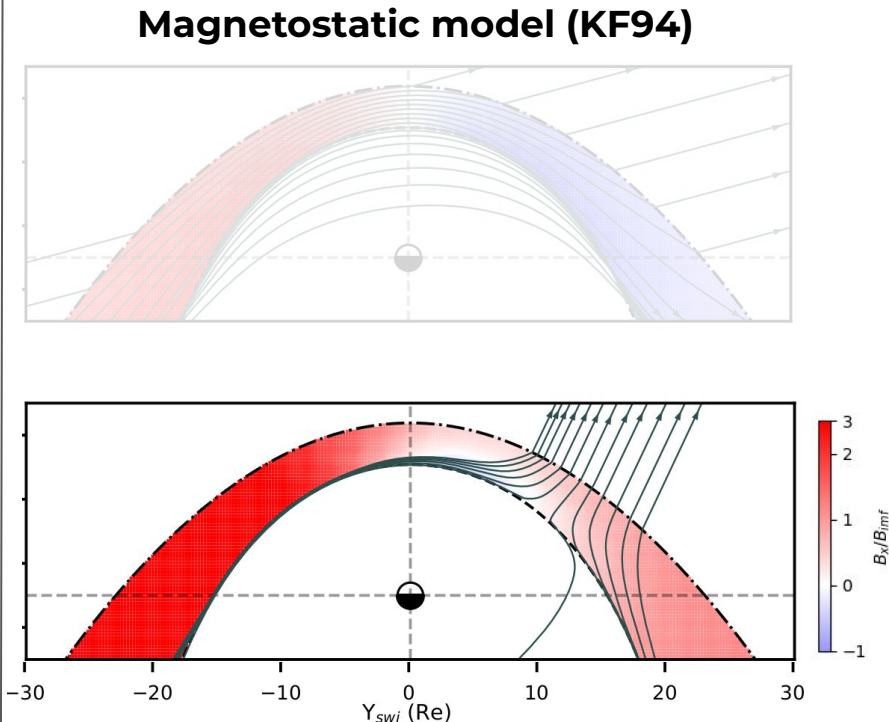
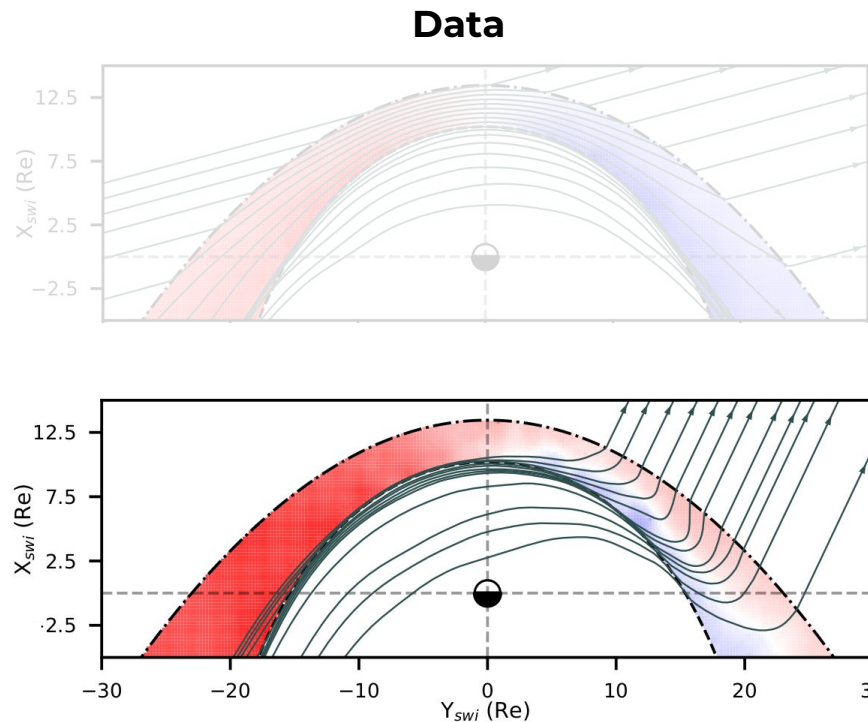


Michotte de Welle et al. 2022

Agreement model/data for radial and perp. IMF

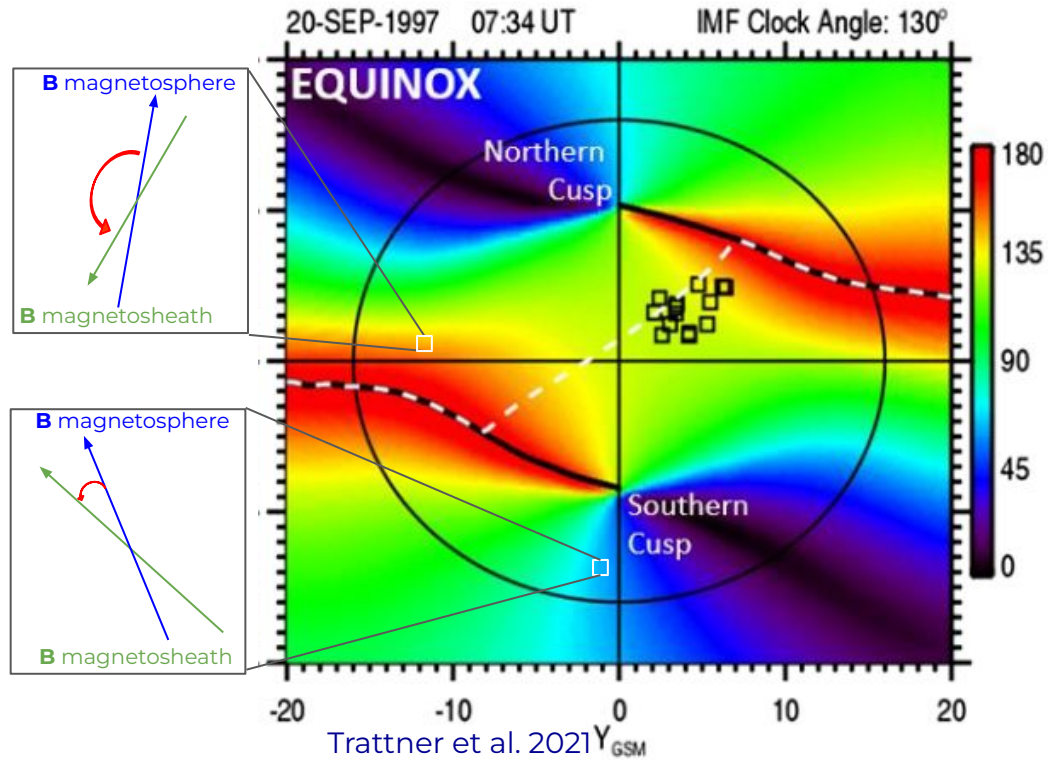


Disagreement model/data for intermediate IMF inclination



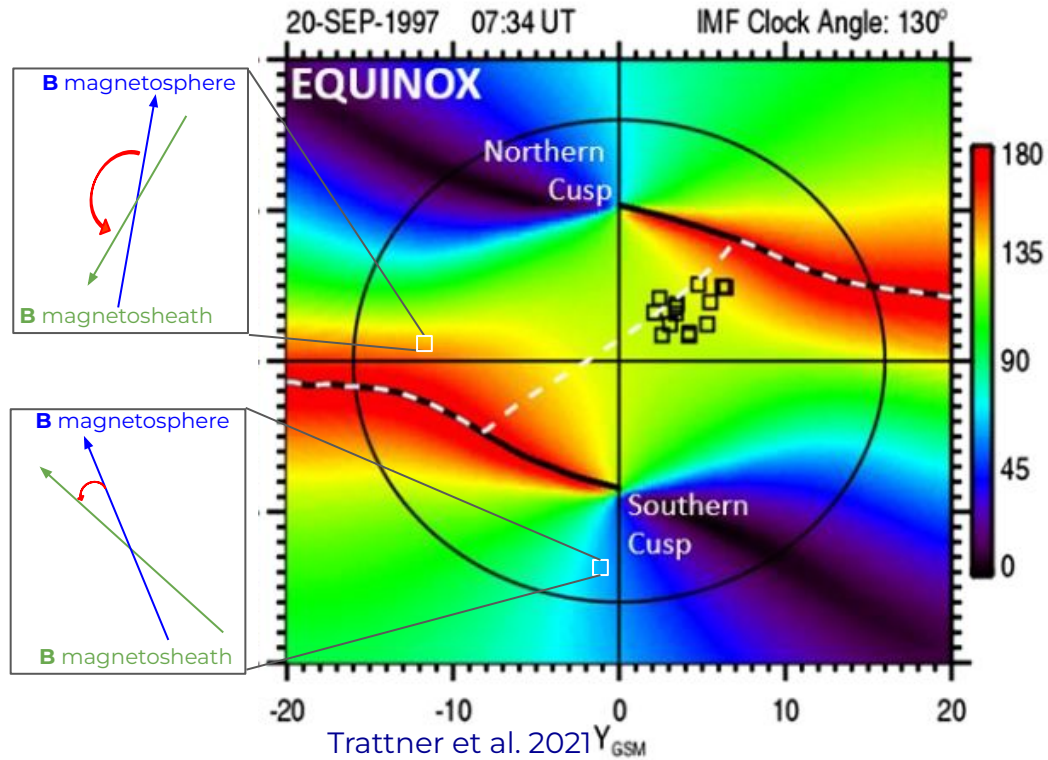
Leading model of magnetic reconnection

Maximum Magnetic Shear model (Trattner et al. 2007): The X line maximizes the magnetic shear angle at the magnetopause

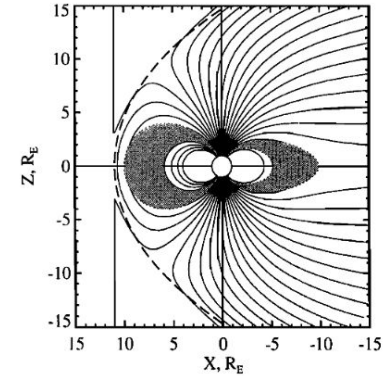


Leading model of magnetic reconnection

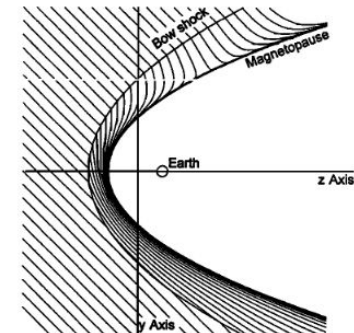
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Magnetospheric magnetic field:
Tsyganenko 1996

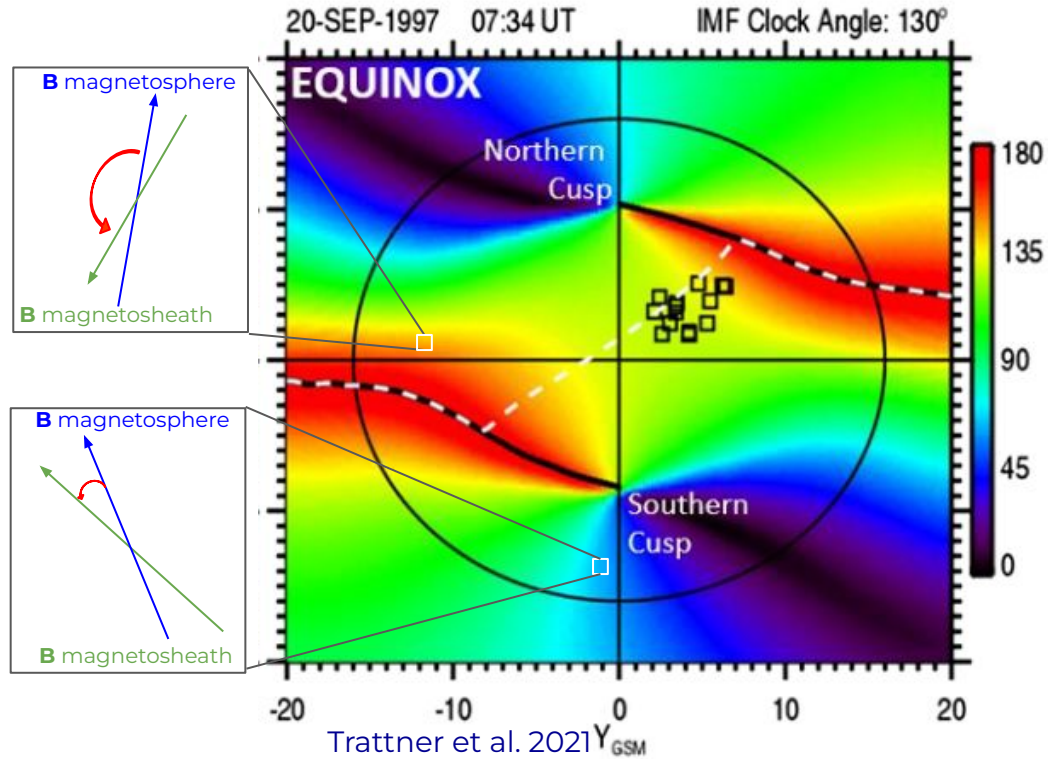


Magnetosheath magnetic field:
Kobel & Fluckiger 1994

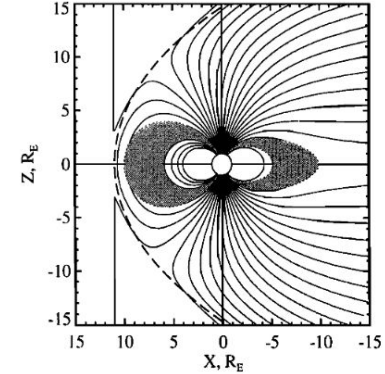


Leading model of magnetic reconnection

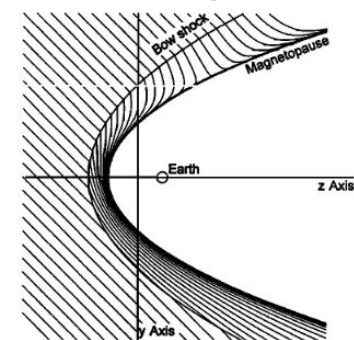
Maximum Magnetic Shear model (Trattner et al. 2007): The X line maximizes the magnetic shear angle at the magnetopause



Magnetospheric magnetic field:
Tsyganenko 1996



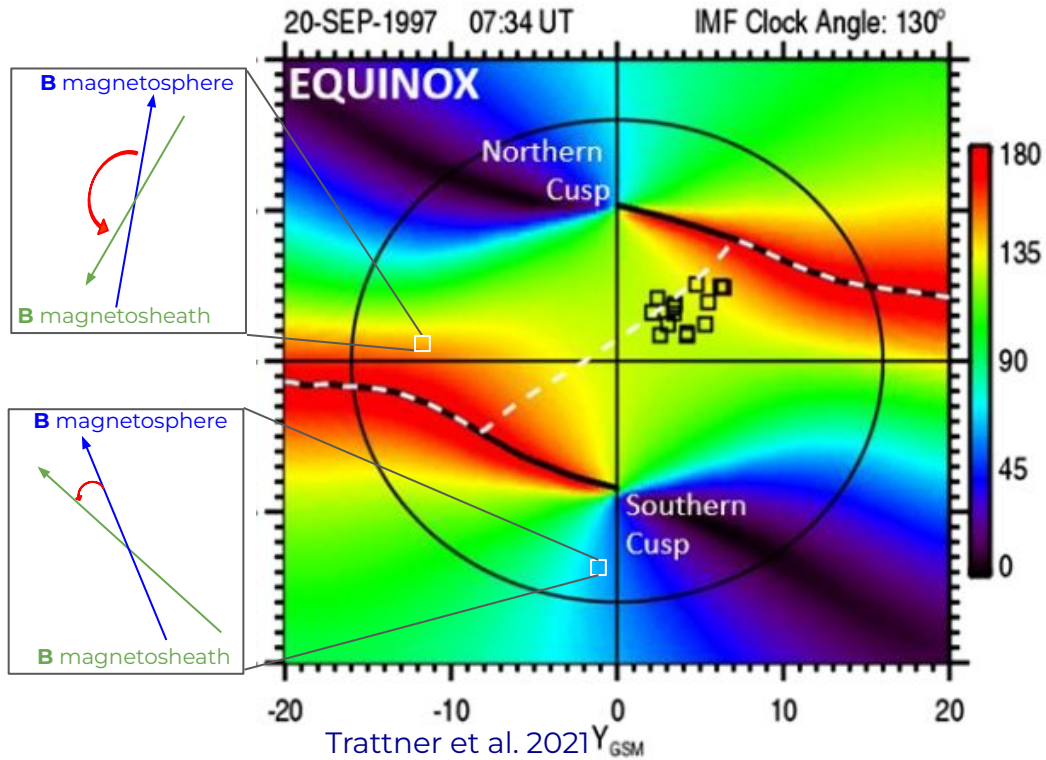
Magnetosheath magnetic field:
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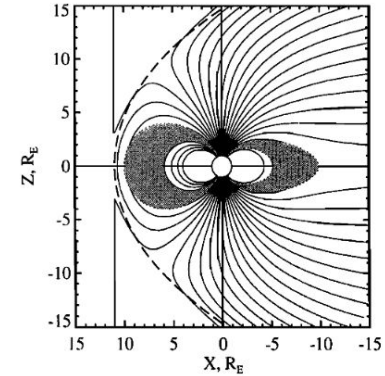
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Maximum Magnetic Shear model (Trattner et al. 2007): The X line maximizes the magnetic shear angle at the magnetopause

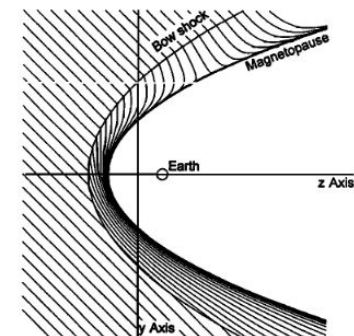
How do modeled shear maps compare to in-situ data?



Magnetospheric magnetic field: Tsyganenko 1996



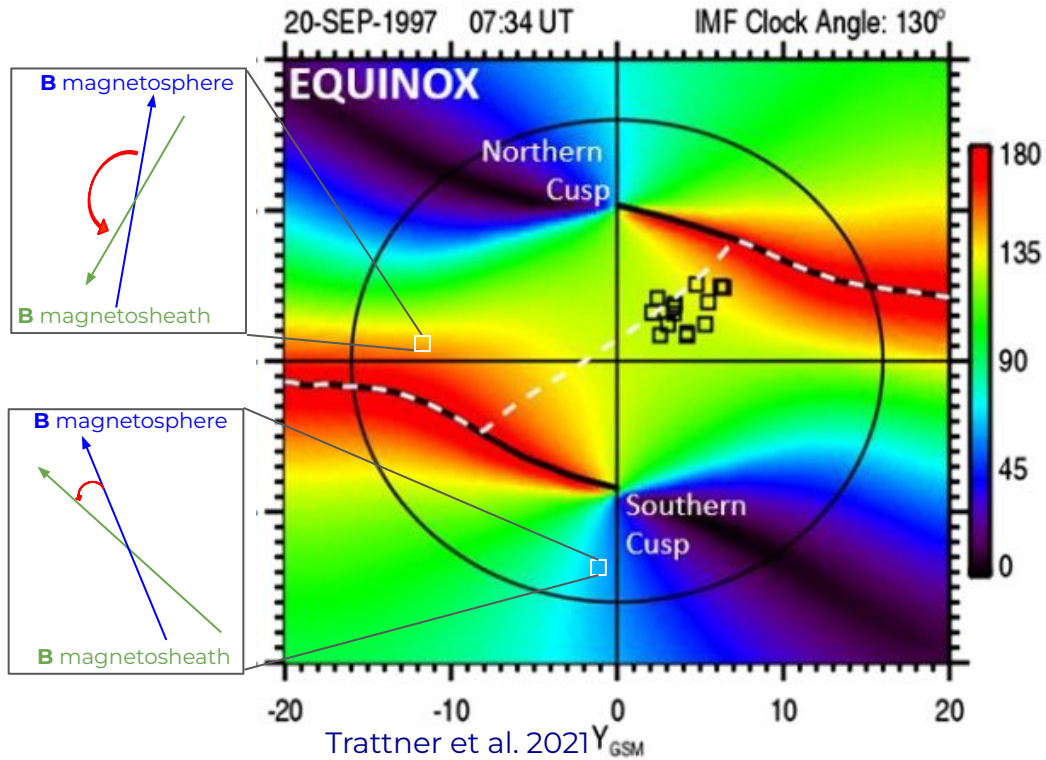
Magnetosheath magnetic field: Kobel & Fluckiger 1994



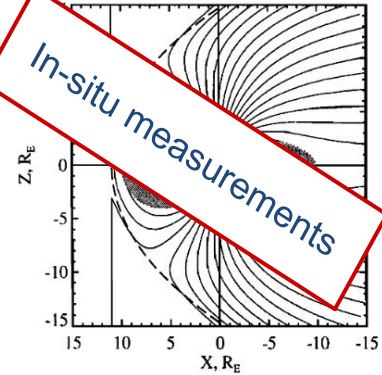
Leading model of magnetic reconnection

Maximum Magnetic Shear model (Trattner et al. 2007): The X line maximizes the magnetic shear angle at the magnetopause

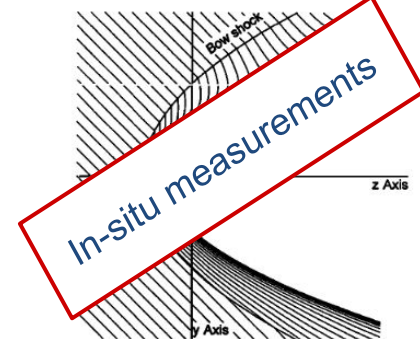
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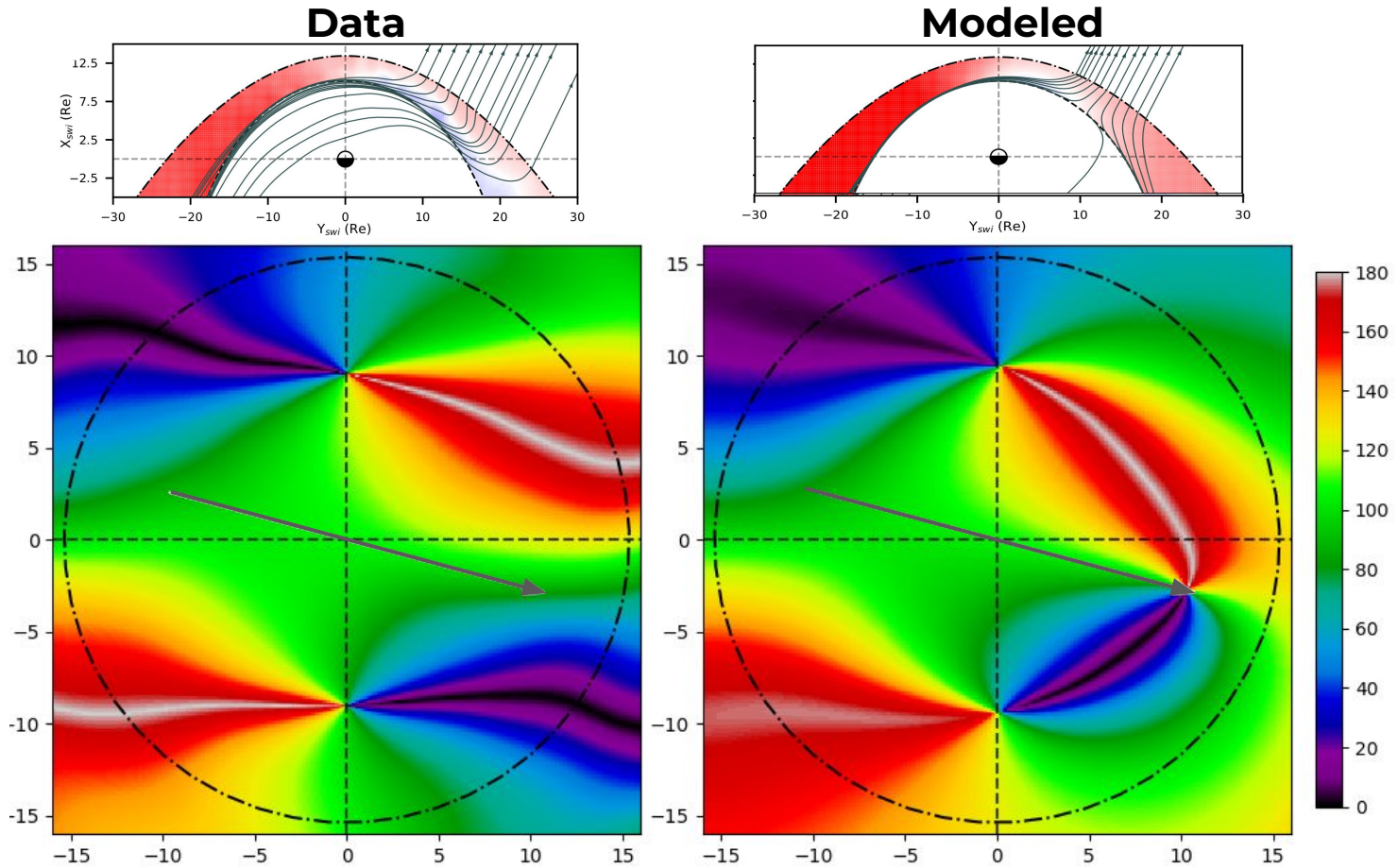
Magnetospheric magnetic field:
Tsyganenko 1996



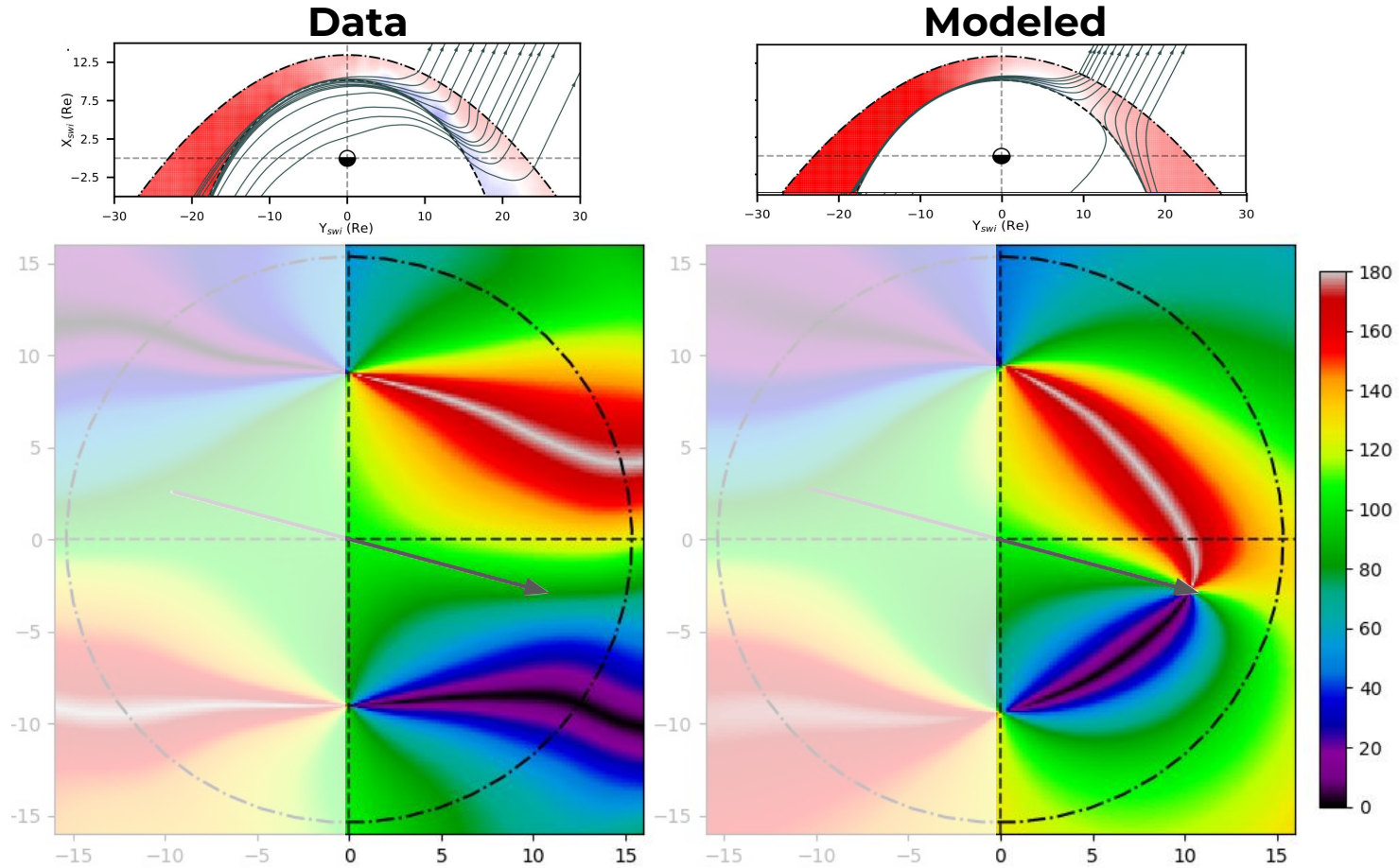
Magnetosheath magnetic field:
Kobel & Fluckiger 1994



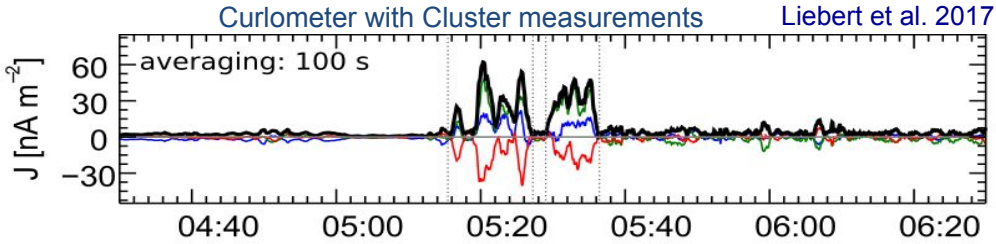
Observations disagree with model predictions



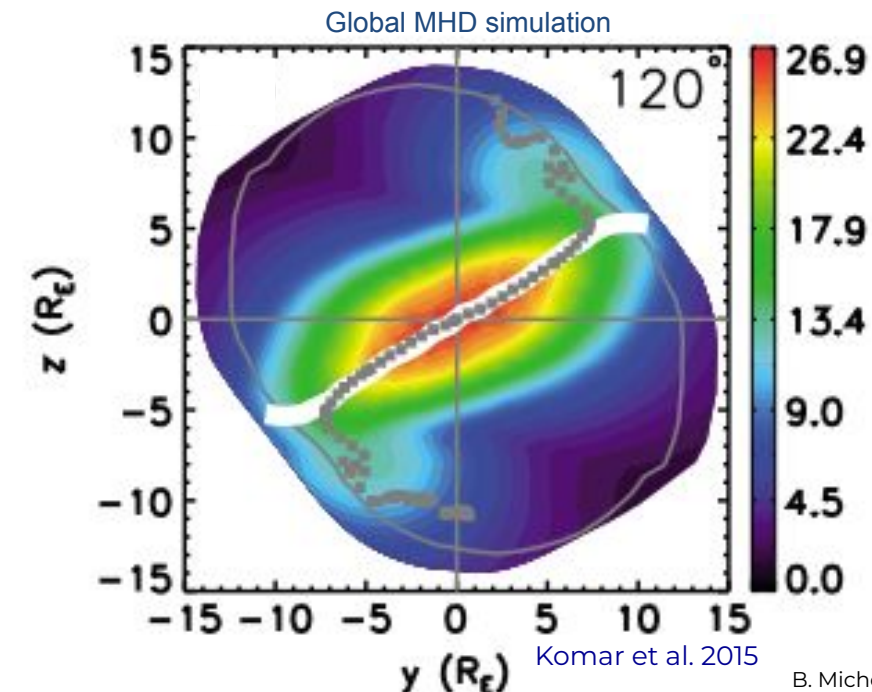
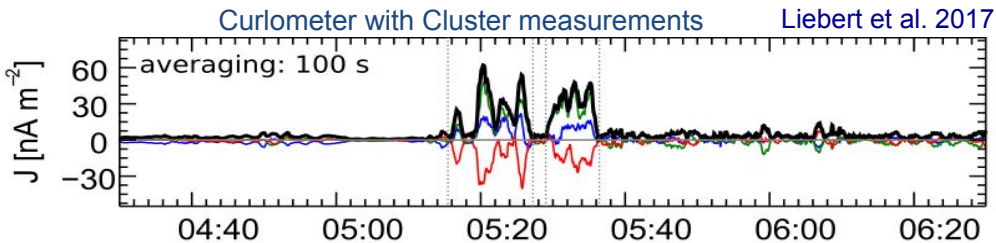
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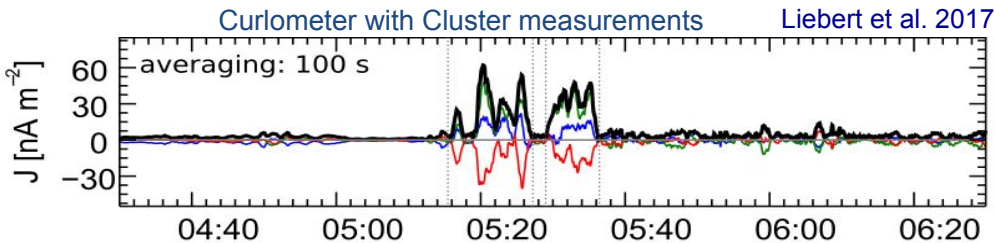
Global structure of the current density ~ MHD models/Obs



Global structure of the current density ~ MHD models/Obs

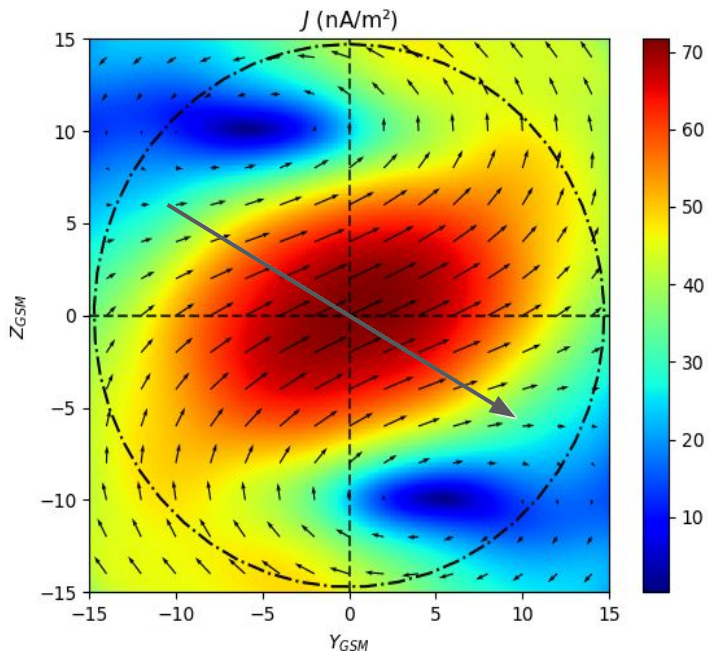
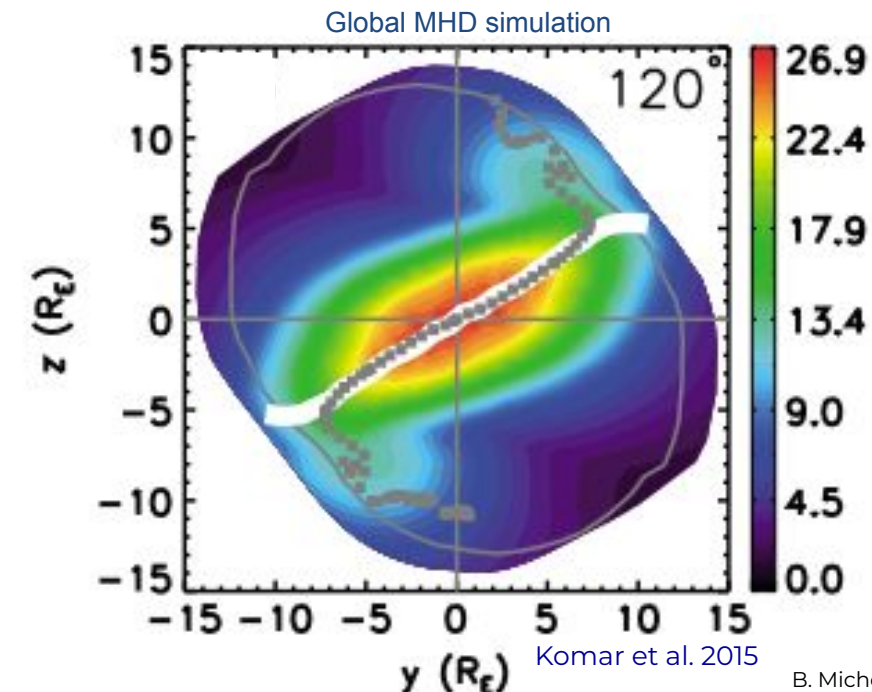


Global structure of the current density ~ MHD models/Obs



Pattern similar to MHD simulations for multiple IMF orientation

Assumed MP thickness = 800 km

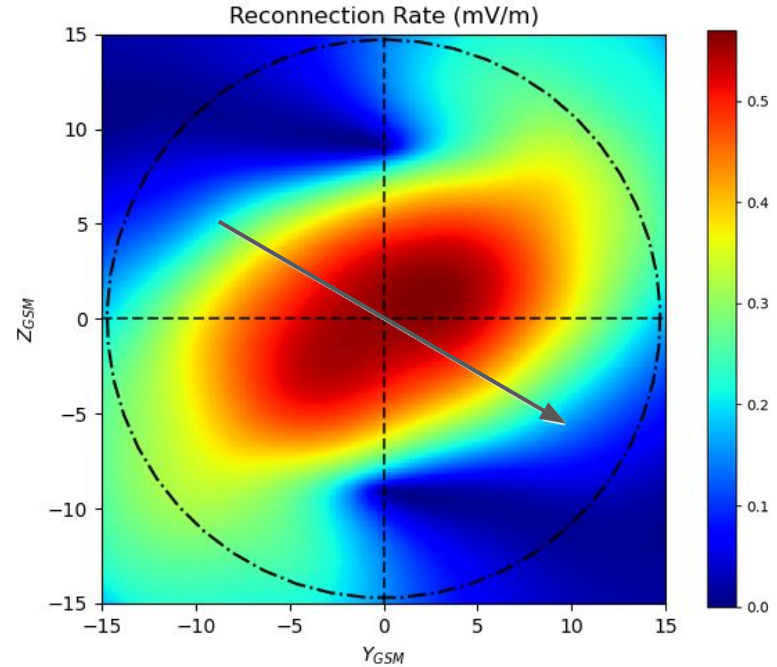
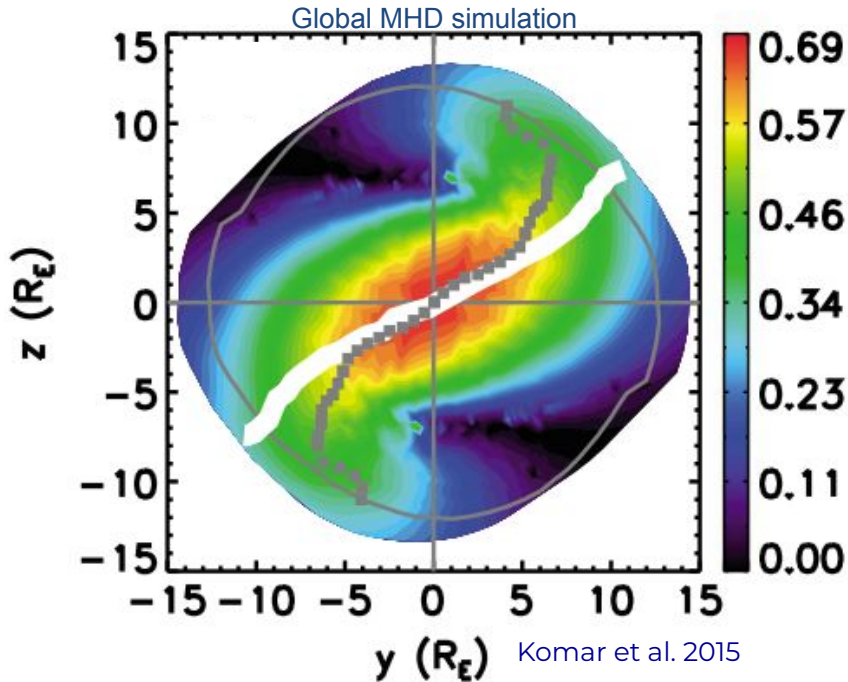


Global structure of the reconnection rate ~ MHD models

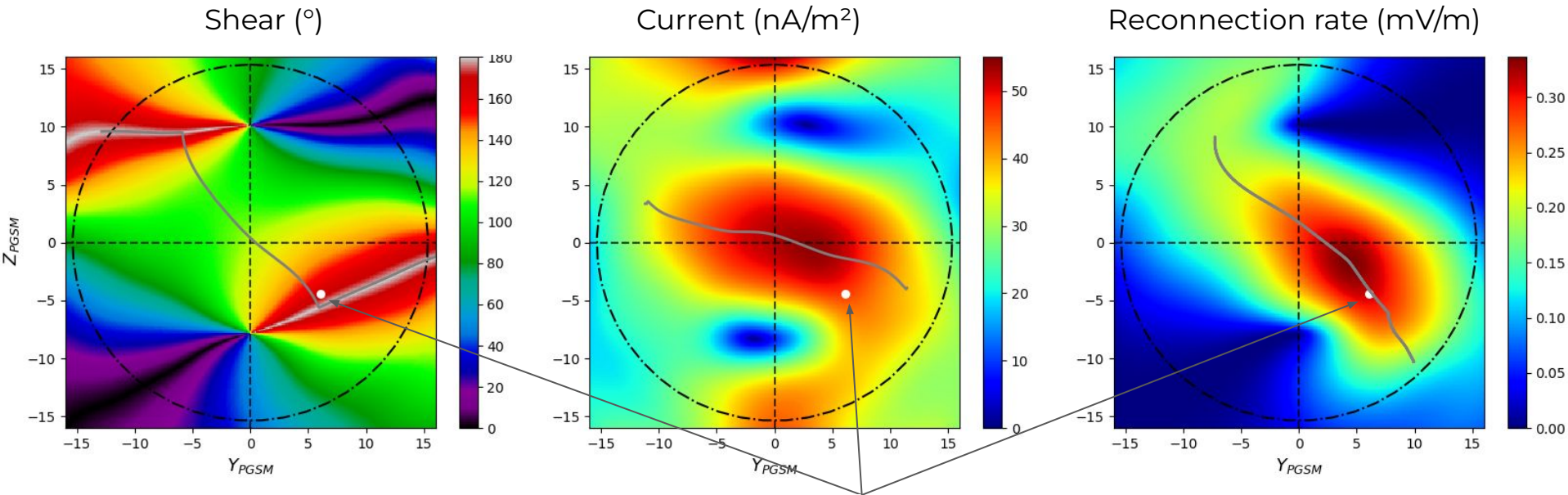
Cassak-Shay formula (2007) :

$$R = 0.1 \frac{(B_1 B_2)^{3/2}}{\sqrt{\mu_0 (B_1 \rho_2 + B_2 \rho_1)}}$$

Pattern similar to MHD simulations for multiple IMF orientation



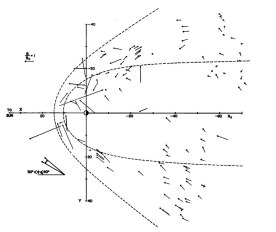
Correlation with magnetic reconnection observations



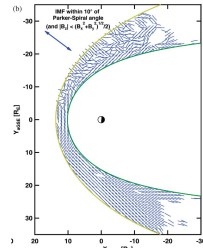
Magnetic reconnection observation on the 16/10/2015 10:33 (Webster et al. 2018)

However observations still very local ...

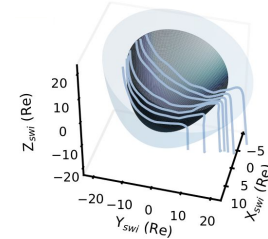
Next: Paradigm shift in the use of reconnection observations



Behannon et al. 1969



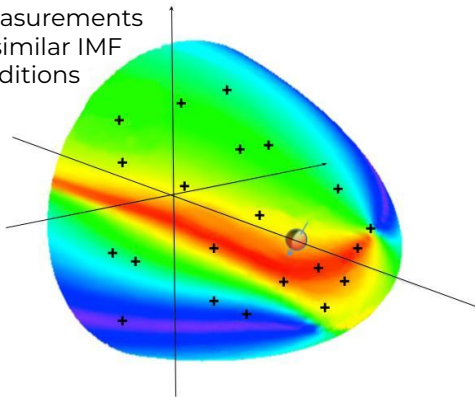
Petrinec 2012



Michotte de Welle et al. 2022

Machine learning:
Massive data extraction

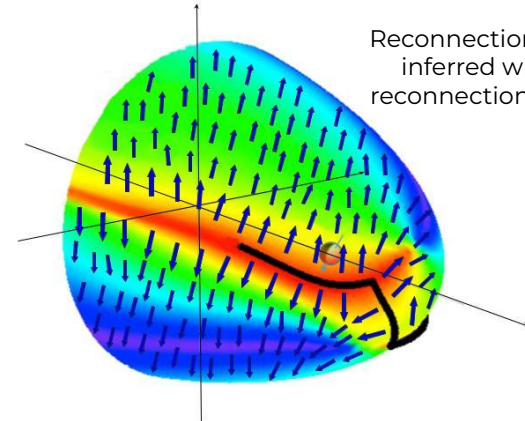
Local measurements
under similar IMF
conditions



Automatically identify
reconnection
signatures using
machine learning tools



Reconnection line
inferred with
reconnection flow

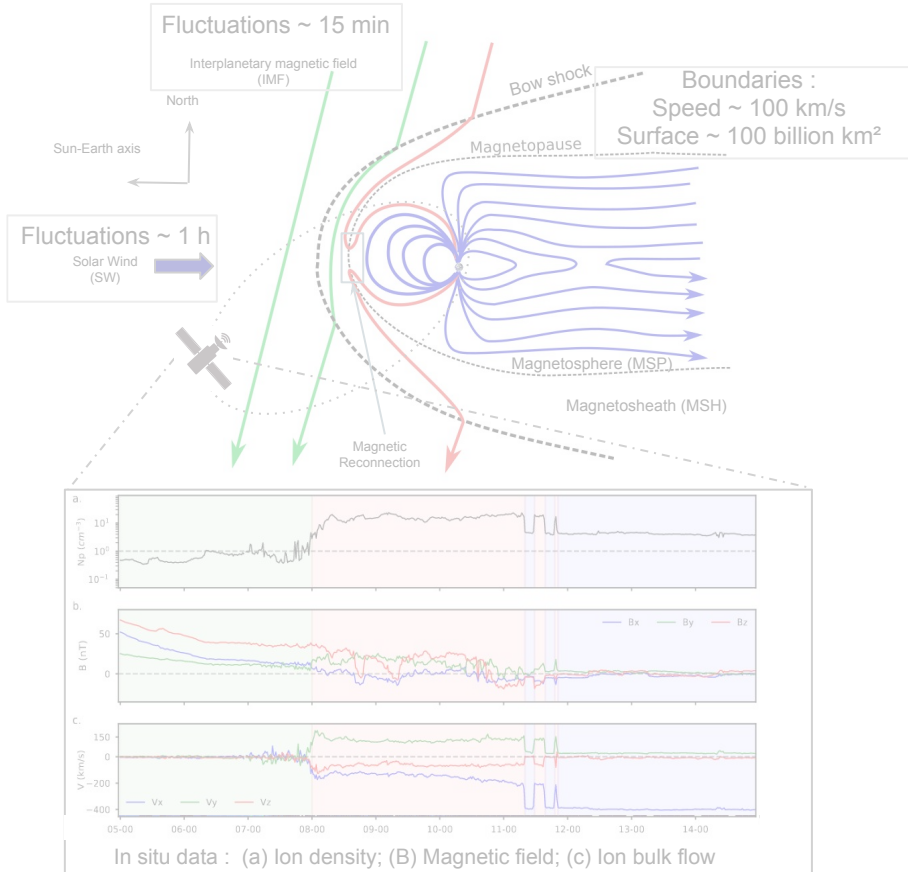


Summary

- Critical role of magnetic reconnection in Sun-Earth interaction: Matter, momentum, and energy transfer from the interplanetary medium to the magnetosphere.
- Lack of consensus on magnetic reconnection models after 60+ years of study.
- New tools like machine learning and abundant in-situ measurements offer hope for answers in magnetic reconnection study.

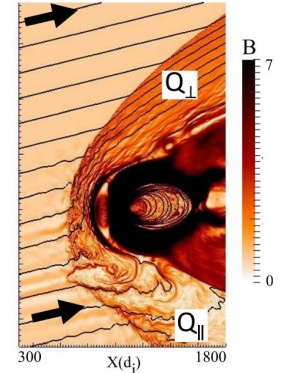
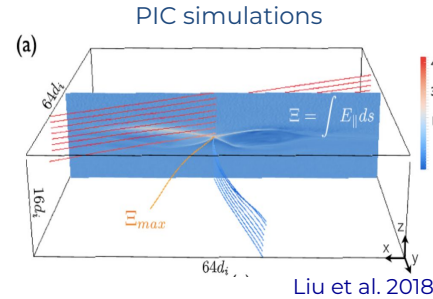
Thank you for attention

Highly dynamic system / complex and multi-scale phenomenon



Studying magnetic reconnection in simulations :

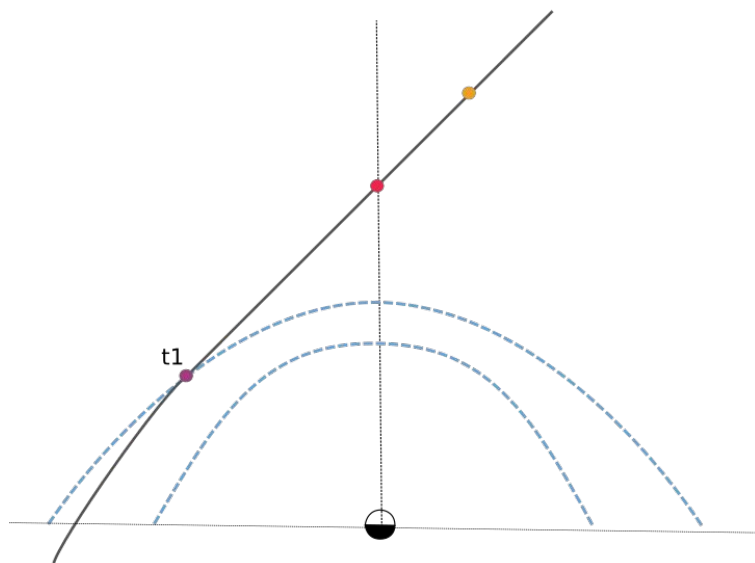
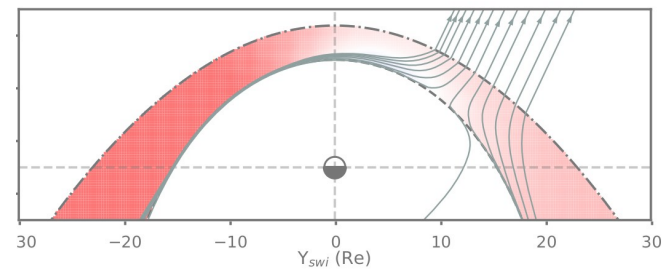
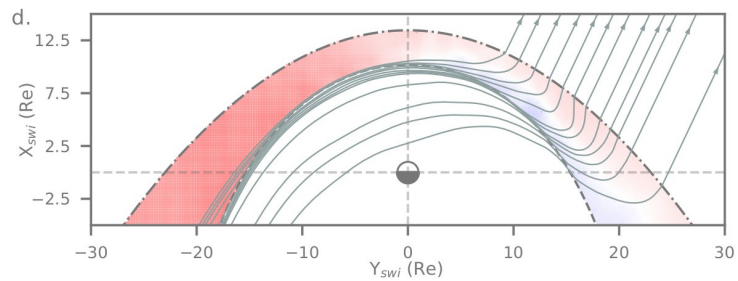
Electron scale (~10 km) → X-line scale (~100 000km)



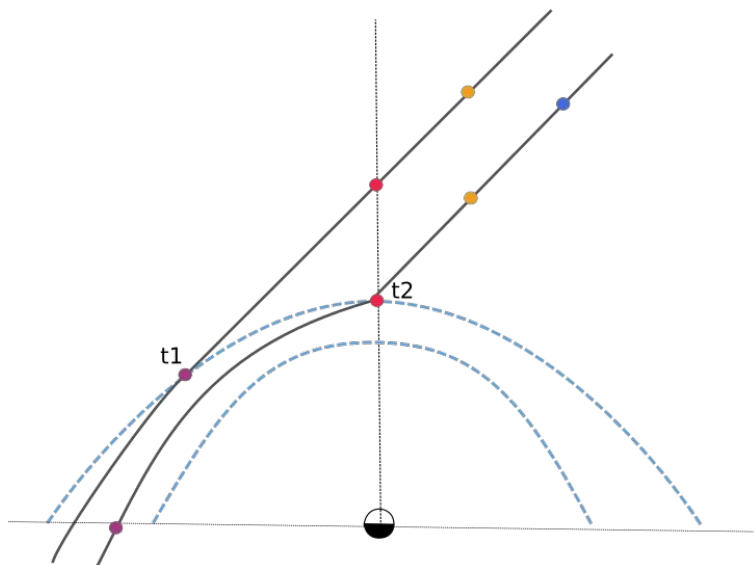
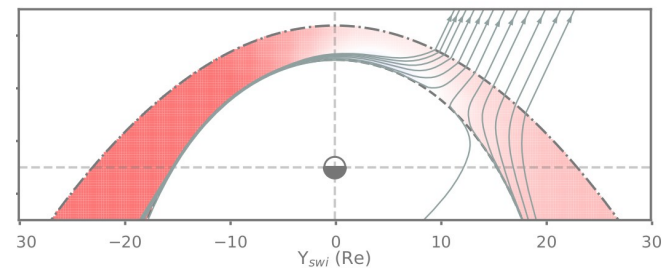
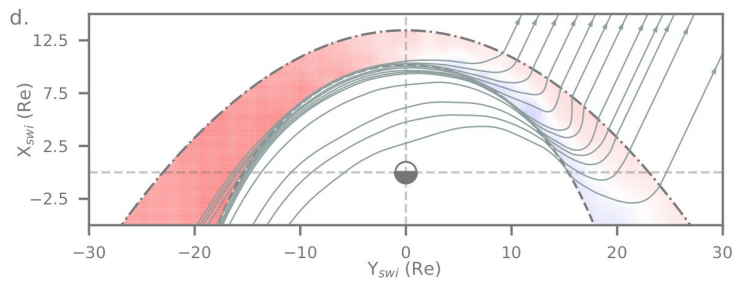
Local approach
= Local physics
but no global
constraints

Global approach
= Global
constraints but
no local physics

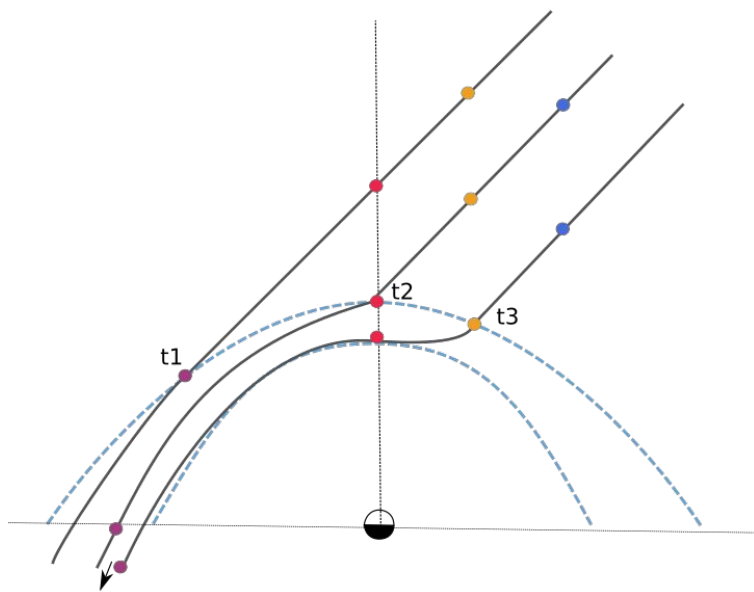
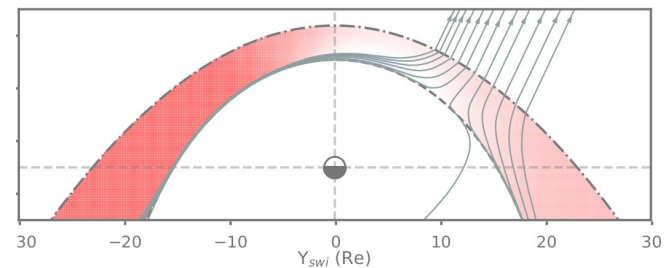
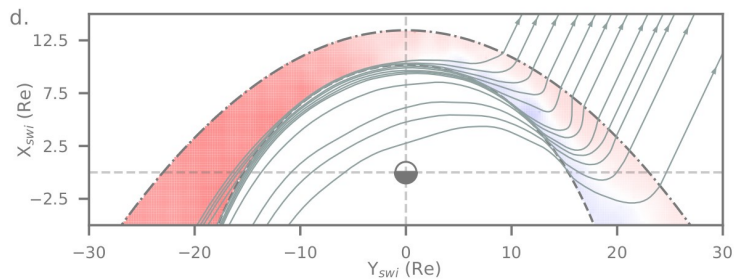
Key roles of the magnetosheath **flow** and system **geometry**



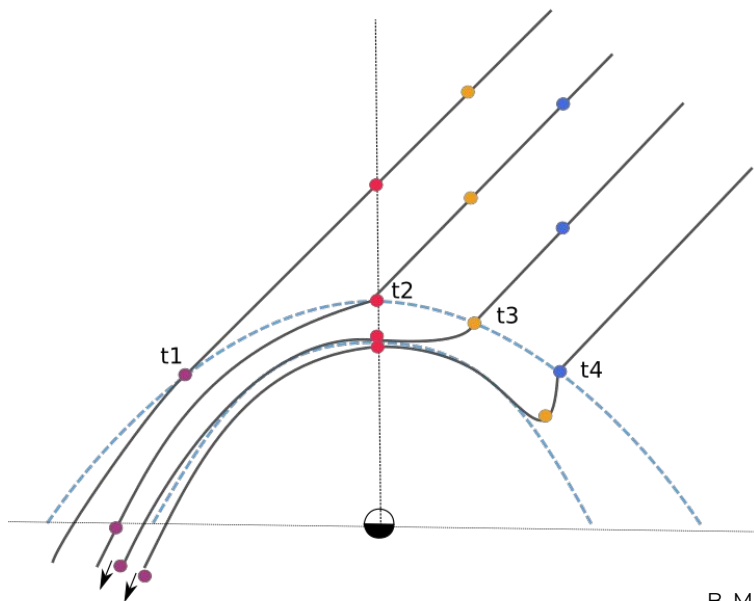
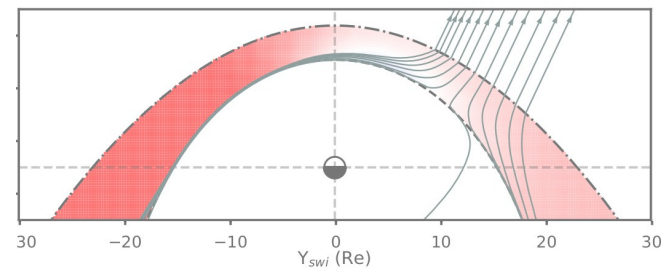
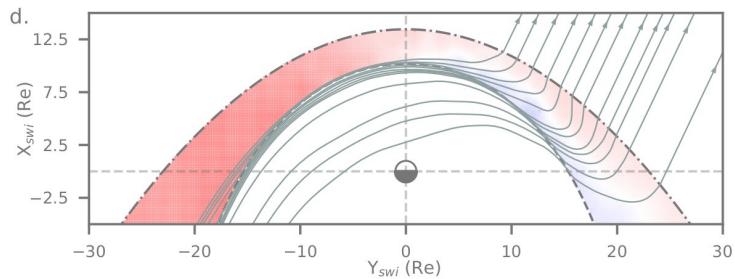
Key roles of the magnetosheath **flow** and system **geometry**



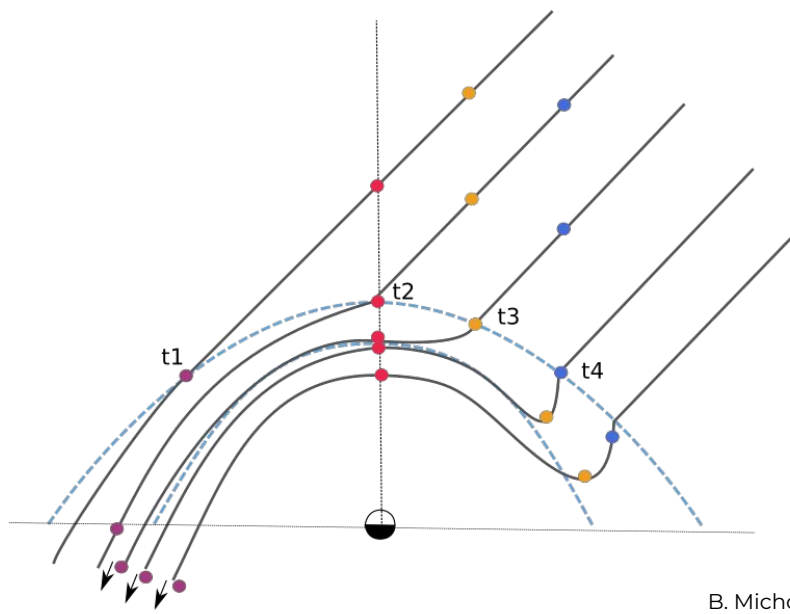
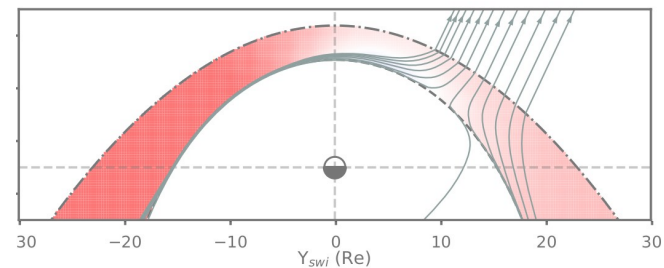
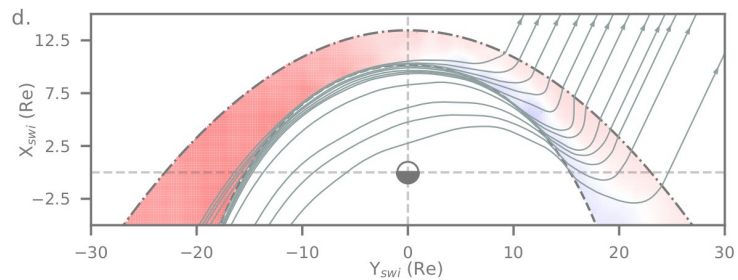
Key roles of the magnetosheath **flow** and system **geometry**



Key roles of the magnetosheath **flow** and system **geometry**

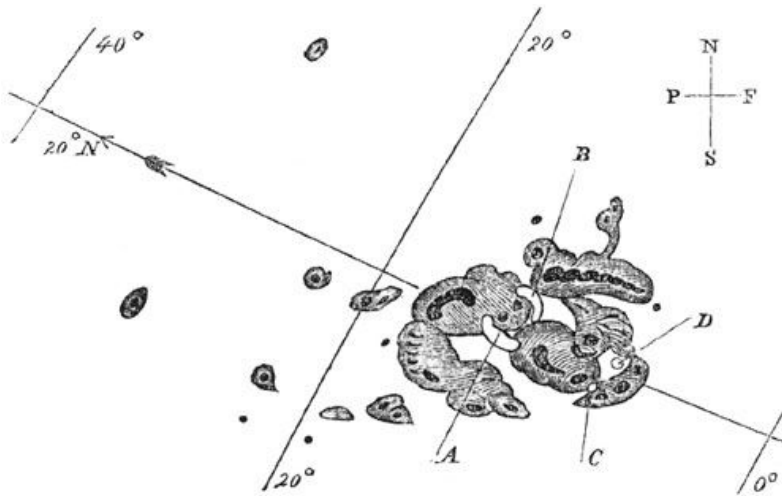


Key roles of the magnetosheath **flow** and system **geometry**



The critical importance of space weather to modern society

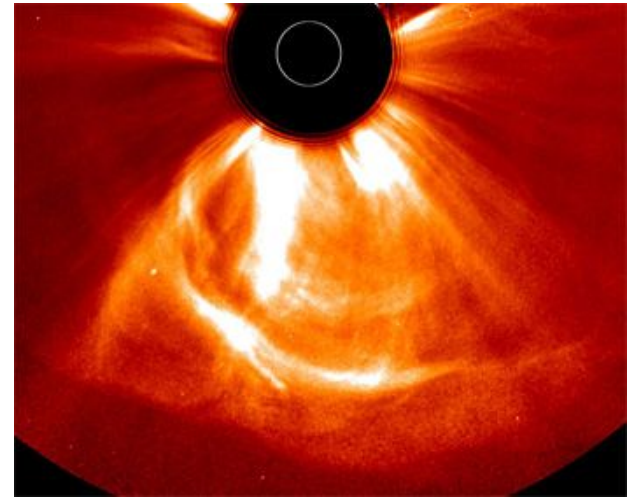
Carrington event



1 and 2 September 1859

- strong auroral displays that were reported globally
- Severe damage to telegraph stations

July 2012 solar storm



23 July 2012

- Missed the earth by few days
- International economic cost estimation: €787–1 108 billion (Eastwood et al. 2018)

Need to predict and quantify magnetic reconnection