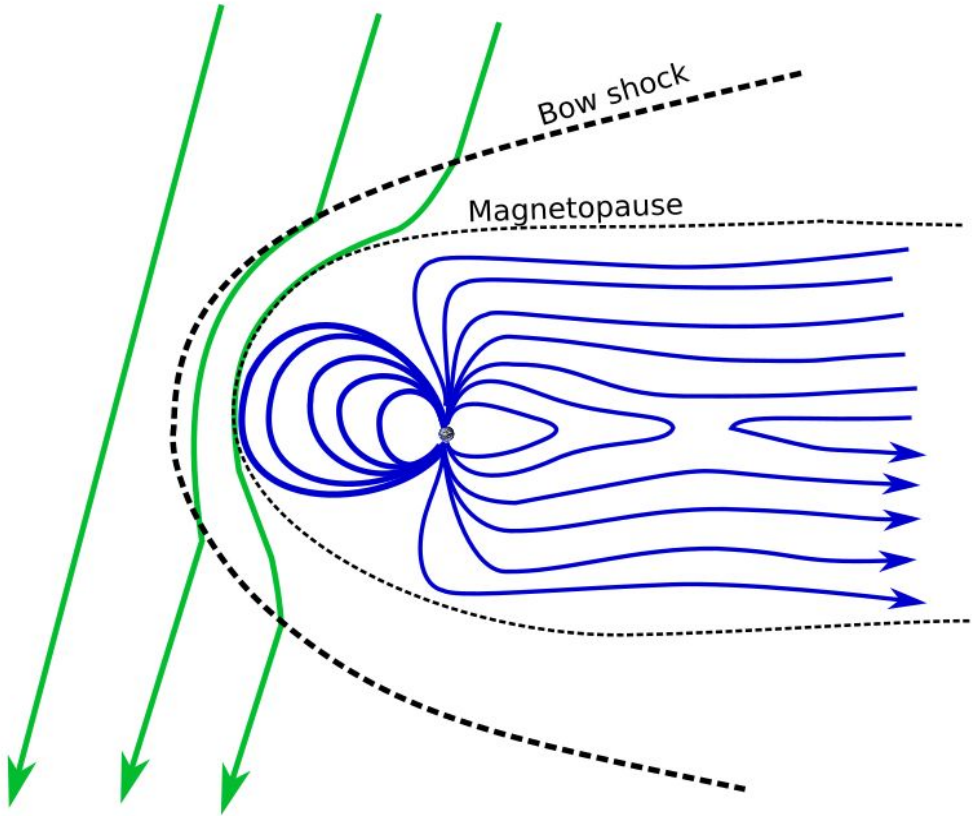
Where is Magnetic Reconnection occuring on the Magnetopause ?

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

Laboratoire de Physique des Plasmas
École Polytechnique, France

Where is the reconnection point ?



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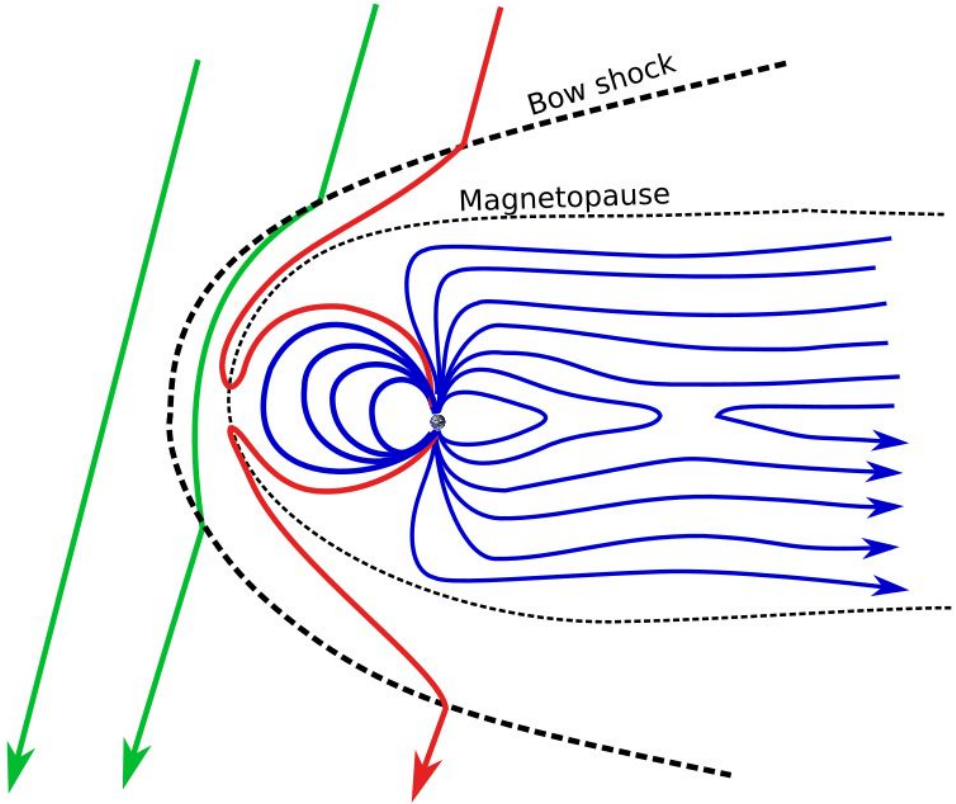

Southward IMF

↓

Low latitude reconnection

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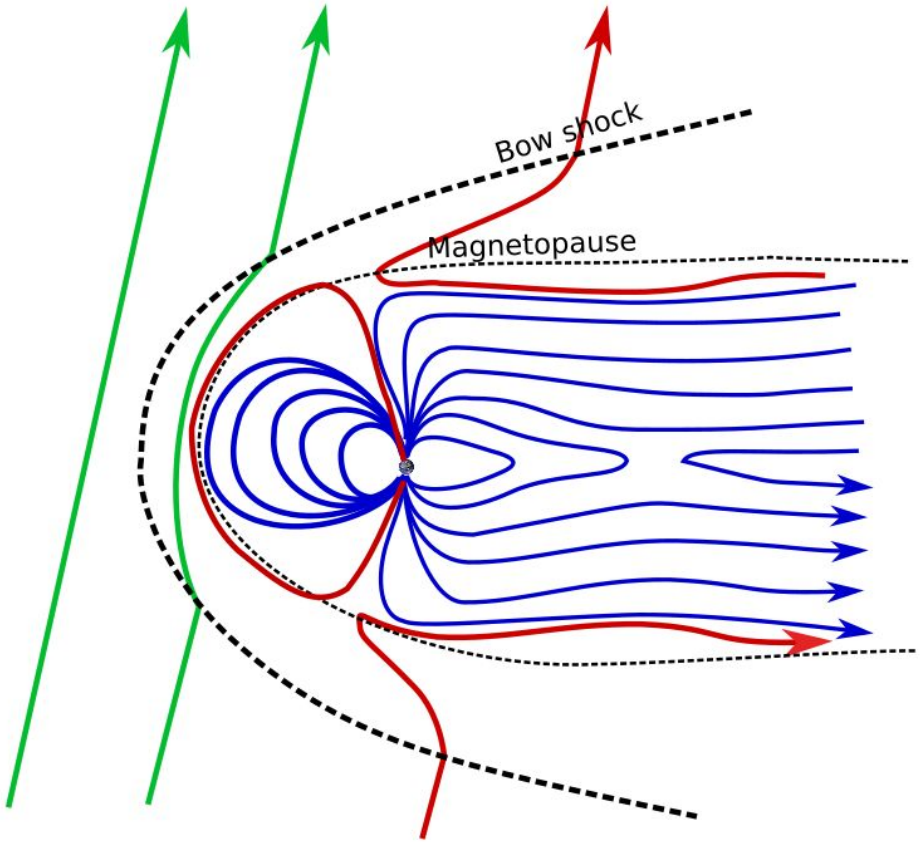
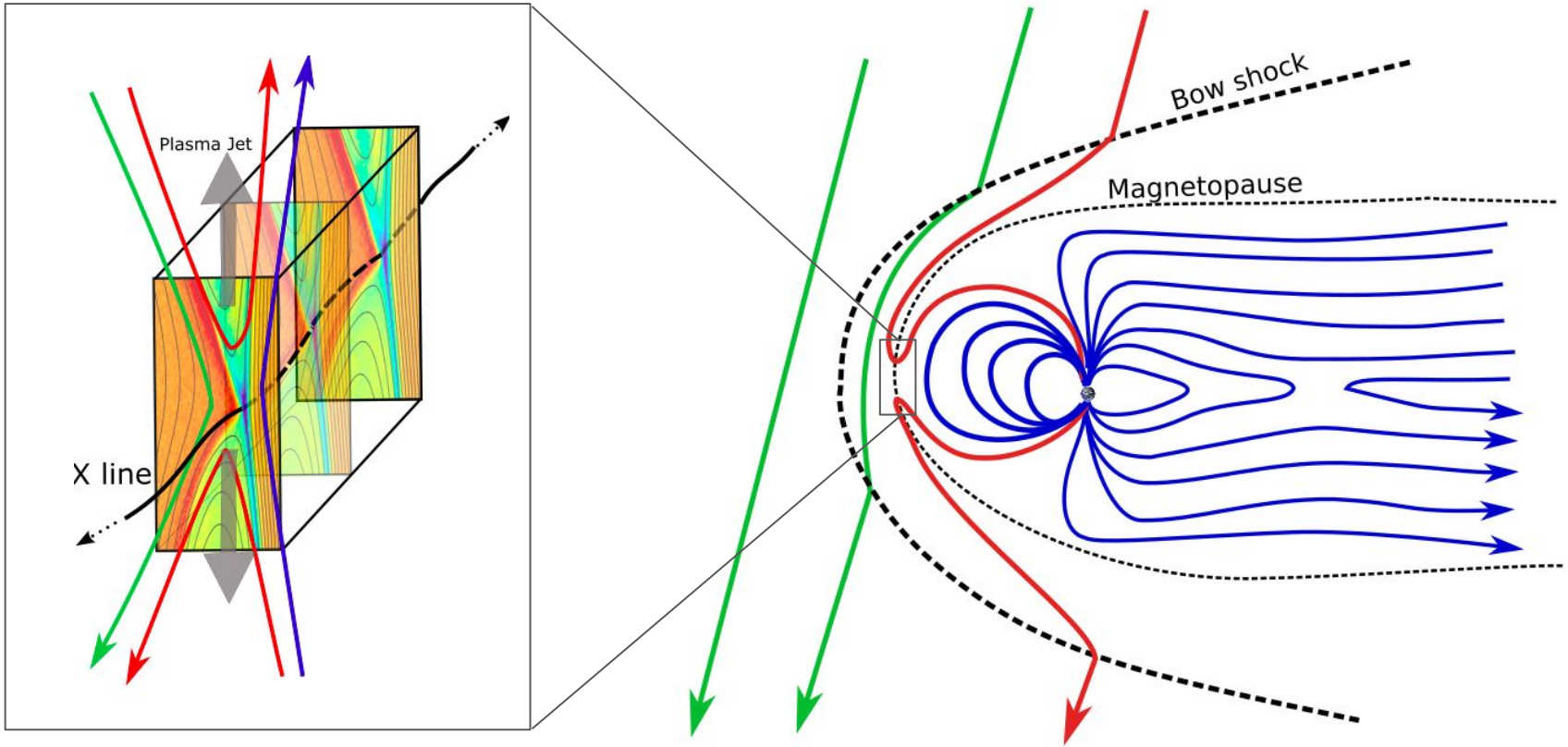


Northward IMF

high latitude reconnection

Where is the reconnection ***line*** ?



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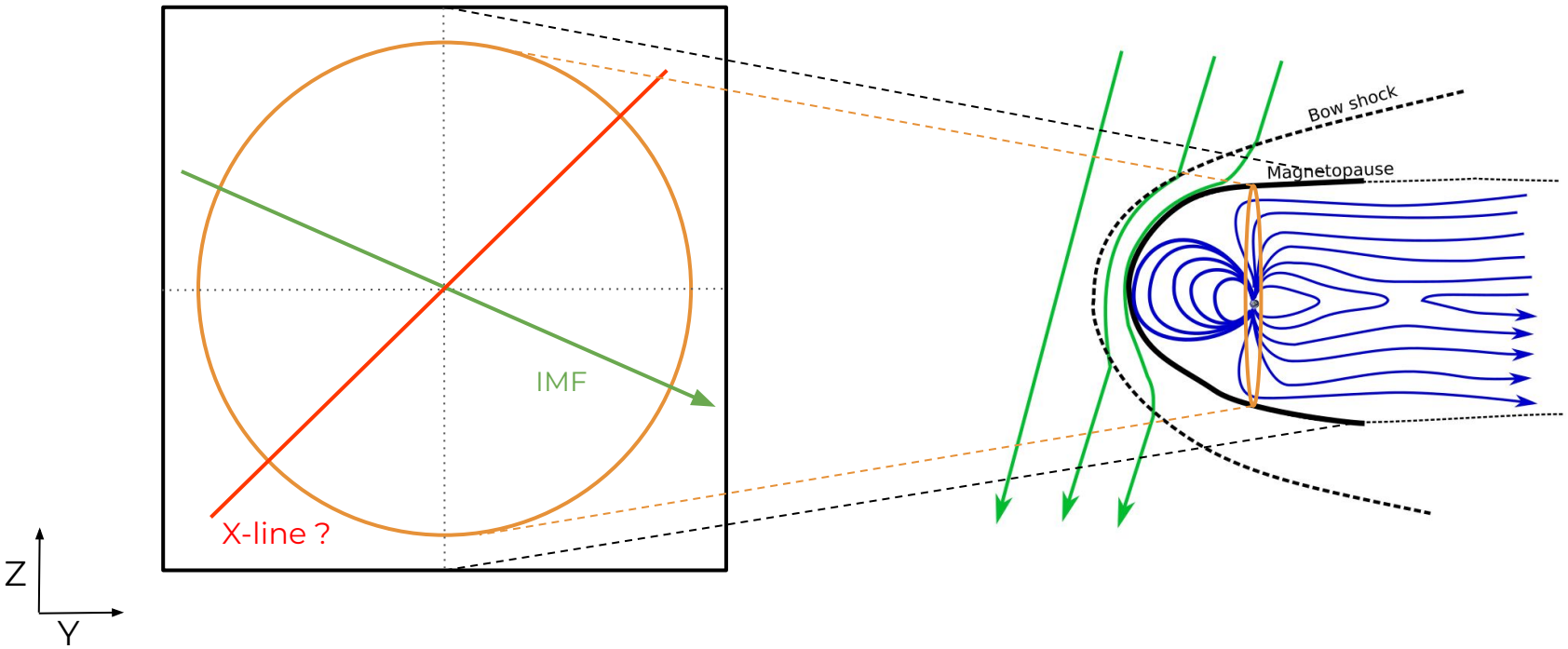

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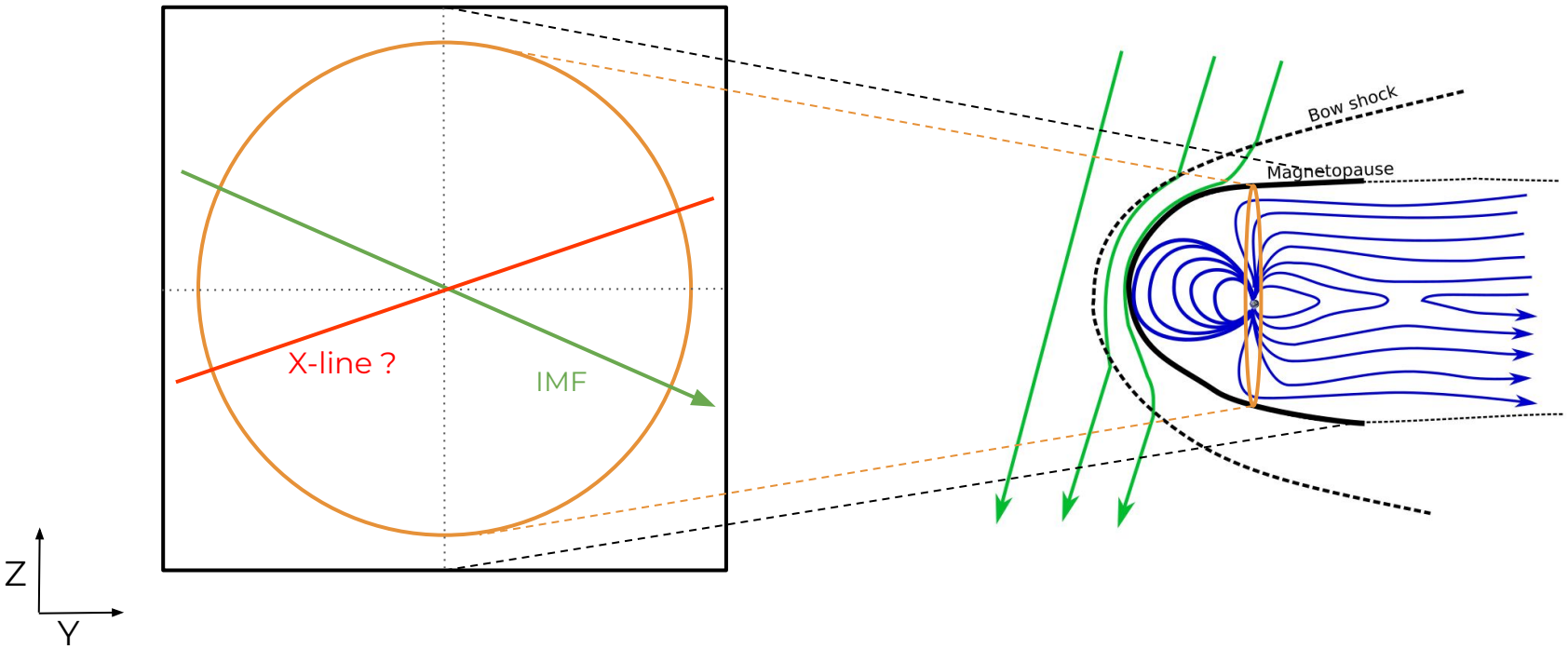

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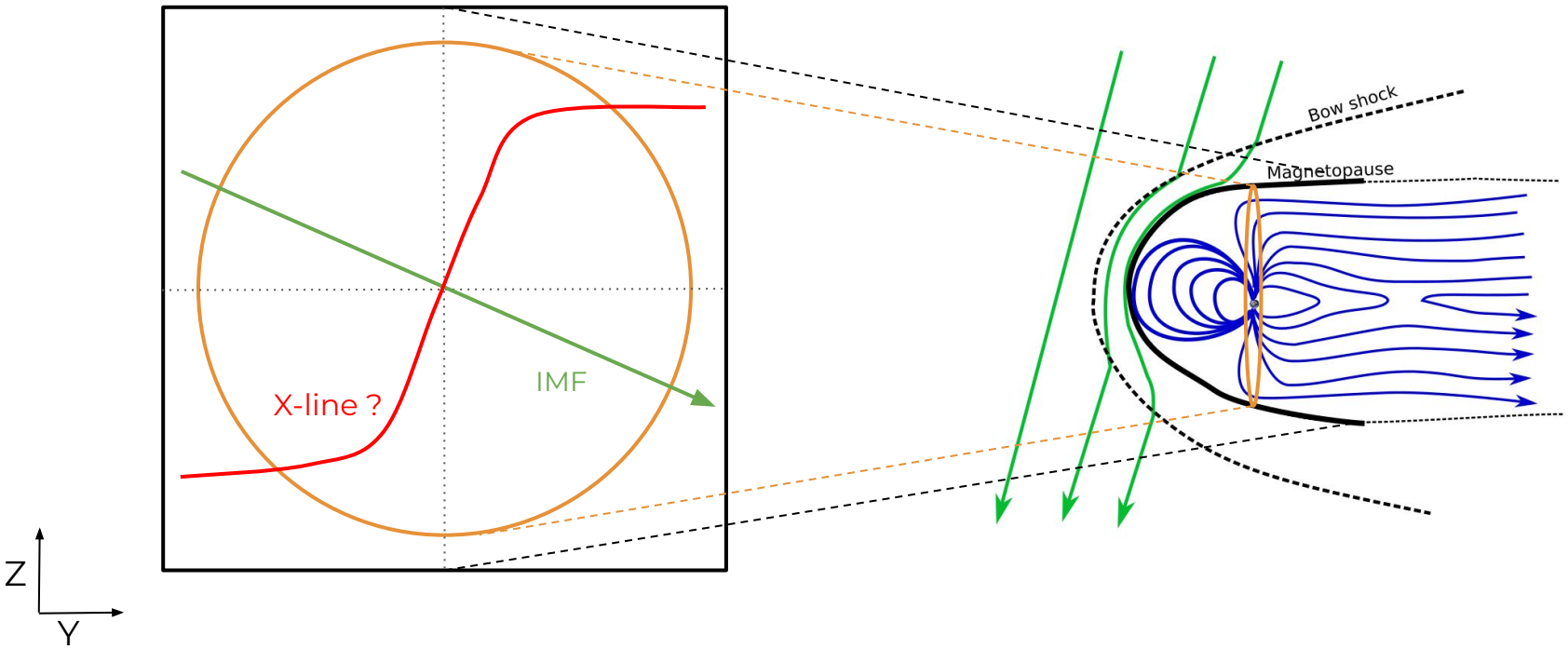

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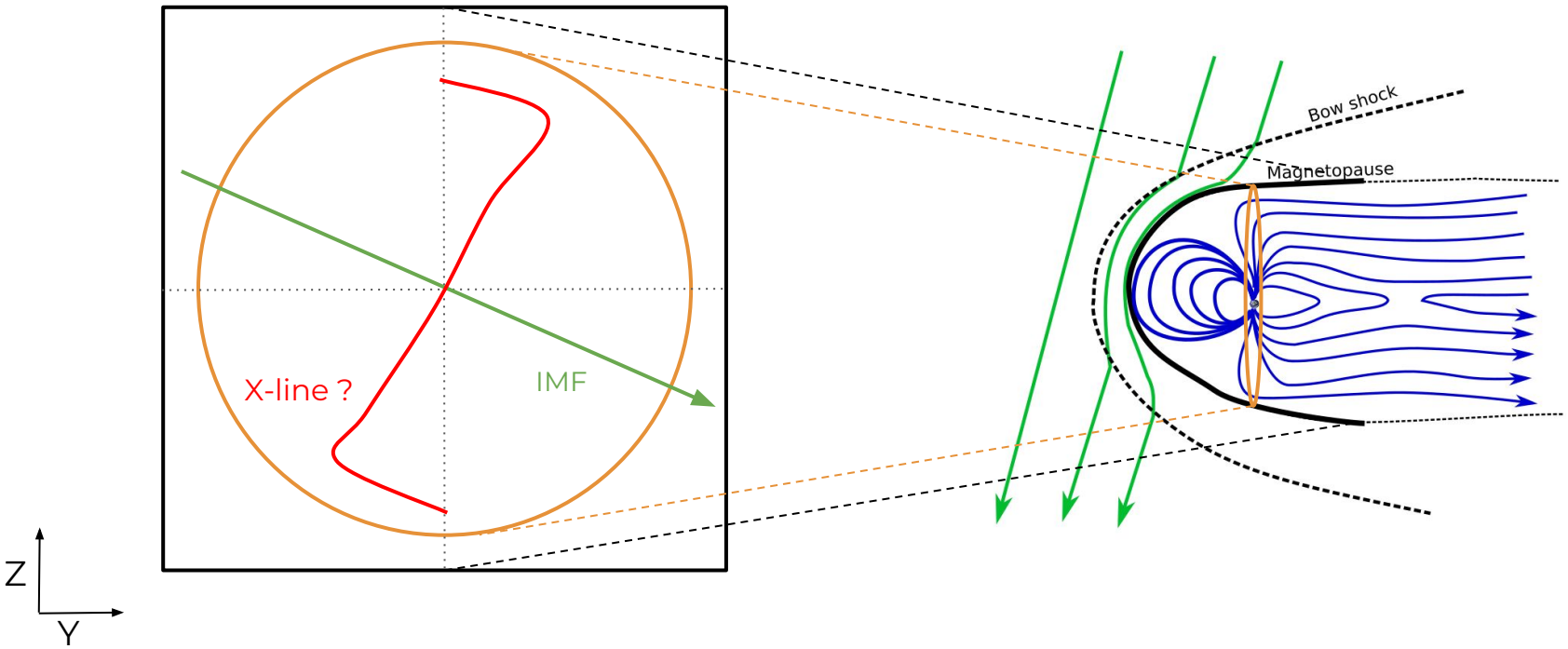

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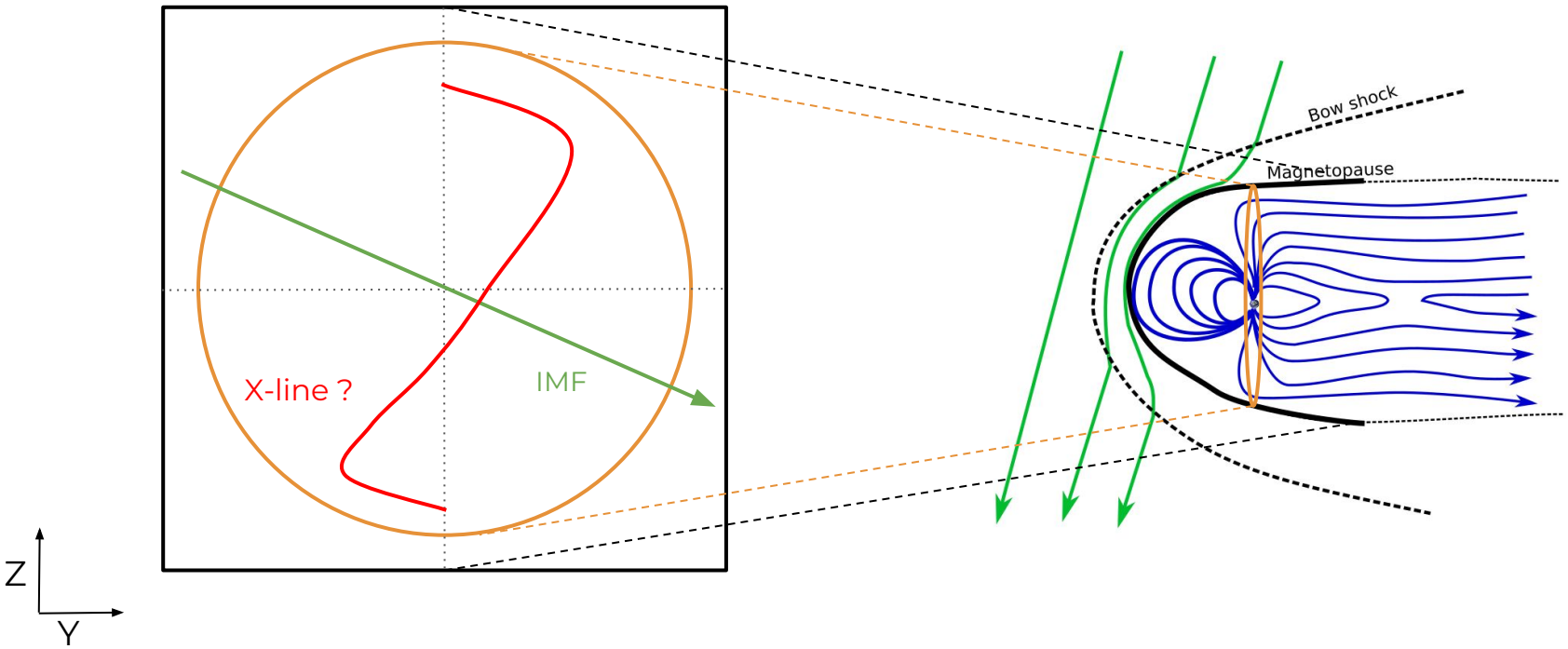
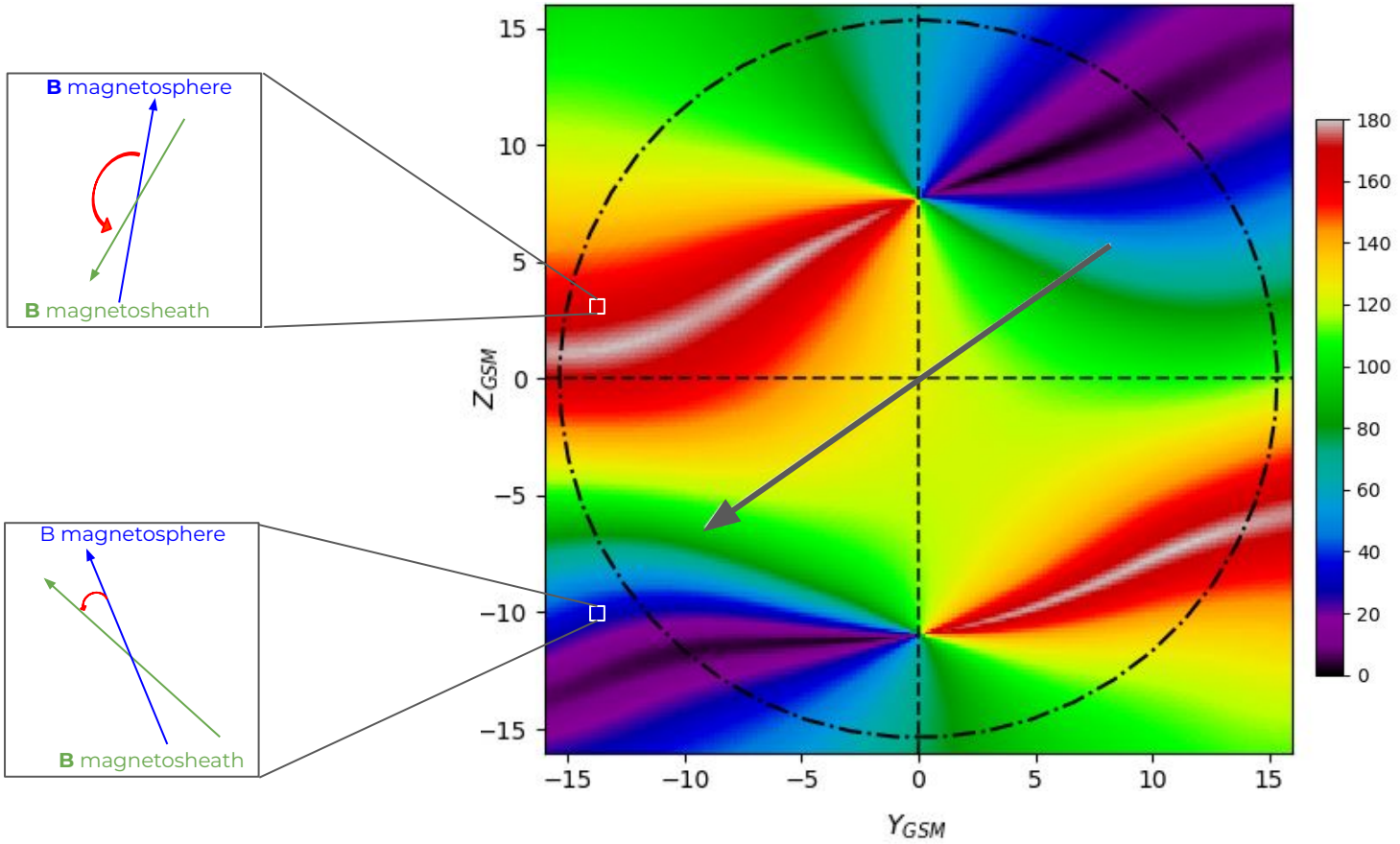


Maximum Magnetic Shear model (Trattner et al 2007)



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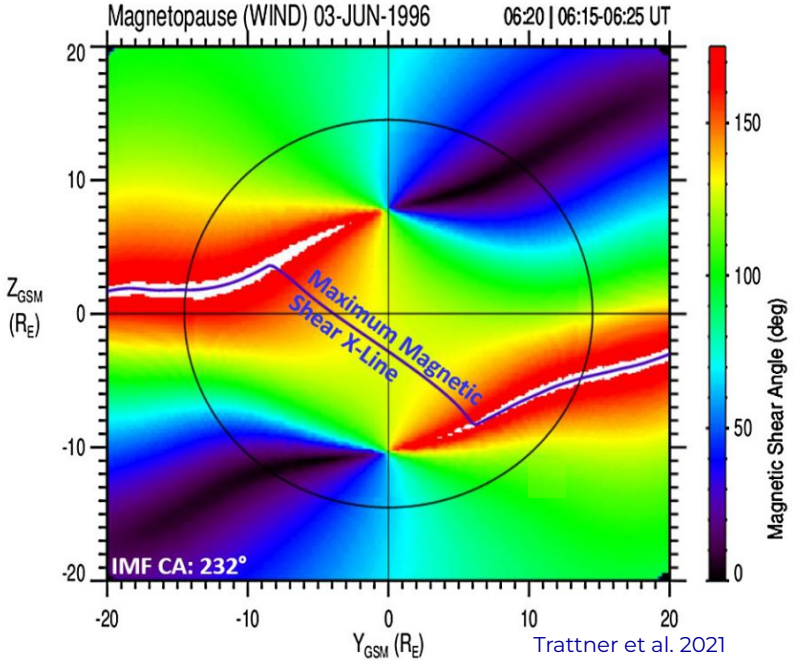

Trattner et al. 2021

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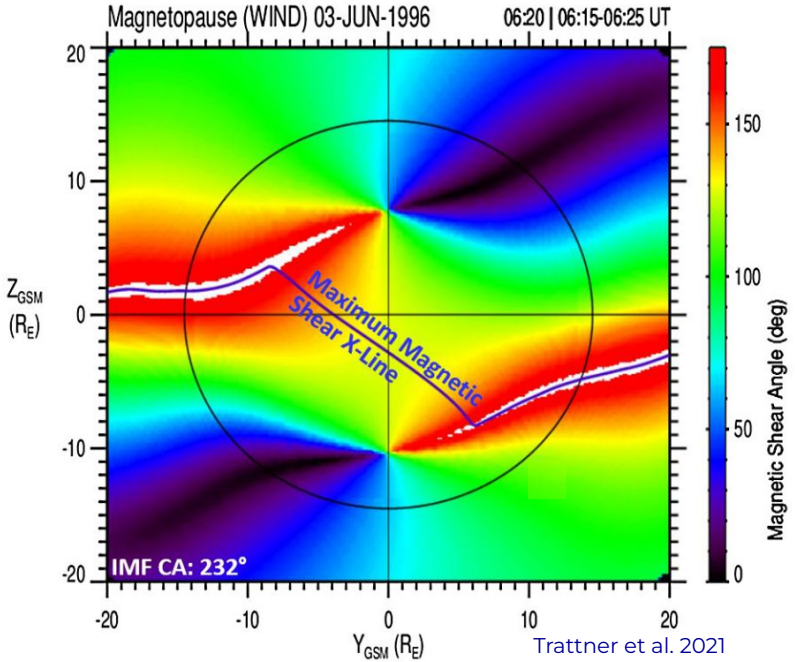

Trattner et al. 2021

- Assumes :
  - *modeled* magnetospheric **B** (Tsyganenko 1996)
  - *modeled* magnetosheath **B** (Kobel et al 1994)

➡ How this modeled map compare to in-situ data ?

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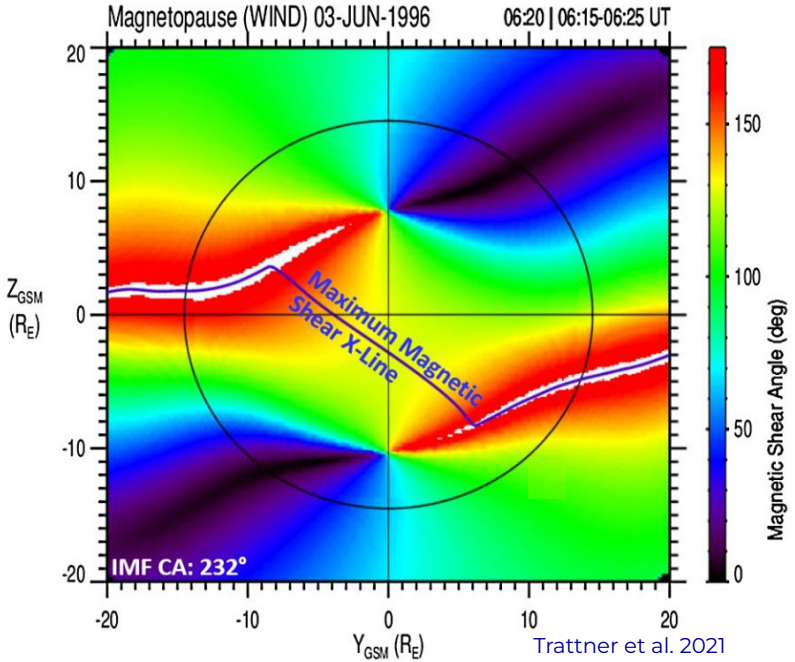

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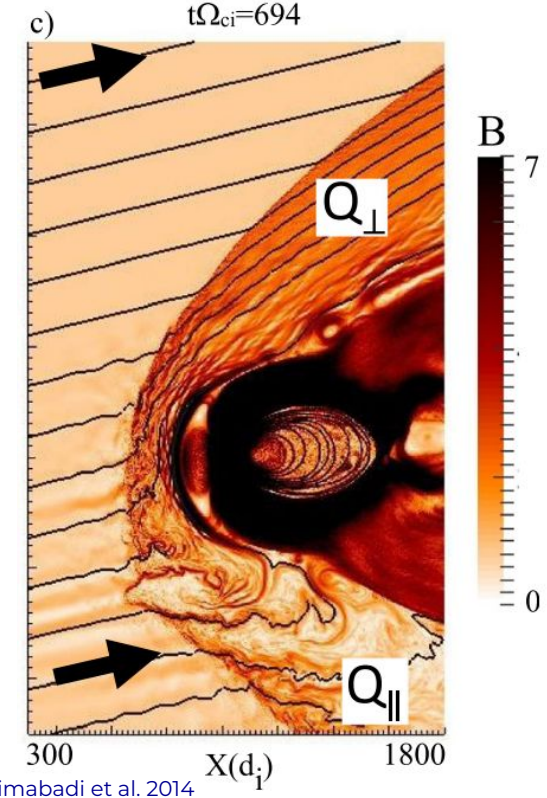
➡ How this modeled map compare to in-situ data ?

- Depends only on **B** shear

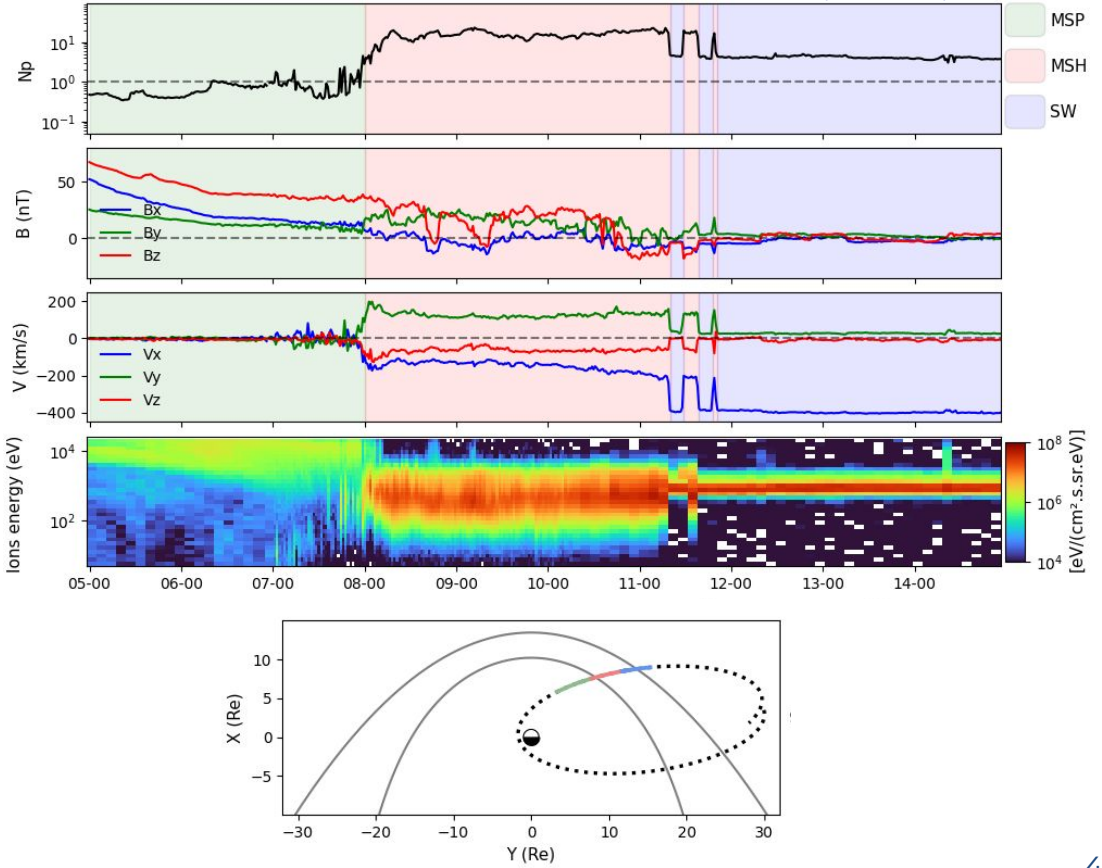
➡ What about other parameters (△N, △V, etc) ?

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

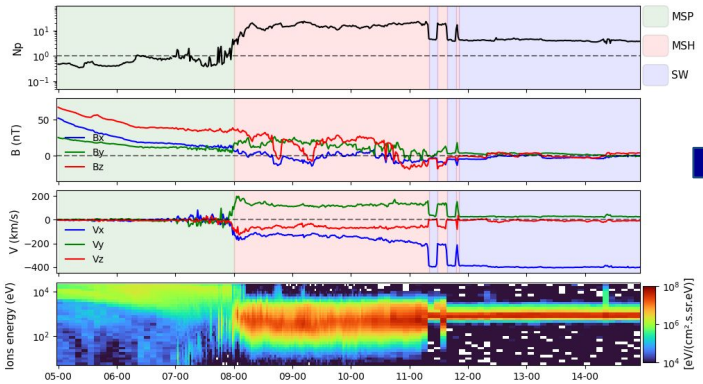


Karimabadi et al. 2014

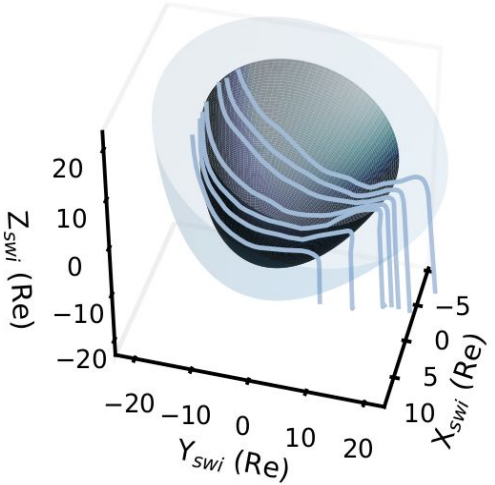
Michotte de Welle et al. 2022 (Submitted)



From in-situ data to global 3D maps



Pipeline



Michotte de Welle et al. (Rejected in Nat. phy.)

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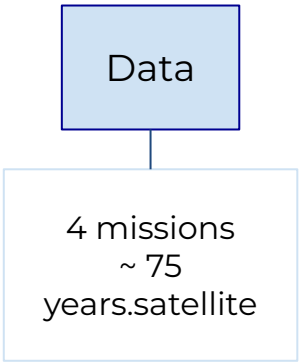

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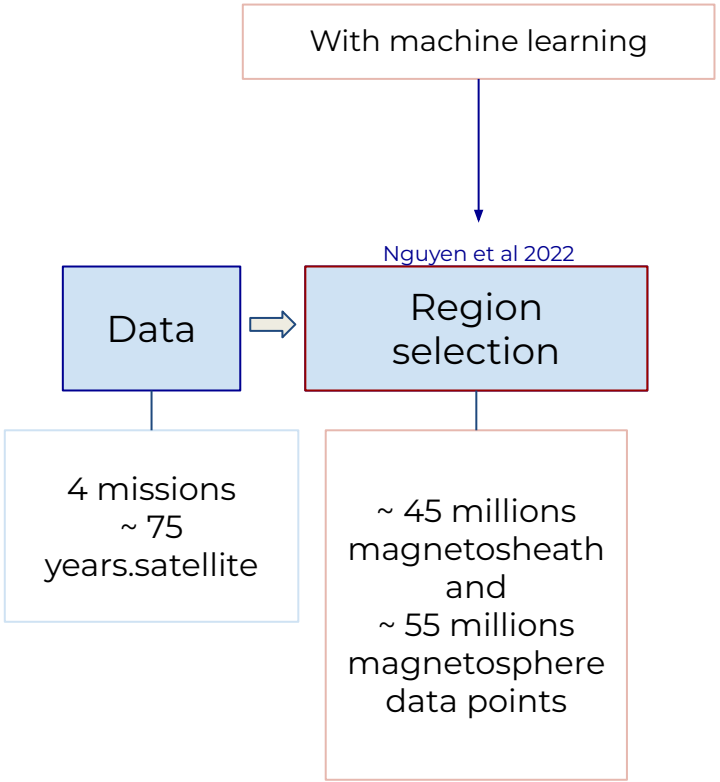
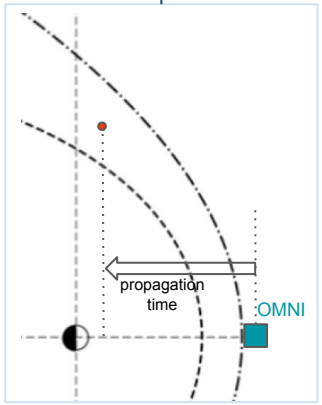


From in-situ data to global 3D maps

With machine learning

Nguyen et al 2022

Safrankova et al 2012

Data	Region selection	Solar wind appariement
4 missions ~ 75 years.satellite	~ 45 millions magnetosheath and ~ 55 millions magnetosphere data points	

From in-situ data to global 3D maps

Poster A. Ghisalberti et al

With machine learning

Magnetopause and bow shock models

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Data → Region selection → Solar wind appariement → Normalisation of the position

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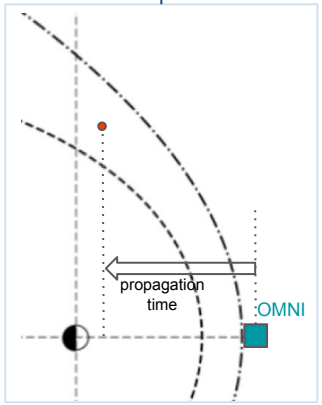

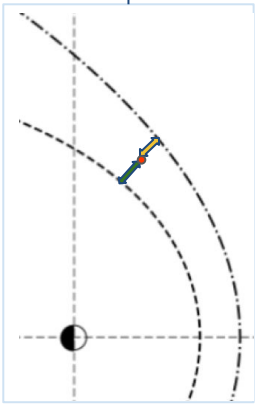

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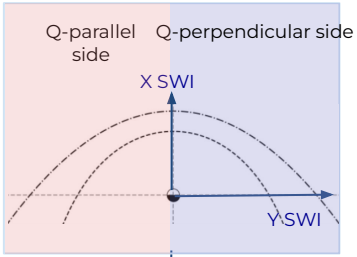

Nguyen et al 2022

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Zhang et al 2019

Data → Region selection → Solar wind appariement → Normalisation of the position → SWI coordinates →

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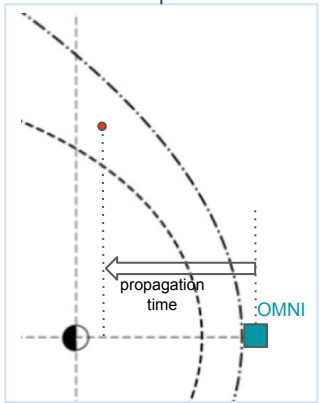
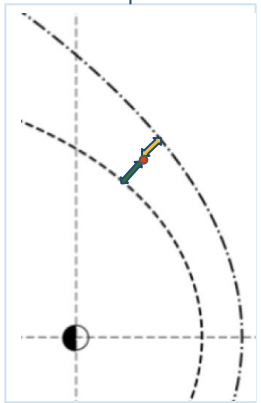
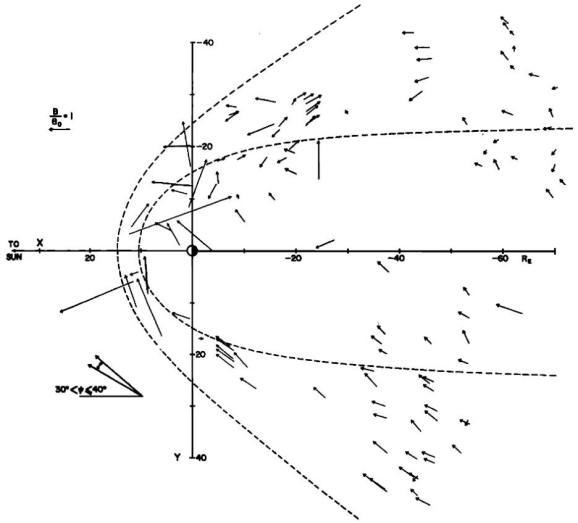




Magnetic draping,
and
Shear angle

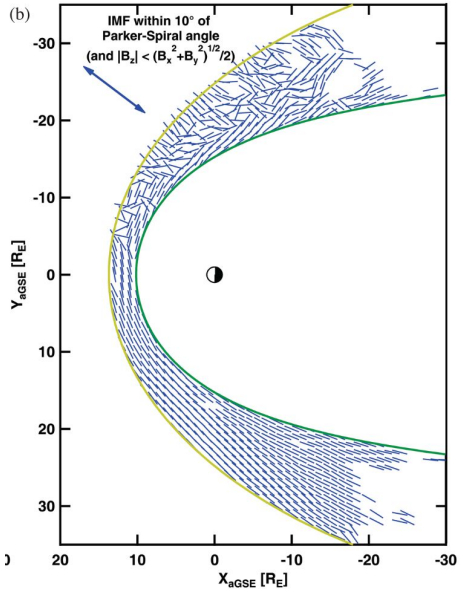
Current density,
and
Reconnection rate

Magnetic field in the magnetosheath from in-situ data



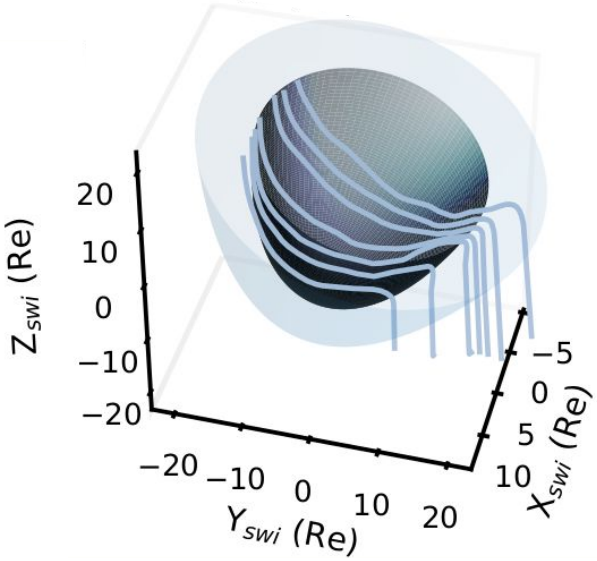
Behannon et al. 1969

Missions :
- Explorers



Petrinec 2012

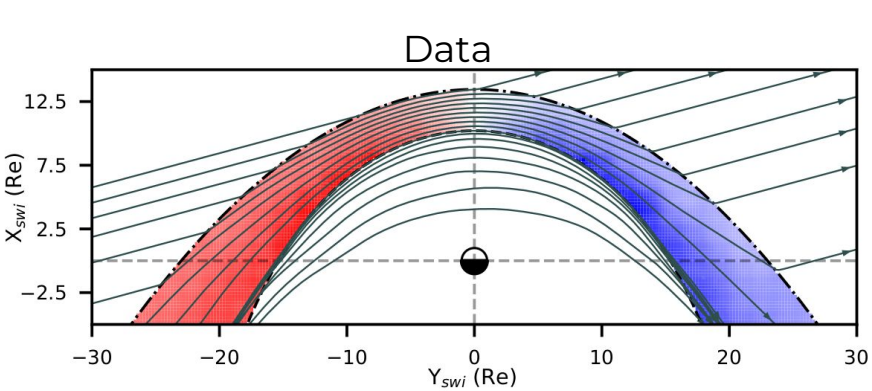
Mission :
- THEMIS

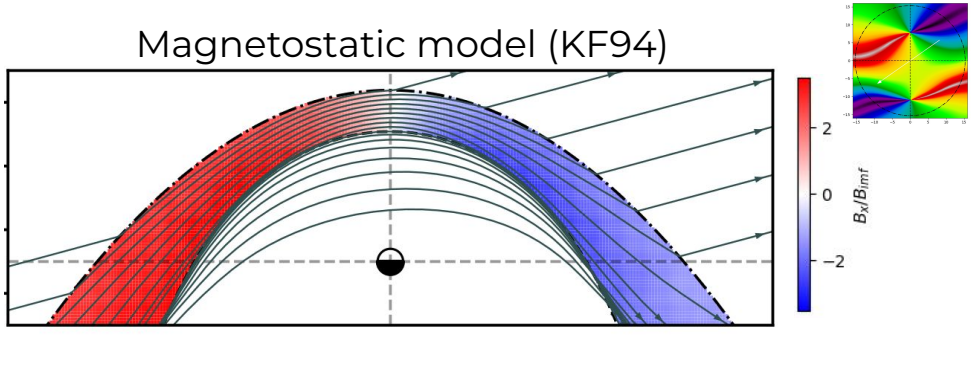


Michotte de Welle et al. (Rejected in Nat. phy.)

Missions :
- Cluster
- DoubleStar
- THEMIS
- MMS

Agreement model/data for radial and perp. IMF

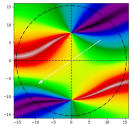


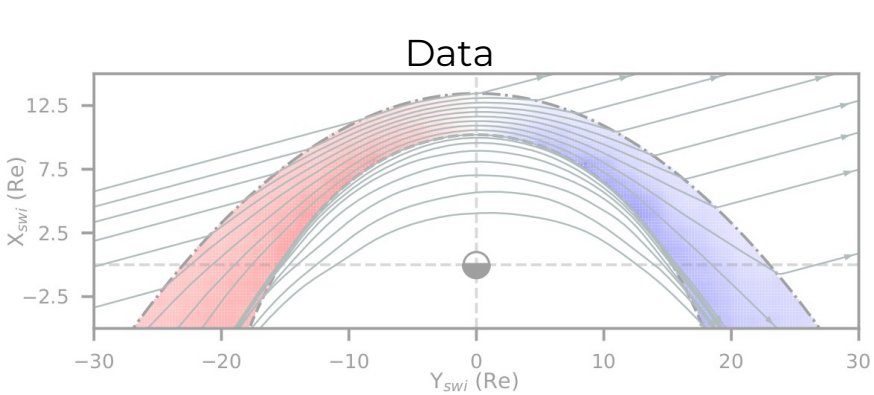


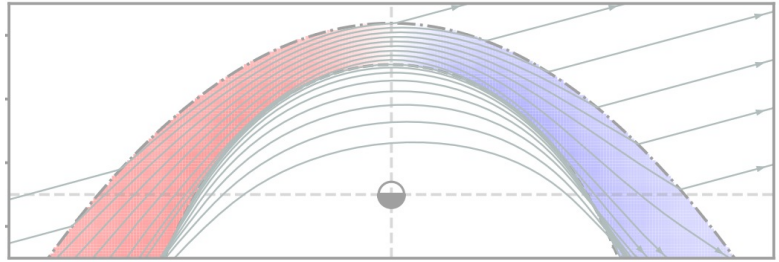
Agreement model/data for radial and perp. IMF

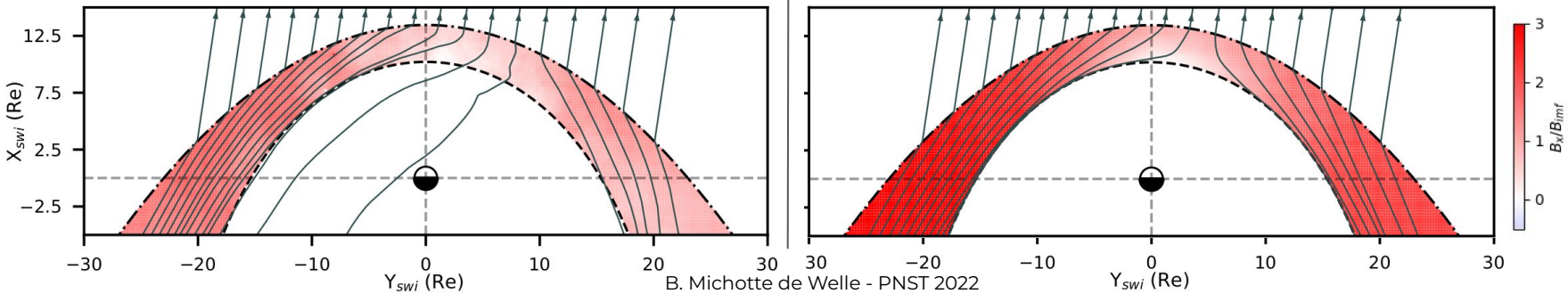
Data

Magnetostatic model (KF94)

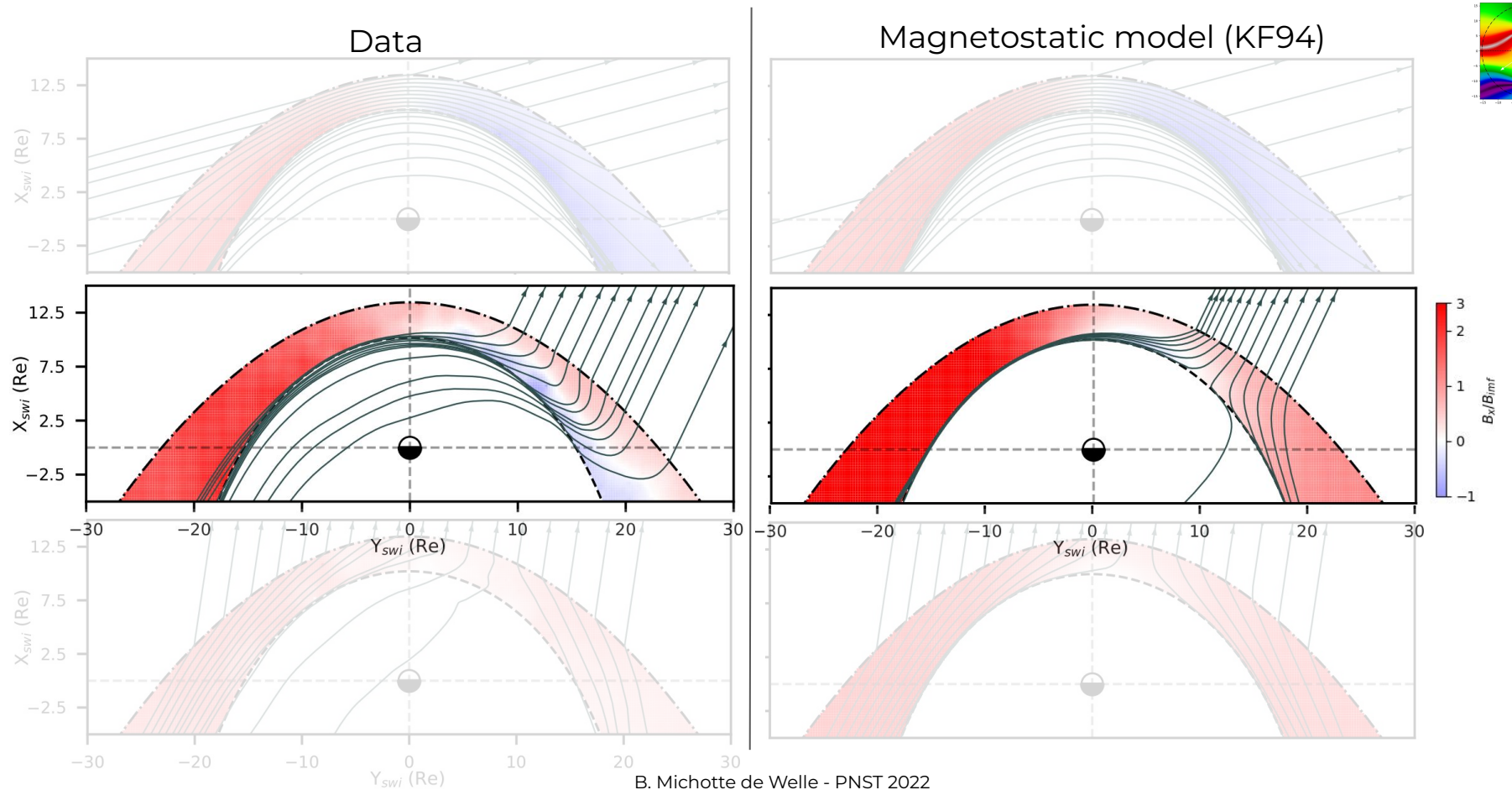




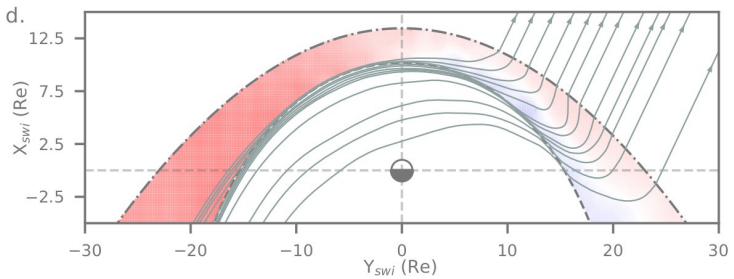


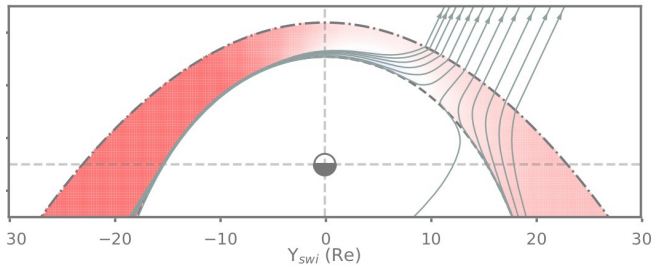


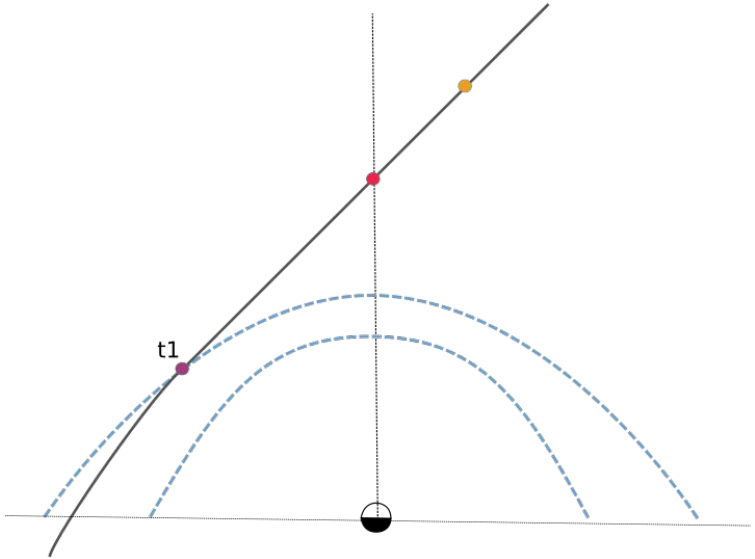
Disagreement model/data for intermediate IMF inclination



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







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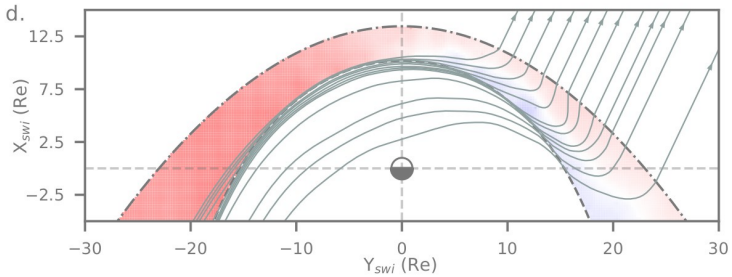

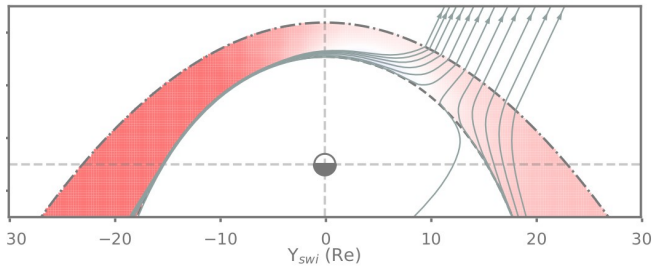

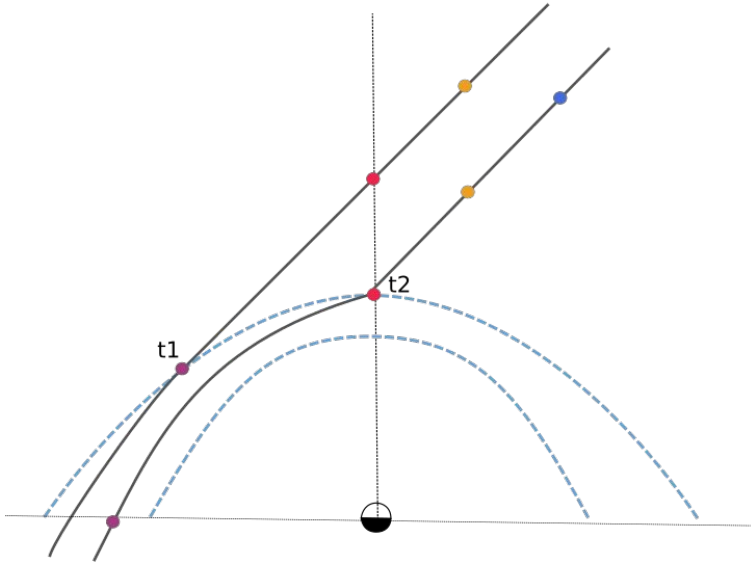

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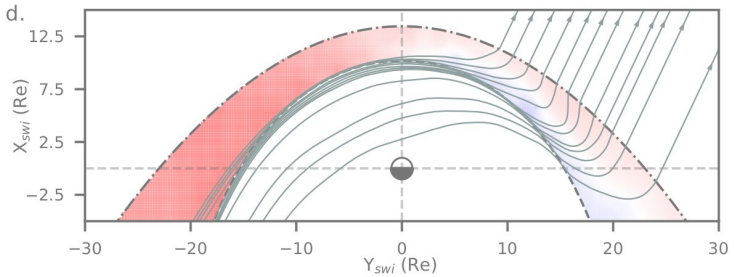

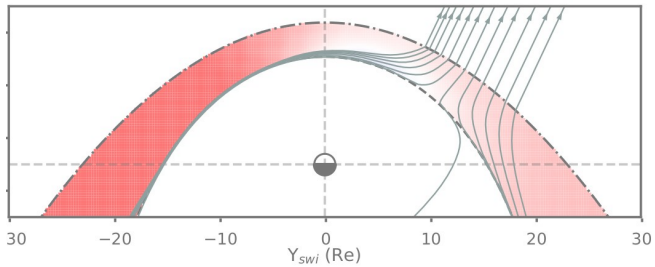

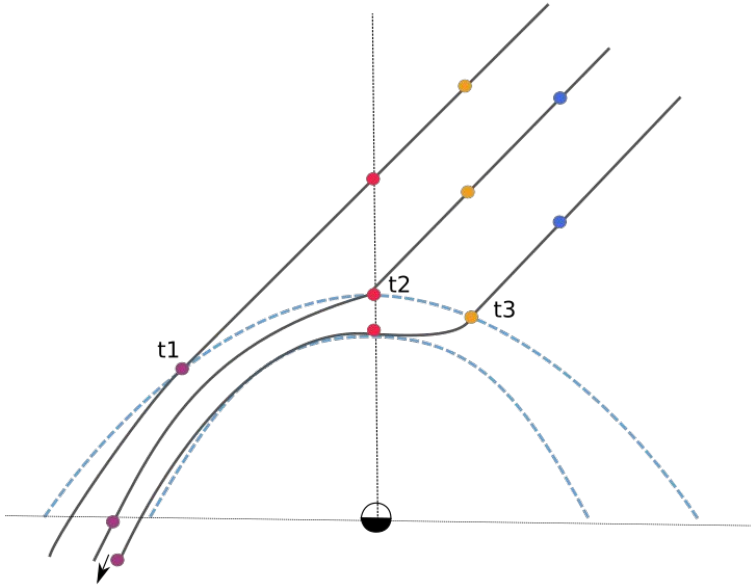

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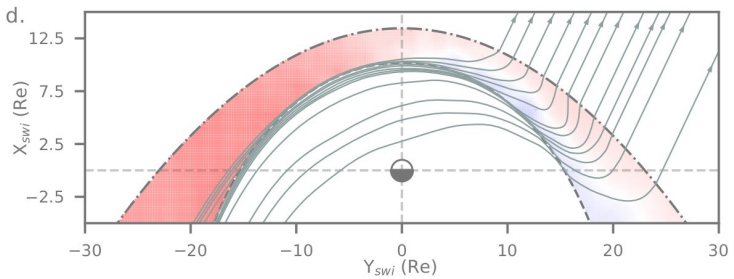

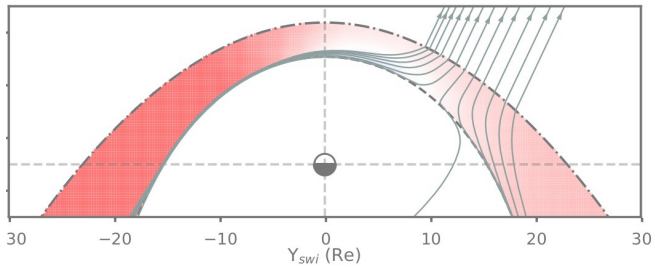

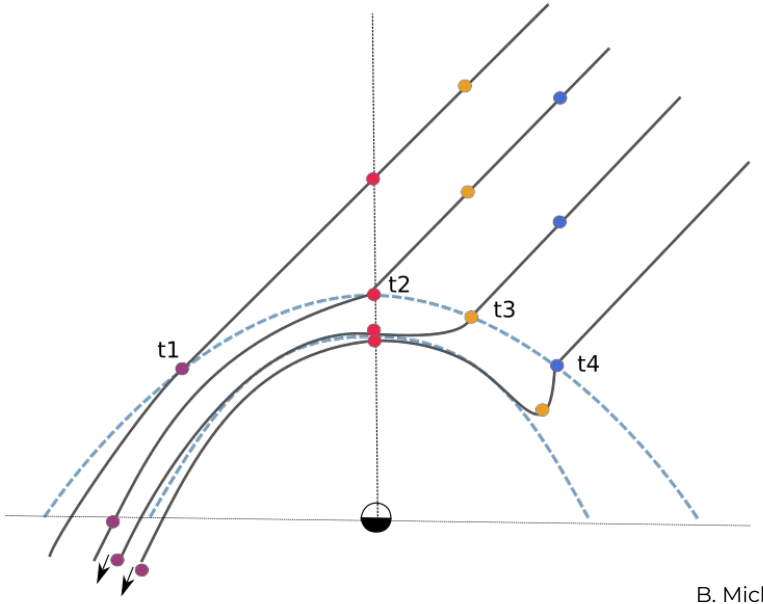

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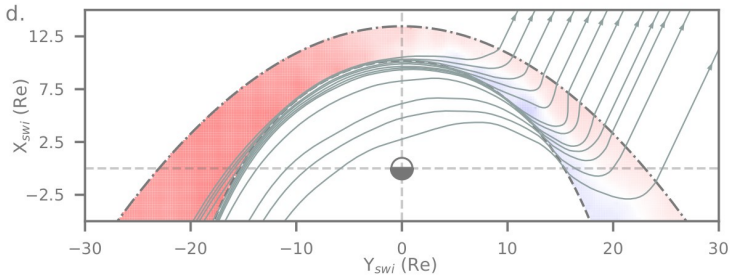
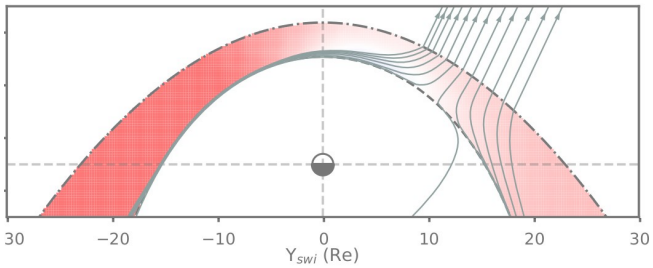
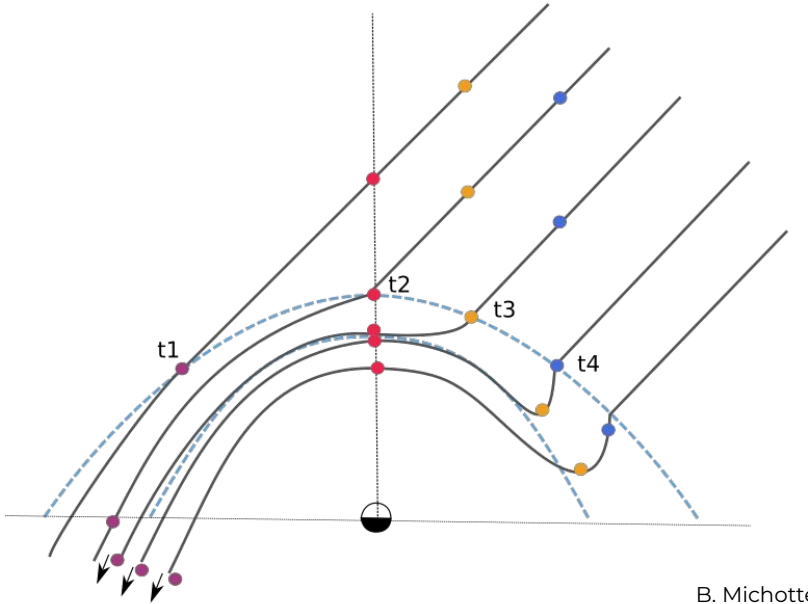
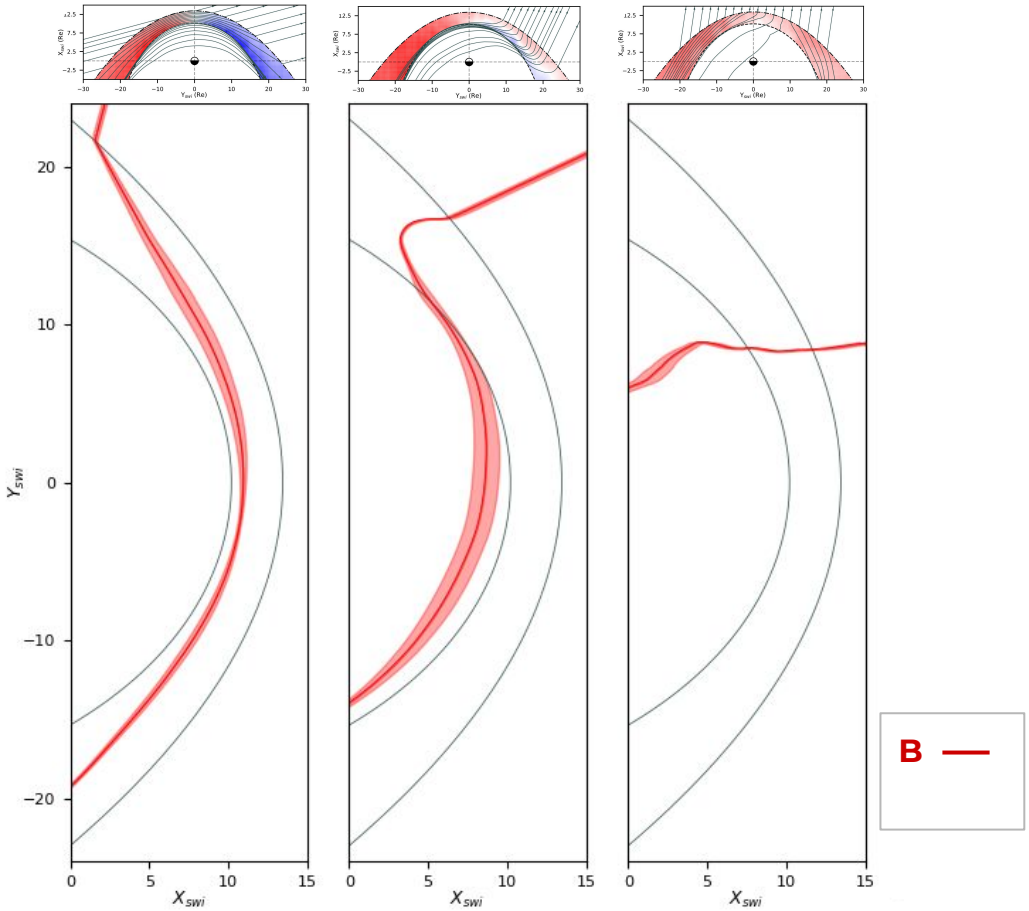






The magnetosheath flow structures the draping around the MP



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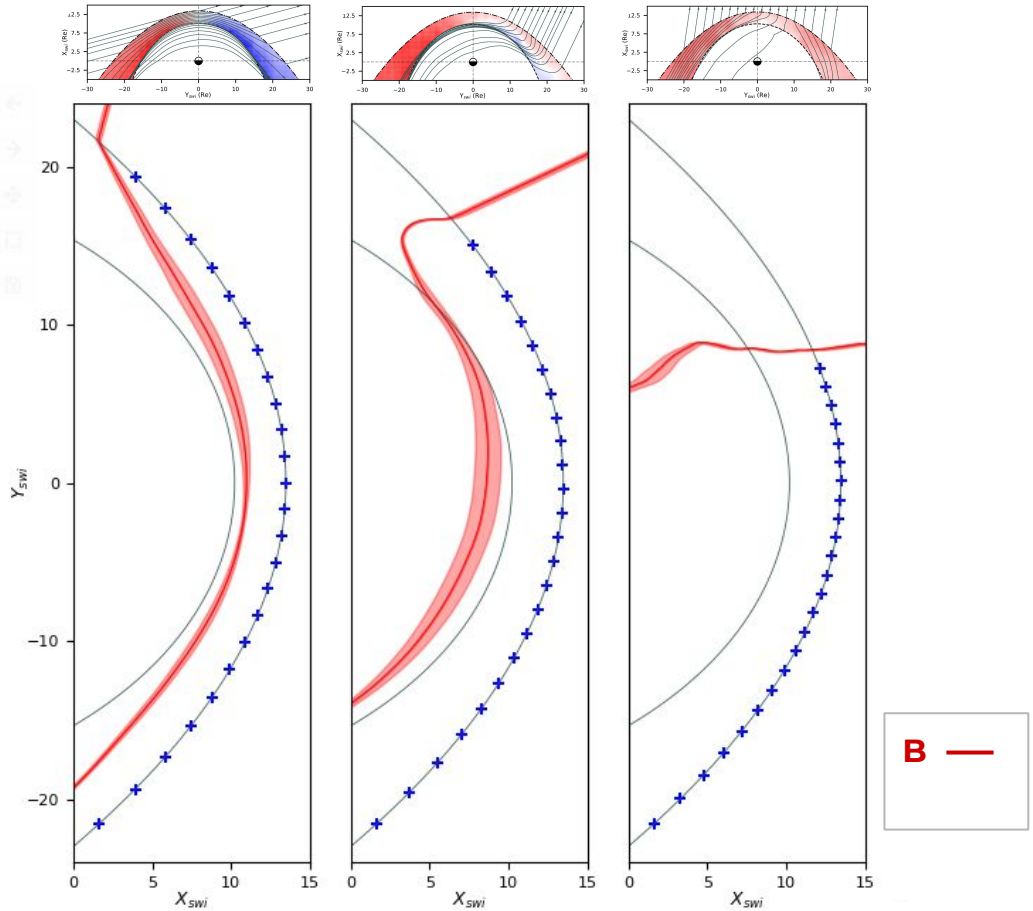

- Assumptions :
  - Constant solar wind velocity
  - Steady IMF orientation

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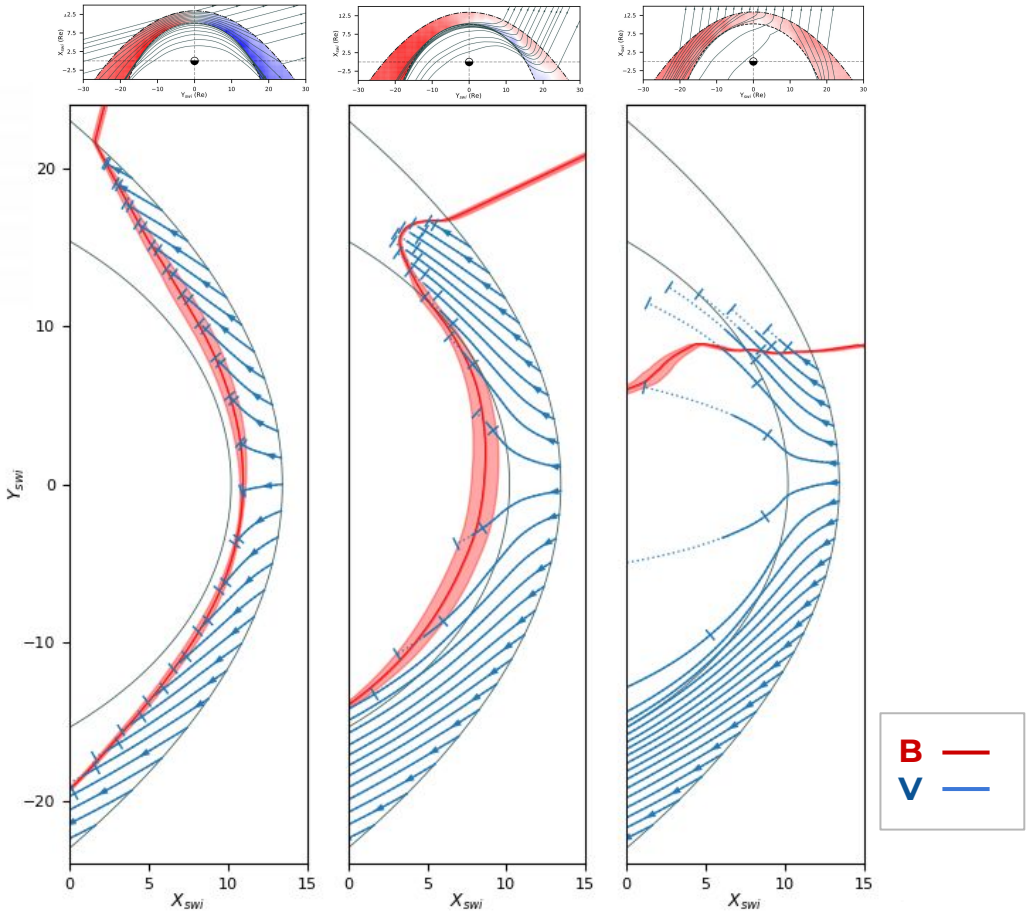

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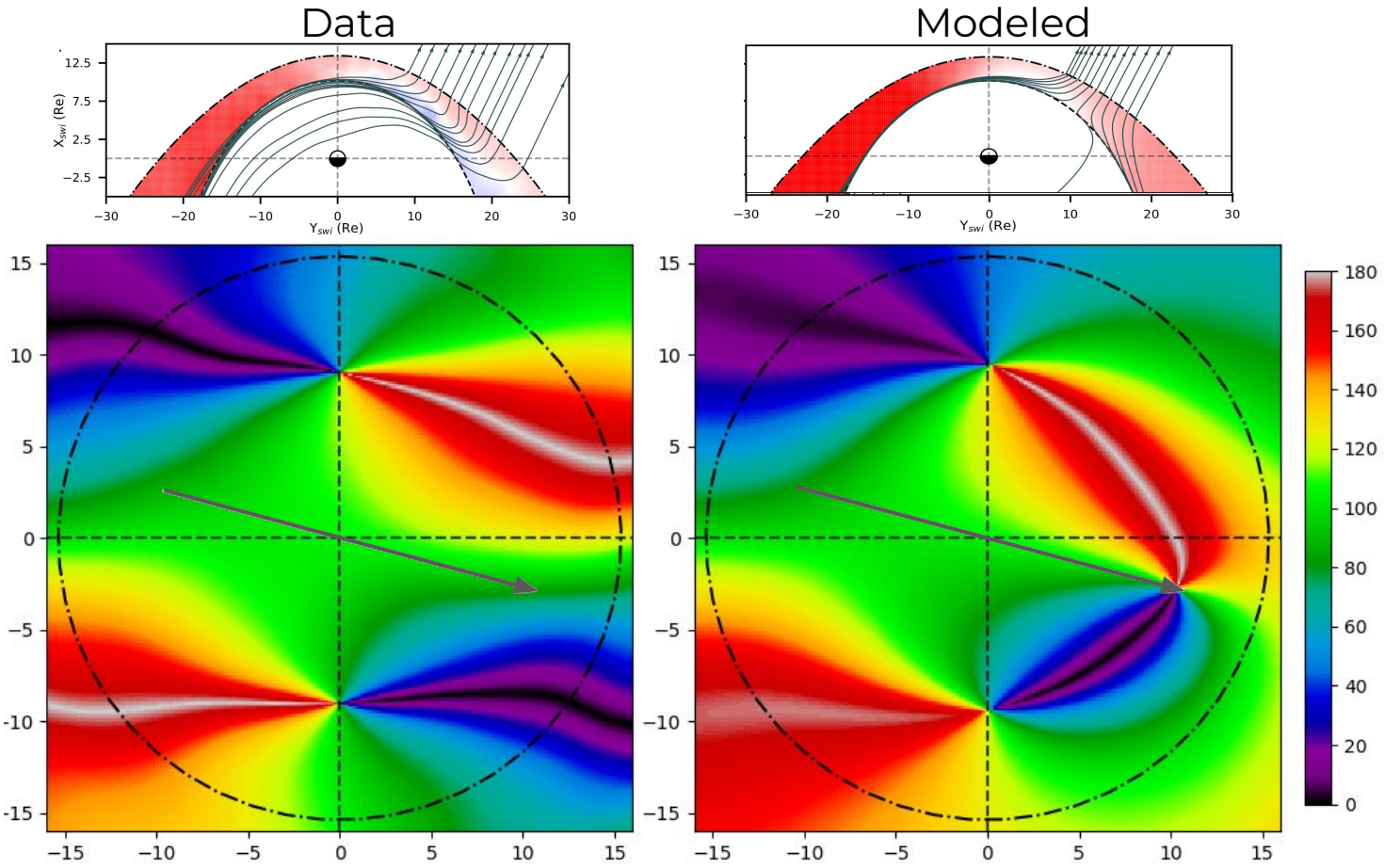
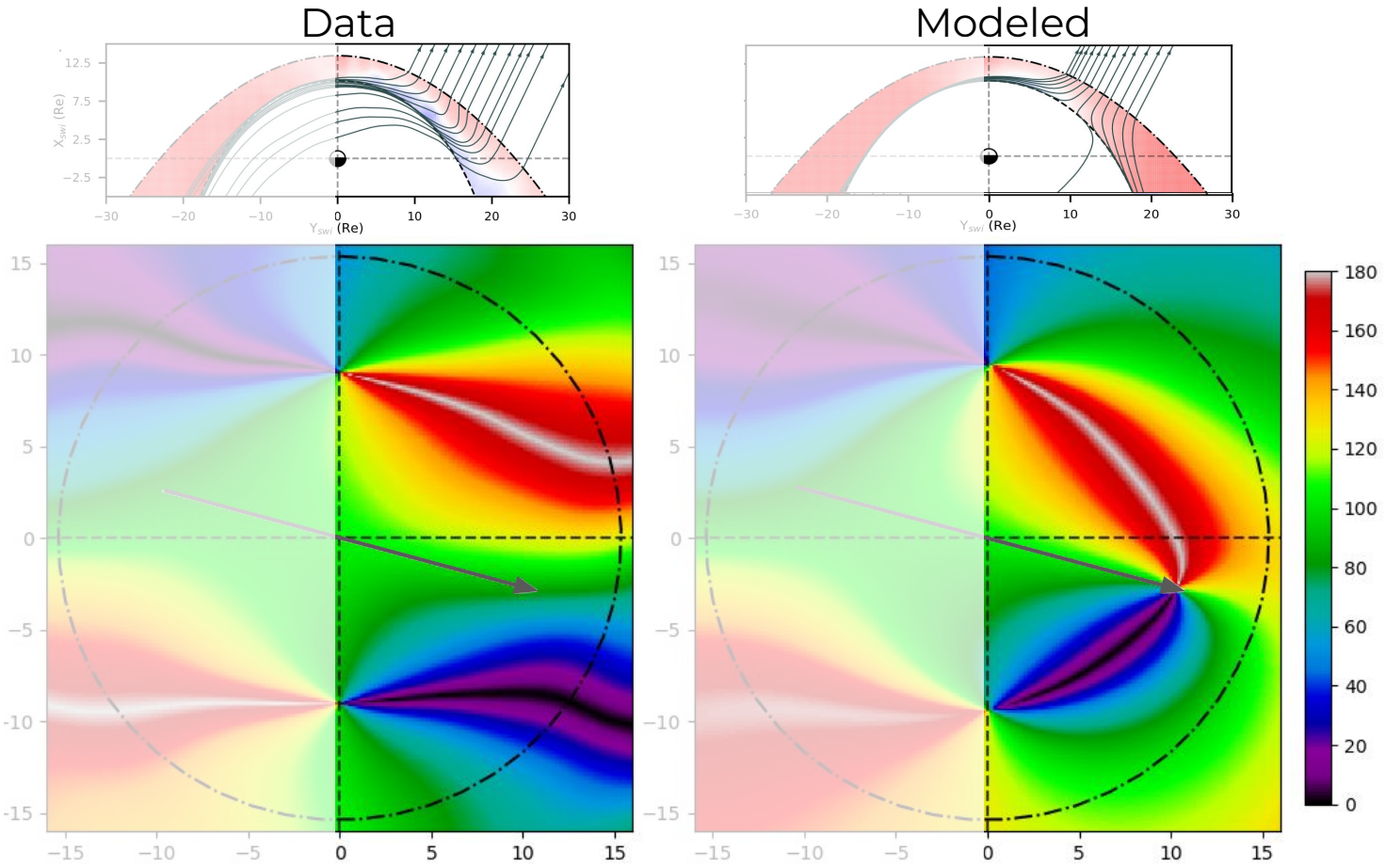
Quantitatively demonstrates that plasma flow drives the magnetic draping

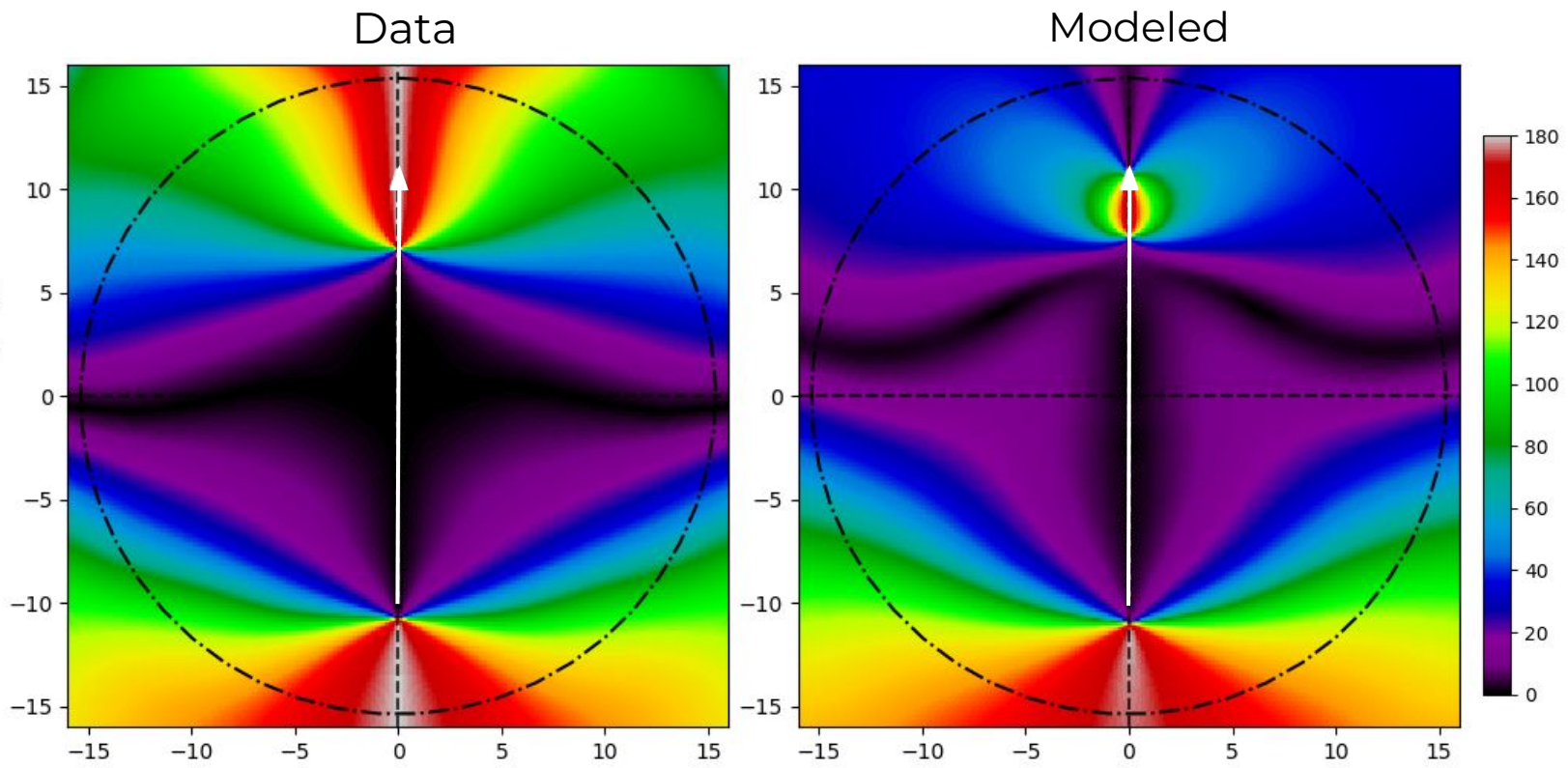
The observed magnetic shear differs from that of the model



The observed magnetic shear differs from that of the model



Northward IMF magnetic shear : more symmetric in data



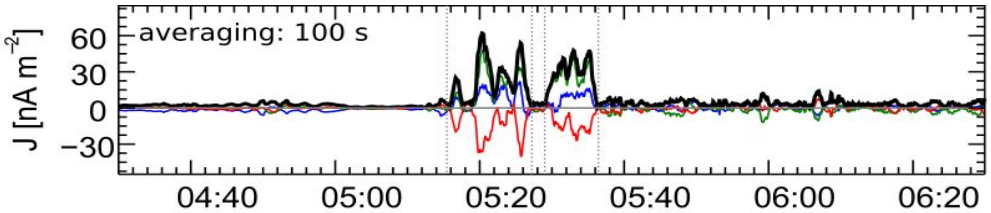
⟹ Dual lobes reconnection ?

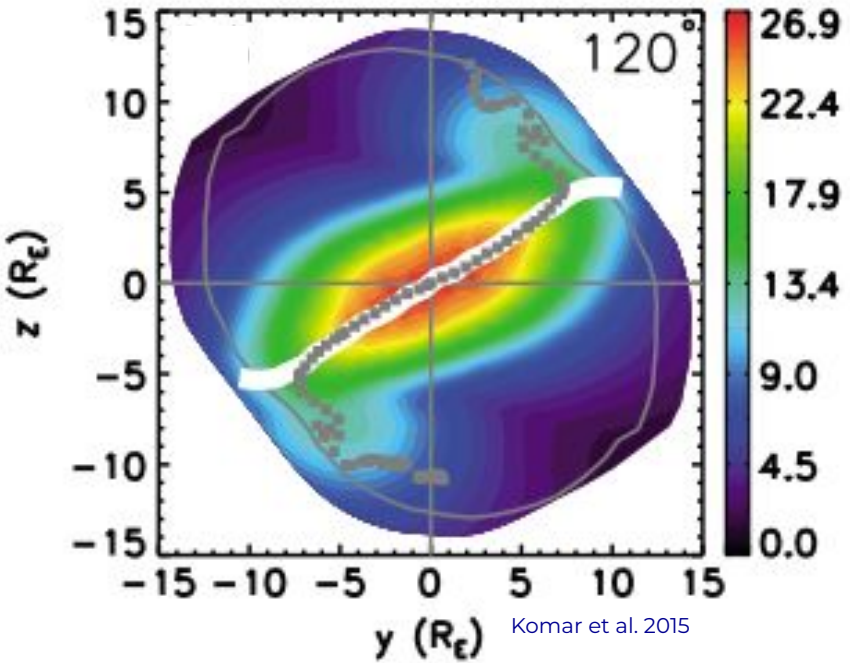
Magnetic draping,
and
Shear angle

Current density,
and
Reconnection rate

Current density at the magnetopause

Liebert et al. 2017

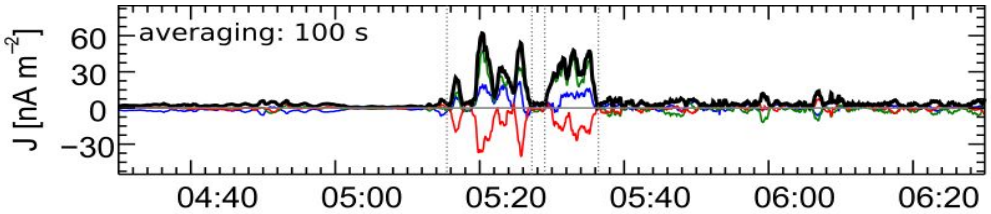




Komar et al. 2015

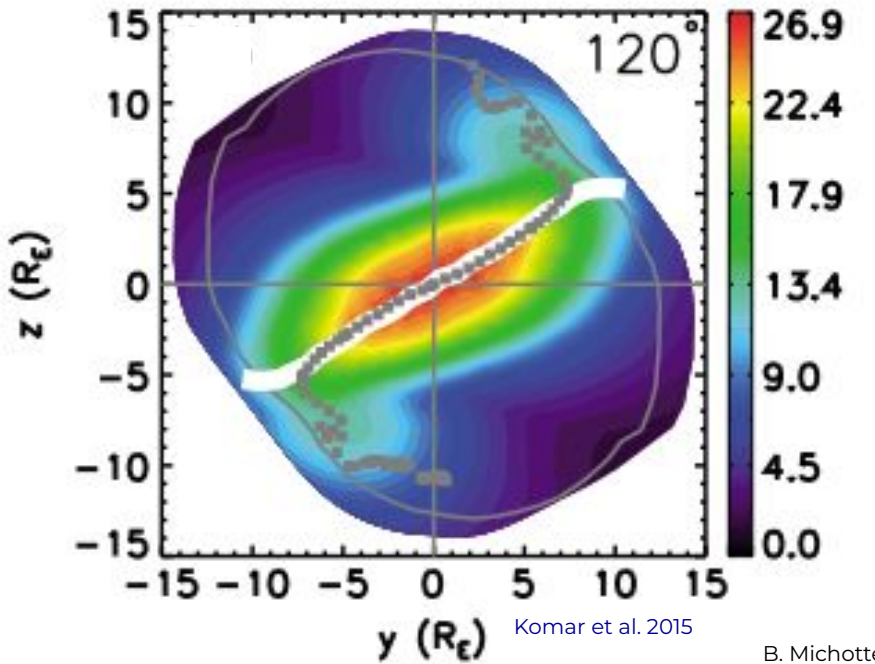
Current density at the magnetopause

Liebert et al. 2017

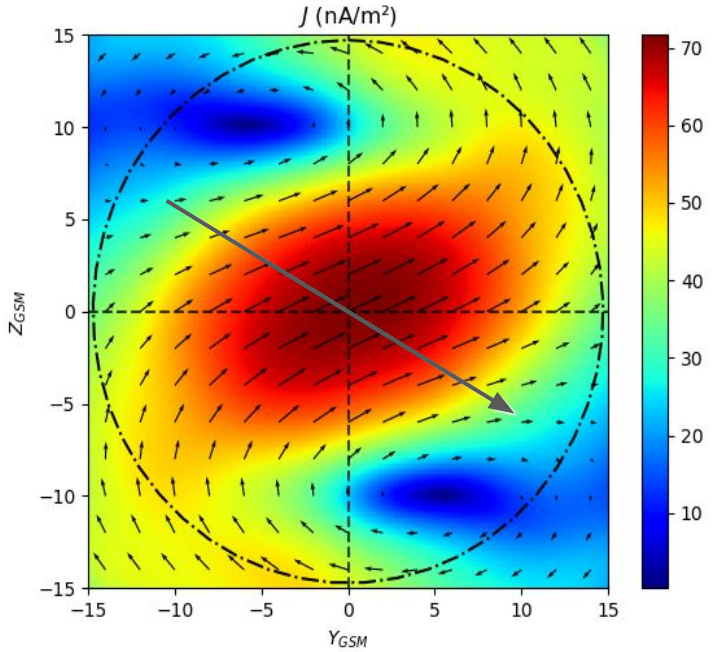


Pattern similar to MHD simulations for multiple IMF orientation

Assumed MP thickness = 800 km



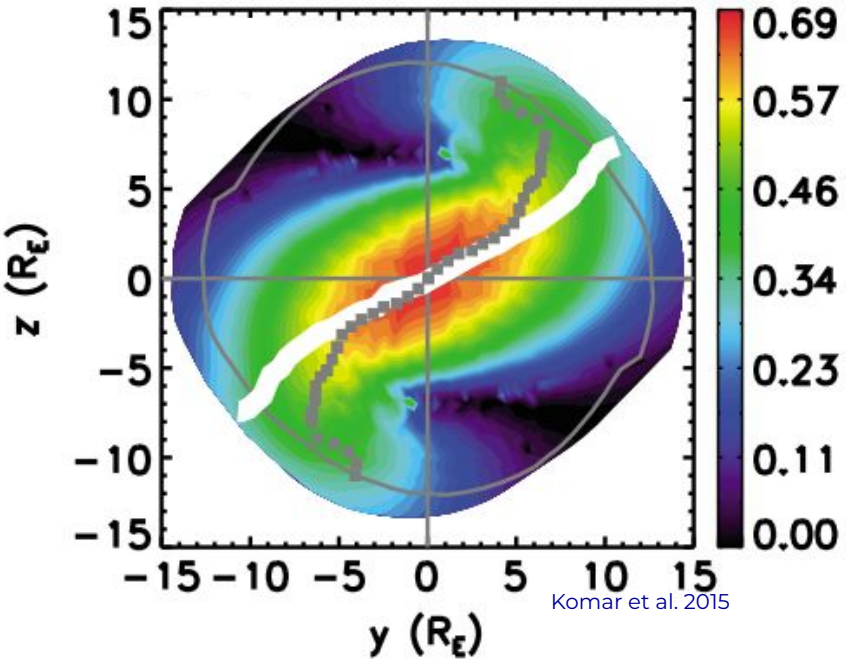
Komar et al. 2015



Global structure of the reconnection rate ~ MHD models

Cassak-Shay formula (2007) :

$$R = 0.1 \frac{(B_1 B_2)^{3/2}}{\sqrt{\mu_0 (B_1 \rho_2 + B_2 \rho_1)}} \left(1 - \frac{v_{shear}^2}{c_a^2} \frac{4 \rho_1 B_2 \rho_2 B_1}{\rho_1 B_2 + \rho_2 B_1} \right)$$



Komar et al. 2015

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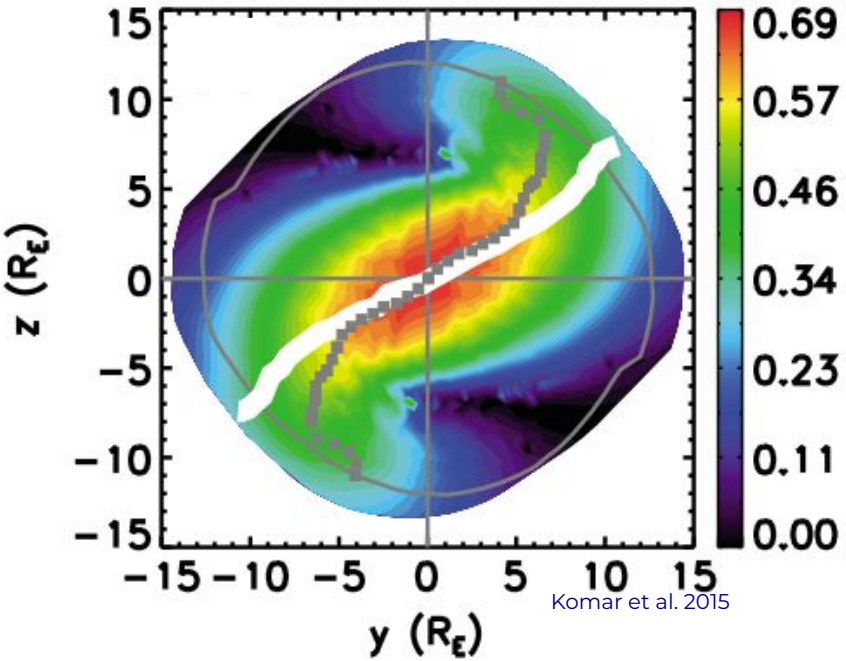
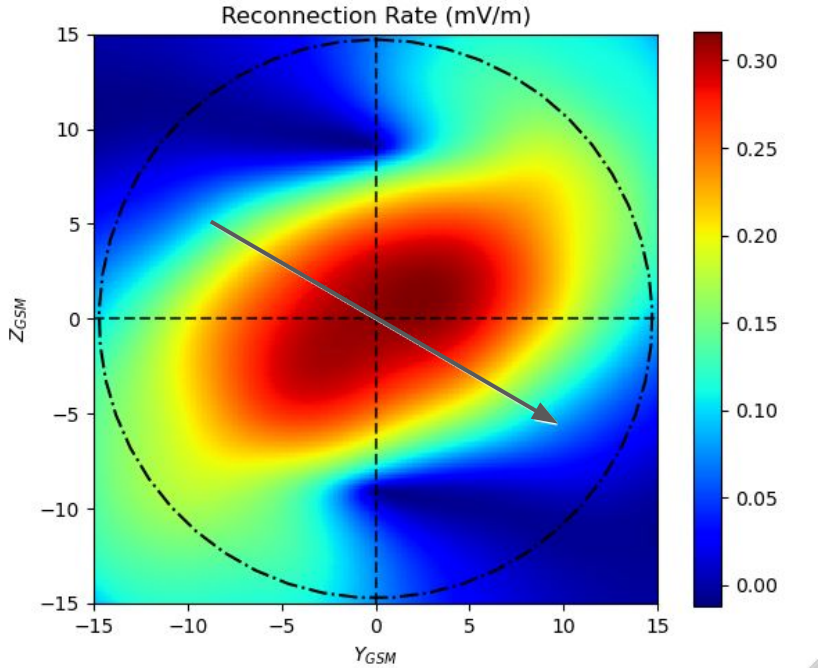
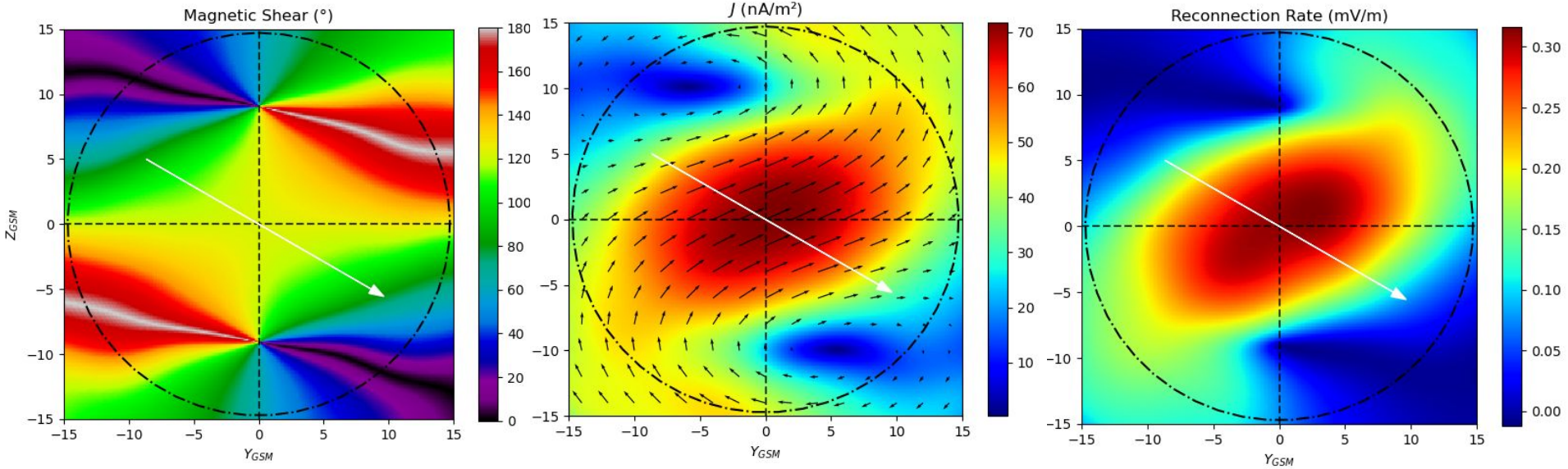


Komar et al. 2015

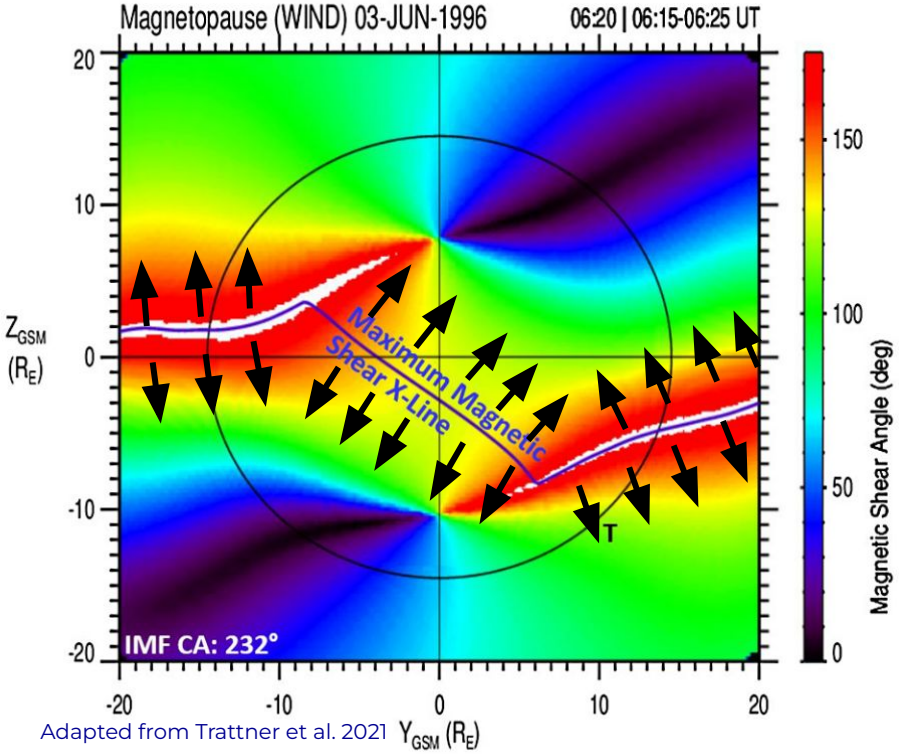


Let’s correlate obs. of magnetic reconnection with:

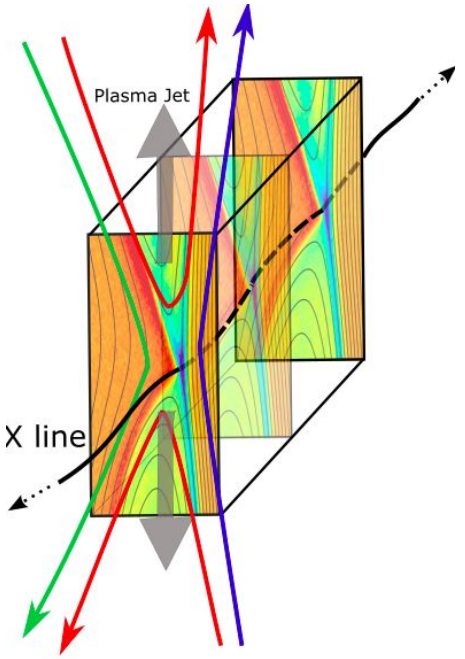


Inferring the X-line location from global reconnection jet maps

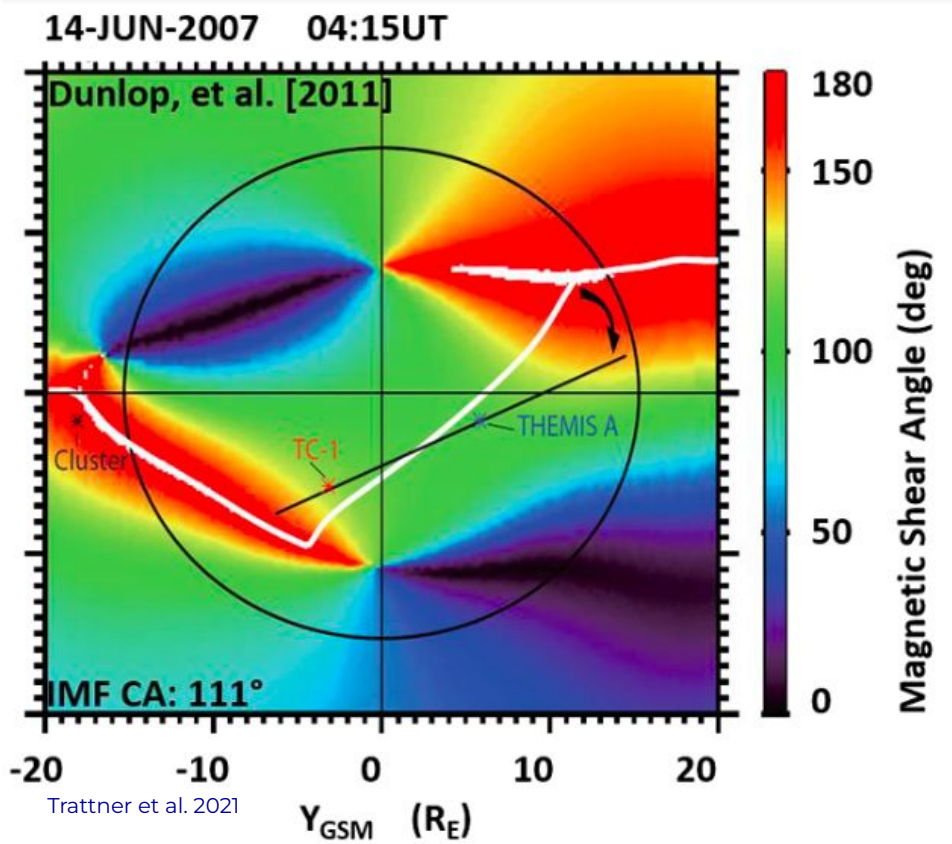
- Ion beams and flow jet escaping from the X-line



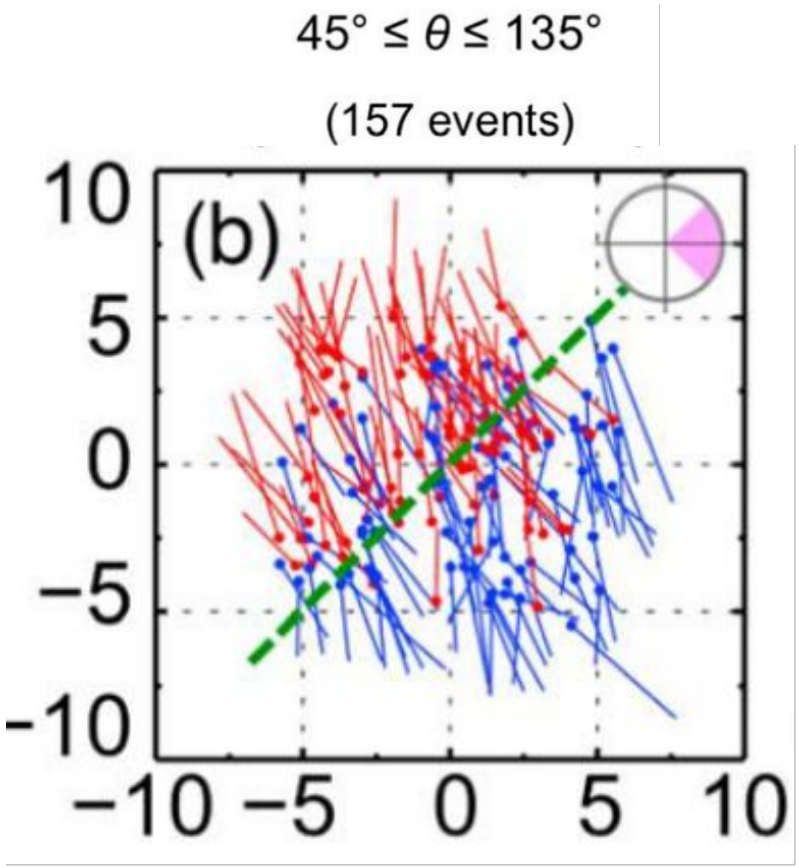
Adapted from Trattner et al. 2021



Inferring the X-line location from global reconnection jet maps

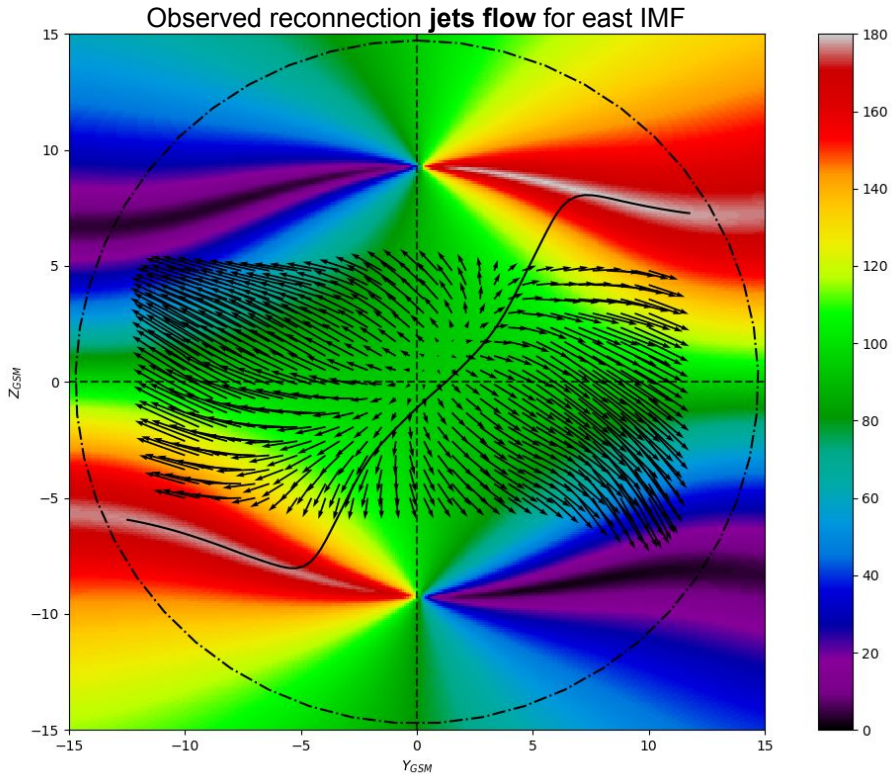


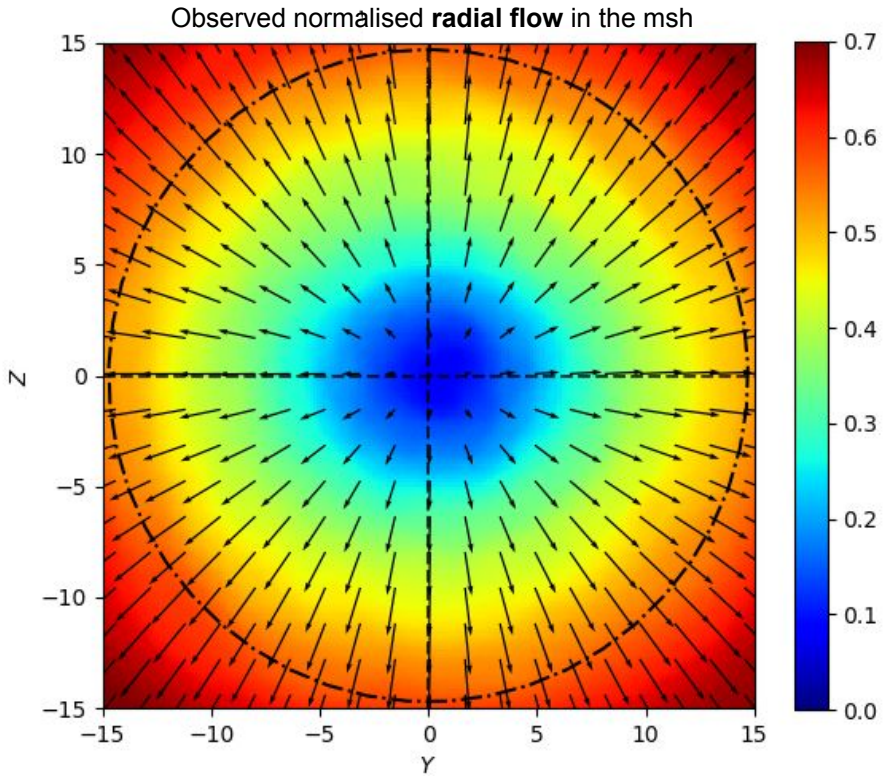
Trattner et al. 2021



Hoshi et al 2018

Inferring the X-line location from global reconnection jet maps

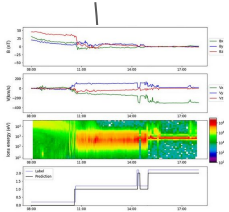




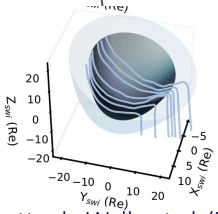
Subset of ~17k jets reconnection (G. Nguyen PhD thesis 2021)

Pattern of the flow from jets differ from the radial flow of the magnetosheath

Where is Magnetic Reconnection occuring on the Magnetopause ?



Nguyen et al. 2022



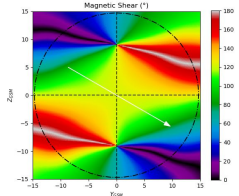
Michotte de Welle et al. (Rejected in Nat. phy.)

- Classification of the near Earth's plasma environnement
- Magnetopause and bow shock models (Poster A. Ghisalberti)
- Global draping of the magnetic field in the dayside magnetosheath
- Magnetic shear maps from in-situ data
- Current density at the magnetopause
- Reconnection rate at the magnetopause

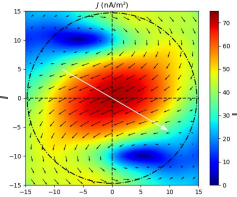
Coming soon :

- Direct evidence of magnetic reconnection (flow jet, flux ropes , ...)
- Correlation with the differents reconnection scenarios

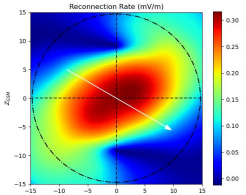
→ Tools for the community



Michotte de Welle et al. (in prep.)



[In progress]



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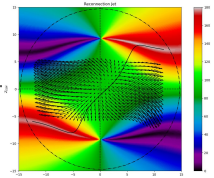
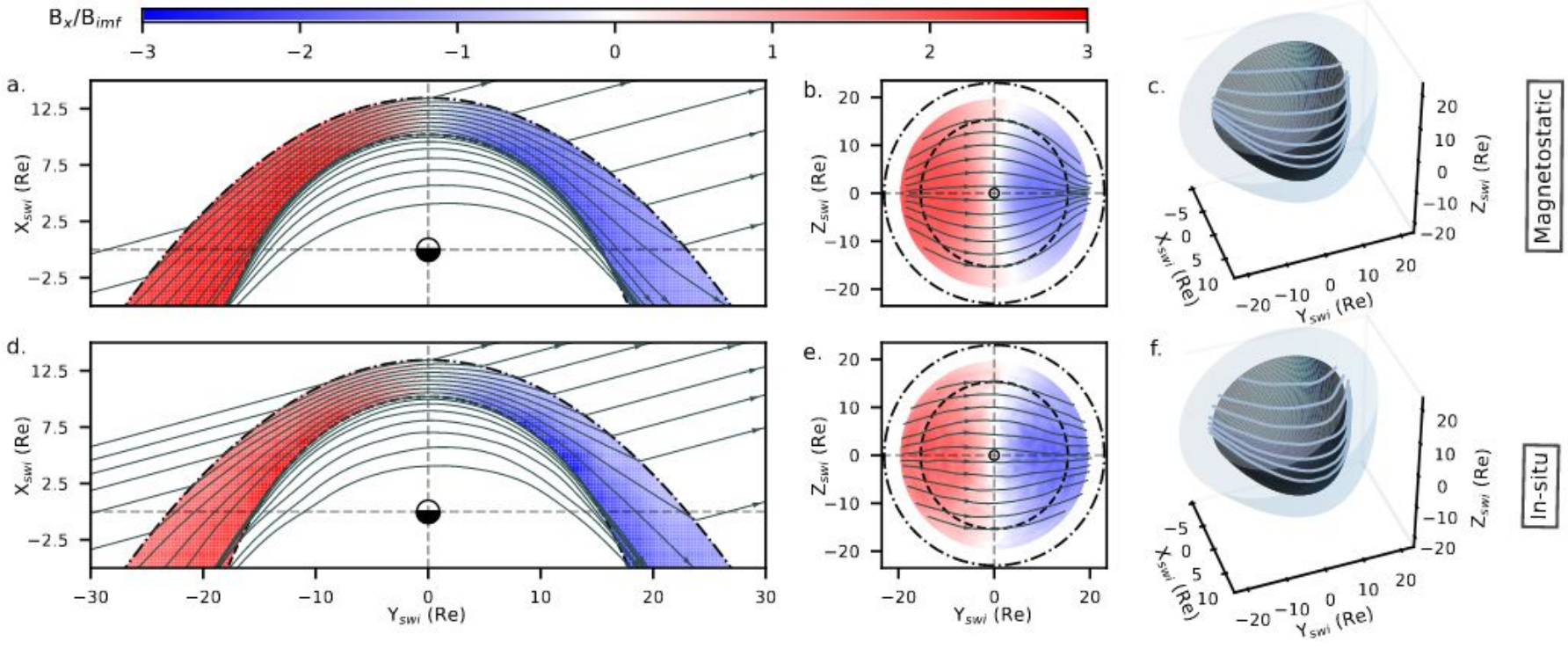
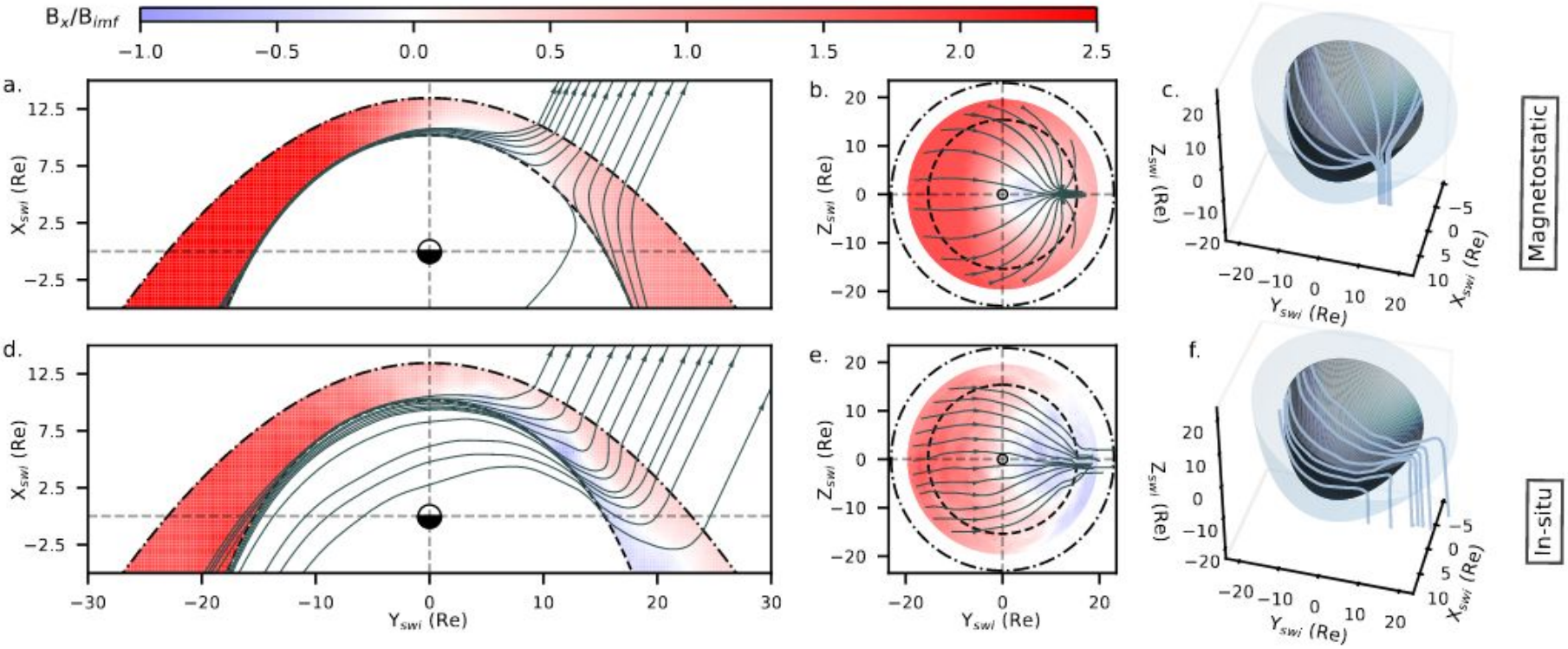
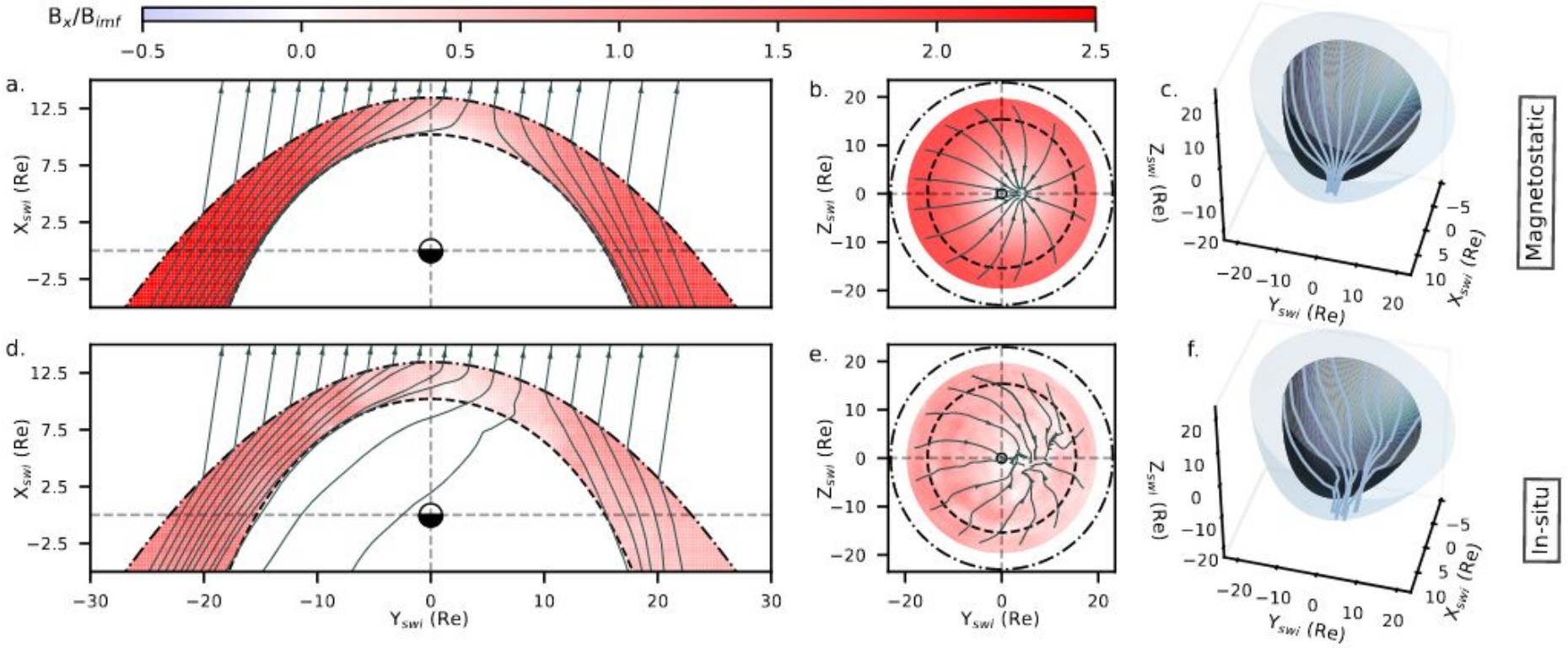


[In progress]


B_x/B_{imf}
−3
−2
−1
0
1
2
3
a.
b.
c.
d.
e.
f.
X_{swi} (Re)
Z_{swi} (Re)
Y_{swi} (Re)
Magnetostatic
In-situ


B_x/B_{imf}
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
a.
b.
c.
d.
e.
f.
X_{swi} (Re)
Z_{swi} (Re)
Y_{swi} (Re)
Magnetostatic
In-situ


B_x/B_{imf}
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
a.
b.
c.
d.
e.
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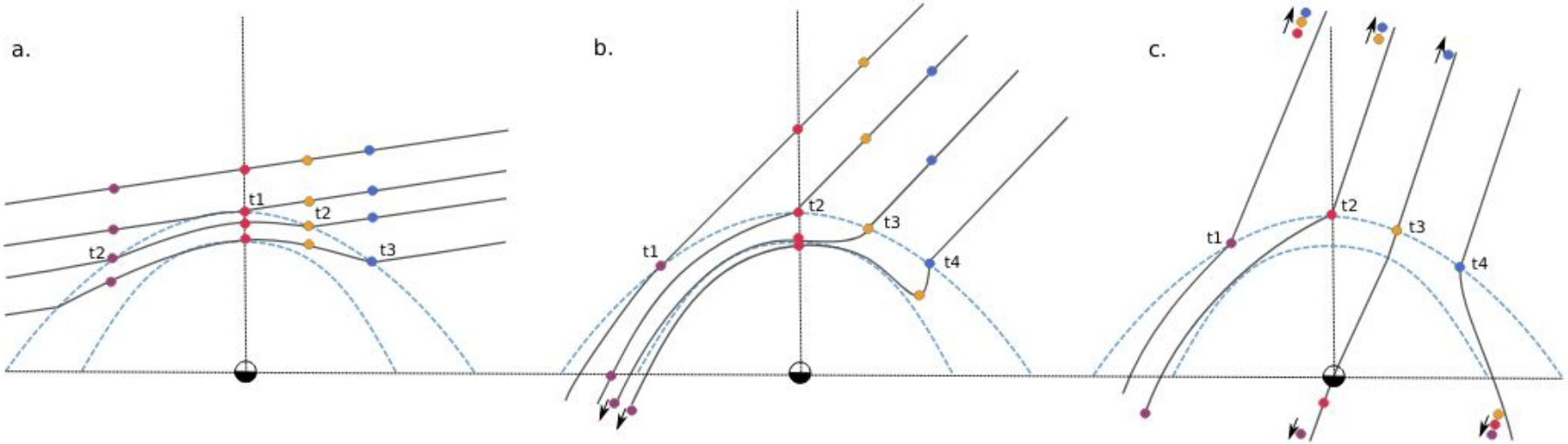
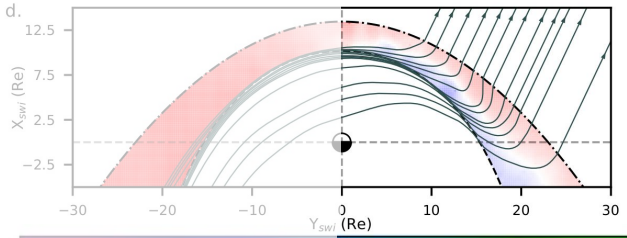
X_{swi} (Re)
Z_{swi} (Re)
Y_{swi} (Re)
Magnetostatic
In-situ

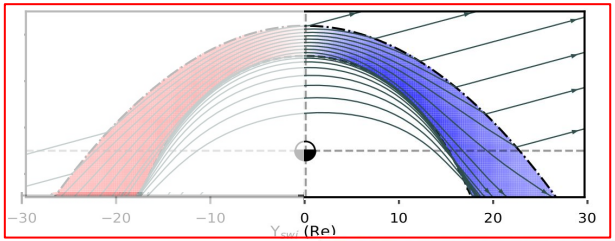

a.
t1
t2
t2
t3
b.
t1
t2
t3
t4
c.
t1
t2
t3
t4

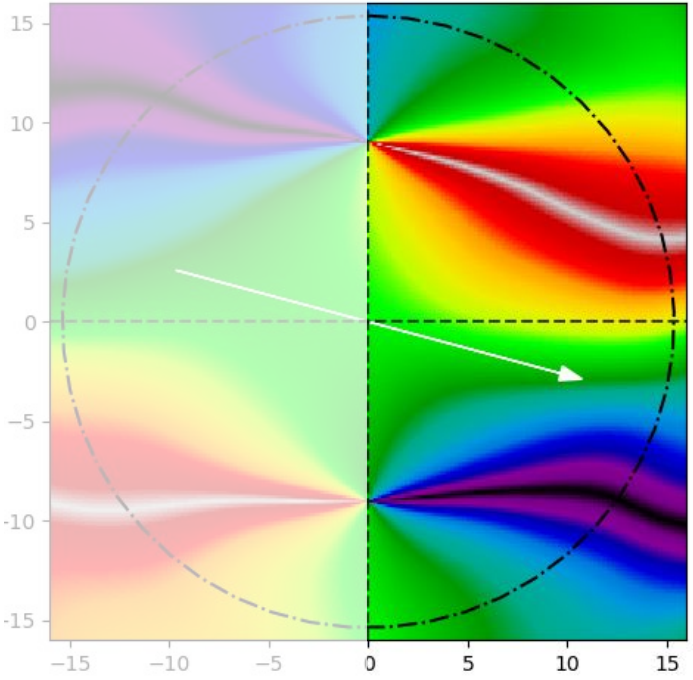
The observed magnetic shear differs from that of the model

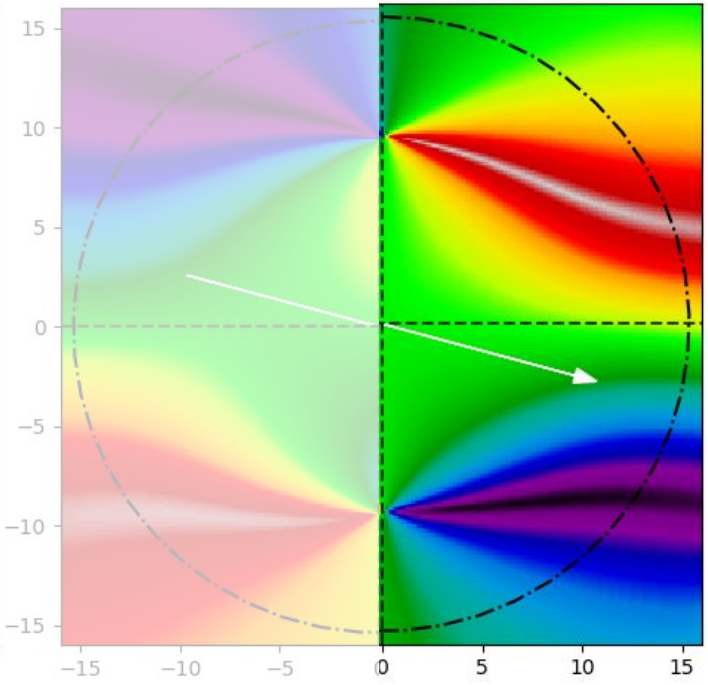
Data



Modeled

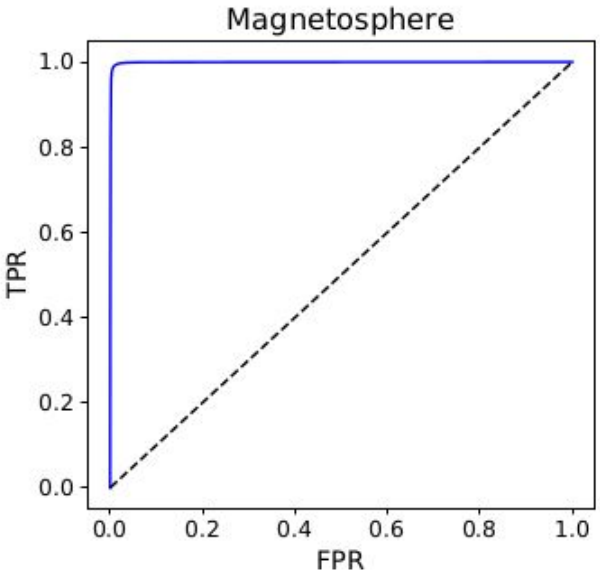


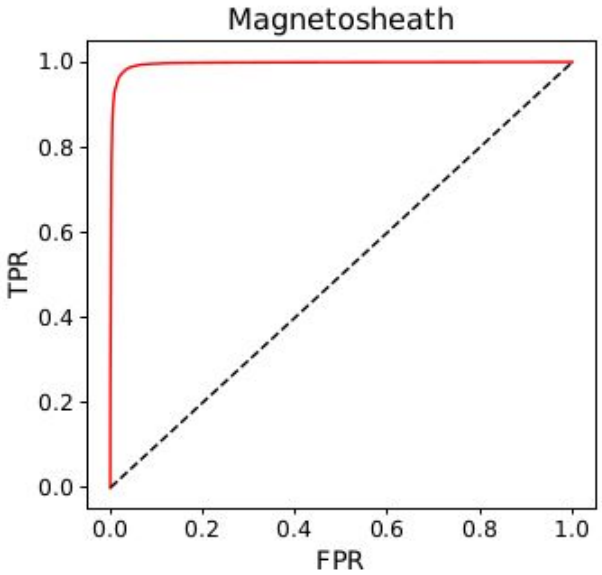


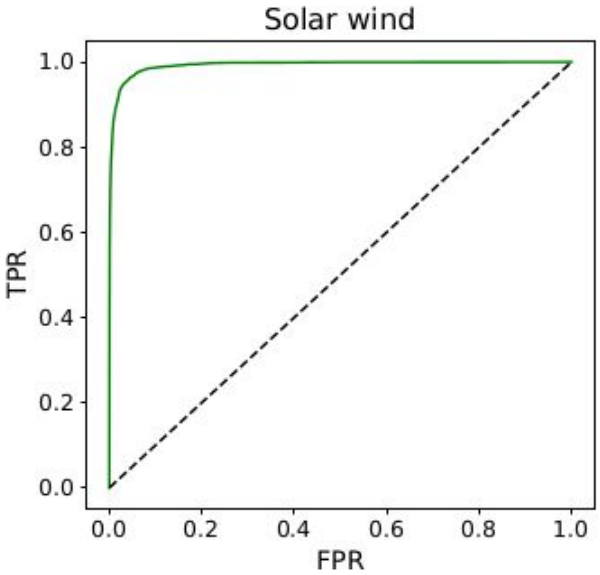


Mission	AUCMagnetosphere	AUC Magnetosheath	AUC Solar Wind
THEMIS	0.999	0.997	0.999
Cluster 1 (without retraining)	0.988	0.983	0.996
Cluster 1 (with retraining)	0.999	0.998	0.999
Double Star TC1 (without retraining)	0.996	0.992	0.996
Double Star TC1 (with retraining)	0.999	0.998	0.999
MMS (without retraining)	0.997	0.994	0.995
ARTEMIS	0.999	0.999	0.999

Nguyen et al. 2022



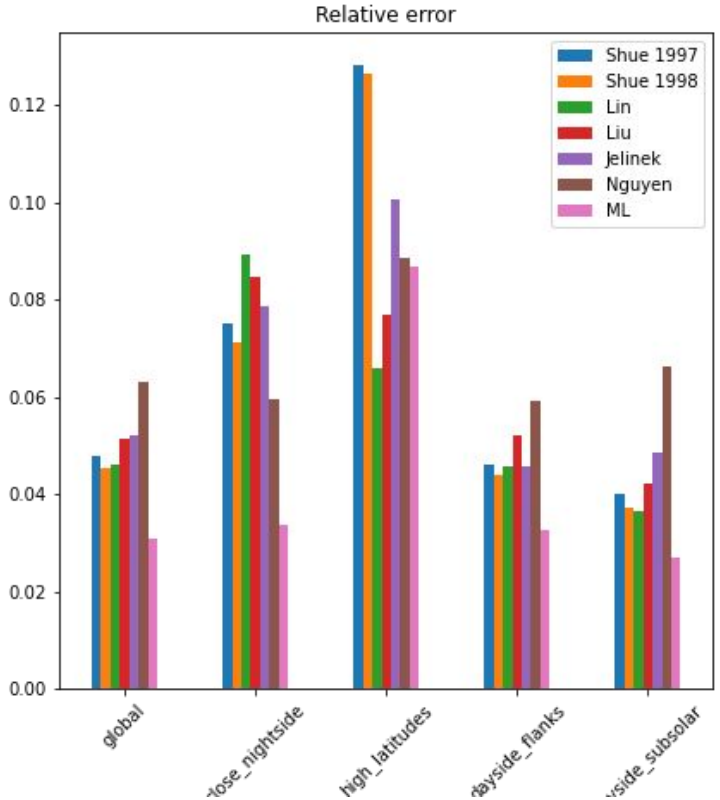


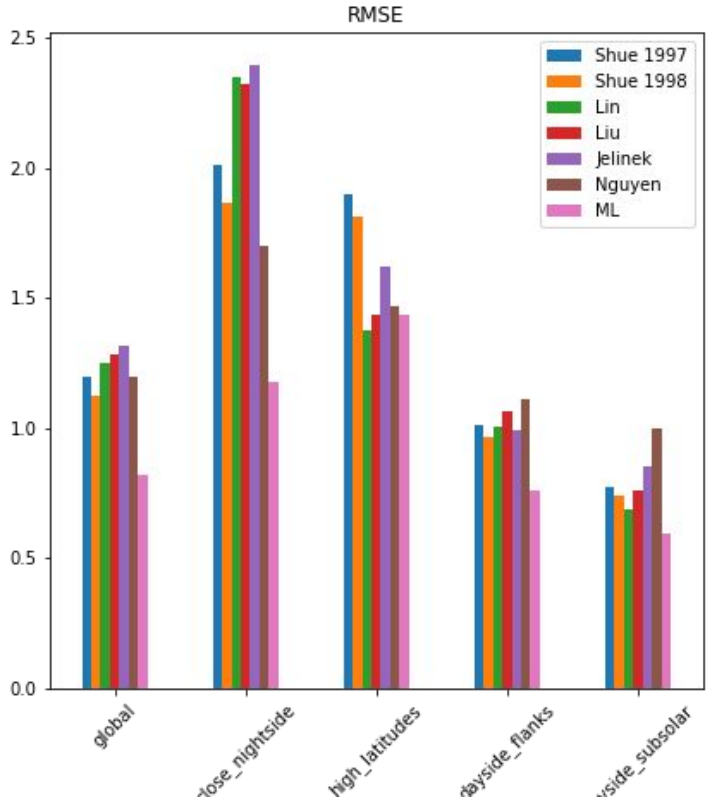


Nguyen et al. 2022

$$TPR = \frac{N_{TPs}}{N_{TPs} + N_{FNs}} \qquad FPR = \frac{N_{FPs}}{N_{FPs} + N_{TNs}}$$

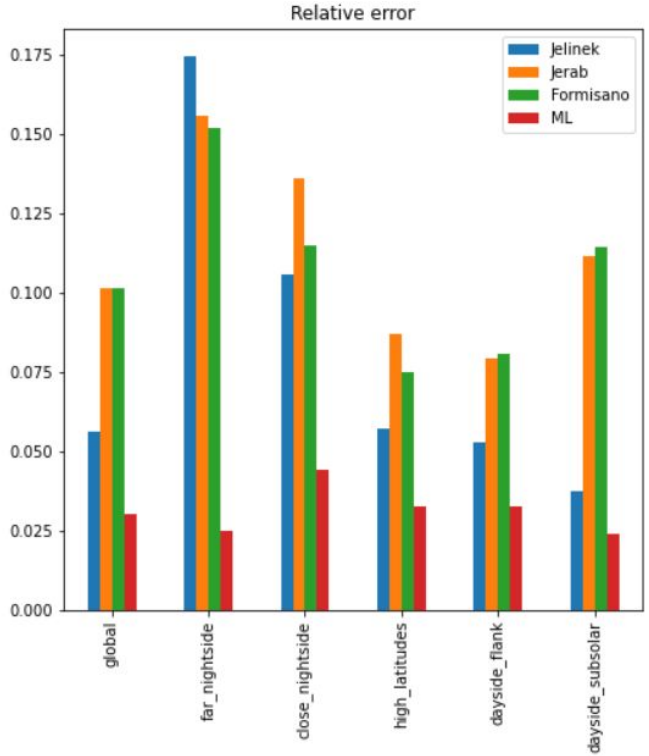
CrossVal MP

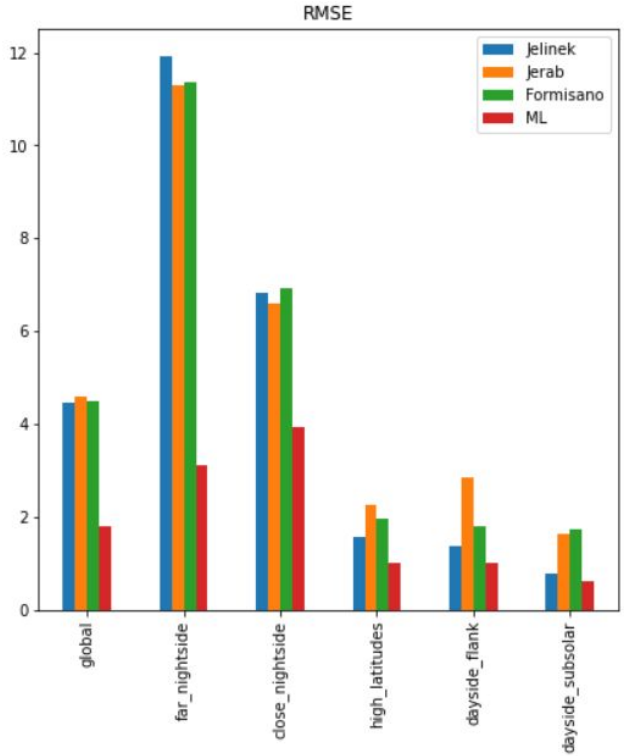




Poster Ambre Ghisablerti

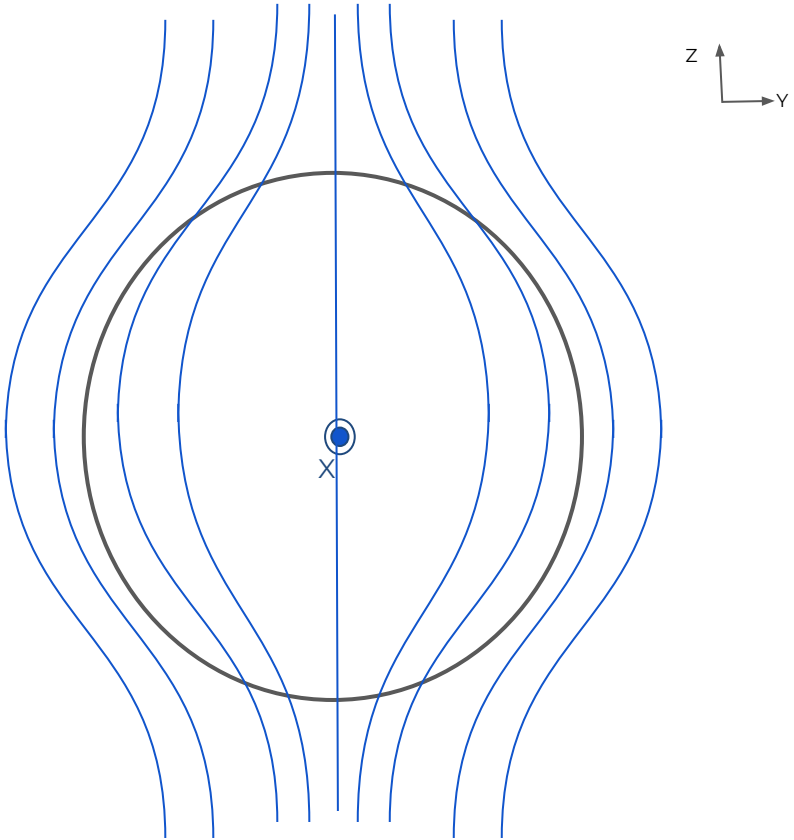
BS





Poster Ambre Ghisablerti

The draping can be considered axisymmetric



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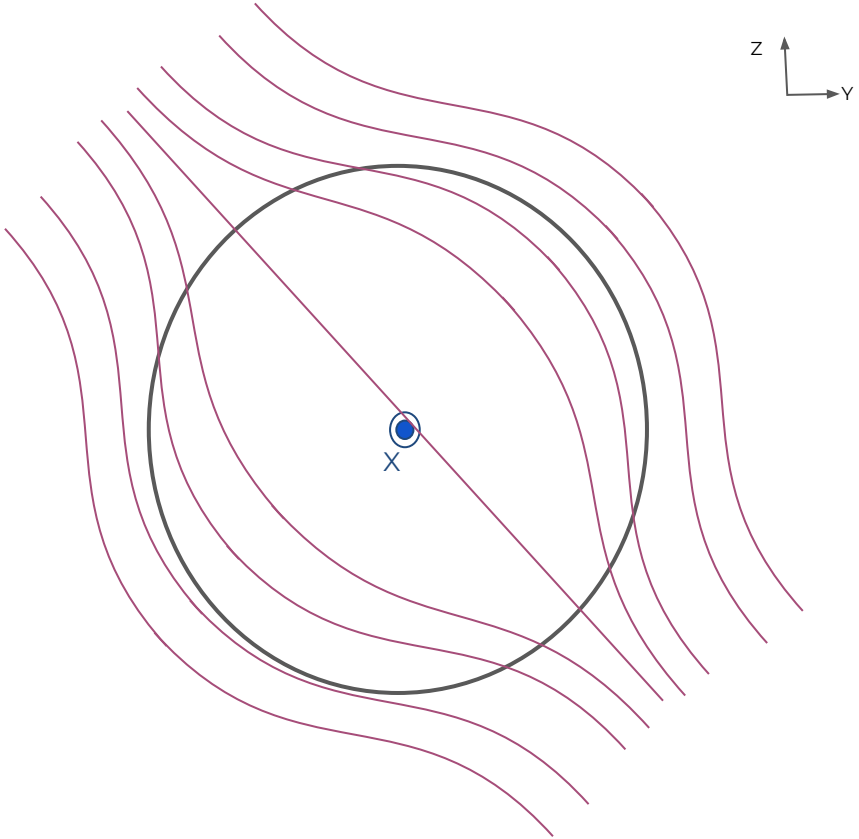
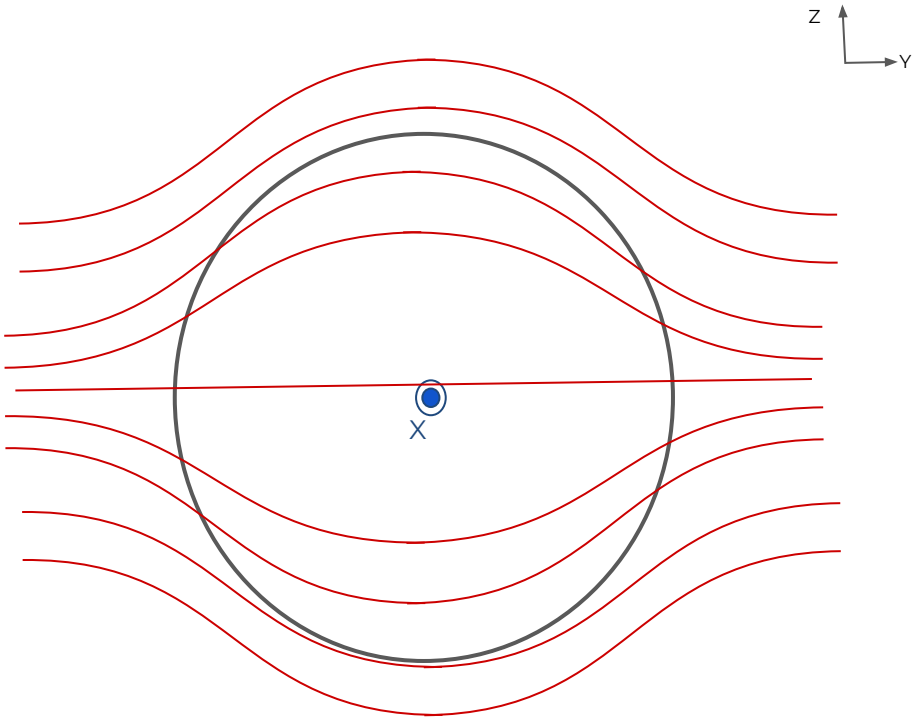


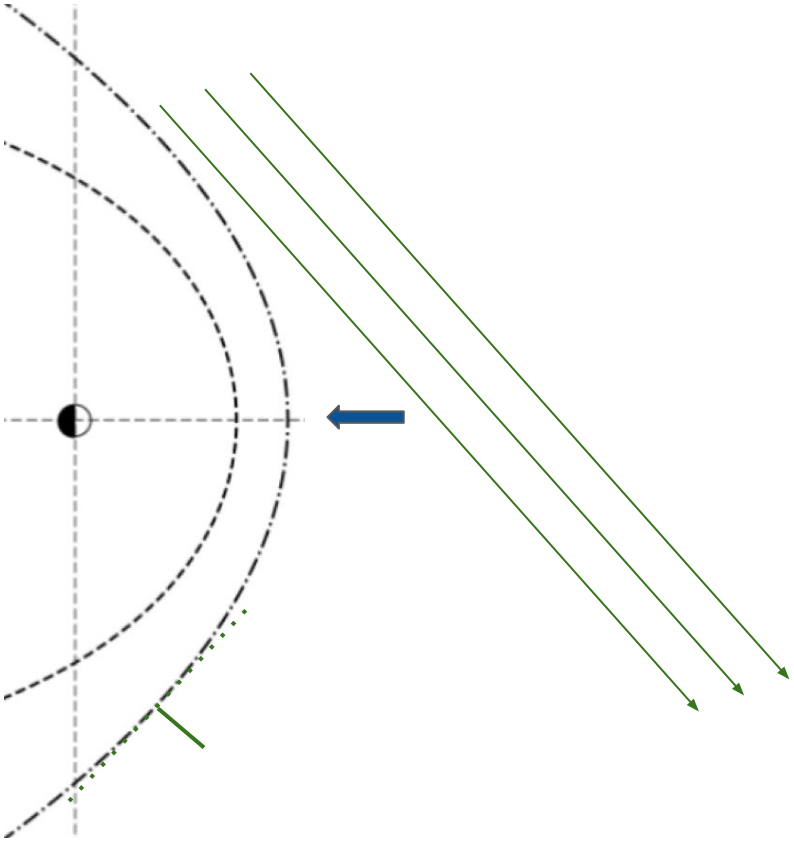
The draping can be considered axisymmetric

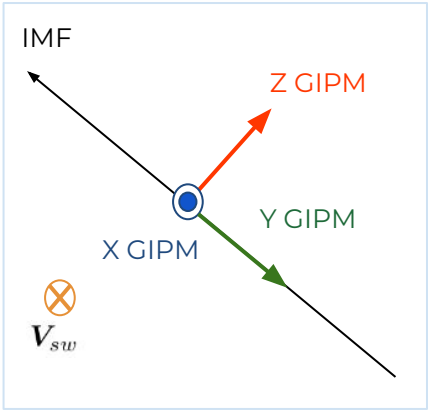


- Neglecting the impact of processes at the MP on the draping
- Considering the boundaries as axisymmetric

The draping can be considered as independent of the clock angle

GIPM coordinate system allows a spatial distribution depending on the IMF direction





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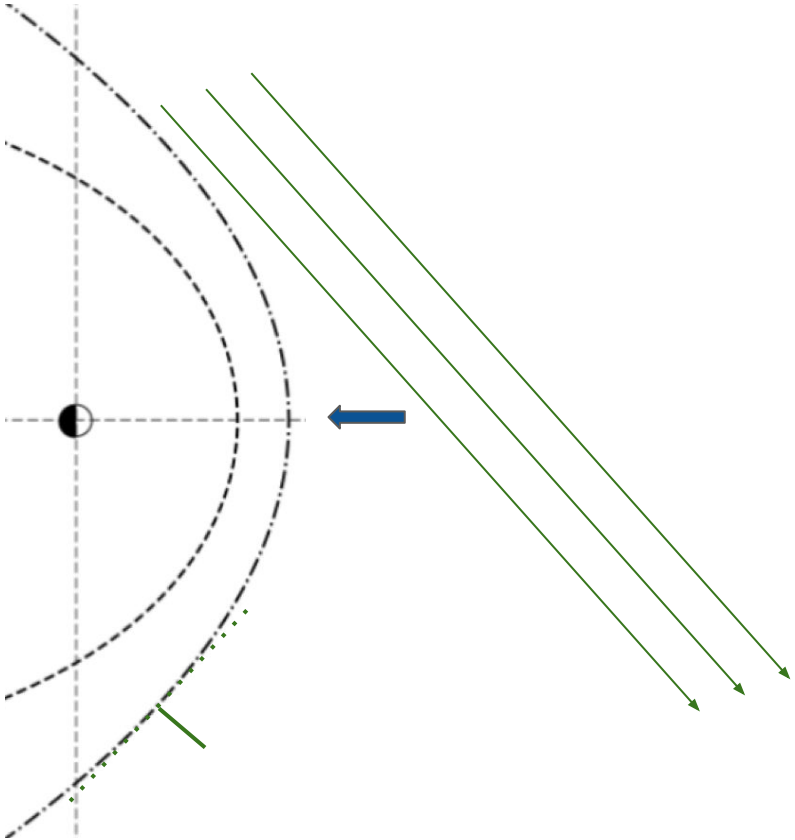
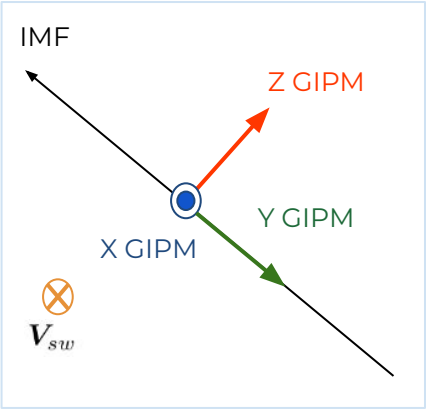
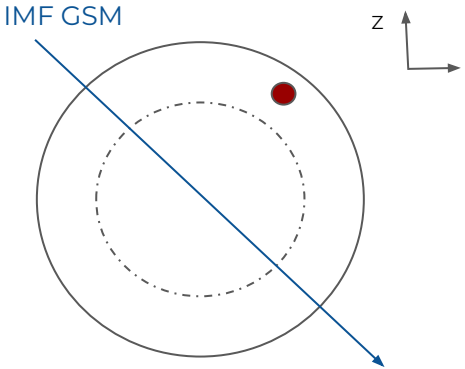
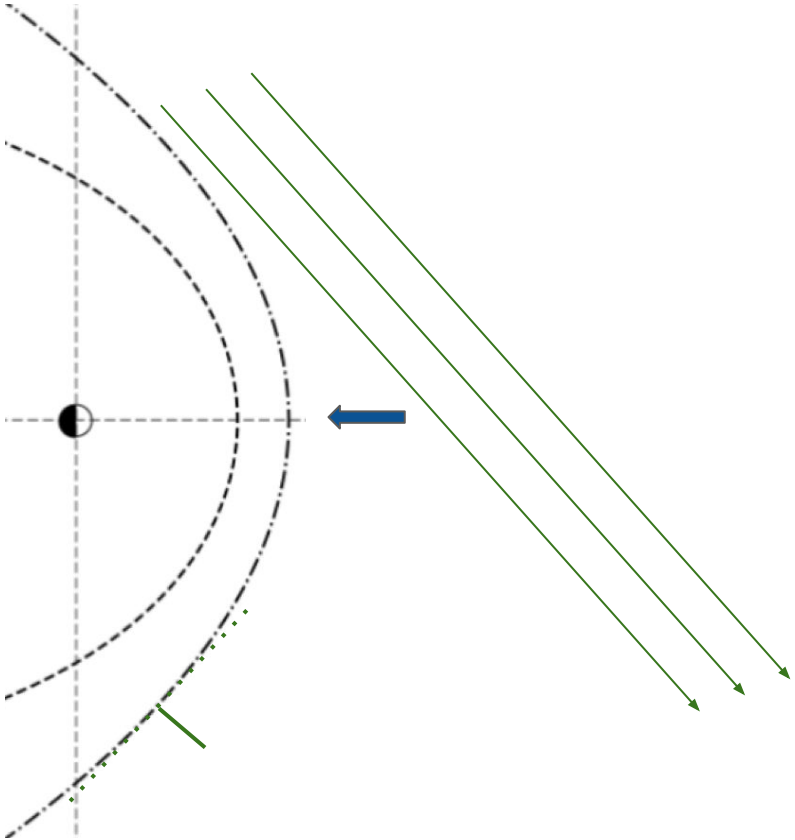
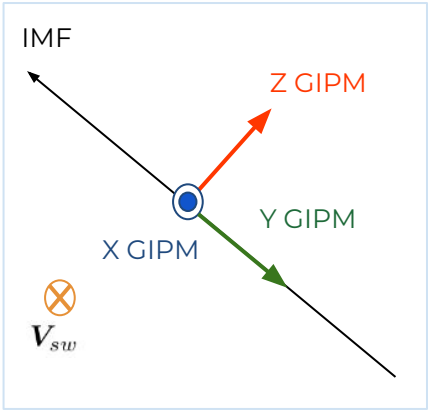


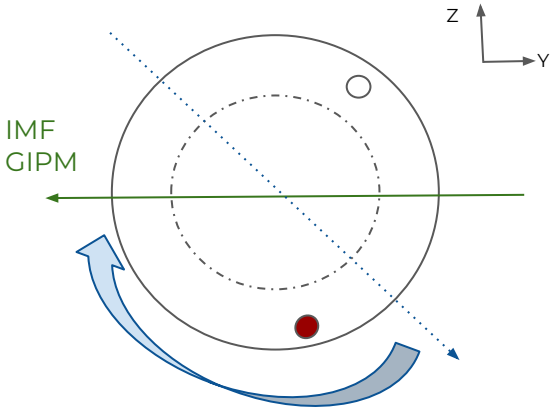




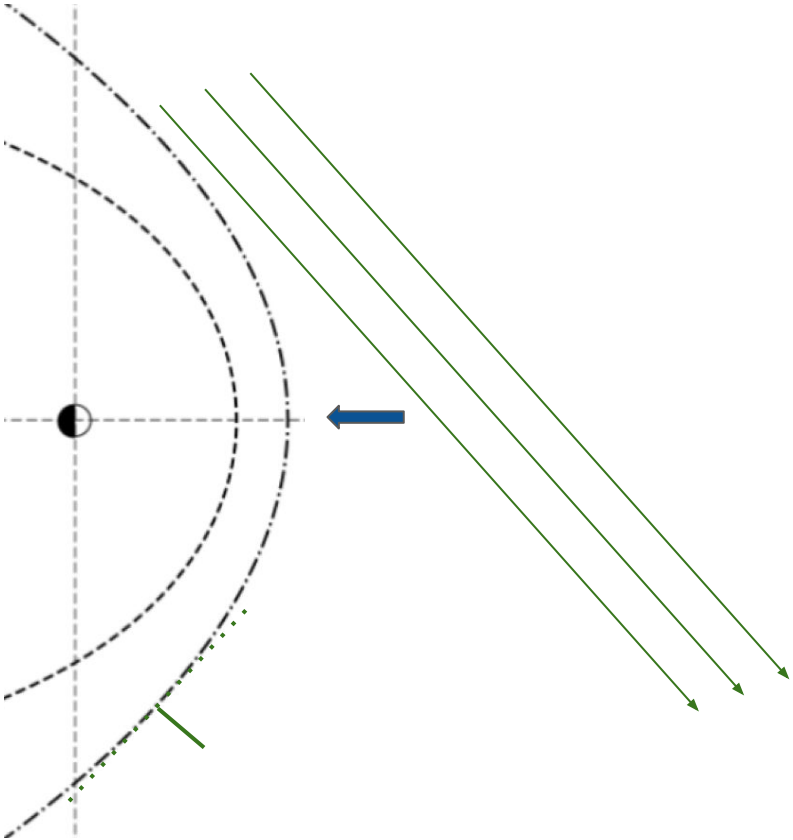
GIPM coordinate system allows a spatial distribution depending on the IMF direction

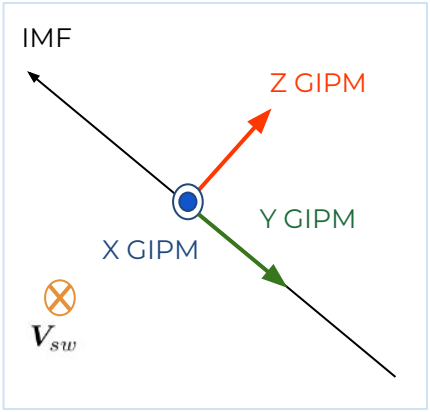


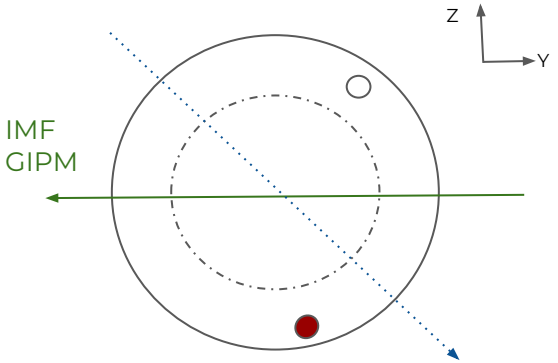




GIPM coordinate system allows a spatial distribution depending on the IMF direction







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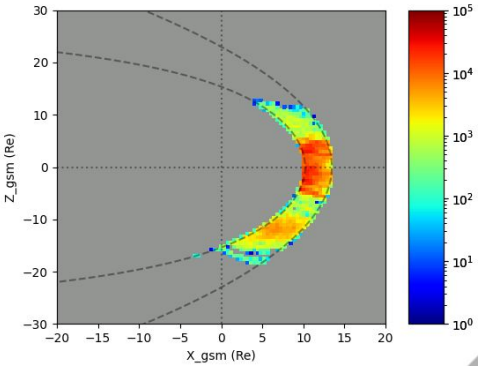

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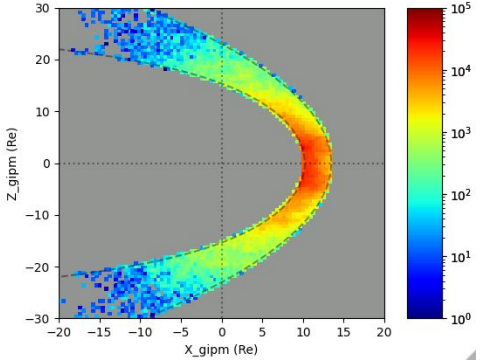

Ortho-IMF plane