BIRKELAND CENTRE
FOR SPACE SCIENCE

High latitude electrodynamics: The asymmetric connection to space

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The covered material is based on work done by or in close collaboration with colleagues at BCSS, including K. M. Laundal, A. Ohma, P. Tenfjord, N. Østgaard, S. Hatch.

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Outline

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- **Background**: What can be learned by examining asymmetries in geospace?
  - Auroral conjugacy
- **Part I**: Sources of asymmetry
  - IMF forcing of the magnetosphere
    - Timescales
  - Role of nightside reconnection
- **Part II**: Importance of lobe reconnection
- **Part III**: Data assimilation: Synthesizing different measurement types to arrive at a regional description of ionospheric electrodynamics

Background

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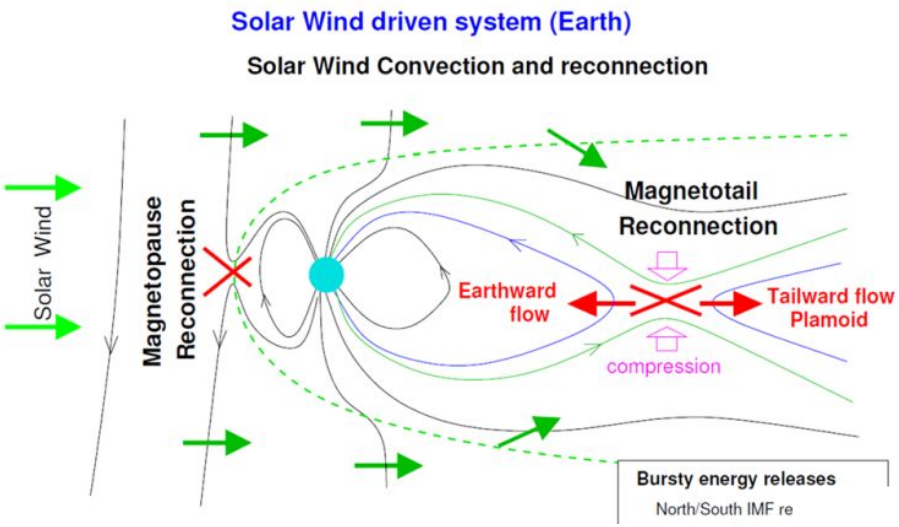
The fundamental mode of plasma circulation in Earth's magnetosphere:

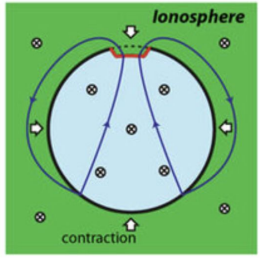
➢ Symmetric opening and closure of open magnetic flux --> Dungey cycle



Loading-unloading nature of the magnetosphere:

Loading (dayside): Solar wind coupling

Unloading (nightside): Bursty, substorm, aurora, magnetic perturbations



Dungey, 1961, Louran et al. 2014

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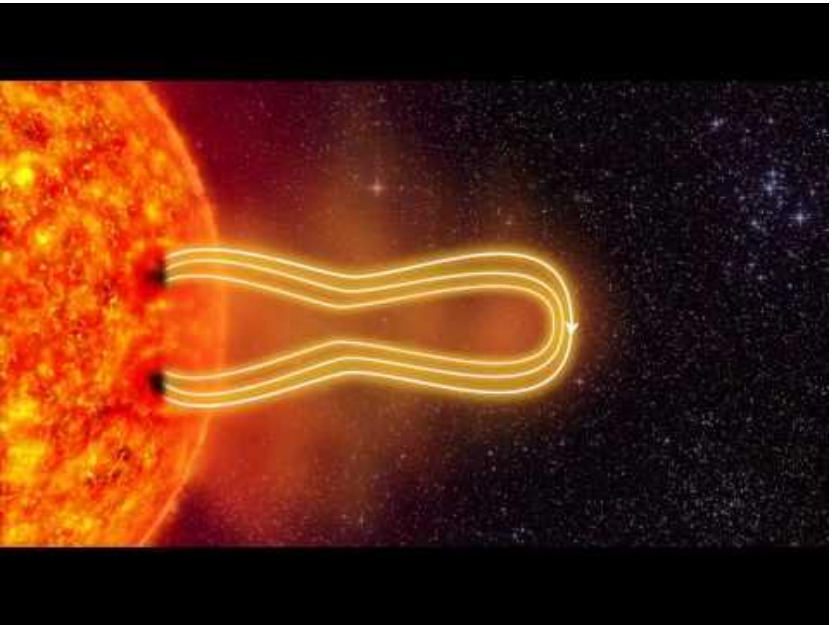

Loading-unloading nature of the magnetosphere:

Loading (dayside): Solar wind coupling

Unloading (nightside): Bursty, substorm, aurora, magnetic perturbations

Background

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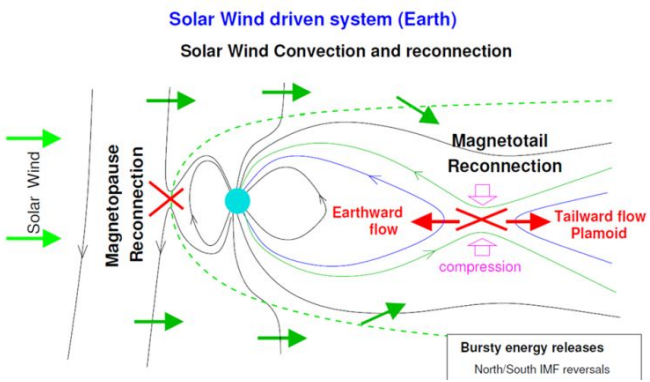
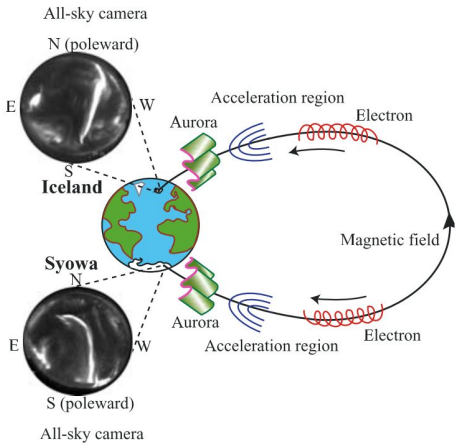
Concept of magnetic conjugacy

- Symmetric opening and closure of open magnetic flux --> Dungey cycle
- Particles move freely along main field
- Earth's main field is to first order a dipole
- Magnetospheric processes are believed to be symmetric
- Acceleration mechanisms operate similarly in both hemispheres?





Sato et al., 2005

Background

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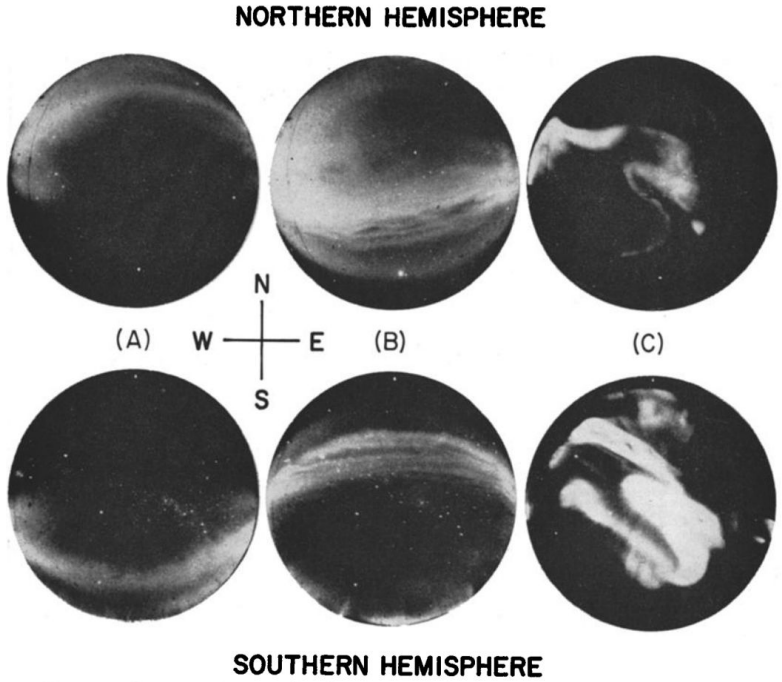
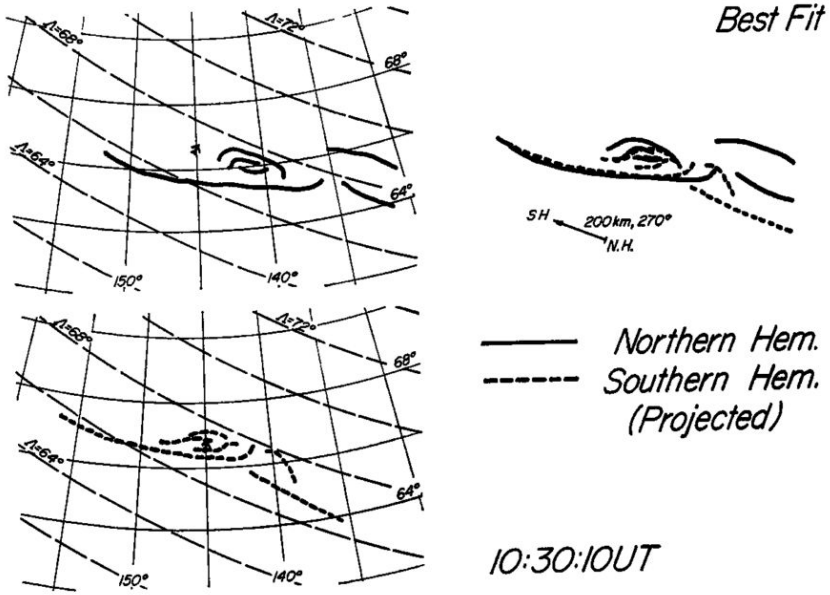
Early simultaneous (conjugate?) observations of aurora from both hemispheres

- Symmetric aurora during quiet conditions



Belon et al, 1969



Stenbaek-Nielsen et al. 1972

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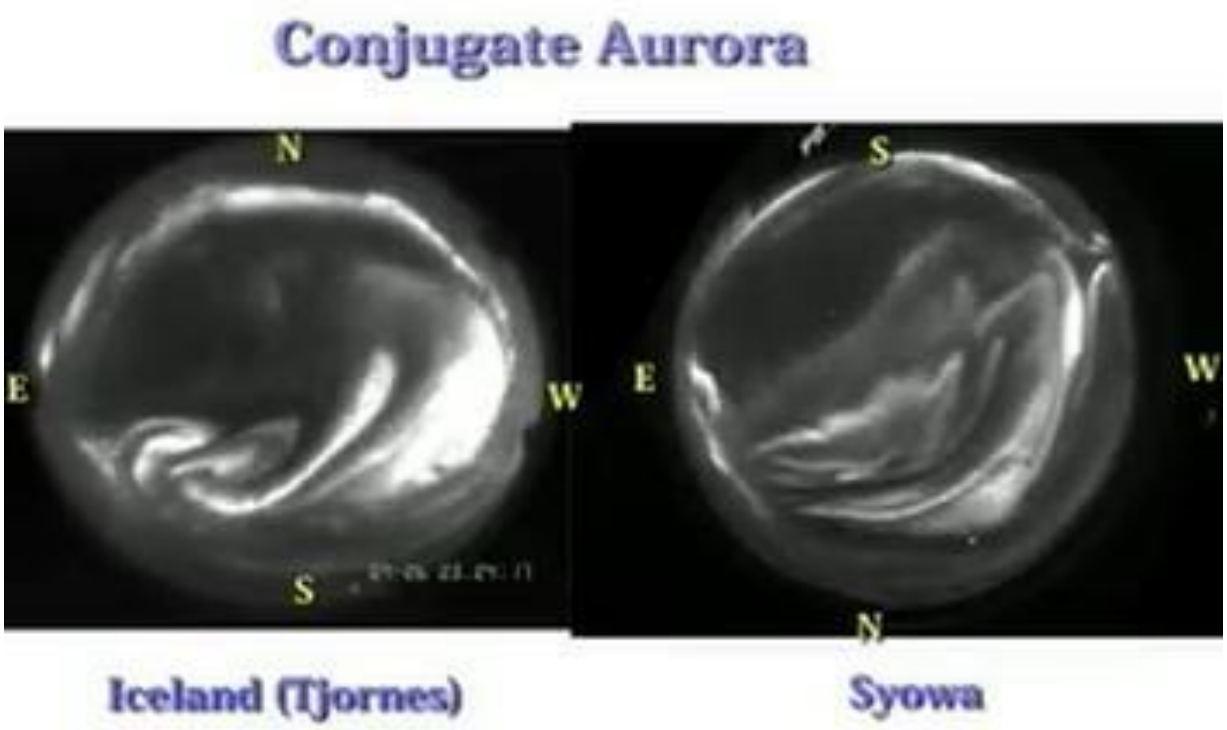

2003-09-26
Courtesy of Natuso Sato

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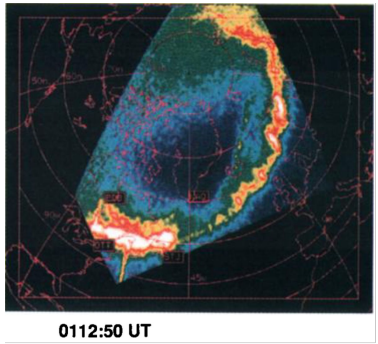
First simultaneous global observations of aurora from both hemispheres

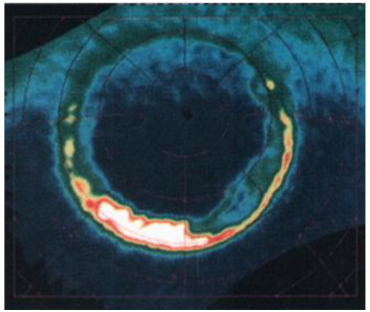
North, Viking

August 3, 1986, 1825 UT

South, Dynamics Explorer 1

Craven et al, 1991





May 3, 1986, 0113 UT

Pulkkinen et al. 1995

Part I: Sources of asymmetry: IMF forcing

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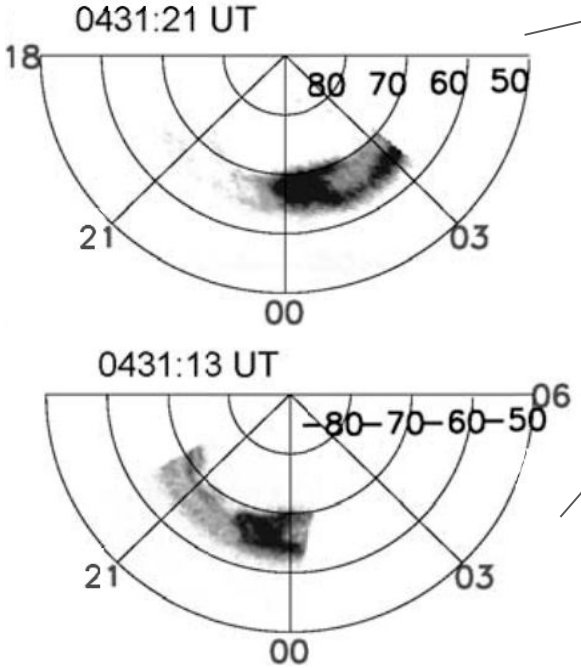
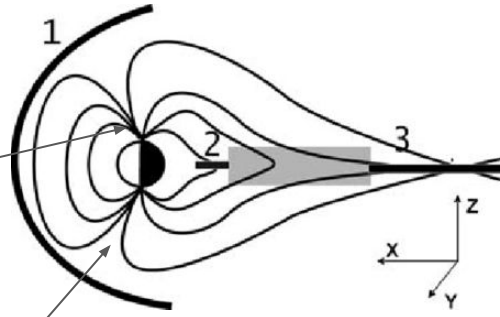
IMAGE and Polar era (2000-2001)

Substorm onset displaced in MLT between hemispheres

- MLT shift correlates with IMF By: A mapping effect

By: Dawn-Dusk component of IMF





Østgaard et al. 2004

Part I: Sources of asymmetry: IMF forcing

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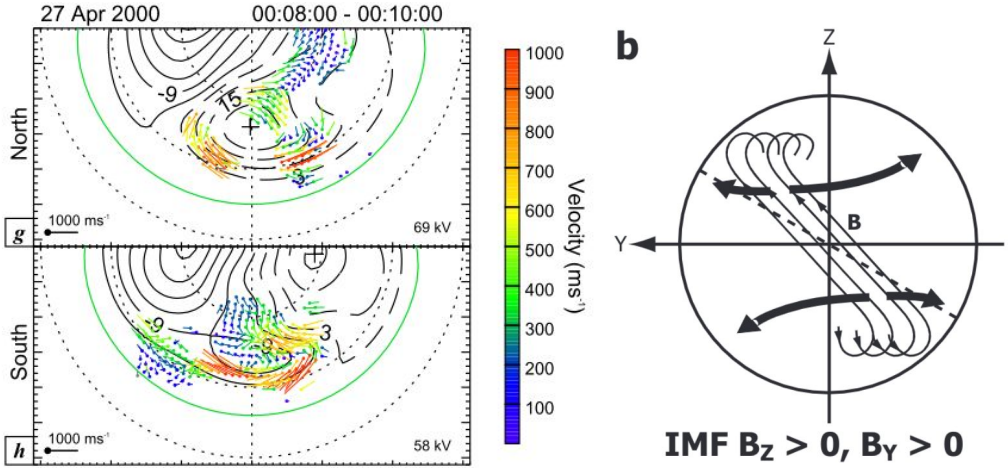
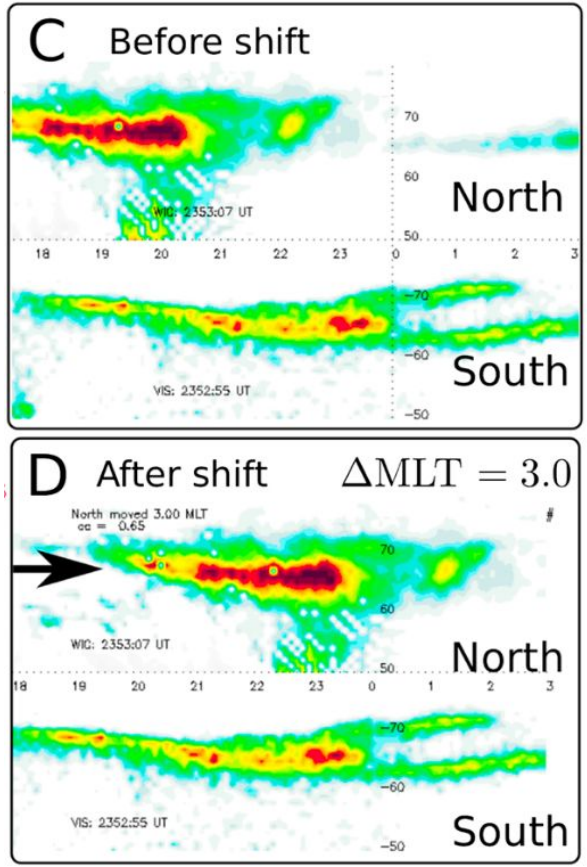
IMAGE and Polar era (2000-2001)

- MLT shift can be substantial. Here shown 3 hrs (right).
- Studies looking at plasma convection suggest even larger displacement during northward IMF [Grocott et al. 2005]



Grocott et al. 2005



Reistad et al. 2016

Part I: Sources of asymmetry: IMF forcing

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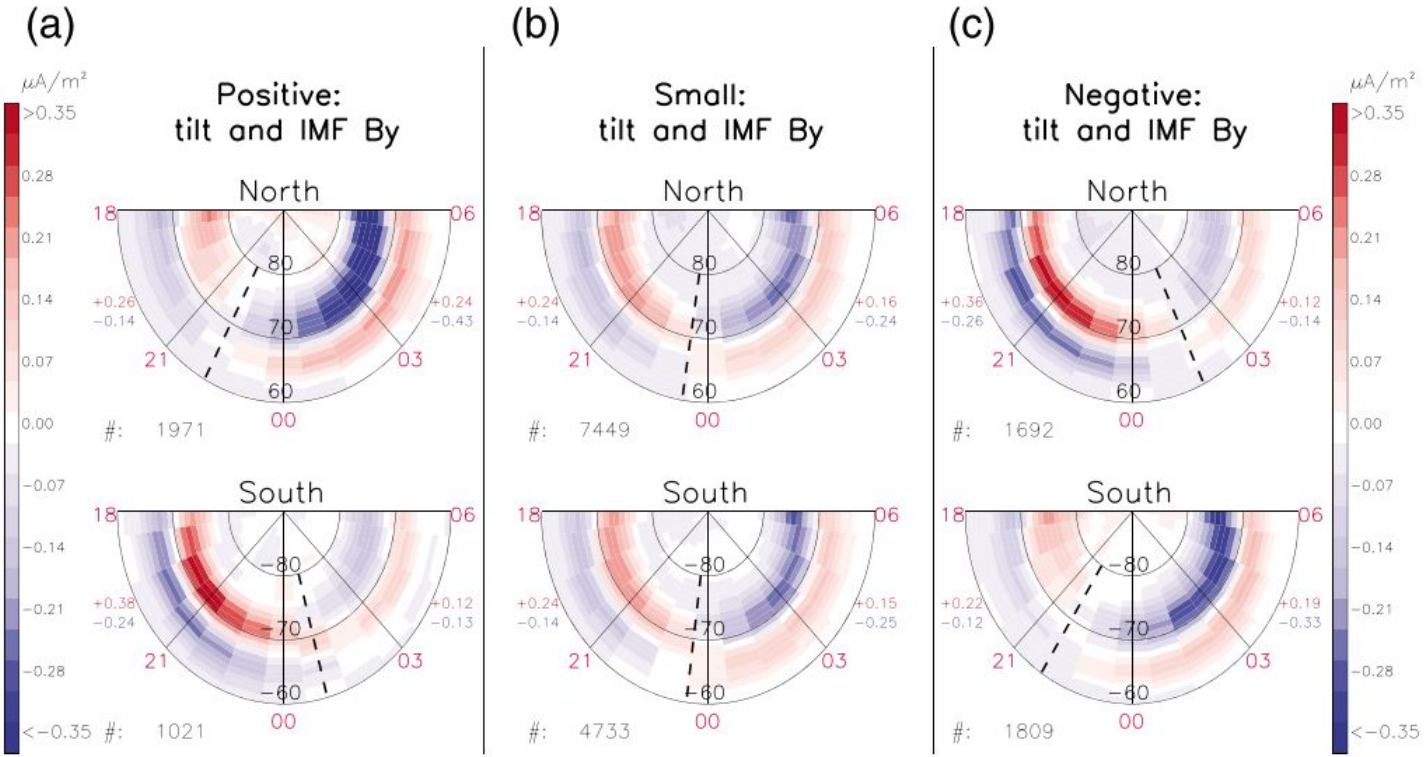
Climatologies also suggest substantial shift on average

Here, average Birkeland current maps from AMPERE sorted by dipole tilt and IMF By [Reistad et al. 2016]



Part I: Sources of asymmetry: IMF forcing

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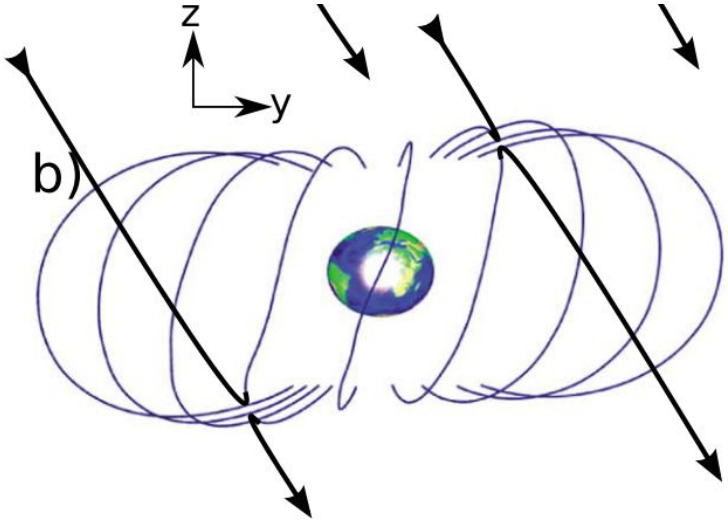
What is the mechanism(s) responsible for "twisting" the closed magnetosphere?

"Cowley view": By enter through tail reconnection

"Tenfjord view": By induced due to asymmetric loading



In both cases: Asymmetric addition of magnetic flux

Part I: Sources of asymmetry: IMF forcing

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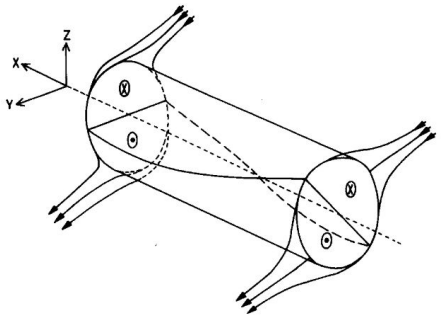
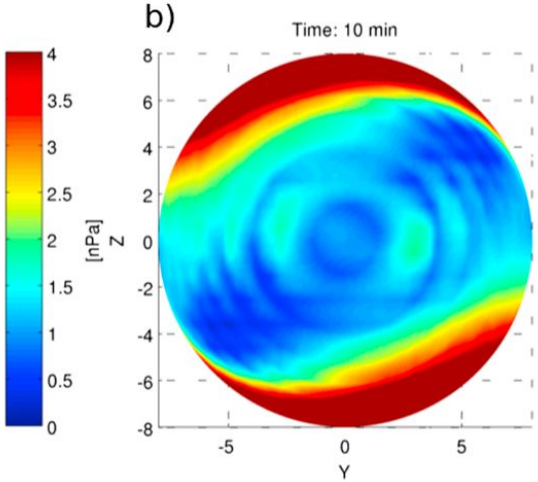


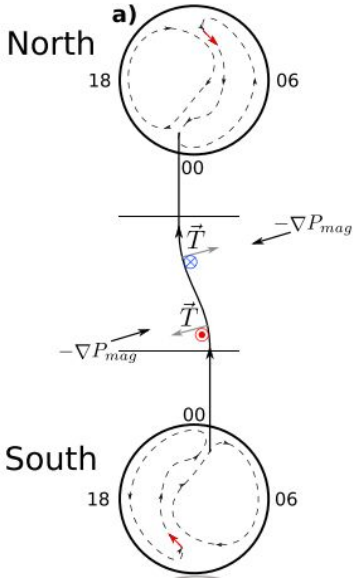
Cowley, 1981

All figures have IMF By > 0



Tenfjord et al. 2015

Left: Seen from the Sun. Asym. magnetic pressure on sphere in LFM MHD model.



Right: Seen from the tail. Deformed closed nightside field line.

Part I: Sources of asymmetry: IMF forcing

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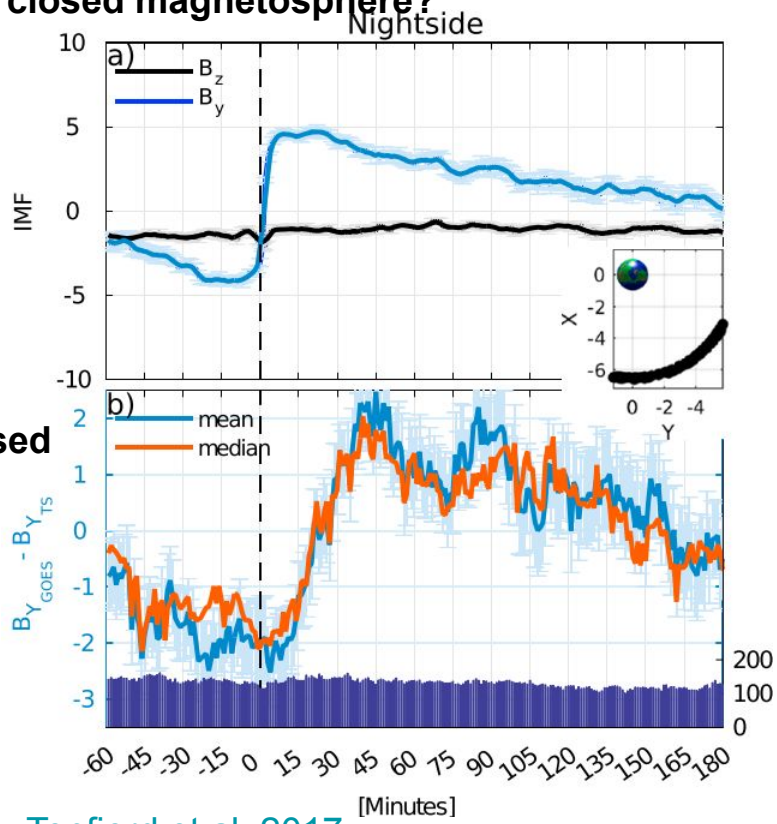
What is the mechanism(s) responsible for "twisting" the closed magnetosphere?
Timescales:

Superposed epoch analysis of By at geosynchronous orbit during IMF By reversals

Prompt response (~10 min after bow-shock)
Reconfiguration ~40 min

Conclusion:
Tail reconnection is not necessary to induce By into closed magnetosphere.



Tenfjord et al. 2017

Part I: Sources of asymmetry: IMF forcing

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What is the mechanism(s) responsible for "twisting" the closed magnetosphere?
Timescales:

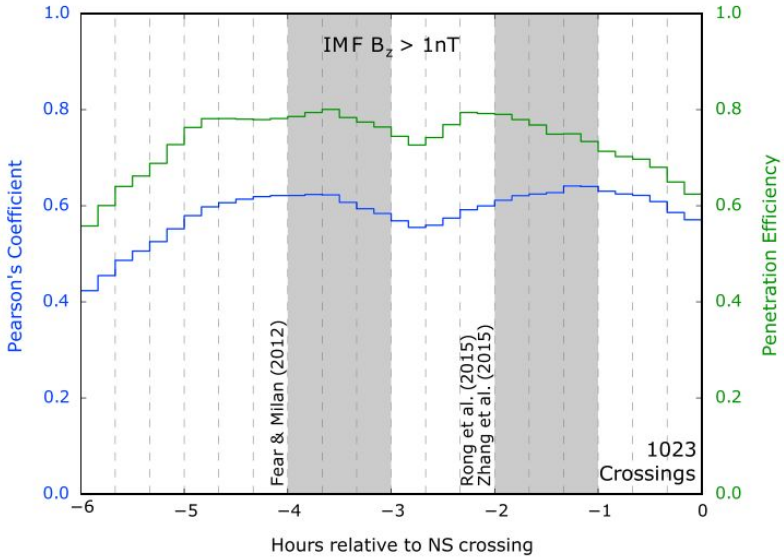
Correlating By in the tail from Cluster with IMF By

Conclude with typical response times of 2-4 hrs

In favor of "Cowley view"

Many case studies in the tail (mainly using Cluster) show similar large time-lags.

Challenge:
Presence of By in the tail are highlighted during tail activations



Browett et al. 2017

Part I: Sources of asymmetry: Nightside reconnection

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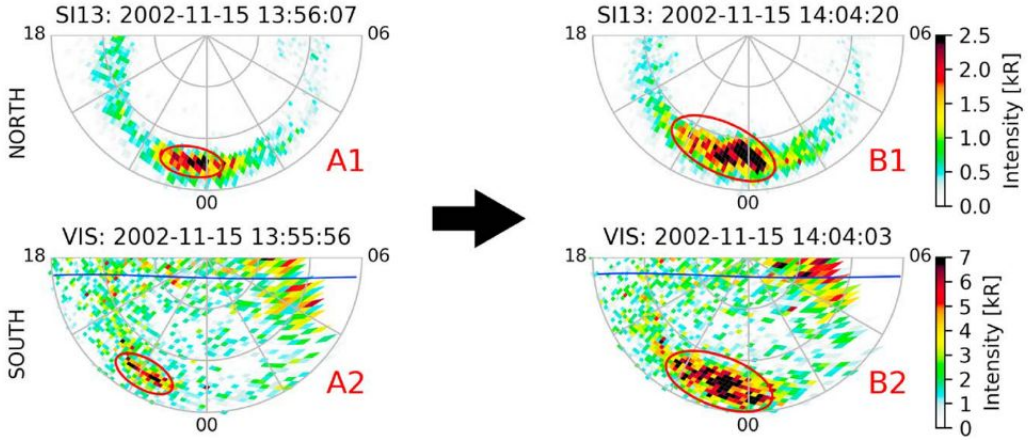
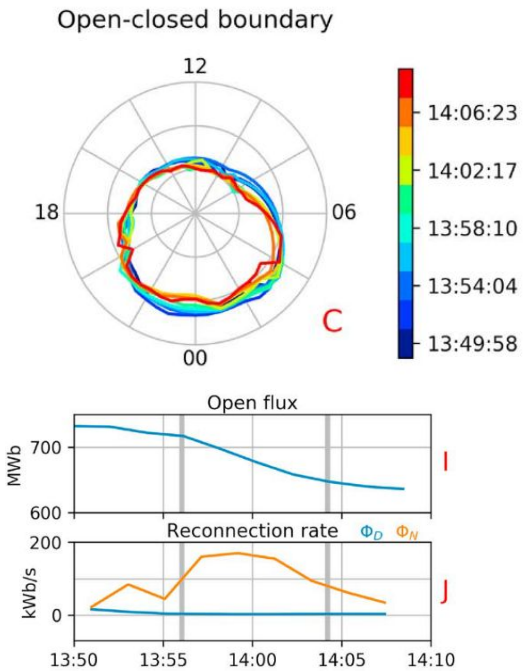
What is the role of nightside reconnection in “twisting” the closed magnetosphere?

Conjugate imaging: Nightside reconnection reduce asymmetry.





Ohma et al. 2018

Part I: Sources of asymmetry: Nightside reconnection

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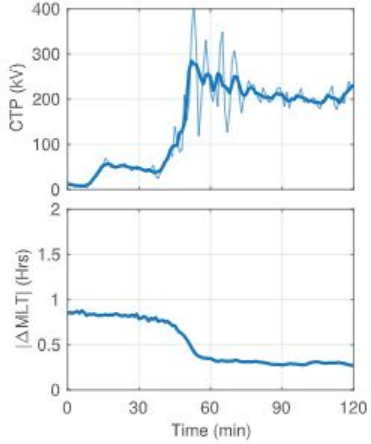
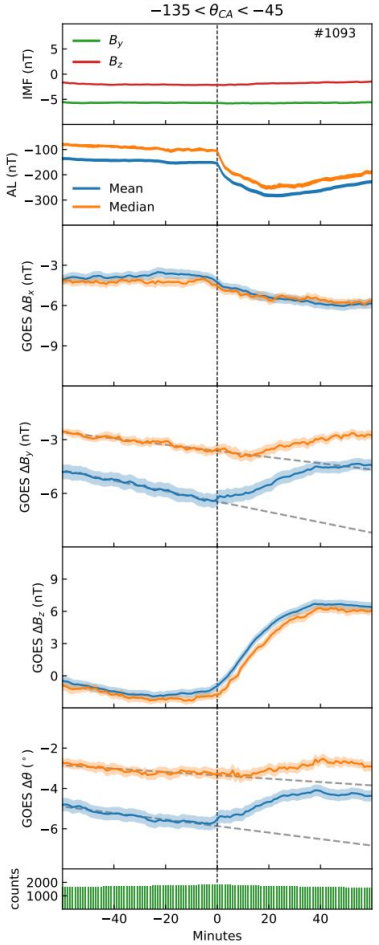
What is the role of nightside reconnection in "twisting" the closed magnetosphere?

MHD analysis and in-situ magnetospheric response in By show consistent results: **Nightside reconnection reduce asymmetry.**



Ohma et al. 2021

Ohma et al. [in review]



Part I: Sources of asymmetry: Nightside reconnection

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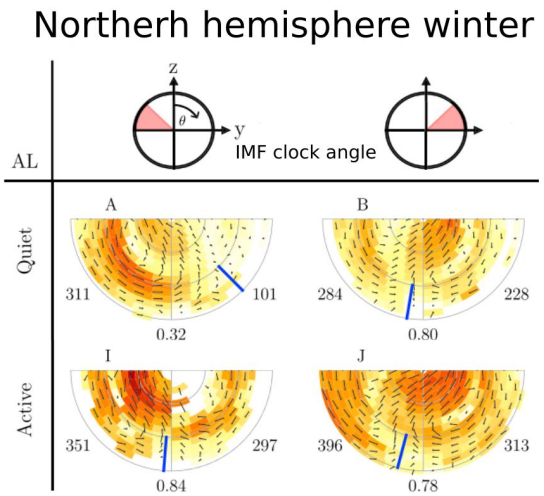
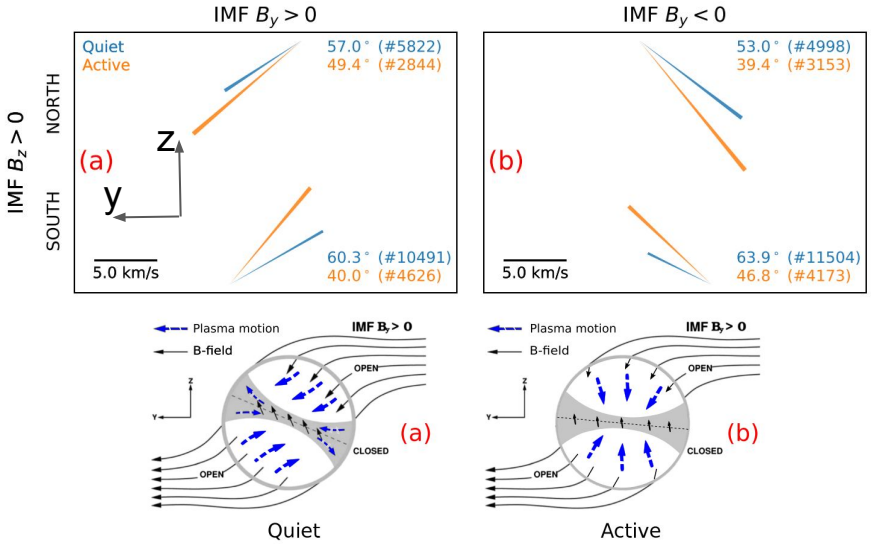
What is the role of nightside reconnection in "twisting" the closed magnetosphere?

Left: Ionospheric convection more symmetric during active conditions (SuperDARN)

Right: Lobe convection more symmetric during active conditions (Cluster EDI)



Reistad et al. 2018



Ohma et al. 2019

Part I: Sources of asymmetry: Nightside reconnection

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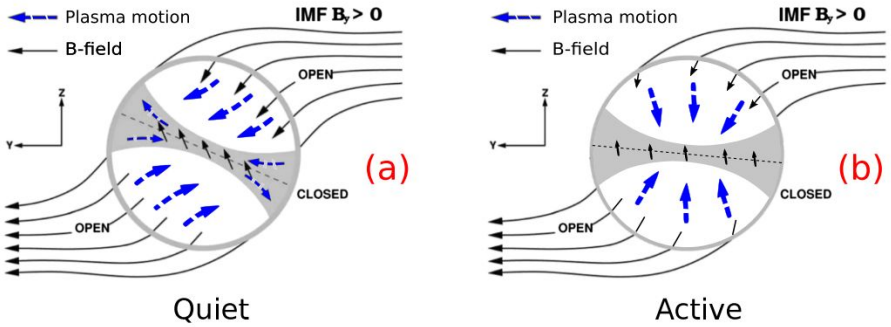
What is the role of nightside reconnection in “twisting” the closed magnetosphere?

Interpretation of results:

1) Nightside reconnection initiate convection and evacuate asymmetric field lines

2) Nightside reconnection change the magnetic pressure across the entire tail (asymmetric forcing less important). Closed field lines reconfigure accordingly.



Part II: Importance of lobe reconnection

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When IMF has a northward component, lobe reconnection take place.

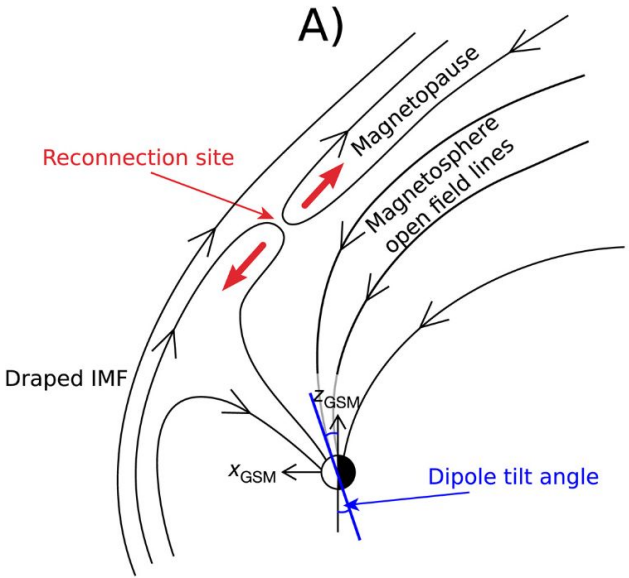
Most of the time, IMF is By dominated (dawn-dusk). Then, both dayside and lobe reconnection take place.

What is the relative contribution of lobe reconnection in the high latitude convection?

Cross Polar Cap Potential = Sum of SW/IMF forcing

What is the quantitative (in kV) importance of lobe reconnection outside pure northward IMF?

This has implications for interpretation of the ionospheric convection in the two hemispheres, as **lobe reconnection can be different in northern and southern hemisphere**



Reistad et al. 2019

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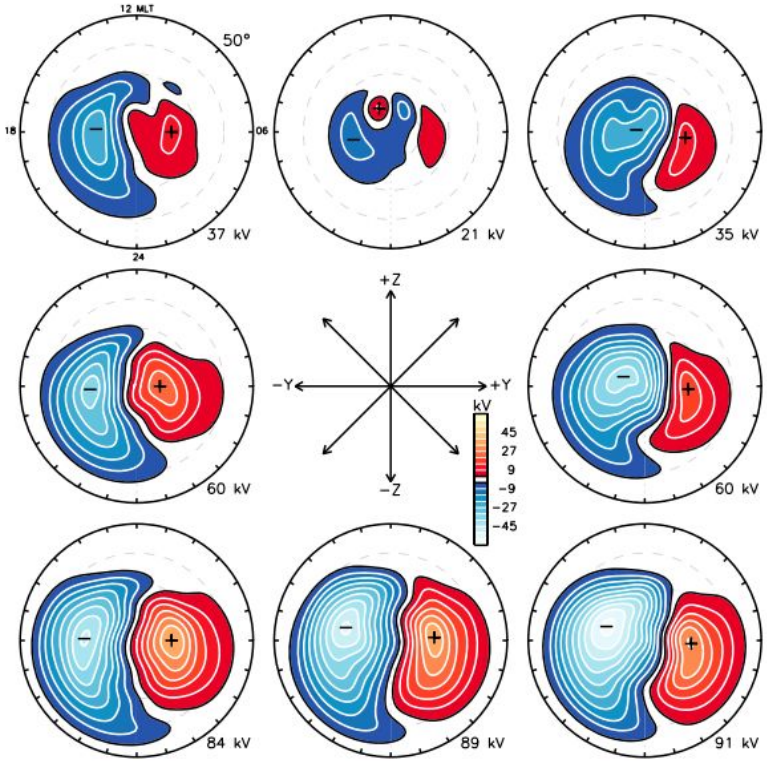

Figure 6. Statistical convection patterns for $3.0 \leq E_{SW} < 20.0$ mV/m and neutral tilt, in the same format as Figure 5. MLT = magnetic local time.

Thomas and Shepherd, 2018

Part II: Importance of lobe reconnection

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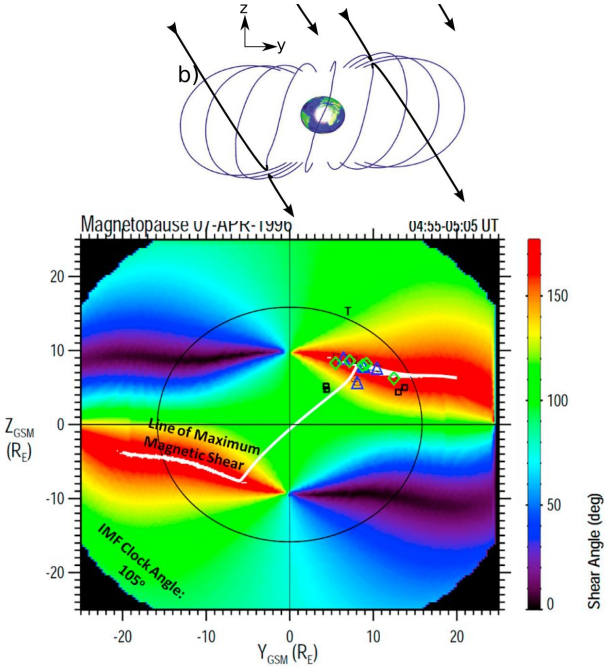
- What control the lobe reconnection rate in the two hemispheres?
  - **To be determined: IMF By dominated periods**



Trattner et al. 2012

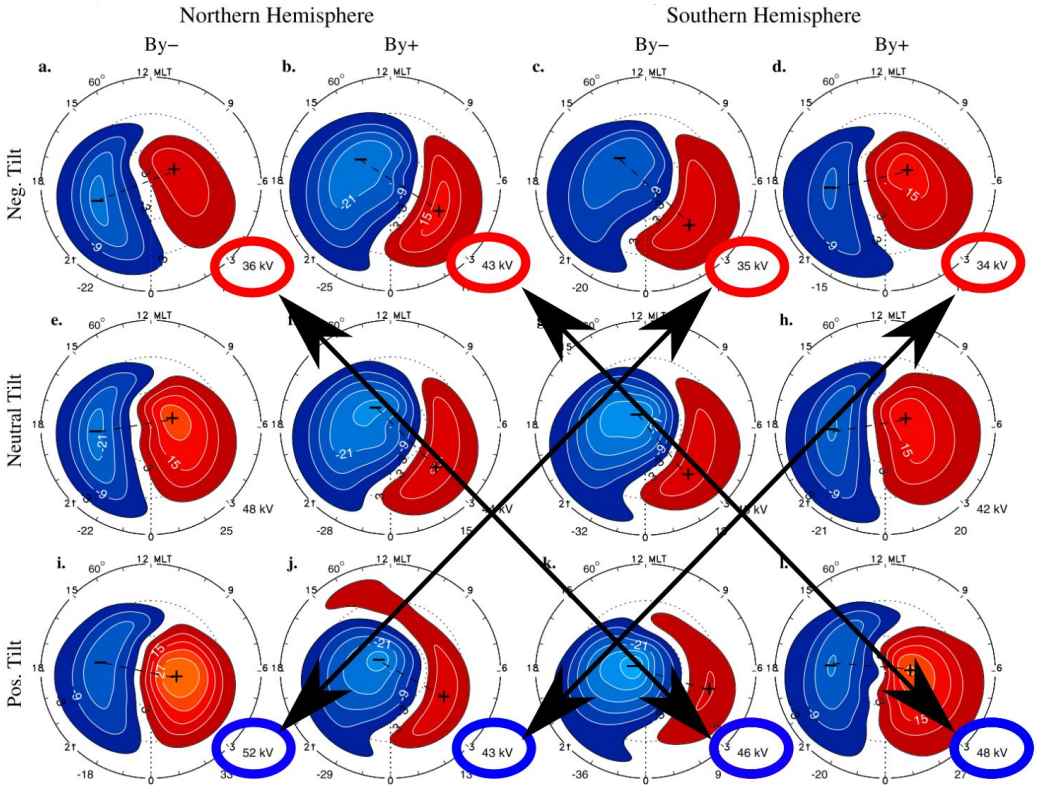


Figure 8. Statistical convection patterns sorted by tilt. IMF B_y+/−, 5 nT < B_T < 10 nT.

Pettigrew et al. 2010

Part II: Importance of lobe reconnection

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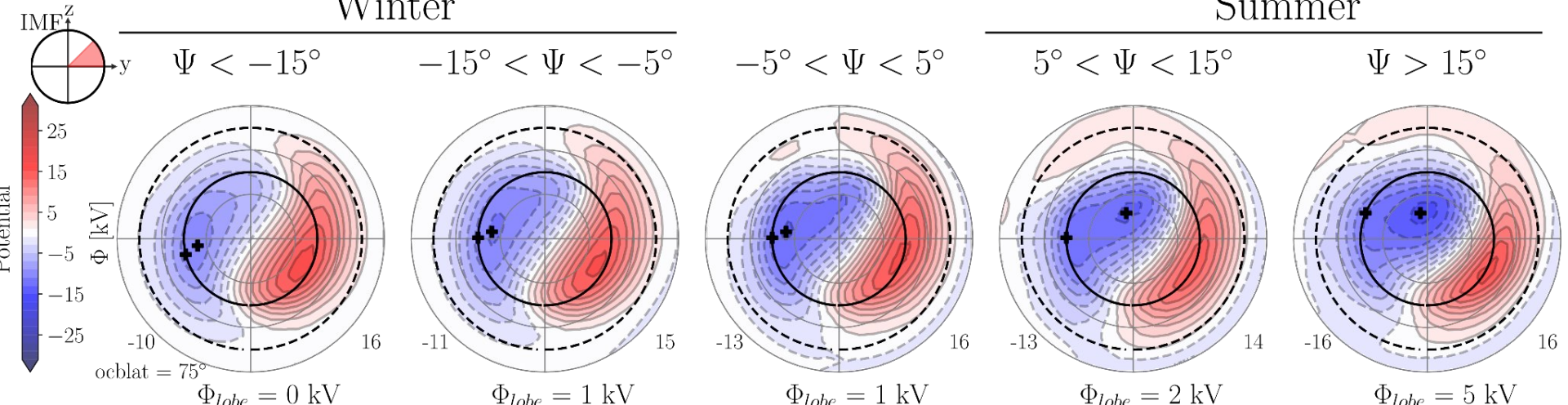
- What control the lobe reconnection rate in the two hemispheres?
  - New quantitative insights
    - Normalization of ionospheric convection to the open/closed boundary
    - During summer, plasma transport from lobe reconnection amounts to ~20% of plasma transport participating in the Dungey cycle
  - Summer and winter hemisphere is forced substantially different

Reistad et al 2021



Part III: Regional Data Assimilation

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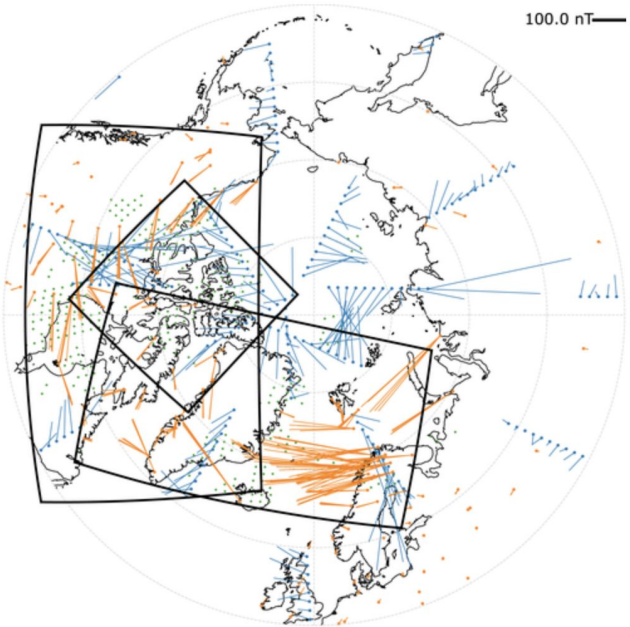
- Observational data exist in large quantities
- Spatial coverage is very non-uniform
- Different measurements inform us about different aspects of the ionospheric electrodynamics
- Traditionally, observations of different quantities are interpreted in isolation
  - B-field on ground, B-field in orbit, ionospheric convection, plasma density, auroral irradiance, etc.
- However, these quantities are related by the physical processes taking place in the ionosphere
- **Solution: Local Mapping of Ionospheric Electrodynamics: Lompe (Laundal et al. 2022)**
- Similar concept as AMIE, but more flexible wrt. resolution and region of interest (AMIE is global)



Example data coverage:
Blue: AMPERE (dB - space)
Orange: SuperMAG (dB - ground)
Green dots: SuperDARN (v_{los})

Part III: Regional Data Assimilation

The Lompe concept:

- Based on ionospheric Ohms law, relating electric currents (horizontal and field-aligned), height integrated conductances, and the convection elecrtric field.
- Uses a Spherical Elementary Current representation, hence an analytic expression exists that relate the magnetic perturbations associated with the ionospheric currents
- The Lompe procedure is defined within a specified region that is well instrumented for the problem to be investigated. The grid resolution is flexible.
- The Hall and Pedersen conductance within the grid needs to be specified
- With the given conductance, all available observations (dB, velocity, FAC) are formulated as linear equations of the model parameters
- When solving the linear set of equations, the solution describe the full electrodynamics consistent with the ionospheric Ohms law

$$\mathbf{J} = \Sigma_P \mathbf{E}' - \Sigma_H \mathbf{E}' \times \mathbf{B}/B$$

Part III: Regional Data Assimilation: A “Space Hurricane”

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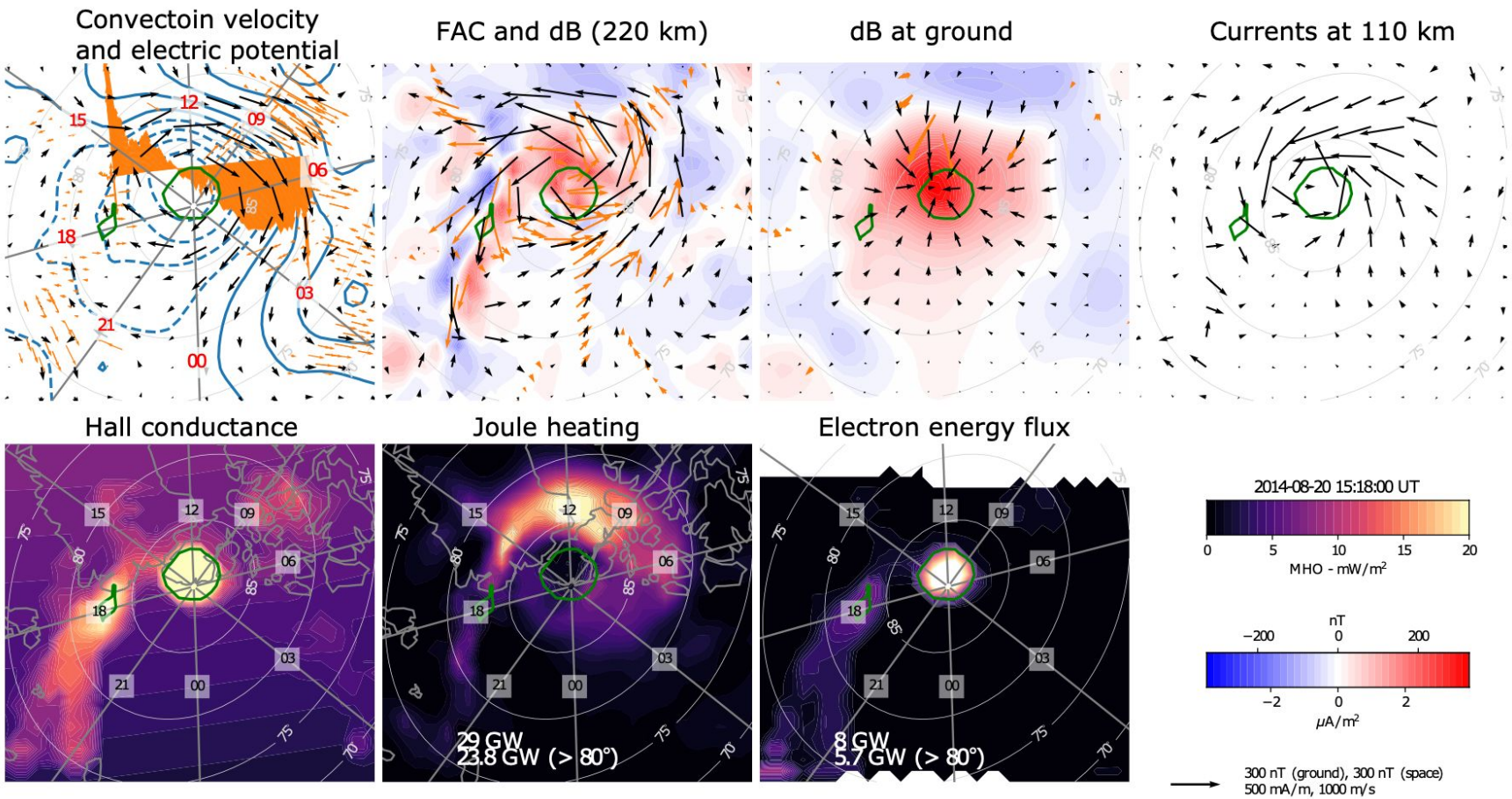

Summary

- From the perspective of asymmetric features of solar wind - magnetosphere - ionosphere interactions, new insights has emerged
- Still many unsolved question remain, some which are currently under investigation
- This presentation reflects my own research experience, largely building on the wide range of research at the Birkeland Centre for Space Science in Bergen on the Sun-Earth connection
- Feedback is appreciated. Contributions and involvement are highly welcomed.