

# Fast flow channels in the magnetotail and auroral oval: Reconnection, substorm and beyond

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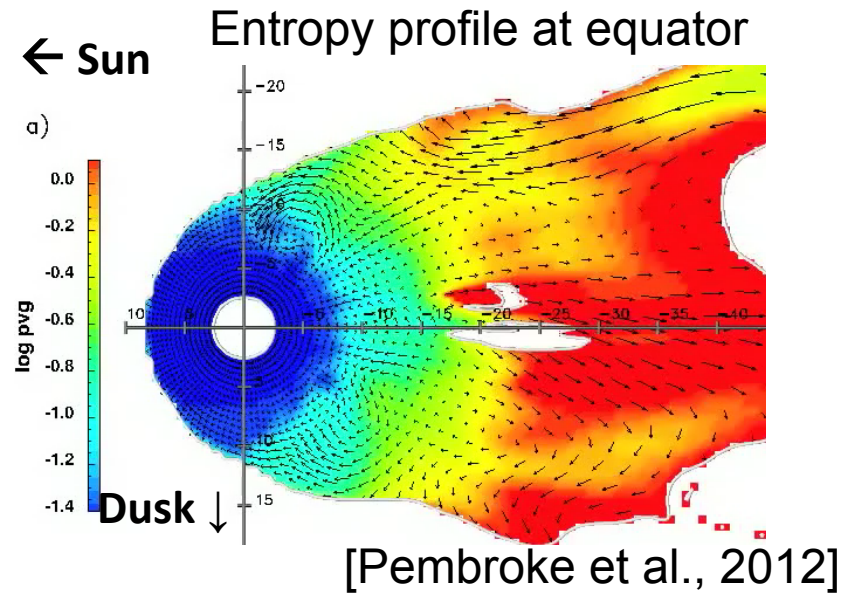
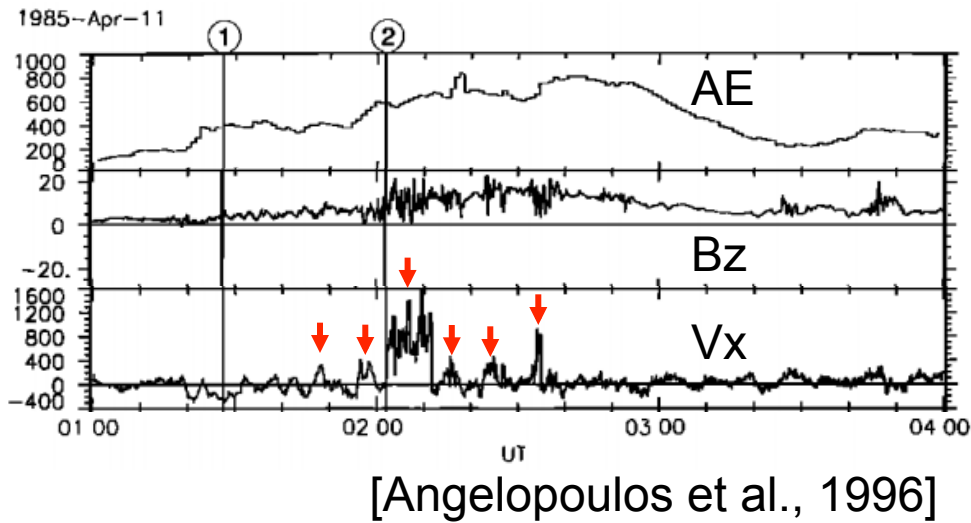
**Acknowledgements:** L. Lyons, E. Donovan, V. Angelopoulos, Y. Zou, B. Gallardo-Lacourt, J. Ruohoniemi, D. Hampton, S. Mende, K. Shiokawa, J. Moen, L. Clausen, and Substorm-Polar Cap FG leaders

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# 1. Importance of substorm and flow channel research at GEM

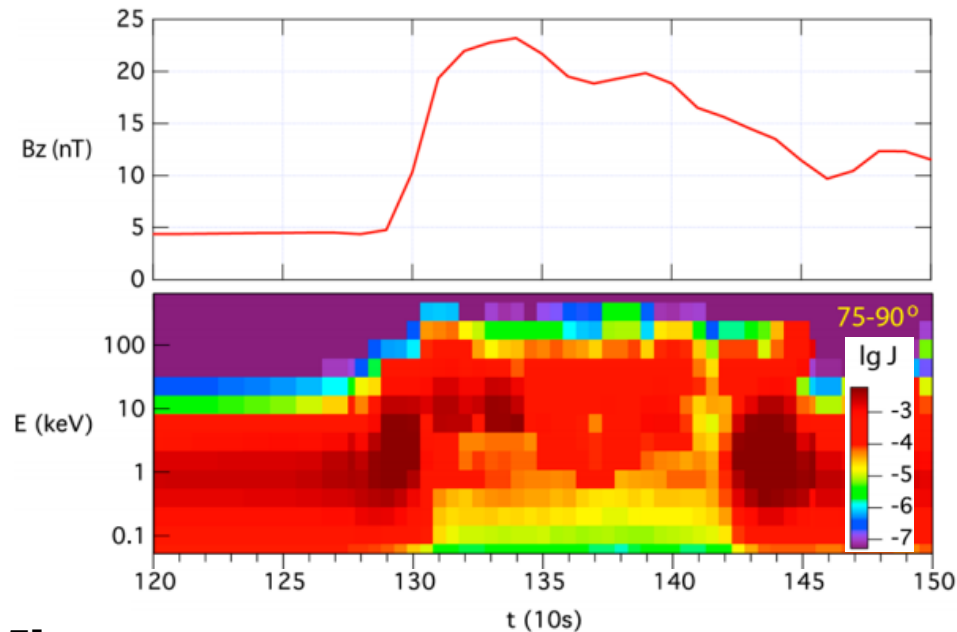


Multiple bursty bulk flows (BBFs) and dipolarizations occur during substorms.

The strong electric field leads to injections of energetic particles into the inner magnetosphere.

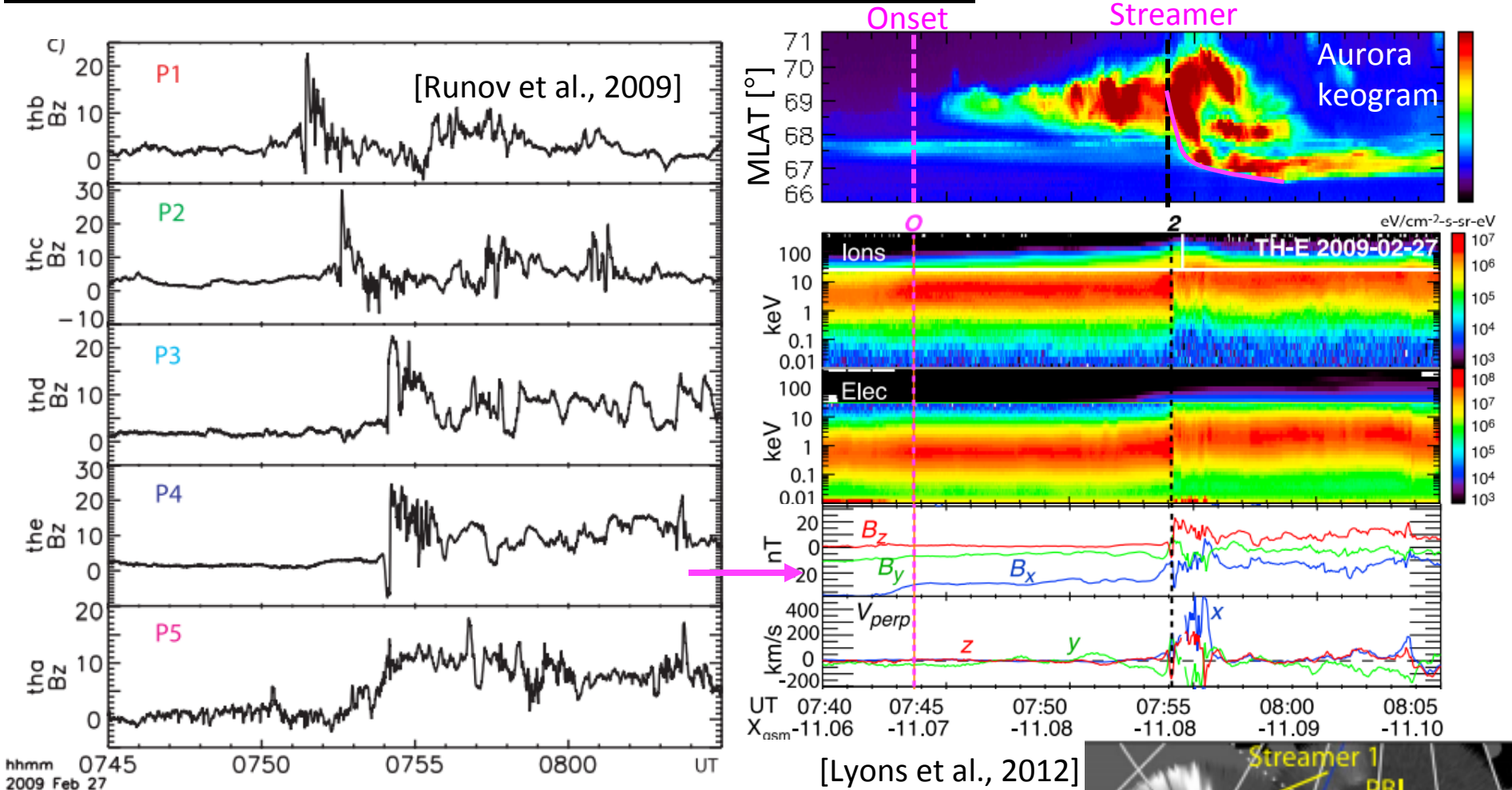
- Enhance the ring current
- Provide seed population to radiation belt
- Intensify precipitation and aurora

[Yang et al., 2011; Sergeev et al., 2012; Gabrielse et al., 2012; Gkioulidou et al., 2015]



[Birn et al., 2014]

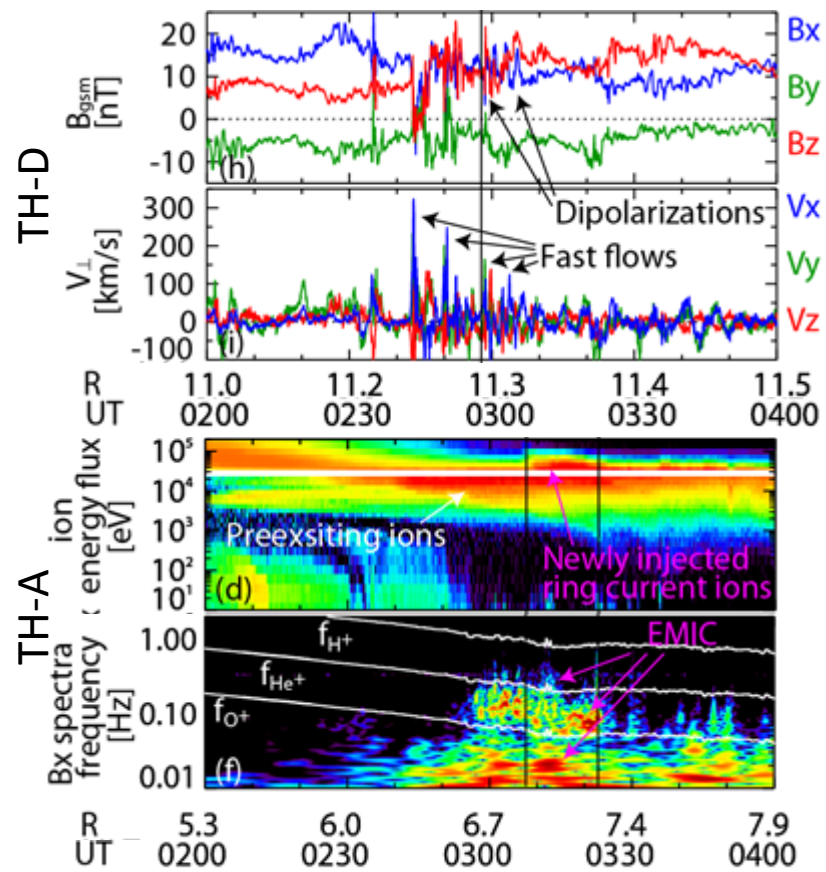
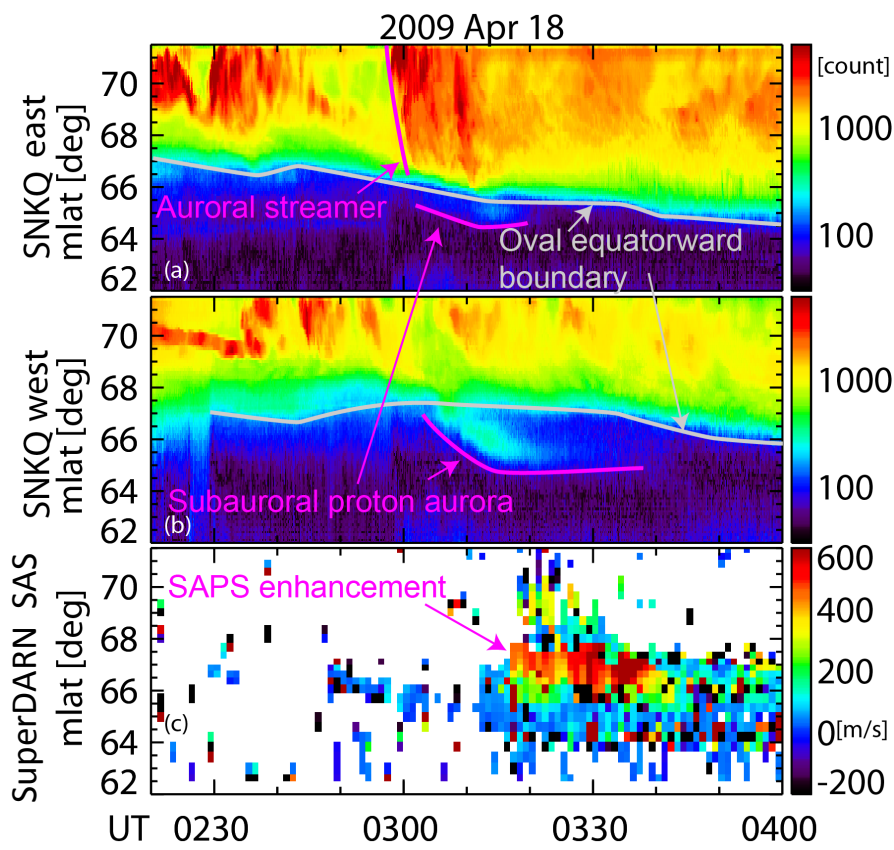
# Andrei's (or Misha's) dipolarization front event



The large injection is associated with a large **auroral streamer** [Henderson et al., 1998; Sergeev et al., 2000; Zesta et al., 2000].

Aurora is useful for detecting location and evolution of fast flows and injection in 2-D.

# Influence onto subauroral flows and proton aurora



- Auroral streamers followed by a new subauroral arc (proton aurora)
- SAPS intensified in association with the proton aurora
- Suggesting a strong influence of fast flows on the inner magnetosphere

[Nishimura et al., 2014; Gallardo-Lacourt et al., this workshop]

# Questions on injection, substorm and reconnection

## Inner magnetosphere

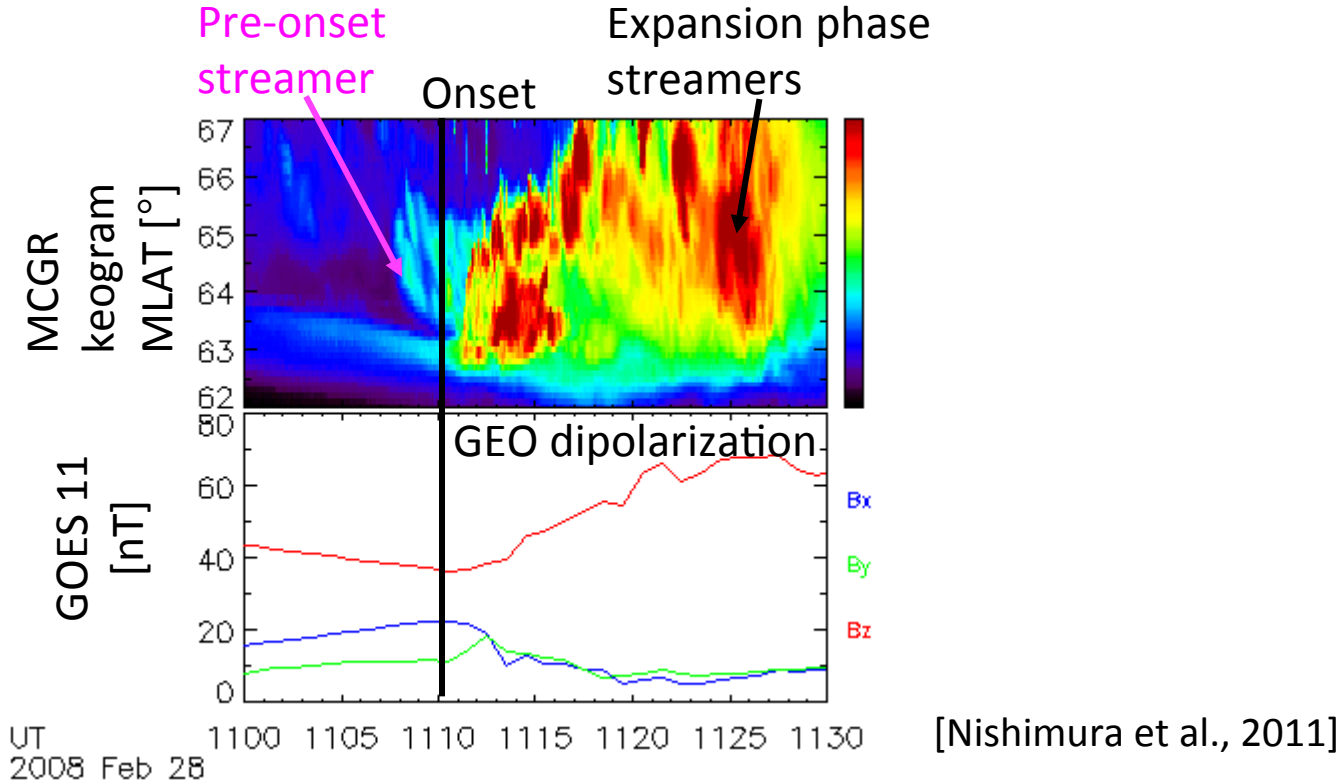
- How can we predict particle injections?
  - Critical for ring current, wave-particle interaction, radiation belt and SAPS
- When do injections occur?
- Where do injections occur in what MLT width?
- What does determine the strength and penetration of injection?

## Magnetotail/aurora

- How can we predict reconnection and substorm?
  - Critical for tail and auroral energetics
- What triggers magnetotail reconnection and substorm onset?
- What determines the reconnection location and size?
- What determines the bubble entropy?

There are lots of common interests between the inner magnetosphere and magnetotail/auroral sciences.

# Are there precursors of substorm onset?

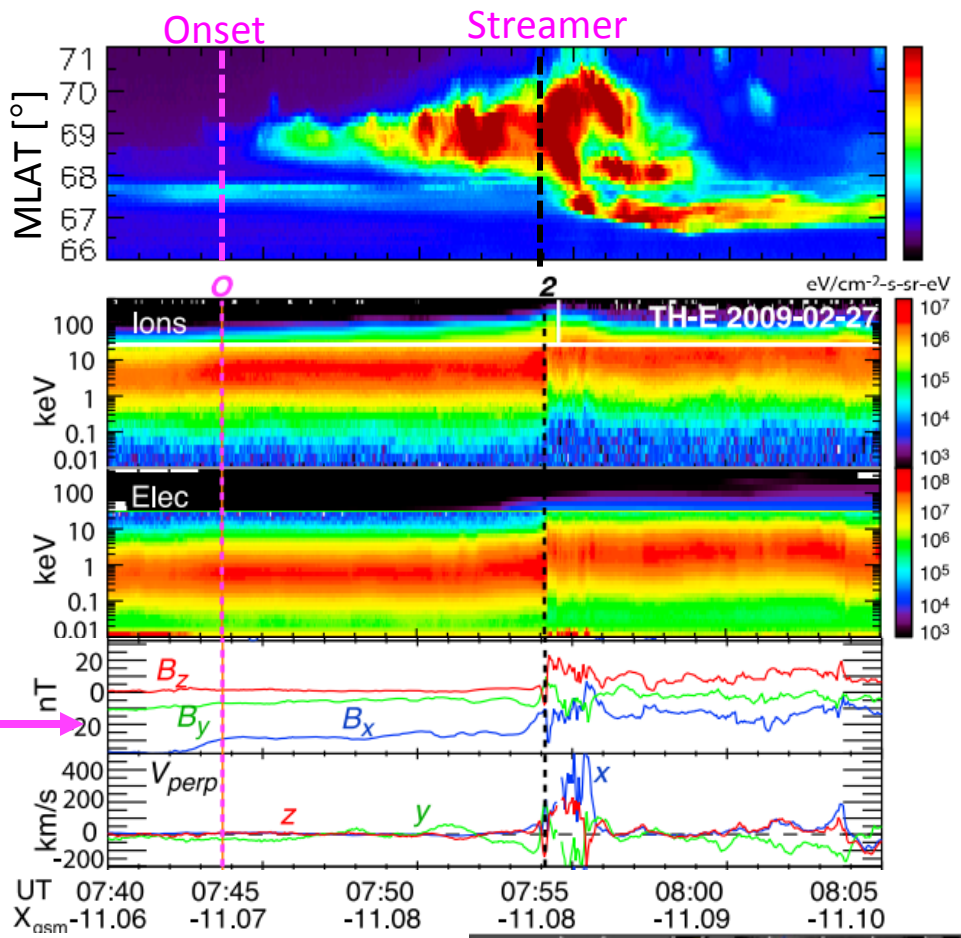
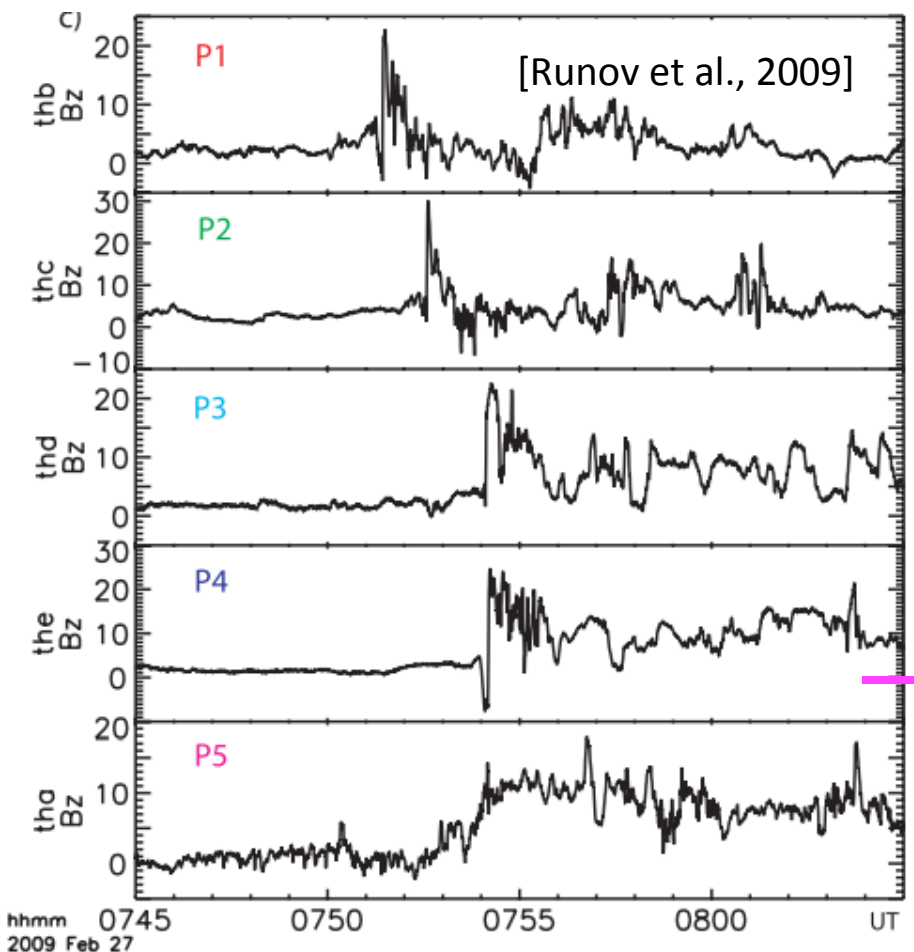


The substorm pre-onset sequence has been one of the most fundamental and controversial topics in the tail science over the past ~40 years.

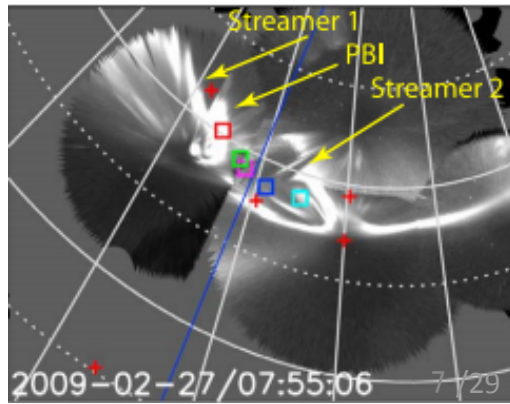
Though still under debate, many substorm events with precursors (like the case above) have been reported.

If precursors are found in common, those would open up a possibility of predicting timing of injections and related phenomena.

# When do injections occur?

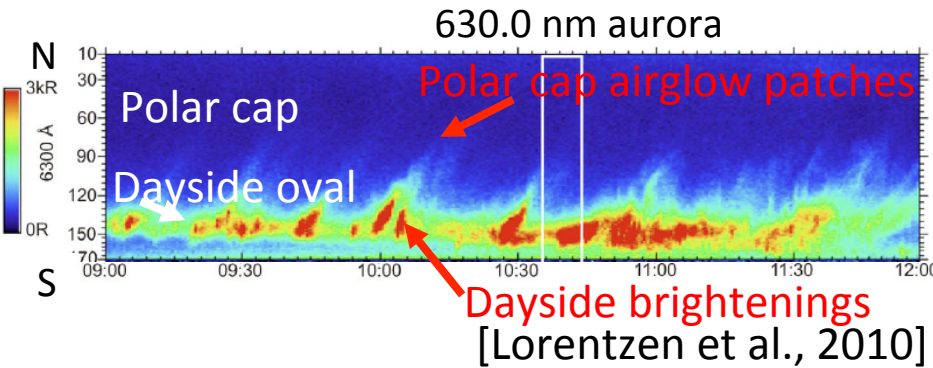


- The onset had little effect at the satellite location.
- The injection and streamer ~10 min after onset.
- Why did an additional intensification (reconnection) occur at that time?



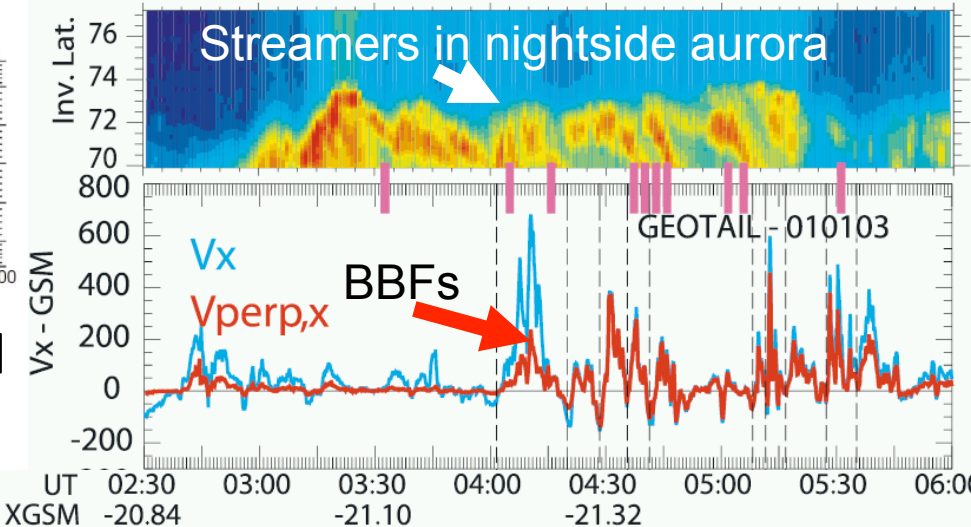
# Global connections of fast flow channels?

## Dayside transients



Also include dayside reconnection, hot flow anomalies, foreshock bubbles, flux transfer events...

## Nightside transients



[Lyons et al., 1999; Sergeev et al., 1999; Zesta et al., 2006]

Also include tail reconnection, bubbles, dipolarization fronts, injections...

Both dayside and nightside reconnections are transient.

Are these related to each other through the polar cap or completely independent?

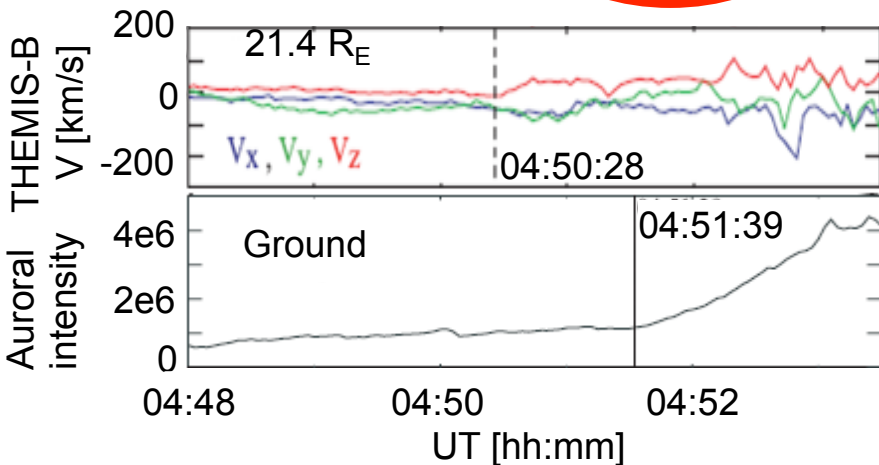
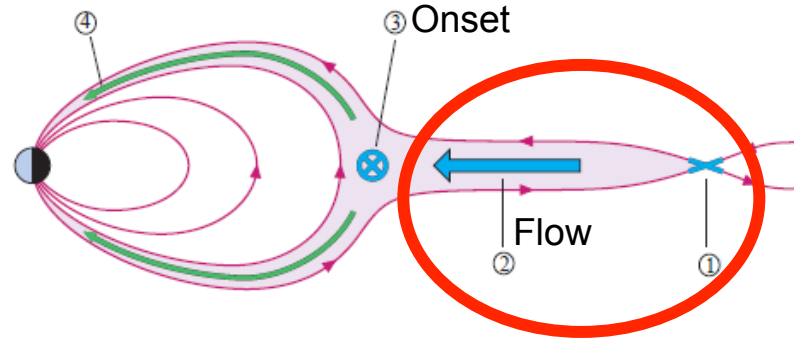


## 2. New tail FG: Testing proposed links between mesoscale auroral and polar cap dynamics and substorms (2015-2019)

FG leaders: Kyle Murphy, Toshi Nishimura, Emma Spanswick and Jian Yang

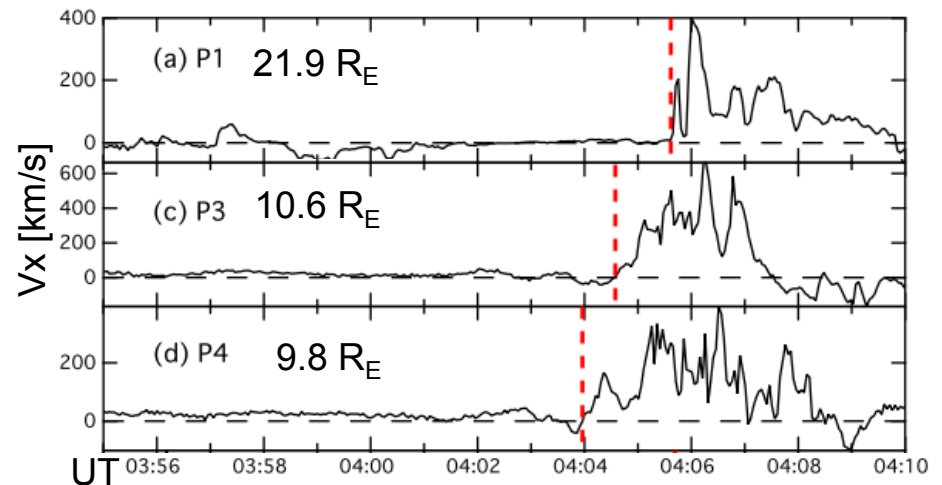
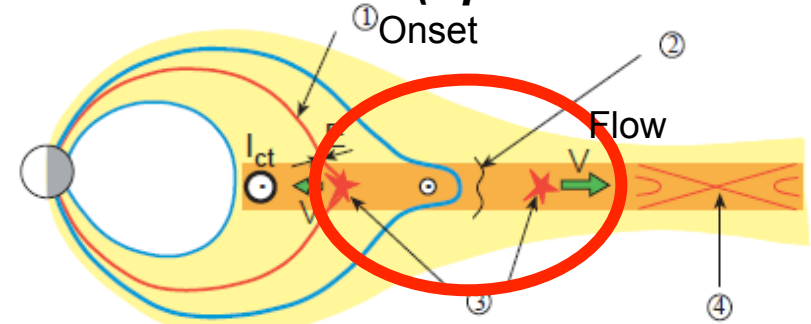
### Why substorms again?

#### Outside-in scenario (Driven onset)



[Angelopoulos et al., 2008]

#### Inside-out scenario (Spontaneous onset)



[Lui et al., 2011]

New ideas emerged in the past GEM Substorm Expansion Onset FG (2008-2013)

# 1. Traditional Outside-in (NENL) [Kepko et al., 2009]

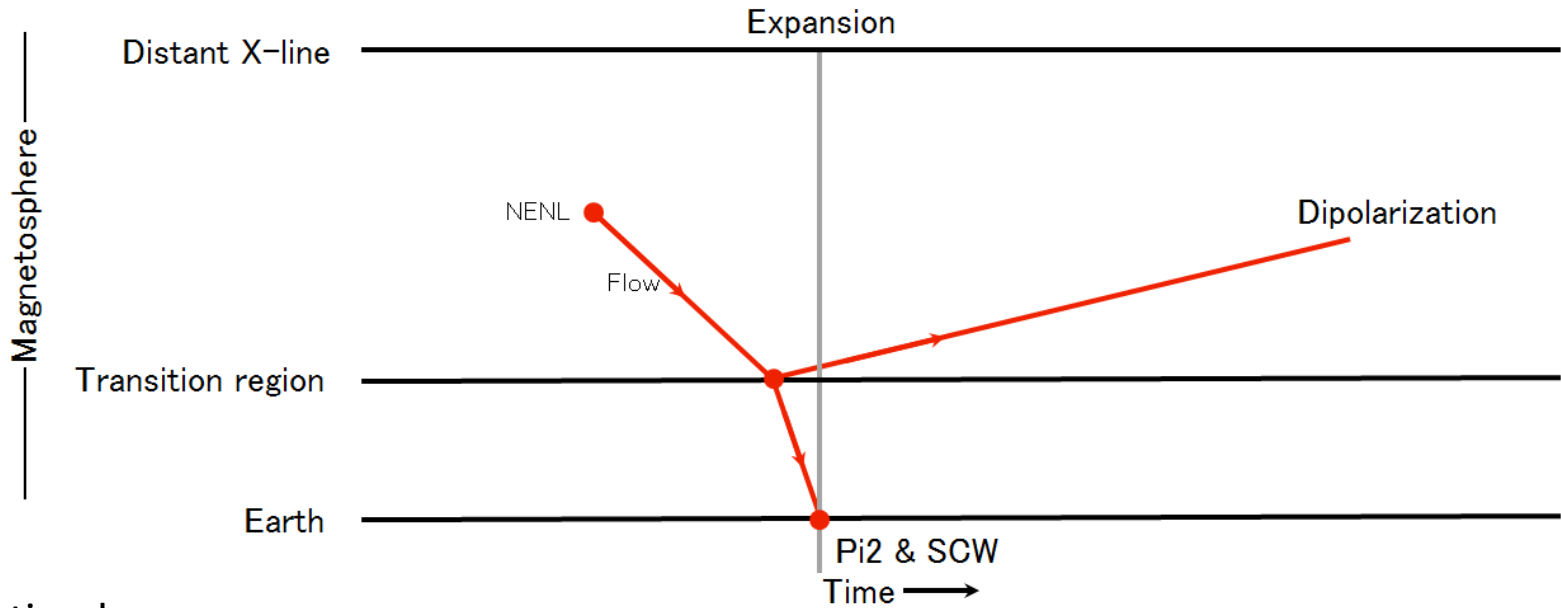
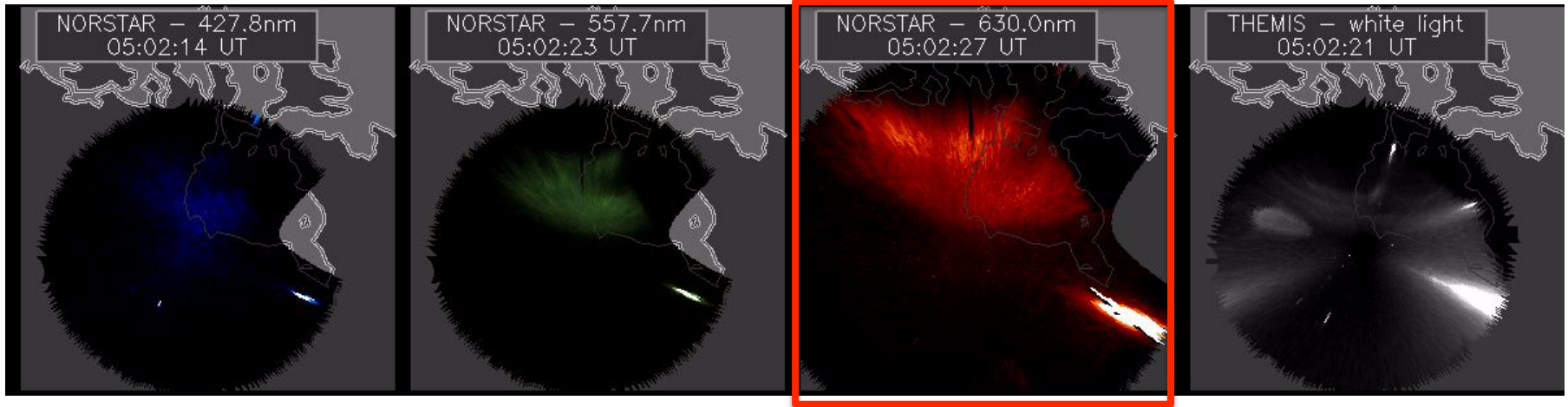


Illustration by  
Larry Kepko

## 2. Traditional Inside-out [Rae et al., 2009]

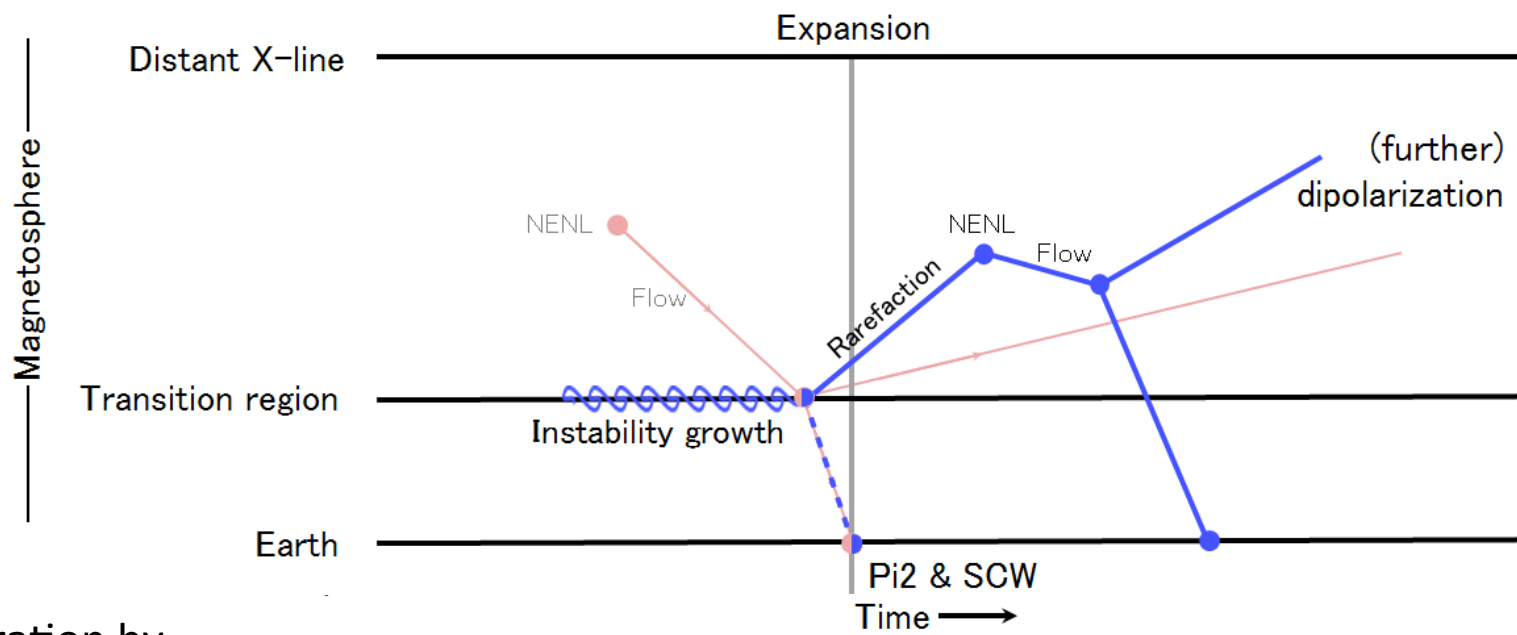
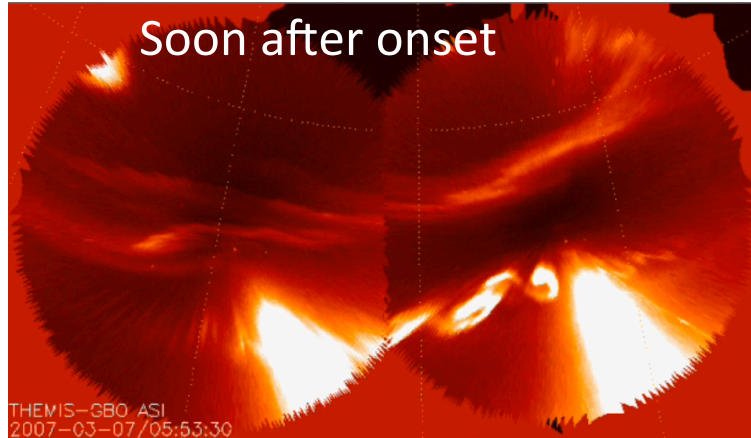
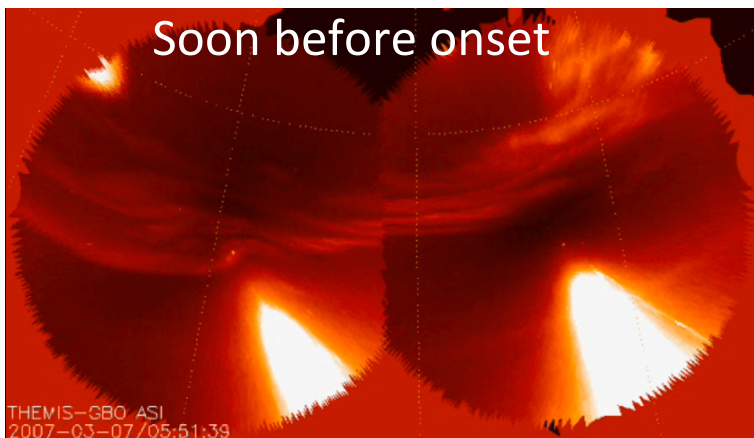


Illustration by  
Larry Kepko

### 3. Out-in-out Hybrid hypothesis [Nishimura, Lyons et al., 2010]

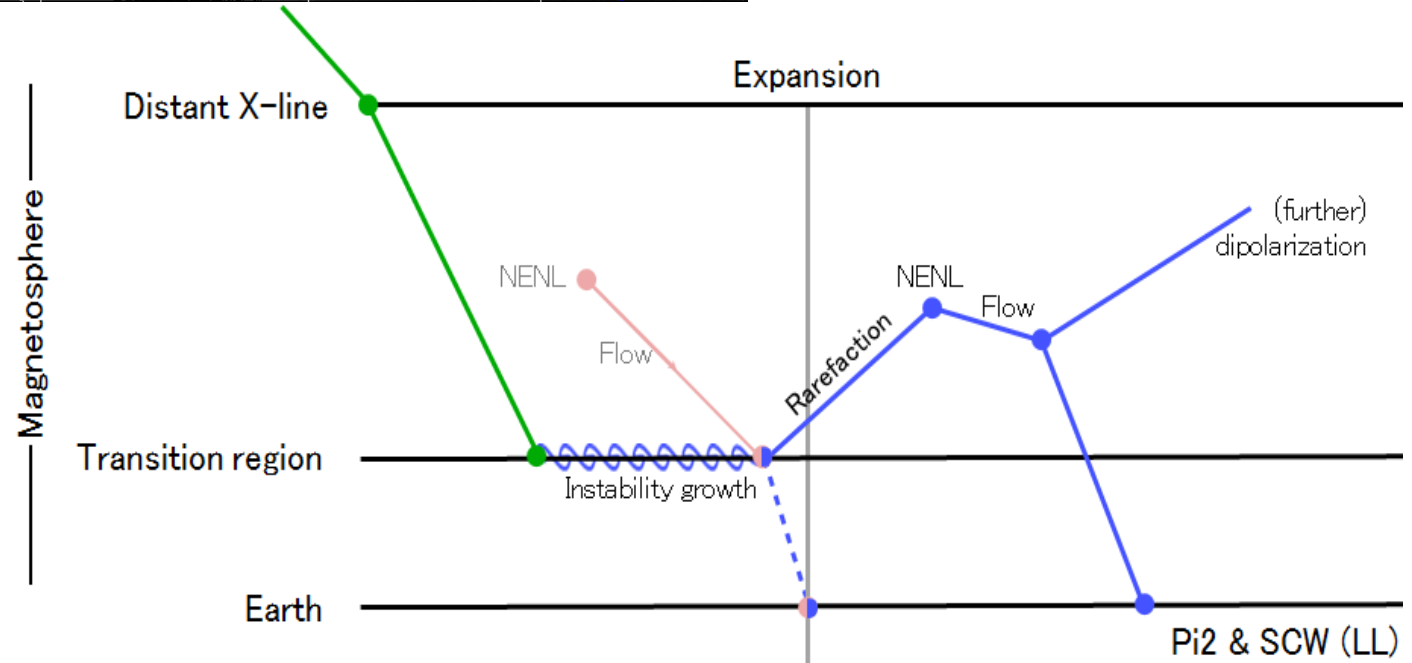
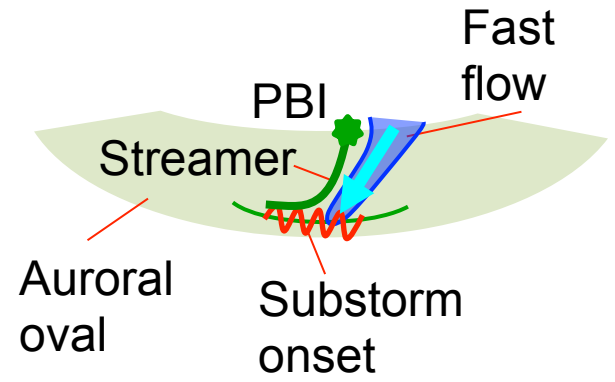
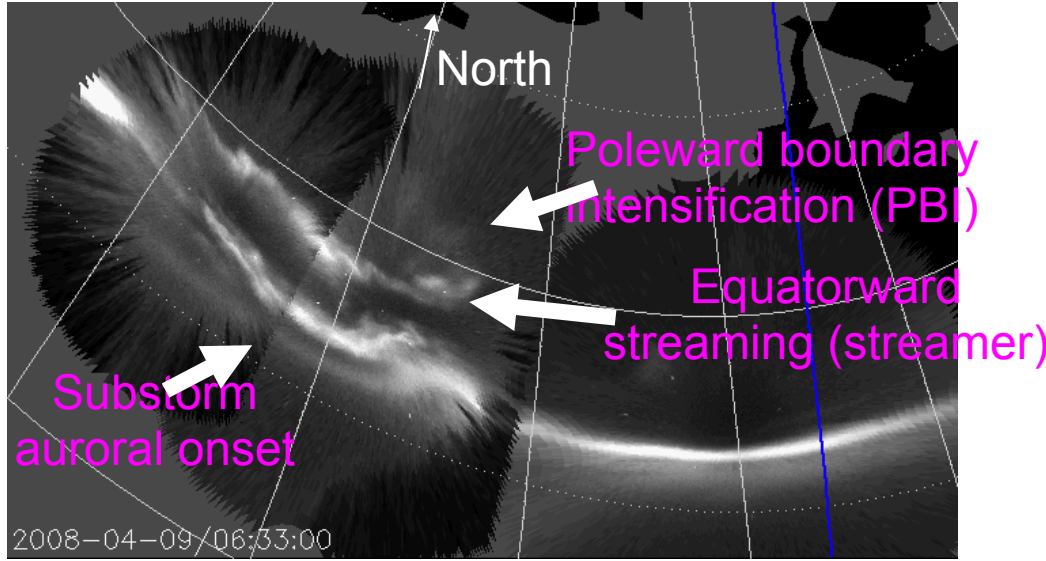


Illustration by  
Larry Kepko

These ideas emerged and were discussed at the past substorm FG.

**However, no community-wide consensus has been achieved.**

- People stick to their favorite events—Few cross-examination effort
- Sessions are filled with talks—Not much time for discussing and testing ideas

### Selected recent papers on substorm precursors using THEMIS/THEMIS ASIs

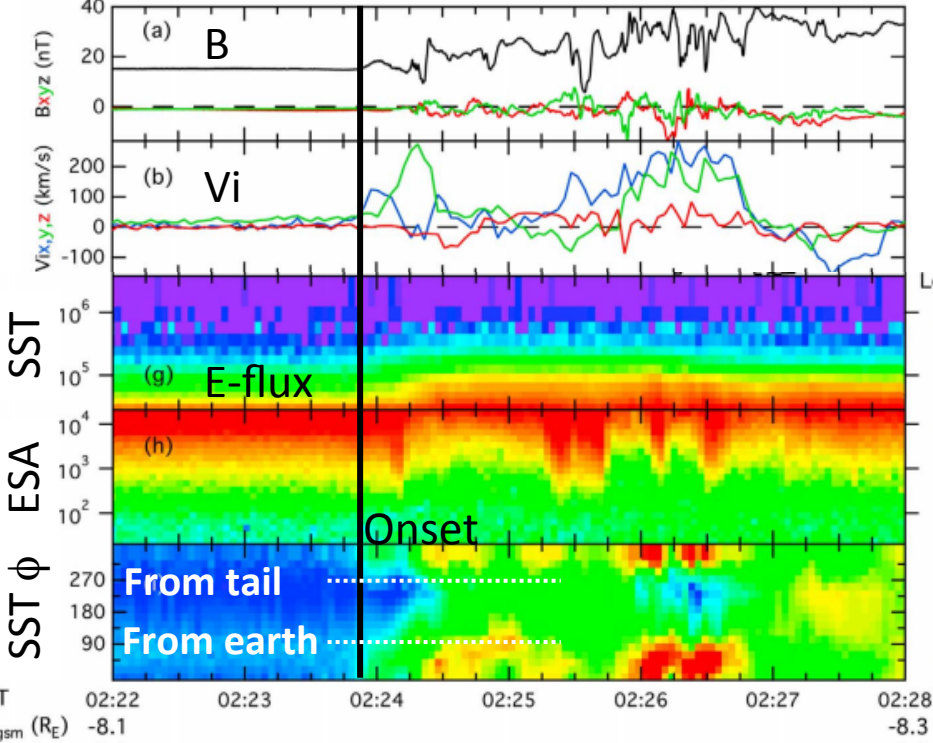
2007-03-07	Rae et al. [2009]
2007-03-13	Donovan et al. [2008]
2007-12-18	Nishimura et al. [2010]
2008-01-29	Rae et al. [2014]
2008-02-04	Nishimura et al. [2010]
2008-02-15	Nishimura et al. [2010]
2008-02-16	Gabrielse et al. [2009], Lui et al. [2011]
2008-02-22	Liu et al. [2009]
2008-02-26 4:00 UT	Pu et al. [2010], Lui et al. [2011]
2008-02-26 4:55 UT	Angelopoulos et al. [2009], Lui et al. [2009]
2008-02-25	Kepko et al. [2009], Lui et al. [2011]
2008-02-28	Nishimura et al. [2010]
2008-02-29	Nishimura et al. [2010]
2008-03-05	Rae et al. [2012]
2009-02-28	Lui et al. [2011]
2009-09-21	Lyons et al. [2011]
2011-04-09	Murphy et al. [2014]
Multiple/Statistical	Lin et al. [2009], Mende et al. [2011], Machida et al. [2014]

With Precursor (Outside-in/Hybrid)  
Without precursor (Inside-out)

The substorm scientists are highly polarized. People rarely examine the same events.

# Lui et al. [2011] event

2009 Feb 28 THEMIS P4 (E)

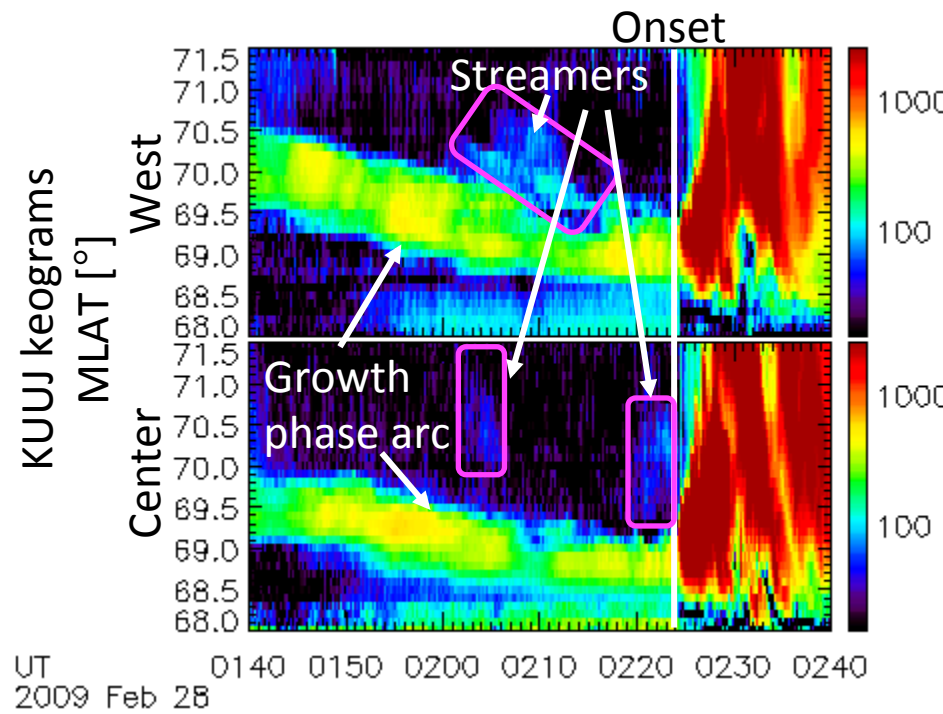


## No precursor

“The observed characteristics in this event constitute **compelling evidence that this near-Earth CDD arose from disturbances originating in the near-Earth region** ...and was **not due to ...arrival of a dipolarization front from mid-tail...**”

[Lui et al., 2011]

## Imager data of their event

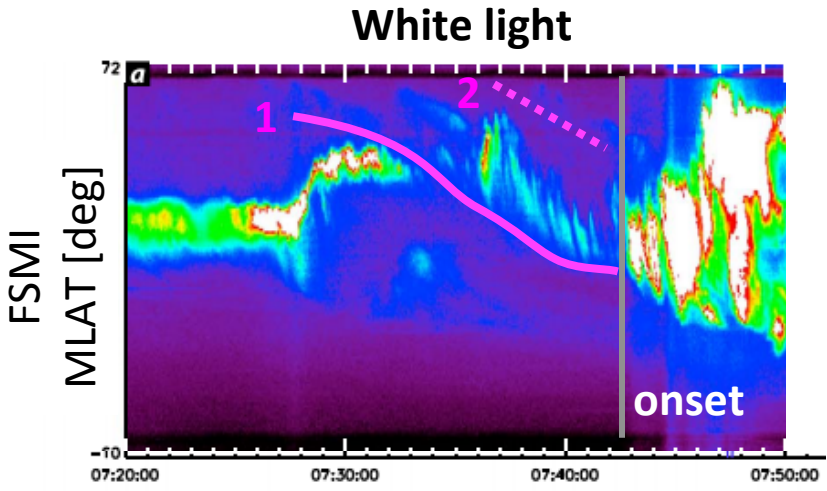


## With precursor streamer

**There are three streamers prior to the onset. Longitudinally localized. Indicating precursor flow channels.**

The lack of precursors at the satellite locations could be because the satellites were away from narrow flow channels.

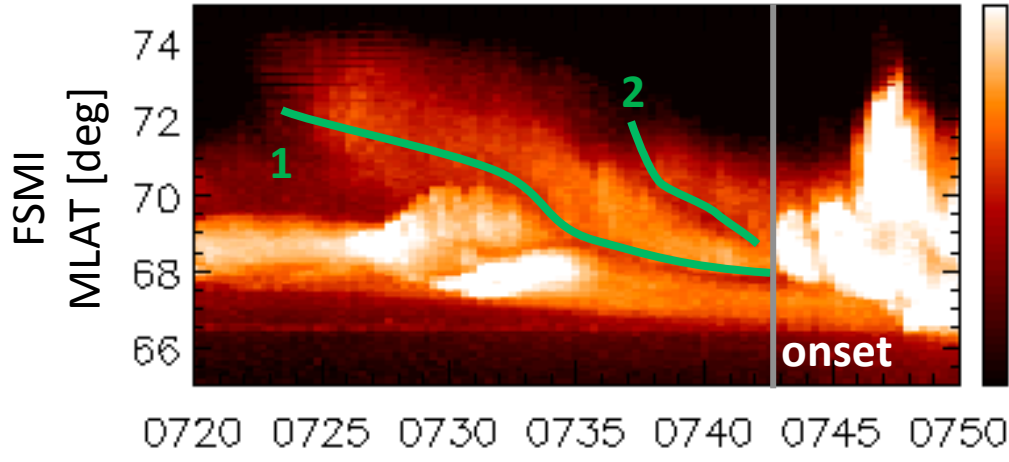
# Rae et al. [2014] event



## No precursor

“The occurrence of PBIs and FLRs is simply statistical, such that they are unrelated to onset but at times their occurrence may both be coincidental...” [Rae et al., 2014]

# Colored data (630.0 nm) of their event



## With precursor streamer

The PBI/streamer (#2) propagated much more equatorward than seen in white light data and contacted the growth phase arc (#1). Indicating a pre-onset flow reaching the onset region.

Additional data may largely change past conclusions.

We should organize community-wide discussions for precise interpretation of substorm precursors.

**Goal: Determine if, when, and under what conditions flow bursts trigger substorms.**

- **Community-wide consensus of substorm precursors**
  - Understanding M-I coupling and mapping of substorm precursors
  - Developing tools to quantify substorm precursors
  - Model validations by characterizing precursors
- 

## **Sessions 1 and 3: Event discussion**

### Opening talks

Lyons, Henderson, Kepko

### Event presentation

Ohtani/Motoba, Nishimura/Lyons, Murphy/Rae/Mann, Miyashita

Focused events: 2008-02-25 0530 UT, 2008-02-28 1110 UT and 2008-03-05 0604 UT

### Panelists

Angelopoulos, (Donovan), Mende, (Frey), Lysak, Runov, El-Alaoui, Borovsky, Birn, Sitnov, Wolf, (Mann), Toffoletto, Pritchett, Raedar, Lyon, Merkin, (Lessard)

## **Session 2: Tools and Methods**

McPherron, Kalmoni, Murphy, Donovan

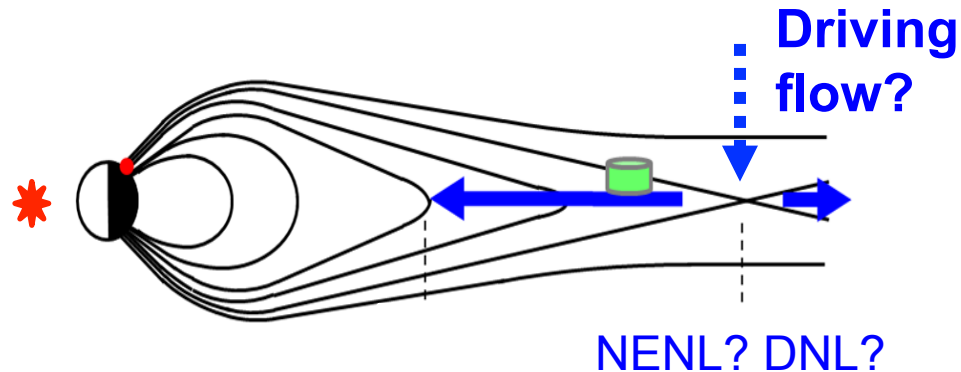
## **Session 4: Joint with Mapping FG**

Ohtani, Spanswick, Roy, Liu, Yue

*Please come and join the discussions (10:30am- Today, Salon 1).*



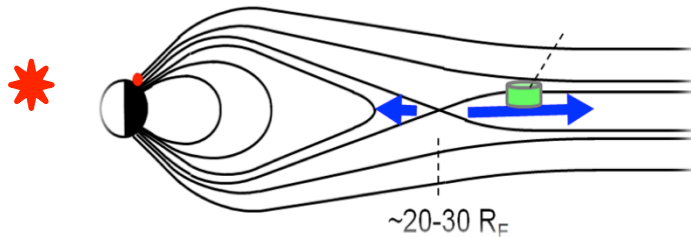
### 3. Questions in the substorm and related fields



- Where do streamers and flow channels originate?  
NENL or DNL? What determines the MLT and its width?
- What do trigger magnetotail reconnection?  
Spontaneous or driven?
- If driven, what is the driver in the lobe and polar cap?  
Polar cap observations  
MHD simulation

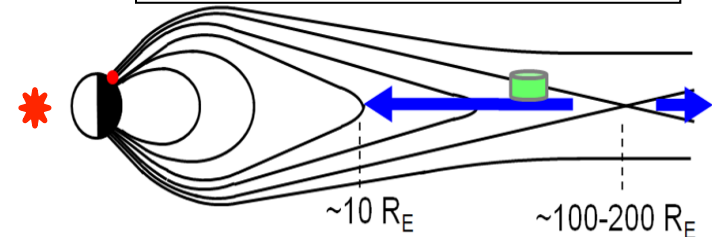
# 4. NENL vs DNL for substorm triggering

Near-Earth Neutral Line?

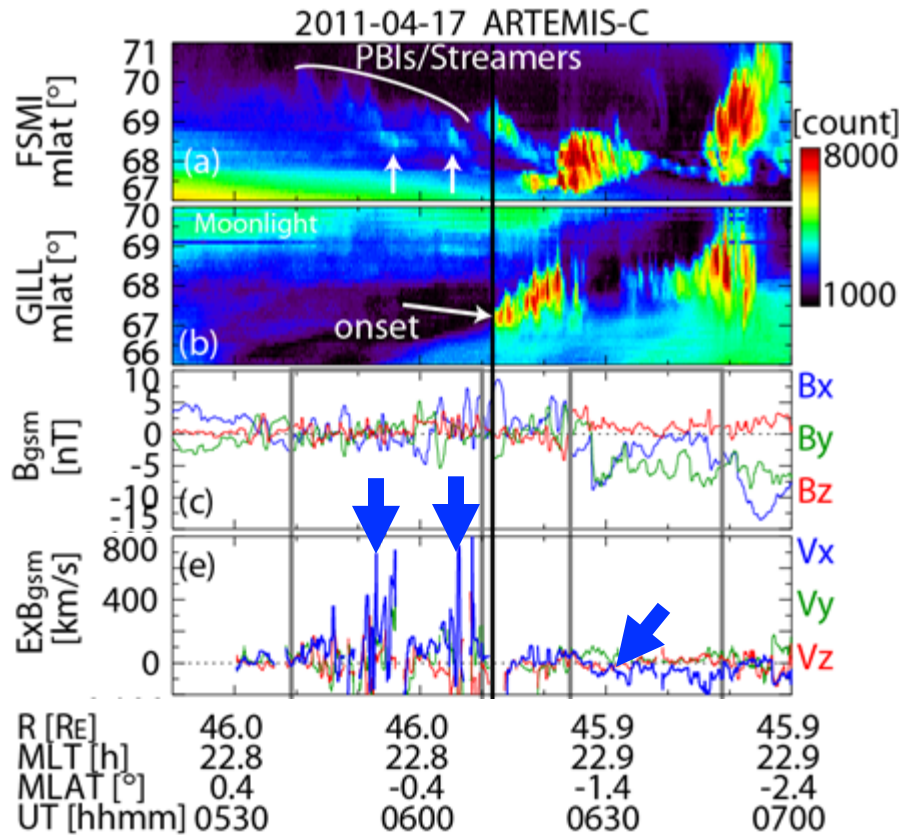


[Nagai et al., 1998; Ieda et al. 1998]

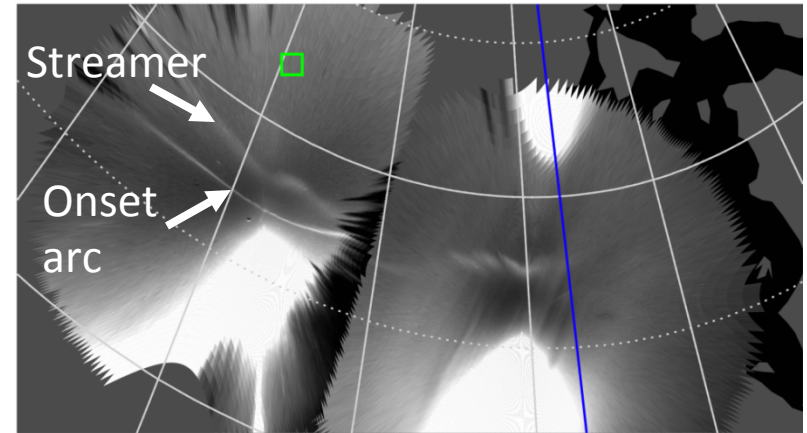
Distant Neutral Line?



[Zesta et al., 2000; Machida et al., 2009]



[Nishimura et al., 2013]



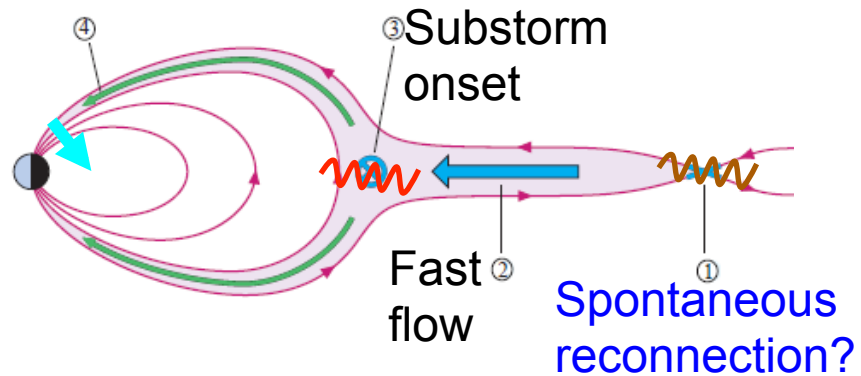
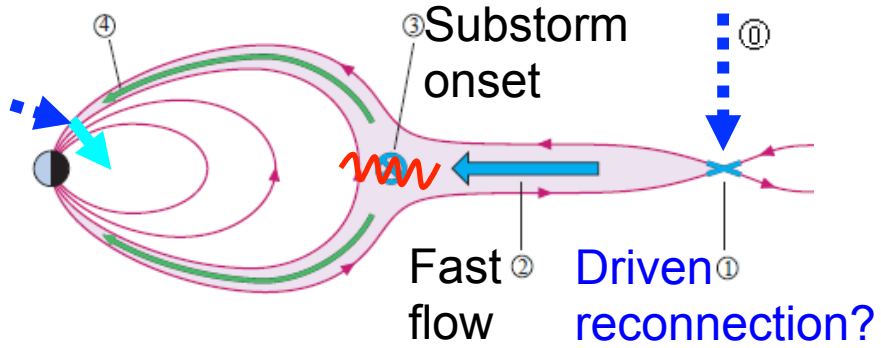
*Aurora:* Streamers

*Plasma sheet:* Earthward flow at  $\sim 46 R_E$

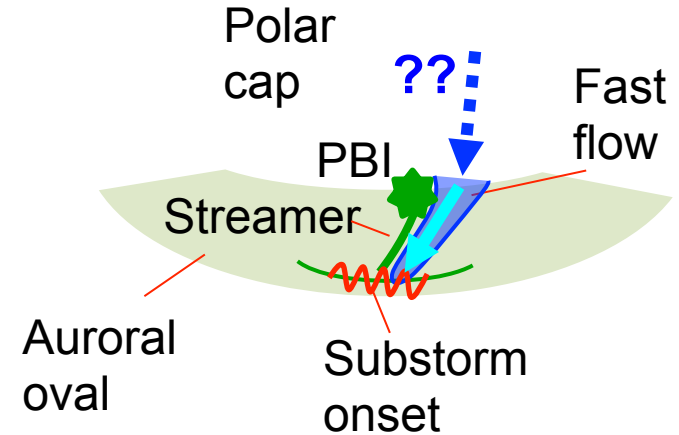
- The pre-onset flows originate further downtail of the ARTEMIS orbit.
- Tailward flows were detected but after onset.

# Where do fast flow channels originate?

Magnetosphere



Ionosphere



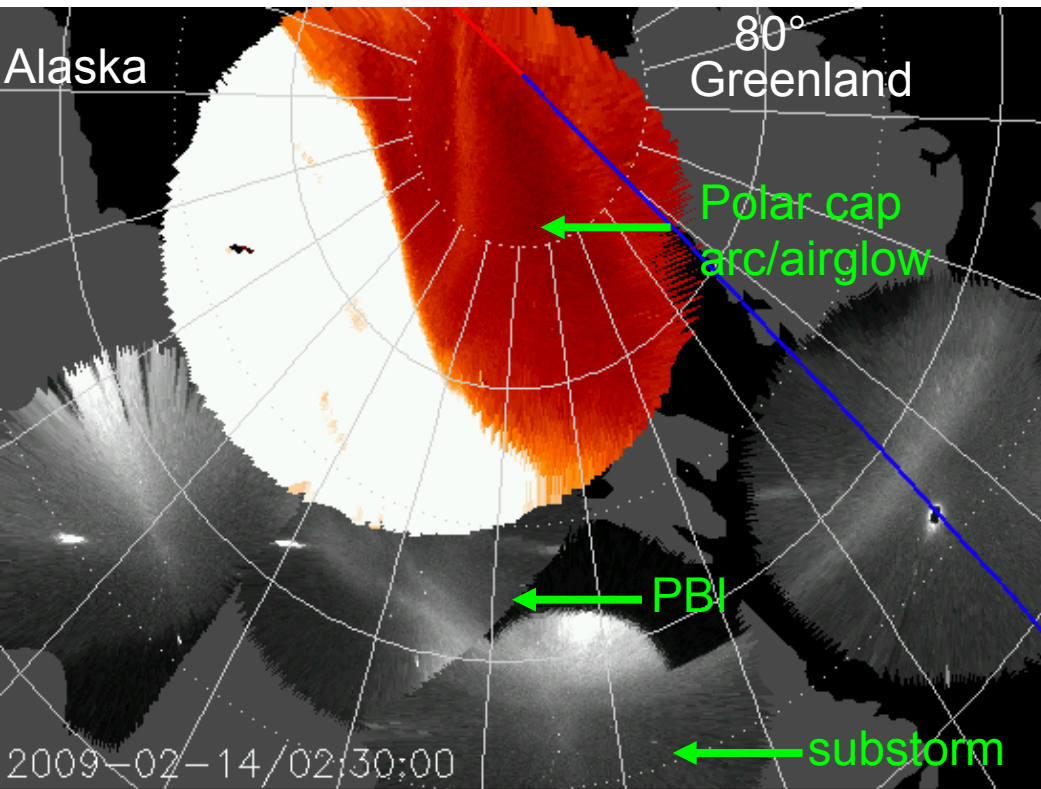
- Is magnetotail reconnection **driven** by incoming flows [Pritchett, 2005]?  
If driven, where are the flows coming from?
- Does that **occur spontaneously** by wave instability [Sitnov, 2013]?

It is difficult to measure the reconnection region continuously.

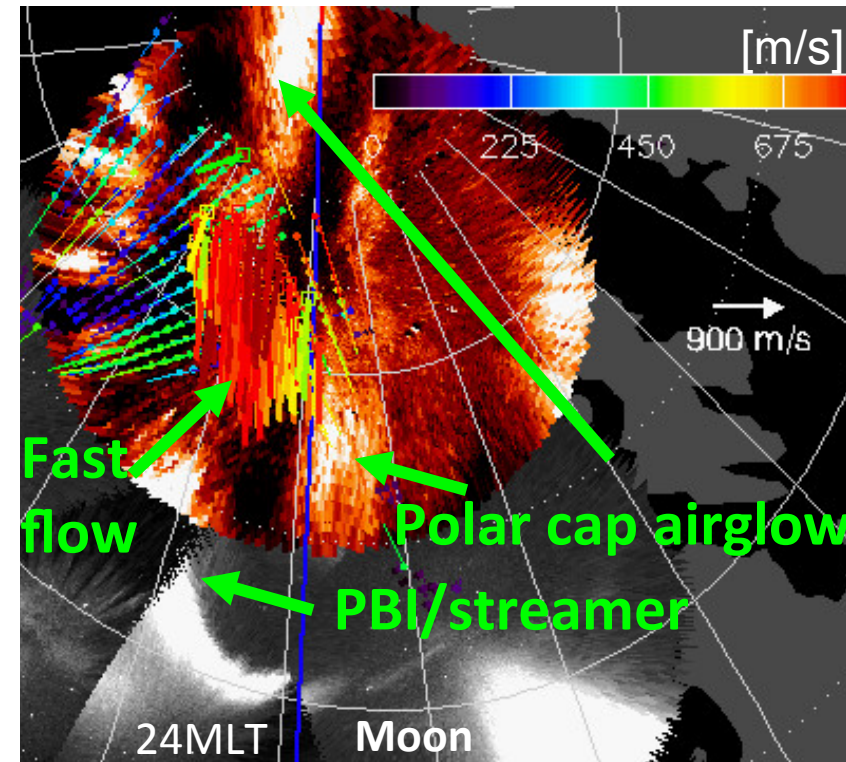
**But 2-D imagers can potentially do by looking at the polar cap.**

# What does trigger magnetotail reconnection?

## Precursor in the polar cap



[Nishimura et al., 2013]



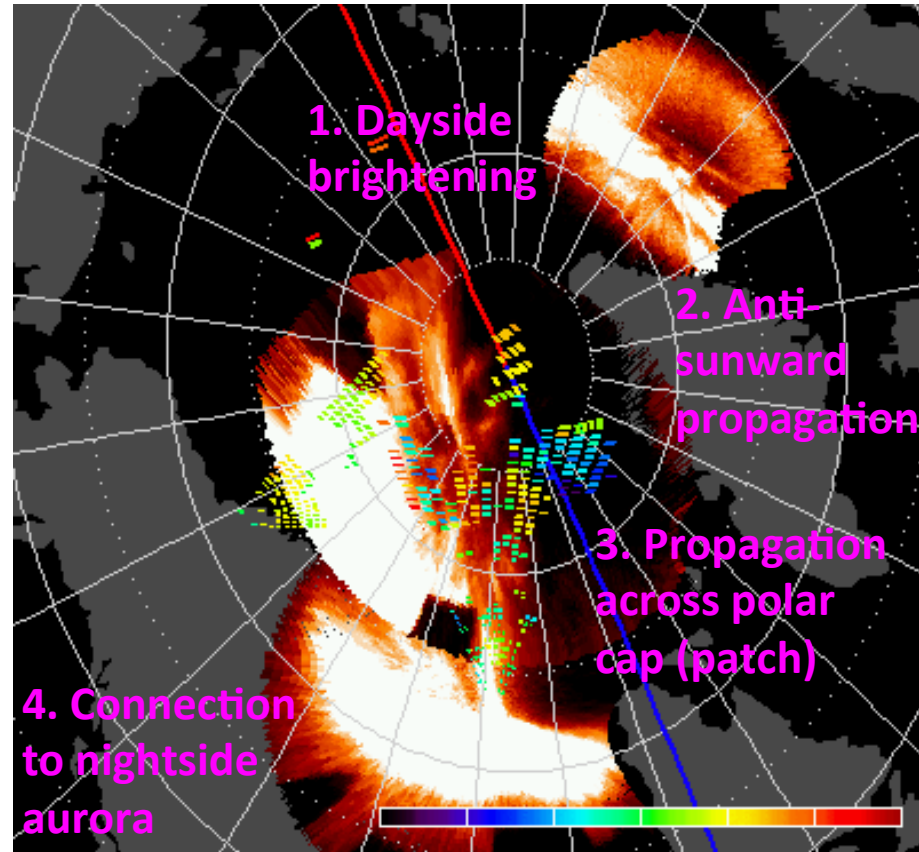
[Zou et al., 2015]

**Dayside → Polar cap → Nightside aurora**

**Suggesting day-night coupling by flow channels as a driver of nightside aurora.**

Monitoring dayside and polar cap can potentially be used to predict nightside aurora and plasma sheet fast flows.

# Coupling between dayside and nightside reconnection



Dayside brightening

→ Patch propagation across polar cap

→ Further poleward expansion in nightside aurora

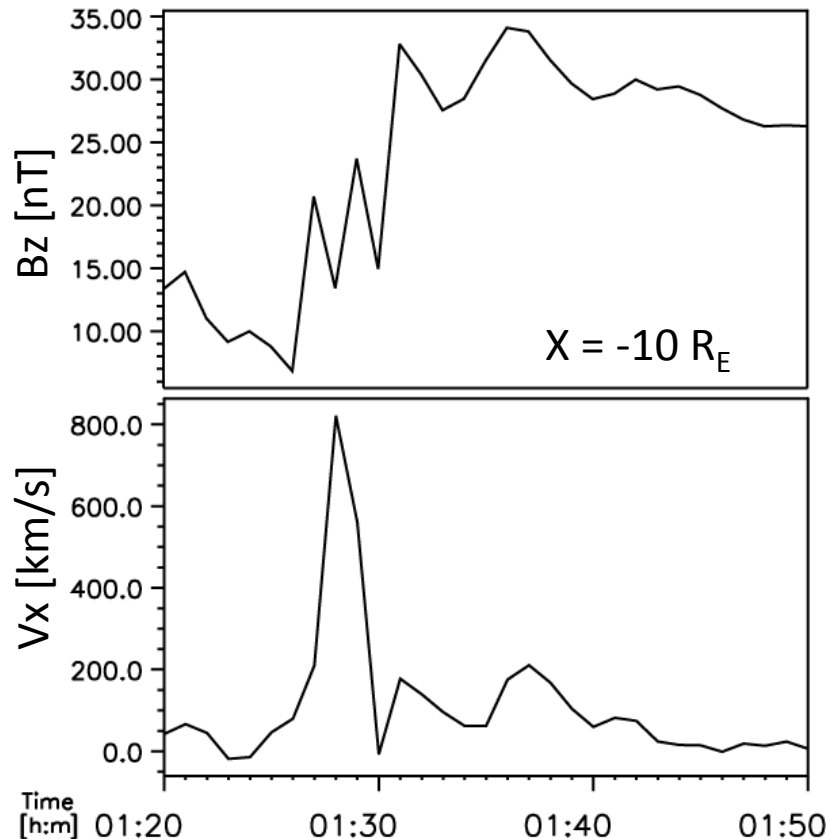
**Dayside transients are suggested to connect to nightside transients.**

**= Coupling between dayside and nightside reconnection by flow channels**

# MHD perspective of nightside reconnection driven by lobe flow channel

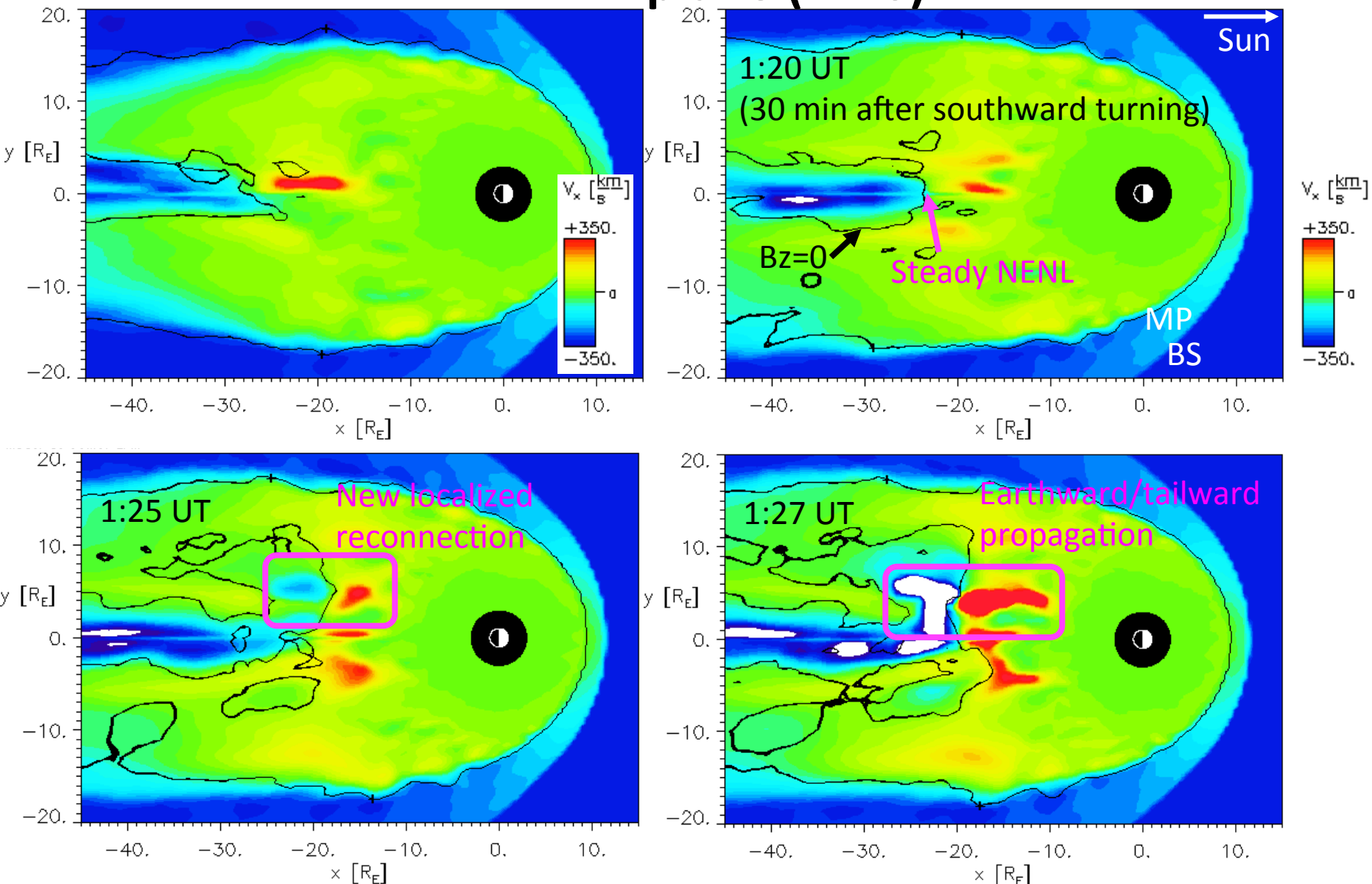
Ionospheric measurements suggest flows driving reconnection, but can we simulate driven reconnection in a global model?

**MHD run (Acknowledgments to CCMC)**



How were the dipolarization and fast flow triggered?

# Vx in X-Y plane (Z = 0)



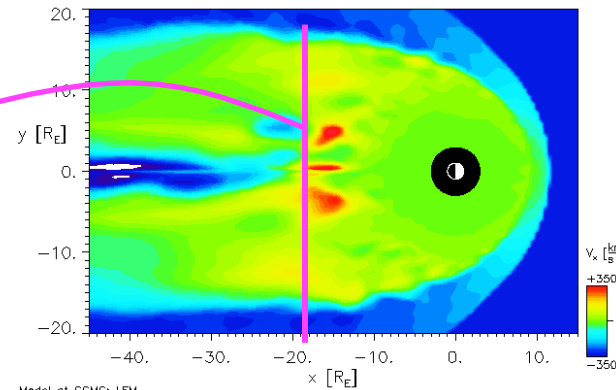
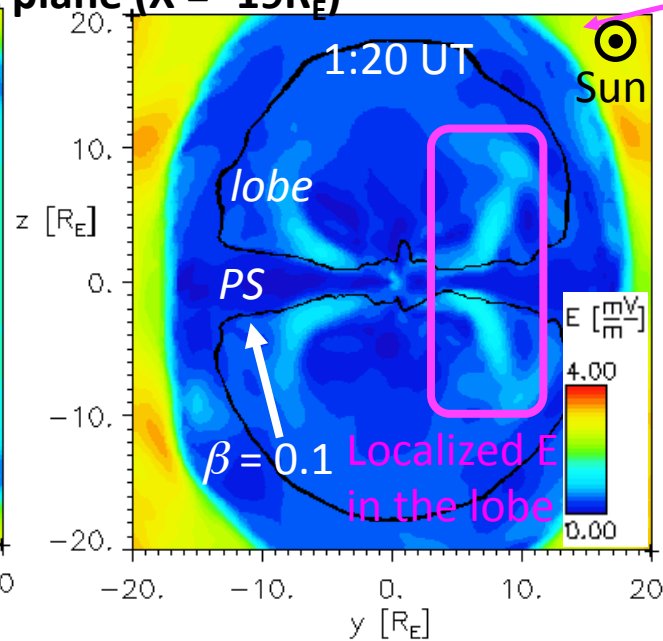
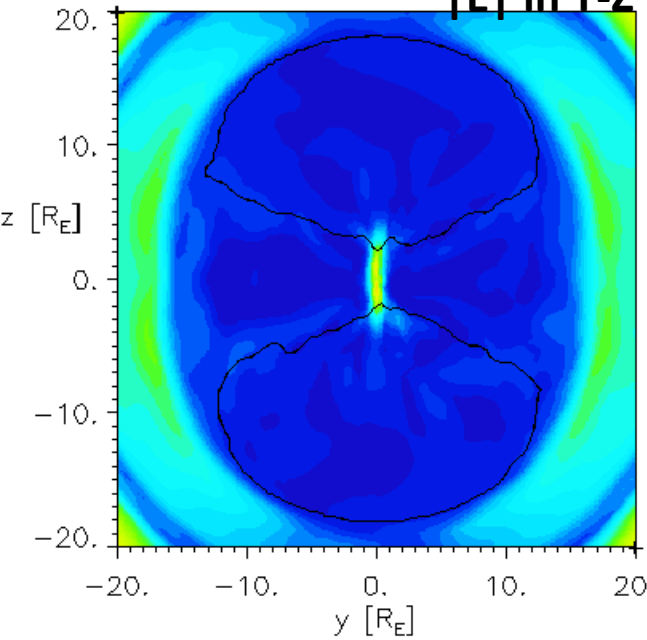
A localized reconnection initiates at premidnight with a  $\sim 3 R_E$  width.

**What does determine the reconnection location and width?**

Numerical resistivity? Spontaneous instability? Driven by lobe structure?

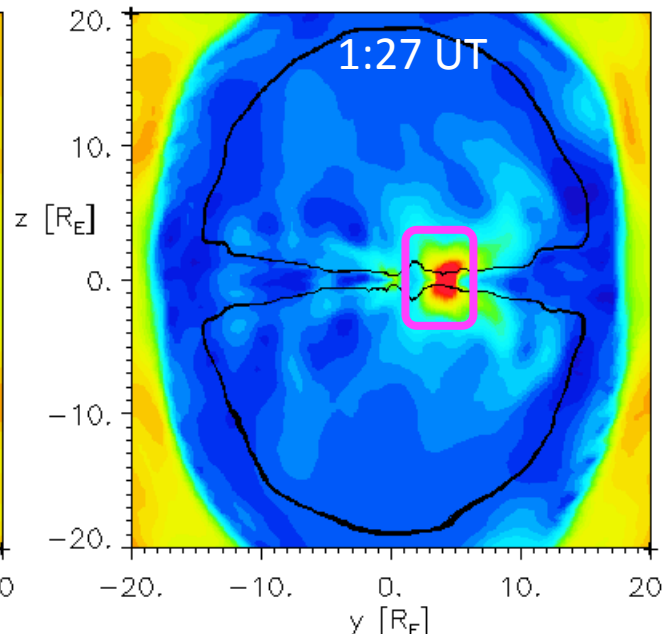
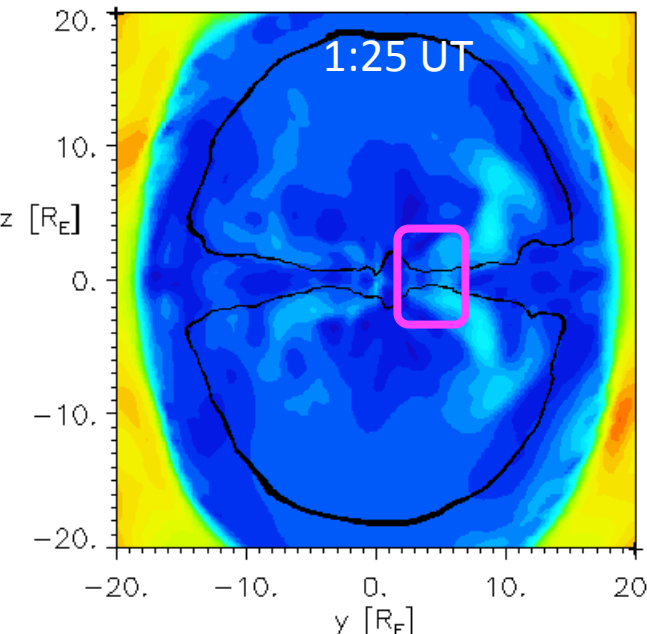
# Lobe electric field structure

$|E|$  in Y-Z plane ( $X = -19R_E$ )



The lobe electric field is not uniform: Has localized channels.

The plasma sheet near the localized electric field gets thinner.

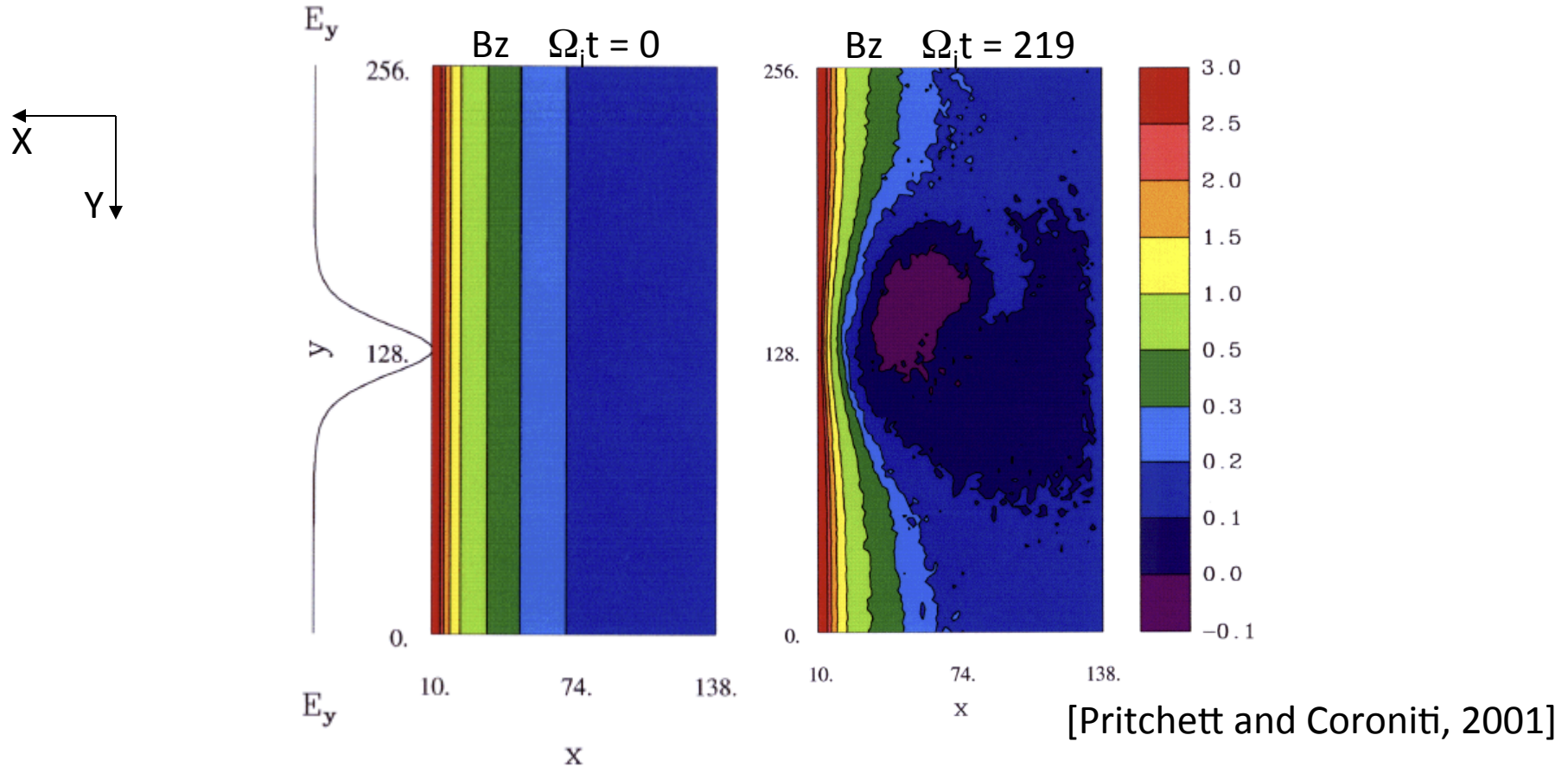


Then the localized reconnection occurs in that meridian.

**The lobe electric field pattern may control the location and size of reconnection.**



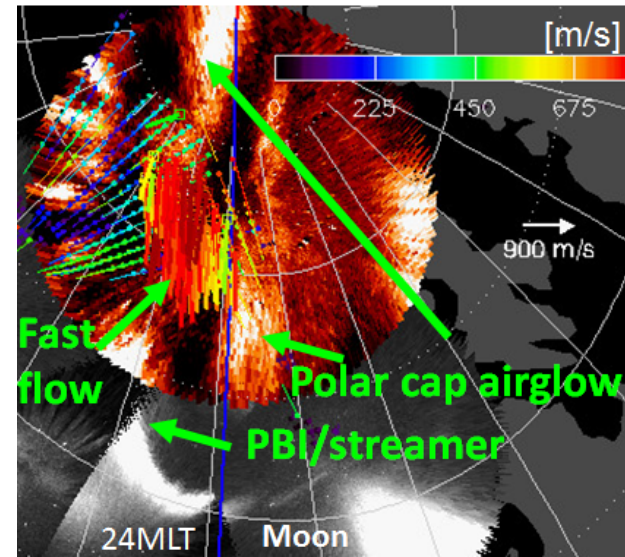
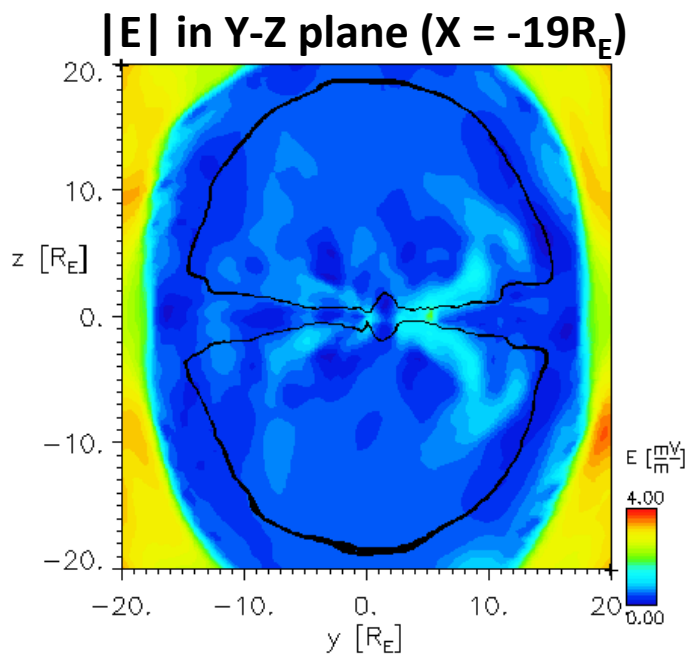
That was in MHD, but this indication is supported by 3-D kinetic simulations.



Localized  $E_y$  is applied at the lobe boundary.

This drives localized plasma sheet thinning and then reconnection.

The driven, localized reconnection in MHD may be real.



**If the lobe electric field is often localized, it might change our view of magnetotail convection.**

Localized dayside reconnection → Localized lobe flows

→ Localized nightside reconnection → BBF/injection

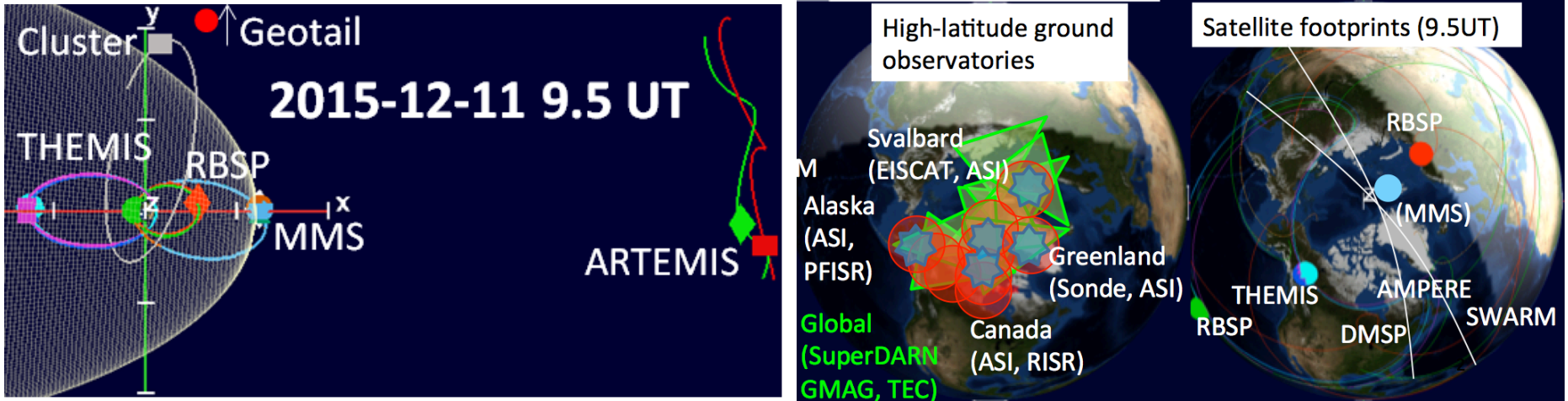
### Challenges:

- What is the physics of localized driven reconnection? → Reconnection FG  
Directly trigger reconnection? Assist internal instability growth?
- How do localized lobe flows connect to DNL/NENL and substorm?  
→ Substorm-Polar cap & Lunar distance FGs
- How do cross-scale (convection, channels and kinetics) coupling play a role and impact plasma transport and injection into the inner magnetosphere? → TIMI & System Science FGs

# 5. Looking forward

## Heliophysics System Observatory (HSO)

[Angelopoulos, Moore, Nishimura, Samara and HSO coordinators]



### Coordinated use of space and ground assets

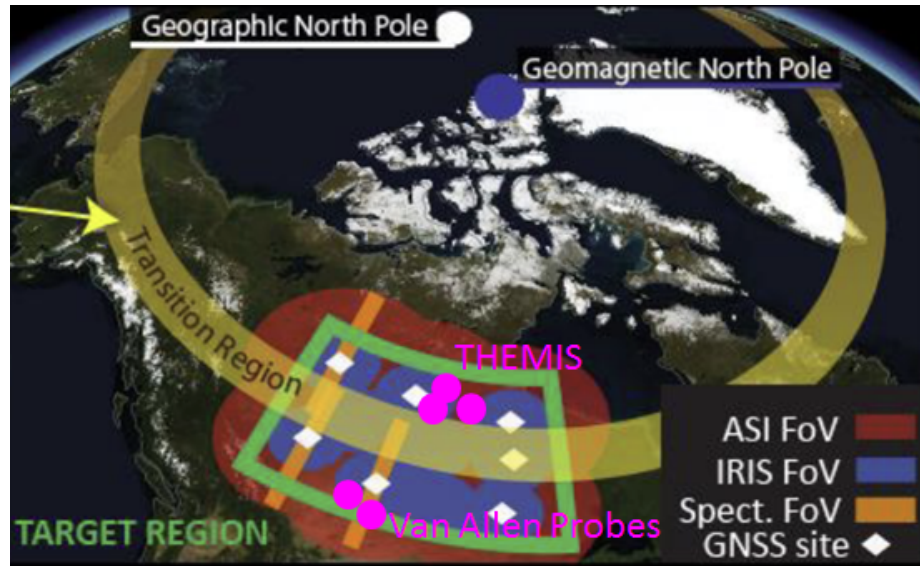
- MMS, THEMIS and RBSP will line up along the Sun-Earth line this winter.
- ARTEMIS will join twice a month (day and night).
- A number of ground-based instruments will be coordinated.
- Global effects of dayside transients
- Cusp-dayside connections
- Nightside reconnection and tail-inner magnetosphere coupling
- Global processes, cross-scale coupling

***Special HSO coordination session at GEM: Wednesday 10:30-12:15, Plenary room***  
**Discussions on science and campaigns**

# Looking forward

## Transition Region Explorer (TREx)

[Donovan et al.]



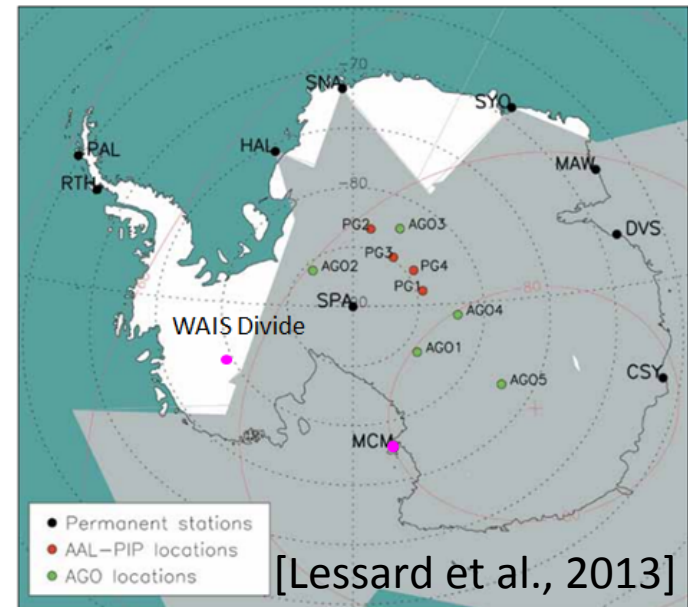
\$8M project approved by Canada

Foundation for Innovation

- Colored imagers (10Hz green, 3s blue)
- Imaging riometers (1 sec)
- in coordination with,
- Red-line imagers (3 sec)
- VLF receivers
- Magnetometers
- Proton photometers
- SuperDARN

Conversations with HSO  
are ongoing.

## NSF Antarctic observation network [Lessard et al.]

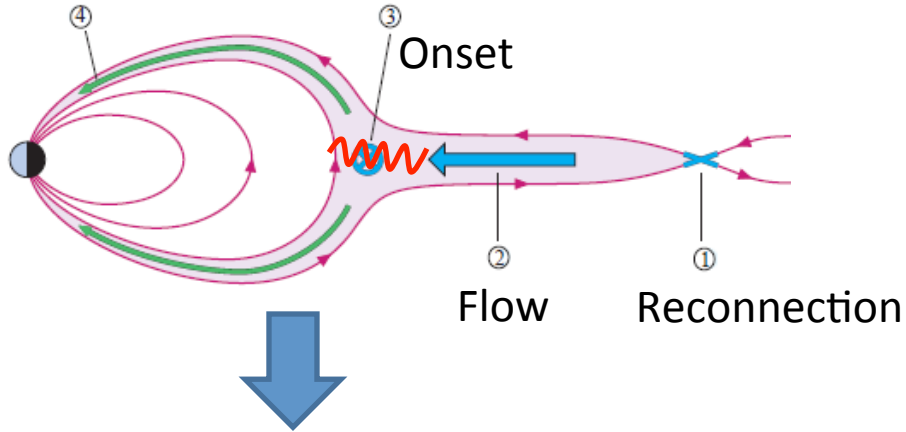


[Lessard et al., 2013]

- A new imager being installed at McMurdo
- Extension to WAIS Divide proposed
- Antarctica-eastern Canada conjugate observations being proposed

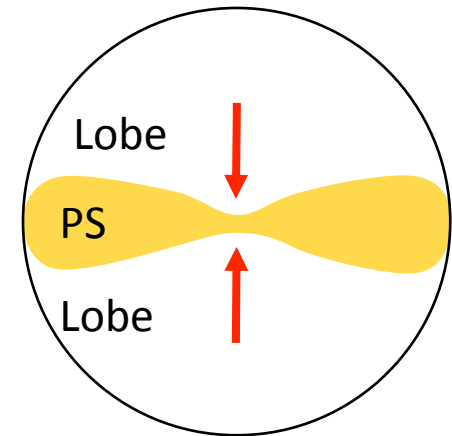
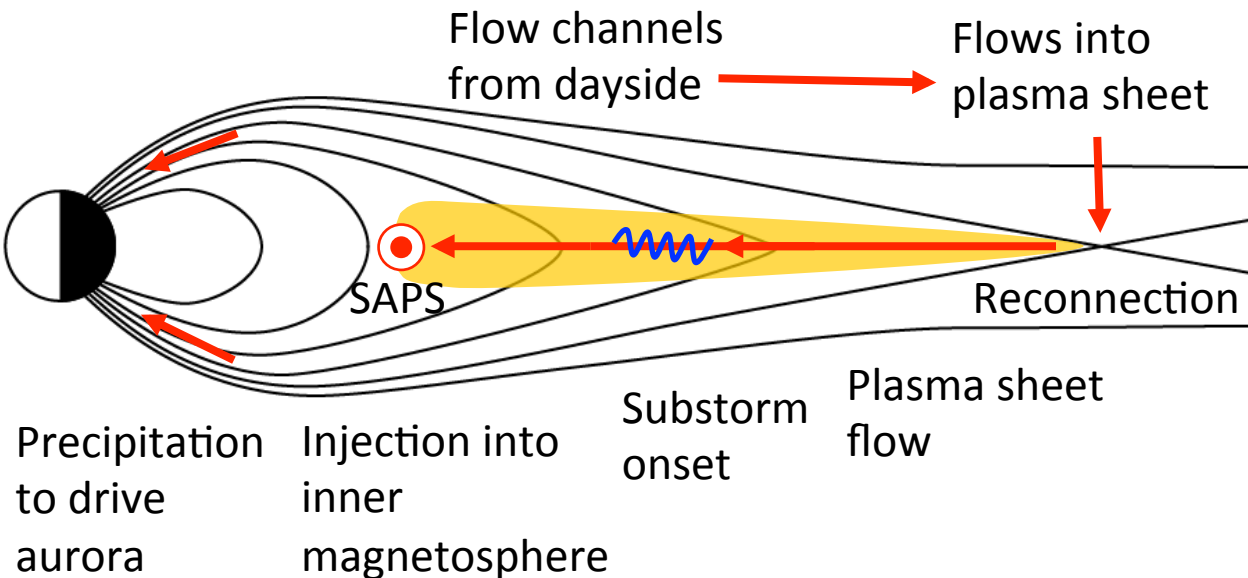
# Summary

## Traditional substorm picture



- Localized flow channels play a crucial role in global plasma transport.
- Substorms are connected closely to other disciplines at GEM.
- A system-level science is desired for understanding global coupling processes.

## Suggested picture, placed on global context



Localized inflow from lobe for driving localized reconnection and BBF