Coupling of Meso-Scale Polar Cap flows Across the Auroral Oval Poleward Boundary to Oval Disturbances

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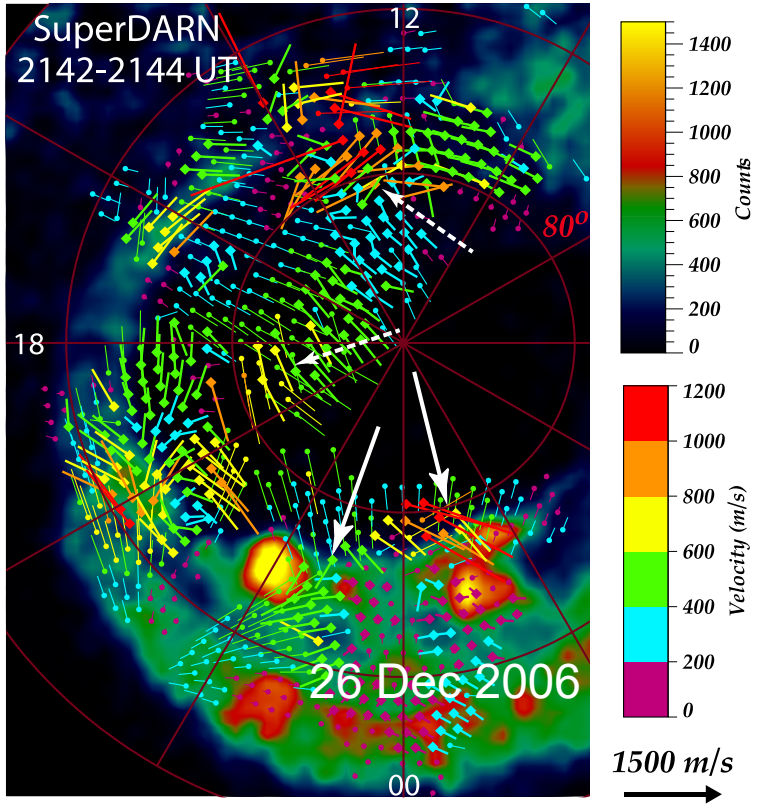
SuperDARN / IMAGE-WIC [Yong *Shi et al.*, 2012]



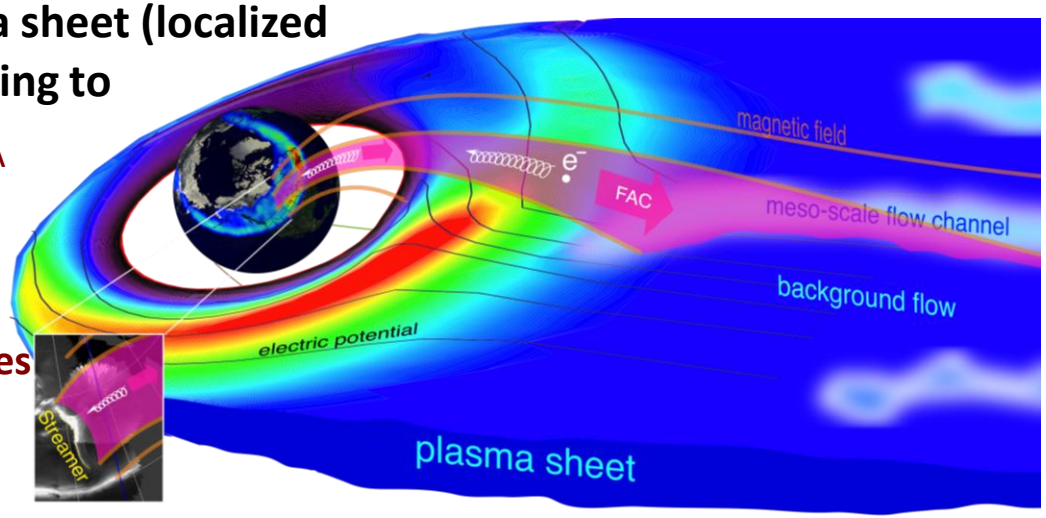
Polar Cap Convection:

- Had been considered **smooth**; **2-4 cells**; $\Delta\phi_{pc}$ important

SuperDARN, with ASIs revealed much localized flow structure

- Some structures long lived (~2-4 hrs sometimes)

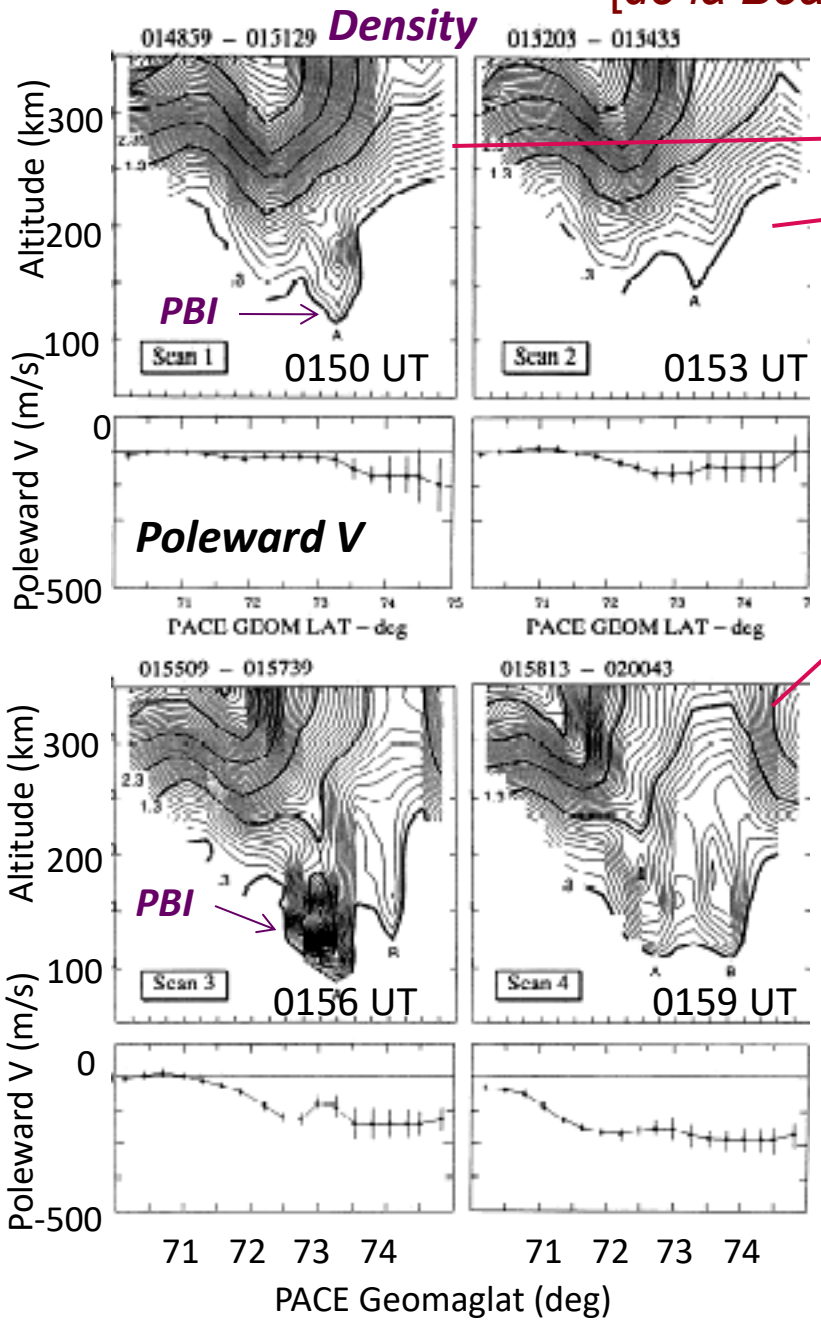
Can cross into oval/plasma sheet (localized driven reconnection), leading to

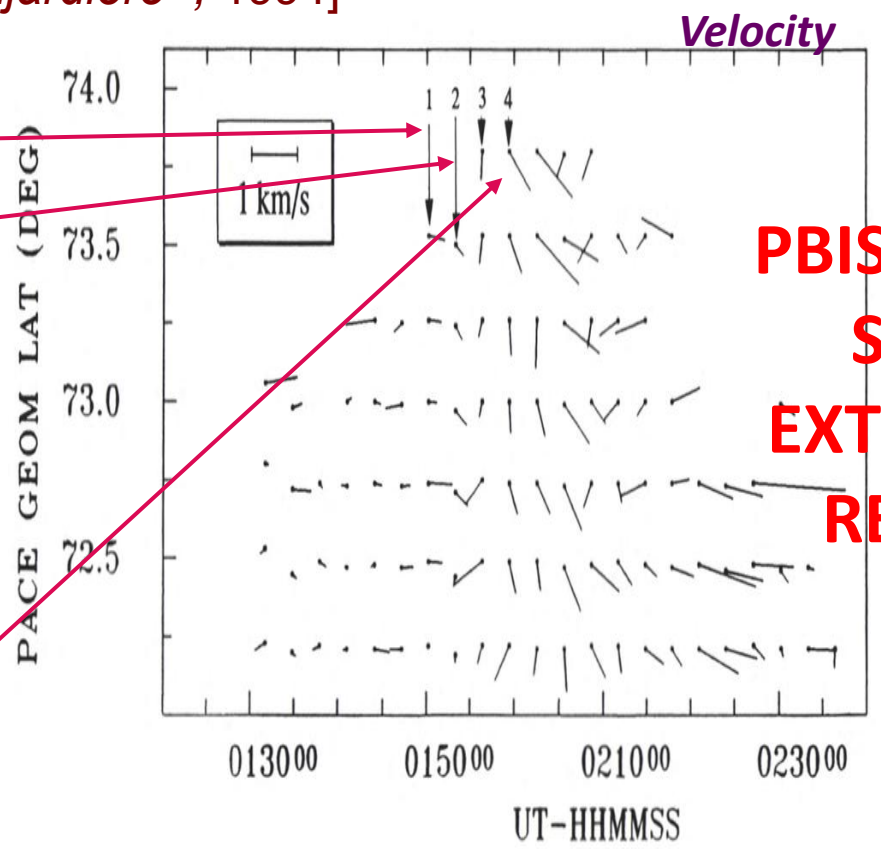


- Ionosphere **flow channels**\ plasma sheet **flow bursts**
- Brings new **lower entropy plasma** into plasma sheet
- Important **oval disturbances**
  - *PBIs*
  - *Streamers*
  - *Omega bands (DAPS)*
  - *Substorm onset, and subsequent surge, spatial size and duration*
  - *Laydown events*

First measurement of polar-cap flow to oval disturbance (Sondrestrom/Goose BAY)

[*de la Beaujardière+, 1994*]

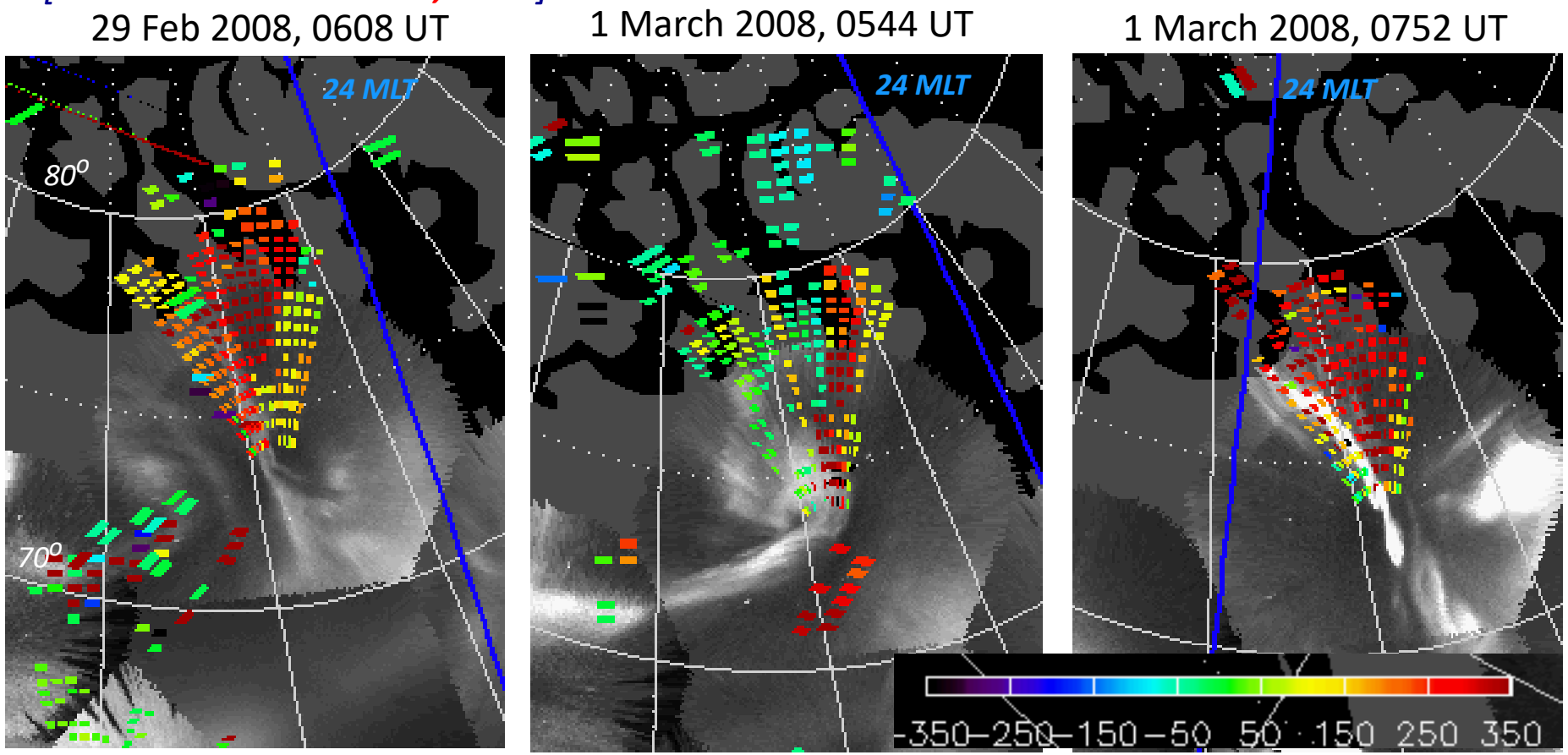




PBIS ARE COMMON, SO LOCALIZED EXTERNALY DRIVEN RECONNECTION COMMON!

- **Flow bursts every ~10-20 min**; **PBIs on westward edge** of bursts
- ***Goose Bay radar/DMSP***: *Bursts extended* ***from within P.C. to well within oval*** **.**
- Equatorward extension **related to streamers.**
- **PC flow-PBI (*Rankin Inlet radar*, ASI)** association **"Remarkable"** [*Y. Zou+, 2014*].

THEMIS ASI image and SuperDARN l-o-s flows (all beams, focus on Rankin Inlet)
[Bea Gallardo-Lacourt+, 2013]



Famous SuperDARN figure: Flow channels extend equatorward with streamers:

- Extend from polar cap ($\Lambda = 80^o$) to east side of 2 streamers, 1 Harang aurora
- Then along streamer edge as far equatorward as there are echoes
- Upward (downward) FAC along west (each edge)

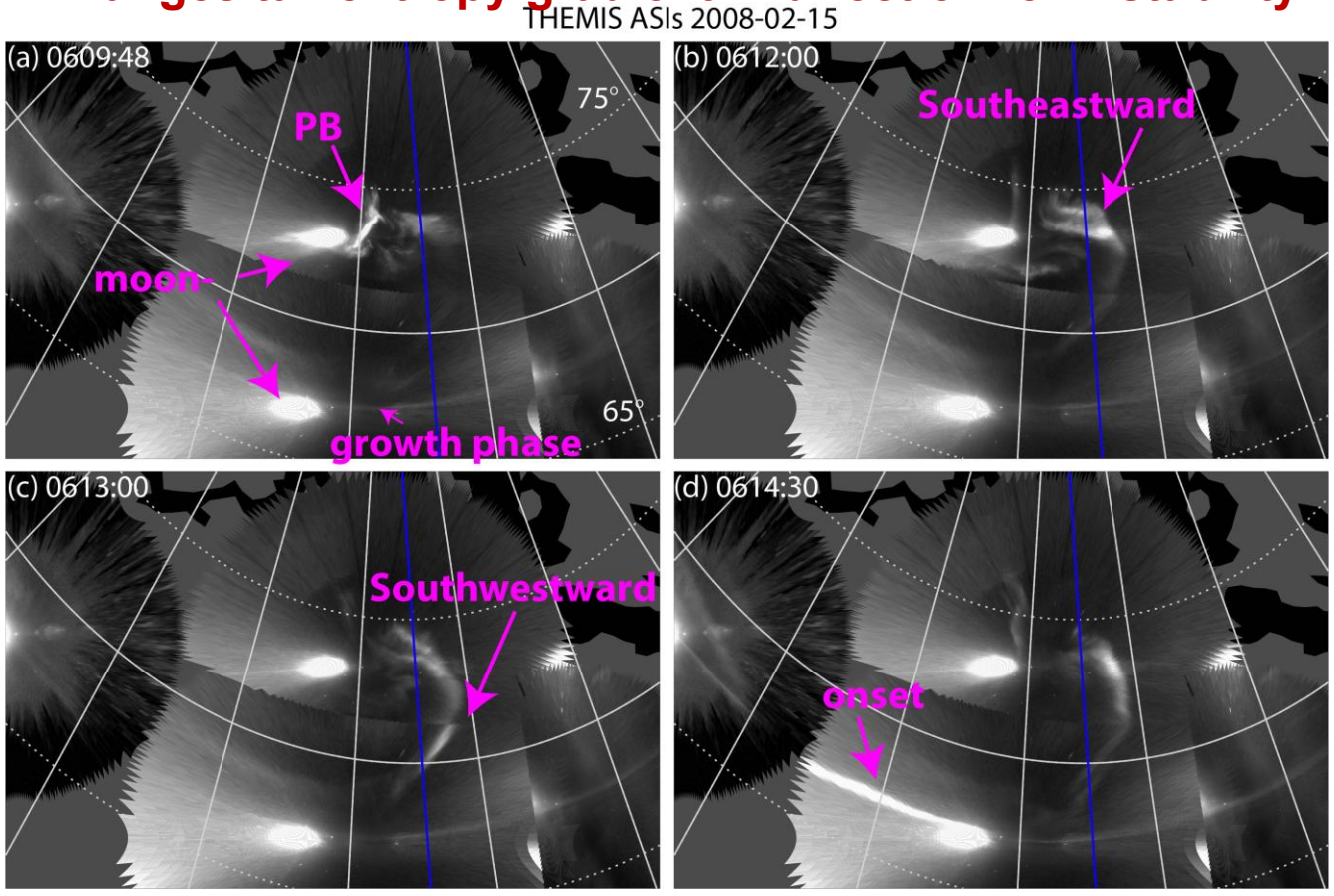
It is the flow channels and associated ionization that cause the substorm H bays
(flow channels can extend from well within polar cap, across PC boundary, to plasma sheet)

Substorms

To trigger substorm onset instability: must have abrupt change in inner plasma sheet conditions:

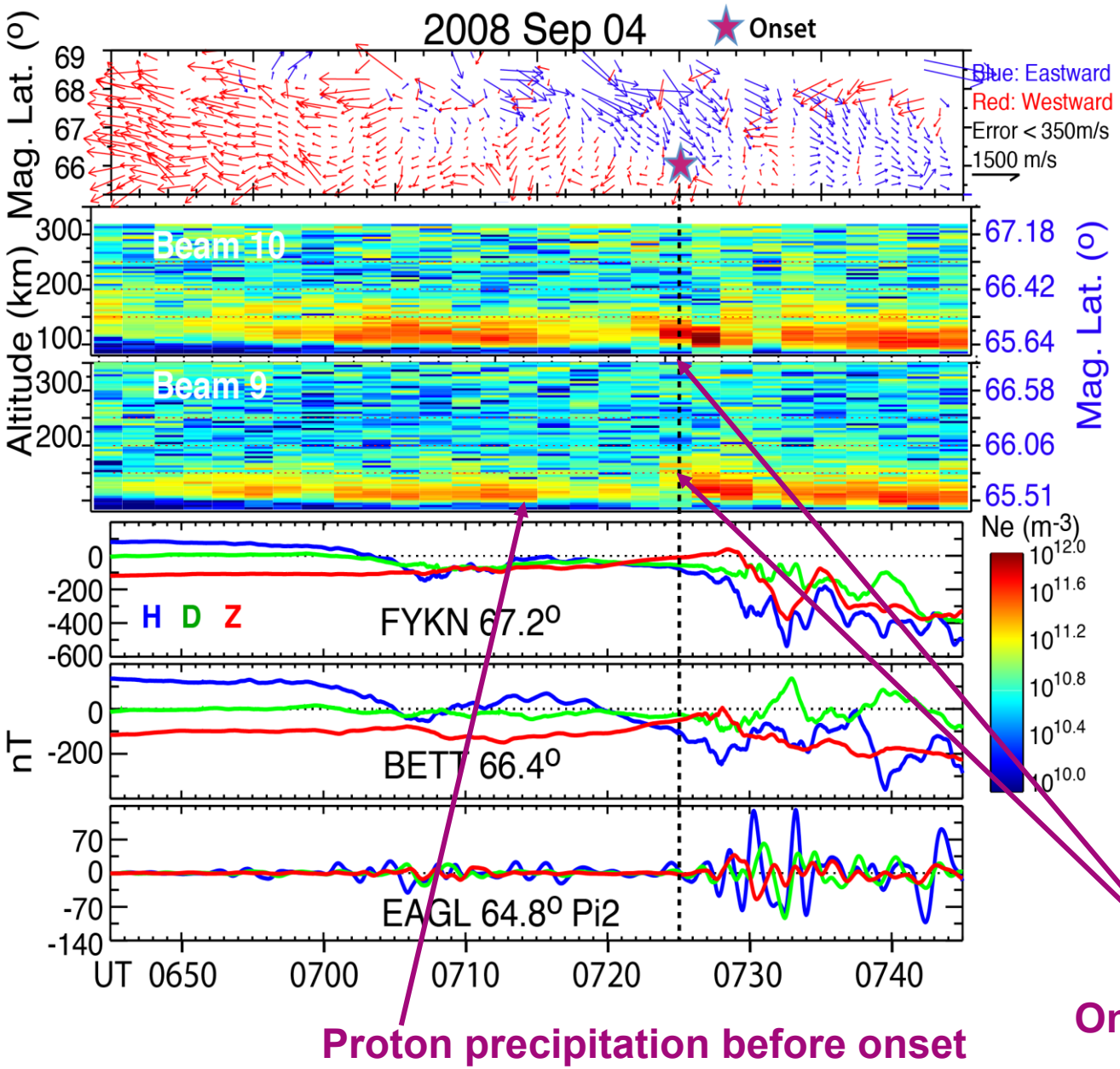
- **Breakthrough: Streamers to onset (*Nishimura+ 2009*)**
- **Streamers reflect: plasma sheet flow burst, reduce entropy flux tubes**

  ⇒ low entropy flow channel to onset
- **Changes tail entropy gradient in direction for instability**



PBI-Streamers to onset seen for 100's cases

- **Implies polar cap flow channels lead to onset**
- **Streamer obs. infer flow to onset**
- ***Can directly test*** using ground radars



Streamers to onset seen for 100's cases

- **Can directly be tested** using ground radar observations of **flows**

Early example ***(Lyons et al., 2009)***

- **Southeastward flow channel to time and location of onset**

Now seen for 10's of examples

Tail flow channels/bursts (thus polar cap flows) **lead to onset**

- But why growth phase arc and **onset instability E-W aligned, and onset expands longitudinally**!
- Related to **why onset streamer** shows flow directed to onset, but **often don't contact onset arc**

Must consider what is E-W aligned in inner plasma sheet!

- **Energy dependent magnetic drift!**
- **RCM modeling of bubble** introduced at tail outer boundary [*Wang+ 2018*]
  - **Flow burst azimuthal spreading by E and B drift** causes E-W orientation of bubble and azimuthal flows
  - **Dawnside:** within bubble/down R1 FAC **(DAPS)** [*J. Liu+ 2020*]
  - **Duskside:** within down R2/SAPS equatorward of bubble [*Makarevich+ 2011; Lyons+ 2015; Gallardo-Lacourt+ 201*

Took advantage of **SuperDARN analysis breakthrough** [*Bristow+, 2016, 2022*]: **High-spatial-resolution velocity measurements** derived using **Local Divergence-Free Fitting** of SuperDARN observations (followed by less-global approach [*Nishimura+ 2024*])

Weak flows ~23-24 MLT

- Some SAPS and DAPS

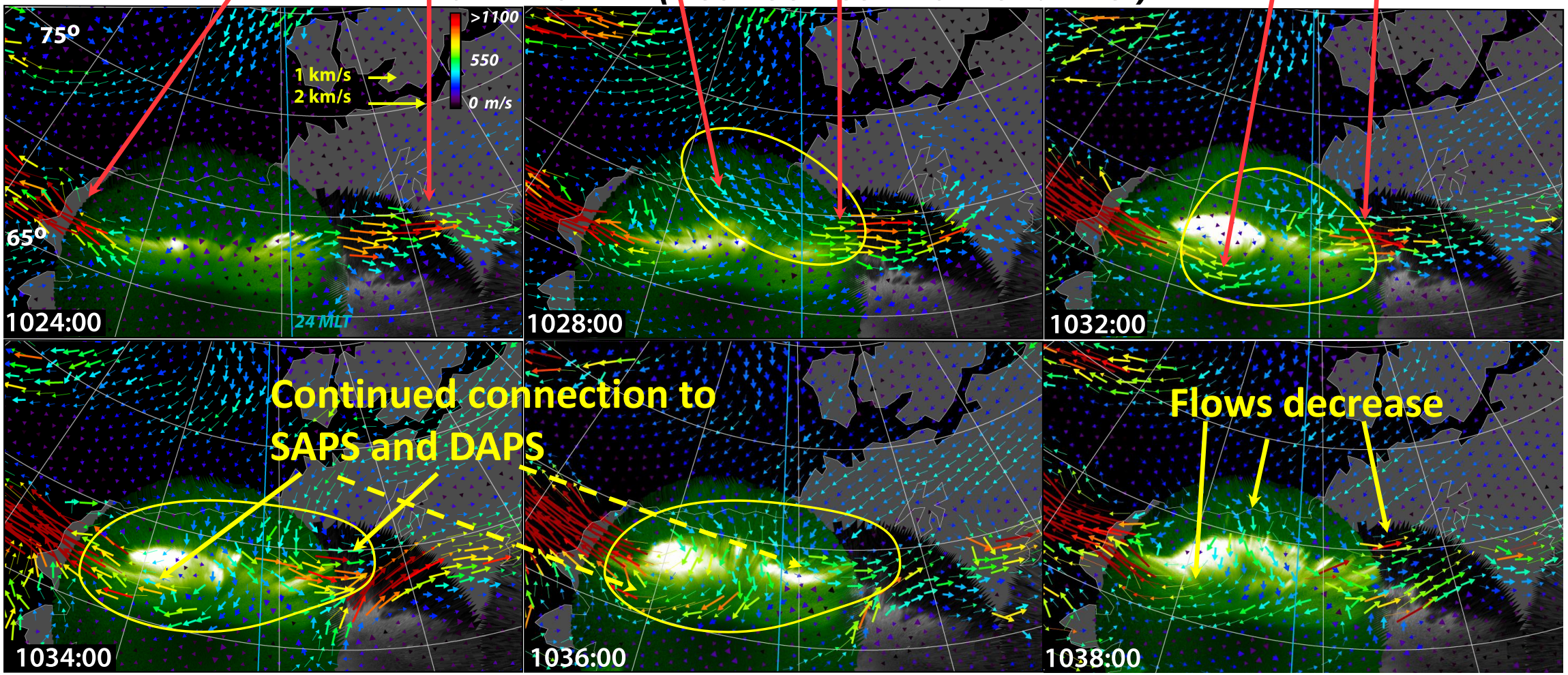
4 min later

- Several 100 m/s channel from polar cap
- Connects to DAPS increase

4 min later: Flow channel

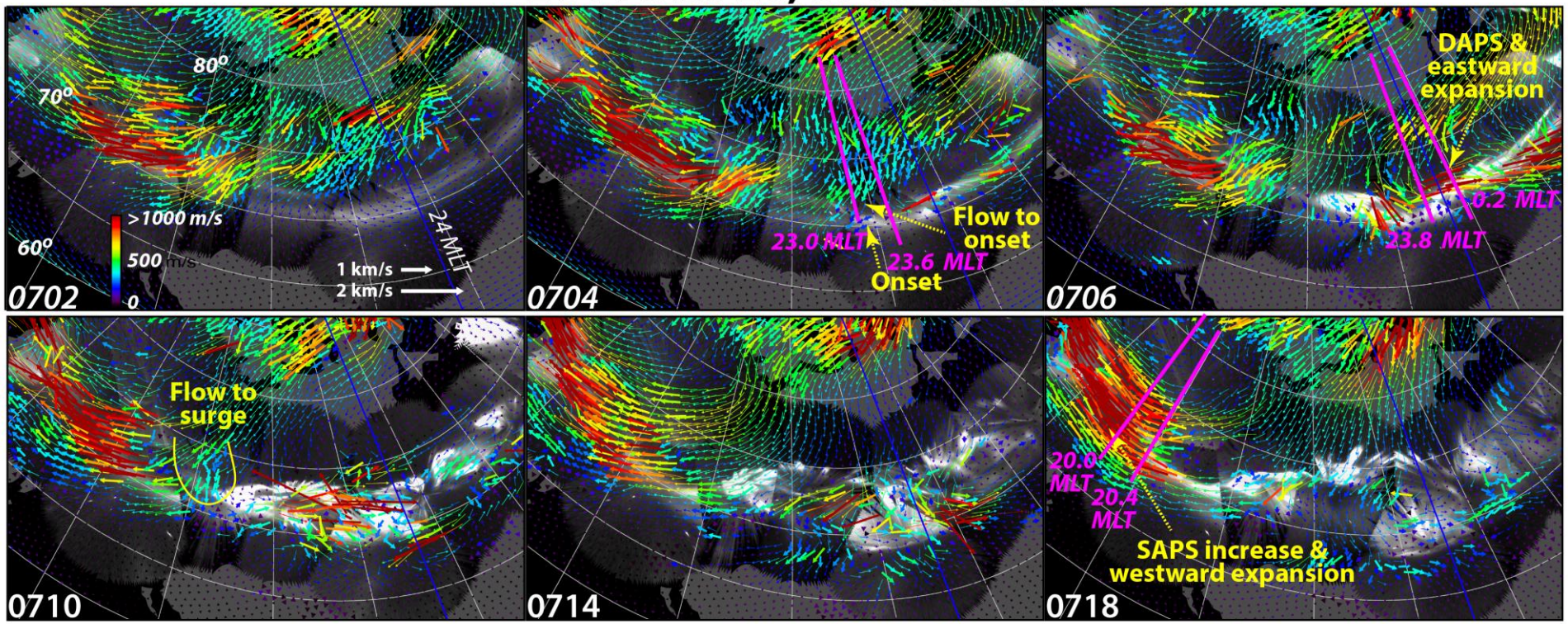
- Connects to DAPS increase
- And to SAPS increase

2012 Nov 11 (between cell flow channel)



See also for substorm flow channels [*Lyons+*, 2021. 2022]

2014 Mar 26, 0703 Onset



SAPS meridians

Onset meridians

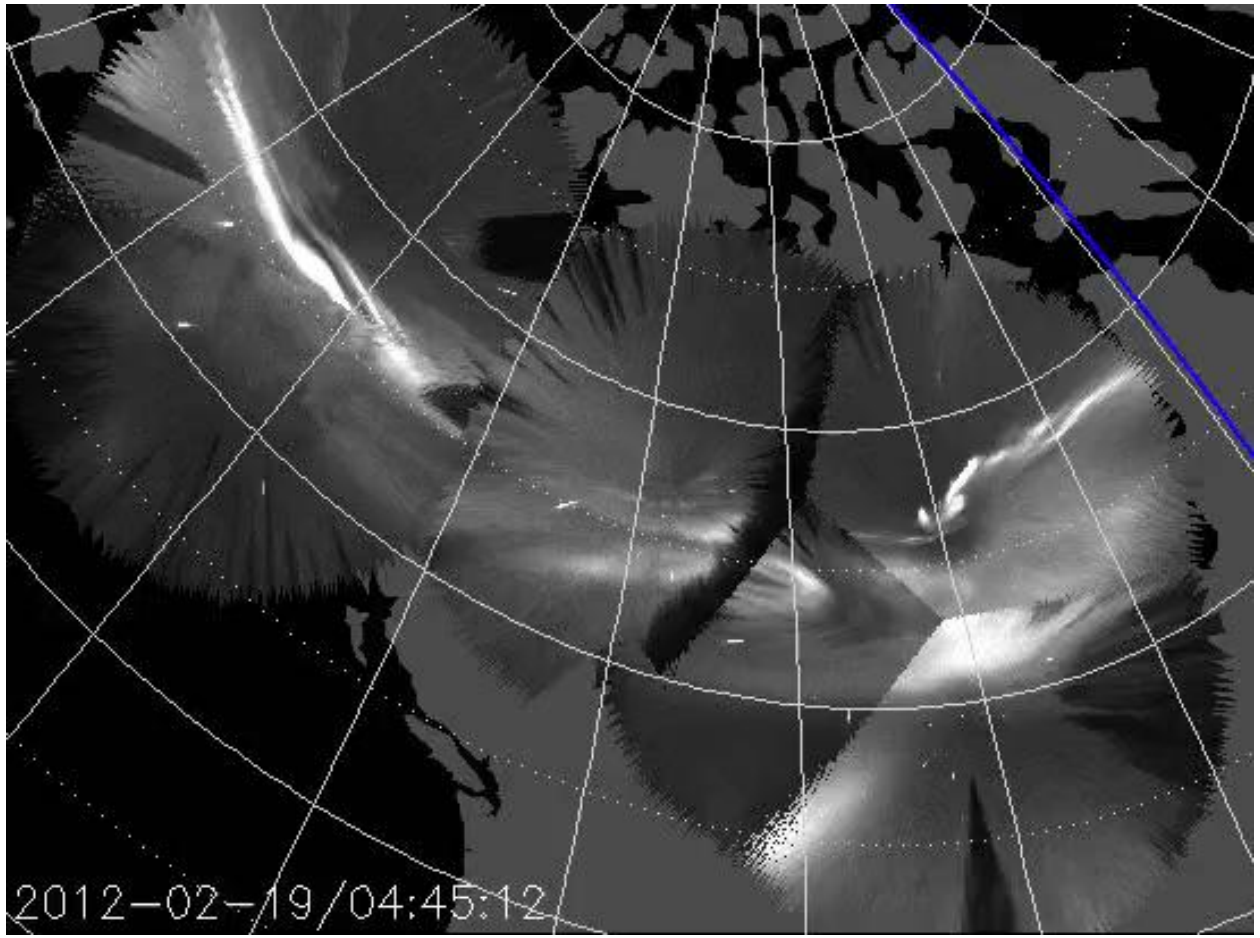
DAPS meridians

Variant of streamers to onset scenario

2012 Feb 19 CME storm

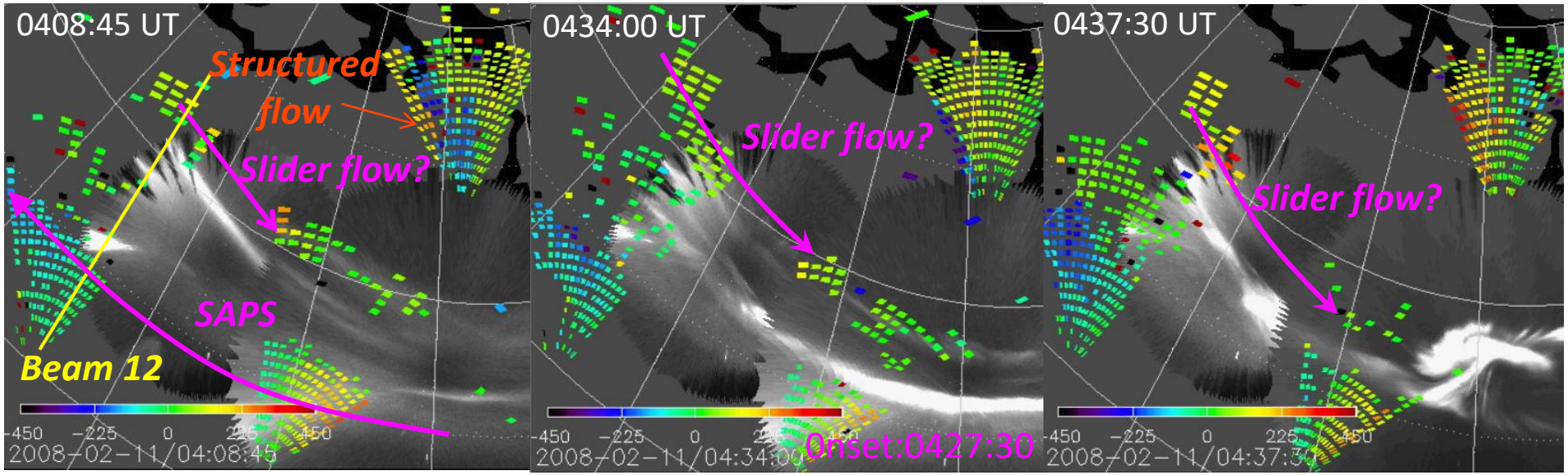
0500-0511 UT: Poleward boundary streamer tilts equatorward:

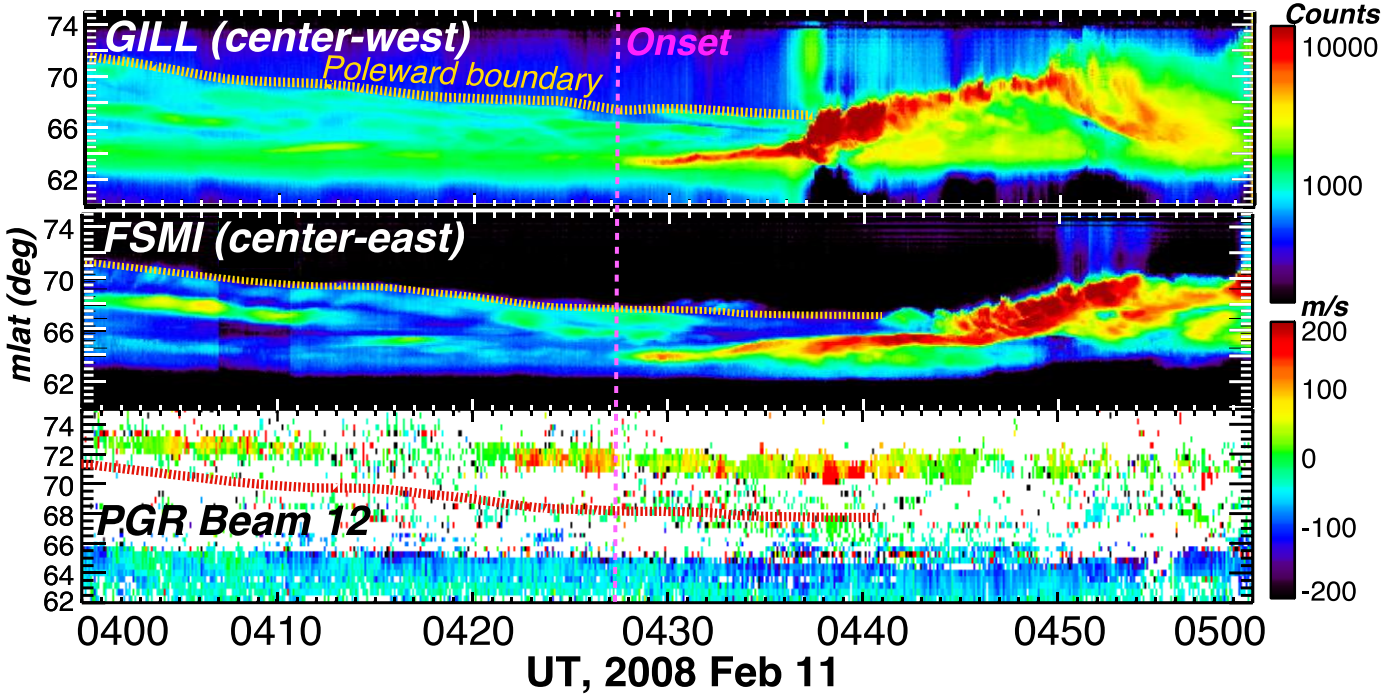
- **Reaches onset MLT, onset first detected 0511:21 UT**
- **⟹ polar cap flow channel** adjacent to tilting boundary streamer **leads to onset**
- **Also:** Expansion activity **expands westward via connection to tilted streamer**



(***Lyons*+, 2013, 2018; *Yadav*+, under review)**

2008 Feb 11 event

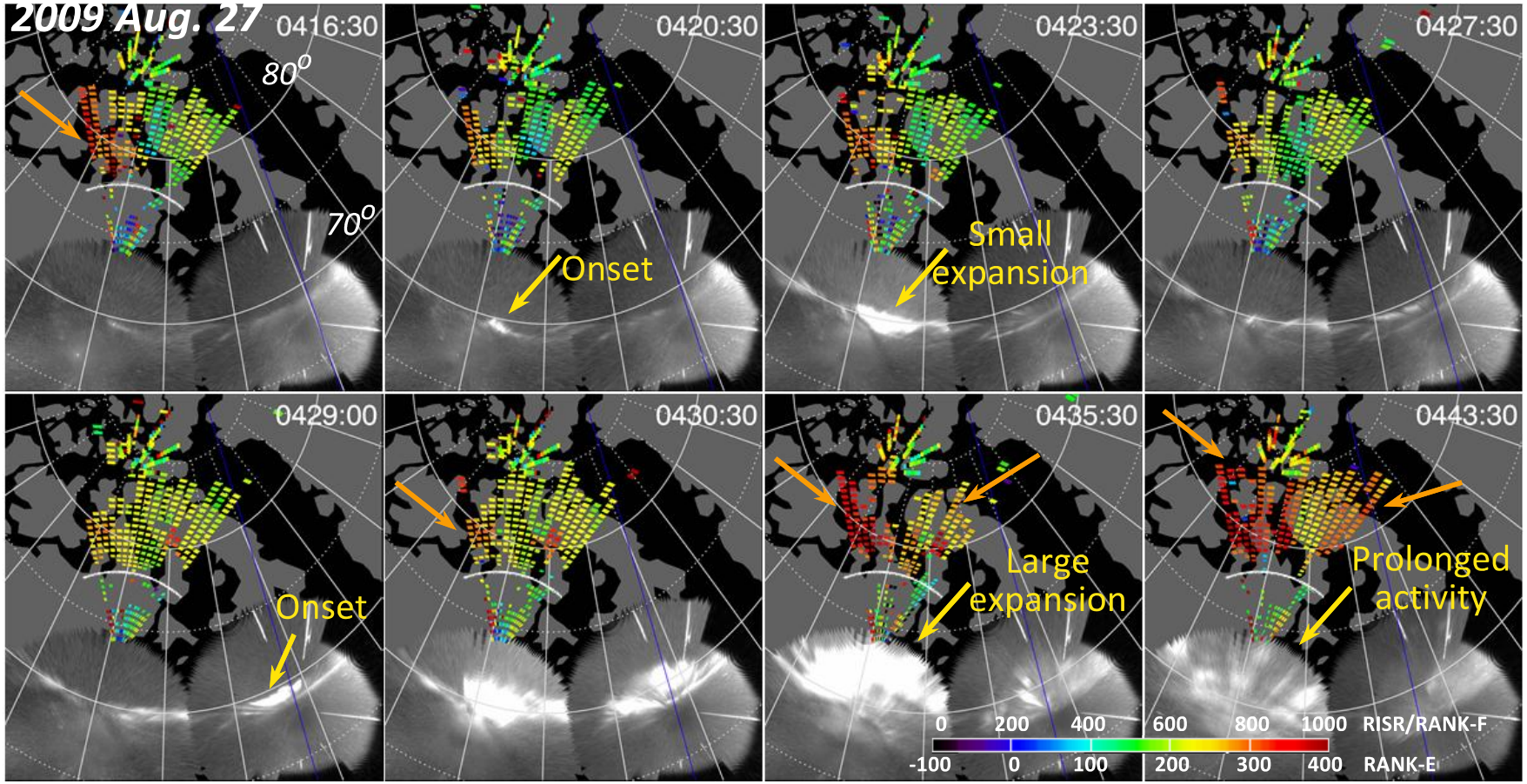




Evidence that enhanced meso-scale **polar cap flows may, in general, be important** for auroral activity and poleward expansion.

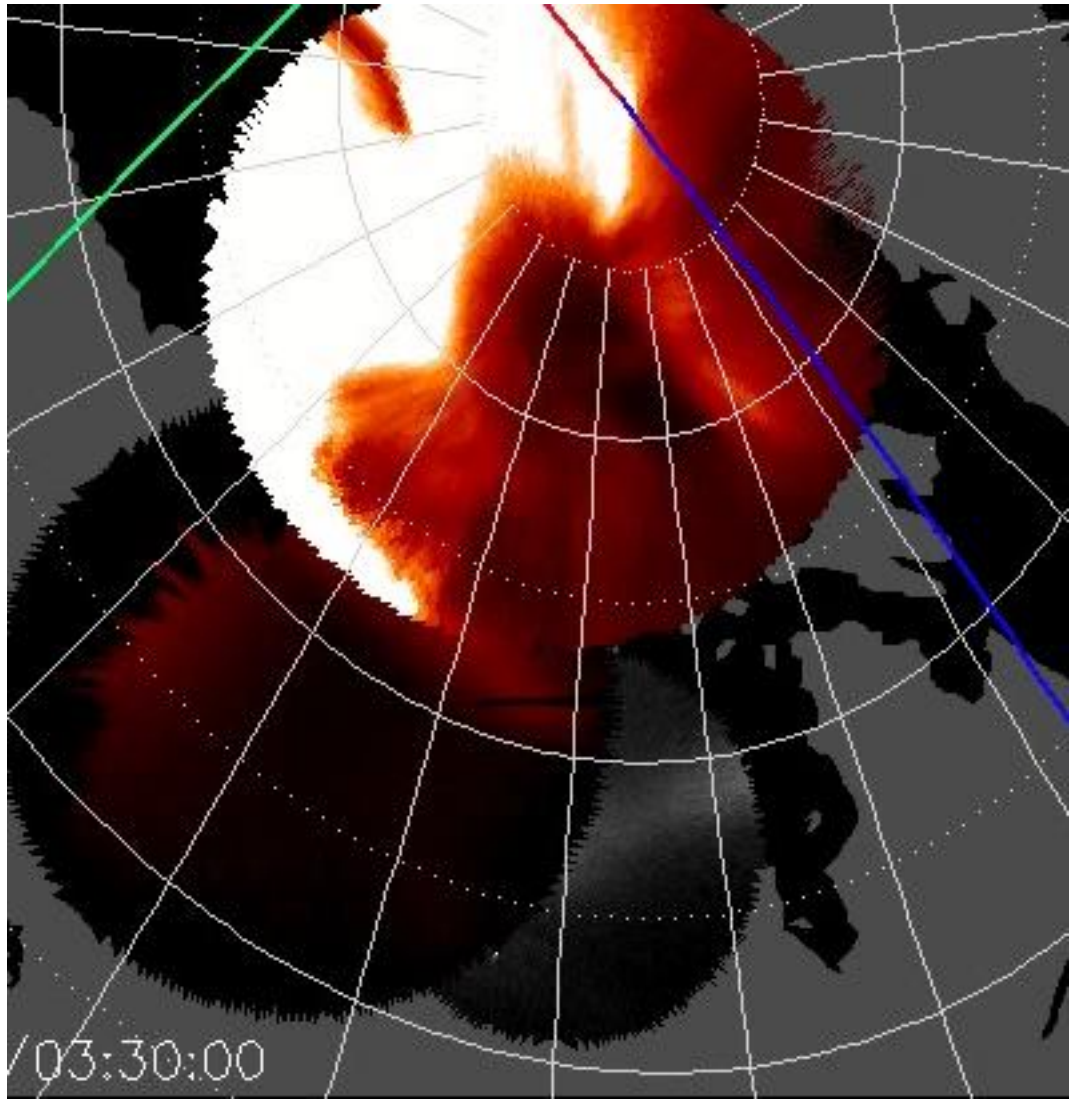
Such flows **after substorm onset:** possibly important in **controlling poleward expansion and duration of post-onset auroral activity**

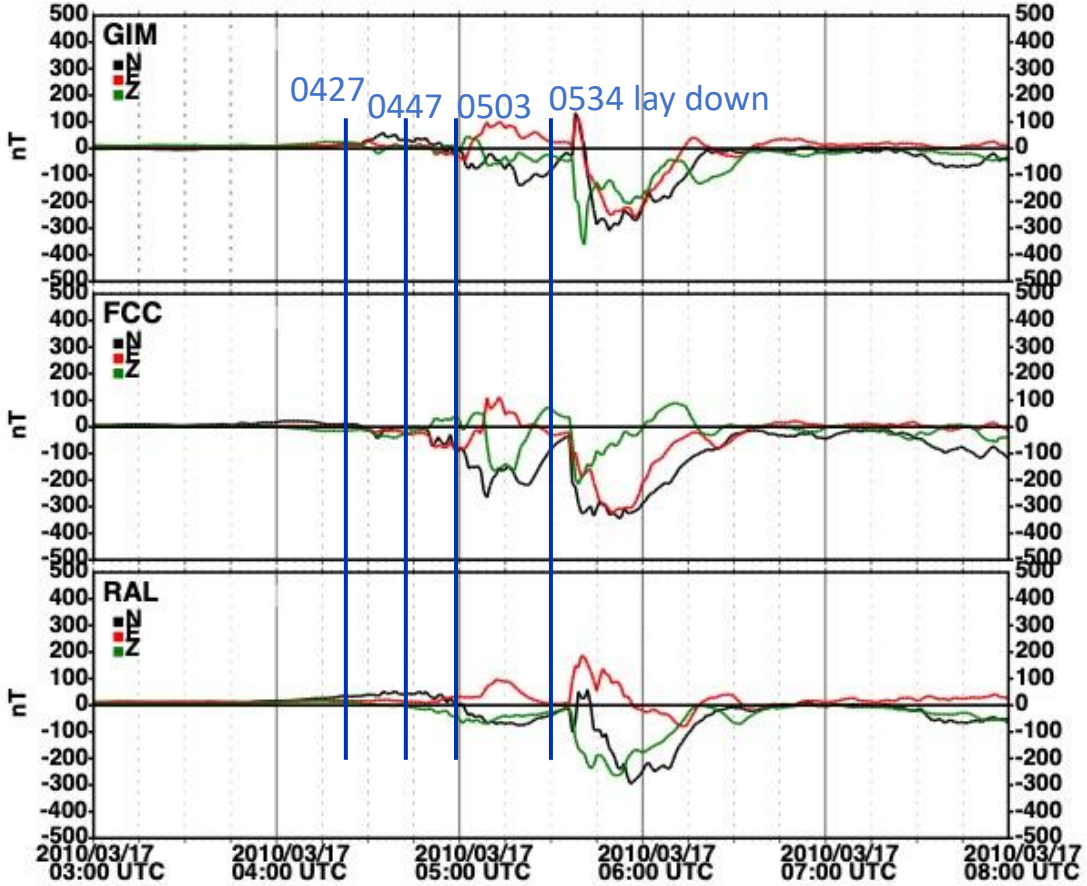
[Lyons +, 2011]: .



2010 Mar 17: By > 0 “Lay-down explosion” Red Line Imaging (Res. Bay, Rank), THEMIS ASI

(PC arc followed from 0330 to 0534 UT “explosion”)

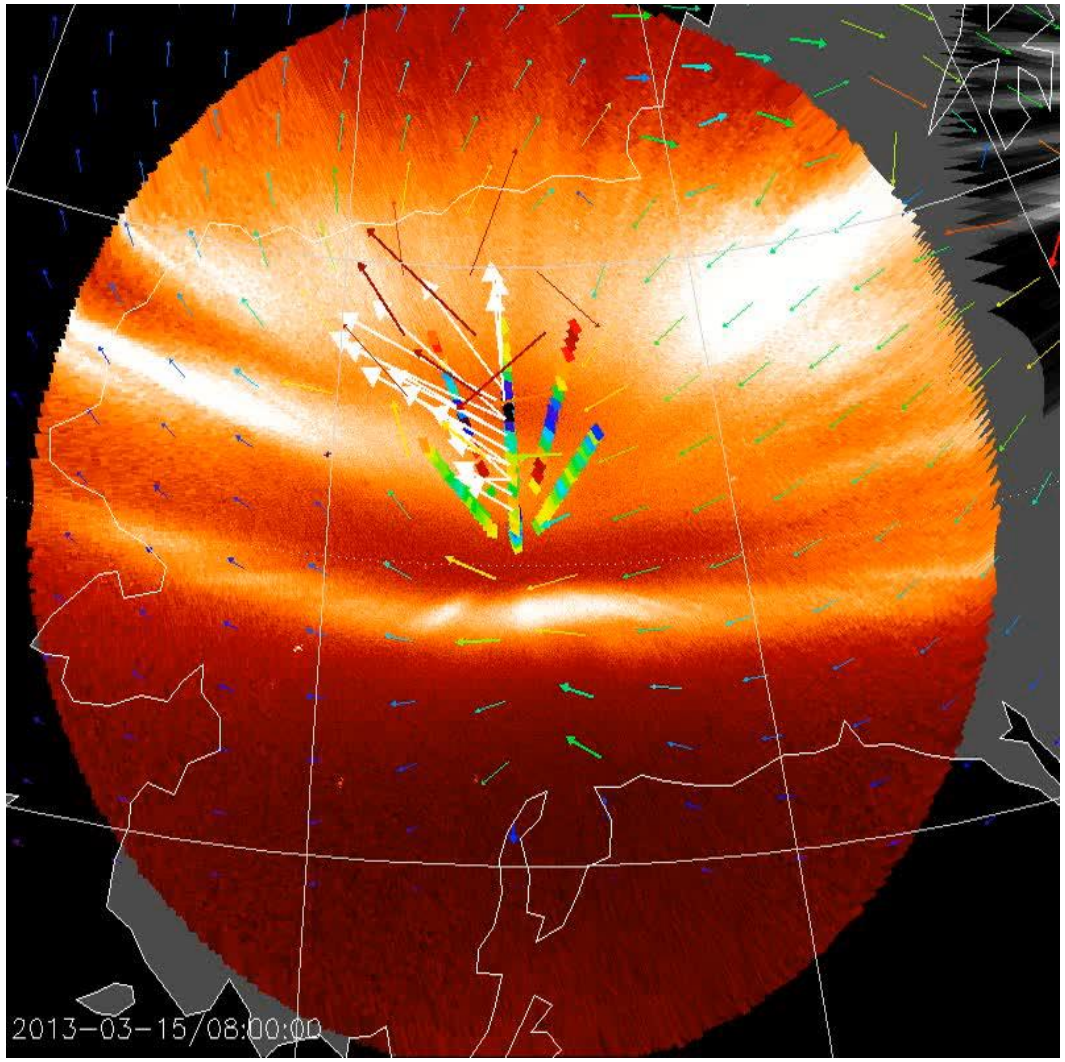




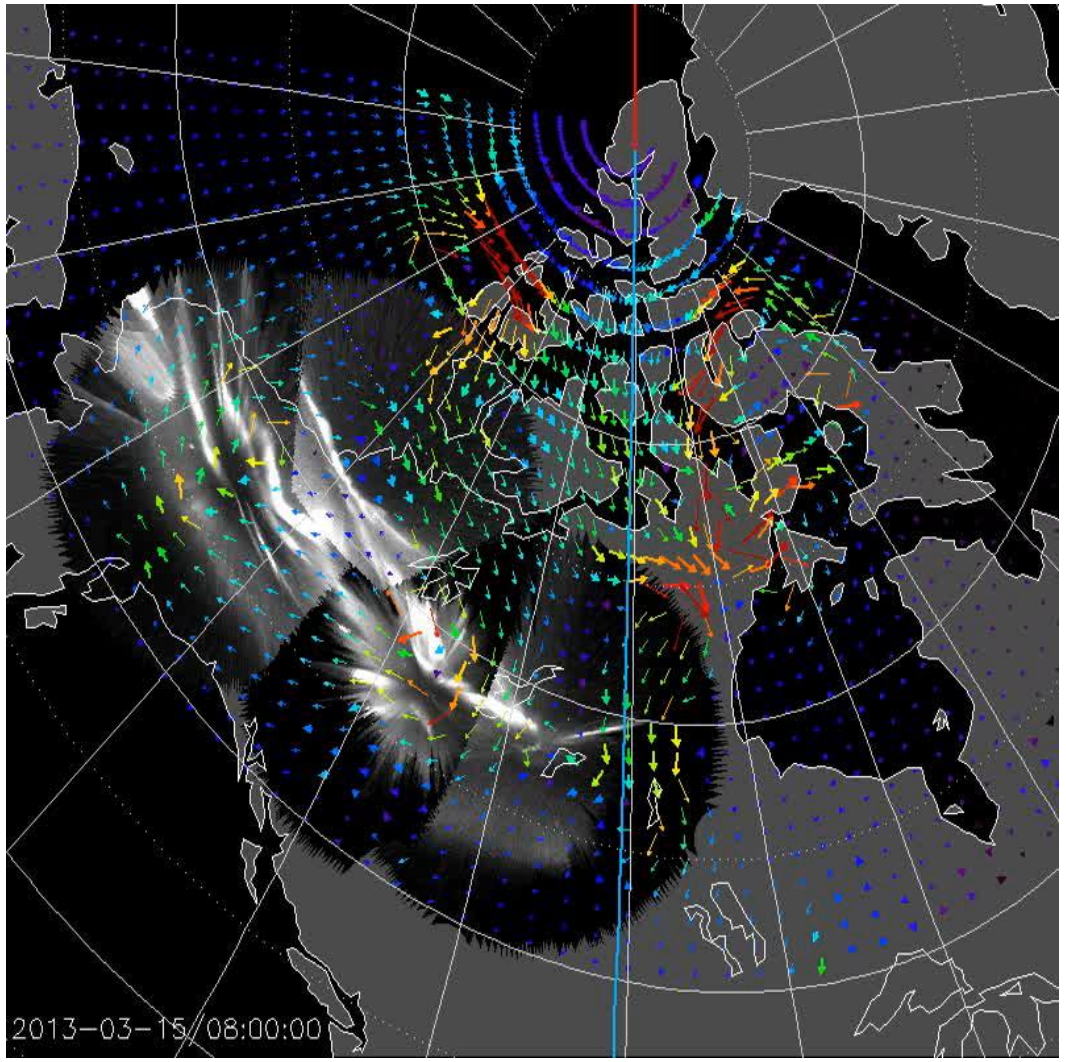
Multiple onsets: 0427, 0447, 0503 UT

Large “lay down” onset: 0534 UT.

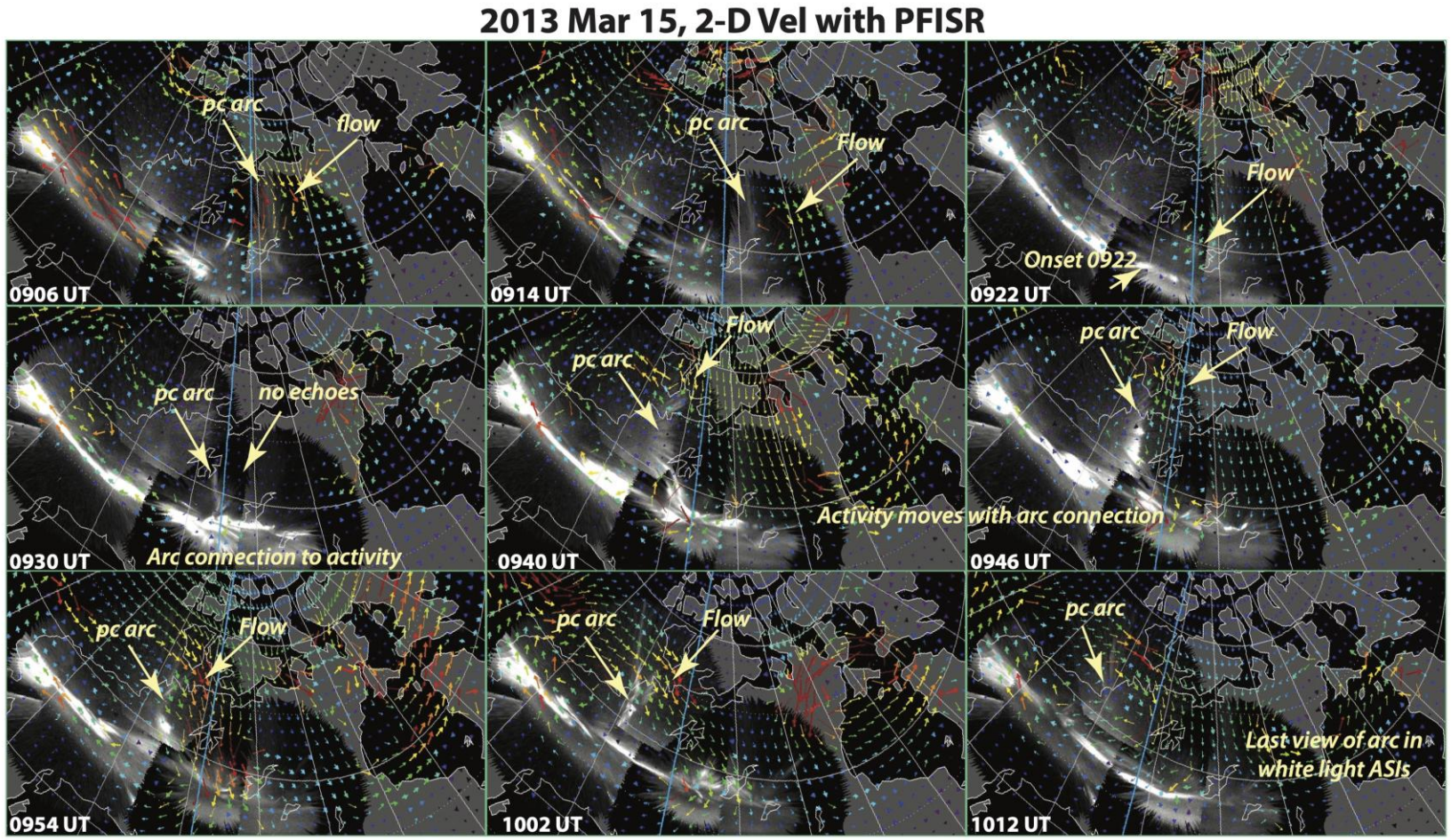
2013 March 15: ~ 2hr pc arc trip across nightside polar cap



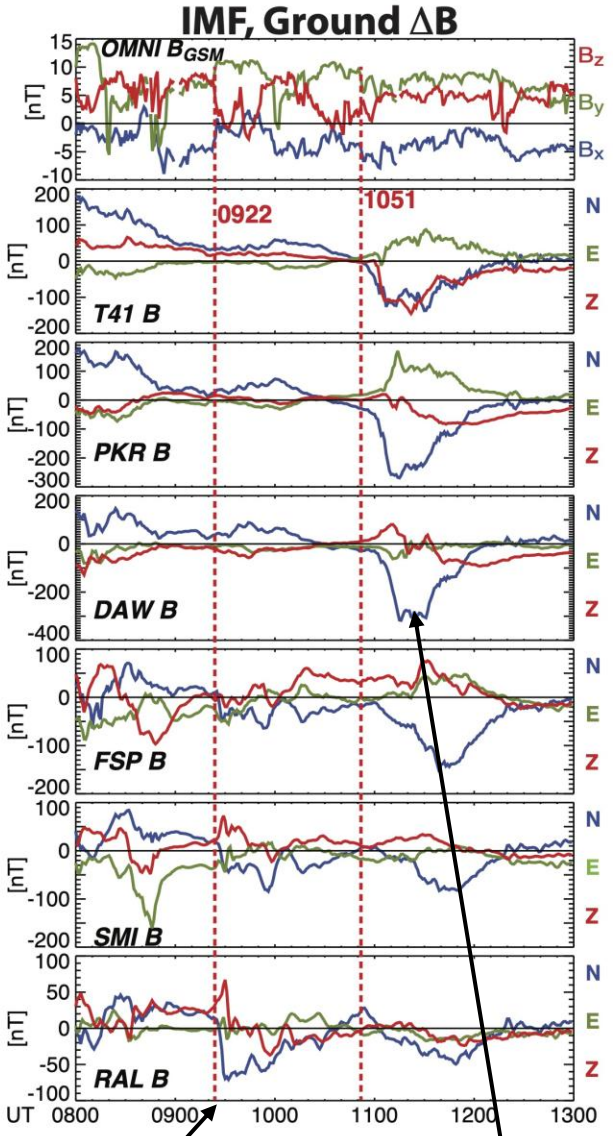
Then trace 1st over Alaska



Trace 1st over Western Canada

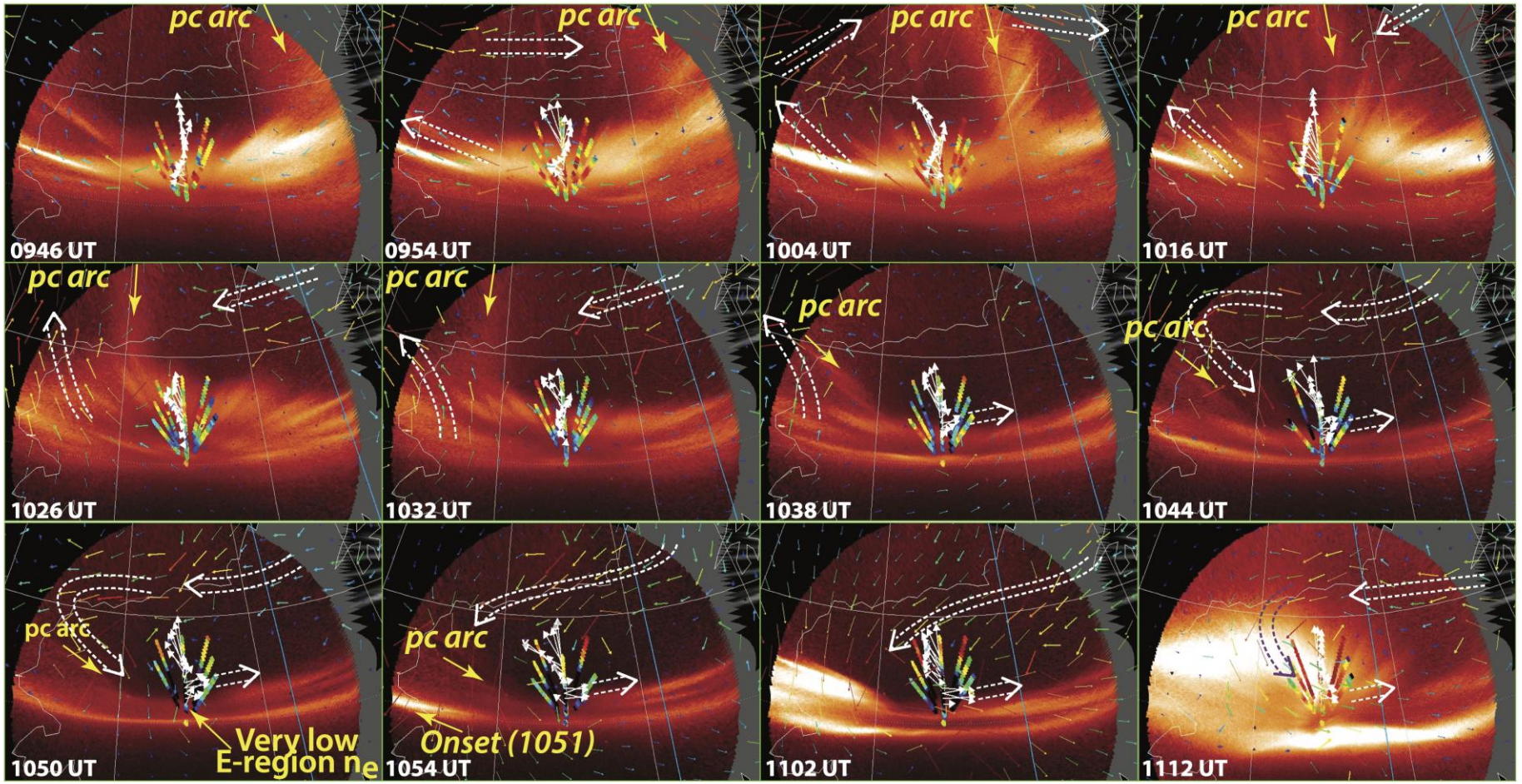


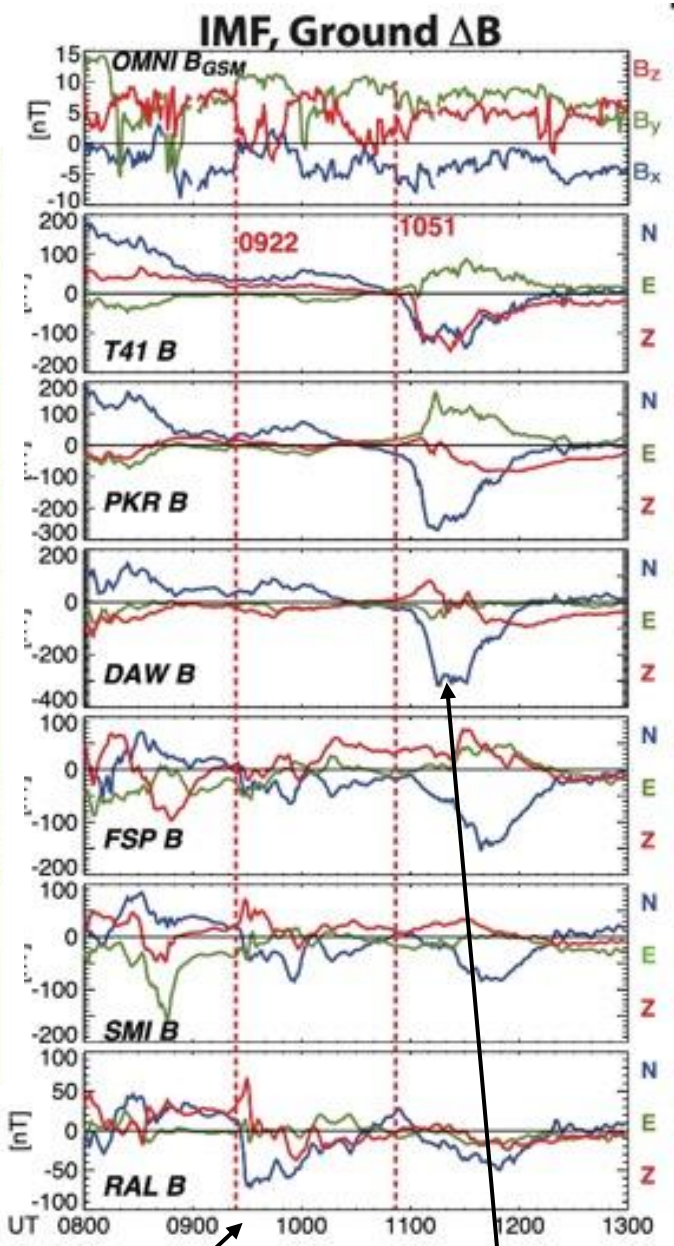
Last view of arc 1012 UT



60 nT 0922 UT onset

300 nT 1051 UT onset

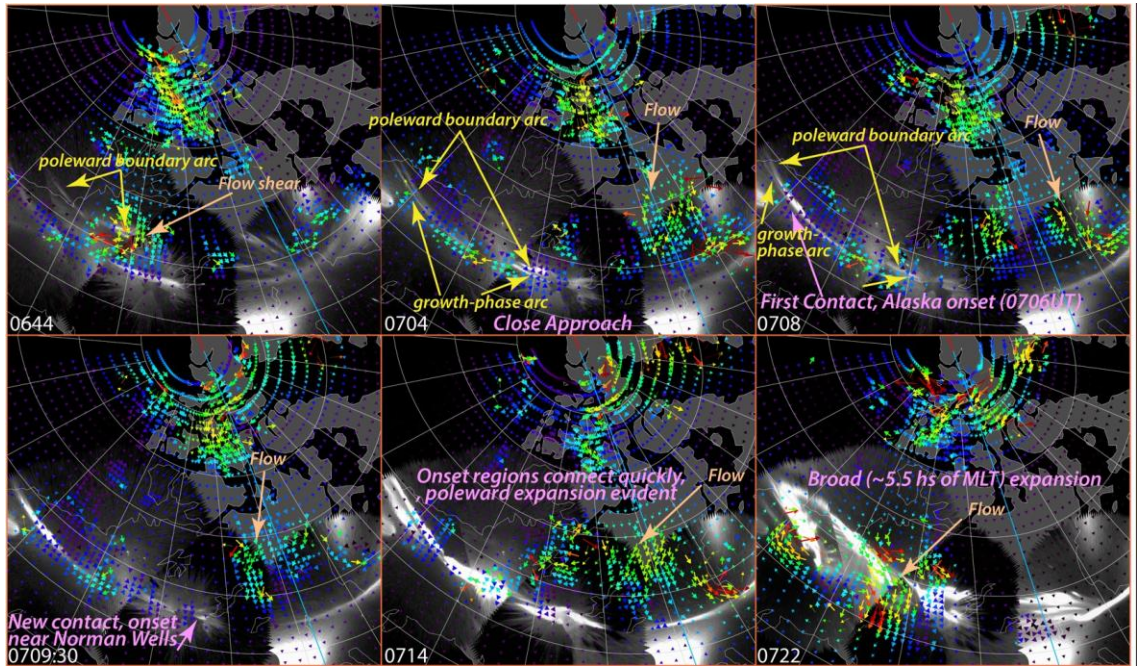




Note:

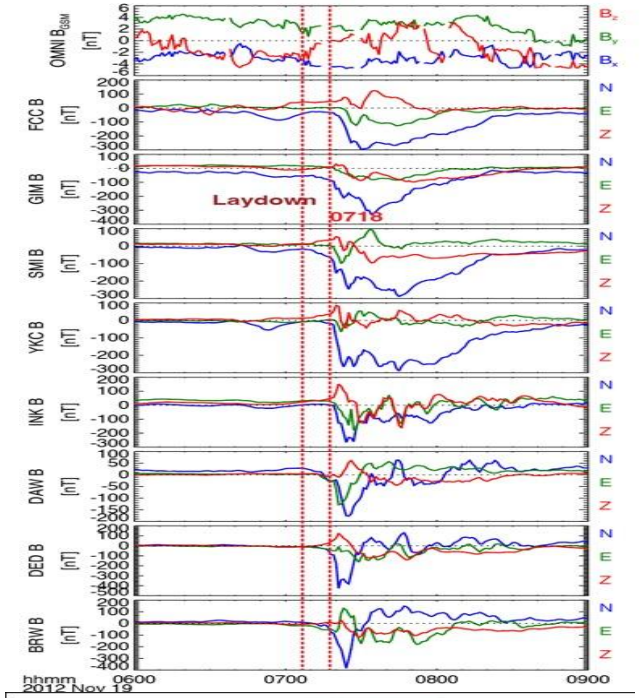
- Equatorward/westward **flow "pushing" pc flow from northeast**
  - **Pc arc like a weather front**
- Flow turning adjacent to oval boundary
- Pc arc **"lays down" along oval poleward boundary**
- **Oval becomes thin** based on aurora and PFISR n_e

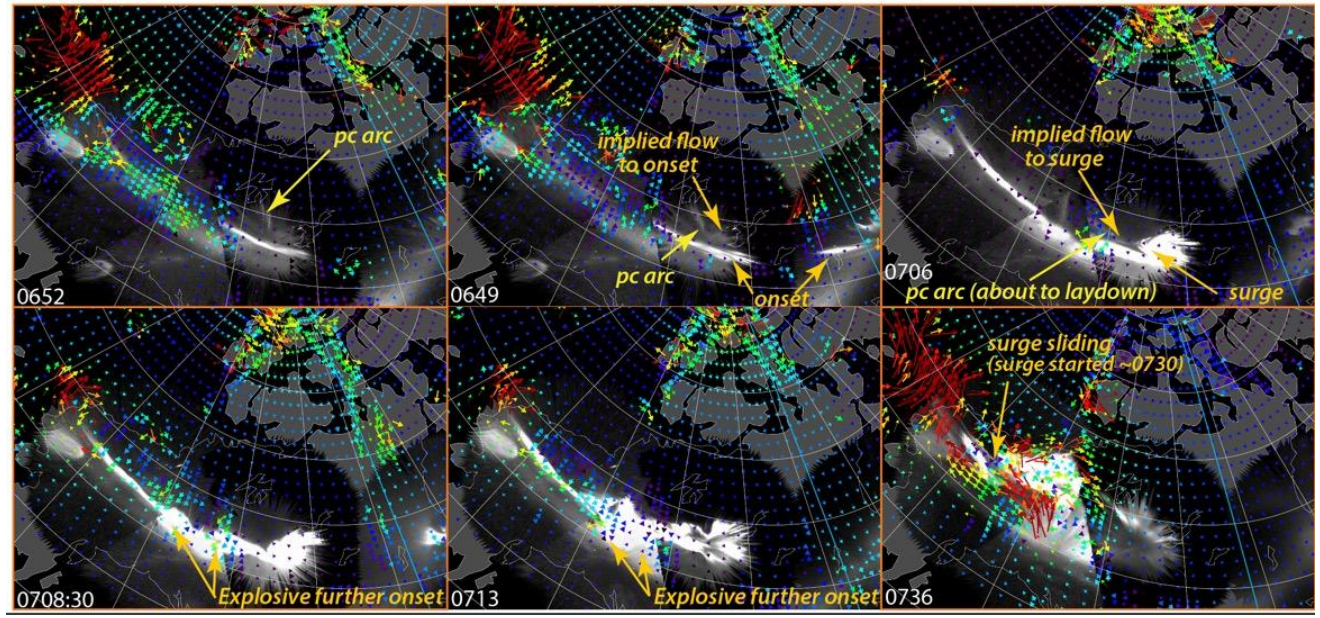
Two More Illustrative Examples



19 Nov 2012: Rapid broad laydown

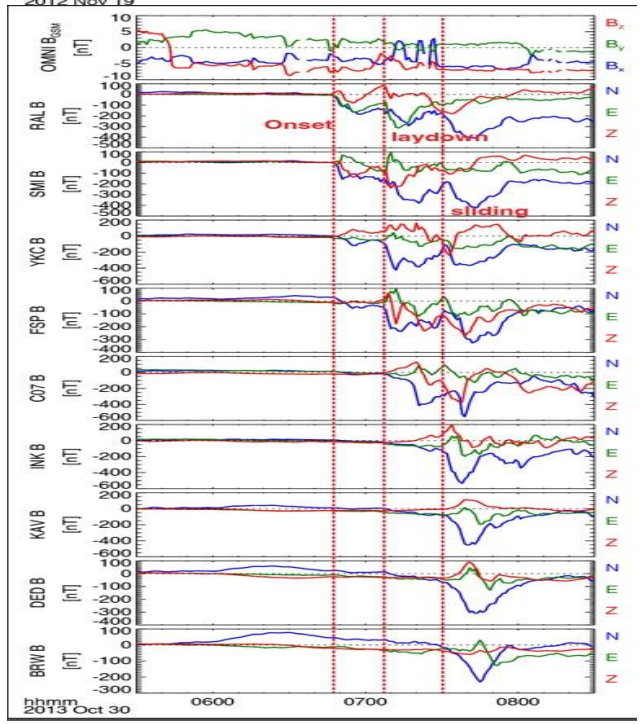
- **Gives rapid broad 400 nT onset**





30 Oct 2013: Laydown west of ongoing surge

- **Gives explosive further onset west of connection to surge**



Summary

Radars & ASI revealed much polar cap localized flow structure

- Some structures long lived (~2-4 hrs sometimes), yielding multiple oval disturbances

Can cross into oval/plasma sheet (localized driven reconnection)

- Brings **new plasma into plasma sheet,** can have **lower entropy**
  - Leads to ionosphere **flow channels**\plasma sheet **flow bursts**
- **Lower entropy plasma intrusion leads** important **oval disturbances**
  - *PBIs*
  - *Streamers*
  - *Omega bands (DAPS)*
  - *Substorm onset; subsequent spatial size and duration, including surge development*
  - *Dramatic "Laydown" events*

Fundamental questions

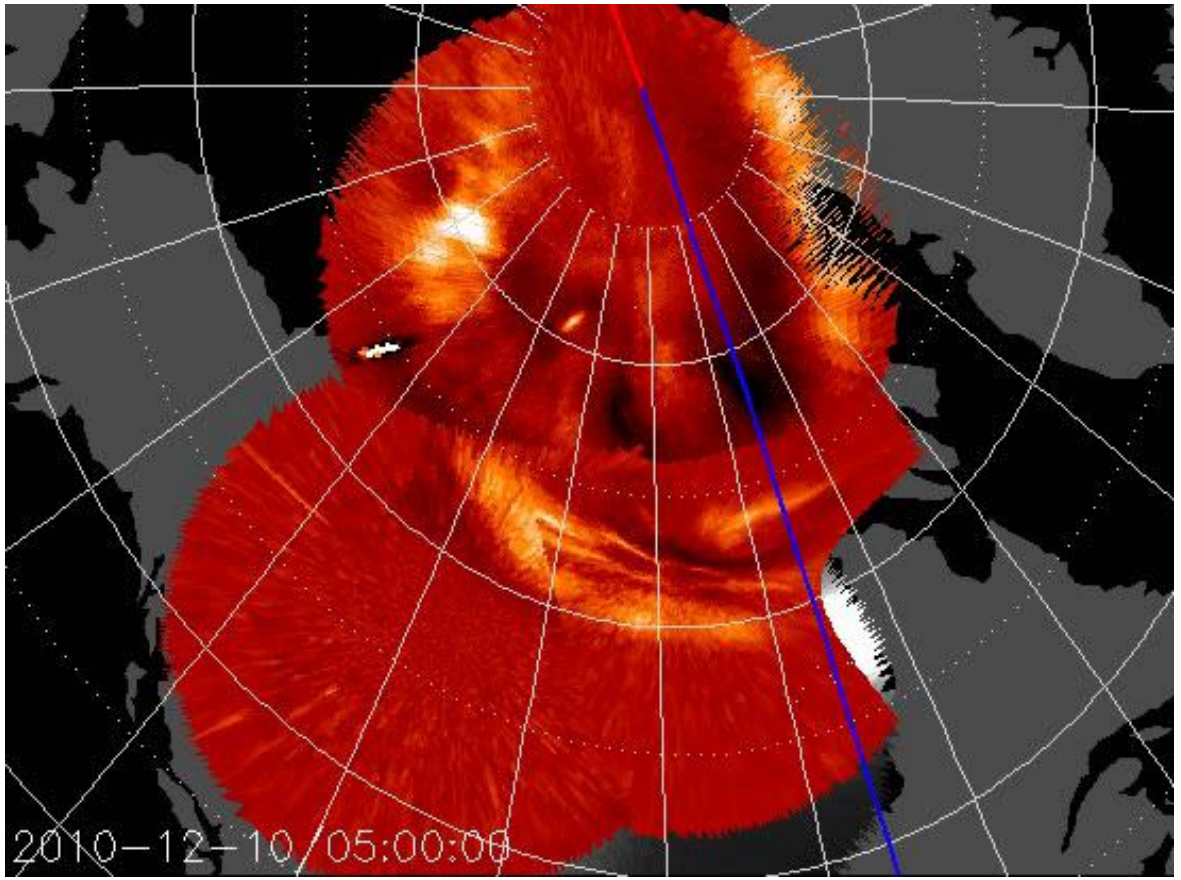
Formation and propagation of structures across open polar cap field lines

- Including connections to magnetosheath structure
- For localized and long-lived ("weather front"-like) structures

Physics of

- **Localized triggered reconnection**
  - formation of **lower entropy plasma sheet**
  - Relation to PBI and streamer formation (i.e., *Ohtani and Yoshikawa*, 2016; Ohtani+ 2018)

- In addition to apparently localized flow channels
- 4 hr red line movie [Y. Zou+, 2015] **dramatically illustrates some polar cap flow channels have long duration leading to multiple disturbances:**
  - **Polar cap arc (thus flow channel) long duration (4 hrs!)**
  - **Connection to oval and weak (~20 nT) disturbances**
  - **Features, thus flows, map continuously from polar cap to oval**



Weak northward IMF Bz; variable By