# PLASMA SHEET FLOWS AND RELATIONSHIP TO SUBSTORMS

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# OUTLINE:

Historical perspective

Organization based on downtail distance

Examples at various substorm phases

Open questions

# Historical perspective.

Pre-ISEE era (~<1977) [Pytte and Hones series]:

Vela at $18R_E$ (and Ogo, Esro, ISIS) establish:
Substorm flows agree with Rx@$15R_E$ geometry.

Growth phase thinning and PS recovery.

Poleward leap of auroras at PS recovery.

Arc maps to very near Earth; seed for CD model established. No flow observations.

IMP6, 7, 8 at ~20-$35R_E$ establish:

50% of onset conditions are associated with PS activity.

80% of onset flows tailward but field topology complex [Hones et al.; Caan et al. JGR'79]

Boundary layer quite distinct [Lui et al., JGR'77]

Plasma sheet flows ubiquitous, Rx unsteady, activity high latitude [Coroniti, JGR'78]

Source location bracketed and size ($\Delta X$~500 km) identified [Sarris et al., GRL'76]

ISEE and IRM era (1977-1990):

ISEE:

PSBL dynamically important [Eastman et al.,'84]

PSBL represents non-local activity; ion DF's dispersed; retreating NL? [Forbes et al.'81]

Retreating plasmoids discovered and linked to substorms [Hones et al.,'82]

IRM [BJ et al.'88; '89; '90]:

Near NS flows just as important statistically as PSBL flows.

Average PS flow small (~30 km/s) both near NS and at PSBL.

PS flow interrupted by short-lived, fast flows.

Positive relationship with geomagnetic activity.

CCE@9$R_E$ [Lui; Lopez; Ohtani: late 80's-'90s]

"Whatever causes onset is close and is moving tailward."
Supported by imagers and mapping arguments.
[Elphinstone, et al. JGR'95; Samson, et al., GRL'92]

pre-ISTP era (1990-1994):

ISEE-IRM [Angelopoulos et al.'92;'94]:

Fast flow samples of BJ revisited:
Flow bursts (1min) within BBFs (10 min).

Transport properties of BBFs dominant in PS.

Relationship to substorm phase unclear.

Relationship to substorm activity is positive.

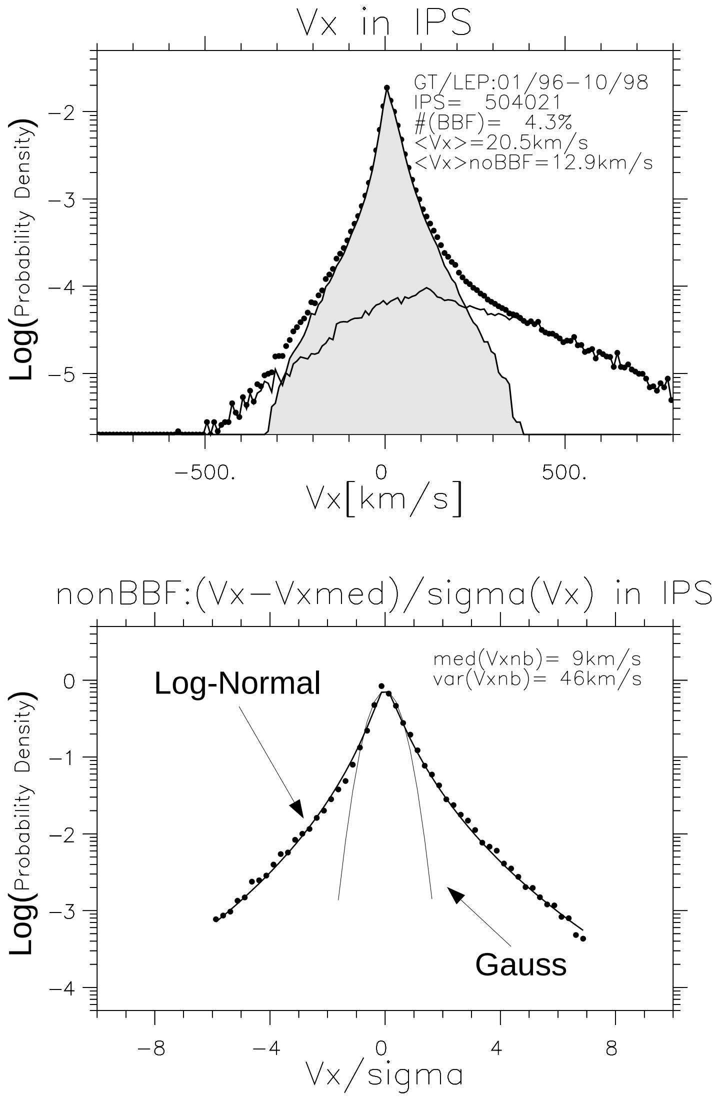
Bimodal nature of flows established.

Geotail era (1994+):

Most frequent observation of Rx=28$R_E$ [Nagai et al.'98]

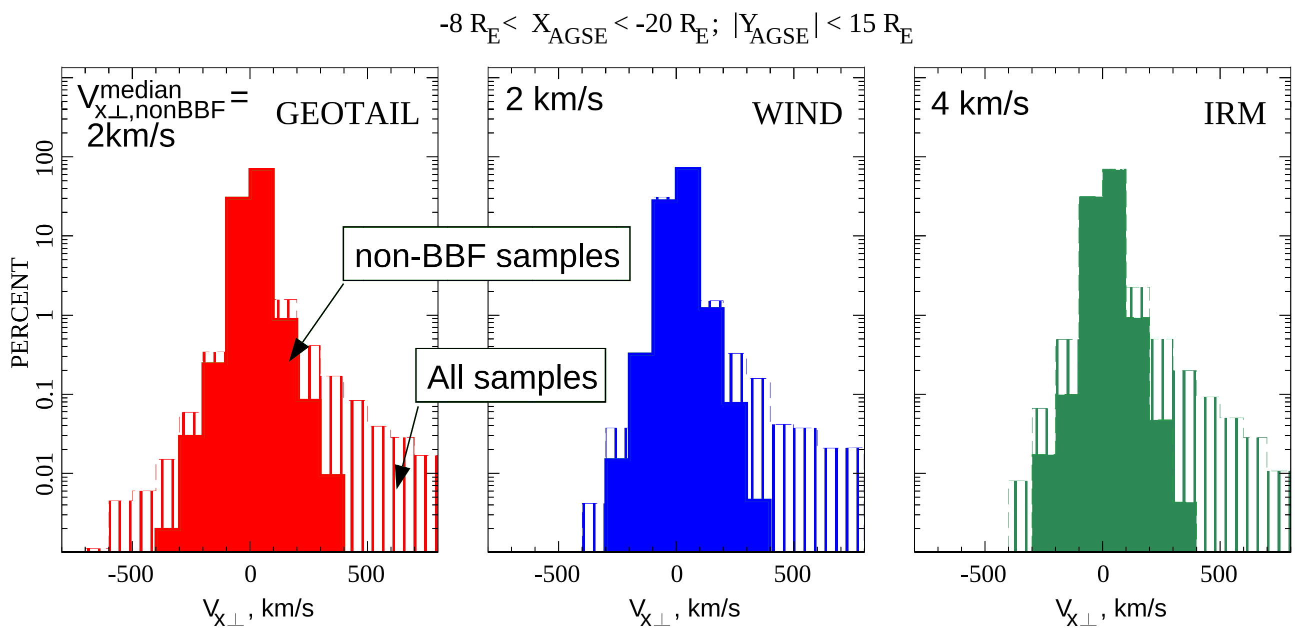
Fast flows and substorms: Ongoing research.

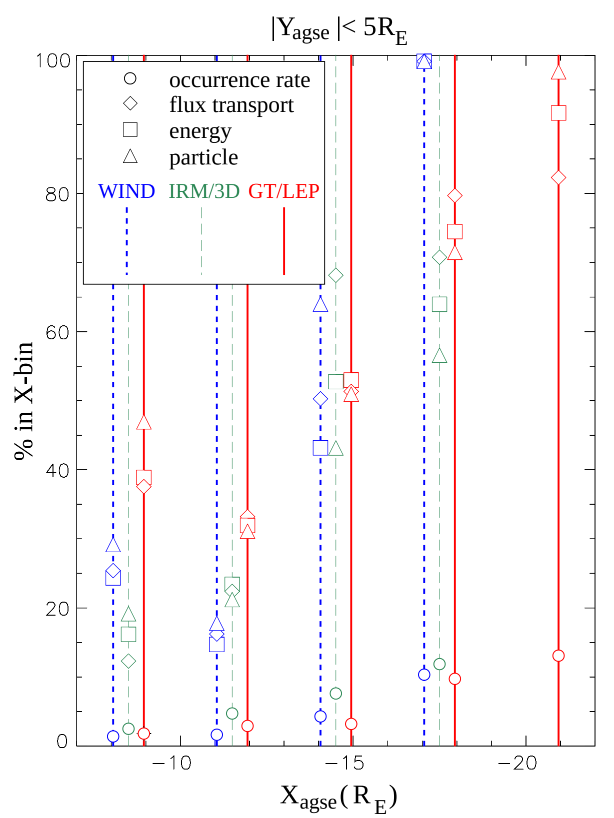
Probability distribution of the flows suggests intermittent turbulence operative.



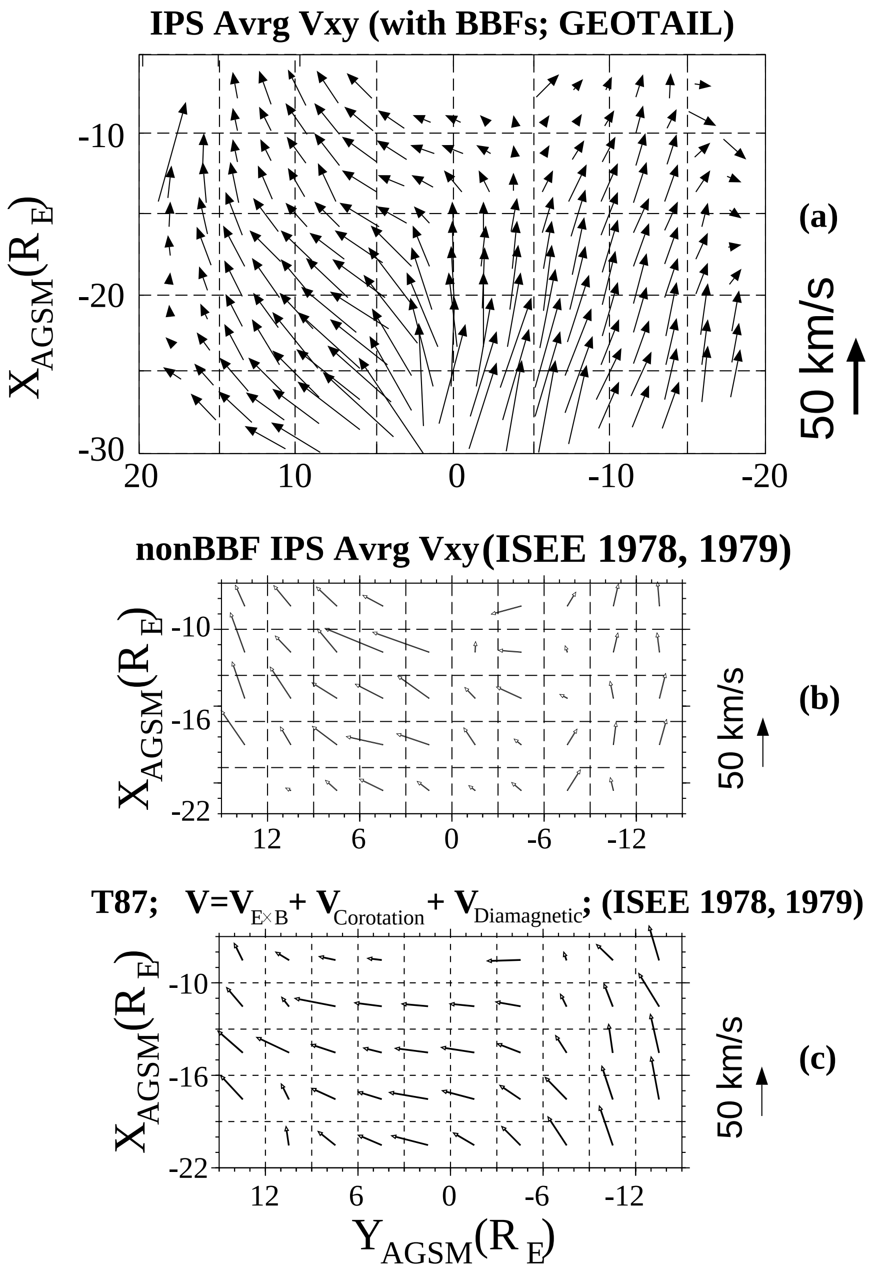

Angelopoulos et al., *Phys. of Plasmas, submitted*, 1999.

# PS flows are bimodal; flow bursts are likely drivers:



Remnant flow is primarily cross-tail drifts at midnight with small Earthward flow near flanks.




Reproduced from Walker et al., *ISSI volume on Sources and Losses of Plasmas*, [1999]. (a) From Maezawa and Hori, JGG, 1999. (b) and (c) from Angelopoulos, ICS3, 1996.

FLOWS BY DISTANCE:

Very Near-Earth (|X|~<15 $R_E$)

Tailward Flows (all short lived prior to small onset):

Angelopoulos et al., ICS2, 1994 (ISEE 1&2)
Sergeev et al., JGR, 1995 (same as above)
Nagai et al., JGR, 1998 (GT@15 $R_E$)
Petrukovich et al., JGR’98 (IB@12$R_E$-GT@28$R_E$)

Earthward Flows (at onset):

Fairfield et al., JGR, 1998 (GT@12 $R_E$)
Shiokawa et al., JGR 1997 (IRM@13 $R_E$)
Angelopoulos et al., JGR, 1999 (GT@10 $R_E$)

Near-Earth (15<|X|<25 $R_E$) [onset, recovery, all latitudes]

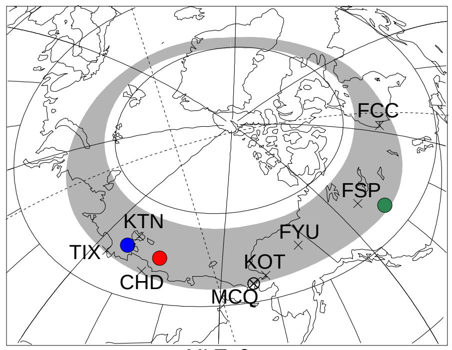
Angelopoulos et al., JGR, 1996 (GT@18 $R_E$)
Lyons et al., JGR, 1999 (GT@16-30$R_E$)
Fairfield et al., JGR, 1999 (GT@16-20 $R_E$)

Mid-tail (|X|>25 $R_E$)

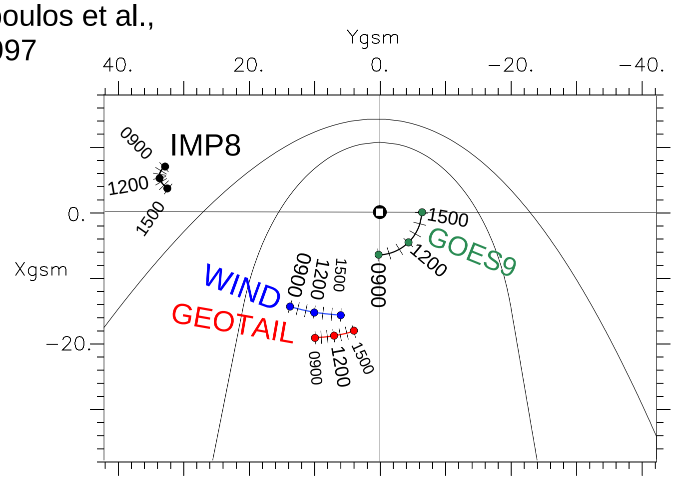
Plasmoids seen at onset (Ieda et al., JGR 1998; Machida et al., GRL, 1999)
Nagai et al., JGR, 1998: (28$R_E$ is most likely site of X-line at or prior to substorm onset.)
Angelopoulos et al., JGR 1995; 1996 (IMP8-GT: even for flows at 28$R_E$, classical substorm signatures)

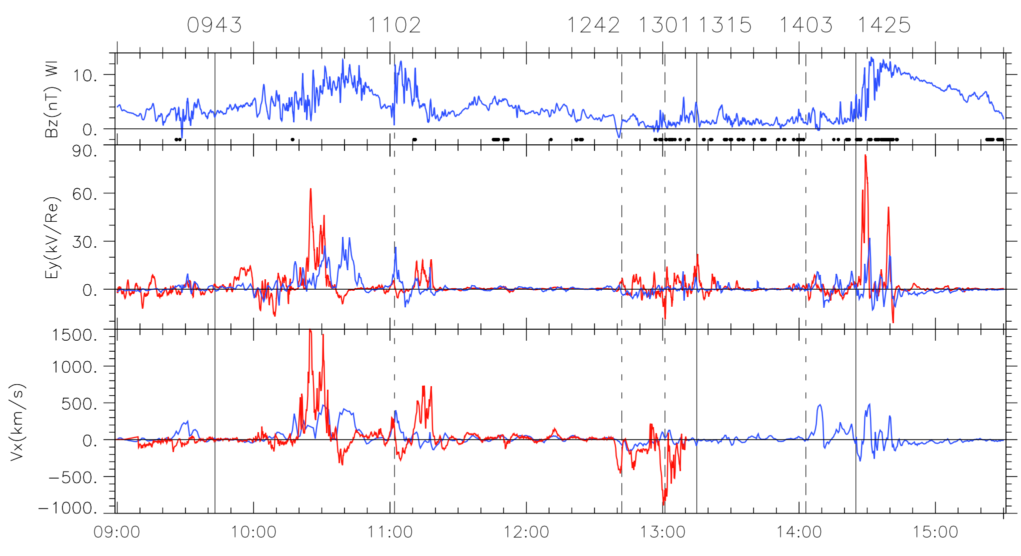
# EXAMPLE #1: GROWTH PHASE / PSEUDOBREAKUPS

GROUND@13:00 UT

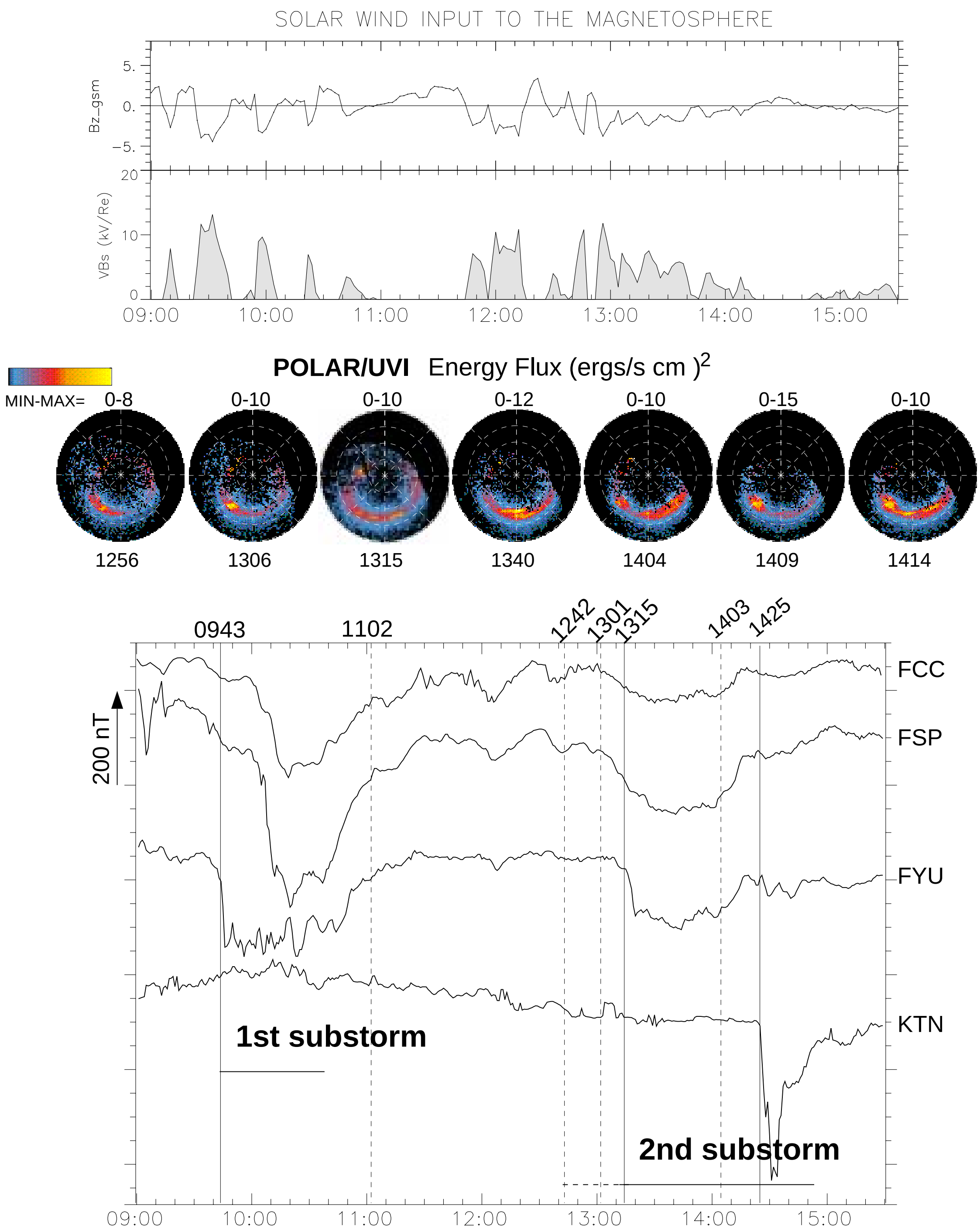



Angelopoulos et al.,
GRL, 1997



# ...Input-Output

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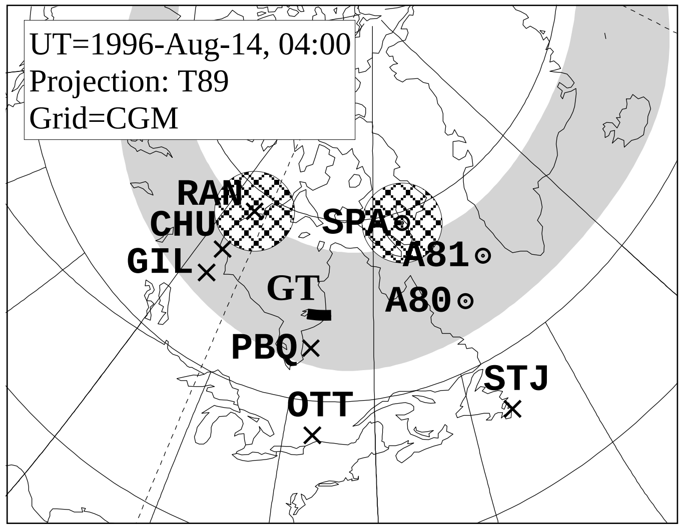
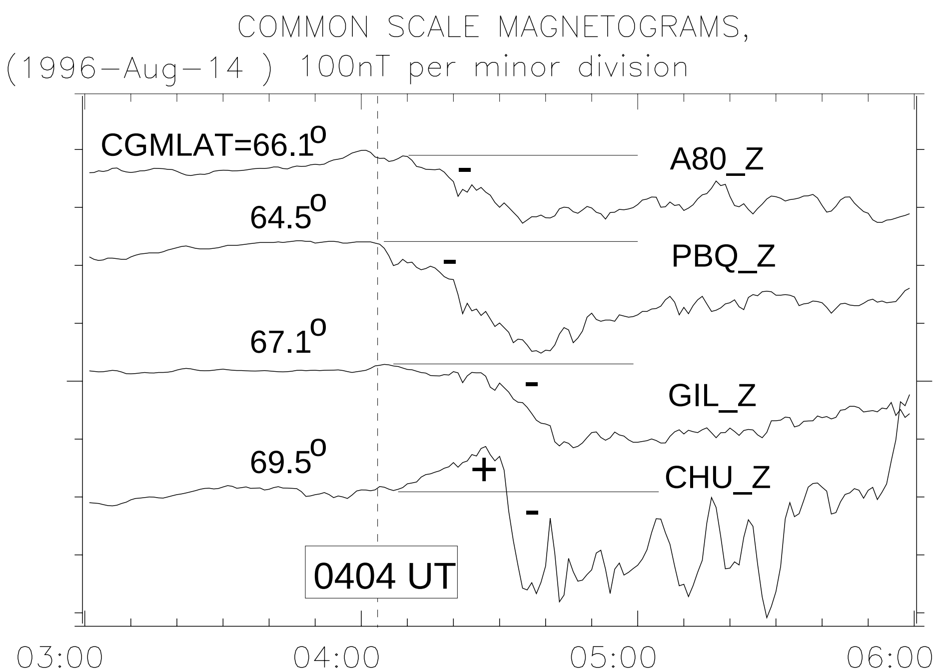
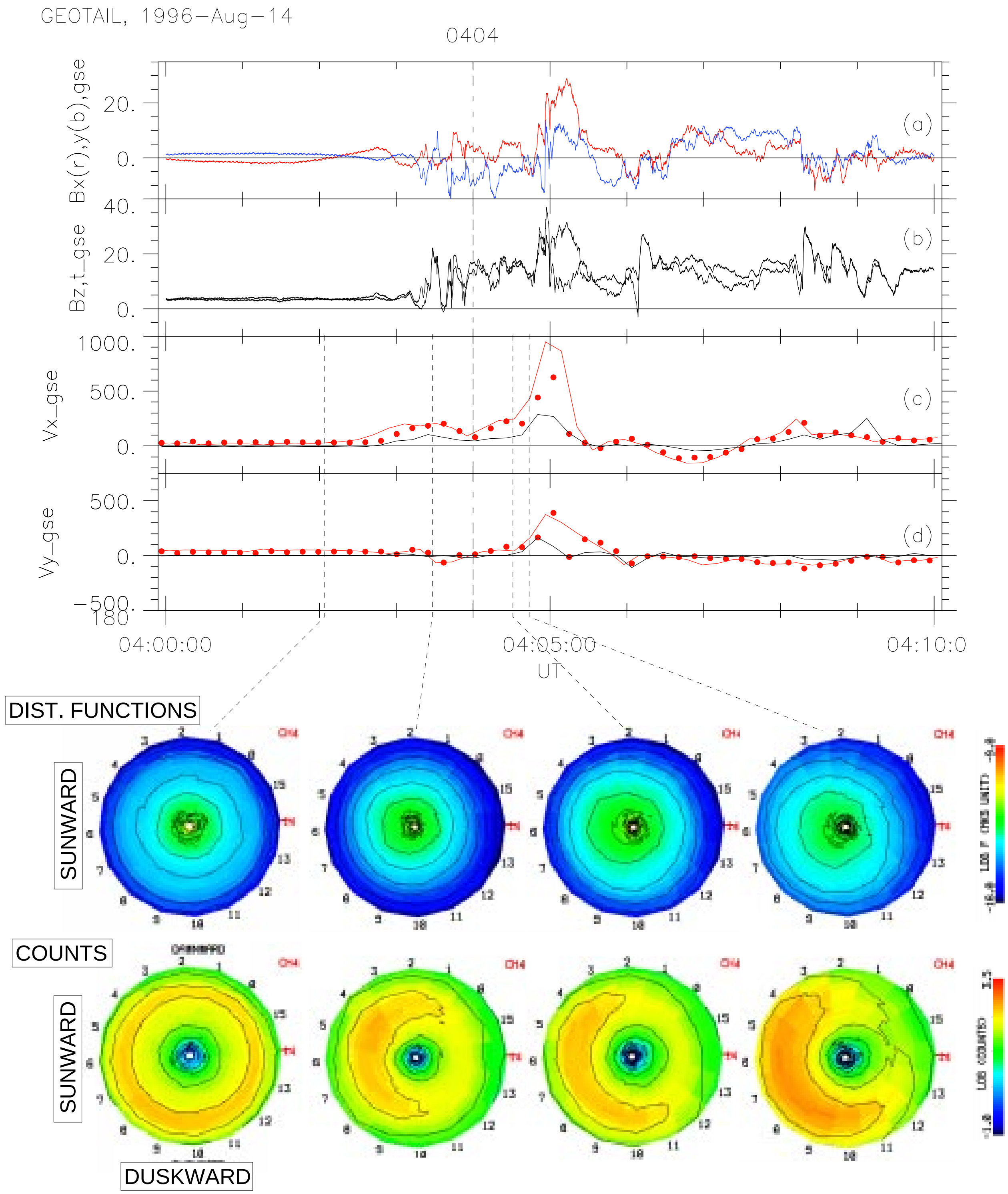
# EXAMPLE #2: ONSET FLOWS




Angelopoulos et al., *submitted, GRL*, 1999.

## At 10 $R_E$...CD and BBFs seen (flows ahead of dipolarization)

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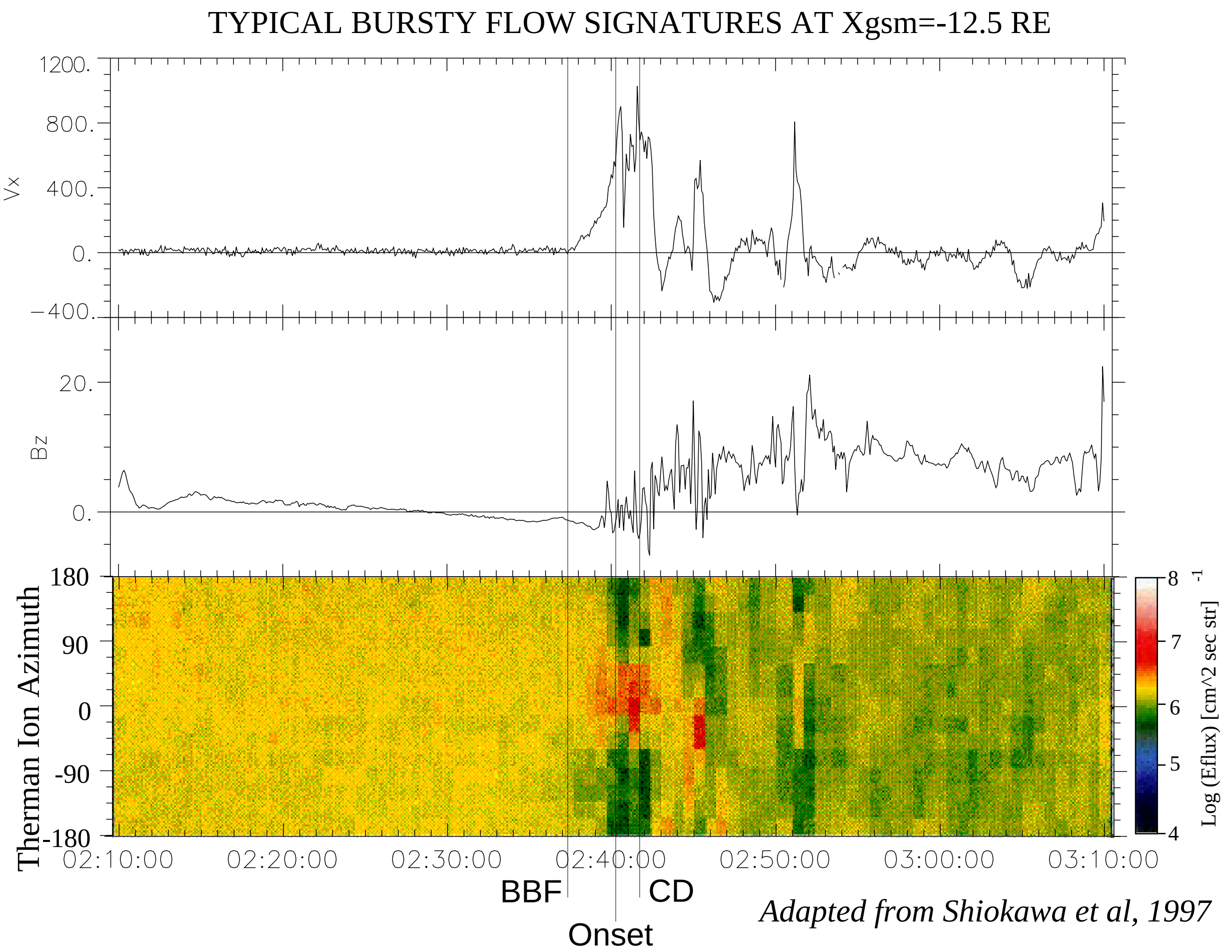
While further downtail, flow onset and dipolarization are increasingly displaced.

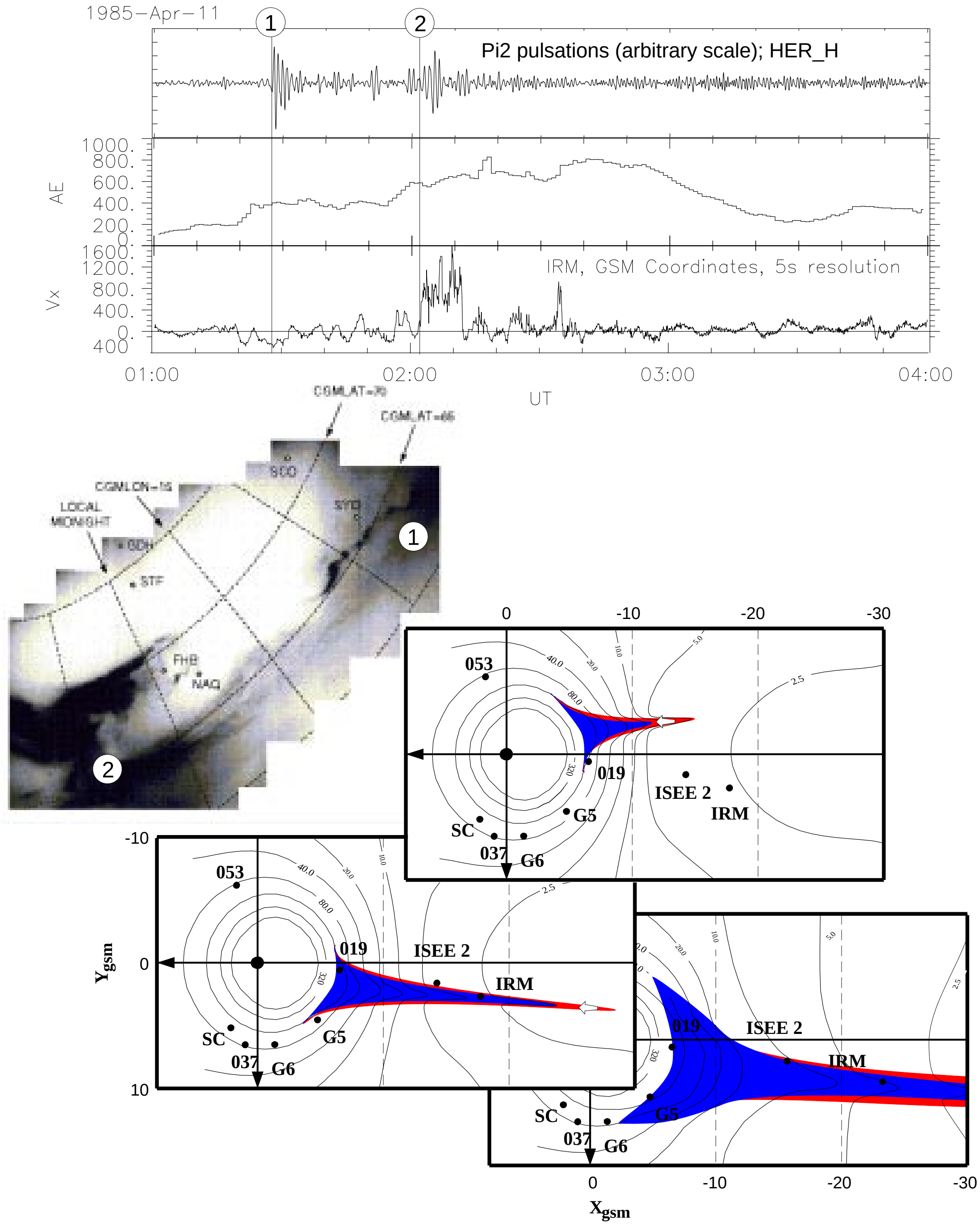
EXAMPLE 3: Shiokawa et al., JGR 1997




*Adapted from Shiokawa et al, 1997*

# EXAMPLE #4. LATE EXPANSION PHASE

## Association with high latitude (71 deg) activation.





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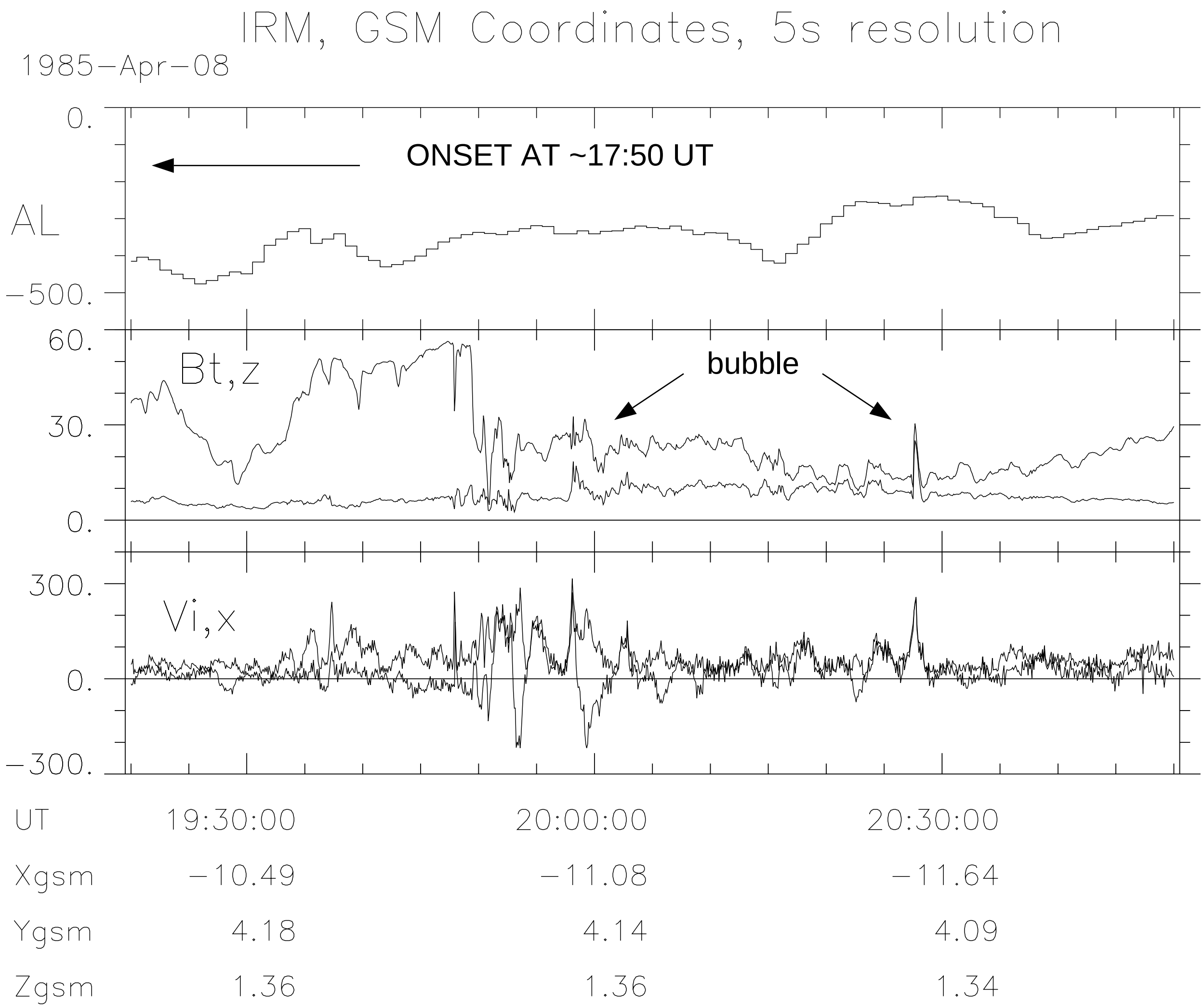
EXAMPLE #5. RECOVERY

Near-Earth field is dipolar but occasionally punctuated by localized "super-dipolar" fast flows, [Sergeev et al., 1996 JGR] reminiscent of the bubbles of Chen and Wolf [1993].

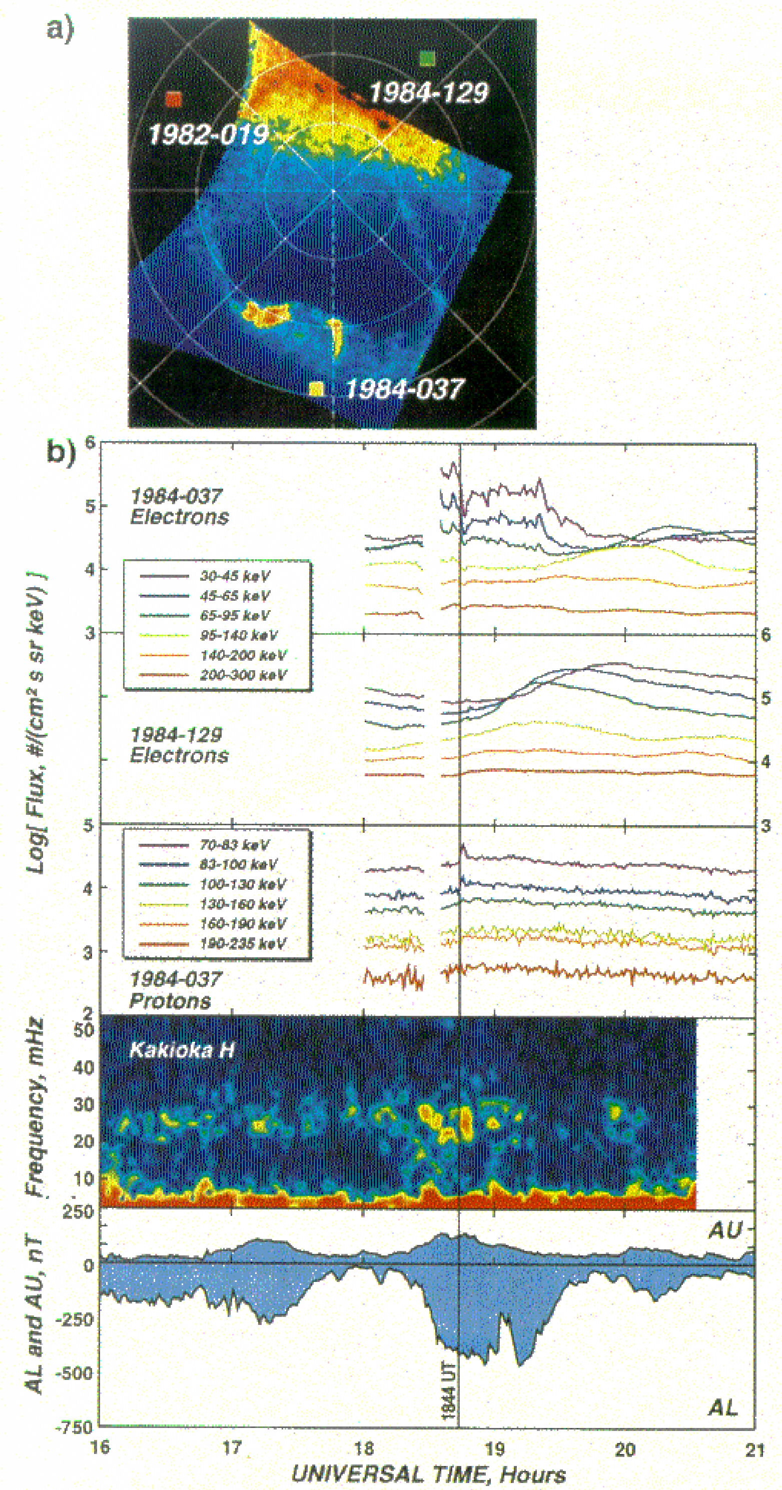
More recently Kauristie et al. find evidence that ionospheric signature of such flows is twin current vortex (ICS3 and JGR-submitted, 1999)




(Adapted from Kauristie et al., ICS3, 1996)

EXAMPLE #6. LATE EXPANSION/ RECOVERY

Sergeev et al., GRL 1999 and Henderson et al., GRL 1998 both showed that late substorm expansion or recovery activations (at the poleward boundary) may protrude from last close field line all the way to geosynchronous region.




[Henderson et al.GRL'98]

## PARTIAL SUMMARY

VERY CLOSE TO EARTH (10-13 $R_E$):

BBFs nearly identical to CD,
except: remote sensing of hot plasma is Earthward.

Excellent correlation with SS onset when at SS meridian

AT PROGRESSIVELY TAILWARD DISTANCES:

Increased localization (and observation difficulty)

Delayed CD observation (if seen at all)

Activations likely to be poleward (be they onset, intensification of recovery)

Reduced “Geoeffectiveness” (Pi2’s, injections, aurora and EJ currents

FAST FLOWS SEEN AT ALL SUBSTORM PHASES:

NORMAL BECAUSE: BBFs represent dominant means of energy transport

Energy dissipation in ionosphere continues at SS expansion and recovery phases

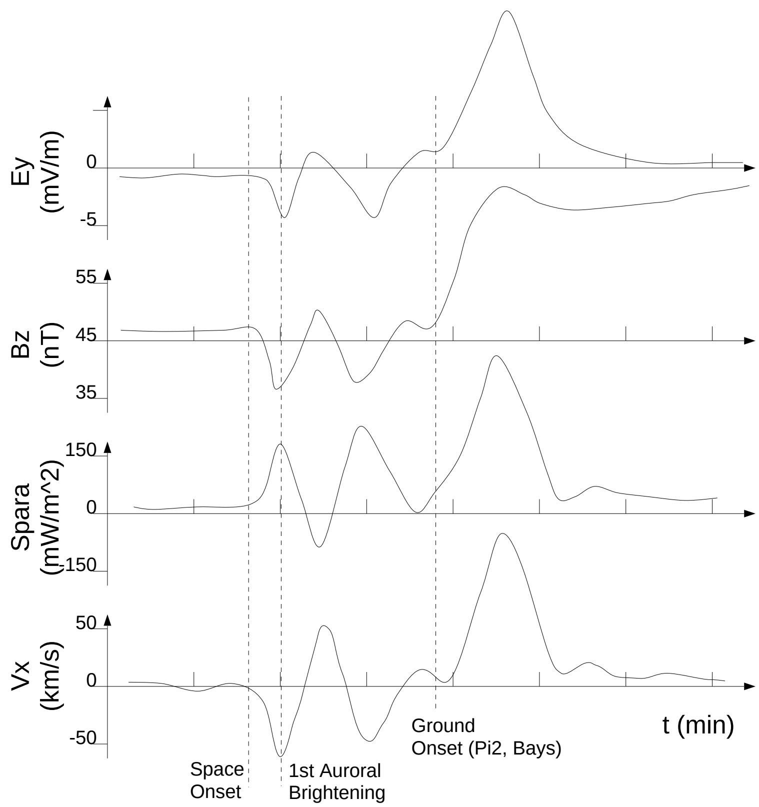
# PUZZLE

Ohtani et al., [1999 Spring AGU presentation]:

> Revisited a classic CCE CD event (8.9 $R_E$). Shown that duskward anisotropy is consistent with pressure gradient, <u>not</u> duskward flow.

Erickson et al., [1999 GEM meeting presentation]:

> Used CRESS data (6.2 $R_E$). Shown that prior to onset, waves grow out of "noise" with initial <u>tailward</u> flow velocity and Poynting flux into the ionosphere.



FOUR MAIN TYPES OF QUESTIONS:

GENERATION MECHANISM OF ELEMENTARY FBs

Reconnection versus current disruption:

DFs to test Rx model such as beam shape and speed: [Fujimoto et al. JGR 1998; Hoshino et al., JGR, 1998]
deHoffman Teller frame [Oieroset et al., Spring AGU meeting, 1999]

PROPAGATION MECHANISM (Force Balance).

Pressure gradients? Interchange motion? Slingshot?

Particle distributions (e,i anisotropy as function of distance)

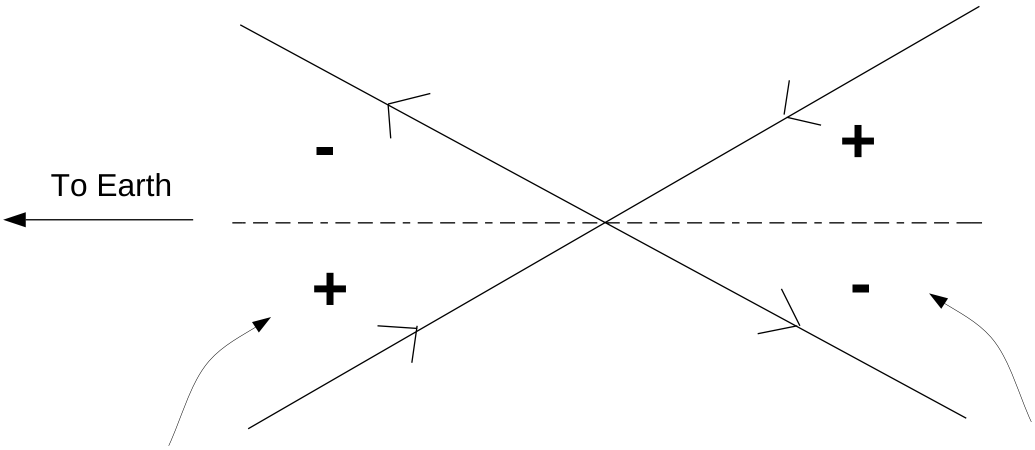
ENERGY DISSIPATION

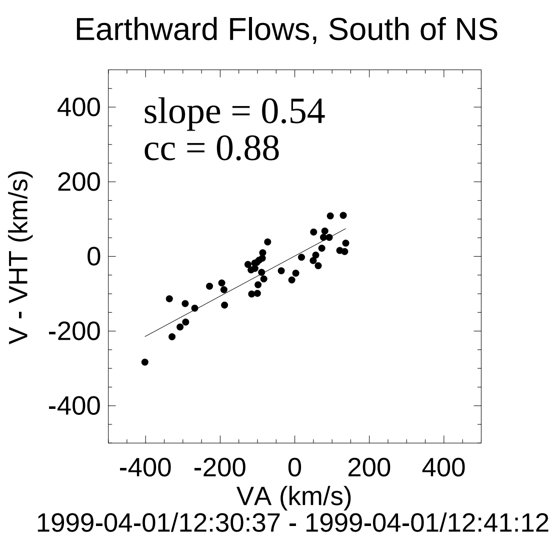
Flow braking and connection to the ionosphere.

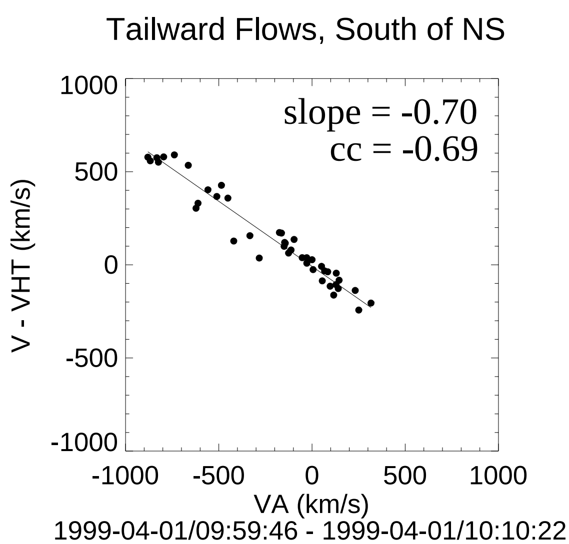
LOCAL TO GLOBAL

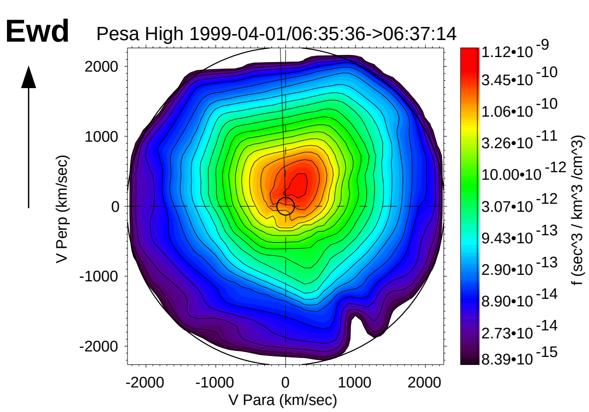
Self Organization? Role of turbulence in momentum and particle diffusion away from BBFs / towards Rx site.

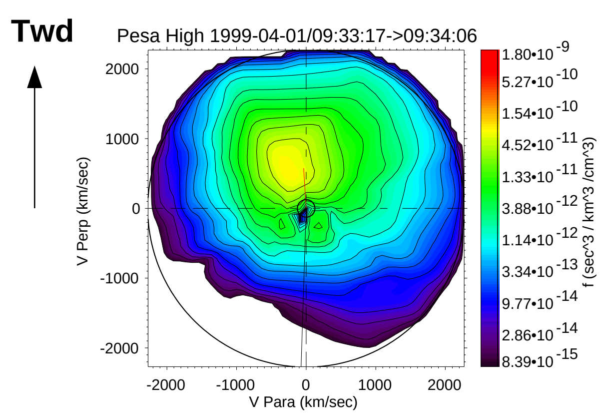
Using the Whalen relation to test Rx hypothesis at $60R_E$ on WIND fast flows [Oieroset et al., Spring AGU meeting, 1999].



CONCLUSIONS:

Significant progress has been made in classification of fast flows and recognition of their key role in global dynamics particularly fueled by the Geotail dataset in conjunction with global POLAR imagery. The potential riches of the above ISTP datasets are still to be fully obtained.

Impulsive, localized acceleration events are key to understanding the global energy transport processes in the tail during all substorm phases. They represent a fundamental energy conversion and transport unit that is ubiquitous across tail at all activity levels and thus deserve our full attention.