Flow bursts intrusion into the inner magnetosphere and some its consequences

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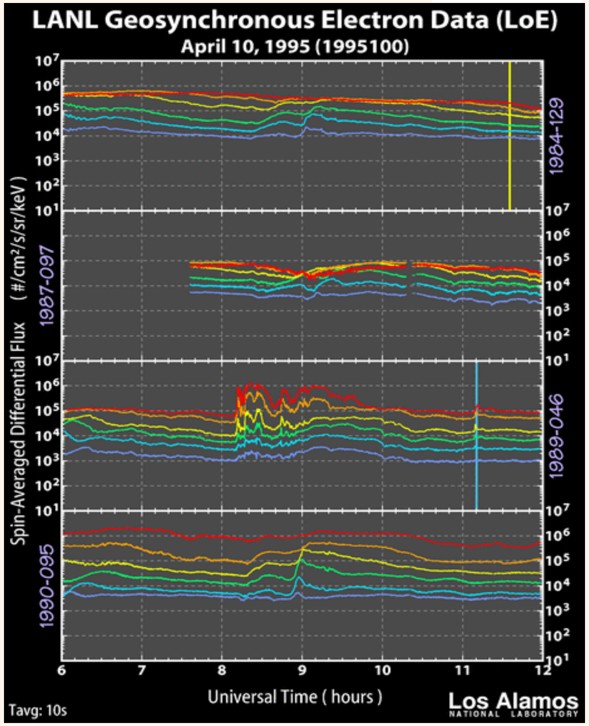
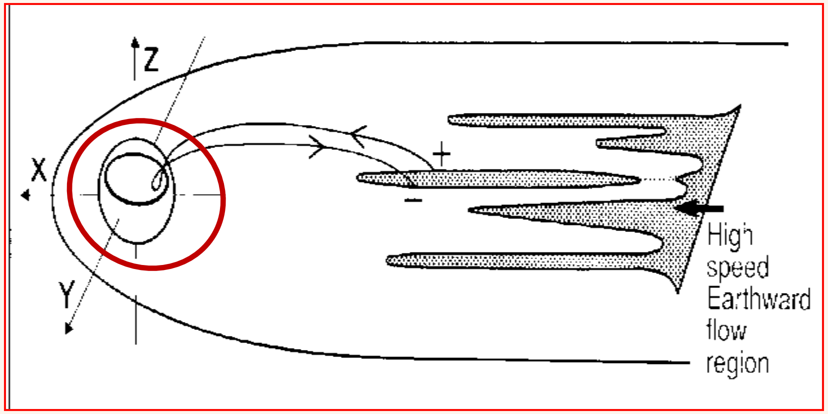
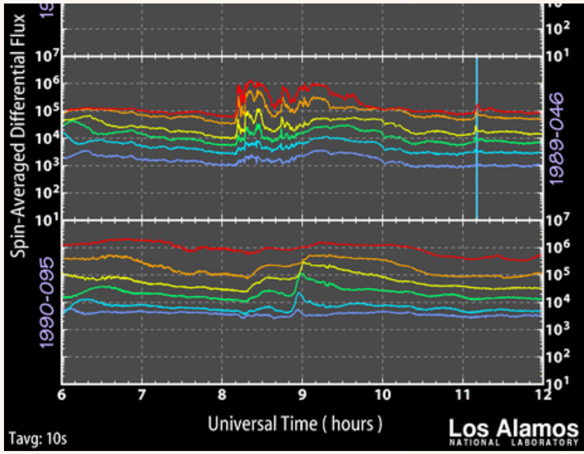


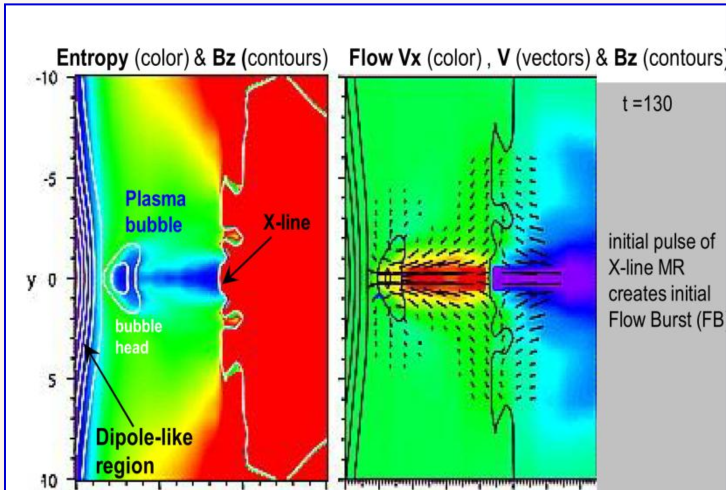


Outline of this talk

A summary about Flow Bursts in closed magnetic flux tubes (BBF, …) combining observational and simulation results, focusing on specifics of innerMSPH effects and consequences



- ✓ Origin of Flow bursts//transient Dipolarizations//Injections
  - Reconnection/ bubble model (nicely integrates simul and observ results)
  - Role of depleted plasma content , entropy evaluation
- ✓ Predictions (*MHD+test particles, RCM*) versus observations
  - DIP/Injection structure (pressure, FACurrents)
  - Generation of substorm current wedge
  - Stopping flow bursts & Penetration distance
  - Acceleration in low bursts (*transport or local acceleration at DFronts?*)
- ✓ Example of deep plasma injection (CRRES)
- ✓ Concluding remarks , implications



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Transient Injections inside of closed flux tubes: - theory/simulations

Merging of 3 different approaches used to describe flow bursts *(Sergeev et al GRL 2012 review)*

- Subsonic **EM pulse model** *(X.Li et al.1998, Zaharia et al., Sarris et al.)*, a formal model, but EM pulse origin is unclear
- **Plasma bubble model** *(Pontius and Wolf 1990, Chen and Wolf… ; MHD simulations Birn et al.2004, Birn&Hesse 2013; RCM-E simulations – Yang et al. 2011,2012, reviews by Wolf et al.2009, Birn et al. 2009)*
- **Transient localized reconnection model** (… *Birn et al. 2011, Birn&Hesse 2013)*

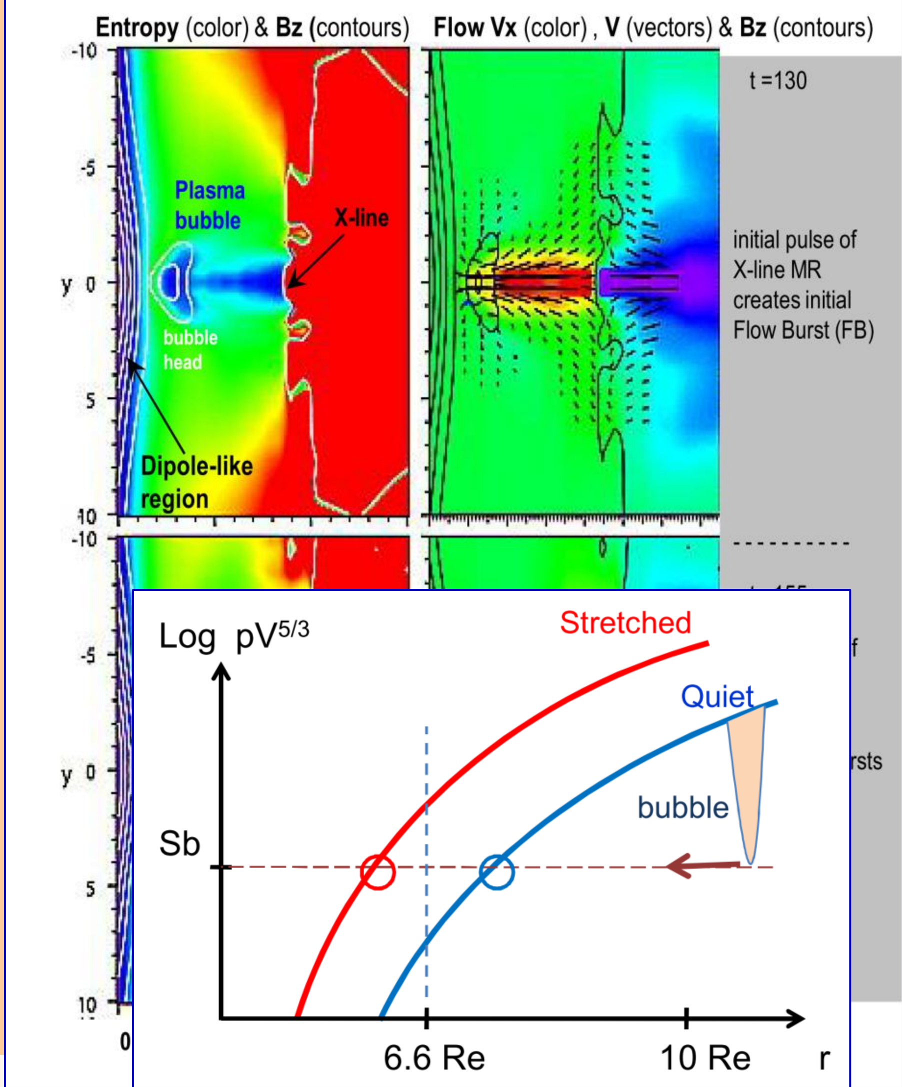
✓ Core elements: (1) a **Bubble** ≡ plasma-depleted **dipolarized** Earthw-flowing flux tube (or channel) channel in closed flux tube region; (2) inhomogeneous **S(r)** profile

✓ Originate via (1) M Reconnection→production of **low-entropy bubbles** , *or* (2) Interchange instab. in minB configurations *(…Pritchett &Coroniti, 2011..)* → modest depletion

✓ ***"Entropy" S ≡ pV$^{5/3}$*** *in the bubble - a key parameter*

(approximate invariant, strictly conserved in ideal MHD)

Equatorial view (*Birn et al., JGR 2011*)



Flow bursts observations in closed plasma sheet flux tubes

Flow bursts *(BBF, RFT, fast flow channels, reconnection outflows, transient DIPs, Dispersionless Injections ..)*

Flow burst = <u>depleted accelerated</u> plasma contained in Earthward propagating <u>dipolarized</u> magnetic flux tube

separated by thin (ion scale) frontside boundary(DF) from ambient plasma tubes

A05207 YANG ET AL.: BU

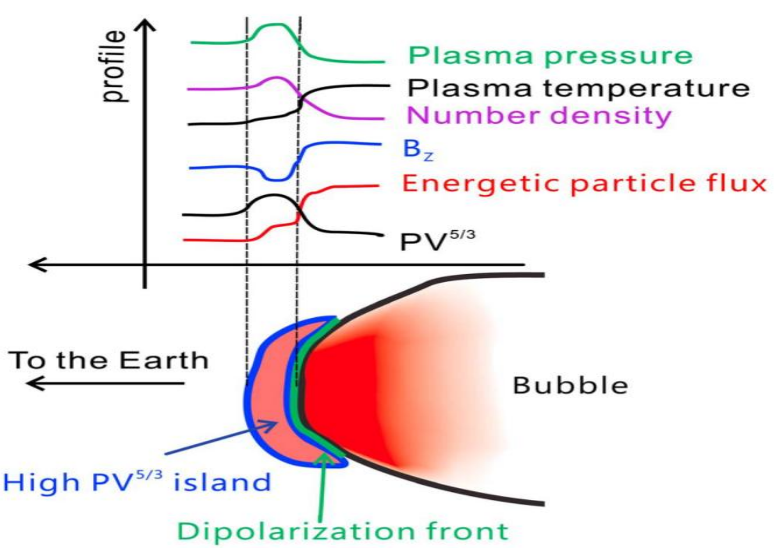
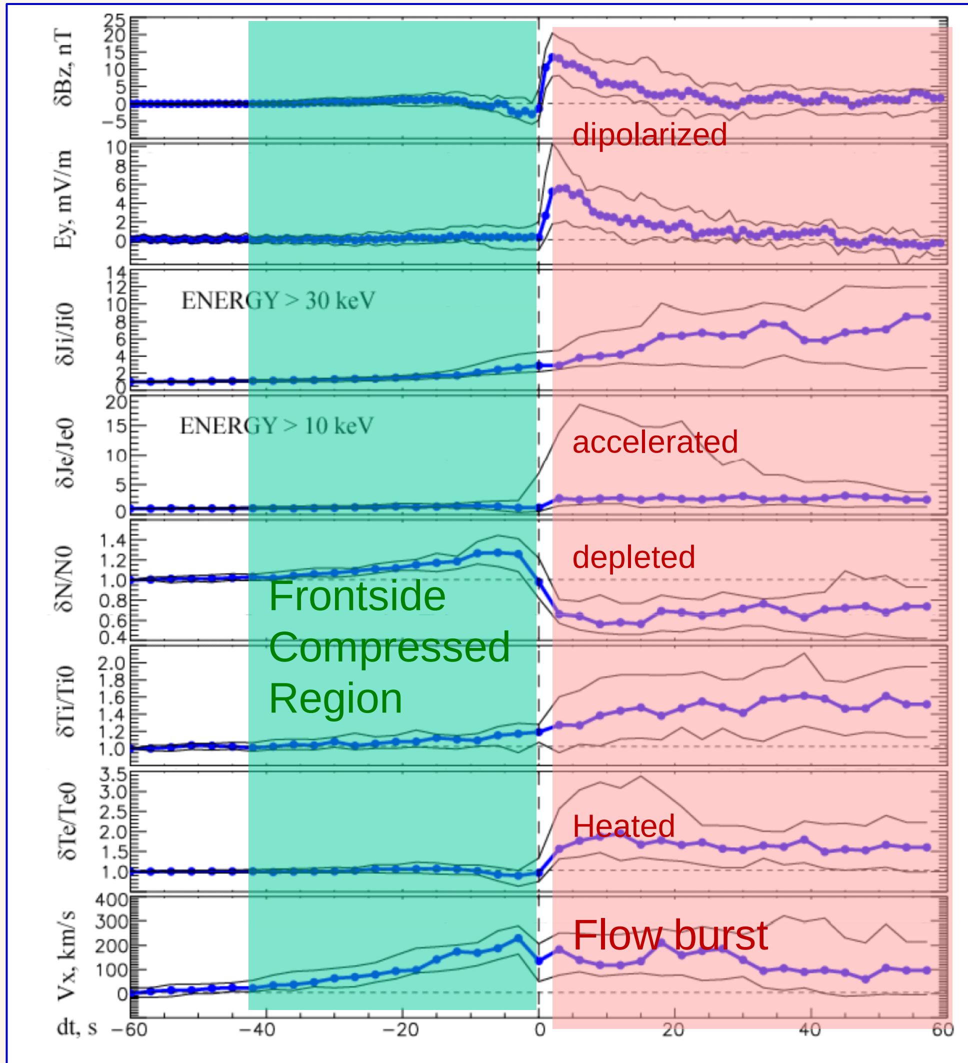


Figure 10. (top) Profiles of key parameters along the structure. (bottom) A cartoon of an earthward propagating bubble and a high-$PV^{5/3}$ island pushed ahead of it, separated by a dipolarization front

DF *Runov et al 2011*



Flow bursts observations : DF and plasma acceleration

- DF has the ion scale thickness (Schmid et 2011, Fu et al., Liu et 2013, very large statistics!!) ==> 1D planar approximation is possible, **DF NORMALS** :
- Narrow transition cold/dense → hot/depleted plasma at DF, depleted plasma tube entropy S = $pV^{5/3}$ and density (plasma bubble), but enhanced specific entropy $P / n^{5/3}$.

- Yang et al 2011 : RCM-E simulation of bubble intrusion: reproduced ion energy spectra change through DF, major acceleration comes from Fermi/betatron acceleration in the contracting plasma tube.
- In this view, sharp spectacular change of energy spectra at the DF are mostly because we cross a simple boundary (TD) between different plasmas

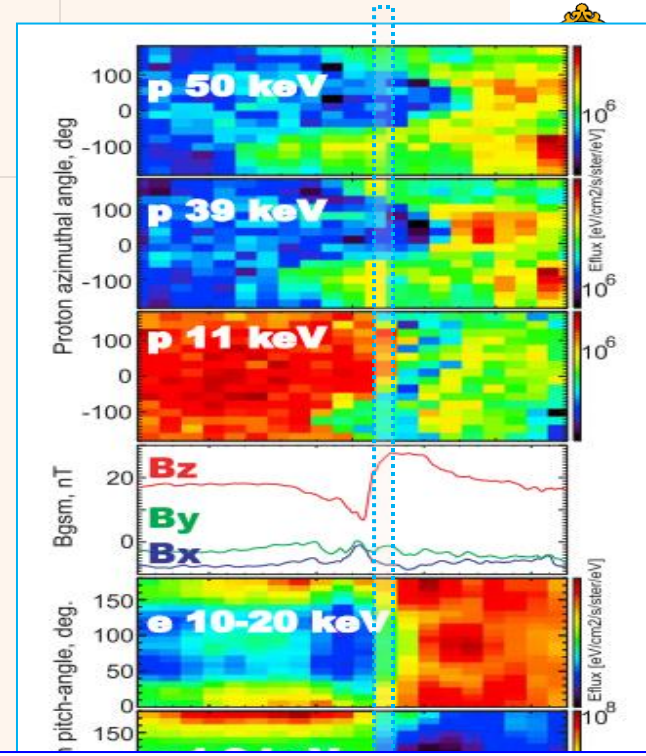
- Drifting Electron Holes (*Sergeev et 1992*): high energy electron flux decrease during injections at GEO - remote indication that accelerated /injected plasma originate from more distant tail regions

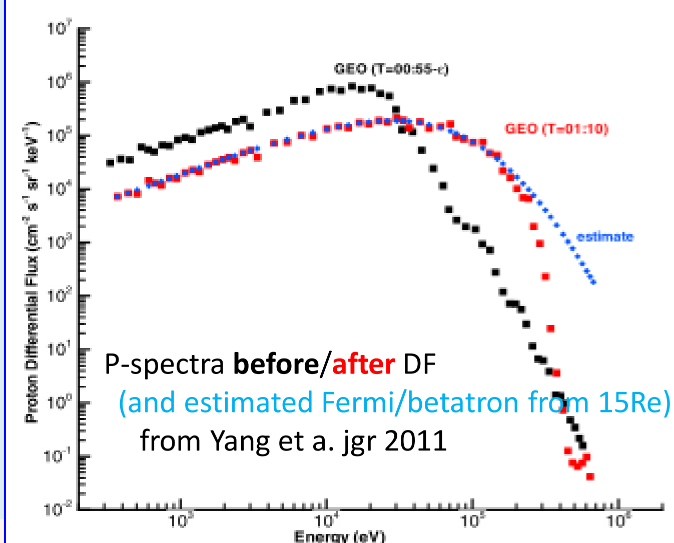
- Claims that plasma is (locally) accelerated at the DipFront are inconsistent with TD-like property of DF (E*J~0 in the dHT plasma frame)

...

DF

Sergeev et al 2009





P-spectra **before**/**after** DF

(and estimated Fermi/betatron from 15Re)

from Yang et a. jgr 2011

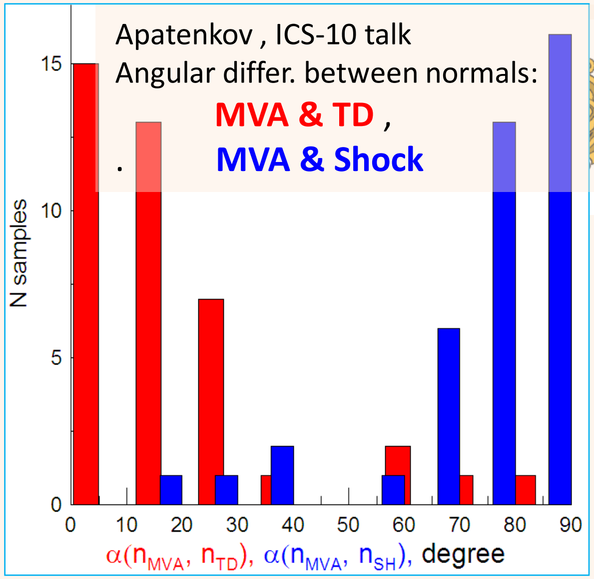
Does DF look like as TD or Shock?

- DF normals :
  - Sergeev et al (2009GRL), normals from MVA/Timing - great preference for TD against Shock
  - Liu, Angelopoulos etc (2013): survey of ~1900 (~1300 with fast particle data) DipFronts from THEMIS : good correspondence of MVA and "TD" normals, saddle shape surface as expected for flux tube
- E-field (En versus Et, large Et –dissipative DF)
  - Fu et al. 2011/2012- basic E-field component along normal; large statistics!
  - Runov et al 2011- claim opposite (dissipative boundary ???), but actually Et <<En inside DF in their Figure 7 !
- Energetic electrons are confined to the bubble proper, do not escape through DF surface (support Bn~0)

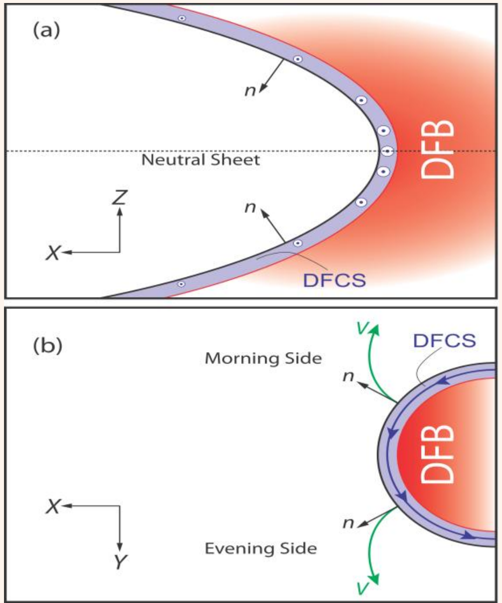
General agreement that **DF has properties close to a Tangential Discontinuity** (DF surface ~ field line surface)

→ non-dissipative boundary (in MHD sense) ?

- Very strong LH waves (up to 60 mV/m) are usual inside DF, but their role in acceleration is unclear
- Resonance-type acceleration of a small group of particles *(Zhou et al.2012, Artemyev et 2012)*

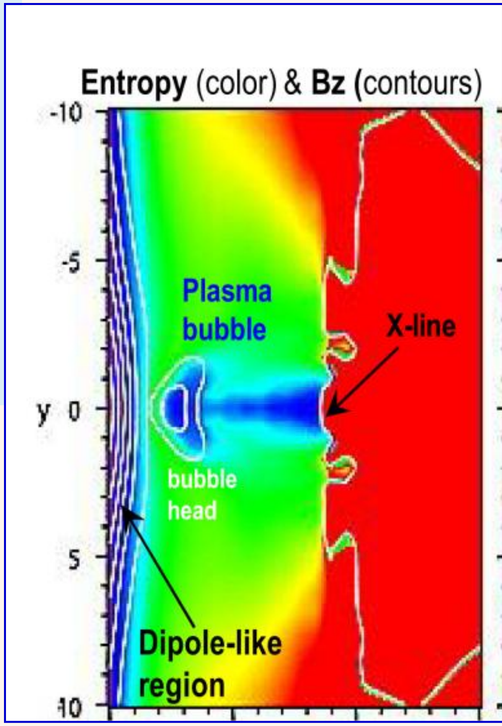


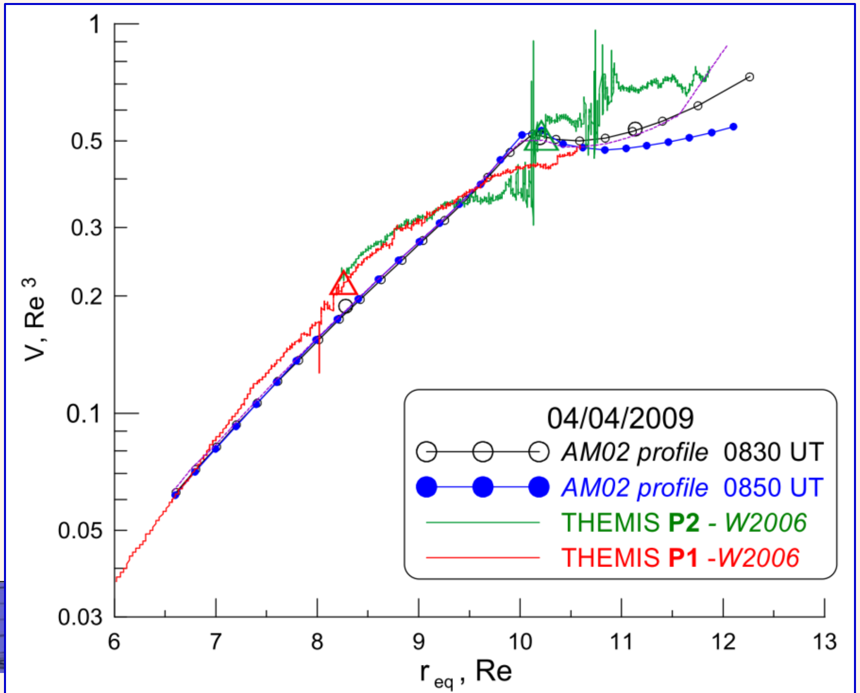
Liu et 2013: median angle between TD and MVA normals is 15° (475events);



How to evaluate $S = p V^{5/3}$ from observations ?

- Plasma sheet P is very isotropic (except for inner region)
- How to evaluate $V = \int ds / B$ based on SC observations?
  - Formula by ***Wolf et al. (2006)*** for ***V* (x,y, Br,Bz,P)** - by fitting many equilibrated tail-like plasma configurations
  - Tested/validated in 3d MHD simulations *Birn et al.(2011)*
  - Tested/validated in THEMIS conjunctions *Sergeev et al.(GRL2014)* for <u>near-equatorial orbits</u>





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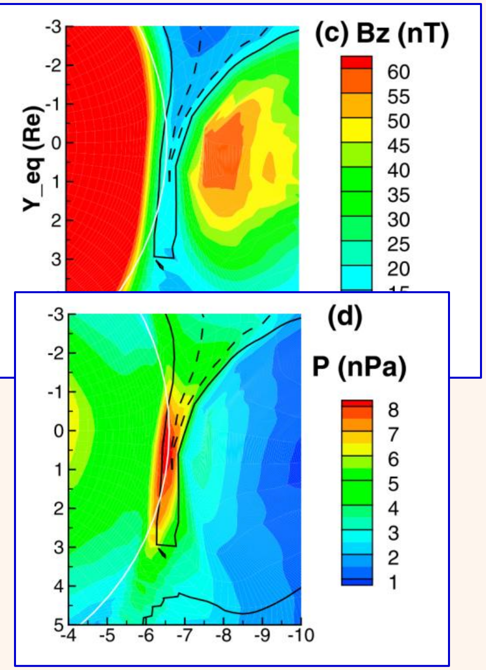
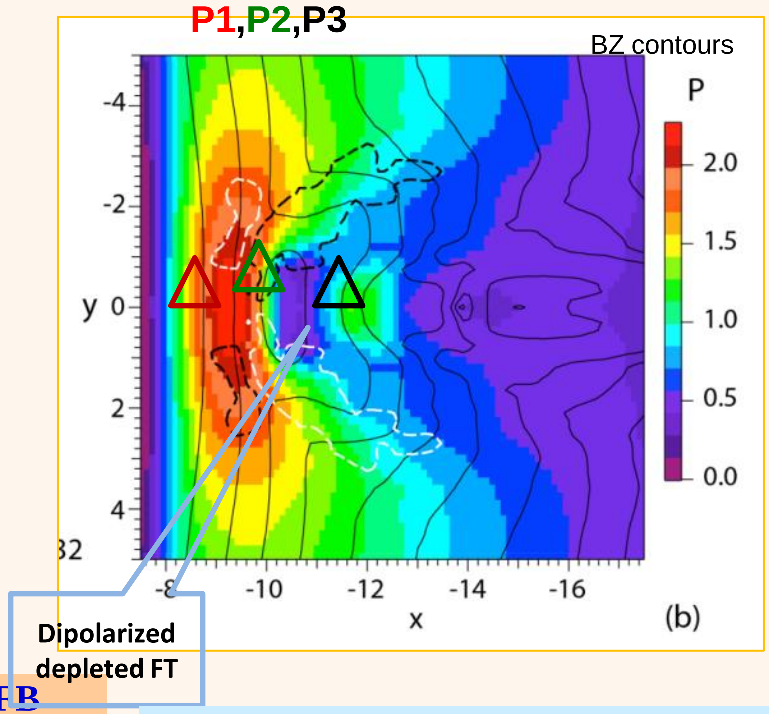
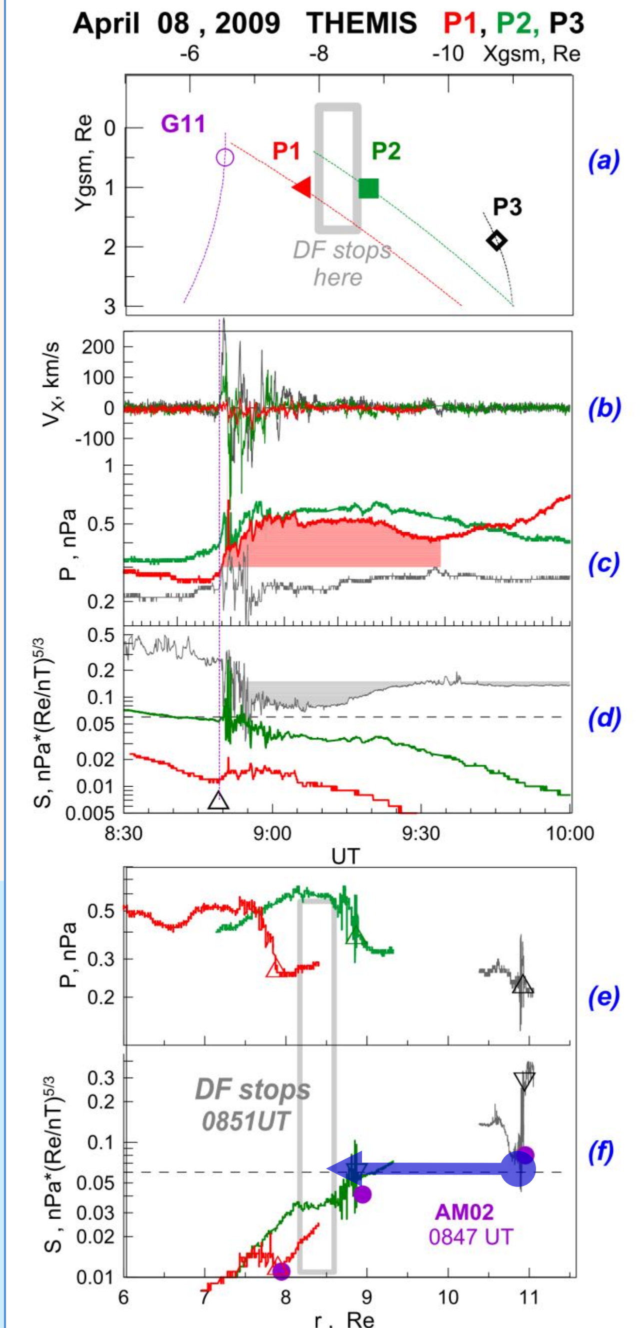
Flow burst structure

RCM-E simulation



MHD simulation





Simulations of stopping FB

(Birn&Hesse,2014 Yang et al.2011)

- Pressure increases in front of DF (also in the tail PS)
- Amplitude increases while moving Earthward
- Max effect where the FB stops

THEMIS radial conjunction

(Sergeev et al GRL 2014)

Remarkable pressure increase at **P1** (*2), ~1Re Earthward of stopping DF) as well as entropy drop at **P3** in the FB

ΔP and ΔS amplitudes and geometry are similar to the simulation results

Bubble entropy ~ entropy at destination place (within a factor 2)

FB/injections & Substorm Current Wedge

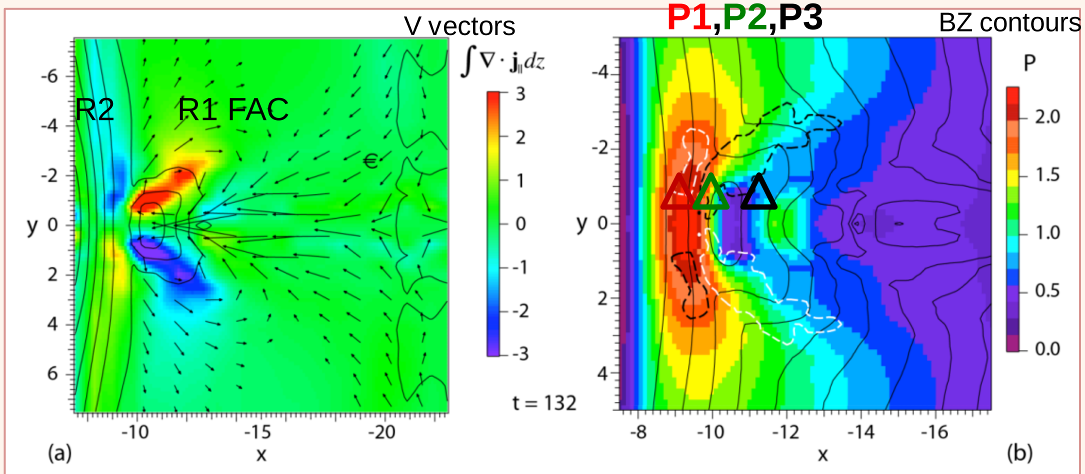


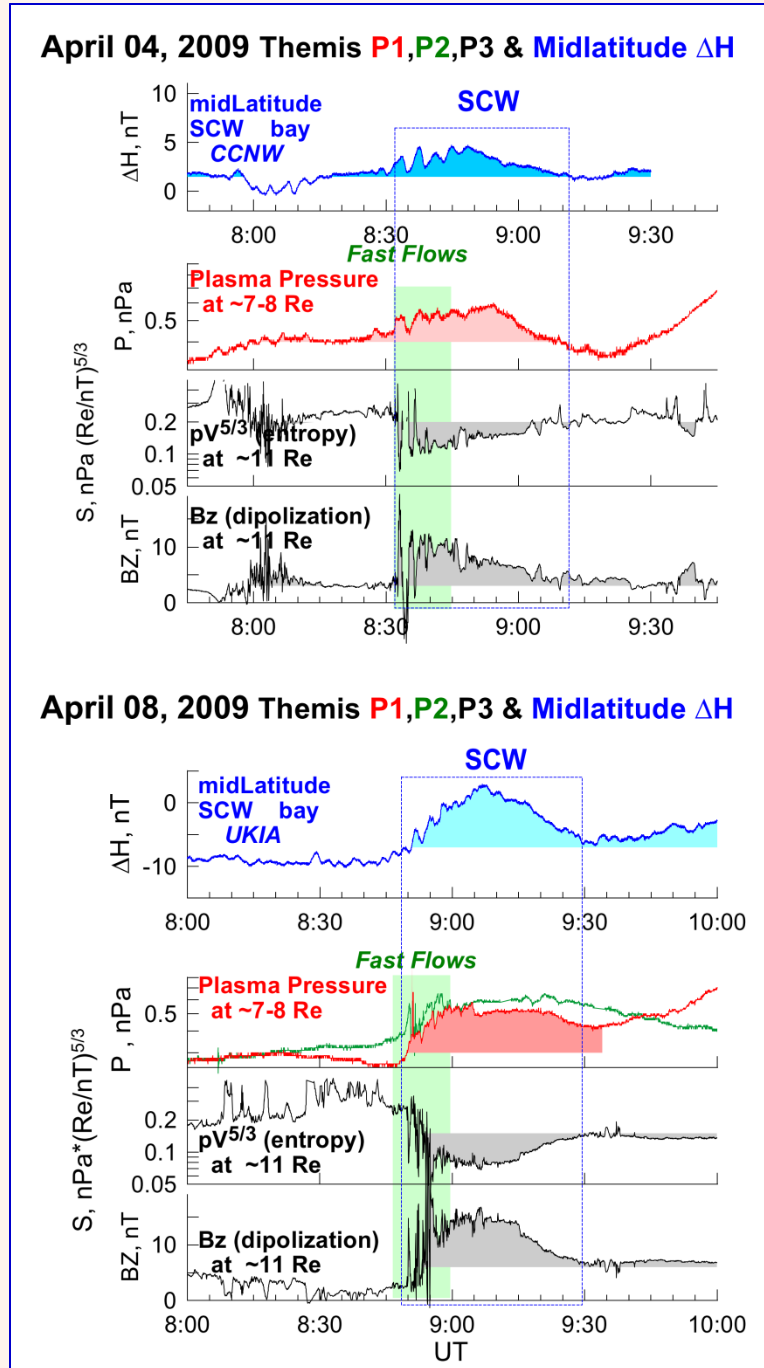
Fig. 4 a) Diversion of perpendicular into parallel currents, based on an MHD simulation of near-tail reconnection and earthward flow (Birn et al. 2011). Color shows the magnitude of

Simulations *(Birn&Hesse 2014, Yang et al.2012)*

- R1 on FB flanks and R2-like FAC in front (*wedgelet!*)
- Correspond to [∇P x ∇V] FAC generation mechanism
- Stronger FACs when approching Earthward, peak near stopping distance

THEMIS radial conjunction *(Sergeev et al GRL 2014)*

- P1 pressure increase as well as **P3 entropy drop** continue for ~30-40 min,
- similar to duration & shape of midlatitude magnetic bay (basic SCW signature)
- ΔP and ΔS amplitudes and geometry are similar to simulation results
- Confirm that ∇P x ∇V mechanism drives SCW FACs
- More depleted bubble - generates stronger FAC $



Transient Injections into the inner magnetosphere - observations

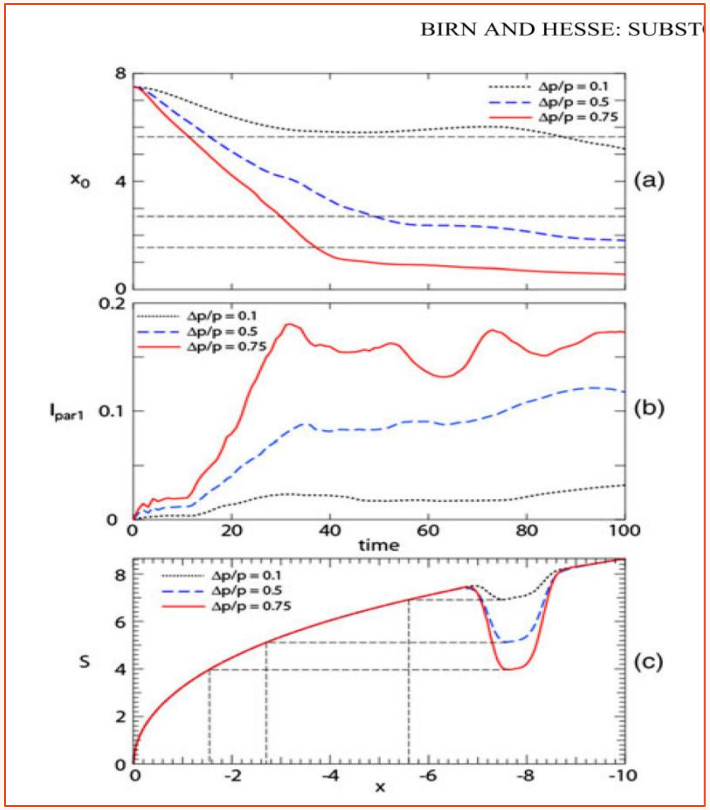
- <u>Considerable part of Flow Bursts do NOT penetrate substantially inward</u>
  - *2-SC comparison (CL-TP1 radial conjunctions, dr~5Re) : ~30%, (Takada et al. 2006)*
  - FB probability sharply decreases $9 \rightarrow 7$Re (Lee et al., 2012) Why??
  - *Many substorm onsets (Aur.Breakups) are <u>not accompanied</u> by GEO injections (only 30% in Boakes et al. 2011).*

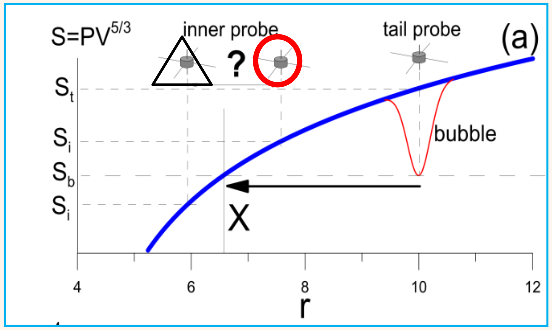
It is not sufficient *to create fast flow channel, should be another factors/processes (another physics) which controls the inward penetration of plasma (injections) .*

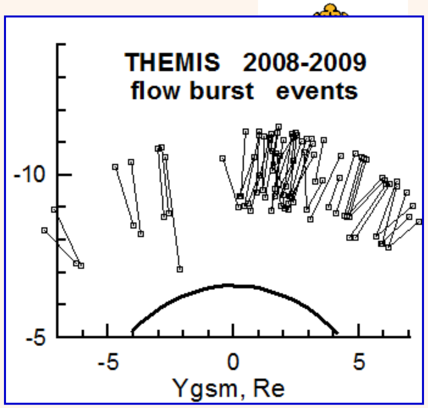
Special ROLE of Bubble ENTROPY (as potential predictor of injection depth)

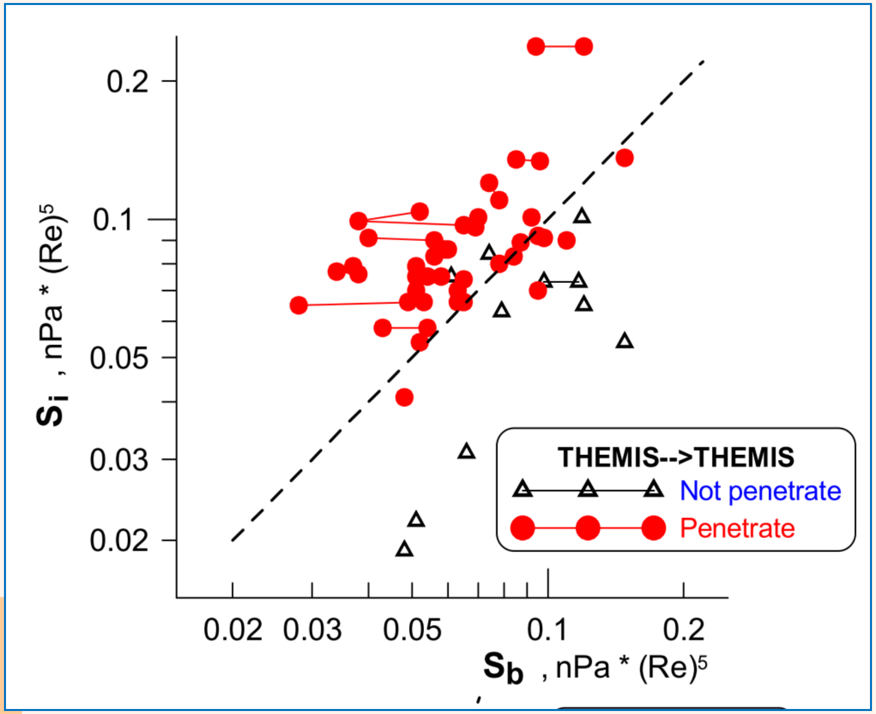
Penetration Distance:

Role of entropy









Bubble MHD simulations *(closed 2d config, S(r), Birn et al. 2004,2014)*

- More depleted flux tube moves faster
- More depleted flux tube penetrates deeper
- Penetration distance – where **S ~ Sb**
- More depleted flux tube generates stronger FAC

THEMIS 2SC test: In the <u>optimized geometry</u> (radial, 2Re separation) **entropy is a good predictor of penetration** to the inner probe *(Dubyagin et al GRL 2011)*

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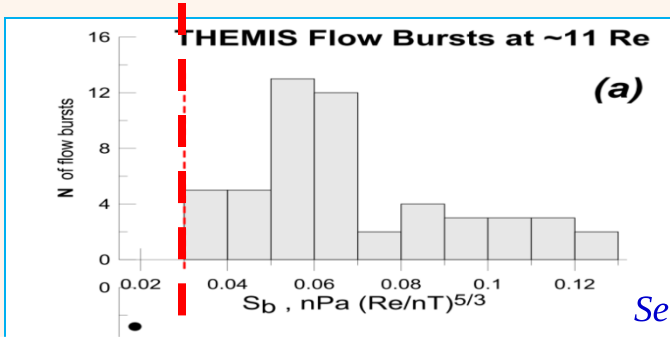
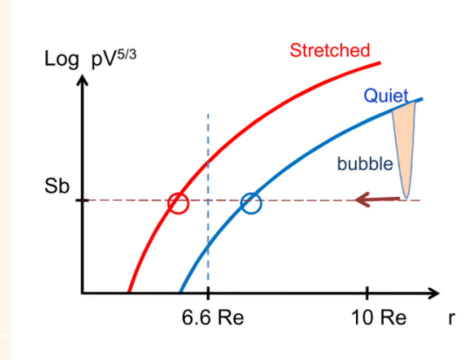
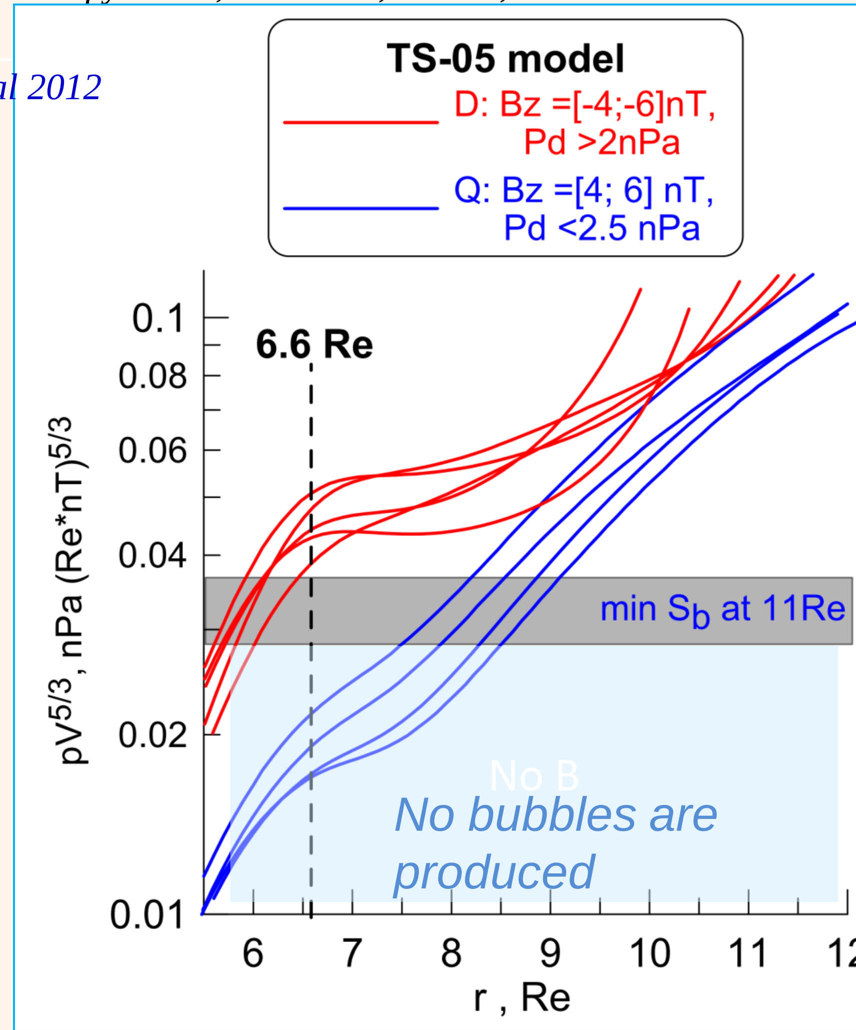
Penetration Distance:
Role of magnetotail stretching



Sergeev et al 2012



Entropy 6.6Re, 00 h MLT, events, SW-based TS 05 models

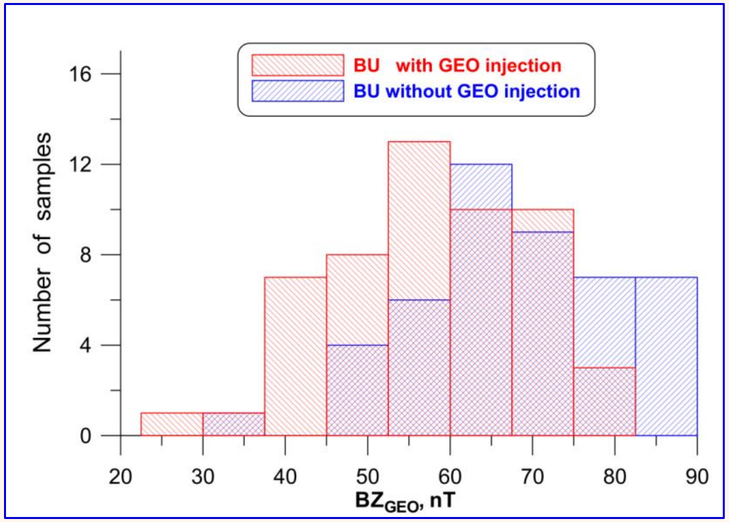


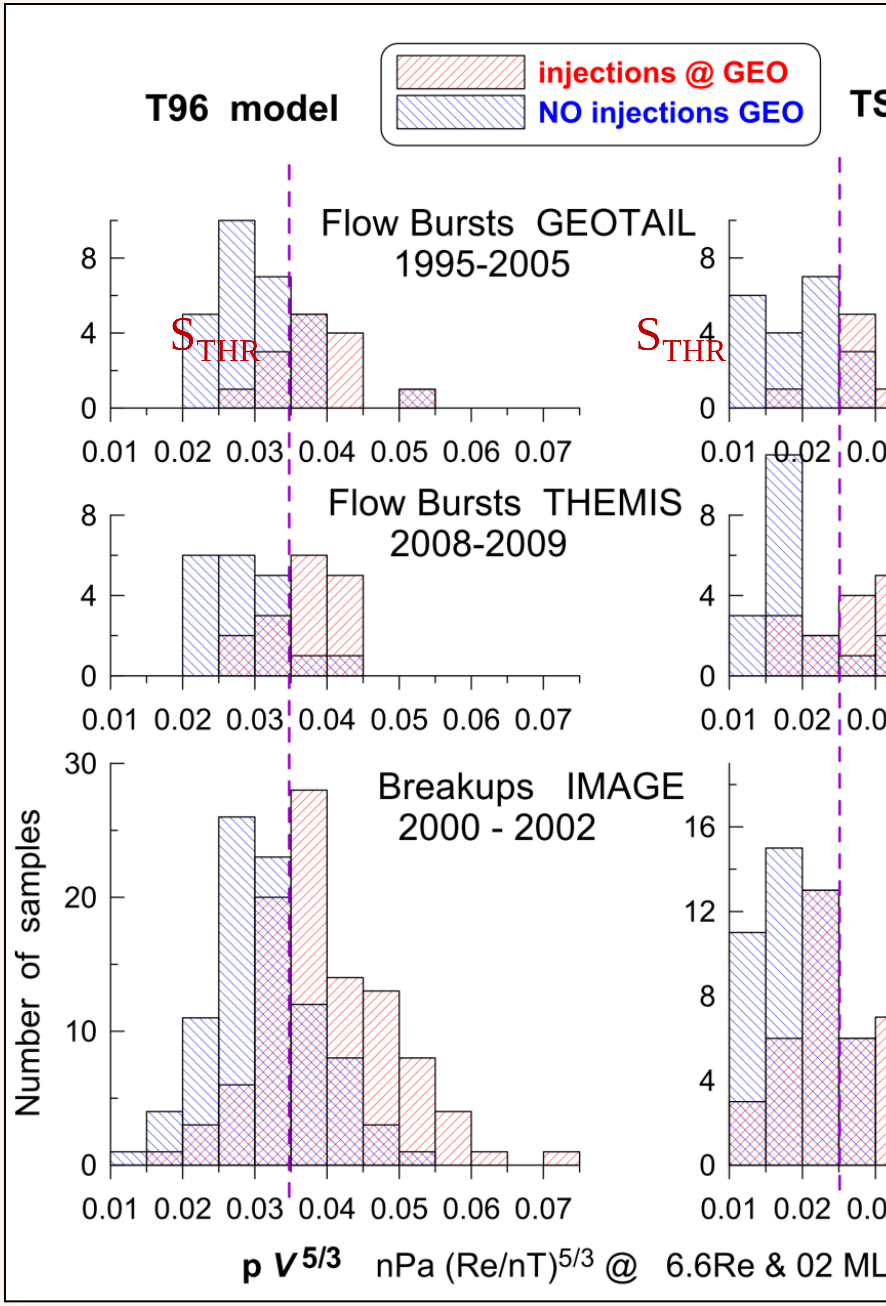
- ❖ Threshold at $S_{GEO} \approx 0.03 \pm 0.005$, corresponds to experimental cutoff in Sb distribution of the bubbles!!
- ❖ Prediction for deep injection (VA probes): probability should quickly drop with decreasing distance; -expected to be seen primarily during **very stretched storm-time-like configuration** (strong stretching + possibility of producing very low Sb < 0.03 at very close XNL)

GEO : injection dependence on the magnetotail stretching

Sergeev et al. JGR 2012

- ✓ Local entropy S_{GEO} - a good predictor of injection probability at GEO : stretched tail favors GEO injection *(in agreement with Takada et al. 2006, and Boakes et al.2011 results)*
- ✓ Threshold at $S_{GEO} \approx 0.03 \pm 0.005$, corresponds to experimental cutoff in Sb distribution of the bubbles!!
- ✓ In terms of GEO BZ – the threshold is about BZ~60nT
- ❖ *Interesting to repeat using BZ observed at GEO as well as for VA probes*





Example of Deep Injection (CRRES)

CRRES equatorial injection at r=5Re

(Maynard et al. 1996, Sergeev et al. 1998)

- Moderate activity, ~600nT AE substorm, -25nT Dst
- Associated with SCW, Pi2 and GEO injection (~5min before
- Stretched configuration : ~45nT at GOES & Bz~170nT locally ,
- Outside the plasmapause
- Dipolarization accompanied EP flux increase

Structure & properties

- Enhanced inward convection and p ↑ ~8min before , accompanied by pressure increase
- Short p-flux and pressure increase & Bz dip (~diamagnetic) prior to DIP (~1000 km ion? scale)
- DIP front with associated flux increase (both p- and e-), followed by ~30nT enhanced Bz-positive bay

These properties look fairly generic, although are observed very close to the Earth!!

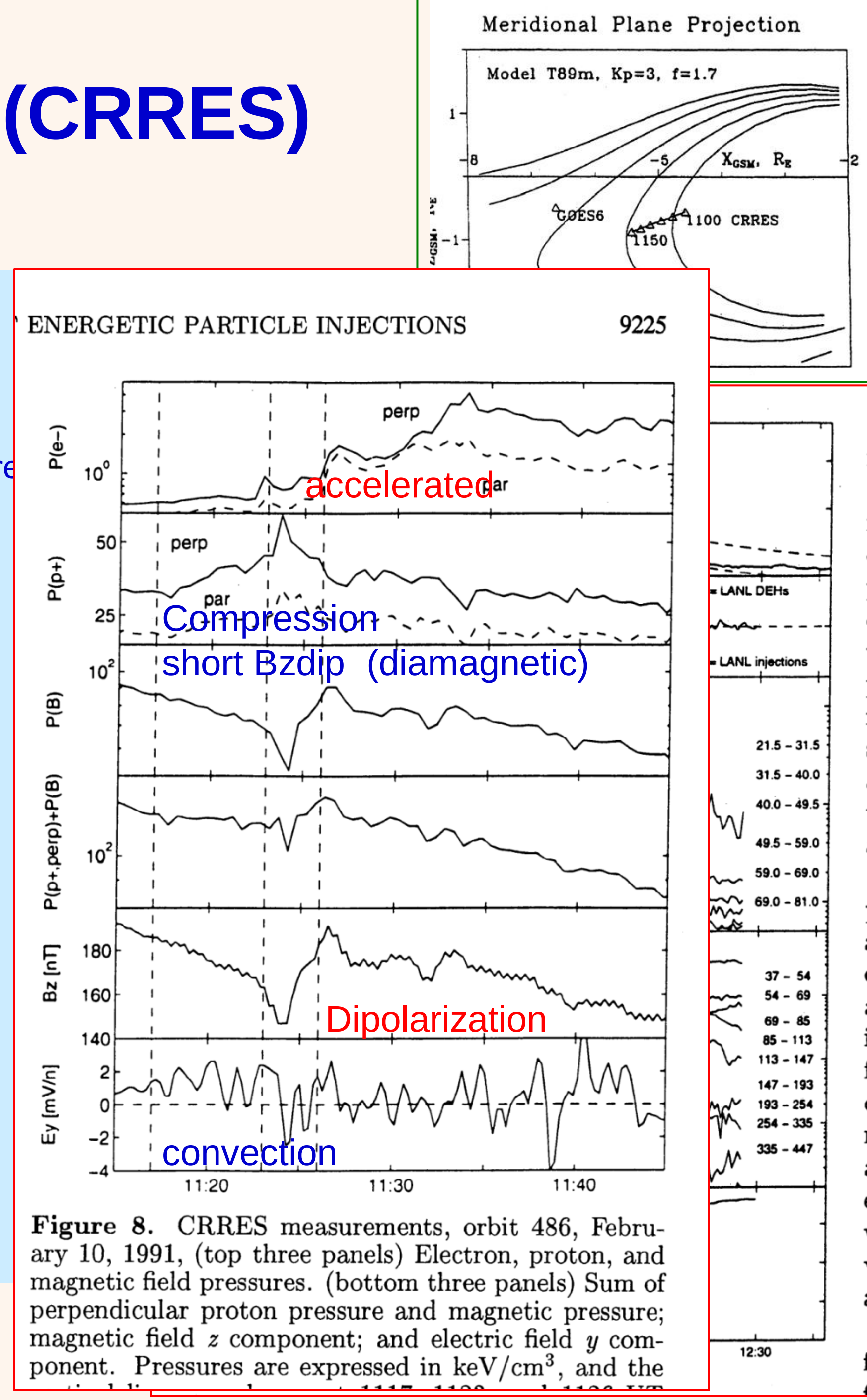


Figure 8. CRRES measurements, orbit 486, February 10, 1991, (top three panels) Electron, proton, and magnetic field pressures. (bottom three panels) Sum of perpendicular proton pressure and magnetic pressure; magnetic field z component; and electric field y component. Pressures are expressed in keV/cm^3, and the

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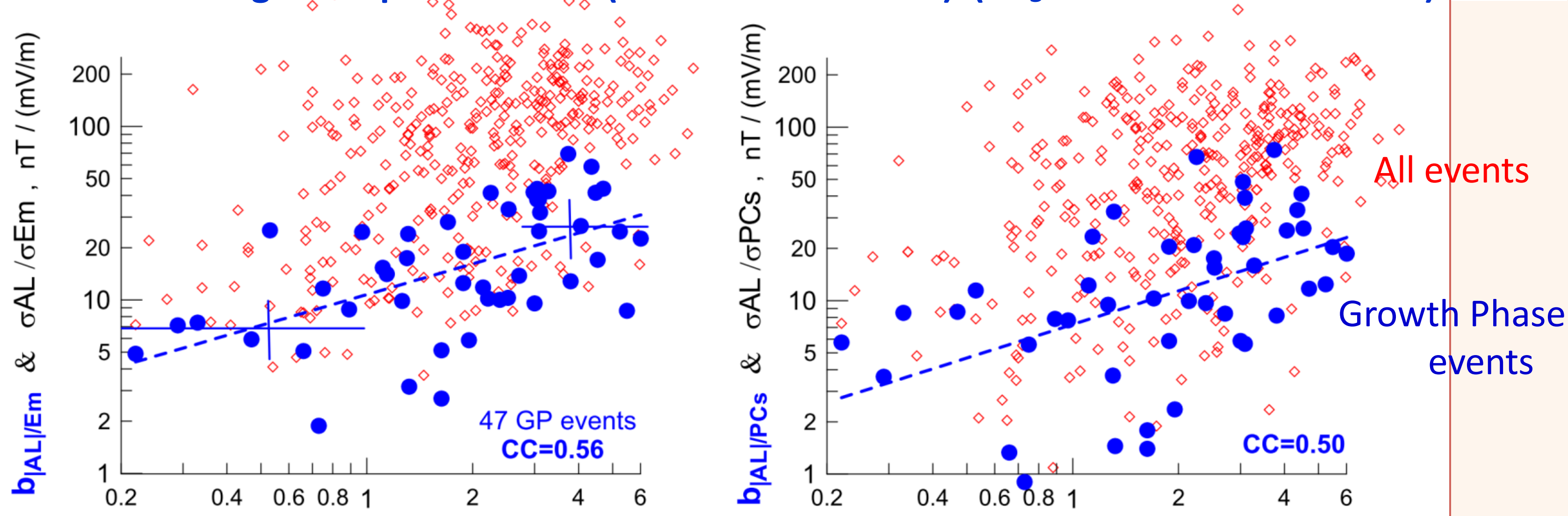
Role of plasma sheet parameters & flow bursts in providing bright auroras and Hall currents

Substorm growth phase events (no SBS acceleration) (*Sergeev et GRL 2014 submitted*)



Em = $VB_{sw}\sin^2(\theta_{sw}/2)$

A low-density/hot plasma sheet generates stronger magnetic variations in the dark nightside auroral zone compared to cold/dense sheet (for similar driving level)

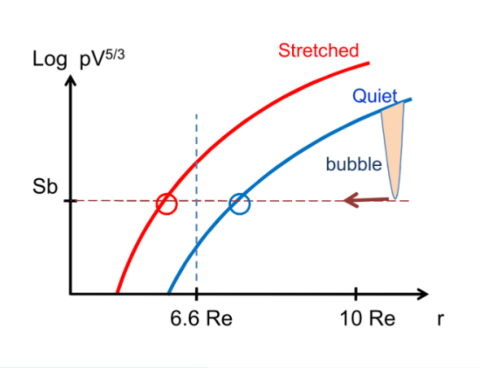
Efficiency to generate strong AZ currents depends on Σ_H

Plasma sheet electrons (**Te~ 0.2…1 keV**) Large **Hall conductivity** requires **Ee > 3-5keV**

Field-aligned acceleration is required which depends on plasma sheet $Te^{1/2}/Ne$

Knight (1973) relationship: $\Delta\Phi_{||} = Q\ j_{||}$ *where* $Q = (2\pi\ m_e\ kT_e)^{1/2} / eN_e$

Summary and questions



What can (stopping) flow bursts contribute to :

- Increase pressure and Inject new material into the inner magnetosphere and RC
- Populate the radiation belts
- Prepare seed population for Rel electrons
- Modify the pressure/entropy profiles to generate the SCW
- Prepare plasma environment to effectively accelerate electrons and provide bright aurora and large Hall conductivity (intense currents)

What can Van Allen probes contribute to FB/injection studies?

- Study the FB structure and evolution (incl."bubble property") in a different (low β) environment
- Check pressure pumping effect (significance & structure)
- Test how well the entropy-based prediction of injection distance work in the inner region

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Dec.16, 2006

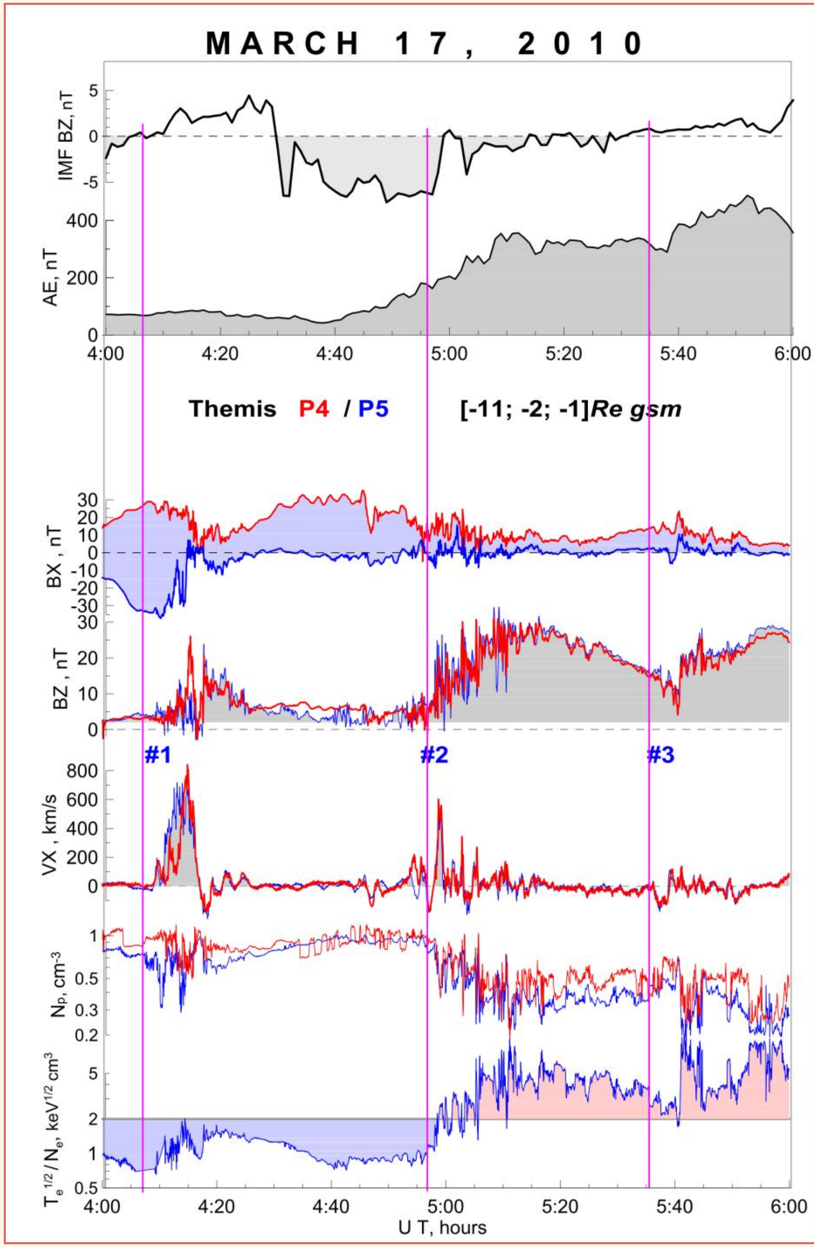
Themis puzzle

- During major radial THEMIS conjunctions (2008,2009) - unexpectedly small number of medium /strong substorms (in AE/AL terms), whereas magnetotail signatures (fast flows, TCS, dipolarization) are OK.

- Pseudobreakups – another name of that puzzle. PBUs ≅ - SBS-like activations including aur. breakup, fast flows, injections, SCW, dipolarization, which have weak (<100nT) associated AZ magnetic variations *(Koskinen et al.1993, Nakamura et al. 1994, Pulkkinen 1996, Aikio et 1999, Fillingim et al 2000, Kullen &Karlsson 2004…)*

Our explanation : nightside contribution to AL depends on additional (missed) variable

Important to explore to interprete correctly the ground magnetic measures of magnetospheric activity, which are most frequent research tool



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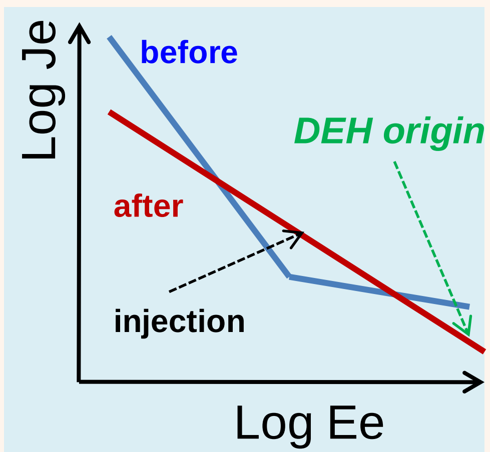
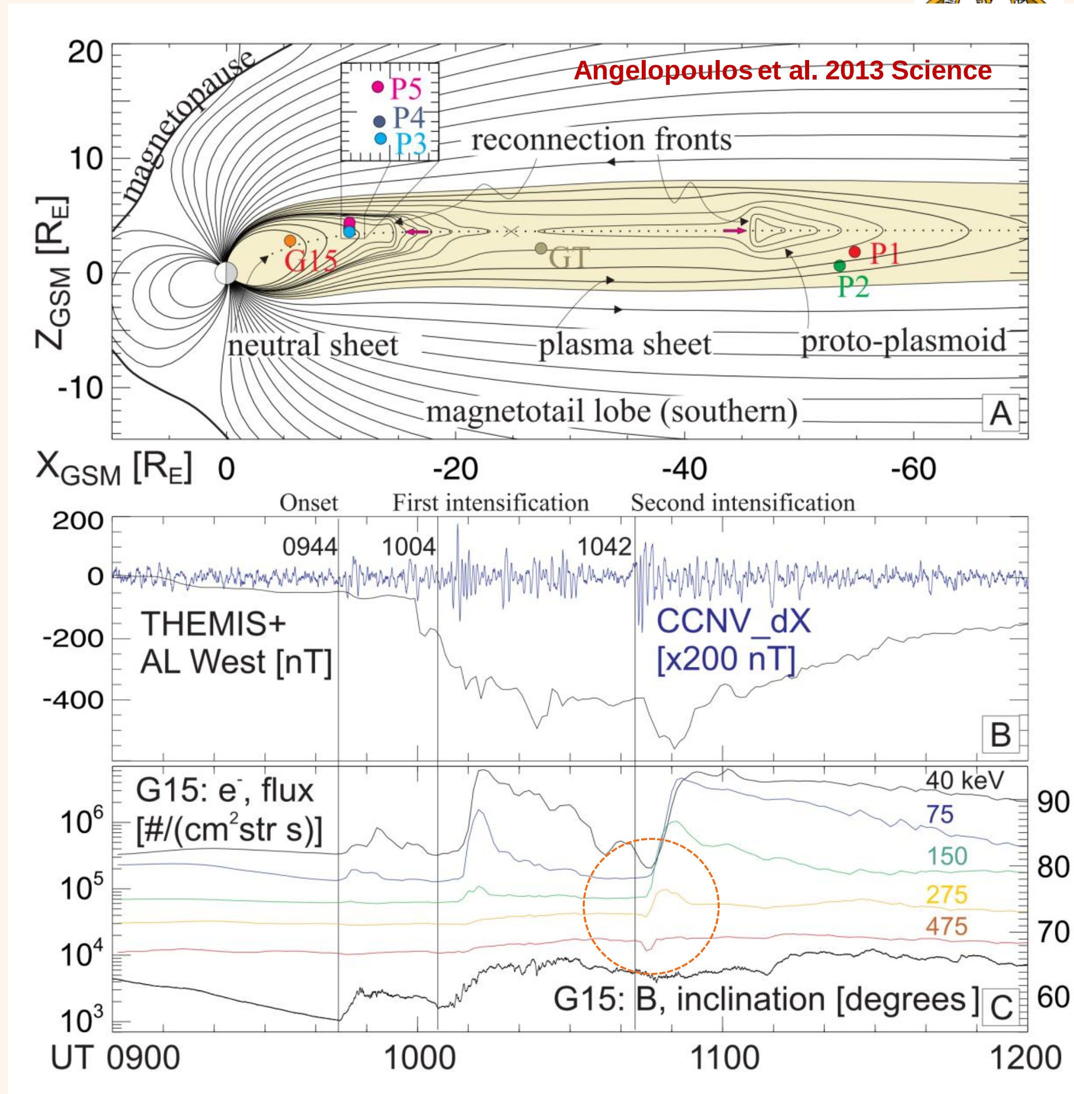
Drifting Electron Holes



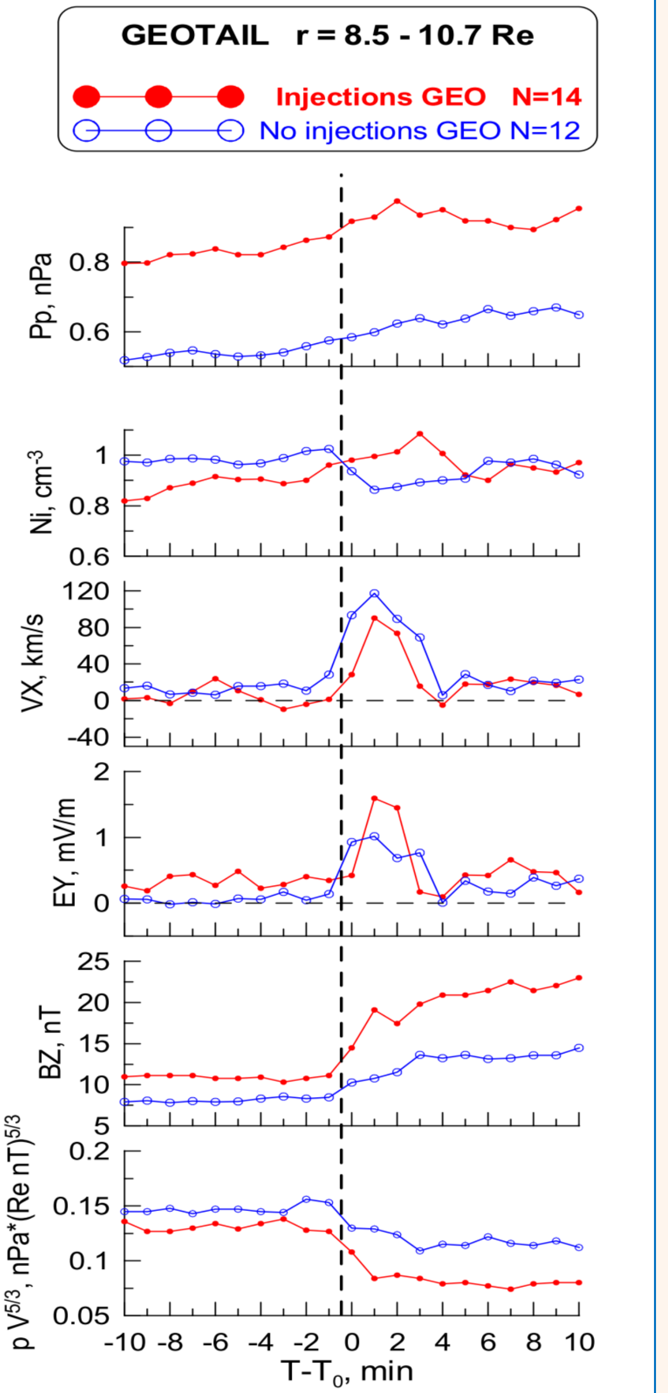
- Sergeev et al JGR 1992



#1 Geotail → LANL :
Flow Bursts at 9-10 Re

Superposed Epoch results (1min averages)

- ✓ Common for bubbles/BBFs (*e.g., Ohtani et al 2004*)
  - ❖ Enhanced BZ, flow VX, flux transport Ey
  - ❖ Depleted $pV^{5/3}$
- ✓ Peculiar at ~9Re are
  - ❖ density/pressure depletion - less clear (1min?)
- ✓ GEO-penetrating flow bursts
  - ❖ Deeper $|\Delta S|$ depletion and larger dBZ in penetrating FBs
  - ❖ Vx or Ey are bad predictors
  - ❖ **Higher pressure before/during penetrating** FBs – effect of background configuration



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