What happens to flow bursts as they propagate towards the Earth

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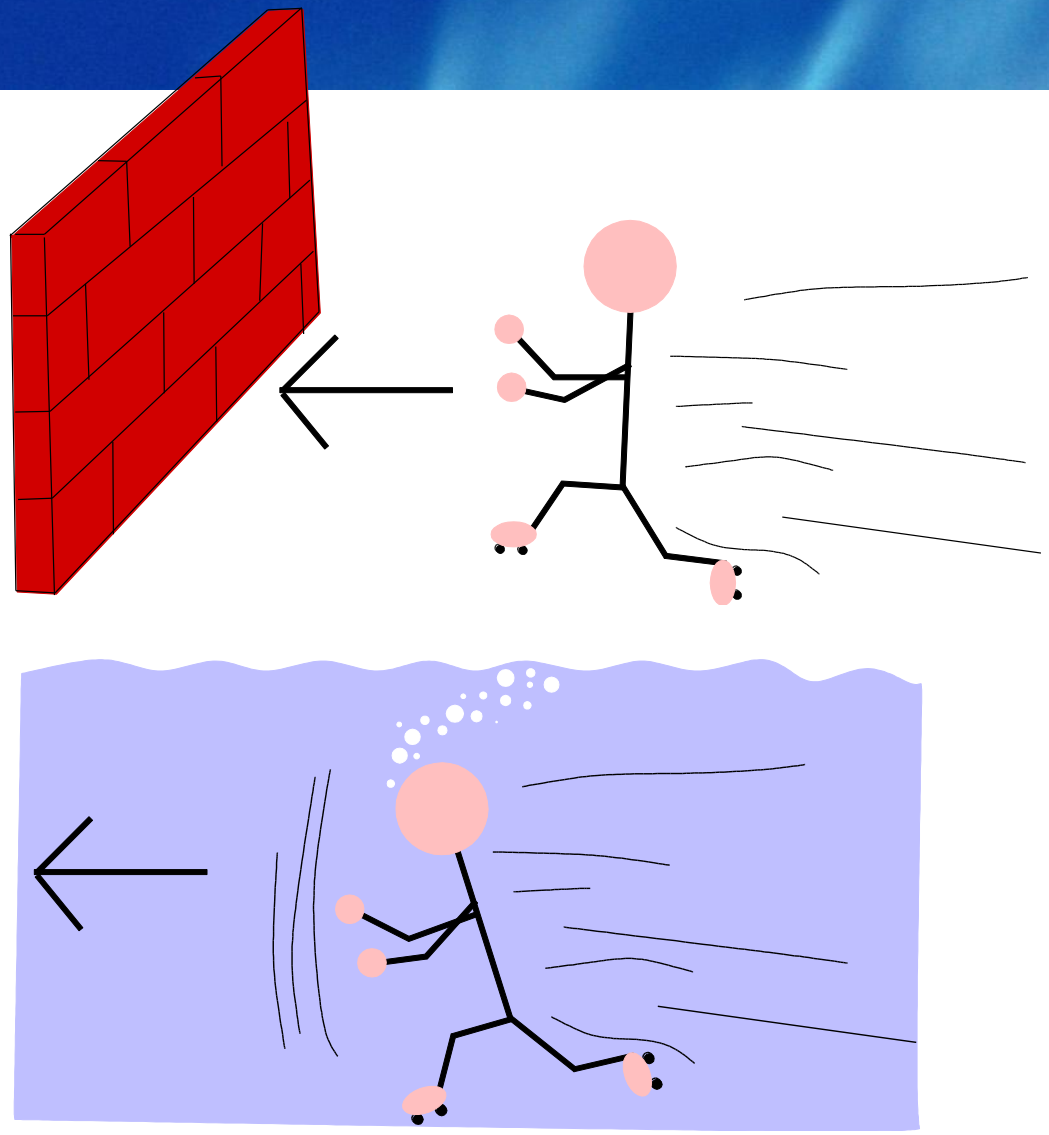
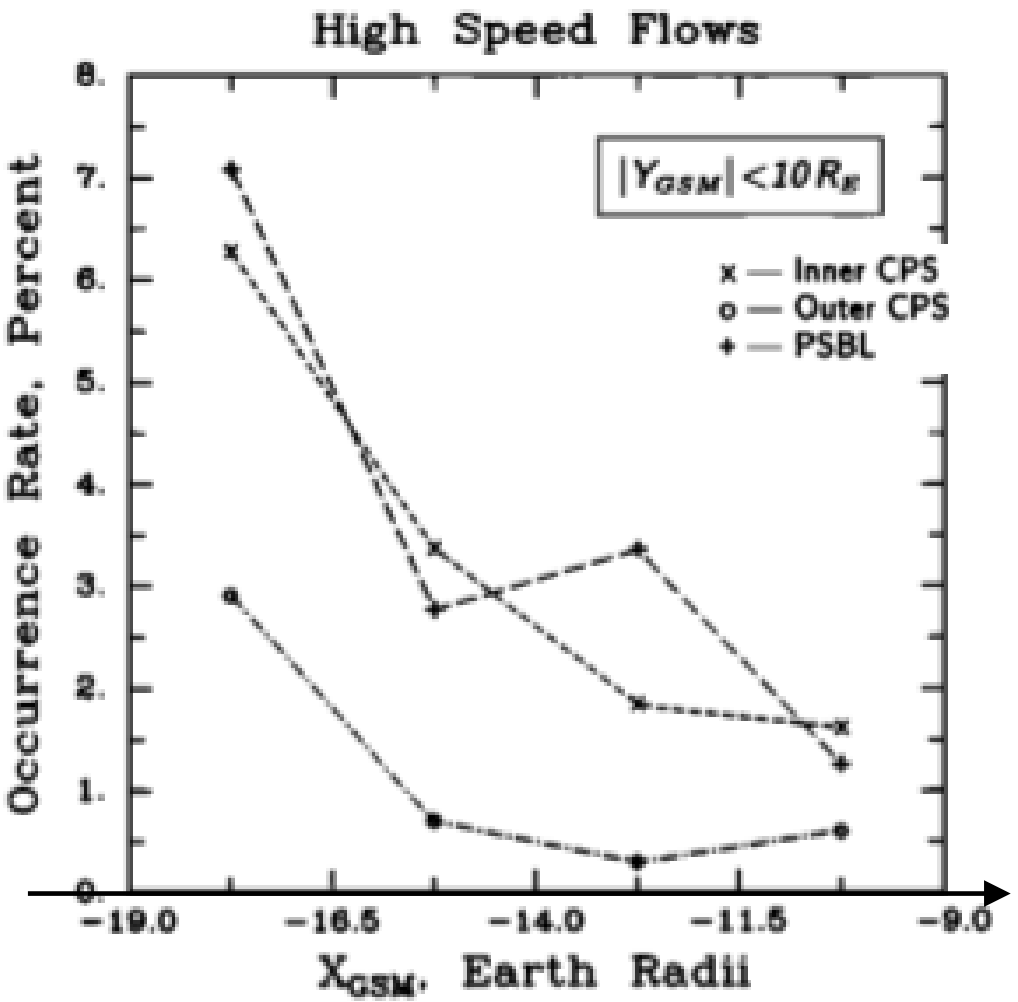
Braking at inner edge of neutral sheet or continuous braking?



Some previous investigations 1990-2012

Baumjohann et al., JGR 1990

- Characteristics of high speed flows (>400 km/s)
- -9<X<-19 R_E (AMPTE/IRM satellite)
- Decreasing occurrence rate towards Earth
- **Indication of more continuous braking?**

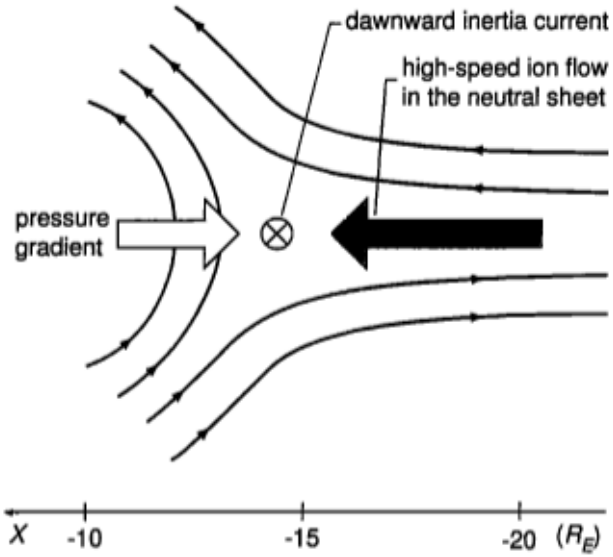


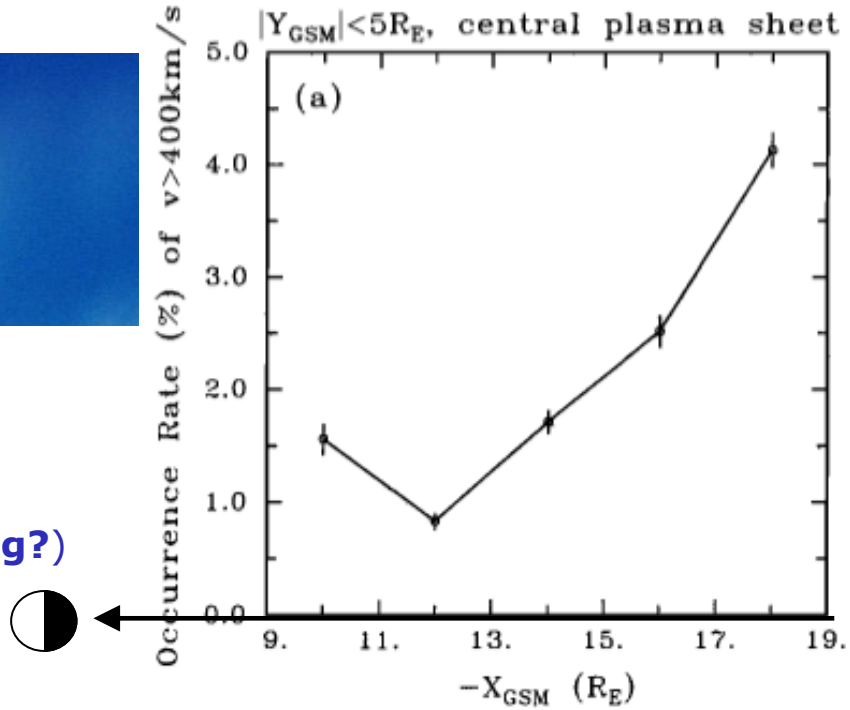
Shiokawa et al., GRL 1997

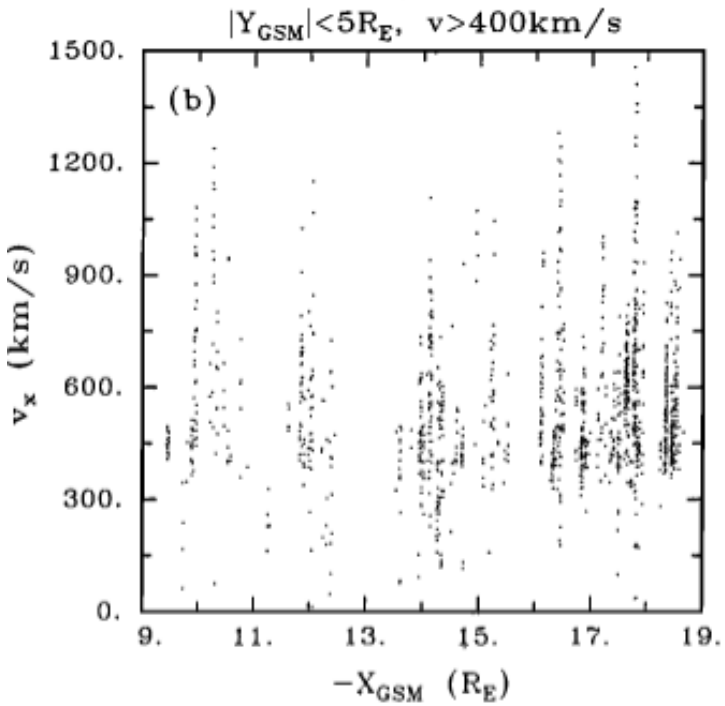
- Braking of high speed flows (>400 km/s)
- -9<X<-19 R_E (AMPTE/IRM satellite)

- Decreasing occurrence rate towards Earth (**braking?**)
- No velocity decrease observed

- Flows >~600 km/s still observed ~10 R_E
- Final stopping at inner edge of neutral sheet



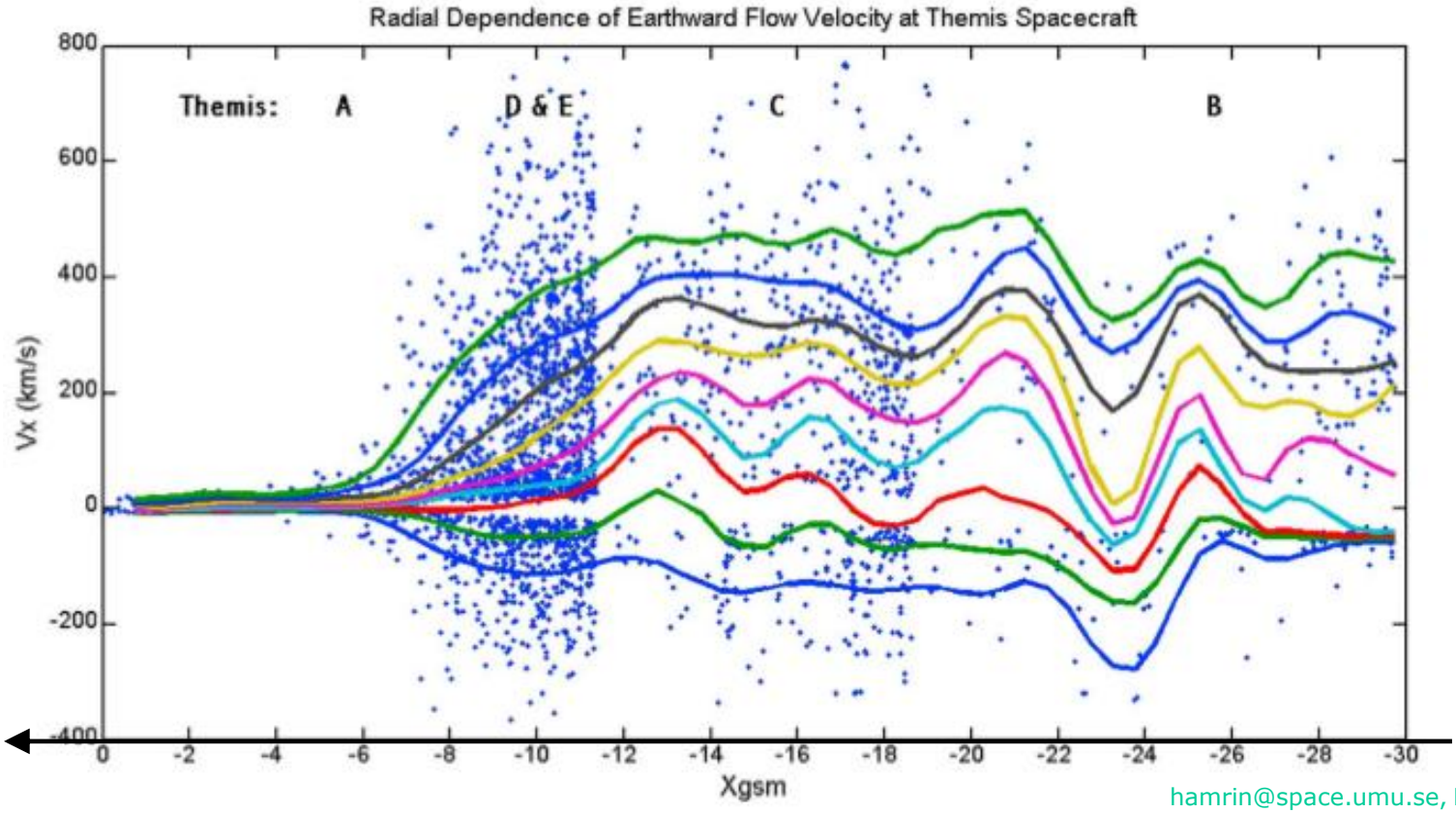




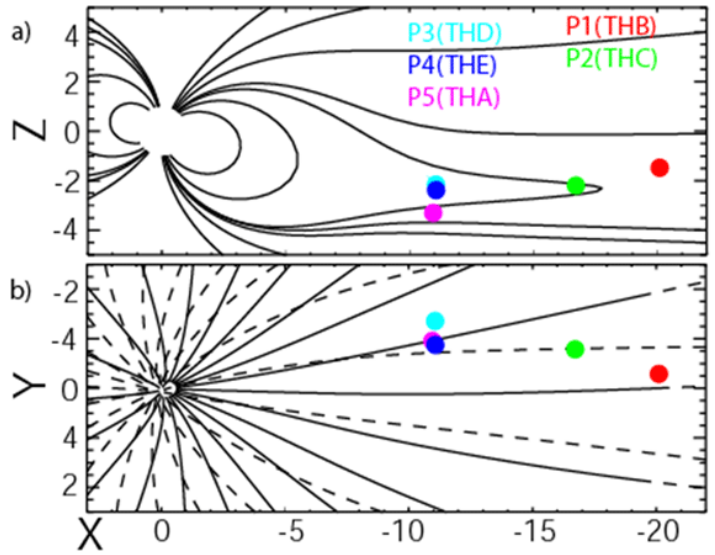
McPherron et al., JGR 2011

- Flows characteristics at inner edge of the plasma sheet
- THEMIS, $|V\perp| > 150$ km/s

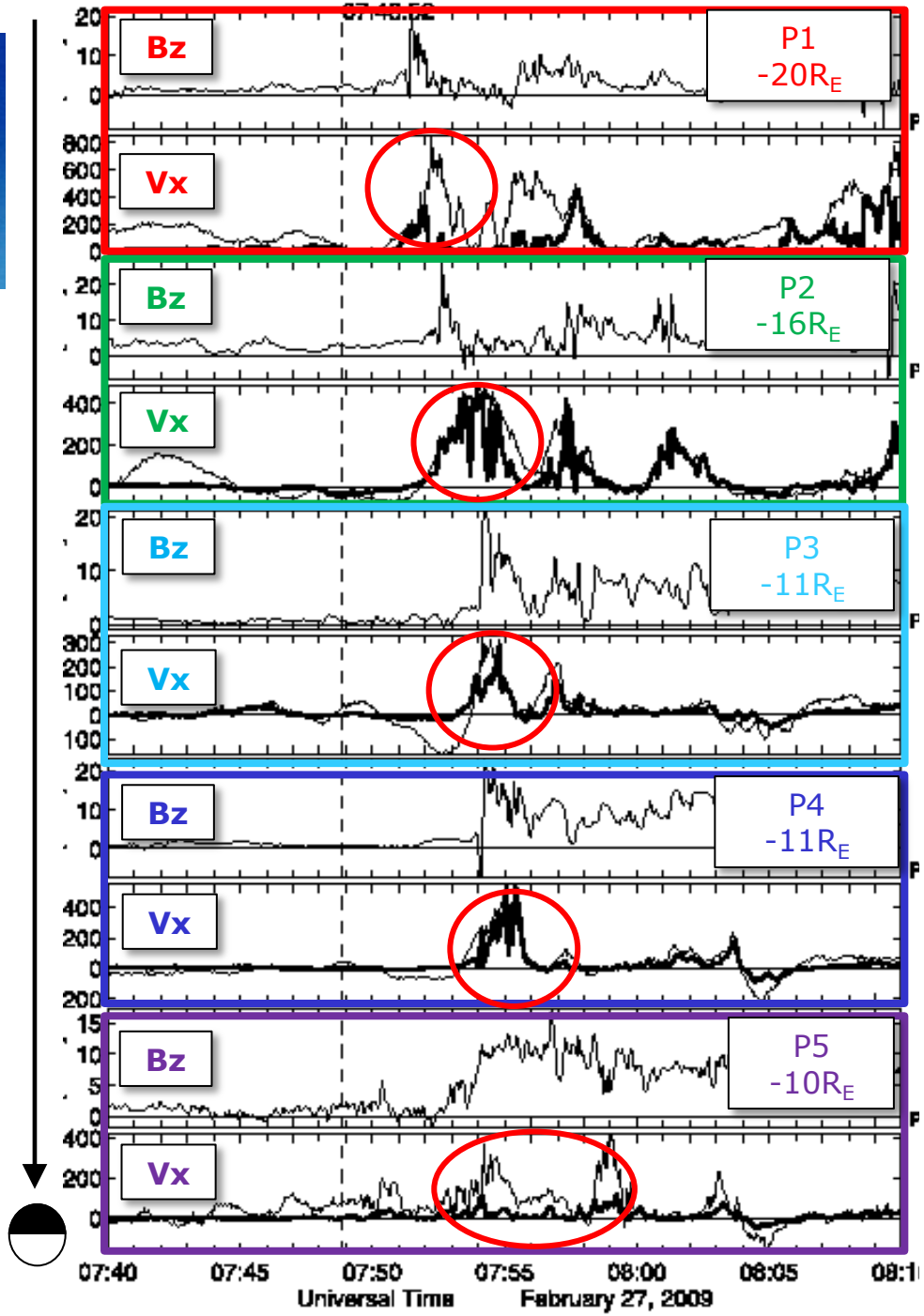
- Only weak velocity decrease inside -22 R_E
- Rapid velocity decrease inside -12 R_E



Ge et al., JGR 2012

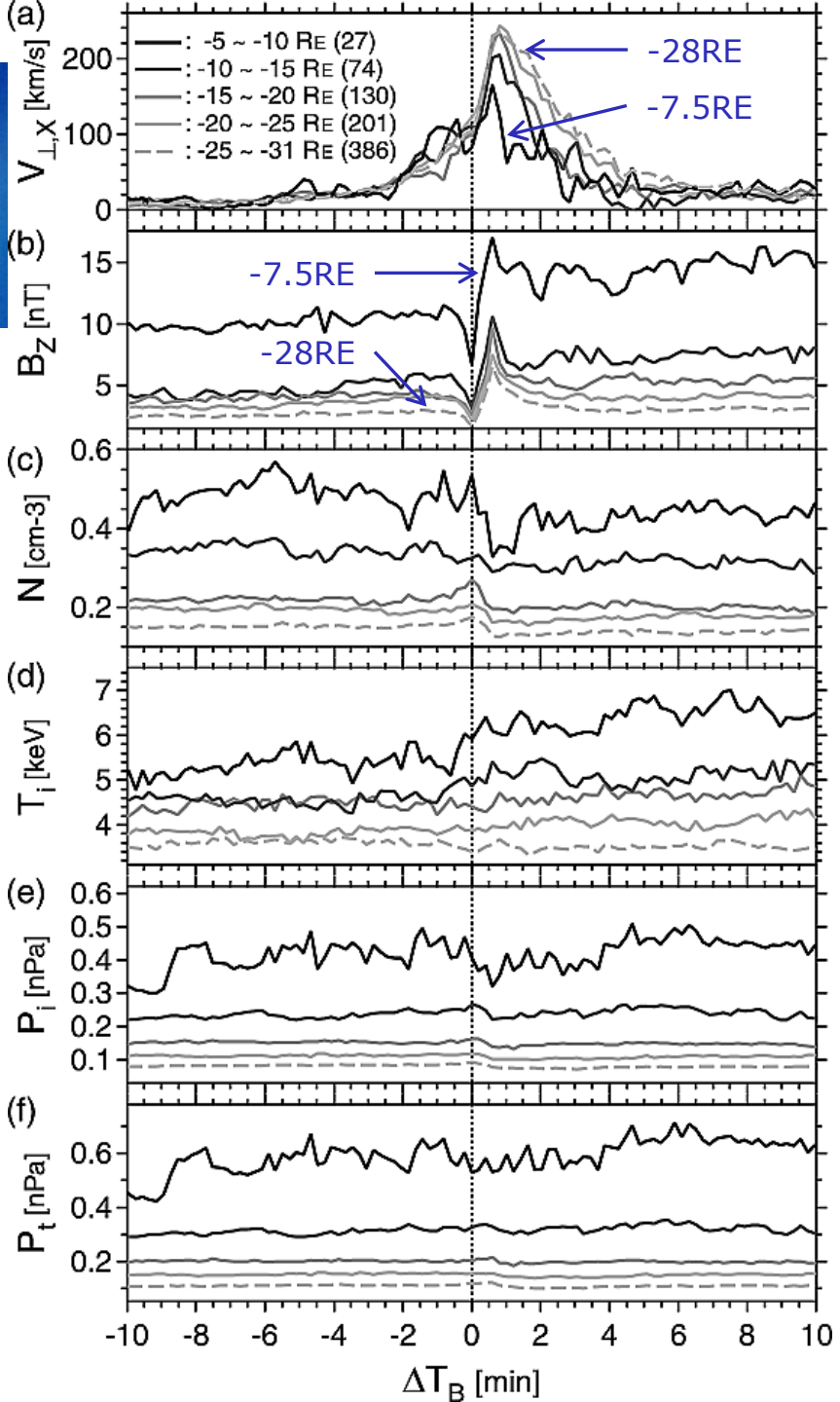


- Dipolarization front study, single event
- THEMIS
- Velocity decrease 800km/s → 400km/s
- **Braking?**

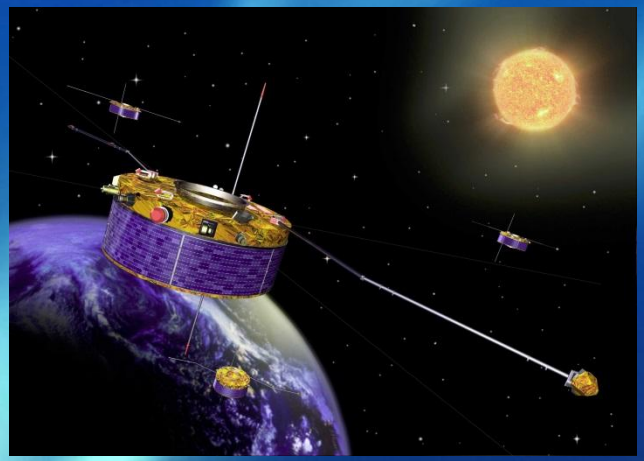


Ohtani et al., JGR 2004

- Temporal structure of convective fast flows
- Geotail -31 R_E < X < -5 R_E
- Superposed epoch study
- More dipolar Bz towards Earth
- V⊥x peak decreases towards Earth!
- **Braking?**



Can we use Cluster multi-spacecraft data to investigate the flow braking ?



Observations of energy conversion

Momentum eq.:

$$\rho\frac{\partial \mathbf{V}}{\partial t}+\rho\mathbf{V}\cdot\nabla\mathbf{V}=\mathbf{J}\times\mathbf{B}-\nabla p=\mathbf{F}_{\text{res}}$$

Poynting's theorem:

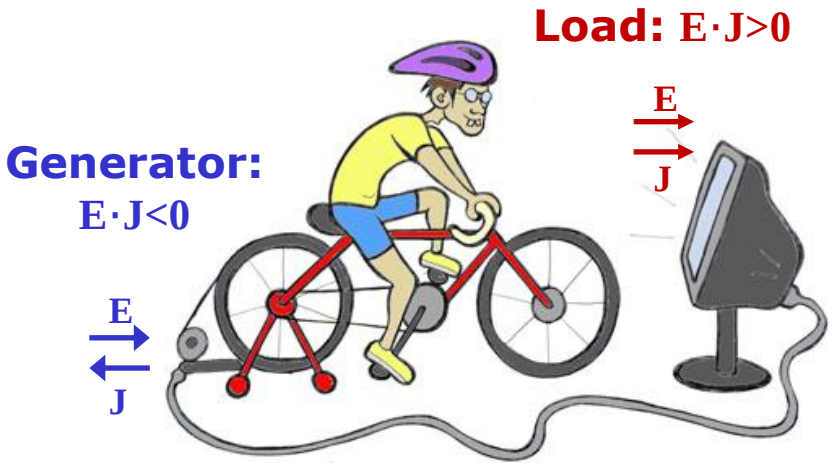
$$\frac{\partial}{\partial t}\frac{B^2}{2\mu_0}=-\nabla\cdot\mathbf{S}-\mathbf{E}\cdot\mathbf{J} \qquad (\mathbf{S}=\mathbf{E}\times\mathbf{B}/\mu_0)$$

Energy of bulk flow:

$$\frac{\partial}{\partial t}\frac{\rho V^2}{2}=-\nabla\cdot\left(\frac{\rho V^2}{2}\mathbf{V}\right)-\mathbf{V}\cdot\nabla p+\mathbf{E}\cdot\mathbf{J}$$

- Energy ($Jm^{-3}s^{-1}$) converted between particles and fields
- **E·J**<0: Energy from particles can be stored locally or transported away as Poynting flux

Energy conversion:
Kinetic energy ⇔ Electromagnetic energy



Multi-spacecraft data needed:

- Curlometer current from FGM, $\mathbf{J}\approx\nabla\times\mathbf{B}$
- Electric field from CIS and EFW, averaged over spacecraft

Simple model

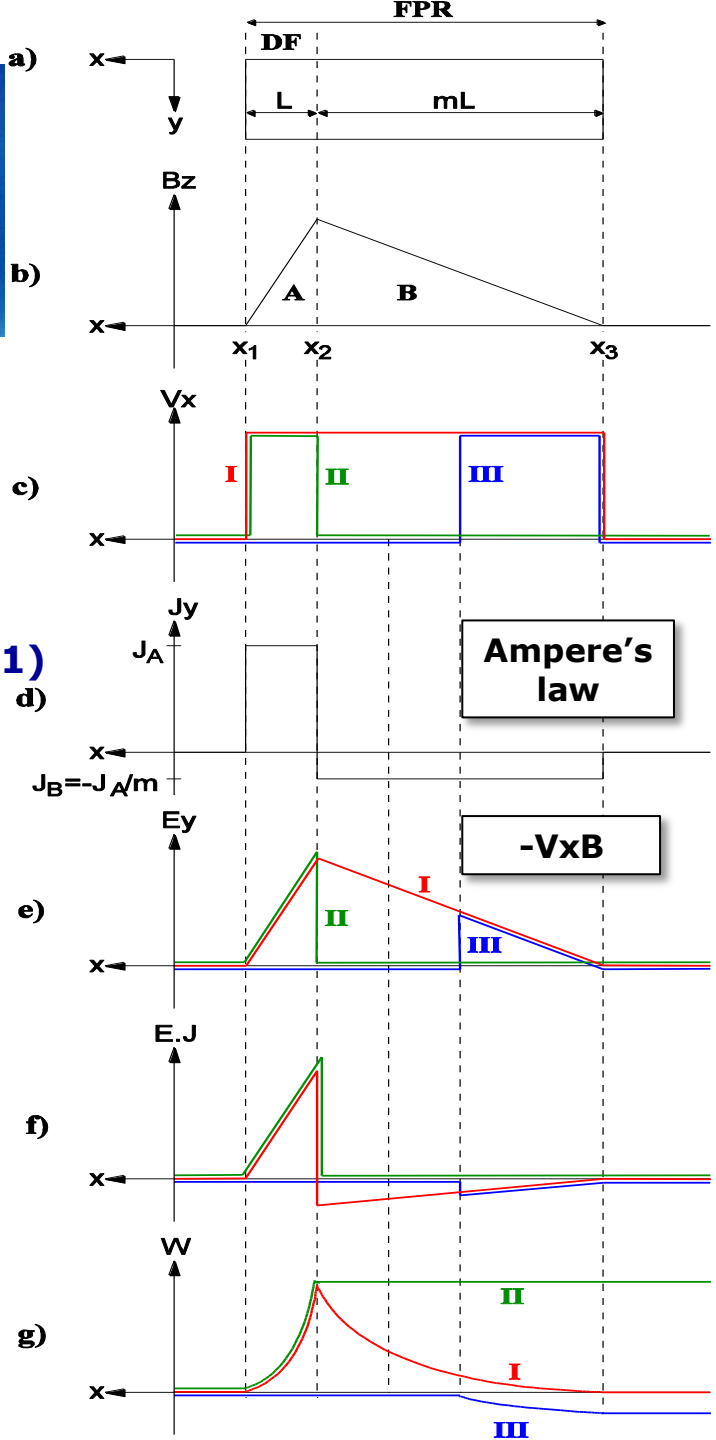
- Flux pileup region (FPR)
  [or DFB = Dipolarizing Flux Bundle]:

- I = Entire FPR moves as a unity
- II = Front of FPR moves ("decaying" – Fu et al., 2011)
- **III = Rear of FPR moves ("growing" – Fu et al., 2011)**
  *Rear flux tubes run into & compress Earthward ones (**obstacle**). Plasma decelerates. Flux is piling-up. Generator /dynamo process. **BREAKING?***

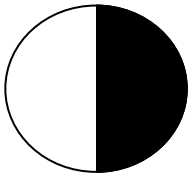
- **Integrate** over entire FPR:
  $W(FPR)=\int \mathbf{E}\cdot\mathbf{J}dx \rightarrow$ **Net energy change**

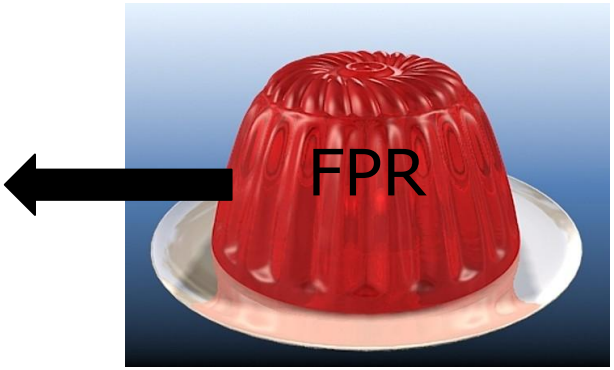
- Straightforward to show that
  W(x3)=0 for case I
  W(x3)>0 for case II
  W(x3)<0 for case III

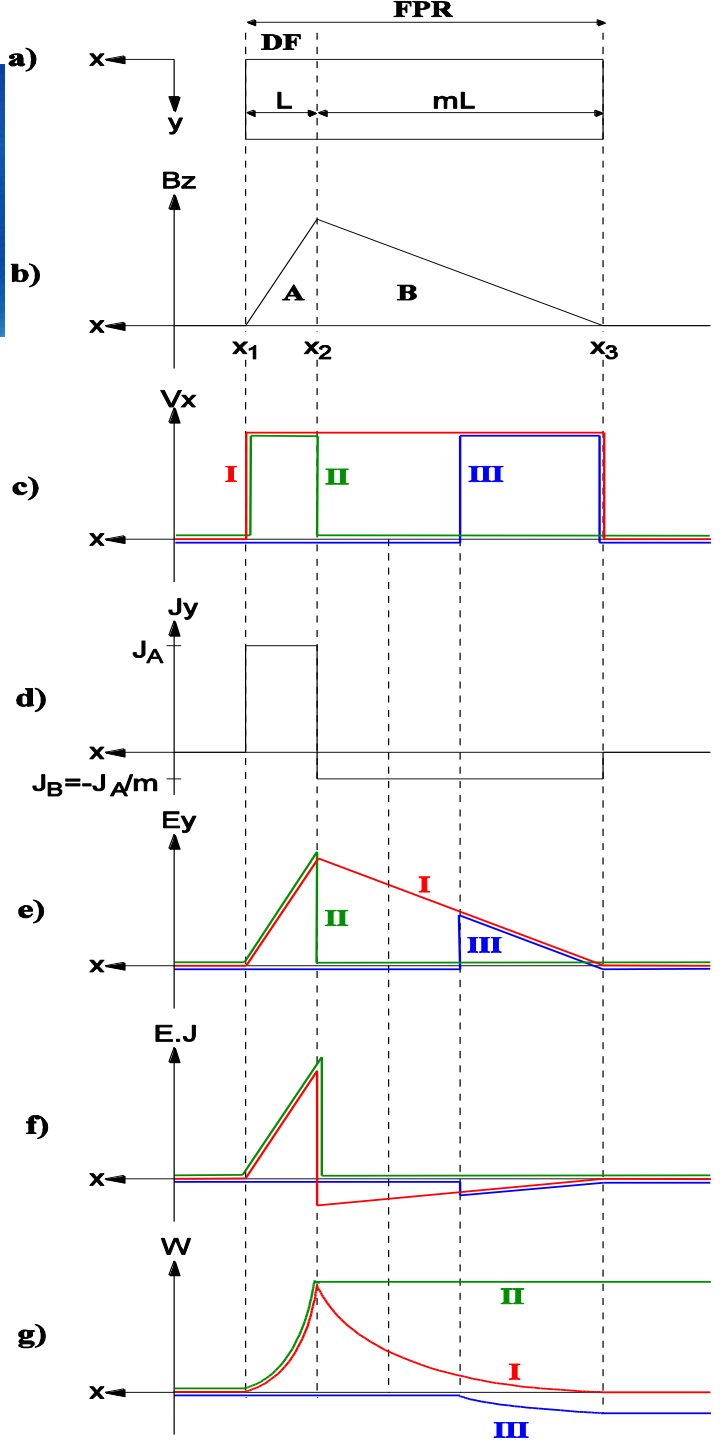
- Complications: Both growing and decaying phases simultaneously, not nicely probing the FPR, etc…



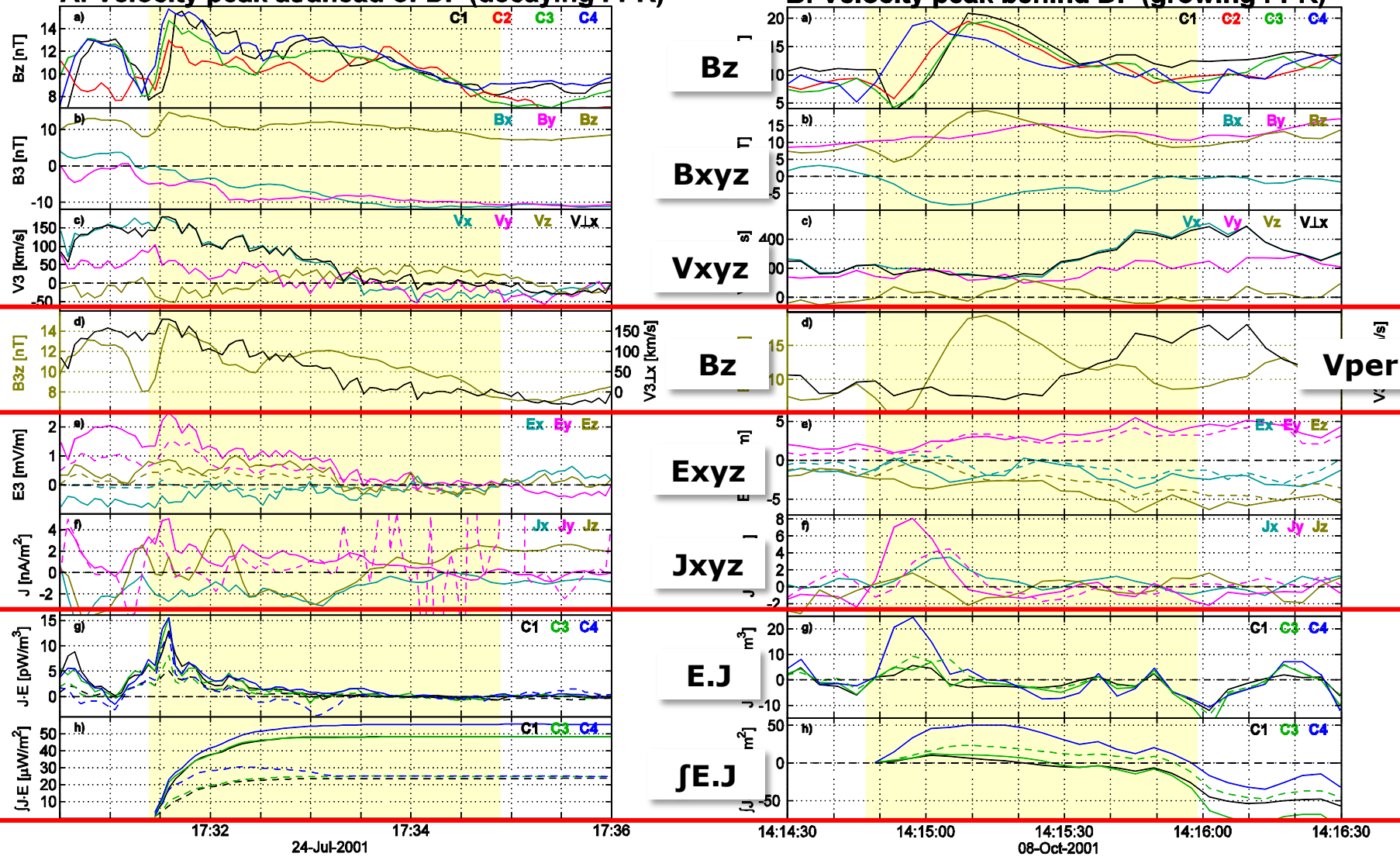
Simple model







Two examples

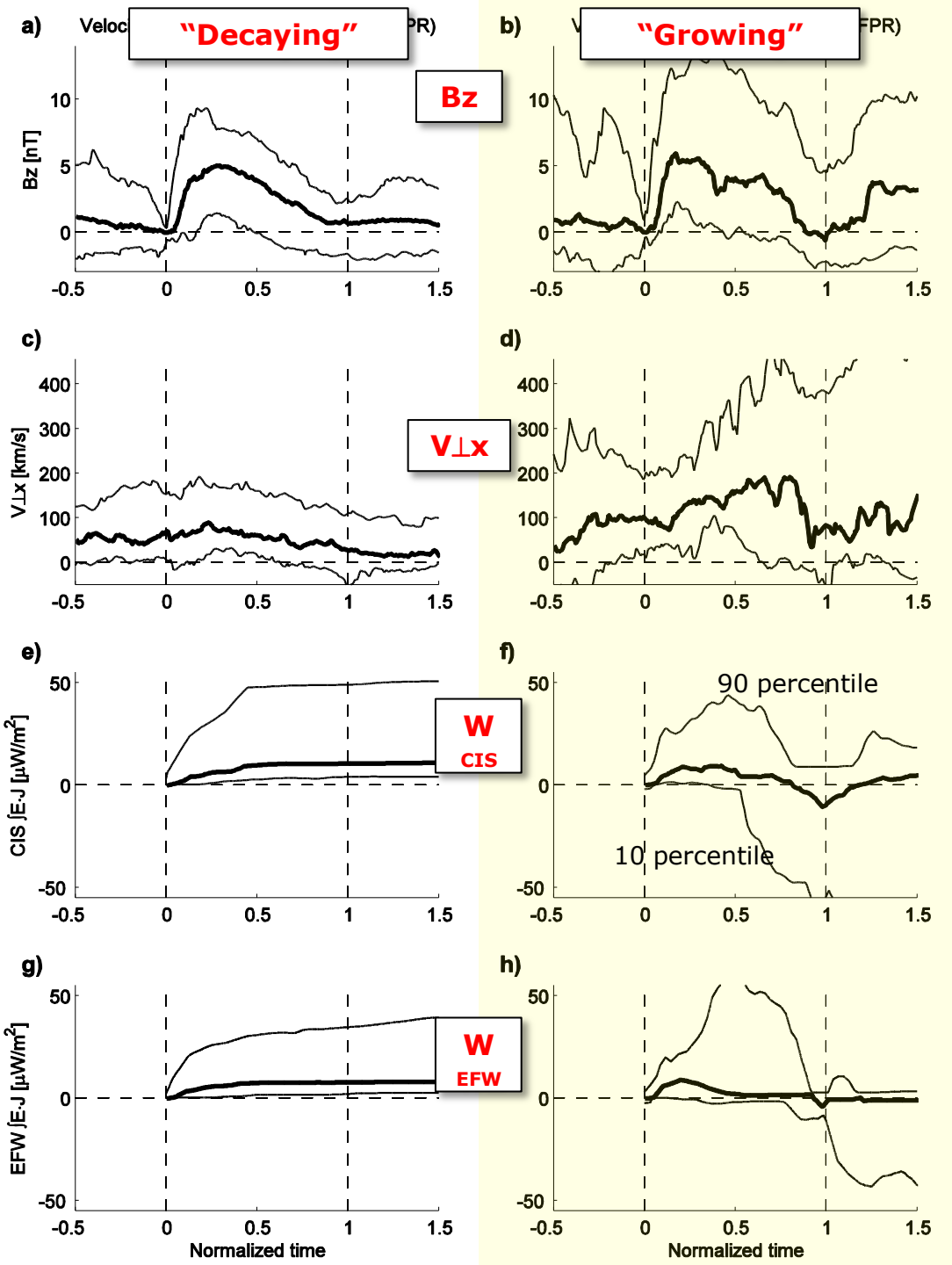


Superposed epoch investigation

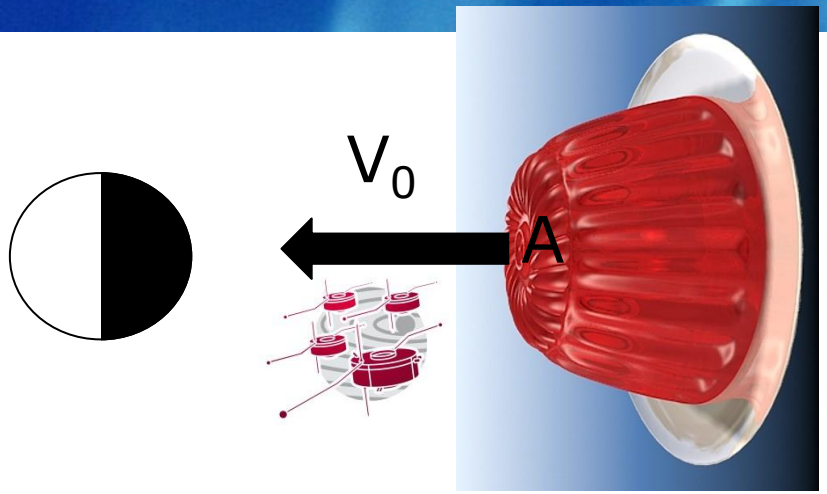
- Cluster 2001
- -14.5<X<-19.5 R_E

- "Decaying":
  - Monotonically increasing curve,
  - Net energy change W>0

- "Growing":
  - Local max in curve,
  - Net energy change W<0



Consistent with previous investigations?



- **Assumptions**:

- W<0 due to flow breaking only
- FPR moves with constant velocity V_0 over Cluster
- Constant FPR mass $M=nm_pAV_0\Delta t$
- $E = MV^2/2$

- **Net energy change** per Adt:

$$W = d/dt\ MV^2/(2A)|_{V0} = nm_pAV_0^2\Delta t$$

- **$W\sim -5\mu W/m^2 \rightarrow$**
  $a\sim -2km/s^2$

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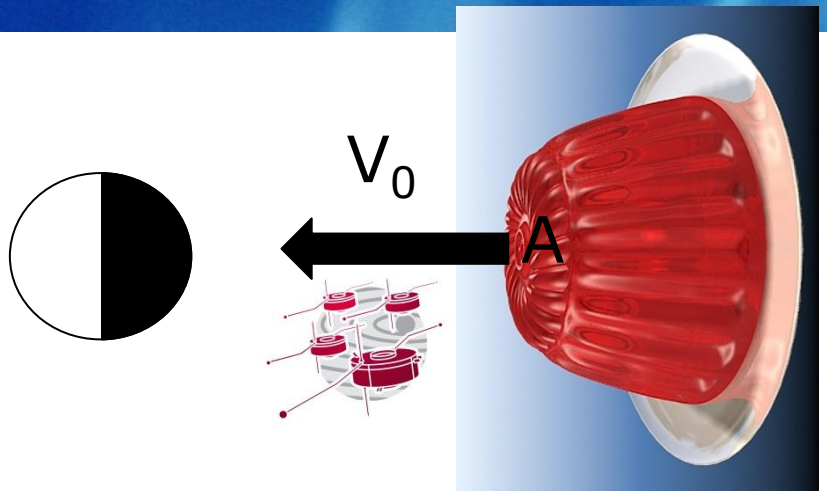

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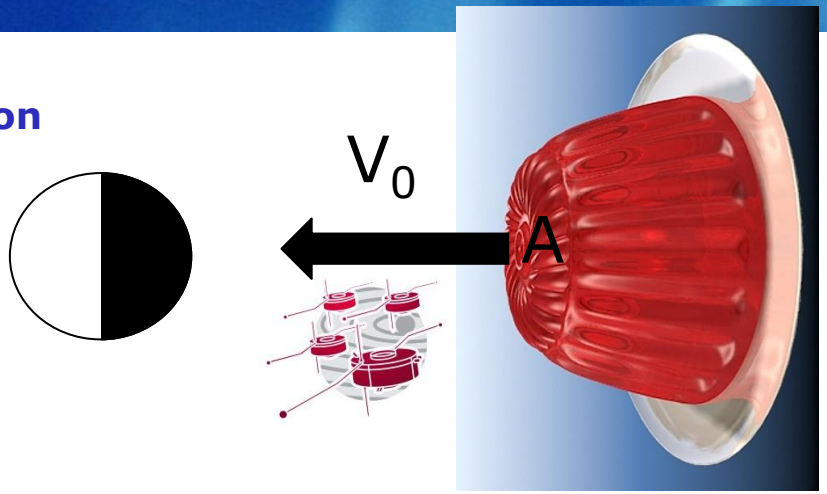
Consistent with previous investigations?

- **Statistical investigation**
- Ohtani et al., JGR 2004

  240→160km/s for
  28→7.5R_E

  W~-0.5μW/m²
  a~-0.13km/s²



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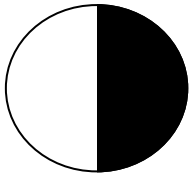

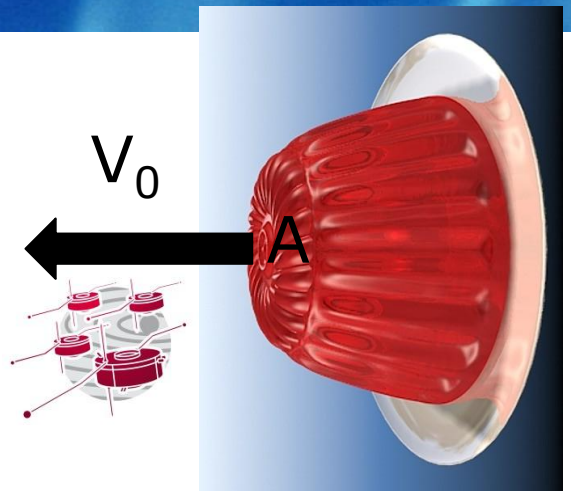

- **Event investigations:**
- Runov et al., GRL 2009
  Ge et al., JGR 2012

  1000→500km/s for
  20.1→16.7R_E (THEMIS P1→P2)

  W~-100μW/m²
  a~-17 km/s²

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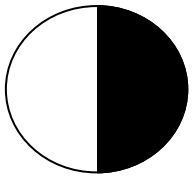

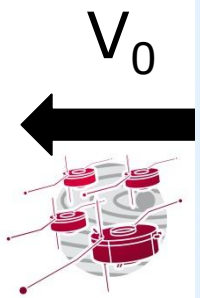

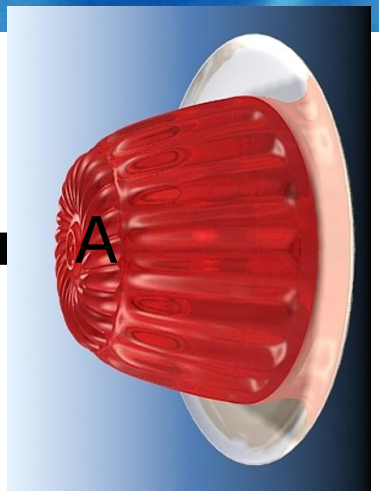

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- **Net energy change** per Adt:

  $$W = d/dt\ MV^2/(2A)|_{V0} = nm_pAV_0^2\Delta t$$

Statistical result < • **W~-5μW/m² → a~-2km/s²** **< Typical event**

Conclusions

- Energy arguments (**E·J**) can be used for studying flow braking

- **Dipolarization fronts can act as local impediments** to earthward propagating flow bursts before they arrive at the inner edge of the plasma sheet

- Observed net energy change (a~-2km/s^2, W~-5μW/m^2) is **consistent with previous investigations** (within the range):

- **Flow peak position relative to the DF** can be used as a **single-spacecraft proxy for energy conversion** properties (useful when multi-spacecraft data are not available)

Challenges:

- Understand other sources/sinks for energy balance (MMS)
- Comprehensive understanding of entire M-I system
- …

Thank you!

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