Magnetopause and boundary layers: Reporter review
2009-2011

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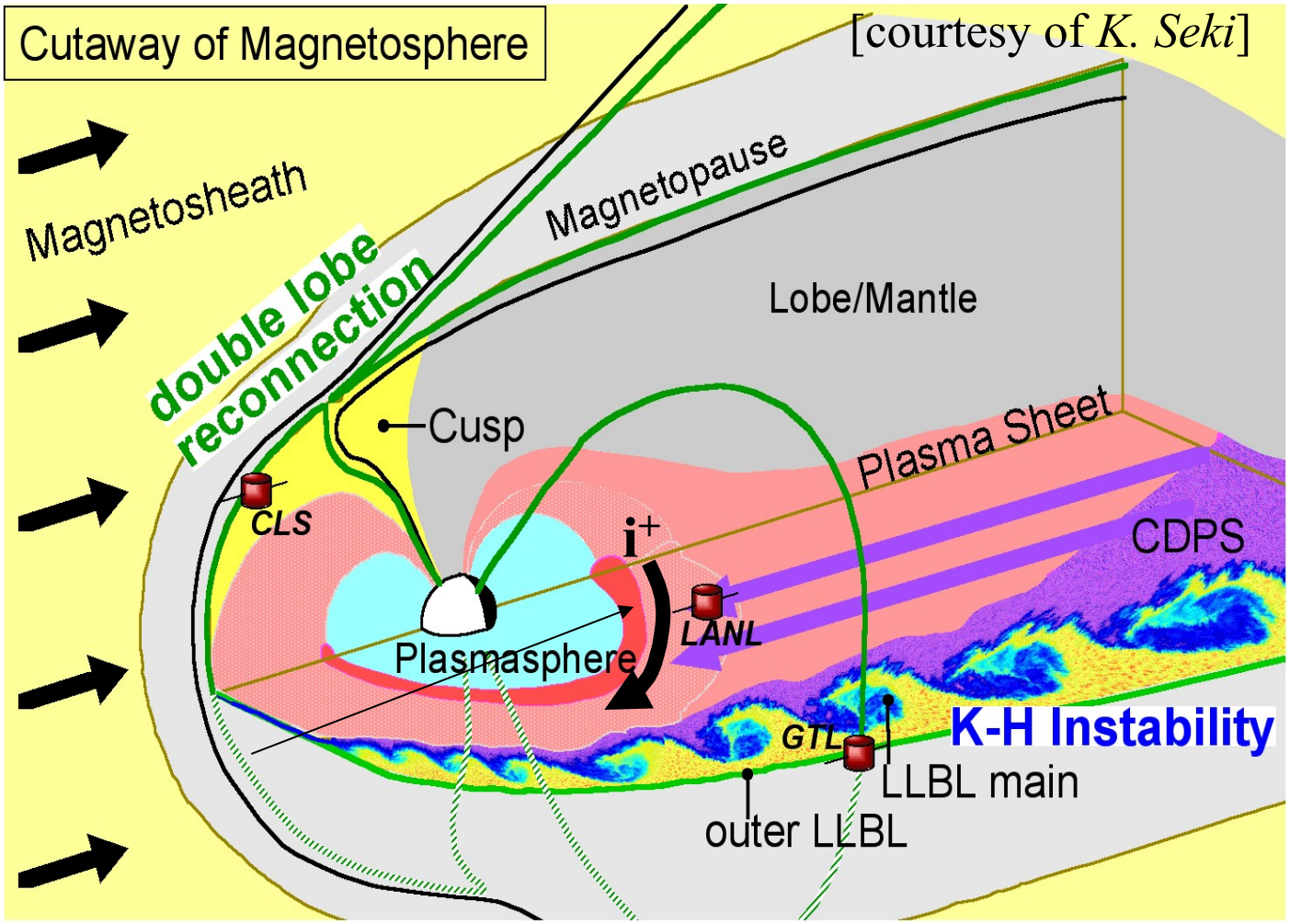
Magnetopause and boundary layers :



- **Solar wind plasma entry occurs at the magnetopause**
- **Key processes allow the formation of the cusp, boundary layers and in turn the plasma sheet**

OUTLINE

- Magnetic reconnection
- Kelvin-Helmholtz and diffusion
- More global aspects
- Conclusion

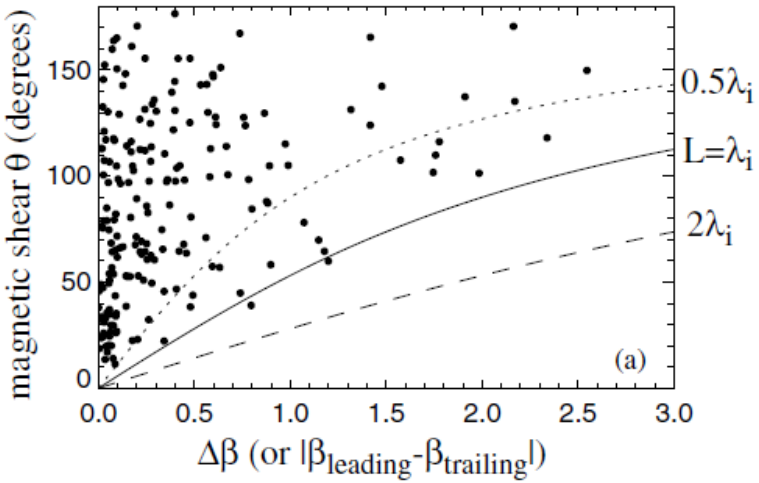
Magnetic reconnection

New insights from magnetic reconnection ***in the solar wind***

- *Phan et al.* [2009] (*Gosling et al.* [2007]): Solar wind X-lines in large-scale current sheets are **extended, not patchy**, and have **no significant warping**

- Reconnection at low shear is suppressed for large Δβ, consistent with **super-Alfvénic drift of the X-line** caused by plasma pressure gradients [*Phan et al.*, 2010]

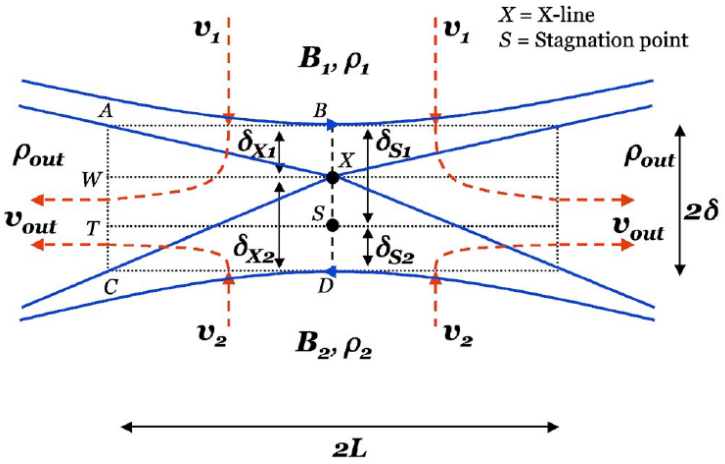
Phan et al. [2009]

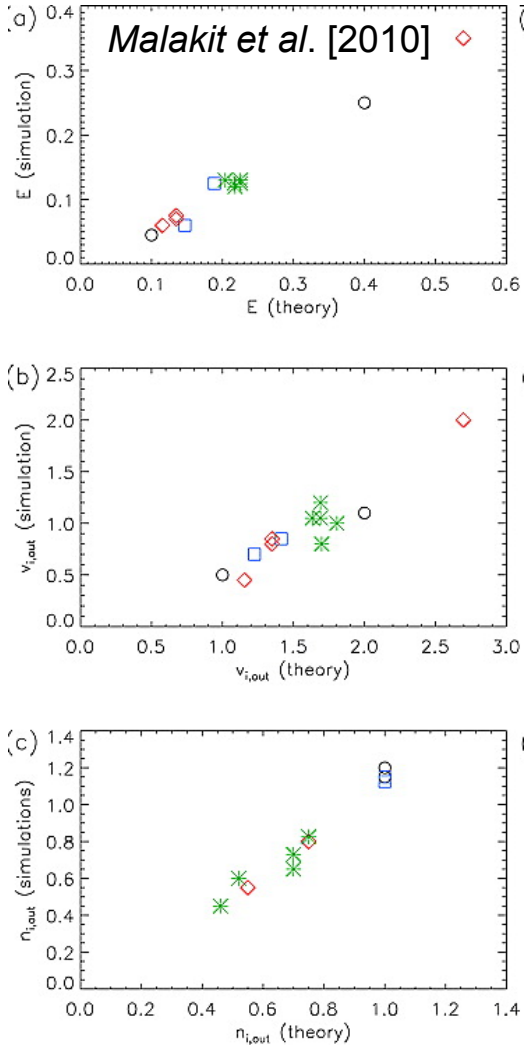


(cf. also *Eriksson et al.* [2009], *Grocott et al.* [2009] and *Lavraud et al.* [2009])

→ *In situ* evidence for a large spectrum of regimes: steady/extended to localized/turbulent

Scaling of asymmetric reconnection, i.e.: MP





- *Malakit et al.* [2010] successfully tested *Cassak and Shay* [2007]'s asymmetric reconnection scaling law **using PIC simulations**

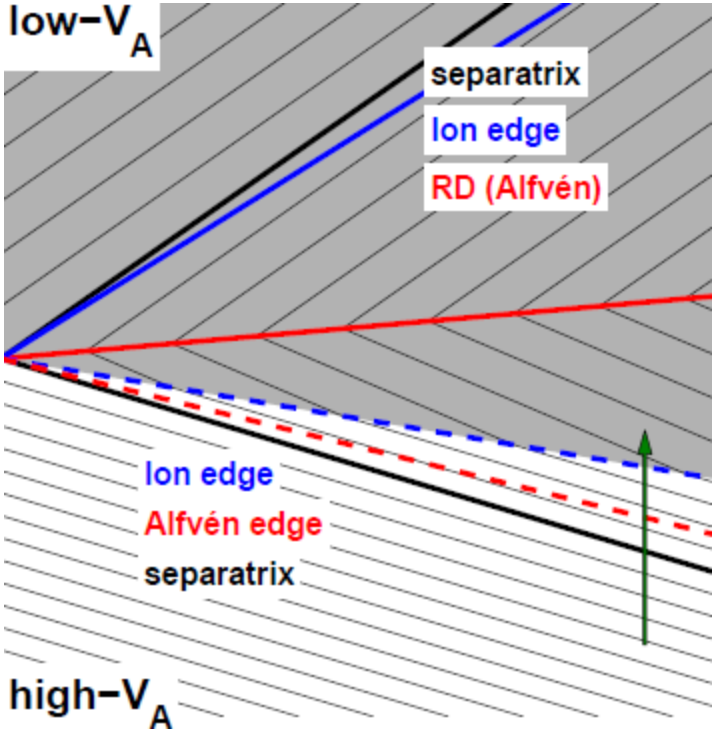
- Cf. also *Birn et al.* [2010]; *Pritchett and Mozer* [2009]; etc.

→ **Observational tests ? reconnection rate still elusive**

Observation of asymmetric reconnection at MP

- *Vaivads et al.* [2010] identified the Alfvén edge associated with asymmetric reconnection at the MP **using Cluster data**

- Cf. also *Lindstedt et al*. [2009]; *Wendel and Reiff* [2009]



Vaivads et al. [2010]

→ Explanation to the absence of bifurcated current sheets, as opposed to solar wind case ?

Magnetic reconnection and driving functions

- *Balikhin et al.* [2008]:
NARMAX modeling finds that the best coupling function has a dependence on clock angle like: $\sin\left(\frac{\theta}{2}\right)^6$

$$\mathrm{CF} = p^{\frac{1}{2}} V^{4/3} B_T \sin^6\left(\frac{\theta}{2}\right)$$

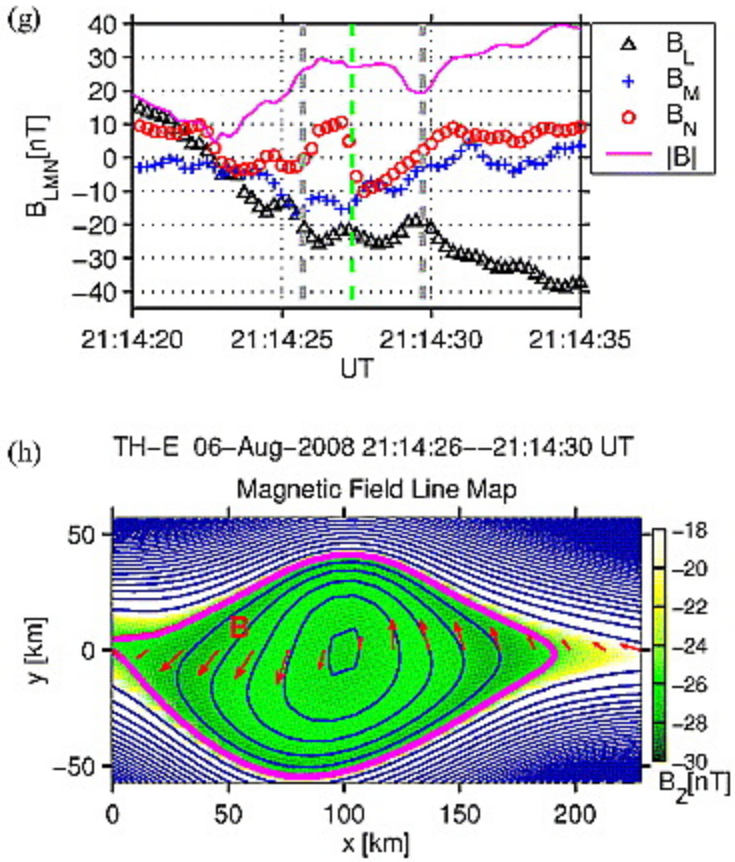
Table 1. List of Coupling Functions

Name	Coupling Function	Reference
I_B	VB_s	*Burton et al.* [1975]
ε	$VB^2 \sin^4(\theta/2)$	*Perreault and Akasofu* [1978]
I_W	$VB_T \sin^4(\theta/2)$	*Wygant et al.* [1983]
I_{SR}	$p^{1/2} VB_T \sin^4(\theta/2)$	*Scurry and Russell* [1991]
I_{TL}	$p^{1/2} VB_T \sin^6(\theta/2)$	*Temerin and Li* [2006]
I_N	$V^{4/3} B_T^{2/3} \sin^{8/3}(\theta/2)$	*Newell et al.* [2007]
I_V	$n^{1/6} V^{4/3} B_T \sin^4(\theta/2)$	*Vasyliunas et al.* [1982]

→ Ways to find the best coupling functions and their physical significance are highly debated

Hall reconnection and secondary islands

Teh et al. [2010]



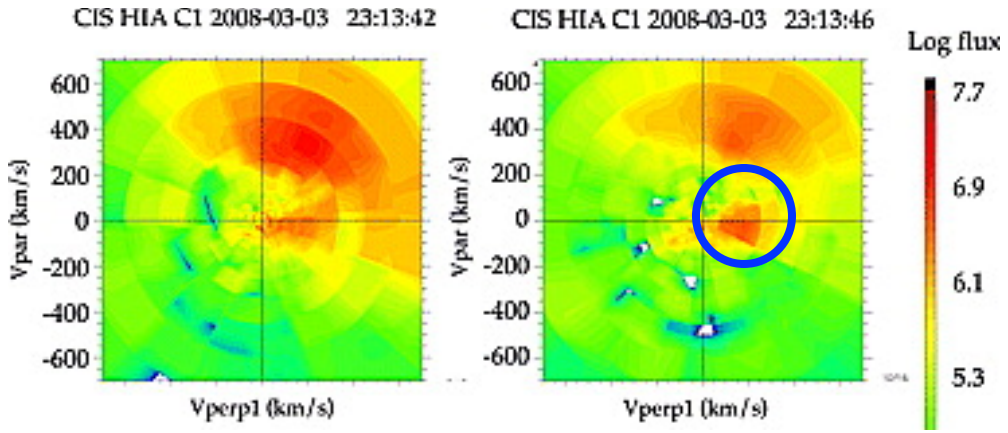
- *Teh et al.* [2010]:
Clear **observation** of a secondary magnetic island at the reconnecting MP

- For magnetotail, see also:
Eastwood et al., [2007]

→ Resolution and accuracy of measurements is a key
More and more quantitative tests : towards MMS!

Magnetopause reconnection and cold plasma

- *André et al*. [2010]: evidence for cold ions **involved** in dayside reconnection.



André et al. [2010]

- Dense plasmaspheric plume **chokes reconnection**.
(cf. also *McFadden et al*. [2009] and older *Borovsky and Denton* [2006])

→ Filling of the plasmasphere and formation of plumes :
A preconditioning of the magnetosphere

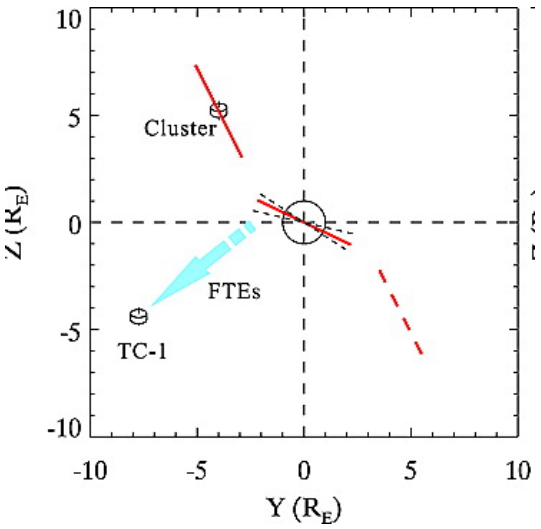
Component ***versus*** anti-parallel reconnection

- *Wang et al*. [2011]: simultaneous component and anti-// merging from two spacecraft compatible **with S-shape X-line**

- *Ouellette et al*. [2010], *Park et al*. [2010], *Cai et al*. [2009], *Hu et al*. [2009]: **Global MHD simulations** also highlight both component and anti-// merging

- *Fuselier et al.* [2010]: Two-spacecraft method to determination reconnection rate: **anti-parallel reconnection** R = 0.08, **component reconnection** R < 0.01.

Wang et al. [2011]



Note: importance of multi-spacecraft data

→ Evidences exist for both "types" of reconnection:
Preferred initiation geometry of reconnection still unclear

Non-steady reconnection: Flux Transfer Events (1/2)

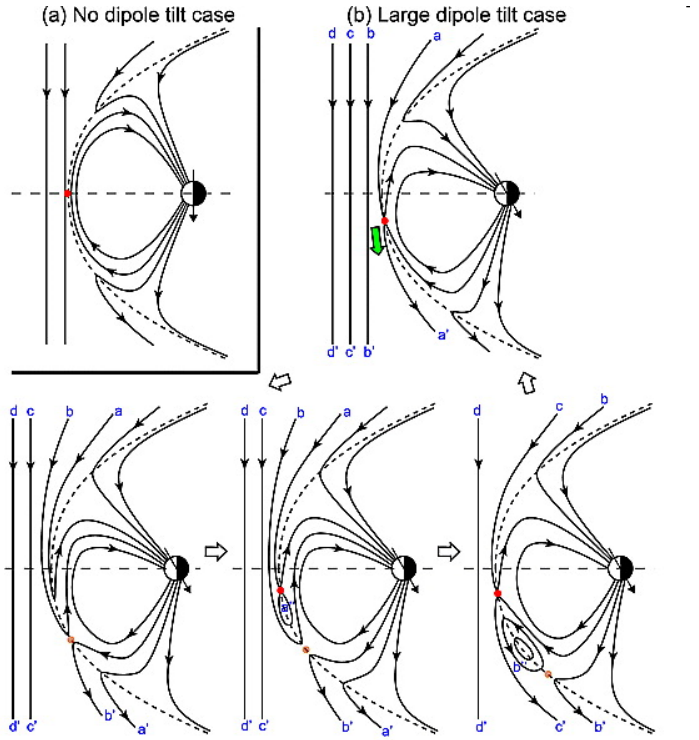
- *Hasegawa et al*. [2010], *Fear et al*. [2010]; *Trenchi et al*. [2011]:
Observations suggest FTE generation results from **multiple X-line** process

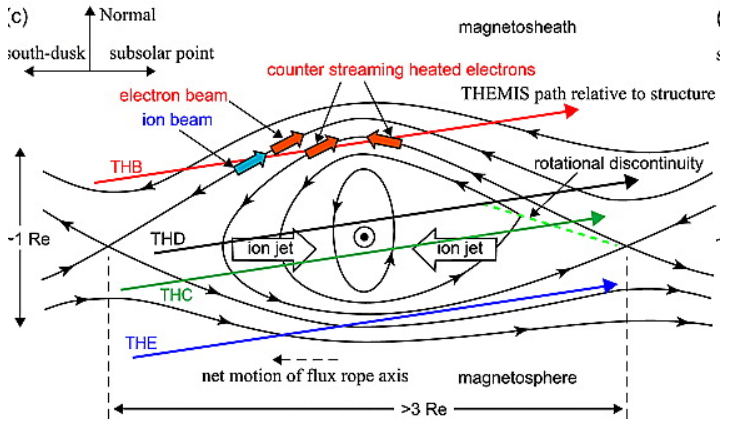
- Also observed in new **3D global hybrid** simulations [*Tan et al*., 2011]

cf. earlier *Dorelli and Battacharjee* [2009] and *Raeder* [2006])

→ FTE generation mechanisms still much debated:
Modeling and reconstruction techniques helpful

Hasegawa et al. [2011]



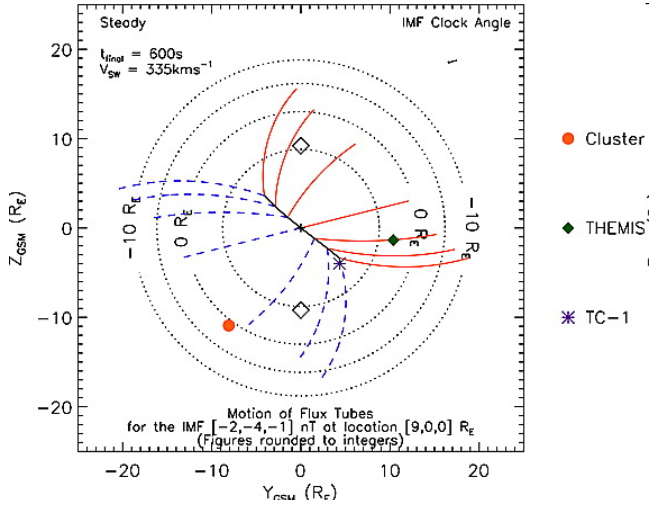


Non-steady reconnection: Flux Transfer Events (2/2)

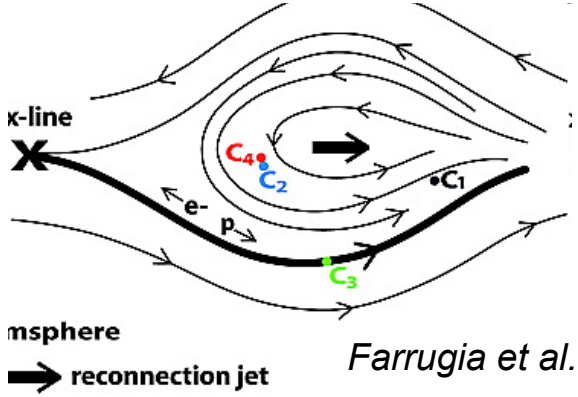
- **Modeling and multi-point observations** of FTE evolution: *Zhang et al*. [2010]; *Sibeck and Lin* [2010]; Fear et al. [2009]

- *Zhang et al*. [2010] and *Farrugia et al*. [2011]: Crater FTE = **initial FTE?**

- *Slavin et al*. [2010]: Mercury-size FTE at **Mercury** increased planets' exposition to solar wind by **up to 20%**



Fear et al. [2009]



Farrugia et al. [2011]

→ Broad range of FTE signatures and evolution, with new implications

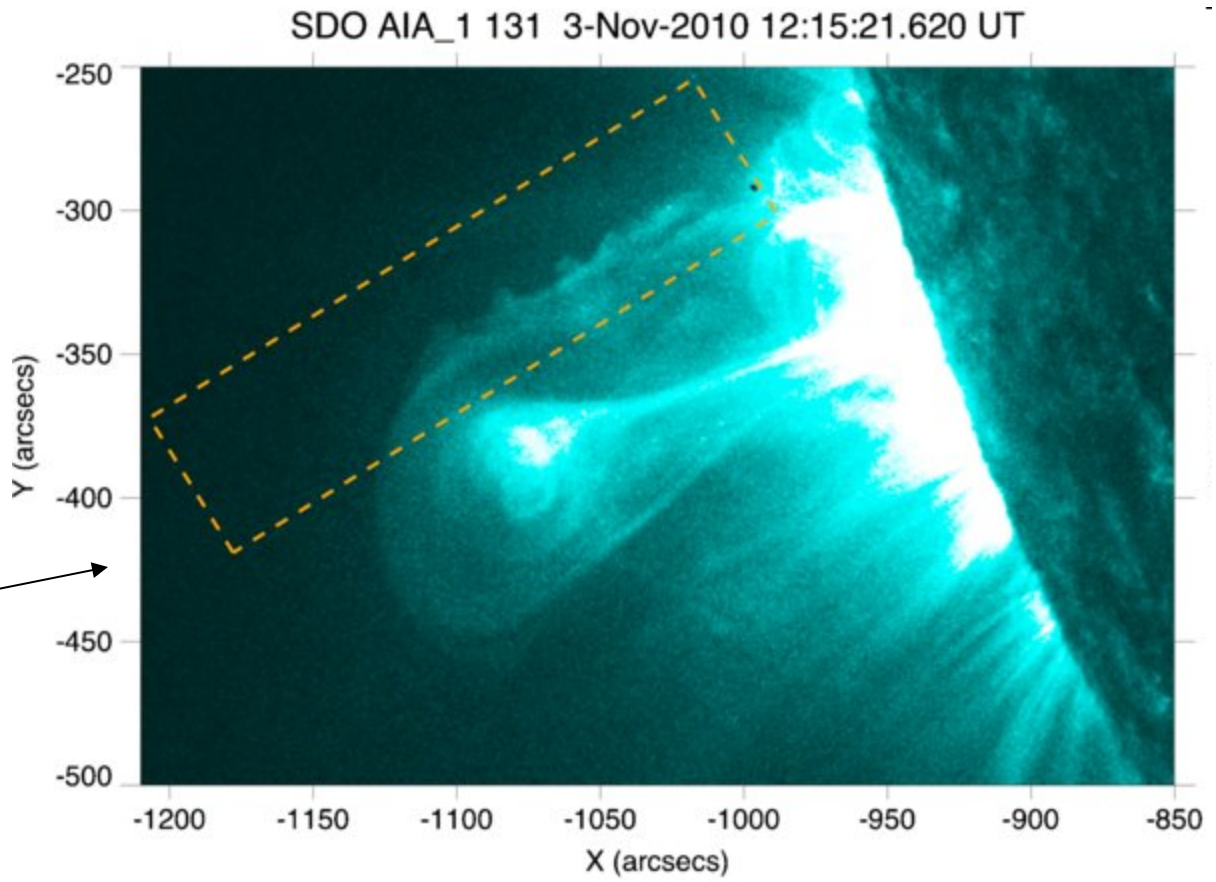
Kelvin-Helmholtz and diffusion

Kelvin-Helmholtz **at the SUN**

- *Foullon et al.* [2011]:
First observations of KH vortices at the edge of a **CME during lift-off**

High resolution data from the Solar Dynamics Observatory

- Cf. also *Ofman and Thompson* [2011]



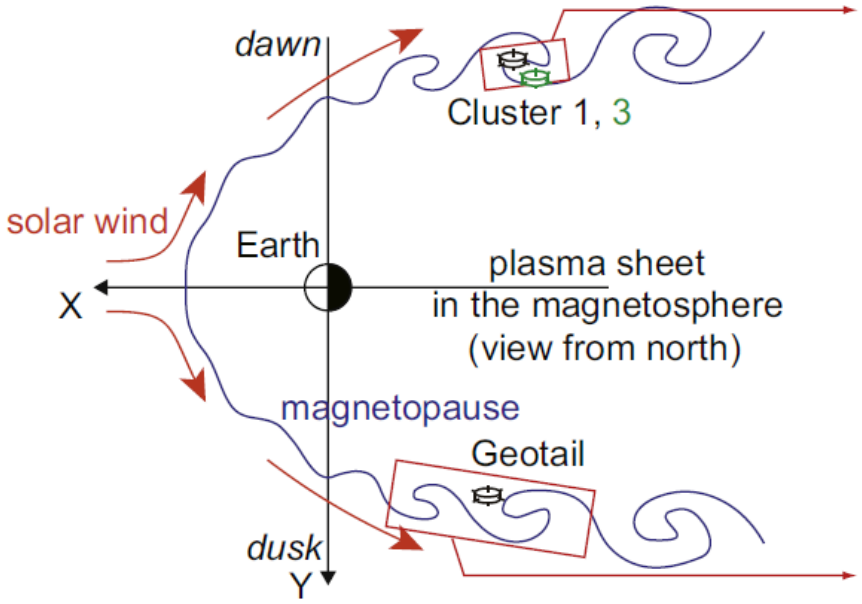
→ Ubiquity of the KH instability

Global aspects of Kelvin-Helmholtz: **observations**

- *Nishino et al.* [2011]: Simultaneous dawn and dusk observation of Kelvin-Helmholtz waves suggesting **preferential transport at dawn** through wave-particle interactions

- Cf. also *Farrugia et al.* [2010]; *Agapitov et al.* [2010]; *Cattaneo et al.* [2010]; *Foullon et al.* [2010]; *Lavraud et al.* [2009]
Masters et al. [2010] (Saturn)
Boardsen et al. [2010] (Mercury)
Sundberg et al. [2010] (Mercury)

Nishino et al. [2011]



→ Quantifying the role of KH is hard to do:
Multi-point observations are important

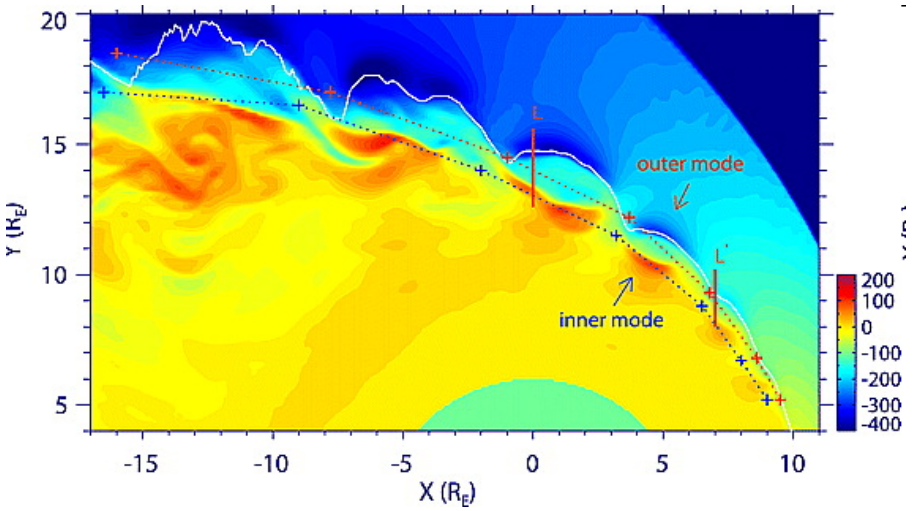
Global aspects of Kelvin-Helmholtz: **simulations**

- *Guo et al.* [2010]: Global MHD simulations show **two modes** at the inner and outer edge of boundary layer

- *Merkin et al.* [2011]: Multi-fluid MHD simulations suggest **O^+ populations** weakens the development of flank KHI

- Cf. also *Lai and Lyu* [2010] and *Nakamura et al.* [2010] (Mercury) *Walker et al.* [2010] (Saturn)

Guo et al. [2010]

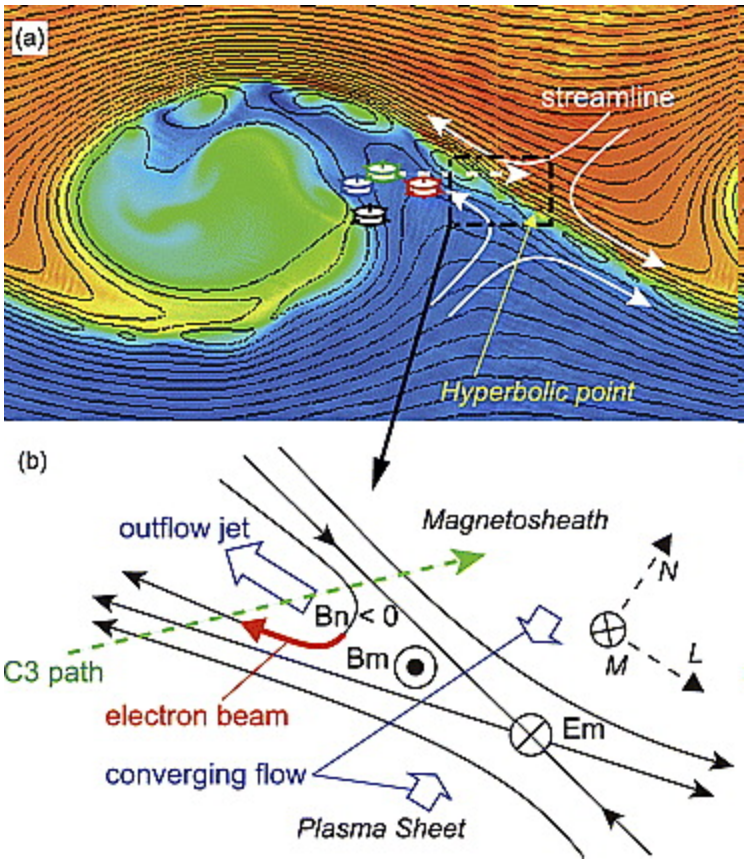


→ Quantifying the role of KH is hard to do:
Global modeling efforts may be a key

Kelvin-Helmholtz ***and*** local magnetic reconnection

- *Hasegawa et al*. [2009]:
in situ observation of reconnection inside a KH vortex

- cf. also KHI studies by:
Califano et al. [2009]; *Cattaneo et al.* [2010]; *Cai et al*. [2010]; *Eriksson et al.* [2009]



Hasegawa et al. [2009]

→ Evidence for KH influence on plasma transport:
Localized reconnection as secondary entry process

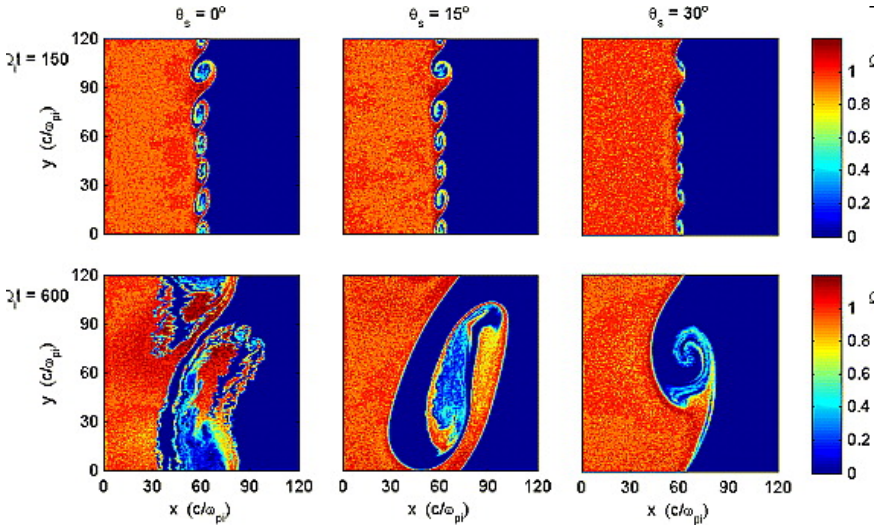
Kelvin-Helmholtz ***and*** secondary instabilities

- *Cowee et al*. [2009; 2010]: Large diffusion expected from Kelvin-Helmholtz **simulations**

- *Guglielmi et al.* [2011]: Analytical study of combined Rayleigh-Taylor and Kelvin-Helmholtz due to **both velocity shear and Pdyn** variations

Cf. also *Palermo et al*. [2011a; 2011b]

Cowee et al. [2010]



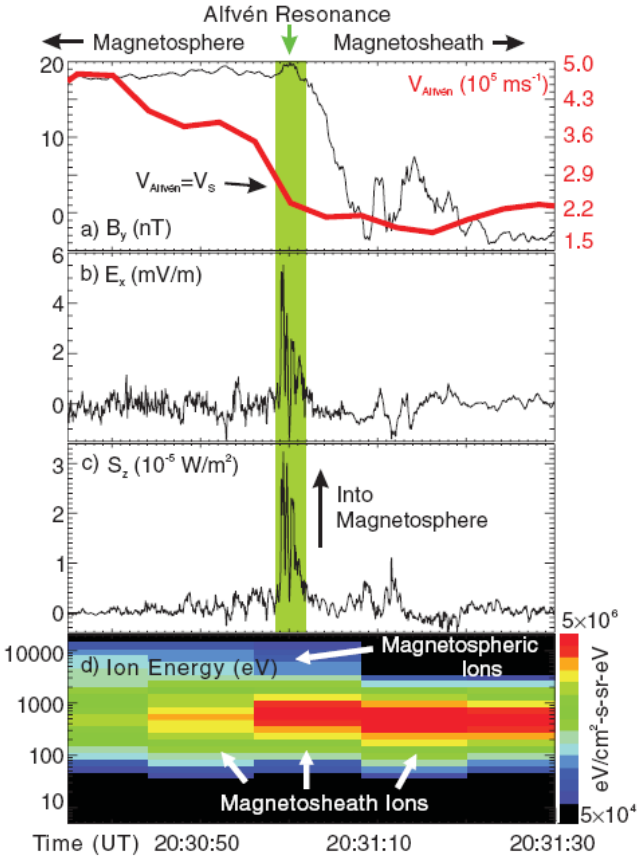
→ Discerning secondary processes in data is hard:
These processes, mediated by KH, are important

Diffusive transport ***alone***

- Diffusive transport at the magnetopause through mode conversion and resulting **Kinetic Alfvén Waves** [Lin et al., 2010]

- Observations [*Chaston et al.*, 2007, 2009]

Chaston et al. [2007]



→ Diffusive mechanisms are not the most studied!

More global aspects

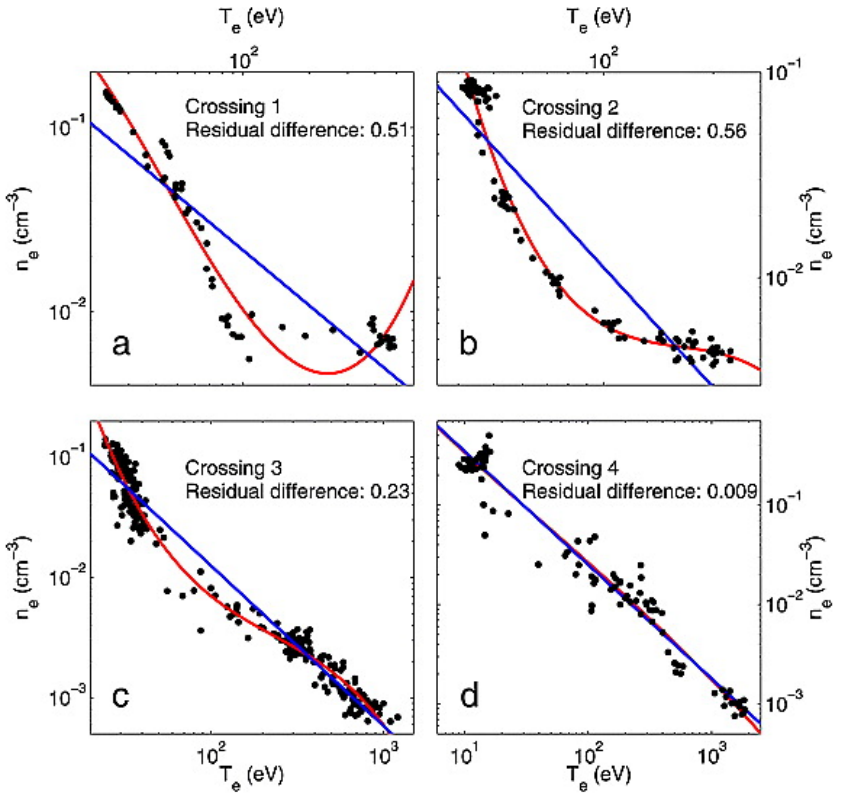
Boundary layer structure: Earth and Saturn

- *Masters et al*. [2011a;2011b]: Changes in N/T profiles **suggest** different entry mechanisms.

- Different profiles at Saturn may indicate **reconnection not predominant there**.

- See also *Tkachenko et al.* [2010], *Rossolenko et al*. [2009], Hasegawa et al. [2009] for boundary layer studies

Masters et al. [2011b]



Note: importance of comparing magnetospheres

→ Boundary layer profiles as signature of plasma entry: Which mechanism leads to which profile unknown

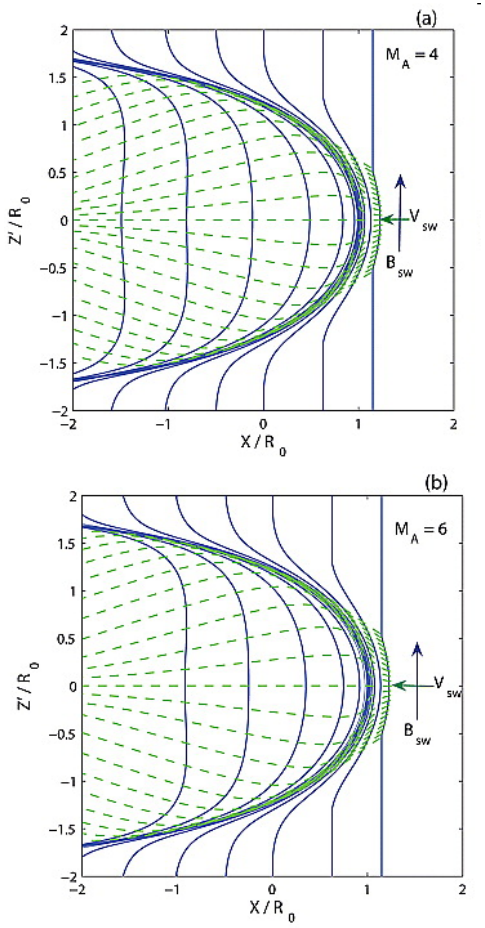
Magnetosheath/magnetopause global interaction

- *Erkaev et al*. [2011]: Analytical and MHD modelling of magnetosheath flows **under low Alfvén Mach #**
Cf. also Lavraud et al. [2009]

- *Amata et al.* [2011]: anomalous sheath flows can deform the magnetopause and lead to solar wind **plasma penetration**

- *Dusik et al.* [2010]: Dominant IMF Bx **inflates** the magnetopause

Erkaev et al. [2011]



→ Unusual conditions (M_A, IMF Bx, etc.) not much studied:
They have important impact on coupling at MP

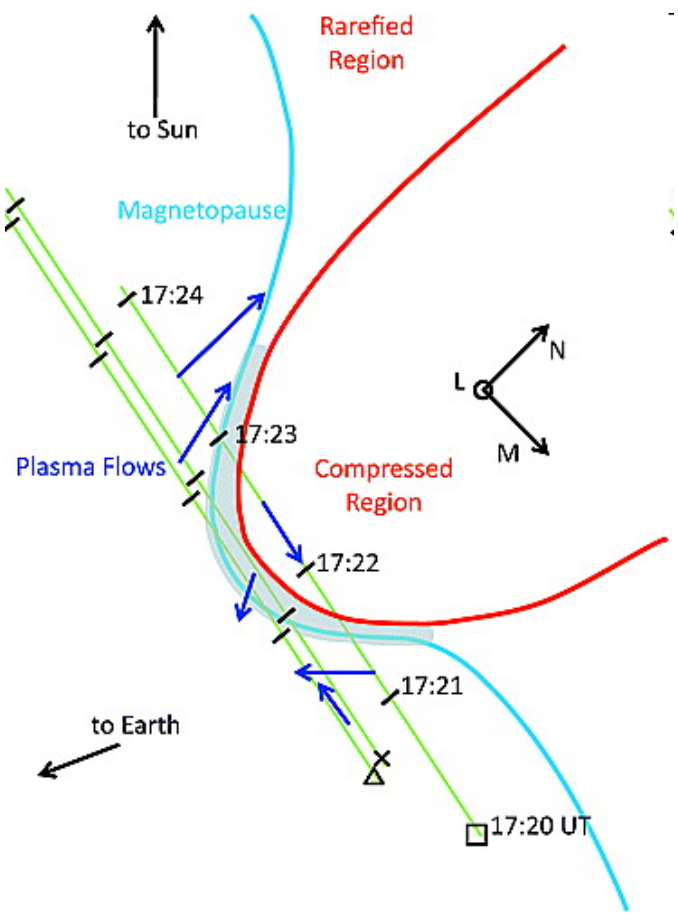
Response to SW/sheath variability/dicontinuities

- *Safrankova et al.* [2010]: Southward IMF does **not necessarily lead** to southward magnetosheath Bz

- Cf. also *Farrugia and Gratton* [2011]; *Samsonov et al.* [2010]; *Pang et al.* [2010]; *Turner et al.* [2011]; *Tkachenko et al.* [2011]; *Kim et al.* [2009], *Ambrosino et al.* [2009], and review by *Tsurutani et al.* [2011]

- *Laitinen et al.* [2010]: Influence of magnetosheath fluctuations (e.g., mirror mode) on **dayside reconnection**

Turner et al. [2011]

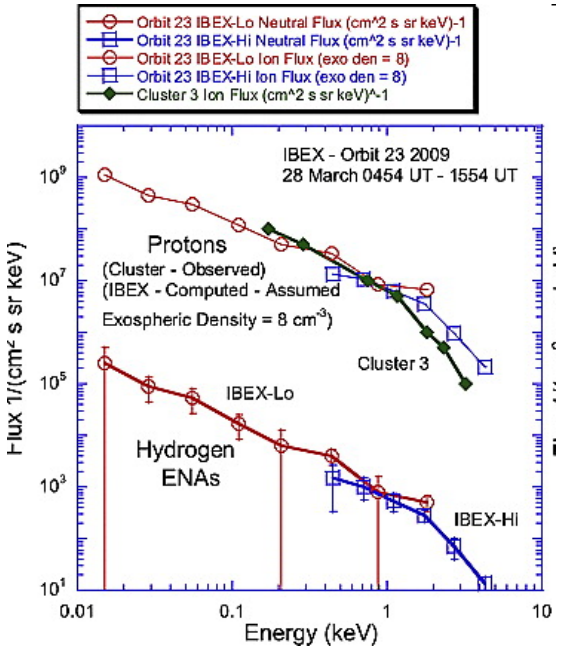


→ SW highly structured [*Borovsky*, 2008; 2010]:
Propagation processes and effects important at Earth

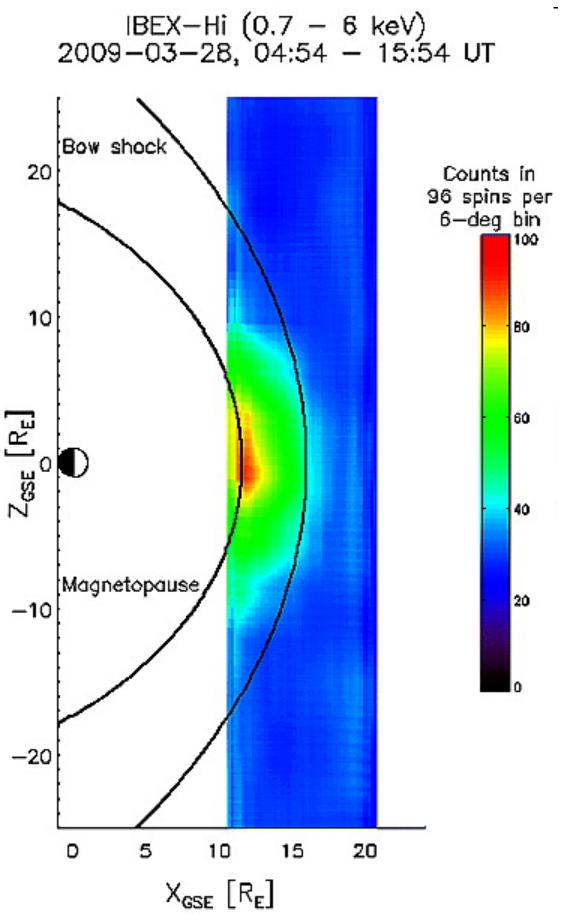
Remote observations of magnetopause and cusp

- *Fuselier et al.* [2010]: Combined IBEX neutral atom imaging and in situ data from Cluster allow to quantify charge exchange at the MP

$ENA/p^+ = \sim 10^{-4}$



Fuselier et al. [2010]



→ Possibilities to image the magnetopause and cusp:
The dream to image the magnetosphere

Conclusion

STATISTICS

of papers for the period 2009 – 2011 (ISI web of science), for topics:

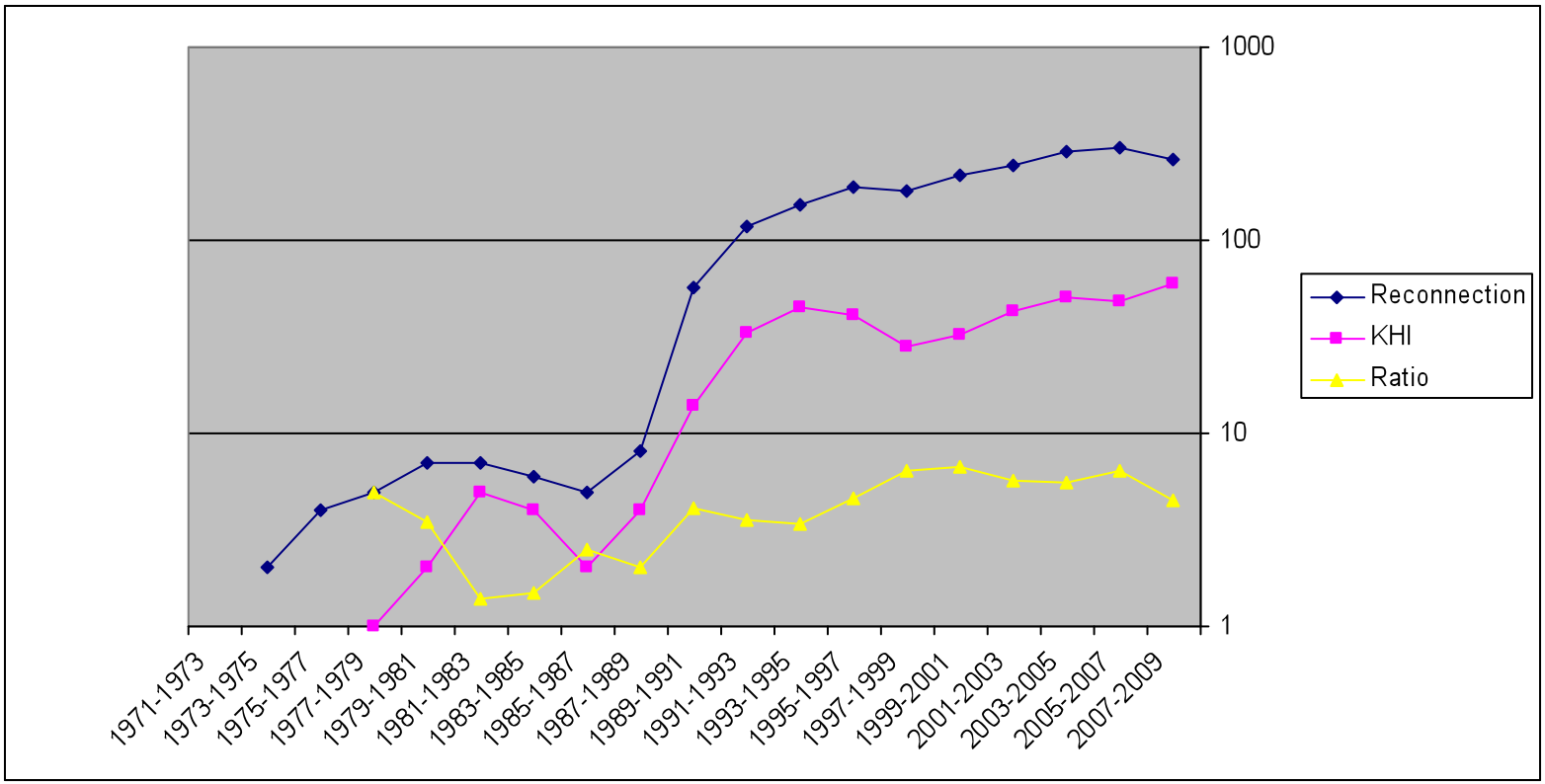
- Magnetopause + reconnection = 158
- Magnetopause + Kelvin-Helm. = 43
- Magnetopause + diffusion = 30

(but most are reconnection diffusion region and radiation belt papers…)

→ Main conclusion:

Reconnection most important (! or ?)

STATISTICS (Cont.)



→ **An old trend!**