Geotail data analysis and related simulation results on magnetic reconnection in the magnetotail

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With contributions from

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This talk

- Where is the reconnection region located?
- What is going on at the reconnection region?
- What triggers the reconnection process?
- Future perspectives: The X-Scale mission

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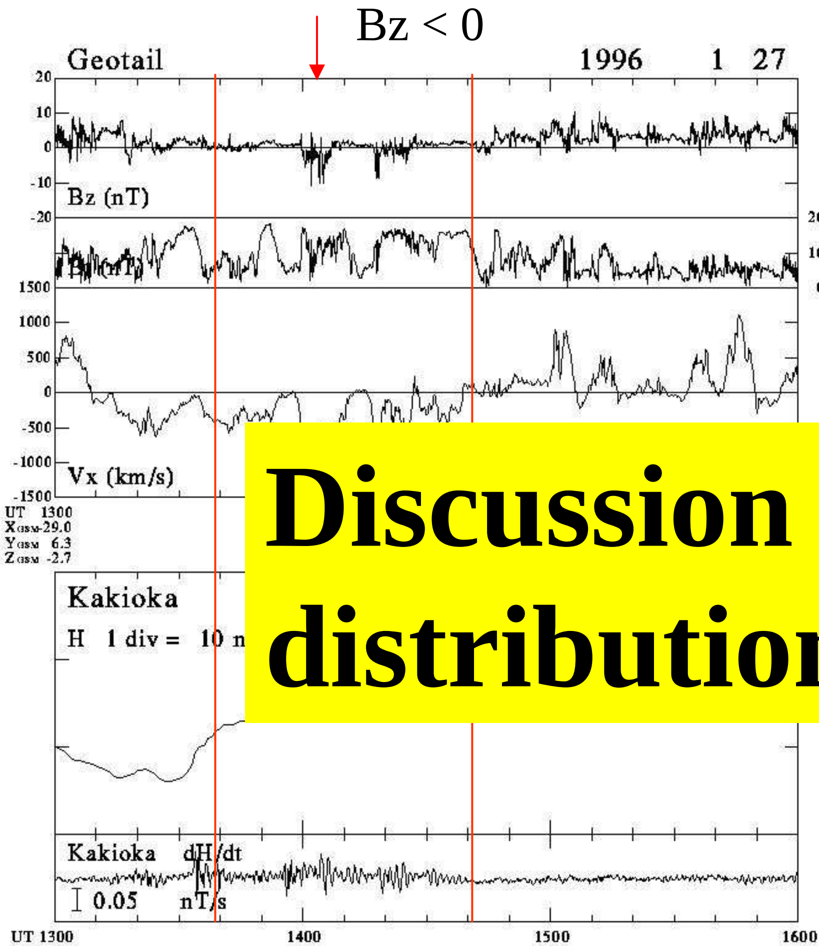
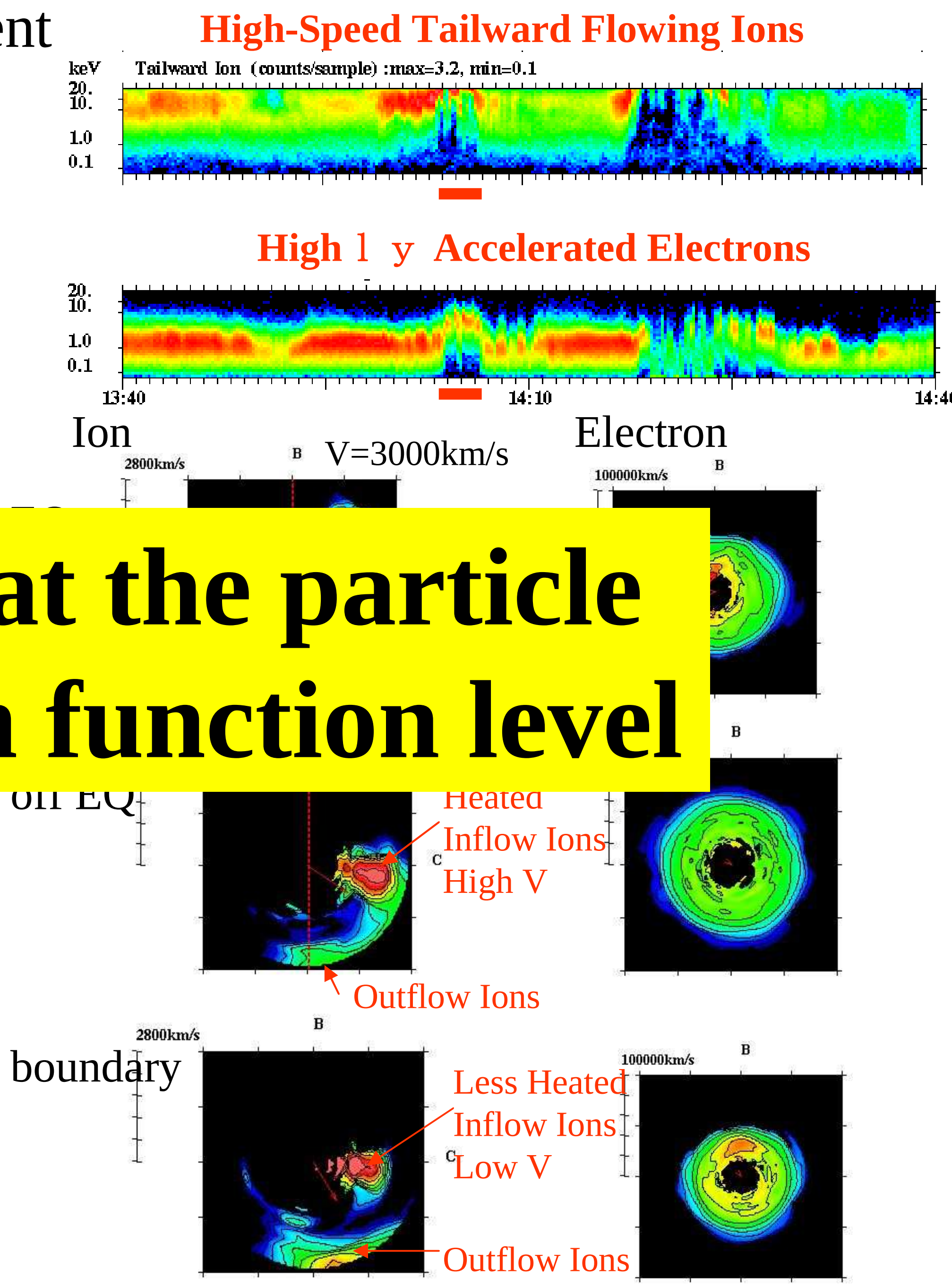
Magnetotail Reconnection Event

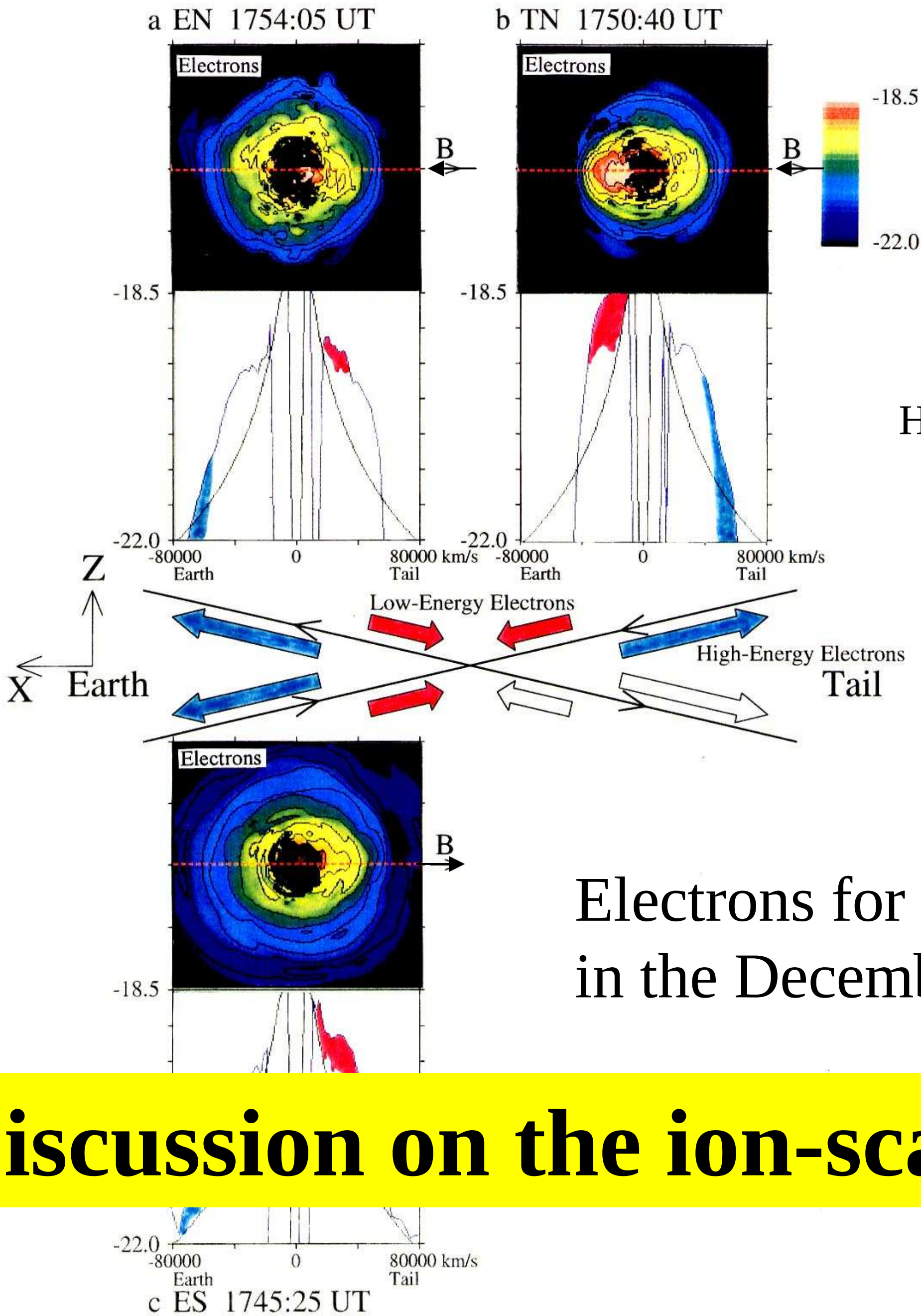


XGSM=-28.9 YGSM=5.8 ZGSM=-2.6 RE



Discussion at the particle distribution function level

Nagai et al. (JGR 1998)



Hall Current density ・・・・ 6〜13 nA/m^2

Electrons for Hall currents
in the December 10, 1996, event

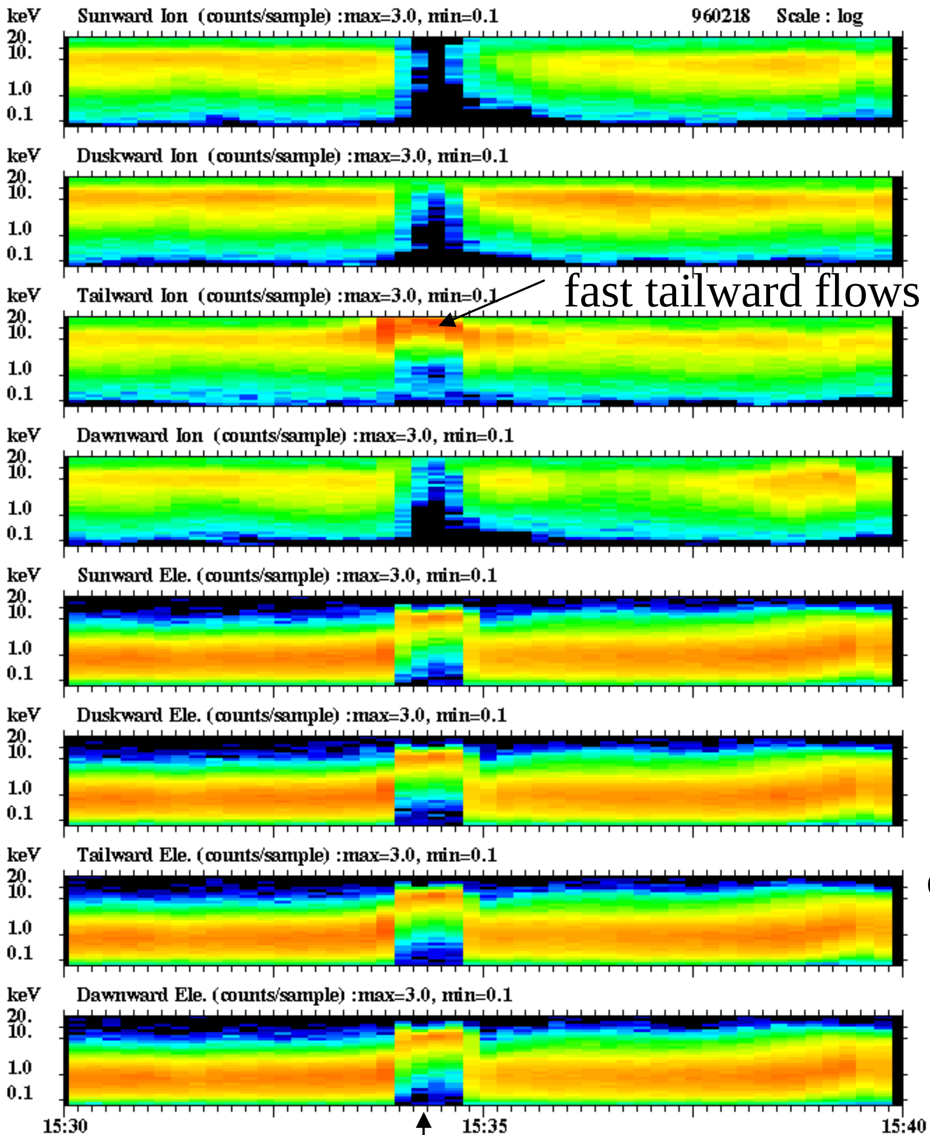
Discussion on the ion-scale dynamics

Nagai et al. (JGR 2001)

How to spot the X-line location:

When the spacecraft is
close to the reconnection region…

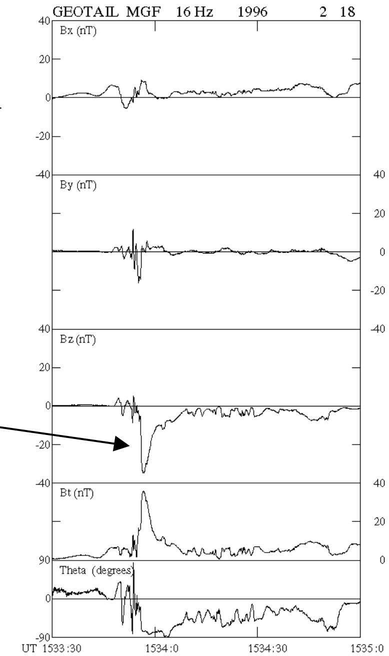
1996/02/18 Reconnection Event



fast tailward flows with Bz < 0

highly accelerated electrons

magnetic field

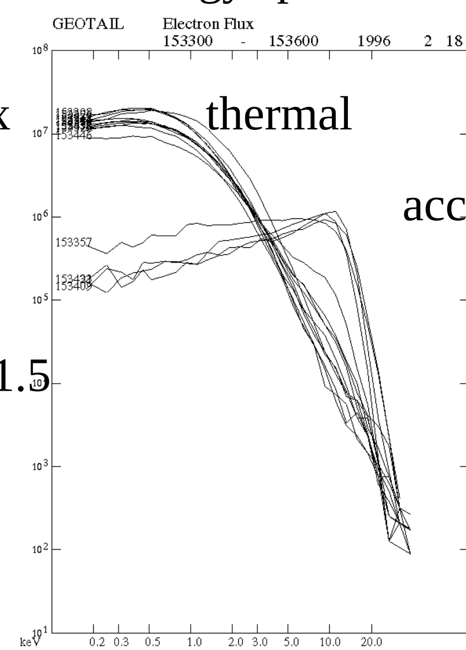


electron energy spectra

flux

thermal

accelerated



energy

criterion

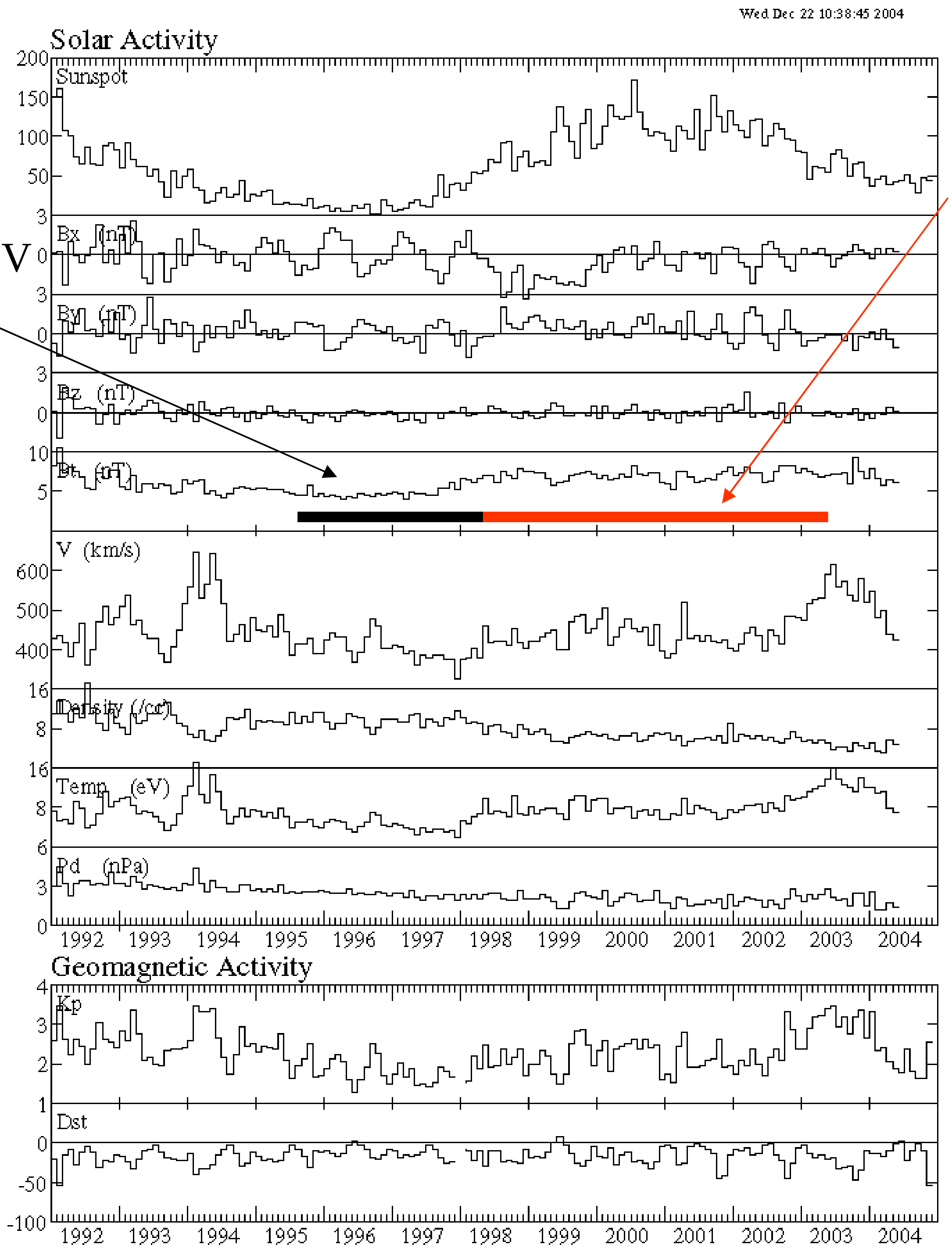
$$\frac{f(5\text{keV})}{f(1\text{keV})} > 1.5$$

Solar Minimum
Low B and Low V

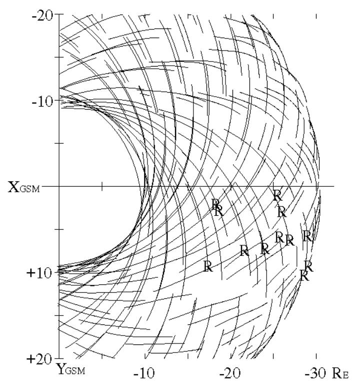
Solar Wind

IMF Bt

Velocity



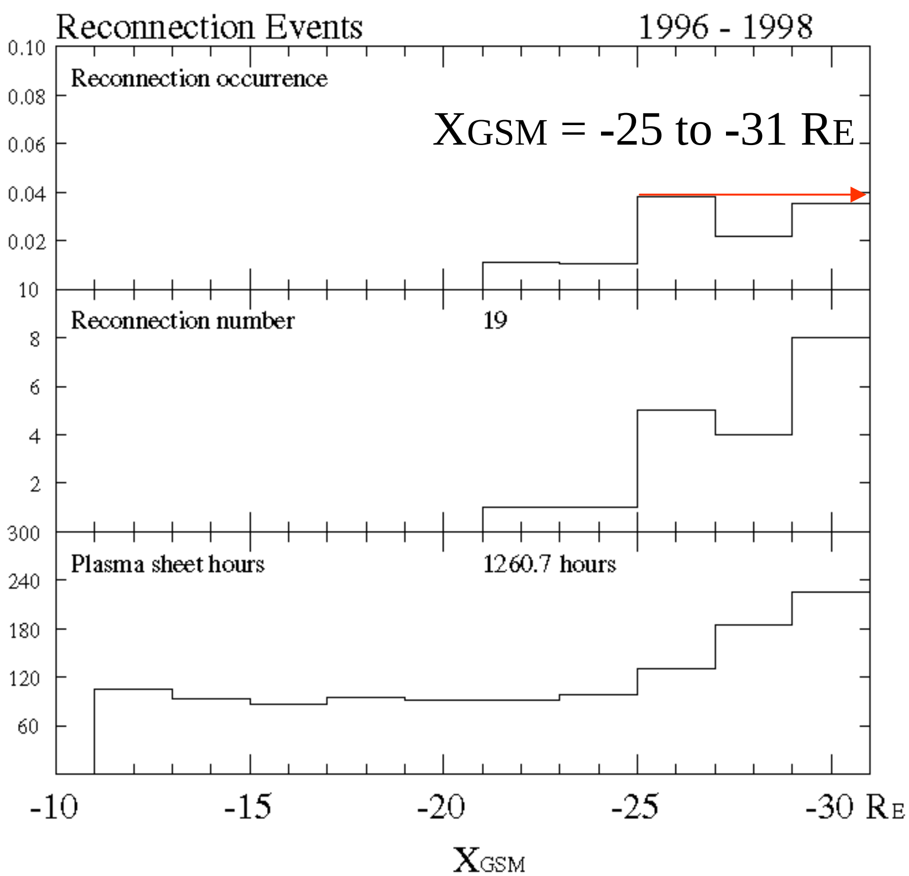
Solar Maximum
High B and High V

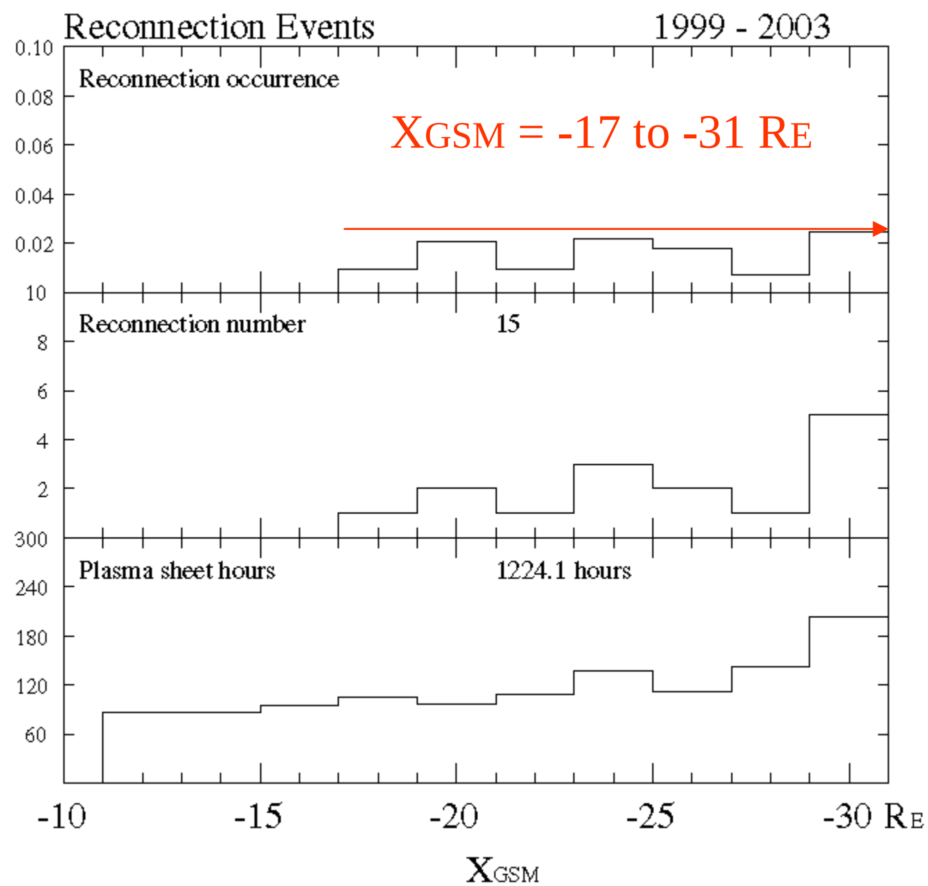


In 1995-1997

Solar Minimum
in 1996-1998
19 events

Solar Maximum
in 1999-2003
15 events

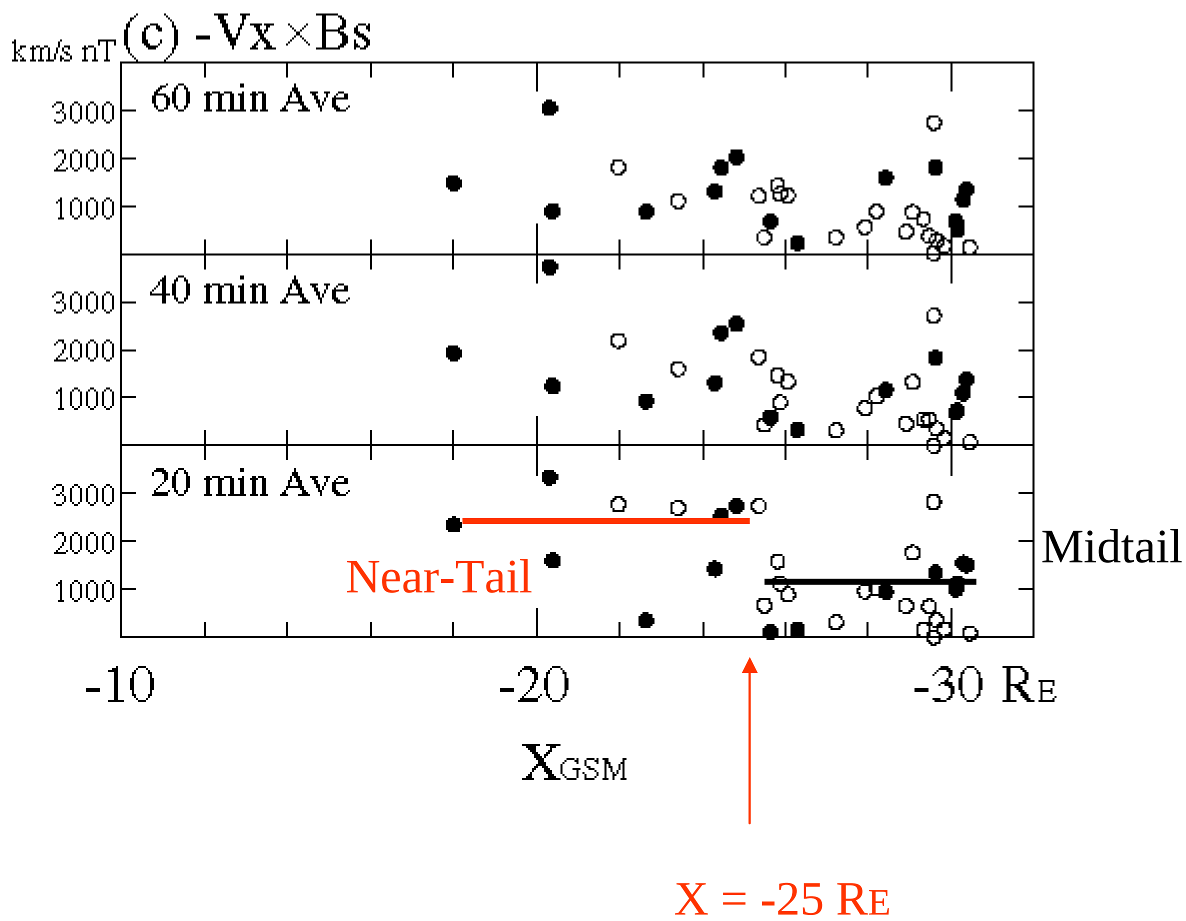




Solar Wind Energy Input

circles 1996-1998 events

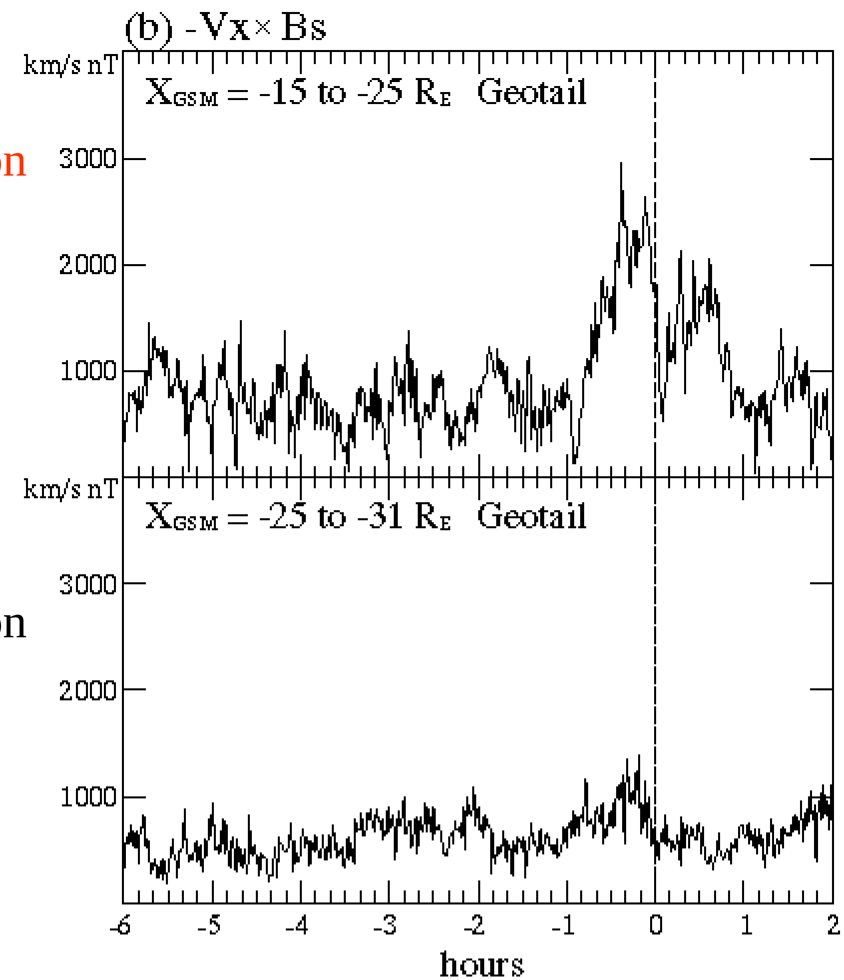
black dots 1999-2003 events



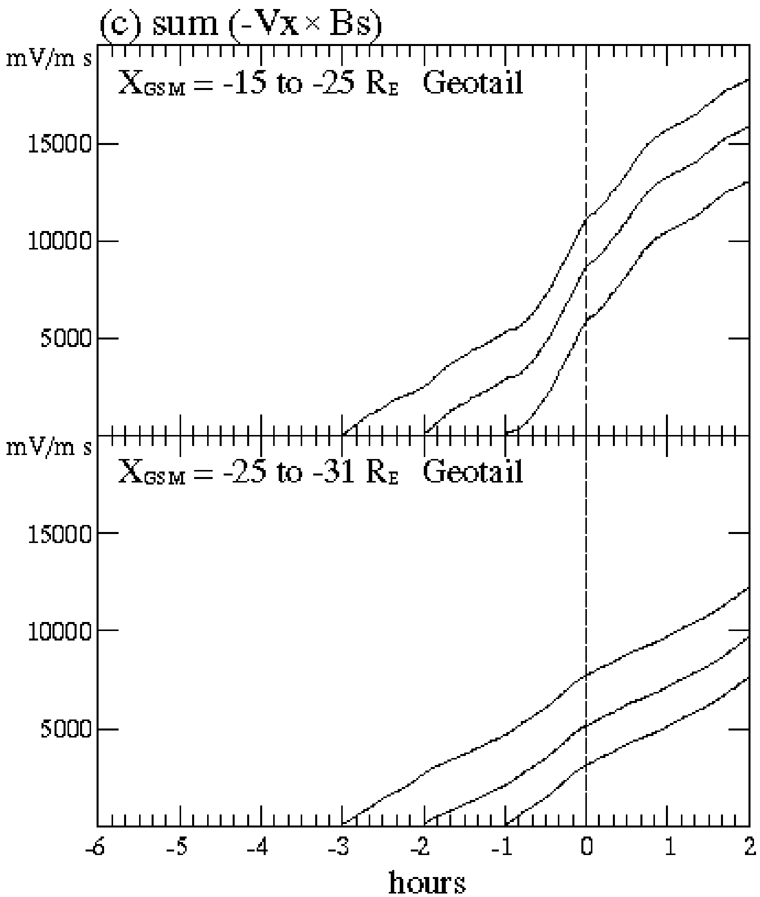
Solar Wind Energy Input

Near-tail Reconnection

Midtail Reconnection

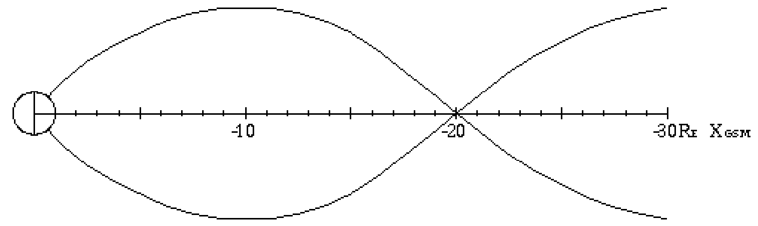


Solar Wind Energy Input



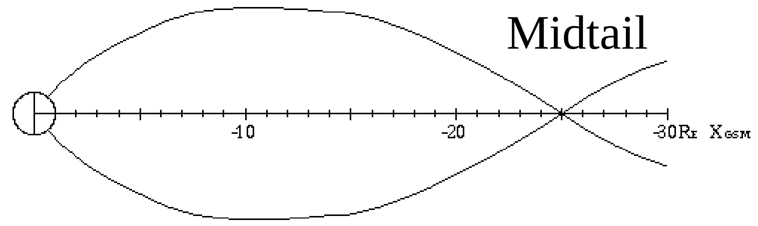
High Efficiency of Solar Wind Energy Input

Near-Tail



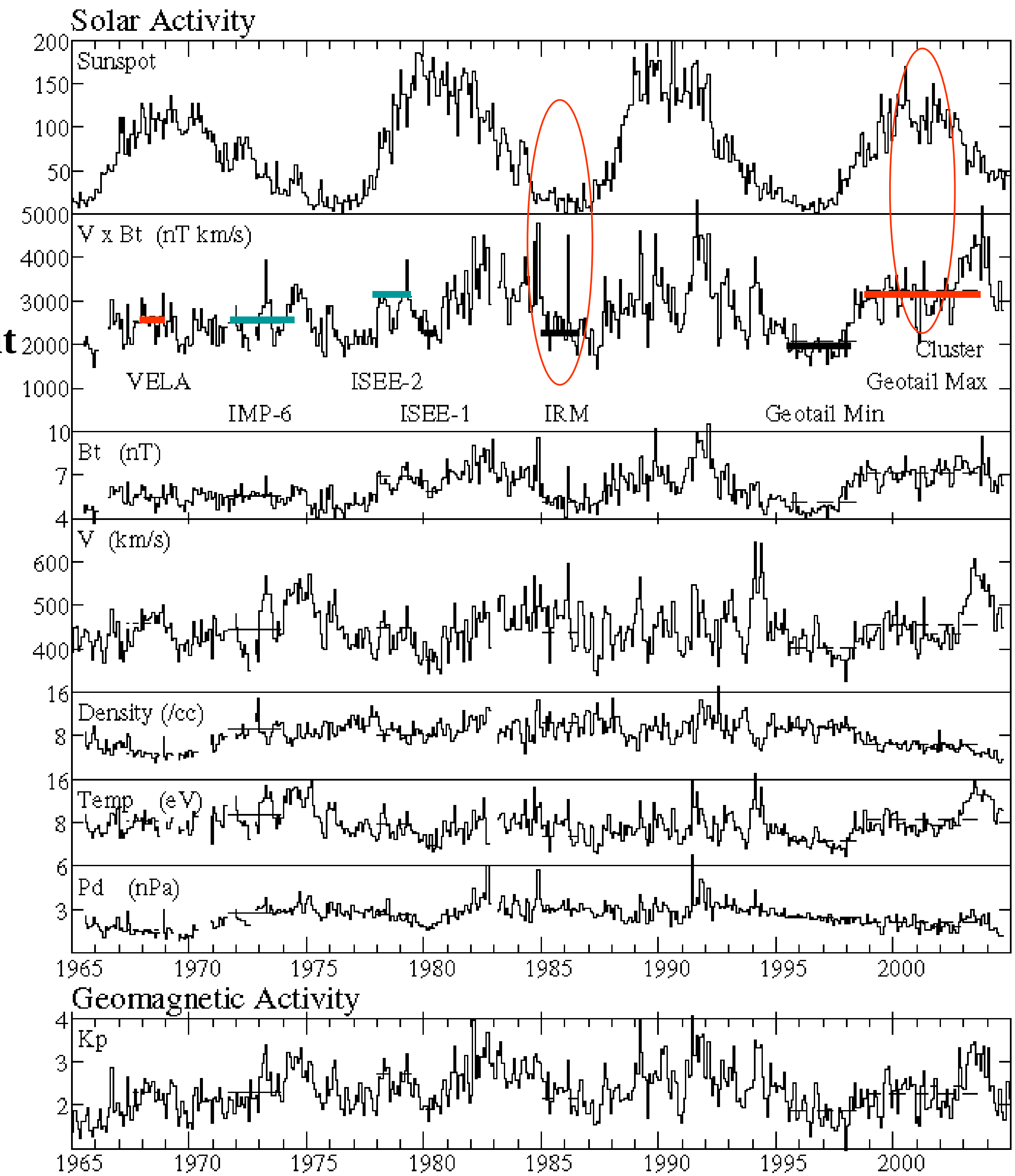
Low Efficiency of Solar Wind Energy Input

Midtail



Cluster sees tailward flows
at X=-19 Re
while AMPTE did not.

Solar Wind Energy Input



VELA

15RE

IMP-6

ISEE-2

> 22RE

ISEE-1

> 21 RE

IRM

> 18 RE

Geotail 1996-1998

> 25 RE

Geotail 1999-Cluster

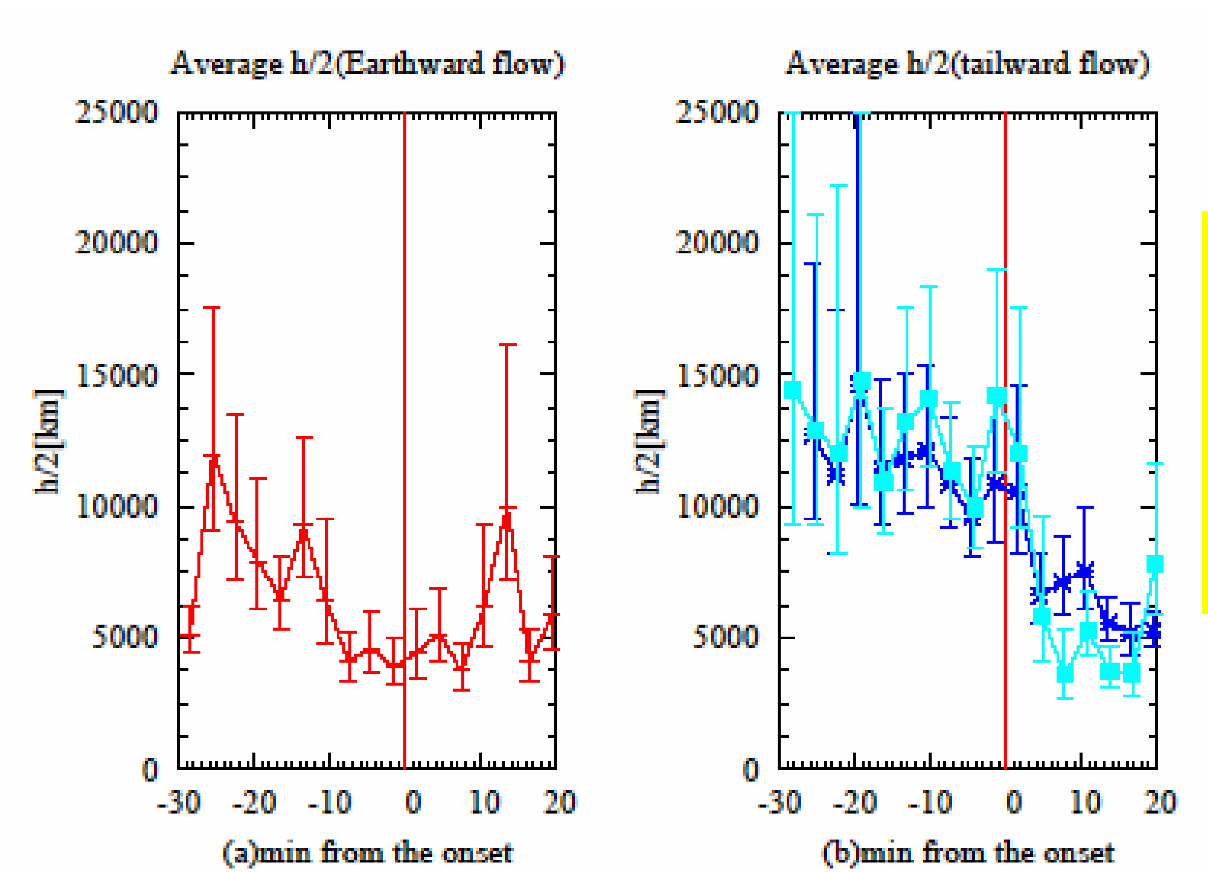
15-30RE

Cluster tailward flow events give us the chance to study physics in the near-X-line region.

Another way of asking "where is the X-line?"

- In which part of the thinned current sheet?

Evolution of thin current sheets in the mid-tail region during the course of substorms



Implication:

X-line located at the tailward-edge of thinned section?

Thin CS prior to detection of earthward flow

Not necessary thin CS prior to detection of tailward flow

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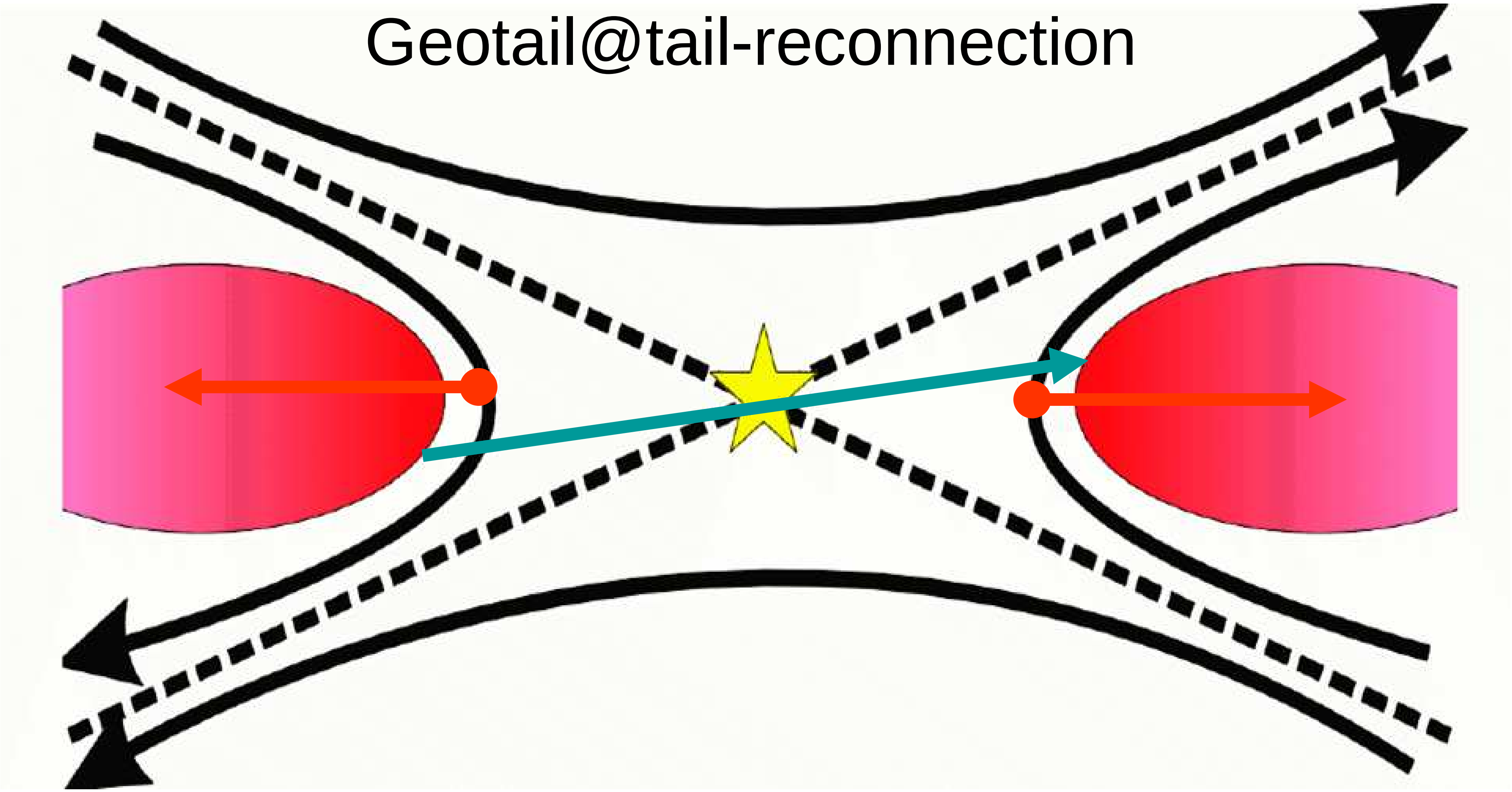
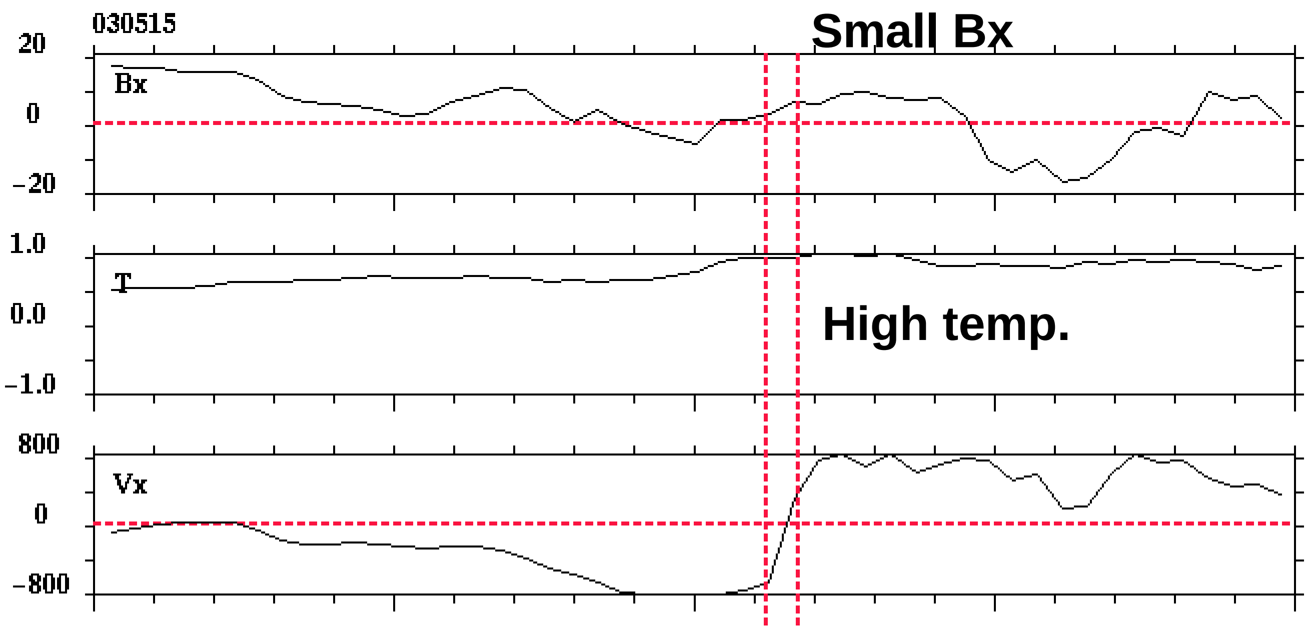
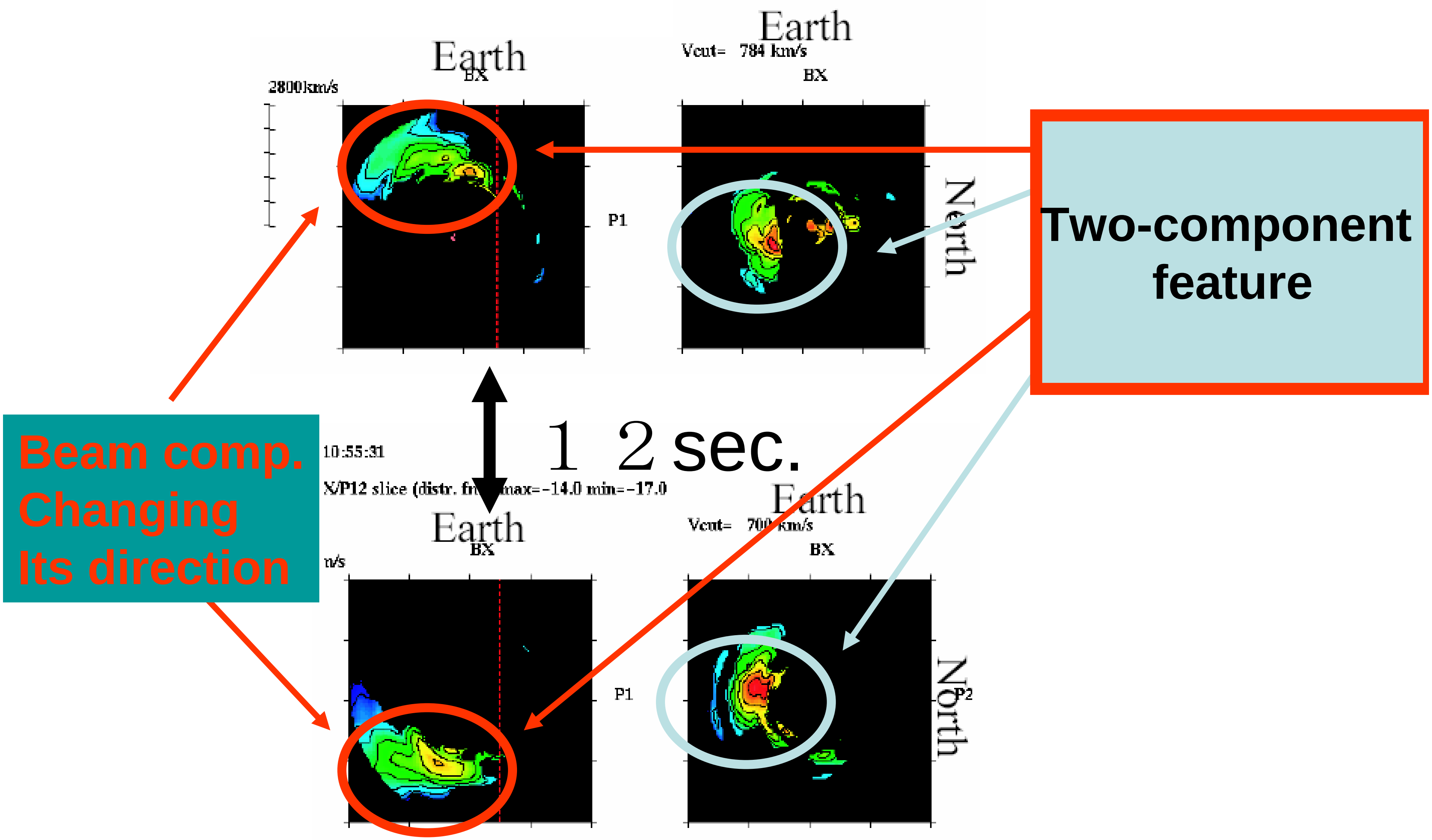


Geotail@tail-reconnection

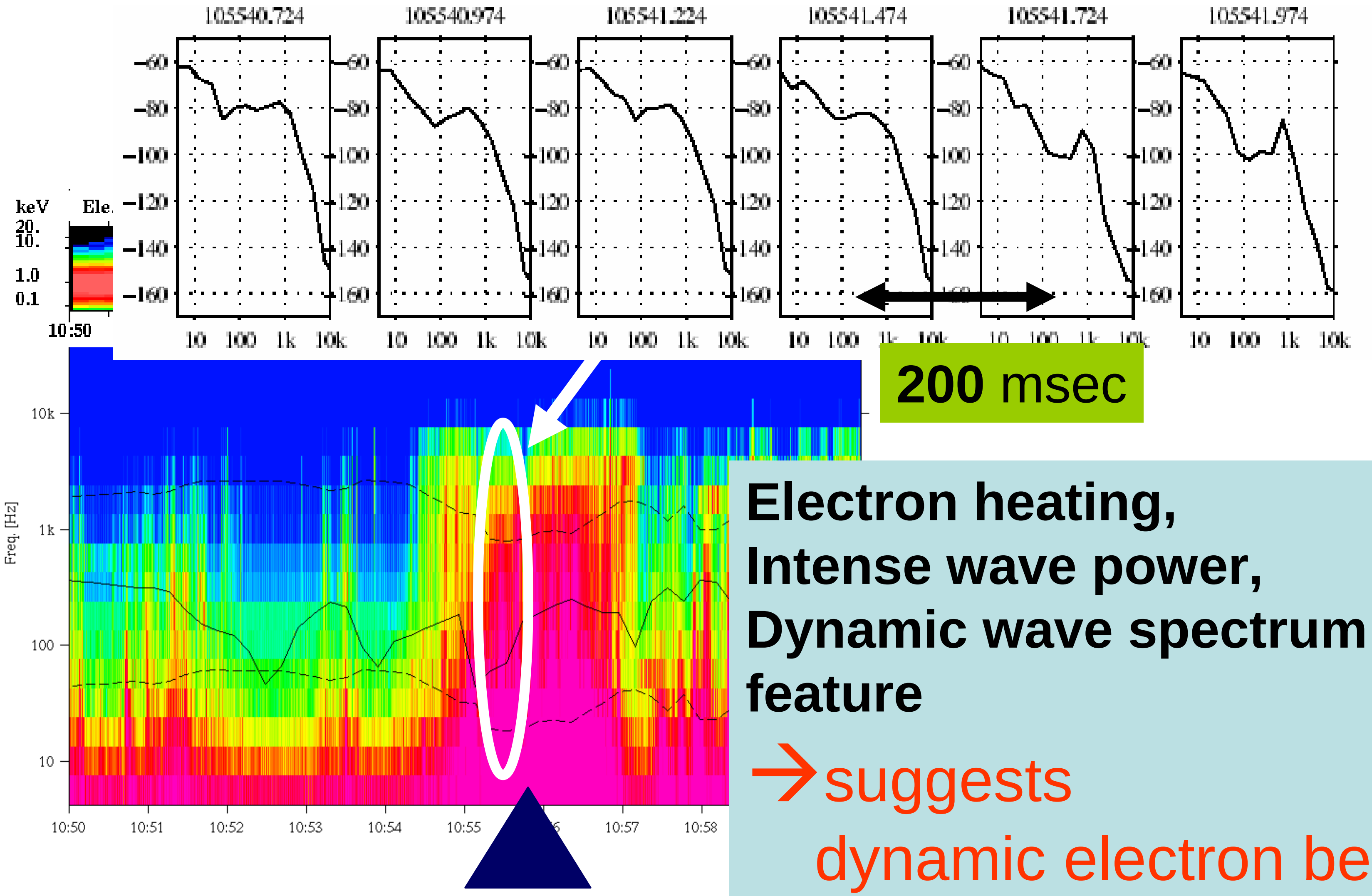


Flow reversal -600km/s → +300km/s
In 12 sec. = 1 sampling time

Dynamic ion behavior visible in the distribution function data



Electron dynamics?



Electron heating,
Intense wave power,
Dynamic wave spectrum feature

→suggests
dynamic electron behavior

Flow reversal

Electron dynamics?

- But there is no way beyond because of the low-time resolution (12 s) of the electron detector.

Have to rely on the wave data
for the moment:

Cluster has a better chance
because of more chance of getting
the wave form data at the right time

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The classic candidate: Lower-Hybrid Wave (LHW)

- Anomalous resistivity at the neutral sheet?

  NO.

- Anything else?

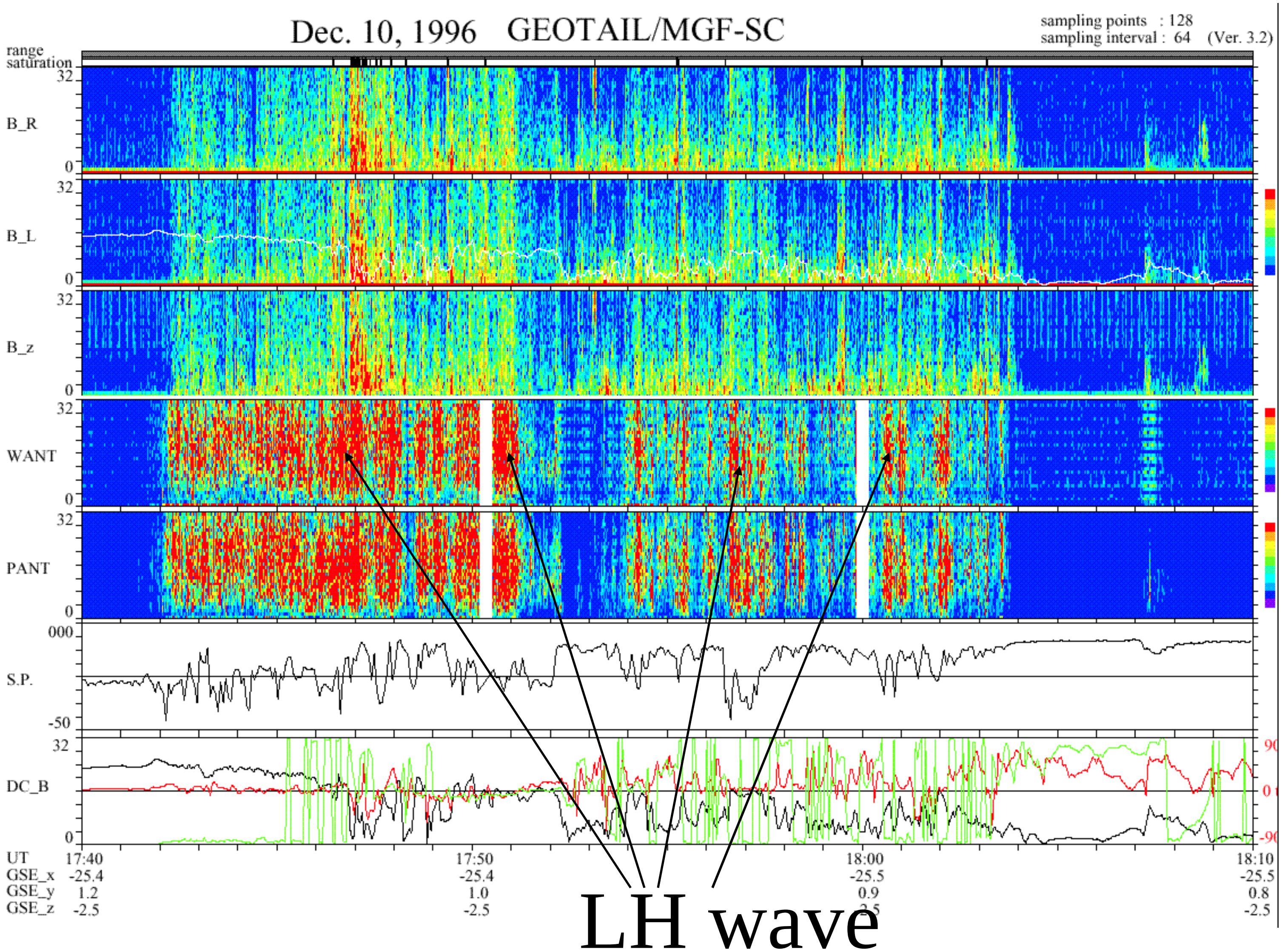
  YES.

GEOTAIL Observation

Did we find LH wave?

YES – GEOTAIL frequently observes LH waves in the plasma sheet (even in high β region)

NO – The observed wave power is insufficient for fast magnetic reconnection. (At least one order smaller)



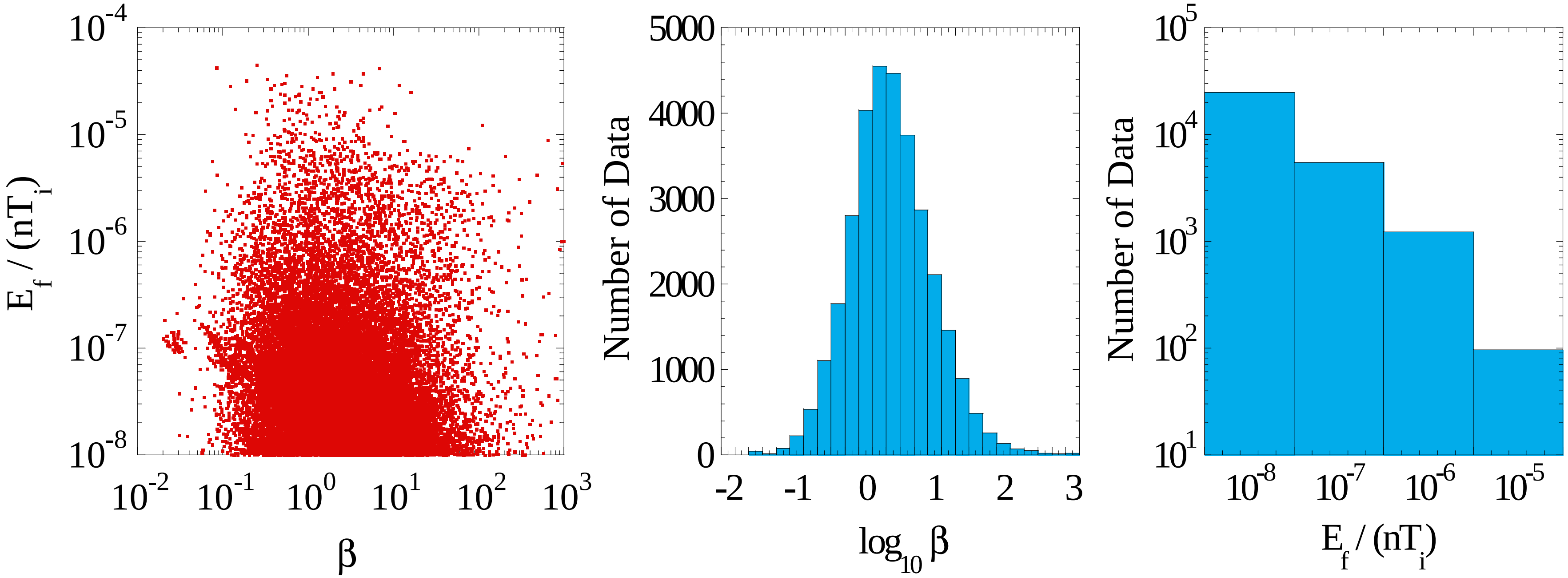
Dec. 10, 1996 GEOTAIL/MGF-SC
sampling points : 128
sampling interval : 64 (Ver. 3.2)
range
saturation
B_R
B_L
B_z
WANT
PANT
S.P.
DC_B
UT 17:40 17:50 18:00 18:10
GSE_x -25.4 -25.4 -25.5 -25.5
GSE_y 1.2 1.0 0.9 0.8
GSE_z -2.5 -2.5 -2.5 -2.5
LH wave

Identification of Instability Mode

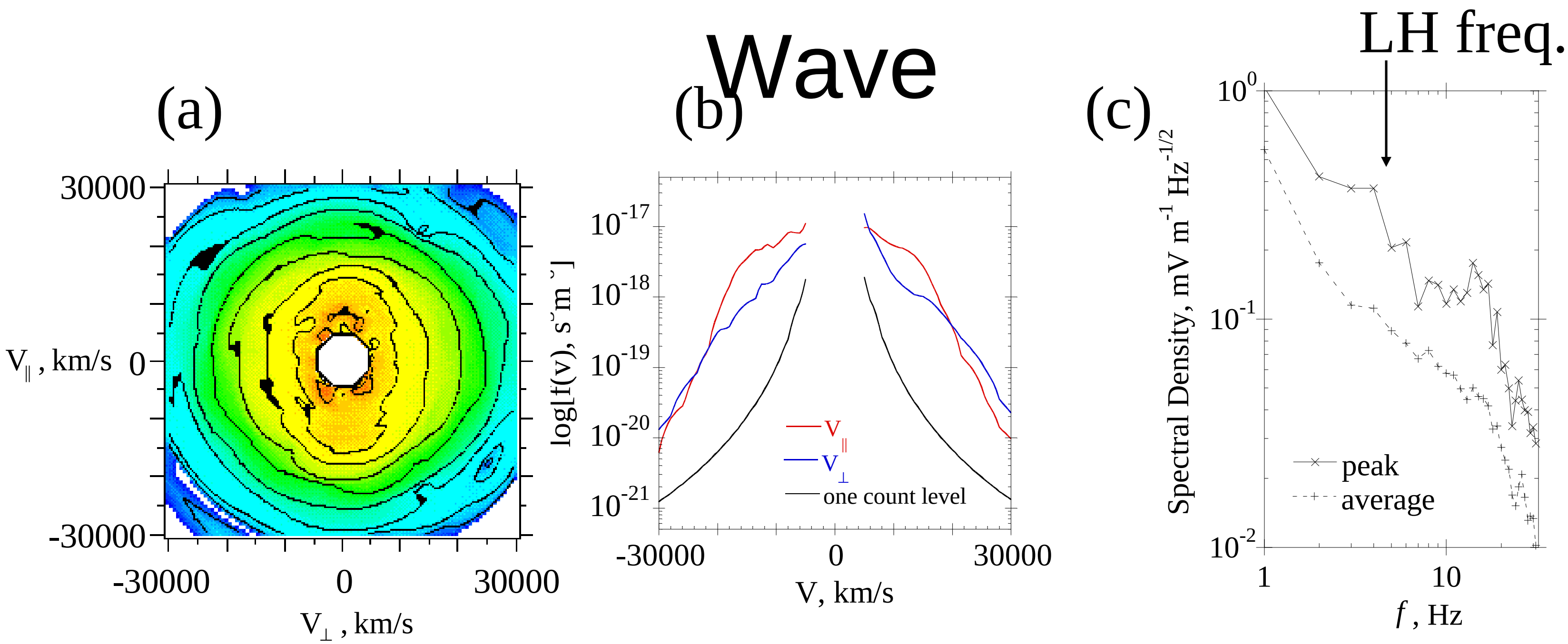
- Comparison between Theory & Observation
  - Positive growth rate
  - Close to the local LH freq.
  - Calcluated $c|B|/|E|$ is consistent
  - Almost perpendicular propagation

Statistical Study on Wave (2-32 Hz) Energy Density in Plasma Sheet (1)

Plasma β dependence



An Example of Electron Distribution Function Associated with LH Wave



Electron distribution function

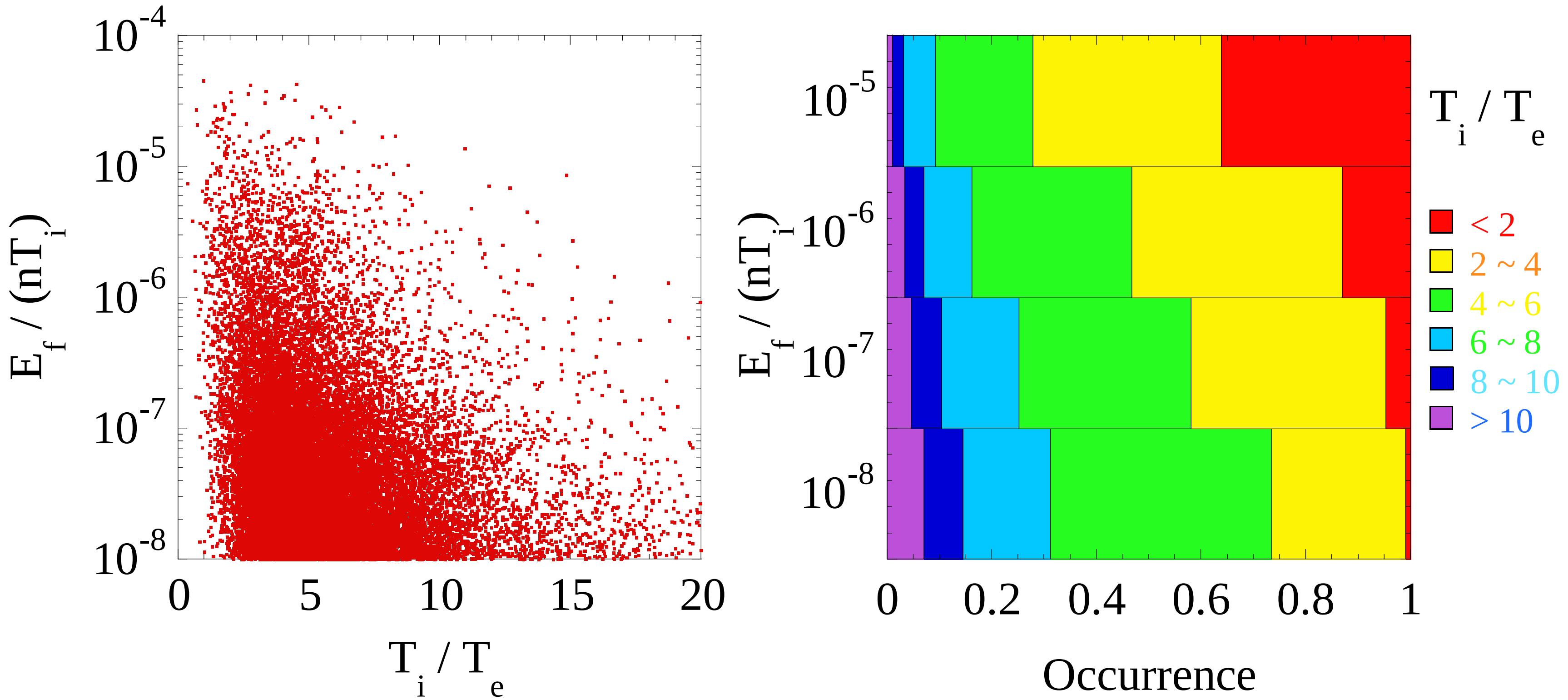
Jan 15, 1994 1256:42-57:42 UT

Electric field wave spectrum

Jan 15, 1994 1256:43-57:42 UT

Statistical Study on Wave (2-32 Hz) Energy Density in Plasma Sheet (2)

Electron heating – Temperature Ratio



Relation between intense LHW and the highly accelerated electrons most likely close to the X-line

Yet to be inspected.

Should be a good topic for Cluster as well.

Thanks to the Uppsala team for bringing this issue to my attention.

Intense LHW at the edge: A simulation study

- It may lead to quick triggering of reconnection even if the current sheet thickness is large (~ ion scale)

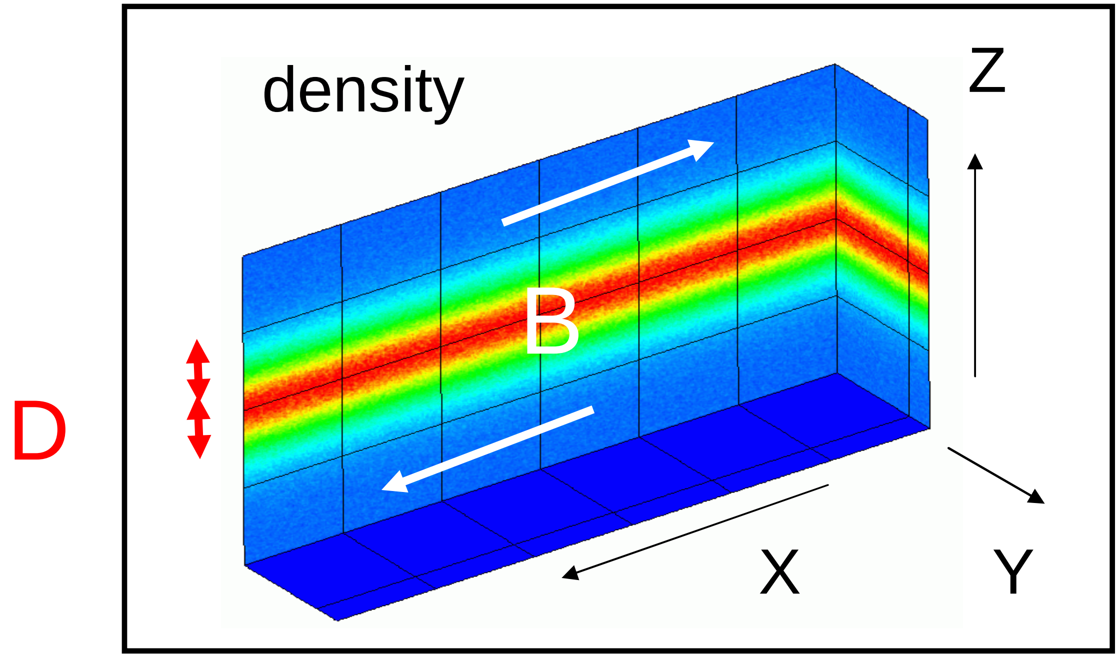
3D Simulation Setup

<u>1D Harris current sheet</u>

~ 10^9 particles

m_i/m_e=400, T_i/T_e=8

Thick current sheet D at ion-scale



QMRT

XSC=Cross-Scale Coupling

LHDI at the edges of thick current sheet
= reduction of current density locally at the edges
Meso-scale redistribution of current density
= bifurcated current layer
Anisotropic heating of electrons at the neutral sheet
= Quick growth of tearing mode

Explosive growth,
by copuling to the bi-furcated layer,
of large scale reconnection

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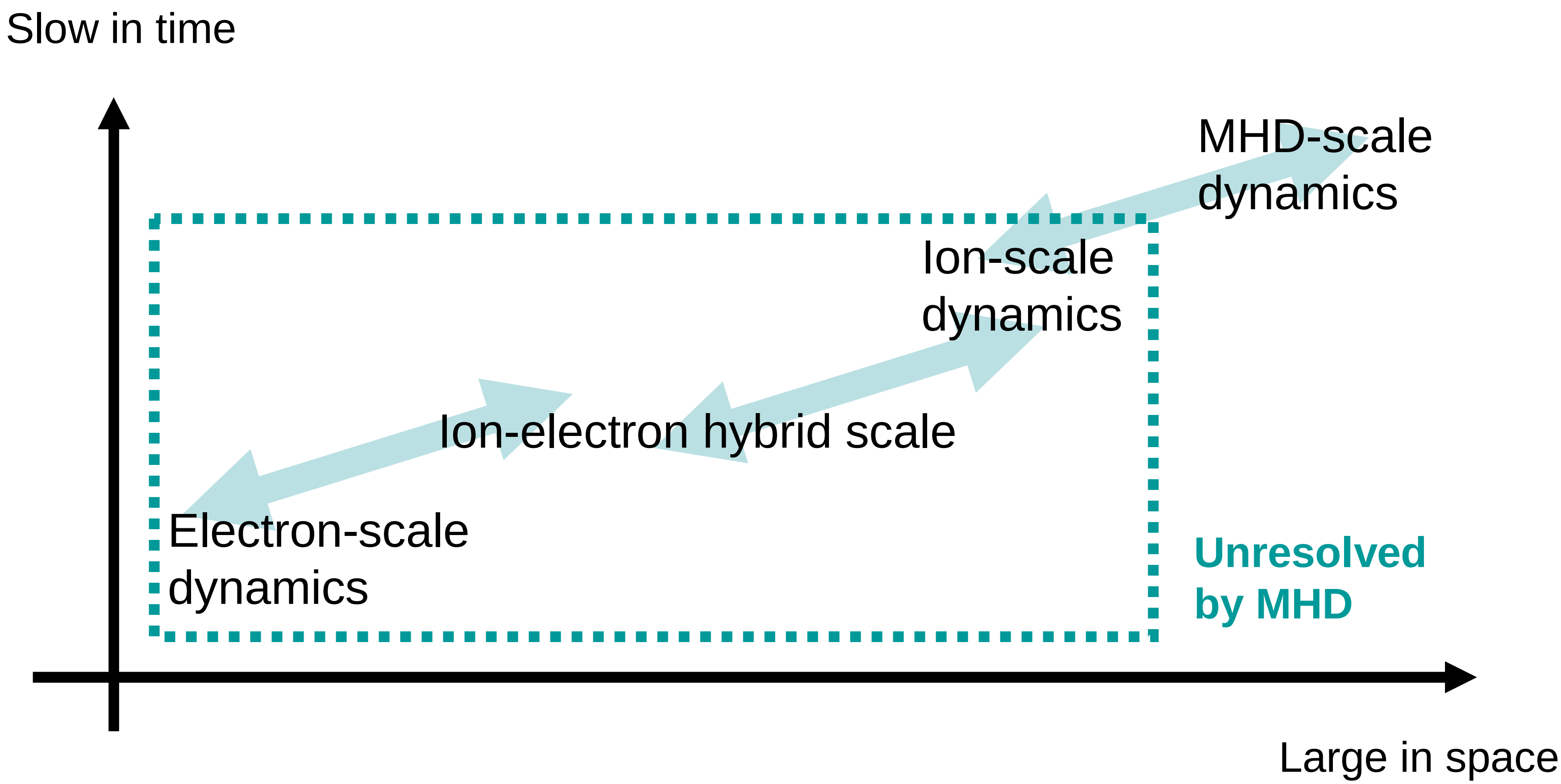
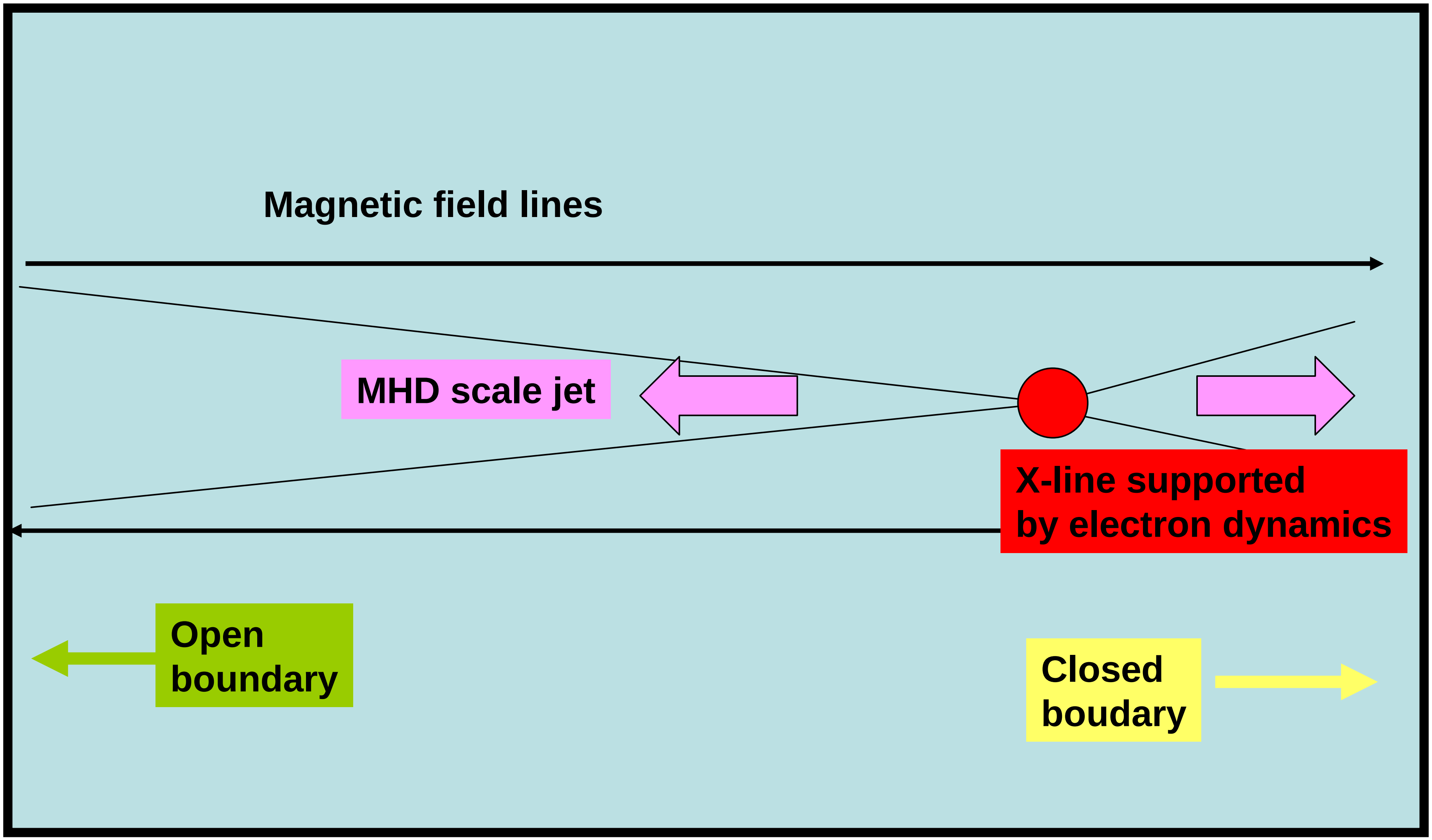
So,
how do we want to understand
the reconnection process?

Cross-Scale Coupling (XSC)



The coupling is dynamic!
Unlikely to be described properly in terms of transport coefficient

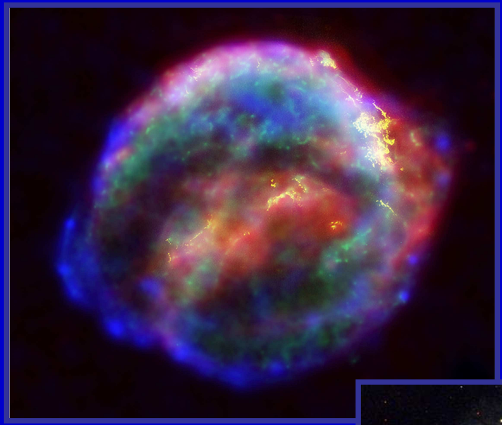
XSC in reconnection



The magnetosphere is the field but our ultimate goal is understanding the Plasma Universe

- We are fascinated by dynamic large scale phenomena in the plasma Universe.
- The large scale dynamic phenomena have key regions that control the global dynamics.
- The key regions is quite often small and embedded in the global structure.
- The key physics in the key region is quite often at micro-scale.

The true understanding of the plasma Universe requires multi-scale to be observed simultaneously



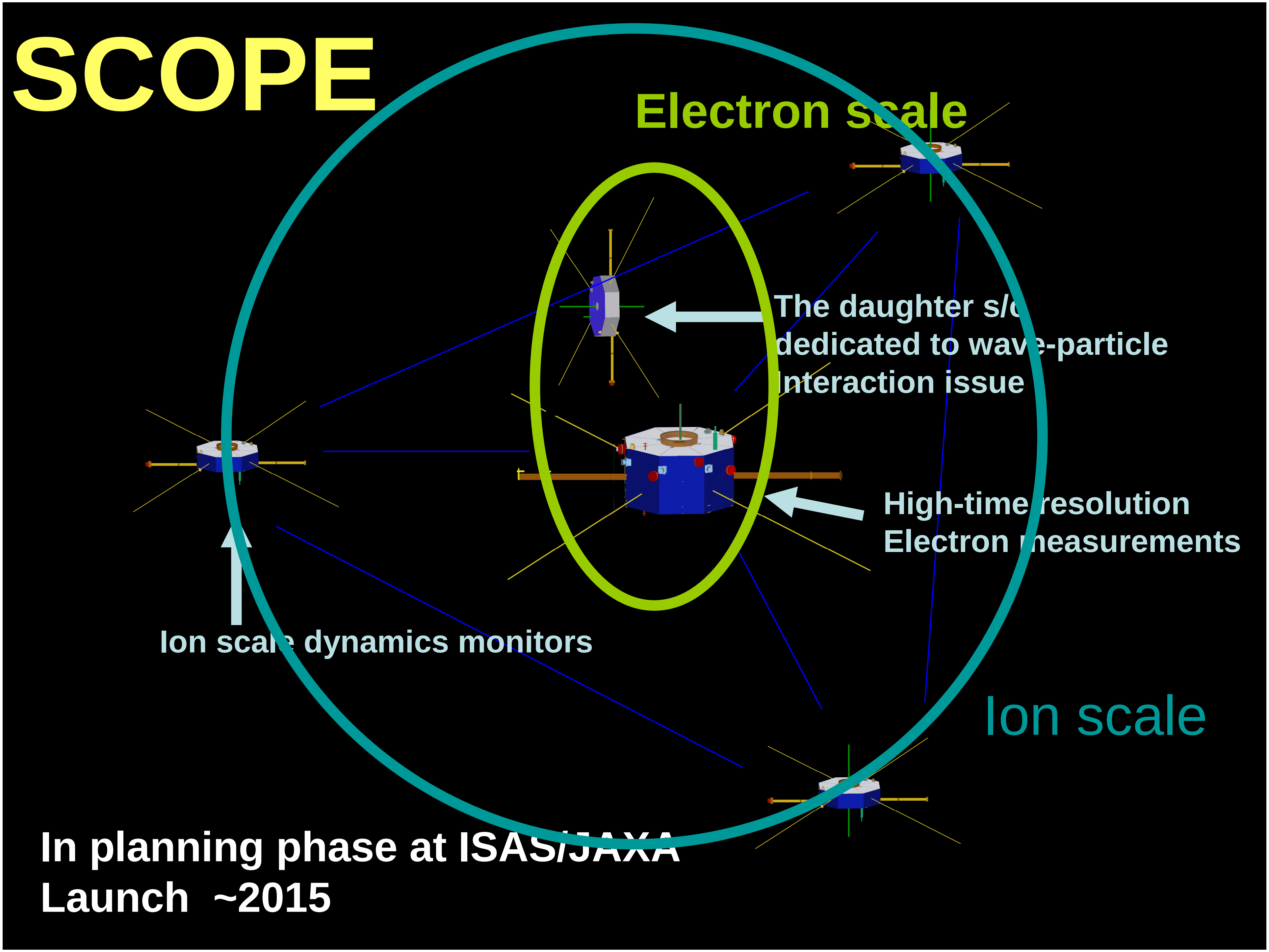
The shape of the mission resolving the Cross-Scale Coupling

- In-situ observations in the magnetosphere
- High time resolution to resolve the key micro-physics in the key regions
- Formation flying observations at more than one scales and that simultaneously

More sophisticated instruments, more and more spacecraft …. Highly demanding!

Mission looking into the cross-scale coupling processes as the natural next step: European and Japanese magnetospheric communities coming to similar mission ideas

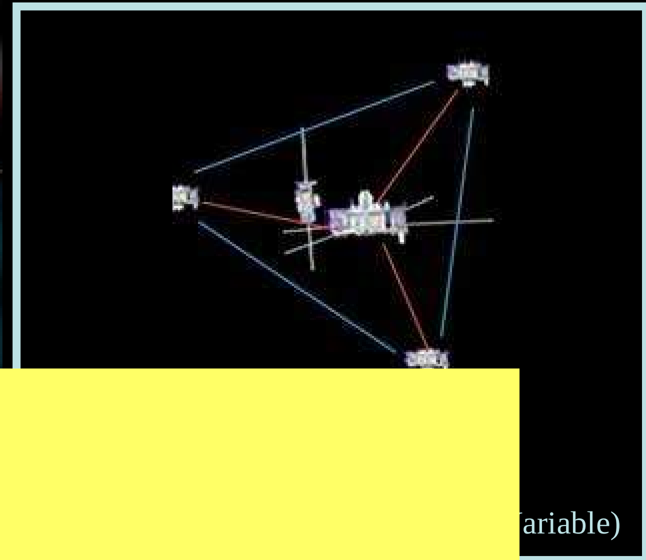
- Europe M^3 based on Cluster-II experience
- Japan SCOPE


SCOPE
Electron scale
The daughter s/c
dedicated to wave-particle
Interaction issue
High-time resolution
Electron measurements
Ion scale dynamics monitors
Ion scale
In planning phase at ISAS/JAXA
Launch ~2015

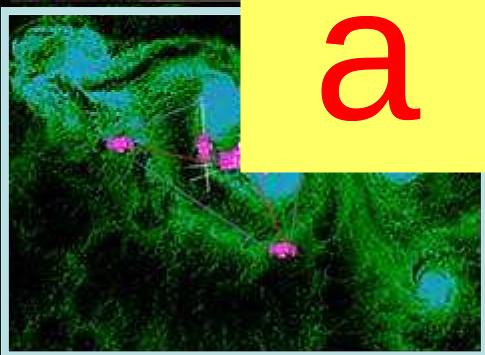
Formation Flight Mission to Reveal Essential Structures of Space Plasma

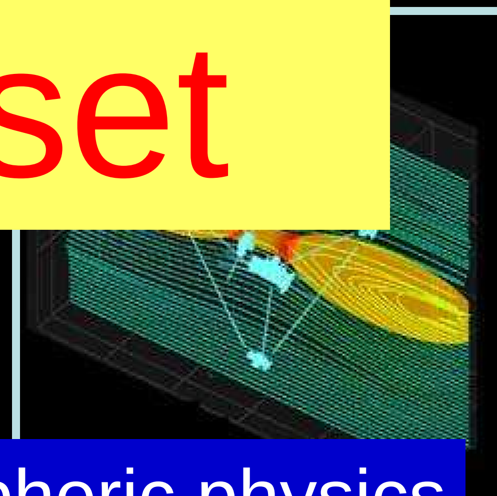
SCOPE

Electron dynamics at the shock



5 s/c is a minimum set



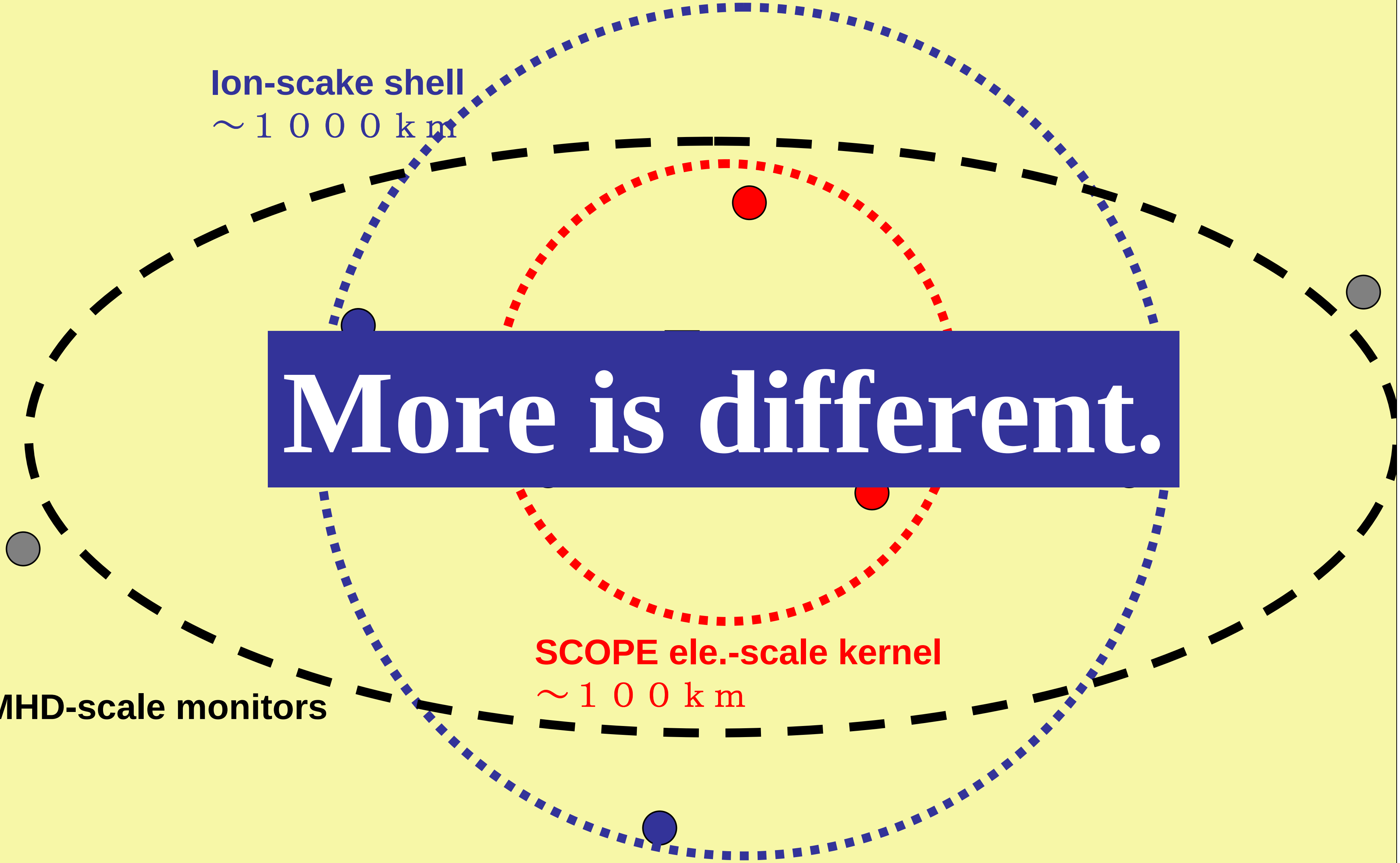


Key regions not only in the magnetospheric physics but also in the plasma Universe context

post-MMS
XSC explorer

More s/c surrounding the electron dynamics resolving core formation (like SCOPE) via ESA-ISAS collaboration should be *the* natural choice

ESA-ISAS “CrossScale”



More is different.

One of the starting points of the discussion on ESA-ISAS collaboration

X-Scale: *LESS BULL, MORE MEAT.*

ESA-ISAS collaboration framework enables us
to form a network and to work even harder
to design the mission.

The demanding mission in a smart way.

The “CrossScale” mission is guaranteed
to become an epoch making mission in the context of
“the plasma Universe” .