COSPAR 2012, July 14-22, Mysore, India

**D3.1-0007-12**

# A mechanism for heating electrons in the magnetopause current layer and adjacent regions

A. Roux[1], **P. Robert**[1], O. Le Contel[1], V. Angelopoulos[2], U. Auster[3], J. Bonnell(4), C.M. Cully(5), R.E. Ergun(6), and J.P. McFadden[4]

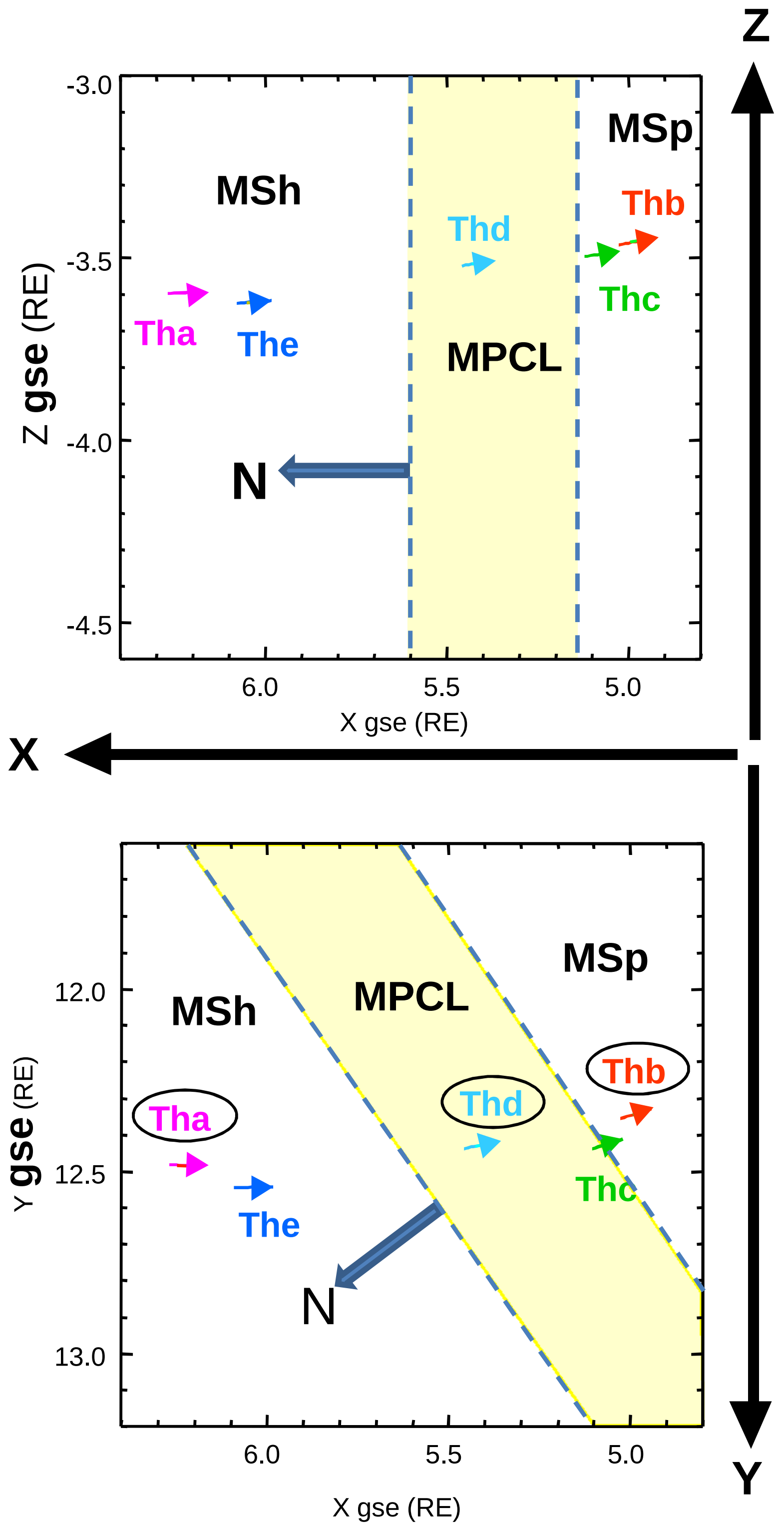
(1) LPP-CNRS, Ecole Polytechnique, route de Saclay, 91128 PALAISEAU CEDEX, FRANCE
(2) IGPP/ESS University of California, Los Angeles, CA, 90095-1567, USA
(3) Institut fur Geophysik und extraterrestrische Physik der Technischen University at Braunschweig,, Germany
(4) Space Sciences Laboratory, University of California, Berkeley, 7 Gauss Way, Berkeley, CA, 94720-7450, USA
(5) Department of Physics, Umeå University, Umeå, Sweden
(6) Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, Colorado 80309, USA

# 1) Introduction

THEMIS data are used for this study.
Choosed event : 20 Mai 2007 ~ 22:00
because :

- 5 S/C are aligned
- It covers simultaneously :
  -the magnetosheath (MSh),
  -the magnetopause current layer(MPCL),
  -magnetosphere (MSp)

- For convenience, we will choose hereafter to plot only Tha, Thd & Thb data



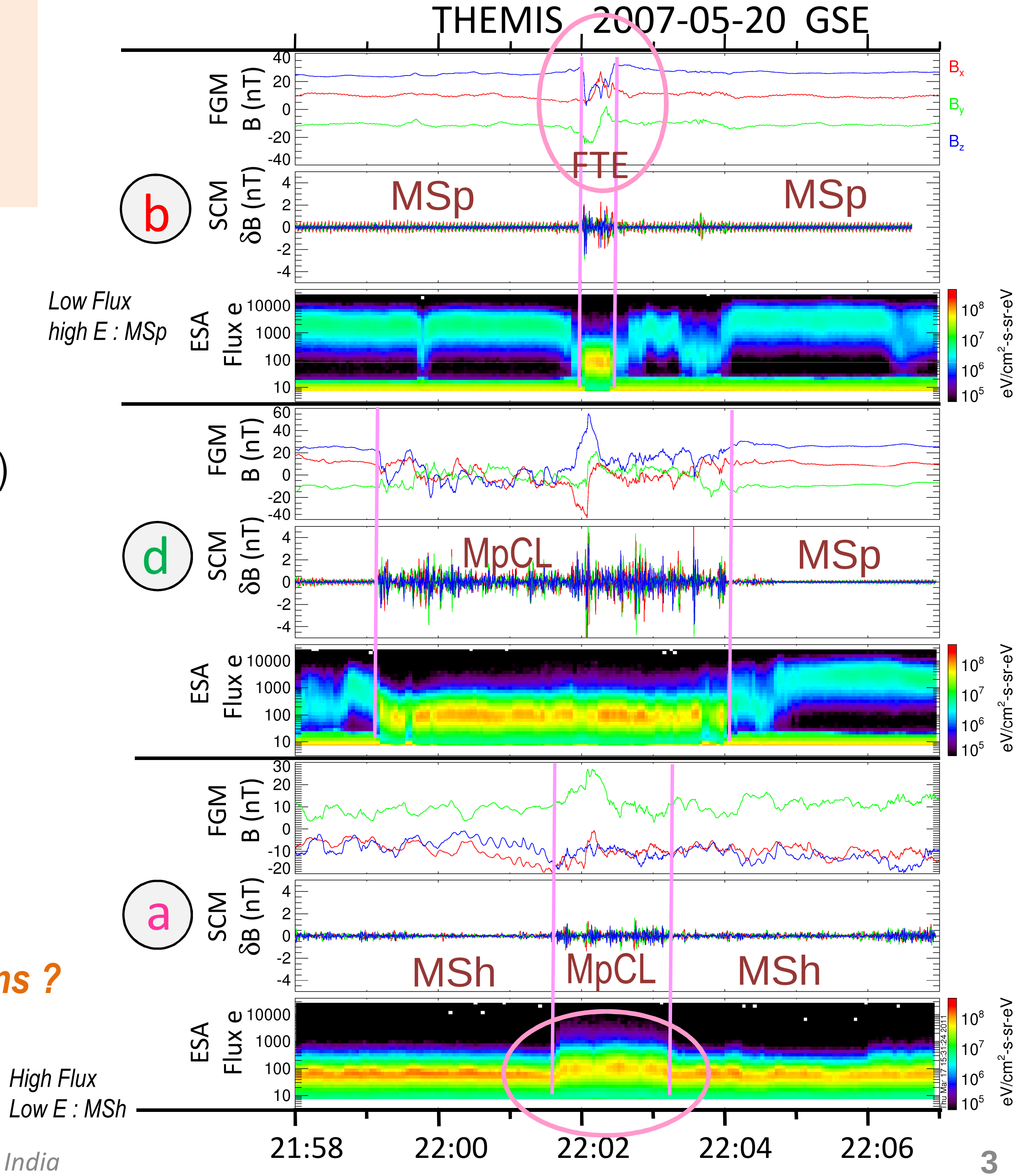
# 2) Relationship between electron heating and waves observed simultaneously

## *a) electrons*

- Thb is located into MSphere and crosses rapidly the CL (FTE on B)
- Thd stays 4mn into MpCL.
- Tha is located into MSheath and crosses briefly MpCL

- 3 S/C see into MpCL heated electrons from MSheath : Te~35eV =>70eV (see Tha)

➡ ***Question 1: do the waves heat the electrons ?***



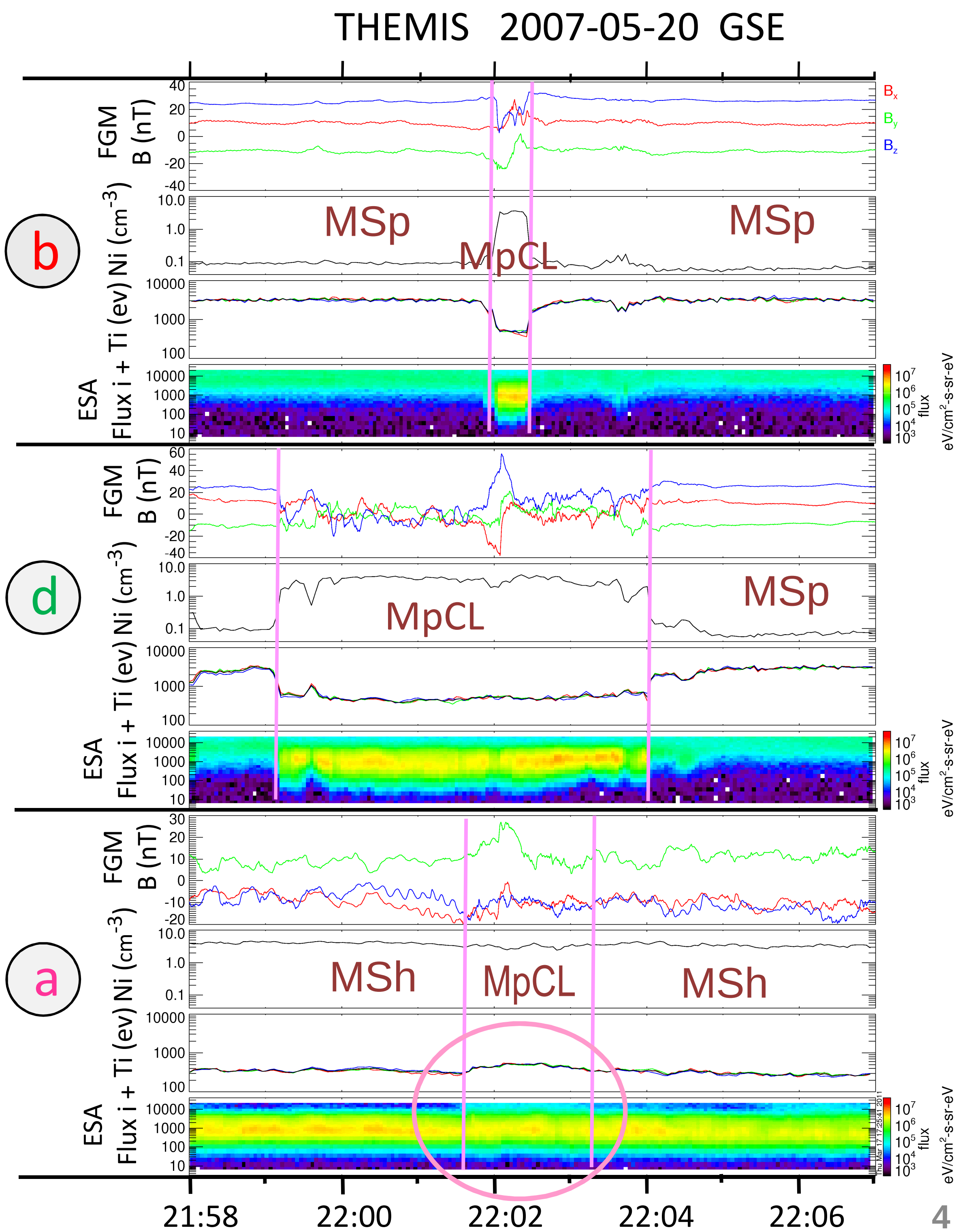
## *a) Ions*

- No heating during MpCL crossing (see Tha)
- Temperature in MpCL (All S/C) is the same as temperature in MSh (Tha).
- Same density : Ni(MPCL) ~ Ni(MSh)

➡ Msheath plasma enters into MpCL

➡ ***Question 2: How Alfven waves ($V \sim V_A$) could heat fast $e^-$ rather than slow ions ($V_i \sim V_A$)?***

➡ ***Question 3: How to characterize theses waves?***



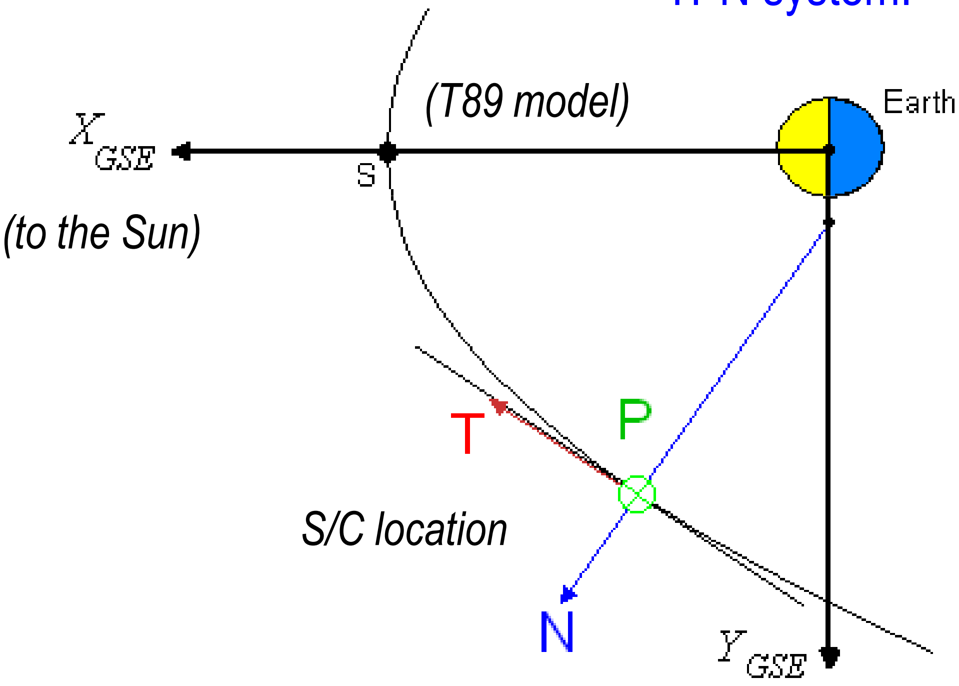
# 3) Definition of a new coordinate system to organize the data

## a) One performs an MVA on FGM (Thb) during the Mp crossing

| λ1 | λ2 | λ3 | |
|---|---|---|---|
| 0.985 | 0.163 | 0.037 | |
| L | M | N | |
| 0.434 | −0.424 | 0.795 | G |
| −0.566 | 0.558 | 0.606 | S |
| −0.701 | −0.713 | 0.002 | E |

| T | P | N | |
|---|---|---|---|
| 0.538 | 0.829 | 0.153 | L |
| −0.843 | 0.534 | 0.070 | M |
| −0.024 | −0.167 | 0.986 | N |

TPN system:




!! • The N LMN output normal is the same as the N TPN output normal

➡ This means that Bo field rotates into the local tangent plane to the paraboloide ~ Mp.

➡ We defined a simple coordinate system which is the same for the 5 S/C, and independent of the time duration of the selected period, which is useful. We will see on next section that such a system is particularly convenient to organize magnetopause data.

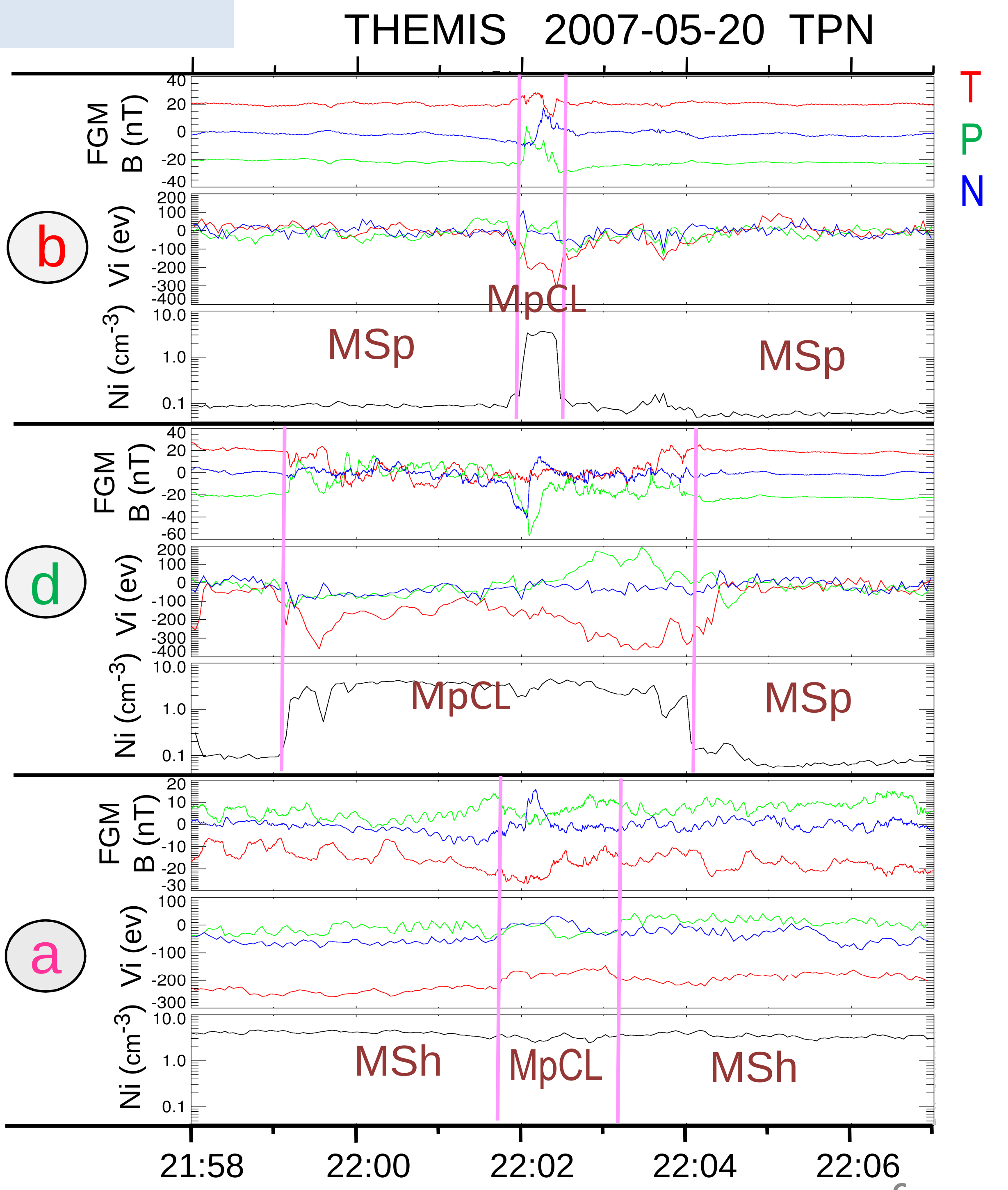
## 3-b) Data organization in TPN system

- $B_N$ = 0 on both sides of the Mp (3 S/C)

➡ The DC field is tangent to the paraboloide

- $V_i$ = 0 into the MSp (Thb), but $V_i$ // **T** into the MSh (Tha)

➡ The ion flow is into the tangent plane of the paraboloide , along the T azimuthal component.



# 4) Wave polarization on both FGM and SCM

- MVA on filtered FGM data between 0.8 and 2Hz (max. available frequency)
- Idem for SCM between 0.8 and 4 Hz.
- Results in TPN

**FGM**

| λ1 | λ2 | λ3 | |
|---|---|---|---|
| 1.000 | 0.694 | 0.523 | |
| **T** | **P** | **N** | |
| −0.139 | 0.066 | 0.988 | Lw |
| −0.384 | −0.923 | 0.008 | Mw |
| 0.913 | −0.378 | 0.153 | Nw |

!!

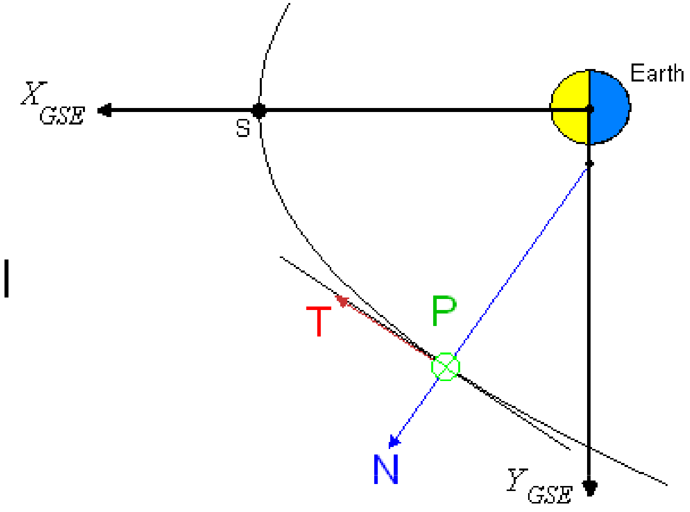
**SCM**

| λ1 | λ2 | λ3 | |
|---|---|---|---|
| 1.000 | 0.826 | 0.457 | |
| **T** | **P** | **N** | |
| −0.079 | 0.620 | 0.780 | Lw |
| −0.301 | 0.731 | −0.612 | Mw |
| −0.950 | −0.283 | 0.129 | Nw |

- The FGM wave fluctuation matrix is diagonal in TPN (a little bit less for SCM)
- In two cases the N axis of the LMN system is along the T axis of the TPN system

➡ The wave fluctuations are propagating along **T** (and are vibrating~ along **N** )

# 5) Waves characterization: a little bit of theory

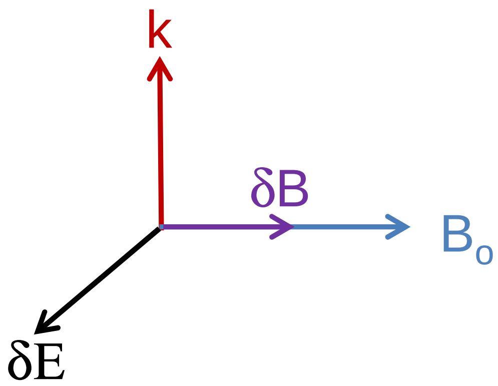



**a- Observations** :

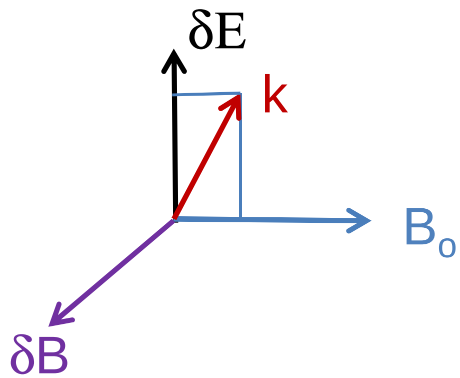
- k // **T** (and not only // Mp), so k azimuthal
- while Bo ~ stable, with Bo // **P**

➡ Therefore k ⊥ Bo

➡ Thus we have two possible kinds of polarization:




*Fast Magnetosound*




*Shear Alfven*

Impossible because δB is along N of TPN, with δB ⊥ Bo

This is our case because δB has a large component ⊥ Bo

**b- Hypothesis :**

- Classical Shear Alfven : $\omega/k_{//} \sim V_A << V_e$ (thermal velocity)
- But to heat electrons, we expect a Landau damping with : $\omega/k_{//} \sim V_e$
- well, but we have $V_A \sim$ 100-200 km/s

  Ve ~ 2000 km/s ($T_e \sim$ 30 eV)

➡ *Nevertheless, as we observe heating, theses waves cannot be classical Shear Alven waves*

KAWs (cf. simulation of Howes et al, 2008, Sahraoui et al 2011)

- Kinetics Alfven waves :

$$\frac{\omega}{k_{\|}} = \frac{V_A k_{\perp} \rho_i}{\sqrt{(\beta_p + 2)/(1 + \frac{T_e}{T_i})}}$$

$\beta_p \sim 6$ for B ~ 10nT

$T_e/T_i \sim 1/10$

➡ *True if $k_{\perp}\rho_i \sim$ 30-60*

- If we use Electric field (only available on Thc) : $\frac{\omega}{k_{\|}} = \frac{\delta E}{\delta B} \gtrsim 2000\ km/s \simeq V_e$

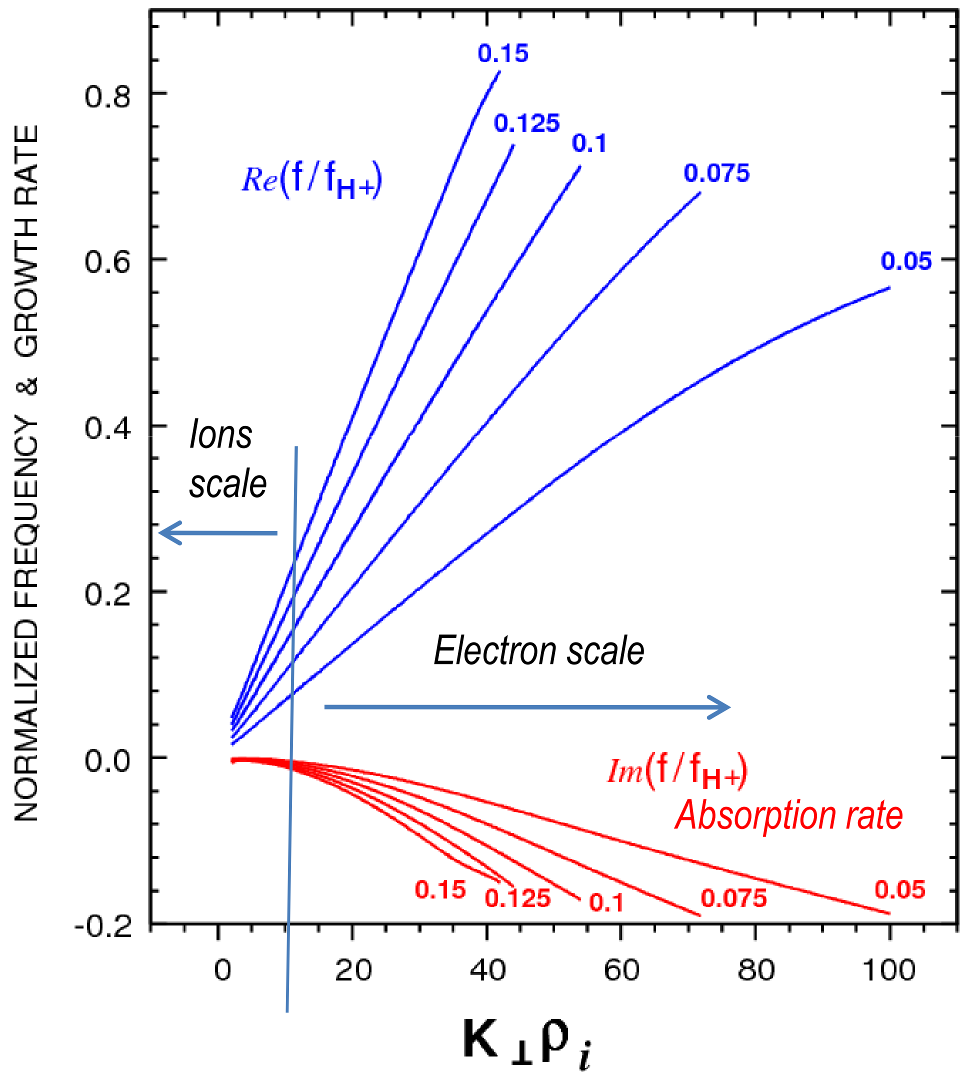
➡ KAW can heat the electrons

# 6) Check our KAW hypothesis

a- computation by **Whamp** program of the absorption rate of KAW by Landau damping on electrons :

- Input : $k_\perp \rho_i$ ~ 10 – 100 ($k_\perp \rho_i >> 1$)
- Input : $k_{//} \rho_i$ ~ 0.05 - 0.15 ($k_{//} \rho_i << 1$)
- We find solutions of $F/F_H+$ with parameters corresponding to the observed values :

$N_i$=4 $cm^{-3}$, B ~ 10nT ($\beta_p$ ~ 6 )
$T_e$~ 36 eV, $T_i$ ~ 400 eV




➡ For $k_\perp \rho_i$ ~ 1–10 (ions scale) we find a low absorption rate (low ion heating)

➡ But for $k_\perp \rho_i$ ~ 20–100 (electrons scale) we find a high absorption rate, and thus a possibility of electron heating.

➡ The KAW can be responsible for electrons heating

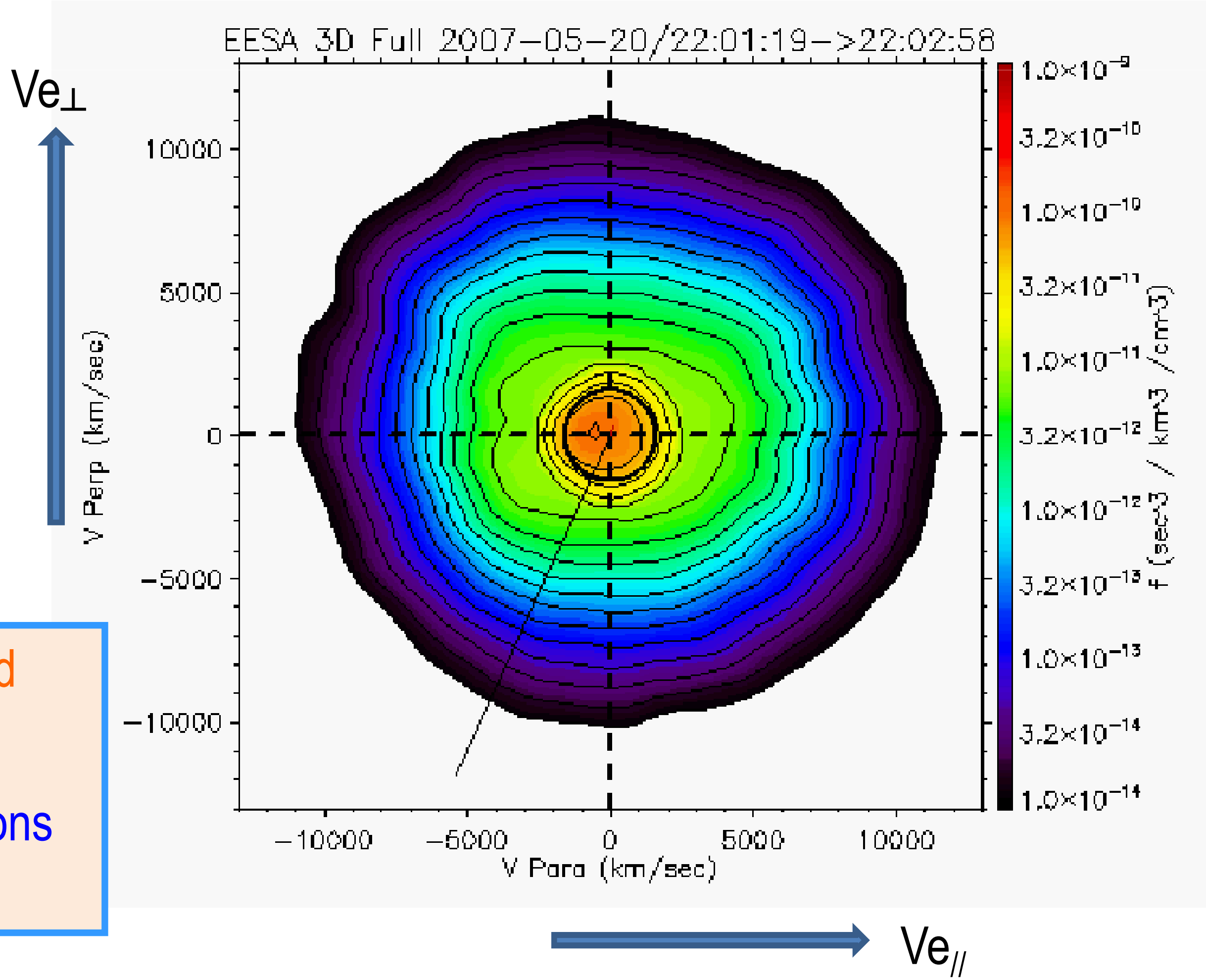
*No theoretical contradiction*

## b- Extra checking on experimental electrons distribution functions

- Whamp results provides also a small $E_{//}$ ($E_{//}$ / $E_{\perp}$ ~ $10^{-2}$) which accelerates electrons along B DC field

- This prediction can be checked on electron distributions functions (on Thd in the MPCL) where we observe $Te_{//} > Te_{\perp}$

➡ Increase of $Te_{//}$ confirms $e^-$ heating in direction // (&anti //)




So we answer the previous questions and can deduce than :

- Waves heat the electrons and not the ions
- They are KAWs

# 7) What is the mechanism which generates the KAWs?

- We observe large gradients (∇B, ∇N, ∇Te)
- Possibility of drift waves
- Literature: Mikhailovskii (1992) :
  Dispersion relation of KAWs with gradients (∇N, ∇Te, ∇Ti et ∇B)

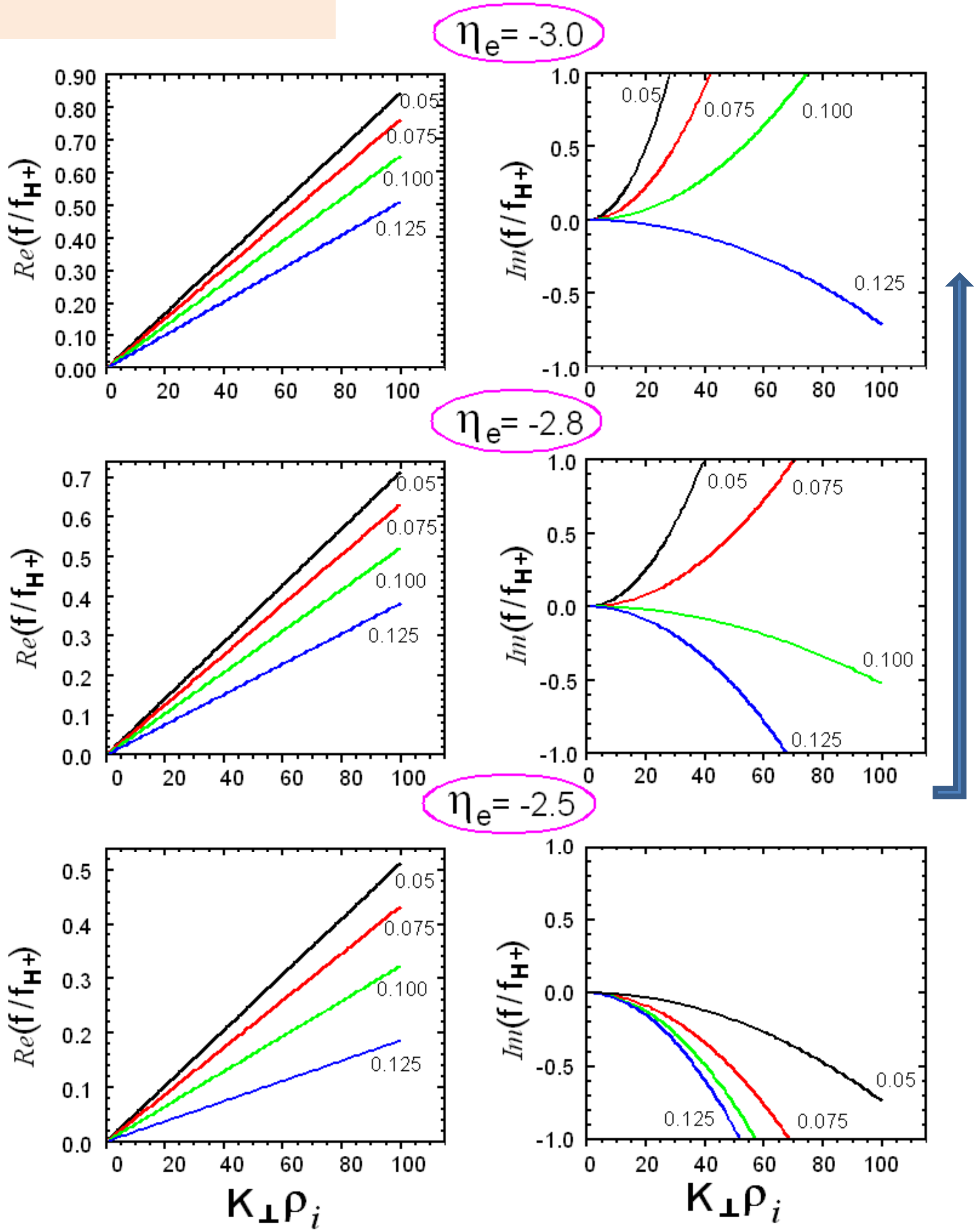
$\eta_e$ : scale∇N / ∇Te

$$\begin{cases} \nabla N \text{ outward} \\ \nabla Te \text{ inward} \end{cases}$$

- We solved numerically the Mikhailovskii's equations to compute real and imaginary parts of $f/f_H+$ ( into the experimental regions) :

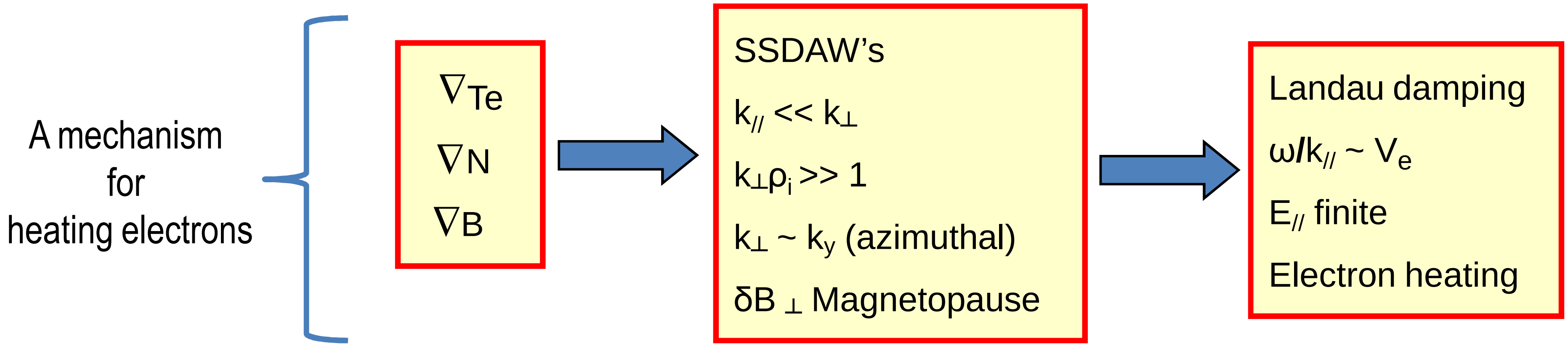
$$\begin{cases} k_\perp \rho_i \sim 0 - 100 \\ k_{//} \rho_i \sim 0.05 - 0.125 \end{cases}$$

For $\eta_e$ < -2.5, we get large growth rates, and therefore such waves can exists in observed experimental conditions.



# 8) CONCLUSIONS

- Strong waves observed in MPCL and adjacent regions could be identified as « **Short Scale Drift Alfven Waves** » with a parallel phase velocity $\frac{\omega}{k_{\|}} = \frac{\delta E}{\delta B} \simeq V_e > V_A$
- They can be generated by strong gradients
- They are propagating azimuthally, along the Mp (simplified by a paraboloïde), with a normal magnetic component
- They are damped by electron heating




***THANK YOU !***

**Fig. 6.** This figure shows mainly data from Thc. From top to bottom:

**(a)** the 3 components of the magnetic field,
**(b)** E/B for different frequencies (3 Hz in red, 12 in green, 48 in cyan and 192 Hz in black) and Va (dotted line),
**(c)** Ew the electromagnetic energy,
**(d)** Te for Thc (green) and Tha (magenta).

The bottom panel shows a spectrogram from Thc; the spacecraft moves back and forth from the MSp to the MpCL.

The thin vertical lines and superposed arrows point out the coincidences between sharp gradients in Te and wave bursts.