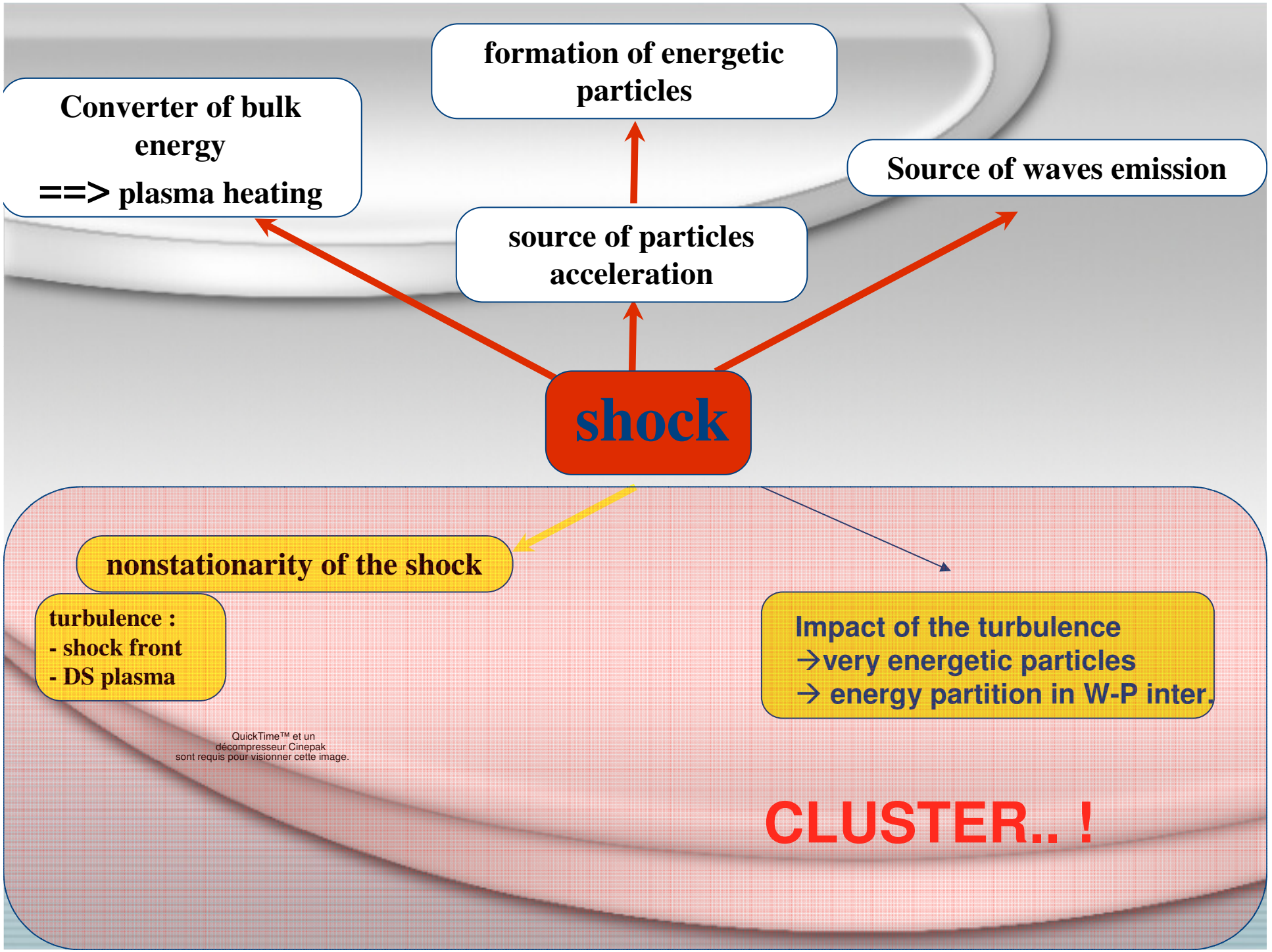
Dynamics of collisionless shocks via numerical simulations:

What's new from CLUSTER and ……prospectives post-CLUSTER ??

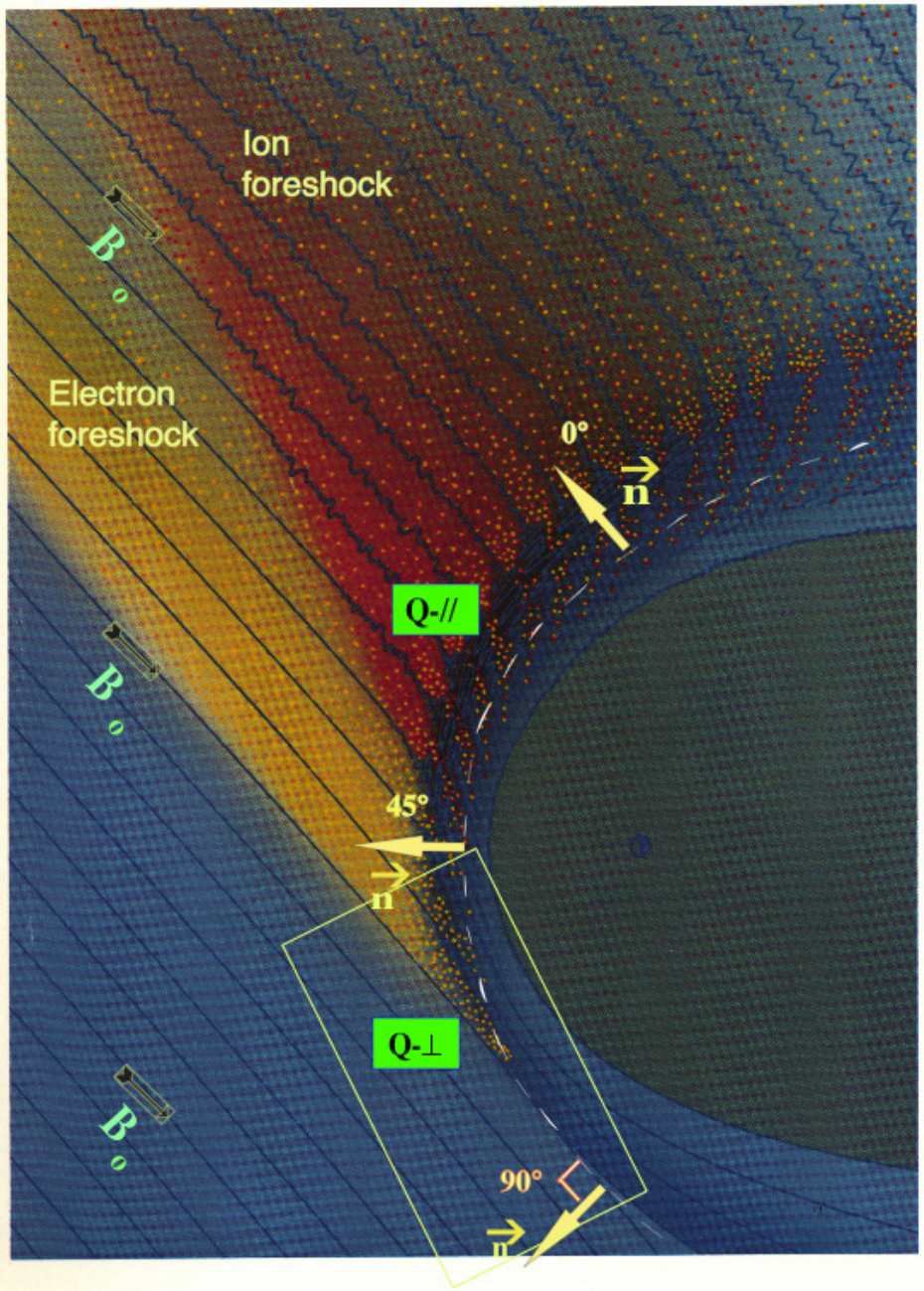
Bertrand LEMBEGE

(LATMOS-IPSL)

….. and many collaborators


formation of energetic particles
Converter of bulk energy
==> plasma heating
Source of waves emission
source of particles acceleration
shock
nonstationarity of the shock
turbulence :
- shock front
- DS plasma
Impact of the turbulence
→very energetic particles
→ energy partition in W-P inter.
QuickTime™ et un décompresseur Cinepak sont requis pour visionner cette image.
CLUSTER.. !

(Tsurutani and Rodriguez, 1981)



Present targets on terrestrial shock:

* Quasi-perpendicular shocks

* Quasi-parallel shocks

* Foreshock (electron, ion)

* Interaction between shocks (IP)

How CLUSTER contributes to analyse:

(i) interplanetary shocks ?
(ii) planetary shocks (ex: Mercure with Bepi Colombo)
(iii) heliospheric shock ?
(iv) astrophysical shocks?

*** Quasi-perpendicular shocks**

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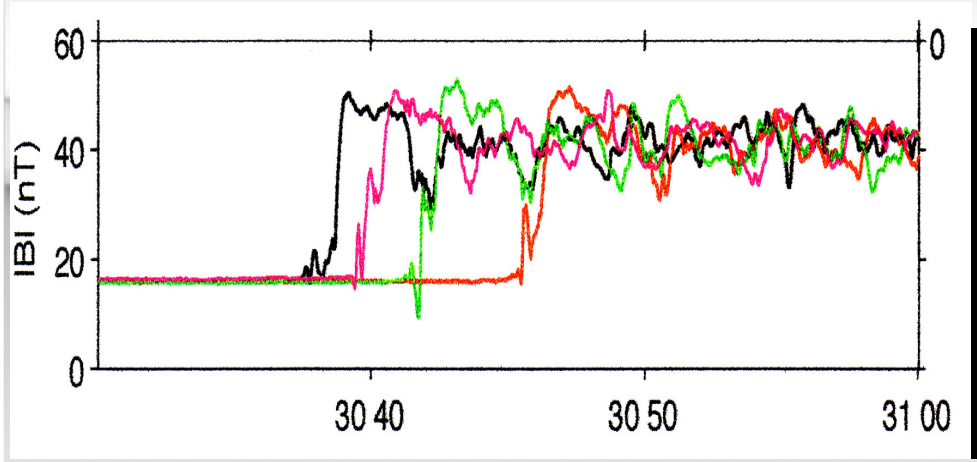
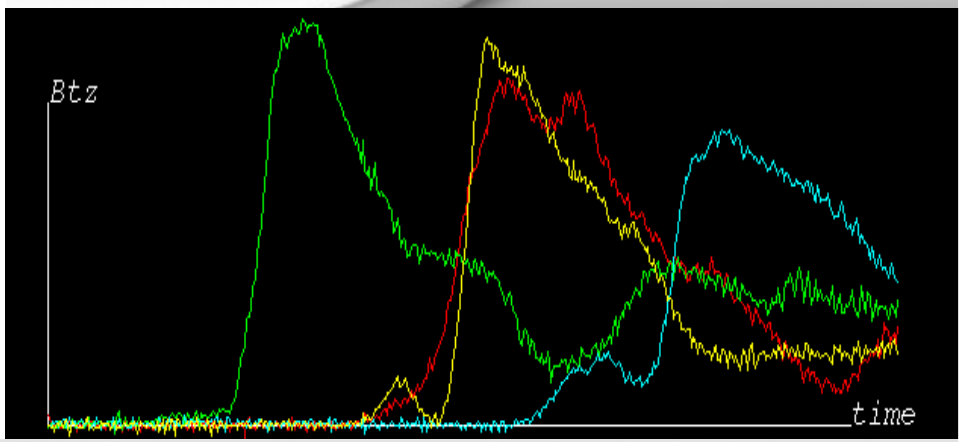
(ex : Mercure (Bepi Colombo mission)

Quasi-perpendicular Shocks

a) Données CLUSTER-2 [Horbury et al., 2001]



c) Local measur. made by Virt. Sat;



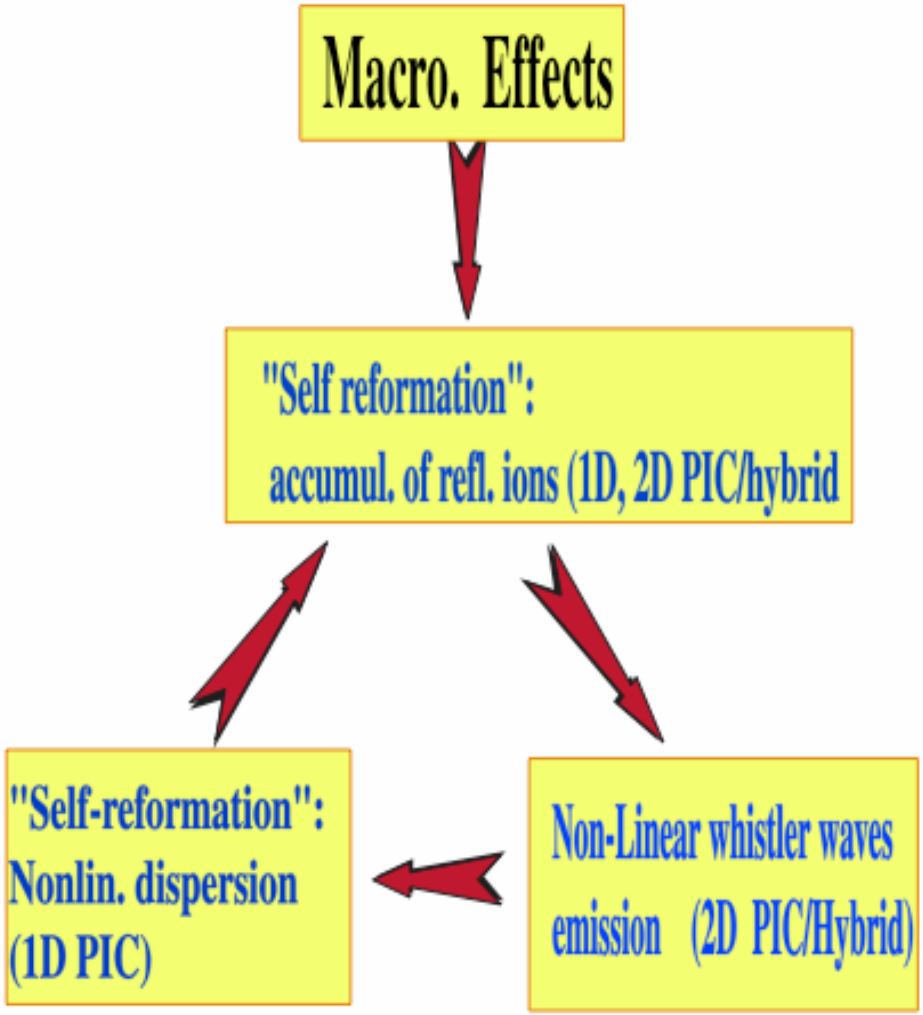
b) Simulation 2-D PIC

QuickTime™ et un décompresseur Animation sont requis pour visionner cette image.

Virtual Satellites (CLUSTER)

Shocks Q-perp. : sources of shock front Nonstationarity

(Without micro-instabil.)



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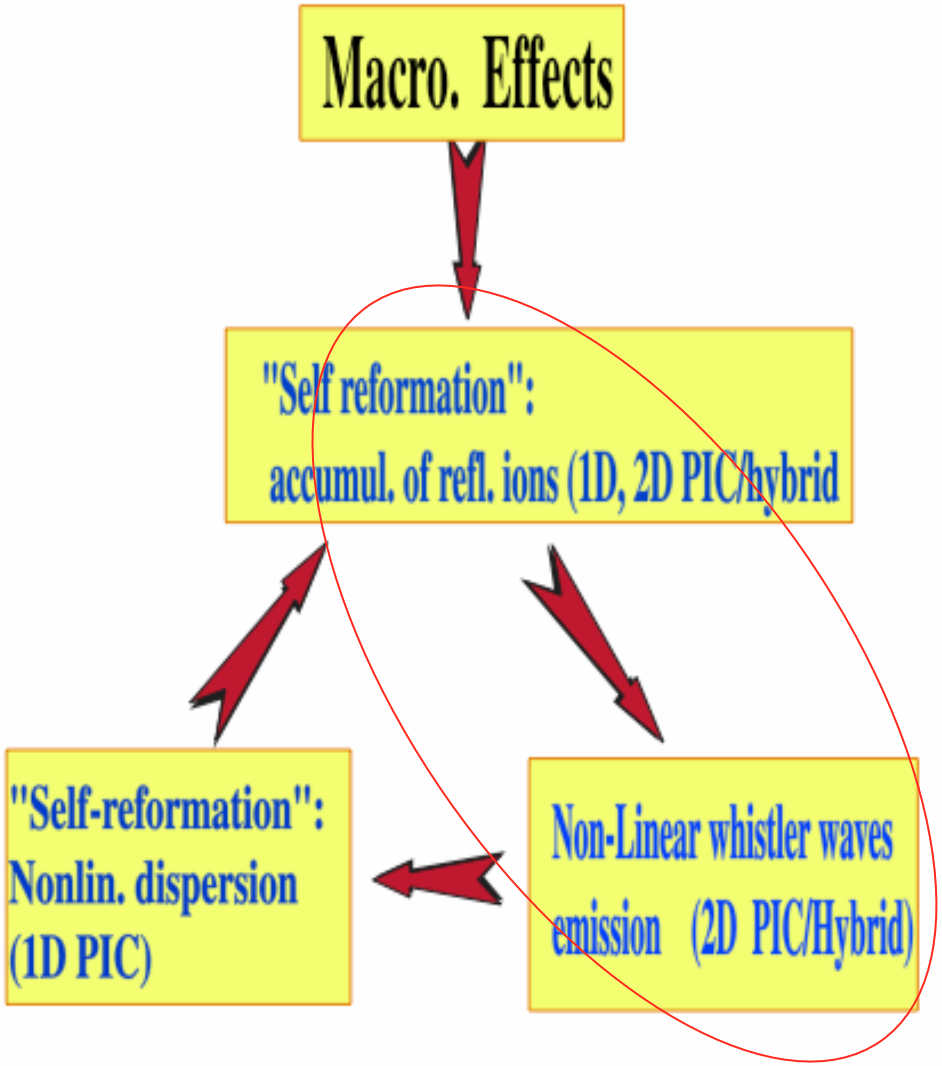

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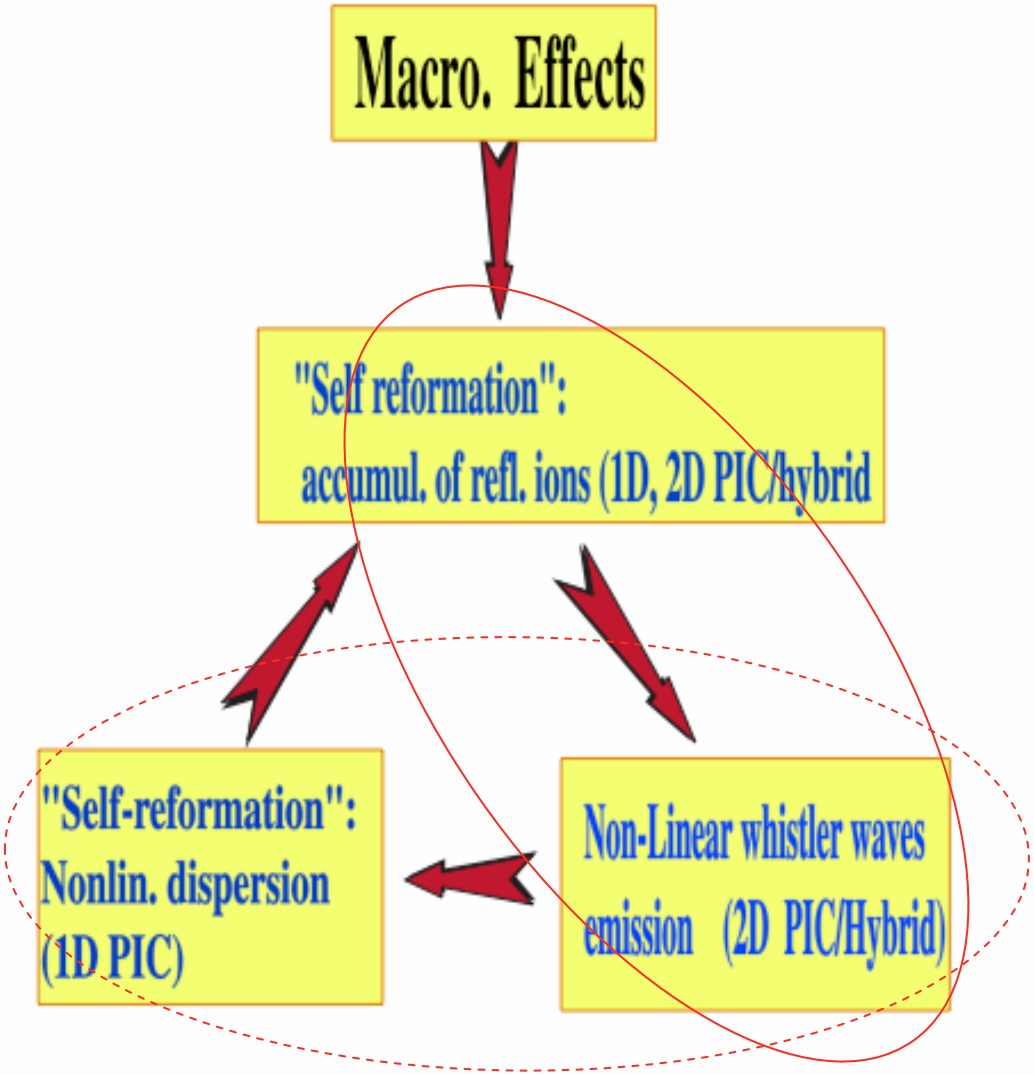

Shocks Q-perp. : sources of shock front Nonstationarity

(With micro-instabilities)

Micro. Effects

Along X:

* ECD ---> SR persists (foot)
* MTSI_1 and 2...--> speeds up SR (foot)
* NL insta (RI-II) by standing US whistler prec.

Shocks Q-perp. : sources of shock front Nonstationarity

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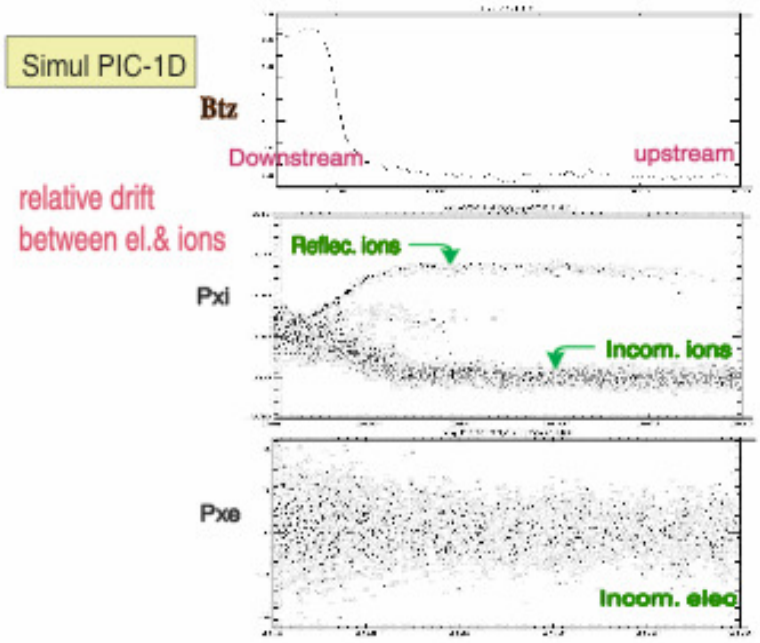

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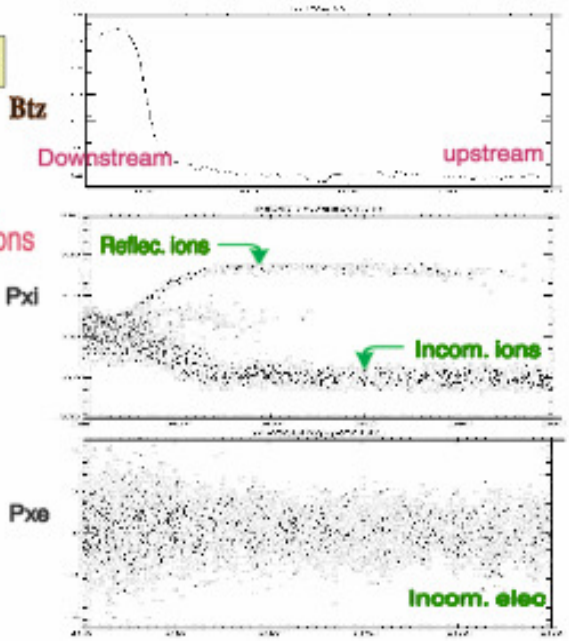
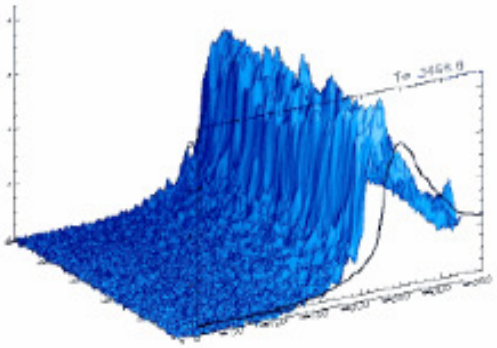
Simul PIC-1D



relative drift
between el.& ions

Simul PIC-2D



* LHD: CFC instab
* Mirror/AIC: $T_{perp.} / T_{//}$

(With micro-instabilities)

Micro. Effects

Along X:
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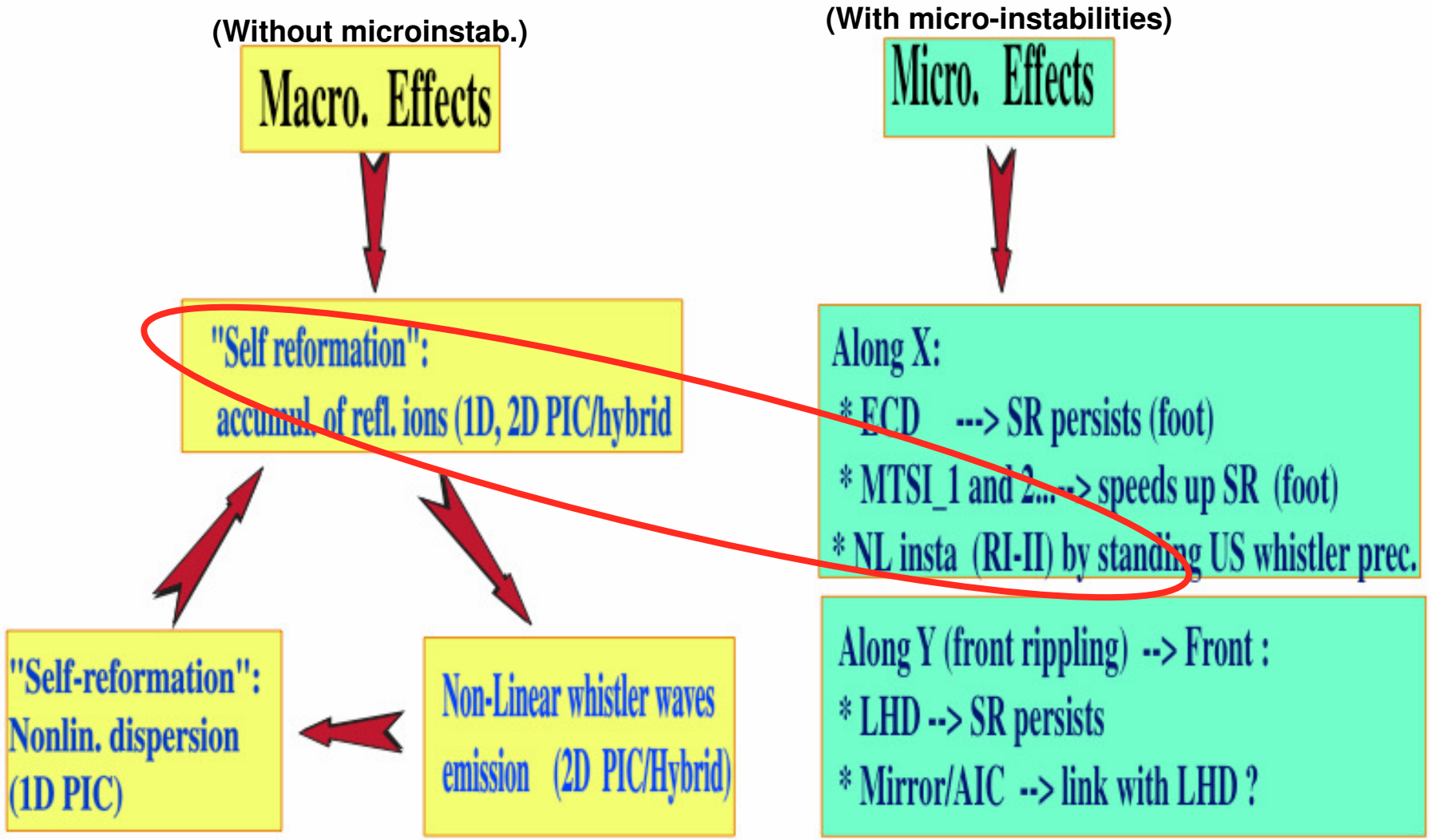
* NL insta (RI-II) by standing US whistler prec.

Along Y (front rippling) --> Front :
* LHD --> SR persists
* Mirror/AIC --> link with LHD ?

Shocks Q-perp. : sources of shock front Nonstationarity



What we know:

(i) Shock front= ramp + foot …+ precursor

(ii) Strong variability of time/spatial scales:

without microinst. : --> from **el. c/ω_{pe}** to **ion ρ_{ci}**

with microinsta : --> from a few 10 λ-D to several ion c/ω_{pi}

Front : Typical example of processes with **multi-scales coupling**

(iii) sensitivity of the processes triggering versus a few main criteria

(iv) Some non-station. processes driven by some micro-instabilities may dominate.. !

(v) strong impact of these NonStation on particles (Bursts of ref. part)

(vi) at present , extension:

- of some processes to 2D and 3D
- to more realistic conditions (Rmass, wpe/wce,…)

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What we do not know:

* is there dominant Non station. process ? --> hot discusssions . ! this depends strongly on US parameters, Ma, Θ, etc.

* coexistence of several processes ? …. or mutual killing. ?

* Variations of spatial scales (front) and particles variations (Ref.): Necessity for an important statistical analysis coupled with CLUSTER data

* impact of these NonStation. on heavy ions (in course) **-> CLUSTER ?**

* but multi-scales coupling (ions - electrons)..--> to analyse simultaneously electrons and ions scales --> **CLUSTER cannot do ??**

* Quasi-perpendicular shocks

*** Quasi-parallel shocks**

* Foreshock (electron, ion)

* Interaction between shocks

* How CLUSTER can contribute to analyse:

(i) interplanetary shocks
(ii) extension to heliospheric shocks ?
(iii) extension to astrophysical shocks
(iv) extension to planetary shocks
(ex : Mercure (Bepi Colombo mission)

Quasi-parallel Shocks

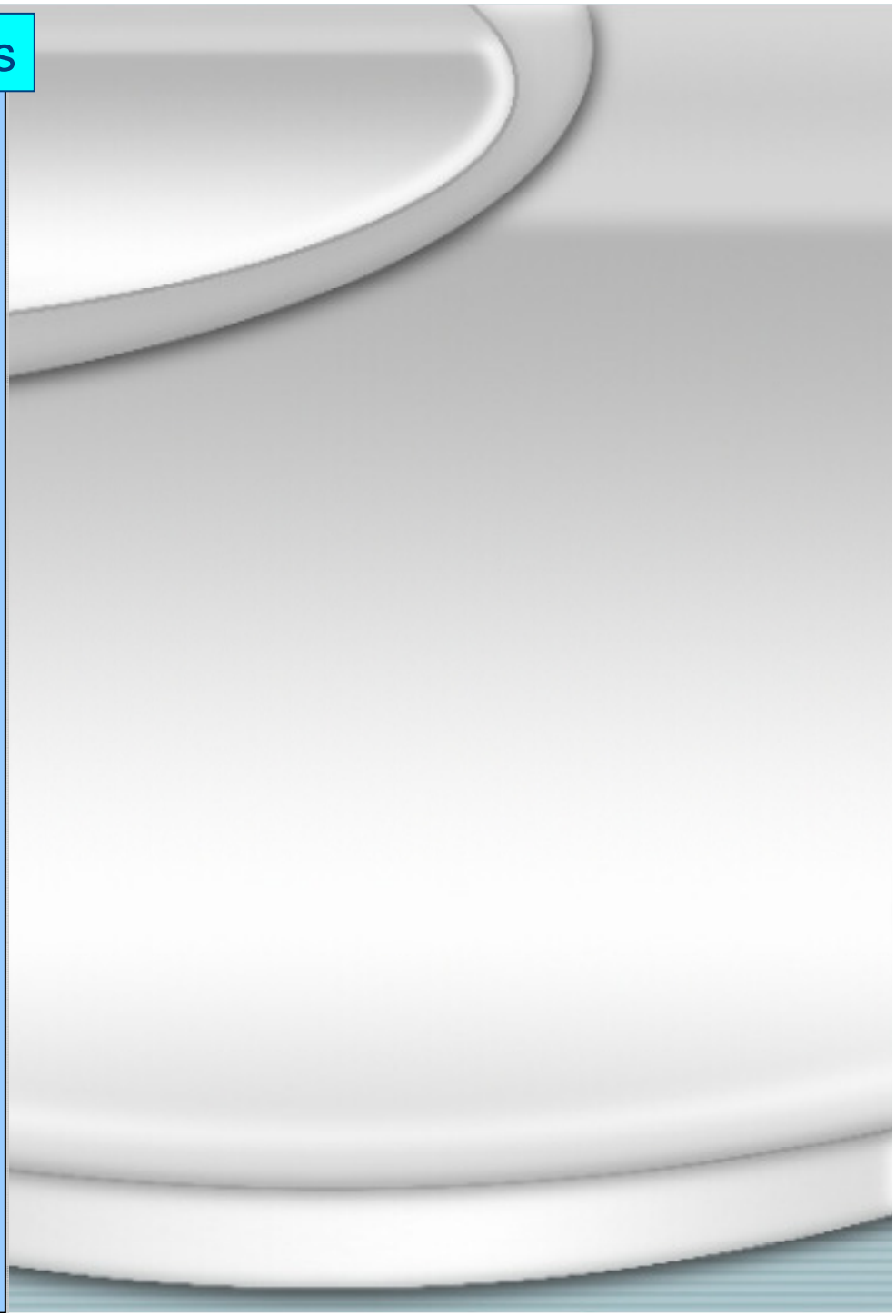
What we know :

(i) Much less studies than for Q-perp shocks

(ii) Q-// shocks:
*very extended and turbulent area: No clear jump
*«Patchwork» of different structures and wave activity:
-> monolithic structures: SLAMS
-> 1D-Hybrid … and 1D-PIC OK
* ULF waves <--> SLAMS
* front edge behave as Q-perp (diff. from shock propagation direc.
--> plasma density depletion behind the SLAMS
--> bipolar/tripolar pulses within SLAMS (Belke et al., 2004)

(iii) Different sources of Nstationa. driven by
* dispersive linear whistler waves
* SLAMS: «self reforma. » of front edge

(accumul. of ref ions)



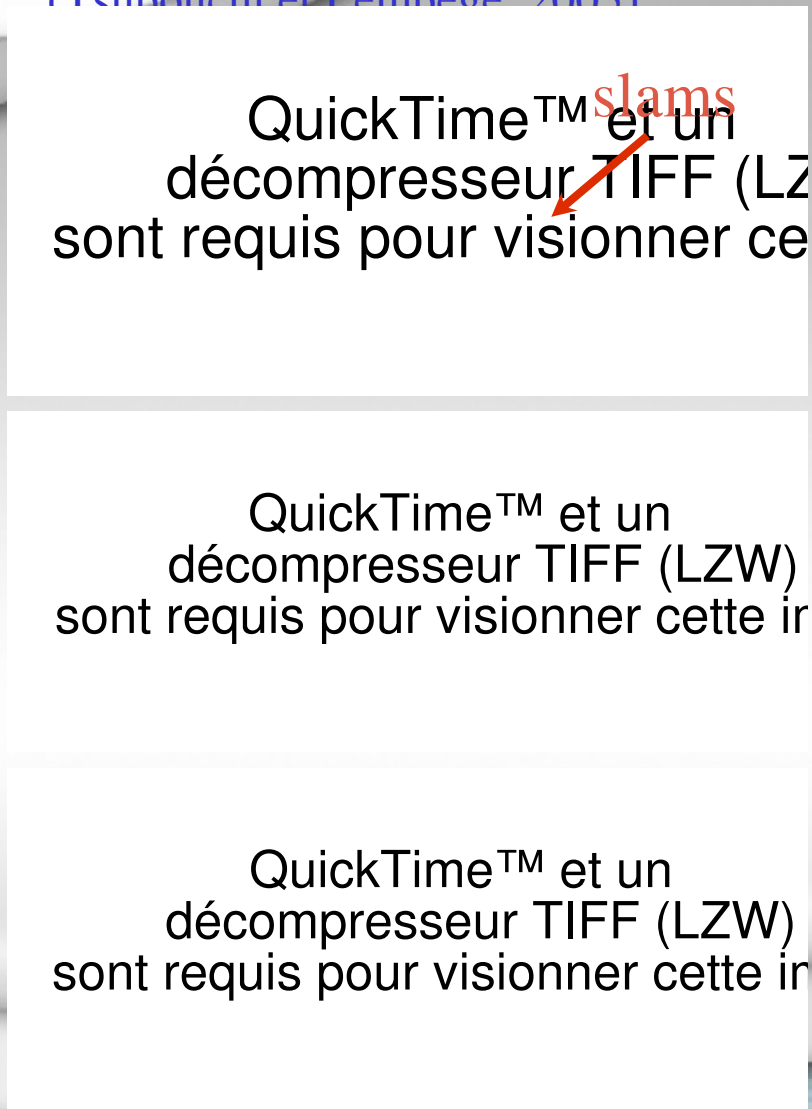
Quasi-parallel shock

a) Experimental measurements (CLUSTER), Loucek et al.; 2002

SLAMS:
* Ion FAB interactions - Solar wind
* progressive “braking”
* front SLAMS: “ Q-perp shock .. ! ”

b) Simulations PIC 1D

(Tsubouchi et Lembege, 2005)



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What we dont know:

(i) Persistence of SLAMS structu. versus time? distance ? and angular range ?
necessity for mapping
--> Multi-satellites necessary (more than CLUSTER)

(ii) SLAMS Scales; questions similar to the front of Q-perp shock may apply.
* on front thickness ?
* on nonstationarity of front edge ?

(iii) Non-station processes:
* do other NS mechanisms of Q-perp apply ?
* dominant process ?
* transition: possibility of simultaneous multi-crossing of the shock in Q-Perp and Q-// regions
--> CLUSTER + other satellites necessary

(iv) Resulting energisation of particles due the mixing of background ULF waves and monolithic structures.

Summary

Step 1: What we know from ISEE / AMPTE-UKS : classification in

* quasi-perp / quasi-// shocks
* subcritical/ supercritical shocks
* Foreshocks

+ particles dynamics supporting this classification

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Step 2: What we know from CLUSTER:

* Nonstationary behavior of shock front
* strong variability of spatial/temporal scale of the front (ramp, foot, whistler….)
* strong variation in the energy partition between the fields energy and particles

Ex: bursts of ions/elec. in time; packs of particles in space (non-uniform. of the front)

* the whole shock environment (DS and US (foreshock)) suffers the conseq. of this variabili.

Summary

Step 3: What need after CLUSTER ?

a) shock crossing **with very-short intersatelite distance (MMS)**

--> to acces smaller microstructure/ wave activity within the foot (signatures to identify dominance of some microinstabili ? When this dominance takes place ?

--> N. Station. due to «micro» of « macro» effects (since some have a comparable impact)

--> impact of the Nonstation (at the front) due to :

* front rippling (which may have diff/ sources --> diff scales)
* oblique emission of large amplitude whistler waves

b) For one crossing : **simultaneous measurements of electron and ion scales**

- multi scales coupling processes
- impact of heavy ions (diff. power laws for Reflec. and DT ions --> Infos on dominance of SDA/SSA processes)

c) **Simultaneous crossing** (multi-missions combined ?):

- in Q-perp and Q-// shocks
  * when/where SLAMS disappear ? Same for GBI and FAB-I ?
  * link between Nonstation.Process respect. proposed for Q-perp & Q-// ?

- in both el. and ion foreshock regions
  * variability of foreshock edges versus Nonstat. ?
  * to which distance Nonstation effects (front) affect far US ?