

Magnetosphere response to the 2005 and 2006 extreme solar events as observed by the Cluster and Double Star spacecraft

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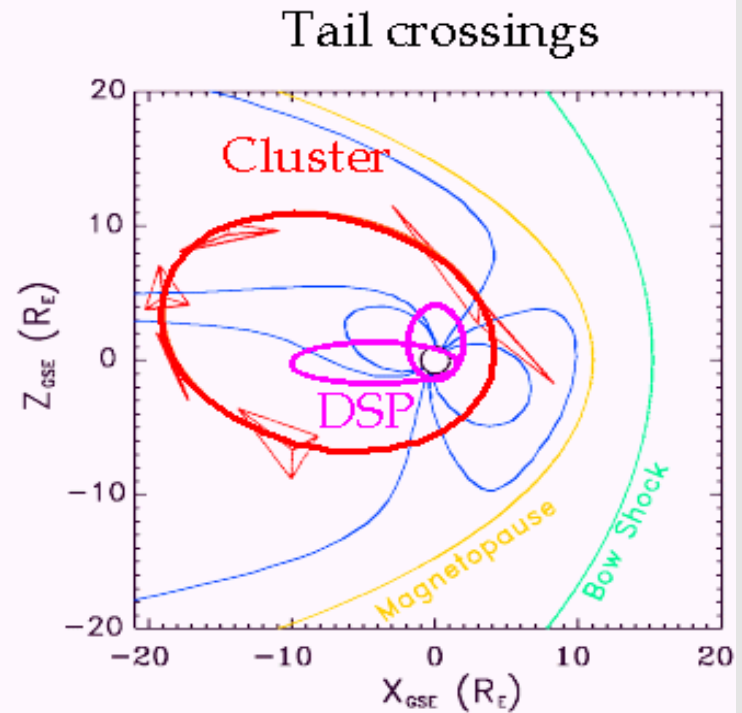
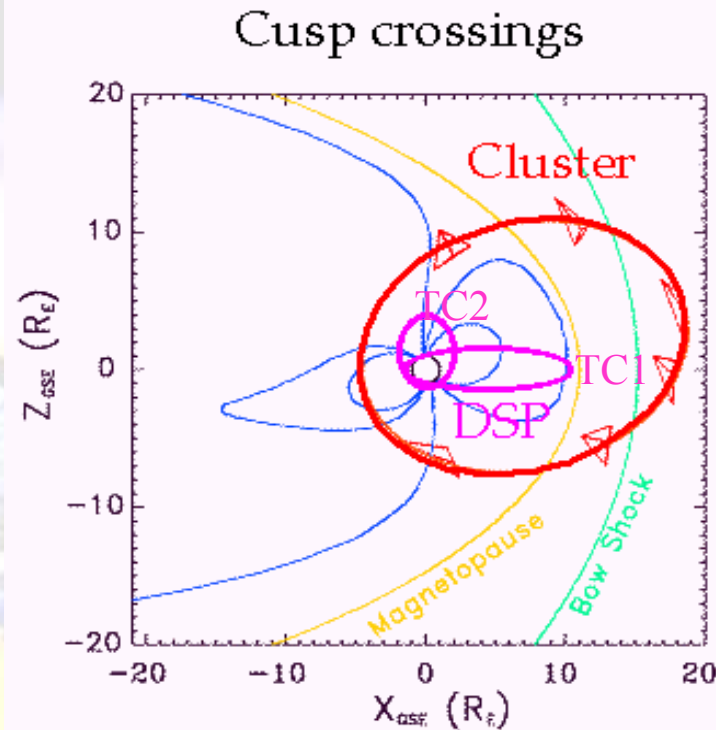
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⁴Applied Physics Laboratory / Johns Hopkins University, MD, USA

Solar Extreme Events 2007 Symposium, Athens, September 2007

CLUSTER and DOUBLE STAR Orbits



- **CLUSTER Orbit:** 4 spacecraft in tetrahedric configuration:

4 x 19.6 R_E , $i \approx 90^\circ$

Launched: Summer 2000

- **DOUBLE STAR Orbits:**

➤ **TC1:** 1.09 x 13.4 R_E , $i \approx 28^\circ$

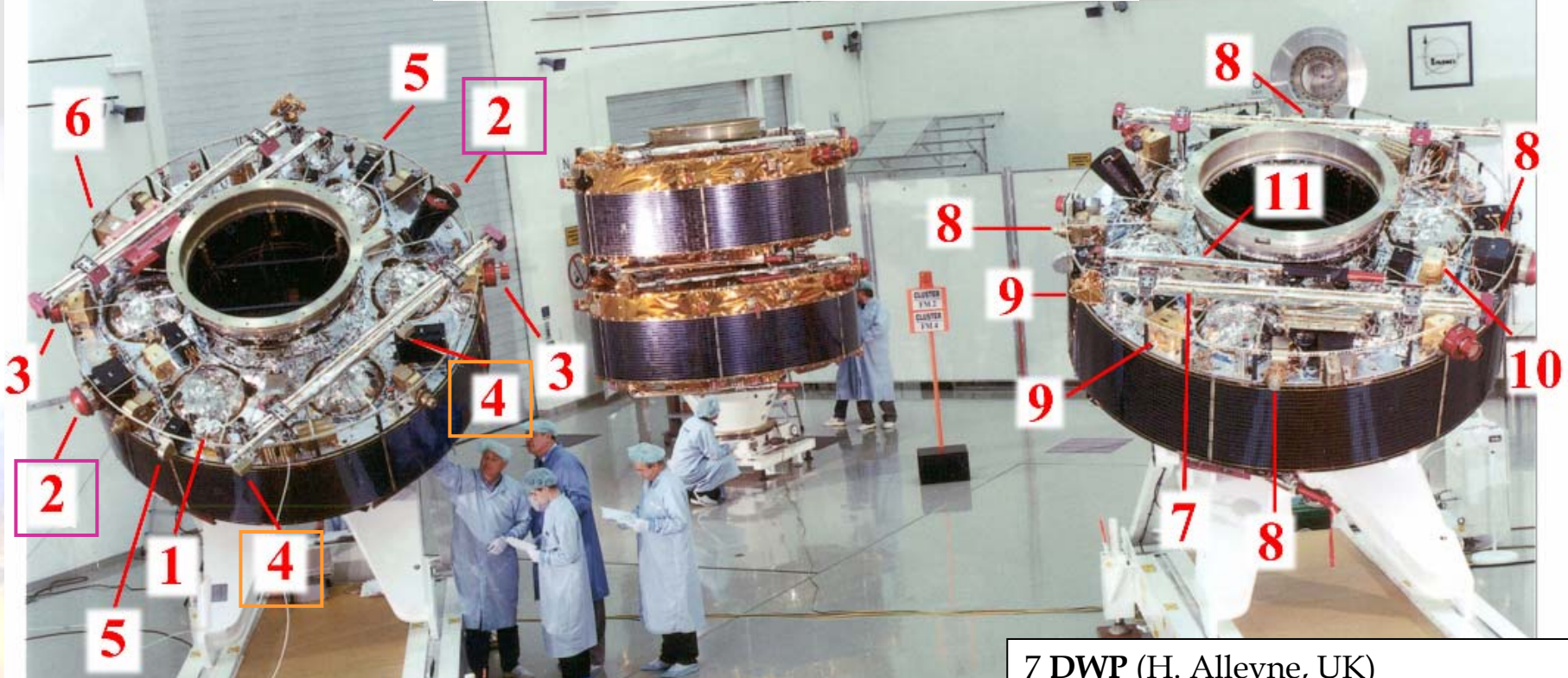
Launched: December 2003

will re-enter the atmosphere on 10 October 2007

➤ **TC2:** 1.10 x 6.8 R_E , $i \approx 90^\circ$

Launched: July 2004

44 Cluster instruments



1 **ASPOC** (K. Torkar, A)
Spacecraft potential
control

2 **CIS** (I. Dandouras, F)
Ion composition
($E < 40$ keV)

3 **EDI** (G. Paschmann, D)
Plasma drift velocity
($0.1 < E < 10$ mV/m,
 $5 < B < 1000$ nT)

4 **FGM** (E. Lucek, UK)
Magnetic field

5 **PEACE** (A. Fazakerley, UK)
Electrons ($E < 30$ keV)
6 **RAPID** (P. Daly, D)
High energy electrons and
ions
($10 < E_{\text{ions}} < 1500$ keV/nuc,
 $20 < E_e < 400$ keV)

7 **DWP** (H. Alleyne, UK)

Wave processor

8 **EFW** (M. Andre, S)

Electric fields and waves

9 **STAFF** (N. Cornilleau-Wehrlin, F)

Magnetic and electric fluctuations

10 **WHISPER** (P. Decreau, F)

Electron density and
plasma waves

11 **WBD** (D. Gurnett, USA)

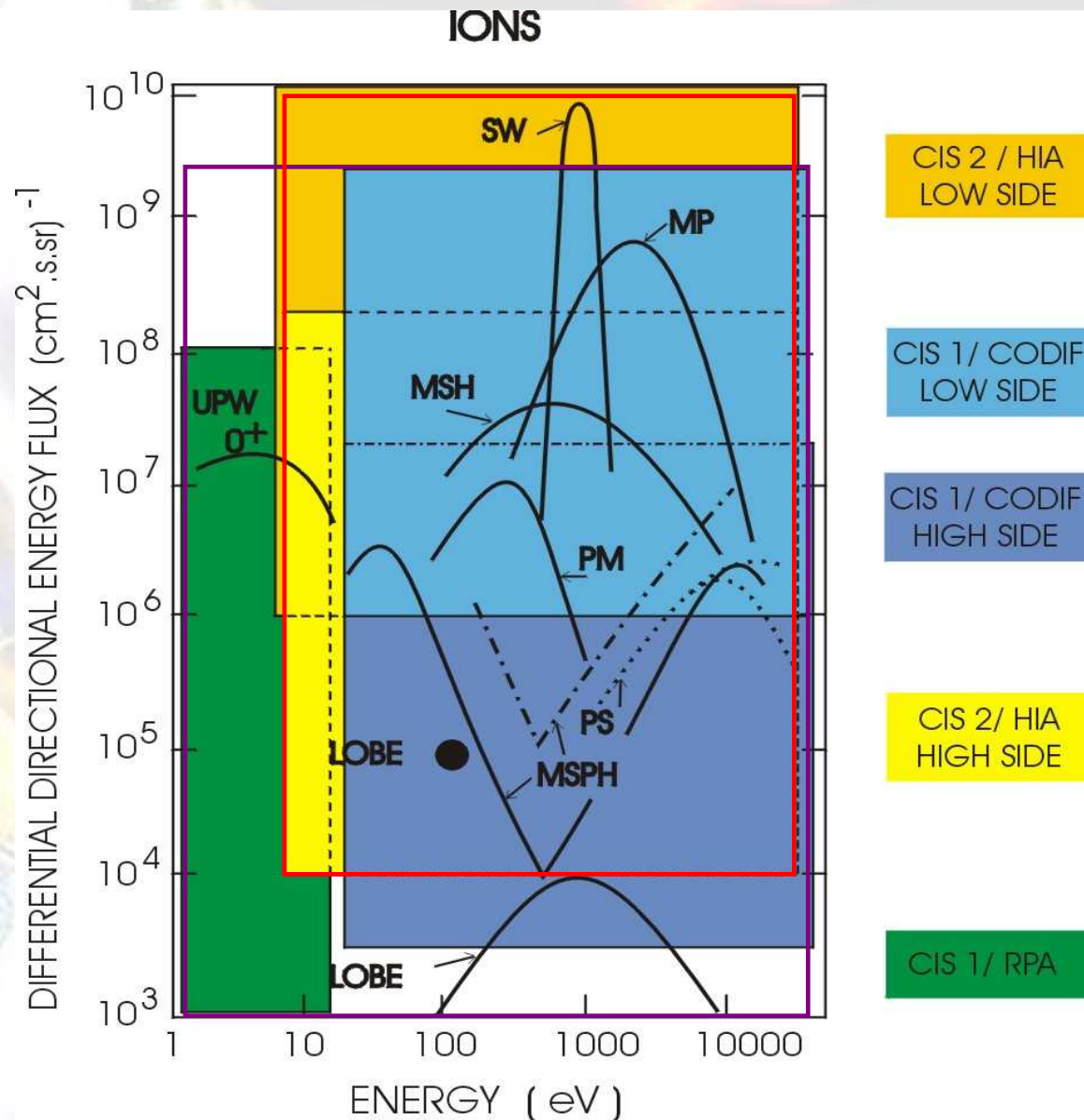
Electric field wave-forms

CIS-Cluster and HIA-Double Star Dynamic Ranges



CODIF Energy Range:
0.7 eV/q – 40 keV/q
(CLUSTER only)

HIA Energy Range:
5 eV/q – 32 keV/q
(CLUSTER and TC-1)



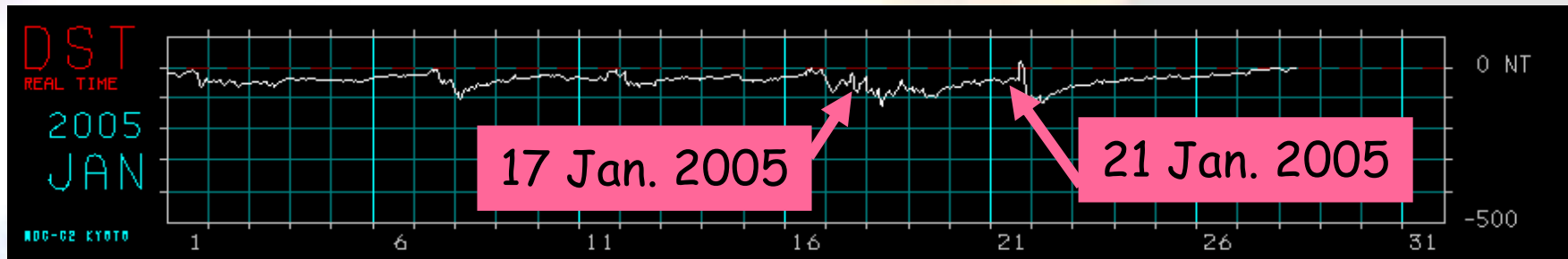
Double Star instruments

Equatorial Double Star		Polar Double Star	
Instruments	PI	Instruments	PI
Active Spacecraft Potential Control (ASPOC)	K. Torkar, IWF, Graz, Austria	Neutral Atom Imager (NUADU)	S. McKenna-Lawlor, Ireland U., Ireland
Fluxgate Magnetometer (FGM)	C. Carr IC, UK	Fluxgate Magnetometer (FGM)	T. Zhang, IWF, Austria
Plasma Electron and Current Exp. (PEACE)	A. Fazakerley, MSSL, Dorking, UK	Plasma Electron and Current Exp. (PEACE)	A. Fazakerley, MSSL, Dorking, UK
Hot Ion Analyzer (HIA), sensor 2 of CIS	H. Reme, CESR, Toulouse, France	Low Energy Ion Detector (LEID) *	Q. Ren and J.B. Cao, CSSAR, China
Spatio-Temp. Analysis of Field Fluct. (STAFF) + Digital Wave processor (DWP)	N. Cornilleau/H. Alleyne, CETP, Velizy, France and Sheffield U. UK	Low Frequency Electromagnetic Wave detector (LFEW) *	Z. Wang and J.B. Cao, CSSAR, China
High Energy Electron Detector (HEED) *	W. Zhang and J.B. Cao, CSSAR, China	High Energy Electron Detector (HEED) *	W. Zhang and J.B. Cao, CSSAR, China
High Energy Proton Detector (HEPD) *	J. Liang and J.B. Cao, CSSAR, China	High Energy Proton Detector (HEPD) *	J. Liang and J.B. Cao, CSSAR, China
Heavy ion detector (HID) *	Y. Zhai and J.B. Cao, CSSAR, China	Heavy ion detector (HID) *	Y. Zhai and J.B. Cao, CSSAR, China

European instruments

* chinese instruments

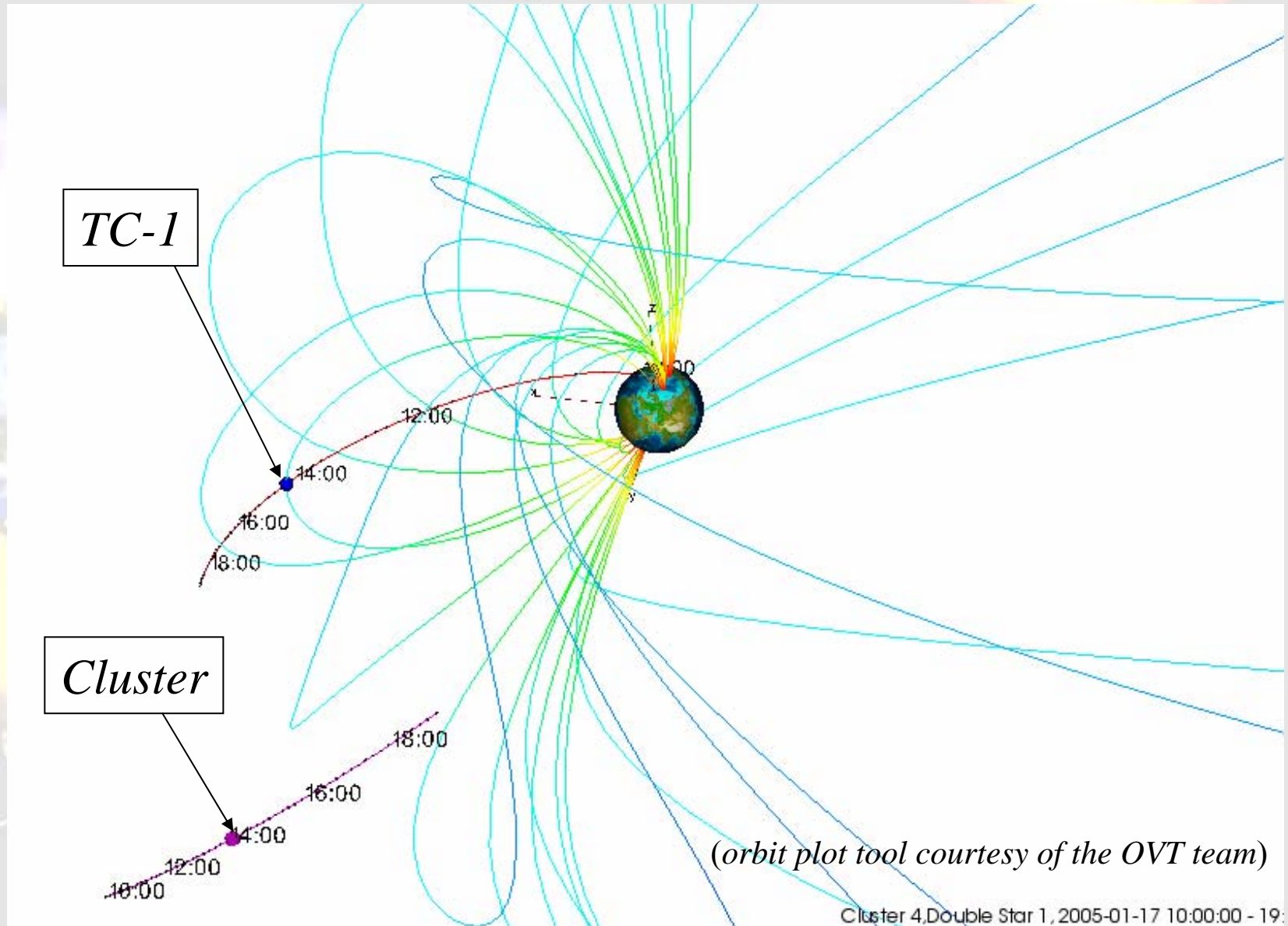
Magnetospheric response to the January 2005 Extreme Solar Events



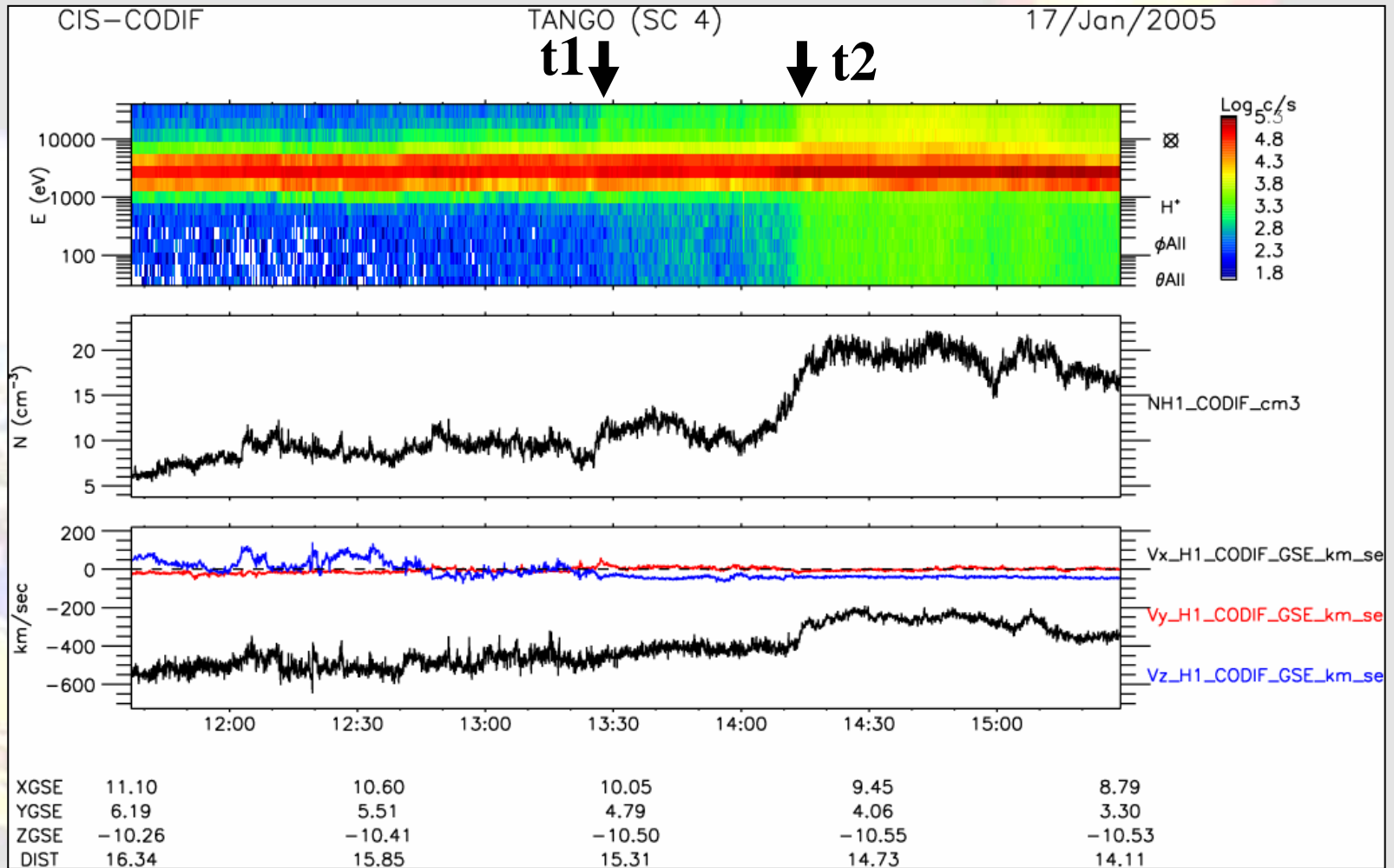
During these two events:

- Cluster in the Solar wind region:
 - ⇒ Observation of the Solar particles arriving to the Magnetosphere.
- Double Star initially in the Magnetosheath:
 - ⇒ Observation of the impact to the configuration of the Magnetosphere.

17 January 2005



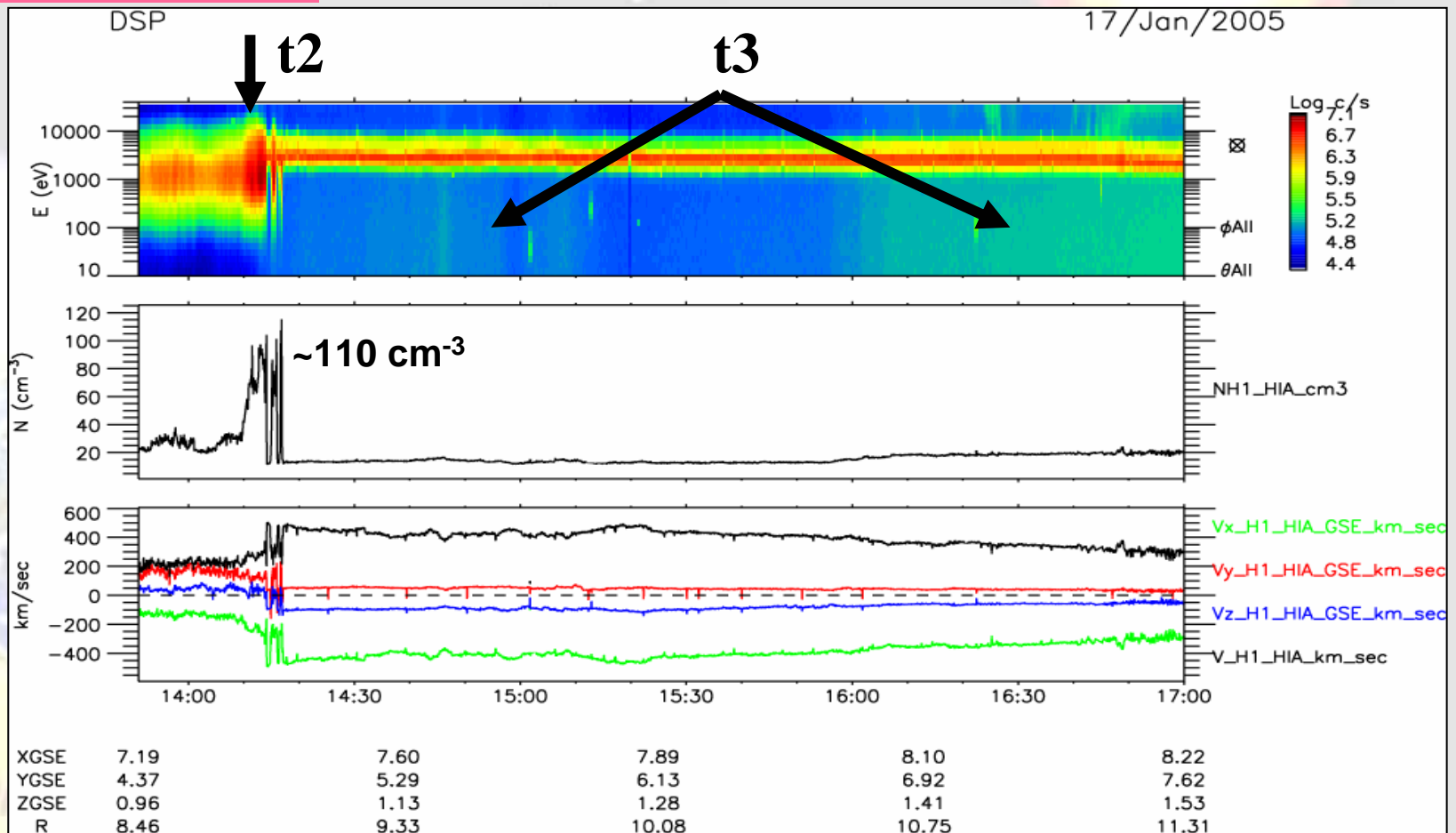
Cluster 4, Double Star 1, 2005-01-17 10:00:00 - 19:



- **t1** (13:27 UT) and **t2** (14:14 UT):

High background recorded by CIS in the solar wind,
characterized by a green 'haze' in the spectrograms.

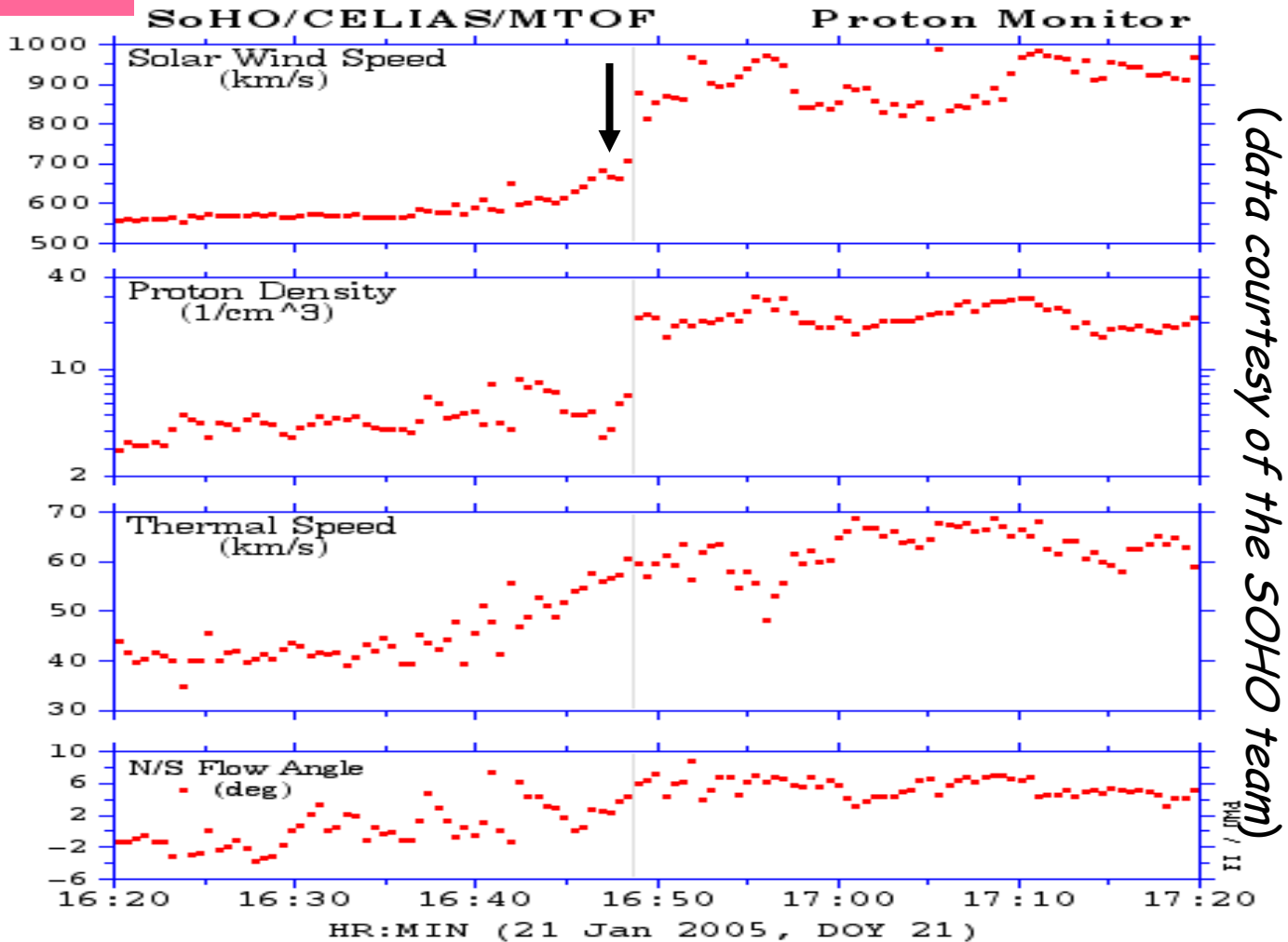
⇒ Arrival of penetrating **SEPs**.



- **t2 (14:10 UT):** Sudden Magnetosheath compression (ion N and V increase).
- **t3:** even if almost 12 R_E far from Cluster sc4 spacecraft, Double Star observes simultaneously an abnormally increased background.
 ⇒ Ejection of very high energy particles by the Sun (\gg MeV energy range), detected simultaneously (at t2) in the solar wind by Cluster and in the Magnetosheath by TC-1 (Background particles).

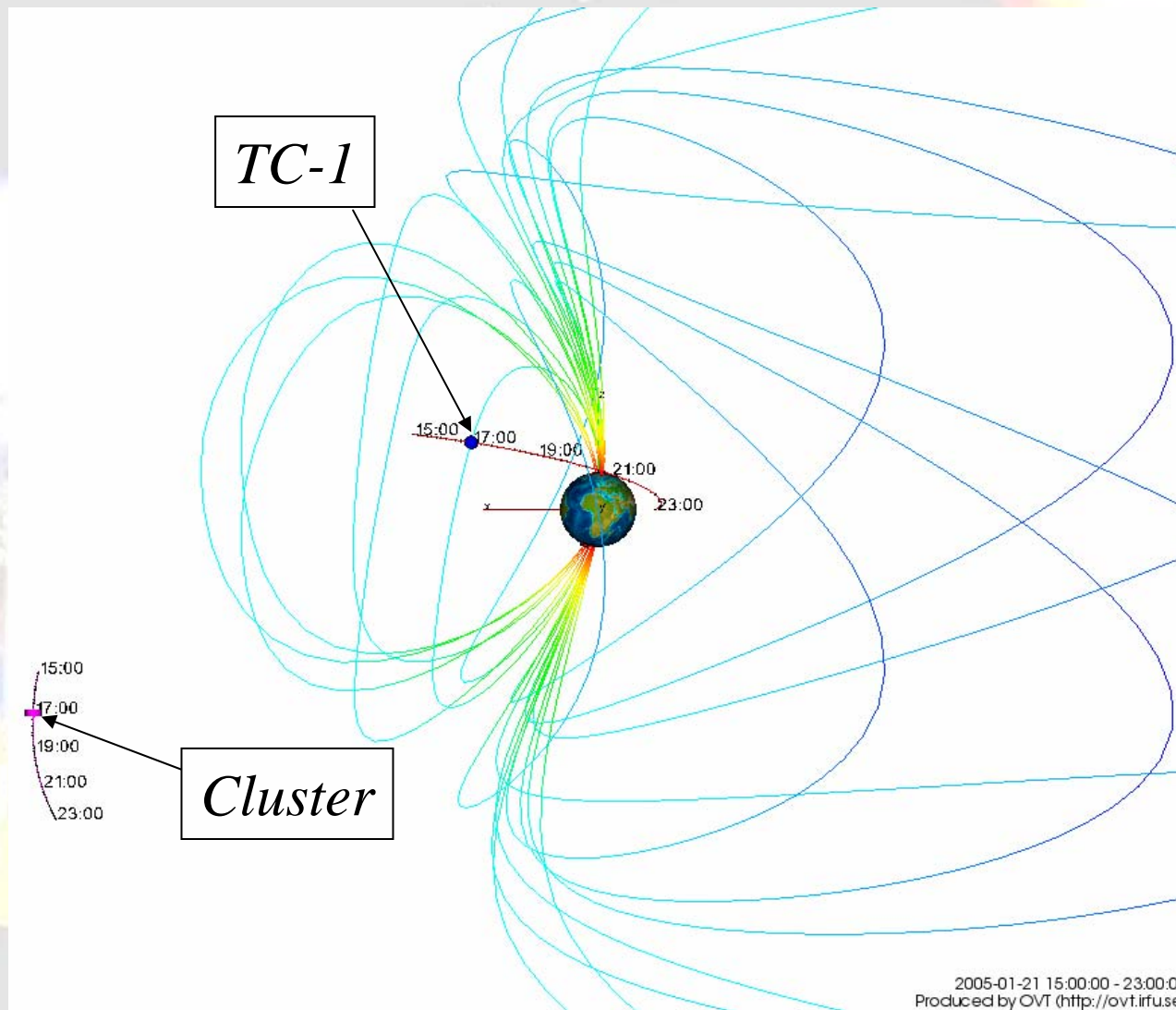
21 January 2005

SoHO/ Cielias

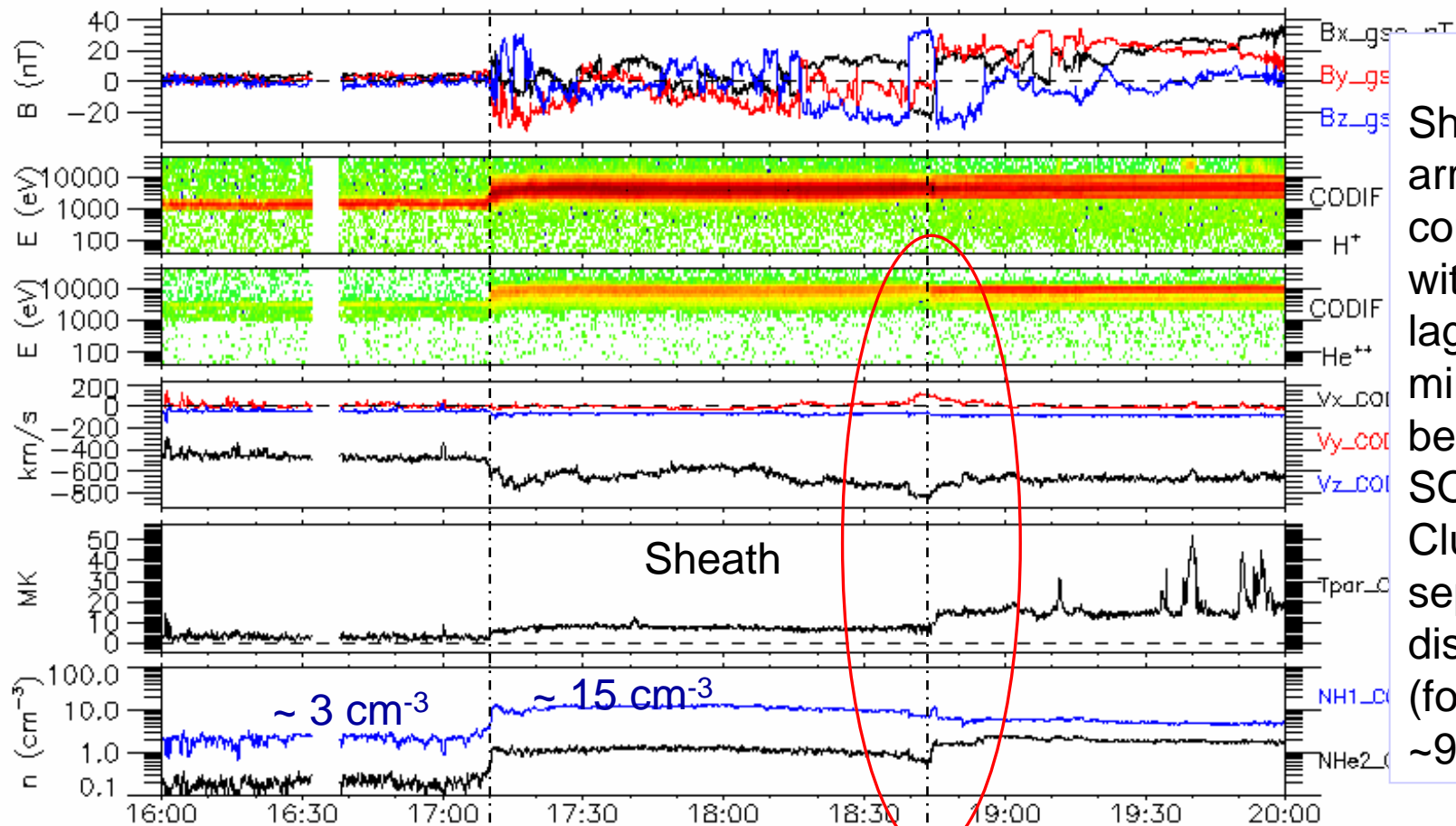


16:47 UT: Sudden increase of the Solar wind speed (from ~550 to 900 km/s) and density (from ~ 5 to 20/ cm³): **ICME arrival**

21 January 2005



- Cluster SC4 was situated in the **solar wind** region, at MLT ~ 14.5 h.
- TC-1 was in the **Magnetosheath** region, at $R \sim 8 R_E$ and at MLT ~ 17.



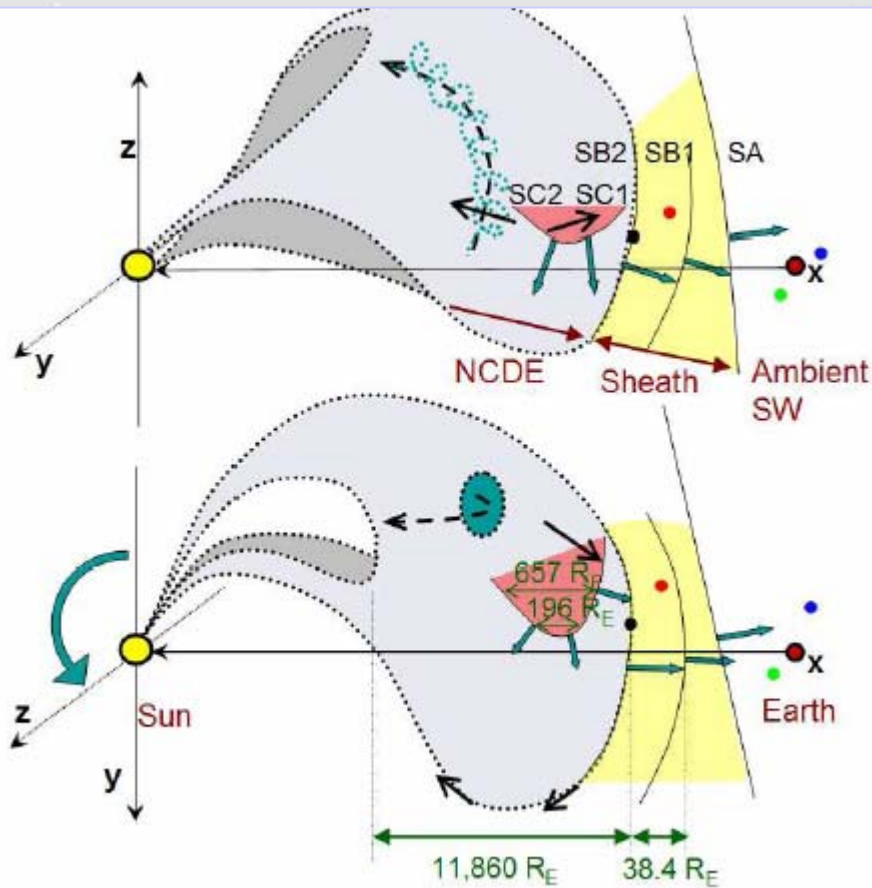
XGSE	14.70	14.73	14.75	14.75	14.73	14.69	14.64
YGSE	11.74	11.55	11.35	11.13	10.90	10.65	10.39
ZGSE	-4.89	-5.24	-5.59	-5.93	-6.26	-6.59	-6.91
DIST	19.44	19.44	19.43	19.40	19.36	19.31	19.23

17:10 : ICME
shock arrival
(hot pileup)

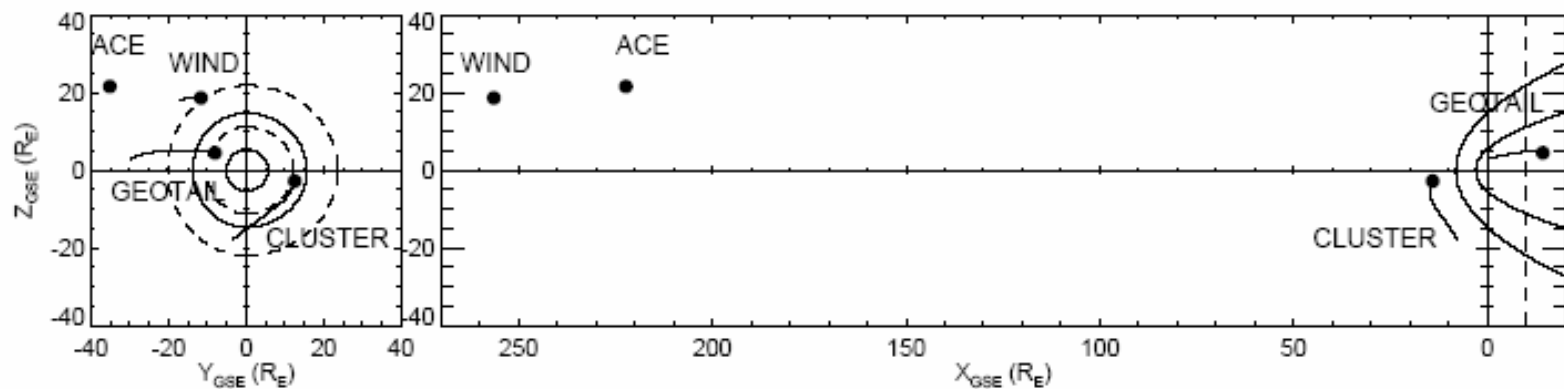
18:44:
Secondary
front arrival

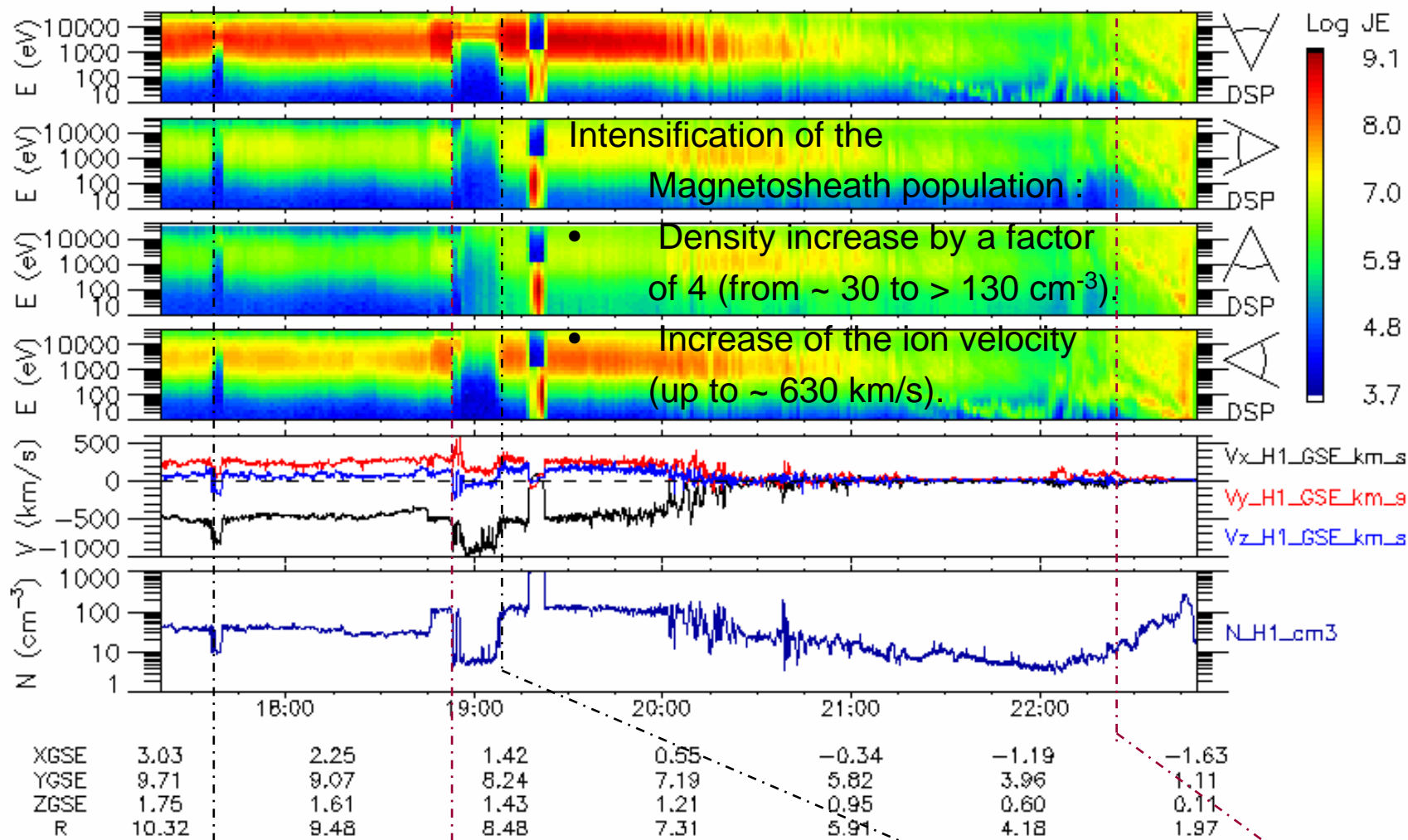
He⁺⁺ enrichment:
arrival of the
« flare driver gas »?

Multi-spacecraft study
of the propagation
of the 21 January 2005 ICME:
Evidence of current sheet substructure
near the periphery of a strongly
expanding, fast, magnetic cloud



C. Foullon et al., Solar Phys., 2007



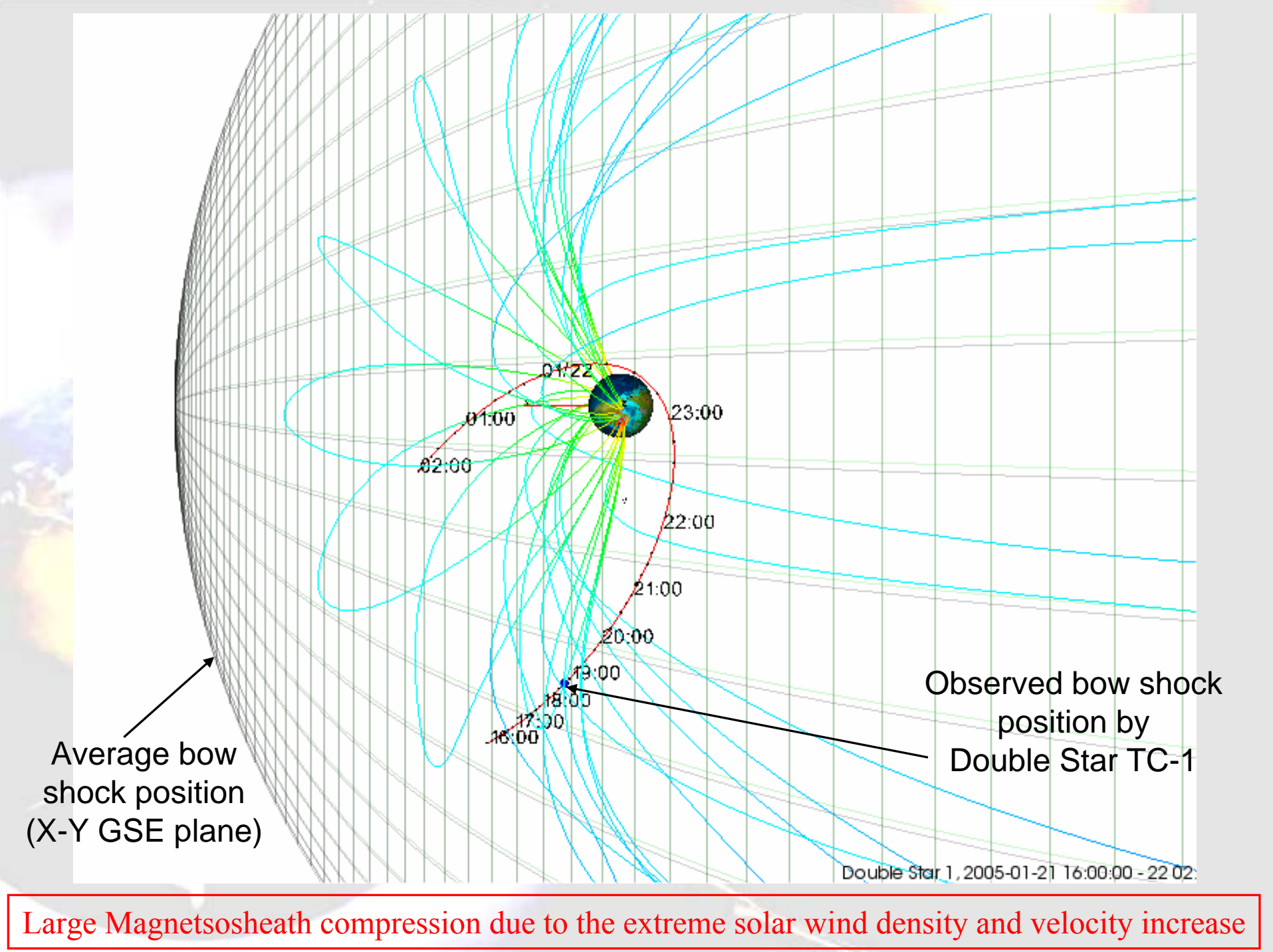


Brief excursion into the solar wind at 17:37 UT, $R=10.13 R_E$

2nd excursion at 18:53 UT ($R=8.84 R_E$): immediate re-entry into the Magnetosheath. Last solar wind excursion at $R=8.76 R_E$ (18:55 UT)

Re-entry in the Magnetosheath at $R=8.54 R_E$ (19:07 UT).

Injected ions in the ring current region



Average bow shock position (X-Y GSE plane)

Observed bow shock position by Double Star TC-1

Double Star 1, 2005-01-21 16:00:00 - 22:02:00

Large Magnetsosheath compression due to the extreme solar wind density and velocity increase

21 January 2005 event

ENA imaging of the Ring Current development:
HENA (onboard IMAGE) remote-sensing observations

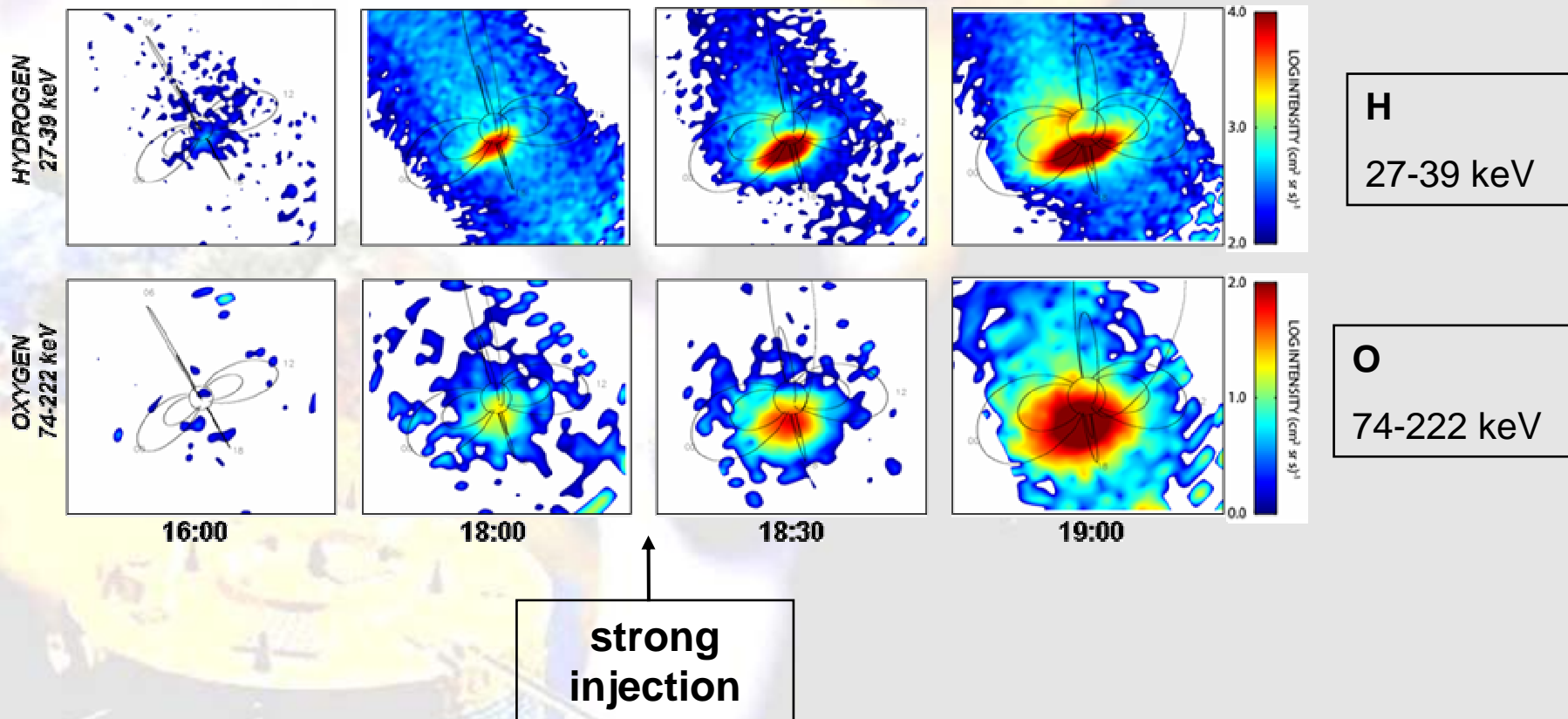
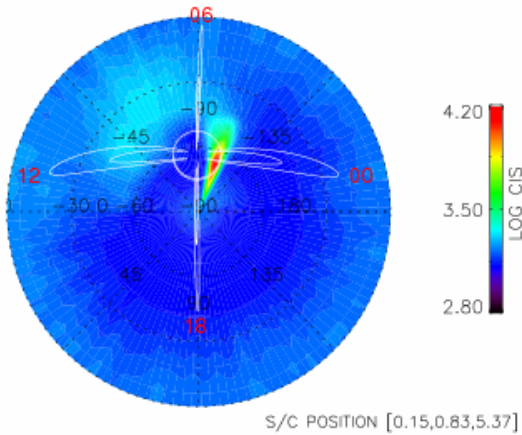


IMAGE viewing the Ring Current from the Southern hemisphere (raw ENA images):

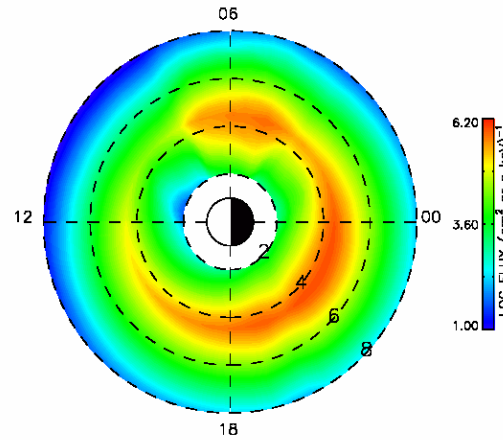
- Initially asymmetric Ring Current
- Strong O^+ component enhancement after 18:30 UT

ENA imaging of the Ring Current development: 22 Jan 2005

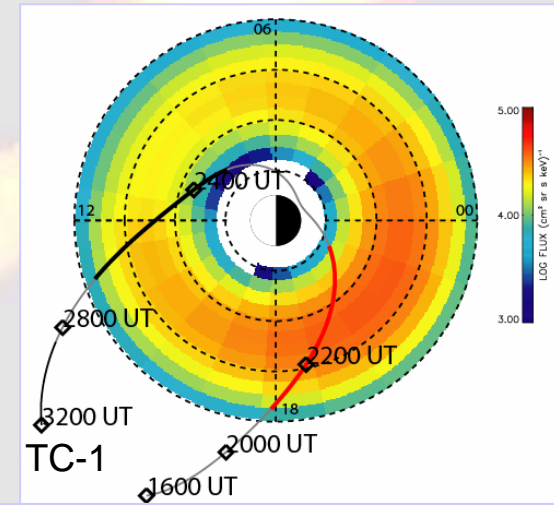
NUADU Measurement



ENA image (50-81 keV) obtained by the **NUADU** instrument over an approximately 30 minute integration time from 00:30 UT on 22 January, 2005



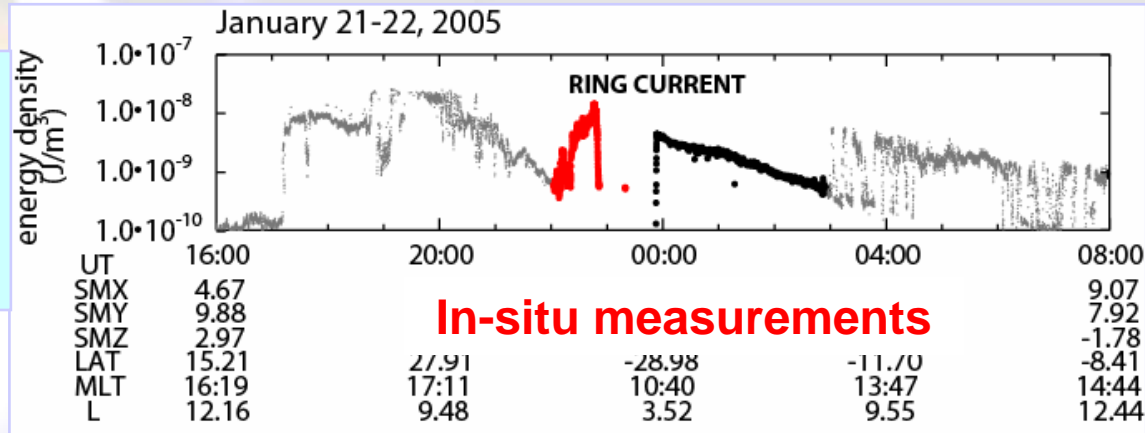
Corresponding **ion distribution** at the magnetic equator retrieved from **NUADU (TC-2)**



Corresponding **hydrogen ion distribution** at the magnetic equator retrieved from **HENA (IMAGE)**: 60-119 keV 01:00 UT on 22 Jan.

Remote sensing

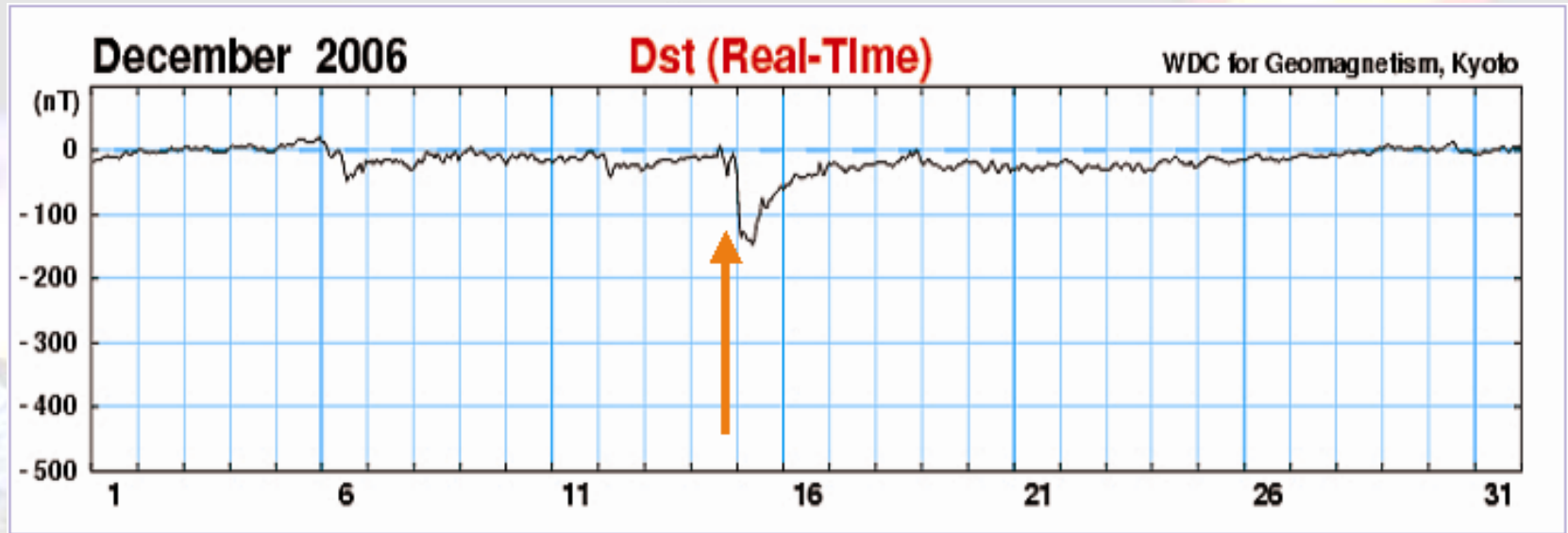
Ion energy densities < 32keV/q measured by **HIA** on **TC-1** from 16.00 UT on 21 January to 08.00 UT on 22 January



In-situ measurements

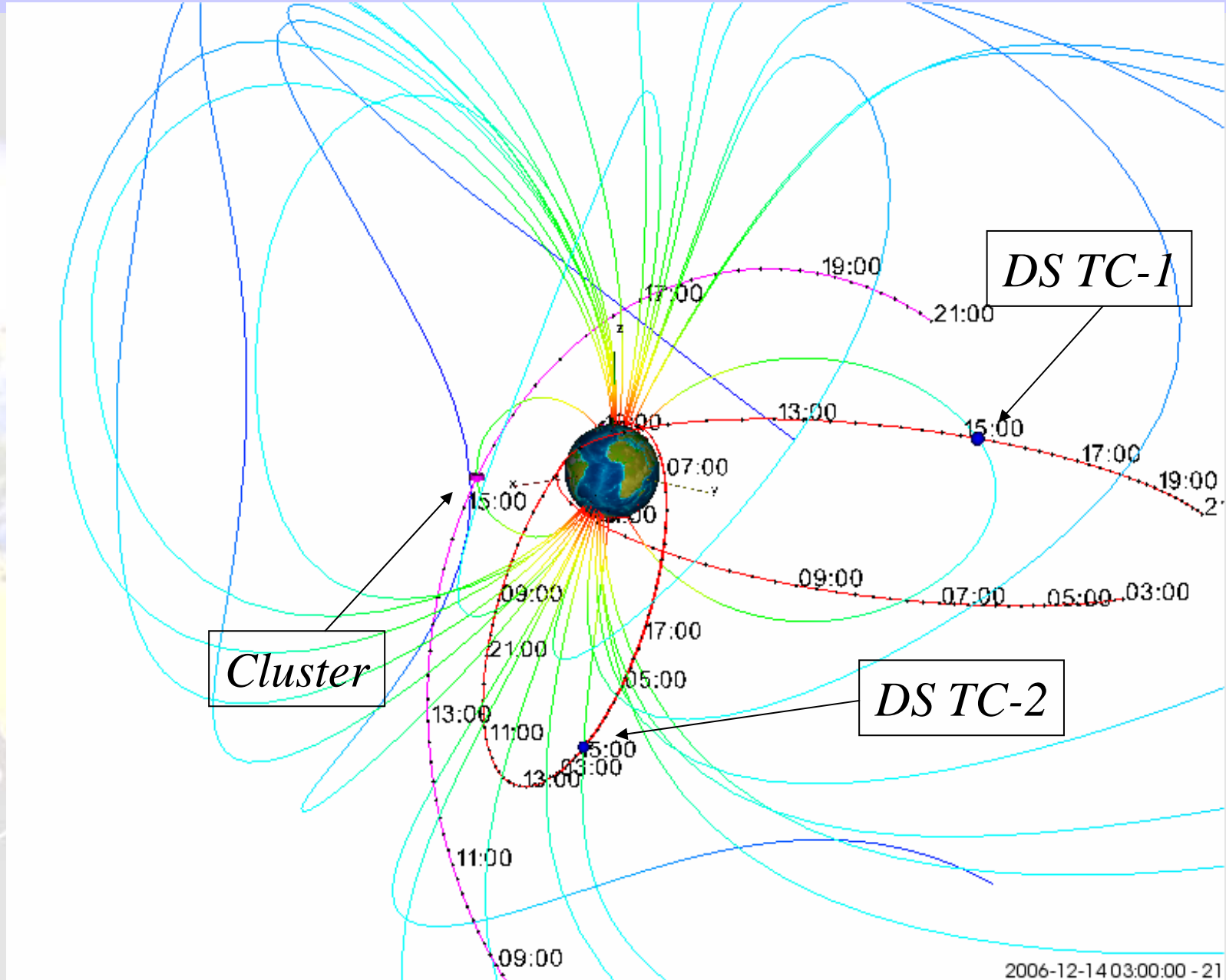
*S. McKenna-Lawlor et al.,
J. Geophys. Res. (subm.), 2007*

14-15 December 2006 super-storm



- Impact of the 13 December 2006 solar flare ejecta on the Earth's magnetosphere :
~14:30 UT on 14 December 2006.
- Solar wind velocity of 930 km s^{-1} was then recorded by ACE, associated with a jump of the solar wind density to $\sim 10 \text{ cm}^{-3}$ and a southward turning of the IMF.
- Simultaneous in-situ measurements in the Ring Current region by Cluster and Double Star TC-1, and ENA imaging by TC-2.

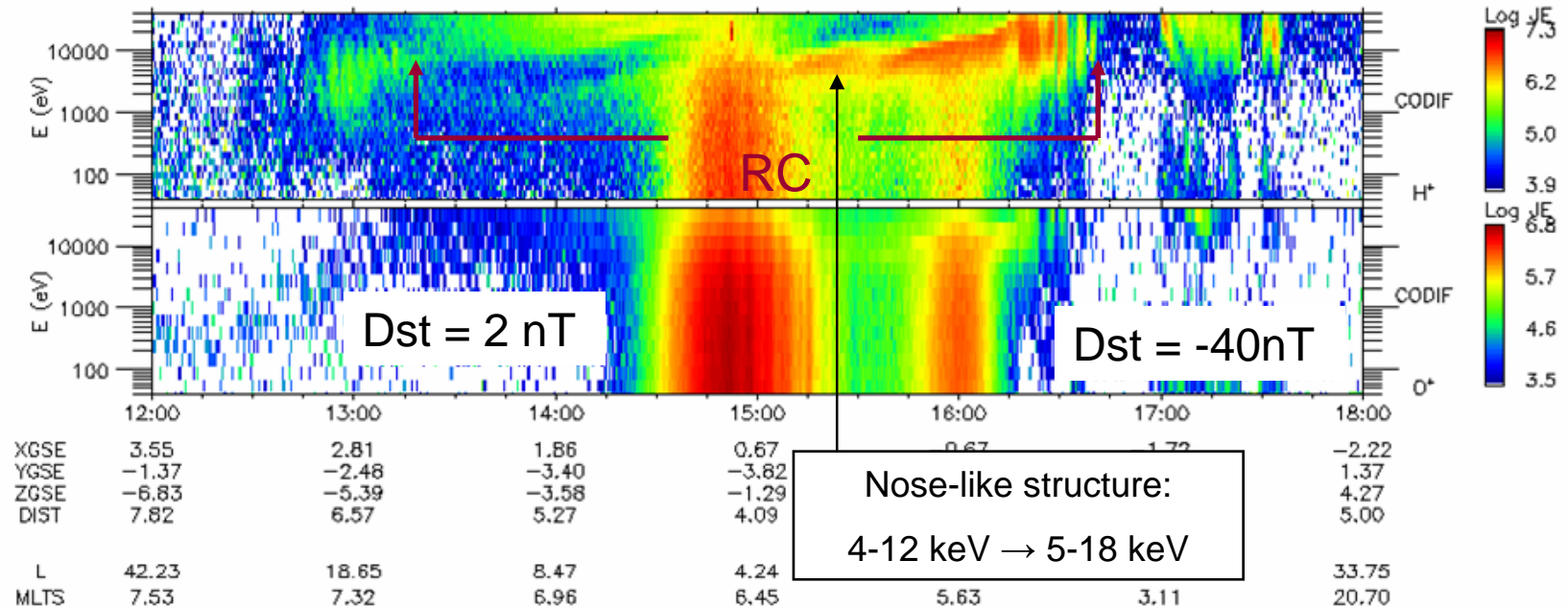
14-15 December 2006



CIS

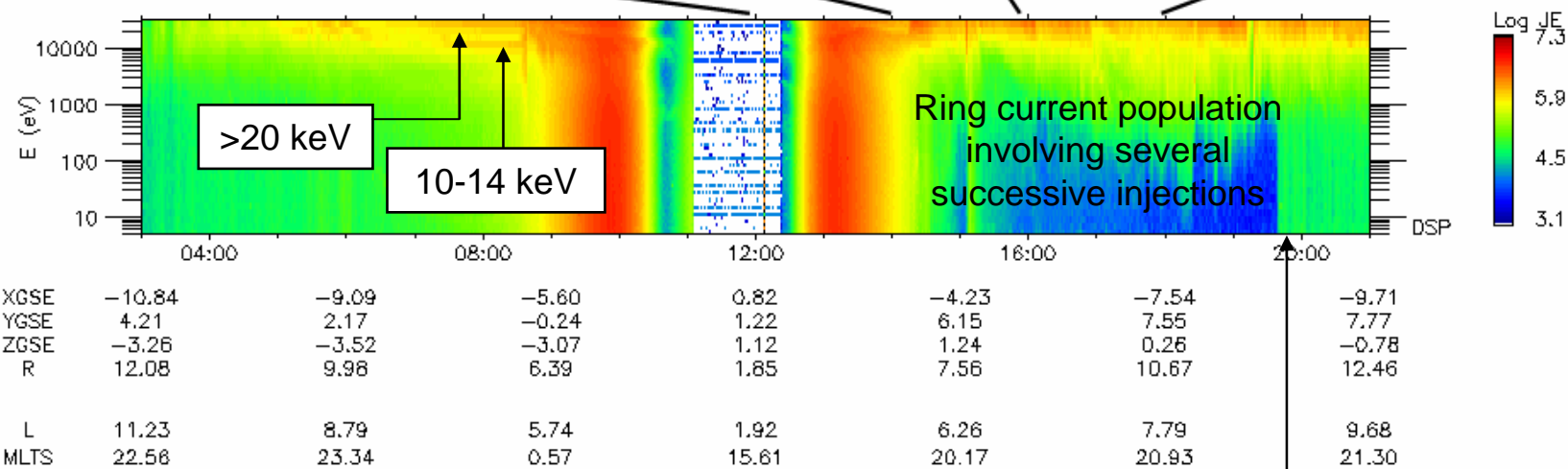
TANGO (SC 4)

14/Dec/2006

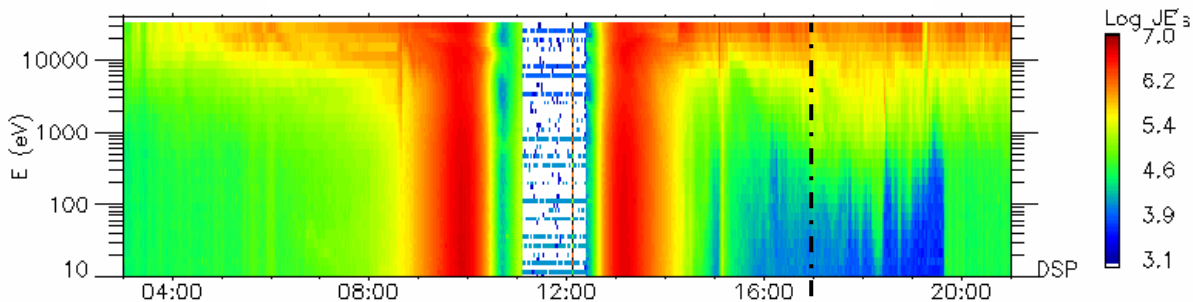


DSP

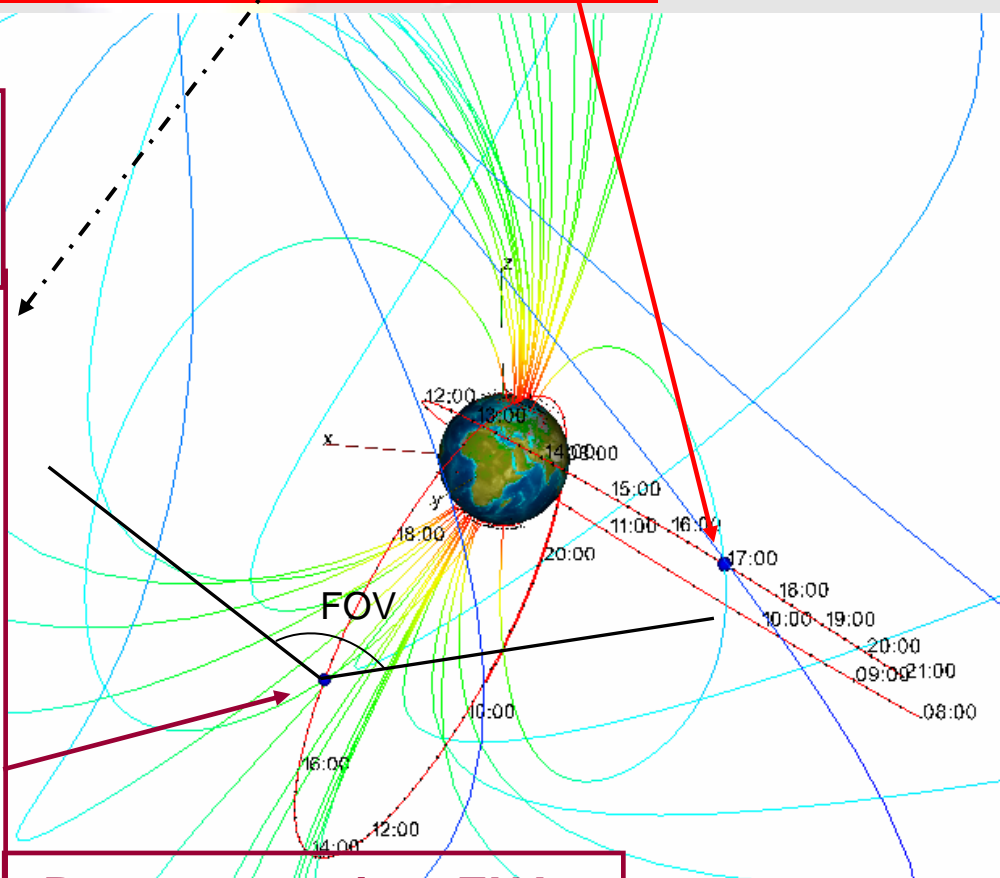
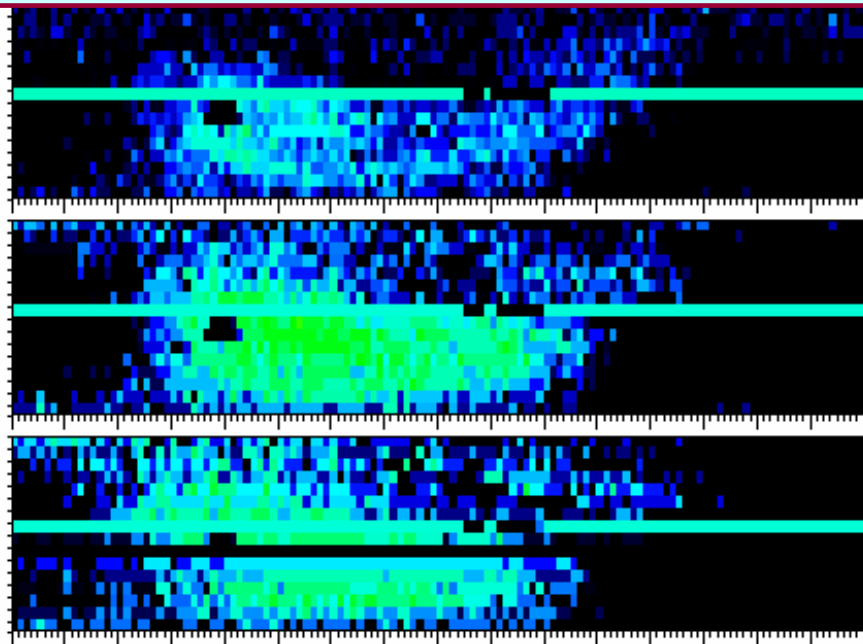
14/Dec/2006



In-situ measurements: ions

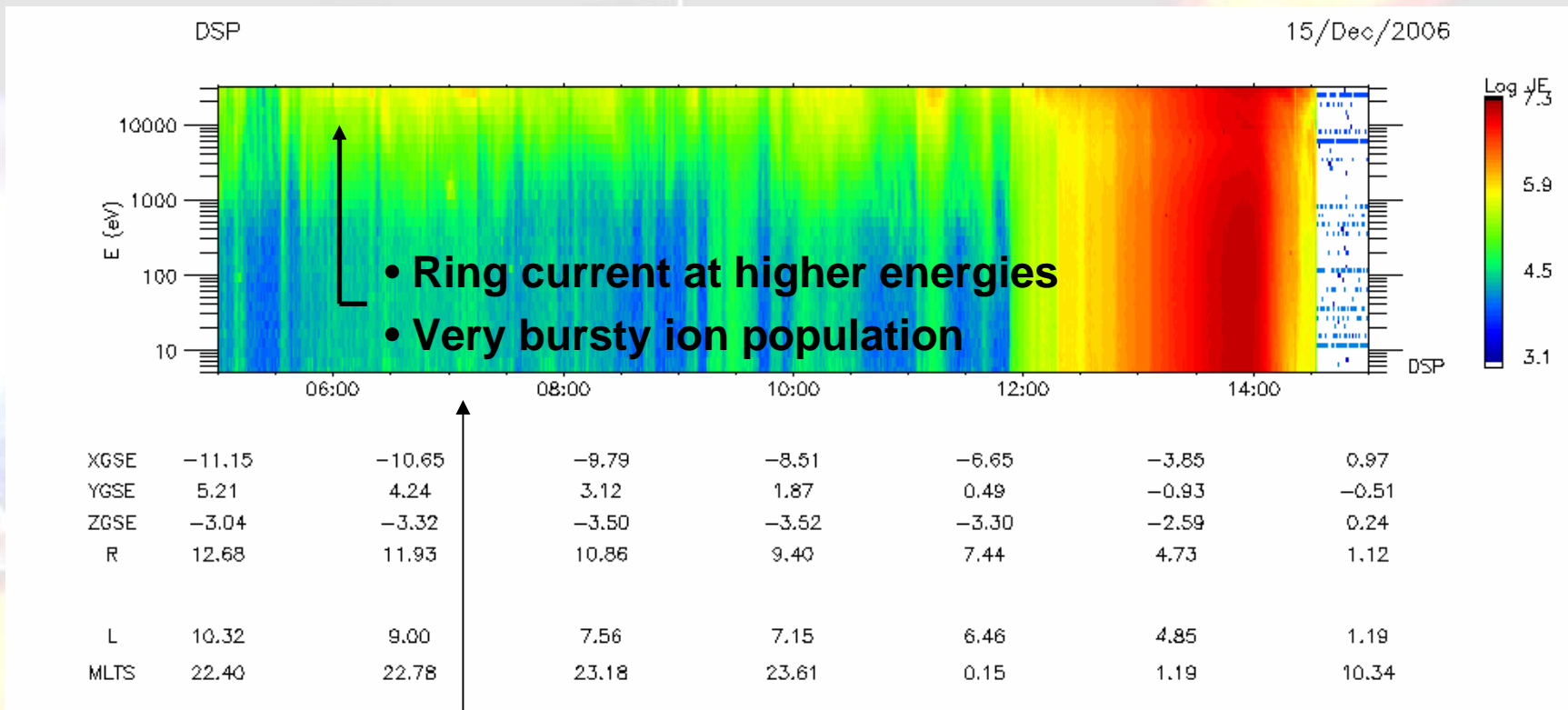


ENA raw image obtained by NUADU
onboard TC-2:
14 Dec. 2006 at 17:05 UT



Remote sensing: ENAs

Next TC-1 orbit : Dst= -116 nT



Dst = -147 nT

Conclusions

Extreme solar events of January 2005 and December 2006:

- *17 Jan 2005:*
 - Ejection of very high energy particles by the Sun ($>>$ MeV energy range), detected simultaneously in the solar wind region by Cluster and in the Magnetosheath region by TC-1 (SEP-induced background).
 - *21 Jan 2005:*
 - ICME with dense solar wind particles having a higher velocity and “catching up” a slower one.
 - He⁺⁺ enrichment
 - Ring current development: initially asymmetric, then symmetric, relatively close to Earth, with strong O⁺ component.
- ⇒ **Strong Magnetosheath compression** observed by Cluster and/or TC-1, and characterized by a strongly increased density, velocity and temperature.
- *14-15 Dec 2006:*
 - Several successive injections of energetic particles in the ring current, which “washed-out” the previously formed nose-like structures.
 - No clear boundary between the ring current and the plasma sheet

Cluster public-access high-resolution calibrated data are being archived at the Cluster Active Archive (CAA): <http://caa.estec.esa.int/>