



Spacecraft - plasma interactions: Lessons learnt from the Cluster Ion Spectrometry

Iannis Dandouras

IRAP / CESR, Université de Toulouse / CNRS, Toulouse, France

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Outline

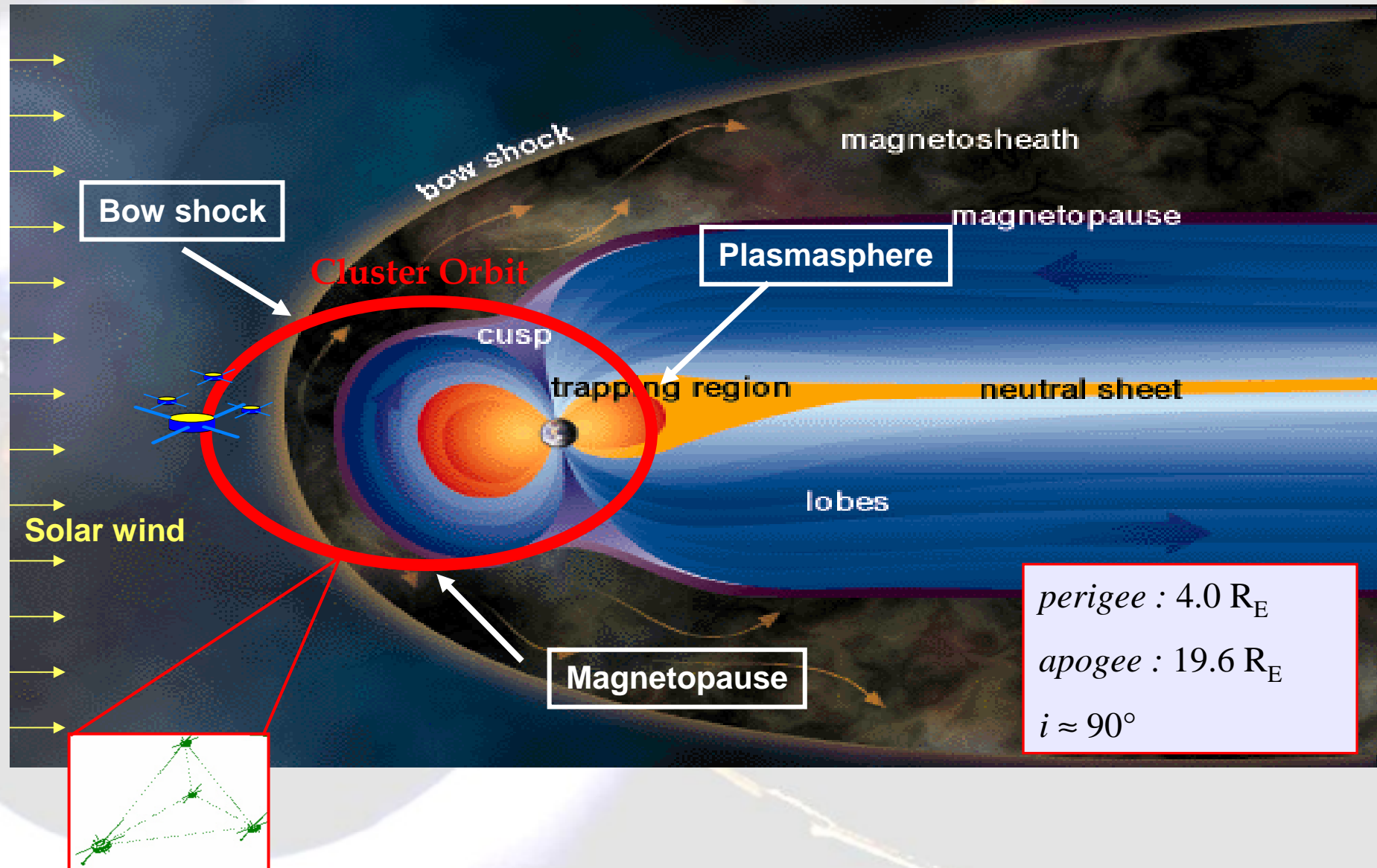
- The Cluster mission and the CIS Experiment
- Ion measurements in low-density plasmas
- Spacecraft charging effects in other regions
- Active spacecraft potential control effects
- Solar eclipse effects
- Penetrating particle effects
- Spacecraft incidents



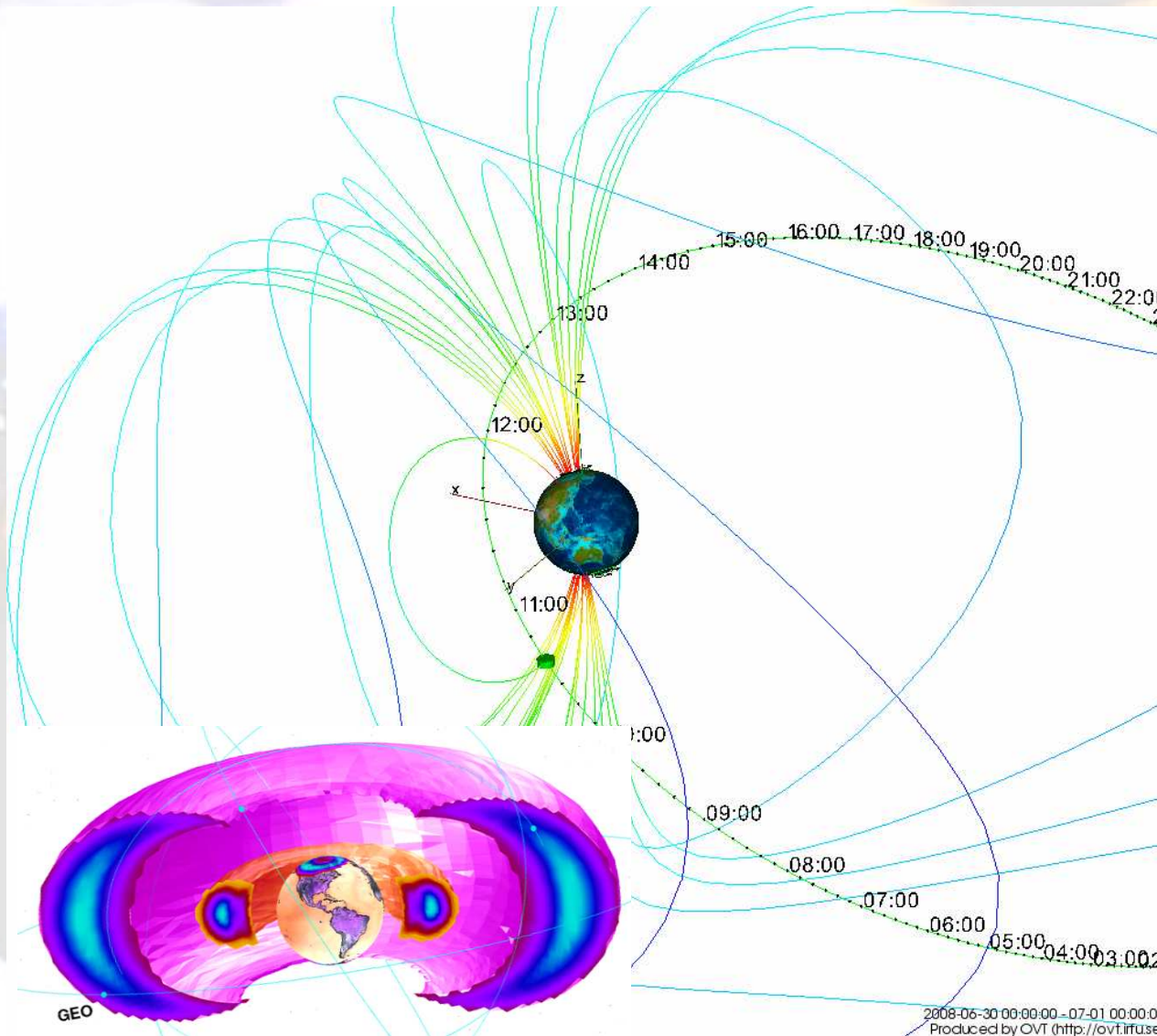
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Cluster orbit: The “early years” (2000 – 2006)



Cluster orbit since 2007 : deeper passages in the inner magnetosphere

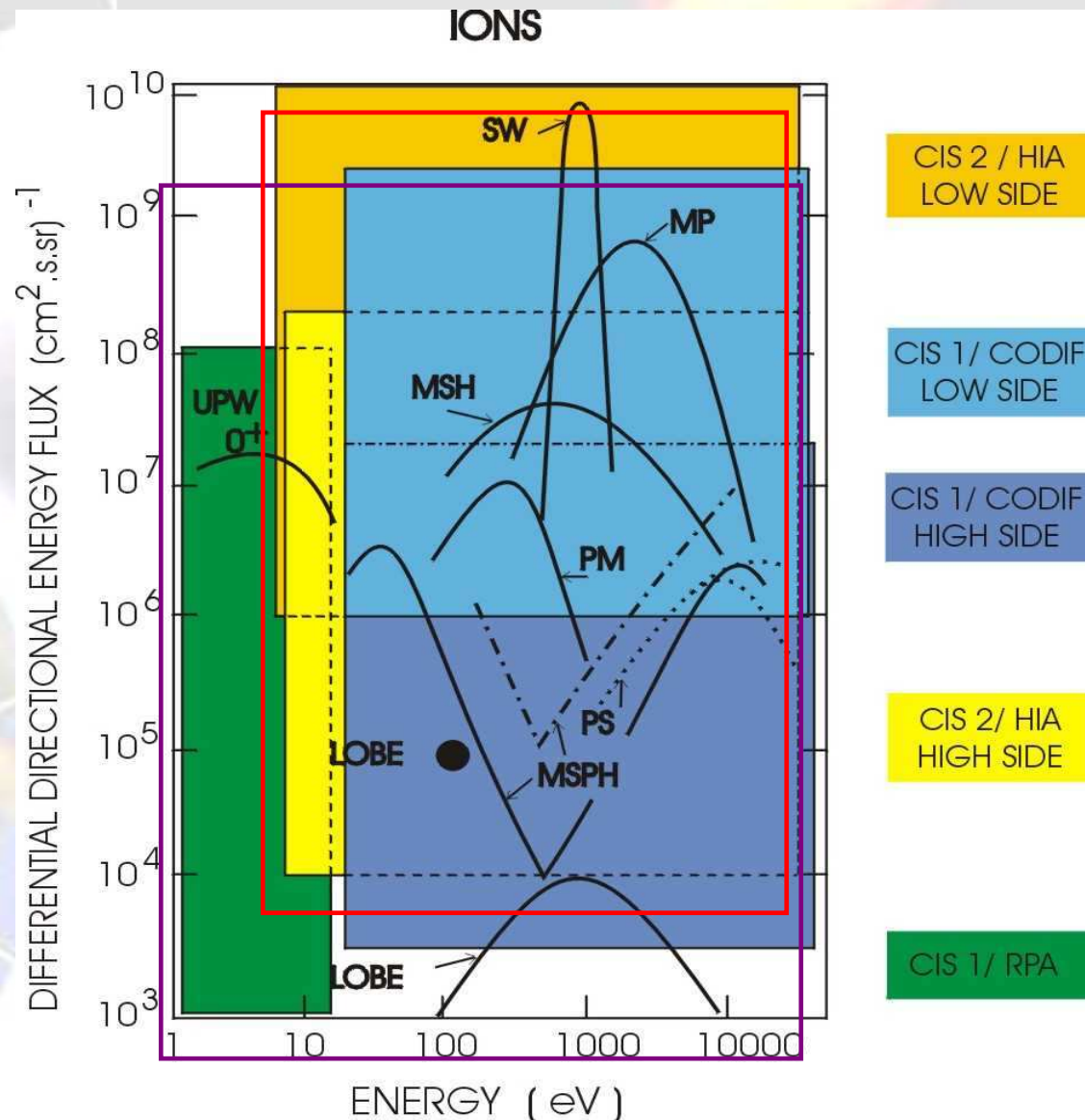


30 June 2008 example:
Cluster was deep in the
radiation belts coming to
Earth at its perigee as
close as $L = 2$.

CIS : Cluster Ion Spectrometry

CODIF Energy Range:
0.7 eV/q – 40 keV/q

HIA Energy Range:
5 eV/q – 32 keV/q



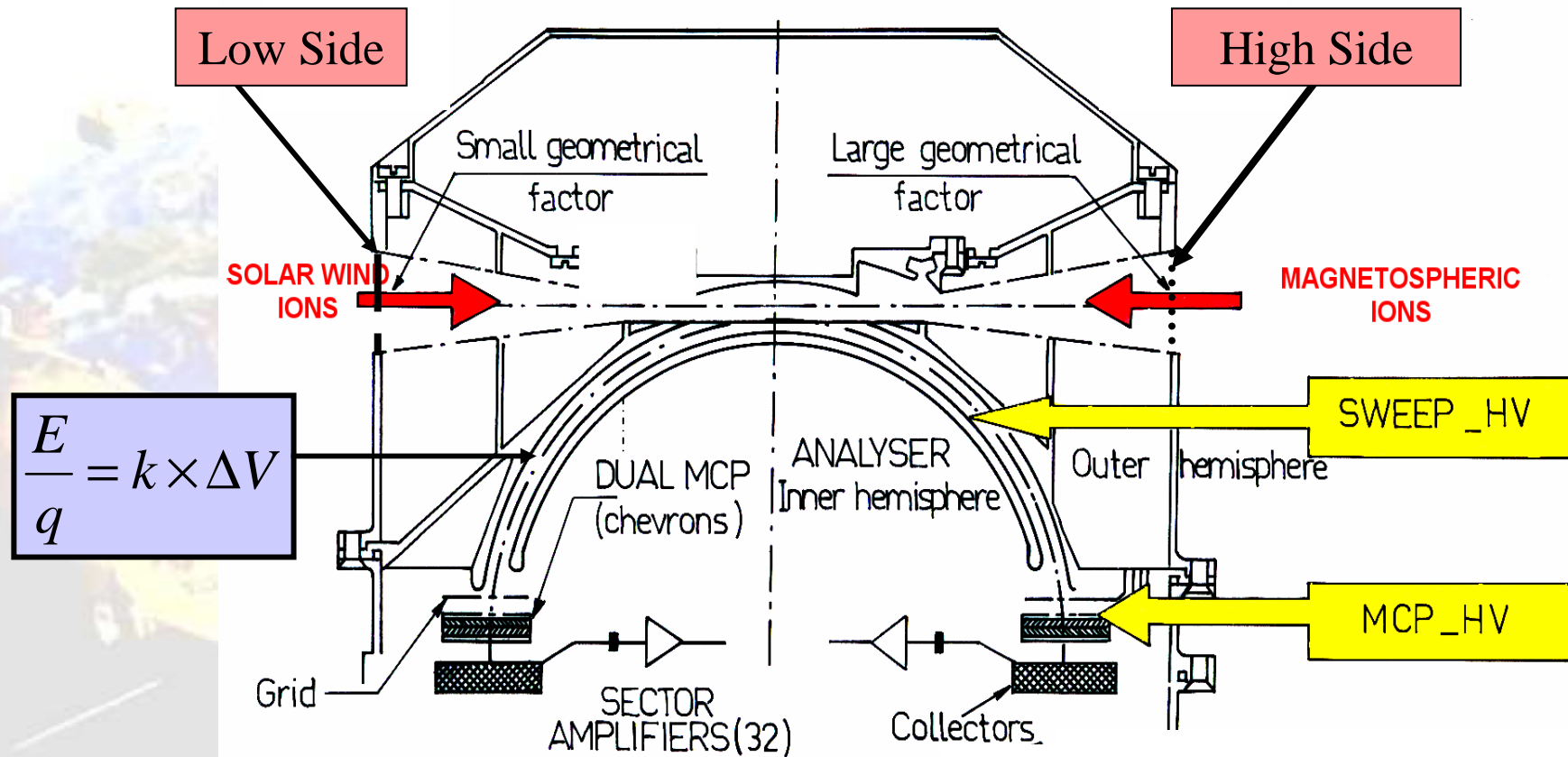
CIS Dynamic Range

HIA: Hot Ion Analyser

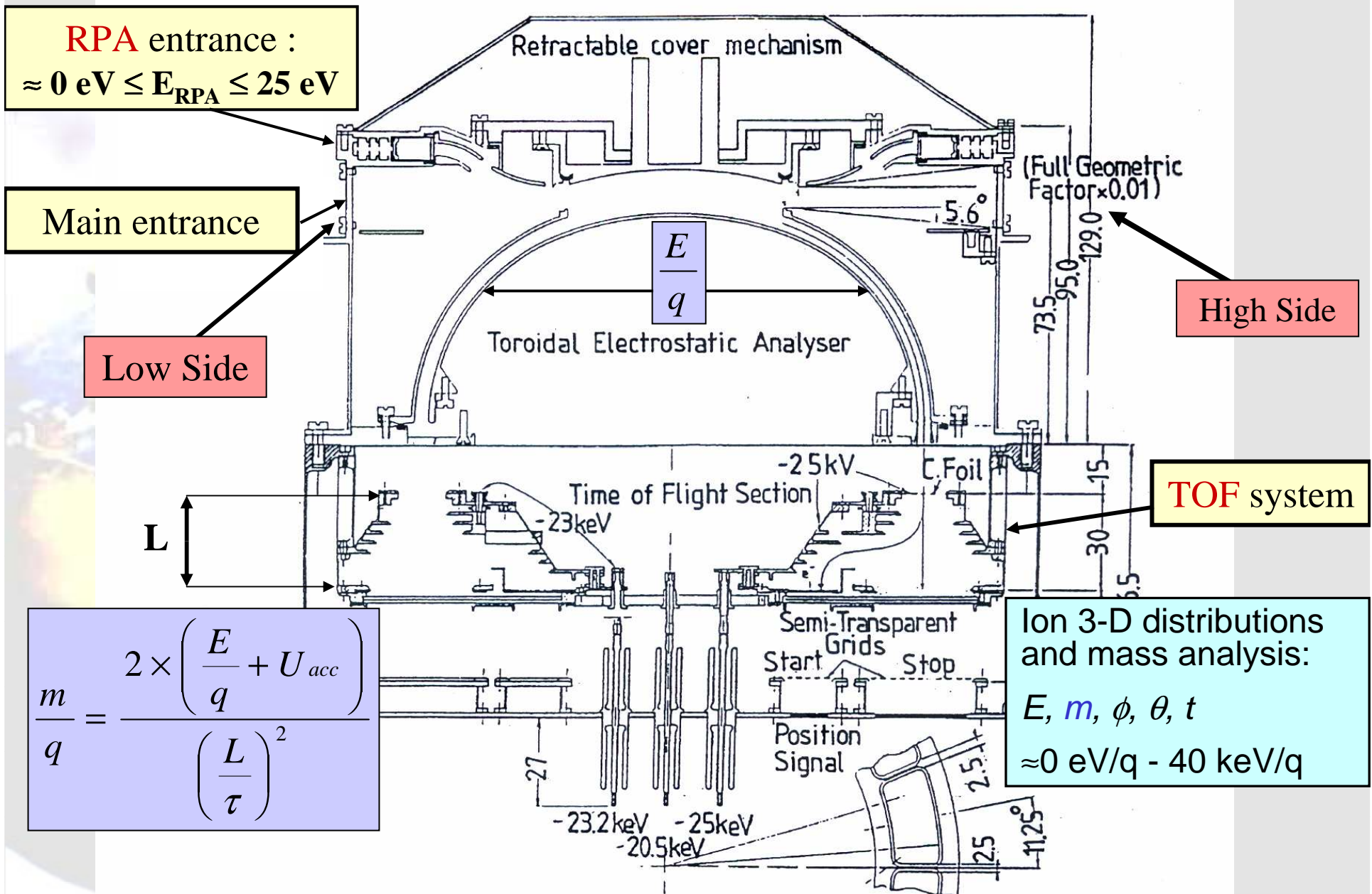
Ion 3-D distributions:

E, ϕ, θ, t

5 eV/q - 32 keV/q



CODIF: Ion Composition and Distribution Function Analyser

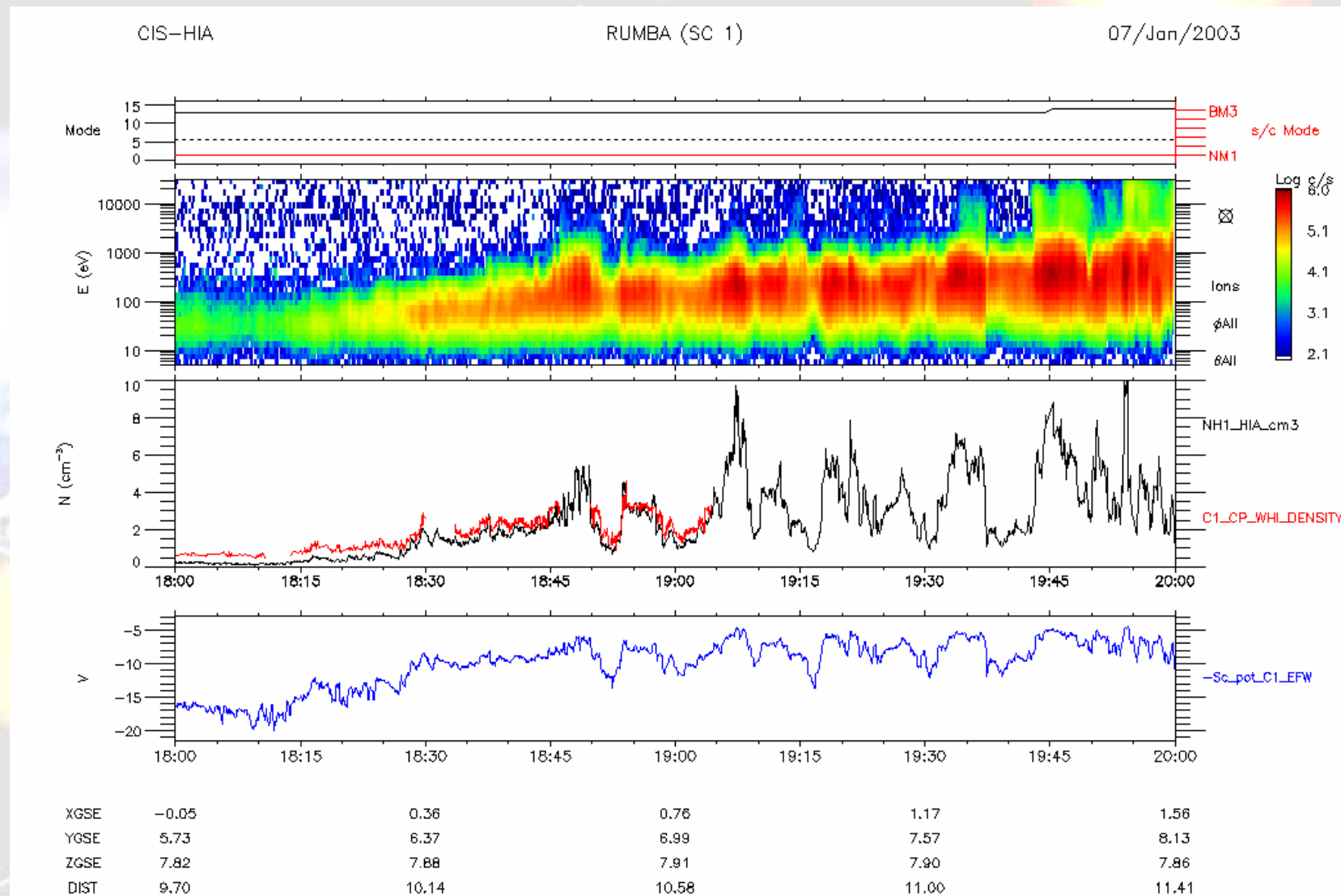




Outline

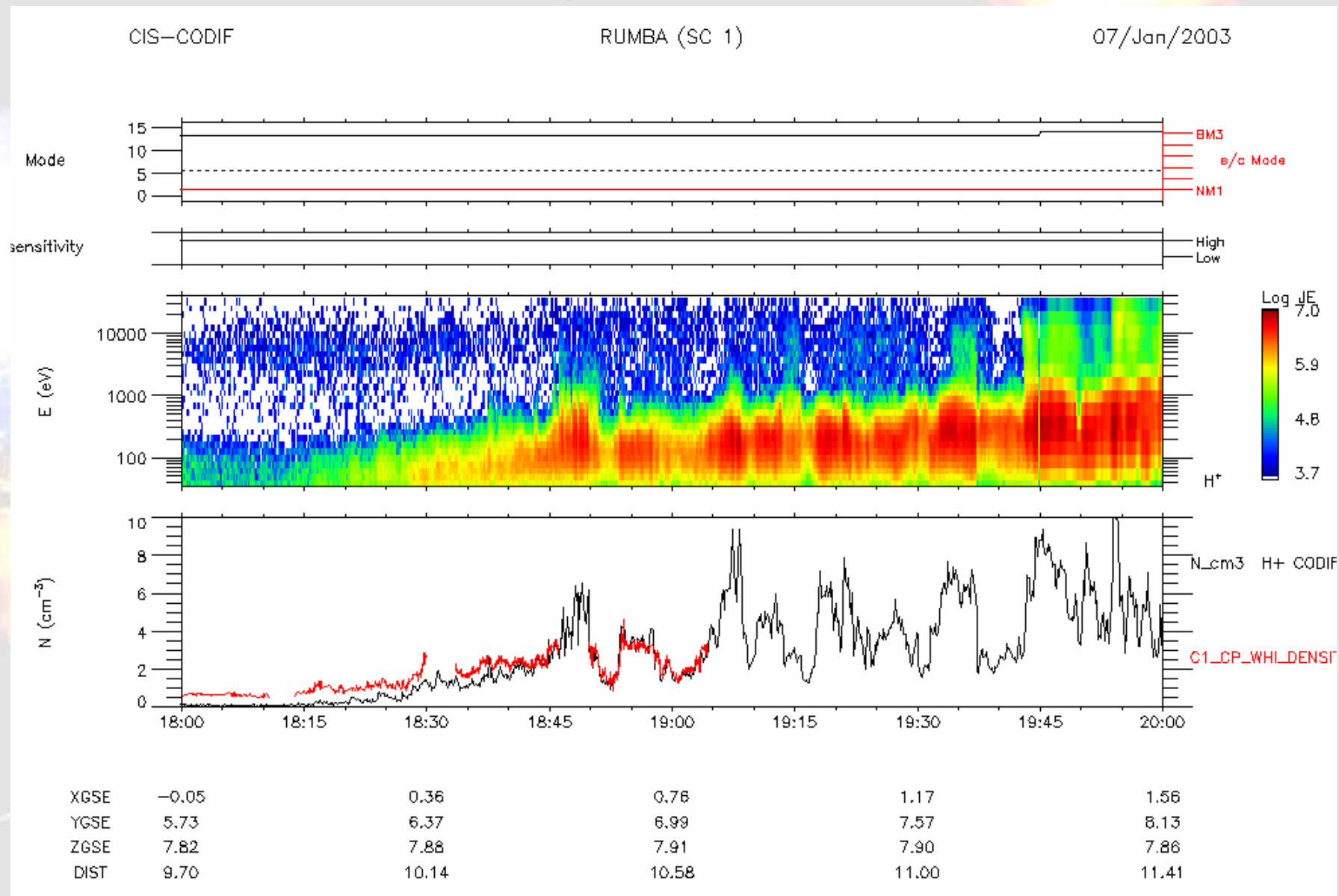
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Entry in the Cusp: from low to higher densities



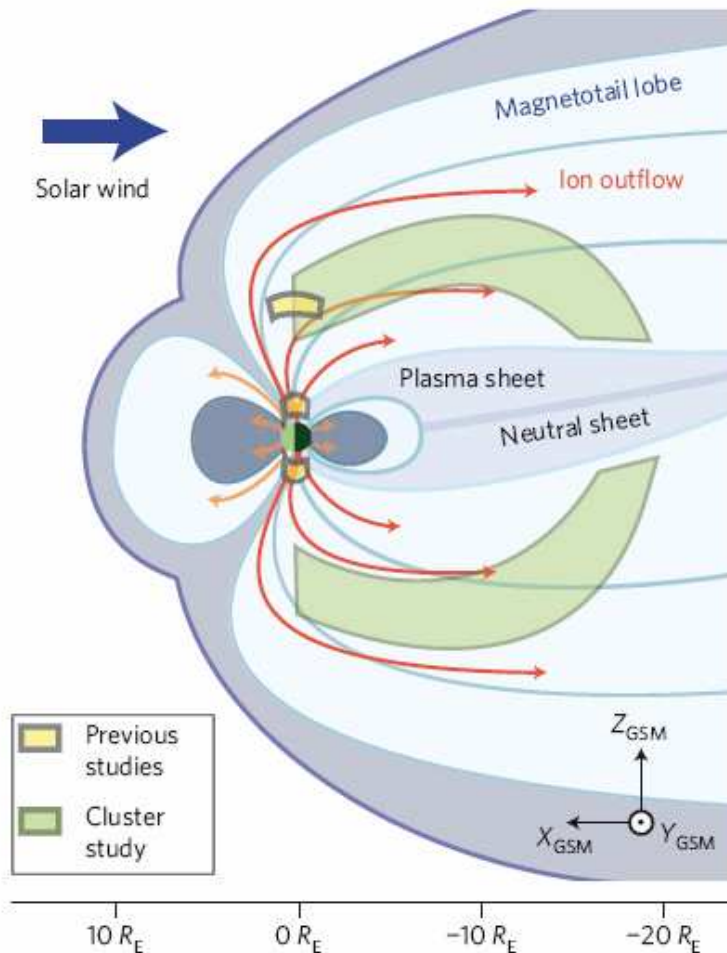
HIA density plot in **black**, and **WHISPER** provided density plot in **red**.
In **blue** is the **negative of the spacecraft potential**, measured by the **EFW** experiment.

Entry in the Cusp: from low to higher densities



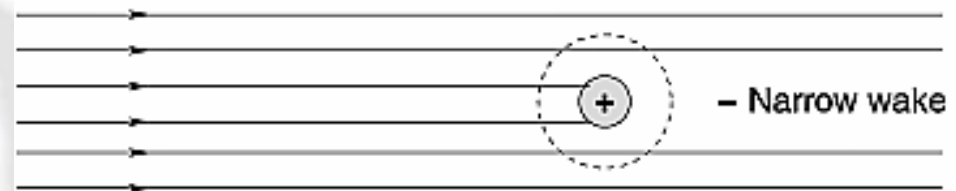
Same event, **CODIF** data

Low-energy (order 10 eV) ion flow in the magnetotail lobes: spacecraft wake

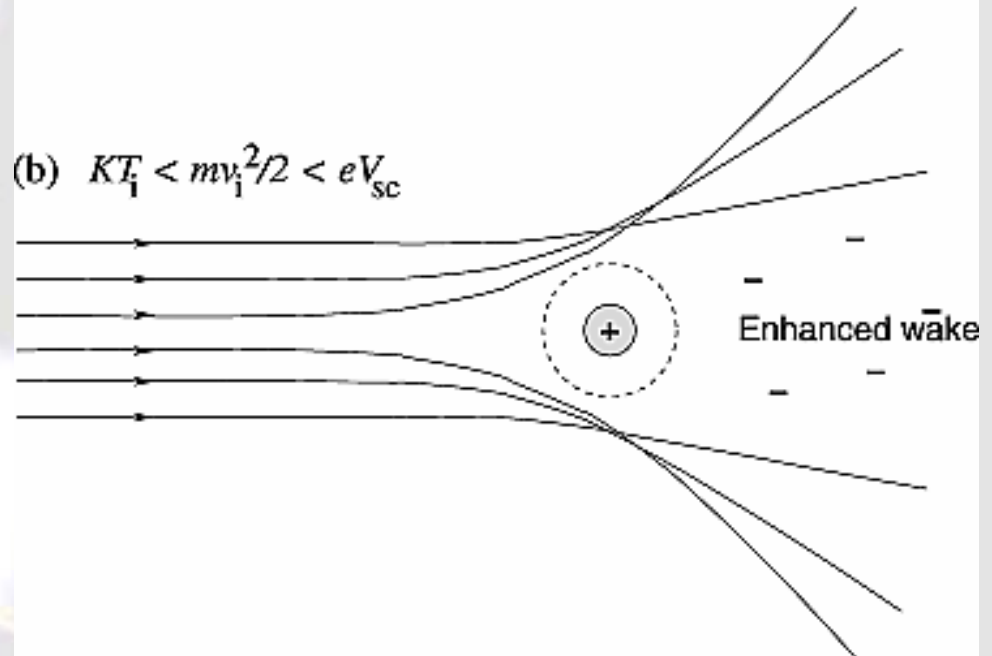


Engwall et al.,
Nat. Geosci., 2008

(a) $mv_i^2/2 > KT_i$, $mv_i^2/2 > eV_{sc}$

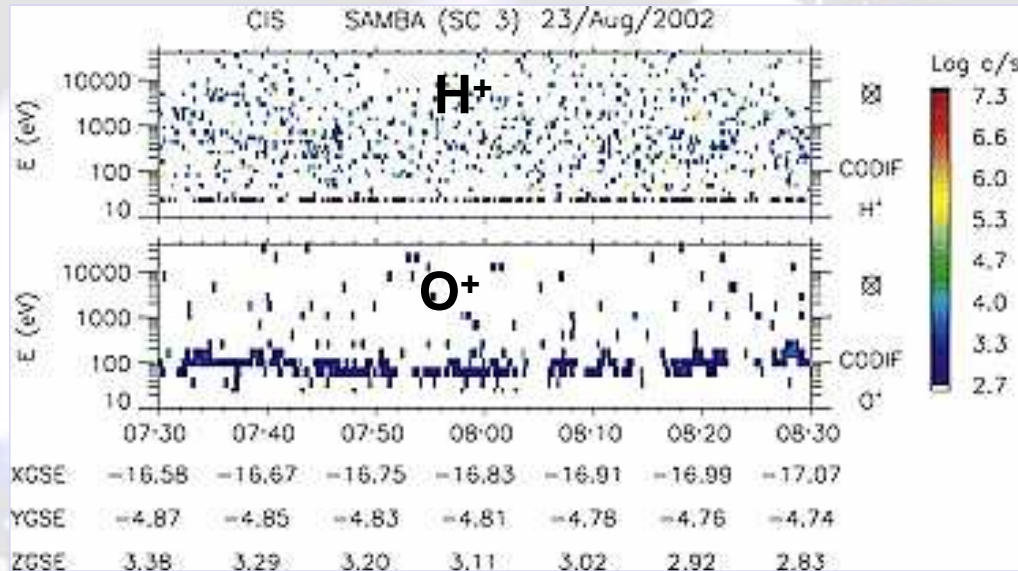


(b) $KT_i < mv_i^2/2 < eV_{sc}$



Engwall et al.,
GRL, 2006

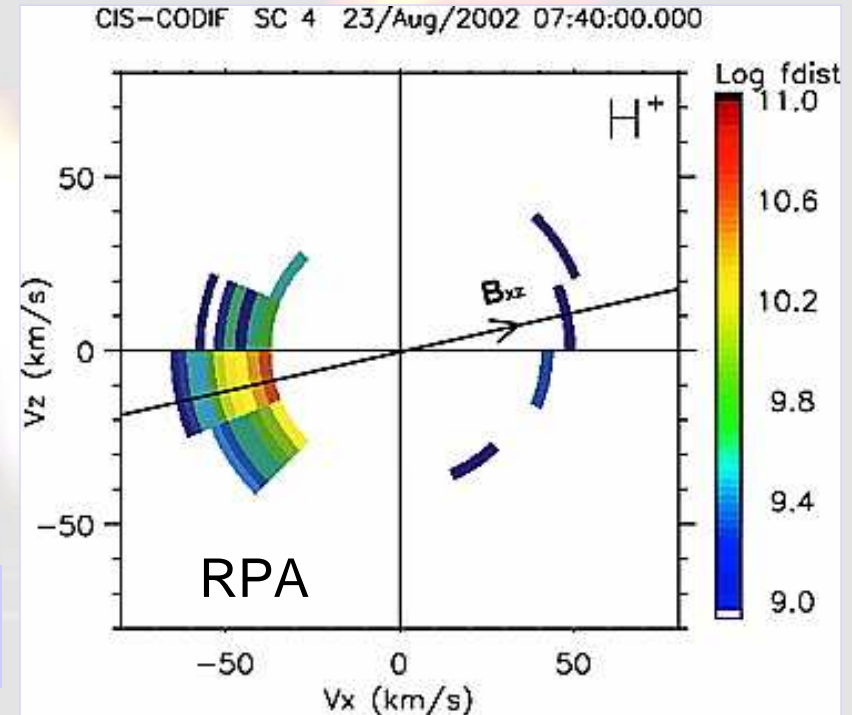
sc3: ASPOC switched off: wake



*Engwall et al.,
GRL, 2006*

- CODIF has detected an **O+ ion beam**, in the **anti-sunward direction**.
- The spacecraft potential (40 – 60 V) is **too high for the detection of the H+ ions** which have typical energies around 10 eV: ~40 km/s ion outflow.
- The thin stripe around the lowest energy in the proton data is an artifact from onboard data compression.

sc4: ASPOC switched on: no wake



- Distribution function for **H+**. Velocities have been **corrected for the spacecraft potential of 7 V**.
- The lowest velocities missing due to the instrument cutoff at 0.7 eV (w.r.t. spacecraft).
- B_{xz} is the magnetic field projected in the x-z-plane.



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- First observations with Cluster of a very dense population of locally accelerated thermal ionospheric ions (H^+ , He^+ , O^+) in a region just **adjacent to the magnetopause** and on its **magnetospheric side**.
- The observation follows a long period of very weak activity. Recurrent motions of the magnetopause (>100 km/s) are associated with the appearance, inside closed field lines, of recurrent energy structures of ionospheric ions.
- The ion behaviour is interpreted as resulting from local electric field enhancements / decreases which adiabatically enhance / lower the bulk energy of a local dense thermal ion population.

Sauvaud et al., Ann. Geophys., 2001

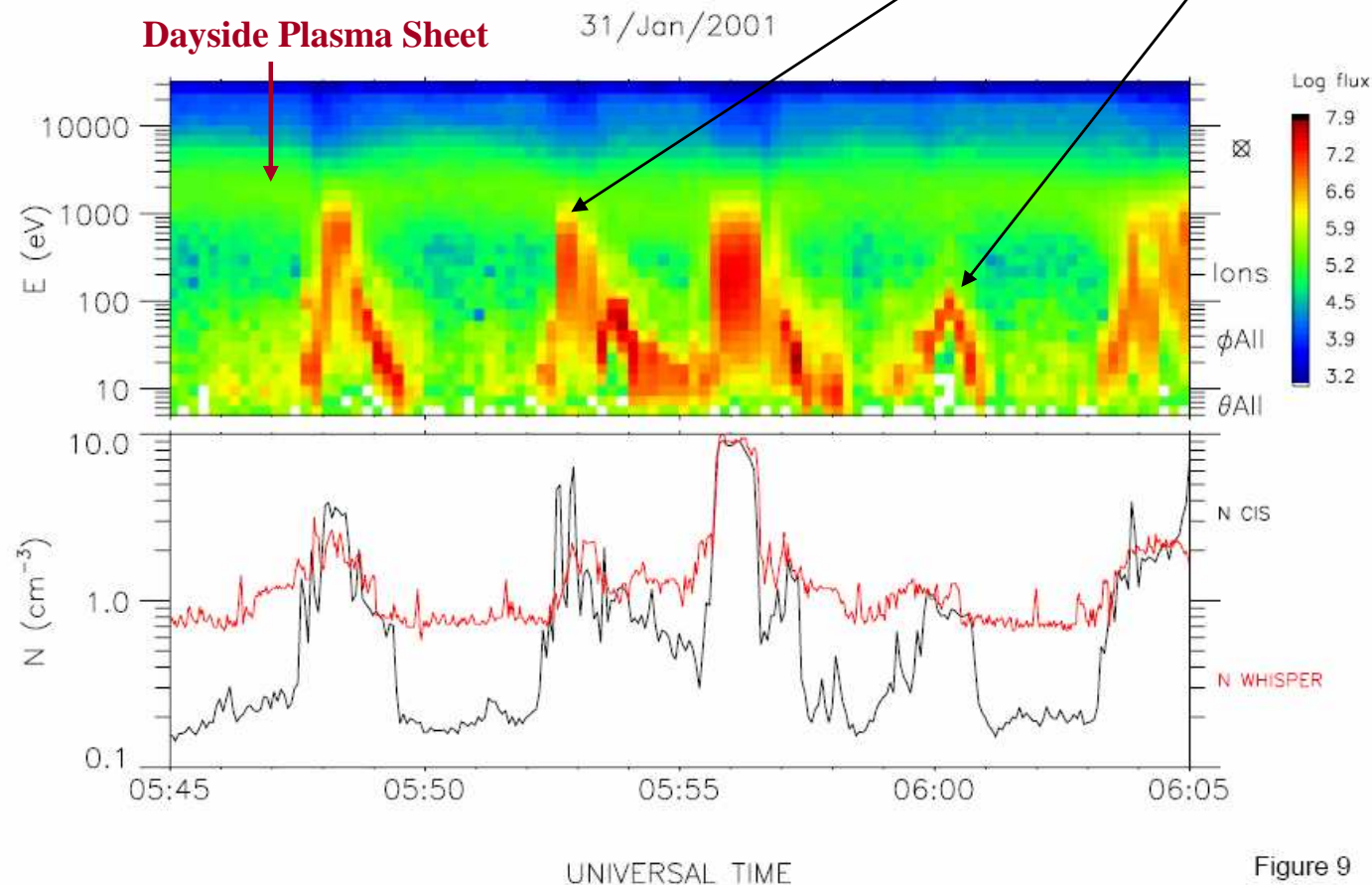
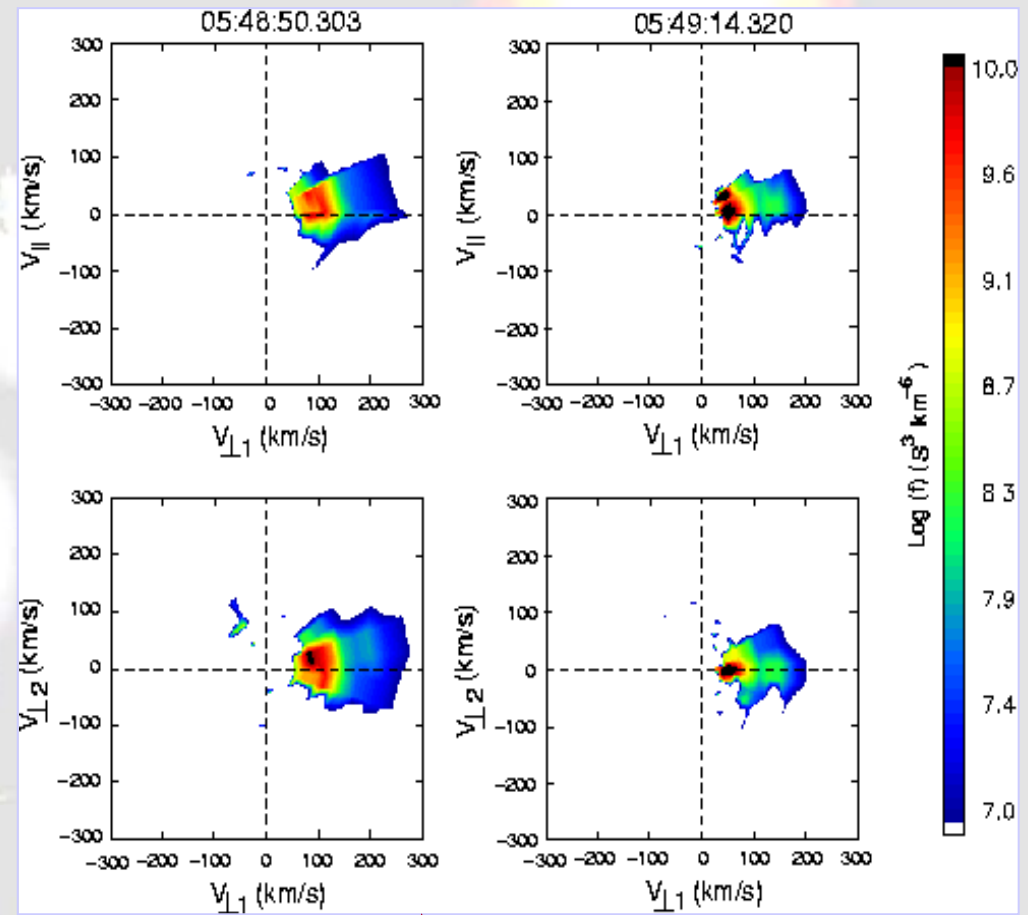
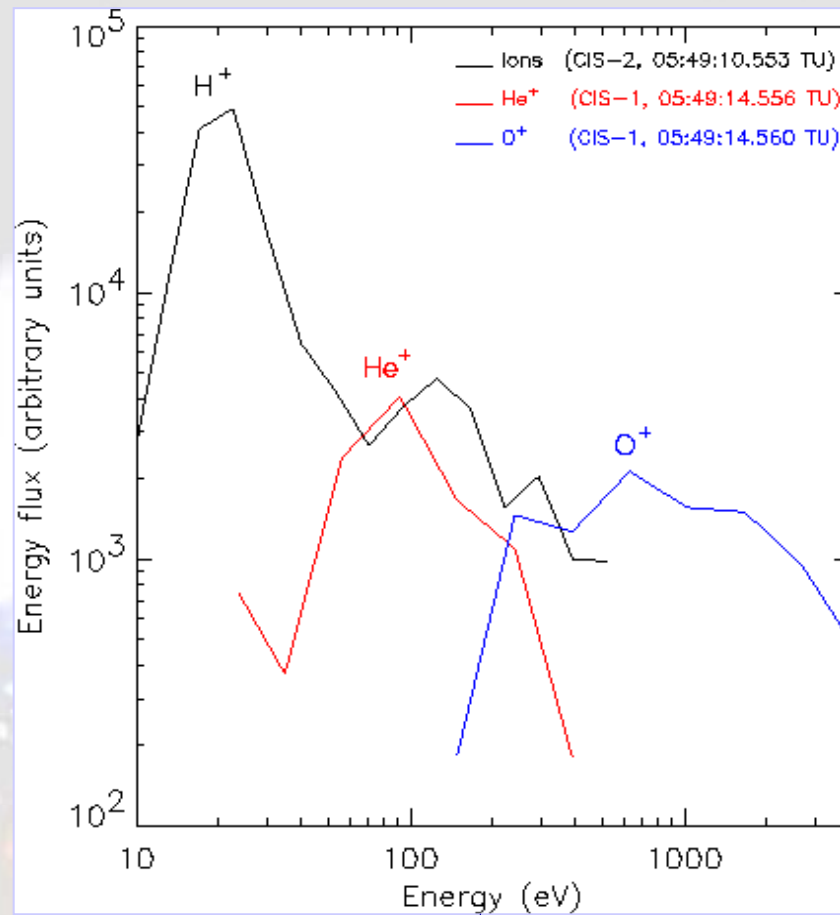


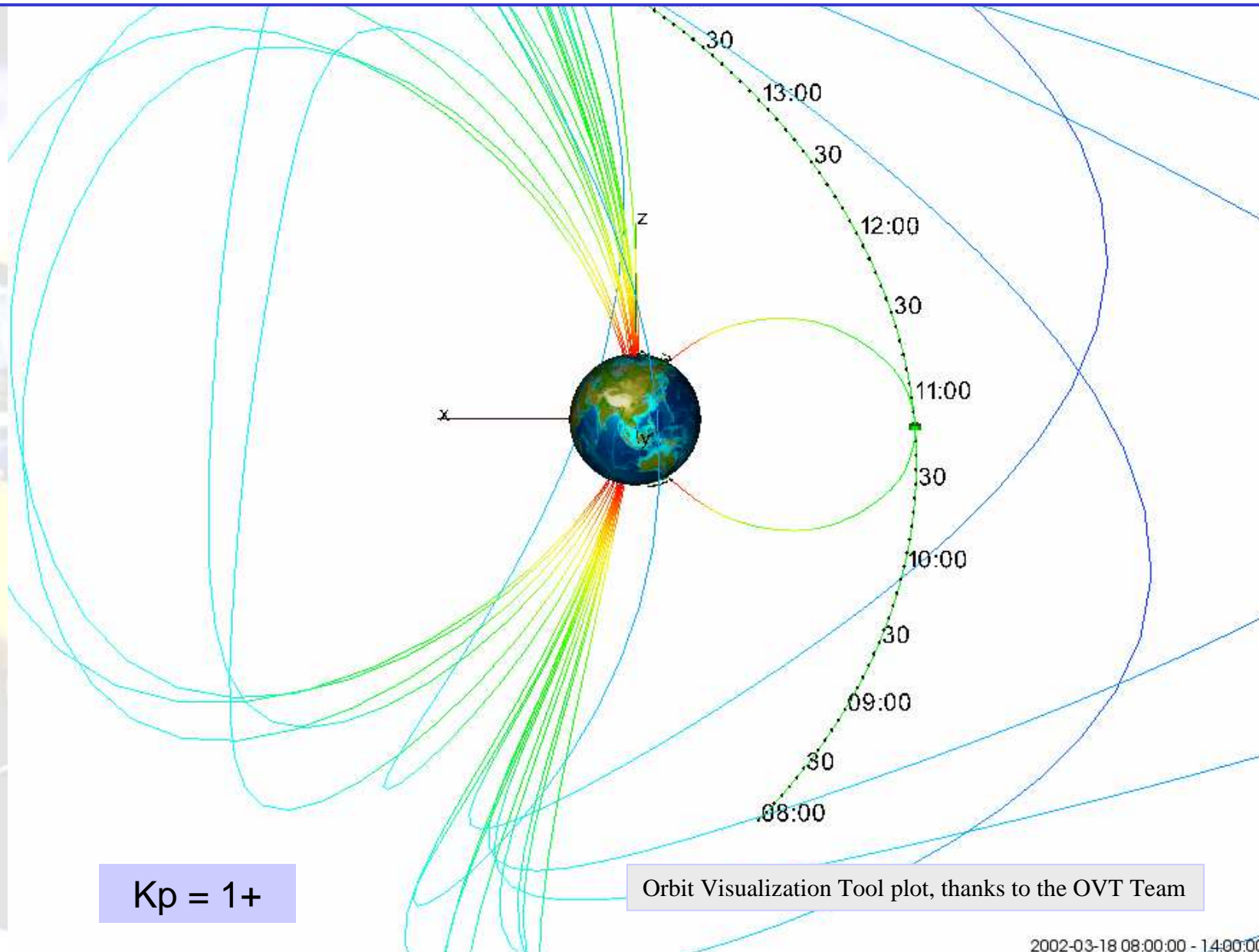
Figure 9



Typical energy spectra (from HIA and CODIF) and distribution functions (from HIA) of the dense population of locally accelerated thermal ionospheric ions in a region just adjacent to the magnetopause

Sauvaud et al., Ann. Geophys., 2001

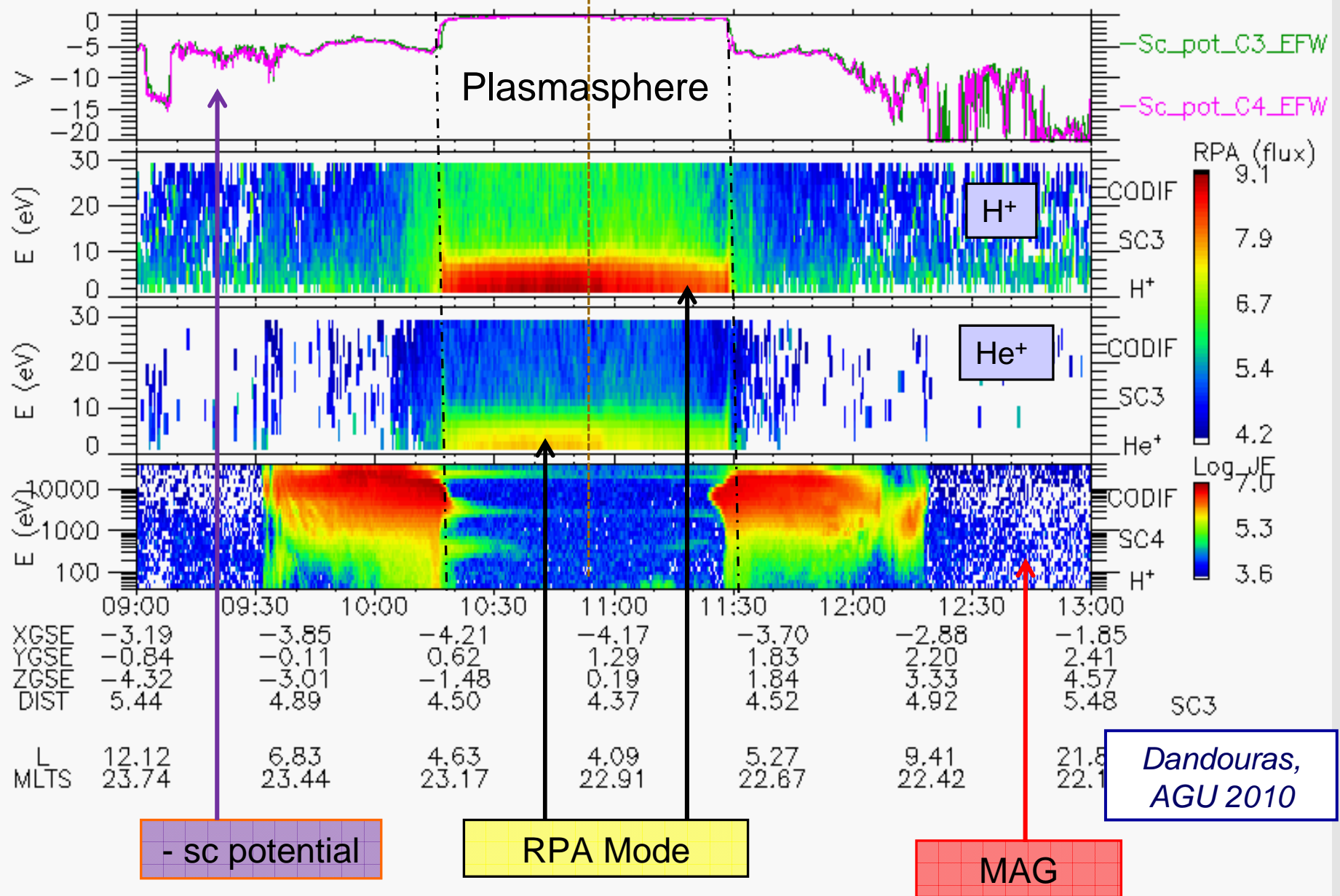
Ion measurements in the dense Plasmaspheric plasma : night-side quiet-time event



CIS & EFW

Magnetic Equator

18/Mar/2002



spacecraft potential EFW data thanks to the EFW team and the CAA

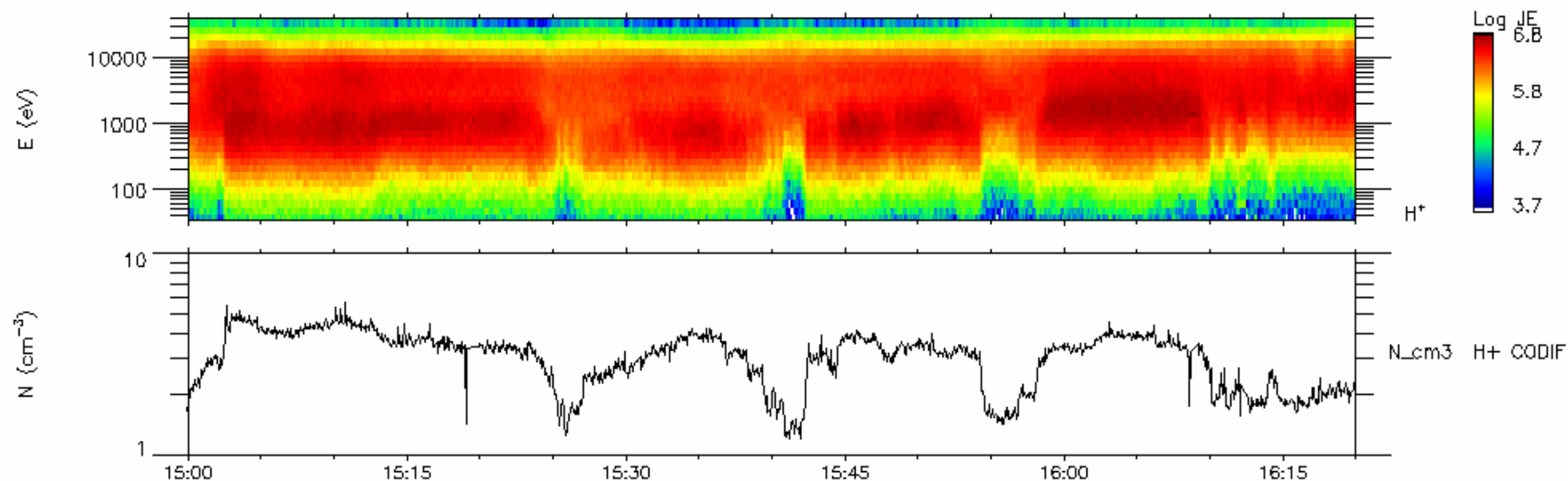
CIS / CODIF data : CIS team

Ion measurements in “dense” magnetotail plasma sheet

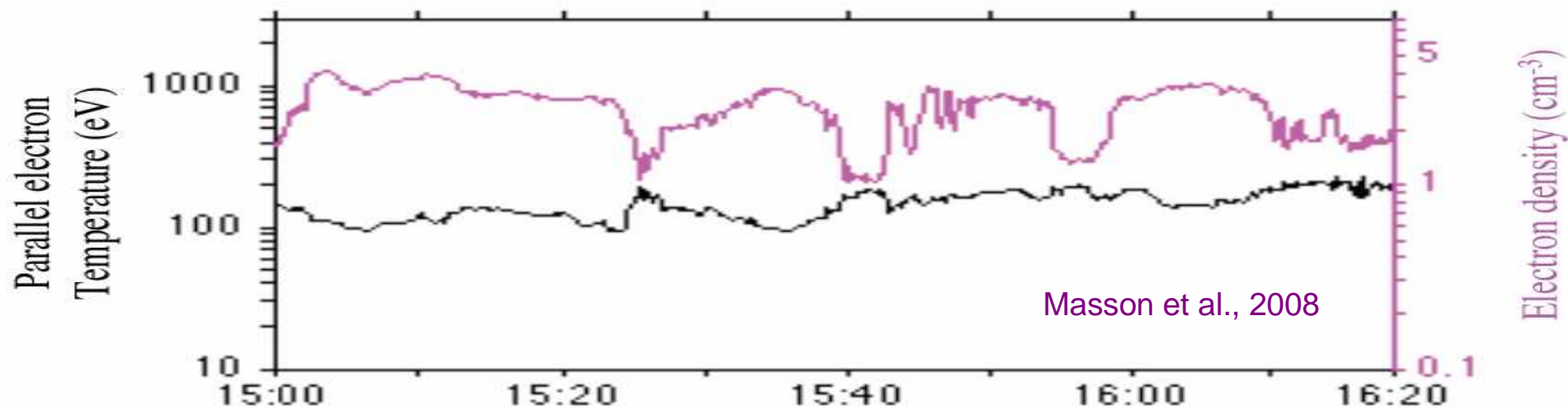
CIS-CODIF

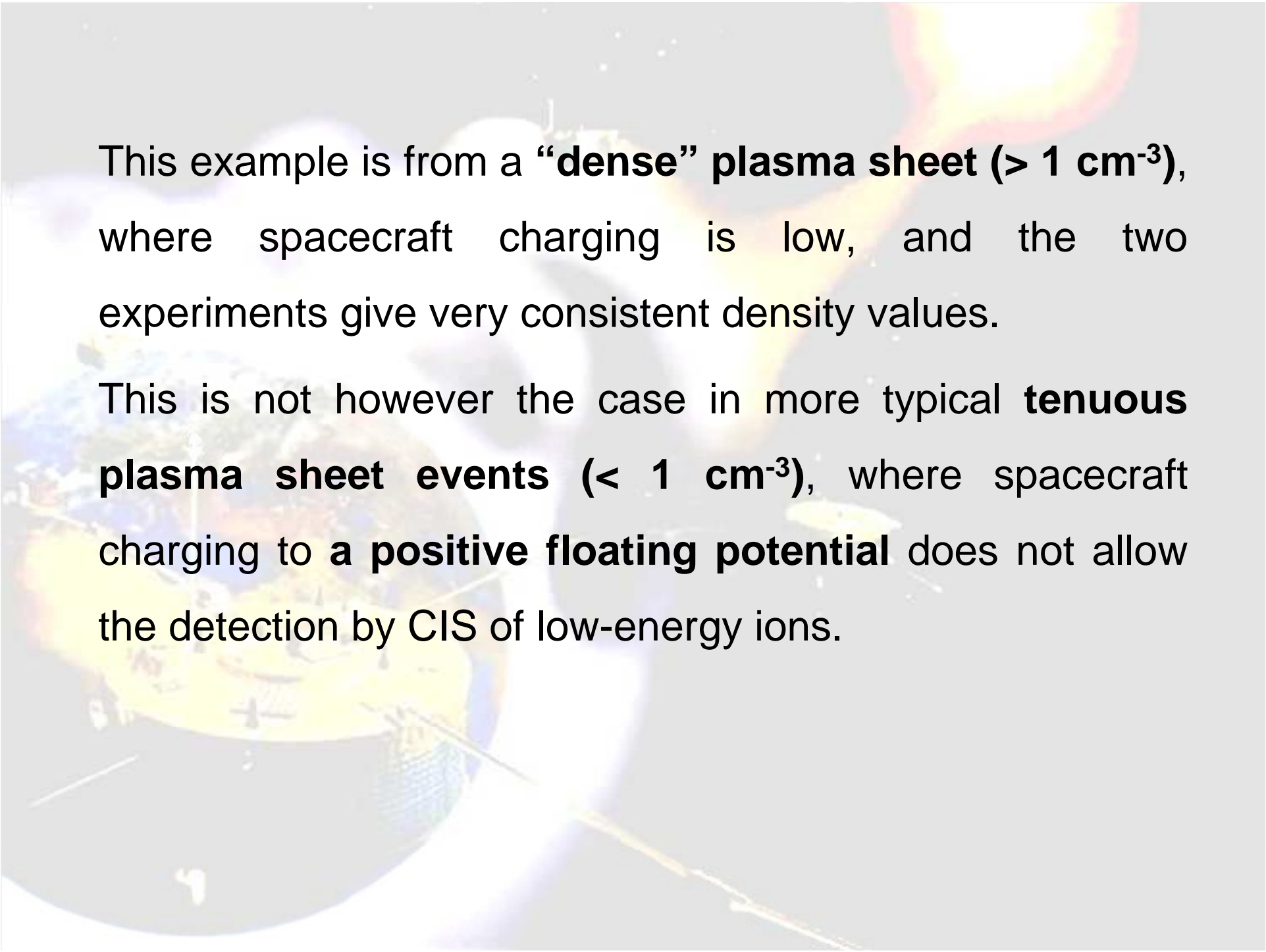
TANGO (SC 4)

17/Aug/2003



XGSE	-15.91	-16.08	-16.24	-16.39	-16.54
YGSE	-6.54	-6.51	-6.48	-6.45	-6.41
ZGSE	2.34	2.15	1.95	1.76	1.56
DIST	17.36	17.48	17.59	17.70	17.81





This example is from a “**dense**” **plasma sheet** ($> 1 \text{ cm}^{-3}$), where spacecraft charging is low, and the two experiments give very consistent density values.

This is not however the case in more typical **tenuous plasma sheet events** ($< 1 \text{ cm}^{-3}$), where spacecraft charging to a **positive floating potential** does not allow the detection by CIS of low-energy ions.



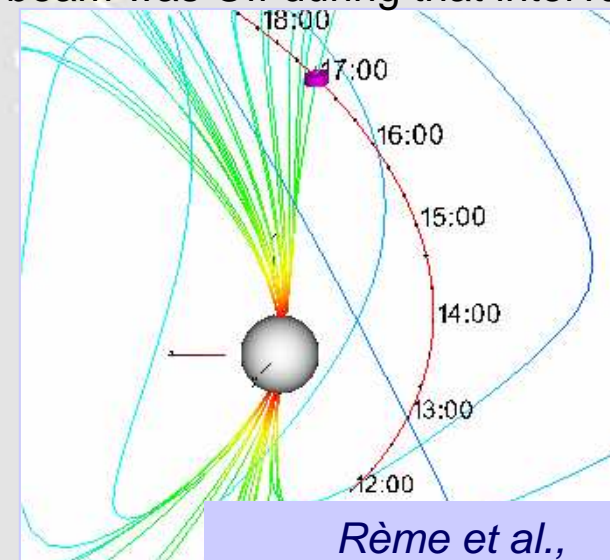
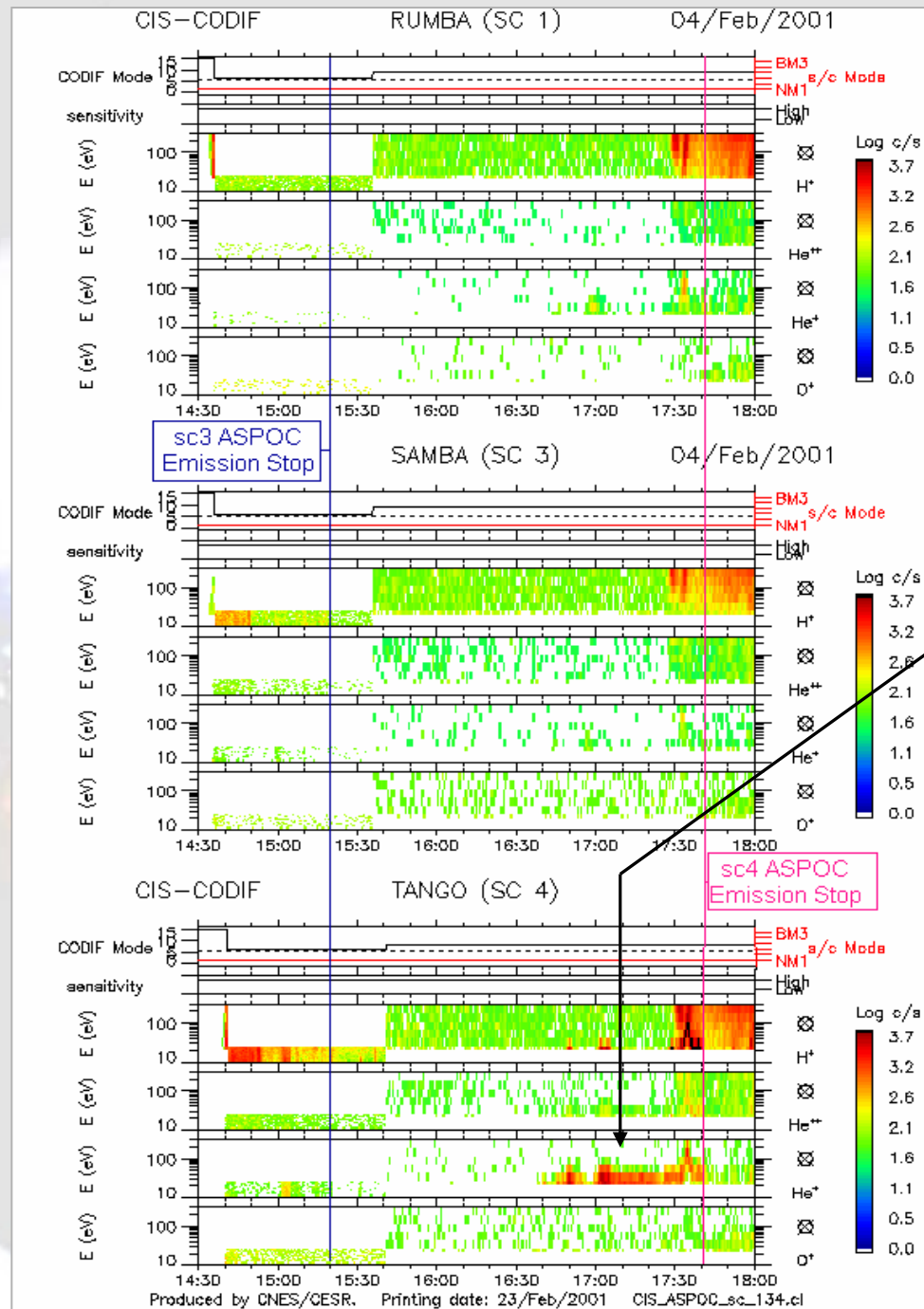
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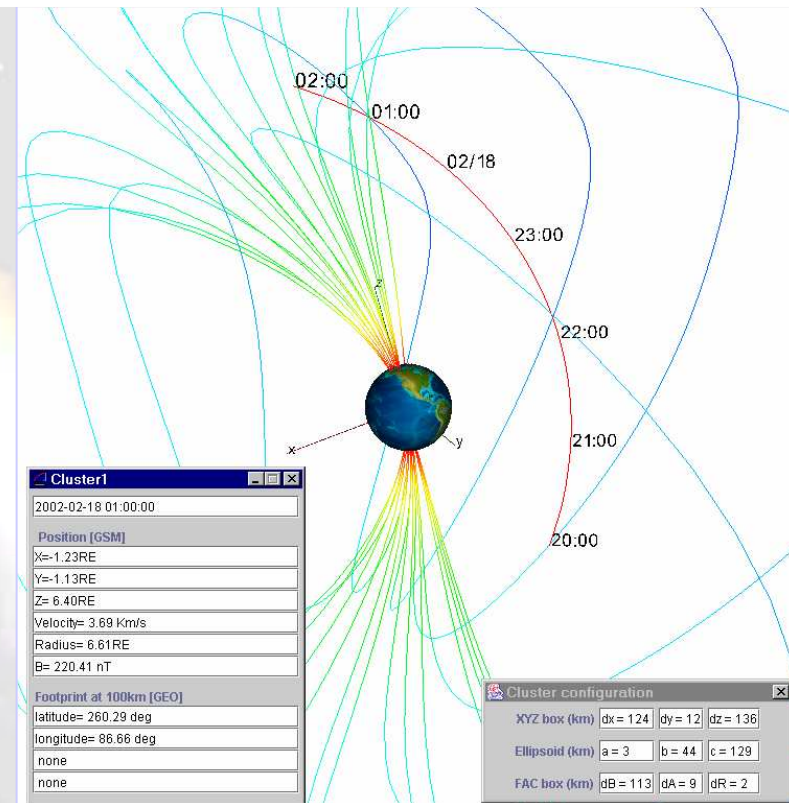
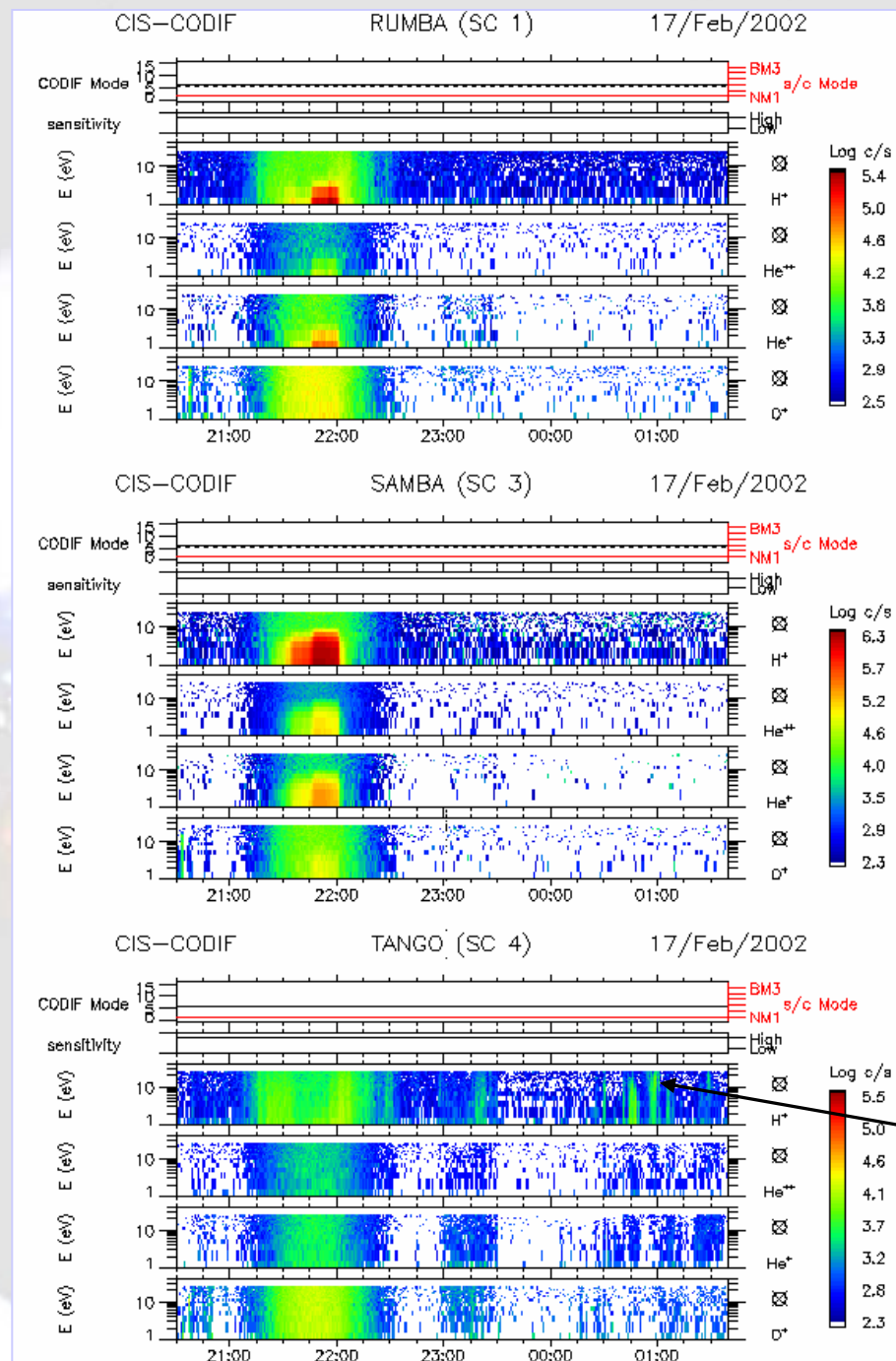
ASPOC helpful contribution in the detection of low-energy H^+ and He^+ ions by CIS (in low density regions)

The **switch-Off of the ASPOC beam** is clearly observable on the CIS data:

- On **s/c 3** CIS stops to observe low-energy H^+ and He^+ after 15:19:57.
- On **s/c 4** CIS stops to observe them after 17:40:57. The effect is particularly clear on the He^+ population (20 to 70 eV), observed on sc 4 from ~ 16:40, and which was never observed on the other two sc, on which the ASPOC beam was Off during that interval.



*Rème et al.,
Ann. Geophys., 2001*



Upwelling H^+ (and He^+) observed on auroral field lines by sc 4, but not by sc 1 and 3 (ASPOC ion emitter operating on sc 3 and 4 during this observation).

- Spacecraft separation **less than 200 km.**

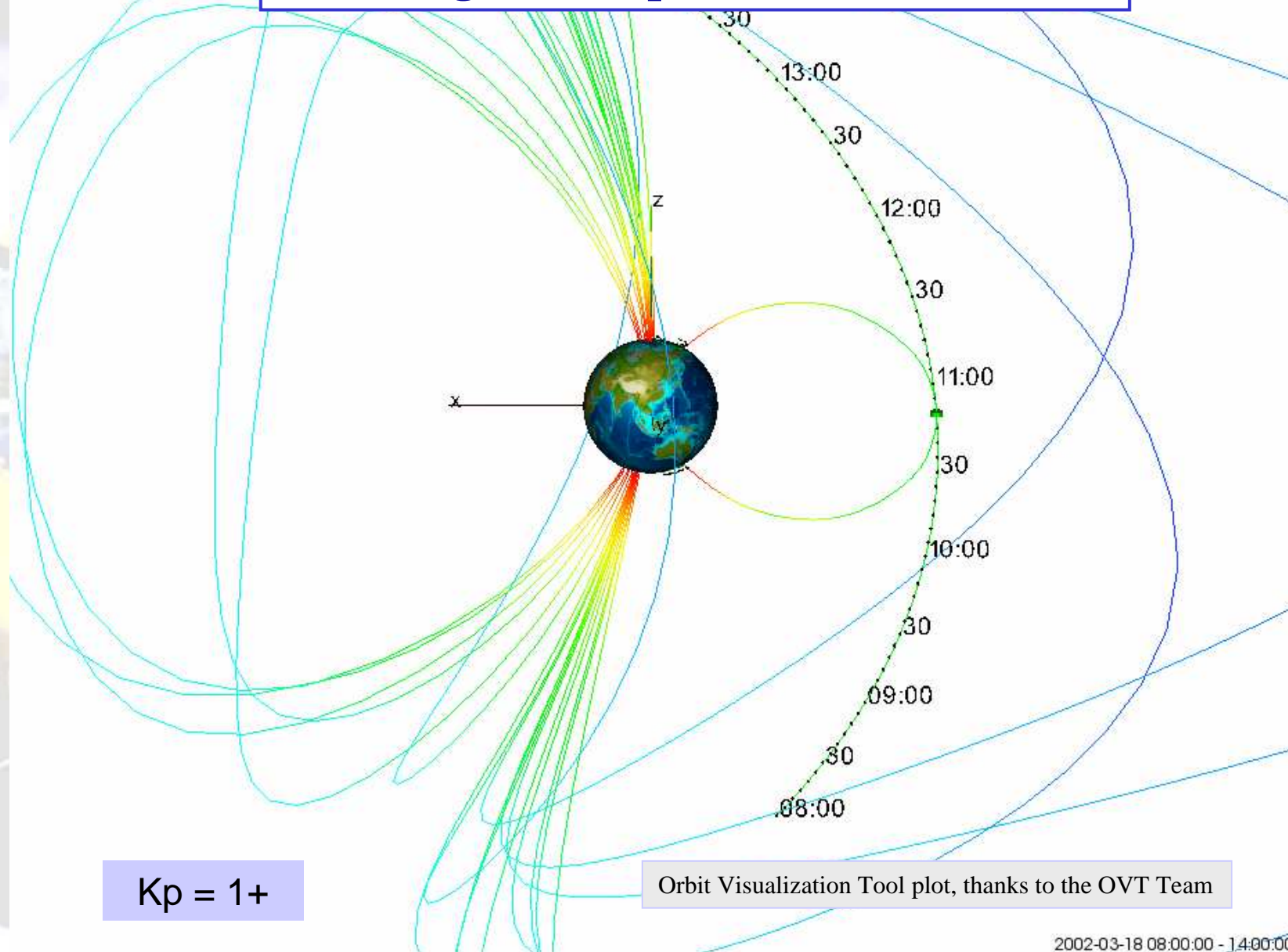
*Dandouras et al.,
1029/159GM03, 2005*



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Plasmasphere cut: night-side quiet-time event

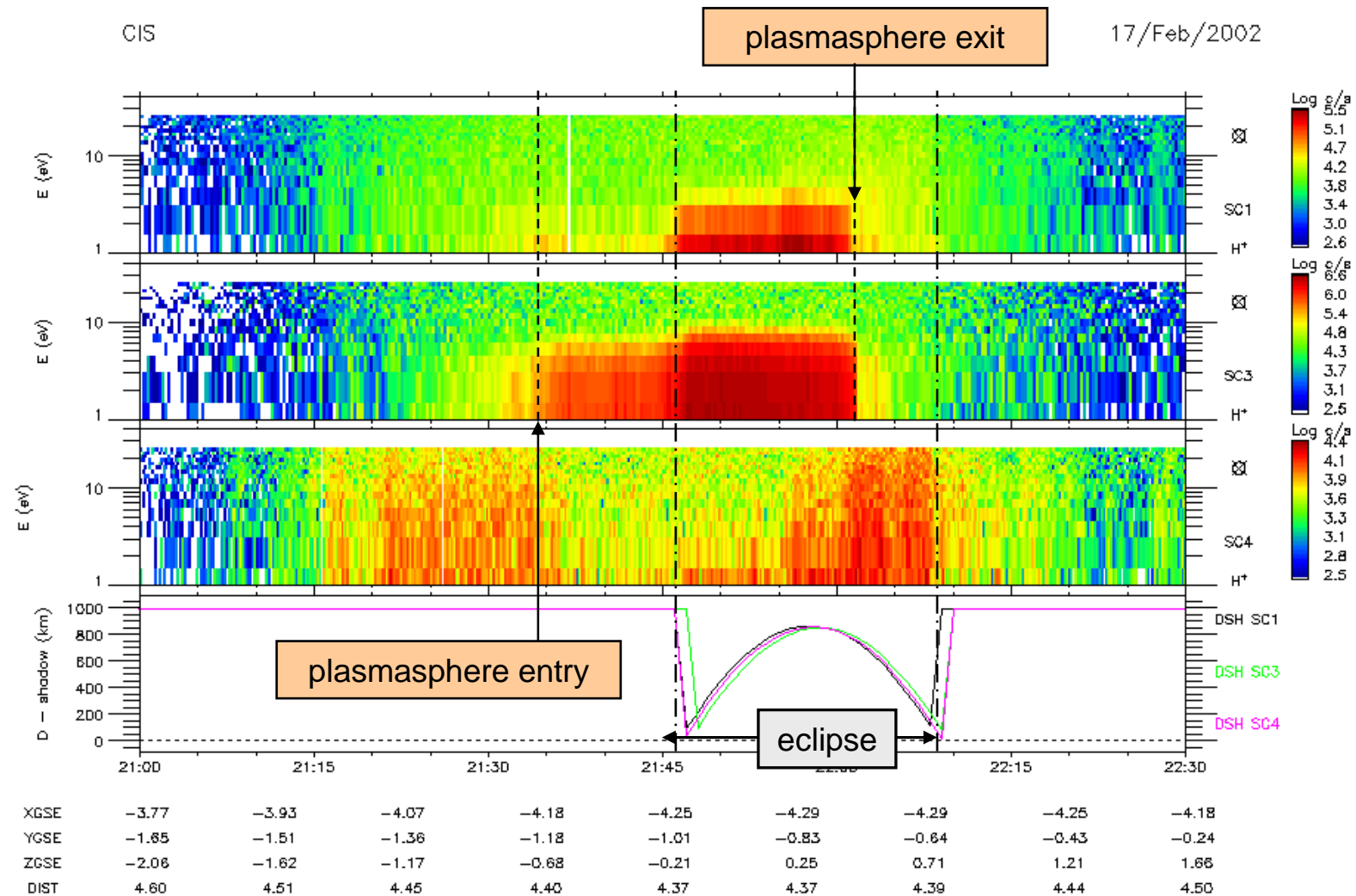


$K_p = 1+$

Orbit Visualization Tool plot, thanks to the OVT Team

2002-03-18 08:00:00 - 14:00:00

Eclipse event: Plasmasphere in the Earth's shadow



Kp = 2

Produced by CESR. Printing date: 09/Oct/2002 rpa_eclipse_3ac.cl

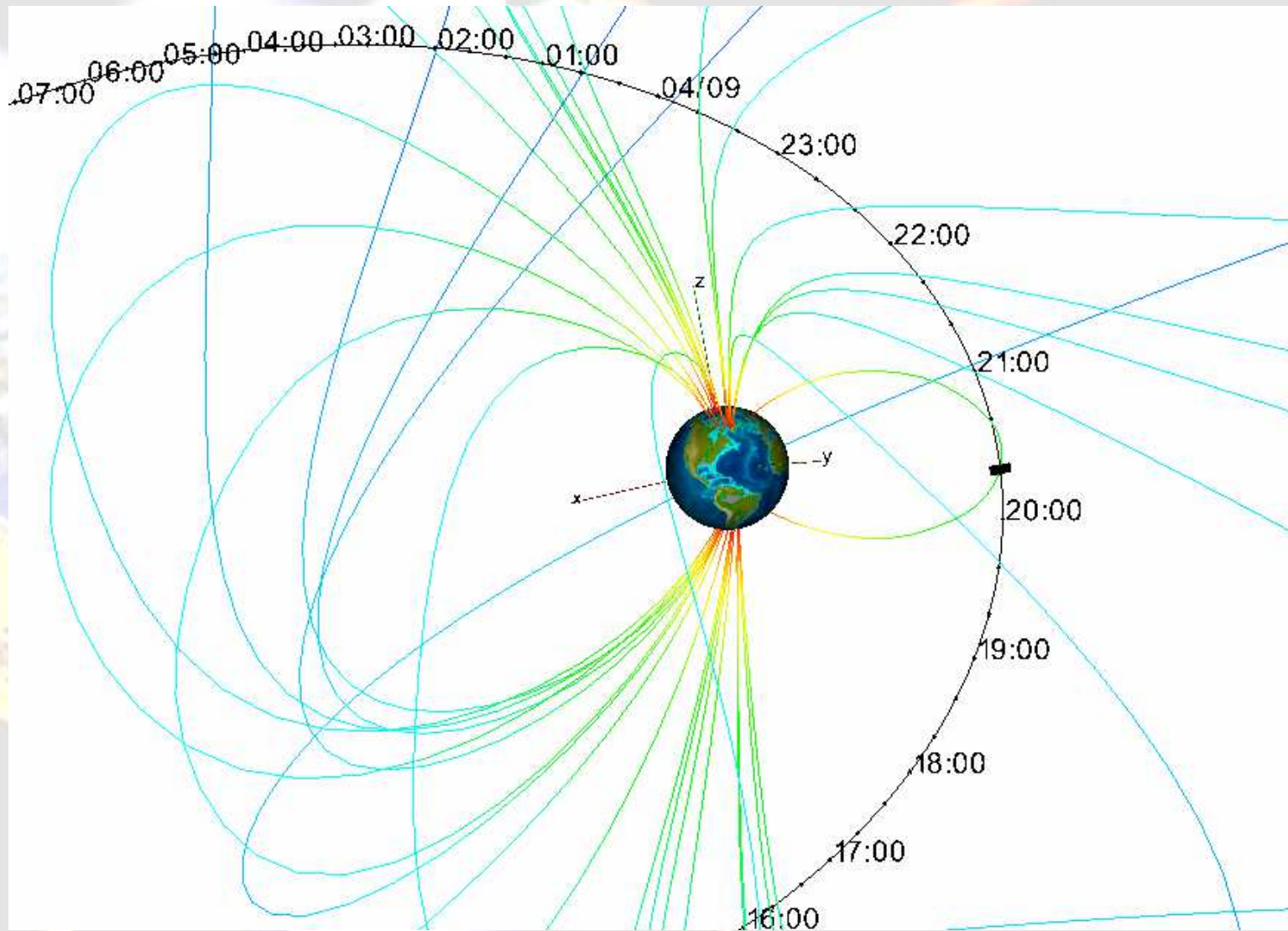
Dandouras, et al.,
1029/159GM03, 2005



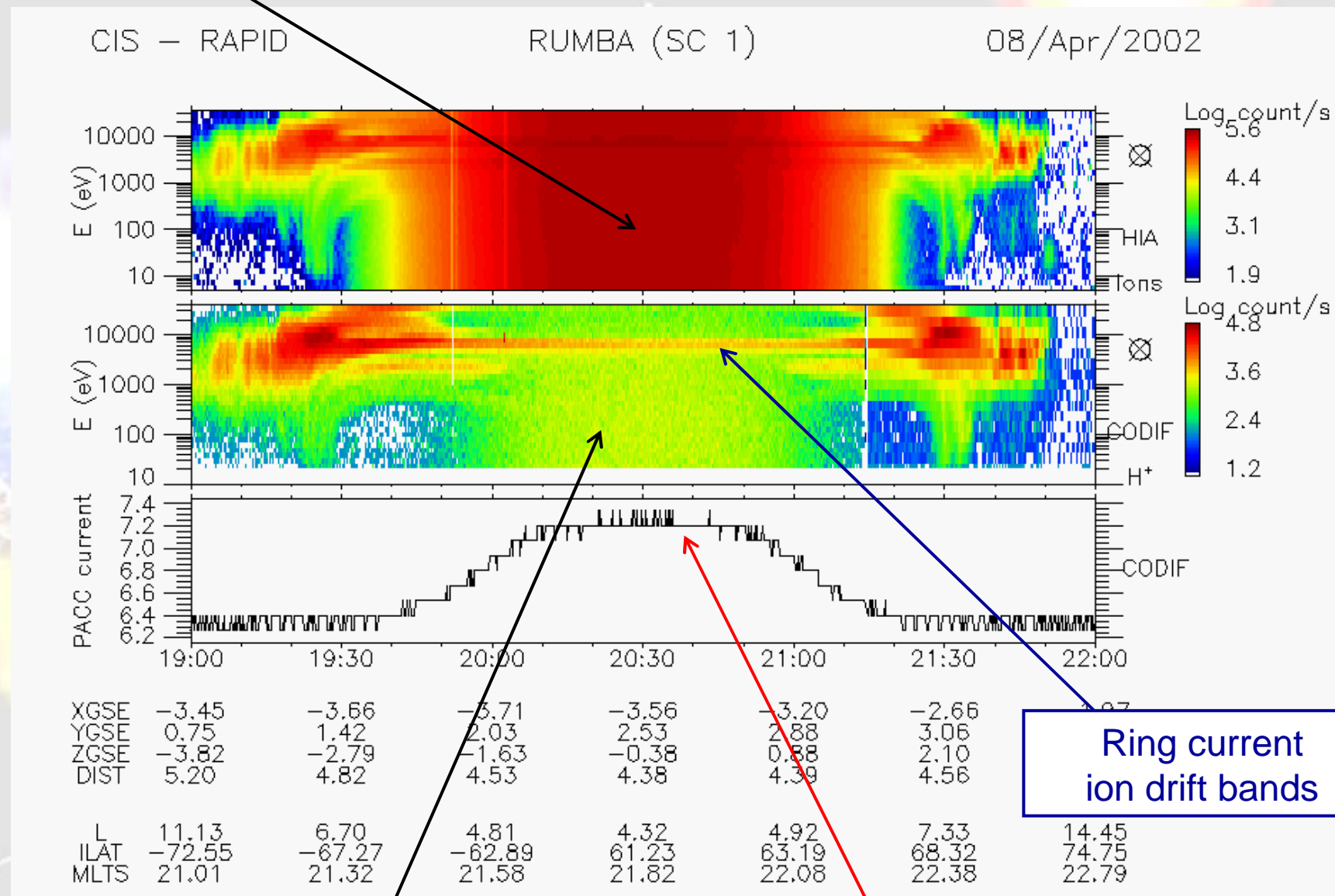
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CIS operation in the outer radiation belt

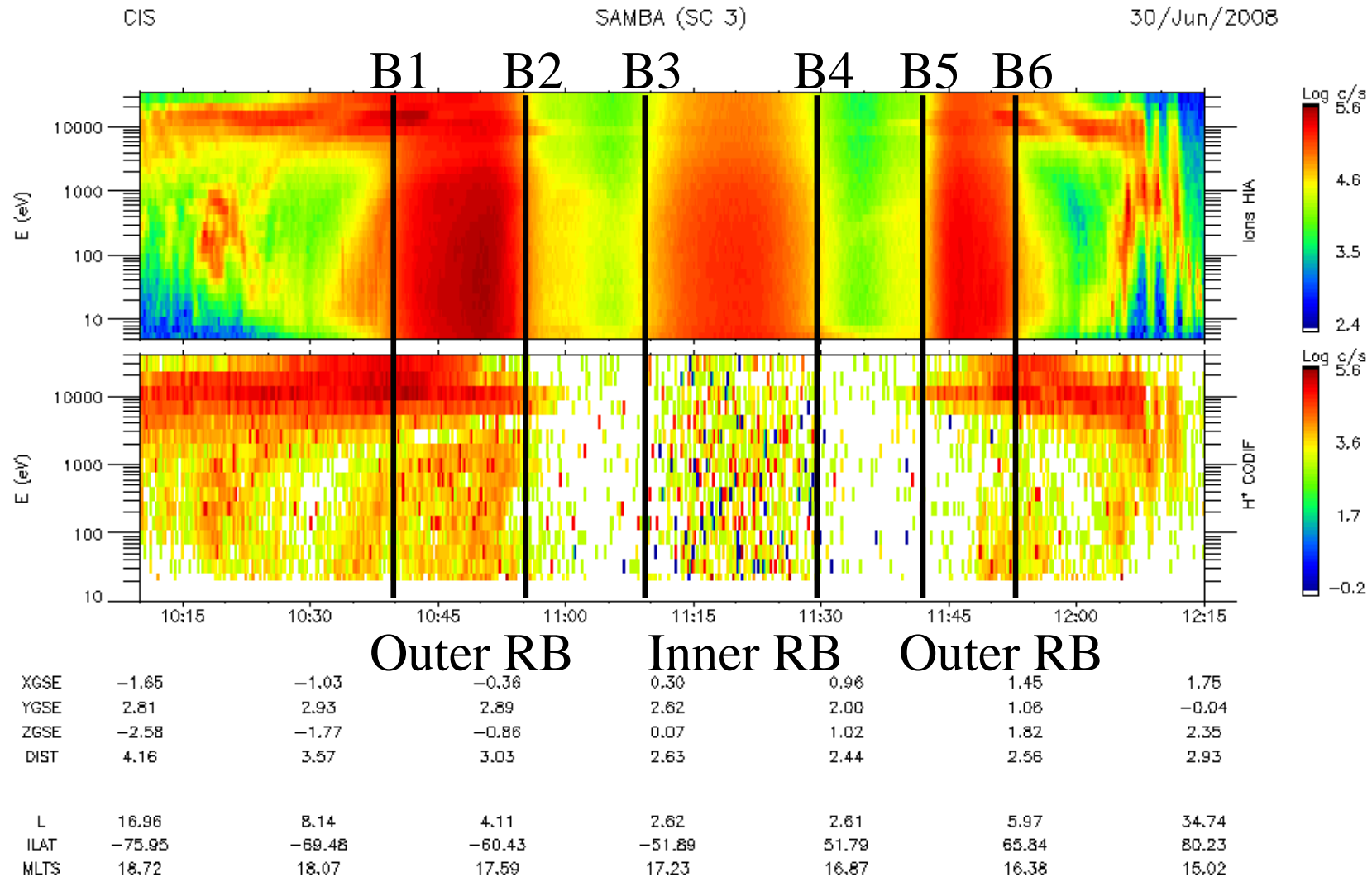


HIA background counts (penetrating high-energy particles)

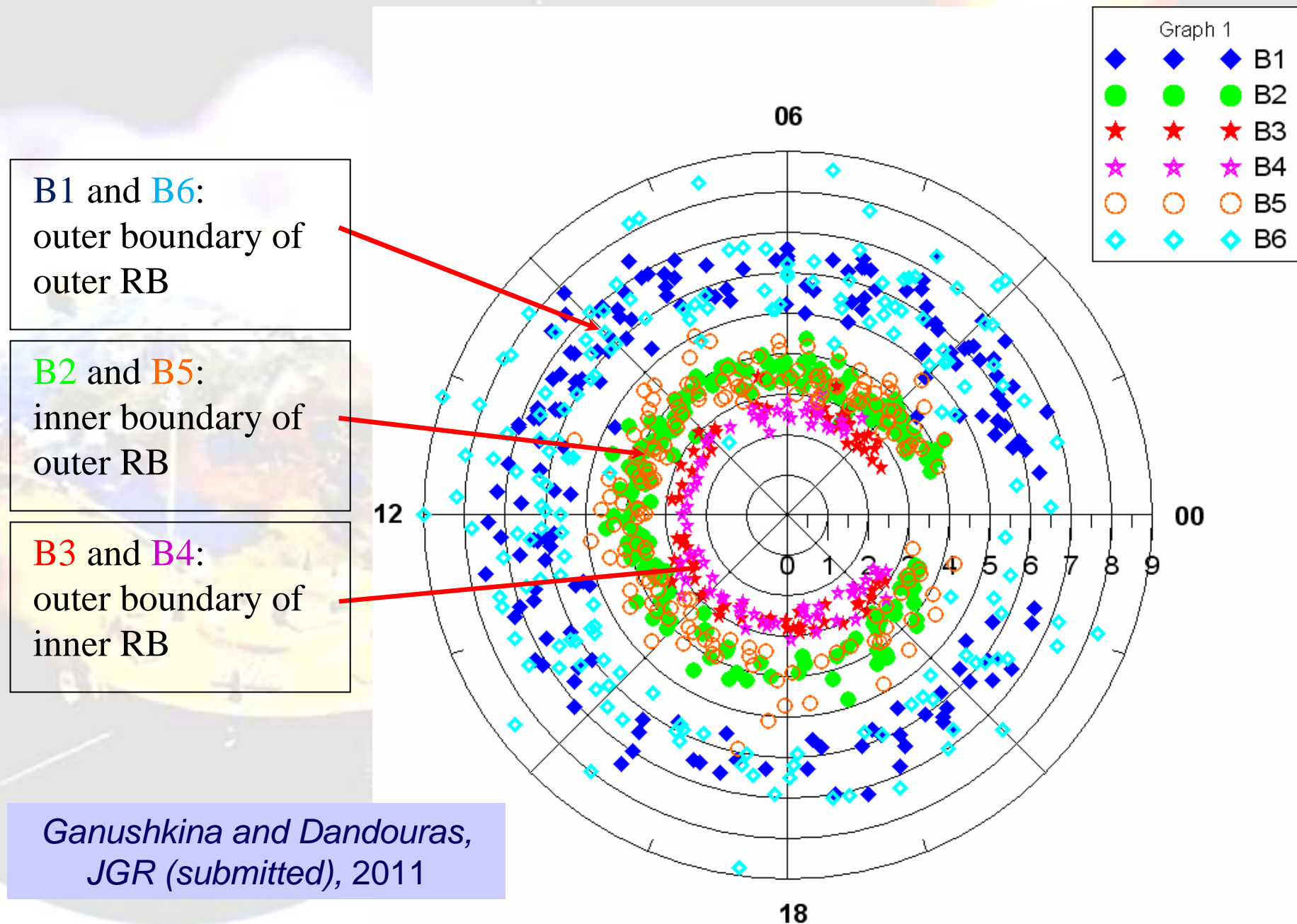


CODIF background counts
(penetrating high-energy particles,
double coincidence)

Boundaries of outer and inner radiation belts as observed by Cluster CIS: Turning instrument background into science data



Locations of boundaries for all events, MLT distribution

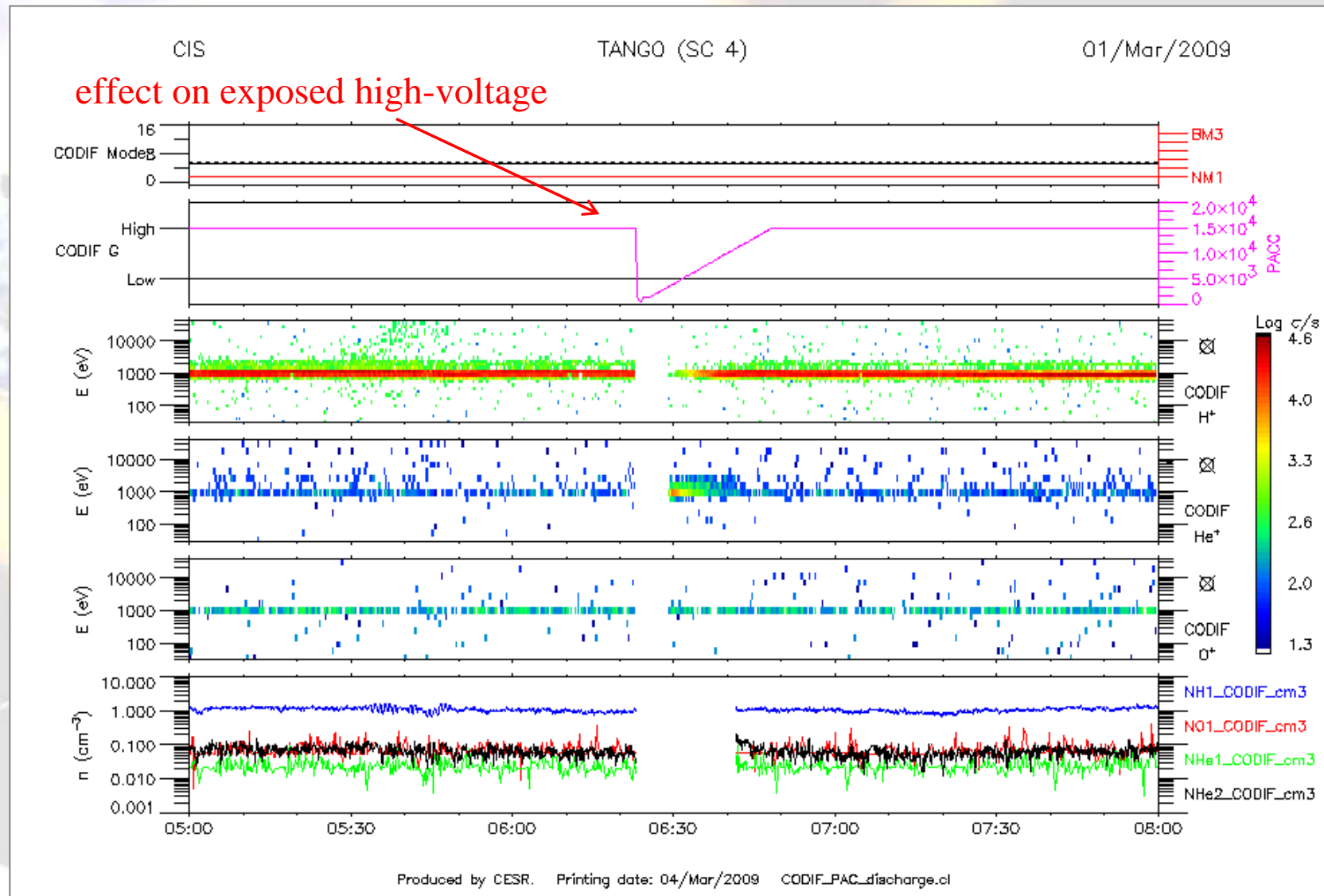


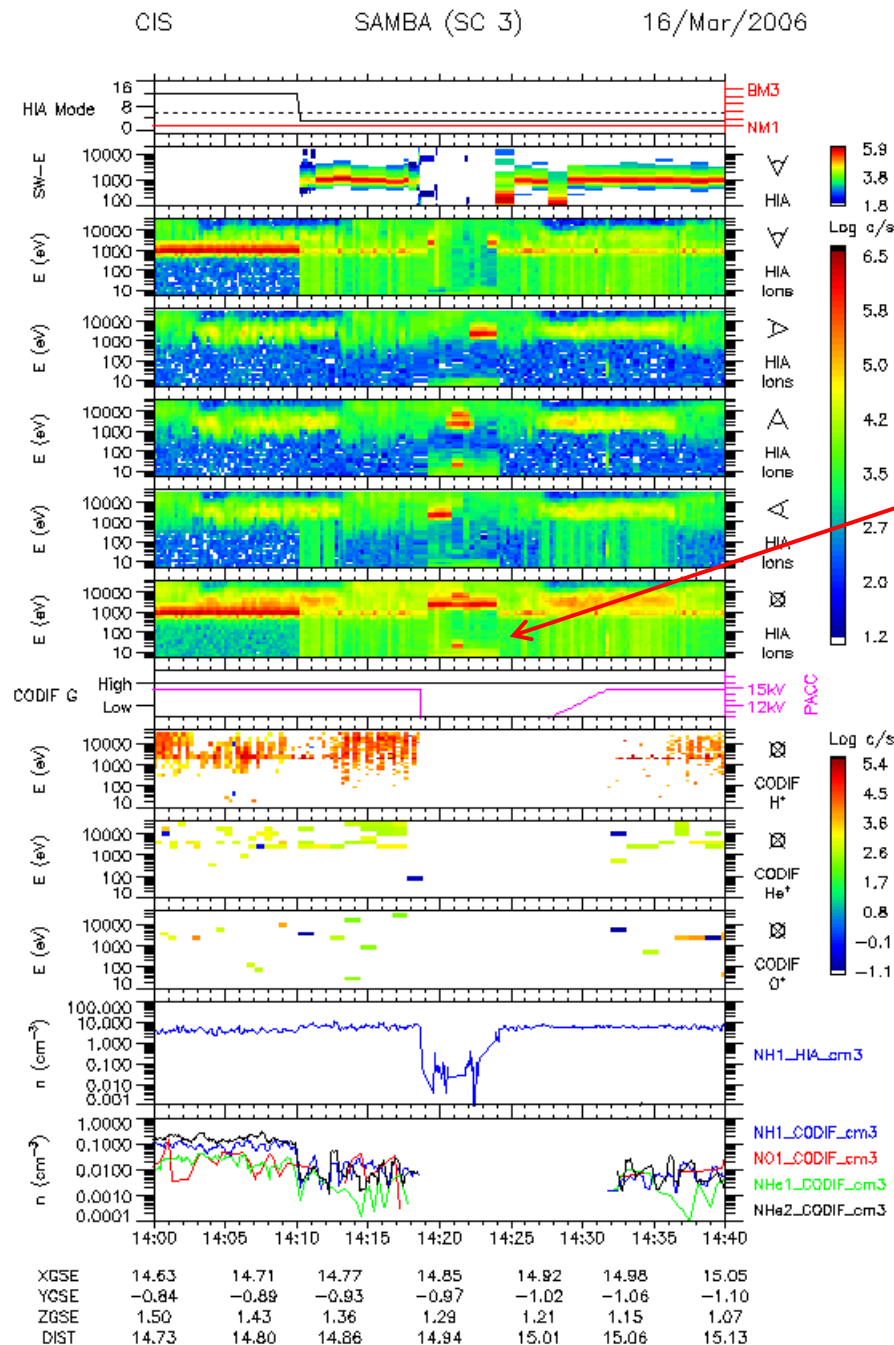


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CODIF s/c 4 post-acceleration **high-voltage discharge**, related to a **battery cell cracking** : release of gas, subsequently ionised



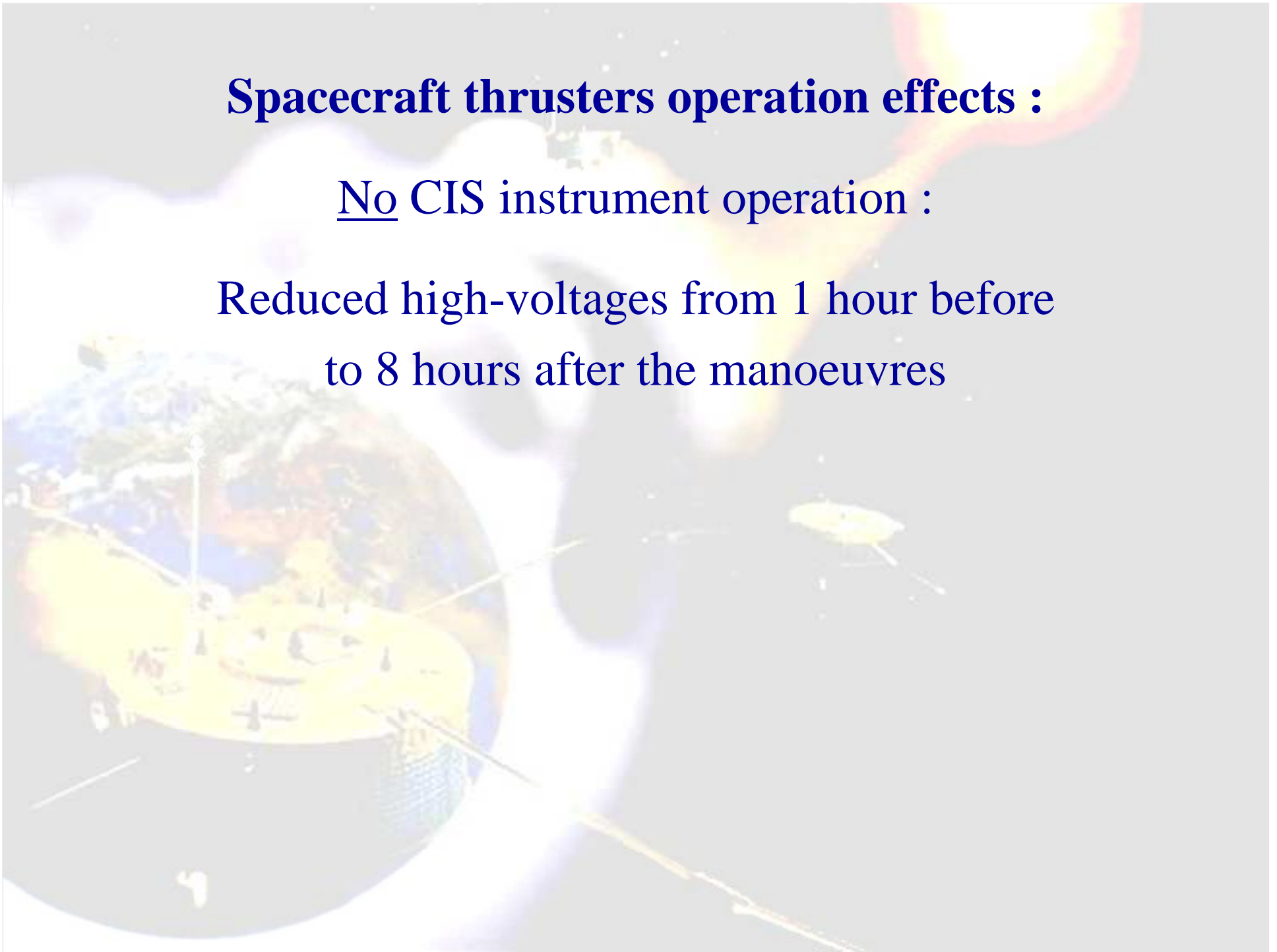


CODIF s/c 3 post-acceleration
high-voltage discharge
and
HIA detection of
low-energy plasma
related to a battery cell cracking

Spacecraft thrusters operation effects :

No CIS instrument operation :

Reduced high-voltages from 1 hour before
to 8 hours after the manoeuvres





Thank you !