Cluster Observations of the Auroral Acceleration Region

KTH Electrical Engineering

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Outline

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-Aurora is an end product of a long chain of interactions between:

the solar wind, the magnetosphere, and the ionosphere.

-The aurora can be produced in discrete forms by accelerated particles or in diffuse forms by those just precipitating without any acceleration.

-The major role in the auroral particle acceleration is played by electric potential structures above the aurora, in the **AAR**.

-We present experimental studies in the AAR; here:

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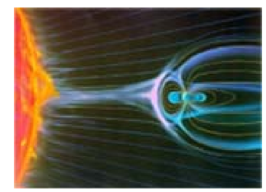
1. Solar Wind- Magnetosphere-Ionosphere interaction

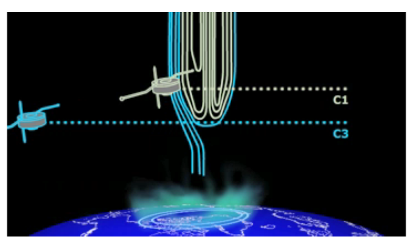


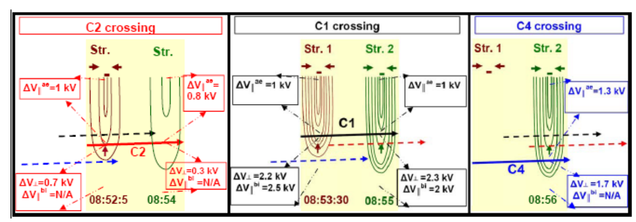
2. Aurora and the AAR

3. Cluster observations of the AAR

4. Summary

5. Future work





1. **Solar Wind-** Magnetosphere-Ionosphere **interaction**

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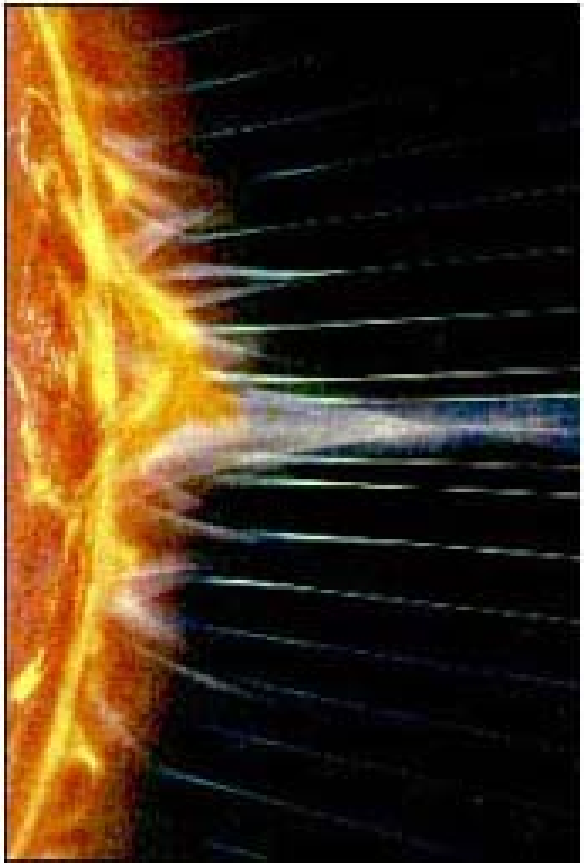
-The upper atmosphere of the sun, the solar corona, ejects a stream of highly conductive plasma, called the *solar wind*.



$n_p \approx 6.6 \text{ cm}^{-3}$ $\qquad T_p \approx 10 \text{ eV}$

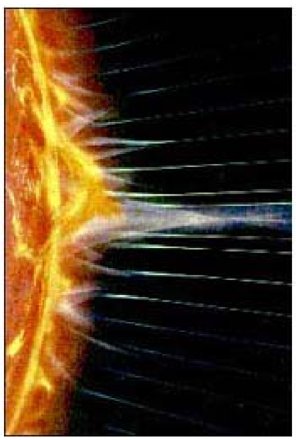
$n_e \approx 7.1 \text{ cm}^{-3}$ $\qquad T_e \approx 12 \text{ eV}$

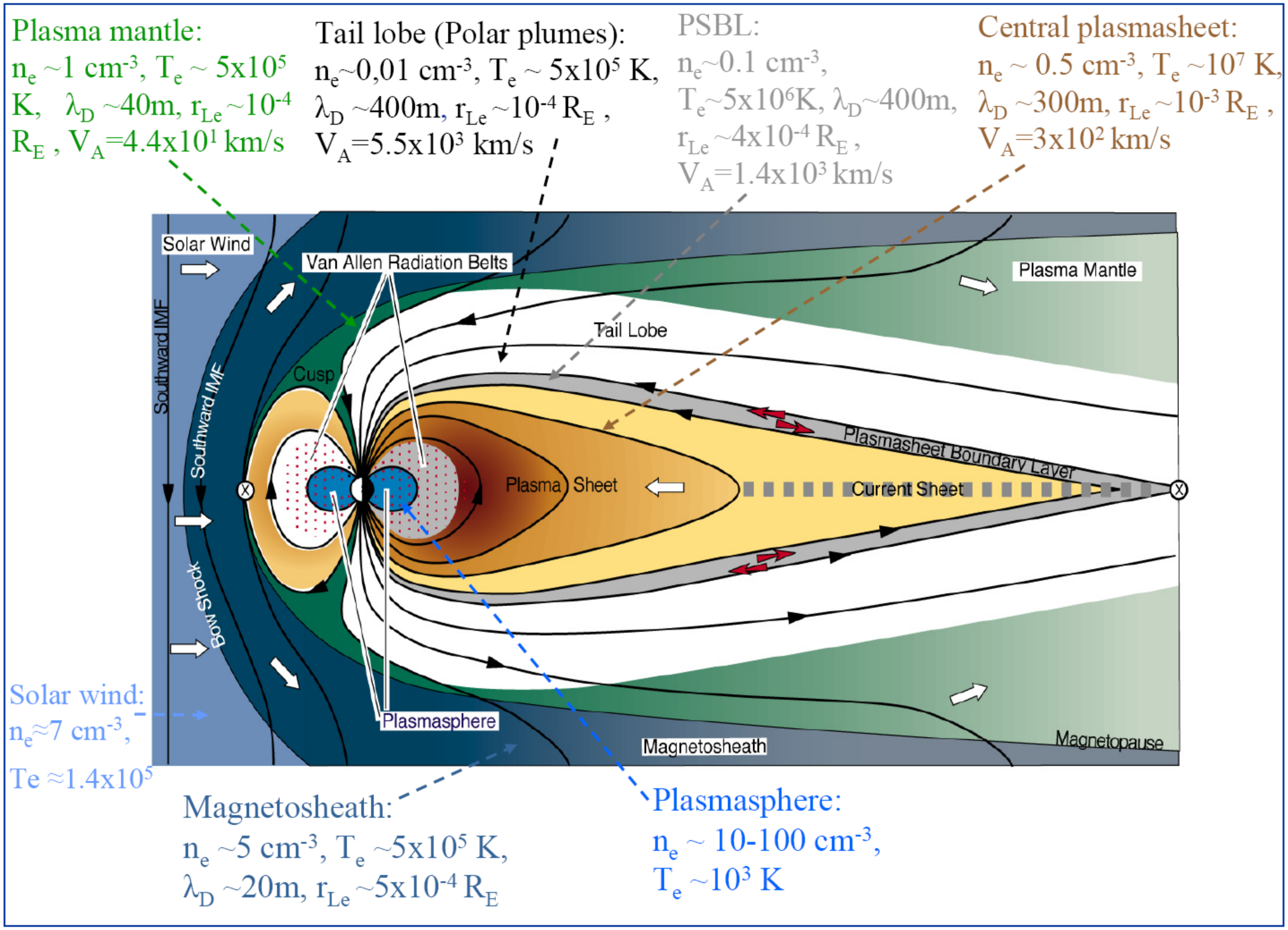
- Speed: 200 - 1000 km/s at the Earth's orbit,

-The frozen-in magnetic field of the sun spreads out into the interplanetary space with the solar wind, as the *Interplanetary Magnetic Field (IMF)*

1. Solar Wind- **Magnetosphere**-Ionosphere interaction

The **magnetosphere:** the region where the Earth's magnetic field has the major control of the space plasma environment around Earth.





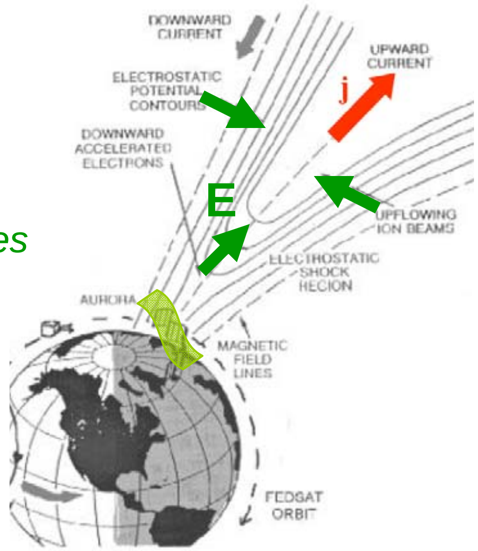
2. Aurora and the AAR

-The nightside auroral oval is the projection (along the magnetic field lines) of the plasma sheet on the atmosphere.

-The aurora is mainly caused by electrons, typically 1-10keV.

-The processes behind accelerating the electrons to such energies are still not clearly understood.

- Upward current region
- Auroral arcs are generally associated with Upward FAC sheets; typically E_W aligned
- Magnetic mirror force → **decreasing number of current carriers** at lower altitudes
- To maintain the current continuity, upward parallel electric fields are required
- This results in converging (negative) *U-shaped electrostatic potential structures*



2. Aurora and the AAR

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Current- voltage relation in the upward current region:

$\Delta\Phi_{//}$ increases the fraction of the Magnetospheric electrons in the loss cone. Hence, the magnitude of the FAC ($j_{//}$) should increase with $\Delta\Phi_{//}$.

Knight relation (Linear region) :

$$j_{//}=K\,\Delta\Phi_{//}$$

where $K=e^2n/(2\pi m_e K_B T_e)^{1/2}$ is the Knight conductance, with n and T_e measured at the top of the potential difference in the magnetosphere.

Electric field studies

Lindqvist & Marklund 1990,
Marklund 1993 statistical study

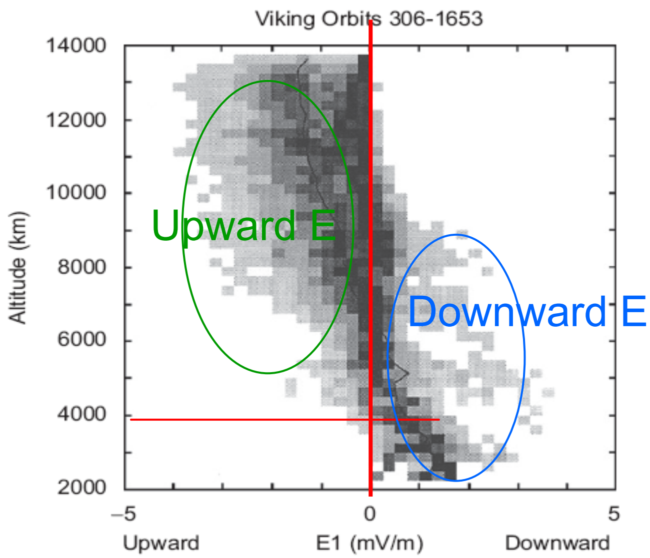
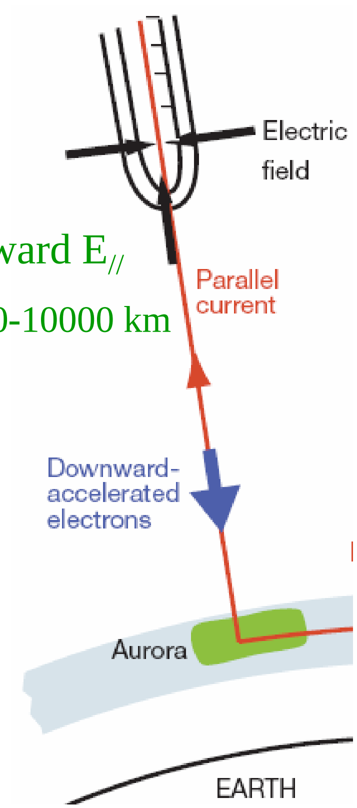


Fig. 4. Statistical properties of the field-aligned electric field as determined from the Viking double-probe experiment. As can be seen, the electric field is on average upward-directed above some 8000 km altitude and downward-directed below 4000 km (after Marklund (1993)).

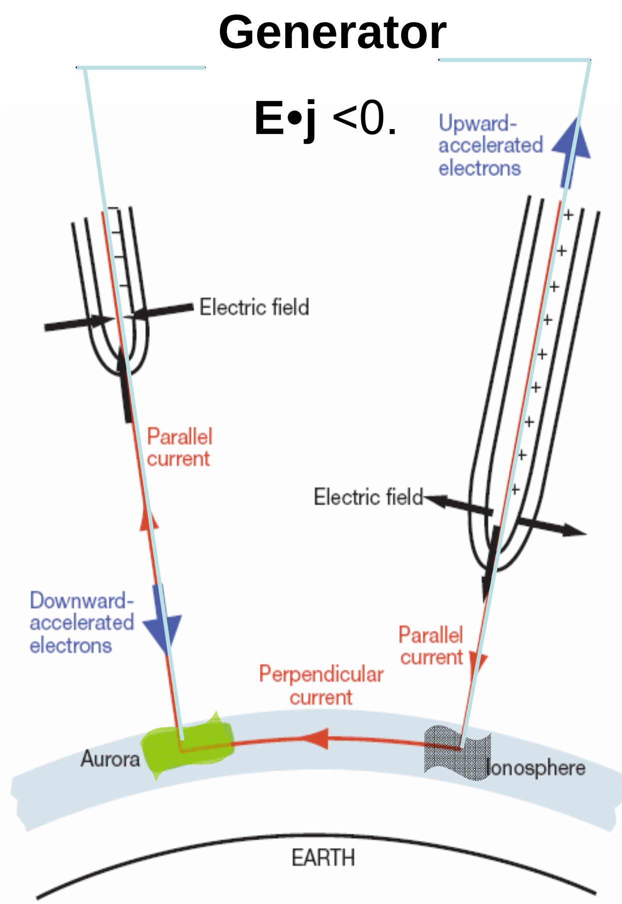


Upward $E_{//}$

3000-10000 km

$1<\Delta\Phi_{//}<10$ kV

Auroral current circuit



2. Aurora and the **AAR**

AAR: region in space where the quasi-static acceleration of charged particles takes place.

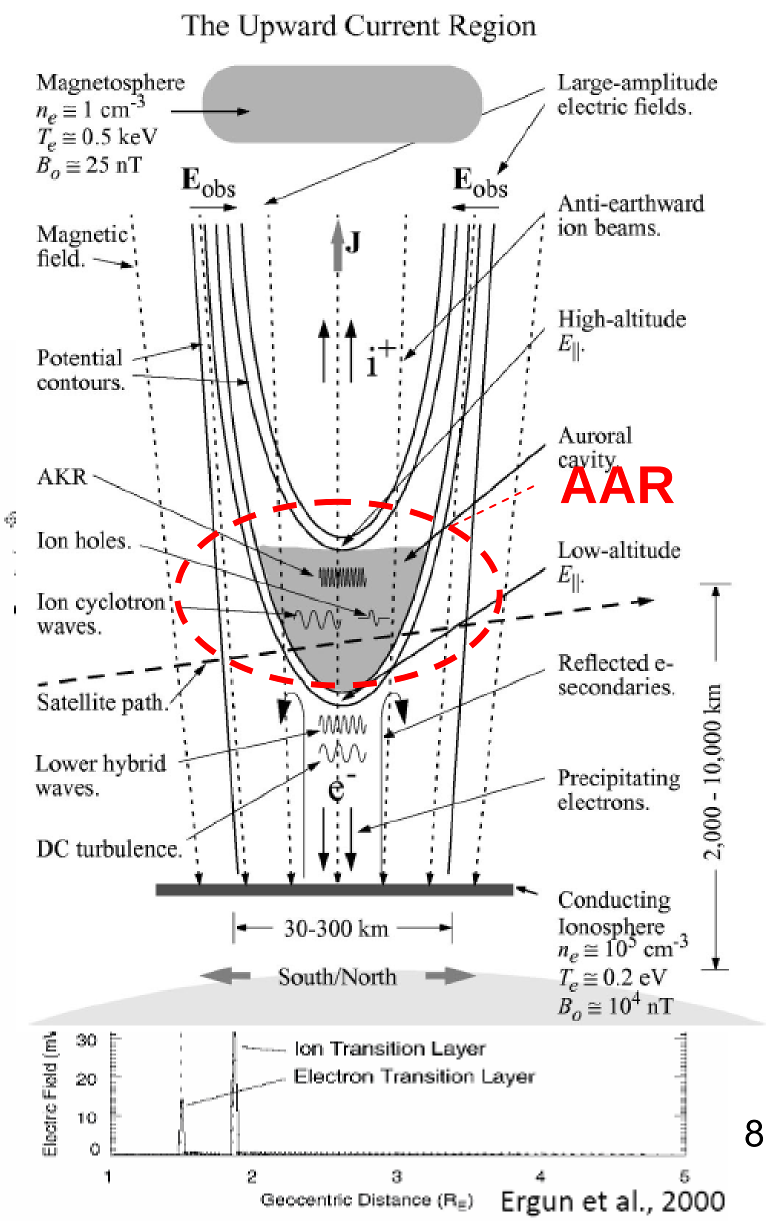
One open question:

-How is the potential distributed in altitude?

-Numerical results suggest that the altitude of maximum acceleration is located where the *B/n* ratio maximizes.

-Ergun et al. (2000) suggested by simulations and FAST satellite data that the parallel potential drop consists two narrow layers and the intermediate region in between.

- Later they added observational support from FAST.



Ergun et al., 2000

2. Aurora and the AAR

Example open question:

Growth and life time of the potential structures

Observations *above* the downward FAC region

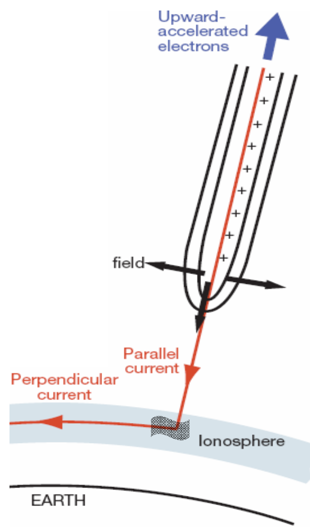
above AAR

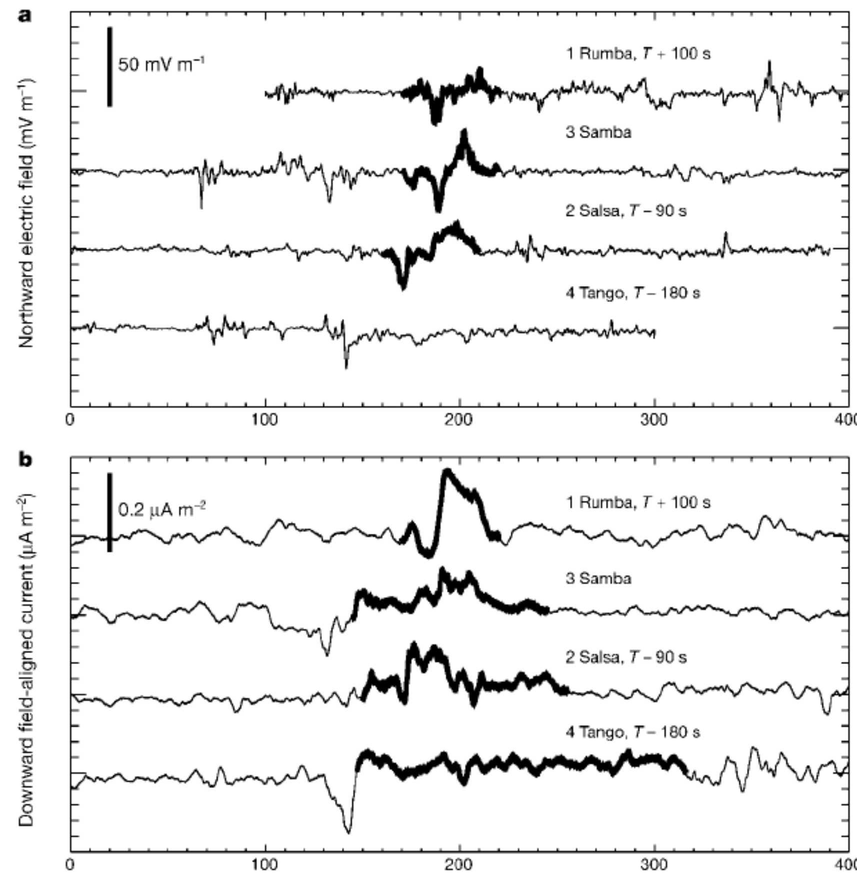
Marklund et al (2001) illustrated the

growth and decay of a diverging

potential structure in downward

FAC region using Cluster data





NATURE | VOL 414 | 13 DECEMBER 2001 | www.nature.com

The instantaneous morphology of the AAR, such as the altitude distribution of the acceleration potential and its stability, requires simultaneous multipoint data to be resolved.
Cluster orbits were lowered in 2008, allowed for multipoint observations of AAR.

2. Aurora and the AAR

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4 Cluster S/C

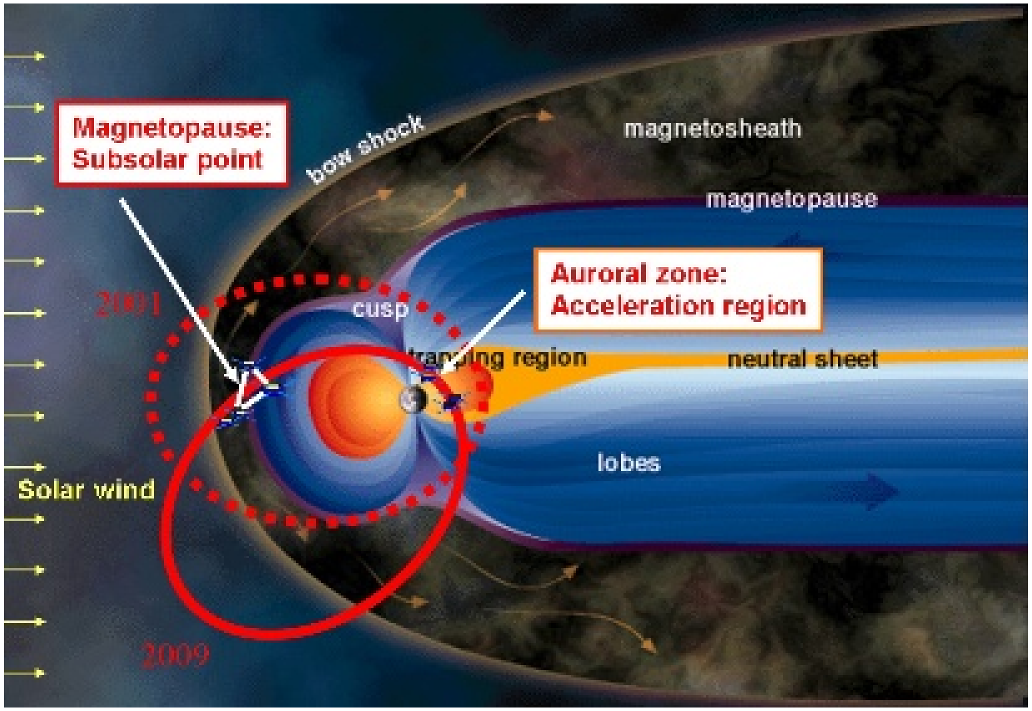
We mainly use data from 4 instruments:

FGM: Fluxgate Magnetometer

EFW: Electric Field and Wave

CIS: Cluster Ion Spectrometry

PEACE: Plasma Electron And Current Experiment



3. Results from two Cluster event studies

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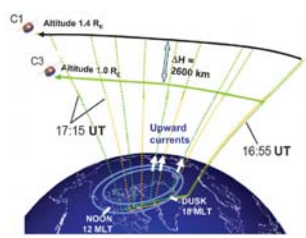
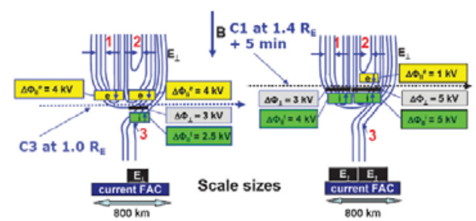
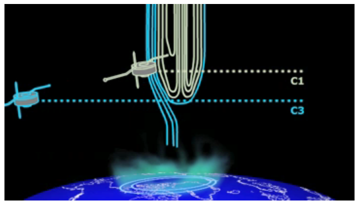
PRL **106,** 055002 (2011) PHYSICAL REVIEW LETTERS week ending 4 FEBRUARY 2011

Altitude Distribution of the Auroral Acceleration Potential Determined from Cluster Satellite Data at Different Heights

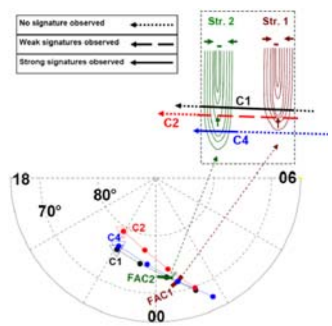


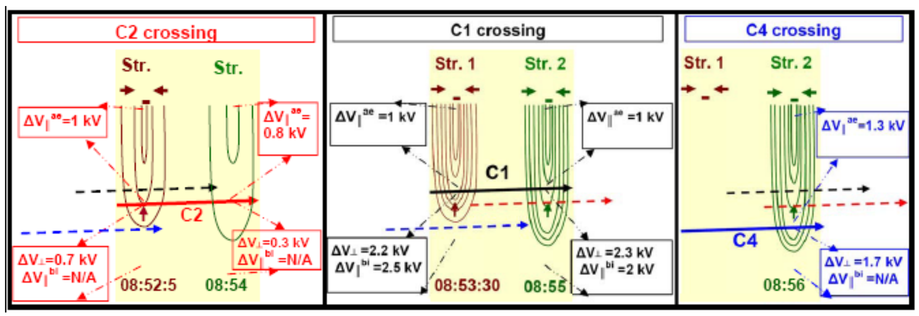




JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, A00K19, doi:10.1029/2011JA016505, 2011

Spatiotemporal features of the auroral acceleration region as observed by Cluster





3.1: Altitude distribution of the auroral acceleration potential determined from Cluster satellite data at different heights
Marklund et al. (2011)

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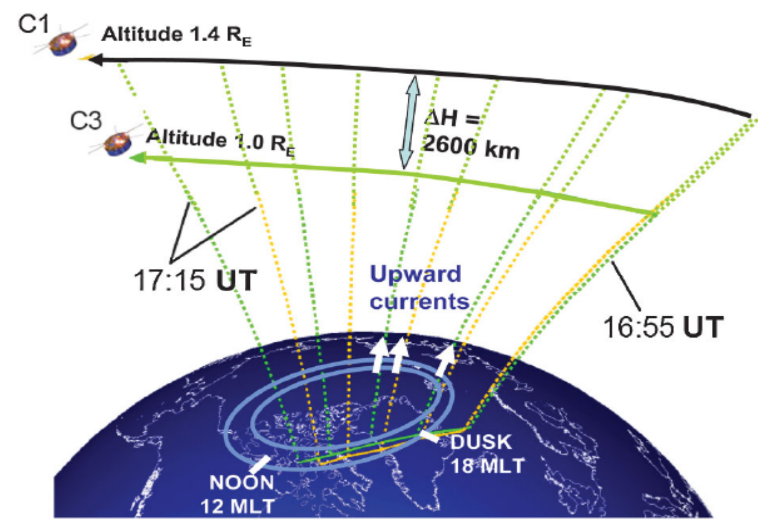
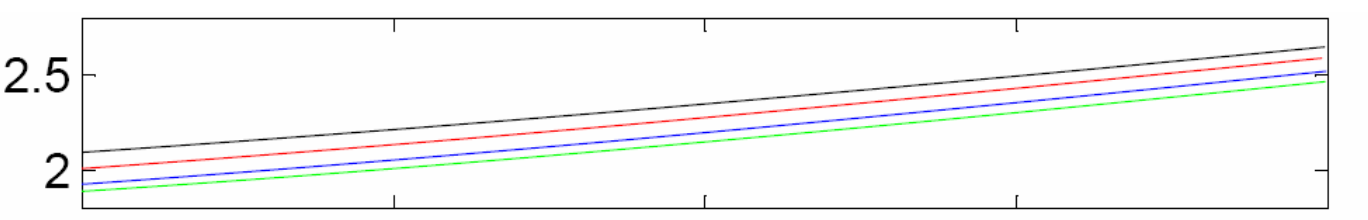
2009-06-05
16:55-17:15 UT
afternoon sector of N auroral oval

ORBIT GEOMETRY



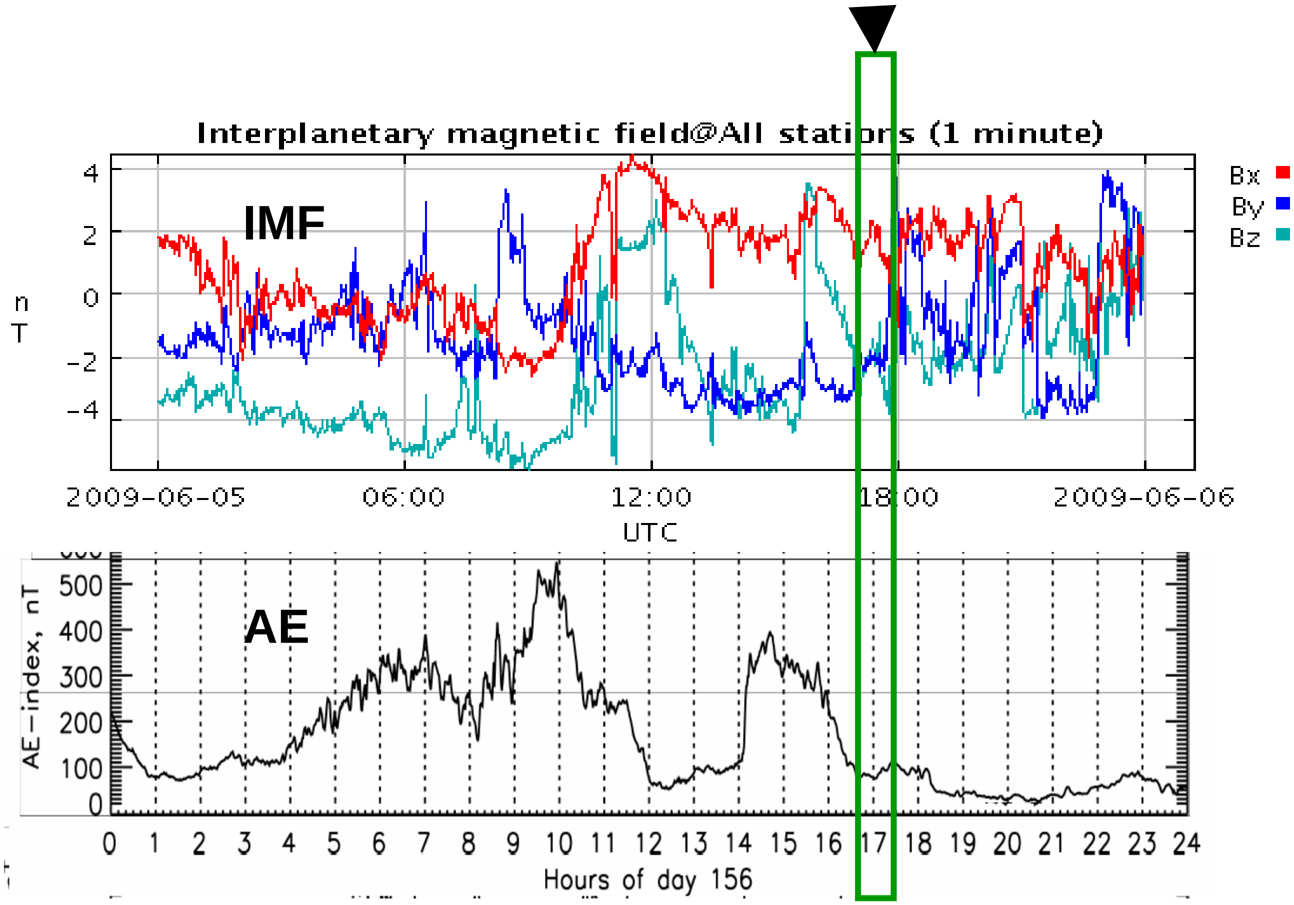
altitude of Cluster s/c (R_E)



16:55 17:00 17:05 17:10 17:15

Event Conditions

Substorm recovery



Cluster 3 data overview from 1 R_E altitude

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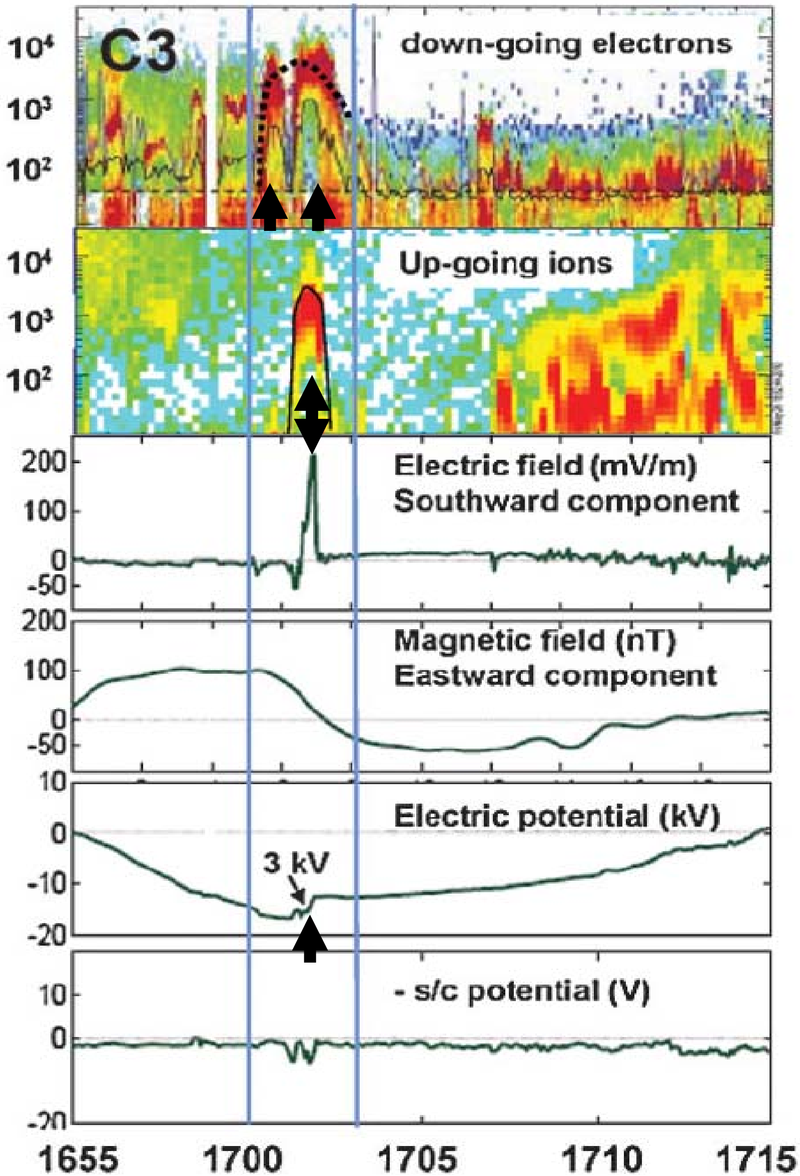

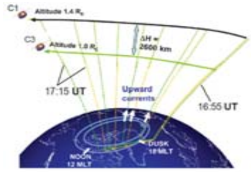

- 2 inverted V-electron beams of peak energies 4 and 5 keV gives acc potential above s/c
- beam of up-going ions, 2.5 keV gives acc potential below s/c
- associated with electric field spike
- Upward field-aligned current carried by the down-going electrons
- Integrating the electric field along the path gives acc potential below s/c
- weak signatures of density cavities

Cluster 1 data overview from 1.4 R_E altitude

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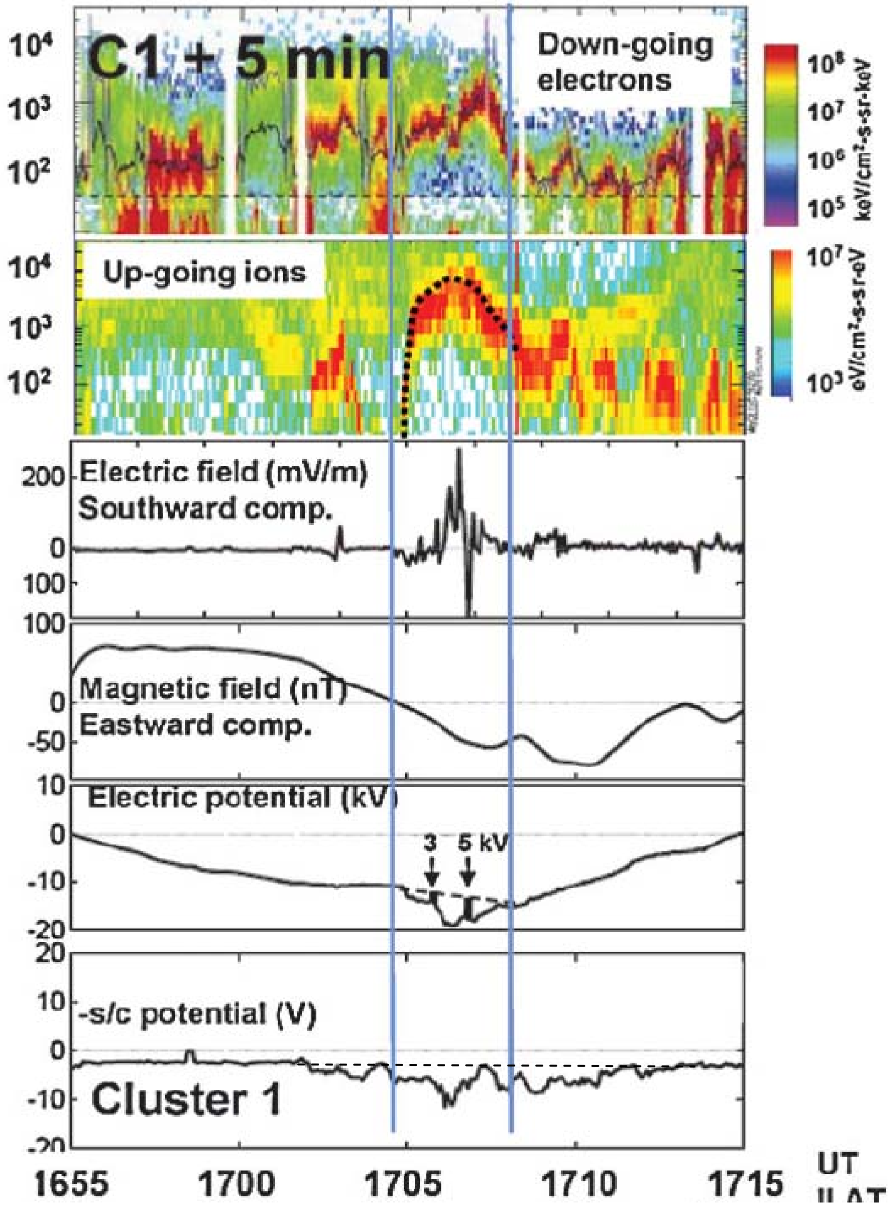

- 2 inverted V-electron beams of peak energies 0.5 and 1 keV gives acc potential above s/c
- broad beam of up-going ions, 4 & 5 keV gives acc potential below s/c
- broad irregular electric field structure
- Upward field-aligned current carried by the down-going electrons
- broad valley in electric potential gives acc potential below s/c
- deeper density cavities

SYNTHESIS of the Cluster 1 and Cluster 3 data

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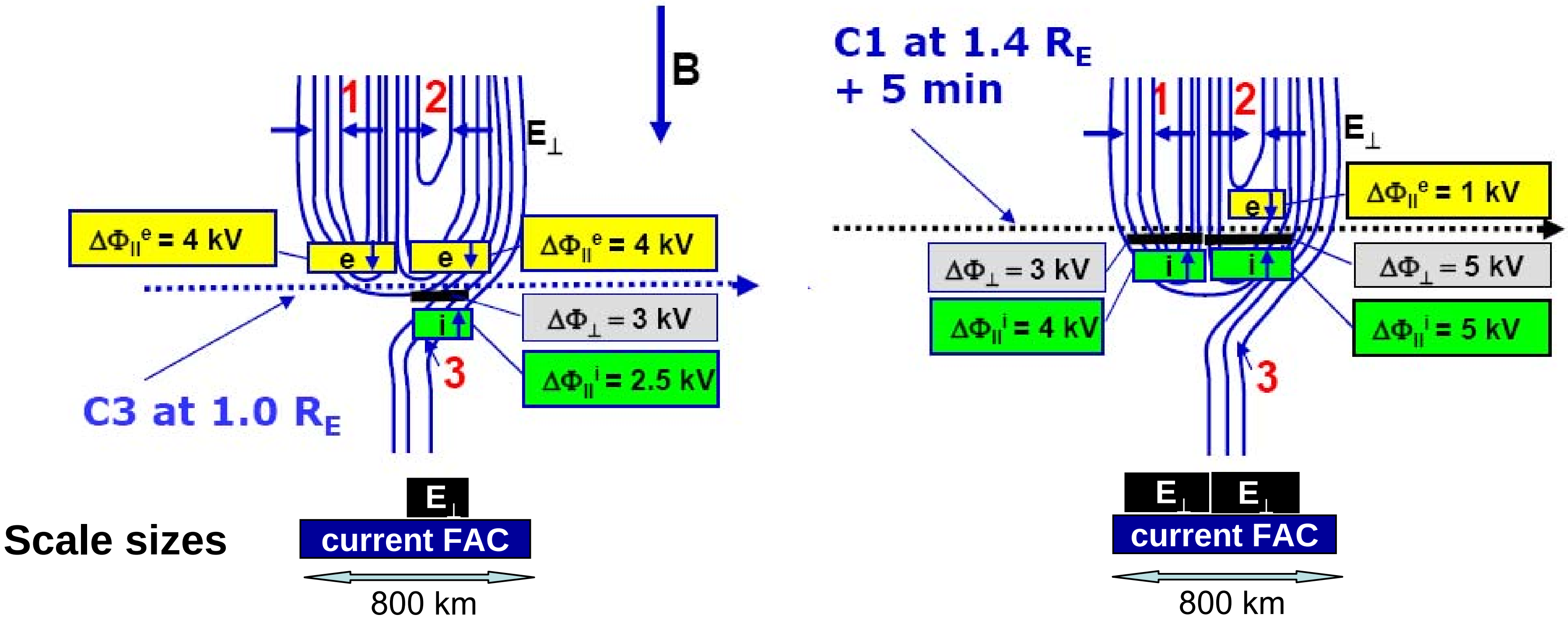

SUMMARY

- Similar energy and width distributions of $e^-_{PA\,=\,0}$ and $i^+_{PA=180}$
- The acc potential is stable on 5 minutes or longer
- $\Delta\Phi_{||}^{Tot}$ along structure 1 & 2,3, are stable at 4 & 6-7 kV
- Scale size of $E_\perp$ << (=) scale size of FAC at 1 (1.4) R_E

Estimates of $\Delta\Phi_{||}$

- ↓ Electrons: peak energy
- $E_\perp$: $\Delta\Phi_{||}$ from $\int E_\perp\, ds$
- ↑ Ions: peak energy

3.2

Growth and decay of a pair of negative potential structures

Sadeghi et al. (2011)

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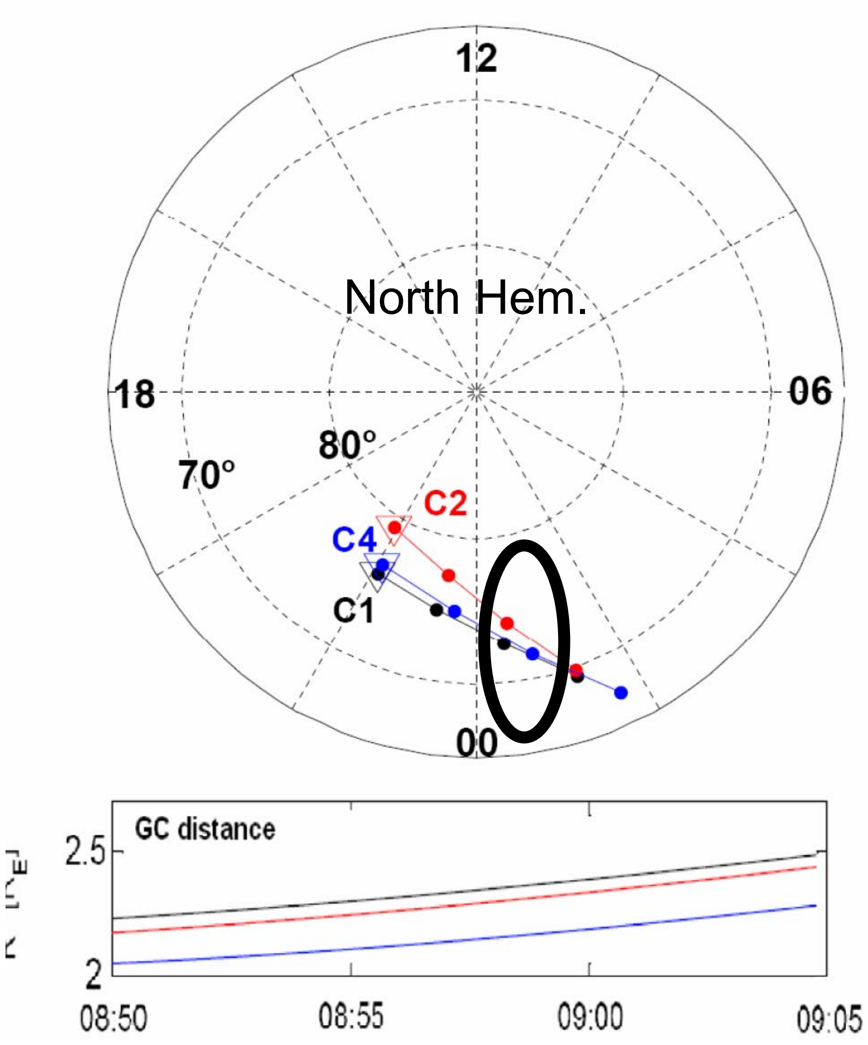
Orbit configuration

2009-Feb-04

-Cluster 1 (at altitude ~1.30 RE)

-Cluster 2 (at ~1.23 RE)
leading Cluster 1 by about 40s

-Cluster 4 (at ~1.13 RE)
lagging Cluster 1 by about 1 min



3. Paper II Event Conditions

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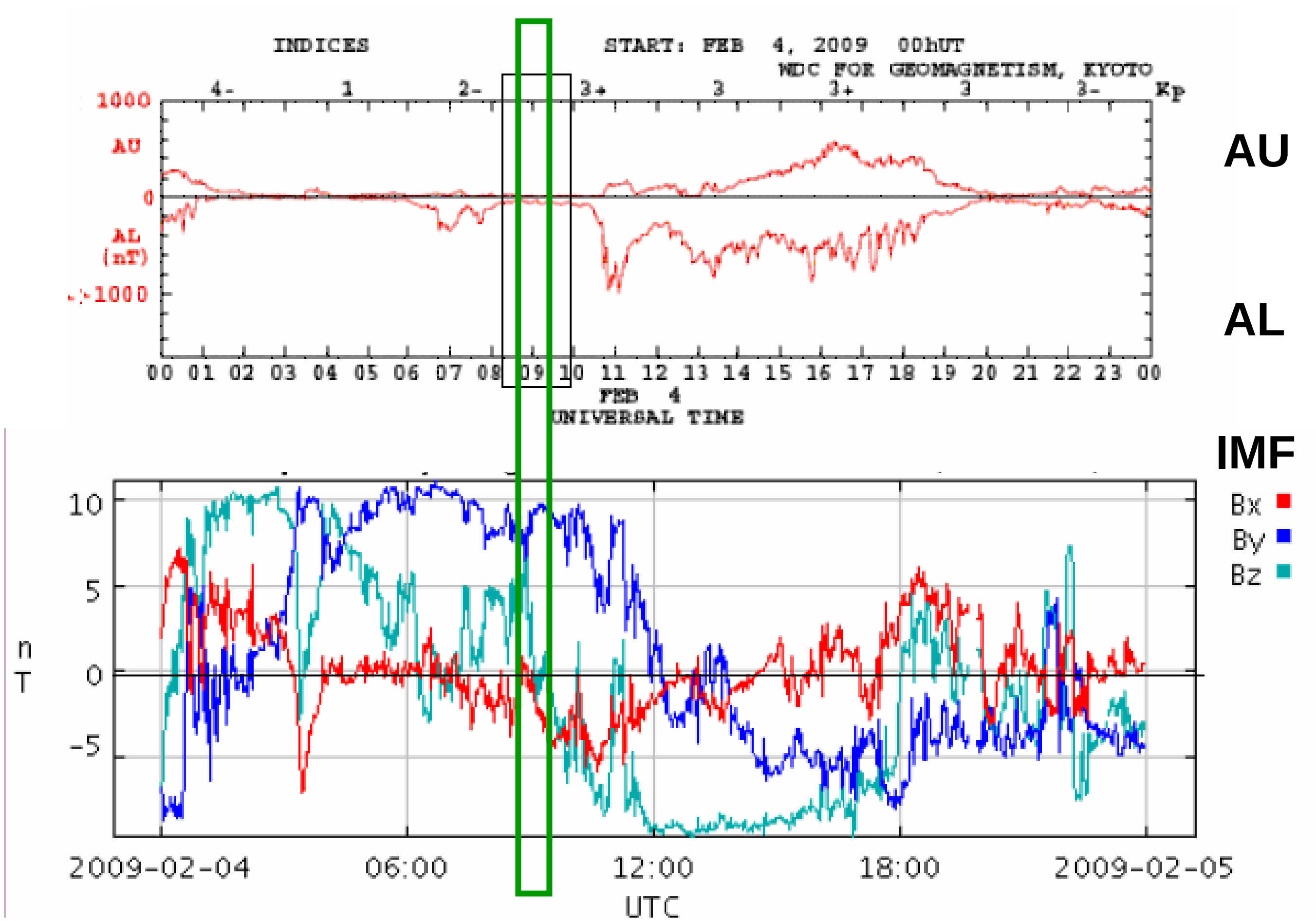
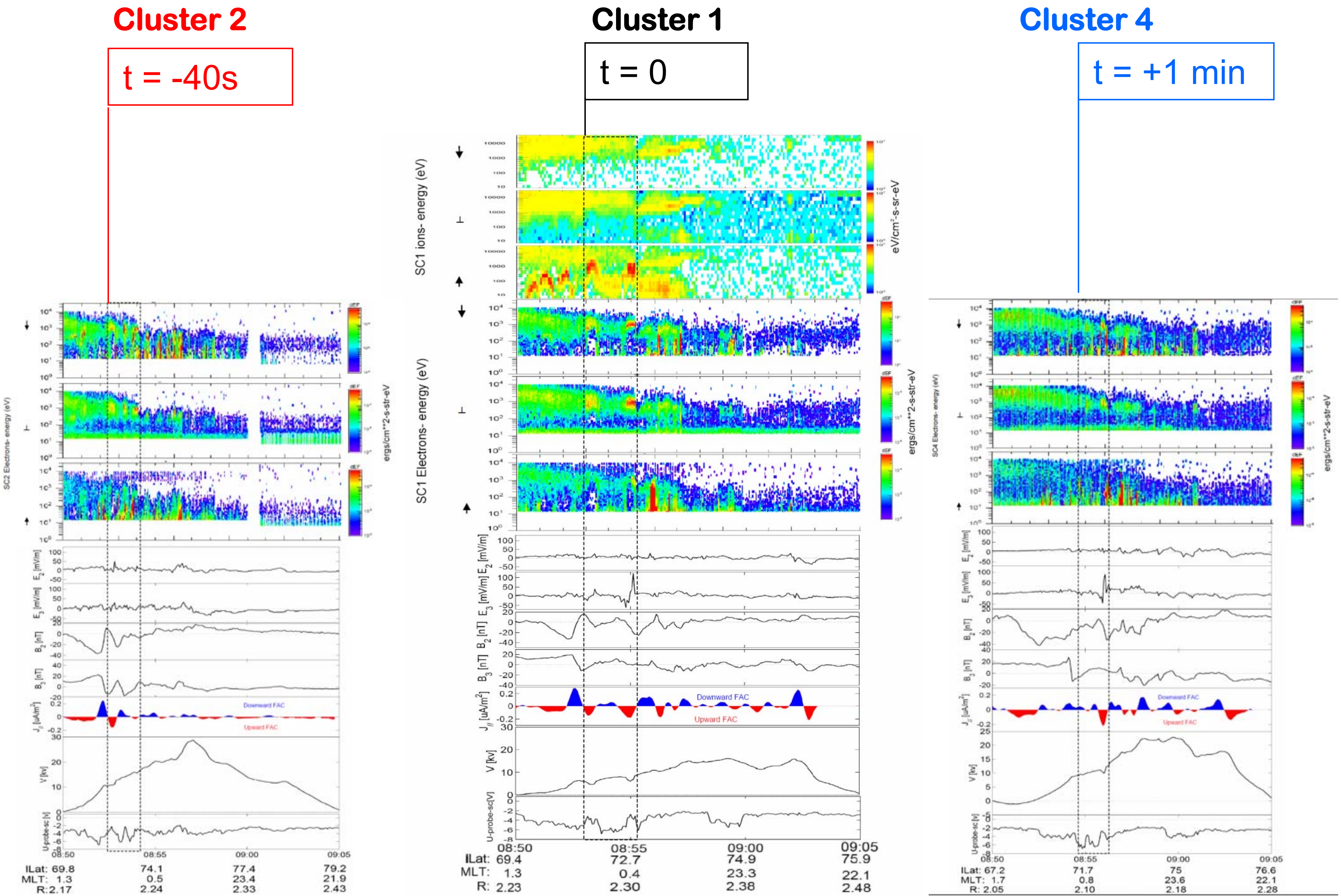
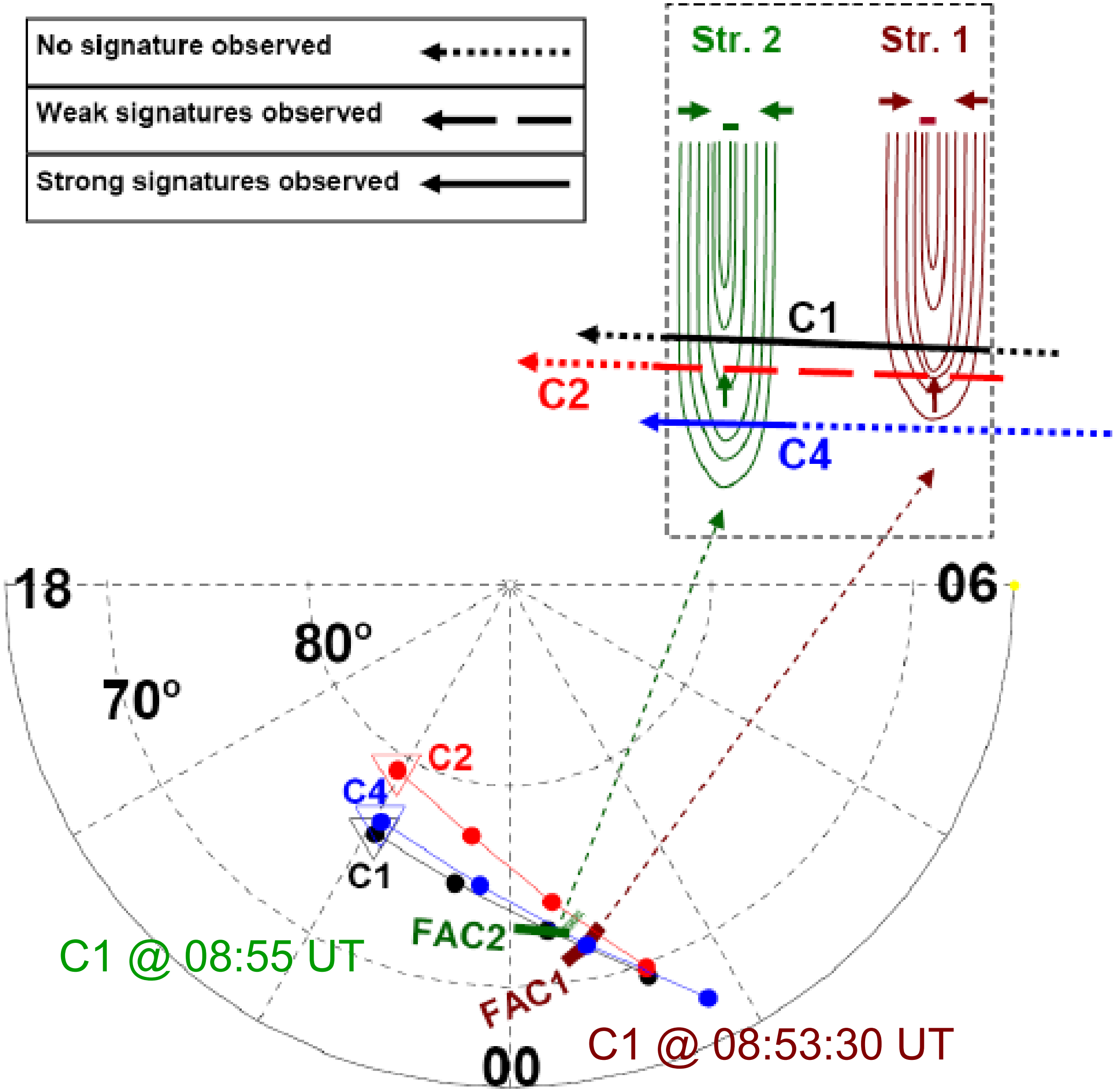
Low geomagnetic activity, AE < 200



3. Paper II Data overview

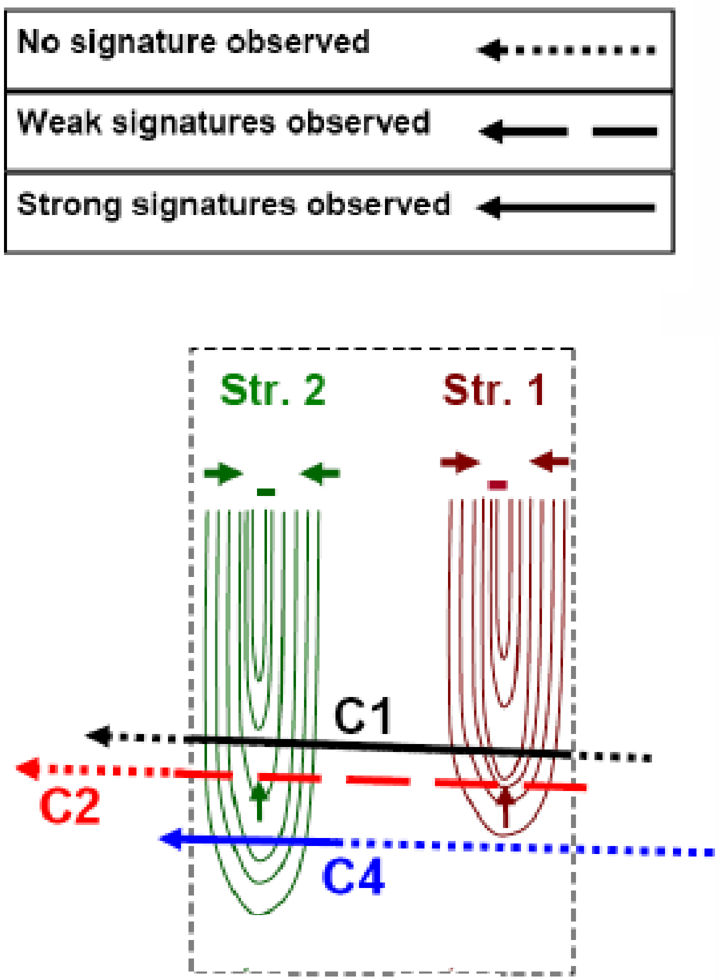


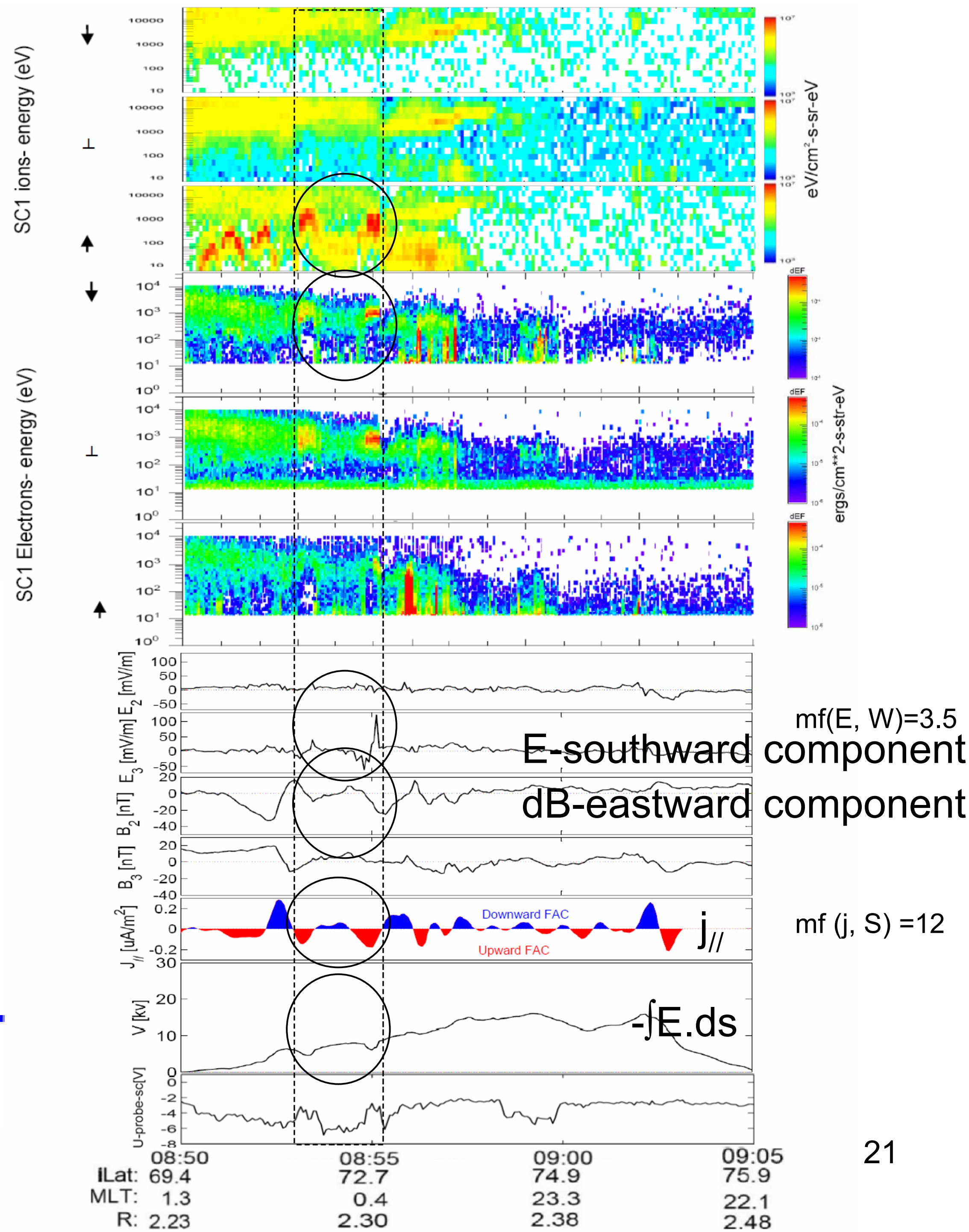
3. Paper II Overview



3. Paper II

Cluster 1 observations

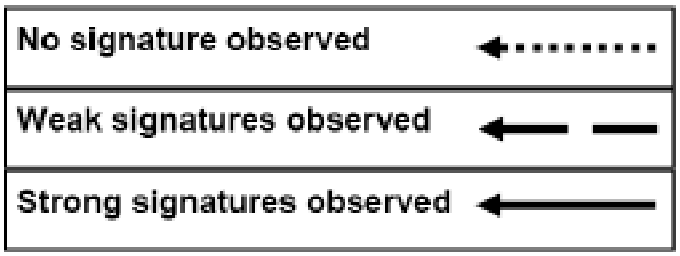


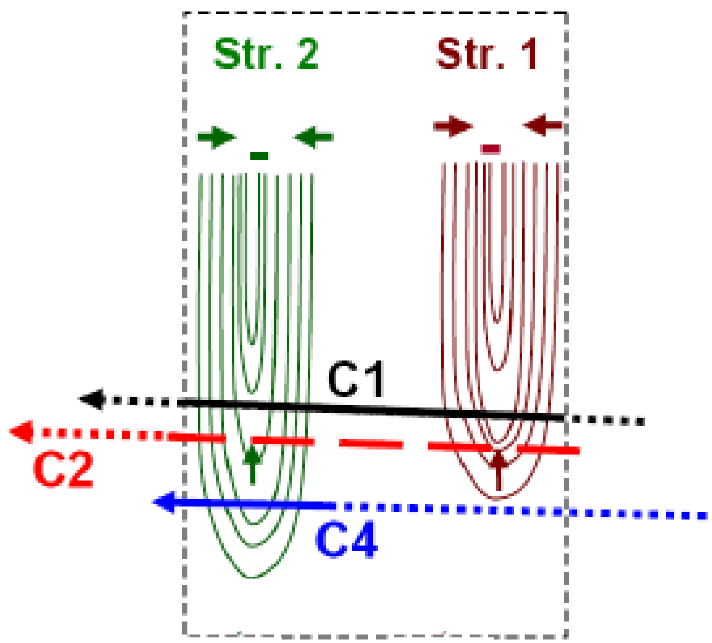


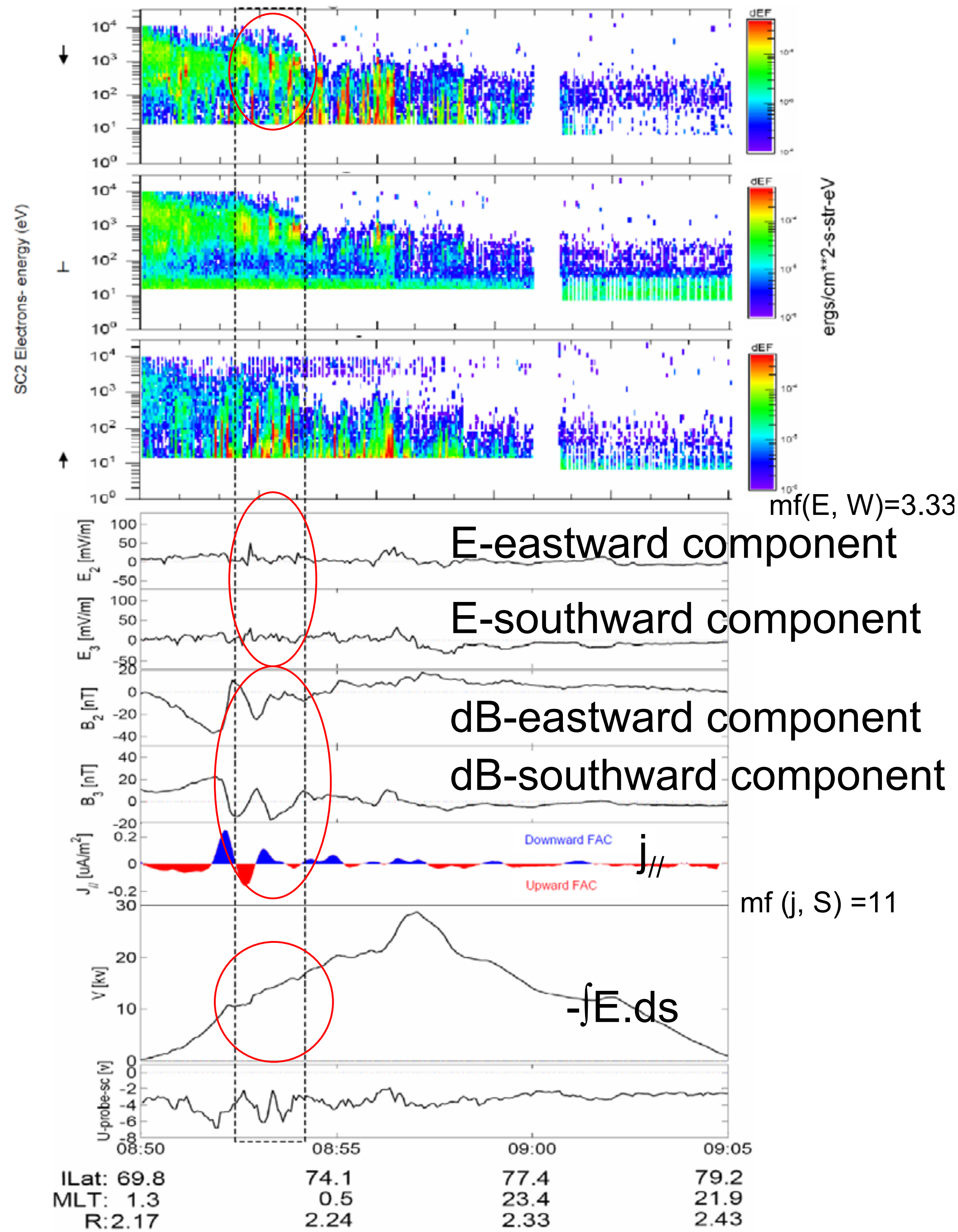
3. Paper II

Cluster 2 observations

40 s before C1

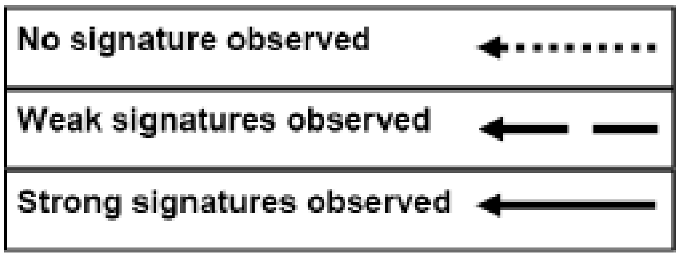


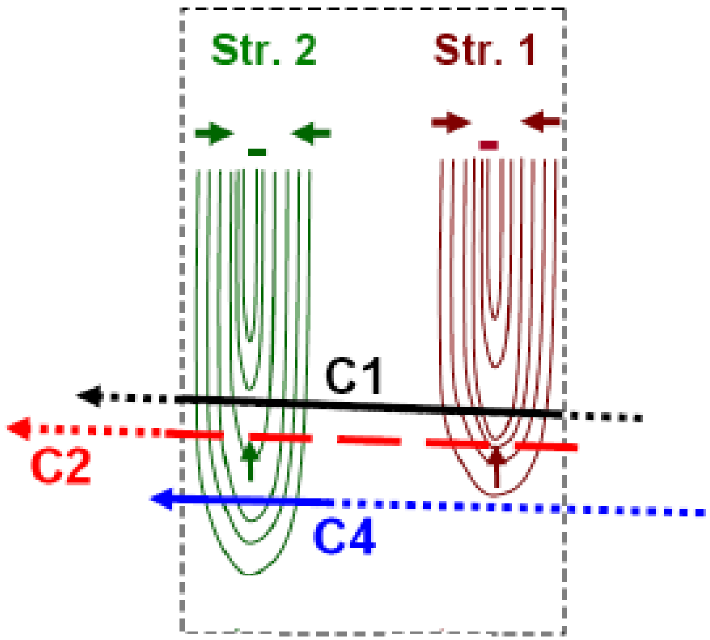


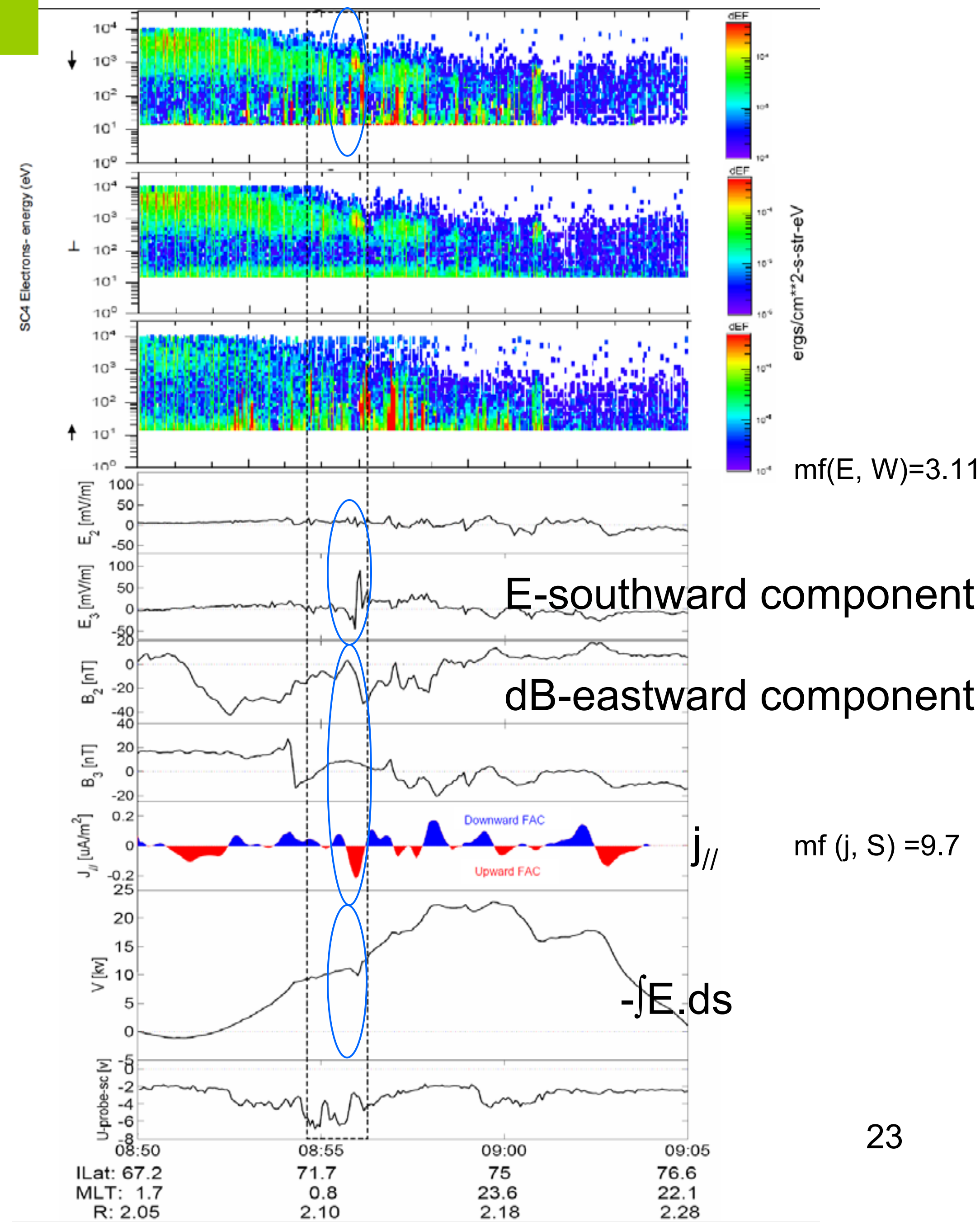


Cluster 4 observations

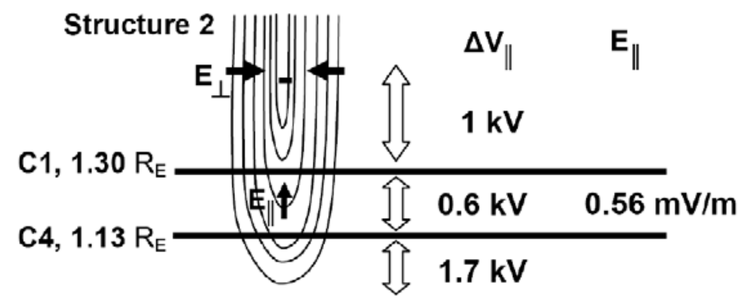
1 min after C1







3. Paper II Summary and Discussion



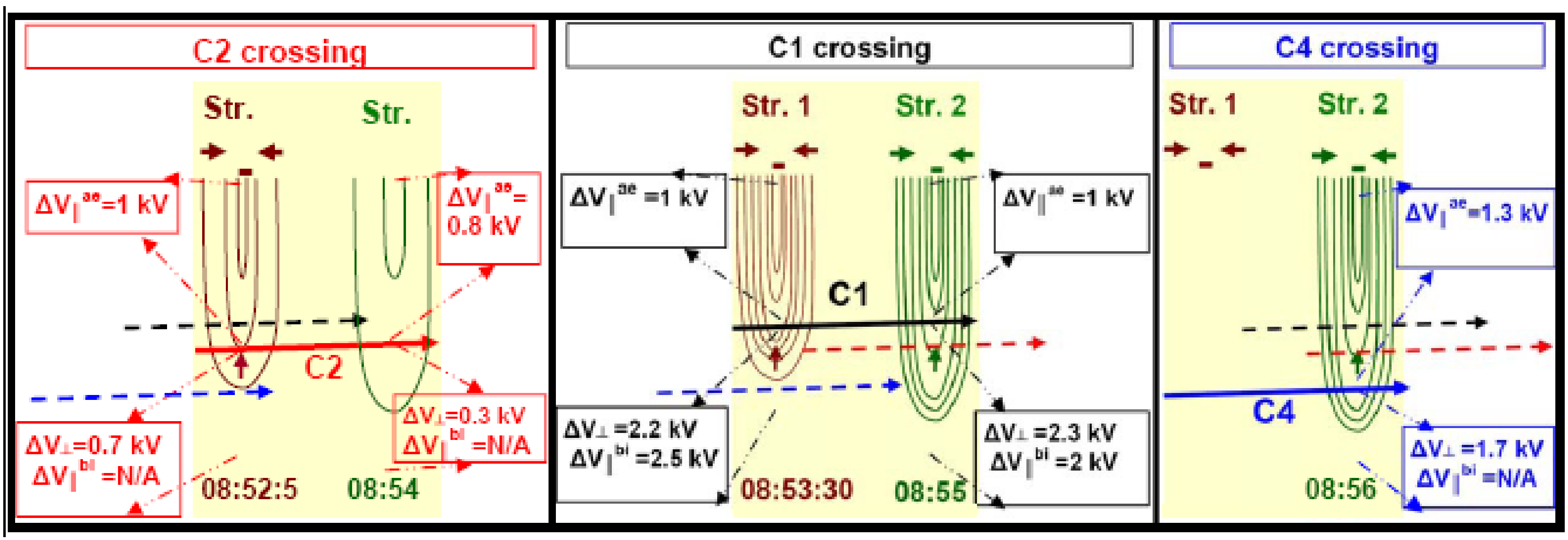
- Structure 1 grew in 40 s and decayed in 1 min.

- Structure 2 grew in 40 s and stayed stable for at least 1 min.

The parallel potential drop between C1, C4 : $\Delta V_{//}$=2.3-1.7=0.6kV

The average parallel electric field: $E_{//}$=0.6kV/1080km=0.56 mV/m (Lindqvist & Marklund 1990,1993: <1mV/m)

- For both structures, the intensification of acceleration potential occurred below 1.3 R_E, but the potential stayed rather constant above.



4. Summary

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Paper I
Here, AAR data of a large-scale dusk-side arc are used to reveal the altitude distribution of its acceleration potential and its stability in space and time. The derived pattern combines two broad U-potentials with a narrow S-potential located below, and is stable on a 5 minute time scale.

Paper II
Here, AAR data of another arc pair are used to derive growth and decay times of the acceleration potentials. For both arcs, the $\Delta V_{||}$ remained roughly unchanged above 1.3 R_E but strengthened below that. For the more stable arc, the average $E_{||}$ between 1.13 and 1.3 R_E was estimated, having a value of 0.56 mV/m.

5. Future work

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-Even closer Conjunction studies with Cluster?!

A toast to *"THE BEER-WARE LICENSE"* then!

Thank you!