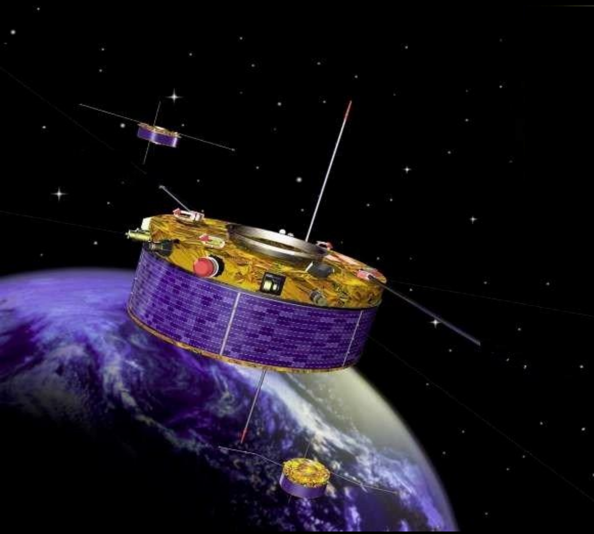
Cluster multi-point studies of the aurora: what did we learn from it ?



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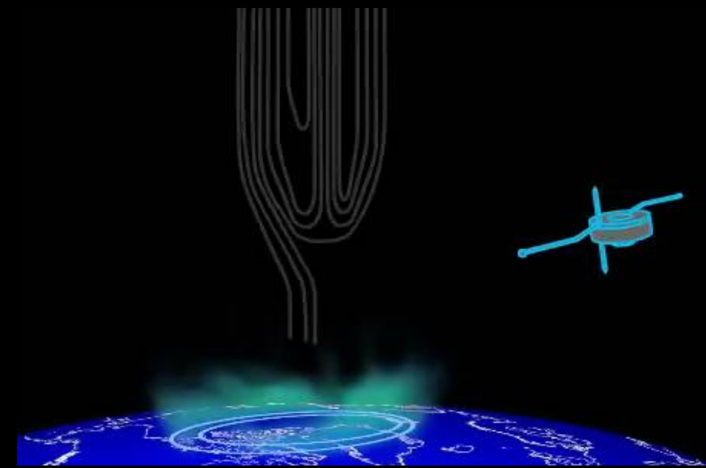
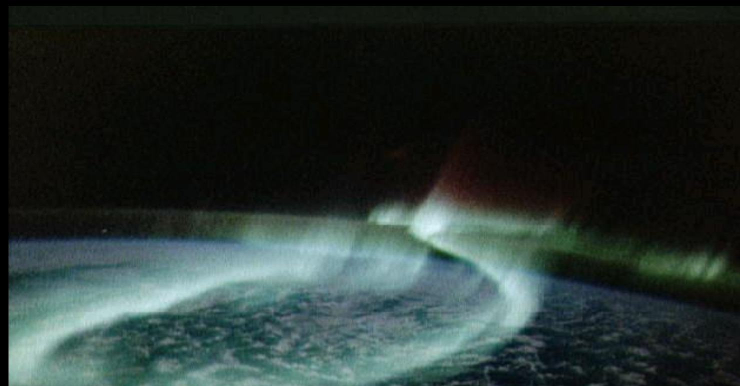
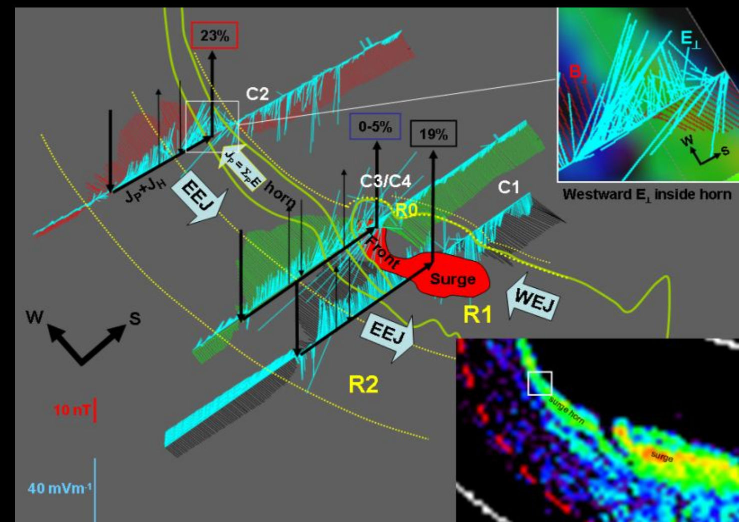




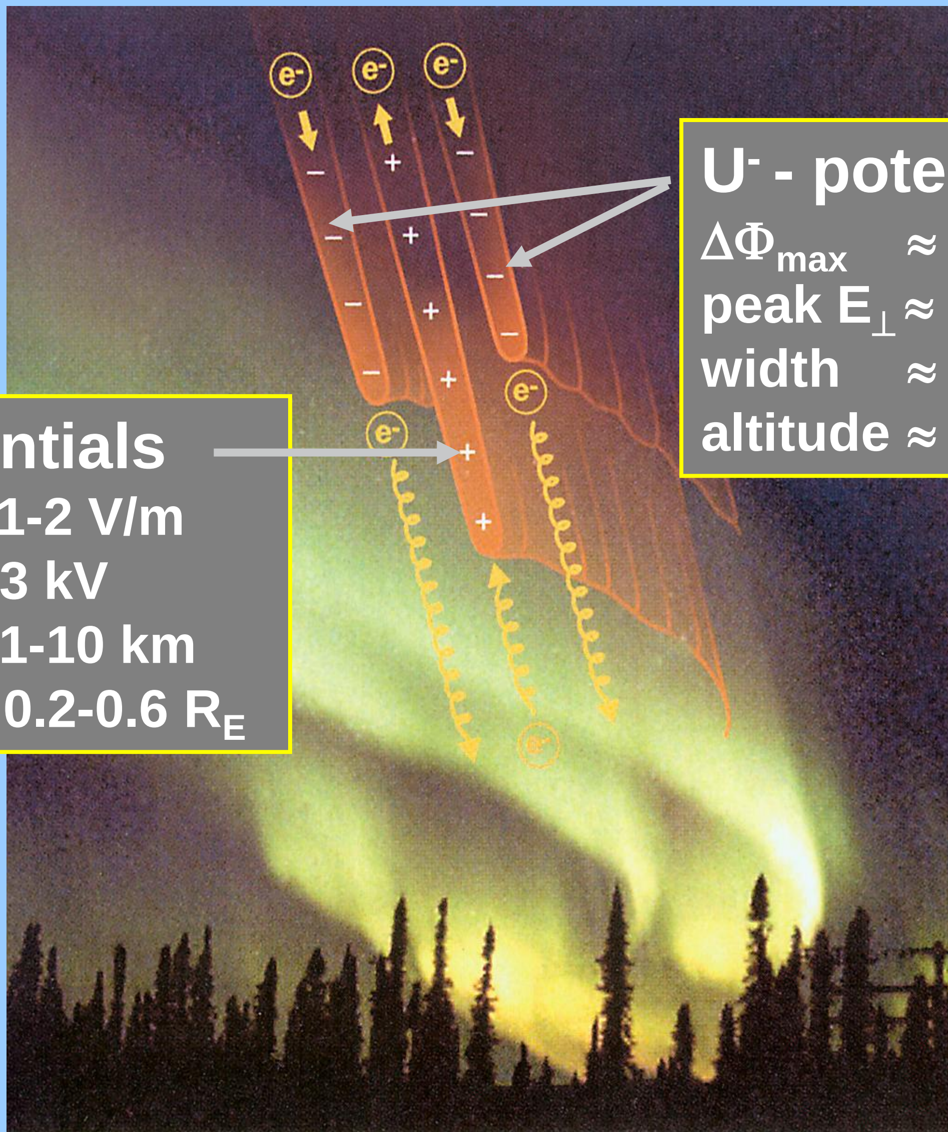
Geospace revisited
Rhodos, 15-20 september 2014



OUTLINE open issues on the aurora-a few examples

Addressed by Cluster	Critical for the study outcome
1. Auroral characteristics Scales, $E_{\perp}$, FACs, n_e gradients	**14 yrs of C1-C4 data, excellent data base for statistical & event studies**
2. Evolution of arcs & potentials Growth, decay, life times?	**Pearls-on-a-string configuration** **Ideal to study the temporal evolution**
3. Structure & Stability of AAR Altitude distrib. of $E_{\|\|}$ and $\Delta\Phi_{\|\|}$?	**Altitude separation between C1 and C3 allows derivation of 2 D acc patterns**
4. U- and S-shaped potentials Rel to plasma boundaries	**Statistics, time lag between C1 and C2**
5. Q-S vs Alfvénic acceleration Rel role, Altitude extent ?	**DMSP images of surge, crossed by C2** **Time lag between C1 and C3/C4**
6. Auroral Density Cavities N_e height profiles, relation to AAR ?	**Good coverage of the AAR by Cluster** **Pseudo-altitude concept**

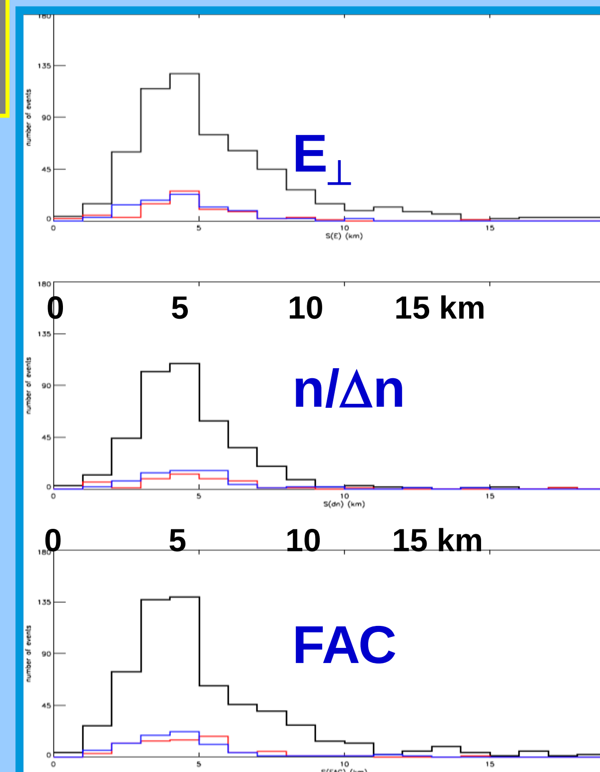
1. AAR characteristics: electric fields, potential drops, scales



U^- - potentials
$\Delta\Phi_{max}$ ≈ -10 kV
peak $E_\perp$ ≈ 1 V/m
width ≈ 3-10 km
altitude ≈ 0.5-2 R_E

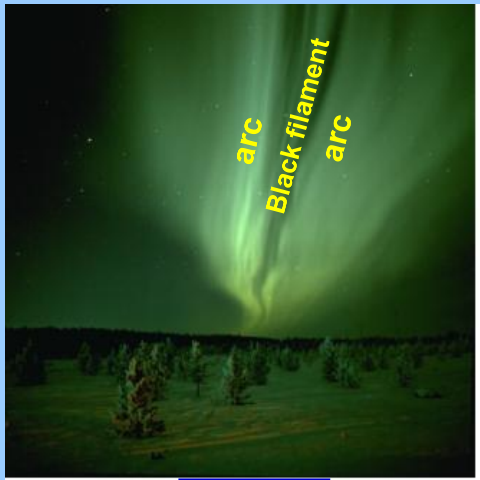
U^+ - potentials
peak $E_\perp$ ≈ 1-2 V/m
$\Delta\Phi_{max}$ ≈ 3 kV
width ≈ 1-10 km
altitude ≈ 0.2-0.6 R_E

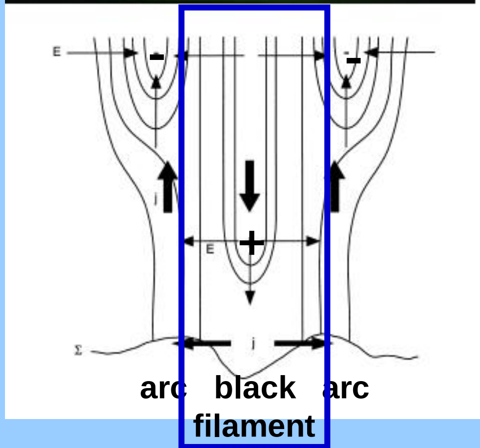
Spatial scales



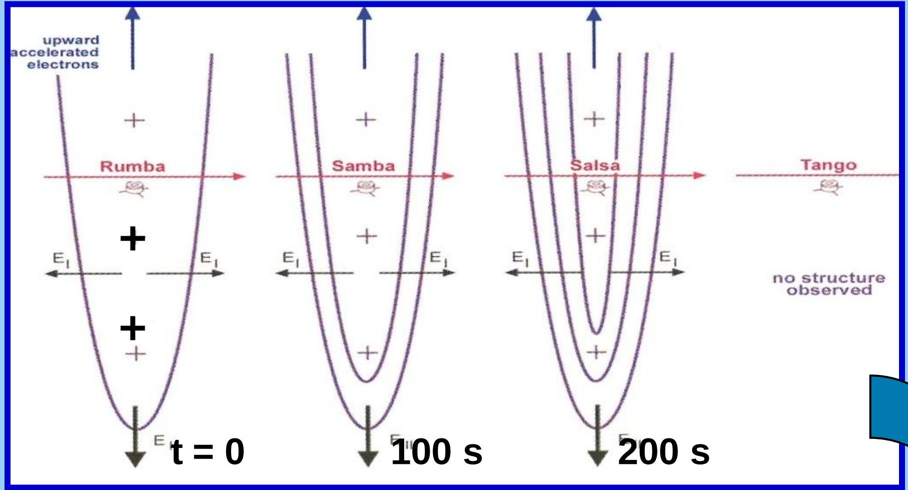
2. Evolution of arcs & potentials-
U⁺ potential growth in downward FACs

EVENT 1
2001-01-14
03 MLT, 04 UT

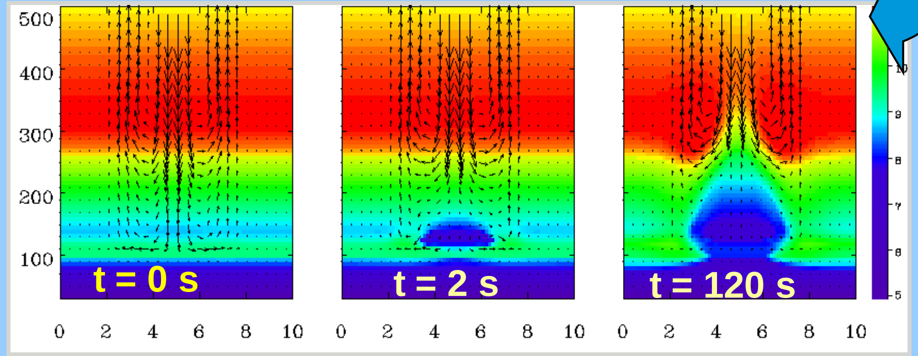




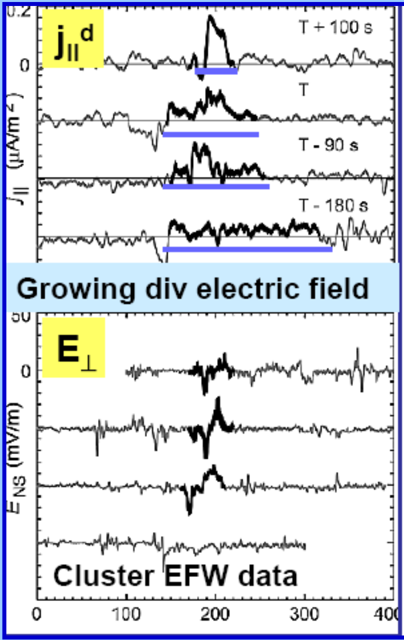
Evolving U⁺-potentials, seen by Cluster

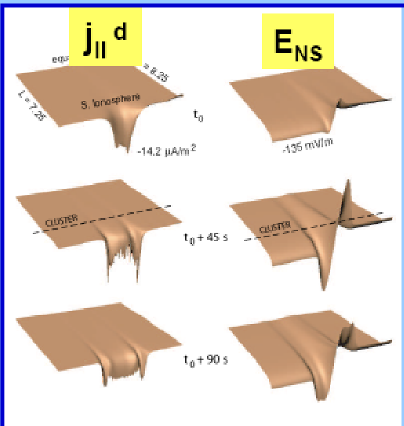


are closely tied to N_e cavity formation



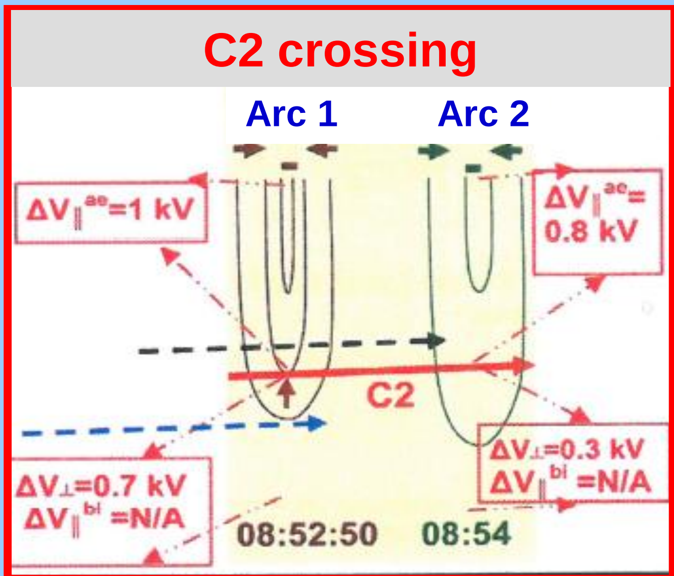
Marklund et al., Nature, 2001

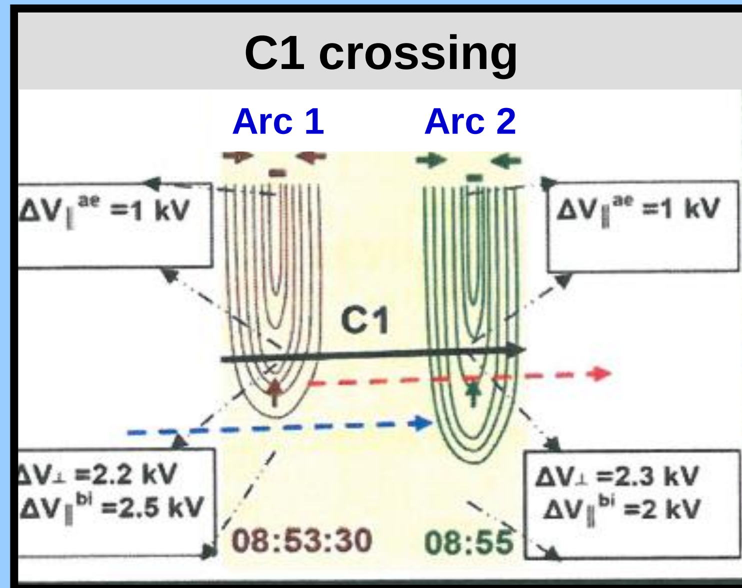


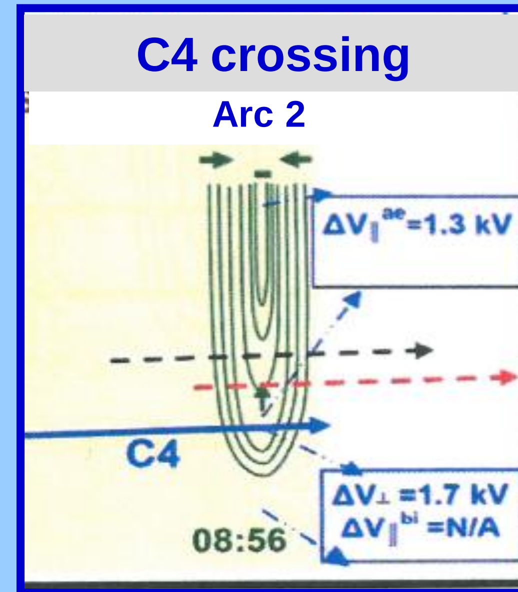


Numerical simulations
Streltsov & Marklund, 2006

2. Evolution of arcs & potentials
Growth & decay of Inv.-V's on ~ 100 s

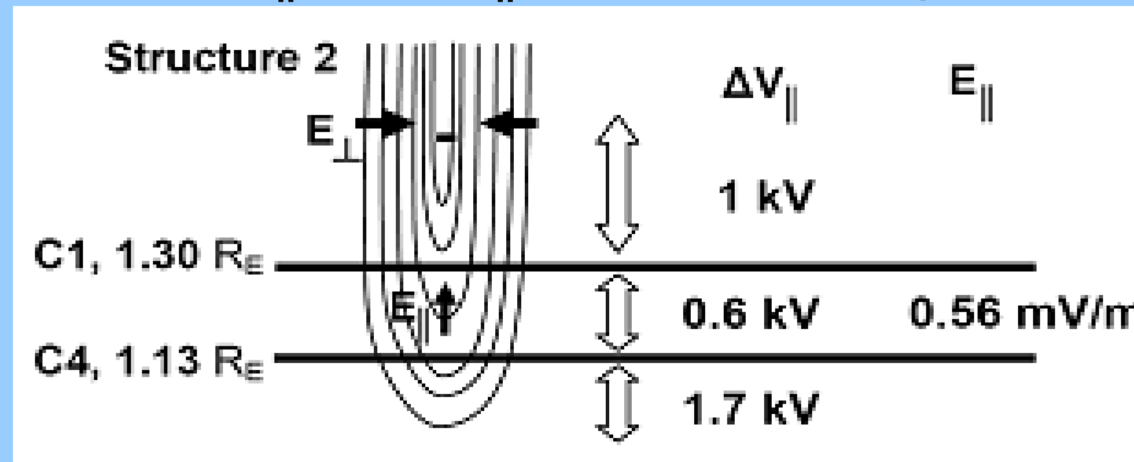






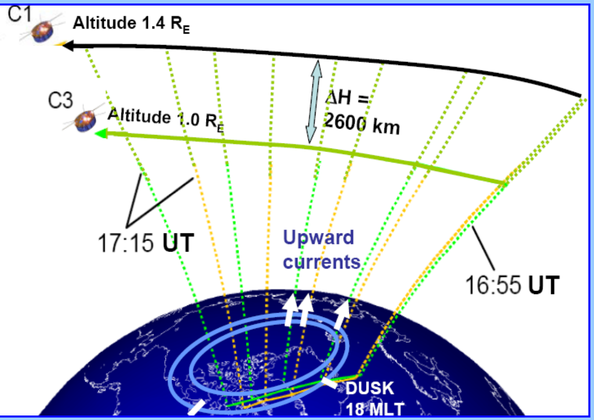
EVENT 2
2009-02-04
0 MLT, 09 UT

Estimate $E_{||}$ and $\Delta\Phi_{||}$ from C1-C4 conjunction



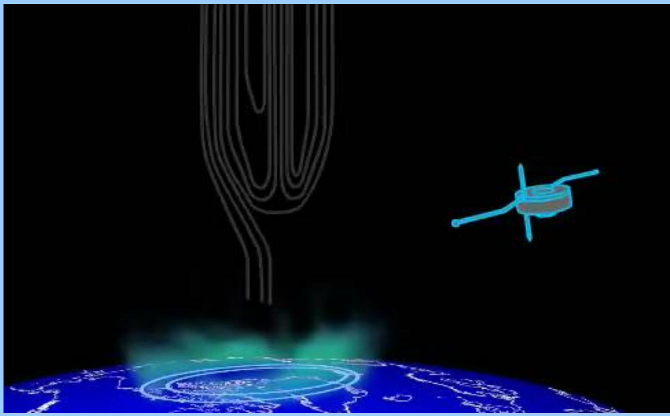
Sadeghi et al., JGR, Sept 2011

3. Structure & stability of the AAR altitude distribution of $E_{||}$ and $\Delta\Phi_{||}$

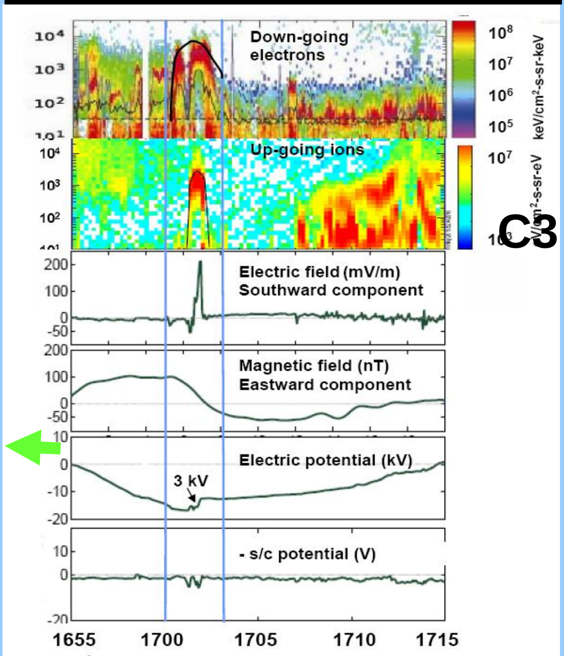


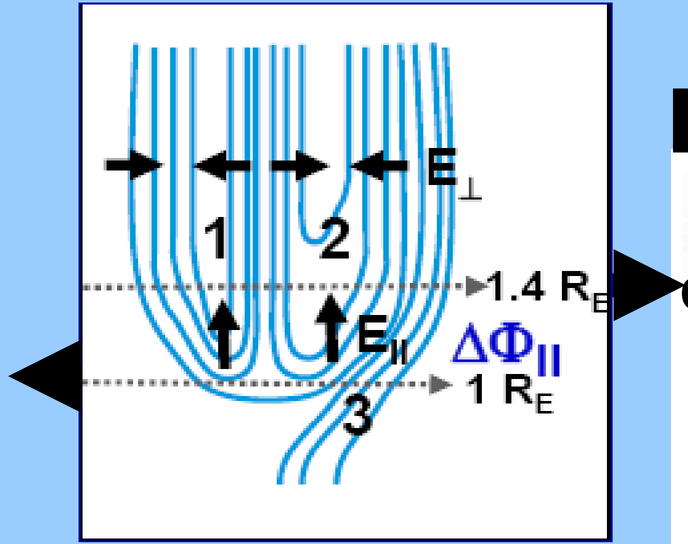
EVENT 3
2009-06-05
18 MLT, 17 UT

Marklund et al., PRL, Feb 2011

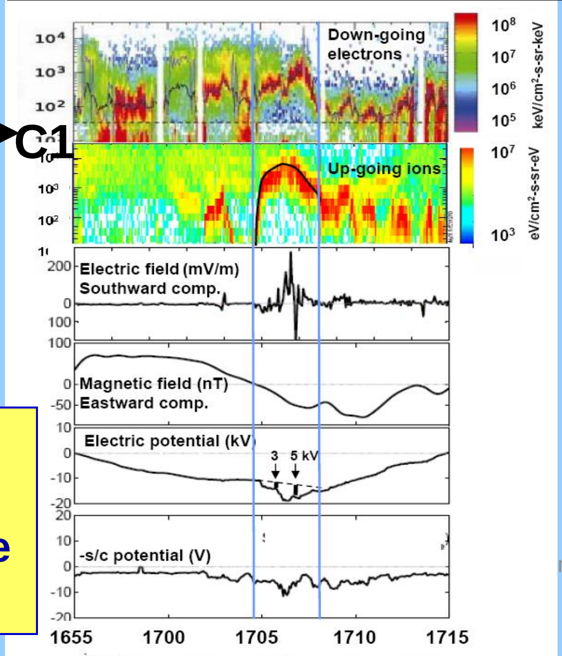


Cluster 3 data from H = 1 R_E





Cluster 1 data from H = 1.4 R_E



Two U-shaped + one S-shaped potential combined, consistent with C3 and C1 data, and stable on a time scale of 5 minutes

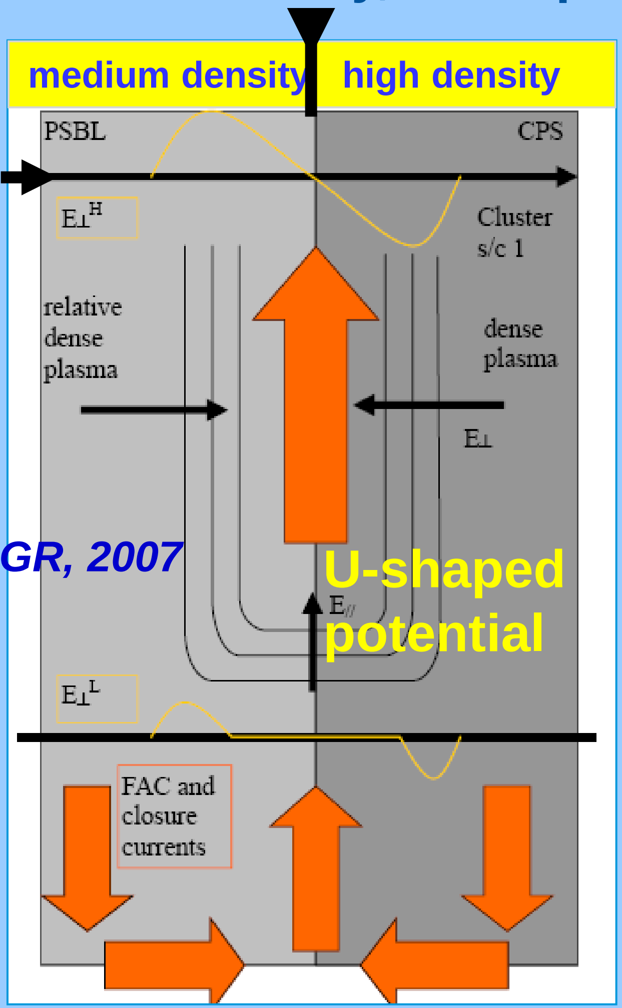
4. Structure & stability of the AAR
U/S-potentials adjust to the boundary shape

EVENT 4
2009-05-01
20 MLT, 15 UT

Marklund et al. JGR, 2007

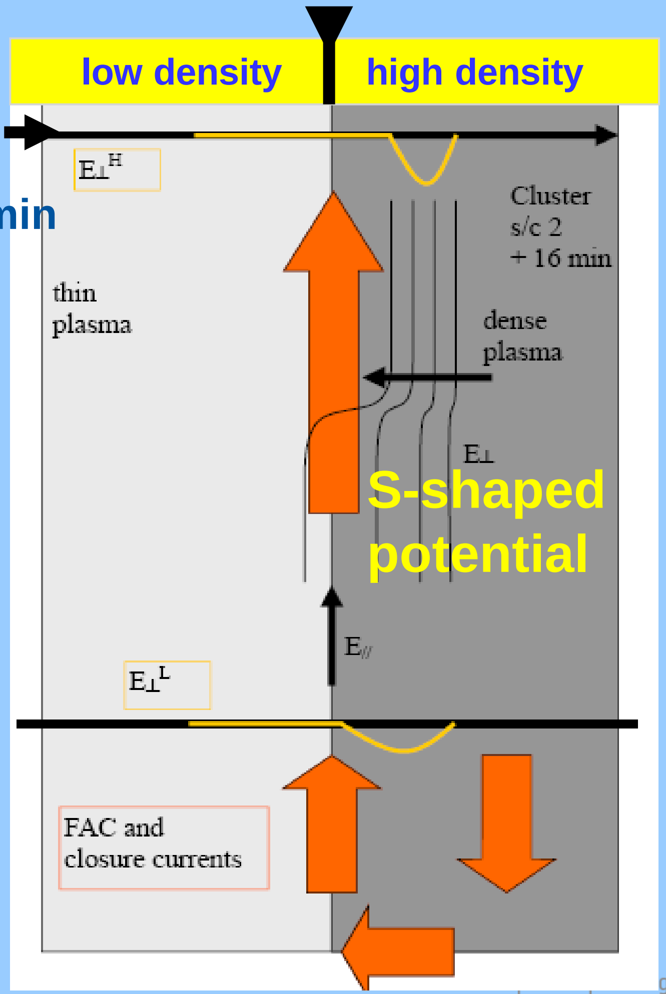
Soft boundary, U-shape

C1
$t = t_0$



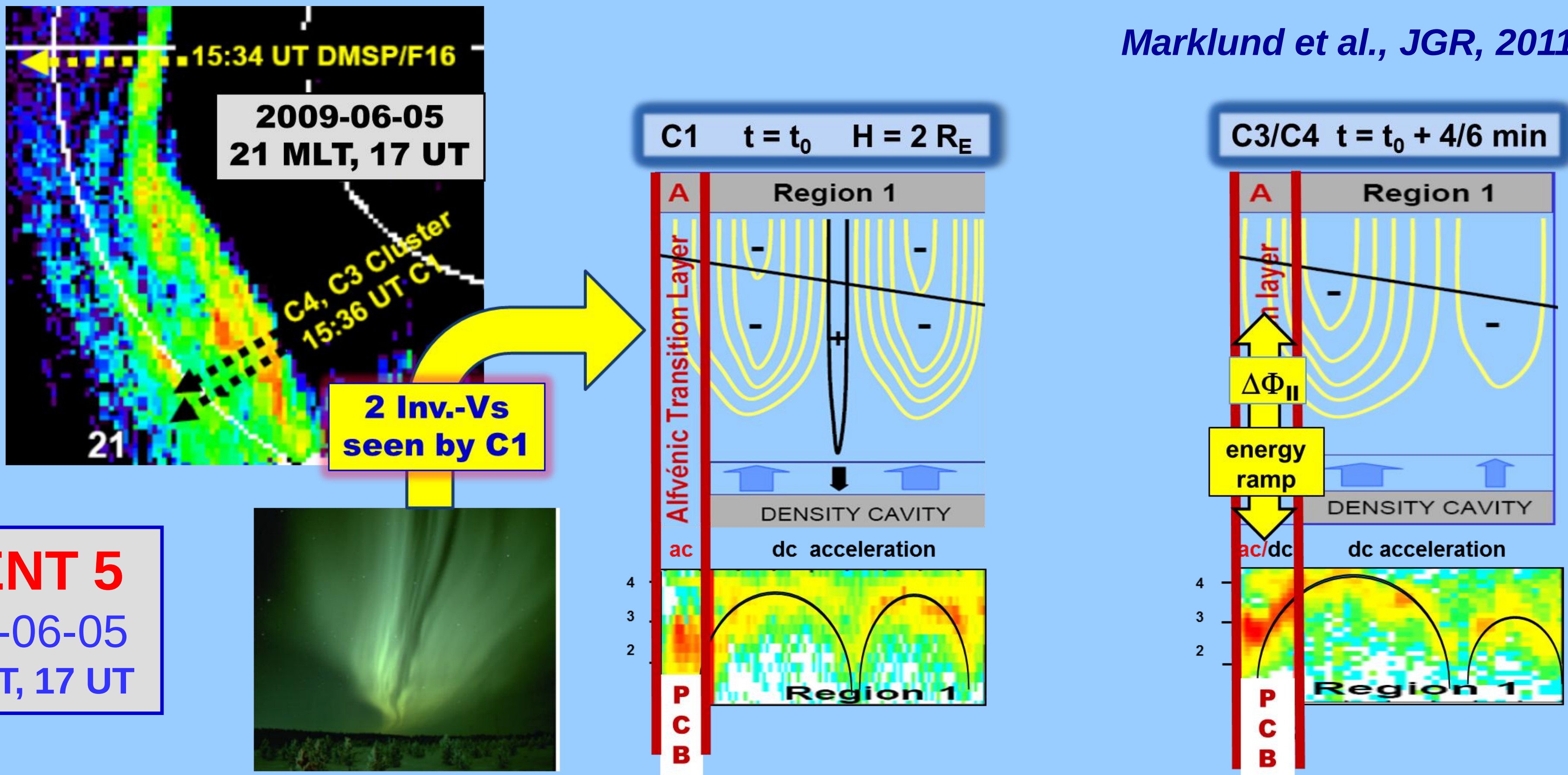
Sharp boundary, S-shape

C2
+15 min



5. Quasi-static vs Alfvénic accele–ration - interaction at the PCB

Marklund et al., JGR, 2011

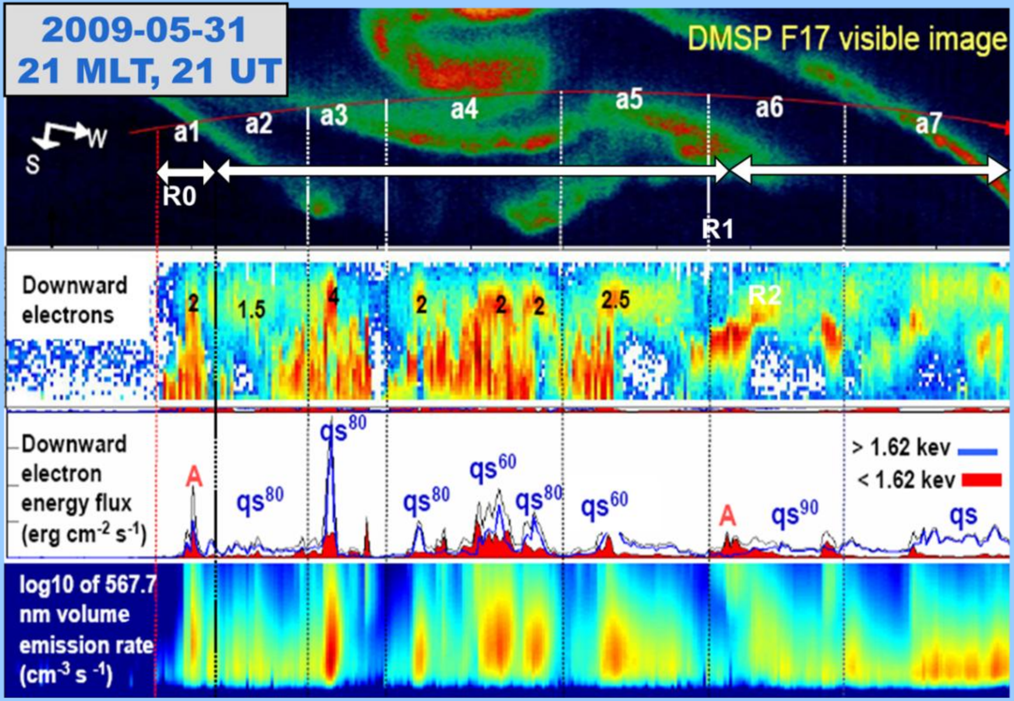


EVENT 5
2009-06-05
21 MLT, 17 UT

❖ $\Delta\Phi_{II}$ of the U-potential, extending into the PCB, raises the ion energy to 10 keV.

❖ Thus, quasi-static & Alfvénic acceleration act jointly on the PCB plasma population

5. Quasi-static vs Alfvénic acceleration– relative role for WTS arcs



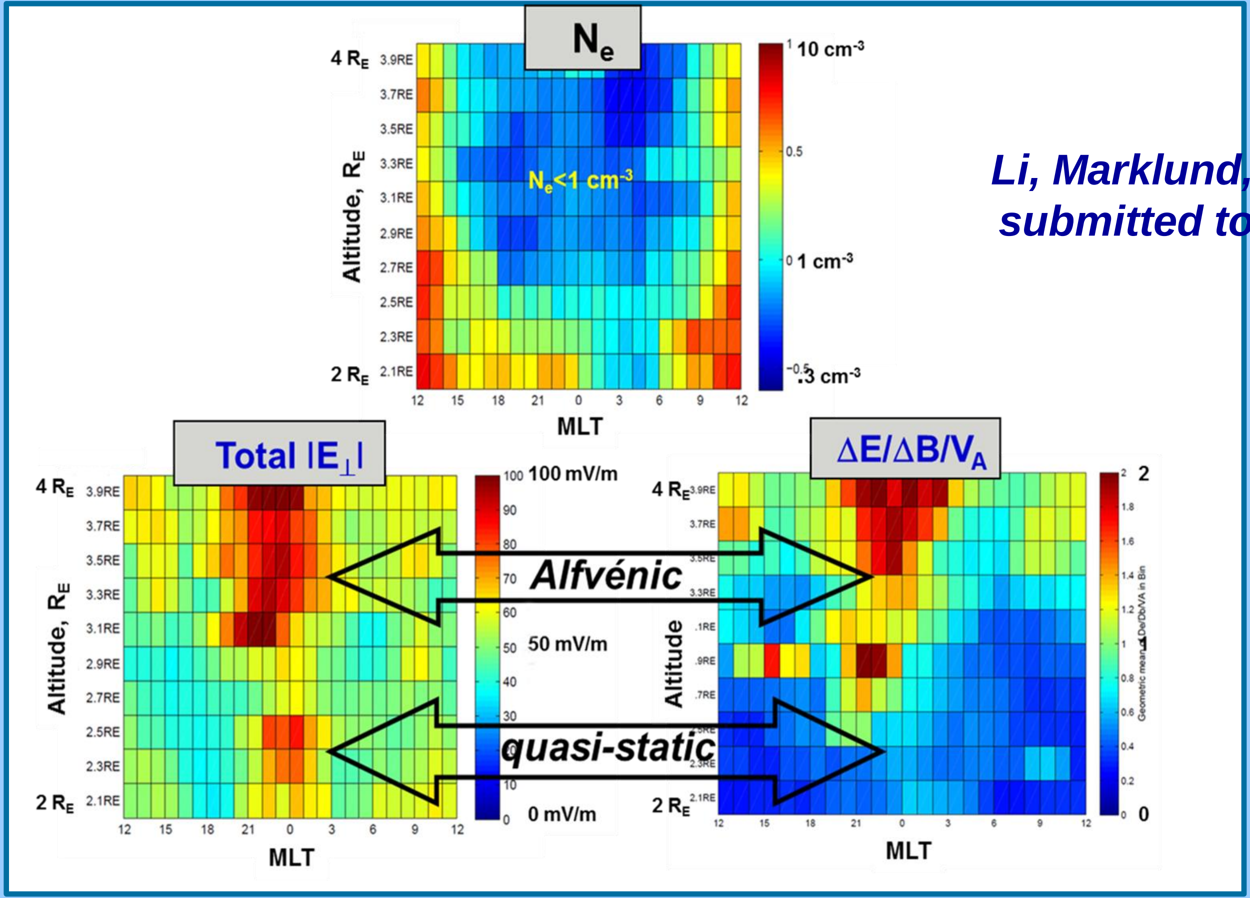
No	Aurora	Acc type	$\Delta\Phi_{\parallel}^{above}$	$\Delta\Phi_{\parallel}^{below}$	N_e-cavity
a1	PCB	Alfvénic	< 2 kV		decrease
a2	weak,broad	Inverted-V	1.5 kV	1.5 kV	yes, clear
a3	Fold	Inv.-V, embedded in Alfvénic region	4 kV	0 kV	no, below AAR
$a4_1$	surge head	Inv.-V surrounded by Alfvénic region	2 kV	2 kV	intense n_e peak
$a4_2$	surge head	Inv.-V, embedded in Alfvénic region	2 kV	1.5 kV	weak n_e peak
$a4_3$	surge head	Inv.-V surrounded by Alfvénic region	2 kV	3 kV	intense n_e peak
a5	fold-W	Inv.-V adjacent to Alfvénic region	2.5 kV	4 kV	weak n_e peak
a6	sub-visual	Alfvénic	< 0.8 kV		increase
a8	surge horn	Inverted-V	2 kV	0 kV	no, below AAR

EVENT 6
2009-05-31
21 MLT, 21 UT

- ❖ **Alfvénic electrons mostly in R1 / quasi-static in R2**
- ❖ **PCB** (Alfvénic), **horn** (quasi-static), **surge head** (60-90% quasi-static)
- ❖ **High (low) energy electrons dominate the ↓ (↑) energy flux**
- ❖ **No N_E cavities within Alfvénic arcs, which extend to high altitudes**

Li, Marklund, Karlsson, et al, JGR, 2013

5. Statistical altitude distributions of Electric fields & N_E ; origin ?



Li, Marklund, Alm, Karlsson, submitted to JGR, May 2014

- Large-scale nightside density cavity, extending in MLT with height
- The altitude distribution of intense $E_\perp$, show a clear gap at 2.8 R_E
- Below 2.8 RE, mainly quasi-static, above Alfvénic fields (

6. Auroral Density Cavities, altitude profiles of Ne in the AAR

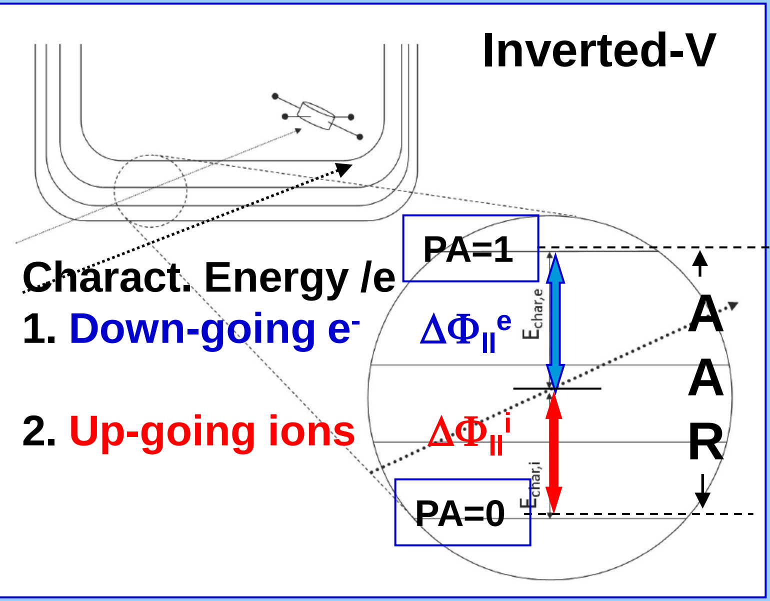
Pseudo altitude

PA (t) = 1- $\Delta\Phi_{||}^{a}$ (t) / $\Delta\Phi_{||}^{TOT}$

related to the AAR

PA = 1 at the top

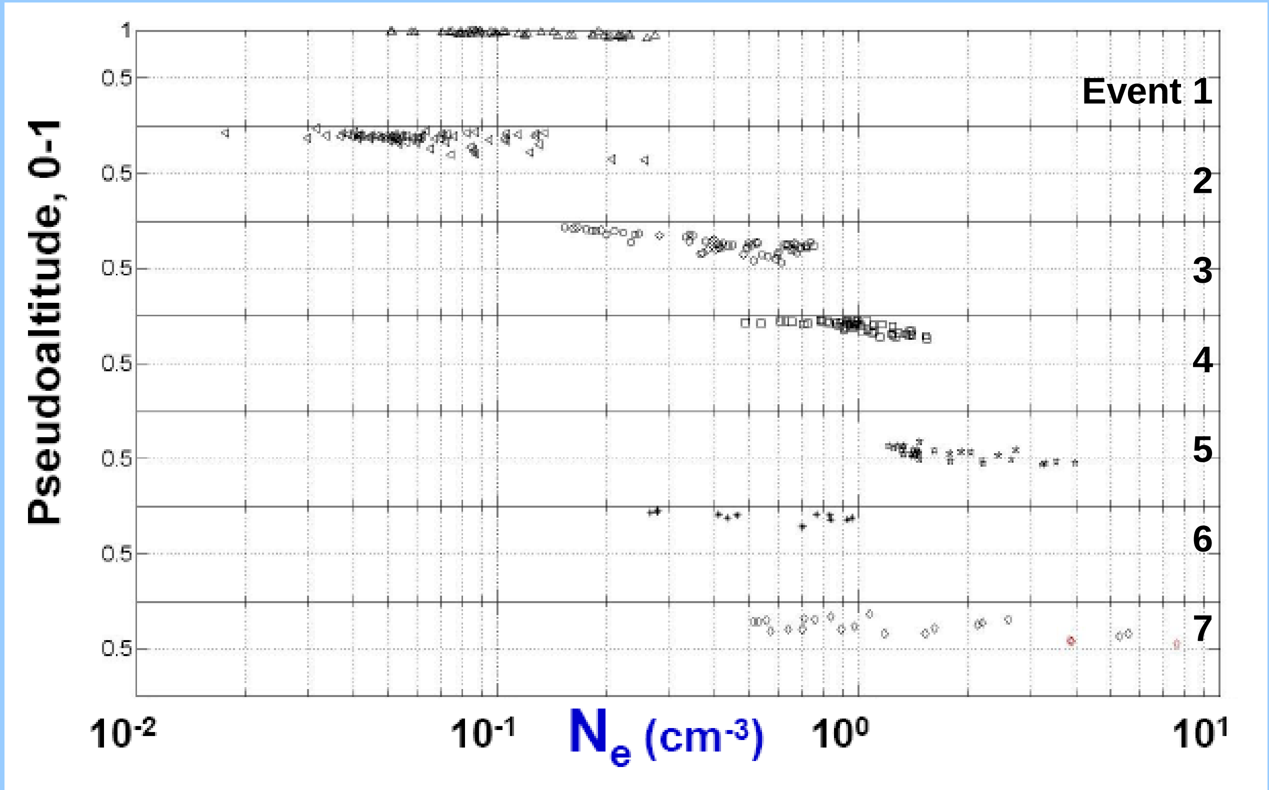
PA = 0 at the bottom



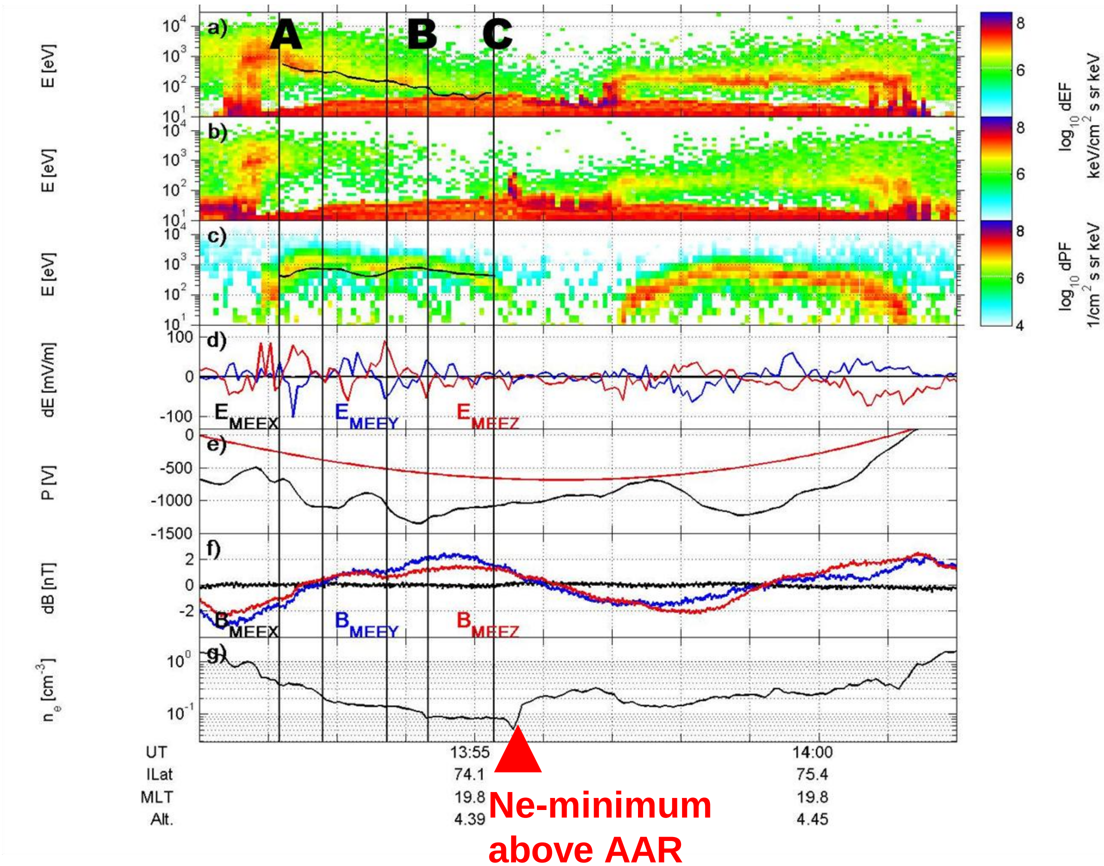
Alm, *Marklund, Karlsson, JGR, 2013.*

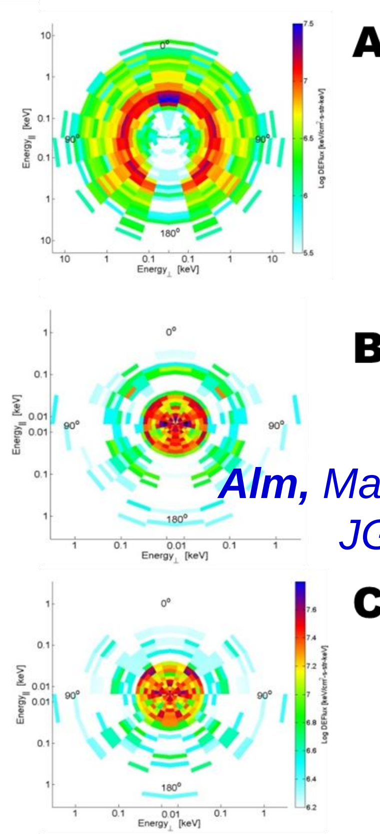
Conclusions from initial study of 7 events

- N_e drops by a factor 10-100, towards PA=1
- Lower limit exists at PA = 0.4-0.5
- No upper limit seems to exist



6. Auroral Density Cavities-not confined by but extending above the AAR

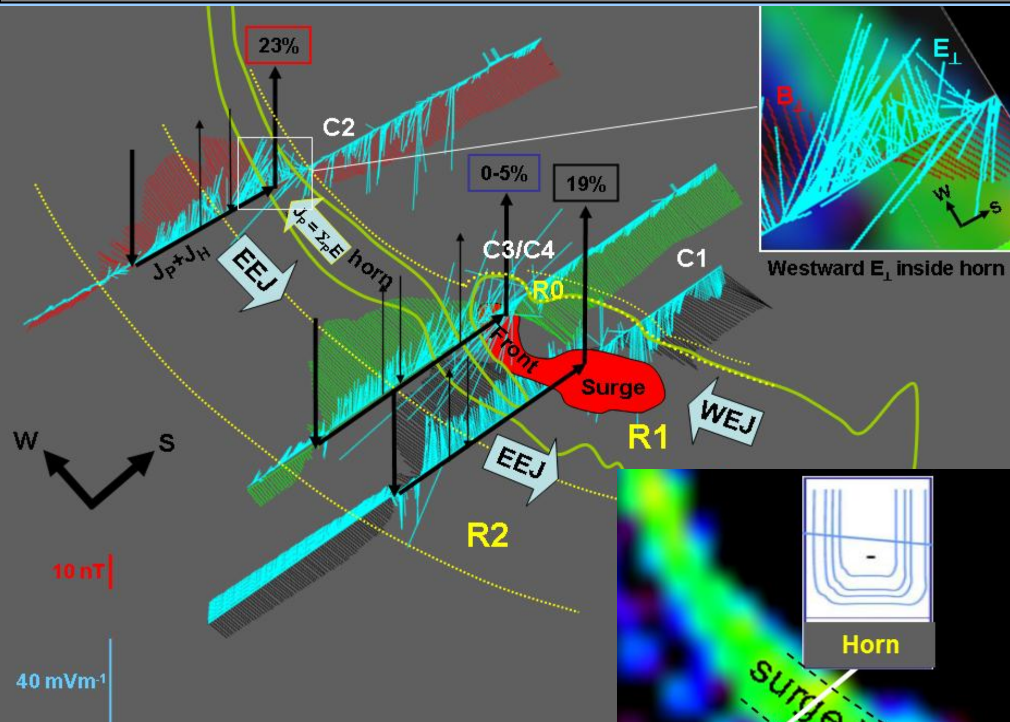




***Alm**, Marklund, Karlsson, JGR, in print (2014)*

- ❖ **At A and B: C1 within the AAR, N_E decreasing, loss-cone distribution**
- ❖ **At C: C1 outside the auroral flux tube, but N_E continues to drop**
- ❖ **Thus, the ADC is not limited by the AAR, but extends beyond it !**

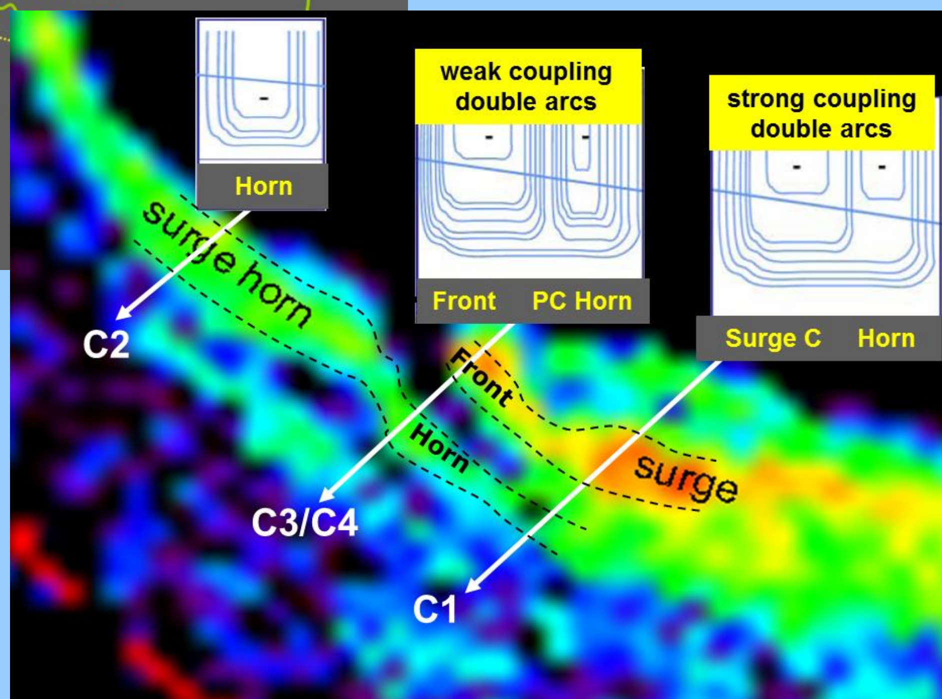
7. Snapshots of the AAR & Electro-dynamics of a surge-horn system



Multi-point Cluster data provide snapshots of the :

1) AAR structure
2) Electrodynamics
3) FAC closure

prevailing at various LT cuts of the surge-horn



EVENT 7
2009-05-31
21 MLT, 21 UT

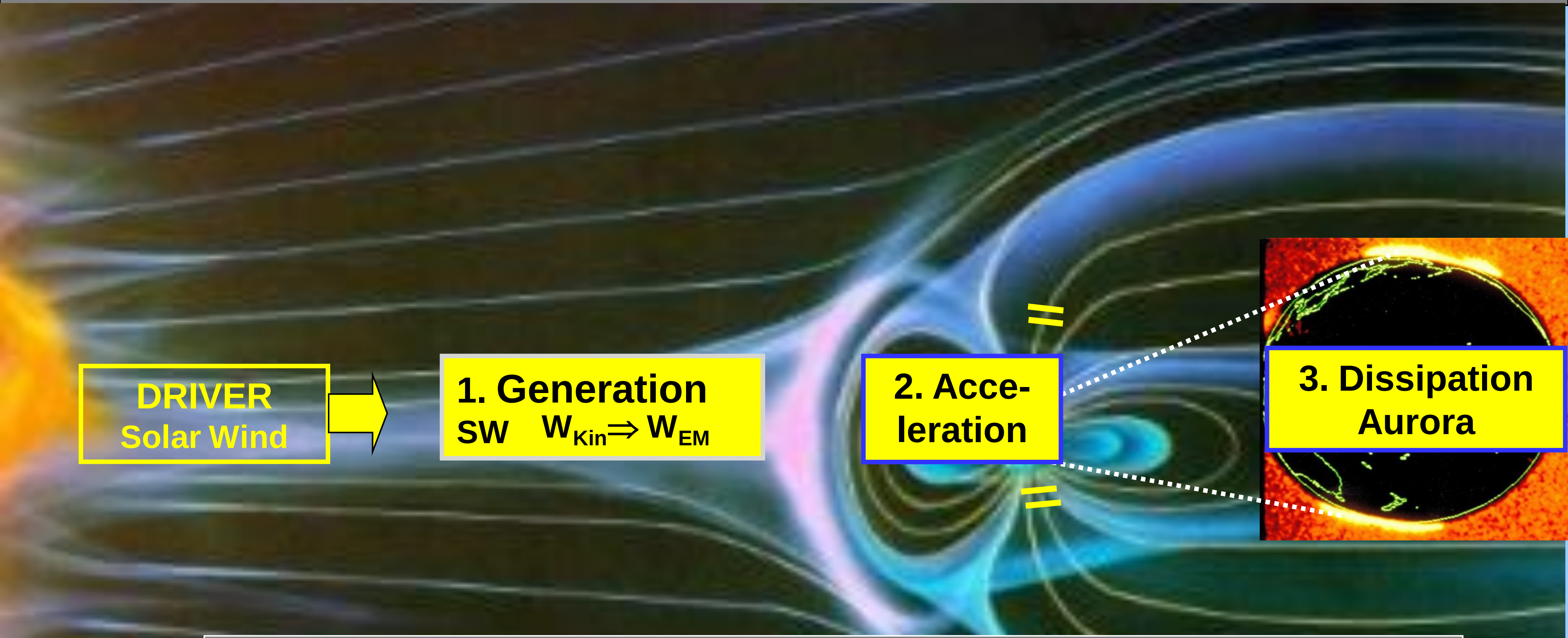
Marklund et al, JGR, 2012.

European Space Agency

SUMMARY: open issues on the aurora addressed/resolved by multi-point data!

1.Auroral charact. & scales	$E_{\perp}$, FACs, $n_e/\Delta n_e$ statistics, peak at ~ 5 km
2.Arc potential evolution	Growth, decay of U^+ & U^- potentials on ~ 100 s U^+ growth tied to ionospheric cavity formation
3.Structure & Stability of AAR	AAR of Inv.-V aurora derived, stable on ~ 5 min AAR snapshots of horn, surge head, surge
4. U- / S-potentials	Occur at soft / sharp plasma boundaries
5. Quasi-static vs Alfvénic acc	Rel contribution (%) derived for surge arcs Operate jointly within PCB aurora Statistical $E_{\perp}$ q-s below 2.8 R_E, Alfvénic above
6. Auroral Density Cavities	N_e altitude profiles revealed within AAR ADCs not limited but may extend beyond AAR
7. Auroral Electrodynamics	Snapshots of ED & FAC closure in surge-horn

Multi-point studies of the aurora
Where to go next ?



To further our understanding of the dynamic aurora, multi-point missions & G-B networks, dedicated to each of 1-3 is important. Simultanous data coverage of the complete chain will soon be a reality and an important key to further progress !