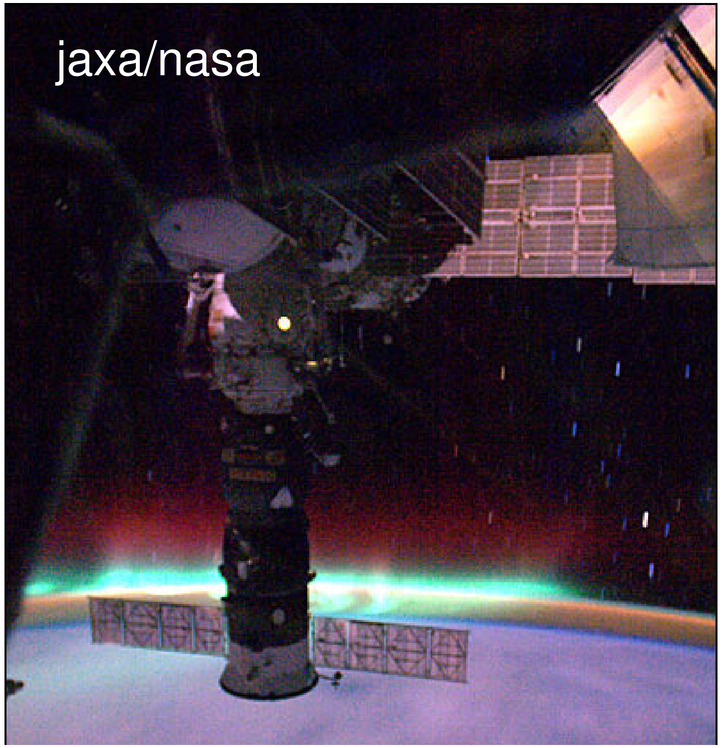
Multi-spacecraft Mission To the Aurora

A Fazakerley: MSSL-UCL

Based on discussions and material provided by colleagues including
G Marklund, KTH
M Lester, Leicester University
(disclaimer: errors are my responsibility!)

Introduction to the Aurorae

The Aurorae are a beautiful, dynamic "space" phenomena appreciated by the general public, but poorly understood by science.



New, *fast multipoint* observations are required to test and stimulate theoretical work

A mission that advances our understanding of the plasma physics of the aurora will interest a broad science community.

Aurorae are known/expected in heliospheric, exoplanet and astrophysical contexts.

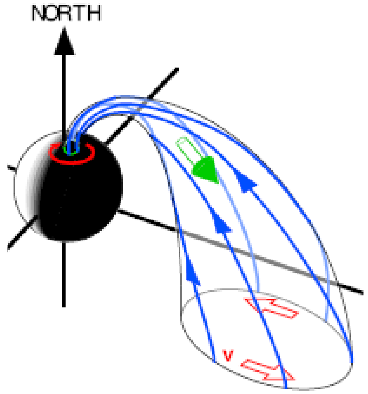
Introduction to the Aurorae

Energy source/generator.

The magnetosphere and solar wind.

Sources of vorticity such as flow shears and pressure gradients in a steady state magnetosphere.

Additional sources associated with dynamic changes imposed by routine solar wind variations as well as extreme events



Energy sink/load.

The ionosphere.

Many forms of energy deposition – joule heating; auroral emissions..

Electron density and conductance depends on season and local time.

Time dependent feedback due to precipitation

The interface/transition region

The auroral acceleration region.

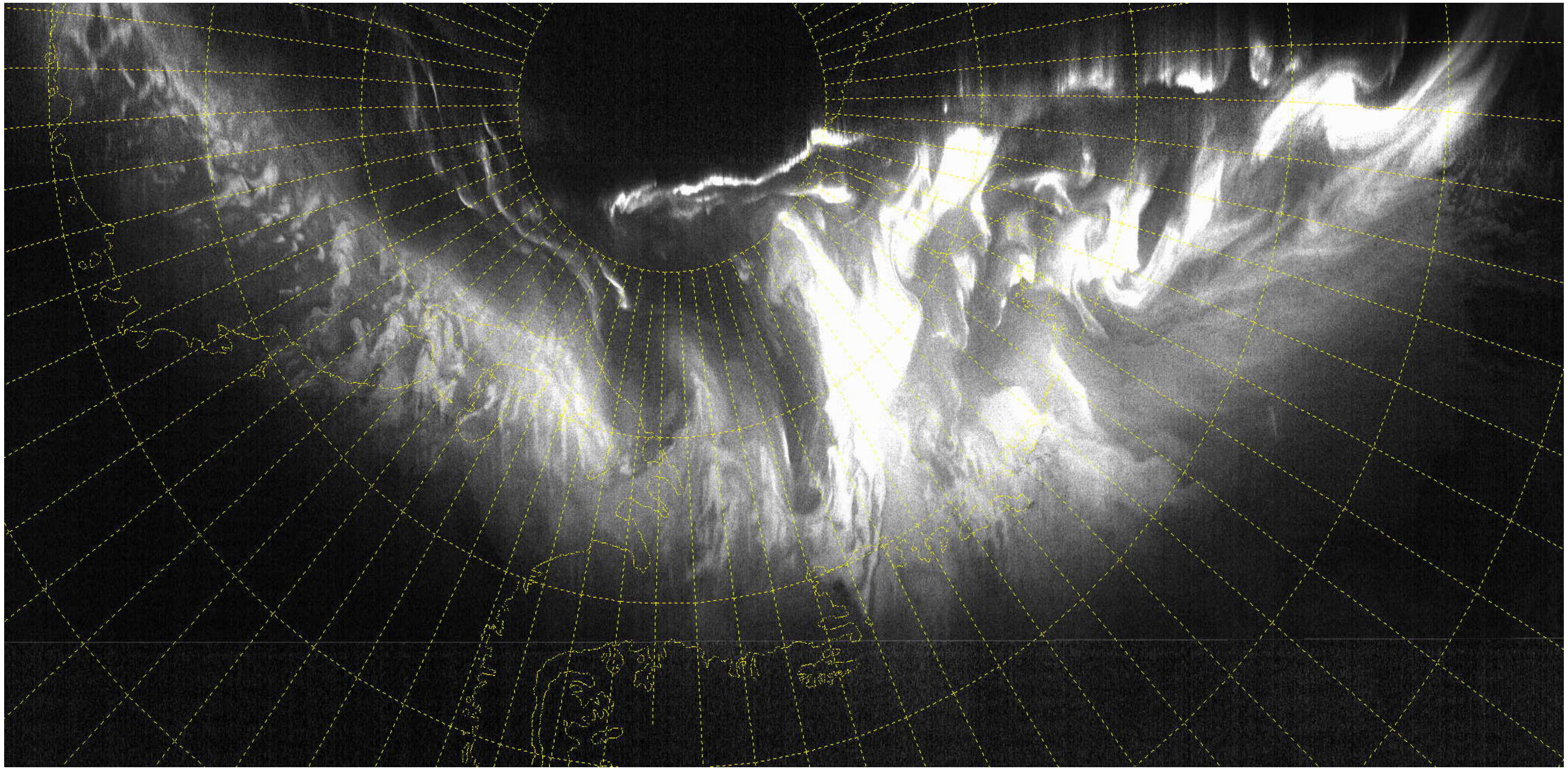
Field aligned currents convey stresses from the magnetosphere. The magnetosphere and ionosphere are (de)coupled through structured time-varying parallel electric fields (violating MHD) and density cavities, plasma waves and particle beams are generated. A lot of open questions about how this all happens!

Auroral spatial scales

Oval	1,000	km
Inverted-V's	100	km
Arcs	10	km
rays, curls	1	km
Filaments	0.1	km

- Global auroral oval defined by MHD scale processes such as the magnetospheric convection flow and Region 1 and 2 FACs

- Inverted V-s may be associated with ion scale: FAC related Alfven waves become dispersive (carry $E_{||}$, generate accelerated particle beams) when wavelengths approach ion scales near Earth



Auroral spatial scales

Oval	1,000	km
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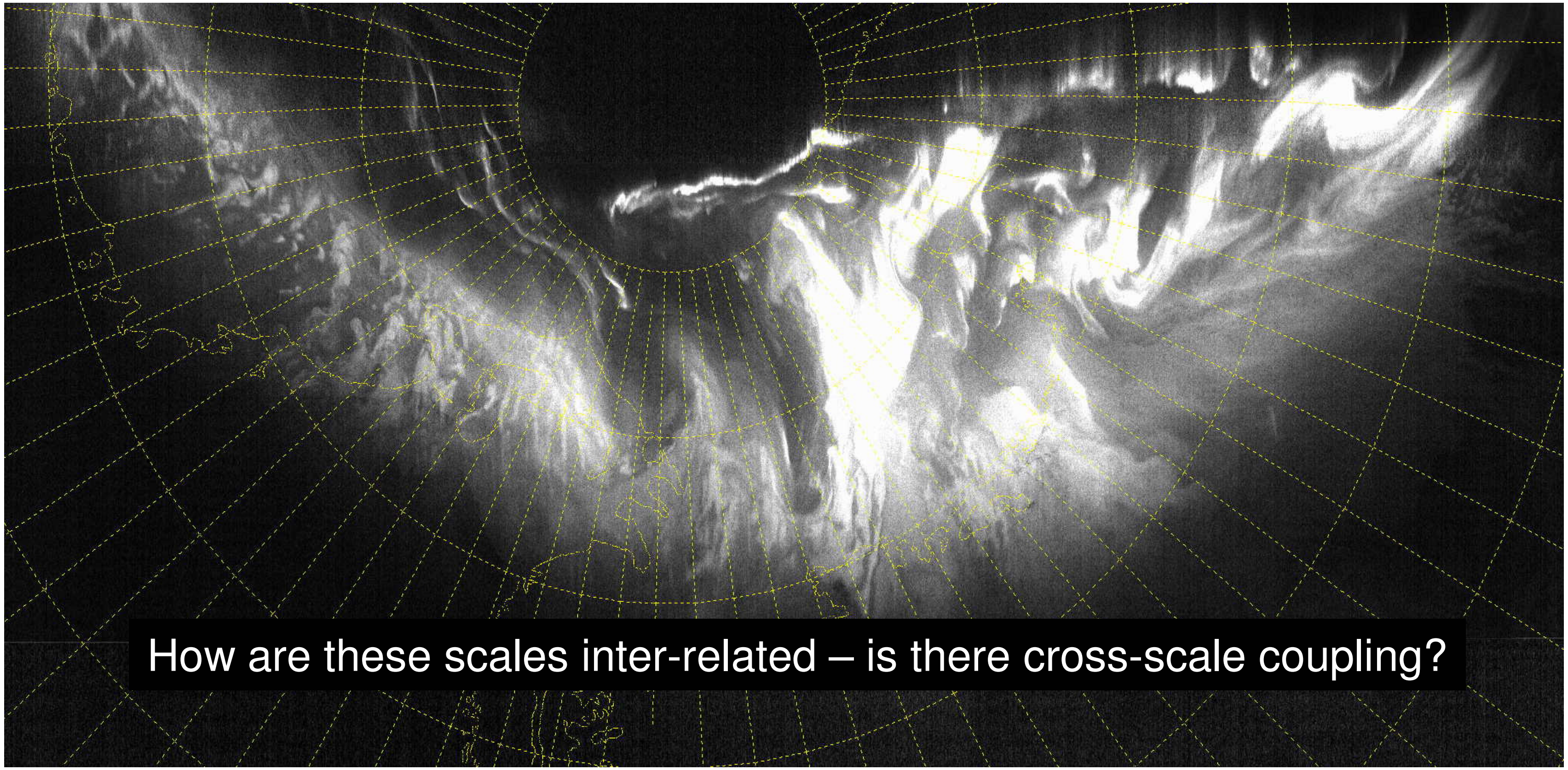
- model Alfvénic arc scales of ~1-10 km broadly agree with fine-scale arc distributions
- are curls generated by K-H like instabilities?
- sub-km arc filaments are not understood: electron scale physics?



Plasma physics measurements in the Aurorae

In the auroral regions we find time varying, moving, electric potential structures organised by the magnetic field.

They exhibit unstable particle distributions which produce/ are due to plasma waves; e.g. auroral kilometric radiation (AKR).

These include ion and electron beams carrying electric currents

Plasma physics measurements in the Aurorae

Parameters to measure at a single point:

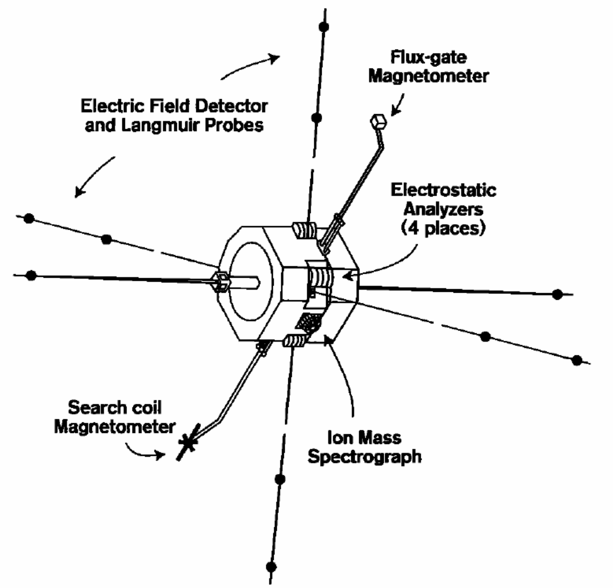
- 3D magnetic and d.c. electric field
- High time resolution particle distribution functions (pitch angles mandatory)
- High time resolution electromagnetic and electrostatic plasma waves

The FAST mission demonstrated the scientific value of such measurements; its biggest advance was provision of very fast particle measurements.

Time resolution controls the scale size of structures that can be studied

Data	Time res.	Ang. Res.	Sample Array
Ion Spectrometer	78 ms	11° x 12°	48 E x 32 α
Electron Spectrometer	78 ms	11° x 10°	48 E x 32 α
Electron Spectrograph	1.6 ms	22.5° x 10°	6 E x 16 α

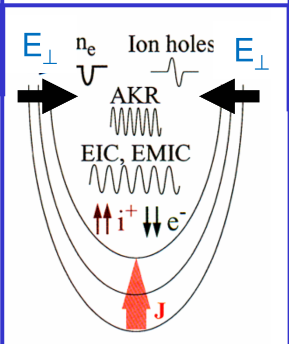
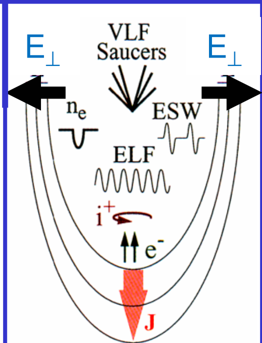
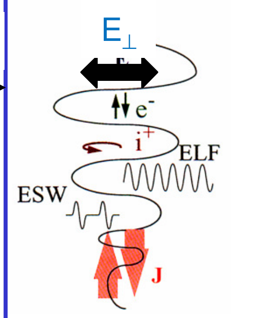
Energy range: ~5 eV to ~ 30 keV
FOV: 360° x 10°

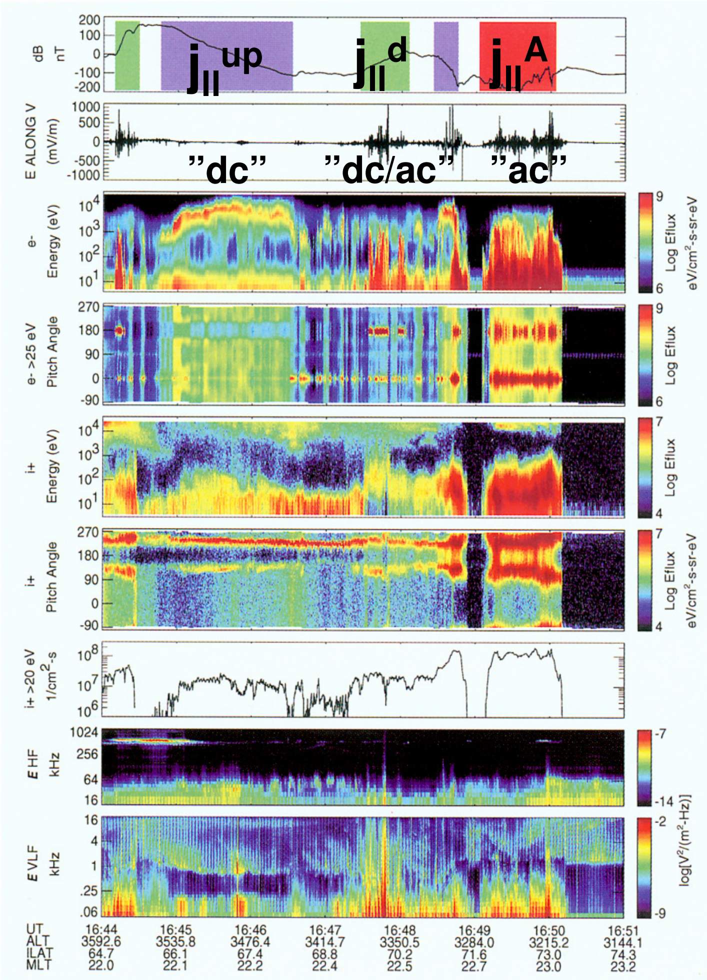


Auroral particle acceleration

Four regions / means of acceleration

1. Quasi-static acc, upward FAC region
2. Quasi-static acc, downw. FAC region
3. Alfvénic acc, arc and oval boundaries
4. Acc by LFEFF's & magnetic pumping

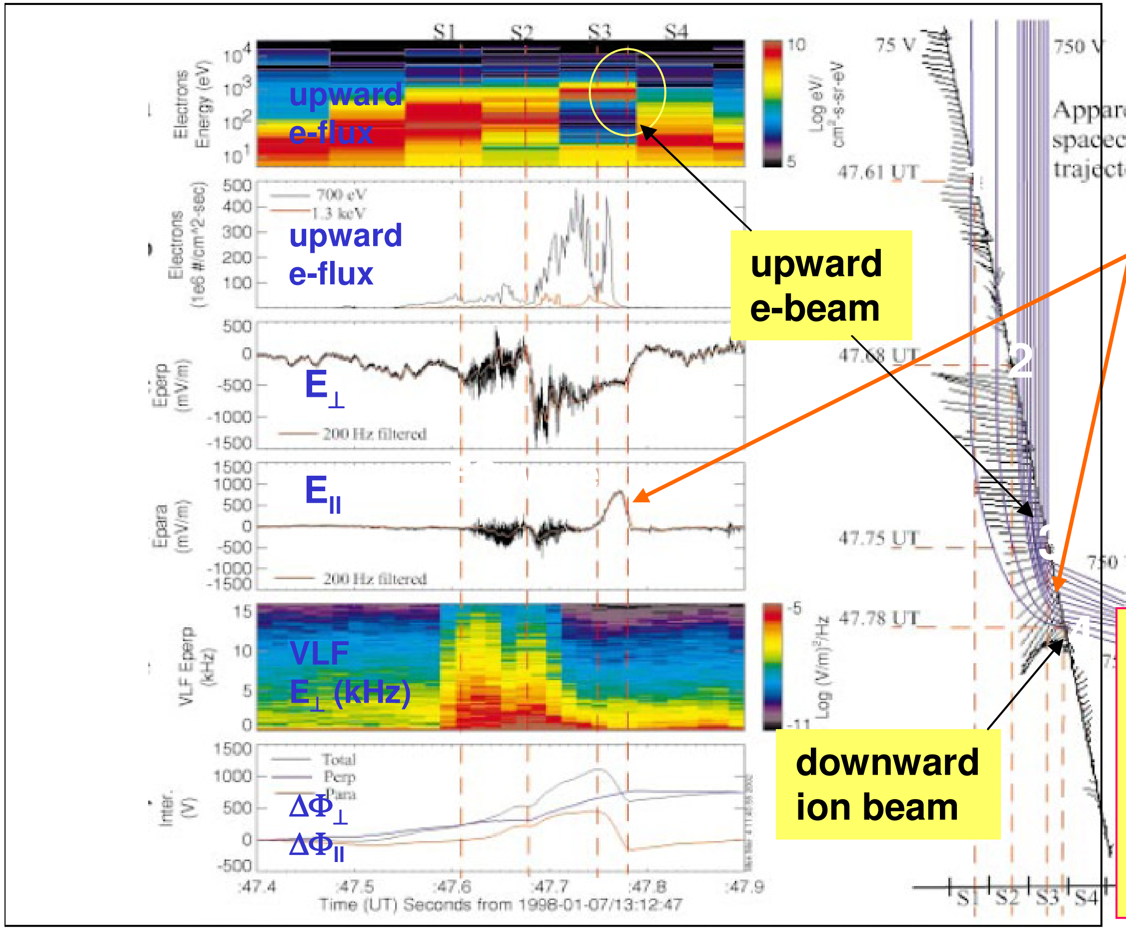
Arc	1. Inverted-V	2. Black	3. Alfvénic
acc potential & related pheno-mena			
acc type	mainly dc	"dc/ac"	"ac"
FAC	upward	downward	time-varying



FAST observations at 3500 km

Auroral particle acceleration

FAST high time resolution observations of Double Layers



Direct observation of DL

- Monotonic Φ-ramp, 0.7 kV
- *thin* layer of $\approx 10\ \lambda_D$
- upward *moving* at v_{ia}

DL’s are strong candidates for the particle acceleration producing discrete aurora & plasma outflow on Earth as well as on other planetary atmospheres

L. Andersson, Physics of Plasmas, 2002

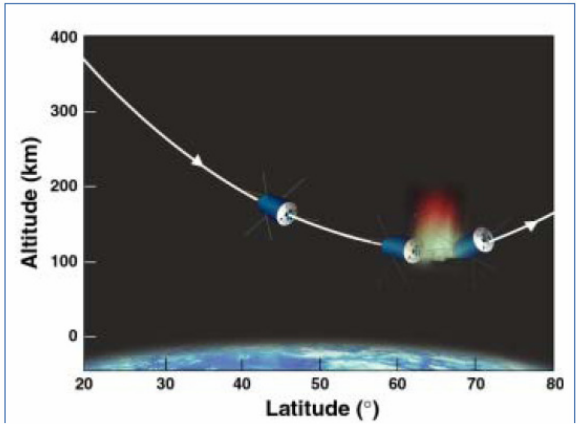
Plasma physics measurements in the Aurorae

Multi-point measurements are required to measure :

• time evolution of potential structures	String of pearls tracking across B
• potential gradients; may vary with alt	Alignment along B; or “petal”
• motion of current sheets;	Optimised tetrahedron; or pair along sheet normal
• thickness of auroral structures	Well sized tetrahedron; or pair along sheet normal
• local vorticity	Well sized tetrahedron; or pair along sheet normal
• field aligned current density	Well sized tetrahedron

Spacecraft separations must be varied to address specific science targets (as Cluster)

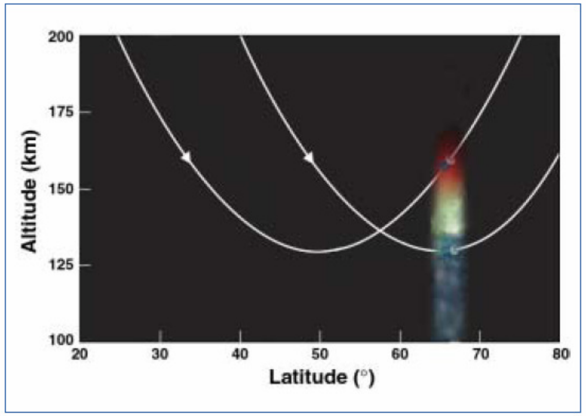
Cluster has begun to address some of these points, but lacks the very fast plasma instrumentation that are required to address others.



Left: string of pearls

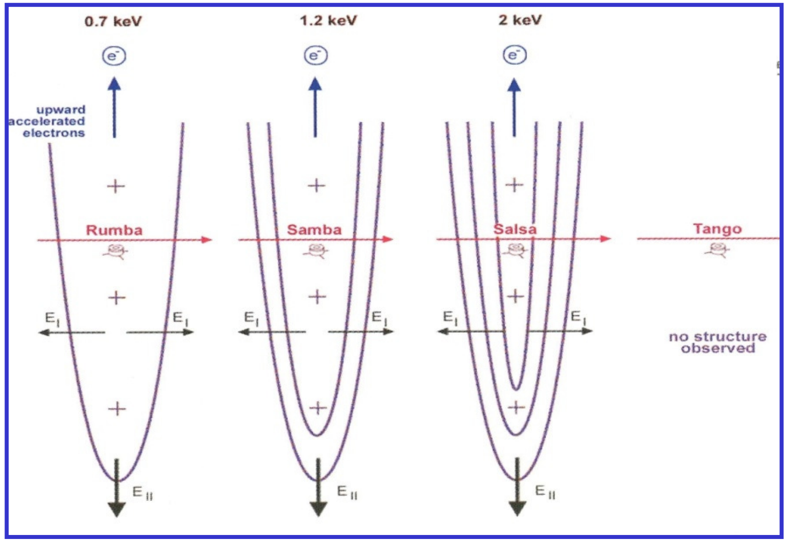
Right: petal orbits

(from NASA GEC study)

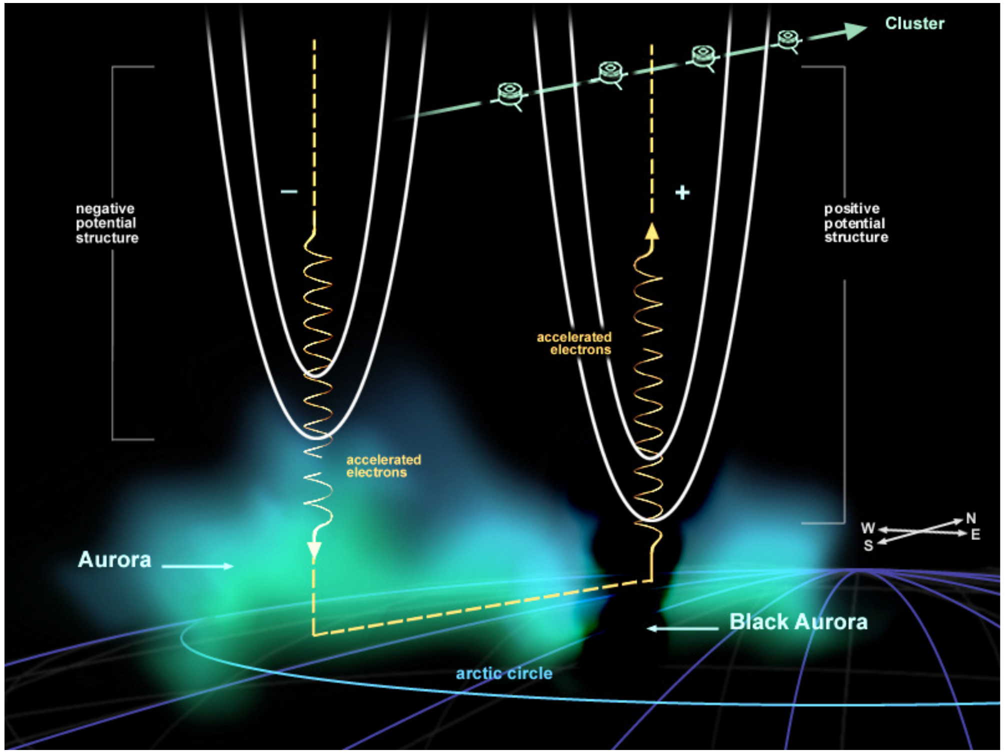


Cluster: Temporal evolution of potential & FAC

Observation (far above AAR, in 2001)



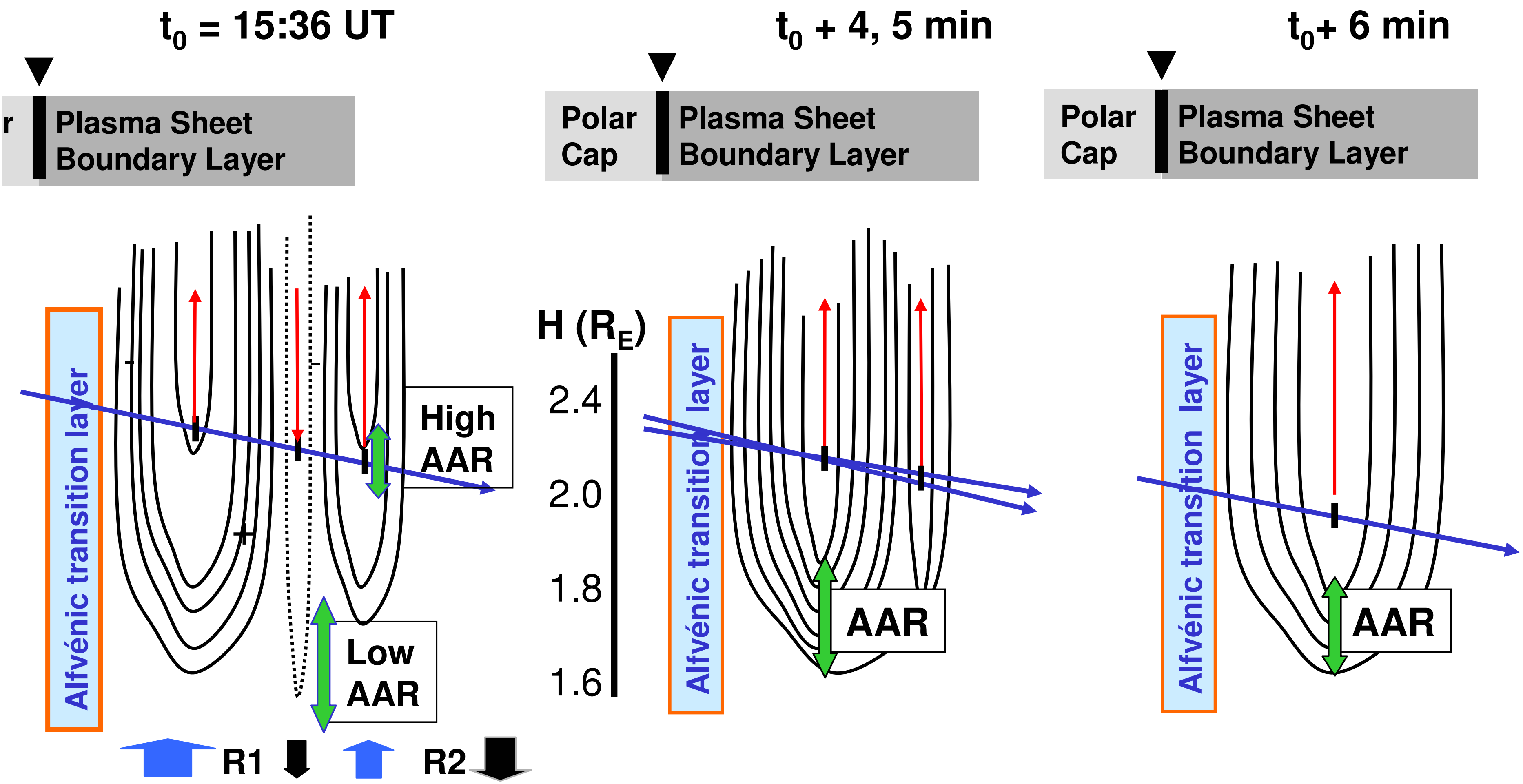
Marklund et al.,
Nature, 414, 724-727, 2001



Cluster: Temporal evolution of potential & FAC

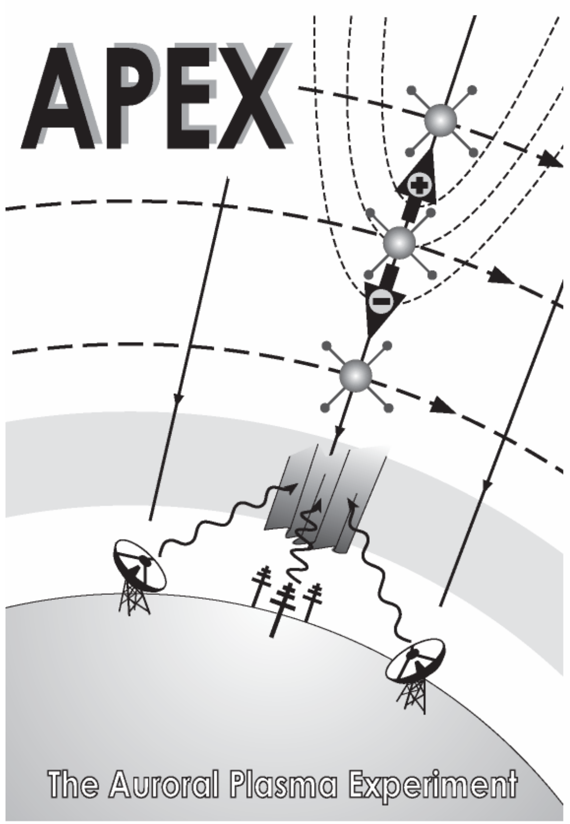
Observation (just above AAR in 2009)

Publication in preparation (Marklund et al.)



Mission Concepts

APEX (proposal to ESA F2; led by Mark Lester)



Goal: investigate auroral acceleration region

Spacecraft: 3

Orbits: Circular with 2,3 and 6 hour periods,
at 1,700 km; 4,200 km; 10,400 km alt.
(under, in and above typical AAR altitude)
all 3 align daily over Svalbard (SPEAR, ESR)

Payload: FAST- class fields and particles; UV imagers

Science case:
Study field-aligned potential structures and FACs together with context imaging
Measure in situ response to active experiments with ground-based heaters (SPEAR)

Other related multi-point auroral mission studies include:
Auroral Multi-scale Mission; Auroral Lites; IBIZA/IMPACT;
Geospace Electrodynamic Connections

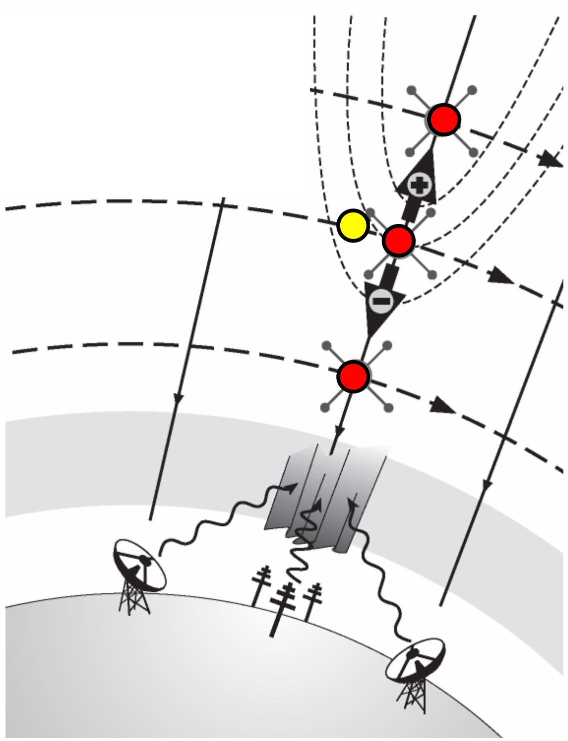
Open science questions

Fundamental processes:

- Particle acceleration
- Ionospheric feedback
- Cross-scale-coupling
- Filamentation

We do not understand

- Formation of $\Delta\Phi_{||}$ and $E_{||}$
- Altitude distribution of $\Delta\Phi_{||}$ and $E_{||}$
- I-V relation for downward FACs
- Coupling to the ionosphere
- Creation of narrow arcs (sub-km)
- Diffuse aurora (including fine structure)
- Pulsating aurora
- Coupling between scales



Conclusion:
It is desirable to measure along and across B at suitable scale lengths. Modify APEX by adding a 4th spacecraft?

Expected interest

UK

Hardware:

Particle instrumentation:	MSSL, RAL
Magnetic fields:	IC
Imagers:	Leicester

Science:

M-I coupling:
Leicester, MSSL, Lancaster,…

Ground-based:
ASK fine scale aurorae – Southampton
SPEAR (no longer UK controlled…)
ESR

Europe

Scandanavians have long history of auroral research (Freja, Munin, Viking)

French are studying a national-level auroral mission

Cluster AAR studies expected to invigorate the auroral community

Summary

MICE: magnetosphere-ionosphere-coupling-explorers (?!)

Many important open questions in auroral plasma physics and magnetosphere-ionosphere coupling which can only be addressed using a multi-spacecraft mission.

Spacecraft, payload at high TRL already.

Analysis techniques already well-established.

Thriving science community.

Coordinated observations with solar wind spacecraft, magnetospheric spacecraft and ground-based facilities such as SPEAR and EISCAT/ESR add value.

Results have wide relevance beyond solar-terrestrial science.

Mission concepts involving 3 or 4 spacecraft seem likely to be affordable within an ESA M-class budget.

anf@mssl.ucl.ac.uk

p.s. An ESA AAR mission would be very well complemented by a UKSA dual micro-satellite “24/7 UV imaging” mission for global context.