Estimating energy spectra of electron precipitation above auroral arcs from ground-based observations with ALIS and EISCAT.

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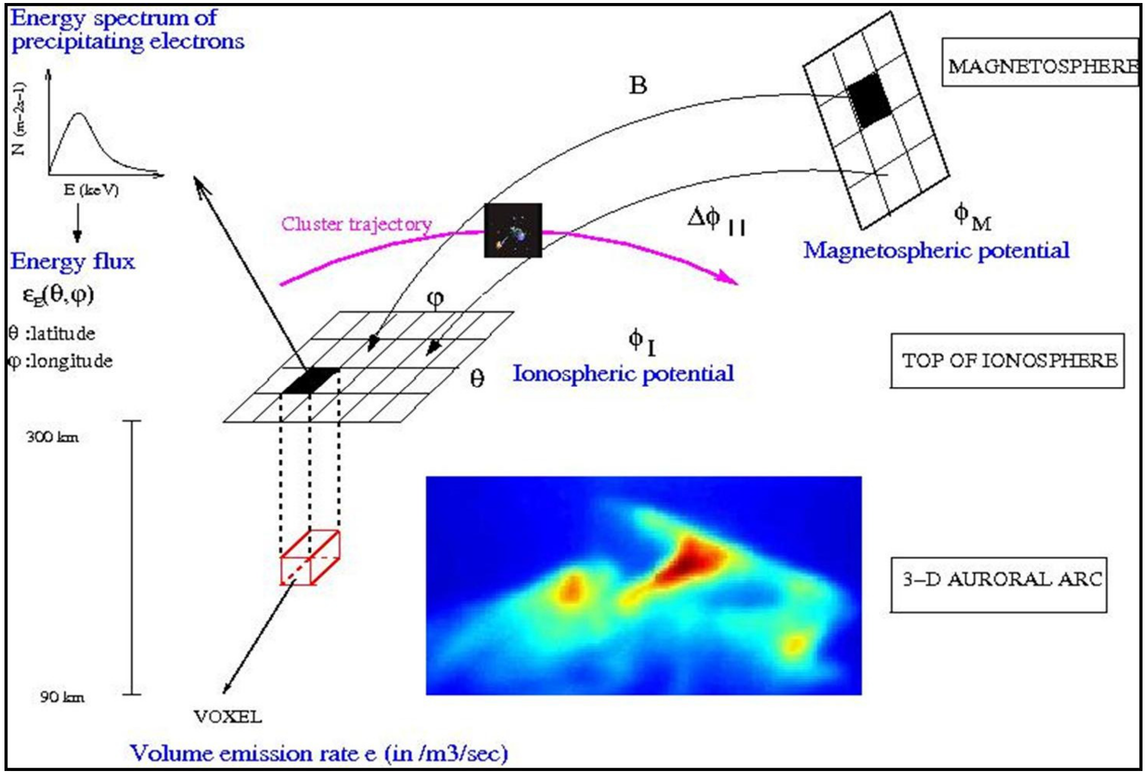
OUTLINE OF THE TALK

- Presentation of the whole project
- ALIS : Auroral Large Imaging System
- Observation campaign of March 2008 : coordinated observations of ALIS and EISCAT
- Inversion of EISCAT data → electron fluxes in 1D
- Auroral tomography with ALIS → electron fluxes in 2D
- Conclusions & perspectives

The whole project



2 parts

1) Ground-based observations (ALIS, EISCAT) → spectra of precipitating electrons and characteristic energies
2) Spectra of precipitating electrons → magnetosphere-ionosphere coupling (with models and s/c data during conjunctions)

This talk : only about first part of the project

ALIS : the Auroral Large Imaging System

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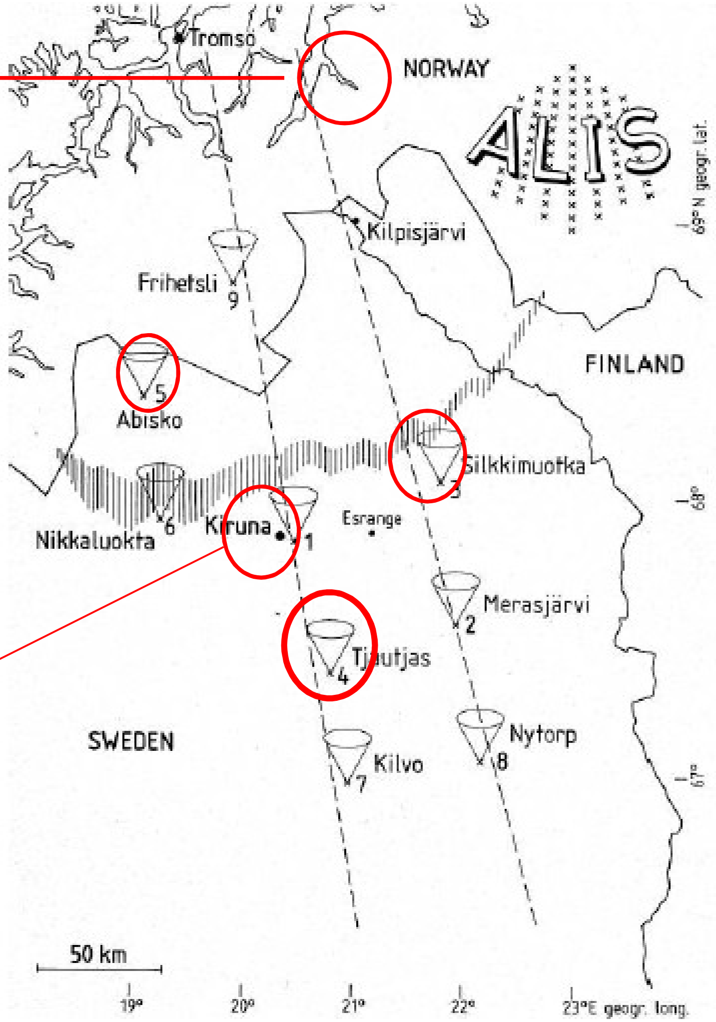
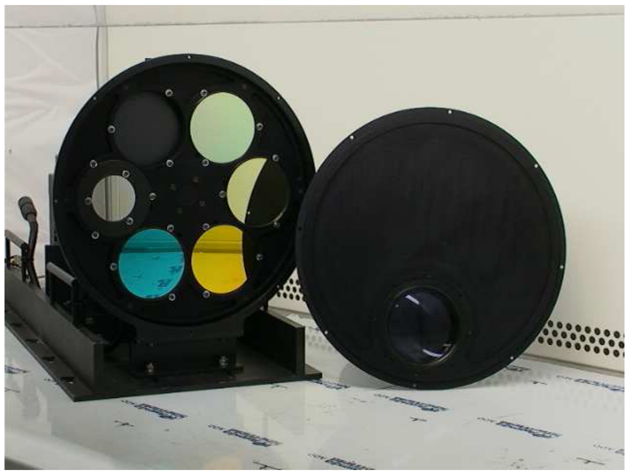
2 stations
K et 0



Gustavsson (1998)

ALIS : the Auroral Large Imaging System

- High-resolution CCD cameras (1024 x 1024)
- Average FOV ~70°
- Narrow interference filters ($\Delta\lambda$=40 Å) for imaging of the green line (5577 Å), the red line (6300 Å), the blue line of N_2^+ 1NG band (4278 Å) and a near-IR line (8446 Å)
- One image obtained every 5 sec (including overhead time due to filter wheel change) $\Rightarrow$ 20 sec resolution for blue line



Brandström (2001)

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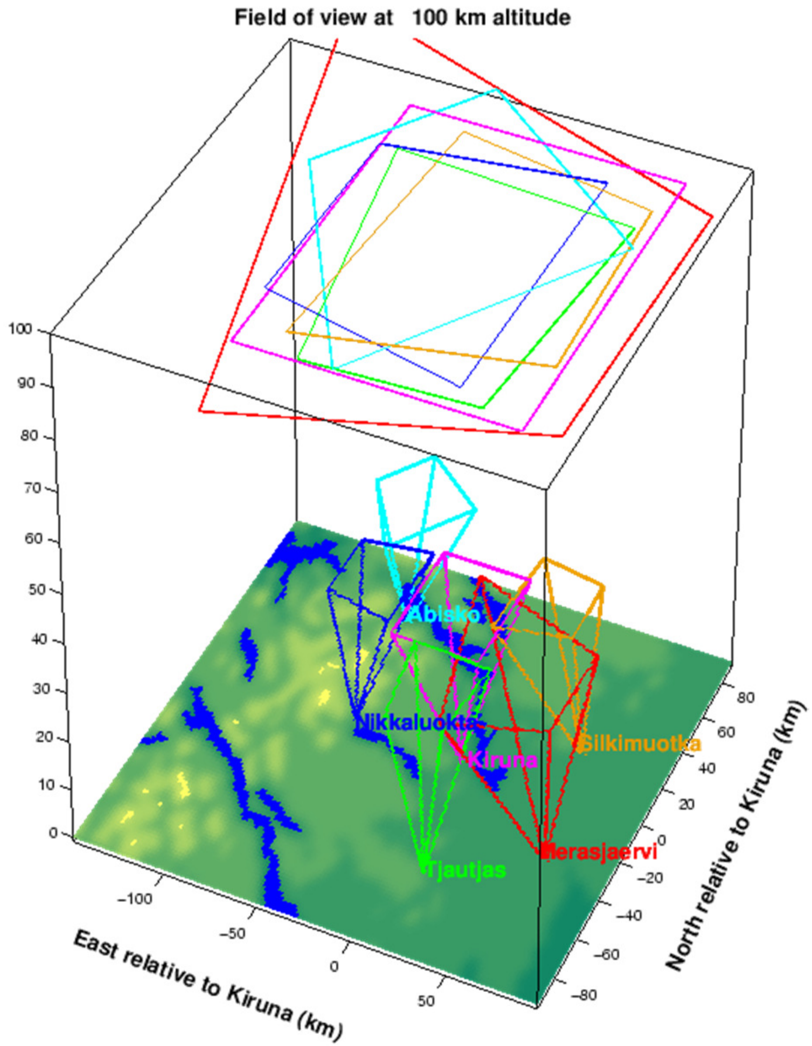
ALIS : the Auroral Large Imaging System



FOVs of the ALIS cameras overlap at 100 km altitude allowing to do auroral tomography

Gustvasson (1998)

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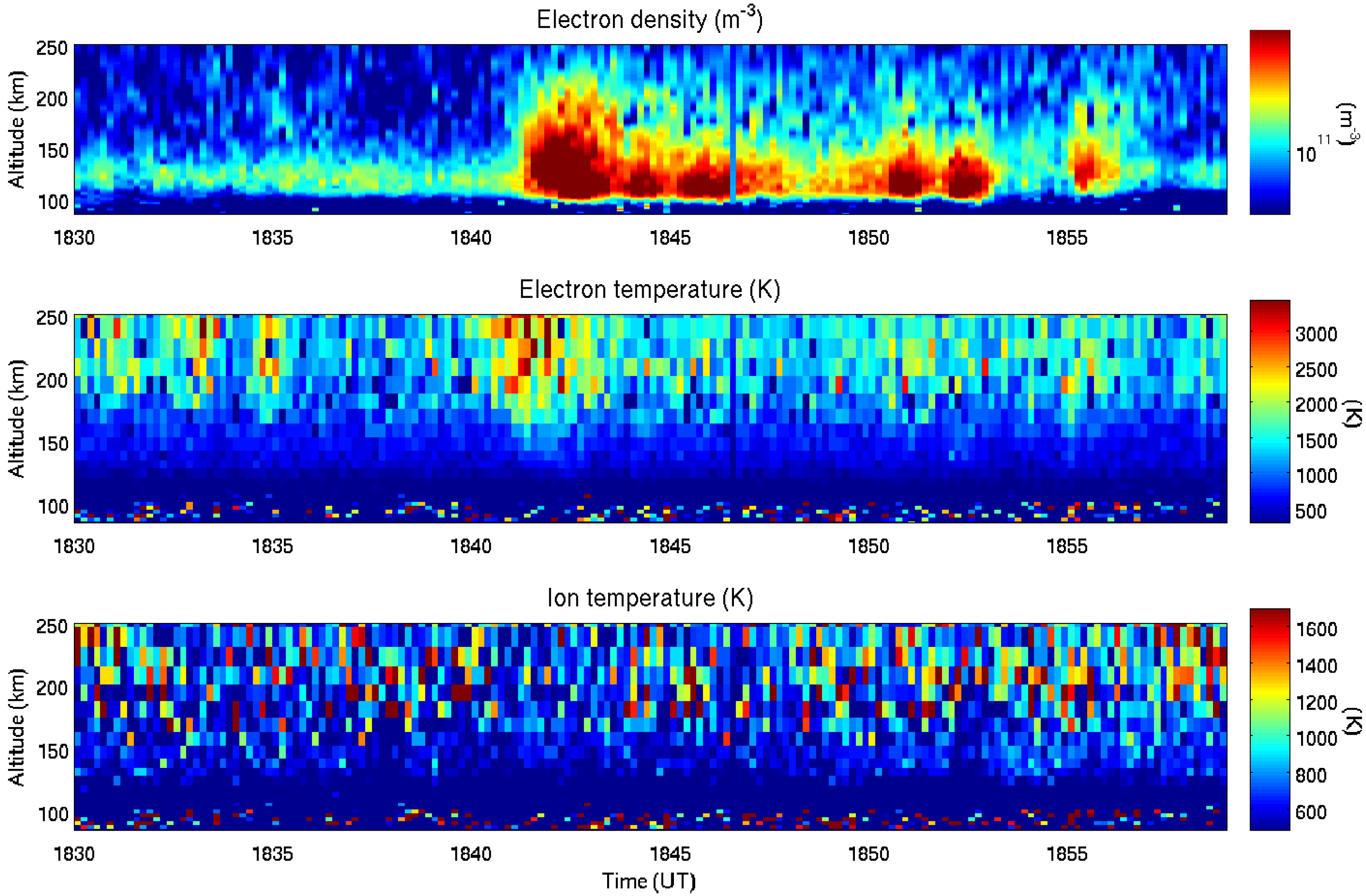
2008 Observation campaign

- Coordinated ALIS / EISCAT observations
- Tri-static UHF EISCAT observations obtained during TNA (Trans National Access) time
- 24 hours of observations between 03/03/08 and 11/03/08
- Nice weather and several interesting auroral phenomena
- This talk about the most stable auroral arc → night of 05/03/08 around 18h40 UT.

2008 observation campaign : EISCAT data

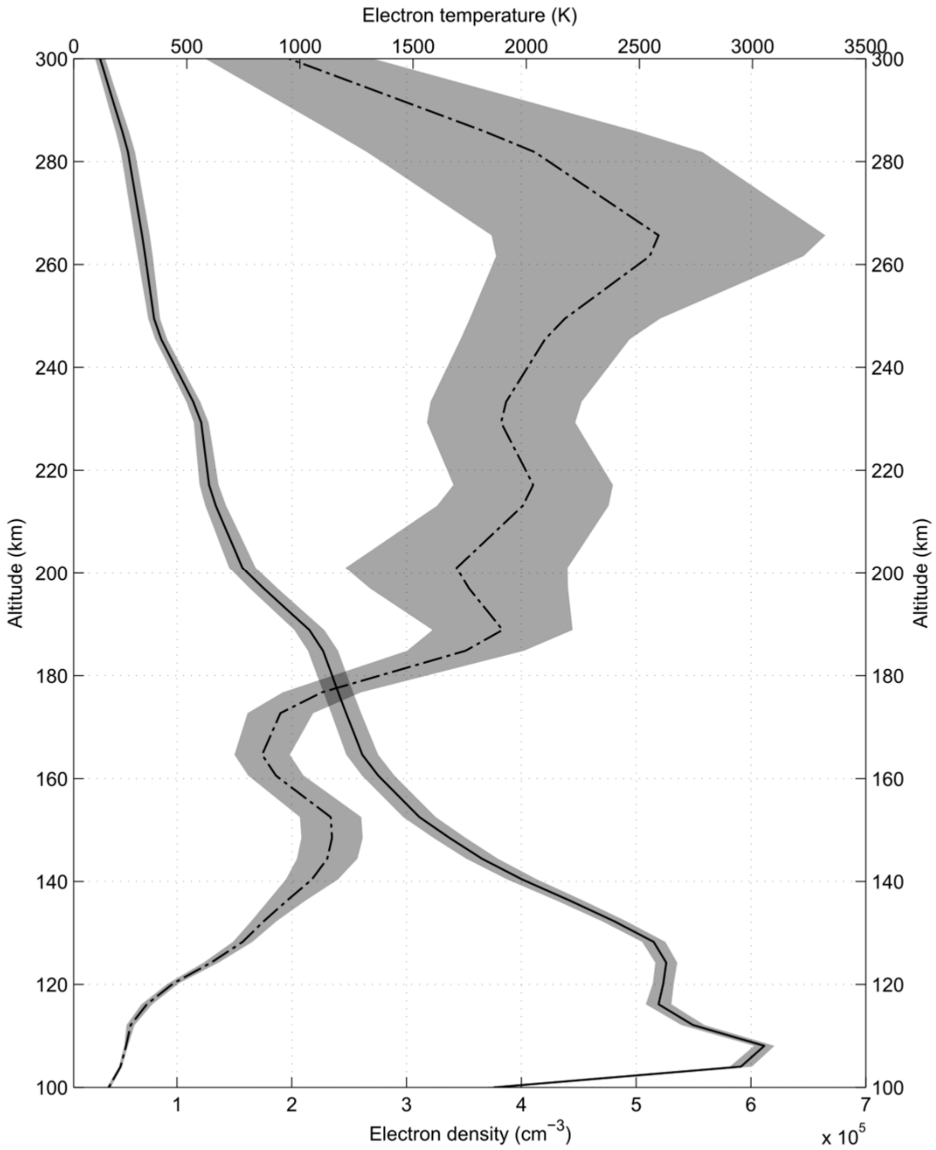


Bright and stable auroral arc

Beata code : alt resolution ~ 1.5-3km ; time resolution ~ 10 sec

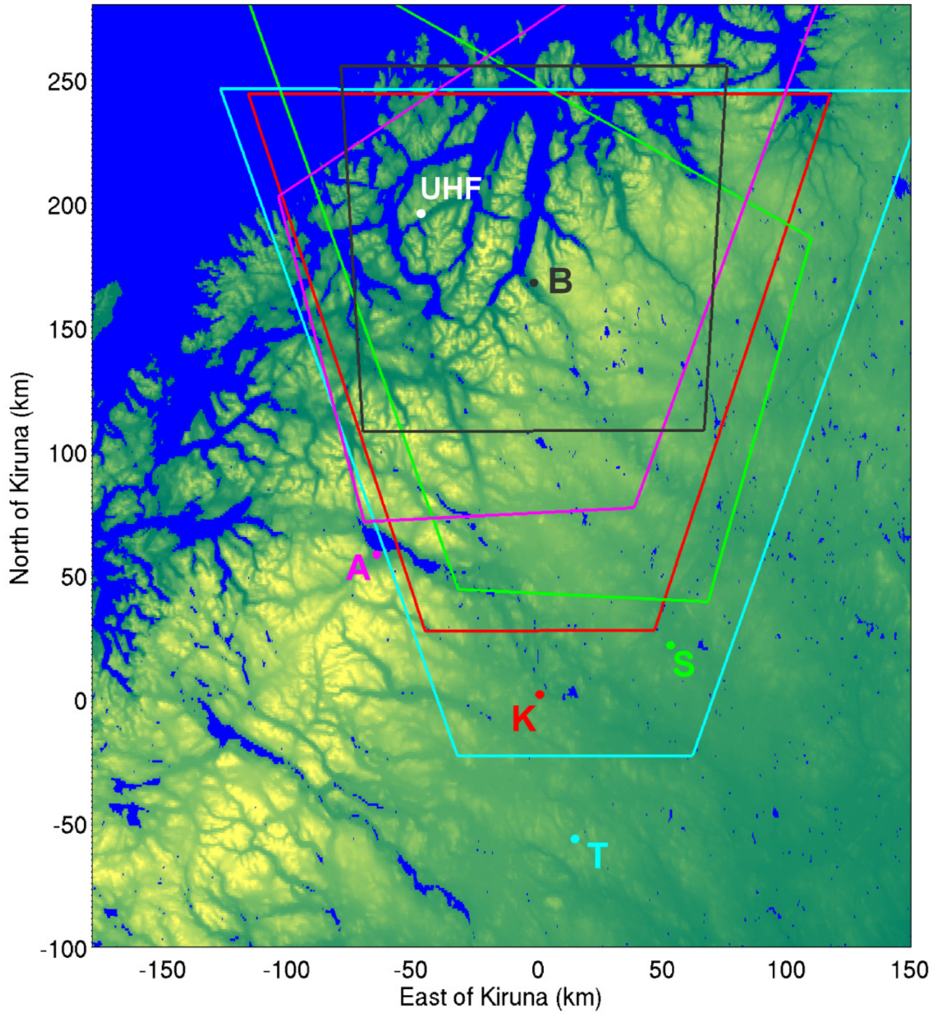
2008 observation campaign : EISCAT data

18:42:39 UT



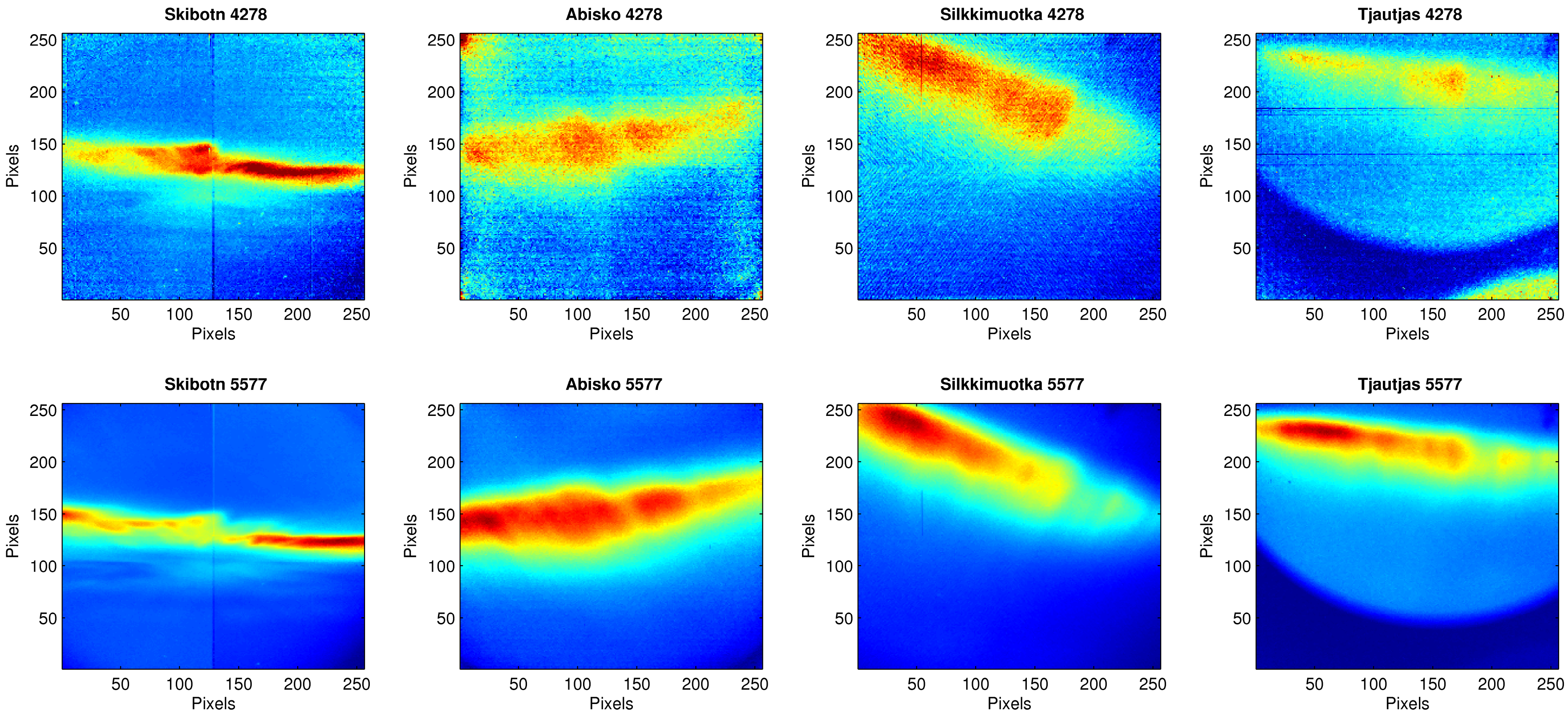
2008 observation campaign : ALIS data

100 km
altitude



2008 observation campaign : ALIS data

Time resolution : between 10 and 20 sec



Bright stable arc nicely visible from 4 stations simultaneously

Inversion of EISCAT data

- Following the method used by Semeter & Kamalabadi (2005)

- We calculate the ion production rate *q* from the electron density data *n* given by EISCAT, assuming stationnarity and quasi-neutrality

$$q = \alpha n^2 + \frac{dn}{dt}$$

- We assume an E region dominated by 0_2^+ & NO^+ and use recombination coefficients α from Sheehan & St-Maurica (2004)

$$\alpha_{O_2^+} = \begin{cases} 1.95 \times 10^{-7}(300/T_e)^{0.70}, T_e < 1200\ \text{K} \\ 1.95 \times 10^{-7}(300/T_e)^{0.56}, T_e > 1200\ \text{K} \end{cases}$$

$$\alpha_{equiv} = (0.478\,\alpha_{NO^+} + 0.373\,\alpha_{O_2^+})$$

$$\alpha_{NO^+} = \begin{cases} 3.50 \times 10^{-7}(300/T_e)^{0.69}, T_e < 1200\ \text{K} \\ 3.02 \times 10^{-7}(300/T_e)^{0.56}, T_e > 1200\ \text{K} \end{cases}$$

we use EISCAT data for T_e

Inversion of EISCAT data : forward model

- The link between the volume production rate of ions, q, at an altitude z and the flux Φ of electrons with energy E is given by

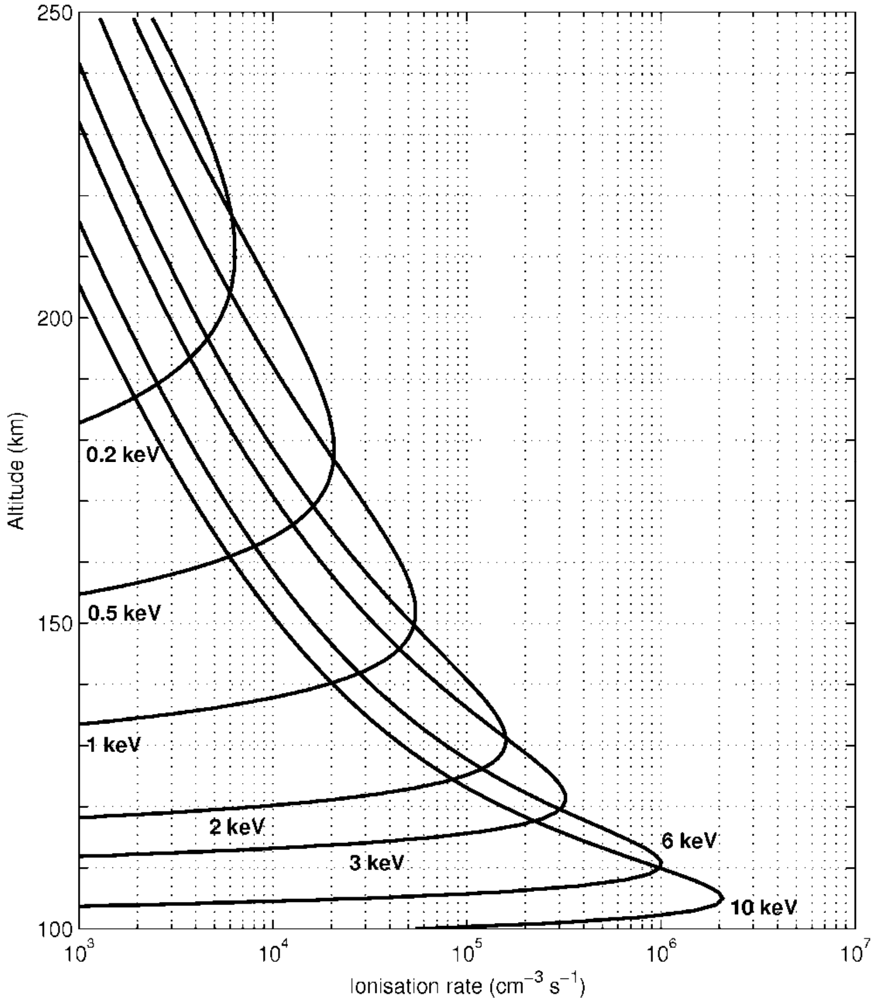
$$\boxed{q(z, E) = \frac{\Lambda\rho\, E}{35.5R} \cdot \Phi \quad [\mathrm{m}^{-3}\mathrm{s}^{-1}]}$$

- Λ = energy dissipation function (Sergienko & Ivanov 1993)
- ρ = atmospheric mass density model (MSISE-00)
- R = electron range in air (Sergienko & Ivanov 1993)

$$R(E) = B_1\, E^{1.67}(1 + B_2\, E^{B_3}),$$

- 35.5 eV ~ average energy lost per electron-ion pair produced [latest version with W(E)]

Inversion of EISCAT data : forward model



$\Phi=10^8$ cm^{-2} s^{-1} eV^{-1}

2 keV → peak at ~ 120 km
6 keV → peak at ~ 110 km

Ionisation rate profiles for monoenergetic electrons

Inversion of EISCAT data : forward model

- If we discretize the spectrum of the precipitating electrons and if we use a finite number of altitudes, we obtain a linear matrix system

$$q(z) = \int_{E_{\min}}^{E_{\max}} A(z, E)\, \phi(E)\, \mathrm{d}E$$

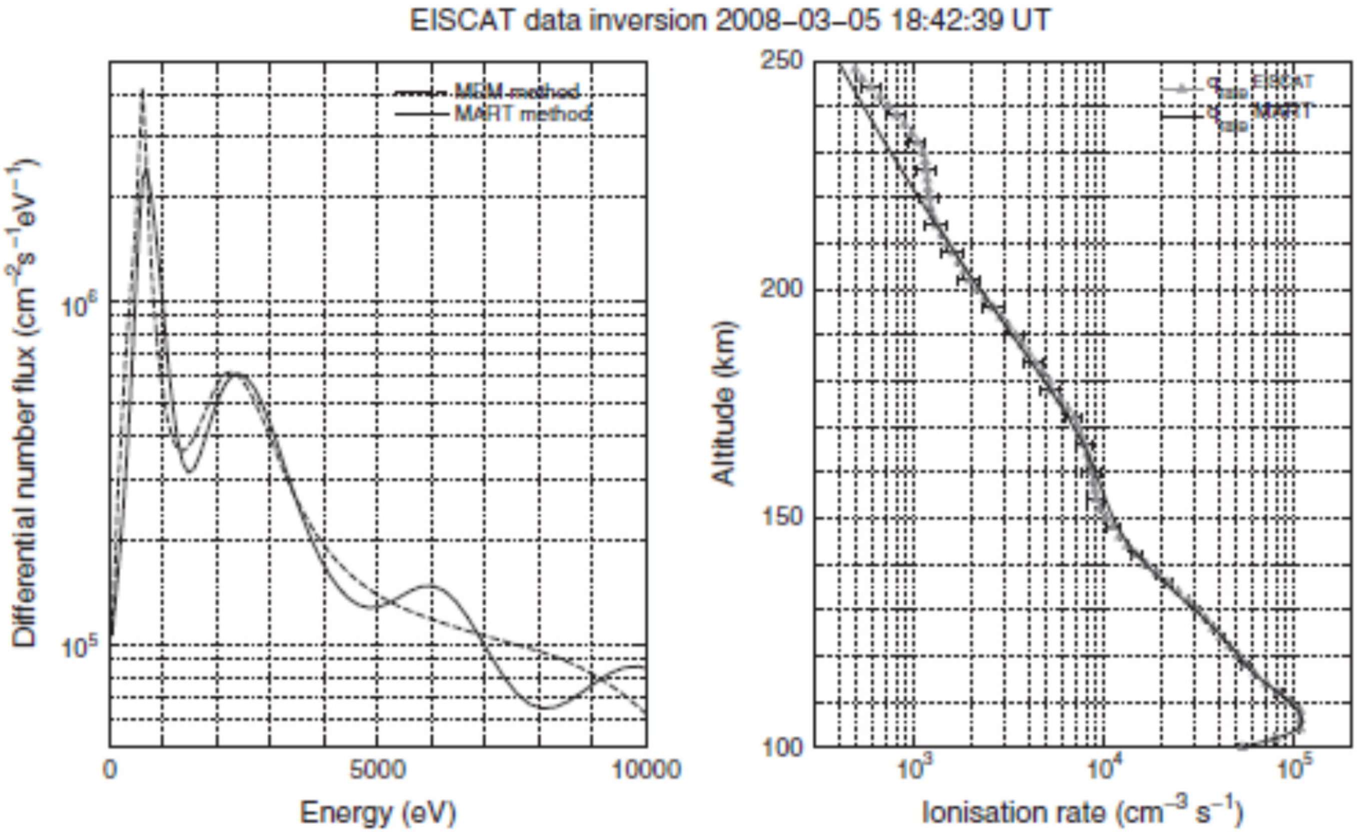
$$q(z_i) = \sum_j A(z_i, E_j)\, \Delta E_j\, \phi_j$$

ϕ_j = number of electrons with energies between E_j and $E_j + \Delta E_j$

$$A_{ij} = A(z_i, E_j)\, \Delta E_j = \frac{\Lambda\left(\frac{s(z_i)}{R(E_j)}\right) \rho(z_i)\; E_j \Delta E_j}{R(E_j)\; W(E_j)}$$

We solve this linear (non-squared) system with MART/MEM

Results of inversion of EISCAT data



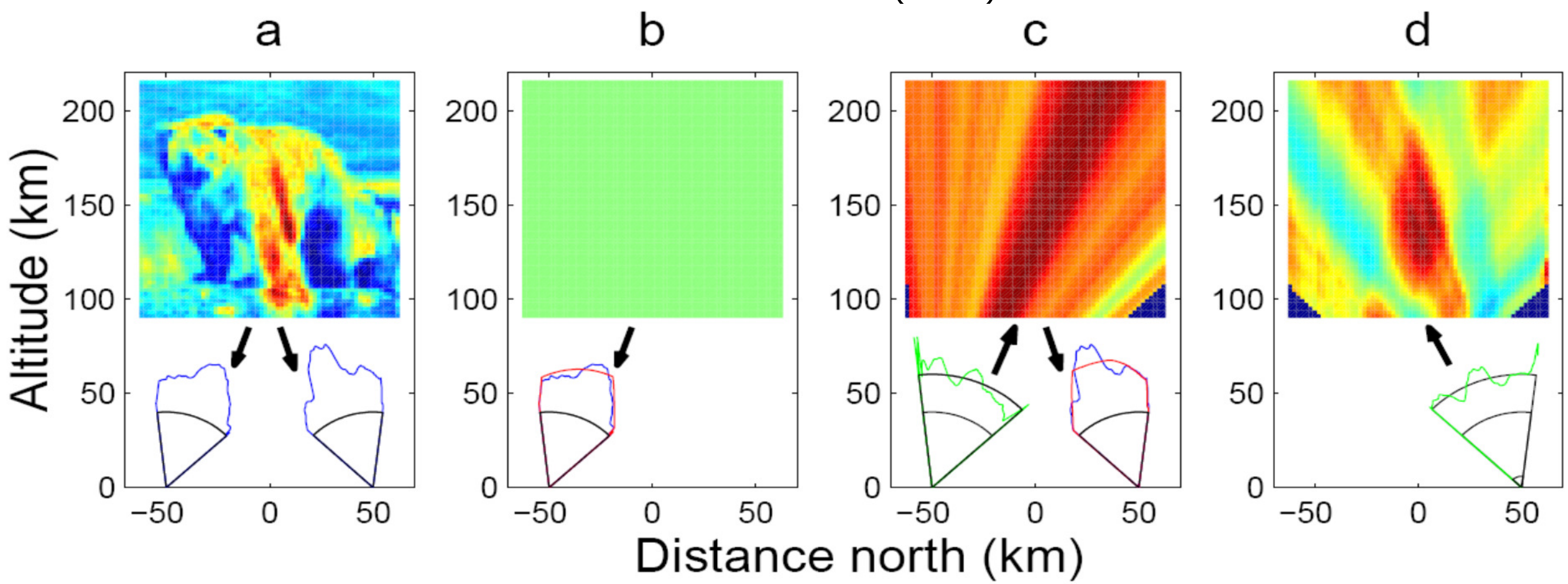
Results of electron fluxes obtained with MART/MEM inversions

Δ : ionisation rate deduced from EISCAT data

projection of *q* from the reconstructed electron fluxes

General principle of auroral tomography

Gustvasson (1998)



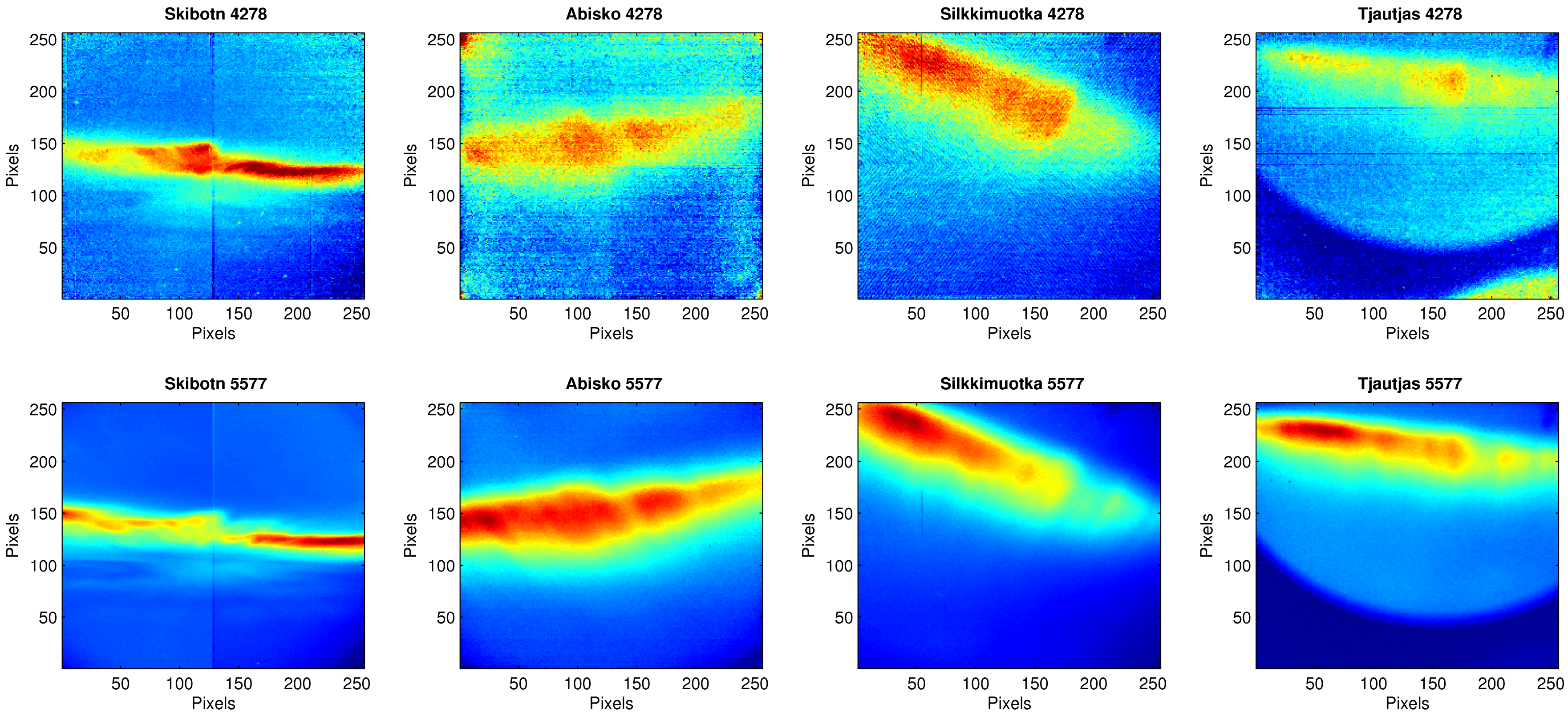
- Intensity in each pixel at each station is a line integral of 3-D auroral VER.

$$\mathbf{I}(\bar{r}_s) = \int_\Gamma \mathbf{K}(\bar{r}_s, \bar{r}')\, f(\bar{r}')\, d\bar{r}',$$

- Discretisation in 'blobs' (3D cos-squared shape) instead of constant cubic voxels. Blobs are oriented along MF line at the UHF radar site (assuming no curvature)
- M x N system : M = 100 x 100 x 75 (spatial resolution ~ 2.5 km), N = 256 x 256 x 4 $\Rightarrow$ transfer matrix ~10^{11} elements
- Iterative solution : ART/**MART**/SIRT/…

2008 Observation campaign : ALIS data

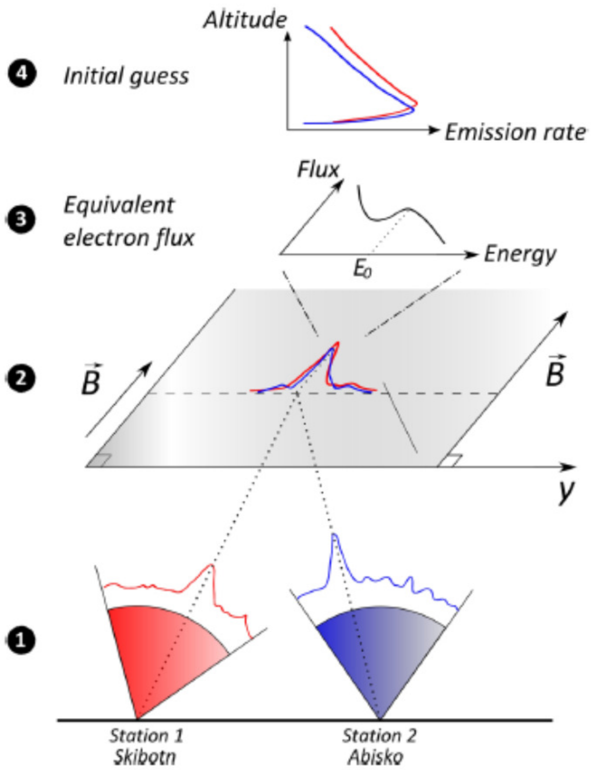
18h42m45s UT

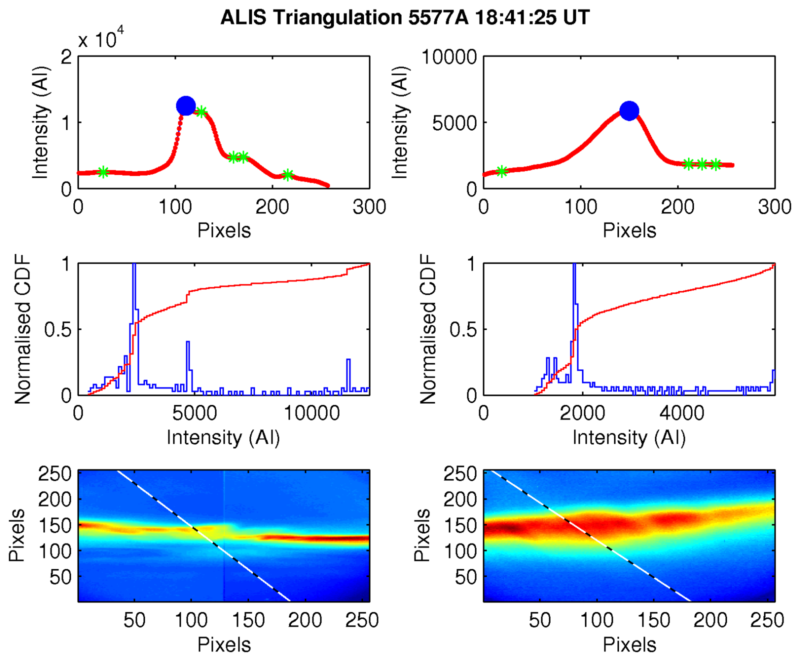


BAST stations

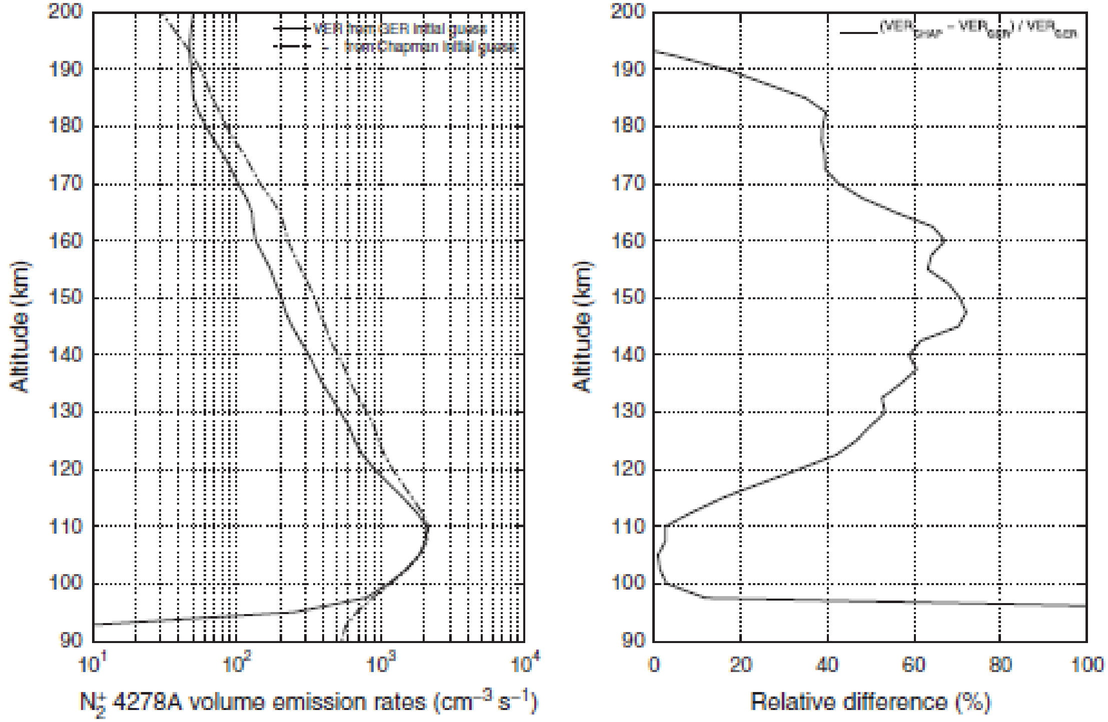
Tomographic inversion of ALIS data : initial guess

- First test : initial guess assumed uniform in lat/long
- Various profiles in altitude have been tested : in particular, a Chapman profile is not sharp enough at low altitudes.
- Later on : development of a more physical initial guess



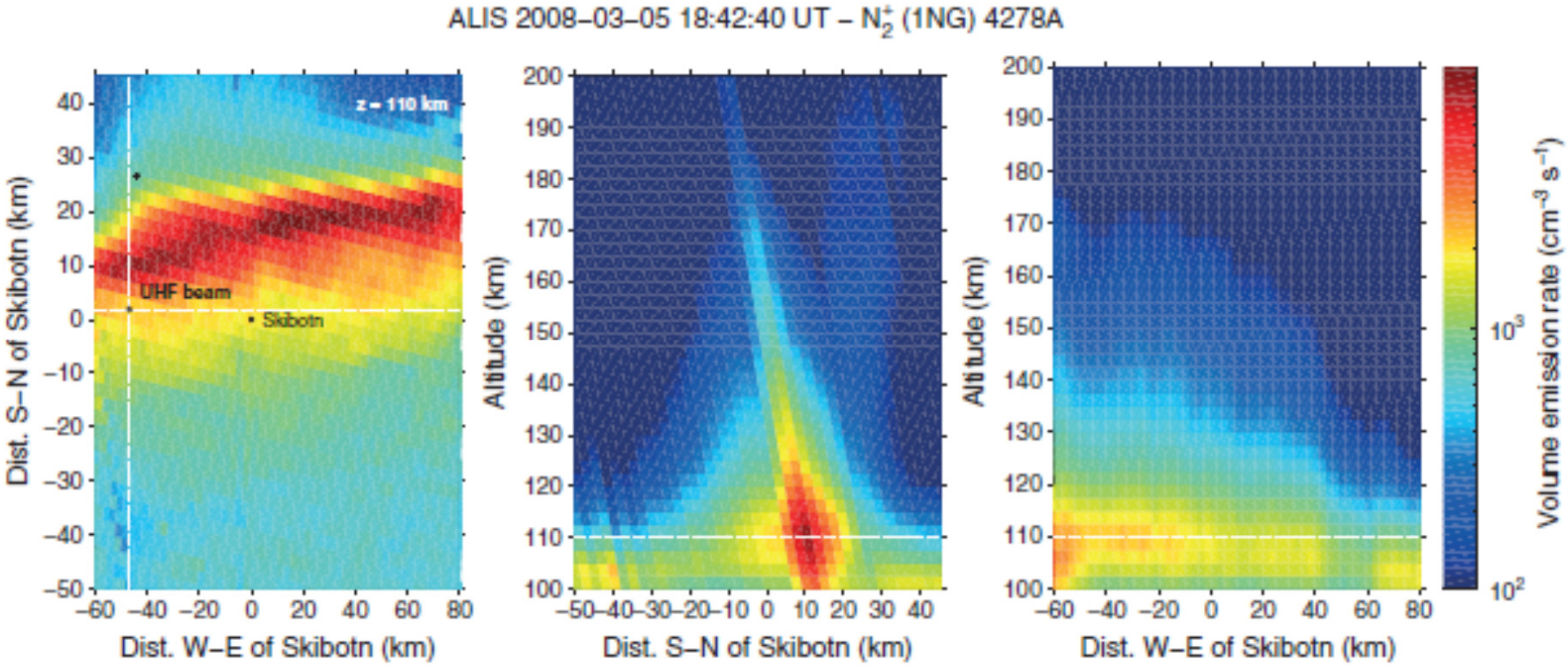


Tomographic inversion of ALIS data : initial guess



A Chapman profile is good only around the peak of the VER so only good to estimate the characteristic energy of the electron fluxes

Tomographic inversion of ALIS data



Horizontal cut at 110 km altitude of the 3-D blue VER

Vertical cut of the 3D VER in the N-S direction

Vertical cut of the 3D VER in the E-W direction

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Inversion of the blue line volume emission rates

- We invert η_b, the Volume Emission Rate (VER) of the 4278Å blue line to retrieve the fluxes of precipitating electrons

$$\eta_b = \zeta\, \varepsilon = \zeta \cdot \mathbf{B}\, \phi \qquad \text{cm}^{-3}\ \text{s}^{-1}$$

$$B_{ij} = B(z_i, E_j)\, \Delta E_j = \frac{\Lambda\left(\frac{s(z_i)}{R(E_j)}\right)\rho(z_i)\ E_j \Delta E_j}{R(E_j)}$$

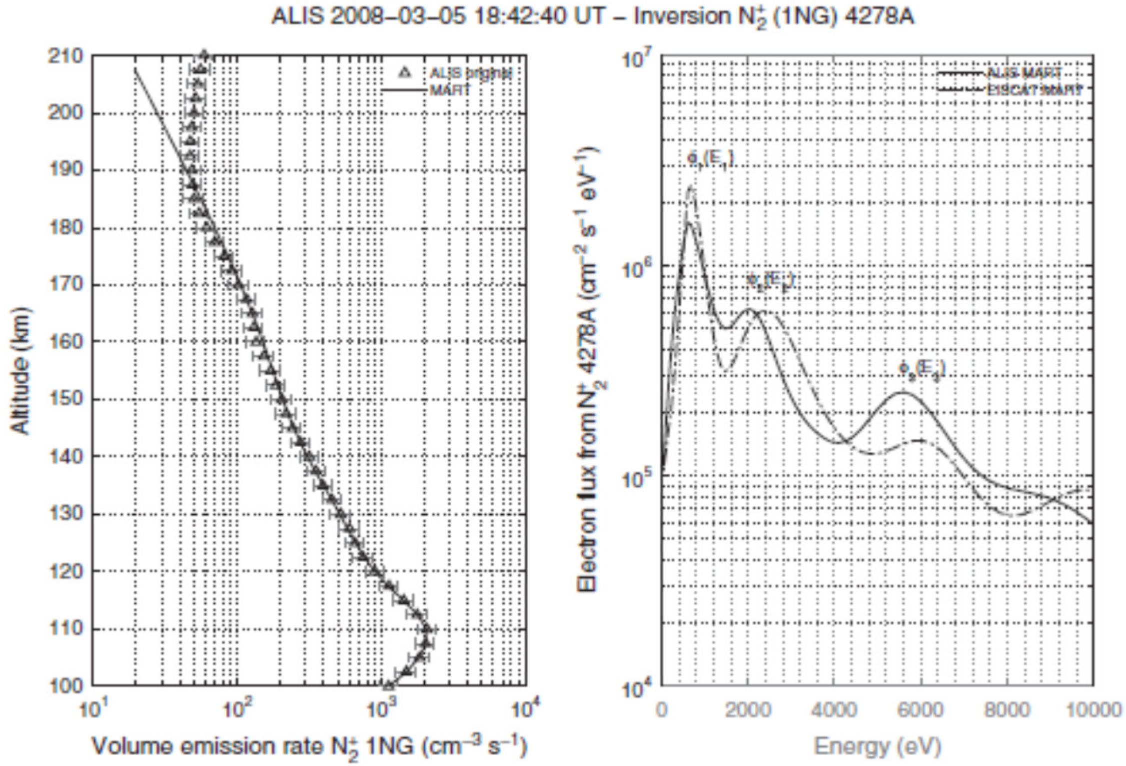
- ε : energy deposition rate
- ϕ : electron precipitation fluxes

- ζ= 0.256 (Janhunen et al 2001) : 1 KeV of deposited energy gives 0.256 blue photons on average (based on theor/lab considerations)
- Excitation efficiency dependent on altitude (Partamies et al 2004)

$$\zeta(z) = \frac{n_{N_2}(z)}{n_{N_2}(z) + 0.7\, n_{O_2}(z) + 0.4\, n_O(z)} \cdot 0.628.$$

Results from the blue line inversion

Example of an altitude profile of VER approximately along the MF line from UHF radar in Tromso



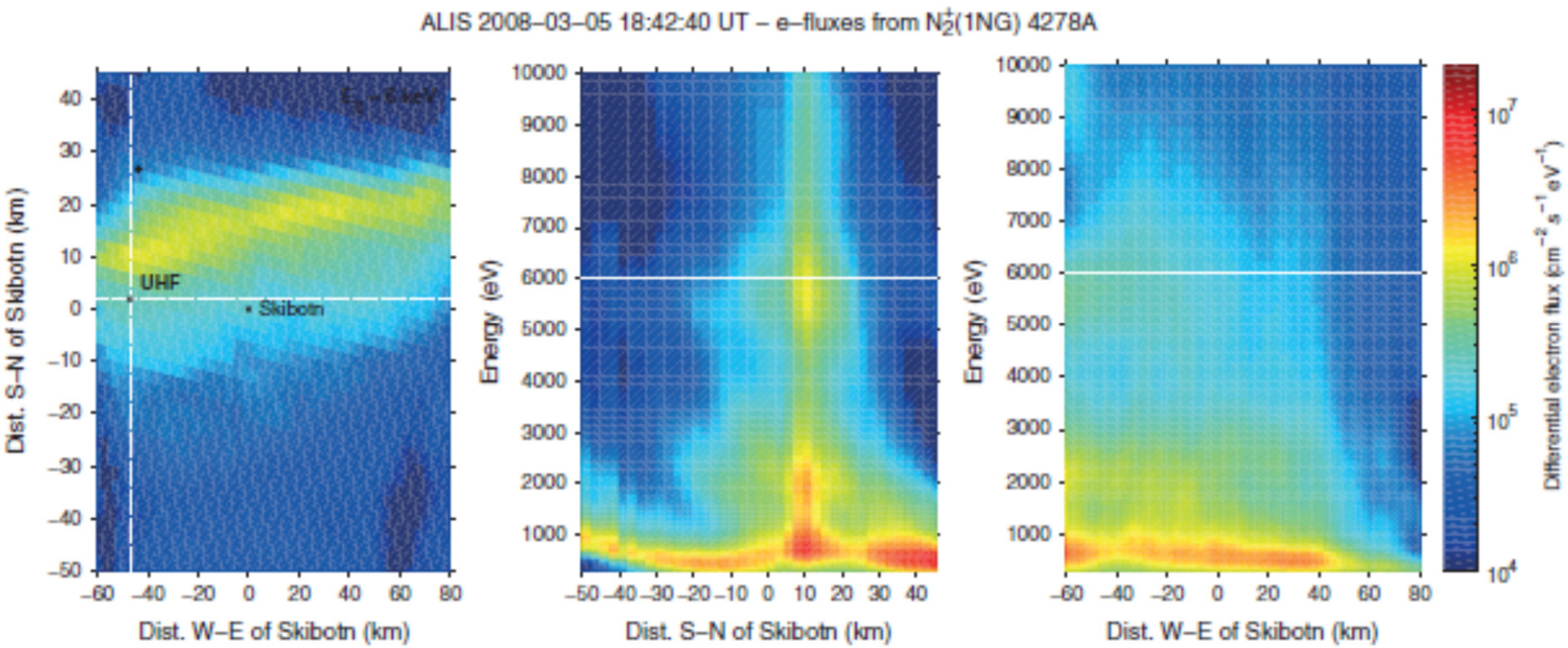
$$\Phi = \int_0^\infty \phi(E)\, \mathrm{d}E$$

$$\Phi_E = \int_0^\infty E\, \phi(E)\, \mathrm{d}E.$$

Table 3. Comparison of the Main Characteristics of ALIS- and EISCAT-Retrieved Fluxes at 18:42:40 UT[a]

	E_1 (eV)	ϕ_1 ($cm^{-2}s^{-1}eV^{-1}$)	E_2 (eV)	ϕ_2 ($cm^{-2}s^{-1}eV^{-1}$)	E_3 (eV)	ϕ_3 ($cm^{-2}s^{-1}eV^{-1}$)	Φ ($cm^{-2}s^{-1}$)	Φ_E ($mW\,m^{-2}$)
ALIS	610	1.6×10^6	2030	6.3×10^5	5620	2.5×10^5	3.16×10^9	18.4
EISCAT	680	2.4×10^6	2415	6.1×10^5	6030	1.5×10^5	3.20×10^9	17.7

2-D map of electron precipitation fluxes



Fluxes at 6 keV
(3rd peak)

Time evolution of the fluxes (ALIS)

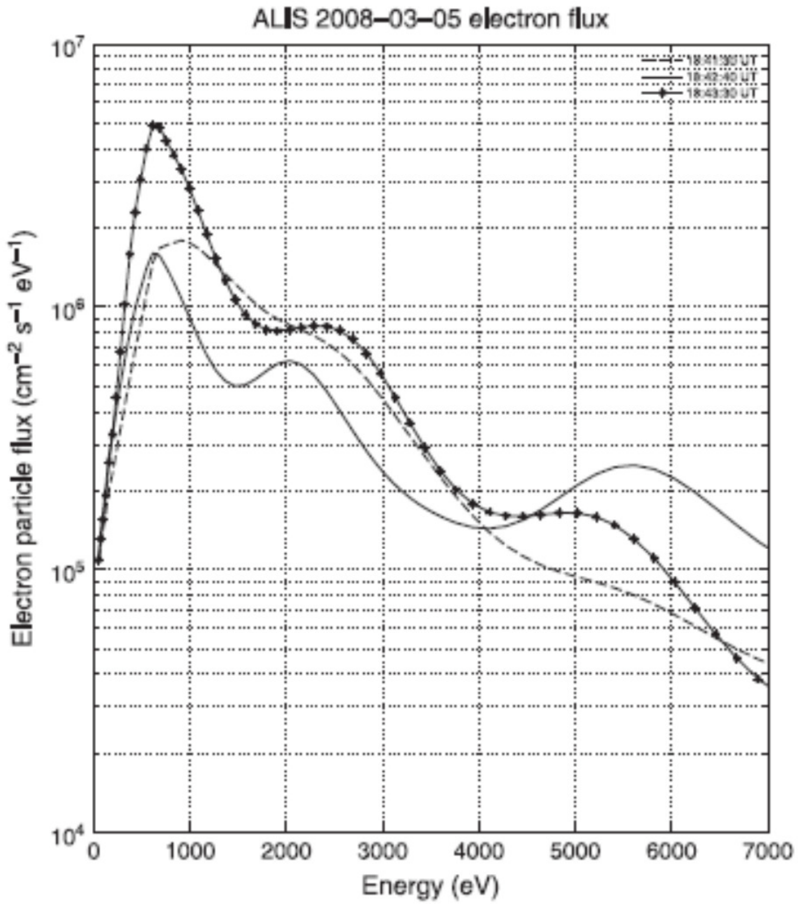
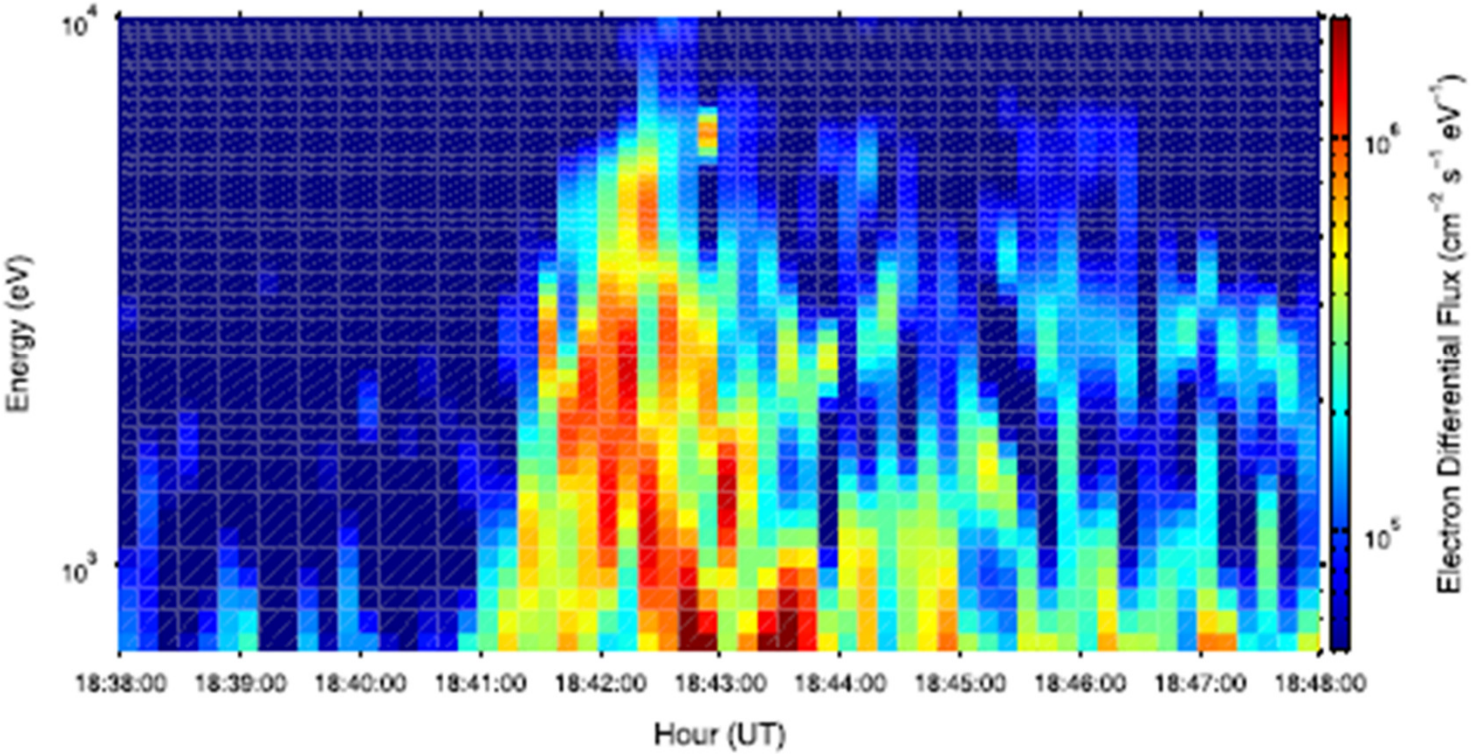


Figure 14. Electron particle fluxes retrieved with ALIS (MART inversion method) at three different stages of the main energizing event and at the EISCAT UHF location: 18:41:30 UT, 18:42:40 UT, and 18:43:30 UT.

Time evolution of the fluxes (EISCAT)

10s resolution



- No inverted V event
- Acceleration by DAWs?

2-D energy flux maps

$$\Phi_E = \int_0^{\infty} E\,\phi(E)\,\mathrm{d}E.$$

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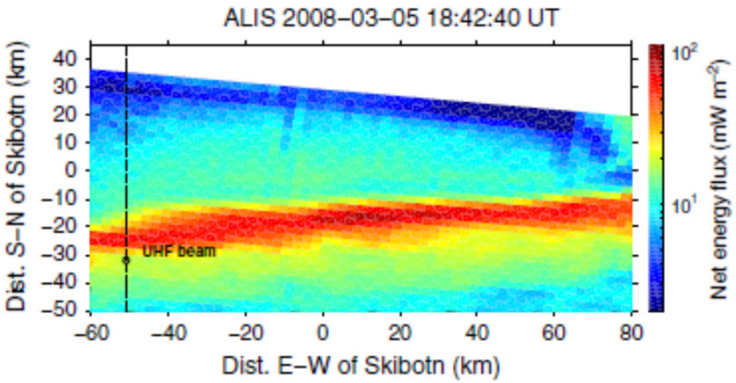

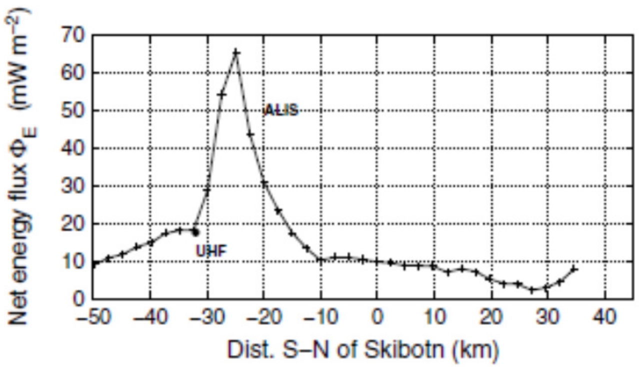

60-80 mW in the middle of the arc

Width ~ 7.5 km

Conclusions & perspectives

- Both methods (inversion from ALIS and EISCAT data) do work very well up to ~ 180 km altitude. EISCAT results are in excellent agreement with those obtained using the ALIS data and validate them. The inversion of ALIS data provides 3-D VER and 2-D differential electron fluxes.

- Analysis of more data from 2008 & 2009 campaigns (+ recent HARE campaigns)

- Better time resolution (5 sec if only 4278Å images), variation with geomagnetic indices, conjugated observations with s/c flying above/below the acceleration region

- Latitudinal distribution of net energy flux ϕE along the arc can be used in combination with a M-I coupling model to infer some characteristics of the magnetospheric generator

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