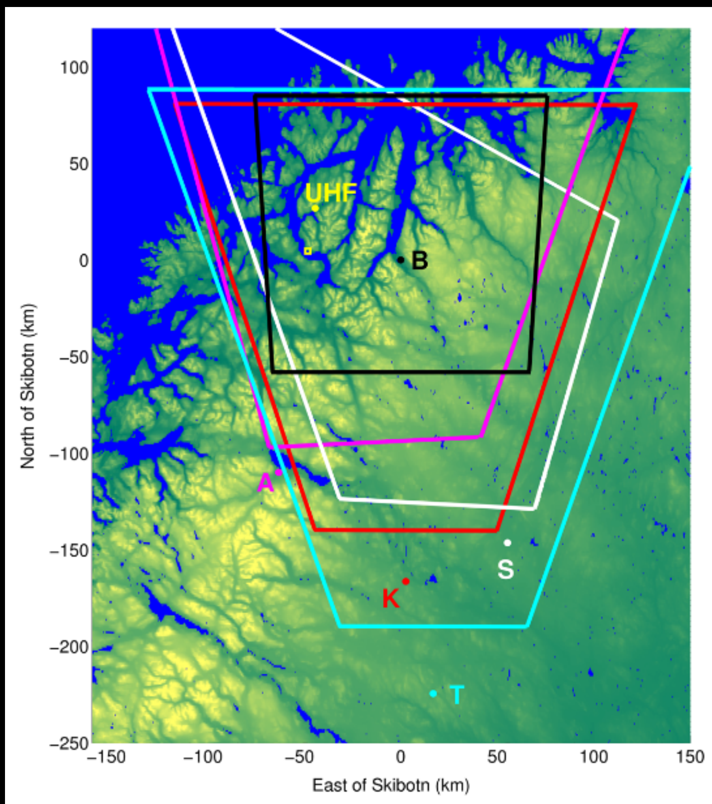
Precipitating electrons using tomographic inversions from ALIS and EISCAT observations during an auroral arc event

MOMA meeting

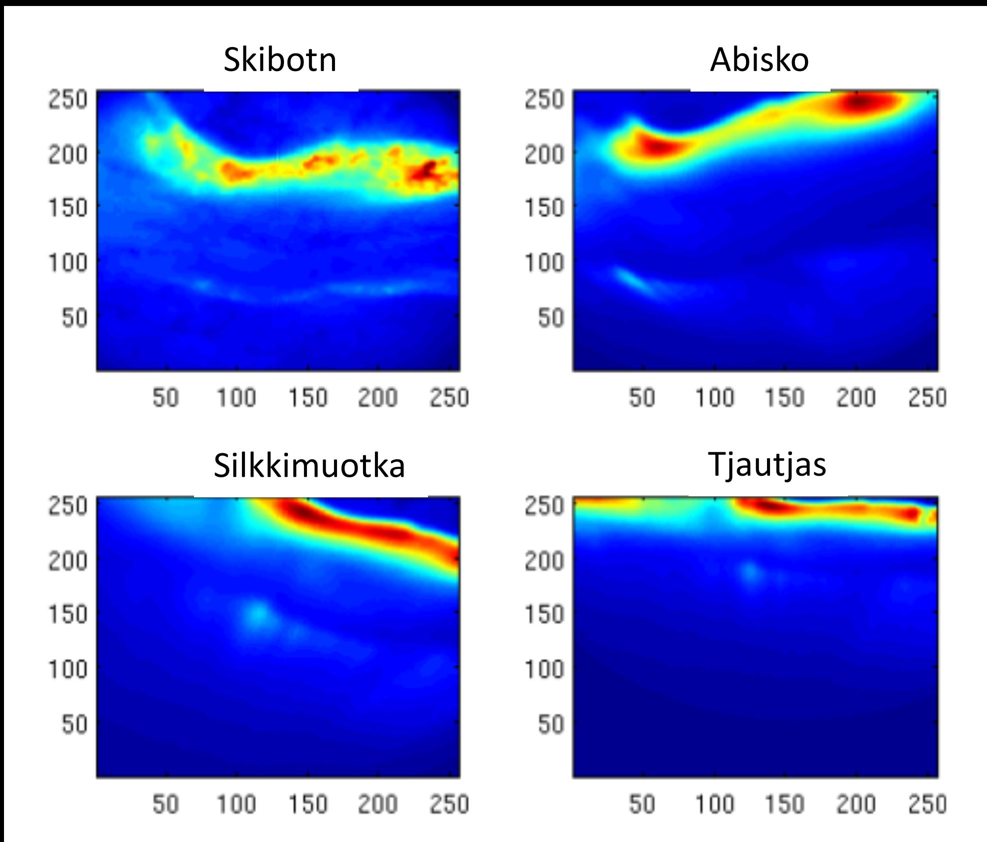
Brussels, December 2020

Aurora Optical Observations



- ✓ ALIS: network of 5 optical stations (Skibotn, Abisko, Silkkimuotka, Kiruna, Tjautjas). High-res CCD cameras observing the same volume of sky above 80 km altitude.
- ✓ Images of auroral arcs obtained using narrow interference filters at 427.8 (blue), 630.0 (red), 557.7 (green) and 844.6 nm (NIR). FOV of each camera ~ 50-70°
- ✓ Simultaneous images from different stations are properly calibrated

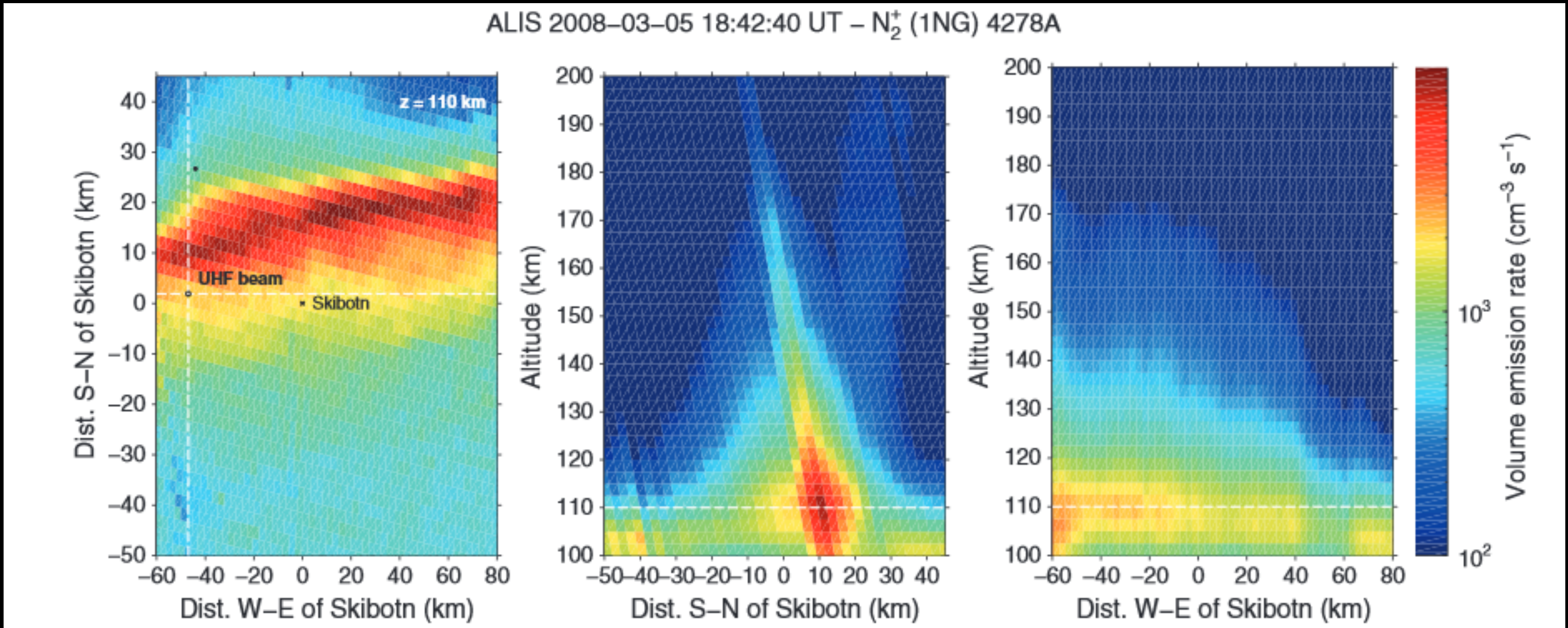
Aurora Optical Observations



March 7th, 20:32:05 UT, 5577 Å

- ✓ Using a 3D reconstruction (tomography technique), we will have access to the ALIS Volume Emission Rates (VER)
- ✓ The 2-D intensity of each pixel in an image for a station s can be seen as a line integral across the 3-D distribution of the auroral intensity source.
- ✓ Multiplicative Algebric Reconstruction Technique (MART) as inversion method (Simon Wedlund et al. 2013)

Volume Emission Rates for the blue line



- ✓ Interest of the blue band of N2+ at 427.8 nm
- ✓ Only excited by electron impact and thus nearly linearly related to the incoming electron precipitation flux.

Inversion of N2+ (1NG) Emissions

✓ Volume Emission Rate is proportional to the energy deposition rate (Janhunen, 2001)

VER = , B Φ, with the precipitation flux Φ and the matrix B which contains all the physics of the degradation of the electrons in the Earth's ionosphere as expressed through the forward model (Rees, 1989)

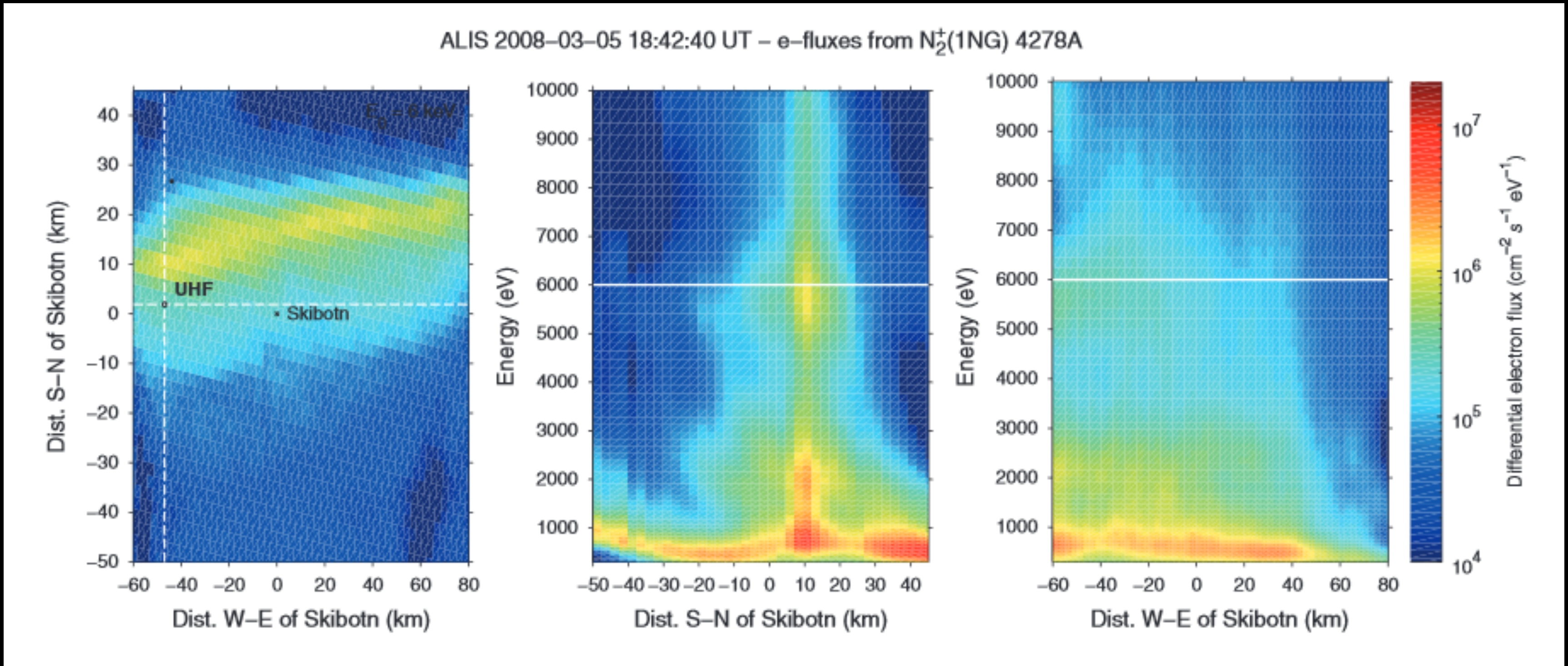
$$B_{ij} = B(z_i, E_j)\,\Delta E_j = \frac{\zeta(z_i)\,\Lambda\left(\frac{s(z_i)}{R(E_j)}\right)\rho(z_i)\,E_j\,(1-\mathcal{A}(E))\,\Delta E_j}{R(E_j)}$$

Λ = energy dissipation function (from Sergienko et al 1993)
ρ = atmospheric mass density model (MSISE-00)
$R(E_j)$ = electron range in air (from Barrett & Hays 1976)

✓ Z, the excitation efficiency , has an altitude dependence (Partamies et al., 2004) such as

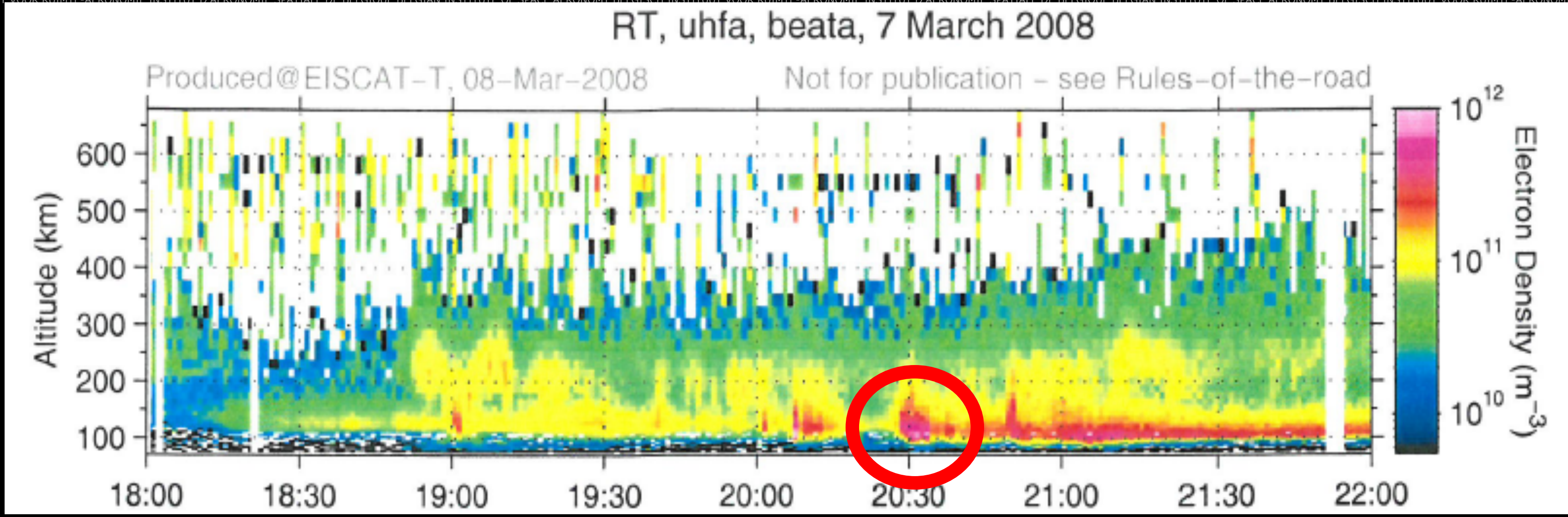
$$\zeta(z) = \frac{n_{N_2}(z)}{n_{N_2}(z) + 0.7\,n_{O_2}(z) + 0.4\,n_O(z)} \cdot 0.628.$$

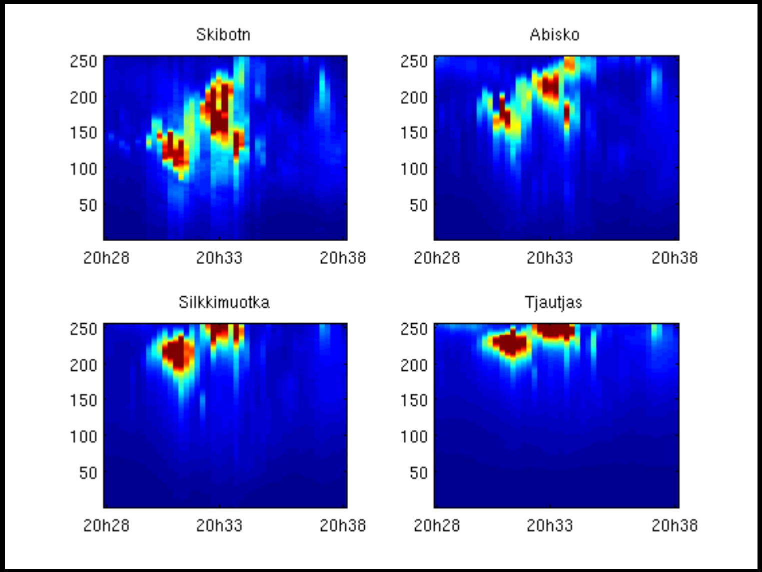
Inversion of N2+ (1NG) Emissions



- ✓ MART technique to invert the precipitating flux from the blue volume emission rate.
- ✓ 2-D electron precipitation flux maps over ALIS at 18:42:40 UT
  - ✓ Energy projection at 6 keV (110 km altitude) in the latitude/longitude plane
  - ✓ Latitudinal projection of fluxes versus energy in the plane passing through the UHF EISCAT radar.
  - ✓ Longitudinal projection of fluxes versus energy in the plane passing through the EISCAT radar.

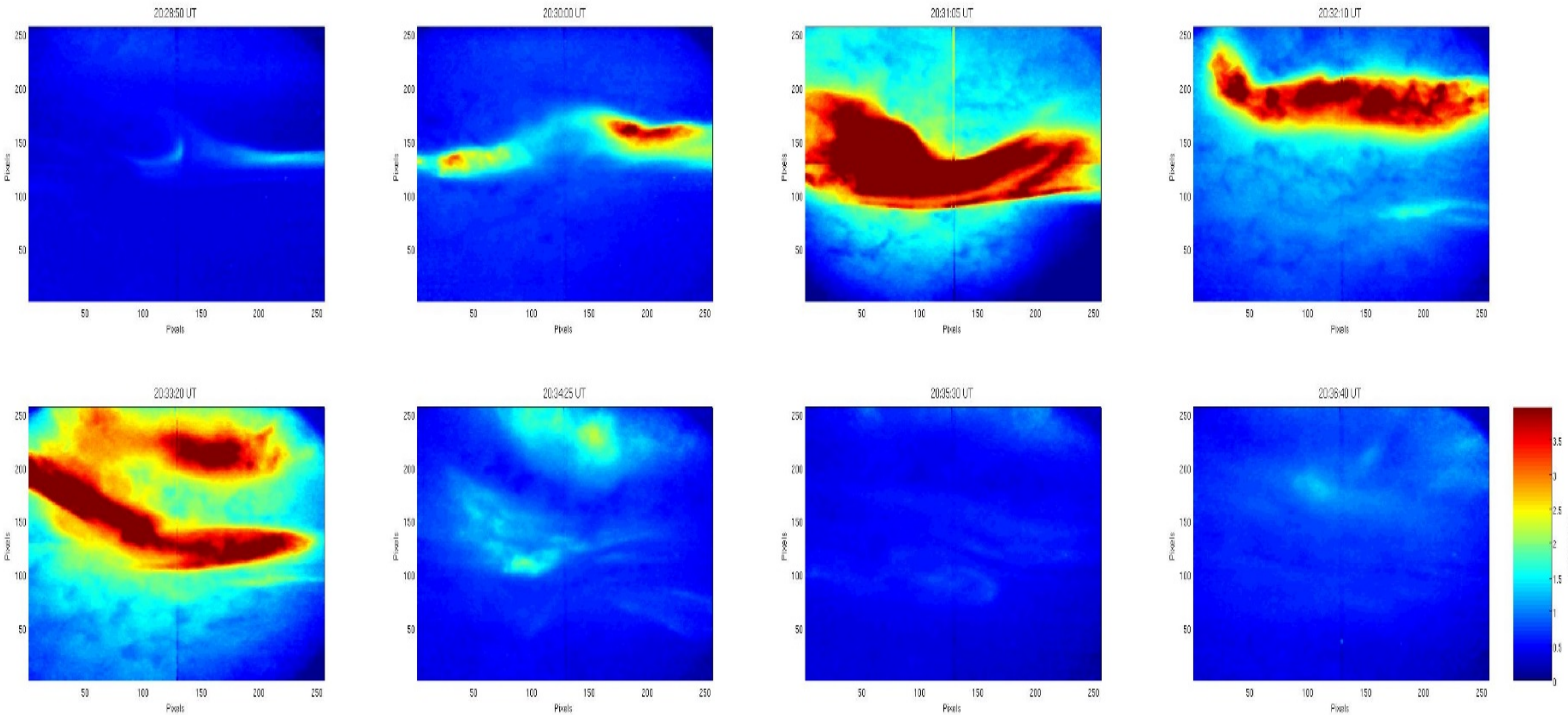
New case study





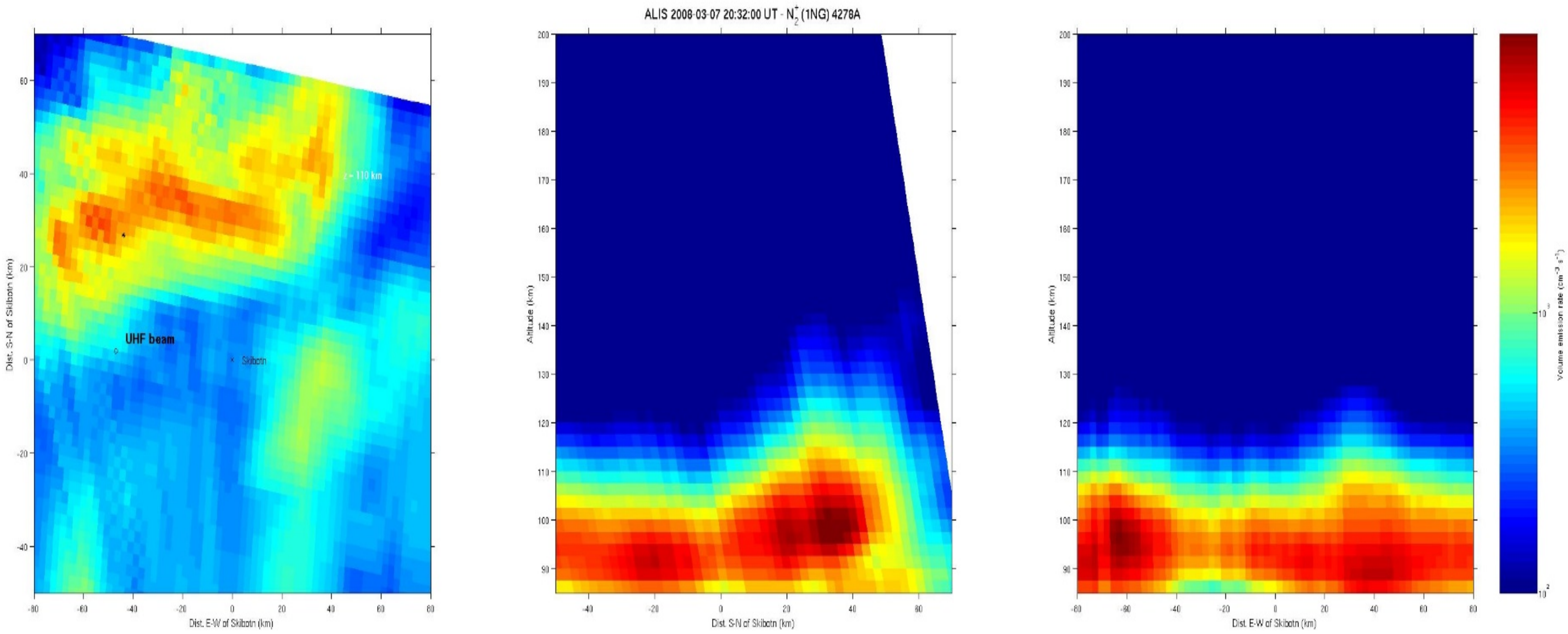
- ✓ Apply the full procedure to a random case
- ✓ What will we obtain from it?
- ✓ Automatic procedure in the future?

Aurora Optical Observations



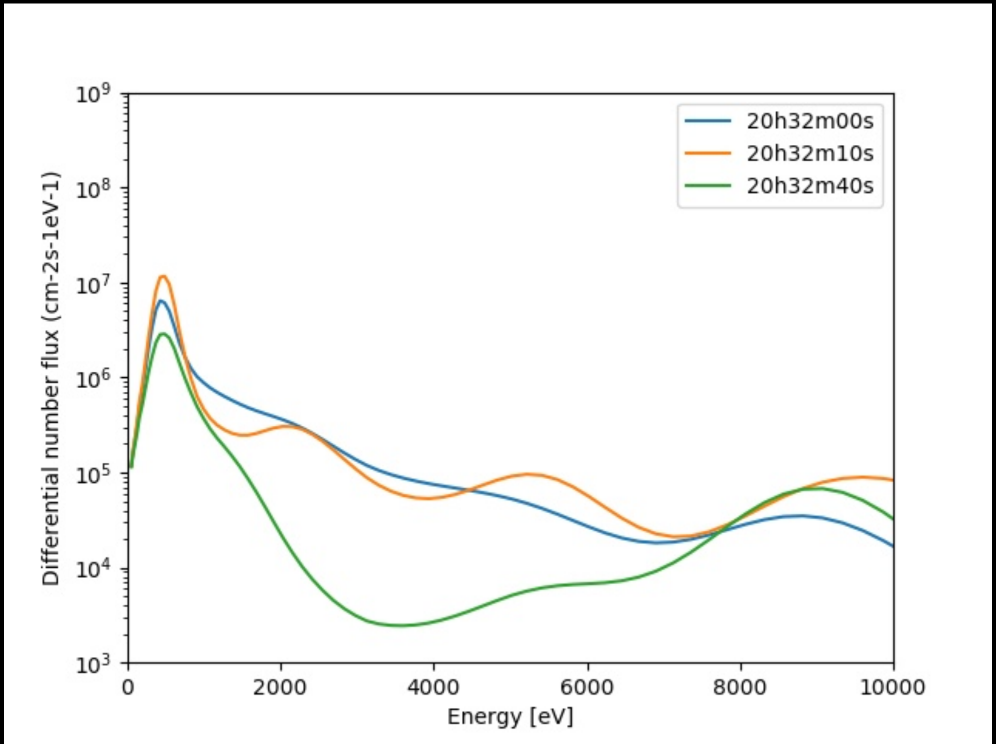
Time sequence from 20:28:50 to 20:36:40 for Skibotn at 427.8 nm

3D Volume Emission Rate (VER)



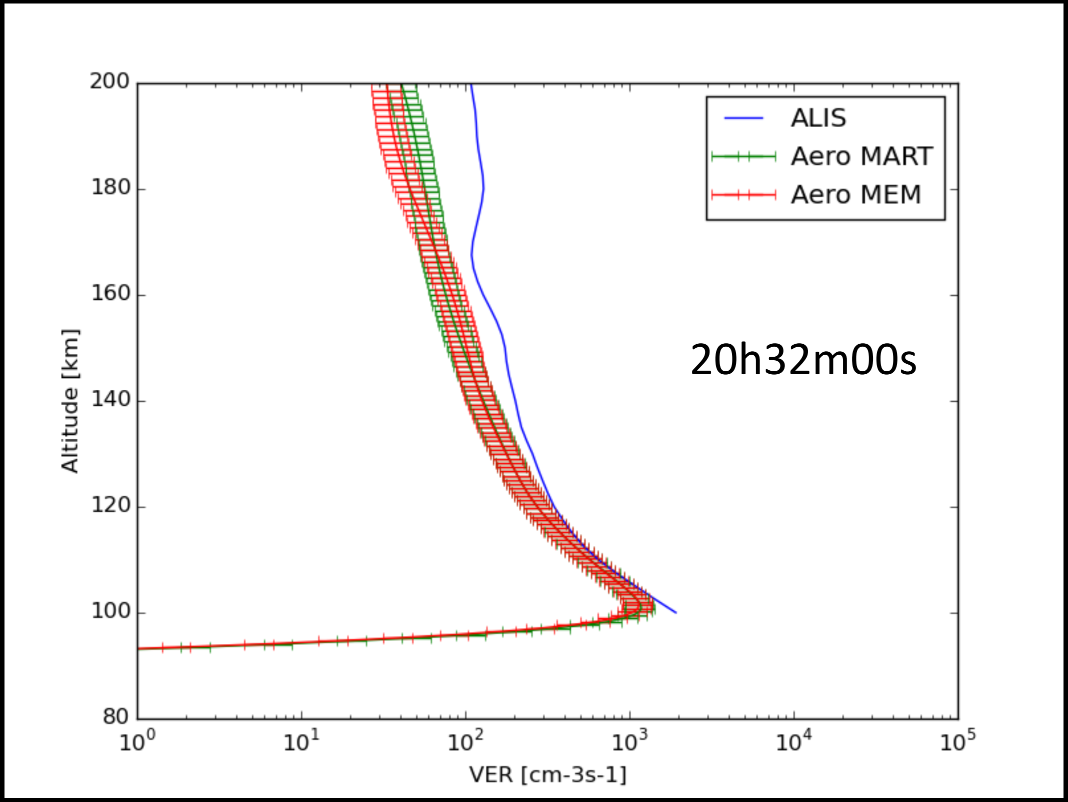
- ✓ One example for 20h32m00s, using 4 cameras
- ✓ Algorithm is pretty sensitive

Inversion of N2+ (1NG) Emissions



- ✓ The inversion method can be applied to the entire time sequence of N_2^+ images at 427.8 nm
- ✓ MART reconstruction, similar for MEM except at low energies
- ✓ Electron particle fluxes at three different stages of the auroral arc, at 20h32m 0s, 10s, and 40s at the EISCAT UHF location.

Comparison with Aeroplanets



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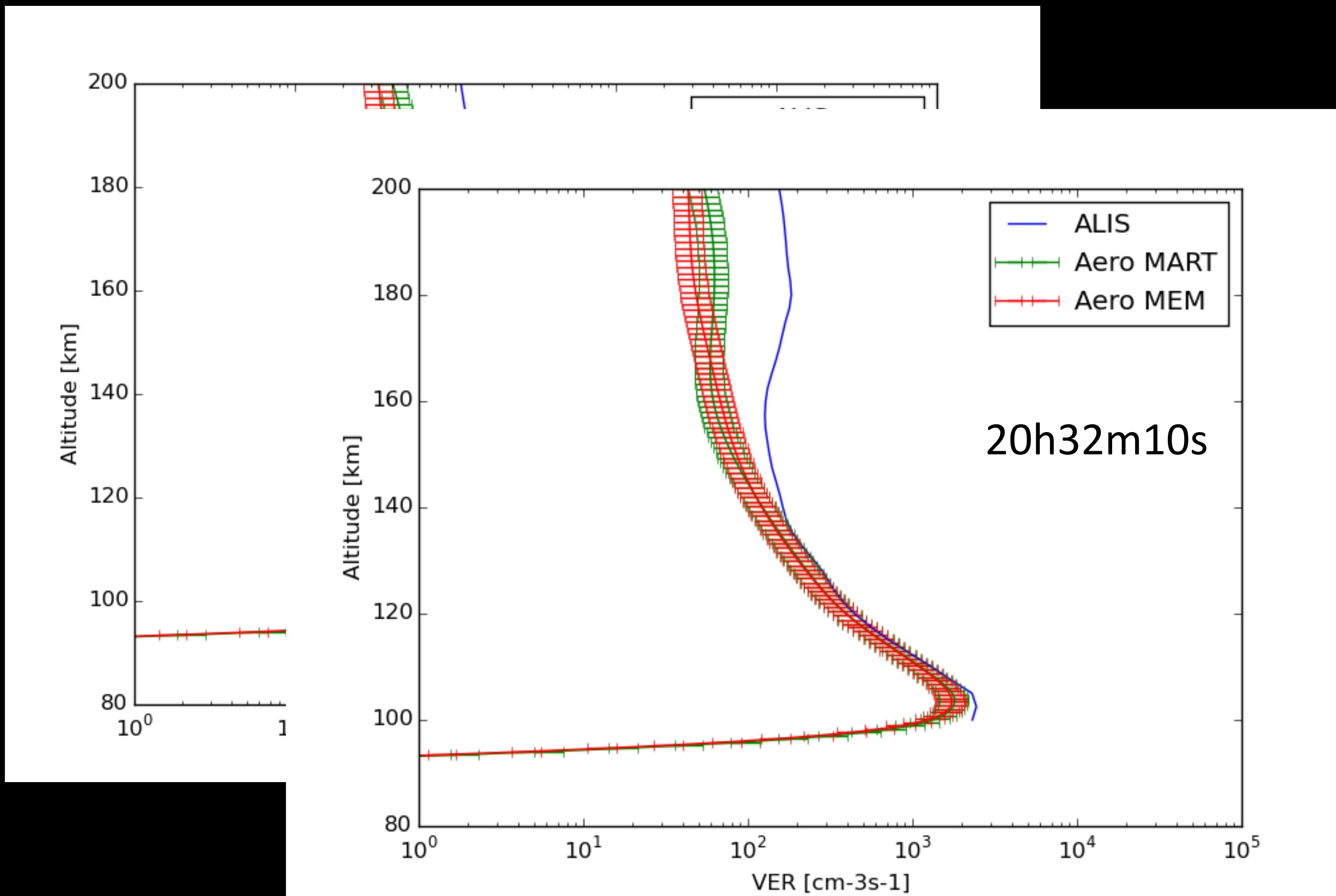

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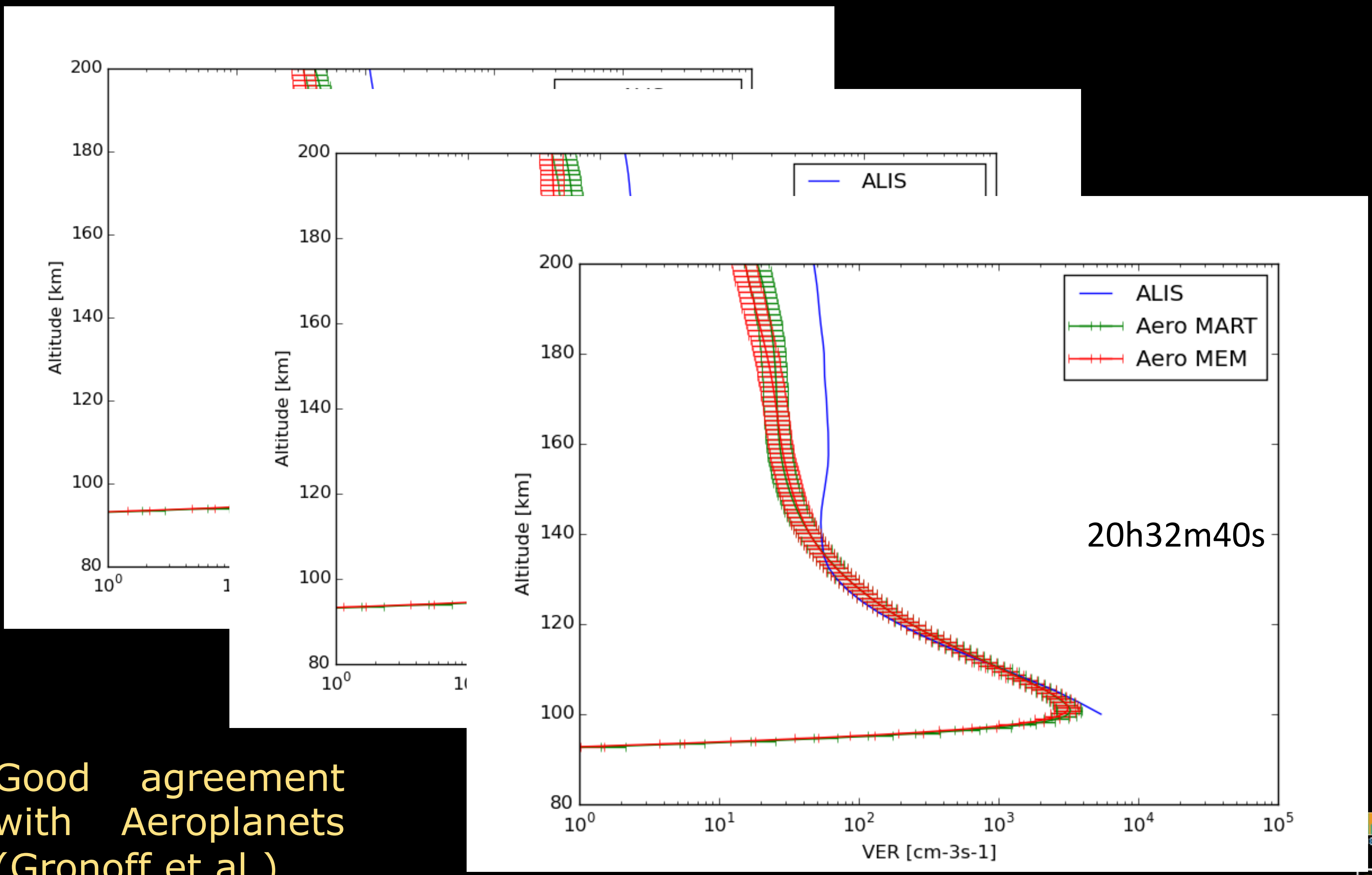
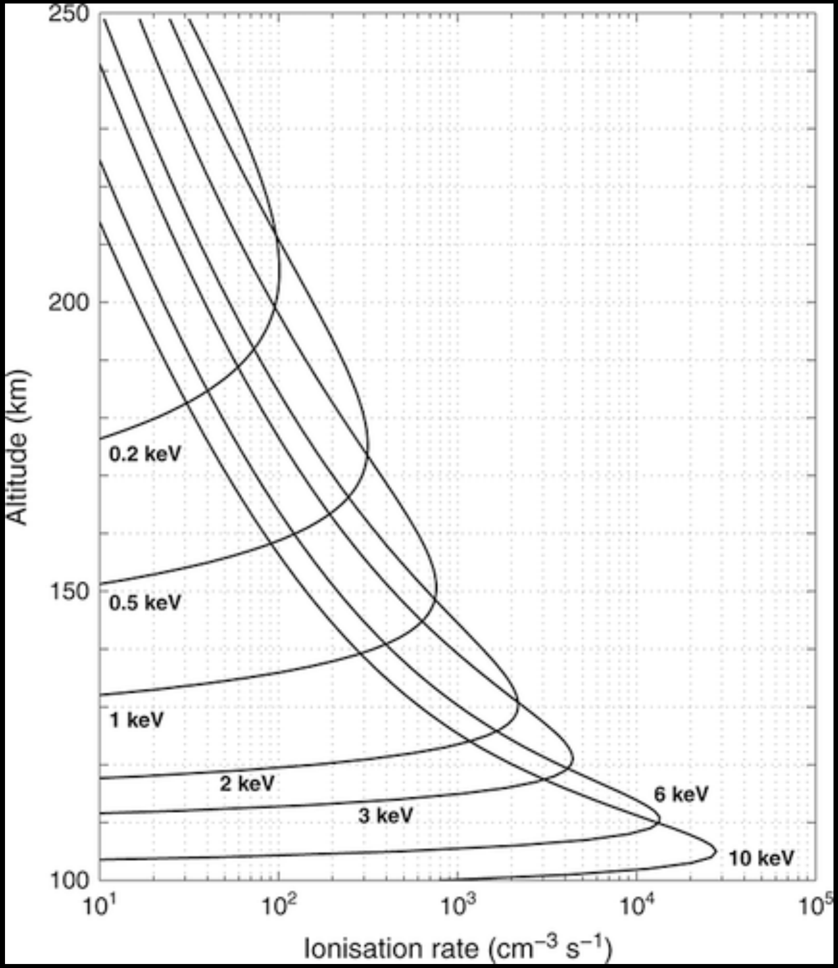


- ✓ Good agreement with Aeroplanets (Gronoff et al.)

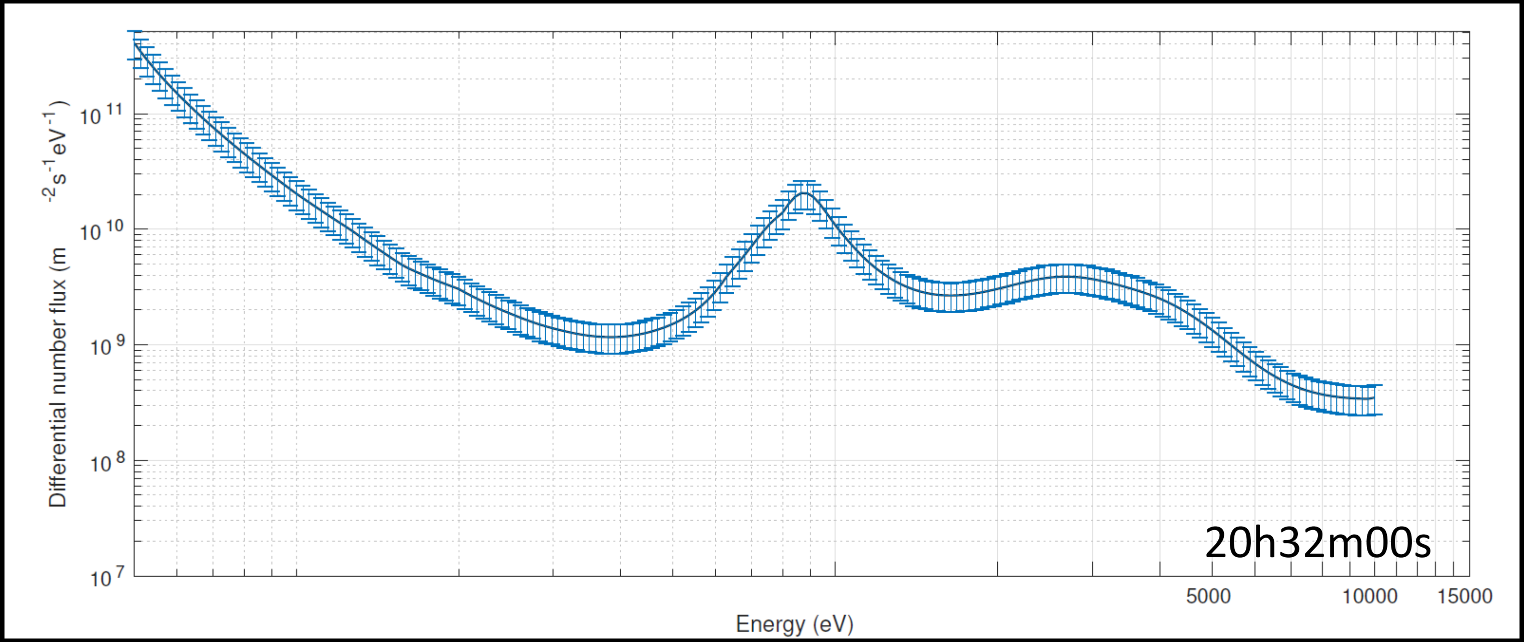
EISCAT data Inversion



$$\frac{dn_e}{dt} = q - \sum_i \alpha_i n_i \, n_e$$

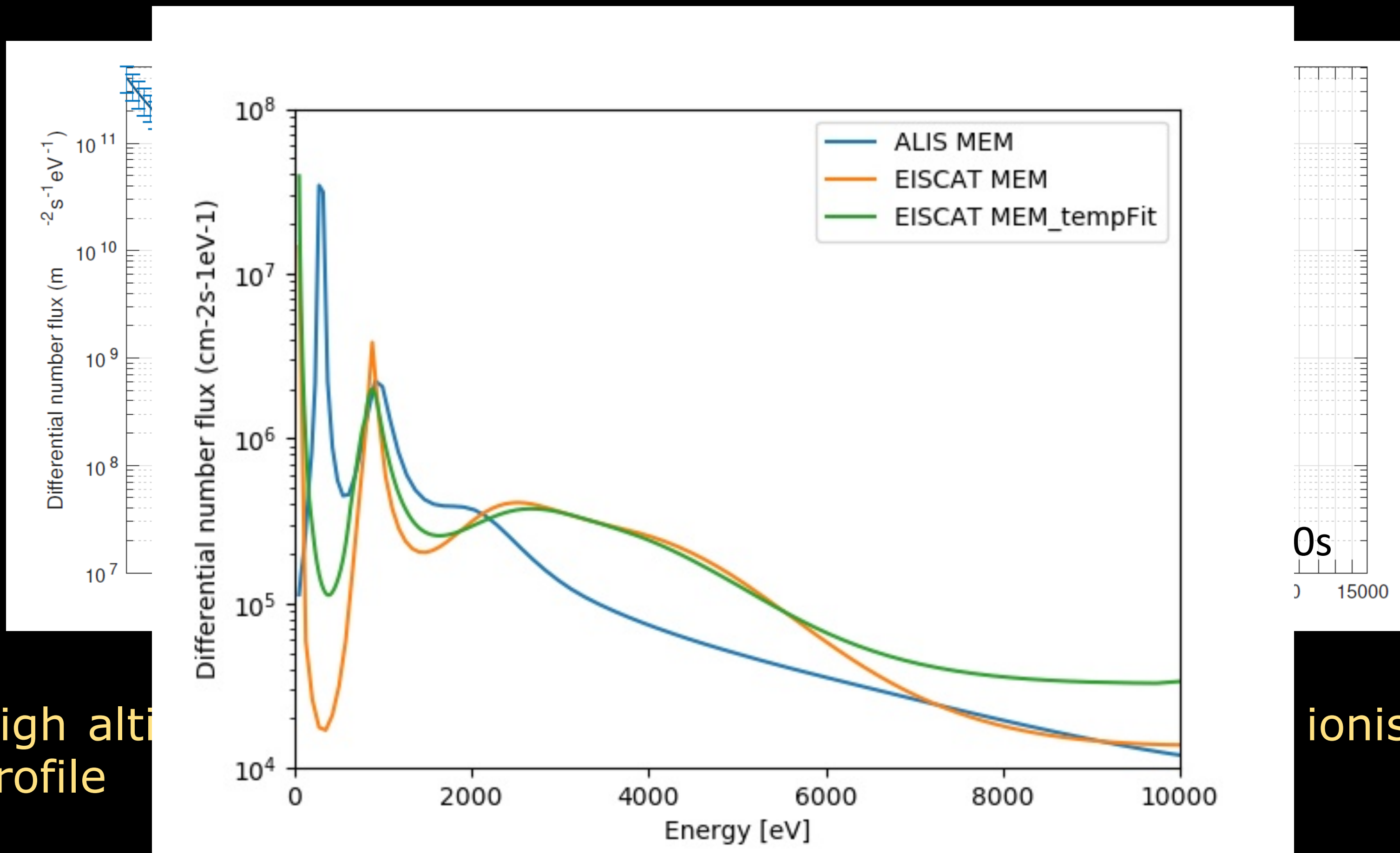
- ✓ Ionisation rate q
- ✓ Average Recombination rate, α_i for NO^+ and O_2^+, dependant to the temperature profile
- ✓ Known altitudes profiles of ionisation allows to invert the problem and to infer the differential electron flux

EISCAT data Inversion



- ✓ High altitudes (> 160 km) difficult to reconstruct (cf the ionisation profile
- ✓ Energy lower than 500 ev highly uncertain
- ✓ Relatively good agreement with ALIS reconstruction

EISCAT data Inversion



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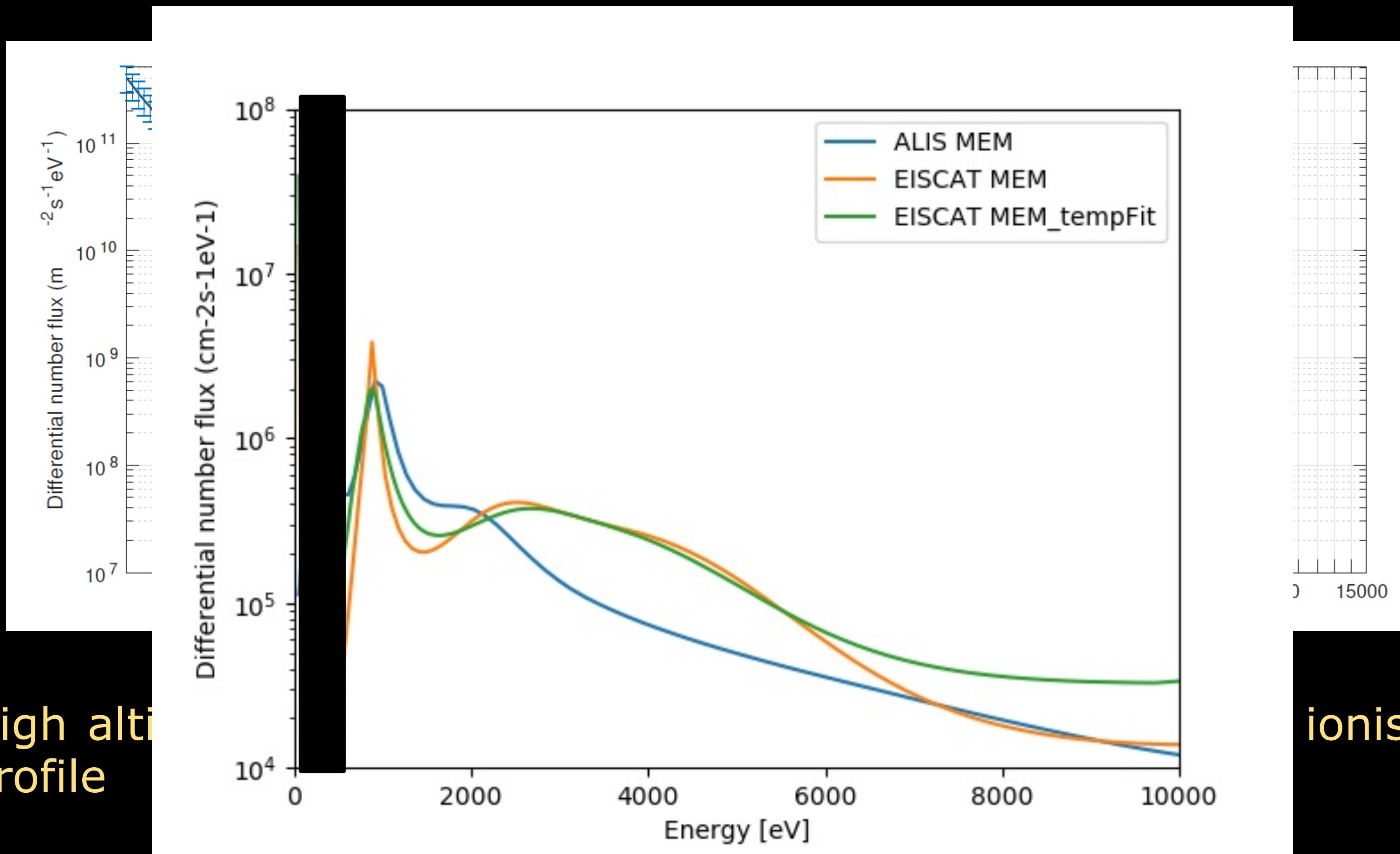

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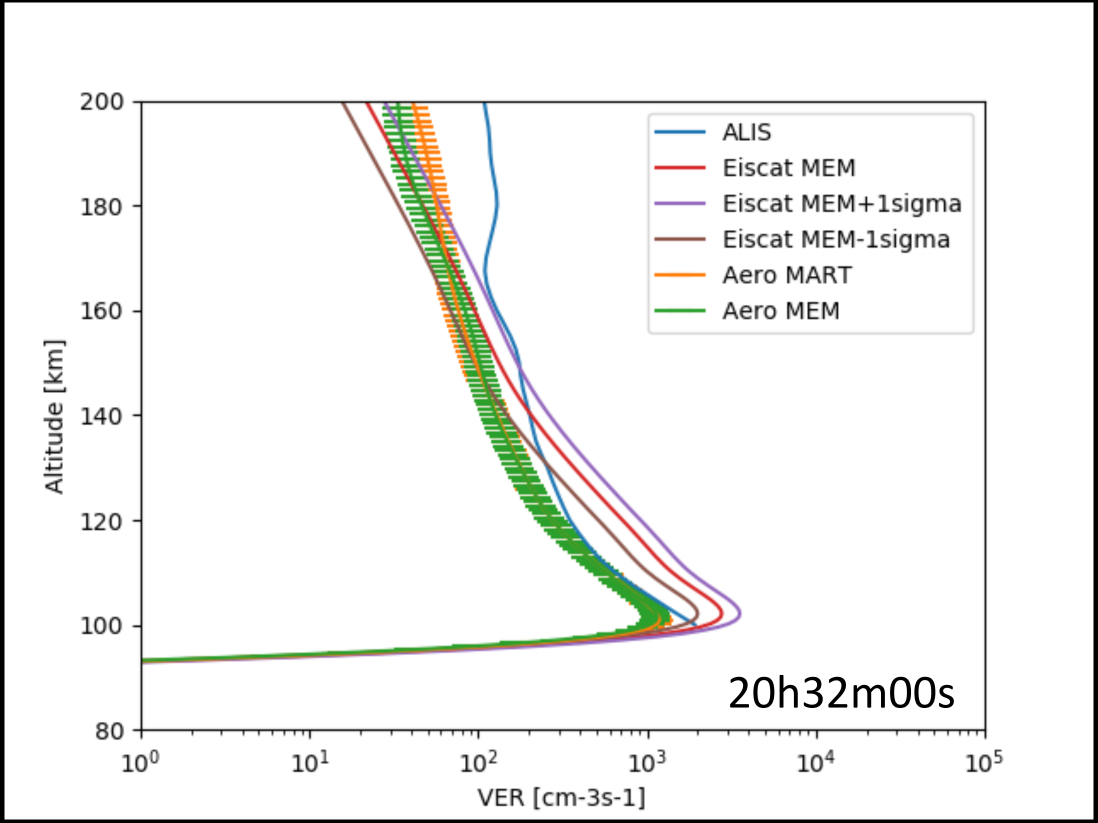
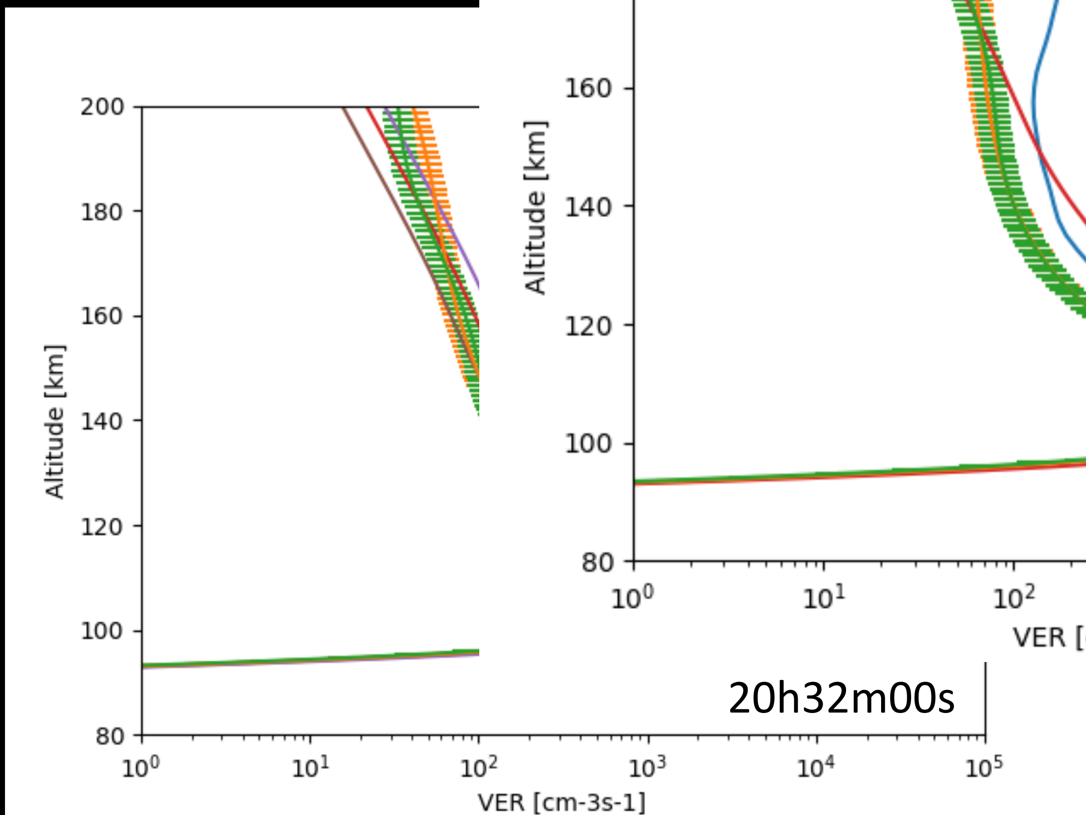
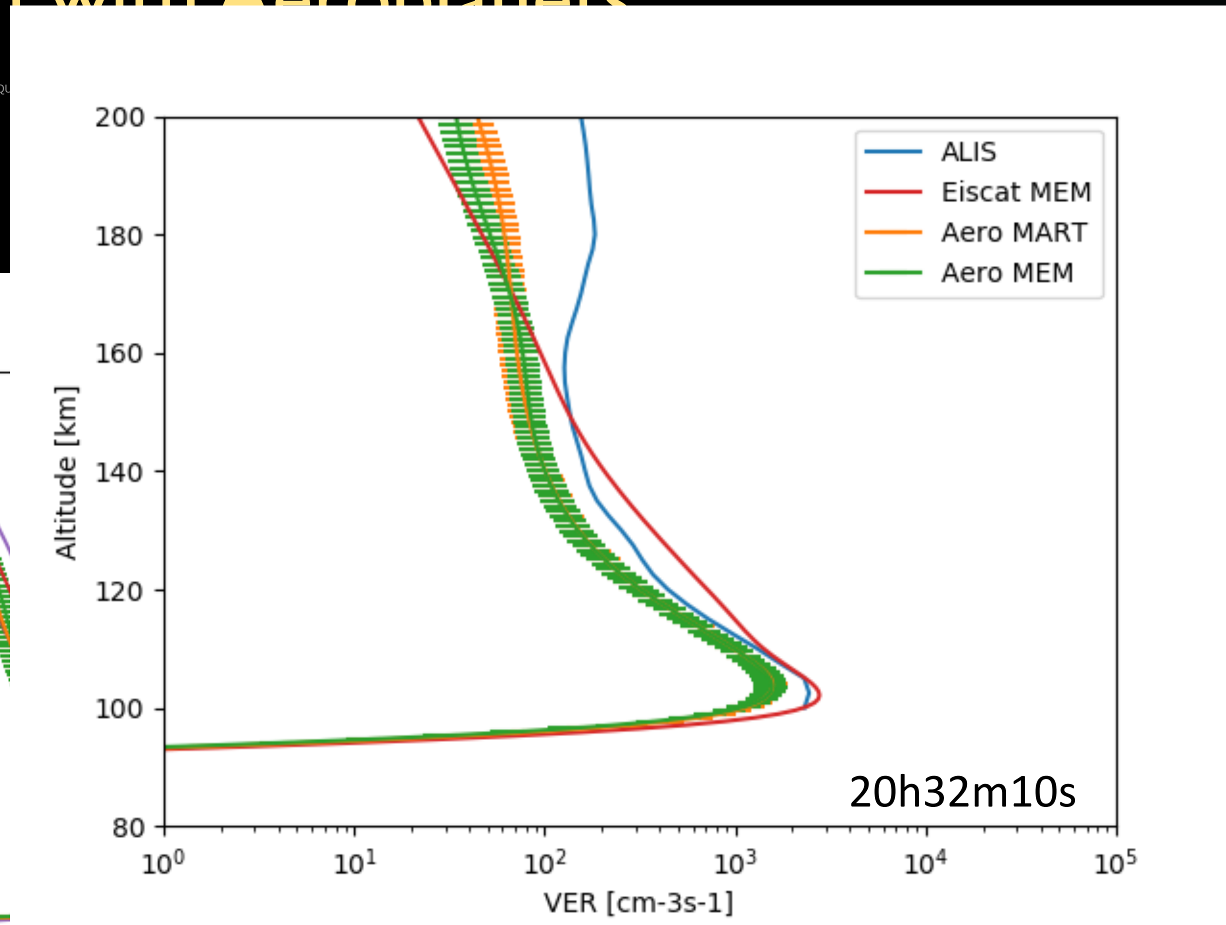
Comparison with Aeroplanets



- ✓ Good agreement between ALIS et Aeroplanets/ALIS as seen before
- ✓ Flux from EISCAT leads to an higher VER at 100 km altitude
- ✓ Comparison with other date and others spectral lines to be done

Comparison with Aeroplanets





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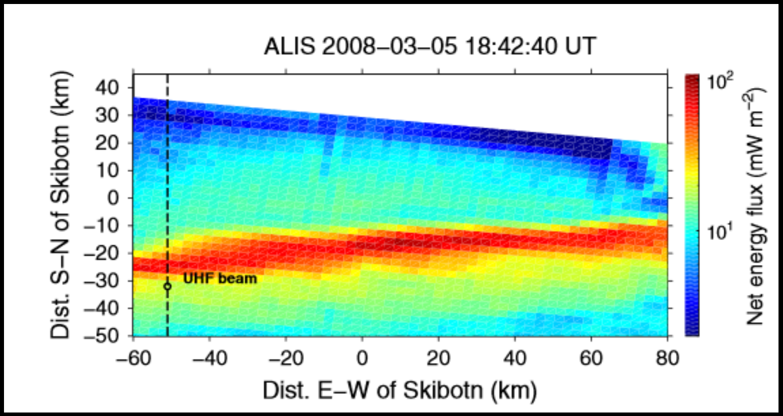
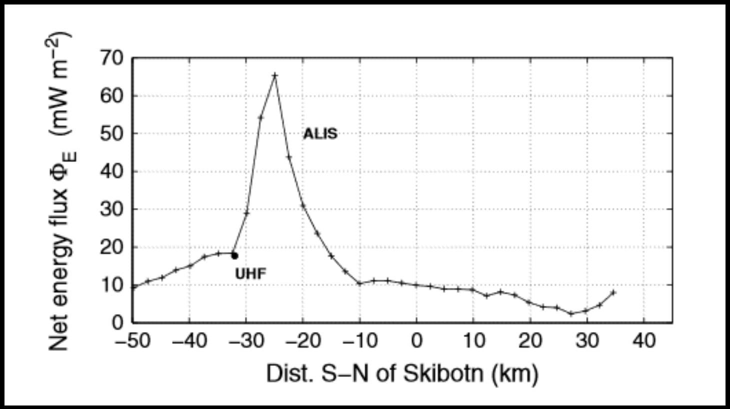
- Comparison with other date and others spectral lines to be done

2-D Energy Flux Maps

- ✓ The net energy flux, $$\Phi_E = \int_0^\infty E\,\phi(E)\,\mathrm{d}E.$$
- ✓ Crucial parameter of magnetosphere-ionosphere coupling models (see Echim et al., 2007). N
- ✓ Net energy flux at 18:42:40 UT derived from EISCAT equal to 17.7 mW m^{-2} while for the ALIS-derived net energy flux along the same field line:18.4 mW m^{-2}, (difference of less than 4%)





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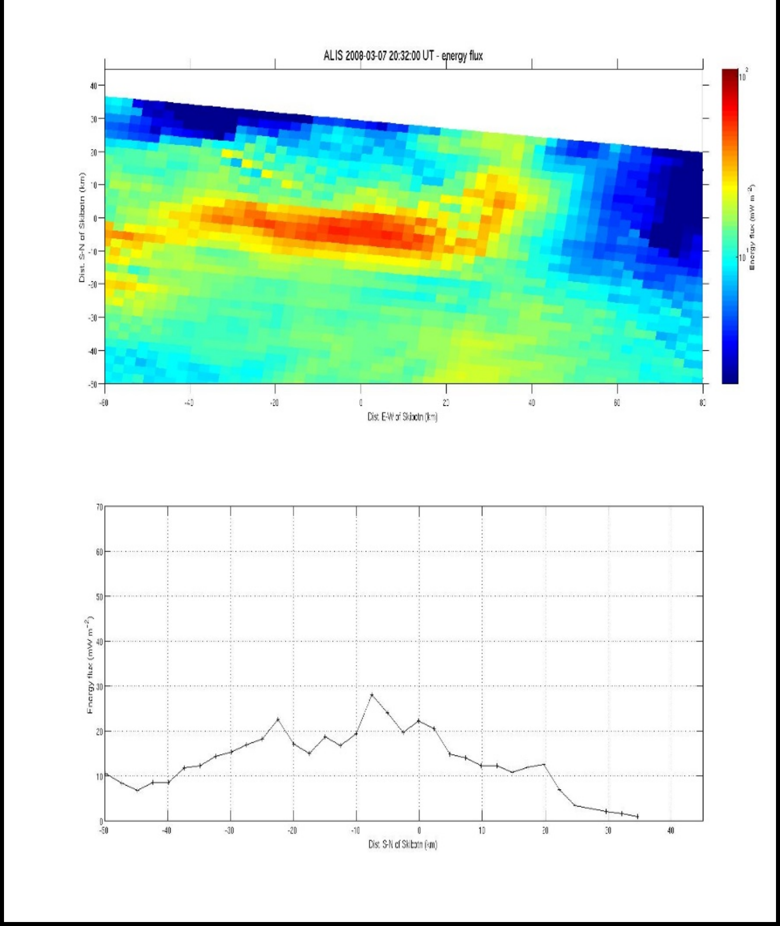

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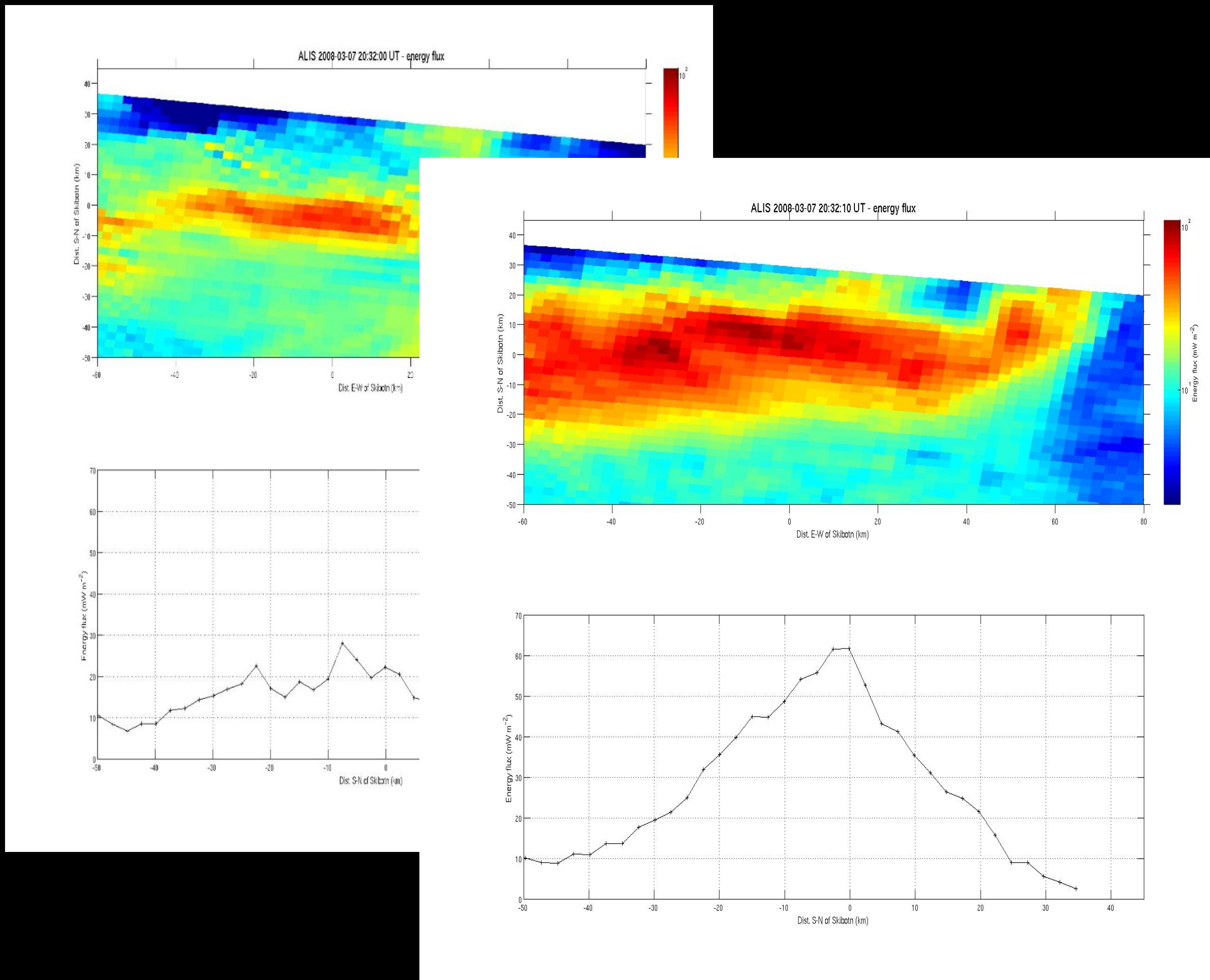

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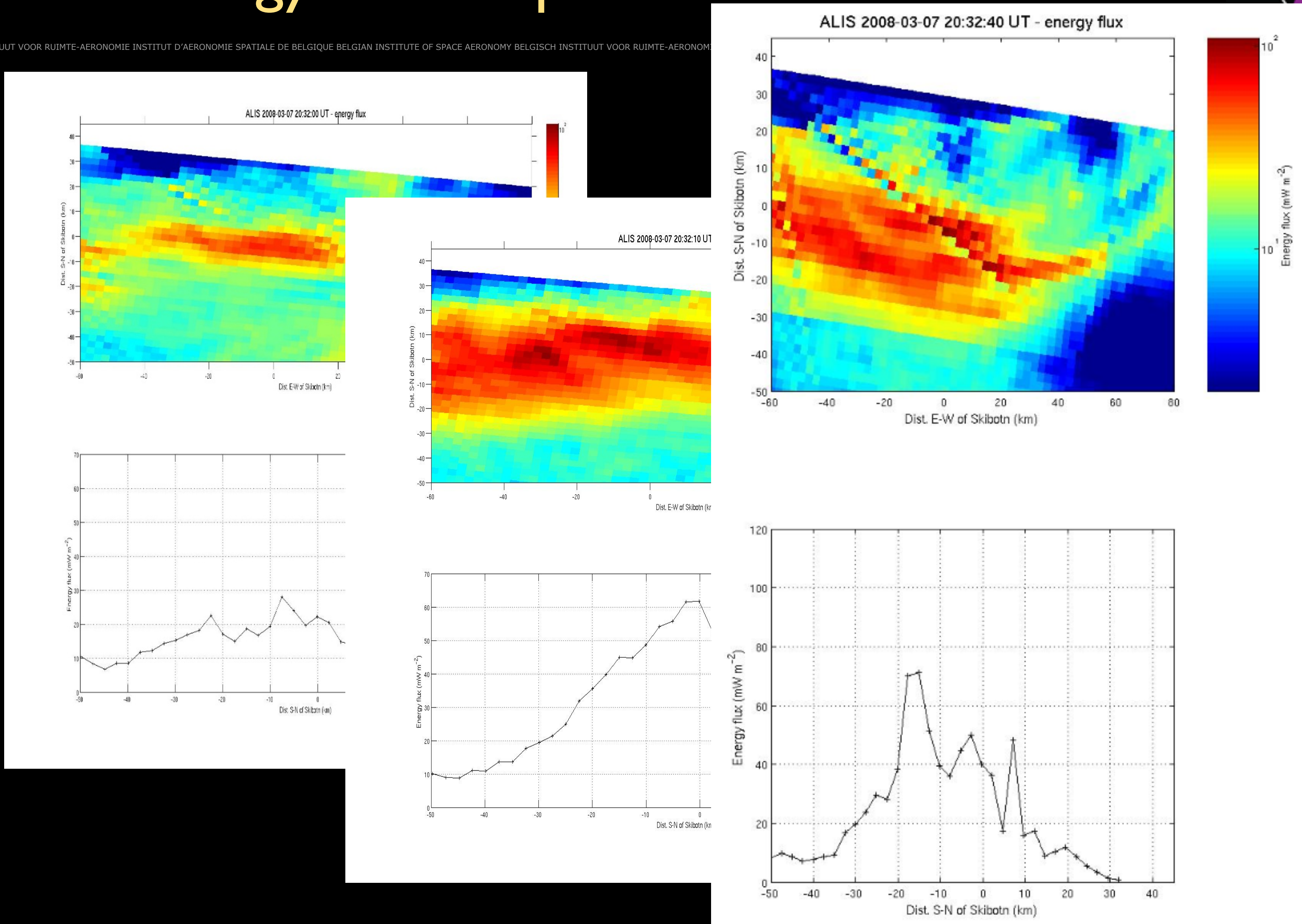

Take home message

Multi-station observations of auroral arc at 427.8 nm

Tomography-like reconstruction

3-D Volume Emission Rate VER at 427.8 nm

MART inversion

- ✓ 2-D (lat/long) spectra of precipitating electrons
- ✓ Net energy flux

M-I coupling model (Echim et al. 2007) in order to infer properties of magnetospheric auroral generators.

- ✓ Same methods will be applied for further existing and future datasets (ALIS 4D)