Atmospheric signature of relativistic electron bursts - EISCAT data archive revisited

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SPECIAL THANKS: The CHAMOS Team (SGO, FMI, BAS, Univ.of Otago)

Question:

Do we see relativistic electron microbursts in the atmosphere?

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REP microbursts (E> 1MeV ,duration <1 s, typical 100ms) are frequently reported from satellites at L=4-6 [Imhof et al., 1992; Blake et al., 1996]

Are these “visible” in the atmosphere?

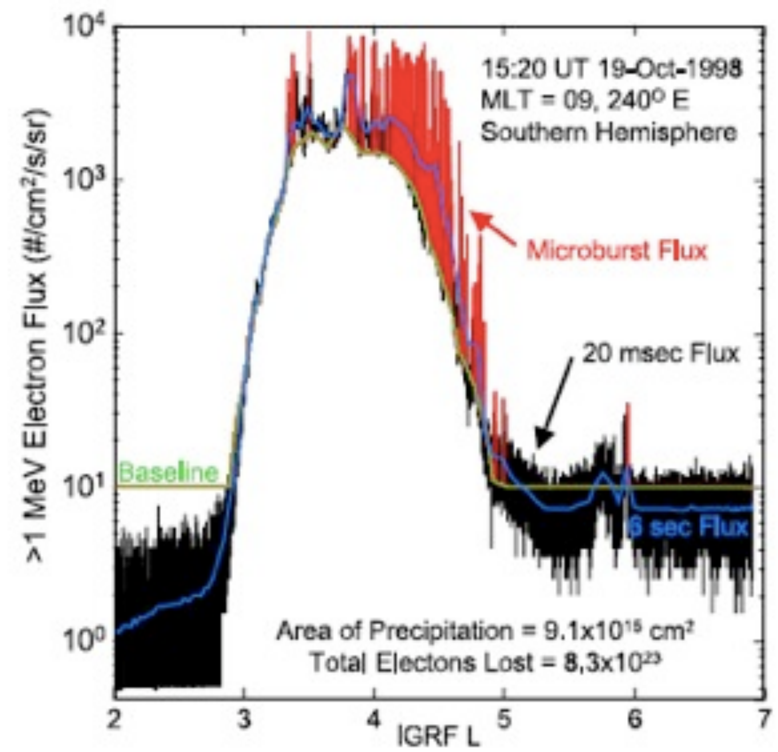


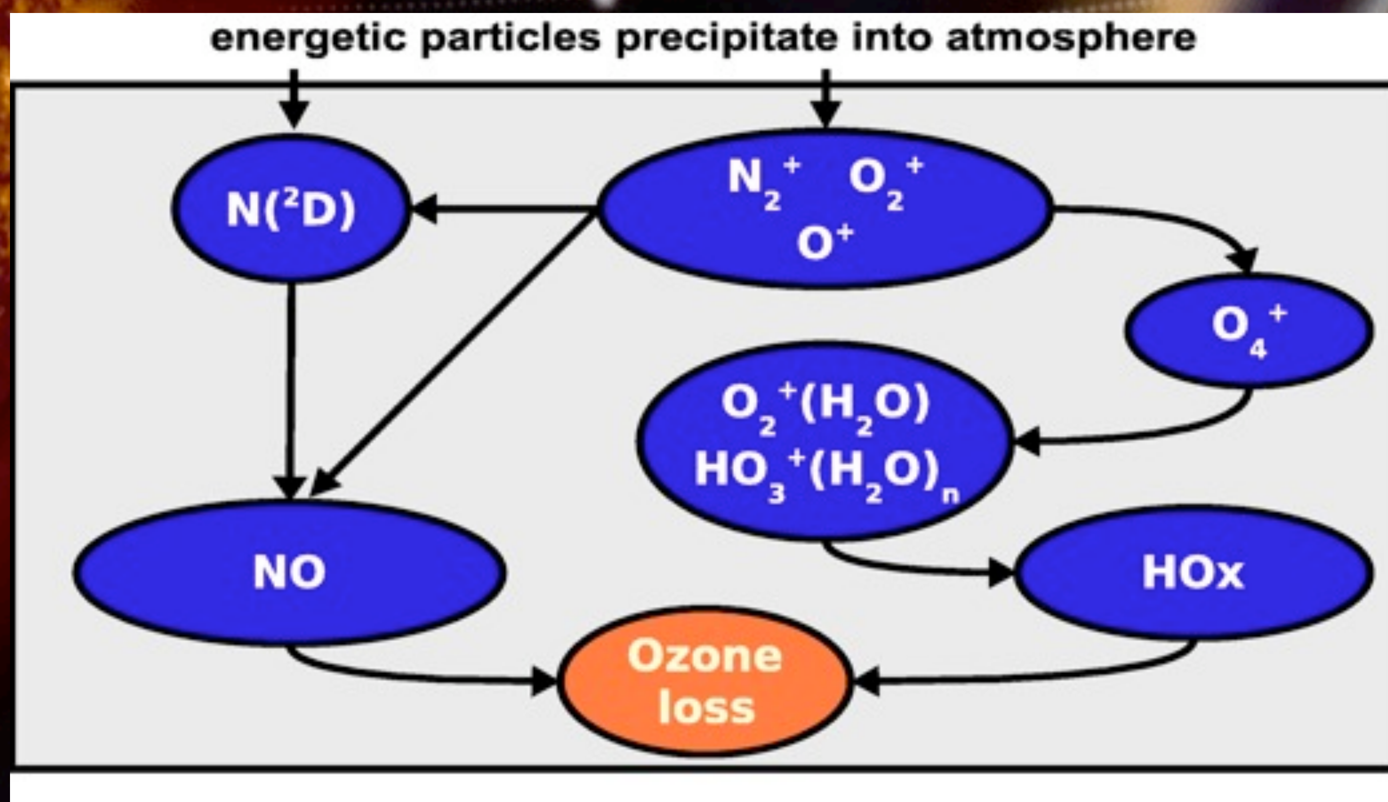
Figure 1. A single SAMPEX pass through the outer radiation belt on October 19, 1998. High resolution >1 MeV fluxes reveal microburst structures. An automated algorithm identifies and measures the electron content of the microbursts.

from O’Brien et al., (2004) GRL, vol. 31, L04802, doi: 10.1029/2003GL018621, 2004

Connection to climate variations?

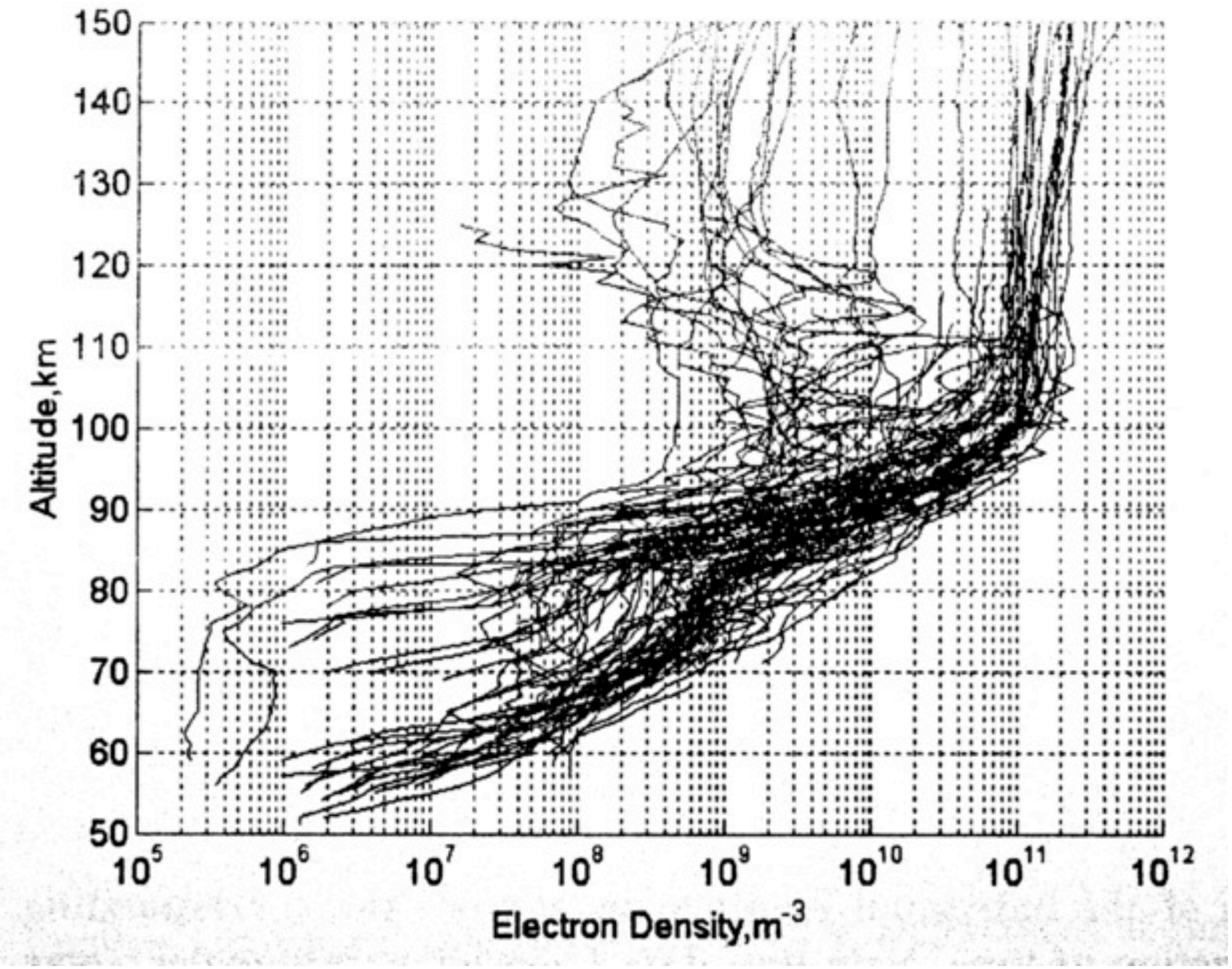
We live in the neighborhood of a star

- Some key questions:
  - How does the space weather affect the climate?
  - How do the atmospheric layers couple to each other?



Variability of the lower ionosphere

- D-region variations
  - day/night
  - [NO] variability
  - electron precipitation
    - Aurora
    - Medium to high-energy electrons
    - Relativistic electrons
  - proton precipitation
    - solar proton events
  - X-rays
    - solar flares
    - bremsstrahlung
  - TLE's
    - sprites, blue jets, elves, gigan jets
  - TGF's
  - Galactic gamma ray bursts



[from Friedrich and Torkar, 2001]

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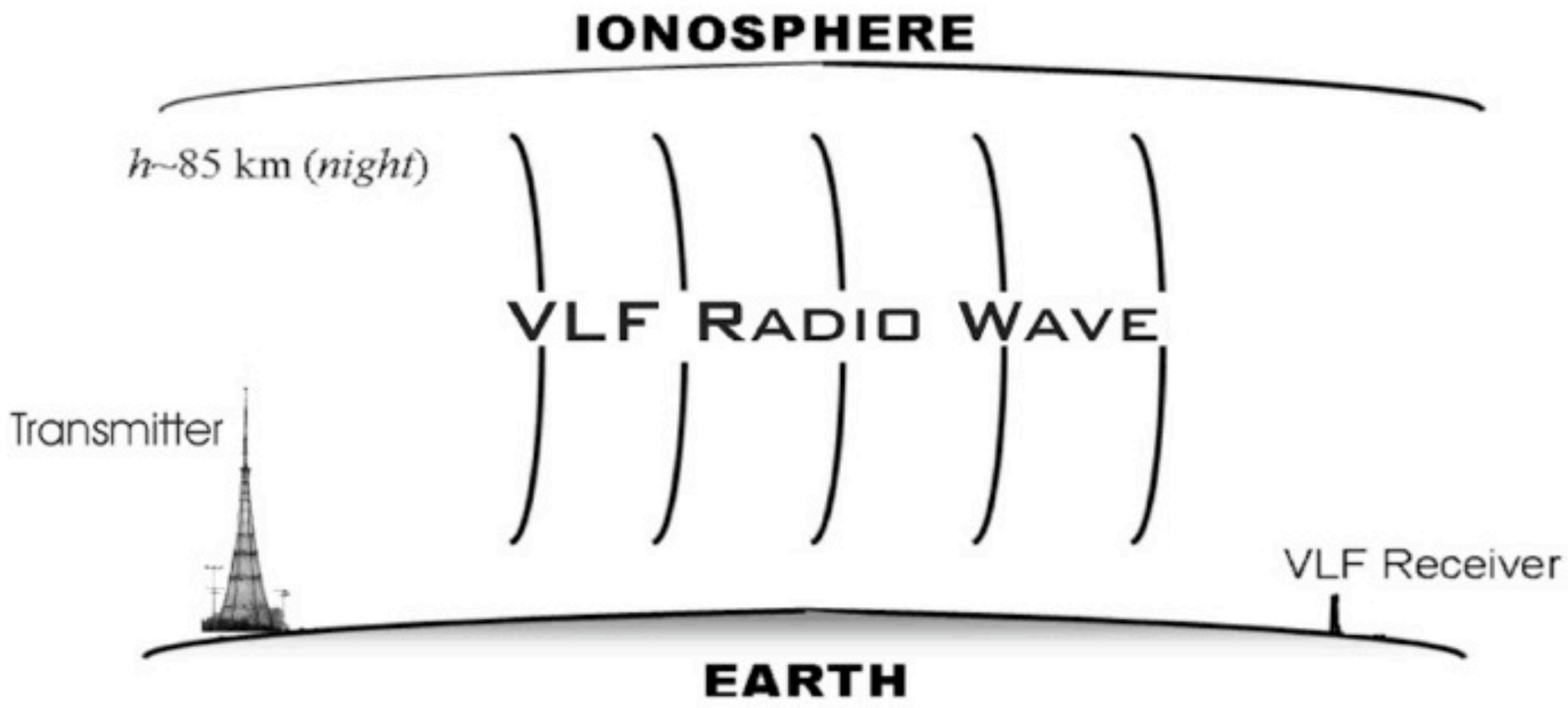
Propagation of VLF radio waves



Amplitude and phase of the received signal are sensitive to pertubations in the lower boundary of the ionosphere along the propagation path. (Fig. by C. Rodger)

REP microbursts in VLF propagation data

- VLF propagation paths across northern polar cap area
- from: Rodger et. al, (2007)

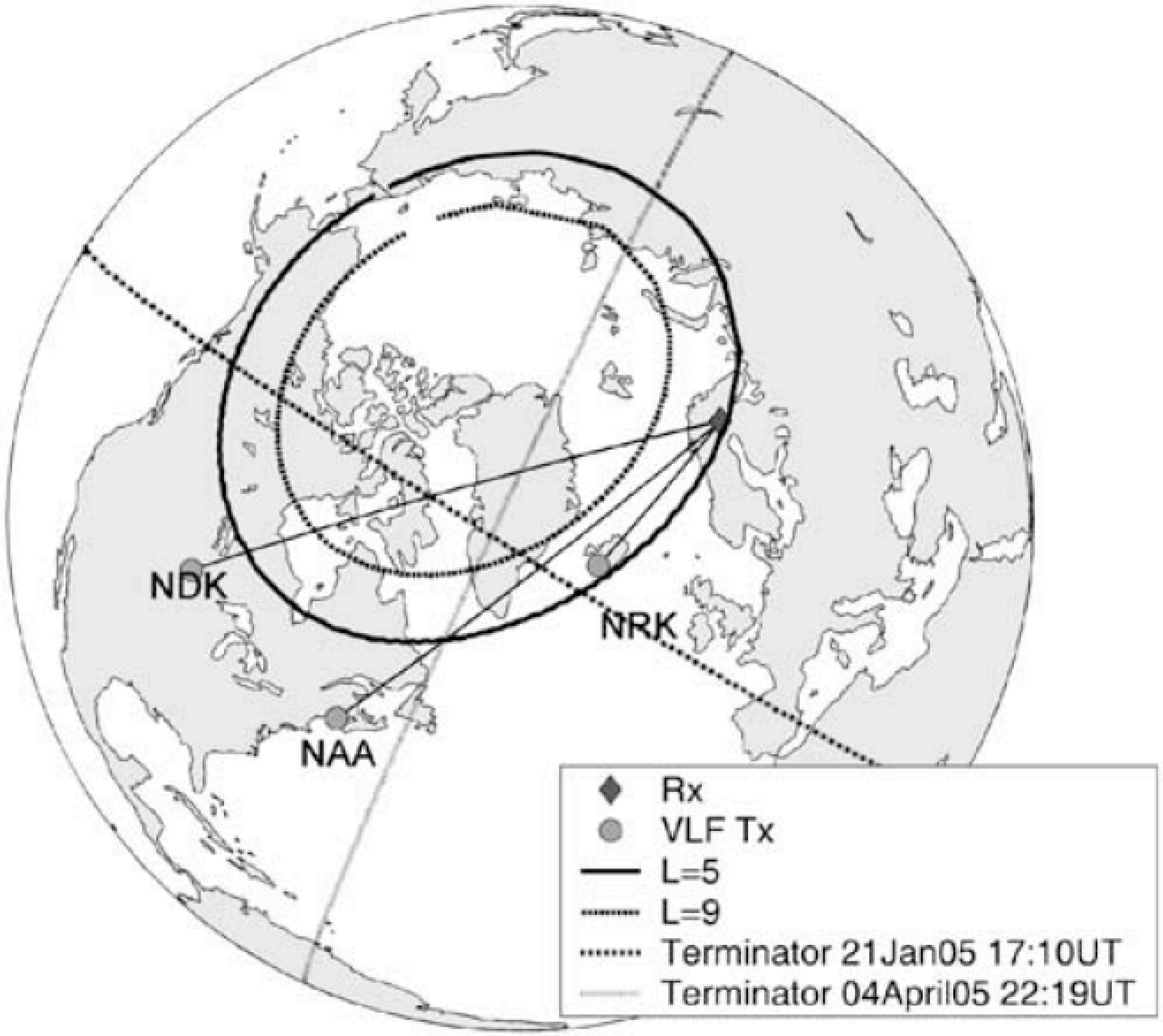


Figure 1. The location of subionospheric propagation paths to the Antarctic-Arctic Radiation-belt Dynamic Deposition VLF Atmospheric Research Konsortia (AARDDVARK) receiver in Sodankylä, Finland.

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REP microbursts in VLF propagation data

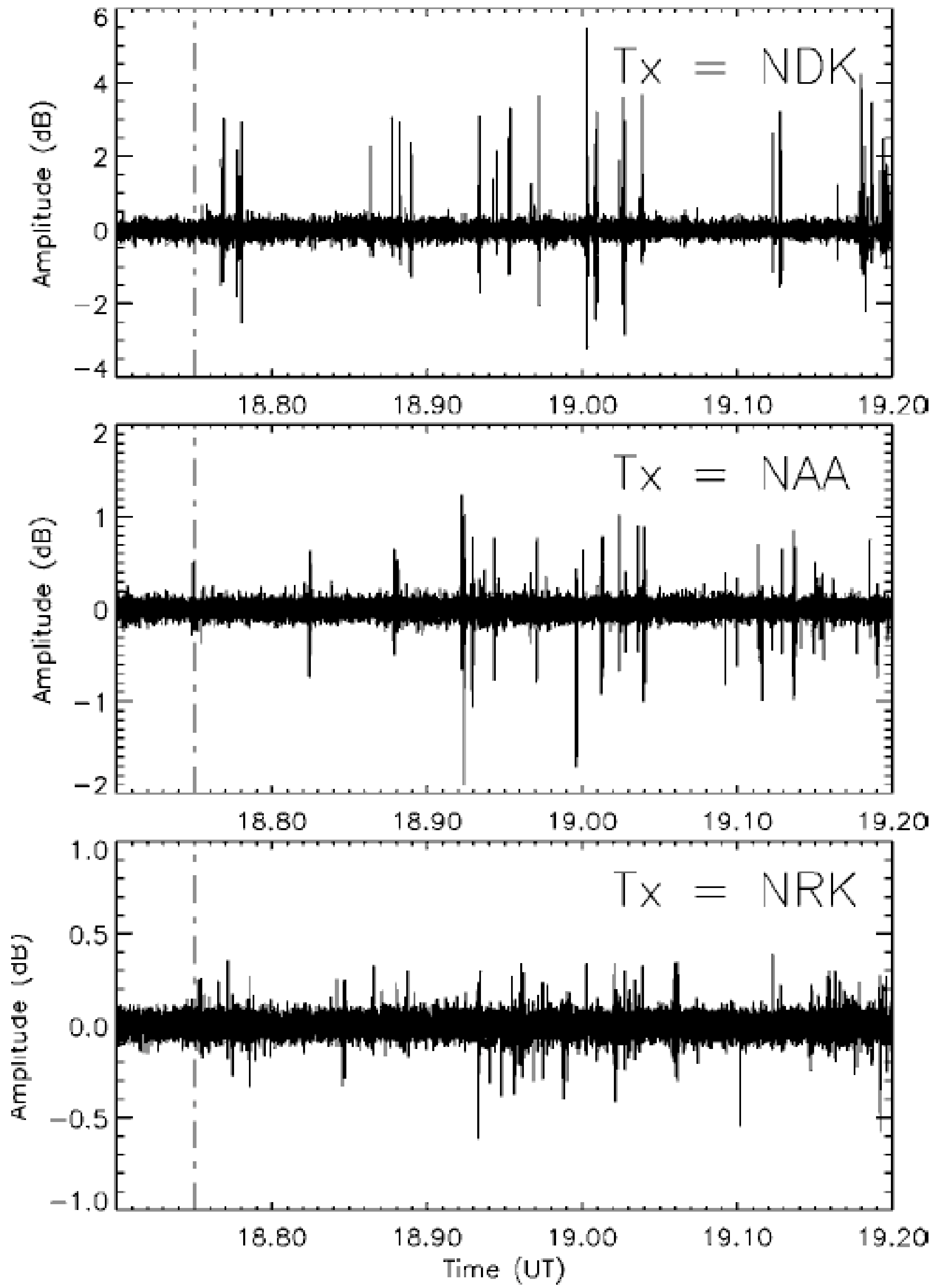


Figure 2. Short-lived amplitude perturbations on subionospheric VLF transmissions received at Sodankylä, Finland, on 21 January 2005.

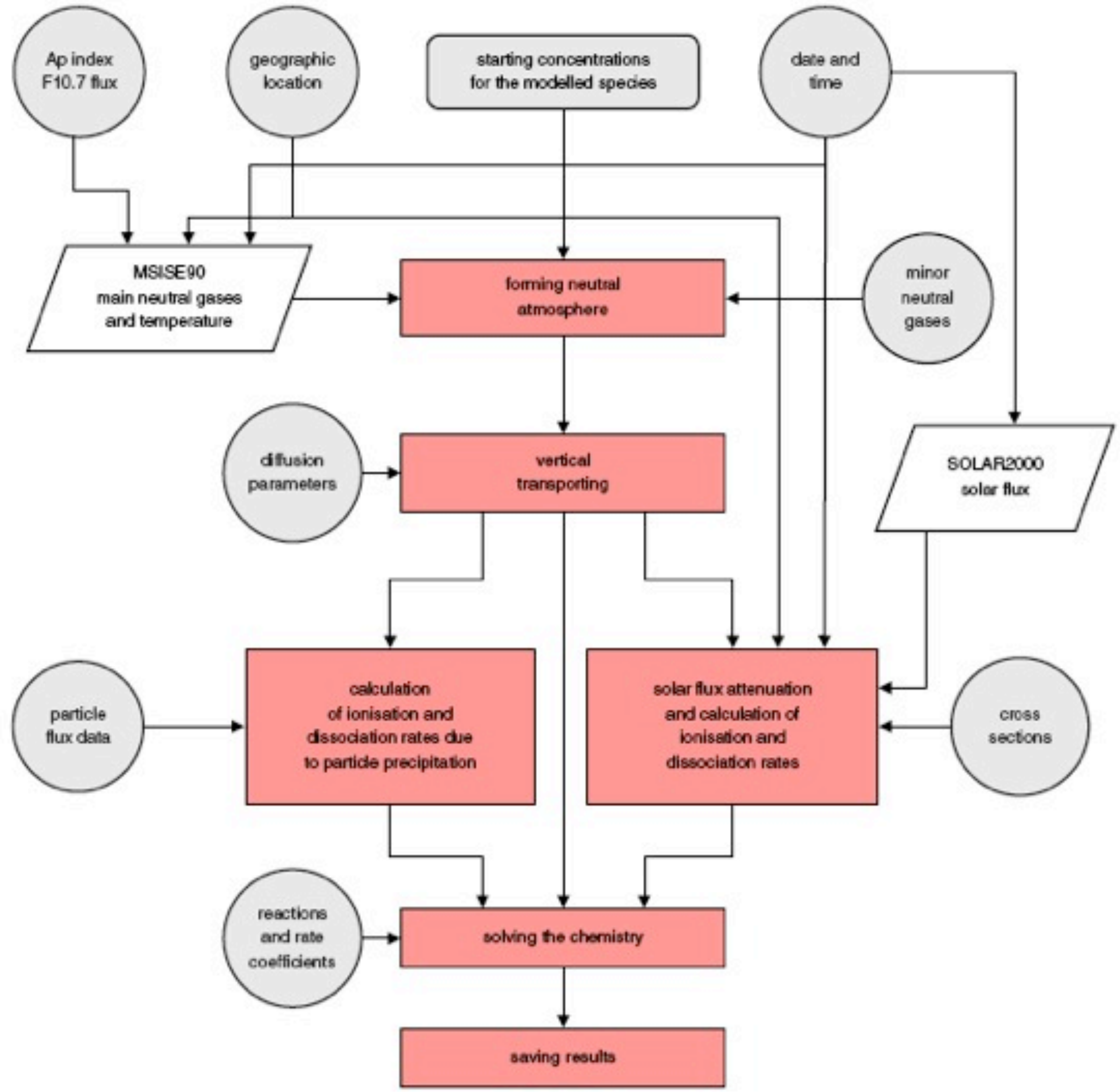
- from: Rodger et. al, 2007

Sodankylä Ion Chemistry model

•coupled 1D neutral-ion chemistry model
•time-dependent concentrations

•79 constituents as unknowns
•36 positive ions
•28 negative ions
•15 neutral species
•altitudes from 20 to 150 km

•neutral chemistry included
•odd oxygen
•O + O3
•odd nitrogen
•N + NO + NO2
• odd hydrogen
•H + OH + HO2



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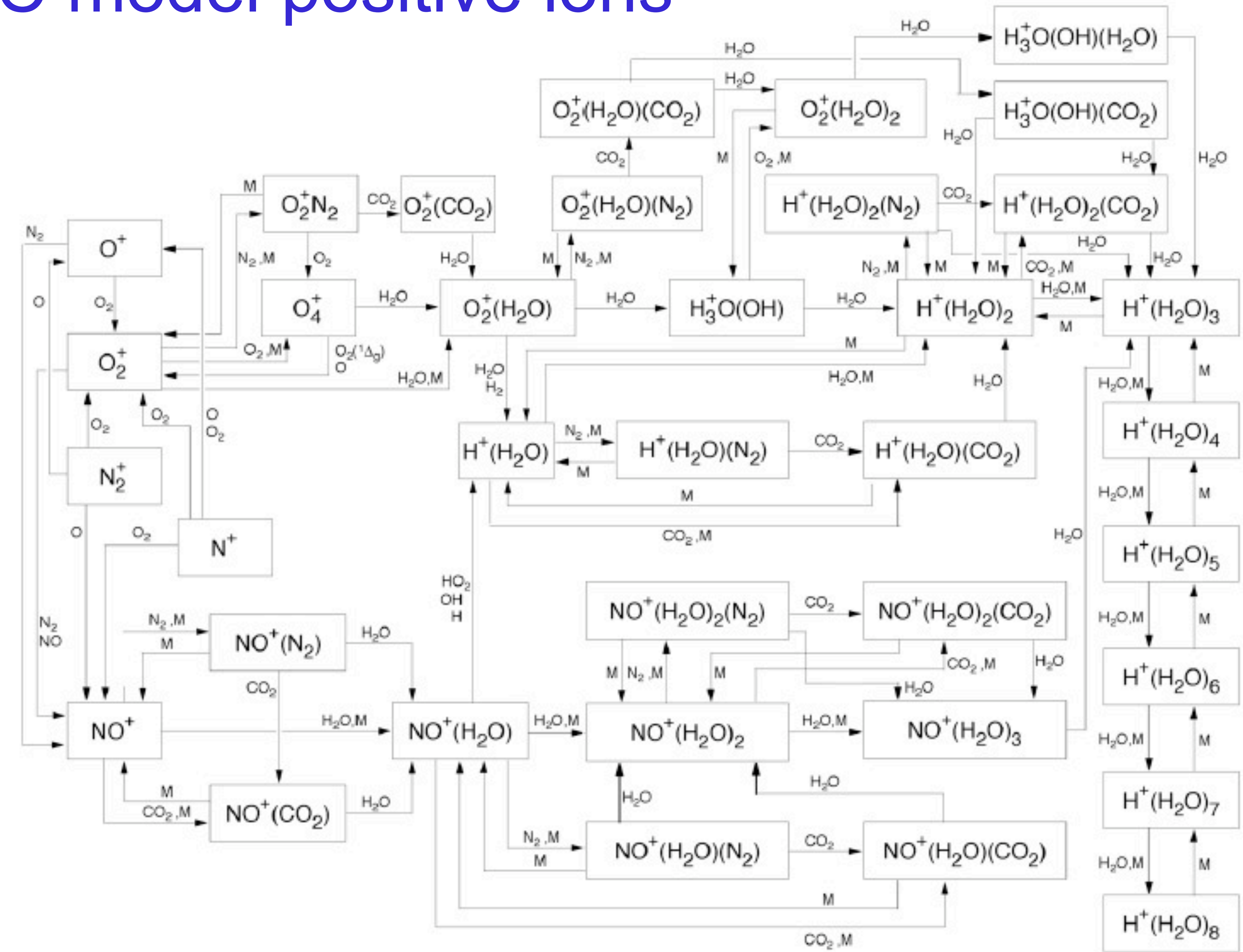
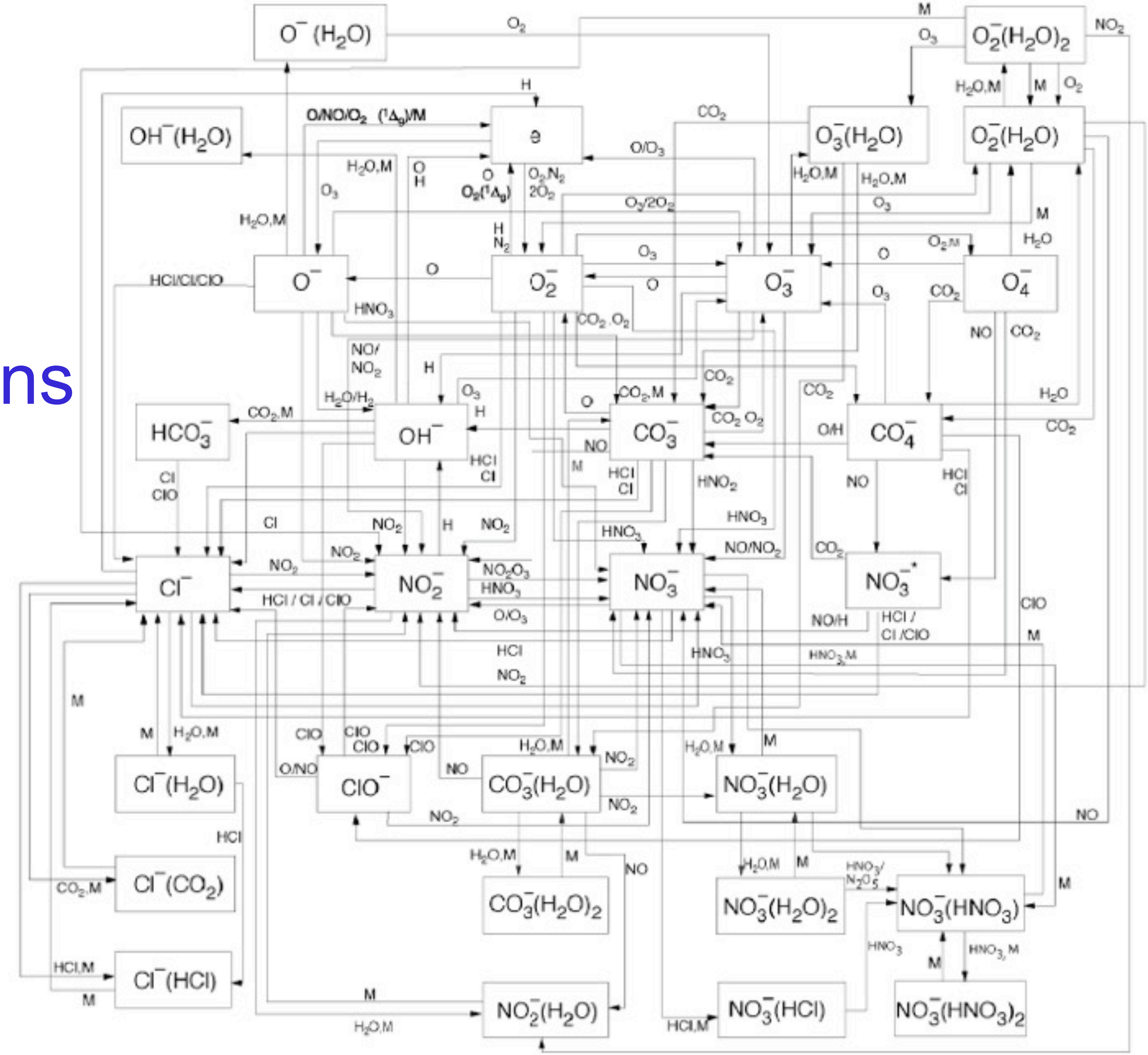
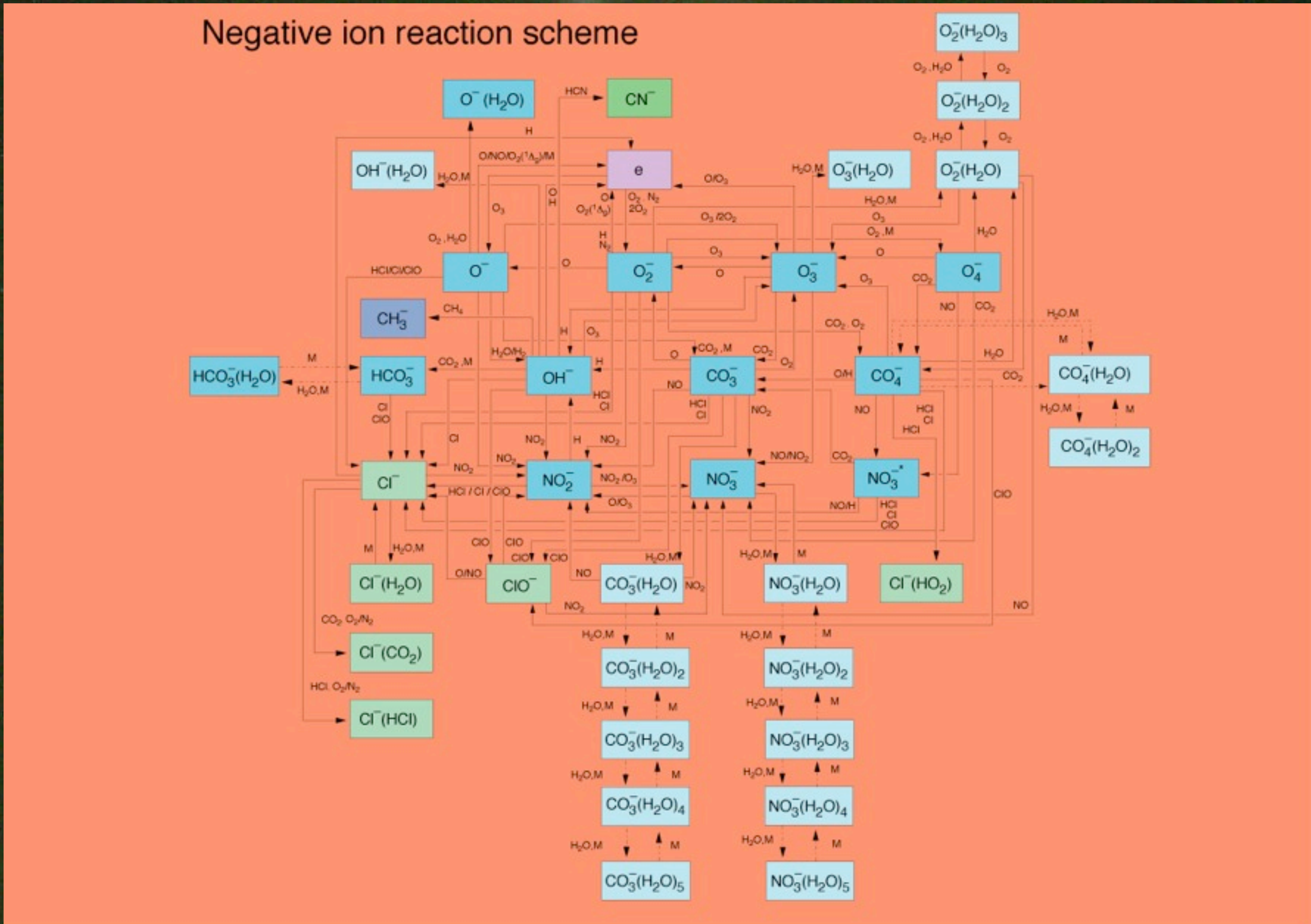
SIC model positive ions



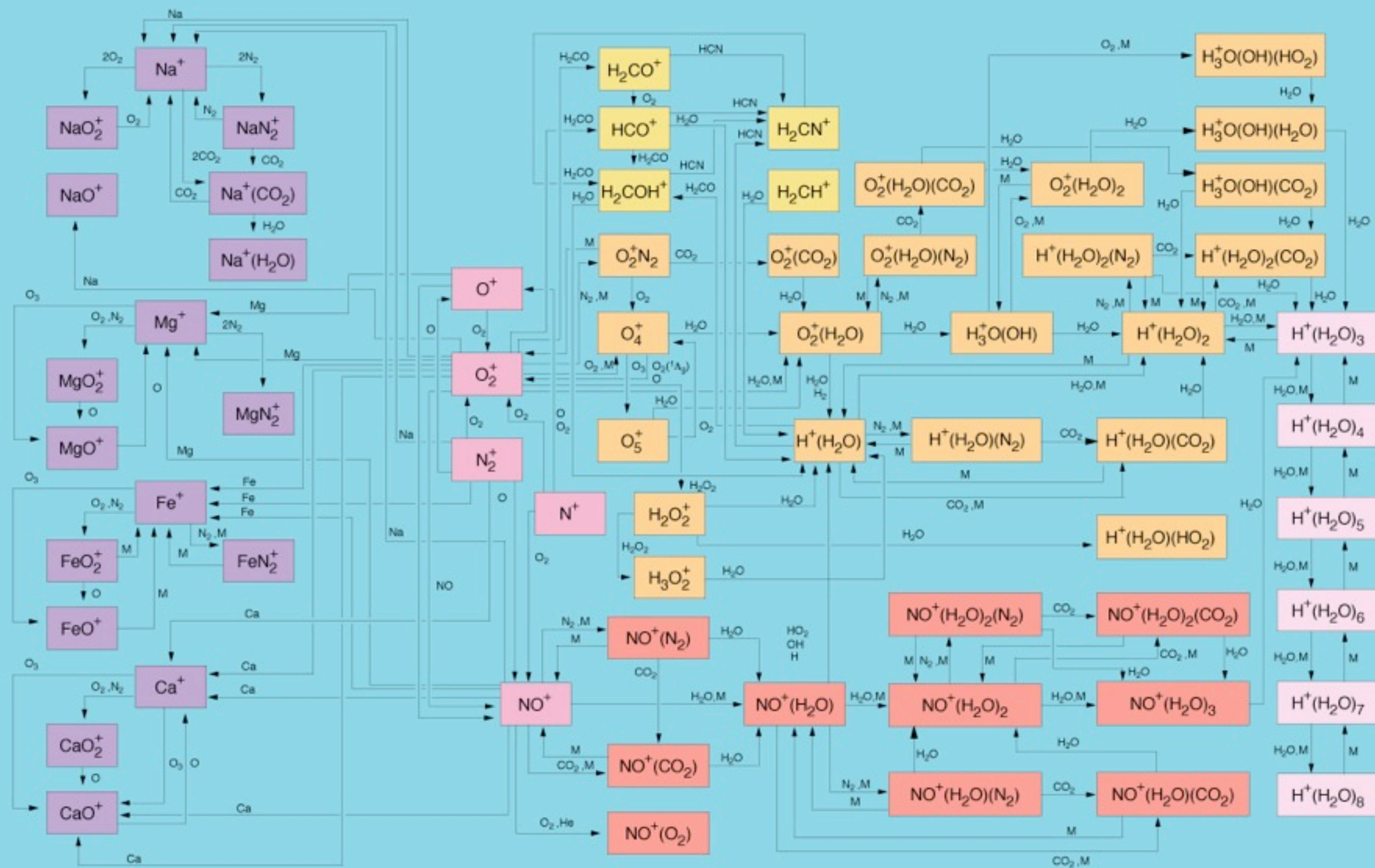
SIC model negative ions



Include more negative cluster ions???



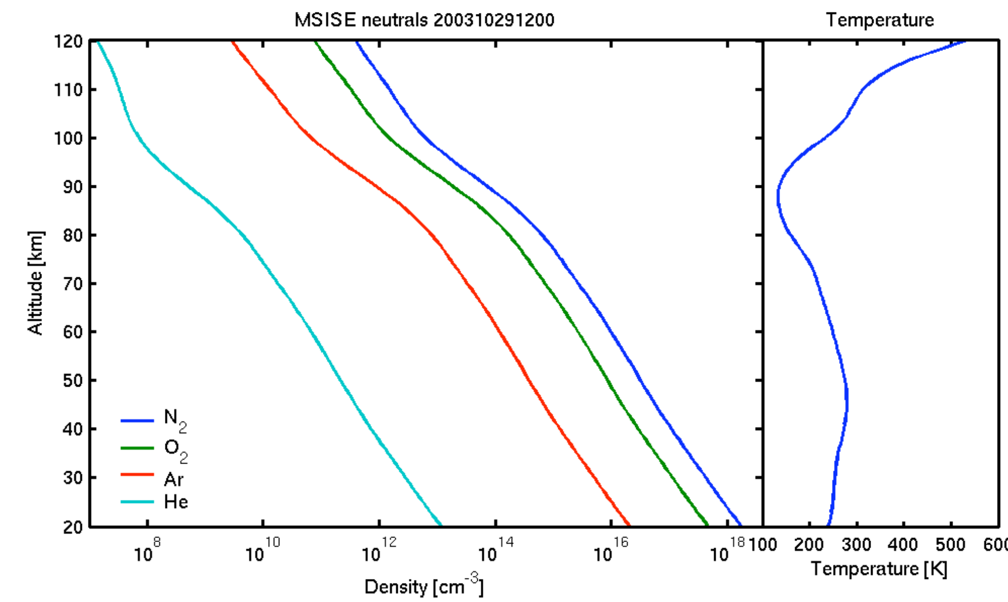
Include metallic ions???

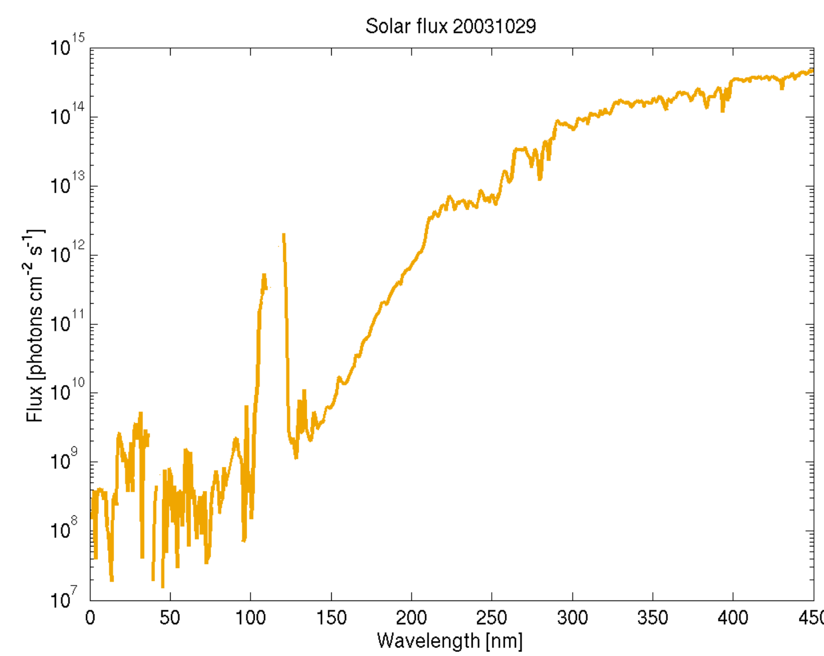


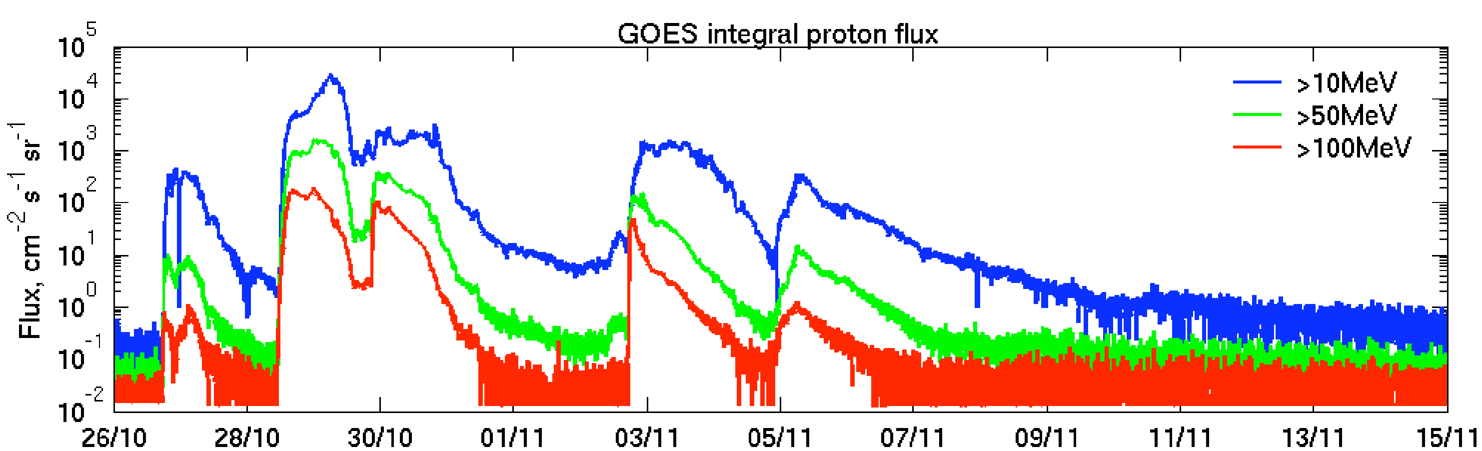
Positive ion reaction scheme

Model inputs

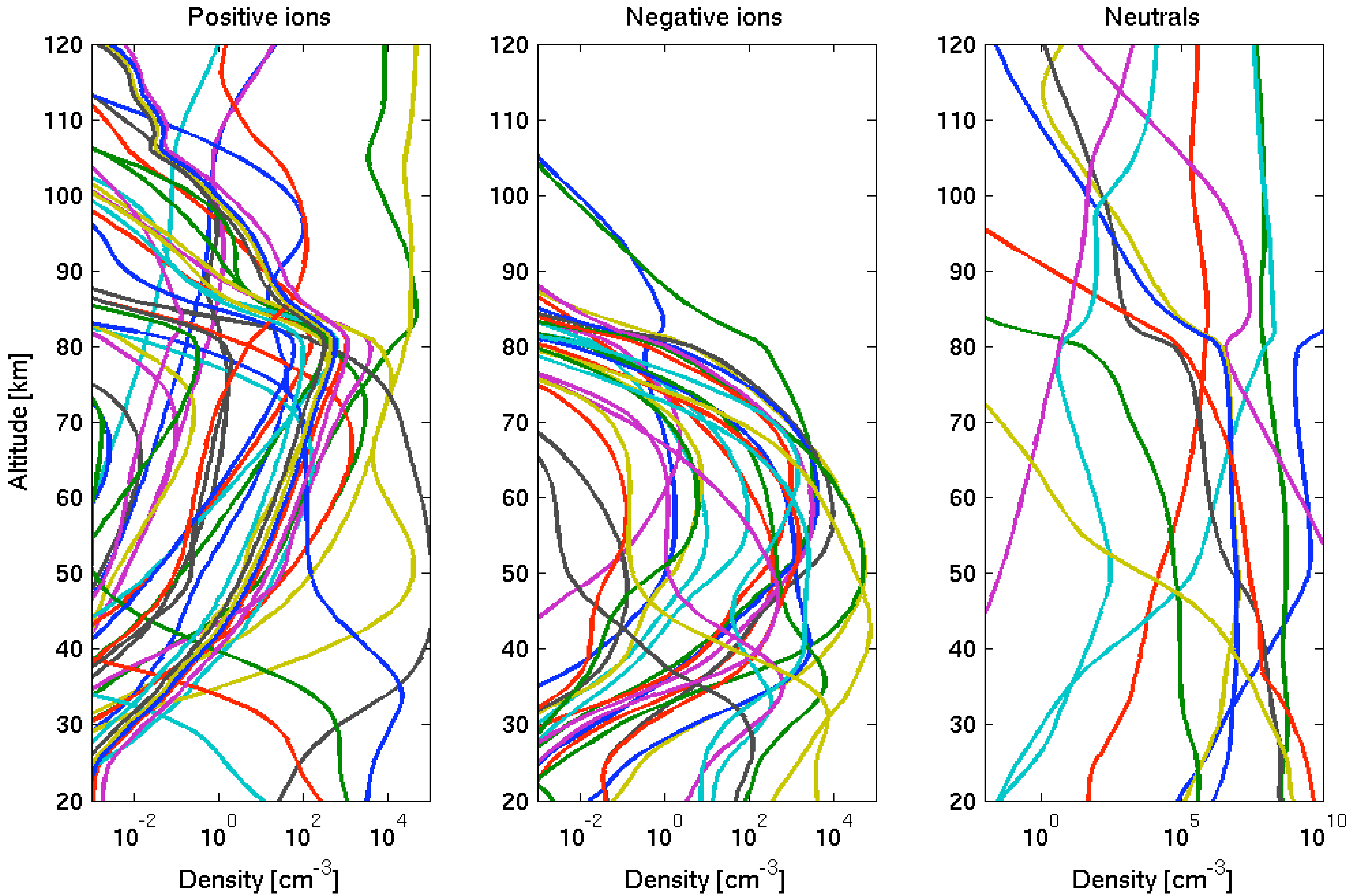
- Neutral background, MSISE-90
  - Geomagnetic activity (A_p)
  - 10.7 cm solar radio flux $F_{10.7}$
- Solar radiation
  - Empirical solar irradiance model SOLAR2000 (Tobiska et al. 2000), used wavelengths 1-422.5 nm
- Proton precipitation
  - Integral proton fluxes from GOES satellites







Model output



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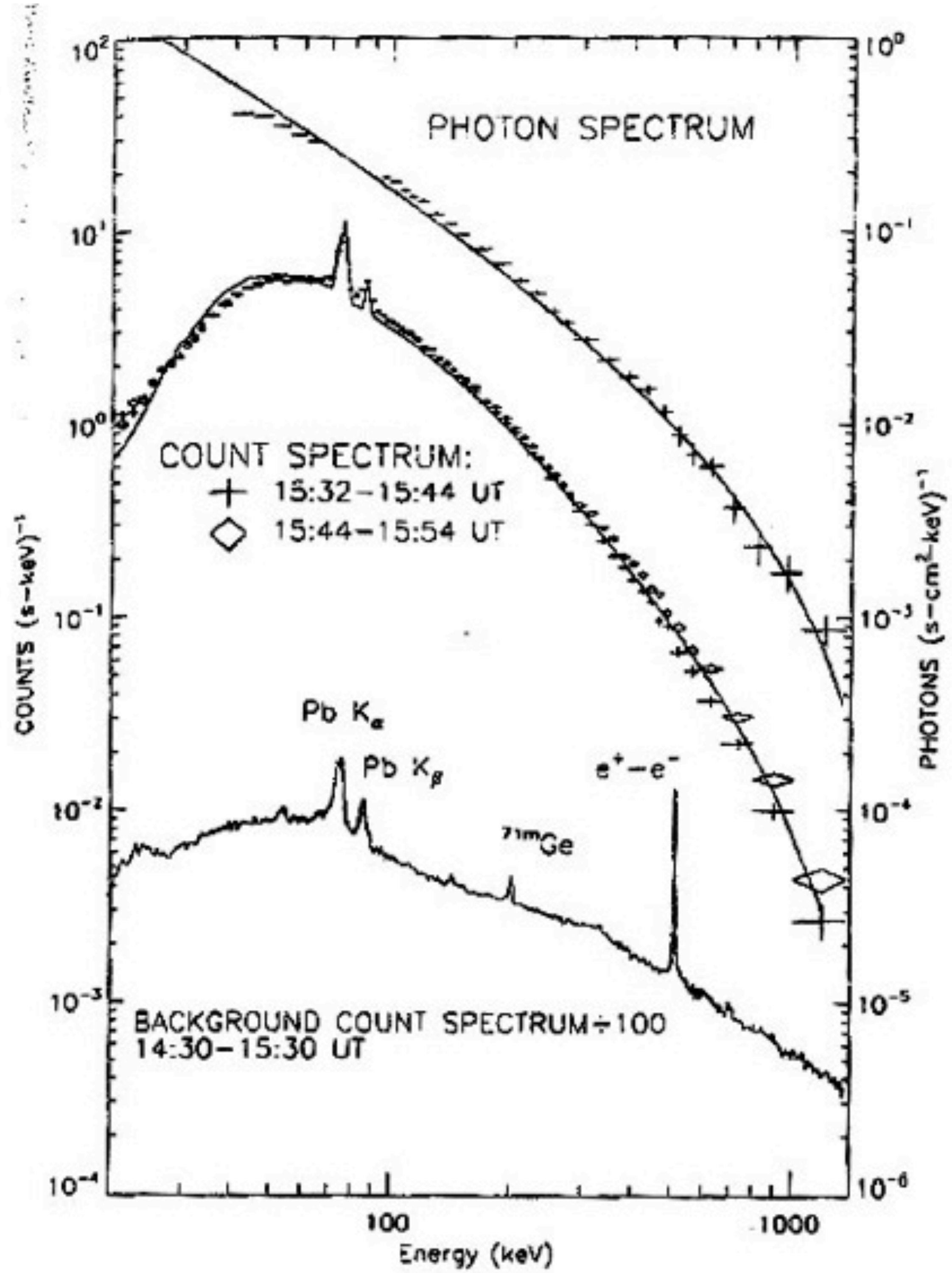
High latitudes: balloon X ray spectra -> REP !

Observed in Kiruna,
Aug 20, 1996
at 1532 UT

<u>Upper solid line:</u>
Model calculation
for 1.7 Mev electrons
Fitted to corrected
spectrum



Lorentzen et al. [JGR, 2000]

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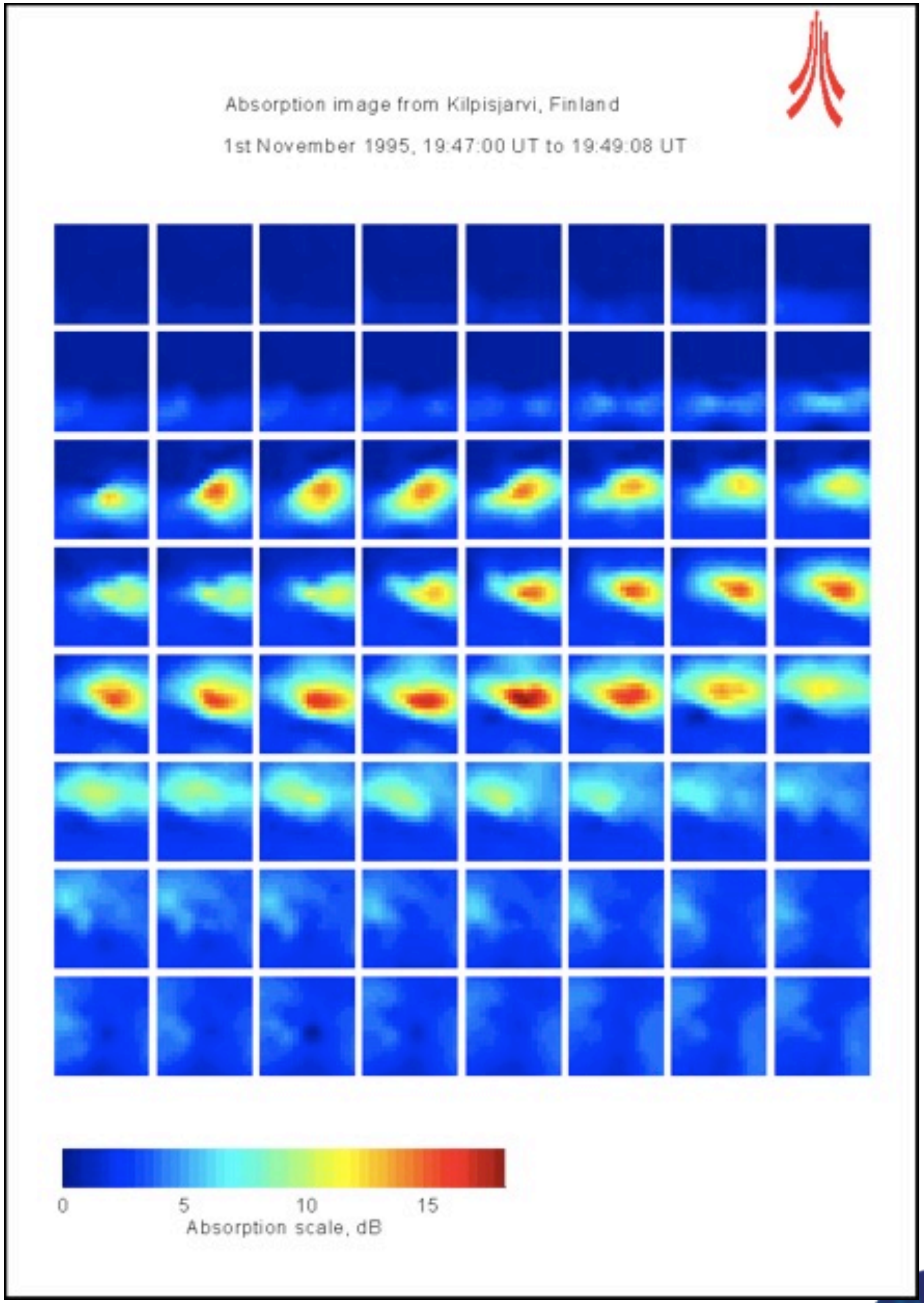
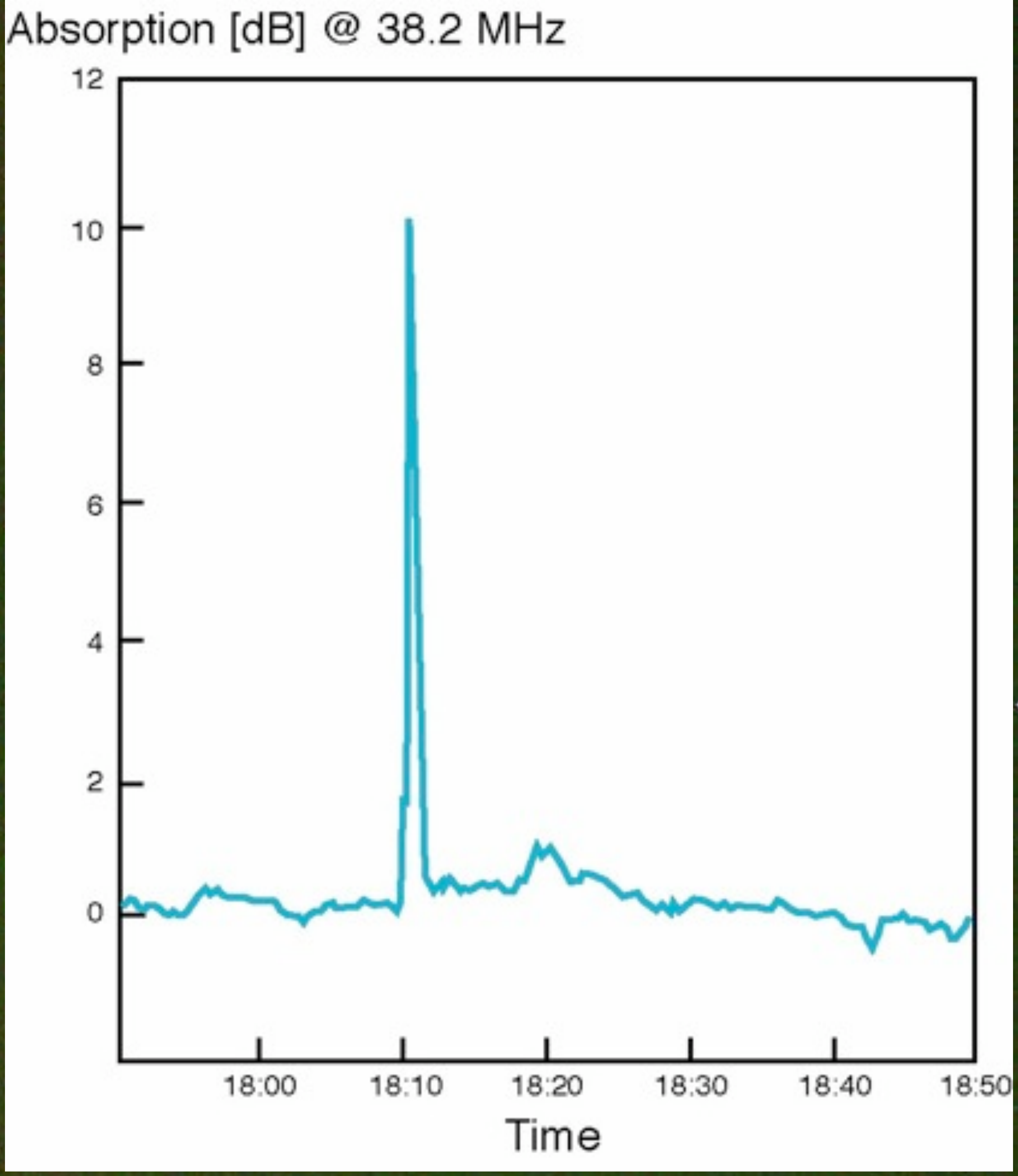
Example: IRIS data 1995/11/01

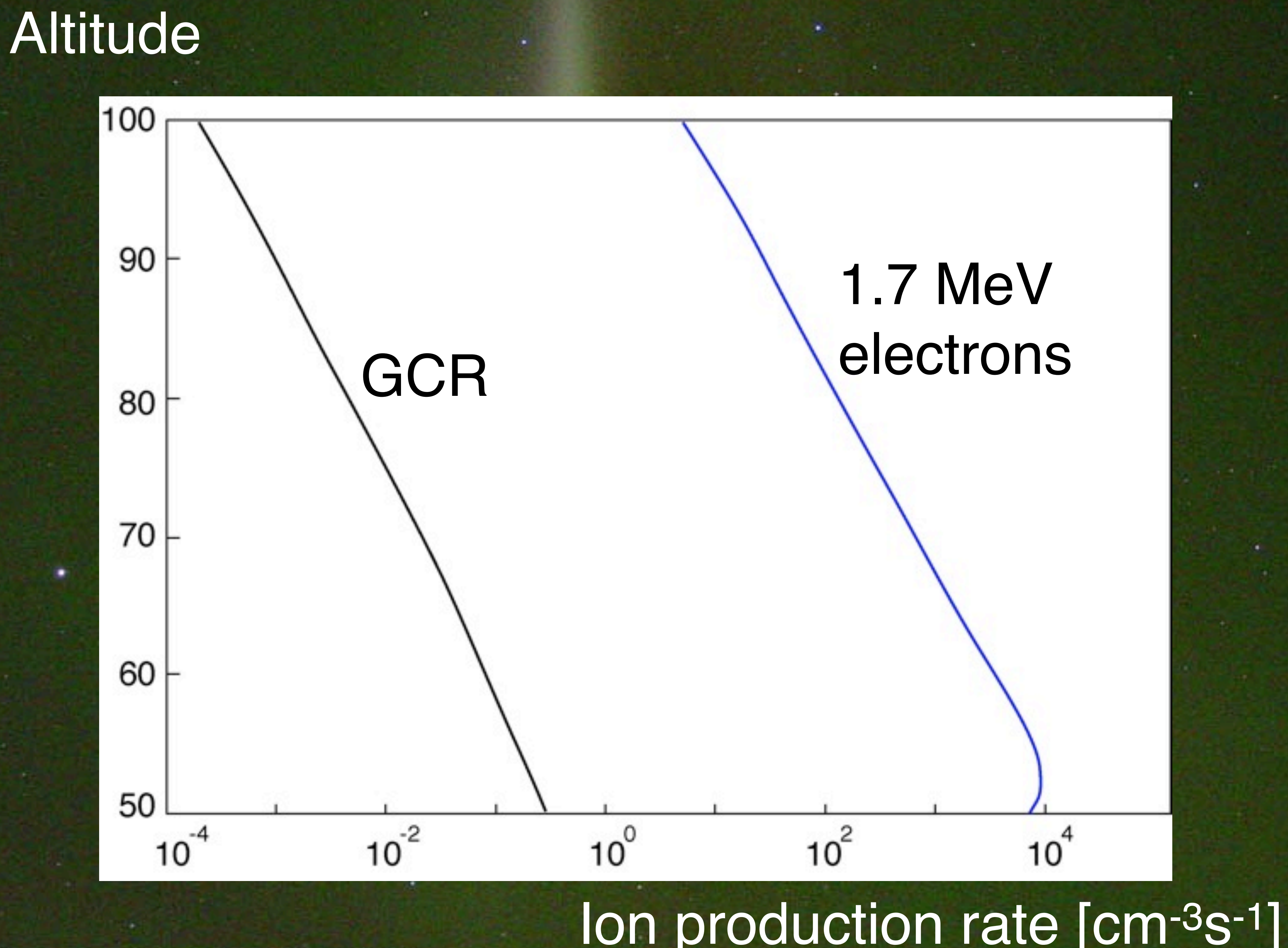


Afternoon absorption spike events

- Also isolated spikes found
- Often extremely large absorption values >5 dB
- Well-defined, confined region of absorption in IRIS field of view
- Example: IRIS beam 32 on 2002-10-27 at 1811 UT

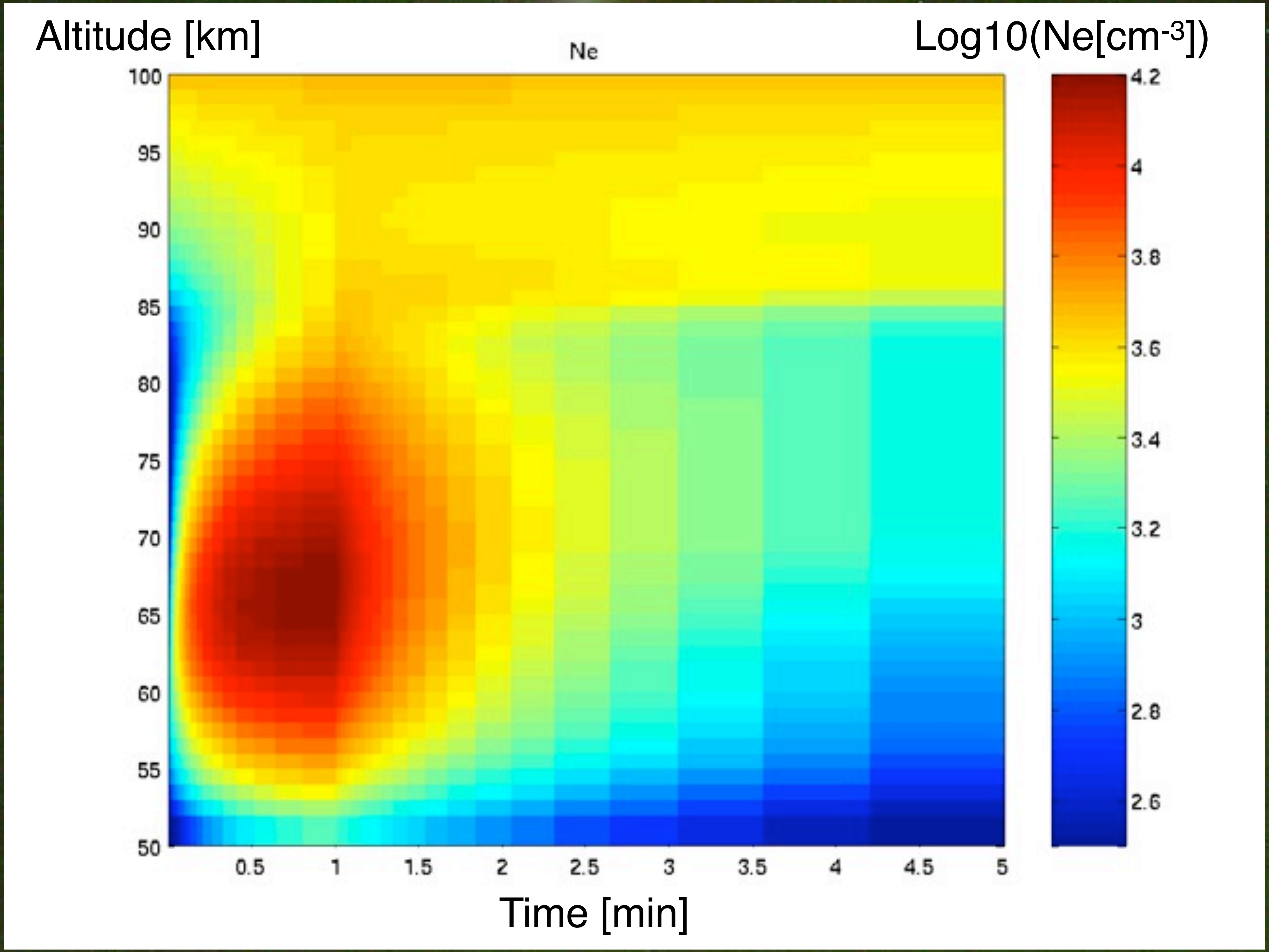


Ionisation

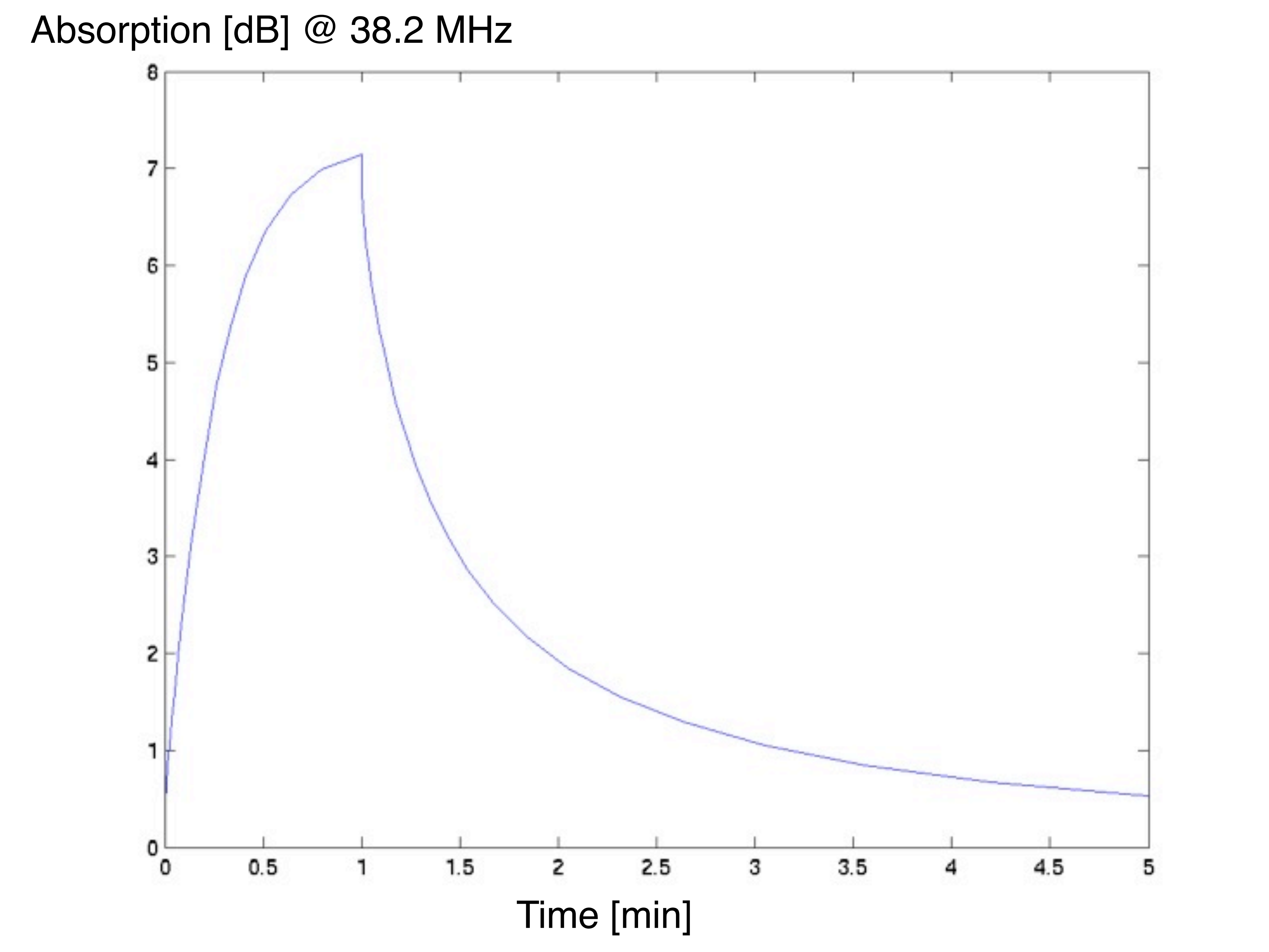


Altitude
100
90
80
70
60
50
GCR
1.7 MeV
electrons
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
Ion production rate [$cm^{-3}s^{-1}$]

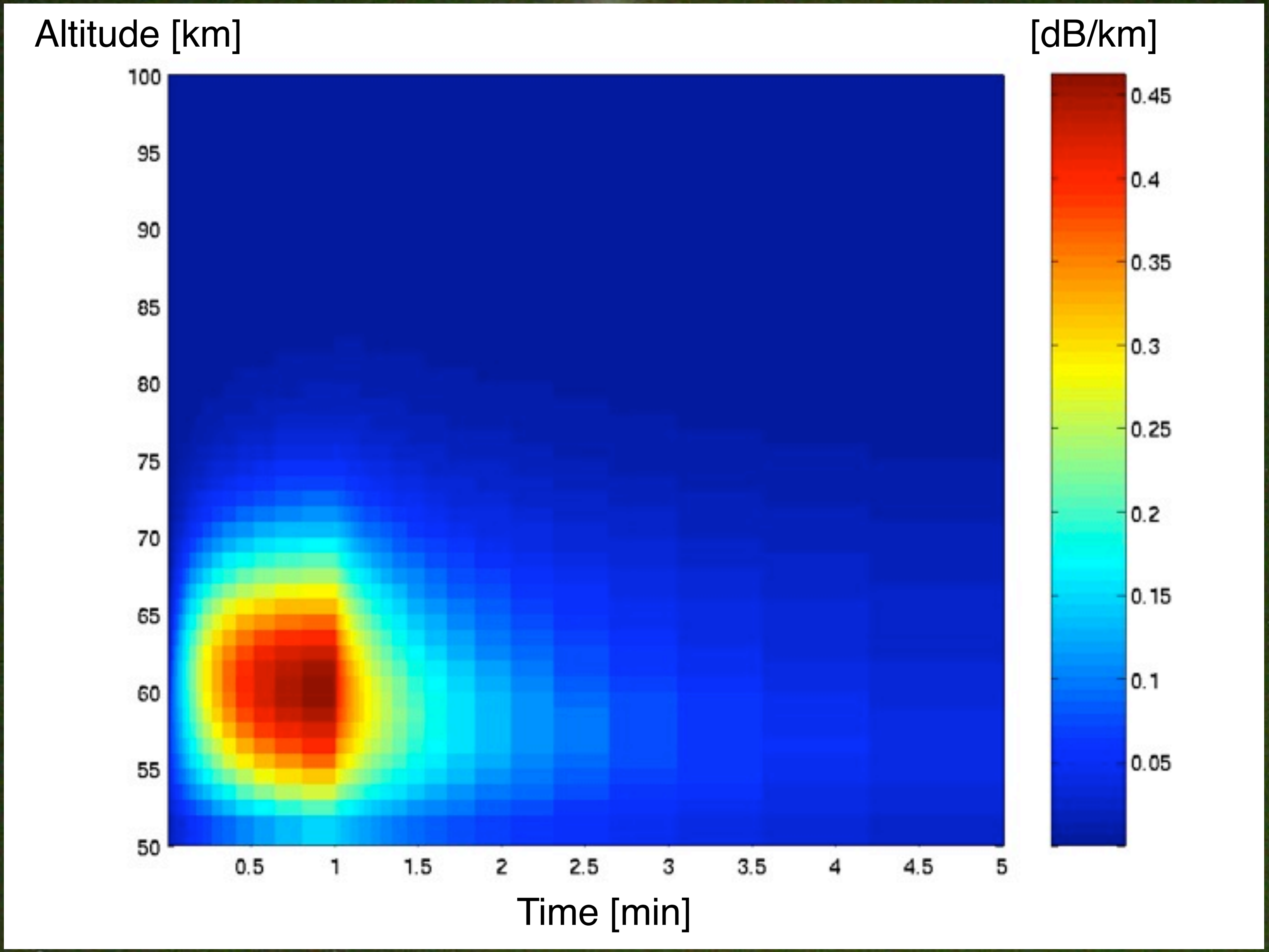
Electron density during first 5 minutes



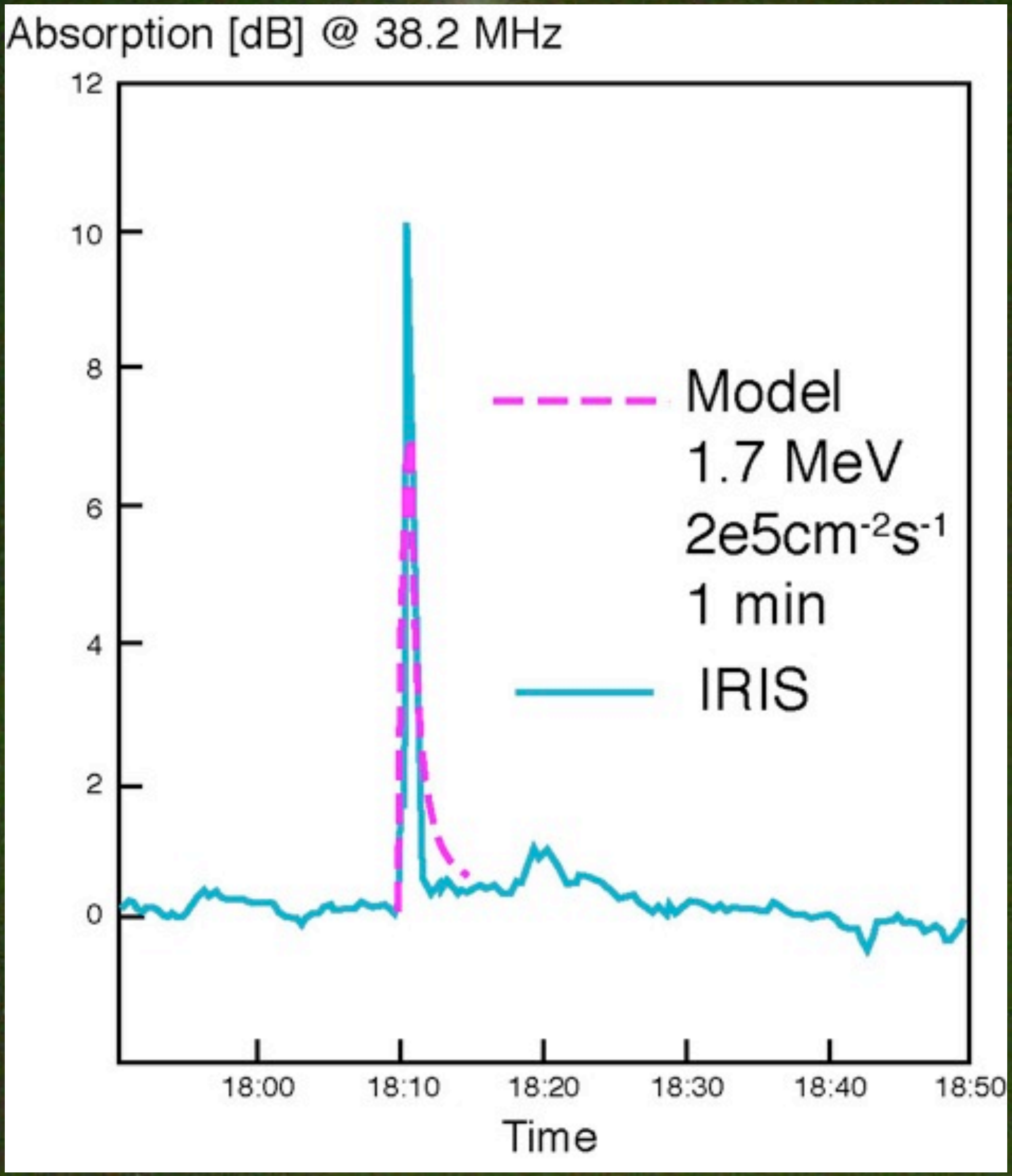
Absorption seen by riometer



Absorption seen by riometer

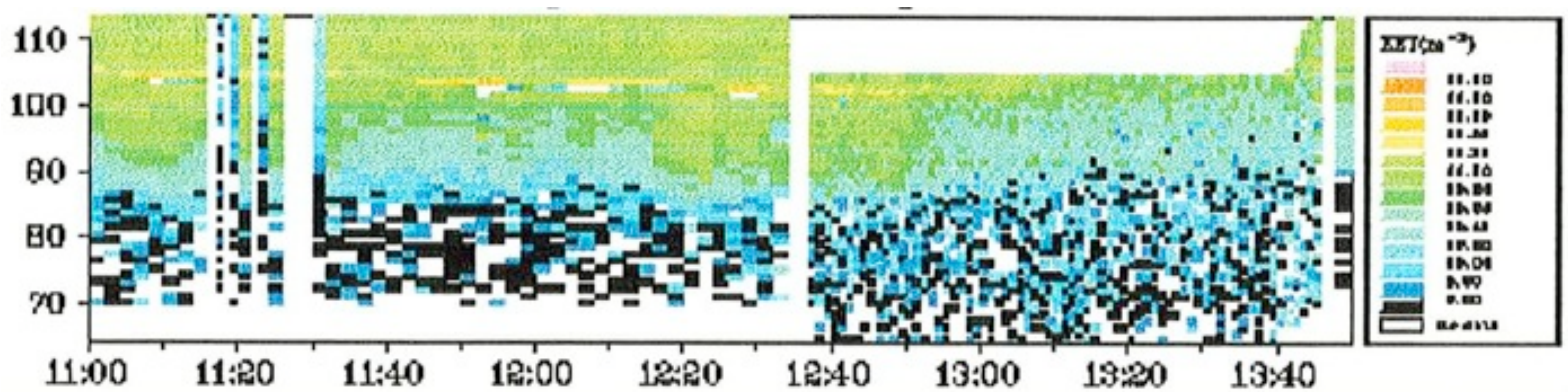


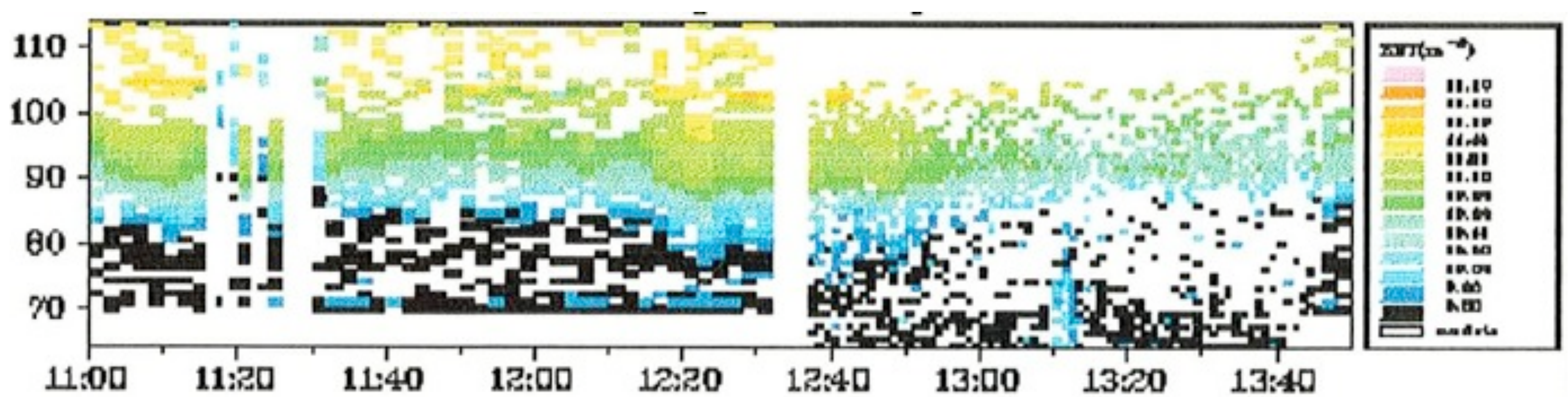
Absorption seen by riometer



EISCAT observation of a REP?

EISCAT VHF, GEN11, 1995/09/15





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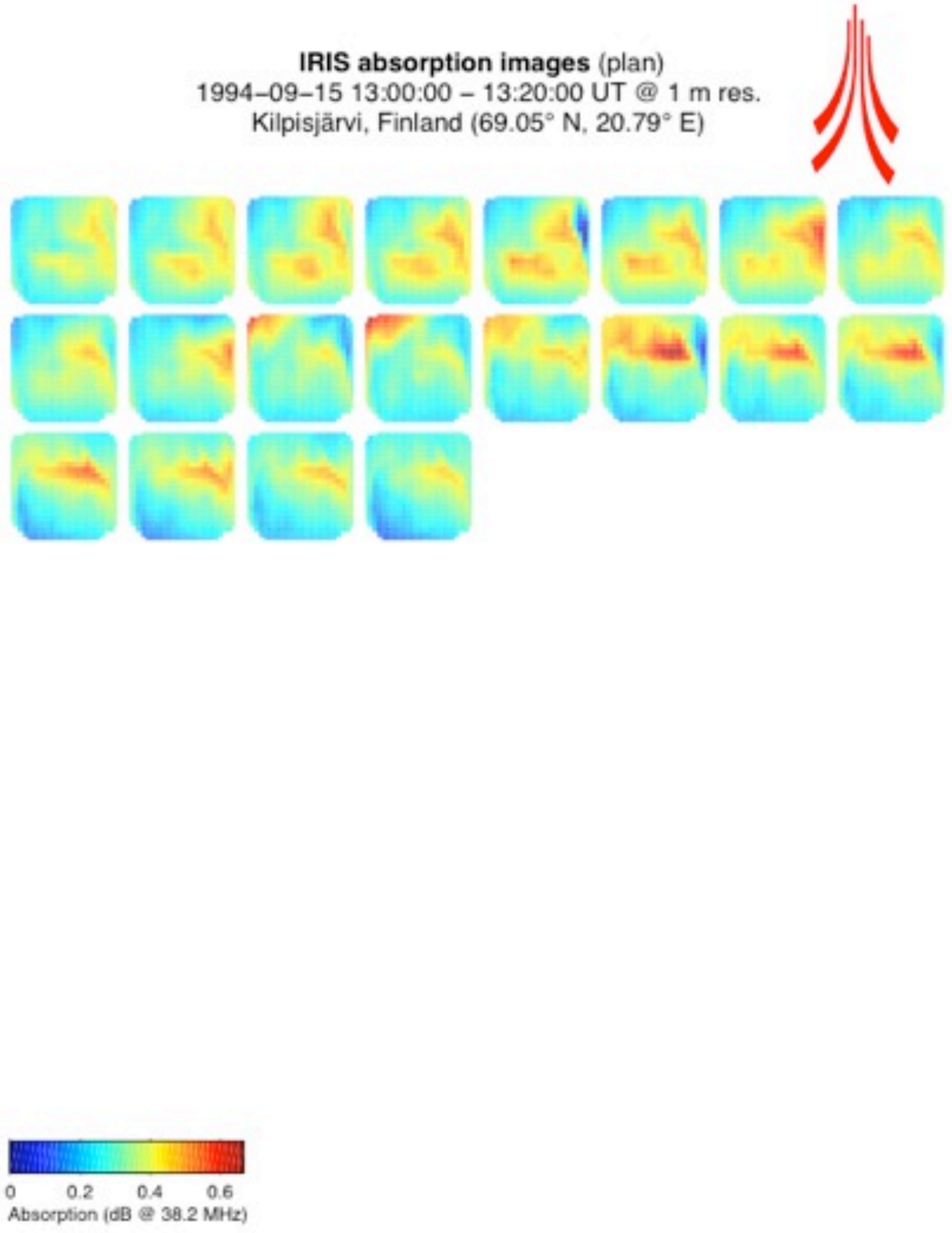
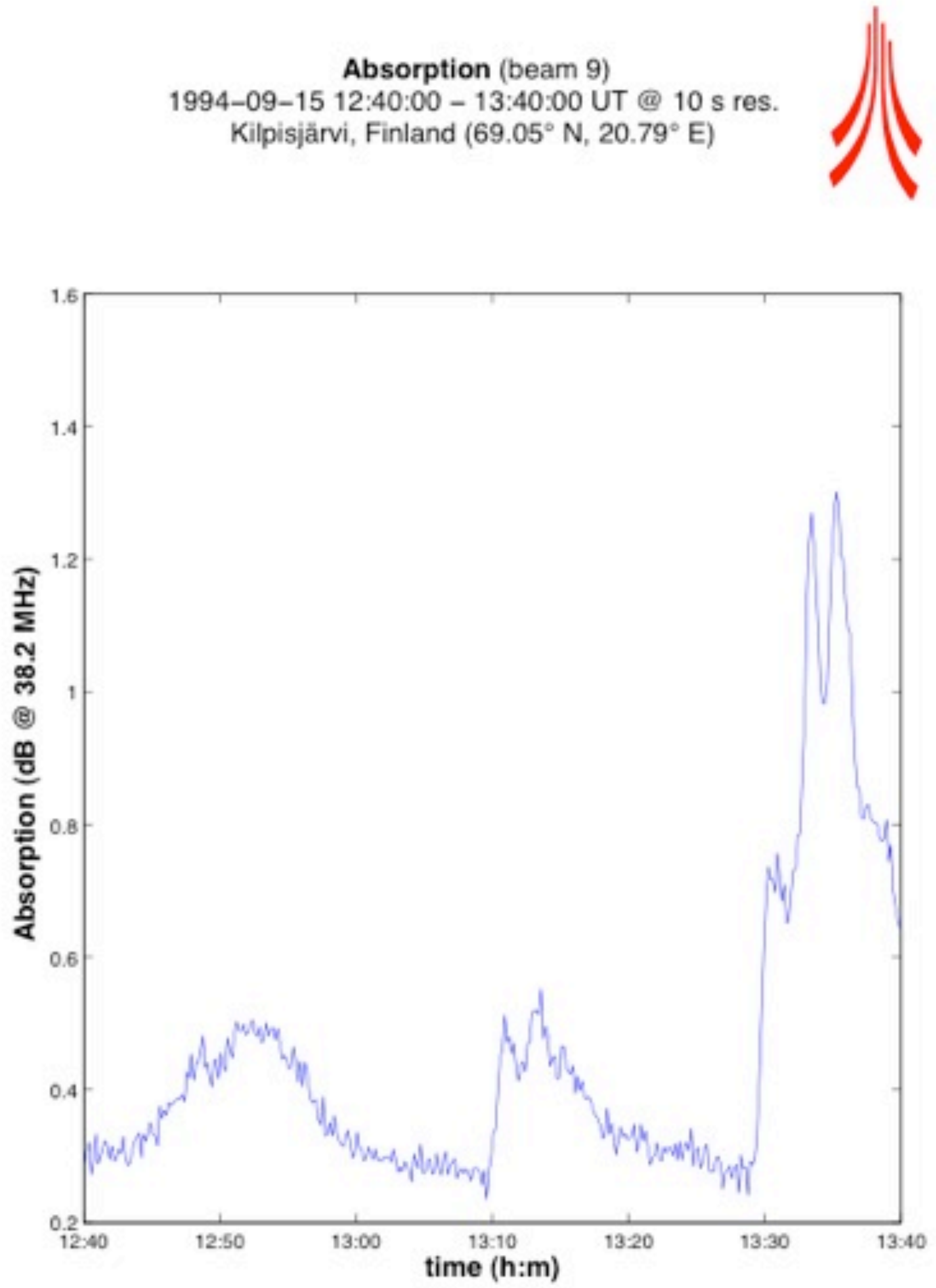
Svalbard
Radar

IRIS data 1995/09/1





AT Svalbard Radar

REP bursts in VLF propagation data

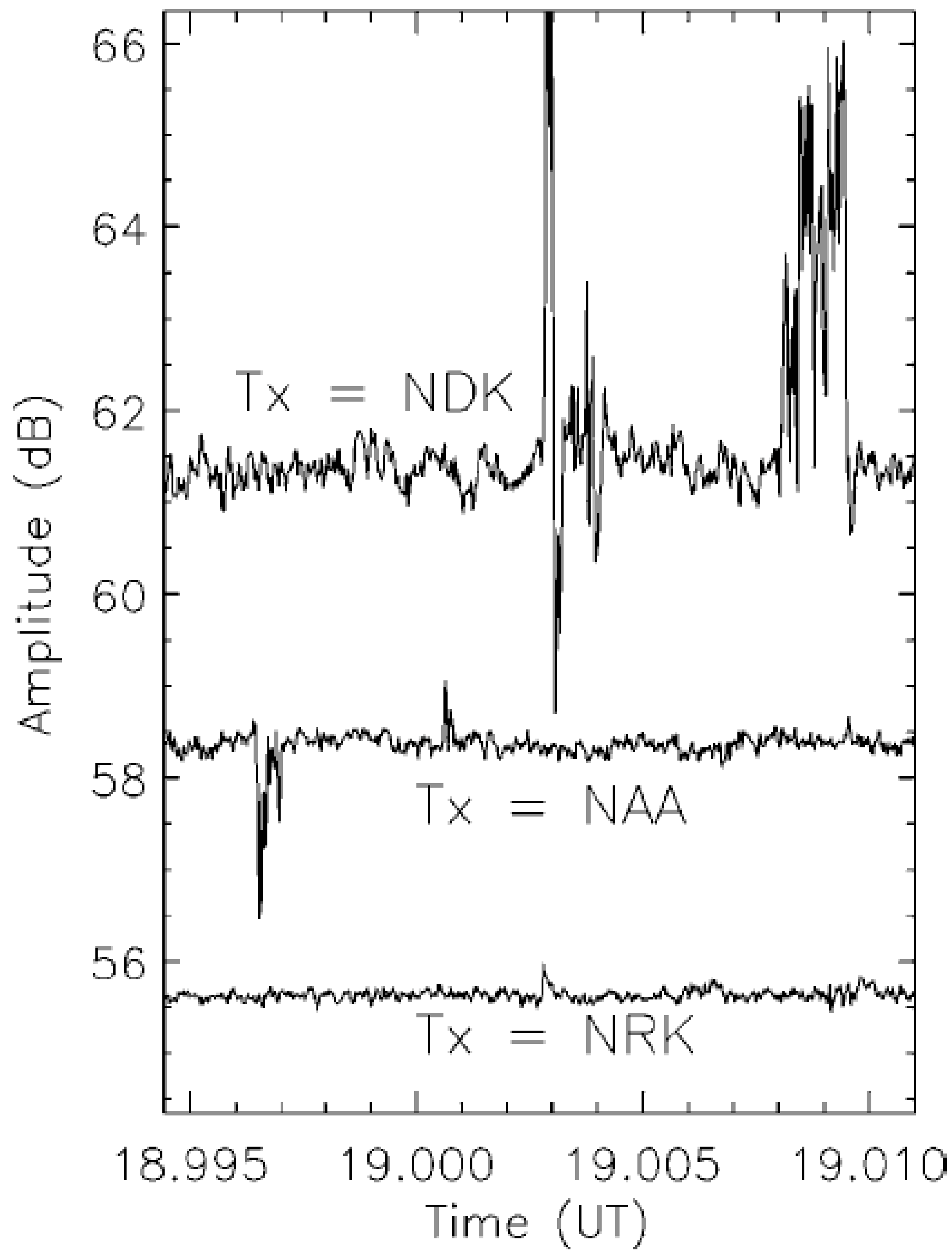


Figure 3. The amplitude of the VLF transmitters received at Sodankylä, Finland, showing a FAST VLF perturbations caused by short-lived bursts of relativistic electron precipitation (REP) on 21 January 2005.

- from: Rodger et. al, 2007

EISCAT Svalbard Radar

REP bursts in VLF propagation data

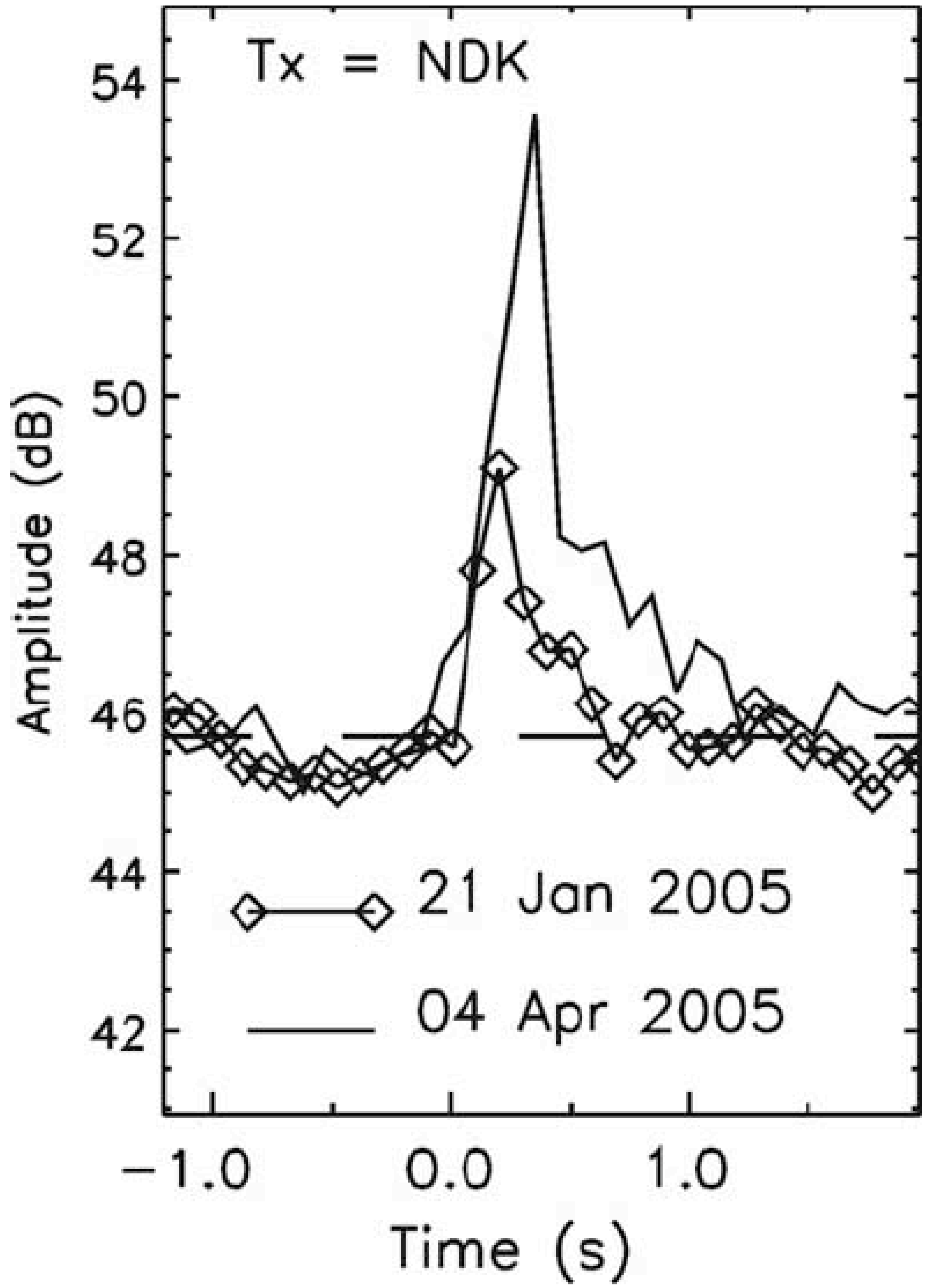
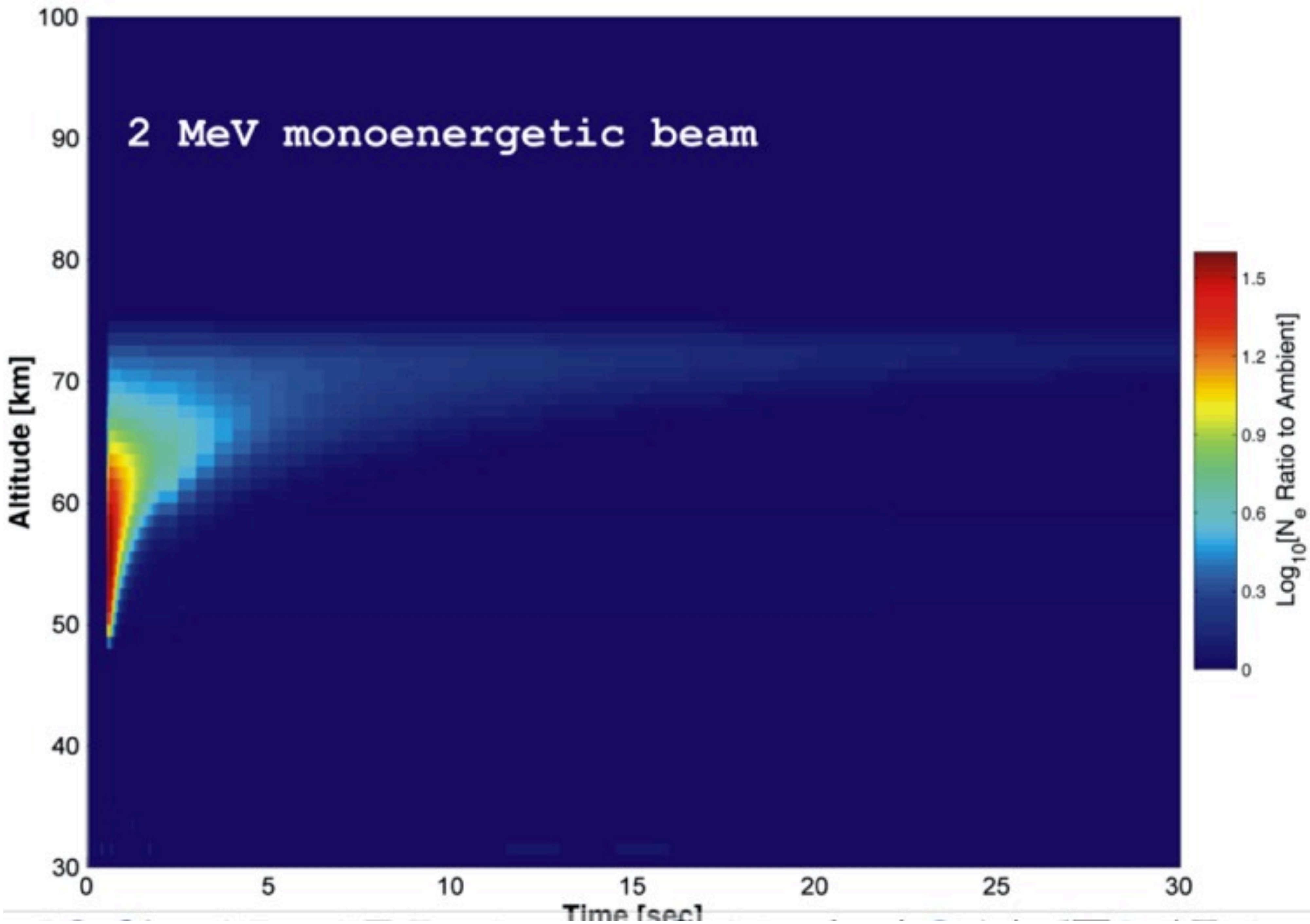


Figure 4. Examples of FAST VLF perturbations on NDK received at Sodankylä caused by REP on 21 January 2005 (line marked by diamonds) and 4 April 2005 (dashed line), showing the contrast between the typical decay times.

- from: Rodger et. al, 2007

EISCAT Svalbard Radar

Modelling a REP burst



(from C. Rodger et al., 2007)

EISCAT Svalbard Radar

Modelling a REP burst

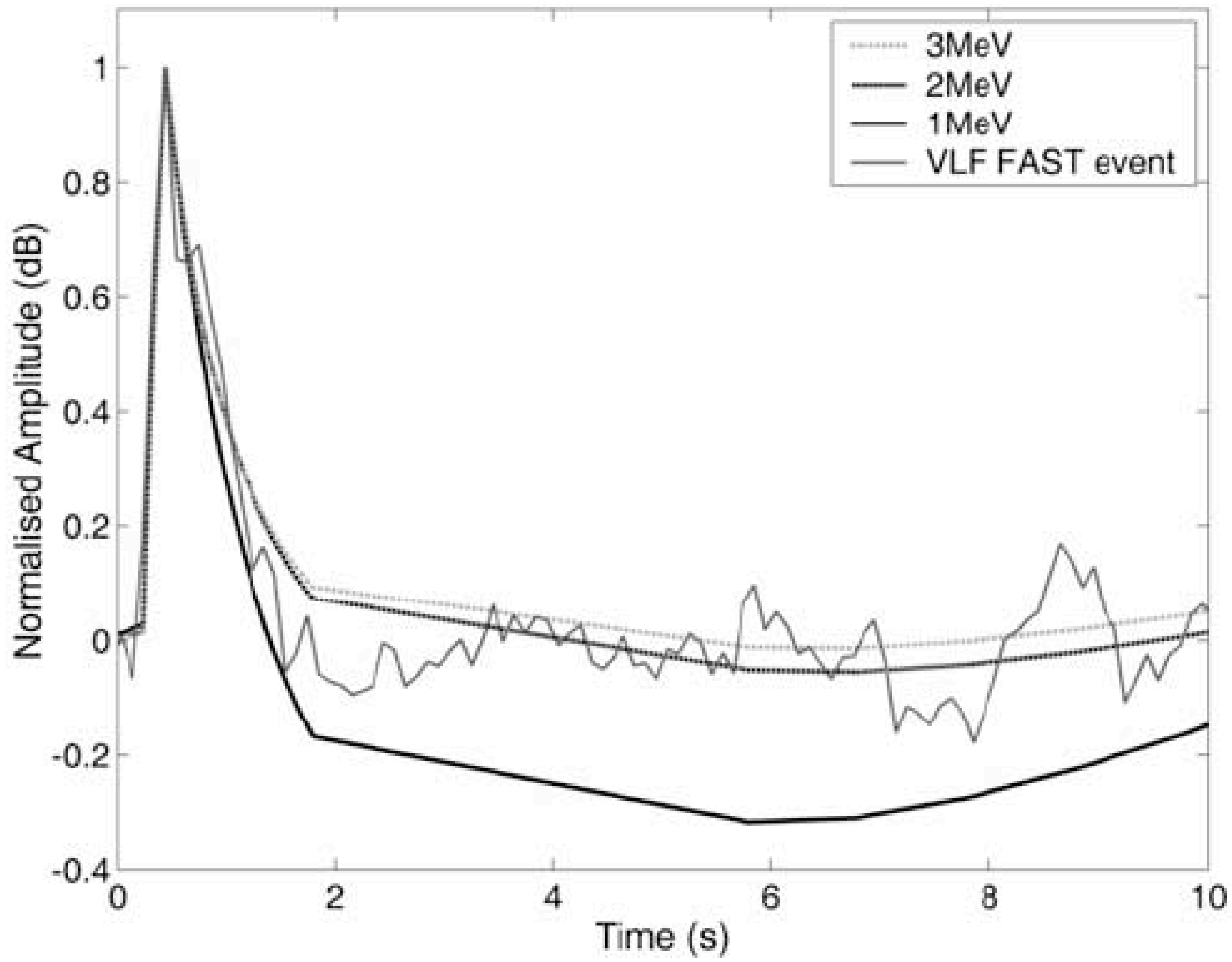


Figure 6. Comparison between the time-decay of the Sodanklya-observed FAST VLF perturbation from 5 April 2005, with those calculated due to monoenergetic 0.1 s REP bursts of varying energies (1, 2, 3 MeV).

(from C. Rodger et al., 2007)

EISCAT Svalbard Radar

Modelling a REP burst

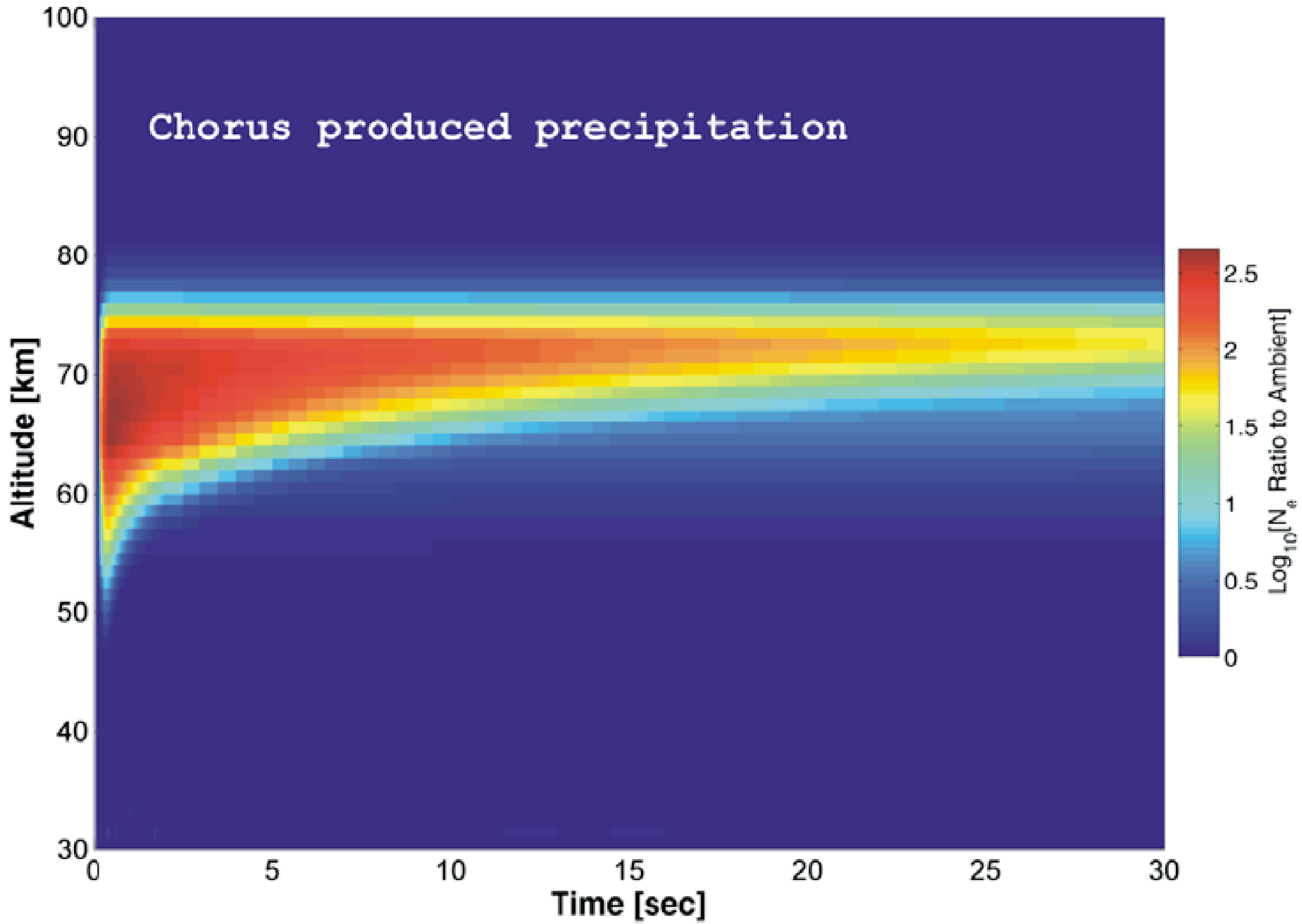


Figure 8. Time varying electron number density calculated by the SIC model, showing the decay of a chorus-produced ionospheric change due to the fluxes shown in Figure 7, top.

(from C. Rodger et al., 2007)

Modelling a REP burst

Data not explained by chorus produced precipitation!

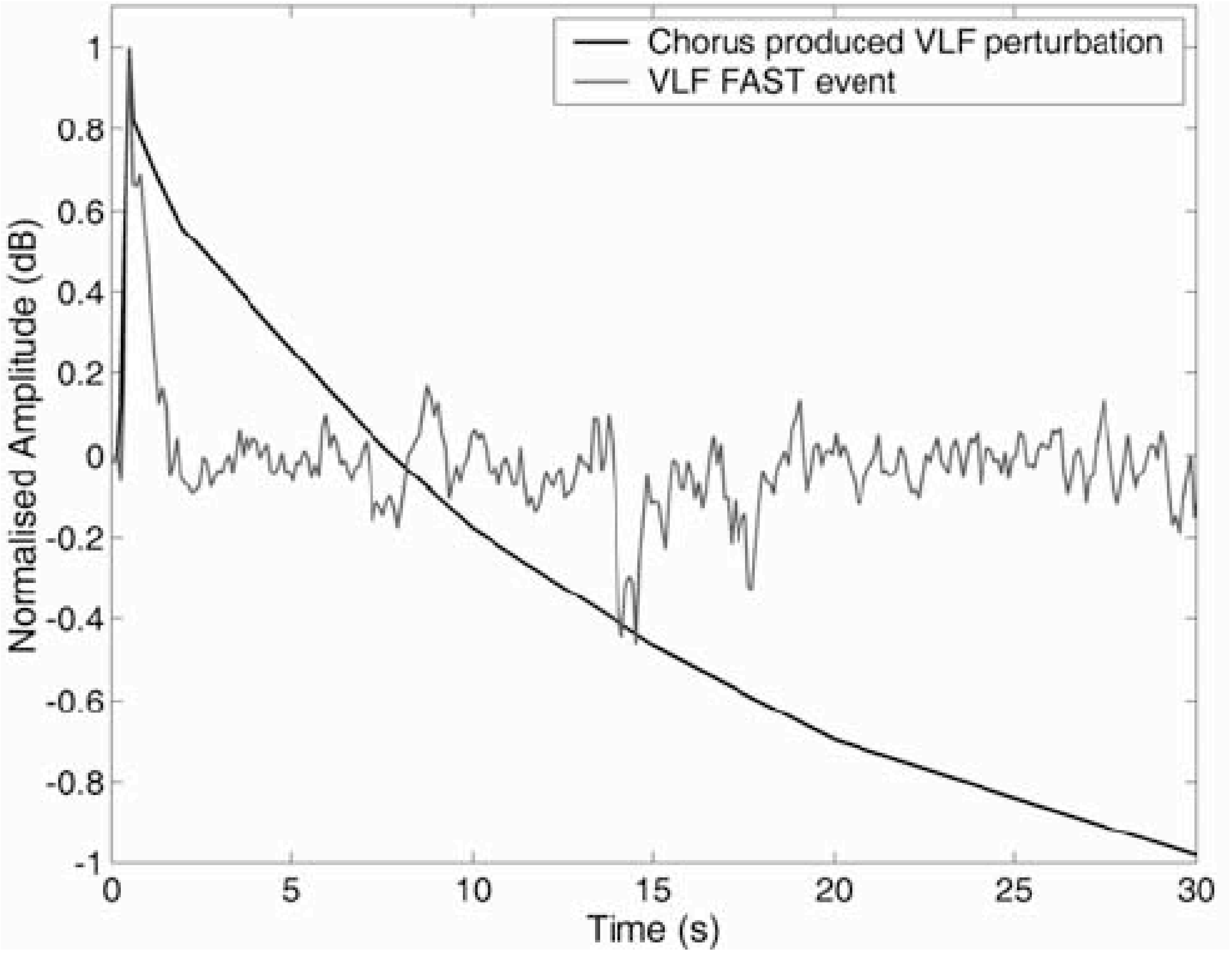
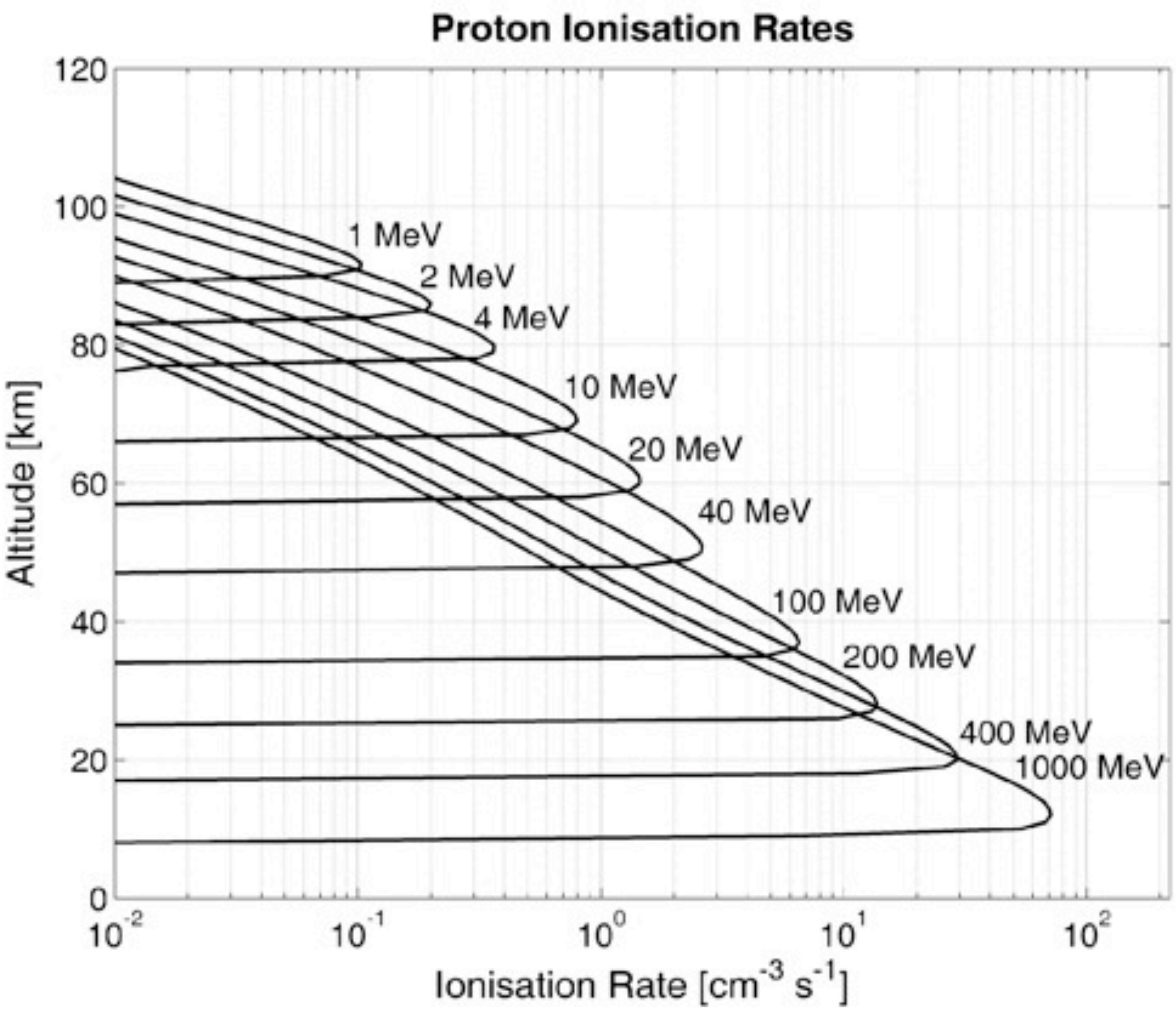
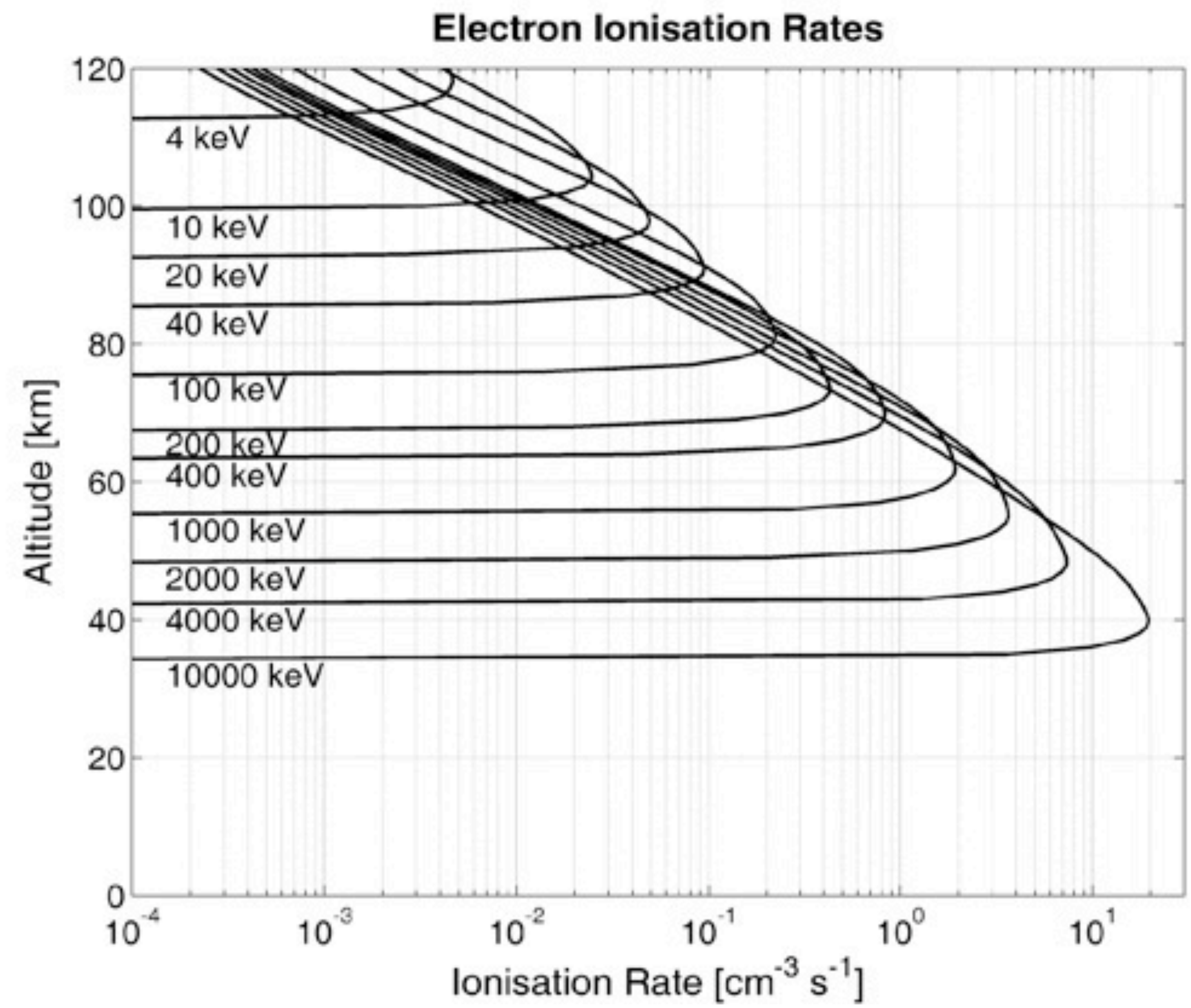


Figure 9. Time varying VLF perturbation produced by a chorus-driven precipitation spectra, to be contrasted with the same observed FAST VLF perturbation from Figure 6.

(from C. Rodger et al., 2007)

High-energy particles penetrate deep into the atmosphere





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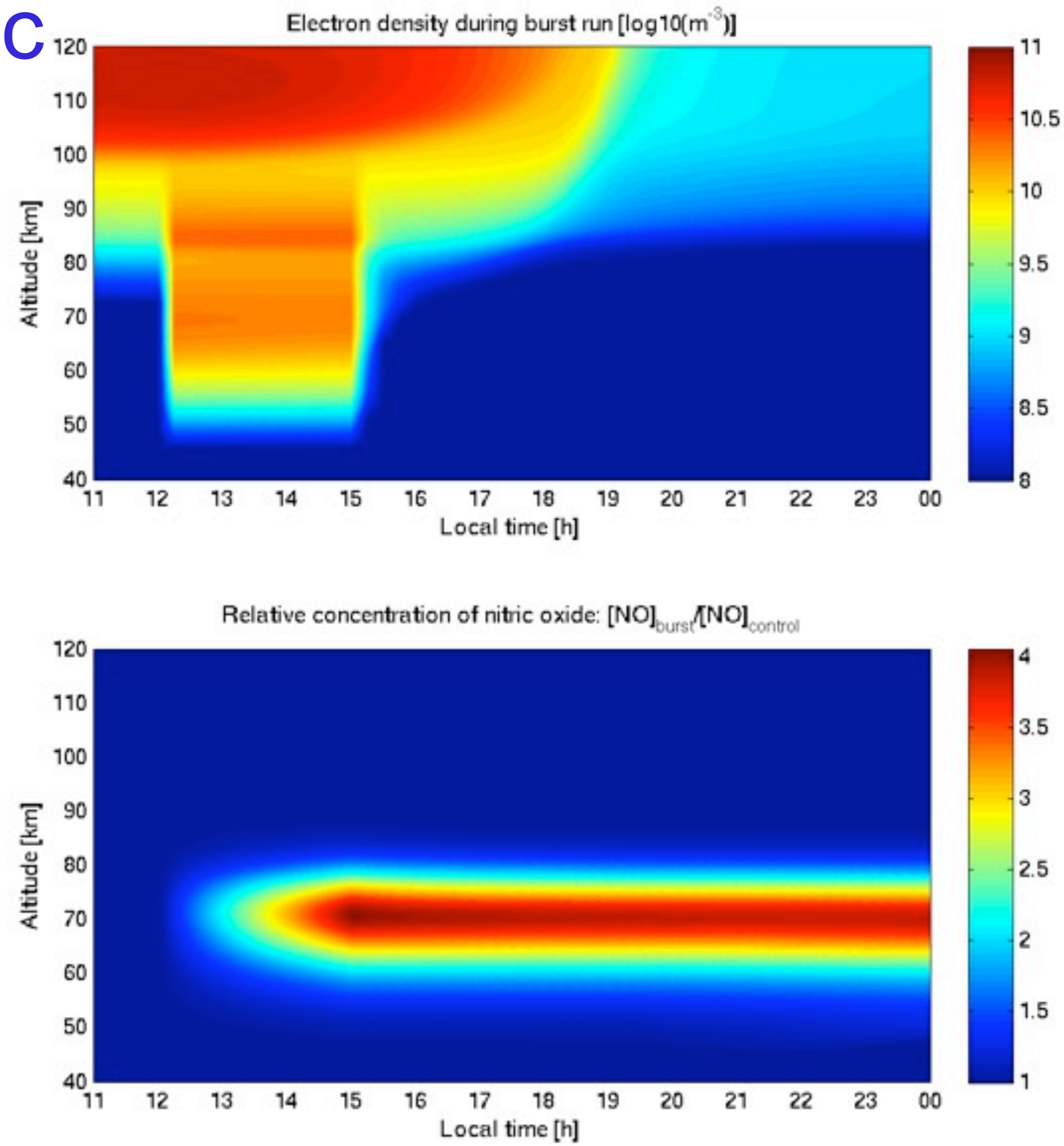
Effect of relativistic electron precipitation



Similar as previous figure, but showing the effect of a 3 hour long burst of REP on electron number density and NOx levels using the precipitating fluxes measured in the bounce loss cone at L=3.5-4 by the UARS on 18 May 1992 (Gaines et al., 1995). The spectrum of the REP event is very hard, containing significant fluxes at energies as high as 5 MeV.

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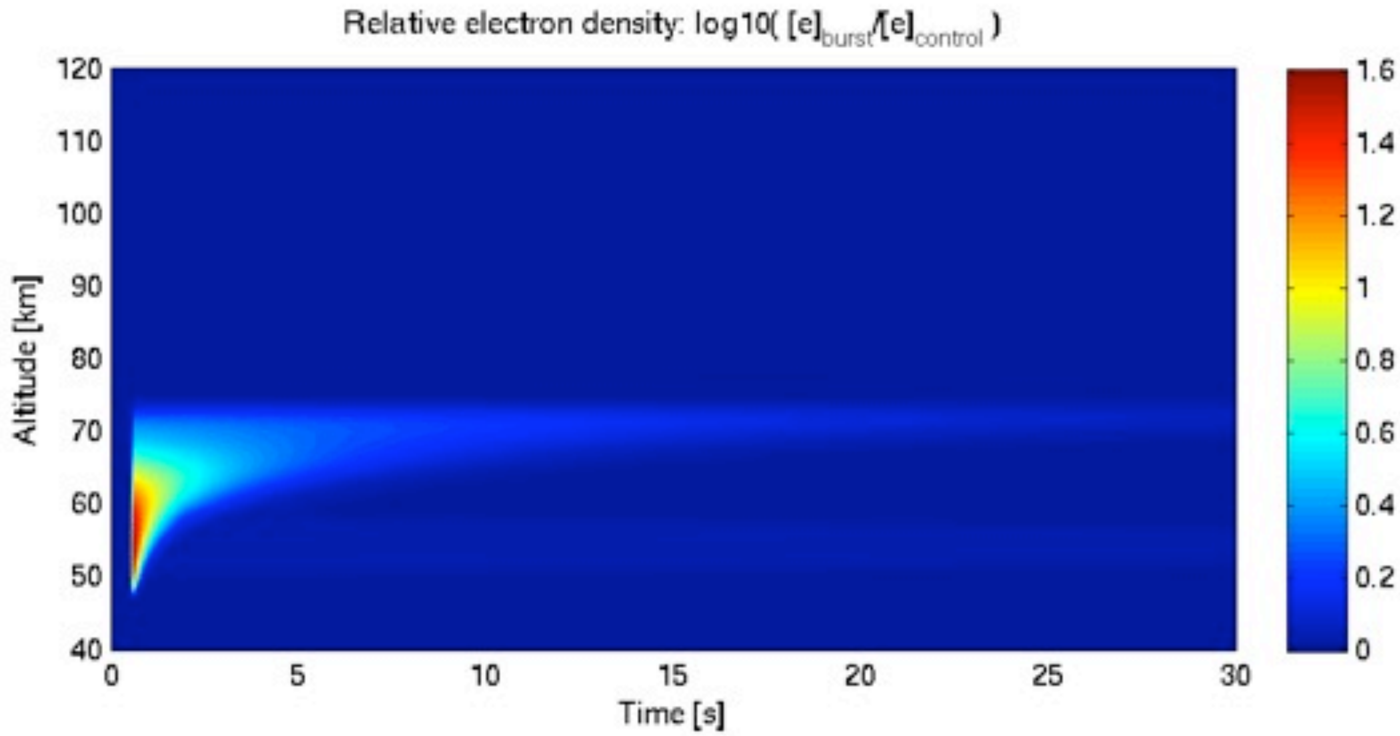
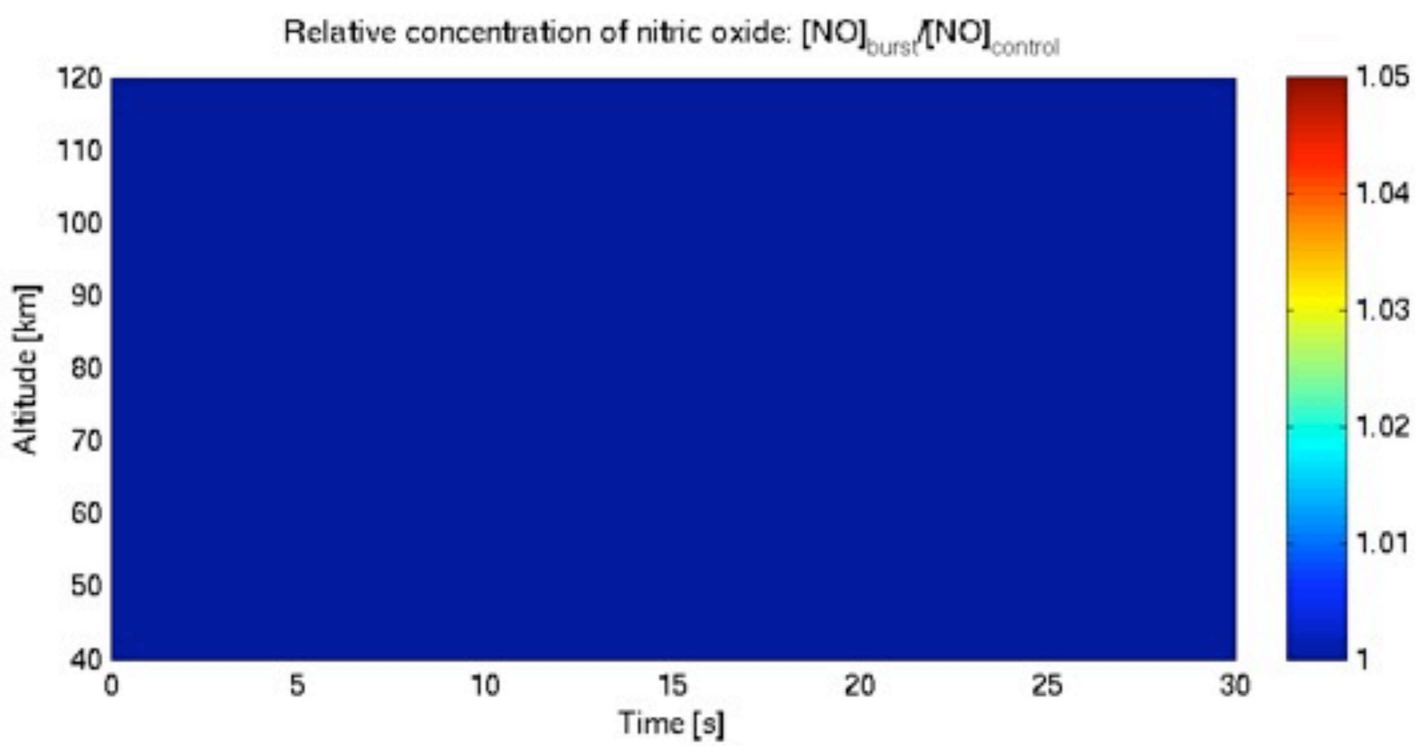
Effect of a relativistic microburst

Same as the previous figure, but showing the effect of a REP microburst on electron number density and NOx levels. We have assumed a 0.1 s burst of 2 MeV monoenergetic relativistic electrons with a flux taken from those reported by SAMPEX.

One single microburst is too short to cause significant changes in [NO].





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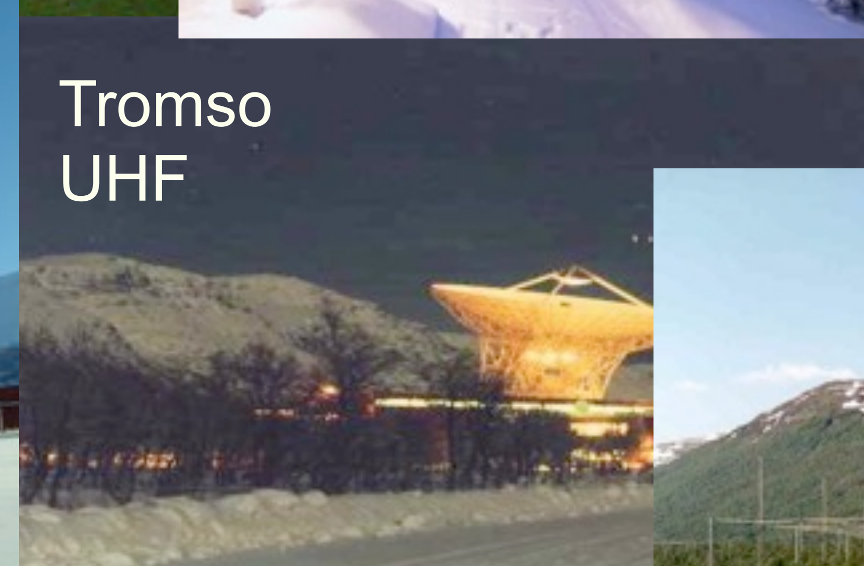
Associate countries and institutes

Contributing:

EISCAT Scientific Association

Headquarters, Rymdcampus 1, SE-98192 Kiruna, Sweden



EISCAT VHF 224 MHz, Tromsø

- Worlds largest klystrons in transmitter
- Antenna cylindrical paraboloid 40 m x 120 m

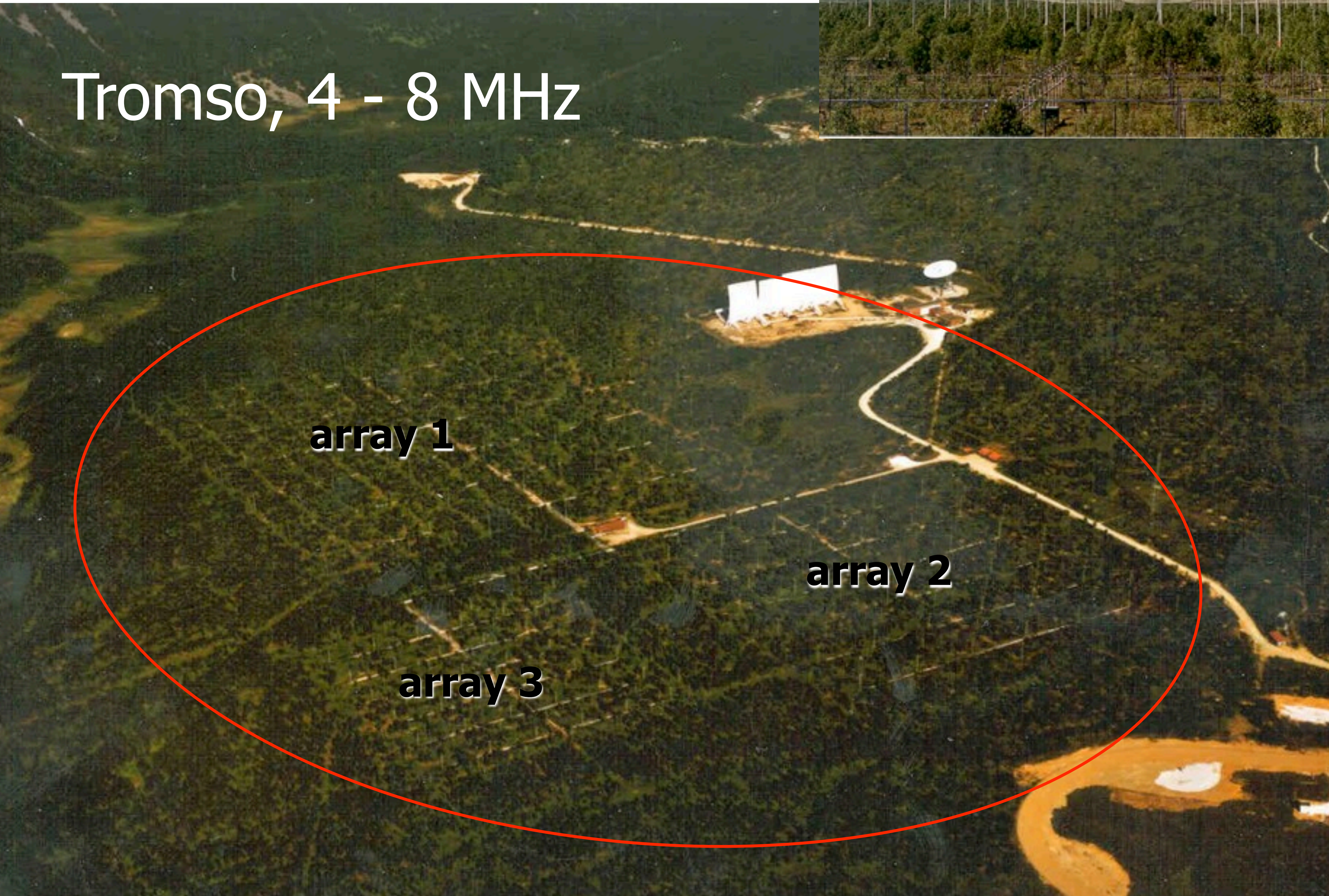
UHF radar, 933 MHz

- 3 identical fully steerable 32 m paraboloids
- Passive reception also at 1.420 GHz
- Tromso UHF monostatic radar continued at least to end of 2013

EISCAT Svalbard Radar

HF Heating Facility

Tromso, 4 - 8 MHz



One of world's most advanced radars: The EISCAT Svalbard Radar

- ESFRI (European Strategy Forum for Research Infrastructures) project: Svalbard Integrated Arctic Earth Observation System (SIOS)
- Proposal for a 3rd antenna by China
- Continued international ISR collaboration

EISCAT Svalbard Radar

EISCAT Data Access

- MADRIGAL data base
    - actually like a virtual observatory
    - access all IS radars
- EISCAT new development:

"Venabili"- system (by Paul Gallop)

- "making the data access really elegant"
- any and all data in the archive
- extensive metadata searches

venabili

30 years – and growing!

"making the raw data access really elegant"

"any and all data in the archive"

6 Aug 2009 EISCAT Workshop Venabili

Approach

User-based login accounts

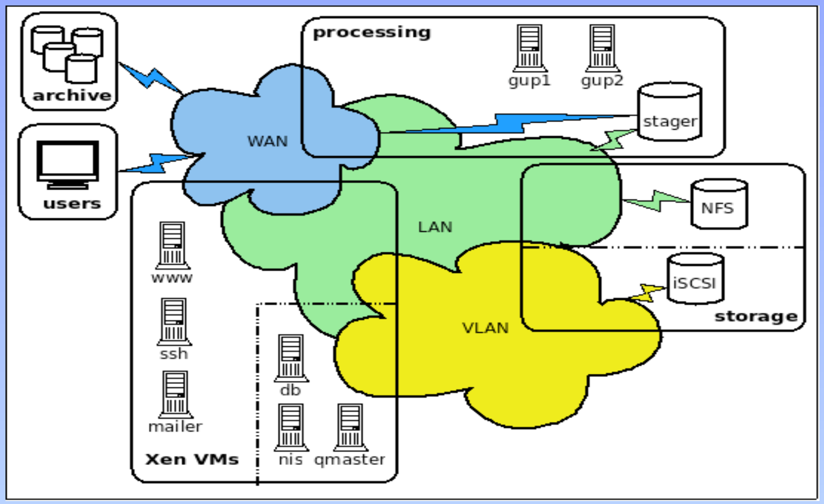
Two-pronged approach to applications:

- microscopic analysis works now!
  - existing applications
  - use complex driver files and setups
- macroscopic processing needs more work!
  - need and use metadata to create driver files
  - dynamically driven

So far we have...

- Databases
  - parameter blocks for all dumps
  - search for and retrieve any dump
- Microscopic software
  - updated versions of RAL software
- Guisdap
  - ported to Octave v3.0
  - no Matlab here!

Technology – connections



Technology - hardware

- Networking stuff
- 2 storage servers
  - 2 Opteron 270 CPUs
  - 4GB RAM
  - 4 x 400GB SATA HS drives
- 2 process servers
  - 2 Opteron 270 CPUs
  - 4GB RAM
  - 4 x 400GB SATA HS drives
- 2 Xen servers
  - 2 Opteron 270 CPUs
  - 5GB (10GB?) RAM
  - 2 x 80GB SATA HS drives

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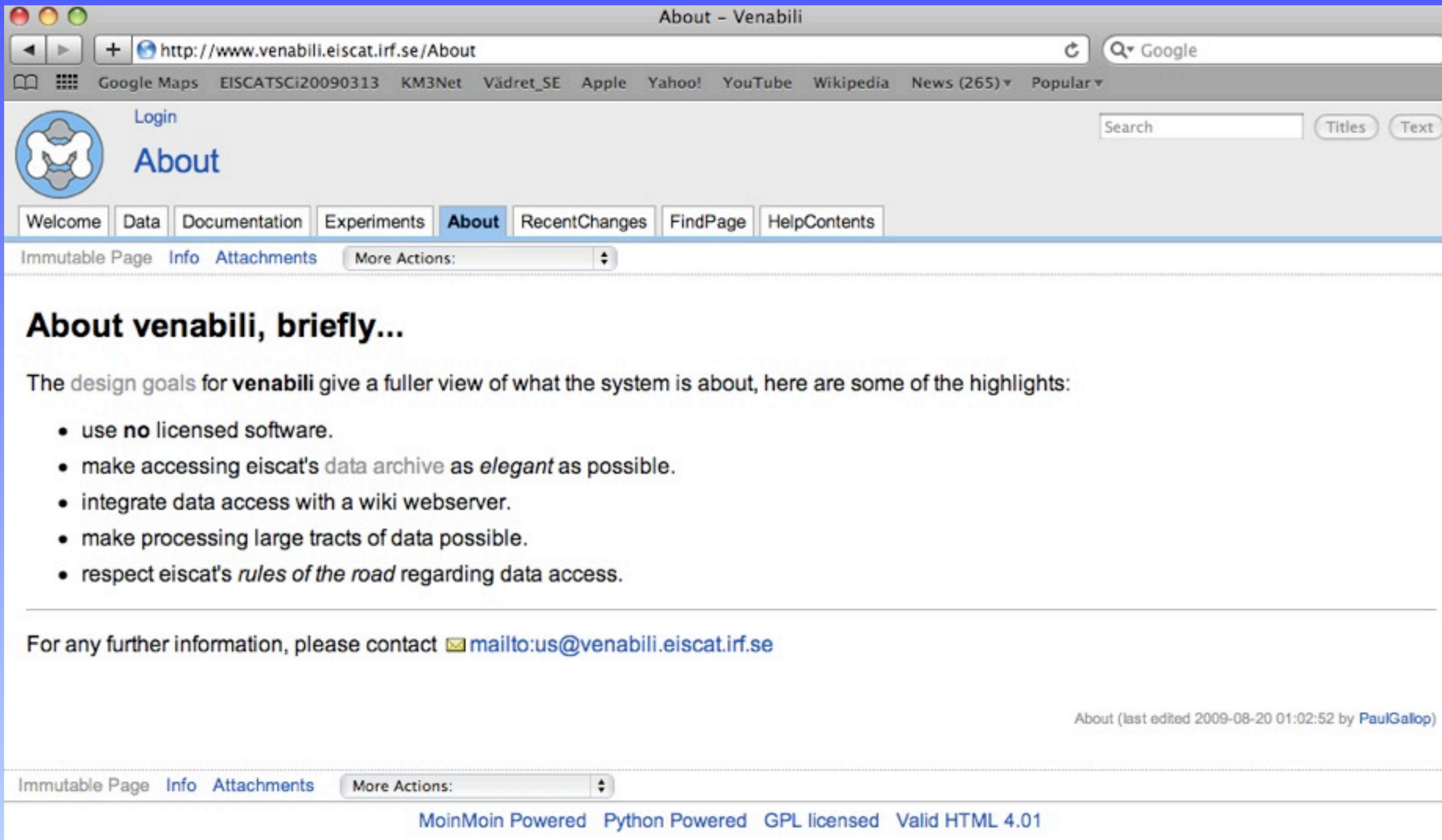
Xen

- Single physical box supports multiple virtual machines
- Easily and quickly create new virtual machines
- Migrate for maintenance, load-balancing
- Snapshotting
- Play with configurations and resources

EISCAT Svalbard Radar

http://www.venabili.eiscat.irf.se



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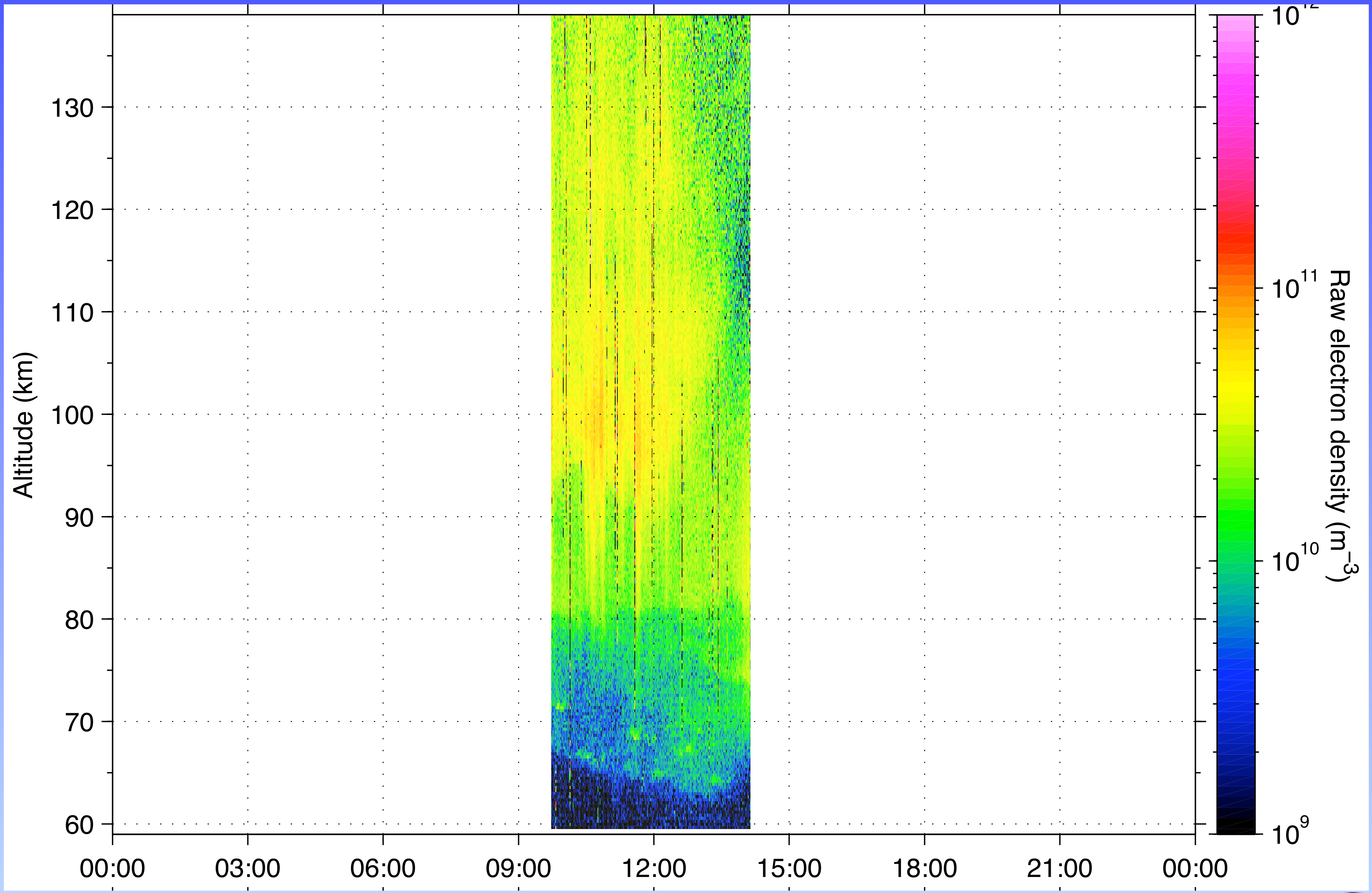
EISCAT Scientific Association

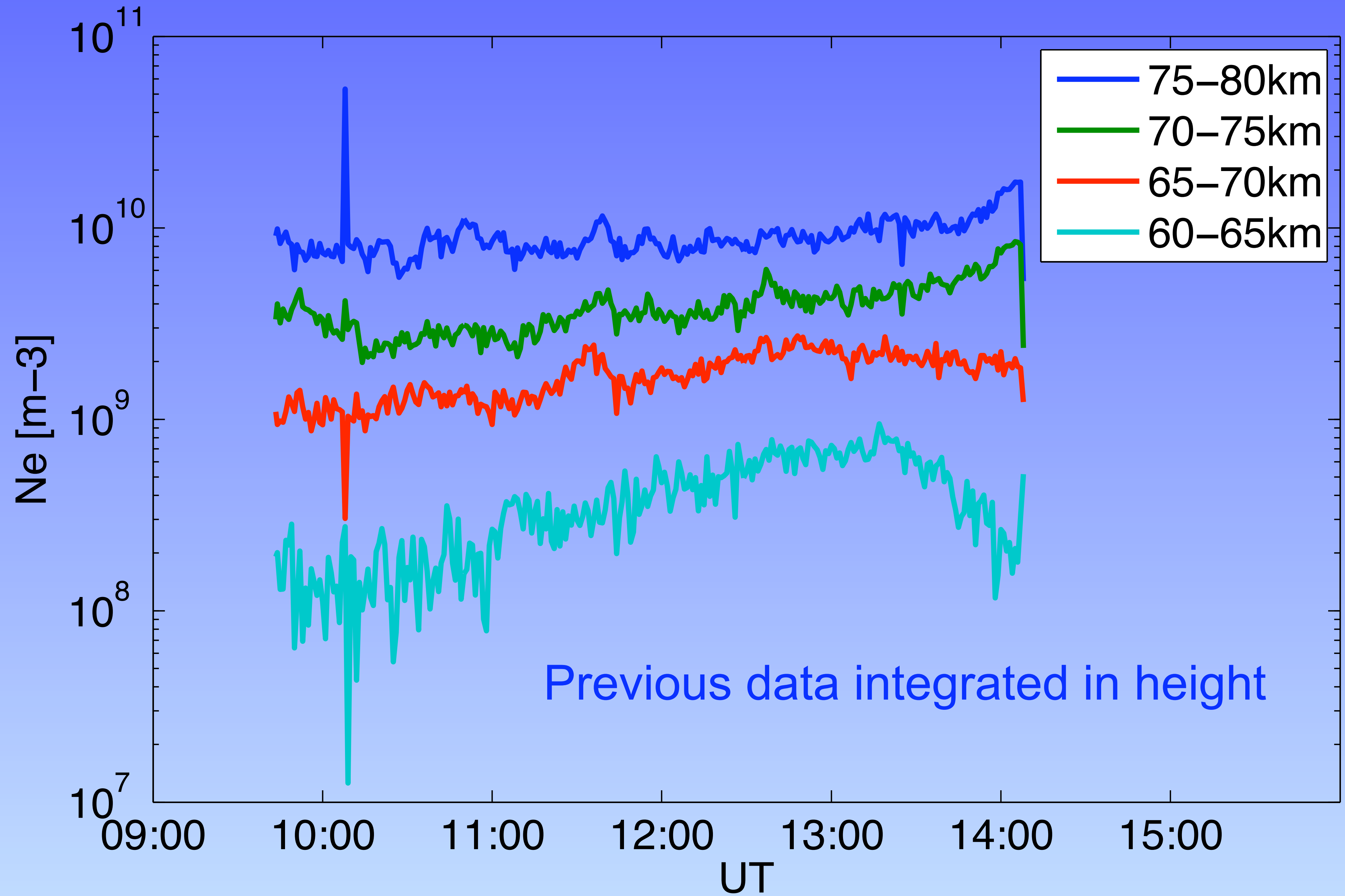
EISCAT VHF, 21 Jan 2005



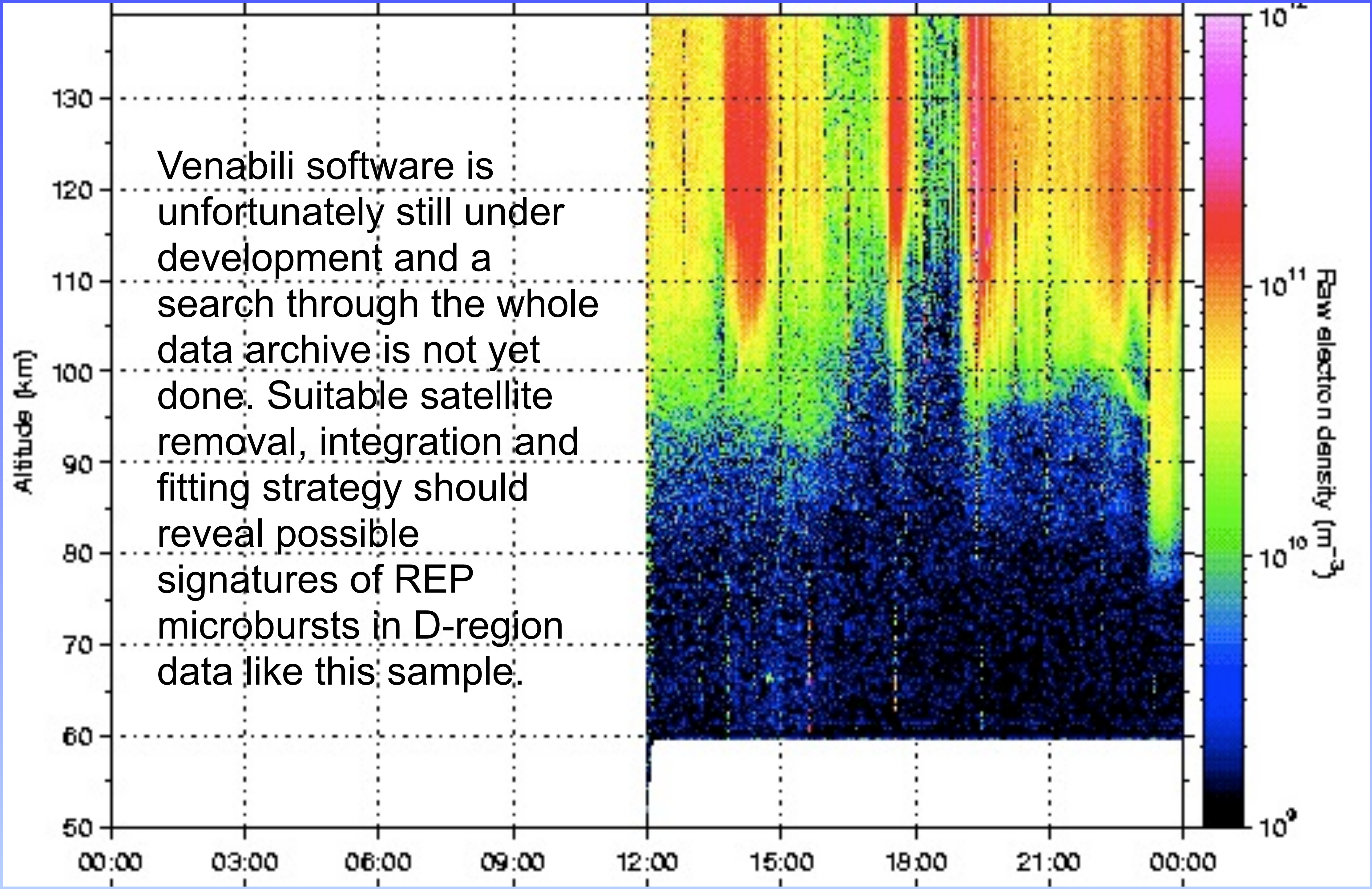
EISCAT Svalbard Radar

EISCAT VHF 21 January 2005

Electron density



EISCAT VHF, 08-09 Mar 2008



Venabili software is unfortunately still under development and a search through the whole data archive is not yet done. Suitable satellite removal, integration and fitting strategy should reveal possible signatures of REP microbursts in D-region data like this sample.

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Conclusions

- First look at sample data did not show signs of REP microbursts reported by other observations
- Venabili should allow:
  - –reanalysis of the data with suitable time resolution and altitude integration, in order to have statistics
  - –search through the whole data archive of D-region experiments
  - –Venabili software expected to be ready for this within next 2 months...