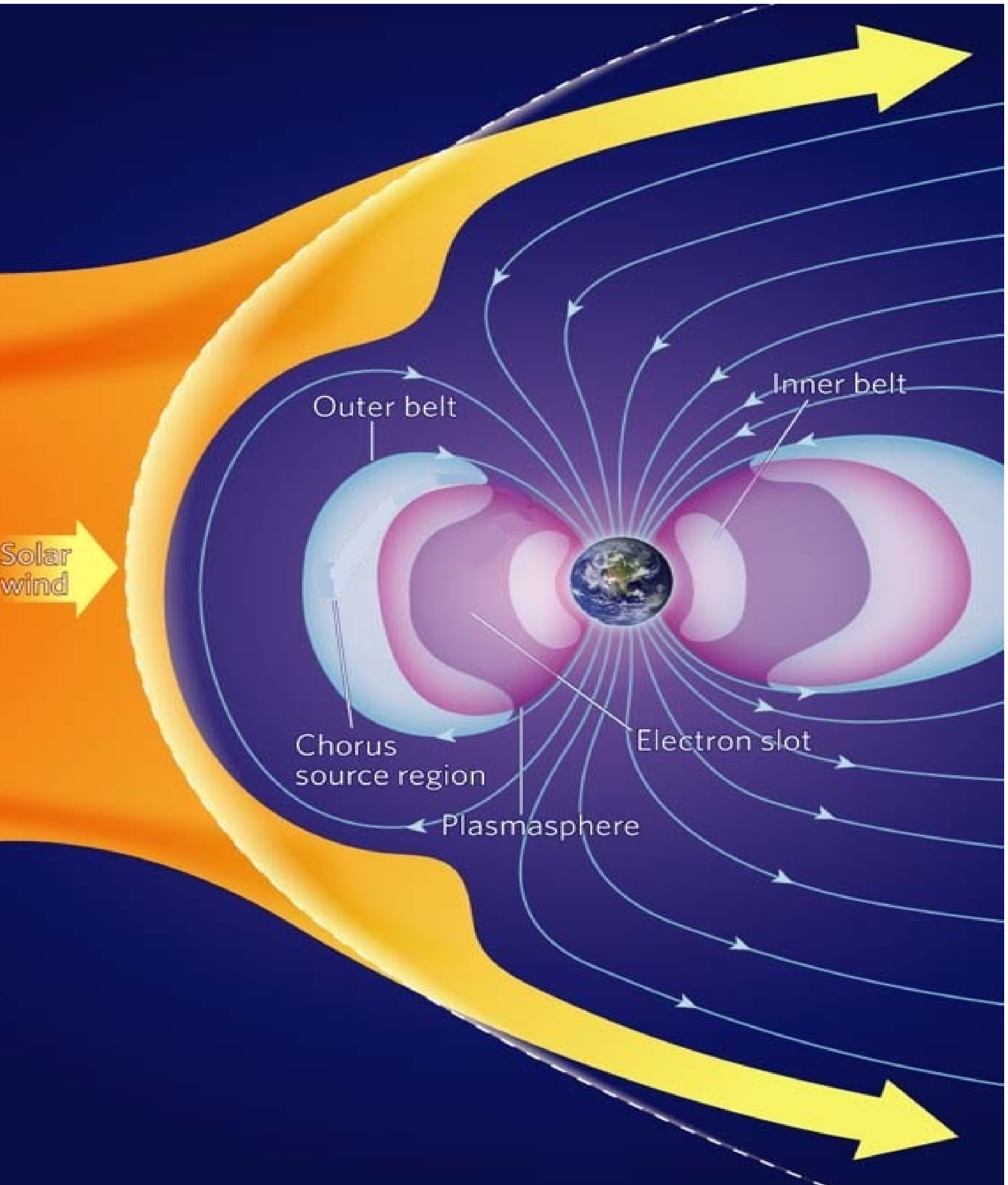
GPUs in a global Earth-based space weather monitoring network

Dávid KORONCZAY[12], János LICHTENBERGER[21], Tamás HETÉNYI[2], Csaba FERENCZ[2]

[1] Geodetic and Geophysical Institute, RCAES HAS, Sopron

[2] Eötvös University, Space Research Group

Context



- Radiation belts: hot plasma

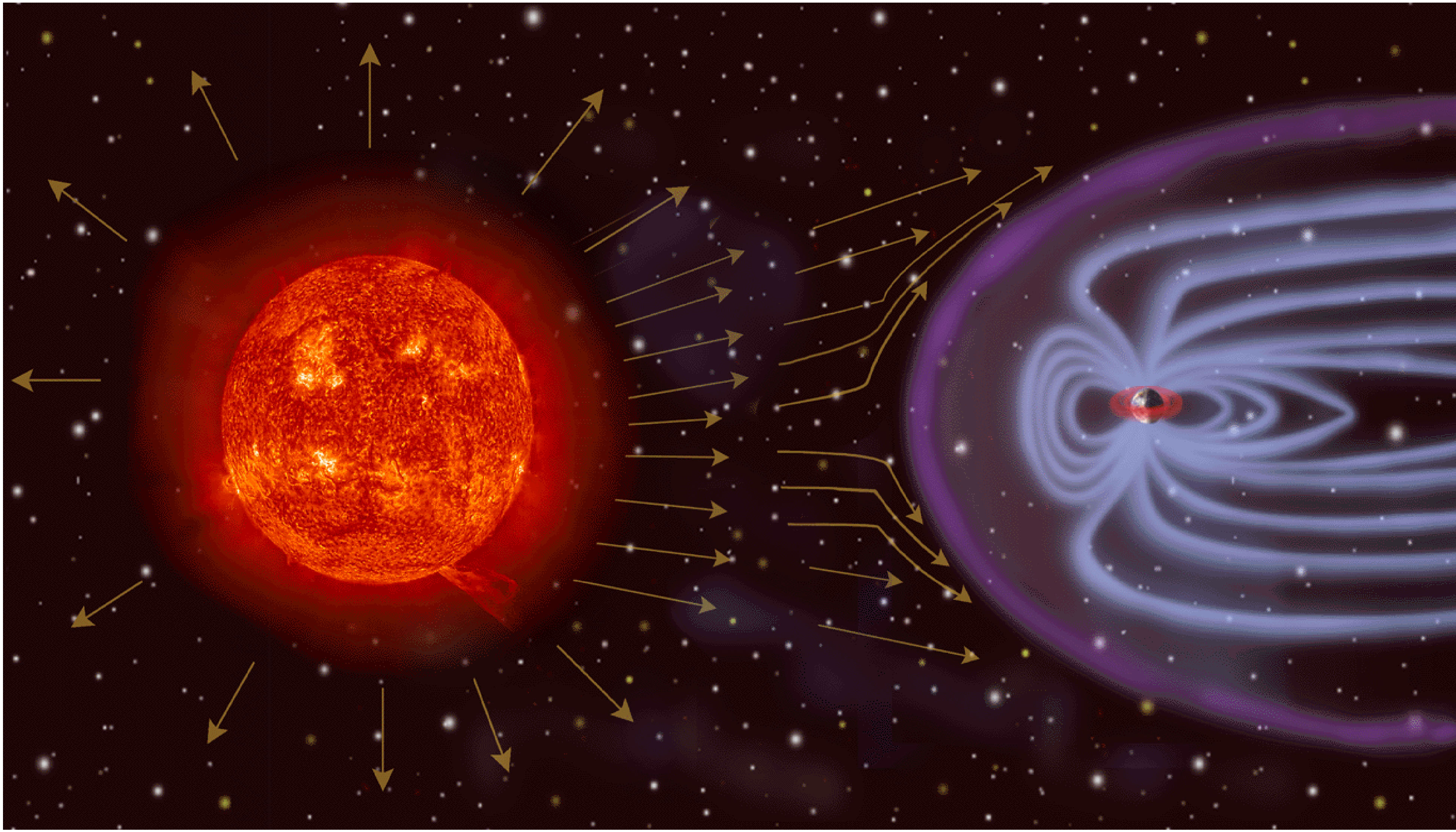
  (energized charged particles)

  - T~ 0.1-10 MeV (electrons) ~ 10-100 MeV (protons)
  - Flux ~-10000/cm^2/s

- Plasmasphere: cold plasma

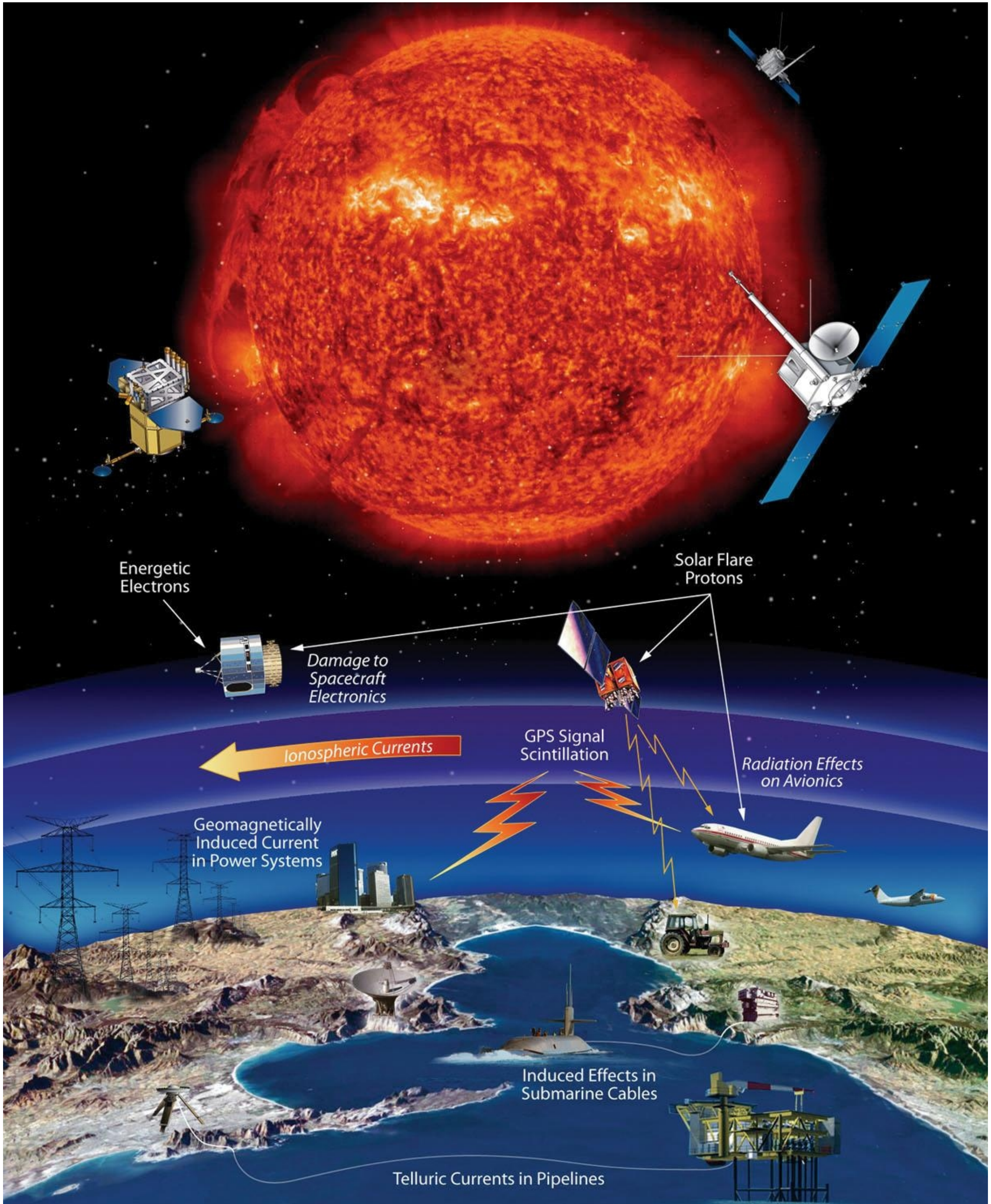
  - Temperature: T~ 1 eV
  - Charge density: N~100-10000/cm^3

Space weather:
changes in the upper atmosphere due to the effect of our Sun



Effects of space weather on our infrastructure:

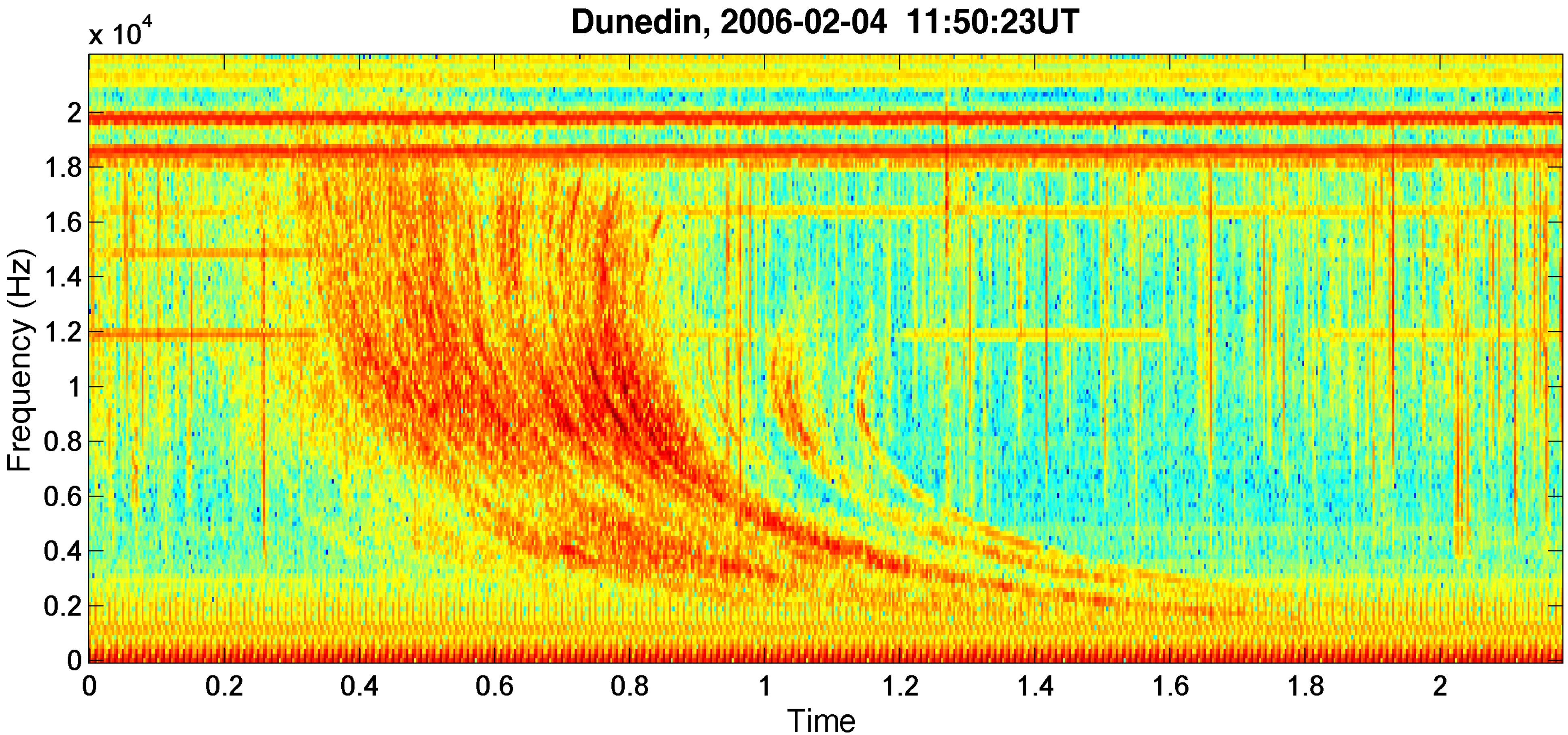
- satellites (electronics, orbit)
- flight (radiation dose, navigation)
- communication (both land and satellite)
- geolocation (GPS and also compass)
- transmission lines, disturbances in electricity supply
- electrochemical corrosion of pipelines


Energetic
Electrons
Solar Flare
Protons
Damage to
Spacecraft
Electronics
Ionospheric Currents
GPS Signal
Scintillation
Radiation Effects
on Avionics
Geomagnetically
Induced Current
in Power Systems
Induced Effects in
Submarine Cables
Telluric Currents in Pipelines

Motivation

- Goal 1: Measure plasma densities at known location ("v.ö. whistler inverziós eljárás")
- Goal 2: Do it in real time and feed it into space weather models, predicting changes in the plasmasphere

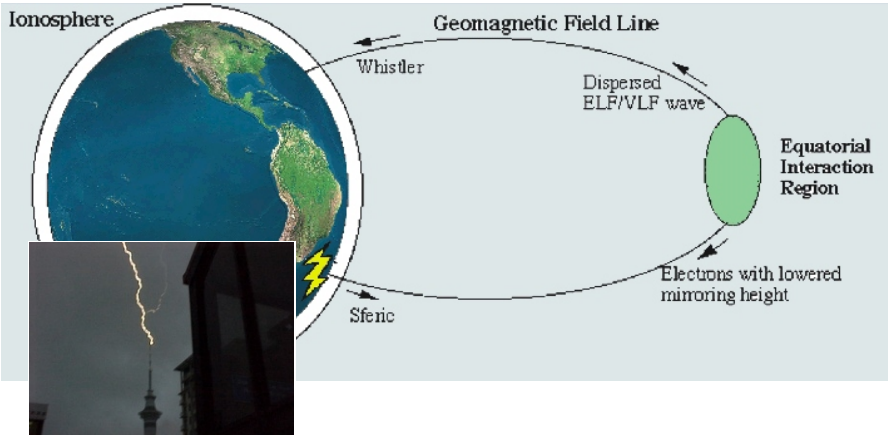
Method



A whistler group + spherics + VLF radio transmitter signals

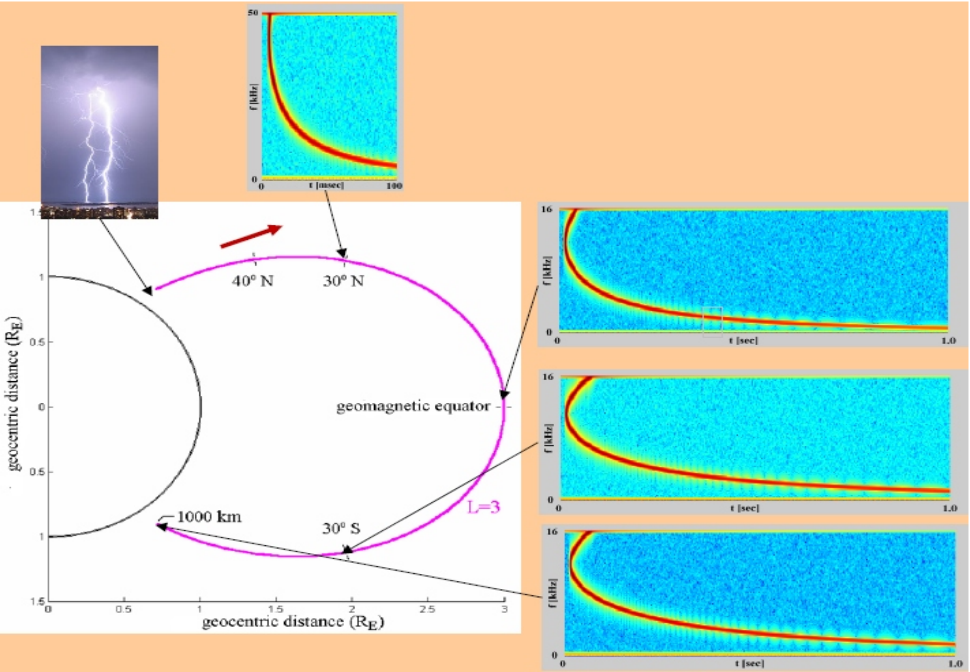
Whistlers

- VLF (3-30 kHz) impulses generated by lightning,
- propagating along magnetic field lines
- Can be observed on the ground and in space



- During propagation in the plasmasphere, they acquire a typical shape on a frequency-time diagram

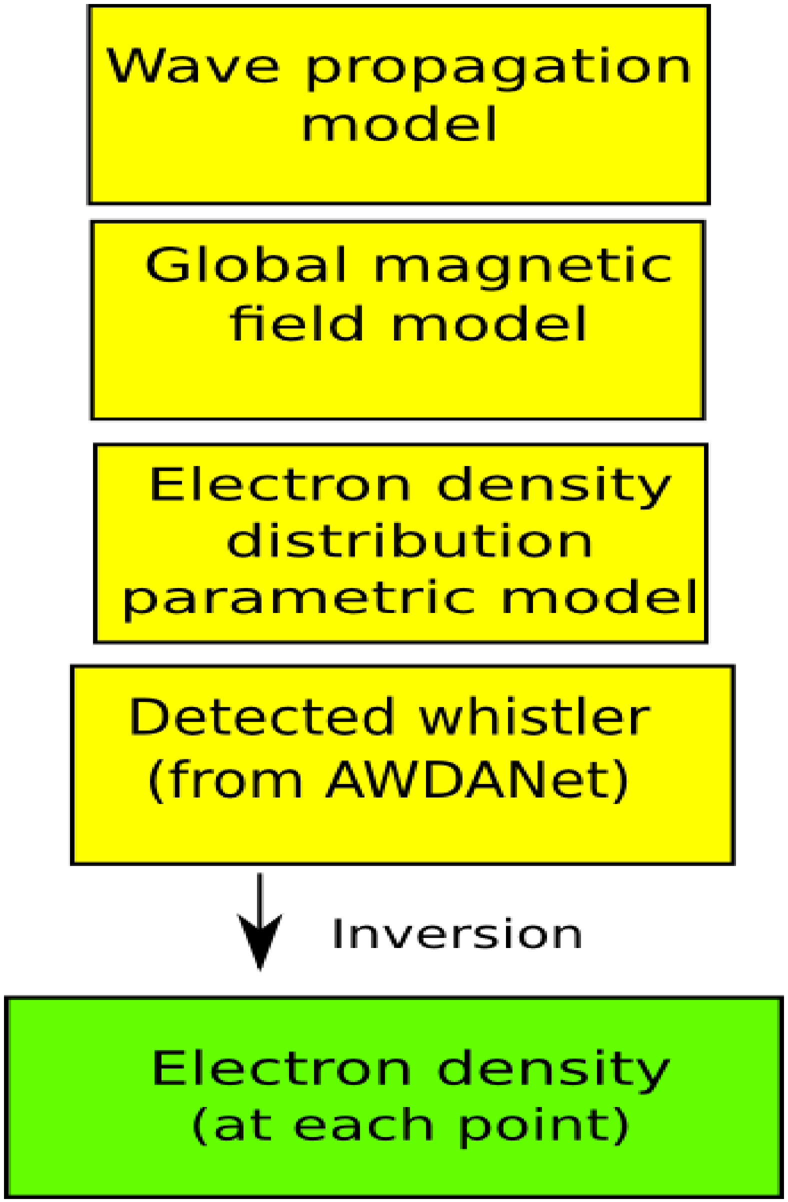
- Their shape is indicative of the total electron density along their path



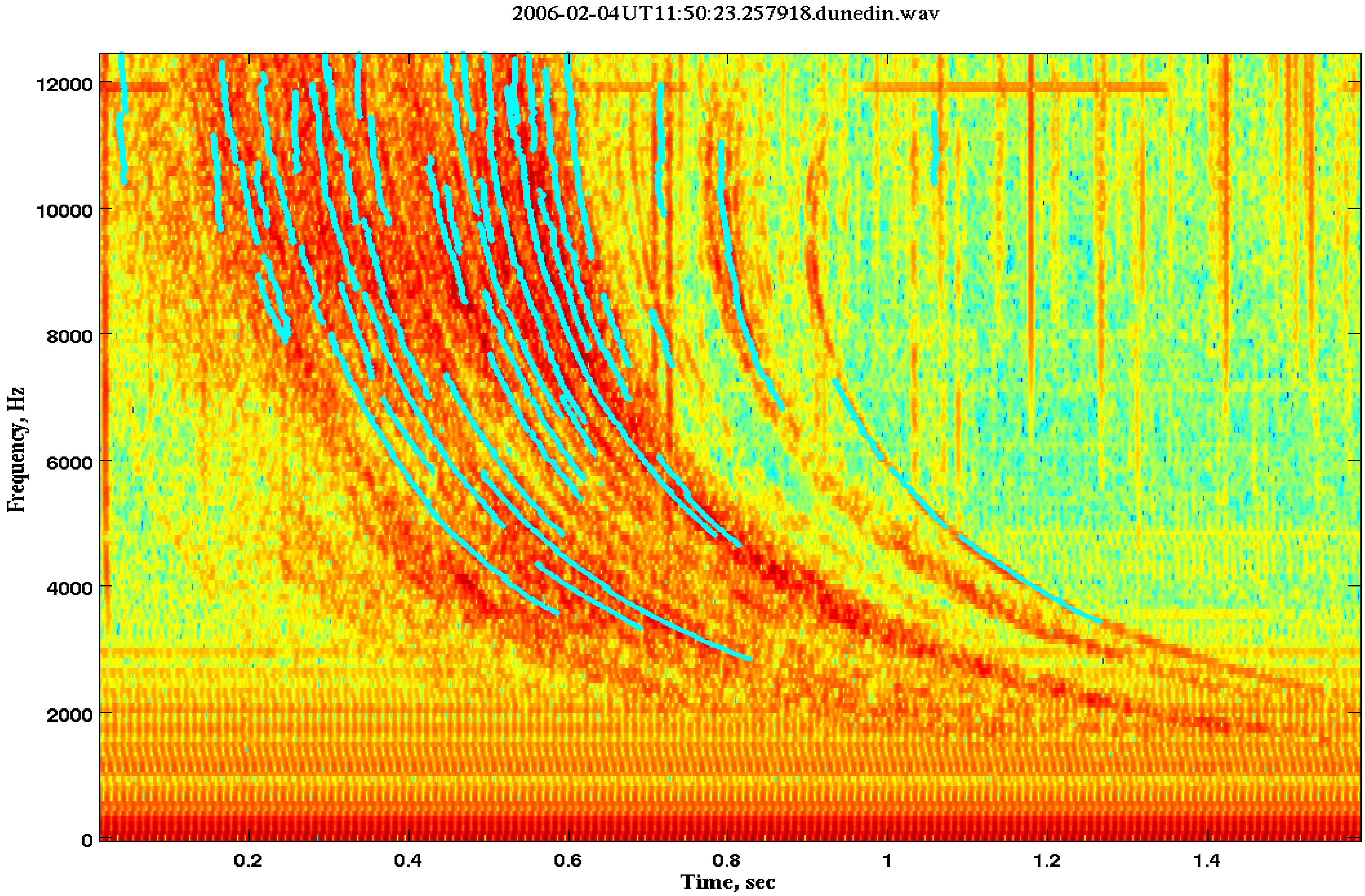
Whistler inversion

- Goal: obtaining physical parameters: plasma density and determining propagation path ("whistler inversion method")

Whistler inversion



Traditional method:



1. identifying curves
2. curve parameters → physical parameters

"AWA = automatic whistler analysis algorithm"

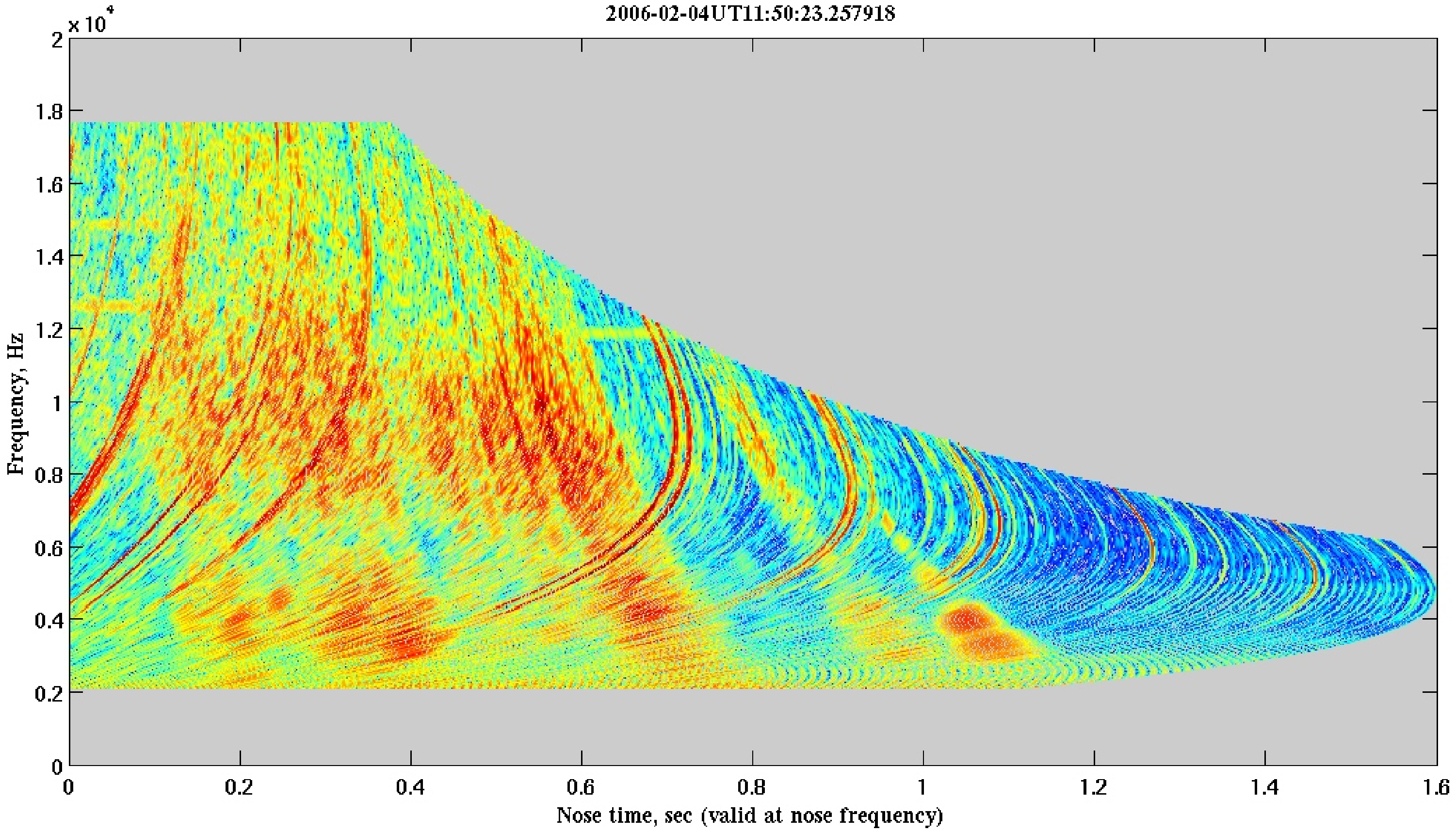
(Lichtenberger, 2000)

- Advantages:

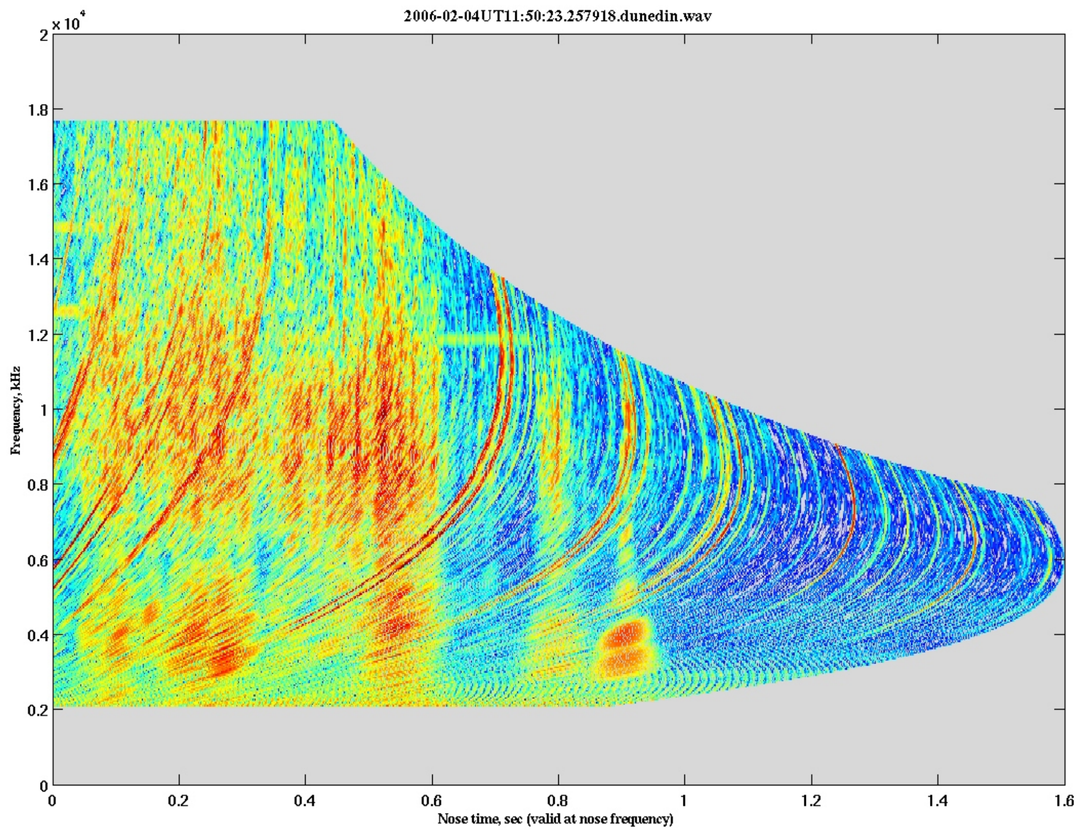
1. doesn't involve the determination of the whistler curve ($f_i - t_i$ pairs), can be automatized

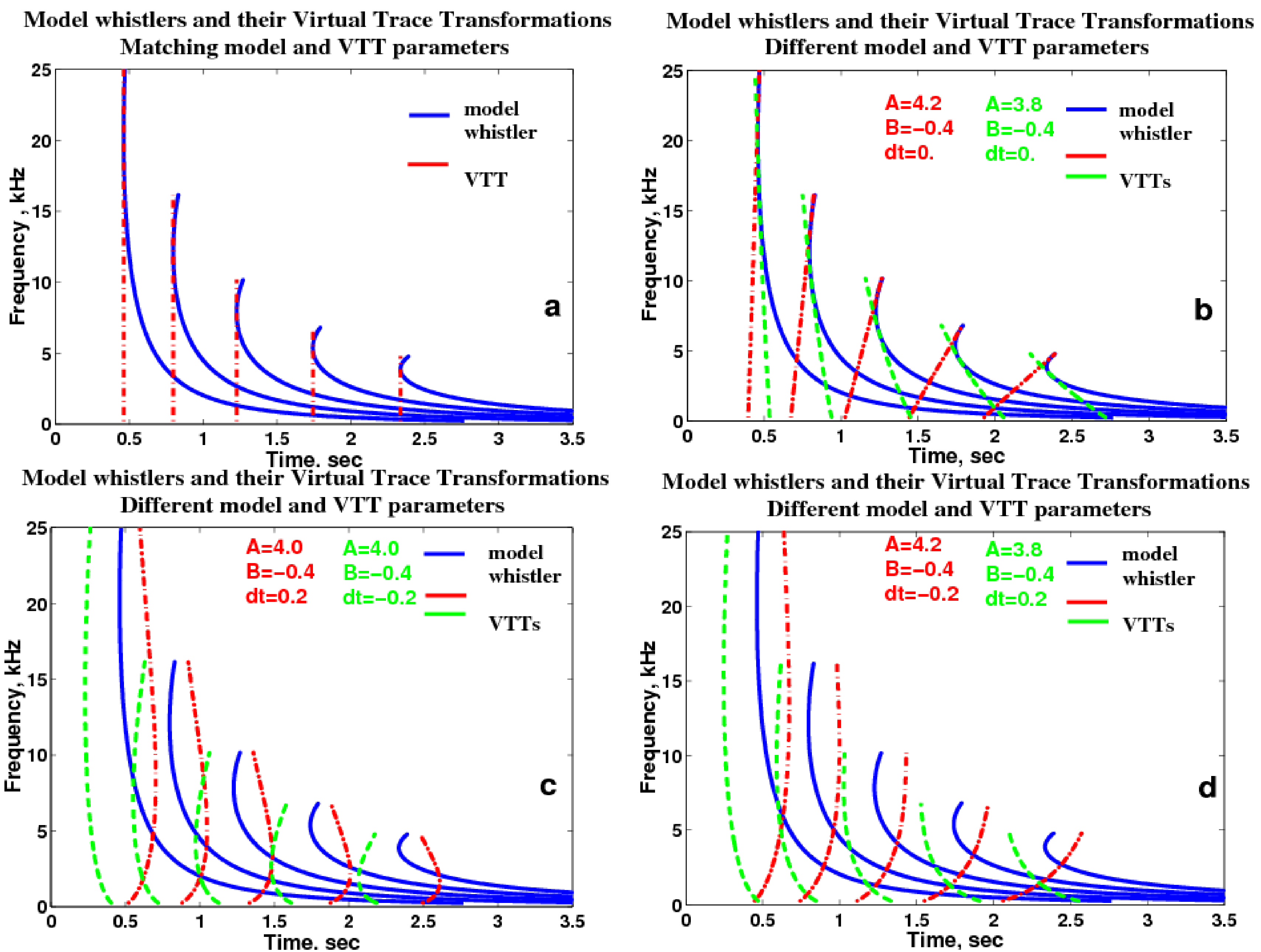
2. multiple path whistlers, are handled as a group (more information, more consistent inversion)

Automatic whistler inversion
(wrong parameters)

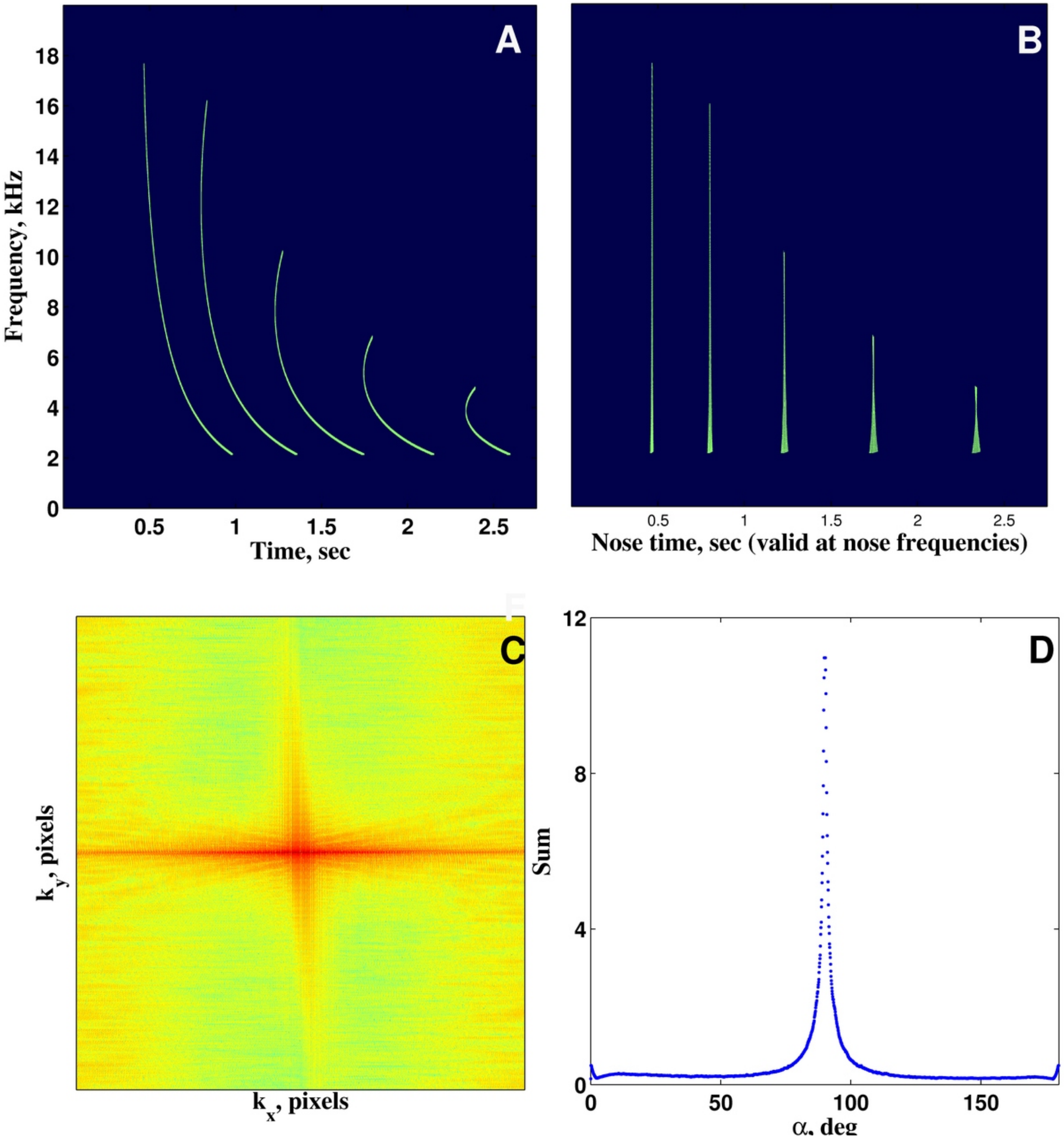


Automatic whistler inversion
(right parameters)

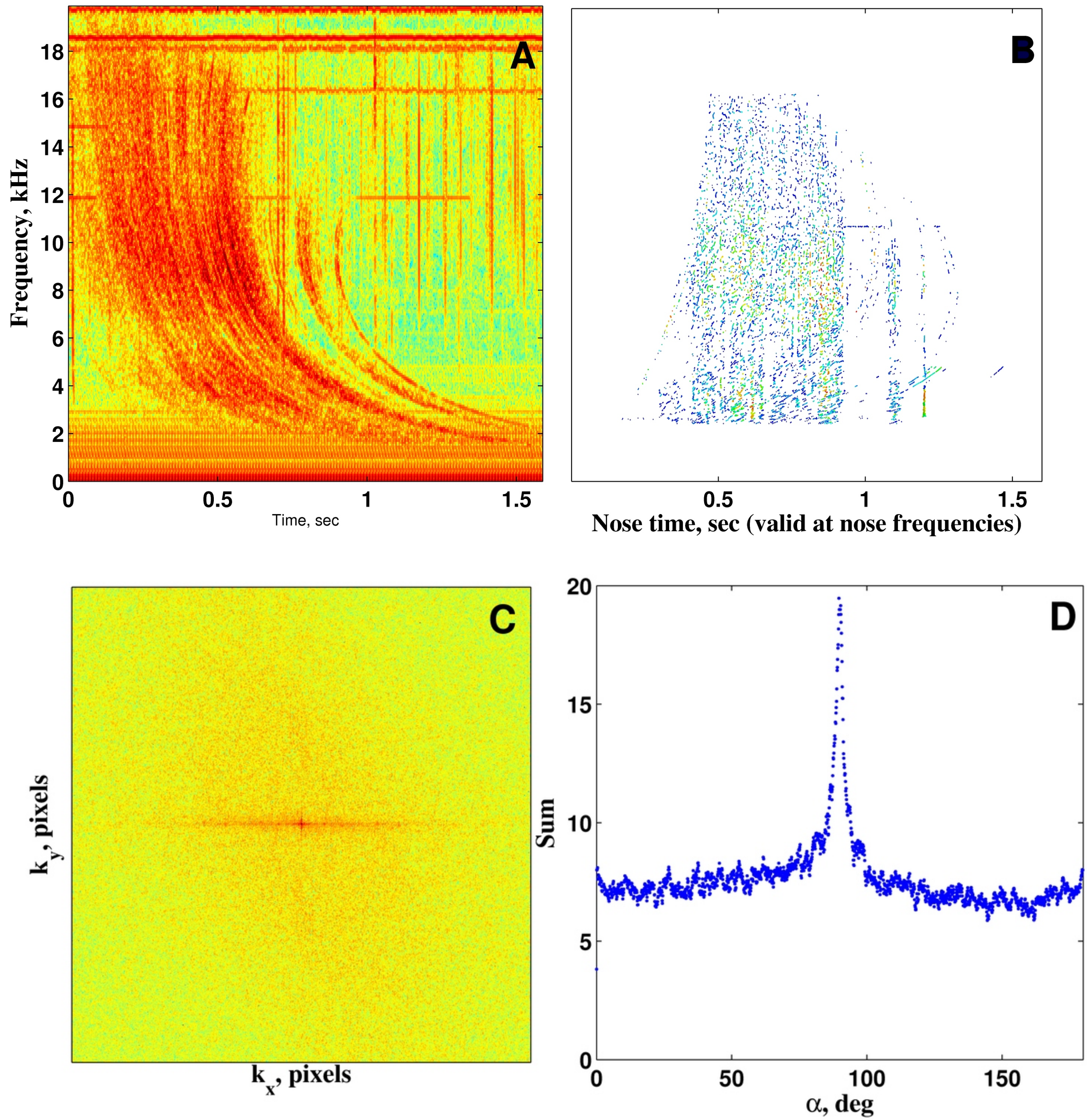



Model whistlers and their Virtual Trace Transformations
Matching model and VTT parameters
model whistler
VTT
a
Frequency , kHz
Time. sec
Model whistlers and their Virtual Trace Transformations
Different model and VTT parameters
A=4.2
B=−0.4
dt=0.
A=3.8
B=−0.4
dt=0.
model whistler
VTTs
b
Frequency, kHz
Time, sec
Model whistlers and their Virtual Trace Transformations
Different model and VTT parameters
A=4.0
B=−0.4
dt=0.2
A=4.0
B=−0.4
dt=−0.2
model whistler
VTTs
c
Frequency, kHz
Time. sec
Model whistlers and their Virtual Trace Transformations
Different model and VTT parameters
A=4.2
B=−0.4
dt=−0.2
A=3.8
B=−0.4
dt=0.2
model whistler
VTTs
d
Frequency, kHz
Time, sec

Test on a modelled multipath whistler group



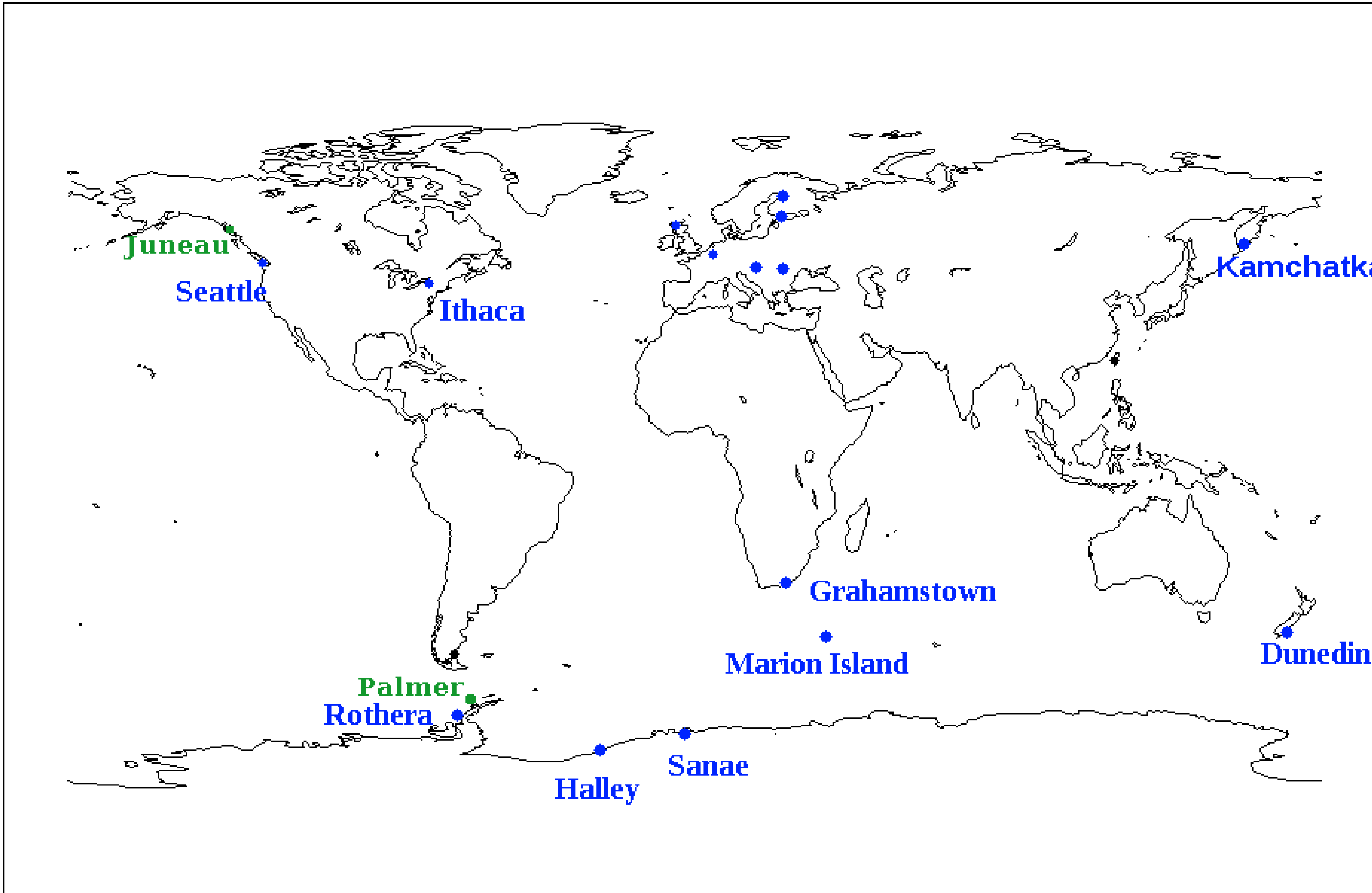
Test on a measured multipath whistler group

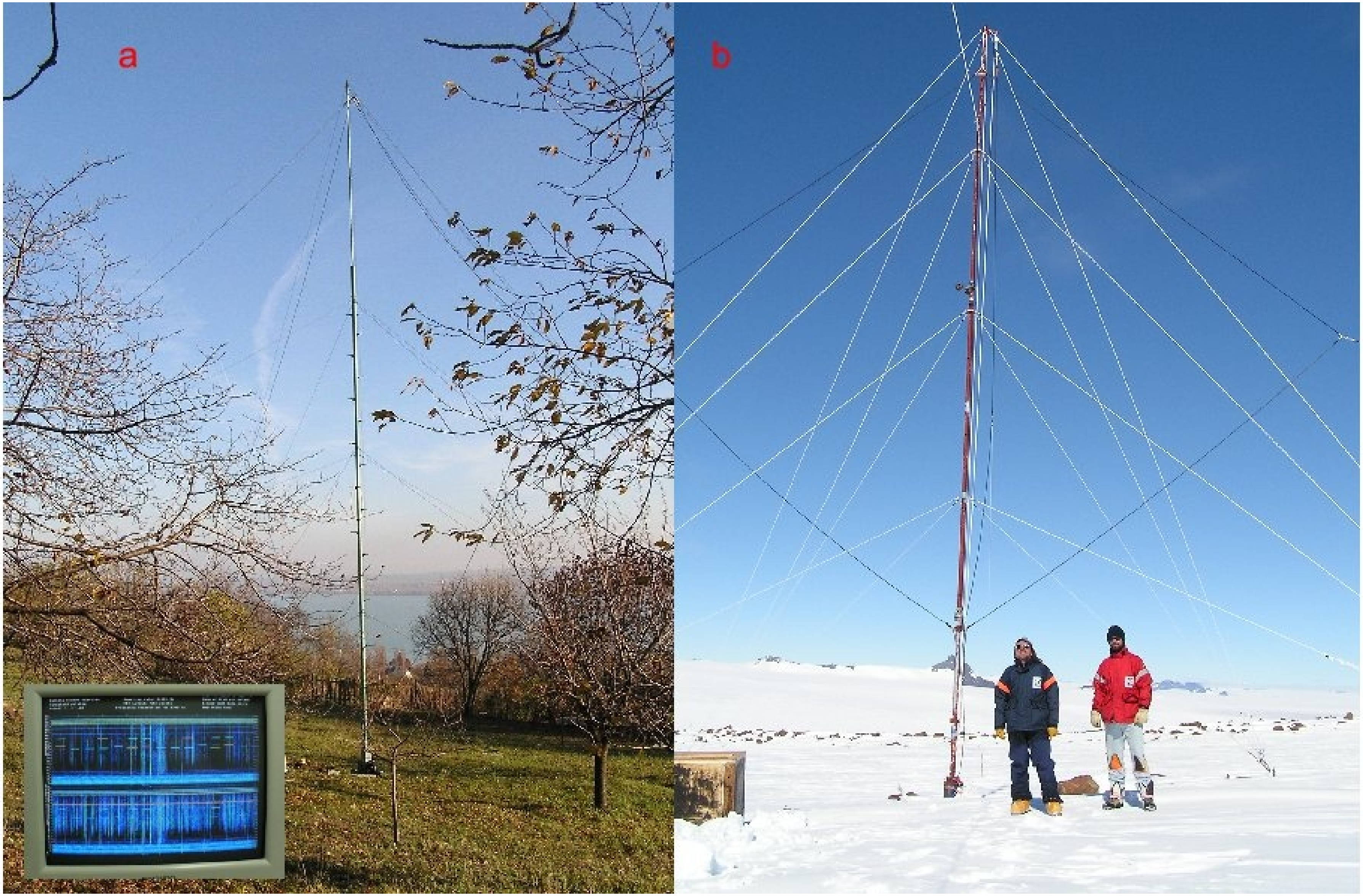


AWDANet

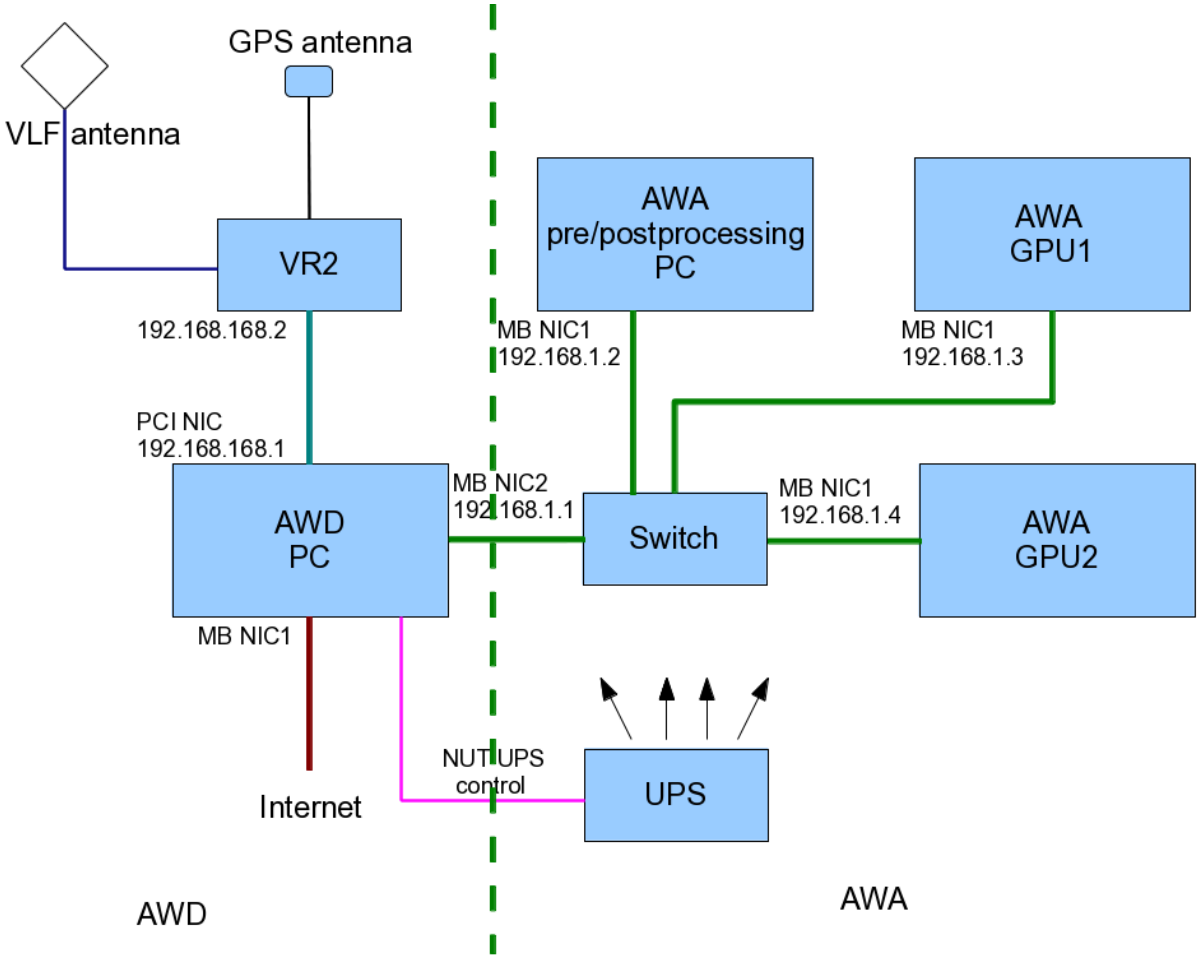
Automatic Whistler Detection and Analysis Network

Stations around the world




a
b

Station setup



Obvious optimizations:

- Improving the code (100x)
- Using some lookup tables (500x)
- Cutting and discarding noise from spectrogram (100x)

→ processing 1 trace takes 3-4 hrs (on an average CPU, = 2.8GHz Core2 Duo)

- Number of whistler detection varies strongly by station and season

- annual detections 100000 or even millions

- in active periods, few hundred potentially invertable whistlers per hour

- We're studying plasmaspheric changes on the scale of hours
- 10-15 snapshots per hour is acceptable
- Necessary: processing a trace group in 250-300 seconds
- We need to accelerate processing 100x

Other condideration:

- Compact solution (light, small volume)
- Affordable (15 global stations)

→ GPU cards

- 2 db GeForce GTX 590 cards per host = 4 GPU cores
- 1-3 such hosts per station = 4-12 GPU cores per station
- Easy to scale
- 6000 matlab code lines + 4500 C/CUDA code lines
- Inversoin of 1 trace ~ 2 seconds

- Testing: GPU core freeze

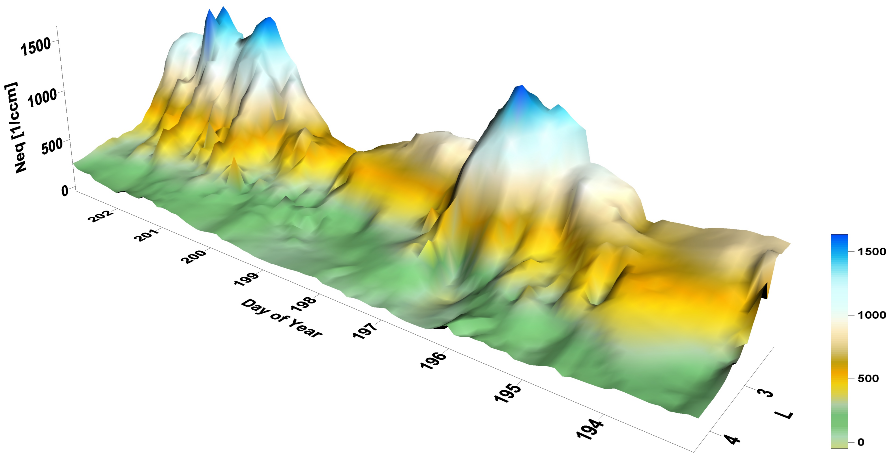
  - occasional, 1 in 10000 runs, continues smoothly

  - long-term: freezes for hours, days, software/hardware(!) reset no remedy, firmware update is risky

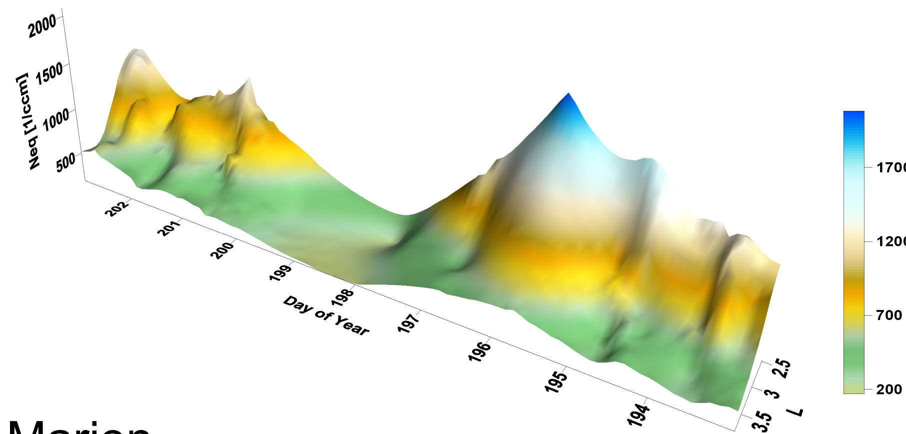
  → turn off “bad” cores

- Additional redundancy: if a GPU host goes down, the others are not affected

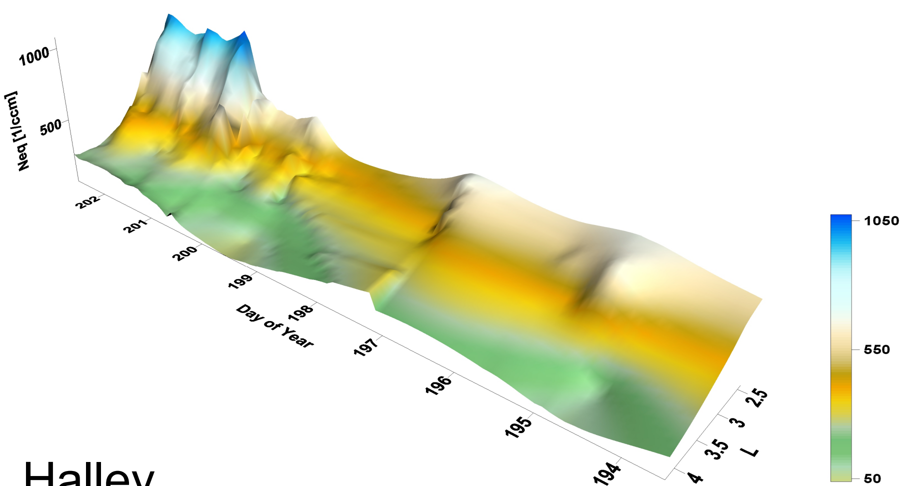
12-21 July 2012



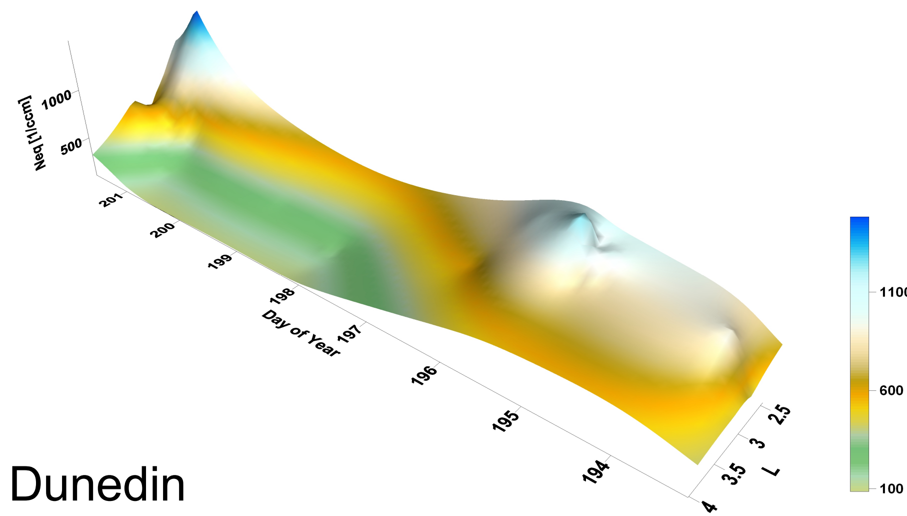
Rothera



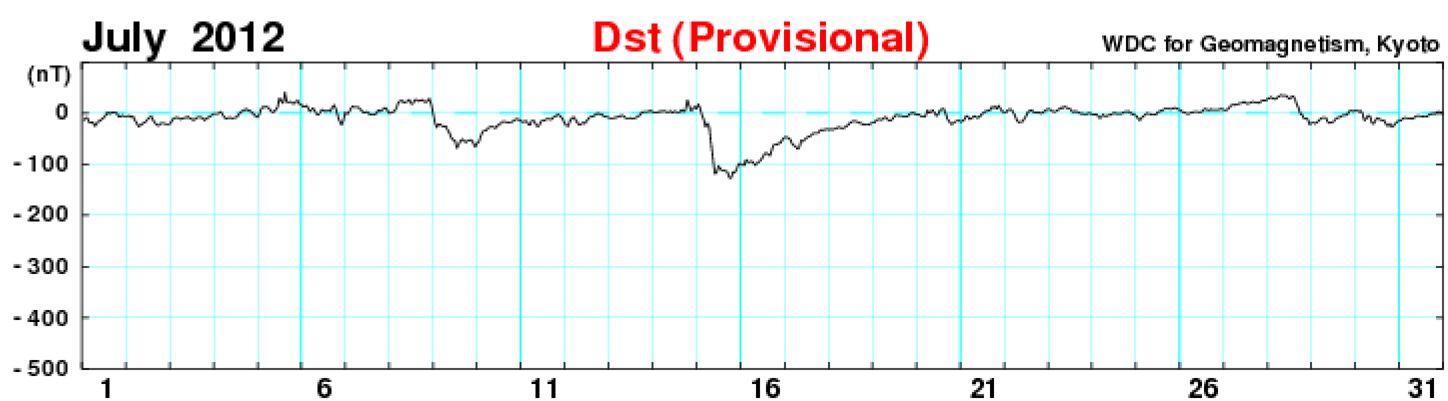
Marion



Halley



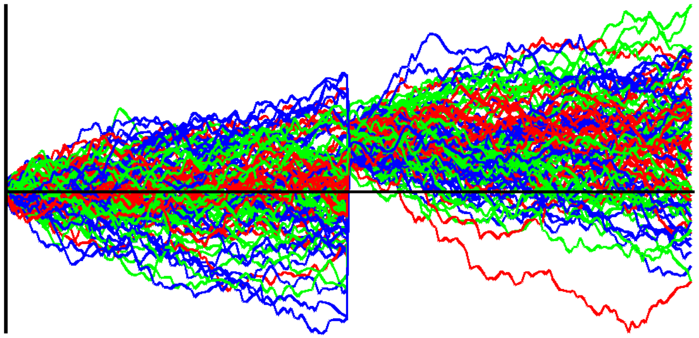
Dunedin



Data Assimilation

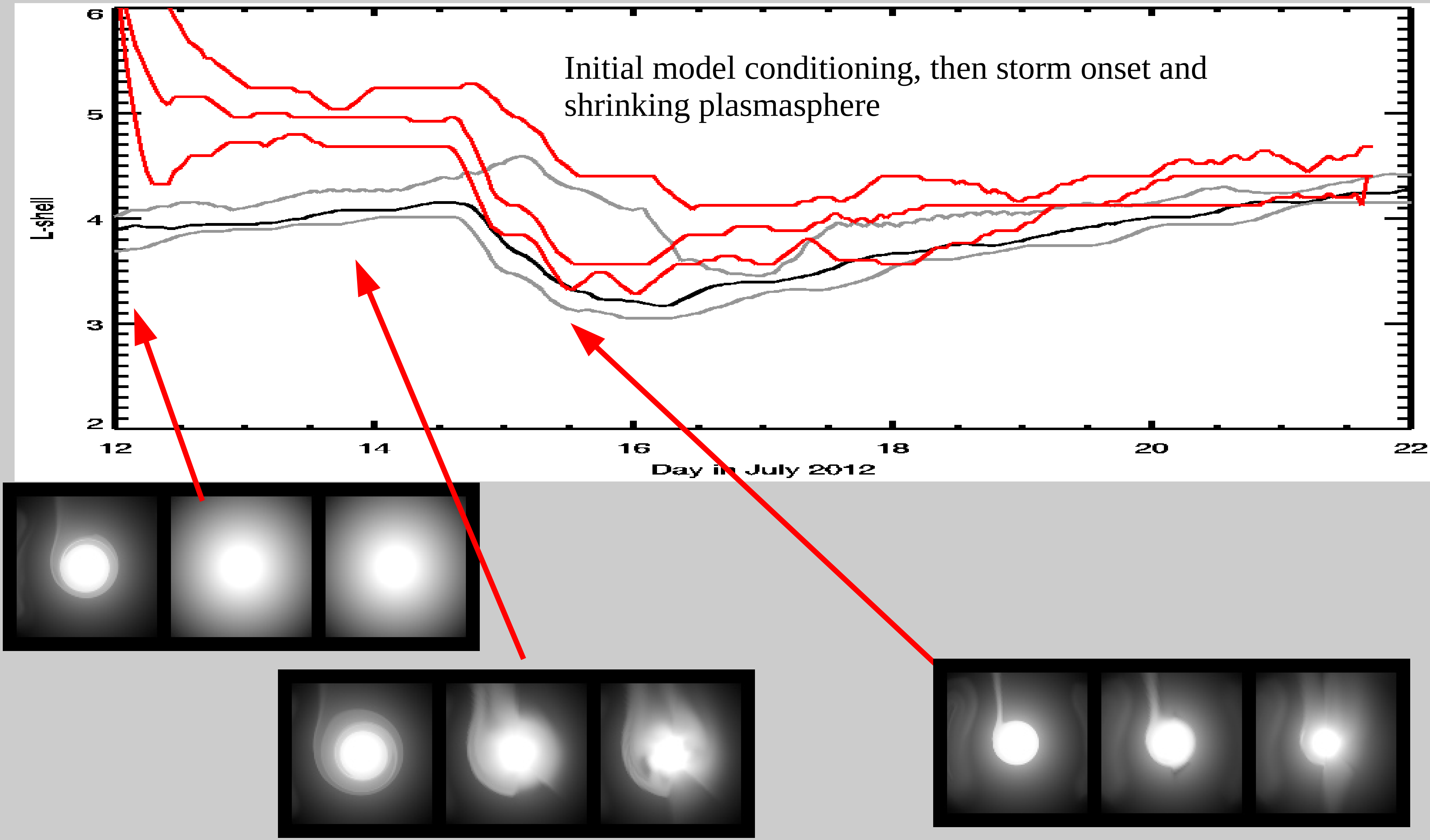
(A. Jorgensen)

- Data assimilation is expressed in Bayesian way: a sprobability distribution evolves through time, determined by
  - (1) The range of possible evolution, taking into account the probability distribution of unknown physics and drivers which are not measured.
  - (2) Measurements which partially constrain the model and thus eliminate some possible evolutionary paths

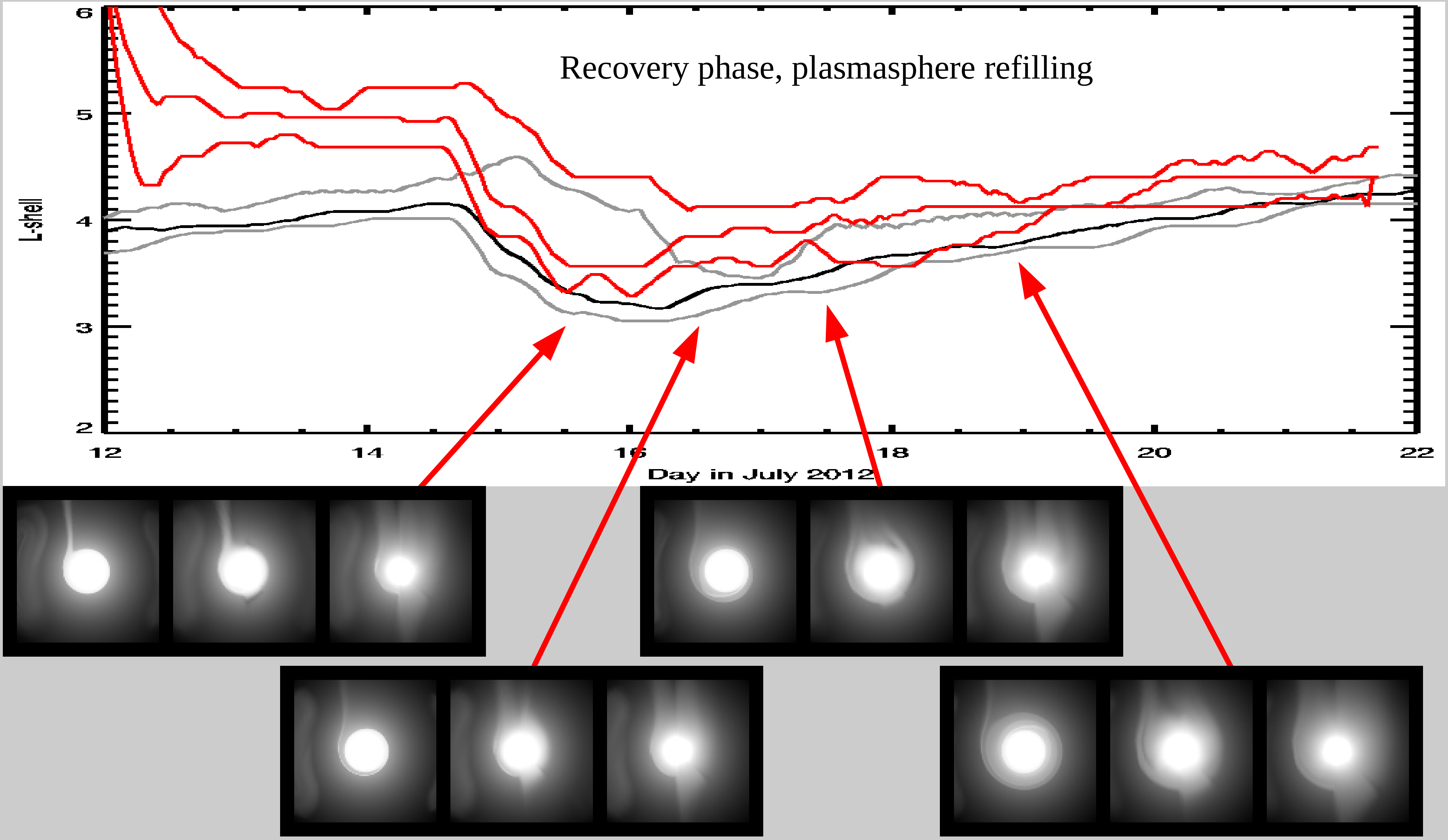


- Example:
  - A plasmasphere model might implement quiet and storm time behavior, and without other knowledge (e.g. solar wind or observations in the plasmasphere) all scenarios are included in the probability distribution
- Useful data assimilation narrows the probability distribution.

Event Study
15 July 2012 – Plasma density maps



Event Study
15 July 2012 – Plasma density maps



The research leading to these results has received funding from the European Union's Seventh Framework Programme ([FP7/2007-2013]) under grant agreement 263218.