EISCAT Data Collections

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PITHIA-NRF Second Training School
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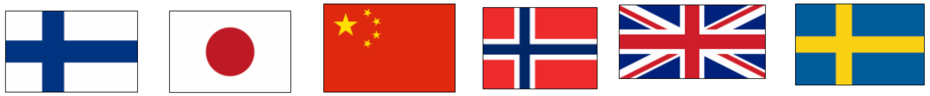
EISCAT in the PITHIA e-Science Centre

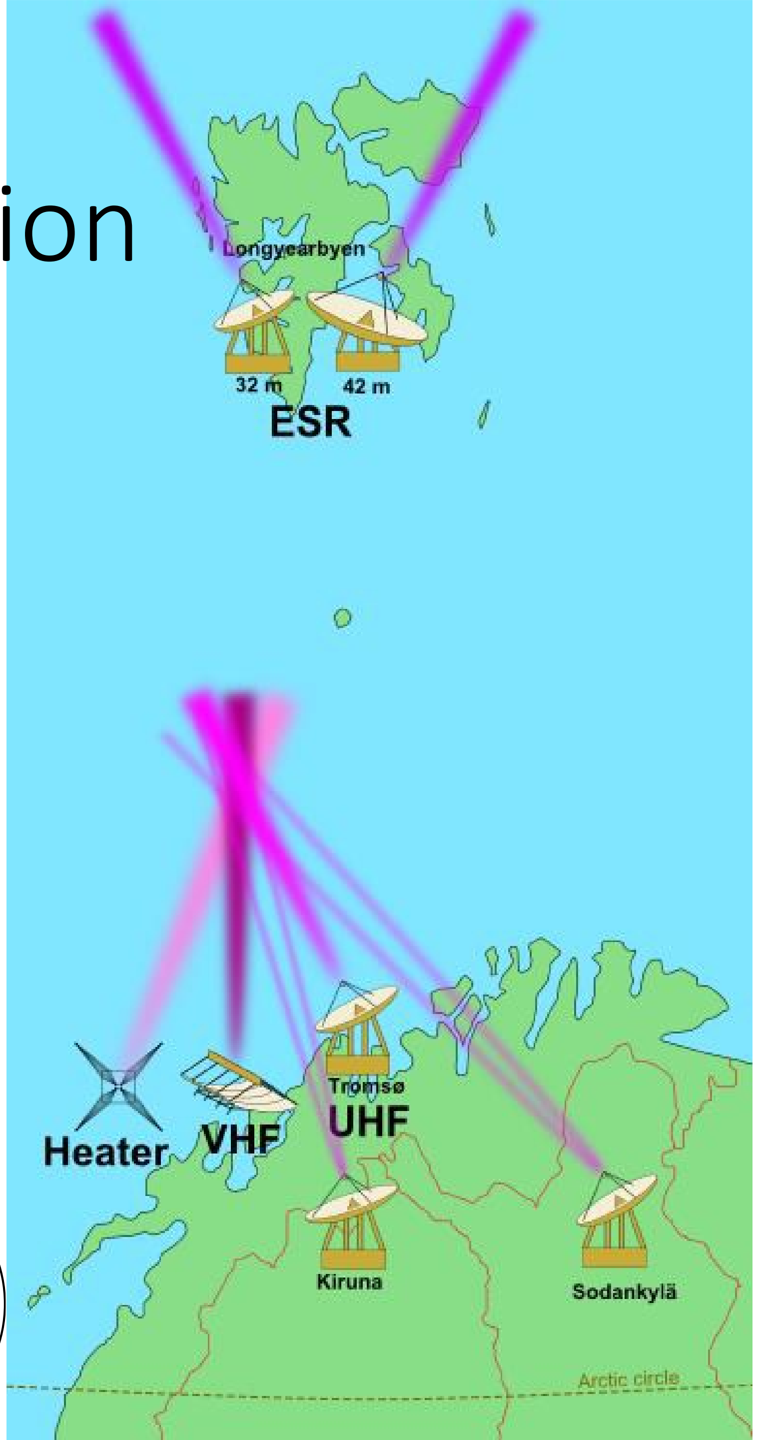
- A search for EISCAT gives seven results:
  - EISCAT Svalbard Dynasonde analysed data
  - EISCAT Svalbard Radar Data in the Madrigal Database
  - EISCAT Tromsø Dynasonde analysed data
  - EISCAT UHF Radar Data in the Madrigal Database
  - EISCAT UHF Radar Vector Data in the Madrigal Database
  - EISCAT VHF Radar Data in the Madrigal Database
  - EISCAT VHF Radar Vector Data in the Madrigal Database

- What is this?

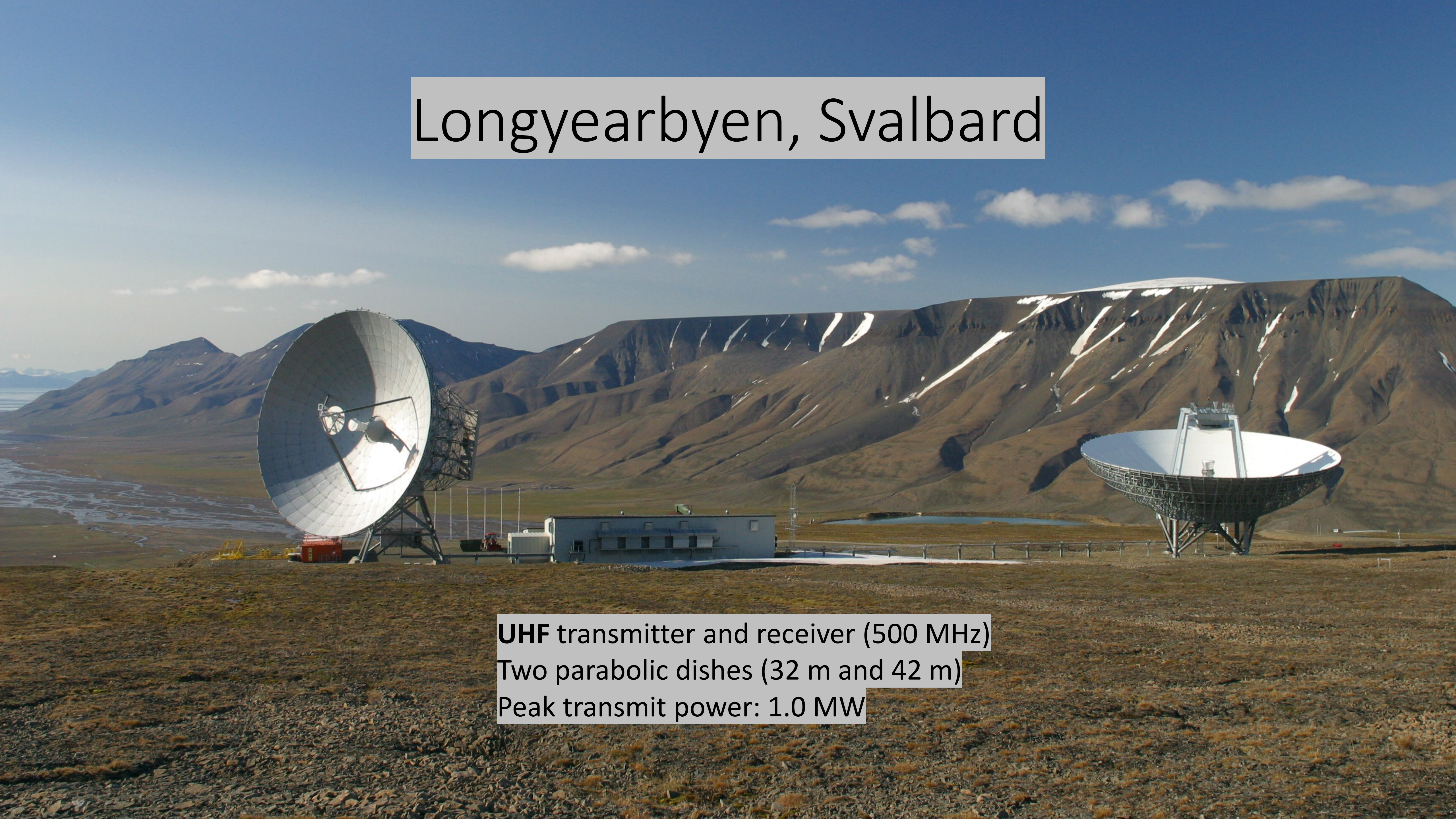
EISCAT Scientific Association

- **EISCAT** is short for **European Incoherent Scatter**
- EISCAT is an **international organisation** performing **fundamental research** in solar-terrestrial and atmospheric physics using **radar systems**.
- EISCAT was founded as an organisation in 1976. The first EISCAT radars started operations in 1981.
- The **EISCAT members** are **research organisations** in Finland, Japan, China, Norway, UK and Sweden. They finance EISCAT through annual fees.

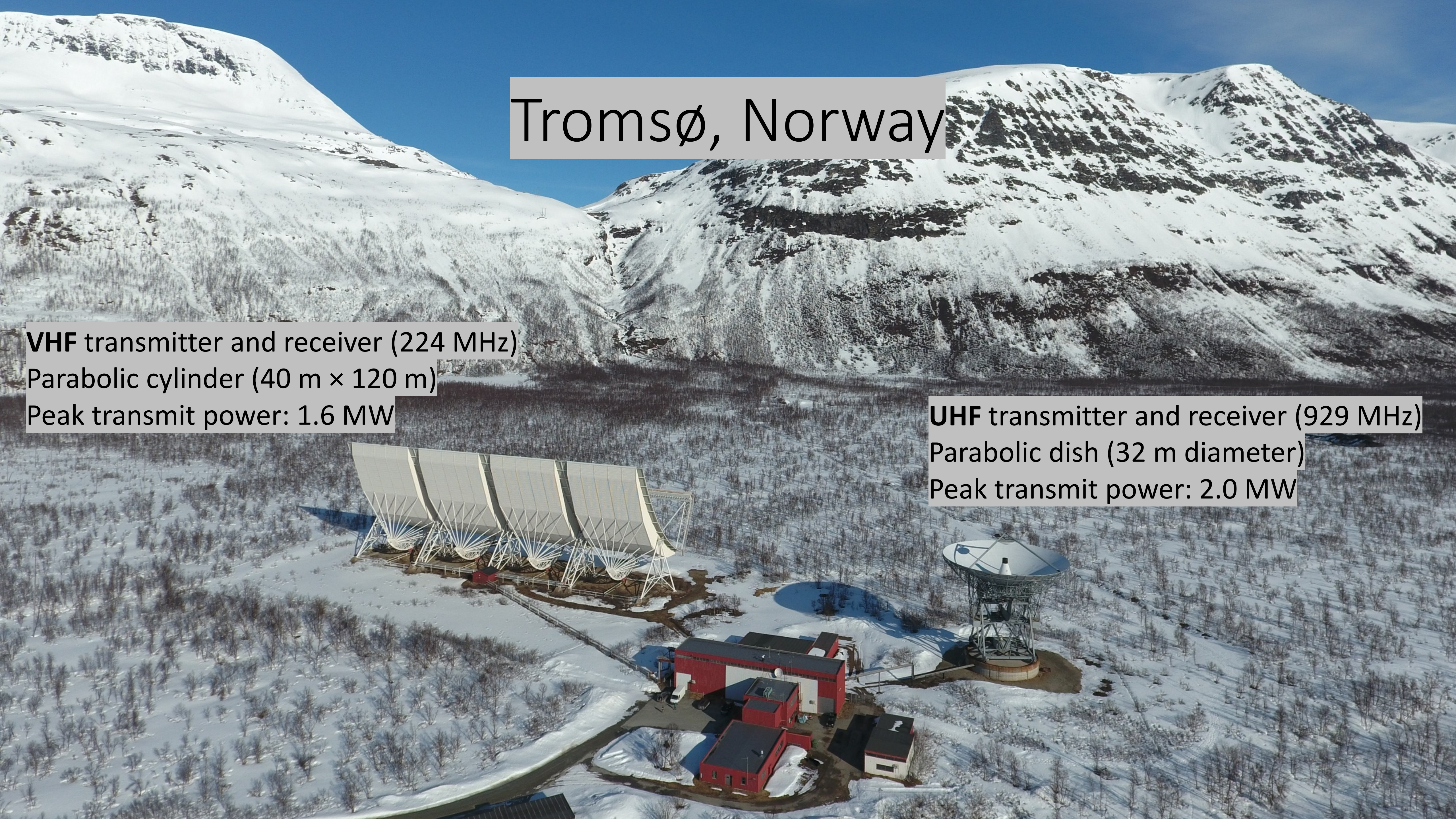


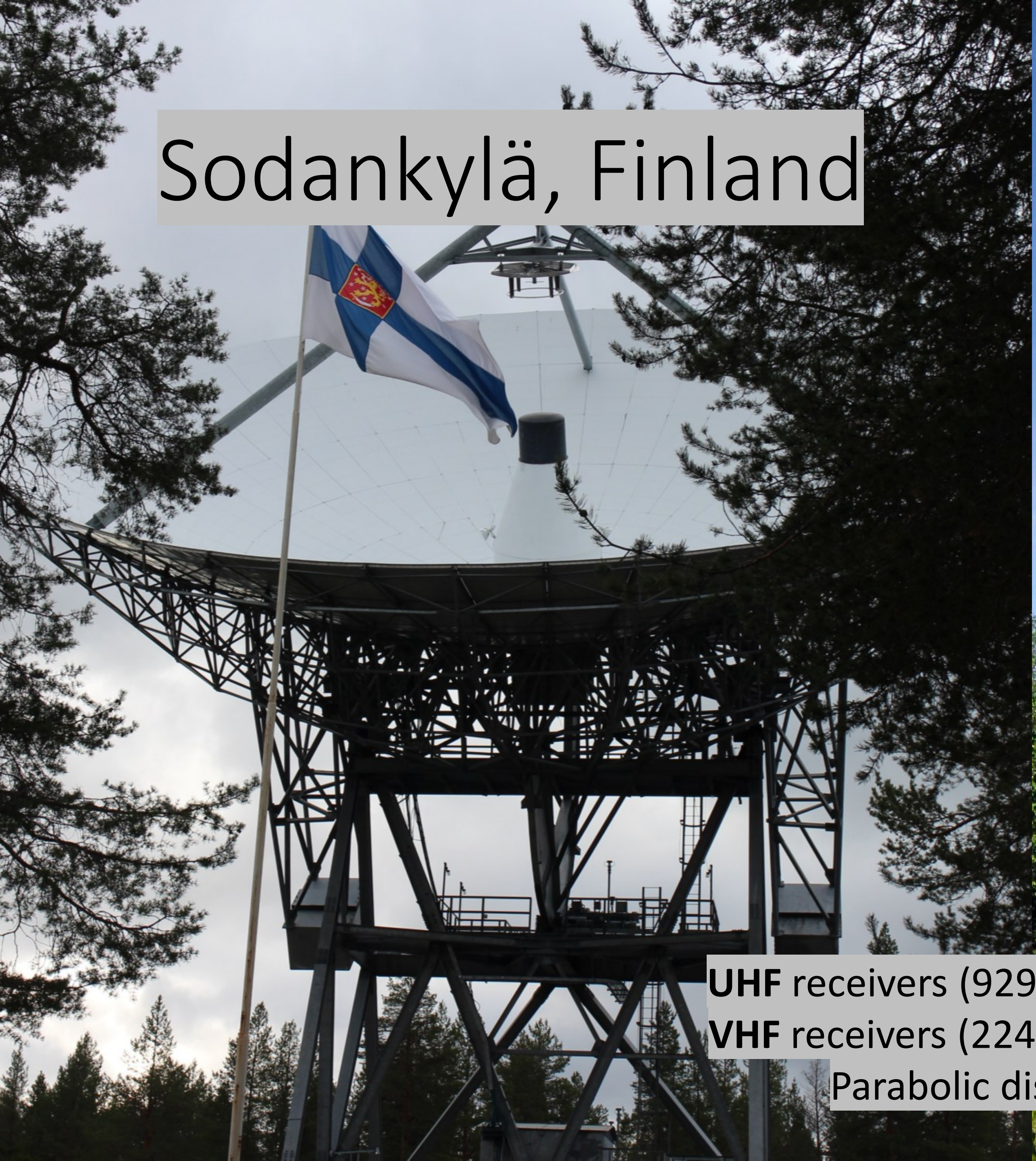


Longyearbyen, Svalbard



UHF transmitter and receiver (500 MHz)
Two parabolic dishes (32 m and 42 m)
Peak transmit power: 1.0 MW

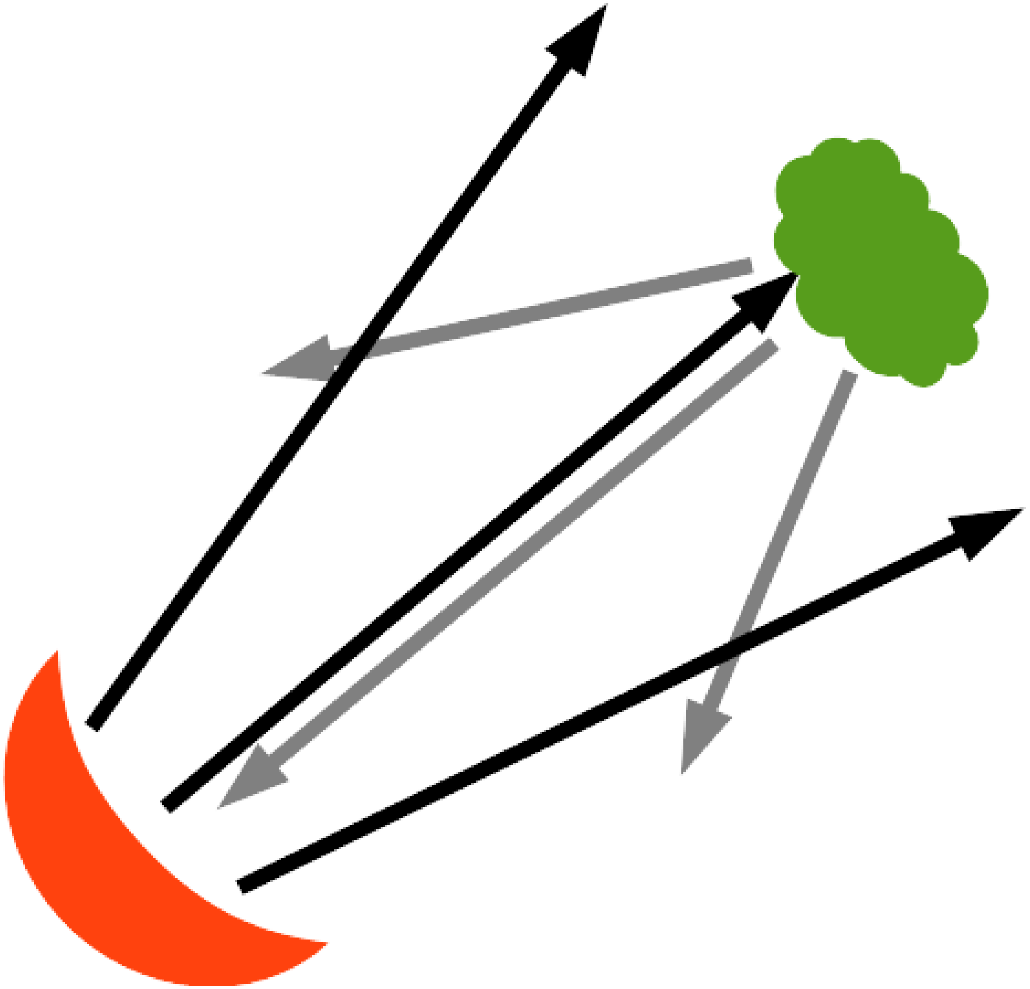

Tromsø, Norway
VHF transmitter and receiver (224 MHz)
Parabolic cylinder (40 m × 120 m)
Peak transmit power: 1.6 MW
UHF transmitter and receiver (929 MHz)
Parabolic dish (32 m diameter)
Peak transmit power: 2.0 MW



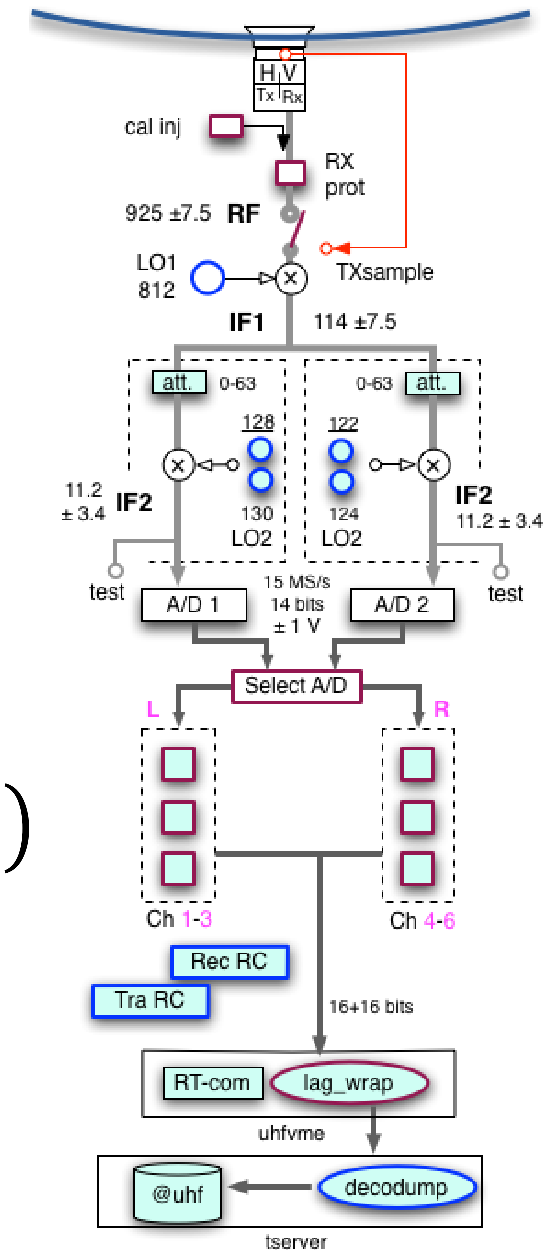
UHF receivers (929 MHz), 1981–2011
VHF receivers (224 MHz), 2011–2022
Parabolic dishes (32 m)

What is a radar?

- RADAR: Radio Detection and Ranging
  - Transmit a radio signal towards what you want to study
  - Analyse the radio signal coming back



EISCAT UHF

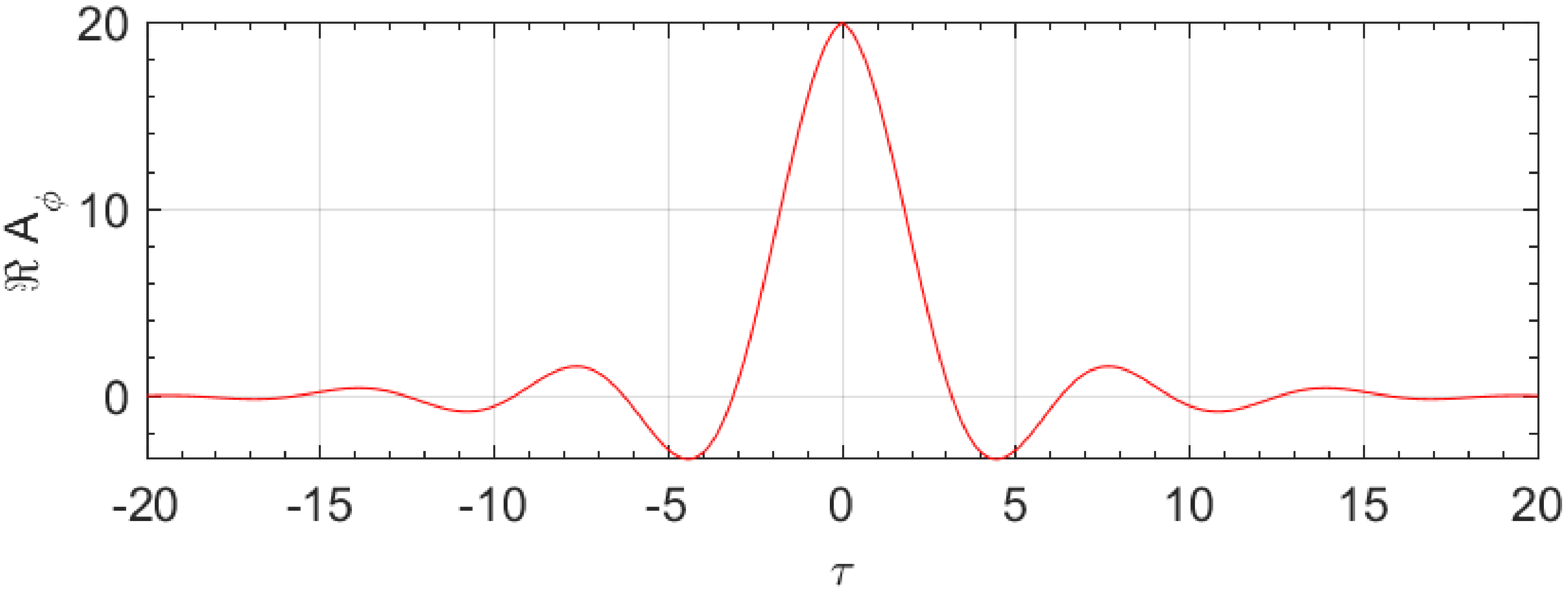


Data from an EISCAT receiver

- The analog signal is down-converted in two steps
- It is then digitised using I/Q samples (complex values)
- Digital signal is down-converted into base-band

- The signal received after pulse k: $\varphi_k(t_i)$
- Auto-correlation of the signal: $A_\varphi(t_i, t_j) = \langle \varphi_k(t_i)\varphi_k^*(t_j) \rangle$
- Another notation: $A_{\varphi,t}(\tau) = \langle \varphi_k(t)\varphi_k^*(t-\tau) \rangle_k$
  - This type of data is stored by EISCAT (level 2)
- Frequency spectrum: $S_{\varphi,t}(f) = \boldsymbol{F}[A_{\varphi,t}(\tau)]$

Coherence time



- The coherence time is the τ corresponding to the first zero crossing by the auto-correlation function.

Coherent / incoherent scatter

- **Coherent scatter**: The coherence time is much longer than the time between radar pulses.
- **Incoherent scatter**: The coherence time is much shorter than the time between radar pulses.

- Lower atmosphere: The coherence time is determined by turbulent fluctuations → >> 5 ms
- Ionosphere: The coherence time is determined by thermal fluctuations → << 5 ms

Coherent / incoherent scatter method

- Radar measurements require summing over several pulses to minimise variance
- Coherent scatter measurements:
  - First sum the signal from many pulses, then do auto-correlation of the result
- Incoherent scatter measurements:
  - Phase information lost between the pulses, but statistical information retained
  - First do auto-correlation for each pulse, then sum the results

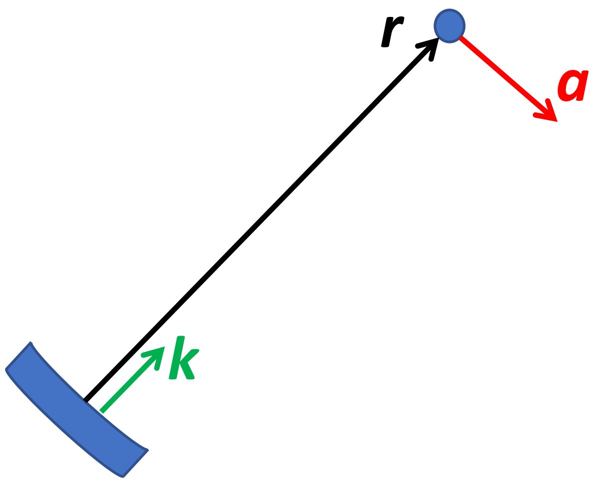
Illuminating a free electron

- Electric field transmitted from the radar transmitter (at the origin):

$$\boldsymbol{E}(\boldsymbol{r},t)=\frac{\boldsymbol{E}_0}{|\boldsymbol{r}|}e^{i(\boldsymbol{k}\cdot\boldsymbol{r}-\omega t)}$$

- The electron (at $\boldsymbol{r}$) is accelerated due to the electric field:

$$\boldsymbol{a}(t)=\frac{\boldsymbol{F}(t)}{m_e}=-\frac{e\boldsymbol{E}(\boldsymbol{r},t)}{m_e}$$



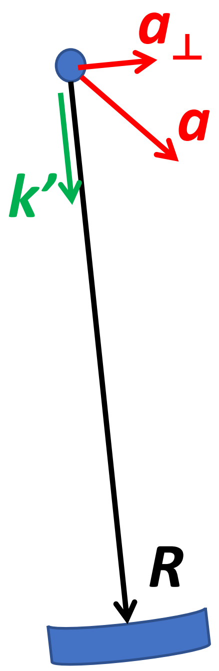
Radiation from an accelerated electron

- Expression for the electric field seen by an observer:

$$\boldsymbol{E}_r(\boldsymbol{R}, t) = \frac{e}{4\pi\epsilon_0 c^2|\boldsymbol{R}|}\boldsymbol{a}_\perp(t - |\boldsymbol{R}|/c)$$

where

$$\boldsymbol{a}_\perp(t) = \boldsymbol{a}(t) - \frac{\boldsymbol{k}' \cdot \boldsymbol{a}(t)}{|\boldsymbol{k}'|^2}\boldsymbol{k}'$$



Thomson scattering

- Elastic scattering of electromagnetic radiation
- Non-relativistic (for electrons: less energetic than X-ray)

- The Thomson scattering cross-section can be calculated:

$$\sigma_t = \frac{8\pi}{3}\left(\frac{e^2}{4\pi\epsilon_0 m_e c^2}\right)^2 = 6.65\times10^{-29}\ \mathrm{m}^2$$

- This small cross-section is the main reason the Incoherent Scatter Radar systems have to be so large (sensitive) and powerful.

"Naïve" incoherent scatter spectrum

- Use Thomson cross-section to determine electron density, from the total received signal power.
- Use doppler spread of the spectrum to determine electron temperature:
  - Assuming Maxwellian velocity distribution of the electrons
$$F(v) \propto e^{-\frac{m_e v^2}{2k_B T}}$$
  - we expect a Maxwellian spread in the spectrum, with a width corresponding to the thermal velocity $v_\theta = \sqrt{k_B T/m_e}$
- This width is $\frac{\Delta f}{f_t} \approx \frac{2v_\theta}{c}$, or about 0.3 MHz for 2000 K electrons measured by EISCAT VHF

First incoherent scatter radar system

- Arecibo, Puerto Rico
  - In operation 1963 – 2020
  - 305 m in diameter

- The spectrum did not look as the naïve approach predicted
  - Significantly narrower main feature
  - Significantly higher spectral peak

What are the electrons really doing?

- We need to consider the ionosphere a plasma, not a gas
- **Collective effects!**

Thermal fluctuations in a plasma

- Electrostatic fluctuations of the electric field in an isotropic 3D collisionless plasma:

$$S(\boldsymbol{k},\omega) = \sum_{\alpha} \frac{\pi n_\alpha q_\alpha^2}{\epsilon_0} \frac{F_\alpha^{(0)}(\omega/|\boldsymbol{k}|)}{|\boldsymbol{k}|^3 |\epsilon(\boldsymbol{k},\omega)|^2}$$

- $F_\alpha^{(0)}(u)$ is the one-dimensional projection of the distribution function on an axis parallel to $\boldsymbol{k}$.
- $\epsilon(\boldsymbol{k},\omega)$ is the **plasma dielectric function**:

$$\epsilon(\boldsymbol{k},\omega) = 1 + \sum_{\alpha} \frac{\omega_{p\alpha}^2}{|\boldsymbol{k}|^2} \int_{\boldsymbol{v}} \frac{\boldsymbol{k} \cdot \frac{\partial f_\alpha^{(0)}(\boldsymbol{v})}{\partial \boldsymbol{v}}}{\omega - \boldsymbol{k}\cdot\boldsymbol{v}} d^3\boldsymbol{v}$$

Plasma dielectric function

- Dispersion relation for electrostatic waves in unmagnetized plasma

$$\epsilon(\boldsymbol{k}, \omega) = 0$$

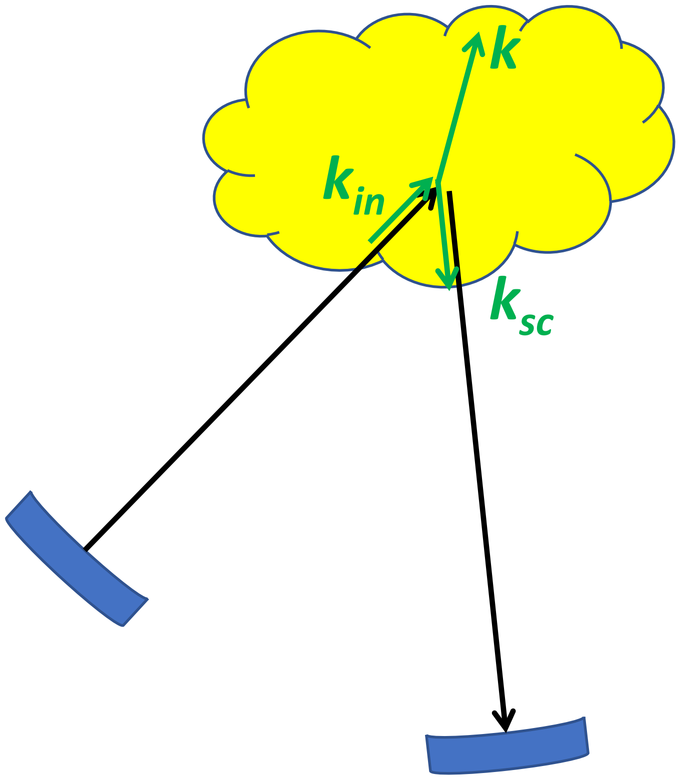
- **Peak in fluctuation spectrum near inherent wave modes!**
- Electron density follows the electric field fluctuations when the waves are electrostatic

Incoherent scattering from a volume

- The radar illuminates a volume, different parts experience different phases of the incoming radio signal
- We have constructive interference when the Bragg condition is satisfied for density enhancements (wave fronts) in the plasma ($\boldsymbol{k}$):

$$\boldsymbol{k} = \boldsymbol{k}_{in} - \boldsymbol{k}_{sc}$$

- Hence, fluctuations of a specific wavelength propagating in a specific directions are picked up by the radar system



Inherent wave modes

- The dominating electrostatic inherent wave modes in a plasma:
  - Ion-acoustic waves

$$\omega = \pm v_{ia}|\boldsymbol{k}|$$

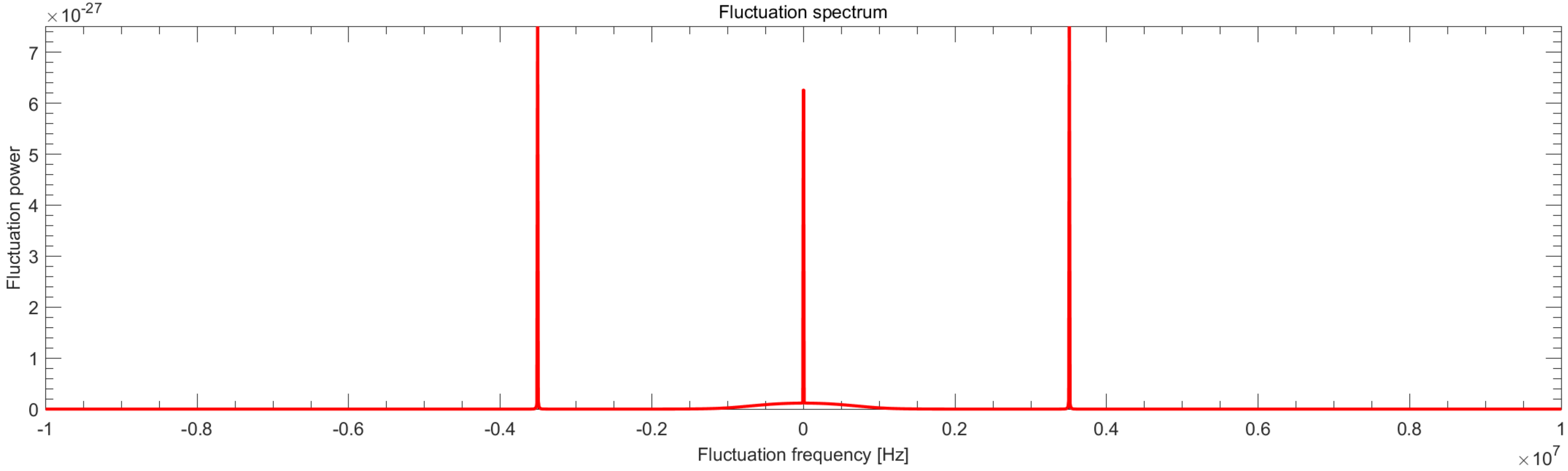
    - v_{ia} is the ion-acoustic speed, essentially the speed of sound
  - Langmuir waves (plasma waves)

$$\omega^2 = \omega_{pe}^2 + \frac{3v_\theta^2}{2}|\boldsymbol{k}|^2$$

    - ω_{pe} is the electron plasma frequency, v_θ is the electron thermal speed
- Spectral peaks expected at these frequencies
  - “ion line”, “plasma line”

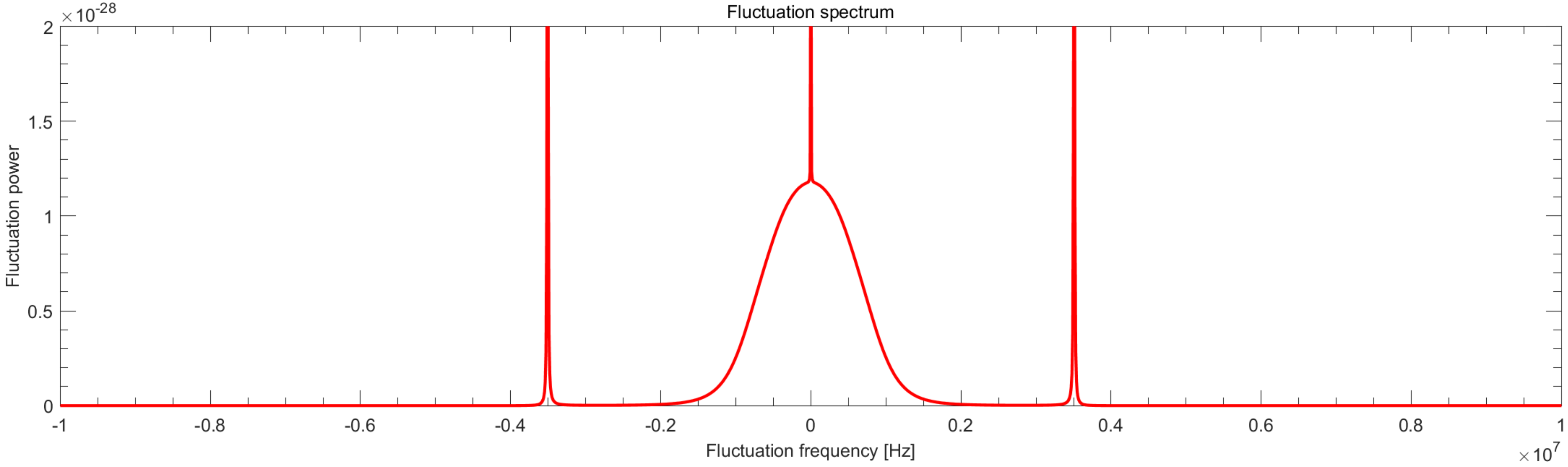
Incoherent scatter spectrum

- Example spectrum for n_e=1.5×10^{11} m^{-3}, T_e=2000 K, T_i=1000 K, O^+ ions, EISCAT VHF frequency.



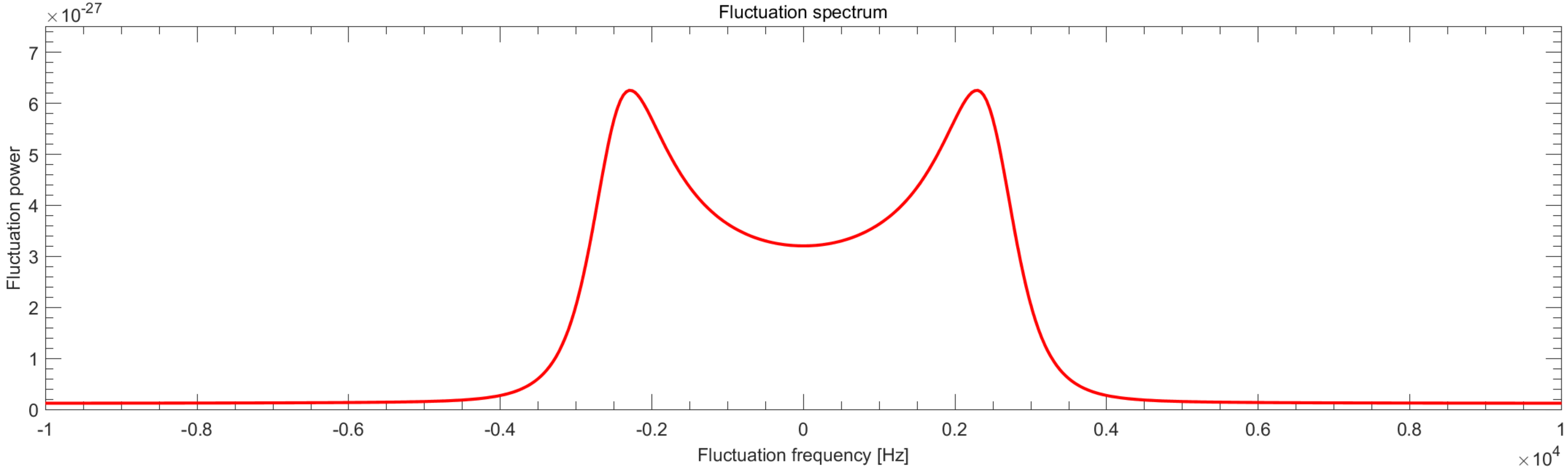
Incoherent scatter spectrum

- The continuum spectrum, corresponding to the naïve approach, is visible



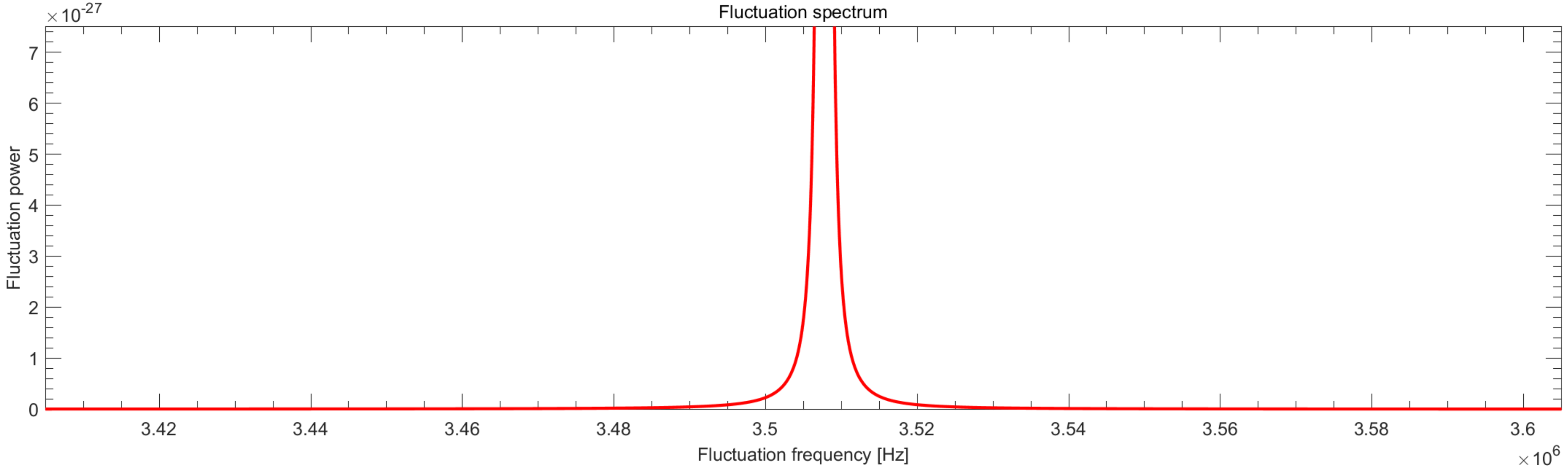
Incoherent scatter spectrum

- “Ion line” is 50 times stronger, and 300 times narrower



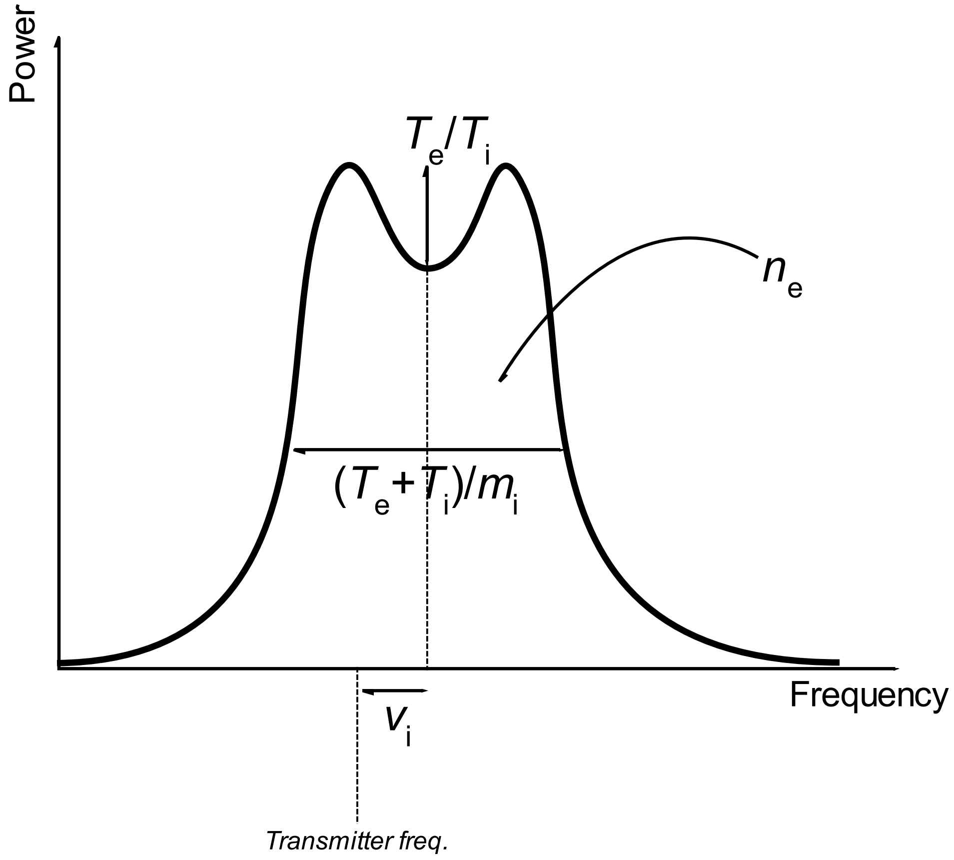
Incoherent scatter spectrum

- “Plasma line” is very strong, but its frequency is very dependent on electron density



The ion line

- The ion line is used to extract useful information about the plasma!
  - The ratio between the electron and ion temperatures (T_e/T_i) from the “peak-to-valley” relation
  - The ratio between the temperatures and the ion mass ($(T_e + T_i)/m_i$) from the width of the spectrum
  - The electron density (n_e) from the total area under the spectrum
  - The ion velocity (plasma flow) (v_i) from the frequency shift



EISCAT data

- This is how EISCAT data is usually presented
- Range dependence of plasma parameters
- These data are stored (level 3 data)

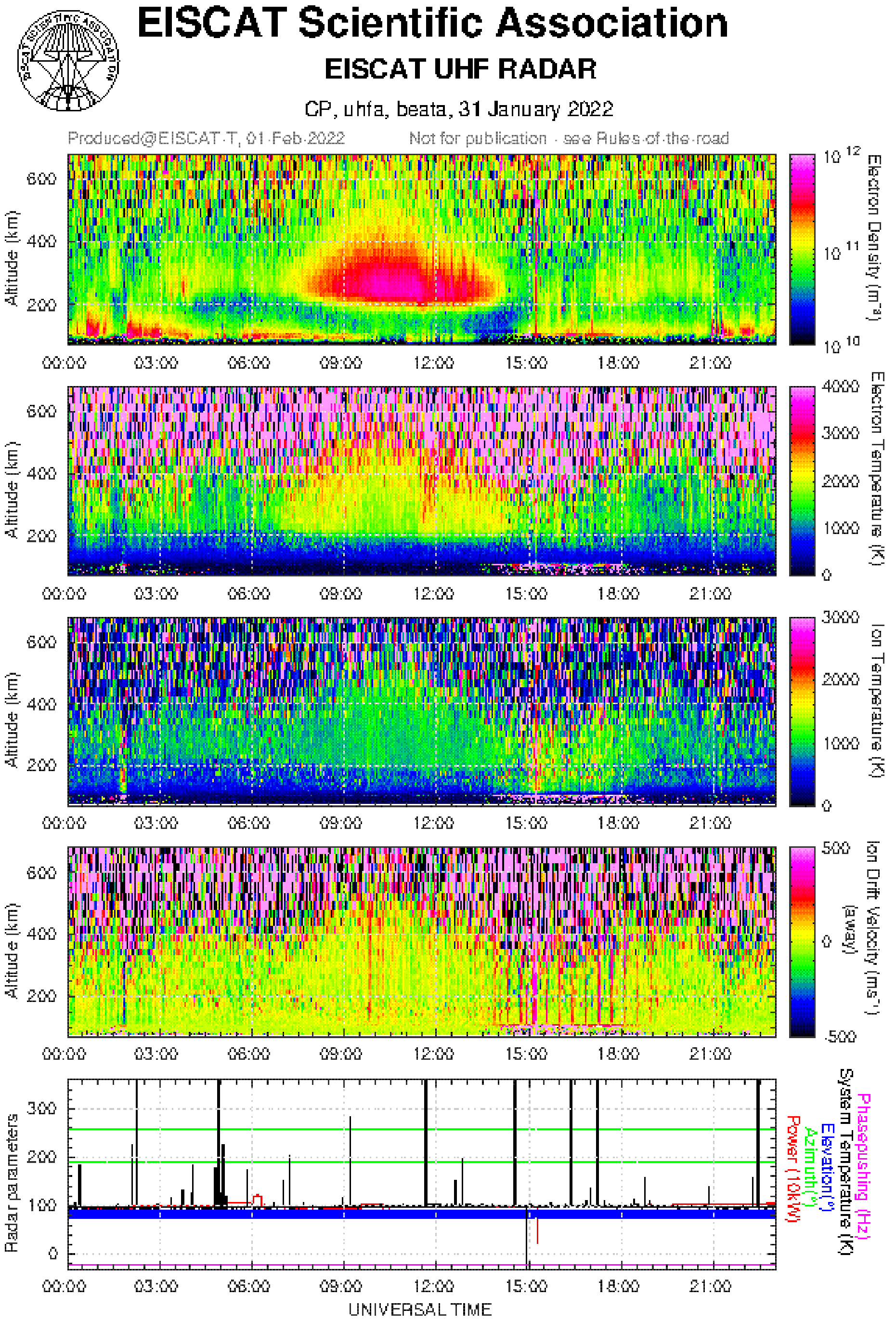
Electron **density**

Electron **temperature**

Ion **temperature**

Ion **drift velocity** (line-of-sight)

(Radar system parameters)



Things to note

- Having receivers in three separate geographical locations makes it possible to measure **full vector velocity** of the plasma drift

- Temperatures and velocities are determined from spectral shape and doppler shift. The electron density may require extra **calibration** efforts.
    - For example due to different antenna gain than expected (often wet snow)
- For calibration purposes EISCAT, has also been operating **Dynasondes**

EISCAT in the PITHIA e-Science Centre

- Back to the list of EISCAT data from the beginning:
  - EISCAT Svalbard Dynasonde analysed data
  - EISCAT Svalbard Radar Data in the Madrigal Database
  - EISCAT Tromsø Dynasonde analysed data
  - EISCAT UHF Radar Data in the Madrigal Database
  - EISCAT UHF Radar Vector Data in the Madrigal Database
  - EISCAT VHF Radar Data in the Madrigal Database
  - EISCAT VHF Radar Vector Data in the Madrigal Database

EISCAT radar data

EISCAT Svalbard/UHF/VHF Radar Data in the Madrigal Database

EISCAT UHF/VHF Radar Vector Data in the Madrigal Database

- Access to the standard set of ionospheric data is from Madrigal

  https://madrigal.eiscat.se

- The link in the e-science centre takes you to directly to a list containing all available EISCAT level 3 data obtained by the chosen radar system
  - You may at some point need to enter name, email and affiliation before you can download the data

Madrigal interface

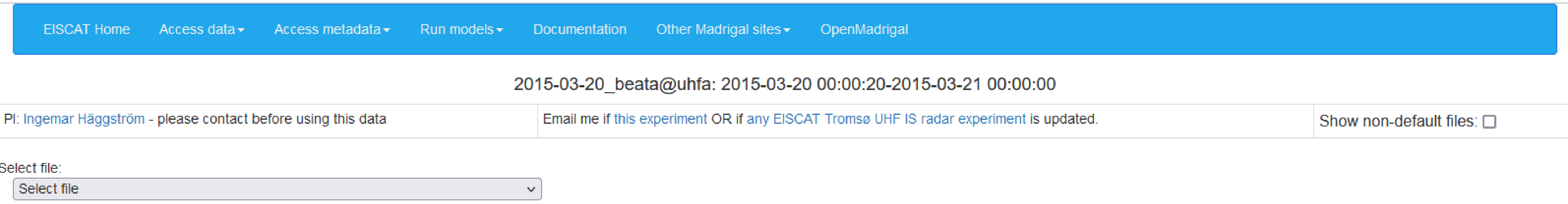
EISCAT Home | Access data ▾ | Access metadata ▾ | Run models ▾ | Documentation | Other Madrigal sites ▾ | OpenMadrigal

List of selected Madrigal experiments

Instrument name	Start	End	Experiment name
EISCAT Tromsø UHF IS radar	1984-01-17 10:00:50	1984-01-17 23:55:00	1984-01-17_cp3c@uhf
EISCAT Tromsø UHF IS radar	1984-01-19 00:01:50	1984-01-19 23:57:30	1984-01-19_cp3c@uhf
EISCAT Tromsø UHF IS radar	1984-01-18 00:00:00	1984-01-19 00:01:40	1984-01-18_cp3c@uhf
EISCAT Tromsø UHF IS radar	1984-02-07 10:00:30	1984-02-08 00:01:40	1984-02-07_cp3c@uhf
EISCAT Tromsø UHF IS radar	1984-02-08 00:01:50	1984-02-08 23:57:30	1984-02-08_cp3c@uhf
EISCAT Tromsø UHF IS radar	1984-06-12 10:03:50	1984-06-13 00:01:40	1984-06-12_cp3c@uhf
EISCAT Tromsø UHF IS radar	1984-06-13 00:01:50	1984-06-13 07:57:30	1984-06-13_cp3c@uhf
EISCAT Tromsø UHF IS radar	1984-06-26 07:00:35	1984-06-27 00:16:05	1984-06-26_cp3c@uhf

- From this list you can click on the experiment you are interested in

Madrigal interface



- Here you need to select the data file from a list
- The files with a name beginning with MAD6400 are the ones containing the electron densities, the temperatures and the ion drifts.

Madrigal interface

- In “Supplement files” you find a list of pre-made plots, and other useful files.
- In “Download file” you can download the data.
  - The available data formats are Hdf5, netCDF4 and ASCII.
  - There are also possibilities to select which parameters to include, and to filter the data before downloading.
- In “Print File” you can display the content of the data file on your screen
- “View file info” and “Cite this file” give useful metadata about the data

Madrigal interface

EISCAT Home | Access data ▾ | Access metadata ▾ | Run models ▾ | Documentation | Other Madrigal sites ▾ | OpenMadrigal

2015-03-20_beata@uhfa: 2015-03-20 00:00:20-2015-03-21 00:00:00

PI: Ingemar Häggström - please contact before using this data

Email me if this experiment OR if any EISCAT Tromsø UHF IS radar experiment is updated.

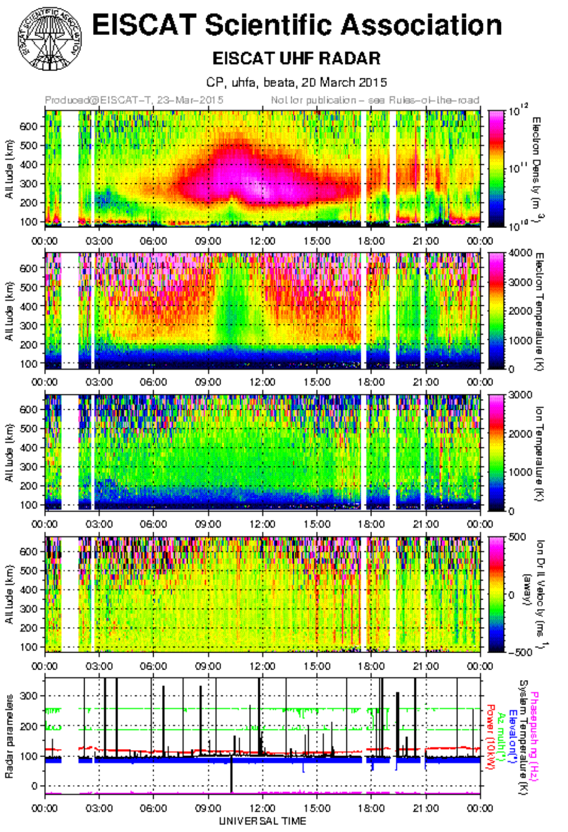
Show non-default files: ☐

Select file:

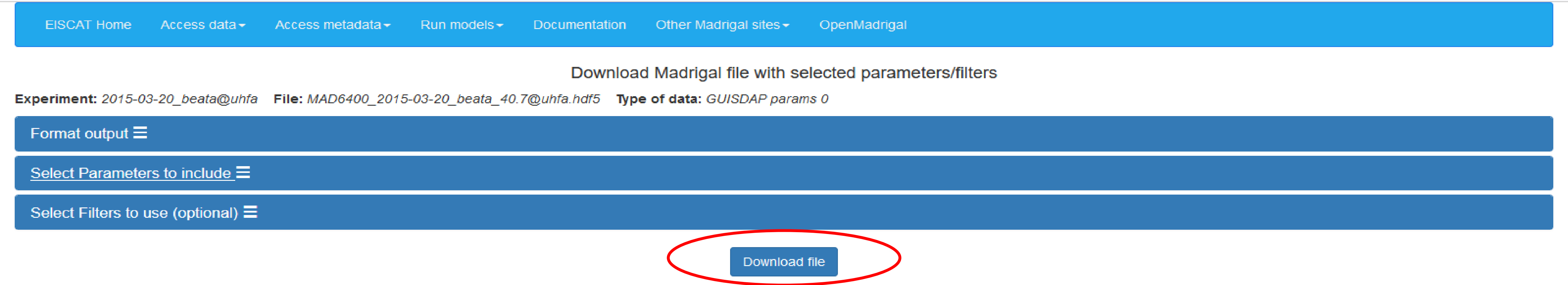
MAD6400_2015-03-20_beata_40.7@uhfa.hdf5: GUISDAP params 0 - Final

Supplement files | Download file ▾ | Print File | View file info | Cite this file

- EISCAT_2015-03-20_beata_40.7@uhfa.hdf5
- 2015-03-20_beata_Nr_uhfa.png
- 2015-03-20_beata_calib-foE_uhfa.png
- 2015-03-20_beata2_0_T_plasmaline.png
- 2015-03-20_beata_uhfa.png
- 2015-03-20_beata_calib-plne_uhfa.png
- 2015-03-20_beata_calib-foF2_uhfa.png
- 2015-03-20_beata_eclipse_uhfa.png
- notes.txt



Madrigal interface



Madrigal interface

EISCAT Home | Access data | Access metadata | Run models | Documentation | Other Madrigal sites | OpenMadrigal

Download Madrigal file with selected parameters/filters

Experiment: *2015-03-20_beata@uhfa* **File:** *MAD6400_2015-03-20_beata_40.7@uhfa.hdf5* **Type of data:** *GUISDAP params 0*

Format output ☰

Select Parameters to include ☰

Select all parms in original file | Unselect all parms in original file

Blue parameters are from the original file | Grey parameters are derivable from those in the original file

The following parameters are automatically included in the Madrigal Hdf5 format:

	YEAR	MONTH	DAY	HOUR	MIN	SEC
	UT1_UNIX	UT2_UNIX	RECNO	KINST	KINDAT	
Time Related Parameter						
	BMONTH	BDAY	MD	DAYNO	BHM	BHHMMSS
	EHHMMSS	FYEAR	UTH	SLT	SLTC	MLT
	B_UTH	SUNRISE_HOUR	SUNSET_HOUR	CONJ_SUNRISE_H	CONJ_SUNSET_H	UT
	BEG_UT	APLT	JULIAN_DATE	UT1	UT2	DUT21
Geographic Coordinate						
	GDALT	RANGE	AZM	ELM	GDLAT	GLON
	SZEN	SZENC	SDWHT	HSA		
Magnetic Coordinate						
	MAGCONJLAT	MAGCONJLON	MAGCONJSDWHT	TSYG_EQ_XGSM	TSYG_EQ_YGSM	TSYG_EQ_XGSE
	TSYG_EQ_YGSE	E_REG_S_LAT	E_REG_S_LON	E_REG_S_SDWHT	E_REG_N_LAT	E_REG_N_LON

EISCAT dynasonde data

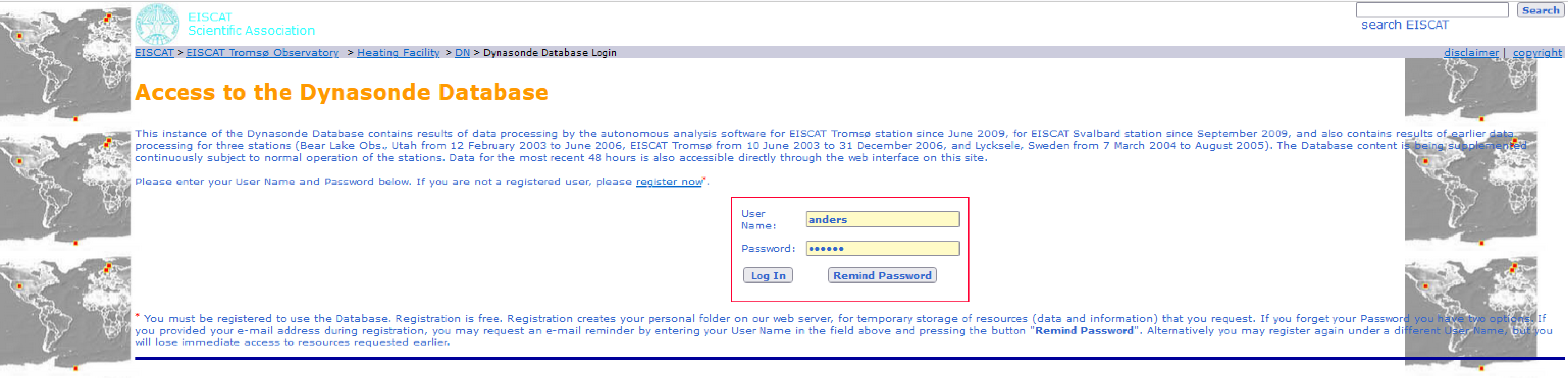
EISCAT Svalbard/Tromsø Dynasonde analysed data

- Access to the dynasonde data is through an EISCAT portal

  https://dynserv.eiscat.uit.no

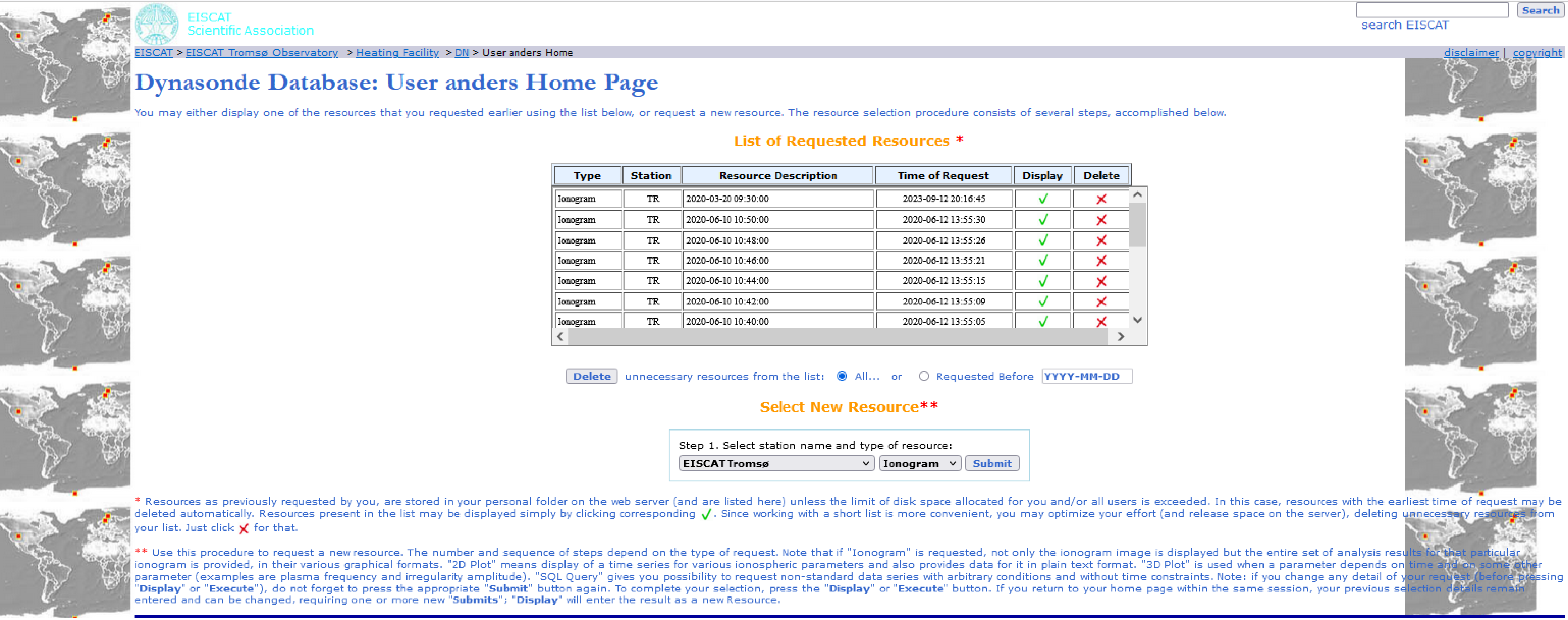
- The link in the e-science centre takes you to a login page.

Dynasonde interface



- You need to be registered as a user to enter
  - This is an immediate process
  - DO NOT USE A USERNAME-PASSWORD-EMAIL COMBO YOU USE ELSEWHERE
    - The user data are stored unencrypted(!)

Dynasonde interface



EISCAT
Scientific Association

search EISCAT | Search

EISCAT > EISCAT Tromsø Observatory > Heating Facility > DN > User anders Home | disclaimer | copyright

Dynasonde Database: User anders Home Page

You may either display one of the resources that you requested earlier using the list below, or request a new resource. The resource selection procedure consists of several steps, accomplished below.

List of Requested Resources *

Type	Station	Resource Description	Time of Request	Display	Delete
Ionogram	TR	2020-03-20 09:30:00	2023-09-12 20:16:45	✓	✗
Ionogram	TR	2020-06-10 10:50:00	2020-06-12 13:55:30	✓	✗
Ionogram	TR	2020-06-10 10:48:00	2020-06-12 13:55:26	✓	✗
Ionogram	TR	2020-06-10 10:46:00	2020-06-12 13:55:21	✓	✗
Ionogram	TR	2020-06-10 10:44:00	2020-06-12 13:55:15	✓	✗
Ionogram	TR	2020-06-10 10:42:00	2020-06-12 13:55:09	✓	✗
Ionogram	TR	2020-06-10 10:40:00	2020-06-12 13:55:05	✓	✗

Delete unnecessary resources from the list: ◉ All... or ○ Requested Before YYYY-MM-DD

Select New Resource**

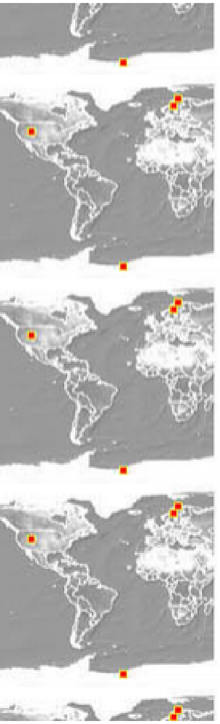
Step 1. Select station name and type of resource:
EISCAT Tromsø | Ionogram | Submit

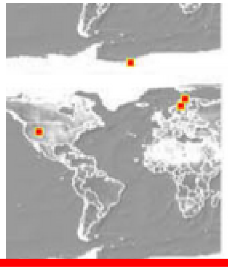
* Resources as previously requested by you, are stored in your personal folder on the web server (and are listed here) unless the limit of disk space allocated for you and/or all users is exceeded. In this case, resources with the earliest time of request may be deleted automatically. Resources present in the list may be displayed simply by clicking corresponding ✓. Since working with a short list is more convenient, you may optimize your effort (and release space on the server), deleting unnecessary resources from your list. Just click ✗ for that.

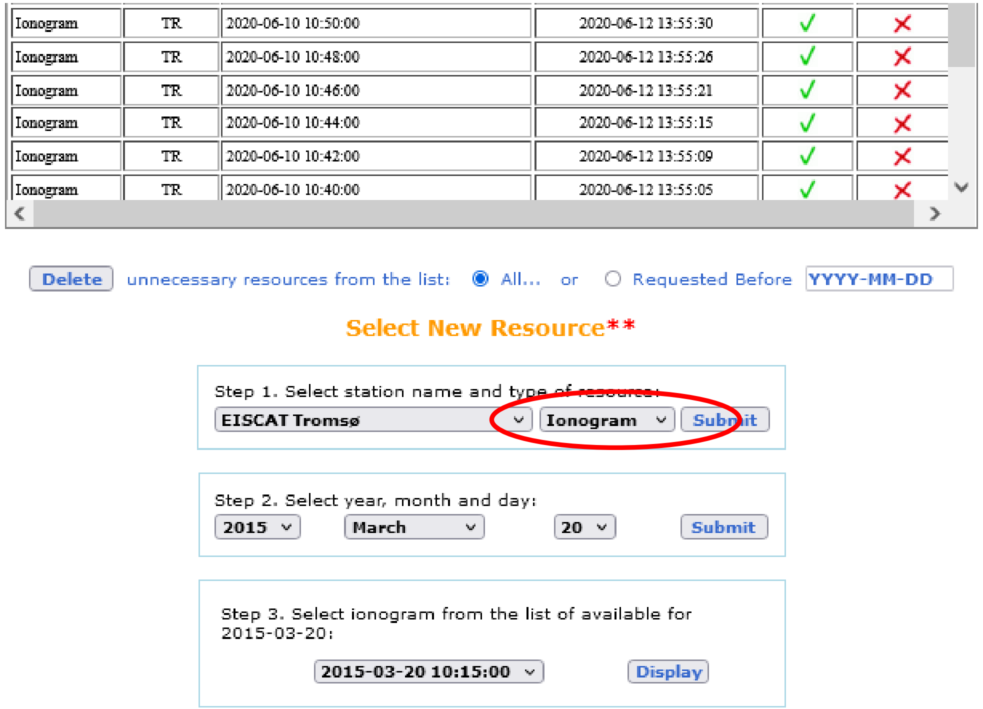
** Use this procedure to request a new resource. The number and sequence of steps depend on the type of request. Note that if "Ionogram" is requested, not only the ionogram image is displayed but the entire set of analysis results for that particular ionogram is provided, in their various graphical formats. "2D Plot" means display of a time series for various ionospheric parameters and also provides data for it in plain text format. "3D Plot" is used when a parameter depend on time and on some other parameter (examples are plasma frequency and irregularity amplitude). "SQL Query" gives you possibility to request non-standard data series with arbitrary conditions and without time constraints. Note: if you change any detail of your request (before pressing "**Display**" or "**Execute**"), do not forget to press the appropriate "**Submit**" button again. To complete your selection, press the "**Display**" or "**Execute**" button. If you return to your home page within the same session, your previous selection details remain entered and can be changed, requiring one or more new "**Submits**"; "**Display**" will enter the result as a new Resource.

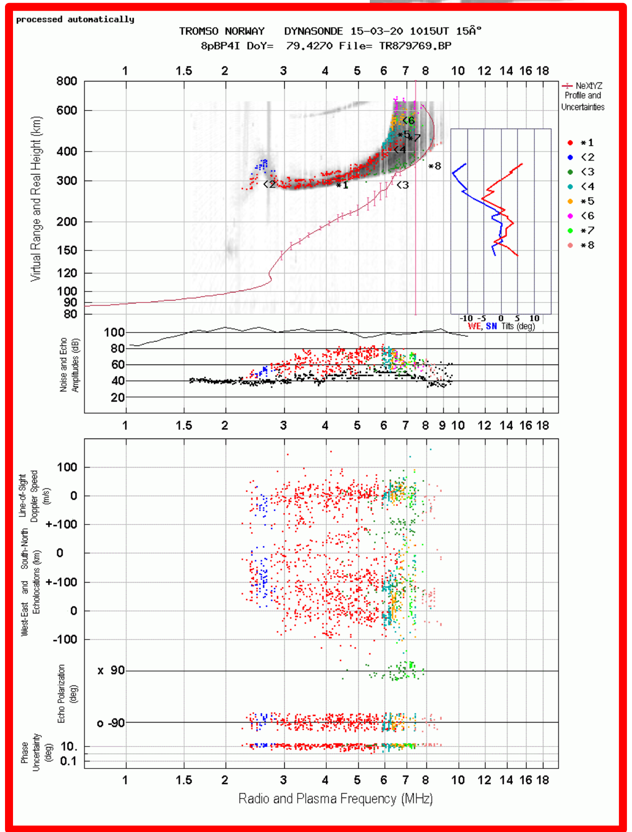
- The system remembers your earlier requests (hence the need for registration)

Dynasonde interface



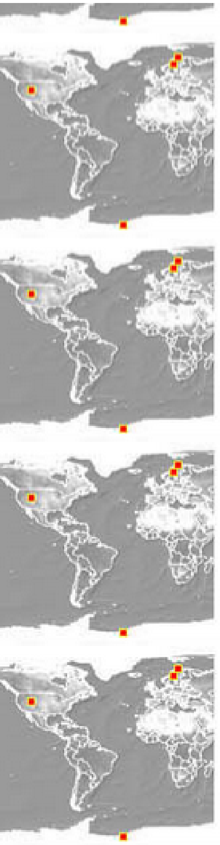


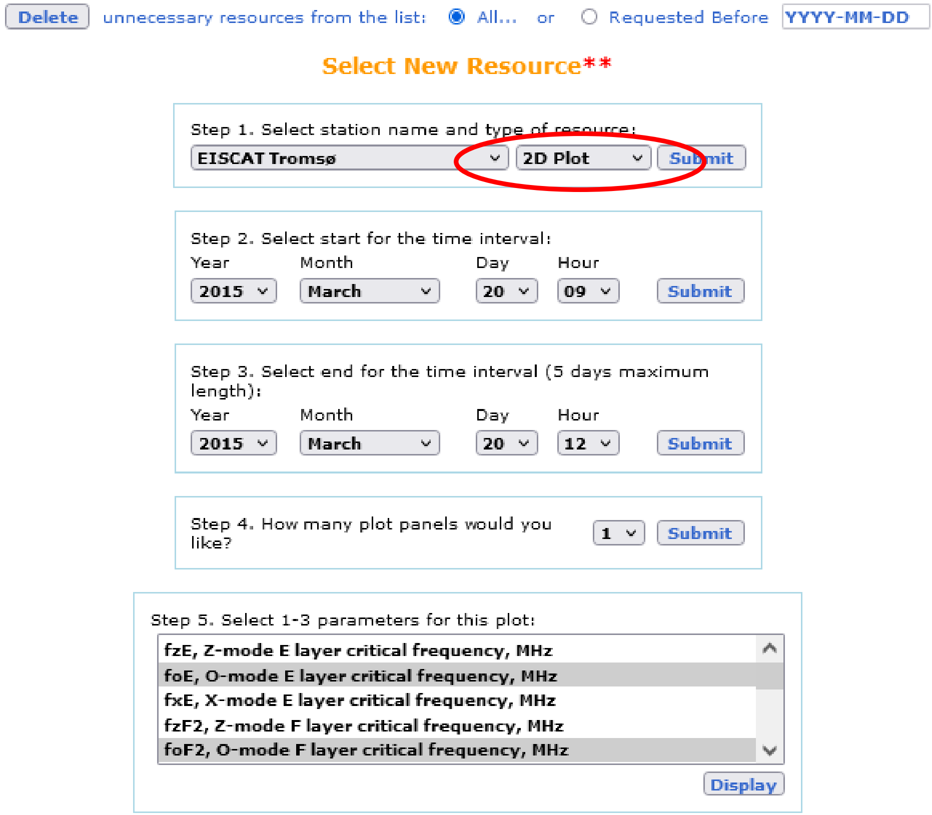


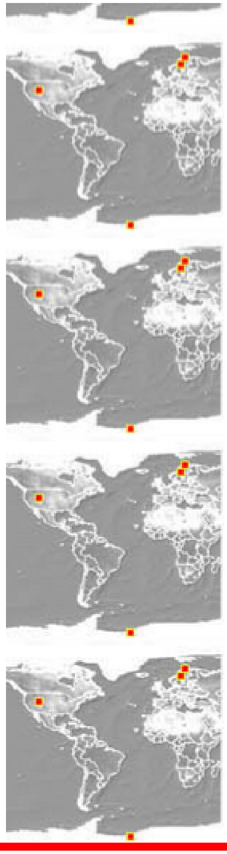


- Accessing specific ionograms is straight-forward

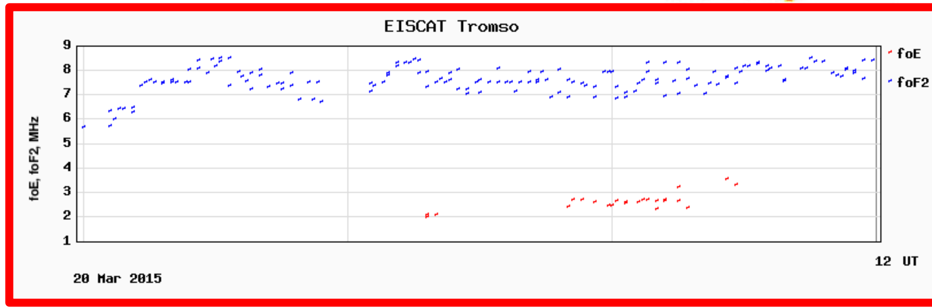
Dynasonde interface



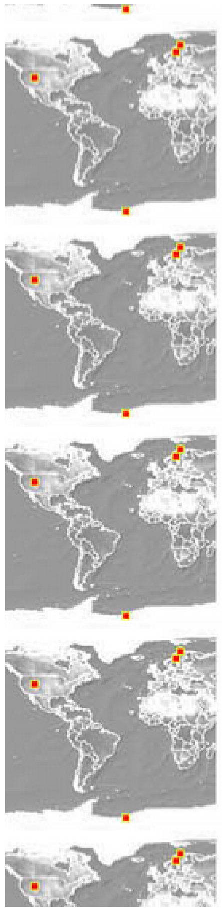


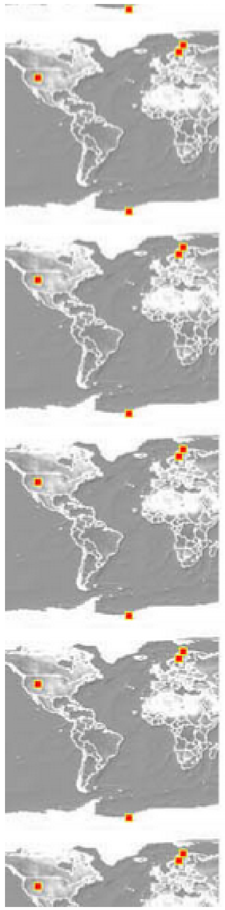


- It is also easy to plot time-series



Dynasonde interface





- To download the data, choose “SQL Query”

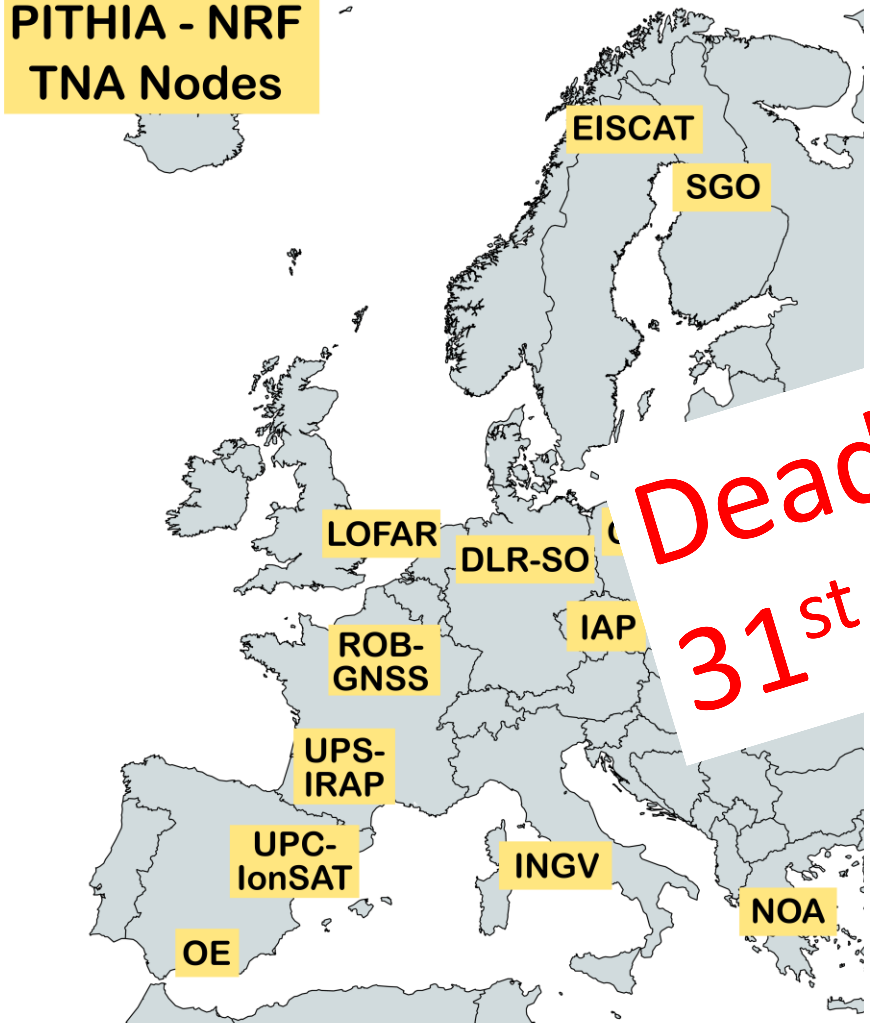
Summary

- EISCAT operates incoherent scatter radars
- EISCAT provides detailed ionospheric data from northernmost Scandinavia and Svalbard.
- The data are accessible through the PITHIA portal.

PITHIA-NRF TNA programme

https://pithia-nrf.eu/pithia-nrf-users/tna

PITHIA - NRF TNA Nodes



Deadline: 31st May 2024

Advantages of the TNA access:

- A **unique opportunity to learn** about ... ments, data and models of your interest
- **Training and su**... ...eld are included in the acc...
- ... scale, such a
- ... for one work ... sessions is flexible based on ... NODE)
- ...mbursement for travel and stay in case of physical ...ess *(the amount and scope varies based on the NODE and will be specified if the project is accepted)*
- **Support** of the project available **for up to 6 months** from its start
- Possibility to apply for **access to multiple NODEs** *(we encourage using data and models from other NODEs of PITHIA-NRF during your access to the primary NODE and you will receive support for those as well)*

The PITHIA-NRF project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007599

Thank you for your attention!

WEB: https://www.pithia-nrf.eu

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