# EISCAT_3D

## The 3rd Generation European Incoherent Scatter Radar System


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# The European Incoherent Scatter System (EISCAT)

- Originally designed primarily for auroral electrodynamics research; sited at the southern edge of the auroral oval,
- International collaboration / ownership (FI, FR, GE, NI, NO, SE, UK),
- Mainland stations built in late 70s, operation started 1981,
  - UHF (928 MHz) RX/TX in Tromsø, RX in Kiruna, Sodankylä
  - VHF (224 MHz) RX/TX in Tromsø
- In late 1980s, user focus beginning to shift towards
  - solar/terrestrial interactions (cf. ESA CLUSTER),
  - middle atmosphere physics and dynamics (PMSE etc.)
- Additional radar on Spitsbergen (ESR) planned 1990-92,
- ESR constructed 1993 – 1998, operations started 1996,
- Japan joining the Association in 1996, China in 2005,
- Mainland systems modernised to ESR standards 1999 – 2001

# The EISCAT radar systems are now 12 – 27 years old -

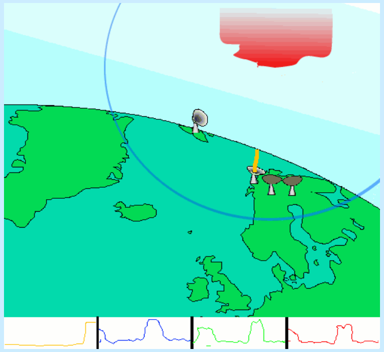
## and next year the Sodankylä and Kiruna UHF sites will lose their spectrum to UMTS 900...

Sodankylä, FI: UHF RX

Kiruna, Sweden: UHF RX

Tromso, Norway: VHF and UHF

Spitsbergen: UHF (500 MHz)



# Post-Y2000 EISCAT Science Directions:

## the case for a 3rd Generation Incoherent Scatter Radar

- Renewed interest in auroral electrodynamics and plasma physics,
- Short time-scale, small spatial scale targets and processes:
  - Quasi-coherent echoes from small plasma targets in E and F regions,
  - Controlled experiments on PMSE using the EISCAT Heater,
  - Routine D-region /middle atmosphere incoherent scatter measurements,
  - Statistics of E-region micrometeor head echoes for planetology,
  - Instantaneous **E** fields at many altitudes along a whole magnetic field line,
- Ionospheric topside processes:
  - H/He/O ratios in polar ionosphere,
  - "Polar wind" plasma outflow
- Mesosphere/D region physics and chemistry…

- But in all these applications, the existing radar systems are almost at the end of the road:
  - Present best cross-beam resolution ≈ 1 km @ 100 km alt (UHF), wanted << 100 m,
  - along-the-beam resolution ≈ 300 m (set by TX band-width), wanted < 100 m,
  - D/E region and topside time resolution ≈ many minutes, wanted < 10 s,
  - 3-d E fields only at one altitude at a time, wanted at 5-10 altitudes simultaneously,
- Plus:
  - partially obsolete, maintenance-intensive mainland transmitter systems,
  - spectrum availability and interference problems…

… a strong case for an all-new EISCAT system !

# The EISCAT_3D Design Study

- Initiated by EISCAT in 2005,
- Four-year feasibility study project, supported by the European Commission under FP6,
- Aim: To develop an outline design for a multi-static, phased-array radar to replace the existing mainland VHF and UHF incoherent-scatter systems –
  - Would put EISCAT in a position to retain the unique multi-static capability even after the demise of the UHF (which will happen towards end 2009…),
  - Operating frequency: high VHF (230-240 MHz); protected spectrum…
  - About ten times better temporal and spatial resolution than what the present systems can deliver (< 1 second for 10% accuracy in IS mode, < 100 m vertically and horizontally at 100 km altitude),
  - Built-in interferometric capabilities at the active ("core") site,
  - Coherency trigger system with programmable threshold will activate high rate interferometry data recording when coherent targets detected,
  - Fully digital receivers with real-time multi-beaming capability at the receive-only sites
  - Non-dispersive time-delay beam steering across the whole 30 MHz bandwidth

# EISCAT_3D Design targets and Central Core Layout

## Radar field-of-view (FOW)

The beam generated by the central core transmit/receive antenna array will be steerable out to a maximum zenith angle of ≈ 40° in all azimuth directions. At 300 km altitude, the radius of the resulting field-of-view is approximately 200 km. In the N-S plane this corresponds to a latitudinal coverage of ± 1.80° relative to the transmitter site.

The antenna arrays at the 3-D receiving facilities will be arranged to permit tri-static observations to be made throughout the central core FOW at all altitudes up to 800 km.

## Beam steering

It will be possible to steer the beam from the central core TX/RX antenna array into any one of > 12000 discrete pointing directions, regularly distributed over its FOW and separated by on average 0.625° in each of two orthogonal planes. The beam steering system will operate on a < 500 μ s timescale.

| Central core parameters: | First phase | Fully instrumented |
|---|---|---|
| Number of elements: | 16 K | 30 K |
| Diameter [wavelengths]: | 87 | 116 |
| Element separation [wl]: | 0.6 | 0.6 |
| P x A [GW m²]: | 91 | 295 |
| One-way Half Power BW [degrees]: | 0.82 | 0.61 |

Cf. the EISCAT VHF system in Mode 1 (full antenna, 3 MW):

P x A = 9.8 GW m², HPBW = 0.6 x 1.7 degrees

## 2.10 Transmitter parameters

| | |
|---|---|
| Centre frequency: | between 220 – 250 MHz, subject to allocation |
| Peak output power: | ≥2 MW |
| Instantaneous –1 dB power bandwidth: | ≥5 MHz |
| Pulse length: | 0.5–2000 μs |
| Pulse repetition frequency: | 0–3000 Hz |
| Modulation: | Arbitrary waveforms, limited only by power bandwidth |

## 2.11 Receiver parameters

| | |
|---|---|
| Centre frequency: | matching the transmitter centre frequency |
| Instantaneous bandwidth: | ±15 MHz |
| Overall noise temperature: | ≤50 K referenced to input terminals |
| Spurious-free dynamic range | ≥70 dB |

## 2.12 Sensor performance in incoherent scatter mode

The parameters of the different subsystems will be chosen such that, for each of the measurement scenarios tabulated below, the radar will generate estimates of incoherently scattered signal power (or equivalently, uncorrected electron density) with statistical accuracies of better than 10 % in the specified integration times:

| Altitude [km] | Electron density [$m^{-3}$] | $T_e/T_i$ | Ion composition | Height resolution [m] | Integration time [seconds] |
|---|---|---|---|---|---|
| | | | | | |
| 80 | $1 \times 10^8$ | 1.0 | | ≤100 | 30 |
| 100 | $3 \times 10^9$ | 1.0 | | 100 | 1 |
| 150 | $1 \times 10^{10}$ | 1.0 | 50% $NO^+$, 50% $O^+$ | 100 | 1 |
| 300 | $3 \times 10^{10}$ | 2.0 | 100% $O^+$ | 300 | 1 |
| 800 | $3 \times 10^{10}$ | 3.0 | 5% $H^+$, 95% $O^+$ | 1000 | 10 |
| 1500 | $1 \times 10^{10}$ | 4.0 | 10% $H^+$, 90% $O^+$ | | 60 |

## 2.13 Sensor performance in in-beam interferometer mode

In interferometer mode, the sensor will provide horizontal, 2D resolution of better than 20 m at 100 km altitude.

# Present idea of 3D TX/RX configuration

- A common TX facility with RX capabilities ("the core"):
  - Close to the present Tromsø (NO) EISCAT site
  - Operating frequency in the (225-240) MHz range
  - Power amplifiers utilising VHF TV power FETs
  - Phased-array system with > 16 K elements, $P_{pk}$ 10 MW
  - Actual antenna configuration and performance TBD
  - > 3 outlier, RX-only array modules for interferometry
  - Fully digital, post-sampling beam-forming on receive
  - Comprehensive interferometric capabilities built-in

- 2 + 2 very large RX-only ("remote") arrays:
  - Actual siting TBD, four promising sites investigated...
  - "Far-out" sites dedicated to F2/topside work,
  - "Half-way" sites dedicated to F1/E/D region work,
  - Filled apertures, long enough to provide ~ 1 km beam resolution at E region altitudes above transmitter
  - Medium gain (~ 10 dBi) element antennas
  - Fully digital, post-sampling beam-forming
  - Sufficient local signal processing power to generate at least five simultaneous beams
  - 10 Gb/s connections for data transfer and remote control and monitoring

An "Esrange option" is also being considered...


Present idea of the EISCAT 3D system geometry. The central core (denoted by a green filled circle) is assumed to be located near the present Norwegian EISCAT site at Ramfjordmoen **(69.58 N, 19.22E)**.

The dashed circle with a radius of approximately 250 km indicates the approximate extent of the central core FOW at 300 km altitude. Receiving sites located near Porjus (Sweden) and Kaamanen (Finland) provide 3D coverage over the (250-800) km height range, while two additional sites near Abisko (Sweden) and Masi (Norway) cover the (70-300) km height range.

# The 3D Central TX/RX Core

- Very large, circular cross-section filled phased array (like this one) with at least 5-K (eventually 16-K) elements,

- Short, broadband X Yagis (like this one) with approx. 7 dBi gain will be used as element radiators,

- Each X Yagi to be fitted with a (400+400) watt VHF transmitter module and a direct-sampling receiver,

- A 5000-element array will just about match the PxA of the present EISCAT VHF; a 16000 element (d≈ 150m) array will come close to the EI_3D target specs,

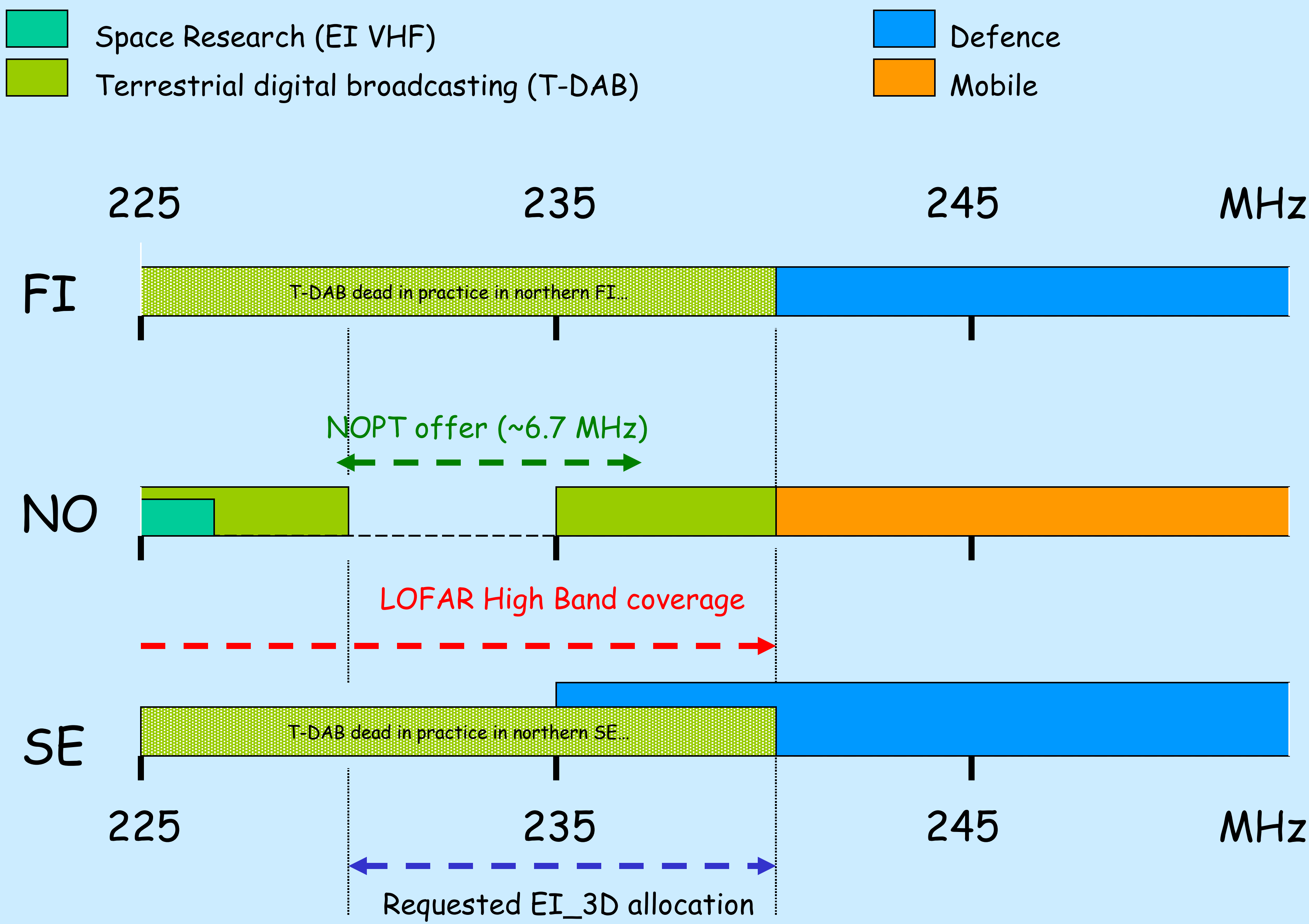
- Outlier receive-only elements for interferometry added to get down to 20 m resolution at 150-km

- Contact established to NXP (formerly Philips Semiconductor); ~ 10 samples of a 400 watt FET device supplied free of charge,

- Three 235-MHz amplifiers constructed; > 300 watt CW output power @ 11 dB gain verified,

- Tests of device performance and reliability when running in pulsed, saturated class-AB2 now started.

# High VHF Spectrum Usage in FI, NO, SE as of 2008-10



# Current status of EISCAT_3D

- Design study now into its fourth year; final report, including a tentative design, to be submitted to the EU by June, 2009,
- FPGA beam-former to be fitted to Demonstrator in late February 2009,
- Multi-beaming, adaptive polarisation tests to run until April 2009.
- Current best cost estimate:
  - Full system (10 x the performance of the present VHF) 60-80 M€
  - Budget system (1.5 – 2x the performance of the UHF) 20-25 M€
- Construction/funding situation unclear;
  - If money were available today, the earliest the new system could be on the air would be about 2012,
  - No current EISCAT owner has committed itself yet…
  - New partners would be welcomed with open arms !
- **But EISCAT_3D made it onto the ESFRI Roadmap on Dec. 9, 2008 !!!**
  - making it likely that the system will eventually be financed and built…

Photo by Torbjörn Lövgren

Photo by Lars-Göran Vanhainen

## What's new? Impact foreseen?

The EISCAT_3D radar system is heavily modular and lends itself to phased construction, both on the large scale, where the multiple radar sites can be constructed either sequentially or in parallel, and on a smaller scale where individual sites are made up of very large numbers of identical elements clustered into larger and larger sub-systems until the full system driven by the scientific requirements has been constructed. This design feature allows great flexibility in the implementation of the construction phase; the system will provide unique monitoring capabilities from a relatively early point in the construction though the more difficult scientific goals so far identified can only be addressed with completion of the full system.

The new facility will greatly extend the range of available data, improving its temporal and spatial resolution by about one order of magnitude as well as the geographic, altitude, and temporal extent. The goals for real time data availability place extreme demands on both data distribution and data storage and will exploit and extend European expertise in ultra-high bandwidth data distribution amongst large numbers of simultaneous data providers and users.



## >Timeline.

Preparatory phase: 2009-2011; construction phase: 2011-2015; operation: 2015-2045.

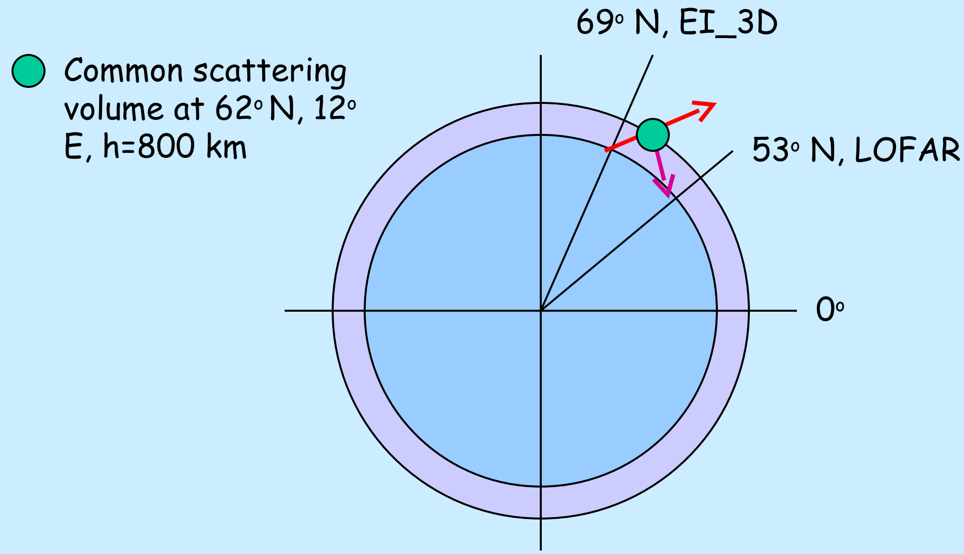
## >Estimated costs.

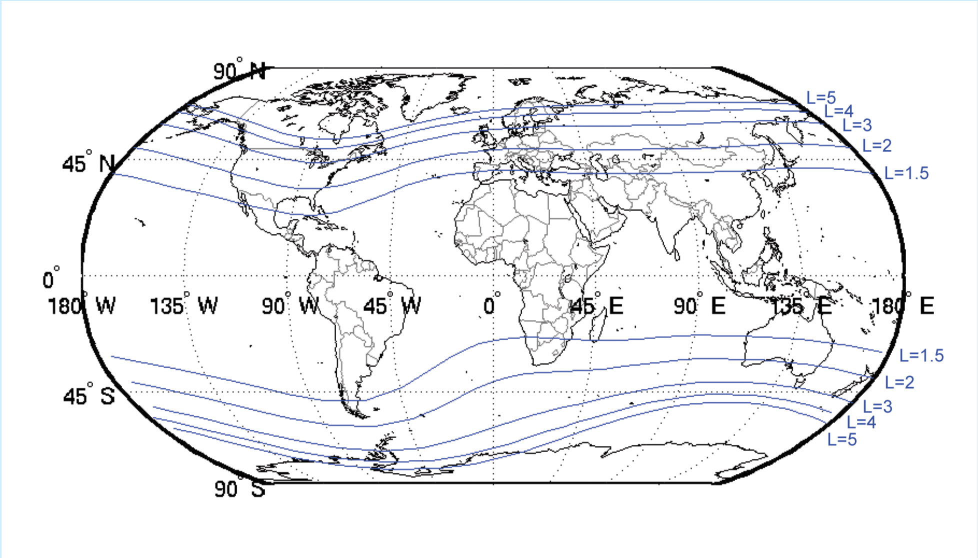
| | |
|---|---|
| Preparation costs: | 6 M€. |
| Total construction costs: | construction cost is estimated at 60 M€ for one active site but may expand up to 250 M€ for all sites. |
| Operation costs: | 4-10 M€/year. |
| Decommissioning costs: | 10-15% of construction costs. |

## >Website: www.eiscat.se

# What can LOFAR offer the EISCAT_3D community ?

- The EI_3D radar transmitter and the LOFAR array can be used together for bi- or multi-static radar measurements of the Earth's ionosphere and magnetosphere south of 67° N:
  - coverage of the topside ionosphere (h=800 km) down to 61° N for e.g. monitoring of ion outflow over a wide latitude range,
  - in the magnetosphere, a wide range of magnetic L-shells (at least down to L = 2.5) become accessible,
  - Neither of these measurements would be possible using only the 3D system in its planned configuration,
  - In addition, generally improved space weather monitoring possibilities…



# Why should EISCAT_3D be of interest to LOFAR ?

- The EI_3D transmitter will transmit a powerful, well-defined and controllable signal at the top end of the LOFAR frequency range; this signal, either scattered from targets of opportunity or incoherently scattered from the ionospheric plasma, could be used by LOFAR as an on-demand signal for various calibration purposes.
- When in full operation, the EI_3D system will provide real-time ionospheric data from about 62° N northwards; these should be of great value for validating and possibly adjusting LOFAR ionospheric correction models.
- Speculative: radar interferometry detection / orbit determination of NEOs using LOFAR for receiving…

All results from the EISCAT_3D study are in the public domain:

**Feel free to make use of them !**

For more info visit e7.eiscat.se