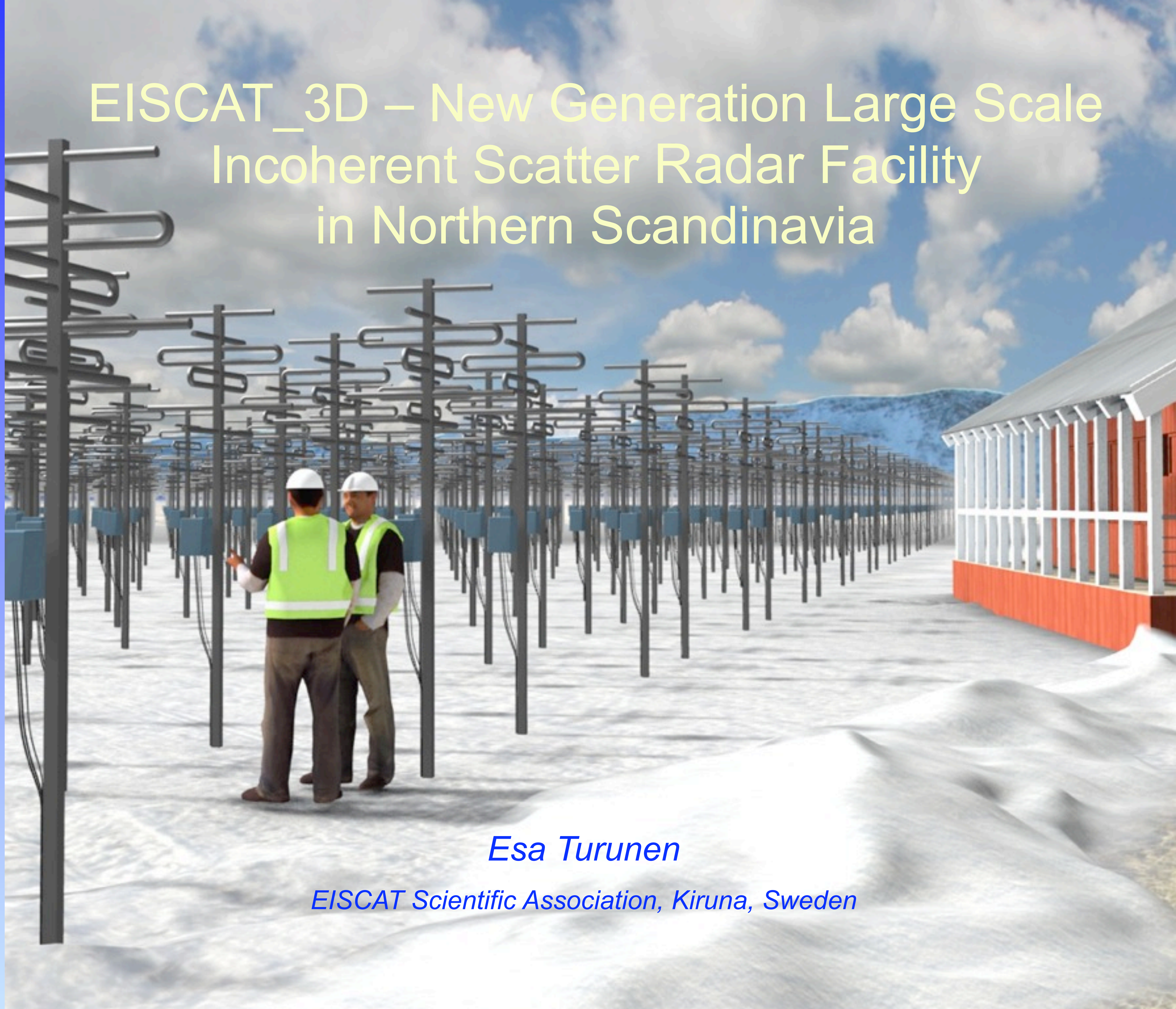

EISCAT_3D – New Generation Large Scale Incoherent Scatter Radar Facility in Northern Scandinavia

Esa Turunen

EISCAT Scientific Association, Kiruna, Sweden

The EISCAT_3D Design Study Team (2005-2009):

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With special thanks to:

EISCAT associates in Finland, China, Germany, Japan, Norway, Sweden and United Kingdom, and supporting partners in France, Russia and Ukraine

The Center of Excellence in Inverse Problems, Finland

Outline of this talk:

Background

EISCAT_3D Design Study project 2005-2009

- design target
- results

Alternative software radar concept

- current results
- proposed architecture

Next steps

- status of the project
- implementation studies 2010-2013
- construction -2015

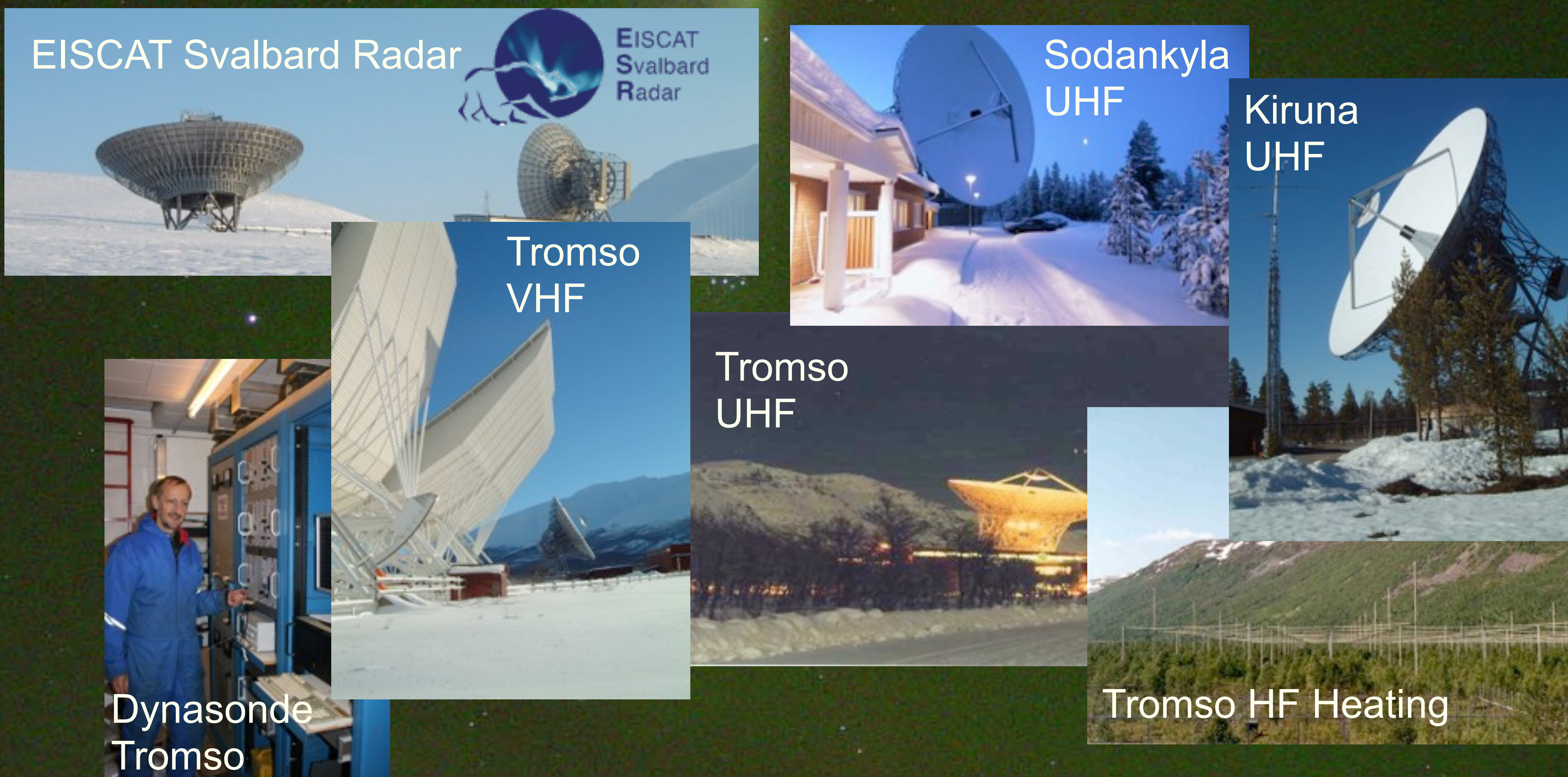
Associate countries and institutes

Contributing partners:

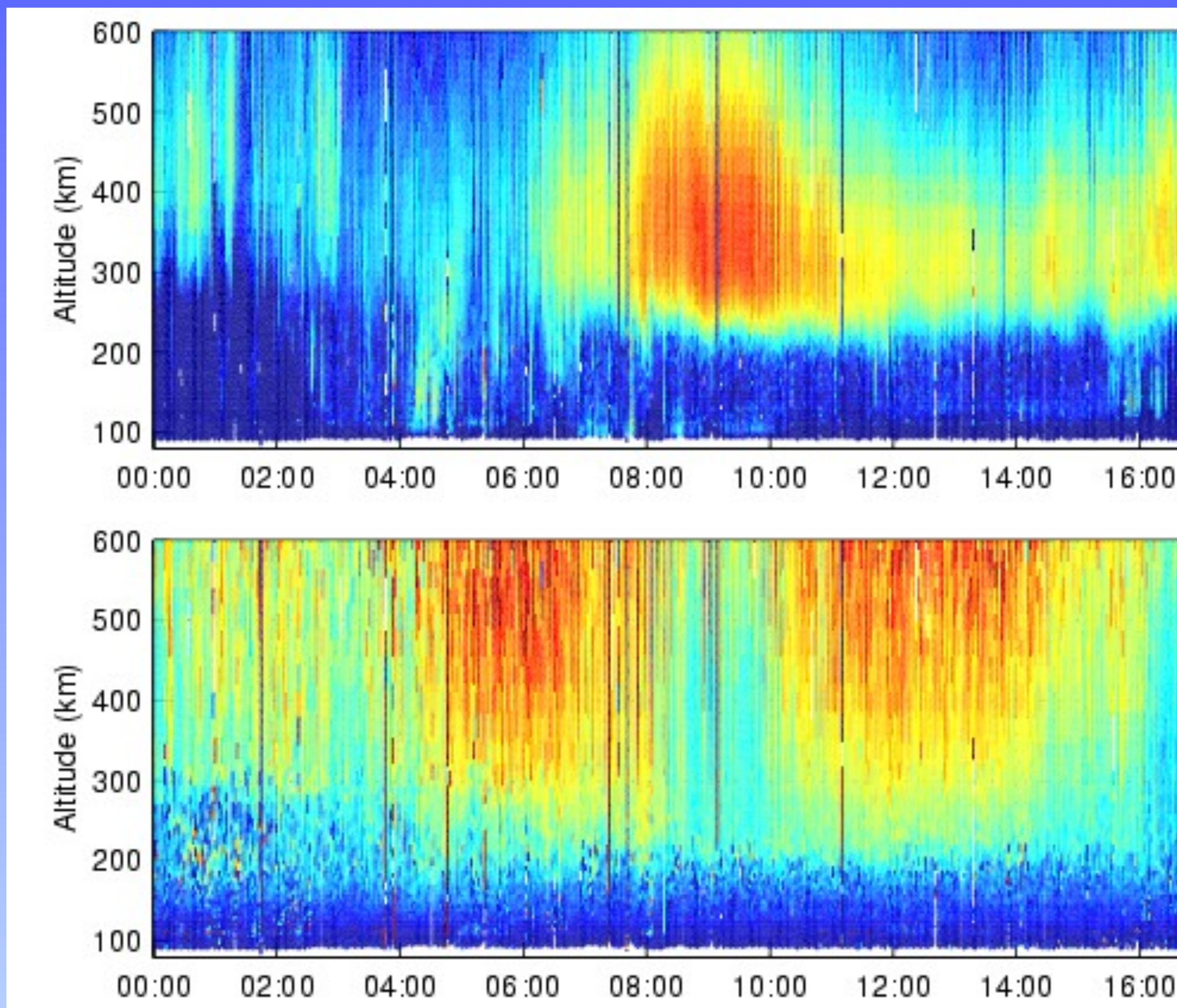
Current EISCAT facilities:

- 3 Incoherent Scatter Radars
- HF Heating Facility
- 2 Dynasondes

Annual operation 3.2 MEUR



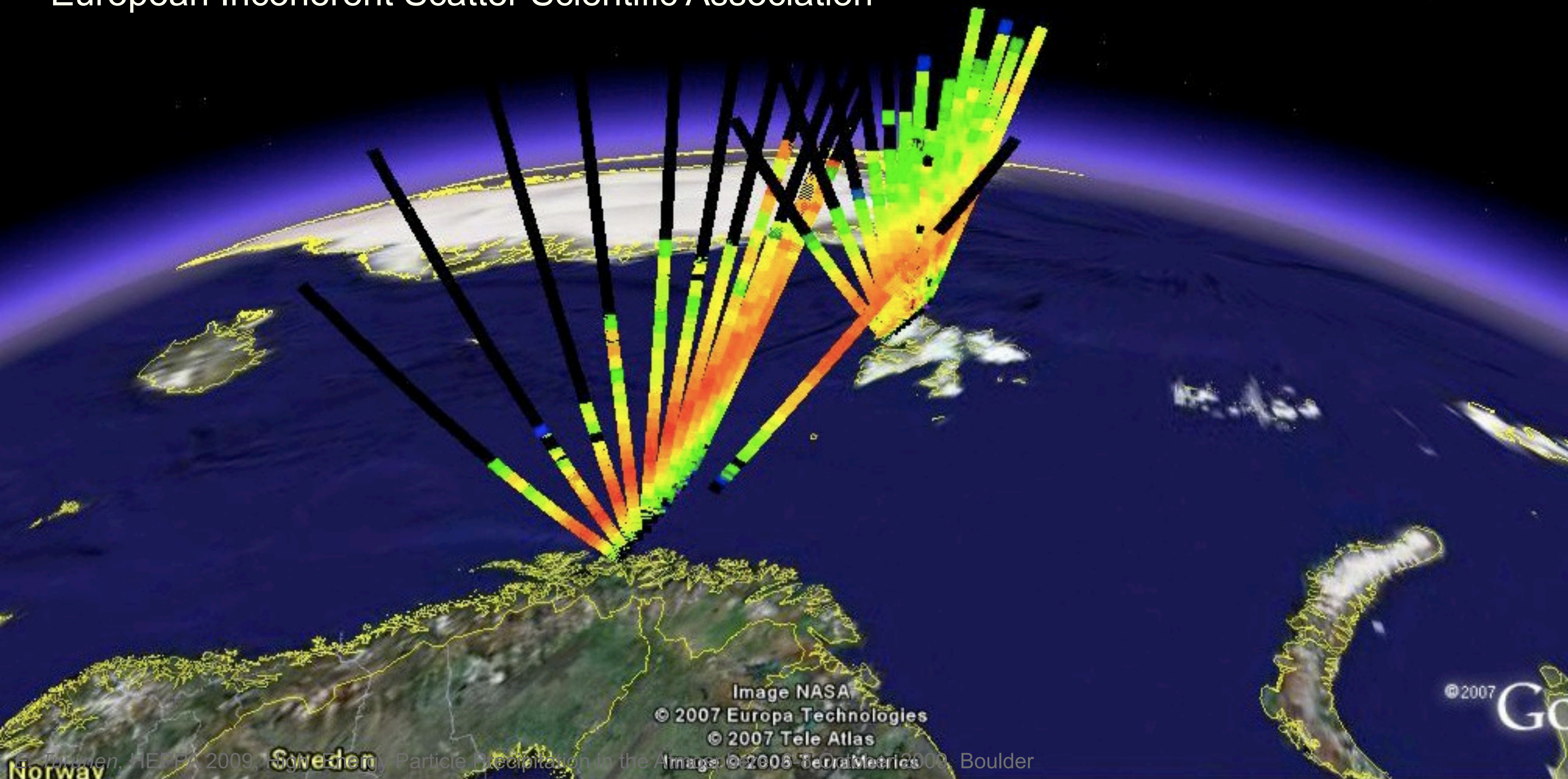
Space-time ambiguities can make the interpretation of radar data quite challenging



Our view is currently at best 2-dimensional
We will turn it to be 3-dimensional

Courtesy of Y Ogawa and A Saito, Google Earth

European Incoherent Scatter Scientific Association



Example on volumetric data: PFISR

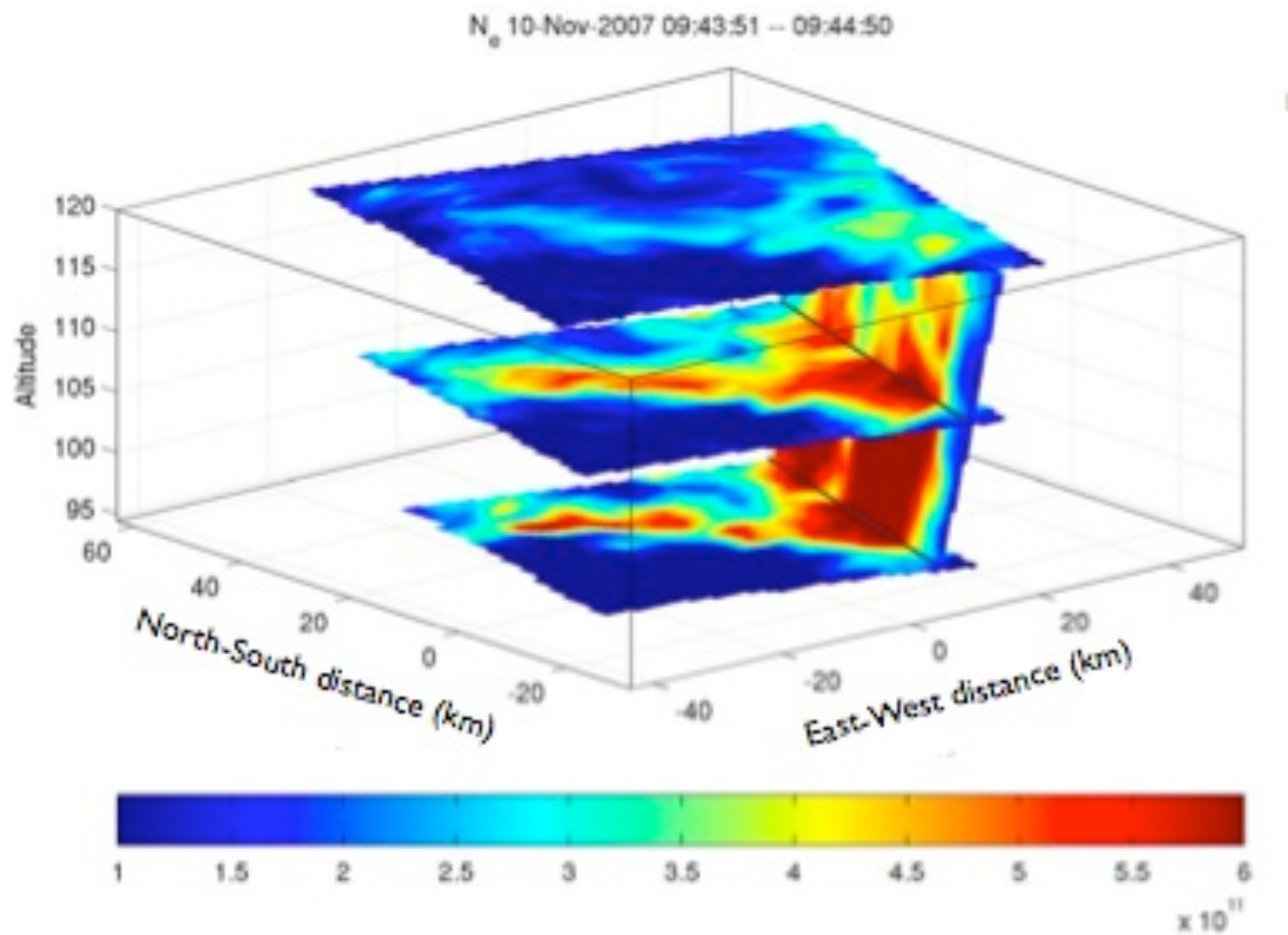


Fig. 2. Volumetric image of *E*-region on 10 November 2007, 09:43:51–09:44:50 UT. The image was produced by averaging 192 pulses-per-position. The horizontal cuts are at 100, 107, and 120 km. The structured density enhancement seen in the image was produced by auroral electron precipitation in the 20 keV range.

Semeter et al., JASTP., 2008

Design Study target (from 2005)

System configuration:

multiple phased-array ISR

- **A central transmitting/receiving core facility**, located at, or close to, the EISCAT Tromsø radar.
- **At least two receiving facilities** for the ionospheric **F1, F2 and topside regions**, located at distances of ~220-280 km south and east.
- **At least two receiving facilities** for the ionospheric **D and E regions**, at distances of ~90-120 km south and east
- Data storage and communication systems located at, or close to, each facility.
- Essentially unattended, **continuous operation**.
- System control, monitoring, data access via Internet.
- Relative time between sites better than 100 ns, absolute time maintained to GPS/Galileo standards.
- At central core beam-steering systems for transmission and reception and several (4–10) outlier, receive-only phased-array antennas for in-beam **interferometry.**
- At **receiving** facilities at least **5 beam formers**

EISCAT 3D Design Specification Document
FP6-2003-Infrastructures-4: EISCAT 3D Proposal #011920

Appendix 1

Tentative EISCAT 3D System Layout

The figure shows one possible layout of the EISCAT 3D system. In this configuration, the central core (denoted by a green filled circle) is assumed to be located near the present Norwegian EISCAT site at Ramfjordmoen. The dashed circle with a radius of approximately 250 km indicates the approximate extent of the field-of-view of the central core at 300 km altitude. Phased-array receiving sites located near Porjus (Sweden) and Kaamanen (Finland) provide 3D coverage over the (250-800) km height range, while two additional receiving sites near Abisko (Sweden) and Masi (Norway) cover the (70-300) km height range.

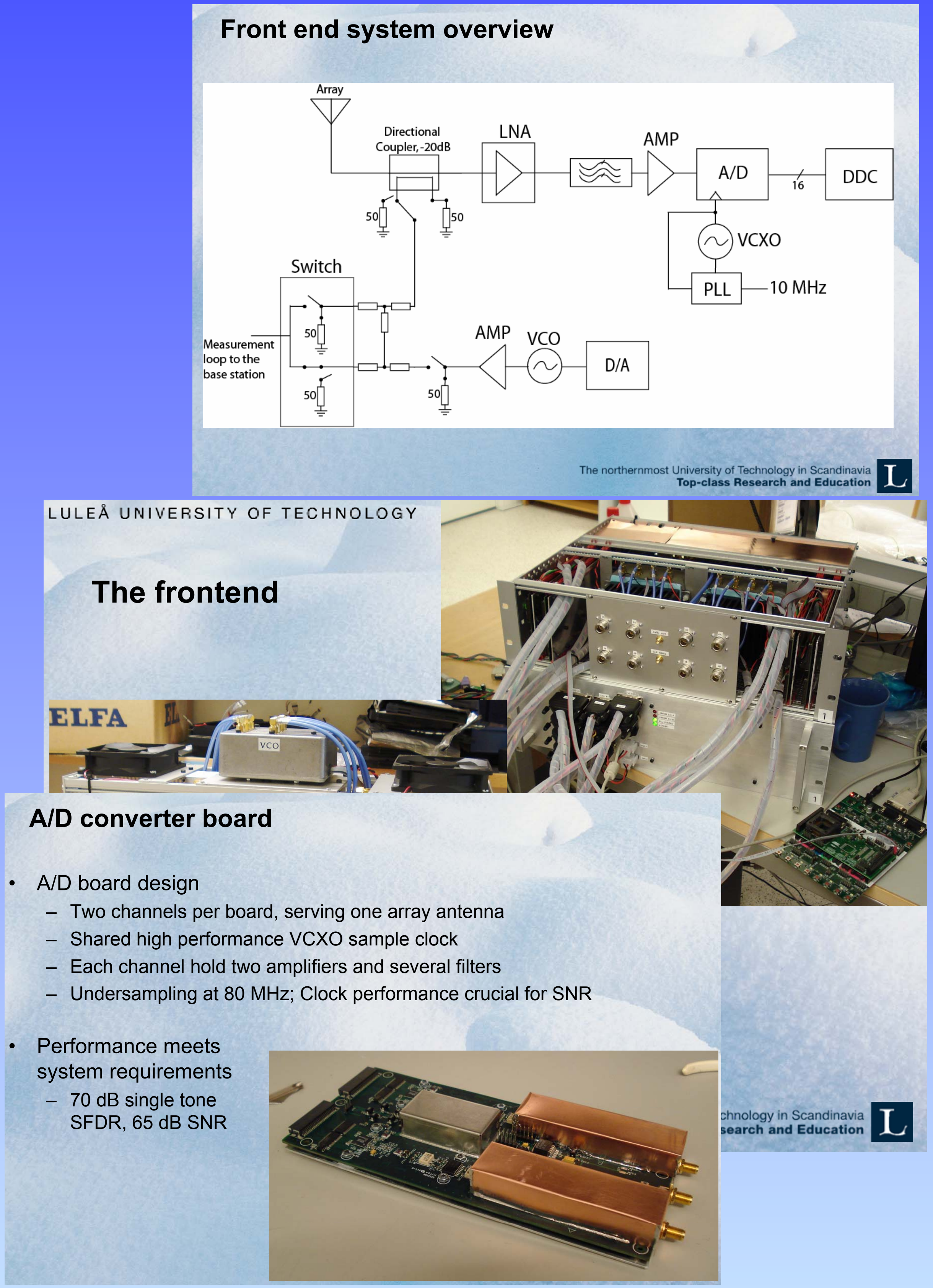
Design Study target

Spatial resolution:

- Along the transmitted beam better than 100 m.
- Horizontally (–3 dB) at 100 km better than 150 m.

Radar field-of-view (FOV):

- Central core steerable out to a maximum zenith angle of ≈40° in all azimuth directions. At 300 km altitude, radius of FOV is approximately 250 km.
- Receiving facilities permit tristatic observations to be made at all altitudes up to 800 km.



Design Study target

Transmitter parameters:

– Centre frequency: between 220 – 250 MHz, subject to allocation

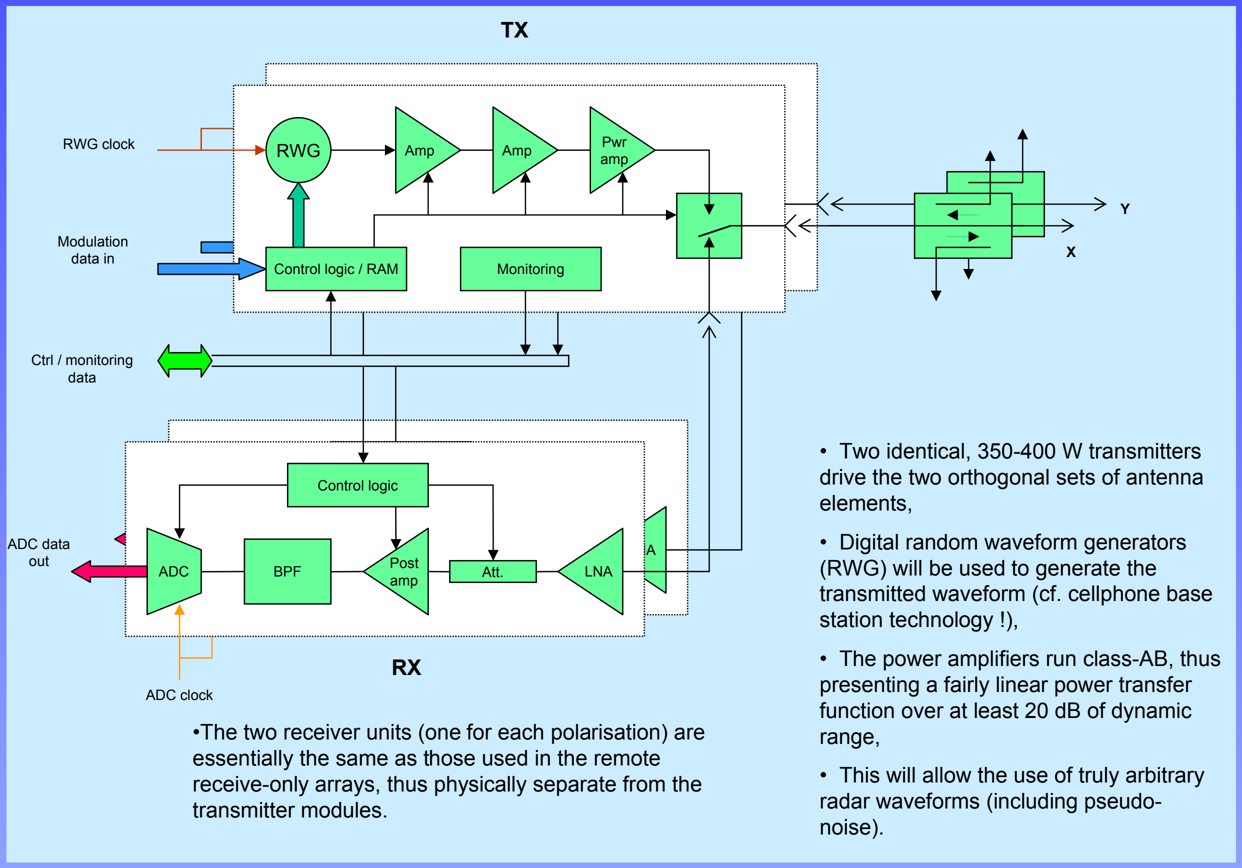
– Peak output power: ≥2 MW

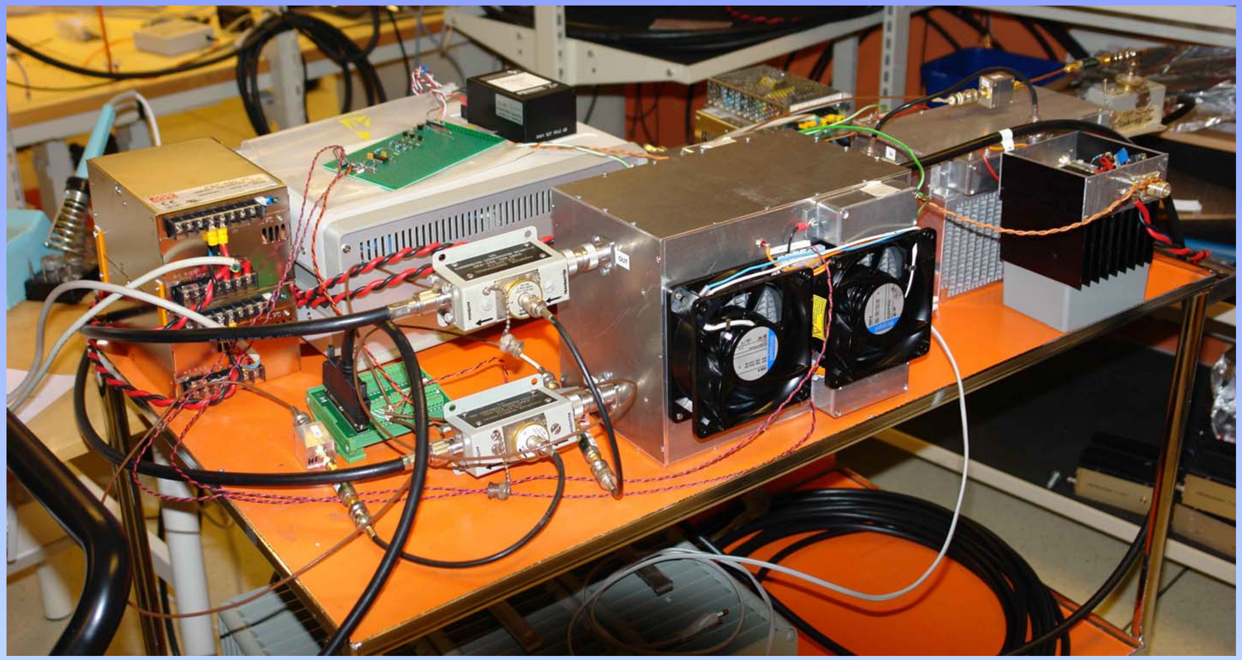
– Instantaneous –1 dB power bandwidth: ≥5 MHz

– Pulse length: 0.5–2000 µs

– Pulse repetition frequency: 0–3000 Hz

– Modulation: Arbitrary waveforms, limited only by power bandwidth





Design Study target

Receiver parameters:

- Centre frequency: matching the transmitter cf.
- 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	1×10^{8}	1.0		≤100	30
100	3×10^{9}	1.0		100	1
150	1×10^{10}	1.0	50% NO^+, 50% O^+	100	1
300	3×10^{10}	2.0	100% O^+	300	1
800	3×10^{10}	3.0	5% H^+, 95% O^+	1000	10
1500	1×10^{10}	4.0	10% H^+, 90% O^+		60

The proposed Yagi antenna

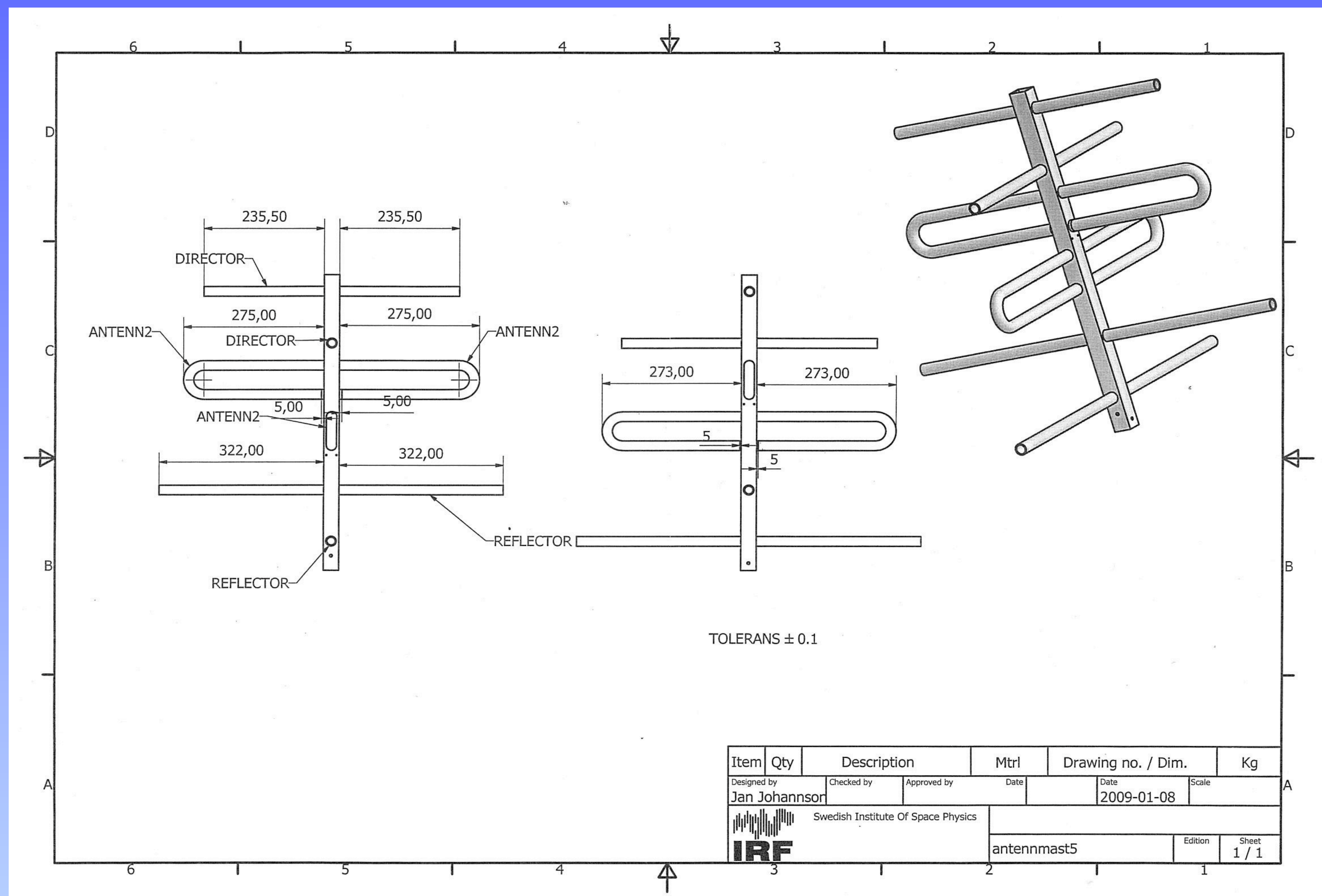
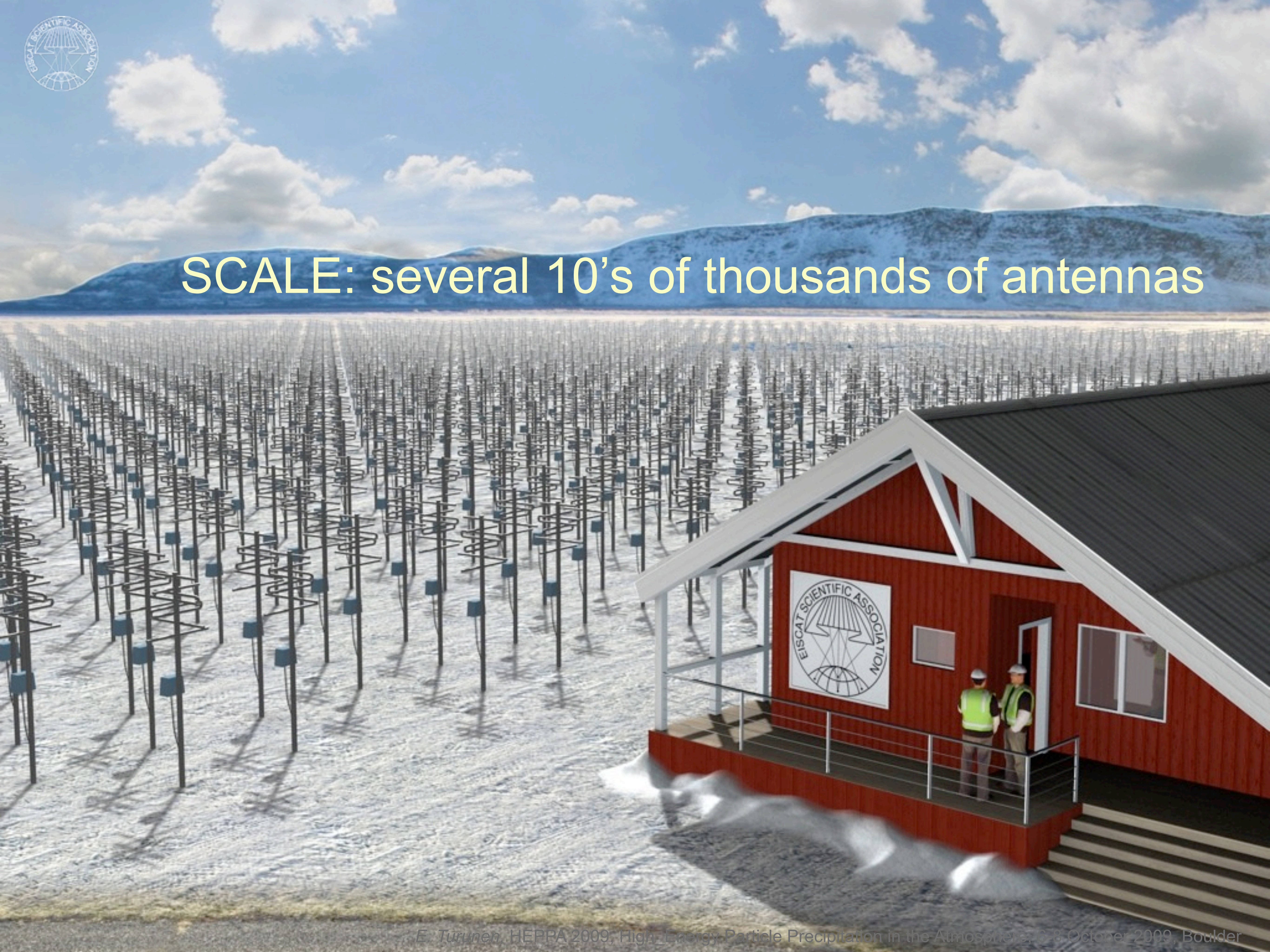


Figure 1. *Mechanical drawing of the "Renkwitz Yagi" recommended for use as the element antenna in the EISCAT_3D Core array.*


SCALE: several 10’s of thousands of antennas
EISCAT SCIENTIFIC ASSOCIATION

MODULAR construction opportunity

Data rates and dissemination challenges

80 MHz sampling, 14/16 bits

16000 element core, 48000 total

9.6 TB/s from central site !

Beam-form in array

~30TB/day per beam

Total data rate ~ 300TB/day

Band-limit 140GB/day per beam?

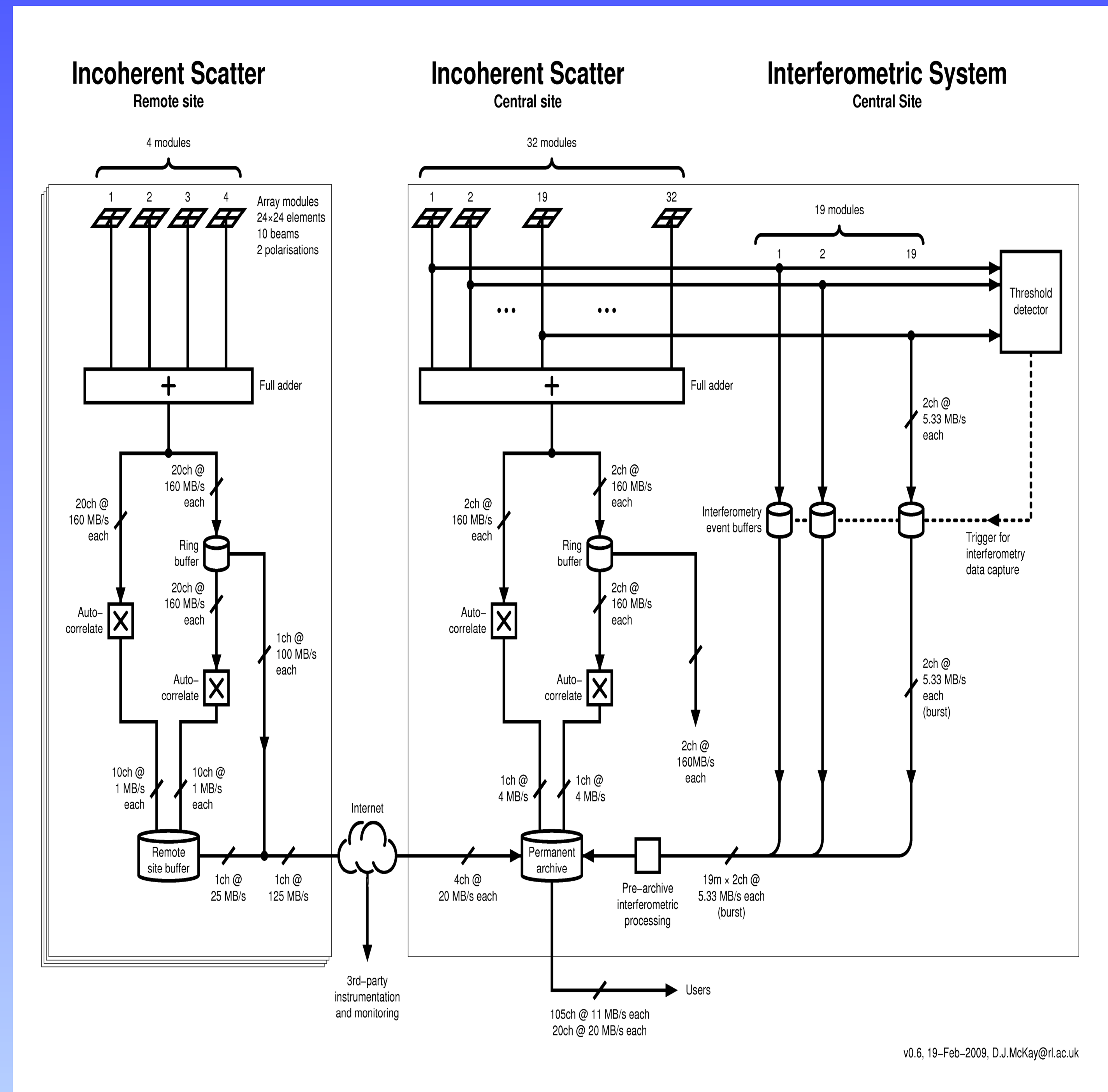
Interferometer 730GB/hour

Support instruments 750GB/day

Short-term ~ 100 TB/site

Long-term storage ~ 1 PB

10Gb/s networking



An alternative to Design Study hardware solution

Based on Software-Defined Radio (SDR)

Development already on existing EISCAT radars:

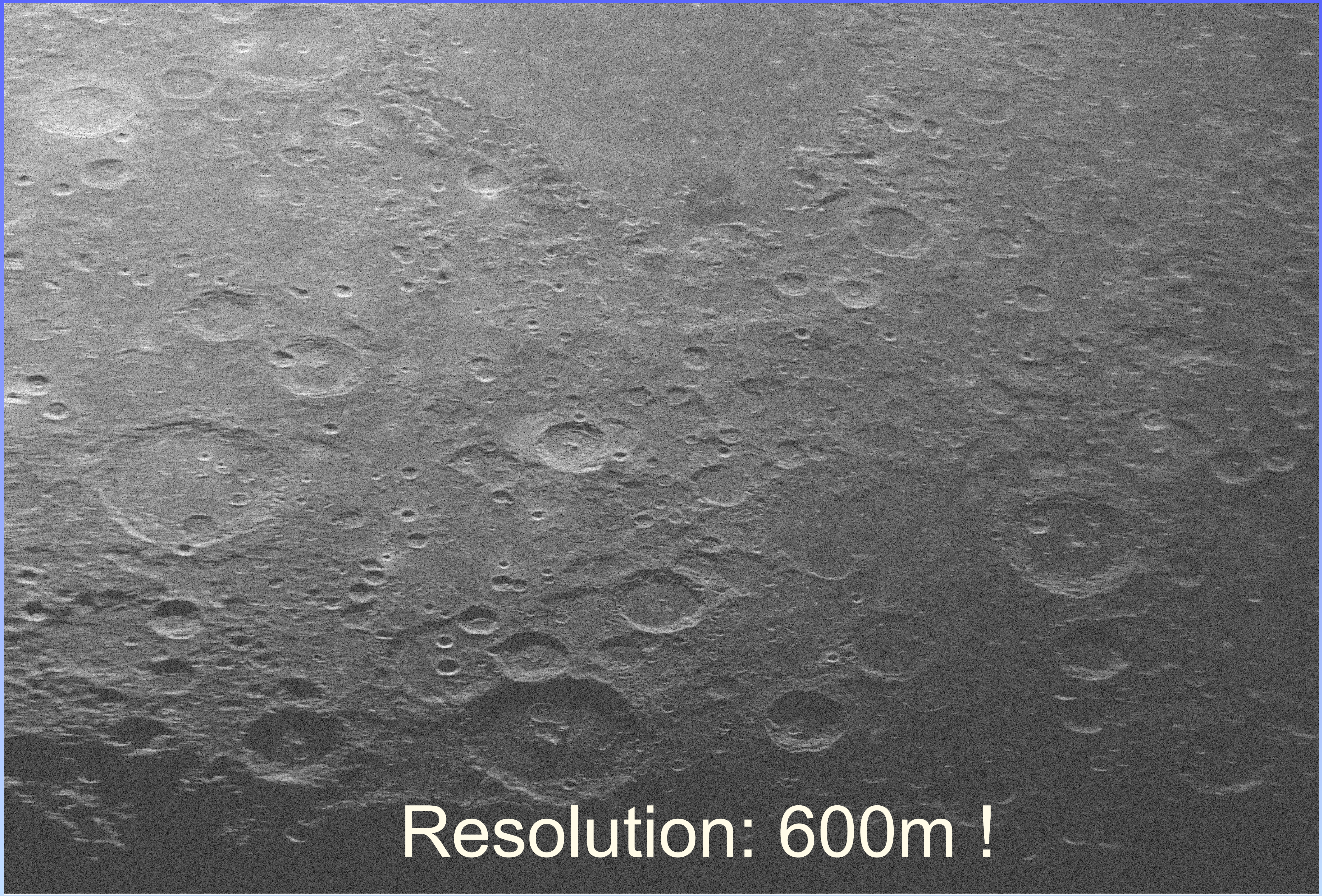
- USRP (Universal Soft Radio Peripheral) by Ettus, Inc.
- USRP1: USB2 interface, Altera FPGA, 2007, 700 USD
- USRP2: EN interface, Xilinx FPGA, now, 1000 USD
- parallel USRP: 8 channels, autumn 2009, 3000 USD
- 10 G EN, PCIe 4 lanes, 1G en x4
- Xilinx SX50 or SX95 FPGA
- Custom FPGA development by J. Corgan (DDC, aux signals)
- Financed by the CoE of Inverse Problems, Finland
- All SW and HW design material is open access
- Linux / MacOS / Windows, Intel SSE as the SDR engine

ETTUS HW for 8 Msamples/s DDC

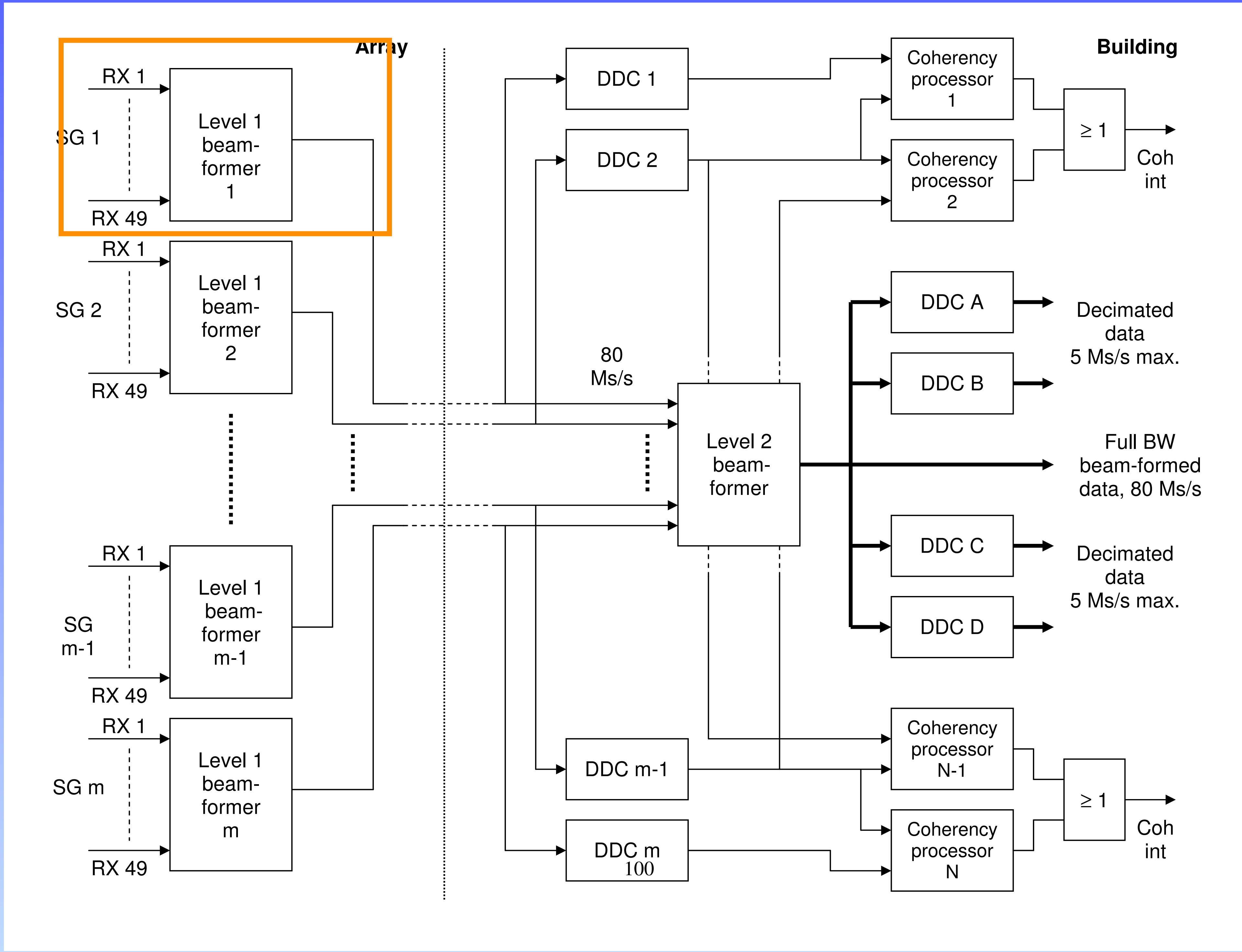
Present EISCAT SDR applications:

- Space debris
- General-purpose IS experiments
  - Ambiguity inversion along lag profiles replaces traditional decoding
  - Software relies on amplitude domain data to simplify bookkeeping
- Lunar mapping
  - Pulse compression up to 2000 bauds (2000^2 int time factor)
  - Also fractional baud length coding
- Meteor head echoes
- Heater produced fast and sharp layers

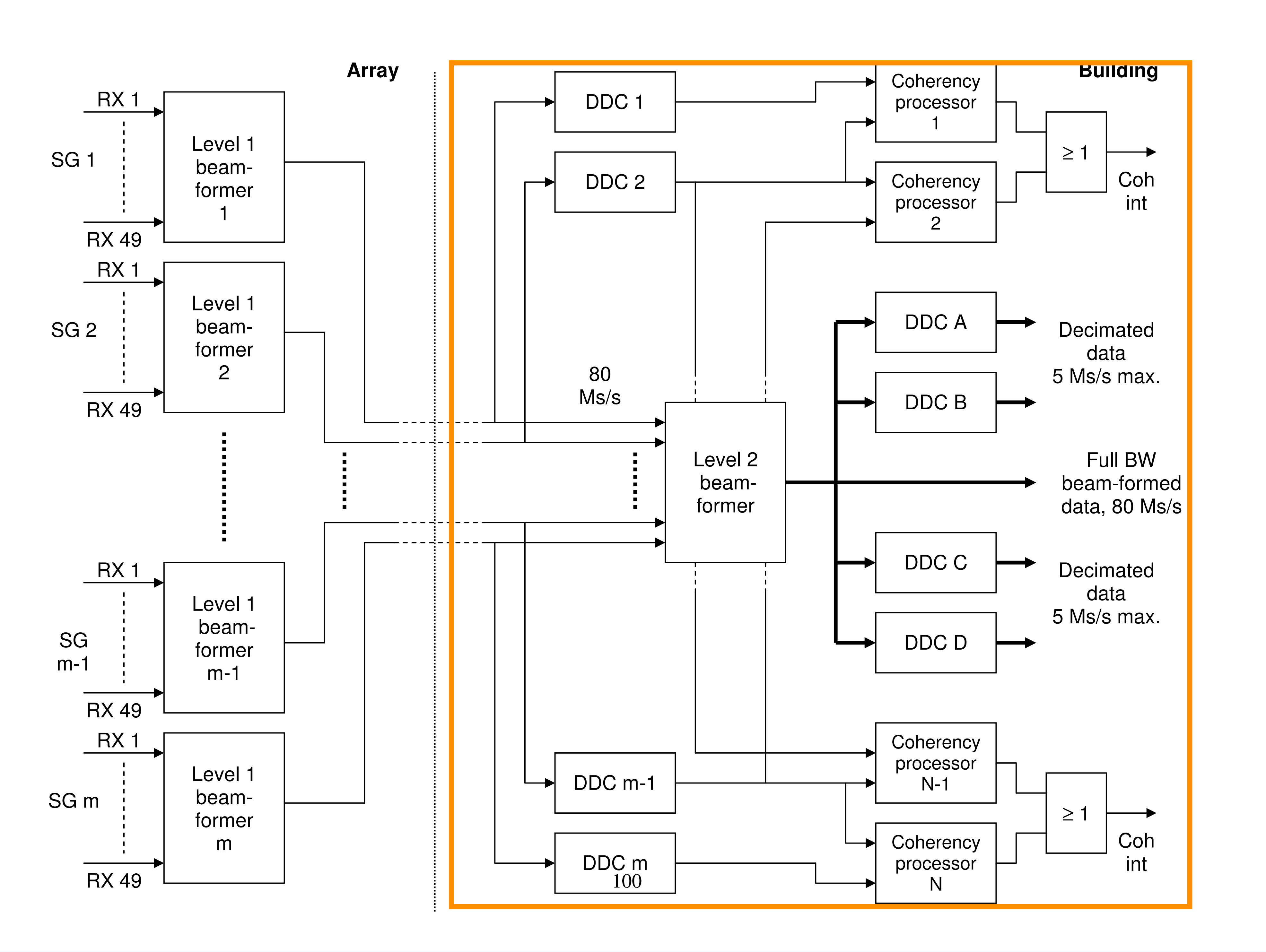
Example: Radar reflectivity map of the Moon



Possible architecture for EISCAT_3D



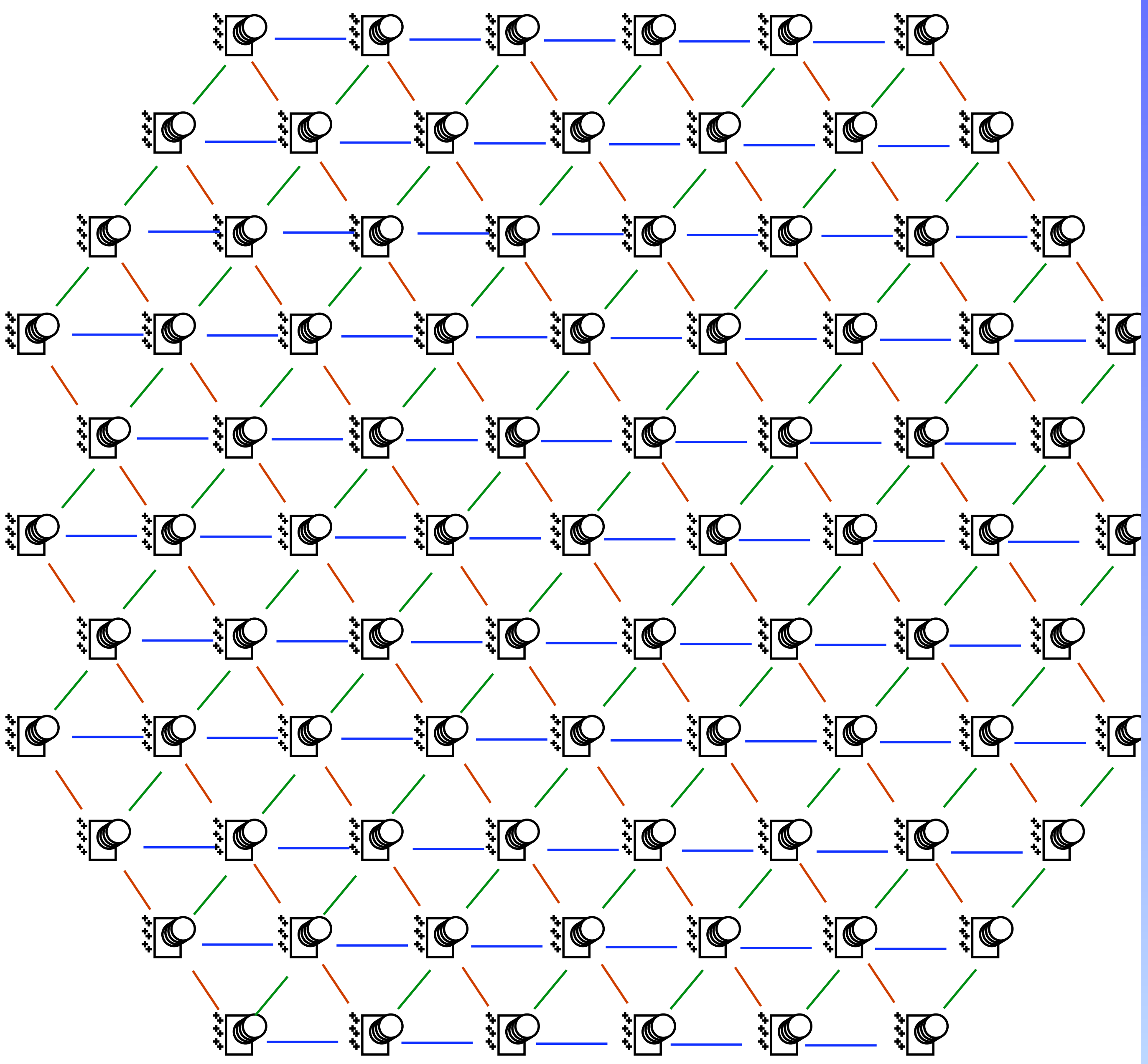
What about the level 2 beamforming



Level 2 beamforming is done in a computer network

notes

- Each Level 1 unit is connected to 6 neighbors by 10G ethernet lines.
- 3 independent streams of $10G/80M/16 \approx 7.8$ full speed data can be routed for beamforming sums.
- totalling 23 beams.
- with band-limited data, much more, eg. for 5 MHz, 8*23=184 simultaneous beams



European Strategy Forum
on Research Infrastructures

ESFRI

The EUROPEAN Next-Generation Incoherent Scatter Radar proposal EISCAT_3D was accepted on the ESFRI Roadmap of Large-Scale European Research Infrastructures for the next 20-30 years.

The Svalbard Integrated Arctic Earth-Observation System SIOS was also accepted to the ESFRI Roadmap. ESR is an essential part of SIOS.

EUROPEAN ROADMAP FOR RESEARCH INFRASTRUCTURES

Roadmap 2008

ESFRI

ESFRI, the European Strategy Forum on Research Infrastructures, acts on issues related to the development of high scientific quality European research infrastructures.

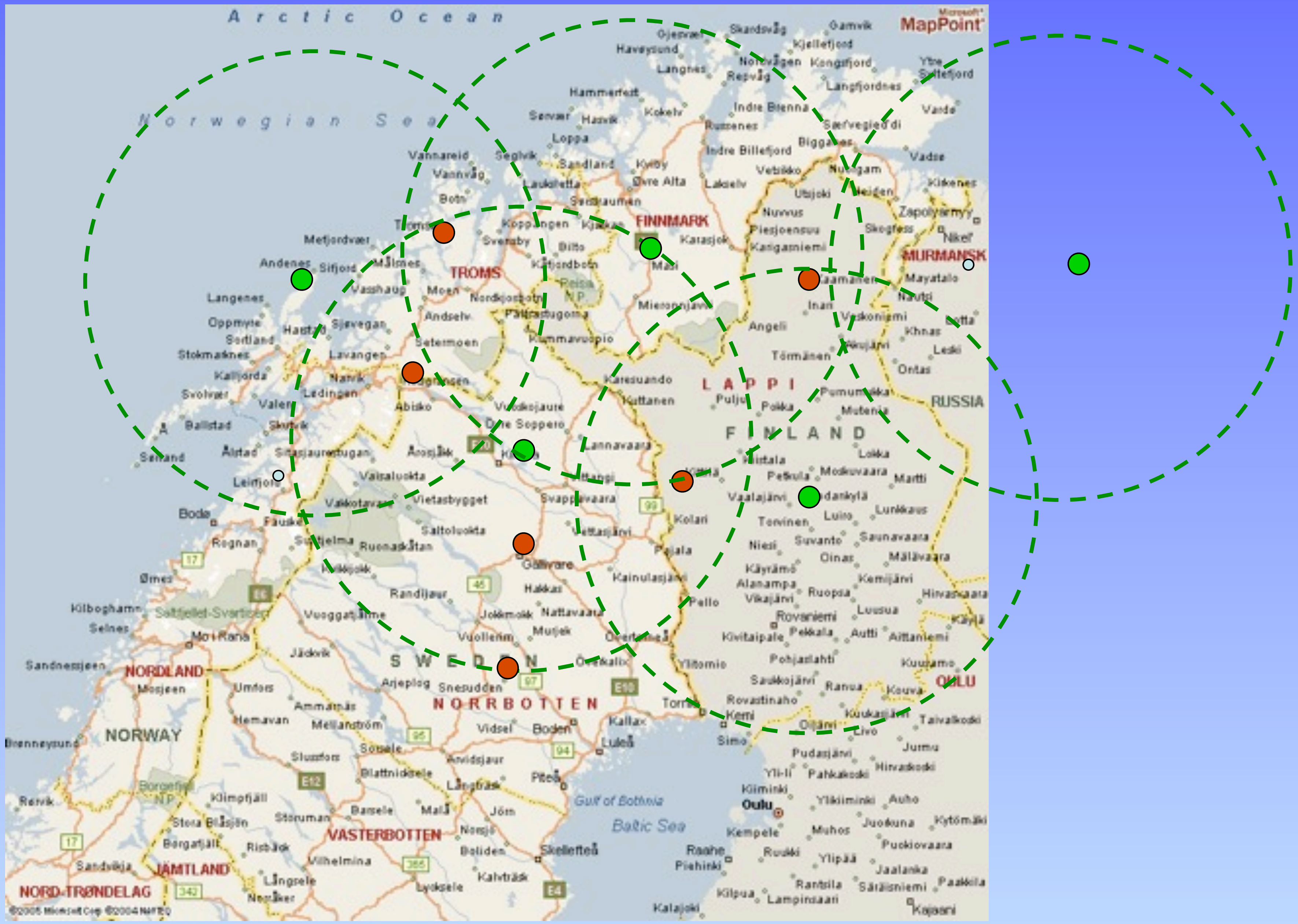
- Delegates nominated by the Research Ministers of the Member States and Associated Countries
- Includes a representative of the European Commission
- The Swedish Research Council proposed EISCAT_3D on the ESFRI Roadmap
- ESFRI accepted the proposal in December 2008.
- The ESFRI EISCAT_3D proposal emphasizes modular construction of a large distributed radar facility, with a possibility to have several active sites in the final concept.
- The timeline and rough cost estimate proposed for the ESFRI EISCAT_3D is given below:

Timeline:	Preparatory phase 2009-2011	
	Construction phase 2011-2015	
	Operation 2015-2045	
Estimated costs:	Preparation:	6 M€
	Construction:	60 M€ one active site
		250 M€ all sites
	Operation:	4-10 M€/year
	Decomissioning:	10-15% of construction

Website: http://www.eiscat3d.se/

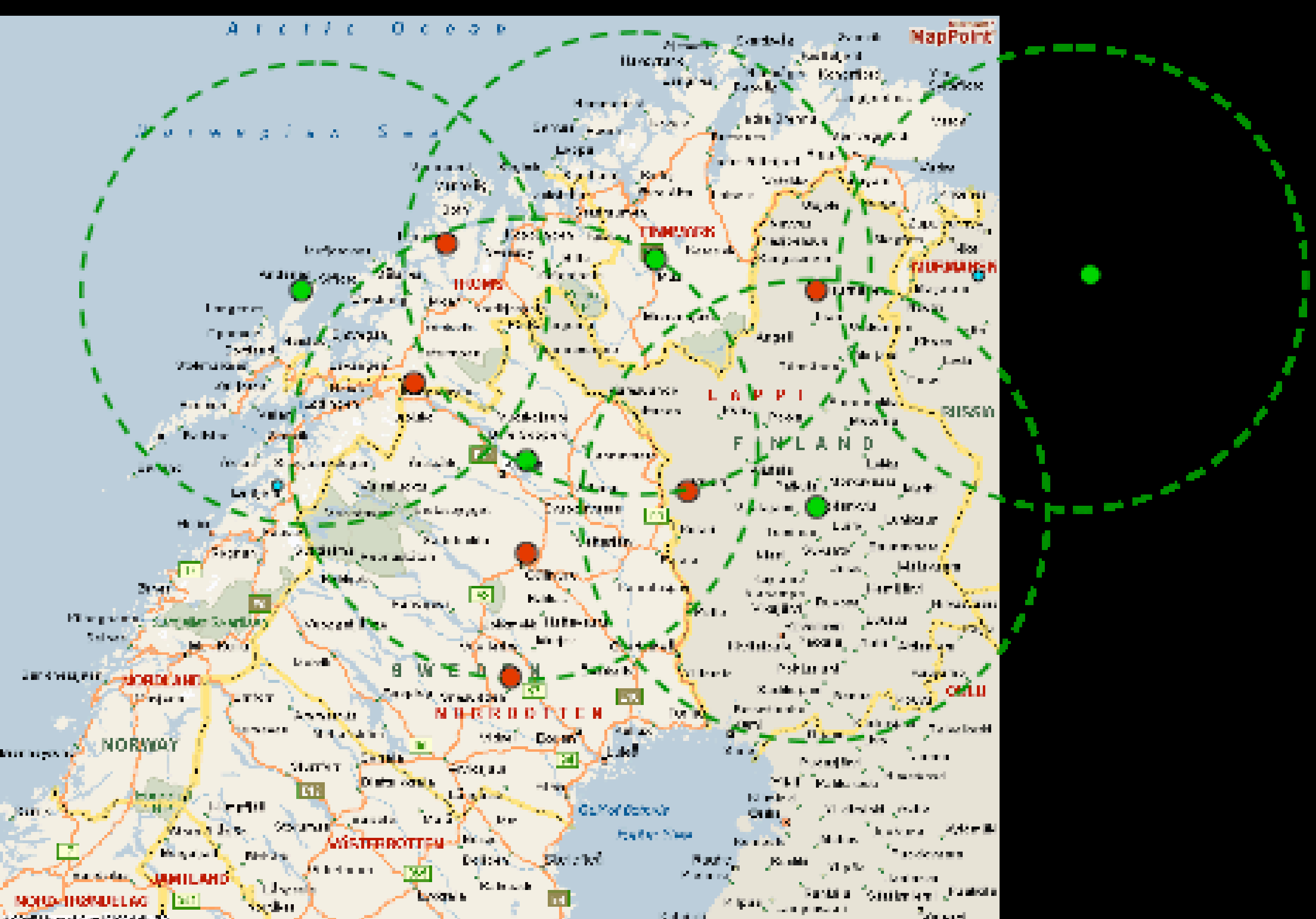
Modular construction:

- WE CAN THINK BIG HERE! Several active sites!

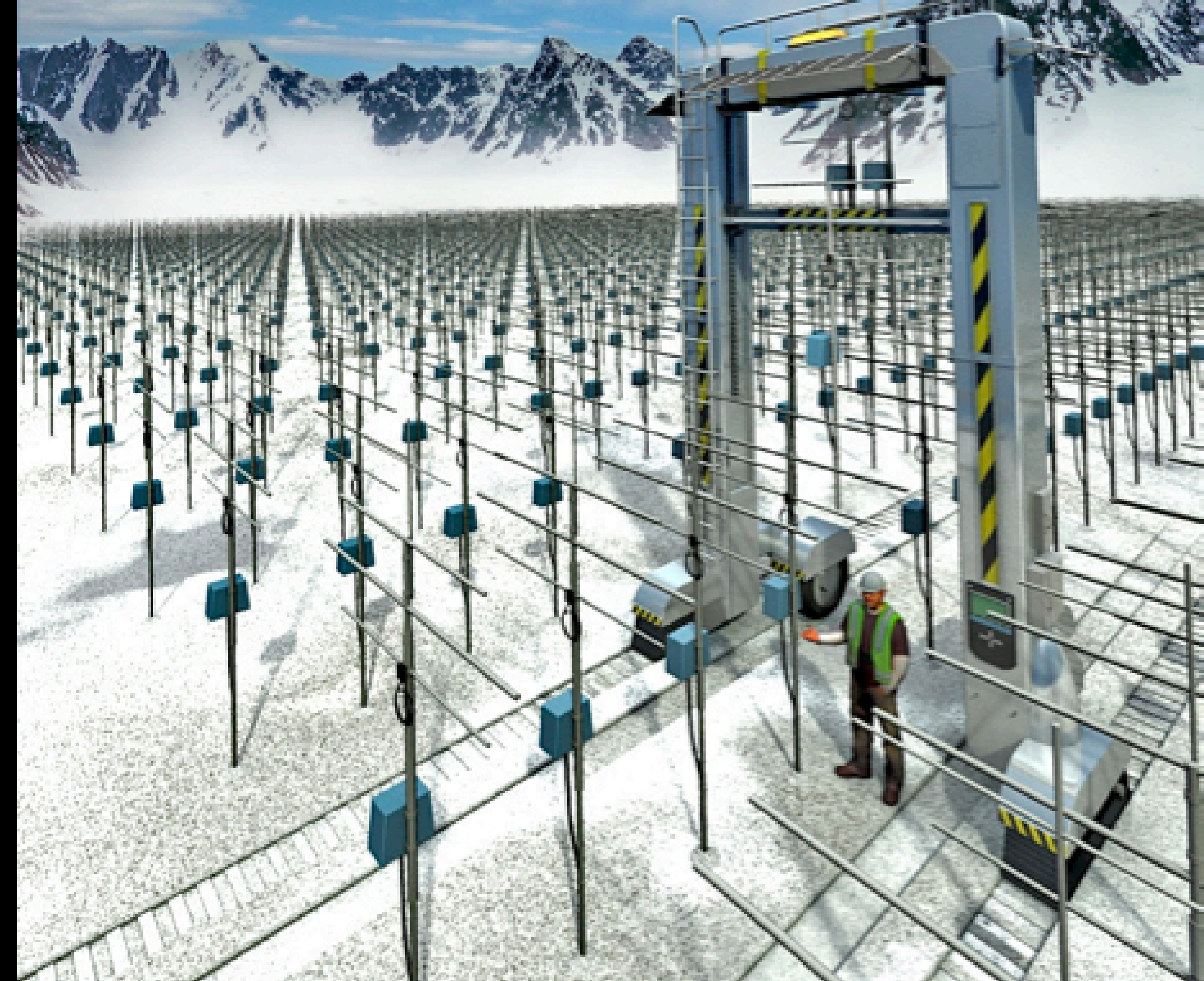


EISCAT 3 D

- Design Study 2005-2009
- Implementation studies 2010-2012
- Construction 2013-2015
- Operation 2015-2045



- Modular construction
- Site locations need to be considered carefully
- Sites may be very different in size and purpose
- WE COULD ALSO THINK OF A MID-LATITUDE SITE



EISCAT_3D Design Study finished 30.4.2009

Documents were submitted to EU, June 2009

National applications:

- Swedish universities' joint national infrastructure application 29.4.2009
  - 2 receiver sites
  - one small Tx/Rx
- Norwegian users sent application 4.6.2009
  - 2 MNOK
  - for preparatory studies
- Finnish users sent application 23.9.2009
  - 400 000 EUR
  - prototyping a software radio and distributed computing solution in 50 MHz radar
  - converting 32m dish to an atmospheric radar

Norwegian government published 12.3.2009 their development programme for Northern Areas

They explicitly mention the need to construct EISCAT 3 D

Unique science opportunity in order to answer important fundamental questions:

- Energy input from solar wind -> magnetosphere ->ionosphere
- Solar variability effects in the atmosphere in the Arctic
- Coupling of atmospheric regions
- Turbulence in the neutral atmosphere and space plasmas
- Dust and aerosols in upper atmosphere
- Ion outflow at high latitudes

EISCAT_3D + EISCAT Svalbard Radar
+existing infrastructure (Andoya, Esrange,SIOS, Heating, Radar, Lidar, Riometer, Magnetometer, GPS, Tomography receivers, etc.)

European
Window to Geospace in Northern Scandinavian Arctic

Get involved in EISCAT_3D!

Nothing is set in stone yet – the present proposal is a draft and can easily be changed at this stage.

We need to submit an EU FP7 application at the beginning of December, for the preparatory phase of the ESFRI project in 2010-2013.

Note for HEPPA community: The ionisation rates will be measured in the whole atmosphere, in a large geographical area, with high resolution, as a 3D image!