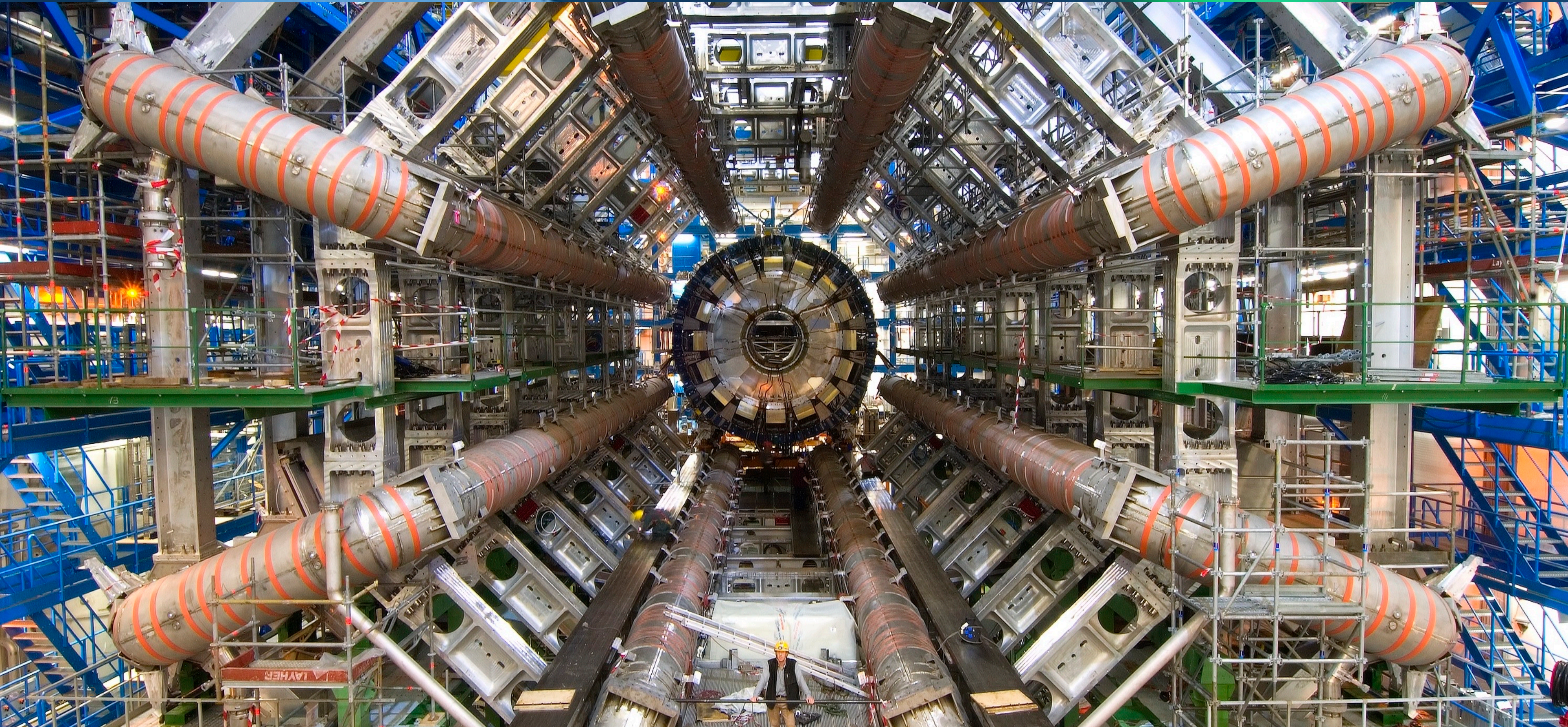
TERABIT TO THE TUNDRA

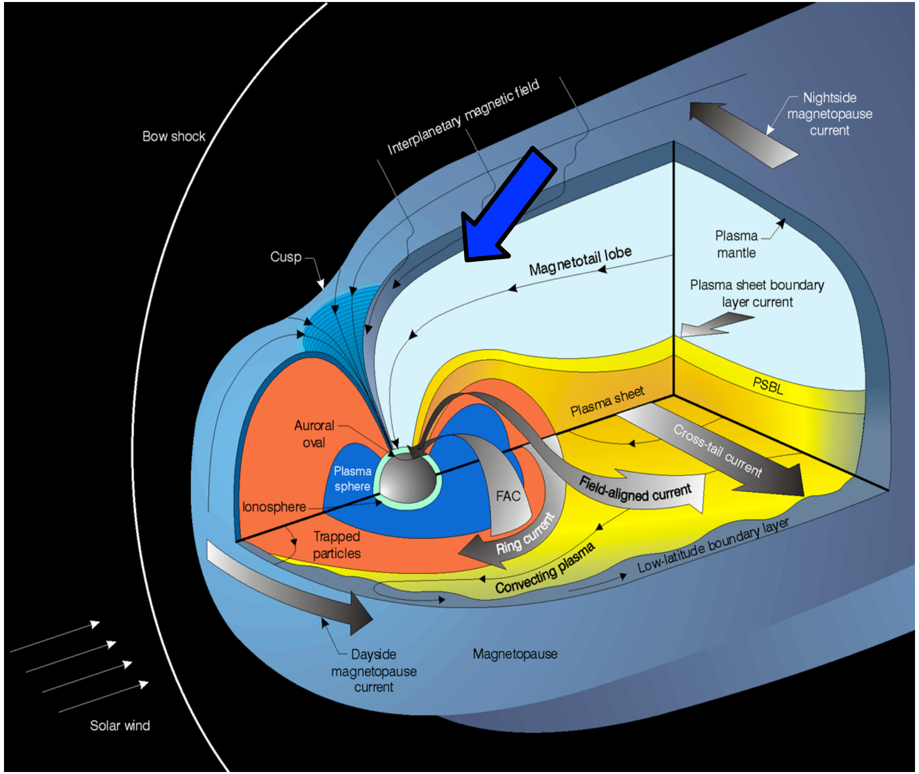
Anyone, anywhere, any time.

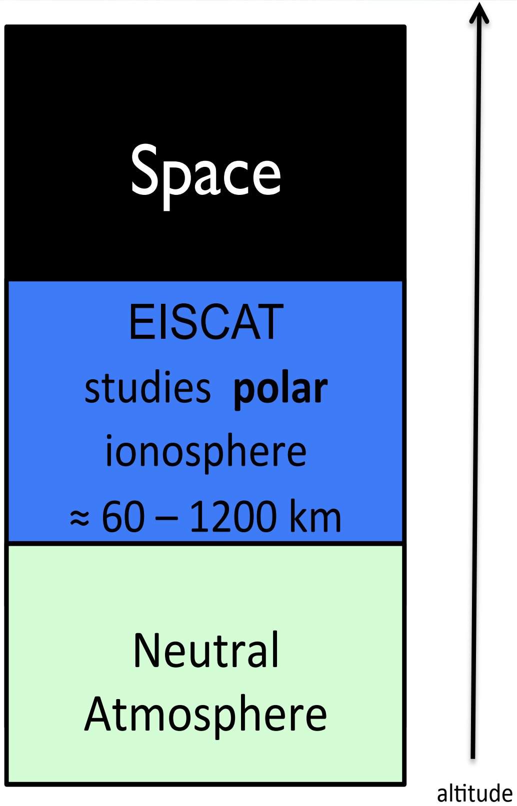
Research is **completely unconstrained** by the physical location of instruments, computational resources, or data

Big Science

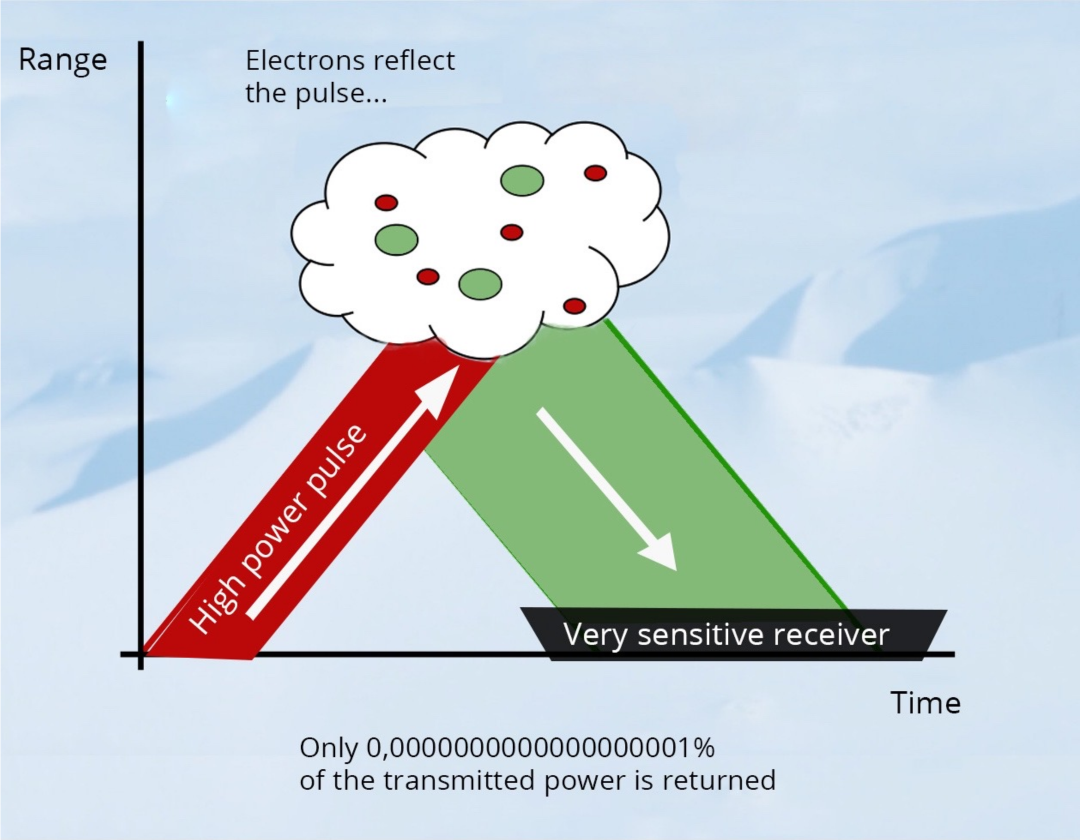


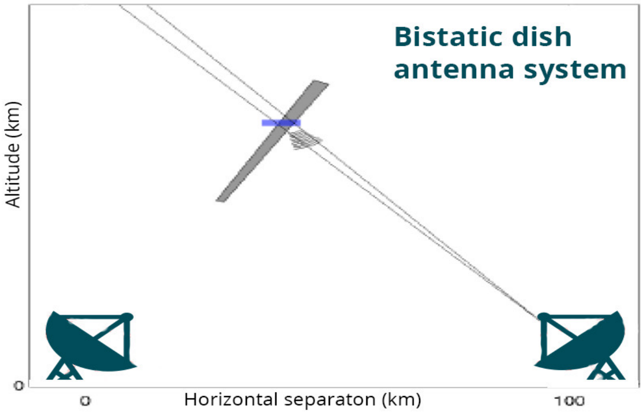
How is earths atmosphere coupled to space?

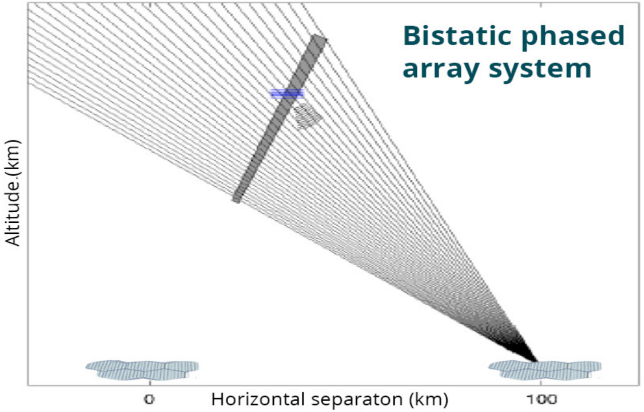




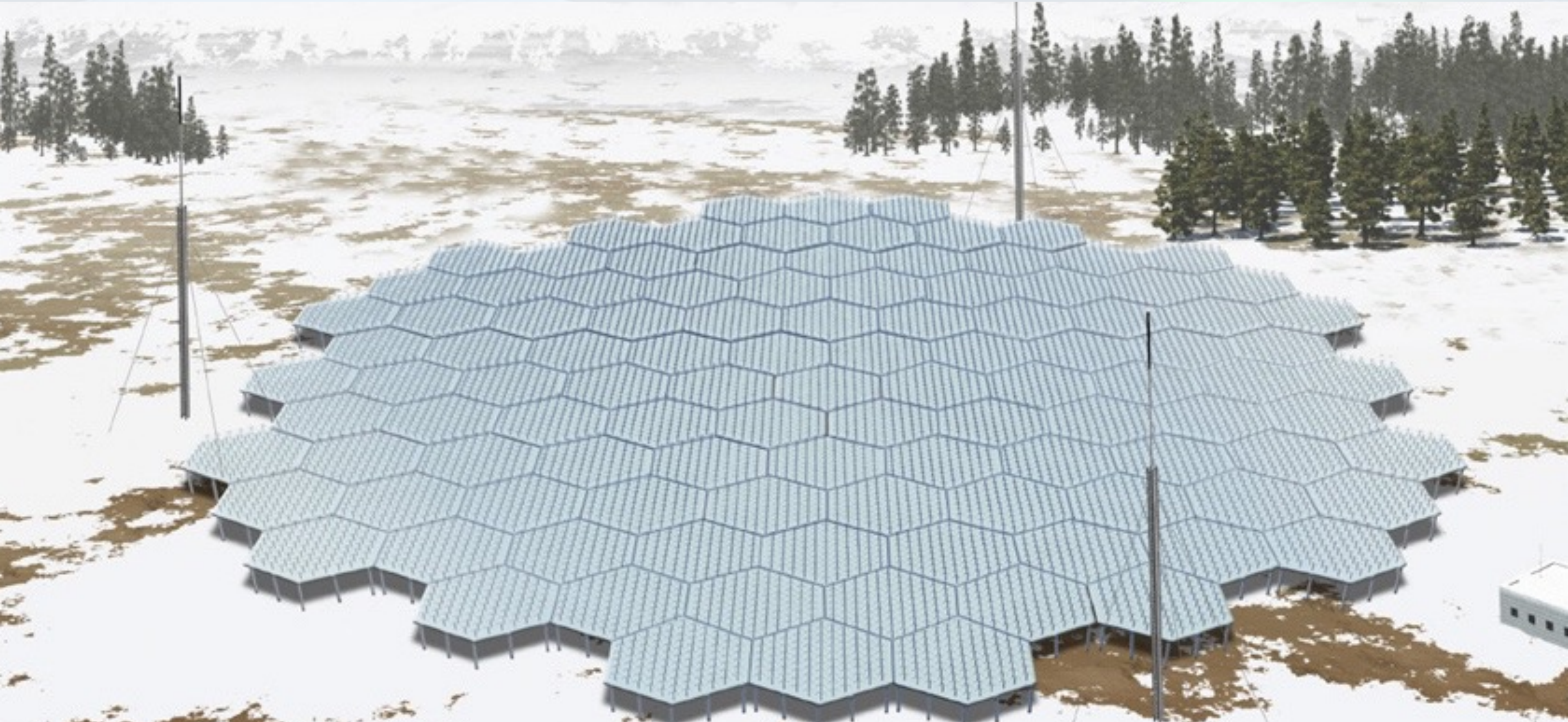
Incoherent scatter radar







EISCAT-3D



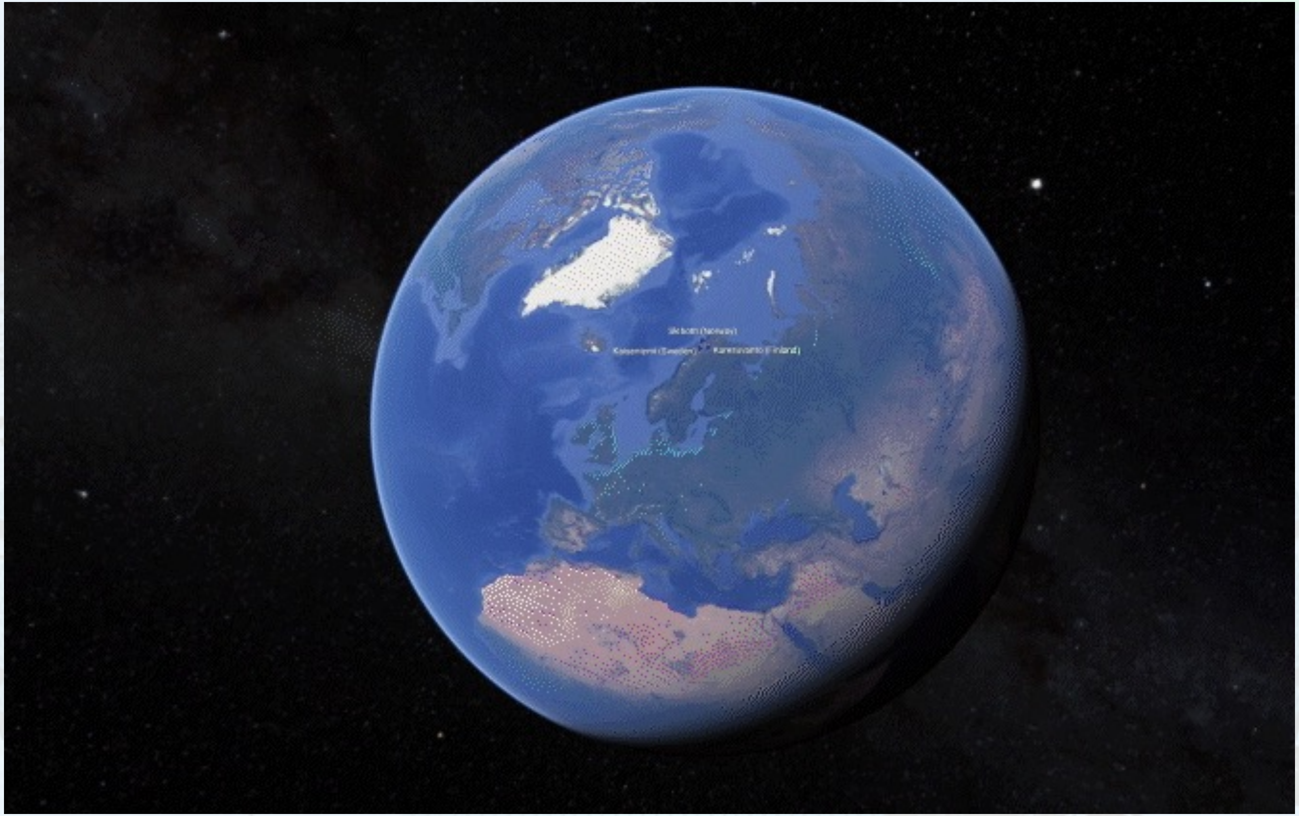
Applications

- Ionosphere studies
- Space weather studies, forecasting
- Space debris tracking
- Auroral observation
- Meteor studies
- Planetary imaging
- Many applications in collaboration with other instruments, satellites, etc.

EISCAT-3D Site

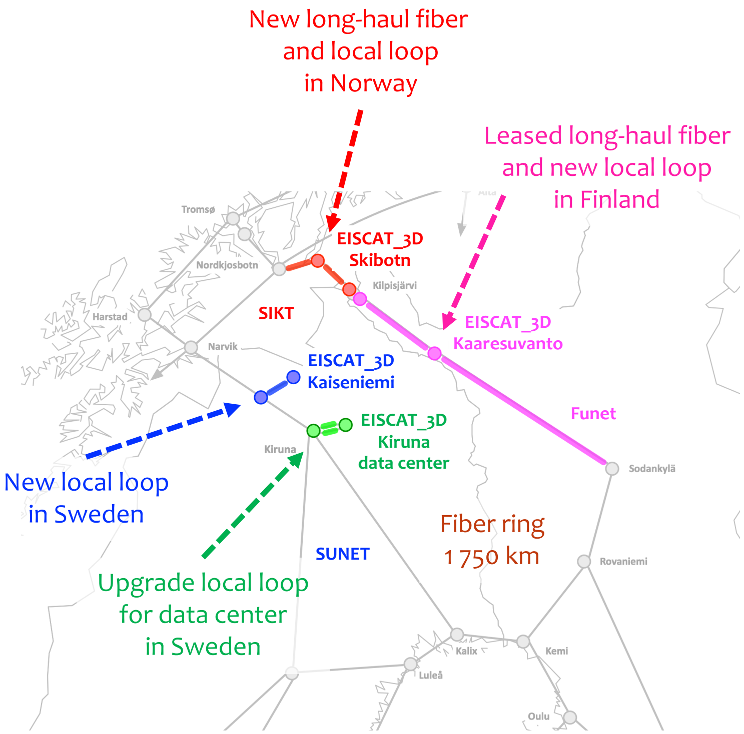
Images: EISCAT Scientific Association

Networking



EISCAT_3D and fiber networks in the arctic region

- Joint project between EISCAT, NORDUnet and the Nordic NRENs in Finland (Funet), Norway (SIKT) and Sweden (SUNET)
  - Including the authors, a lot of our colleagues have involved in planning and implementation stages
- Three antenna sites with 2 optional locations in Norway and Sweden
  - **Skibotn**, Norway, **transmitter** and **receiver** site
  - **Kaiseniemi**, Sweden, **receiver** site
  - **Kaaresuvanto**, Finland, **receiver** site
- Separate data center location somewhere within the region
  - Later **Kiruna**, Sweden was chosen
- None of the antenna sites had fibers available
  - Required building new local loops and building or leasing fibers for the missing long-haul routes
- Fiber ring to avoid extensive service breaks
  - Difficult to fix issues in winter times due to harsh weather
  - Reuse existing fiber topologies where available
  - Flexibility to serve multiple potential data center locations



Network architecture – the beginning

- Network planning started in 2015 together with the NRENs and EISCAT
  - Original EISCAT_3D architecture based on computing at the sites
  - Bandwidth requirements up to **53 Gbps** per site after local process computing
- Services to be offered with IP/MPLS networks
  - Traditional design with router-to-router connections at the border locations
  - Router connectivity to each antenna site
  - Extensive use of backbone links which need to be upgraded as well
- NRENs were using optical line systems from 2000s
  - Designed for 10G with dispersion compensation but 100G possible
  - Fixed-grid and on some spans very limited spectrum available
  - Vendor lock-in with capacity licencing

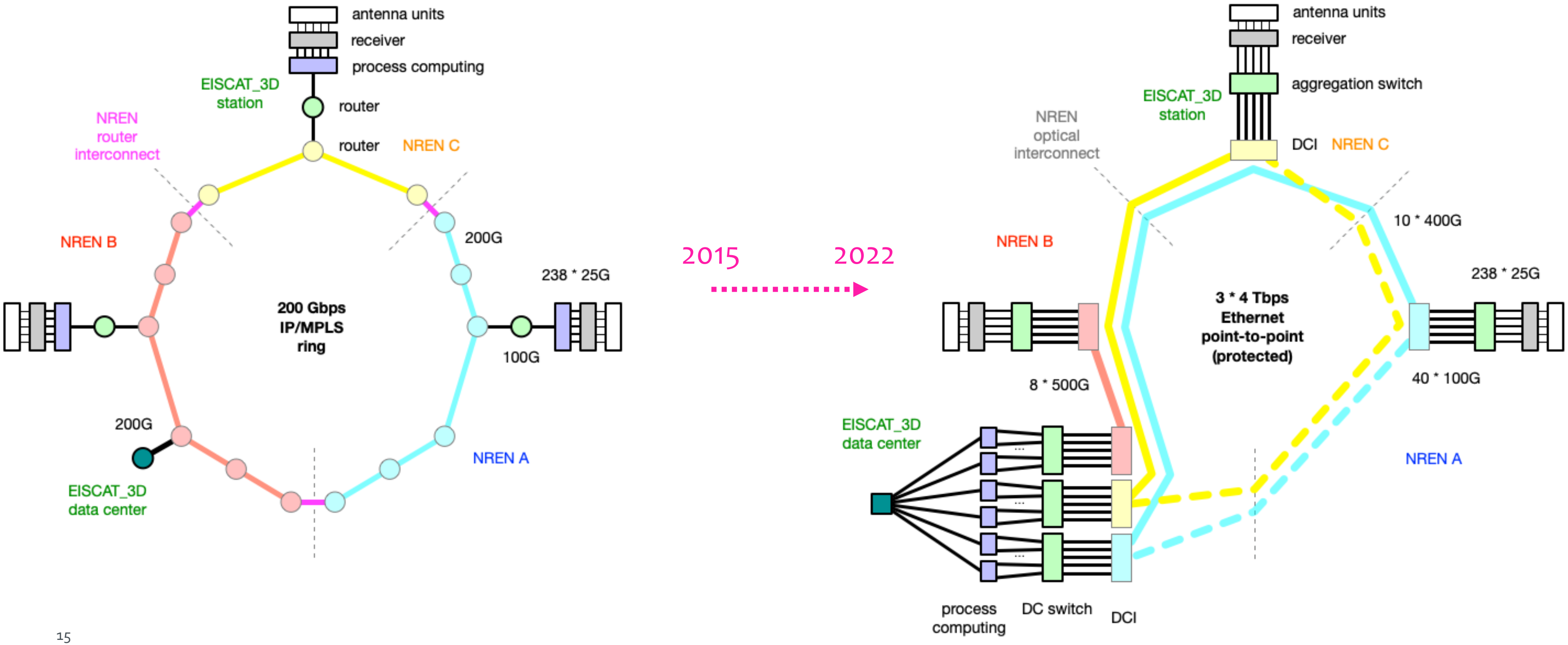
Network architecture – open optical line systems

- During the project existing optical systems started to reach end-of-life
  - Need for new optical line systems to replace the older systems
- SUNET began with their renewal in 2016
  - **Very high OSNR** with hybrid EDFA/Raman amplification
  - **Gridless** spectrum
  - **Open** line system with **licensing-free** spectrum
- Later other NRENs decided to follow the model
  - Economical and technical limitations were practically gone
- Huge development with transponders driven by cloud giants
  - Disaggregated DCIs, up to 600+G line interfaces
  - Significant cost reduction

Network architecture – "Terabit to the Tundra" model

- First proposals to change the original IP/MPLS model
  1. Separate Ethernet ring between the sites and the data center with domain-specific waves
     - No need to upgrade backbone IP routers and links
  2. End-to-end Ethernet connectivity to the data center with alienwaves across the borders
     - Even less waves needed
     - Possibility for optical protection
- But terabit-era was closing, could we refresh the model altogether?
  - Data received directly from the receivers to a single computing location would give big benefits for analysing stage
  - Receivers have Ethernet interfaces and could be transported
  - Increases transmission costs but decreases operational and equipment costs on sites
- EISCAT_3D project scientists were interested about the idea
  - TCO estimates were calculated based on existing DCIs available
  - And eventually it was accepted and chosen

Network architecture – evolution towards terabit



Network architecture – "Terabit to the Tundra" challenges

- "Terabit to the Tundra" model challenges
  - Receivers in EISCAT_3D can generate up to 4 Tbps data rates from each site
    - Need for serious amount of transmission capacity and spectrum
  - Commitment from the NRENs to provide THz level spectrum for the project
- Operation in multi-layer and -domain environments
  - Optical line systems are operated independently by NRENs
  - Transport and optical protection are operated jointly by involved NRENs
  - Packet network is operated by EISCAT
- Monitoring in multi-layer and -domain environments
  - Transport and packet layer metric collection by Streaming Telemetry and/or SNMP
  - Feed metric data to common time-series database and dashboard frontend
  - Later to extend to cover the line systems as well?

Network architecture – packet network

- Will be planned, acquired and managed by EISCAT
- Antenna sites
    - Receiver is transmitting up to 2 x 16 Gbps data streams through 2 x 25 GbE interfaces
    - Switches will aggregate 6 x 16 Gbps data streams into a 100 GbE transport interface
- Kiruna data center
    - Two options, not decided yet:

1. Via switching layer (100 GbE only) to steer traffic to the computing nodes
2. Directly from the transport to the computing nodes

- Most probably no need for deep buffering
    - Continuous data rate, no transforms from higher to lower speeds

Network engineering – optical network design

- Transparent optical interconnects between the networks
  - ROADM-to-ROADM interconnects to pass signals
  - Services logically terminated at the border
- Signal power equalisation between the domains
  - Signals are always online via both optically protected routes
  - Automatic or manual equalisation?
- Transponders and add-drops
  - Tx side filters to keep high launch OSNR in colorless add-drop
  - Receive power level optimised with amplifiers
- Conservative spectrum planning for the services
  - 100 GHz per 400G CP-16QAM (~ 70 Gbaud) : 1 THz per 4 Tbps
  - Could be 87,5 GHz or 75 GHz if performance is good enough: 0.75 THz per 4 Tbps

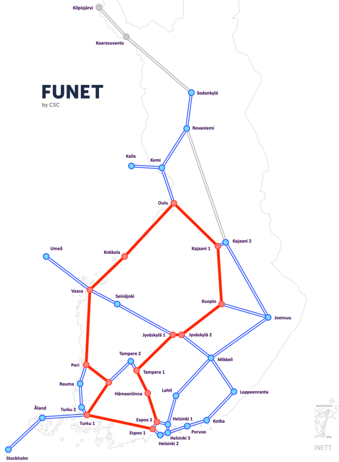
Network engineering – capacity and reach

- All line systems designed to provide high OSNR
- Total OSNR estimated as the ring is not yet online
  - Performance tested with similar transponders over different routes
  - Primary routes relatively short: enough margins
  - Secondary routes (up to 1300 km): lower margins but should be in safe side
- Either 400G or 500G waves are used
  - 400G: Skibotn - Kiruna (primary 450 km, secondary 1 300 km)
  - 400G: Kaaresuvanto - Kiruna (primary 600 km, secondary 1 150 km)
  - 500G: Kaiseniemi - Kiruna (125 km)

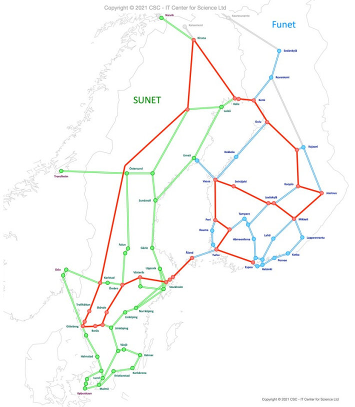
Network engineering – testing line system performance

- Nordic NRENs have performed intra-domain and multi-domain tests to evaluate optical line systems’ performance
  - All tests done close to the specified equipment limits
  - Will give better estimates about the achievable reach
- Short term (hours or days) stability
  - 500G CP-32QAM (69 Gbaud) @ 125 HGz channel, over 500 km
  - 400G CP-16QAM (69 Gbaud) @ 125 GHz channel, over 2 500 km
  - 2 x 200G CP-QPSK (69 Gbaud) @ 150 GHz channel, over 7 000 km
  - 2 x 200G CP-QPSK (69 Gbaud) @ 100+100 GHz channels, over 10 000 km
  - 300G CP-8QAM (69 Gbaud) @ 125 GHz channel, over 4500 km
- Long-term (weeks) stability
  - 2 x 400G CP-16/32QAM hybrid (67 Gbaud) @ 150 GHz channel, over 1 900 km

Funet
2 * 400G
1900+ km
4+ weeks



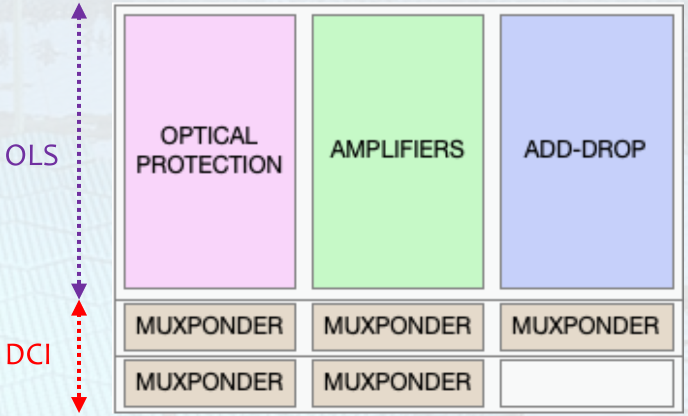
Funet+SUNET
2 * 200G
10 000+ km
few hours



Building the system – equipment

- Transport and protection models were designed by NRENs
  - Only mandatory requirements
  - TCO over 10 year period used to differentiate alternatives
  - Return-to-factory support and own spares to drive costs down
  - Separate network management system to enable joint operation
- Three separate 4 Tbps point-to-point systems
  - Total capacity 12 Tbps
- 4 Tbps point-to-point system configuration (ADVA)
  - OLS platform: optical protection, amplification and add-drop
  - DCI platform: muxponders (max. 2 * 600G per module)
  - 40 * 100GbE LR4 client interfaces towards the packet network
- DCI based transport is very compact and energy efficient
  - 2 RUs for 4 Tbps
  - Less than 3 kW (typical) power consumption per 4 Tbps link

Transport node in EISCAT_3D sites



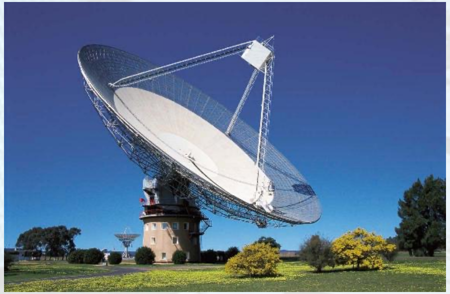
Building the system – site status

- Instruments has been already tested in the test subarray
- Serial production of antenna fields has been finalised
- Instrument production ongoing and should be ready end of 2023
- Equipment installations and commissioning
  - Optical line system extensions and transport: before end of Q4/2022
  - Transport tests: Q1/2023
  - Packet layer : 2023
  - Antenna fields: Norway autumn 2022, Finland/Sweden spring/summer 2023
  - Instruments: Norway winter 2022, Finland/Sweden summer 2023
- First measurements planned
  - Norway: early 2023
  - Full system: end of 2023

Images: EISCAT Scientific Association

Rethinking Networking for Research Instruments

- Integration of Instrument, NREN, and Data Centre networks
  - "It's not just transport anymore"
  - The network is part of EISCAT_3D
  - Helping create a more powerful instrument
  - Enabled by (improved) technology
- New options w/ DCI optical equipment
  - Tunable & High capacity, small form factor, lower cost
- Modern Data Centre and Compute Facilities
  - Hosting, Facility Management, Containerized Computing
  - Large-scale Science Storage Facilities
  - … integrated with instruments



The Role of the NREN

- Delivering the impossible
  - Terabit connectivity at 70'N
- Enabling Partnership for Science
  - Based on science workflows and the data lifecycle
  - Joint Process, NRENs included from early phases
  - Engaging the entire spectrum of e-Infrastructures
  - Helping scientists understand the possibilities
- Much more than a provider / customer relation
  - Terabit to the Tundra is a close collaboration to find the fit between research objectives and technology options
  - Taking the long view, building consensus over years
  - Transforming both the instrument and the network in the process


Thank You!
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