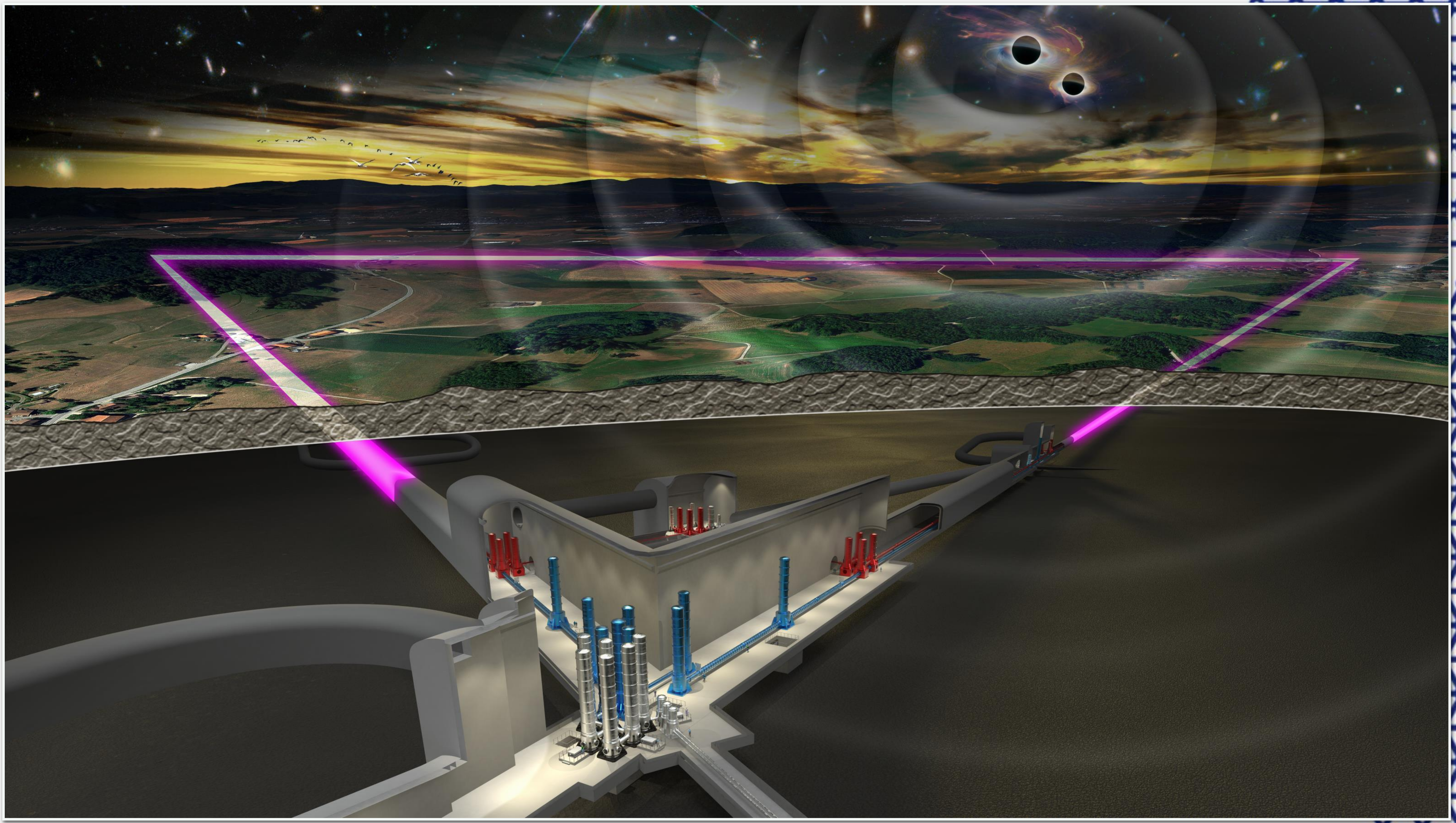


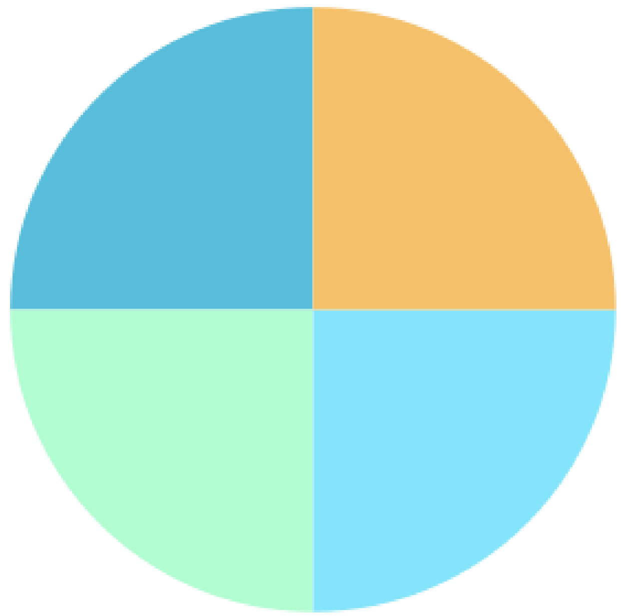
ET-EMR:
TOWARDS ROBUST AND SUSTAINABLE ET HOSTING

ET-PP meeting, Barcelona, May 5, 2026

Stan Bentvelsen (EMR) on behalf of the Project Office

ET: why in the EMR?

A mutually reinforcing system		
SCIENCE	**ECOSYSTEM**	**READINESS**
A single-sited, triangular configuration with the highest discovery potential	Integrated R&D and innovation ecosystem for the Einstein Telescope	Sustainable, future-proof infrastructure delivery
Long-term seismic robustness due to layered geology	A central high-tech region with a dense network of excellent education, research and industry	Resilient cross-border governance with strong political and financial commitment
	Europe's most accessible scientific living environment	



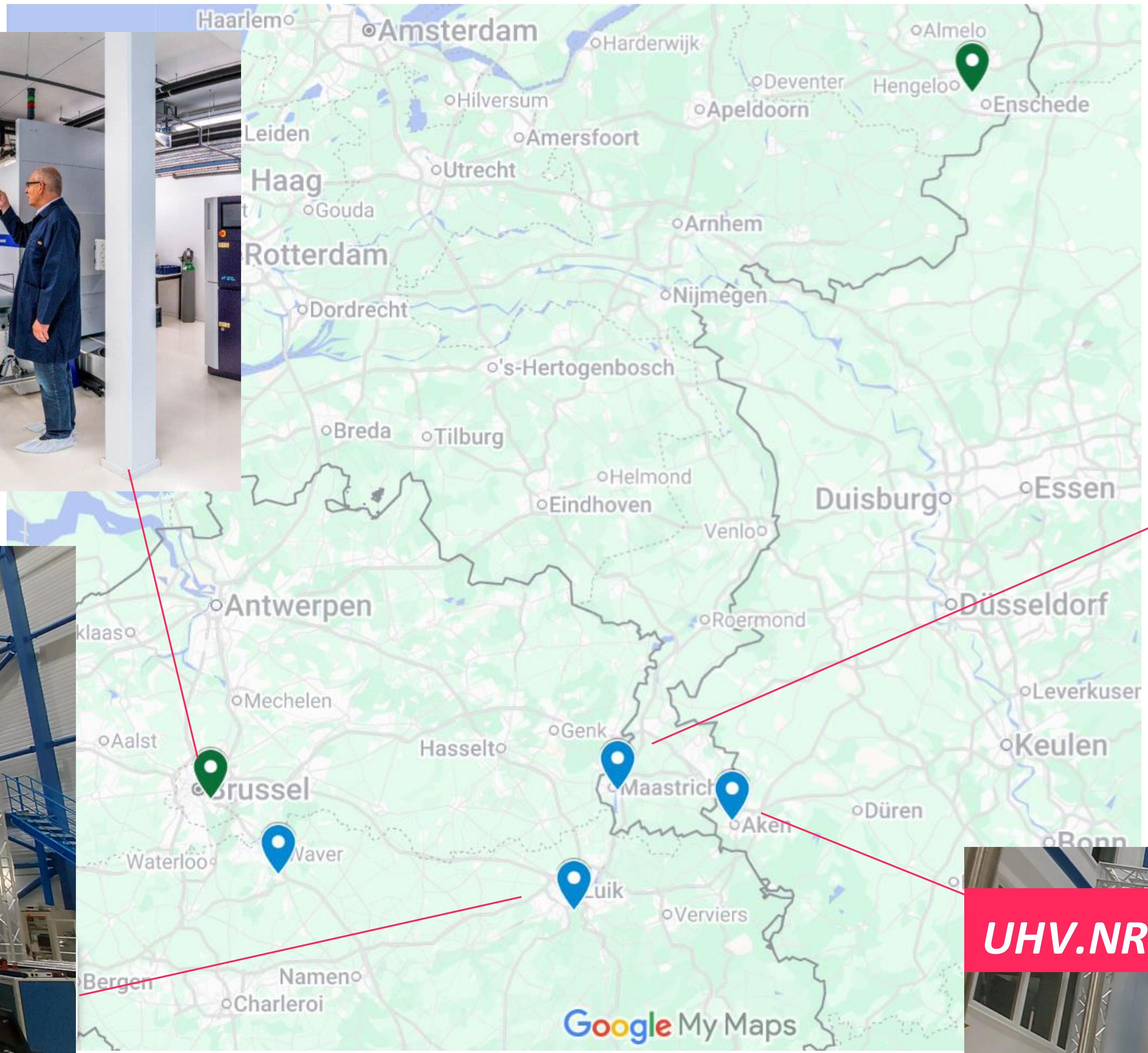
TARGETED COMMUNICATION

EMR: a mature and active R&D ecosystem

EMR hosts a large, coordinated, cross-border ecosystem with active ET contributions across science, technology, and infrastructure.

Partners involved	R&D projects since ~2019		R&D projects pending approval	
45 Institutes **95** Industry	66	139M €	11	58 M€

EMR Integration centres and R&D facilities

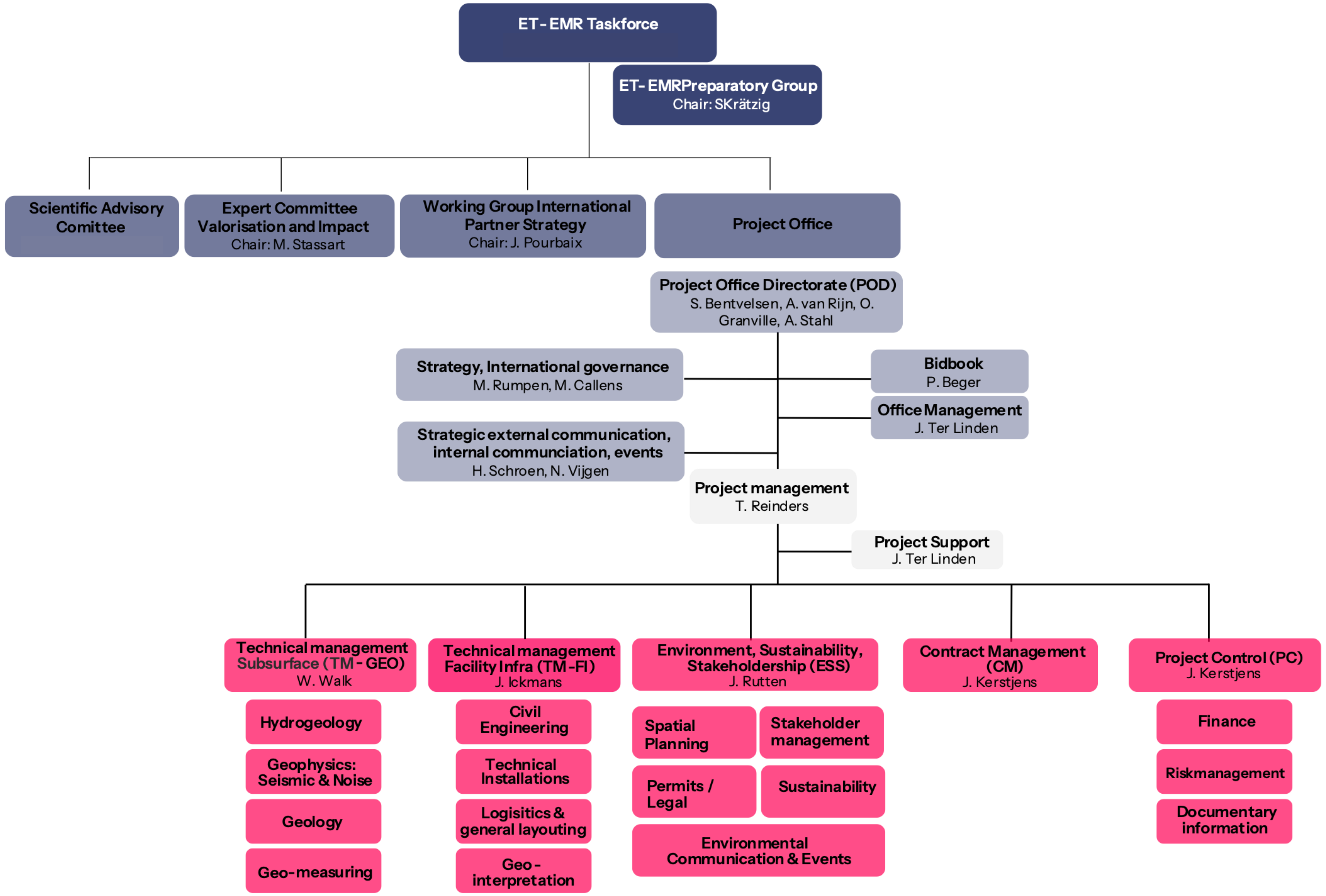


EMR industrial ecosystem

520
Companies interested to contribute

95
Companies involved in preparatory projects

Project Office EMR



Installed by ministries of the participating countries

- Continuous support with changing governments

DECLARATION OF INTENT

BETWEEN THE REPRESENTATIVES

OF THE STATES AND REGIONS IN

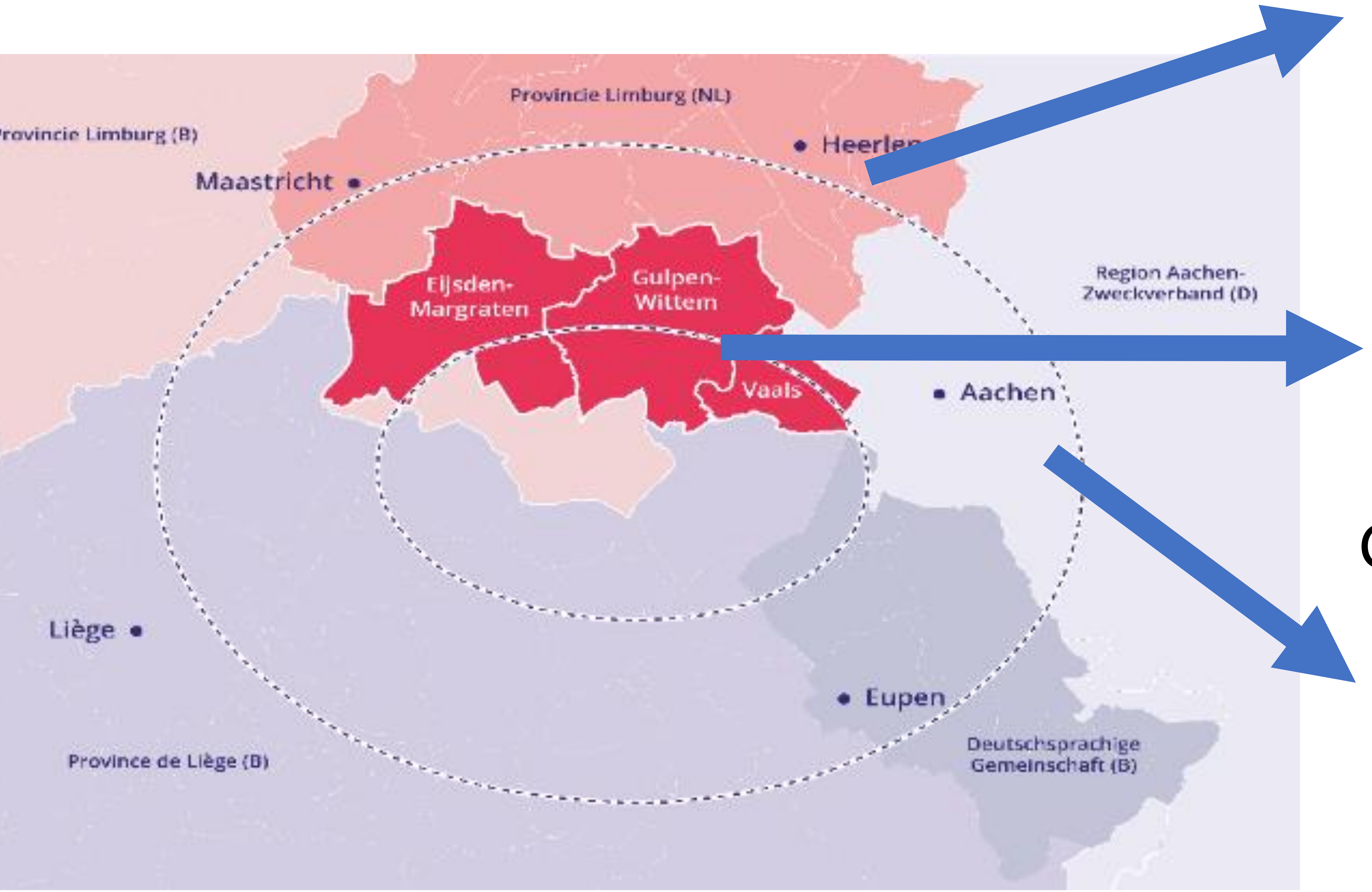
THE THREE-BORDER REGION

BELGIUM-GERMANY-NETHERLANDS

26. September 2023

In Brussels

Commitments of the EMR countries: 1.6 BE



The Netherlands;

- *Feasibility:* NGF (23 M€) and Limburg (2 M€)
- *Construction:* reservation NGF (870 M€)

Belgium;

- *Feasibility:* VL, WAL and FED (12 M€)
- *Construction:* Flanders committed 500 M€ Wallonia 200M€

Germany;

- *Feasibility:* NRW (10,9 M€) and federal (>10 M€)
- *Construction:* NRW commitment to co-finance
- National Roadmap ongoing discussions

In total more than 100 M€ for research and innovation projects in the three countries e.g. additional 16 M€ for science, valorization and education in NL

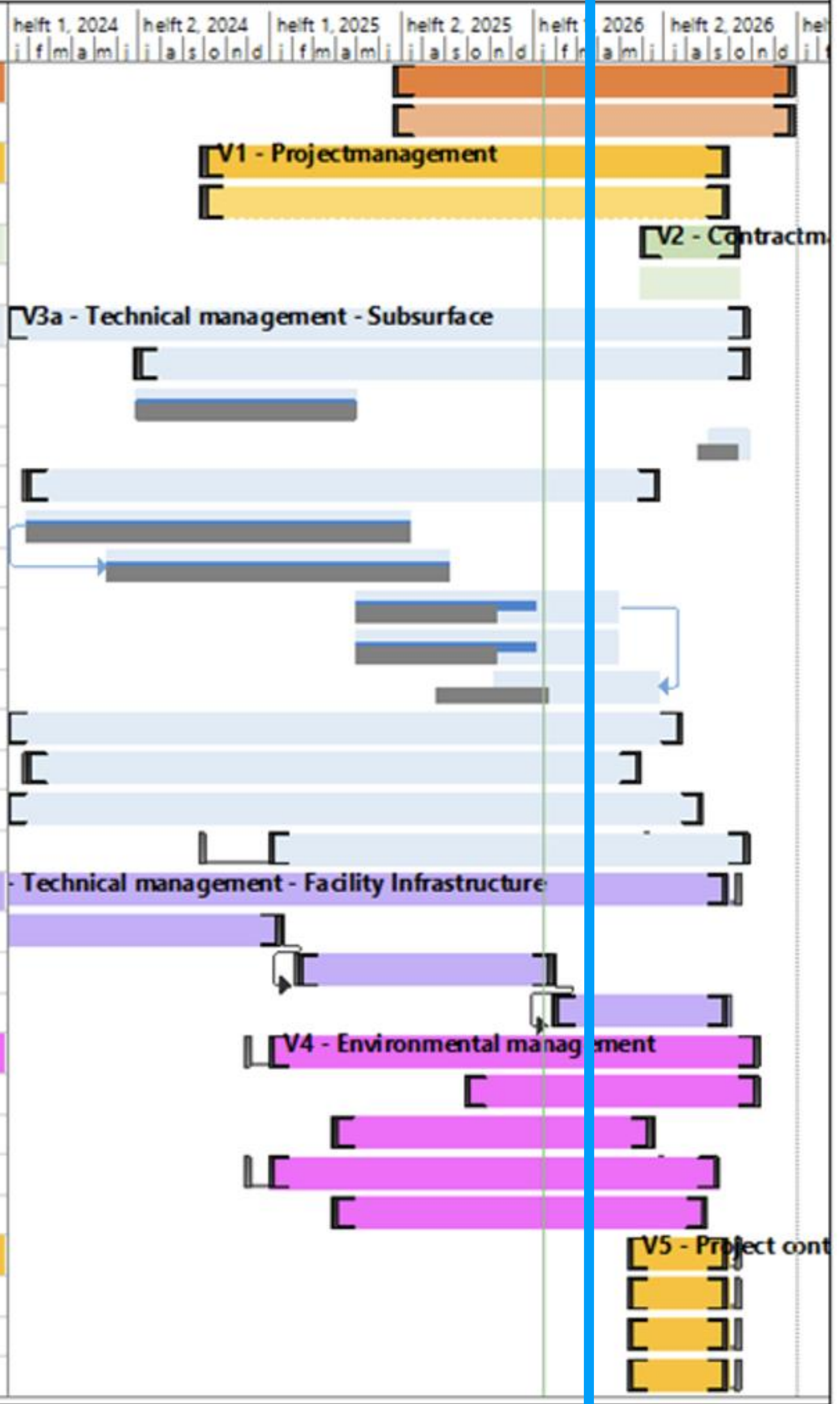
Integral planning toward feasibility/bidbook

Einstein Telescope

P5.2_003 ET-EMR Productenplanning V4.2

don 15-1-26

Id	Taakm	Task Name	Begindatum	Einddatum	Duur
1		V0 - POD	maa 23-6-25	don 31-12-26	399 dagen
2		0.10 - Bidbook	maa 23-6-25	don 31-12-26	399 dagen
6		V1 - Projectmanagement	din 1-10-24	din 29-9-26	521 dagen
7		1.20 - Continue, Unless	din 1-10-24	din 29-9-26	521 dagen
14		V2 - Contractmanagement	maa 1-6-26	vri 16-10-26	100 dagen
15		2.10.010 - Tender plan Engineering and Construction phase	maa 1-6-26	vri 16-10-26	100 dagen
16		V3a - Technical management - Subsurface	maa 1-1-24	don 29-10-26	739 dagen
17		3_0a - TM_org Subsurface	maa 1-7-24	don 29-10-26	609 dagen
18		3.0a.070 - WP08 - Geotechnical criteria - Preliminary geomechanical analysis	maa 1-7-24	woe 30-4-25	218 dagen
19		3.0a.100 - Site Characterisation Report (chapter for Bidbook)	vri 4-9-26	don 29-10-26	40 dagen
20		3.10 - Drilling campaign	din 30-1-24	vri 26-6-26	629 dagen
21		3.10.040 - DC1 Drilling campaign	din 30-1-24	maa 14-7-25	380 dagen
22		3.10.100 - DC1 End of well reports	din 21-5-24	maa 8-9-25	340 dagen
23		3.10.140a - DC2 Drilling campaign - Plot A (Core drilling)	don 1-5-25	vri 1-5-26	262 dagen
24		3.10.140b - DC2 Drilling campaign - Plot A (Doublet)	don 1-5-25	vri 1-5-26	262 dagen
25		3.10.200 - DC2 End of well reports - Plot A	maa 10-11-25	vri 26-6-26	165 dagen
26		3.20 - Hydrogeological Survey	maa 1-1-24	din 28-7-26	672 dagen
29		3.30a - Geophysics - Seismic Survey	din 30-1-24	maa 1-6-26	610 dagen
32		3.30b - Geophysics - Noise	maa 1-1-24	woe 26-8-26	693 dagen
38		3.70 - 3D-model	woe 1-1-25	don 29-10-26	477 dagen
40		V3b - Technical management - Facility Infrastructure	maa 2-10-23	woe 30-9-26	783 dagen
41		3.40 - Context Build up	maa 2-10-23	vri 17-1-25	340 dagen
47		3.50 - FI Assessment Phase	maa 10-2-25	vri 30-1-26	255 dagen
55		3.60 - FI Concept design	maa 2-2-26	woe 30-9-26	173 dagen
61		V4 - Environmental management	woe 1-1-25	don 12-11-26	487 dagen
62		4_0 - OM_org	woe 1-10-25	don 12-11-26	292 dagen
65		4.10 - Stakeholdership	din 1-4-25	woe 17-6-26	317 dagen
69		4.20 - Environment Planning	woe 1-1-25	don 17-9-26	447 dagen
89		4.40 - Sustainability	din 1-4-25	din 1-9-26	371 dagen
98		V5 - Project control	don 14-5-26	woe 30-9-26	100 dagen
99		5.20 - Financial Plan Construction phase	don 14-5-26	woe 30-9-26	100 dagen
101		5.30 - Project Planning Construction phase	don 14-5-26	woe 30-9-26	100 dagen
103		5.40 - Risk register	don 14-5-26	woe 30-9-26	100 dagen



Project: P5.2_003_Productenpla
Datum: don 15-1-26

Baseline Milestone	Samenvatting	Handmatig taak	Alleen einddatum	Voortgang, handmatig	
Baseline Summary	Projectsamenvatting	Alleen duur	Externe taken	Baseline	
Taak	Inactieve taken	Handmatige samenvatting	Externe mijlpaal		
Splitsing	Inactieve mijlpaal	Handmatige samenvatting	Deadline		
Mijlpaal	Inactieve samenvatting	Alleen begindatum	Voortgang		

Overal working plan setup including e.g. quartly reporting

Directorate

Bidbook activities

Project Management

Contractmanagement

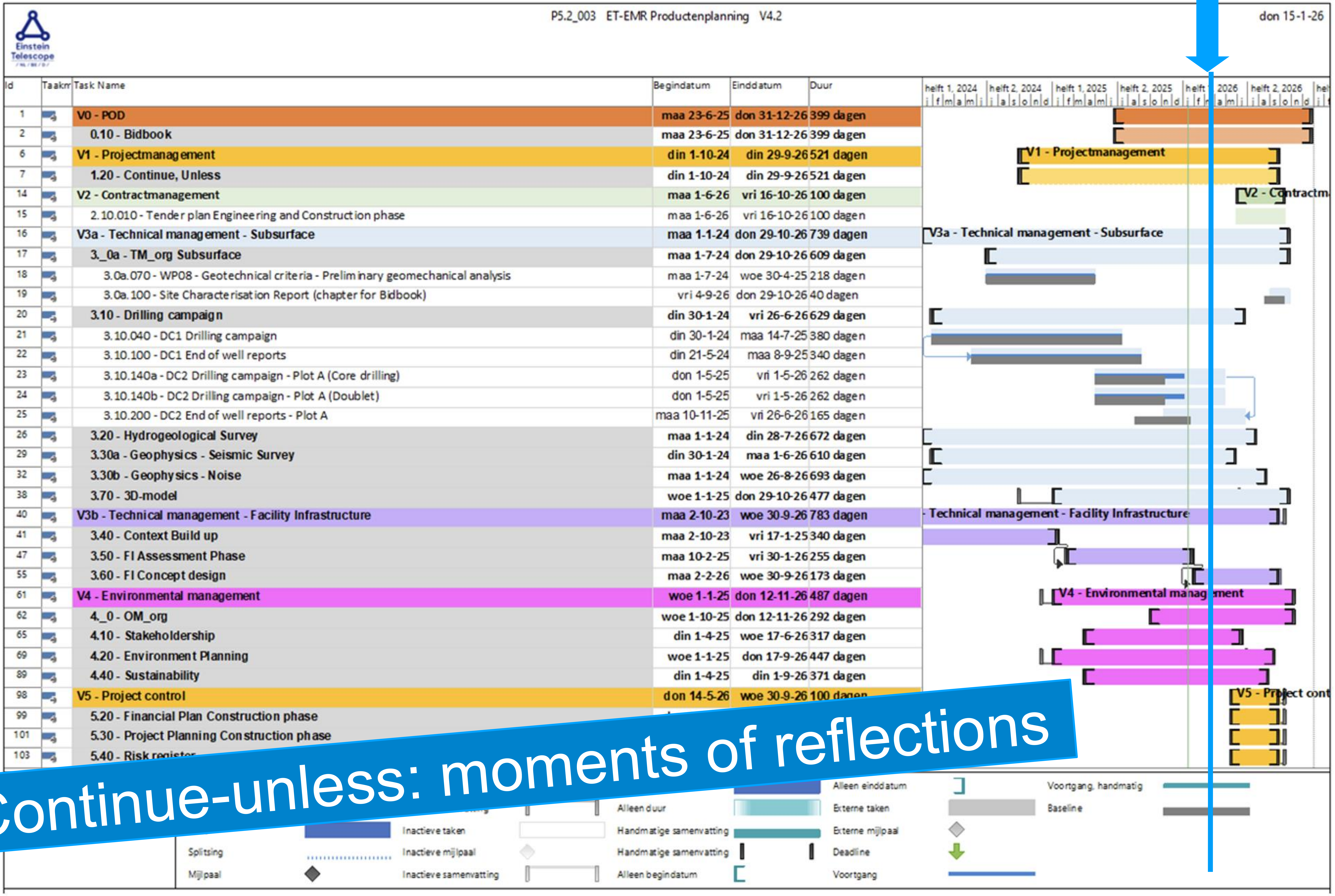
Technical Management-subsurface

Technical Management-Facility Infrastructure

Environment management

Project Control

Integral planning toward feasibility/bidbook



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Overal working plan setup including e.g. quartly reporting

Directorate

Bidbook activities

Project Management

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Technical Management-subsurface

Technical Management-Facility Infrastructure

Environment management

Project Control

Continue-unless: moments of reflections

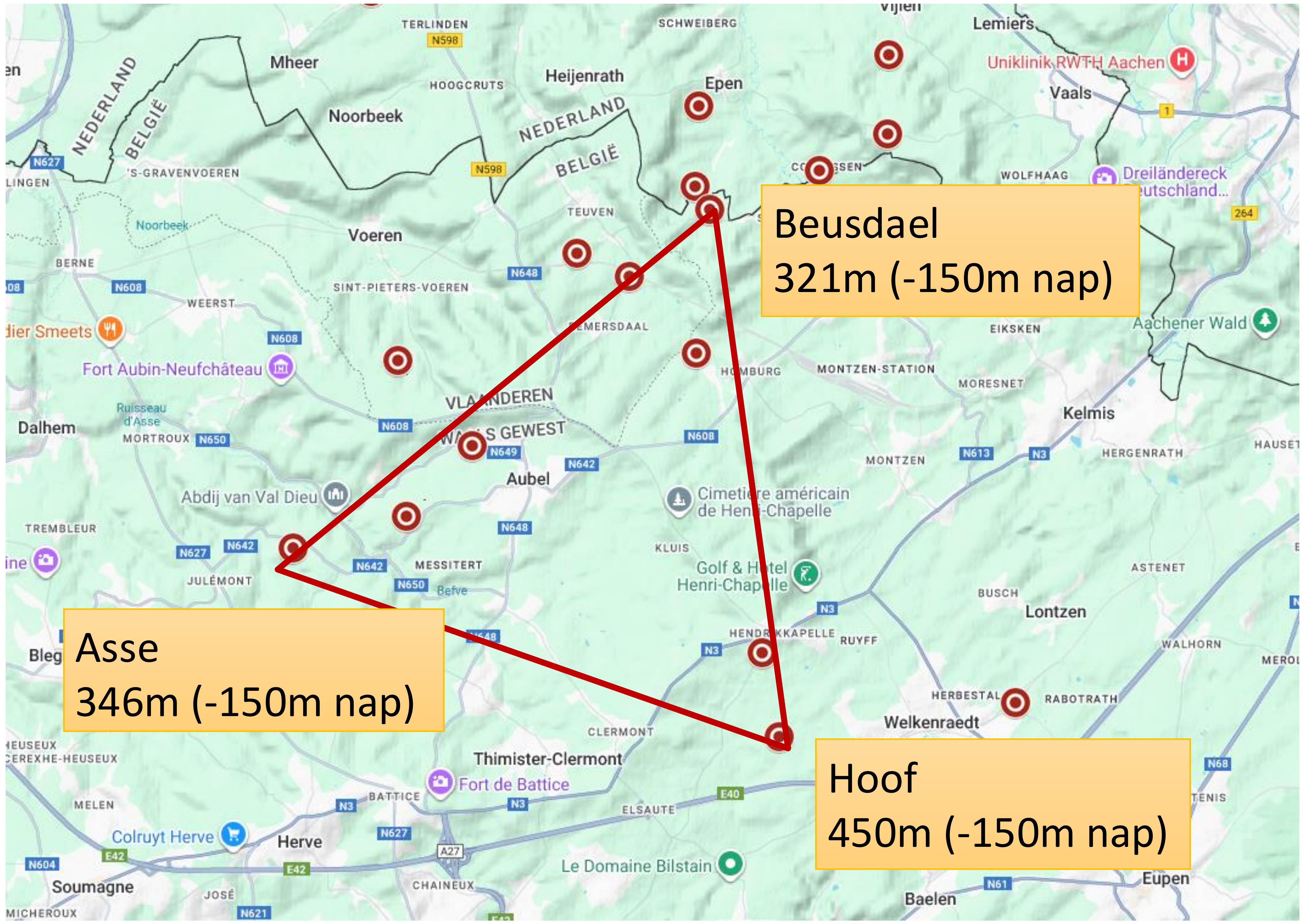
Feasibility studies; subsurface

EMR resources focus on the triangle geometry

- Most promising tracé identified

Feasibility targeted toward de-risking the site:

- Toward a safe and cost efficient construction
  - *Demonstrated, measured site properties*
  - *Predictability and stability over decadal timescales*
  - *Robustness against future environmental and anthropogenic changes*



We are fully committed to study these topics

- Providing reliable data in a realistic timeline
- Acknowledge uncertainties due to limited accuracies
- We will share and validate the toolbox (NN and ANM) with ETC

Subsurface: rock quality

Core Logging and Evaluation
by experienced team of geologists

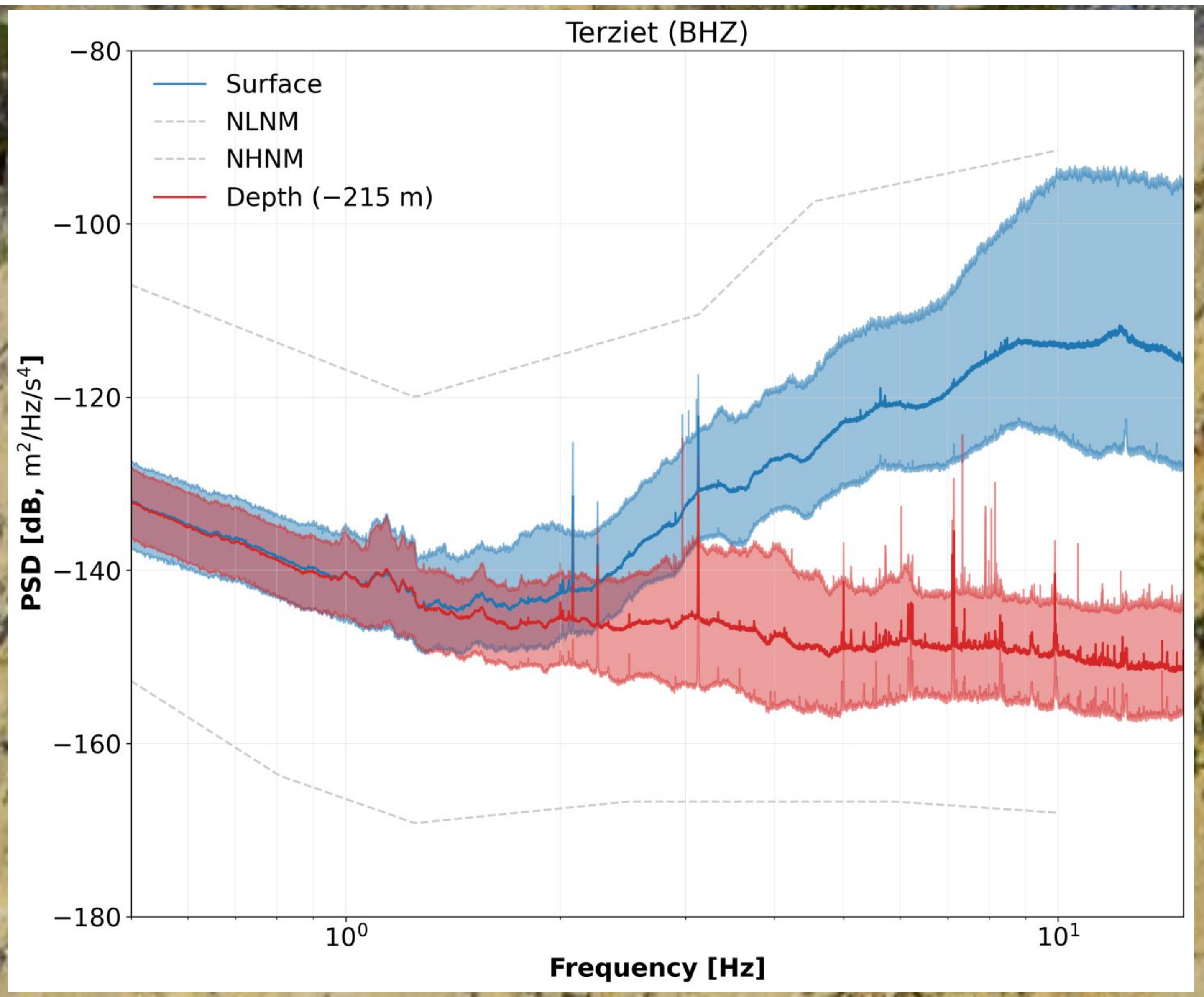
Hard "Competent" Deep Layers

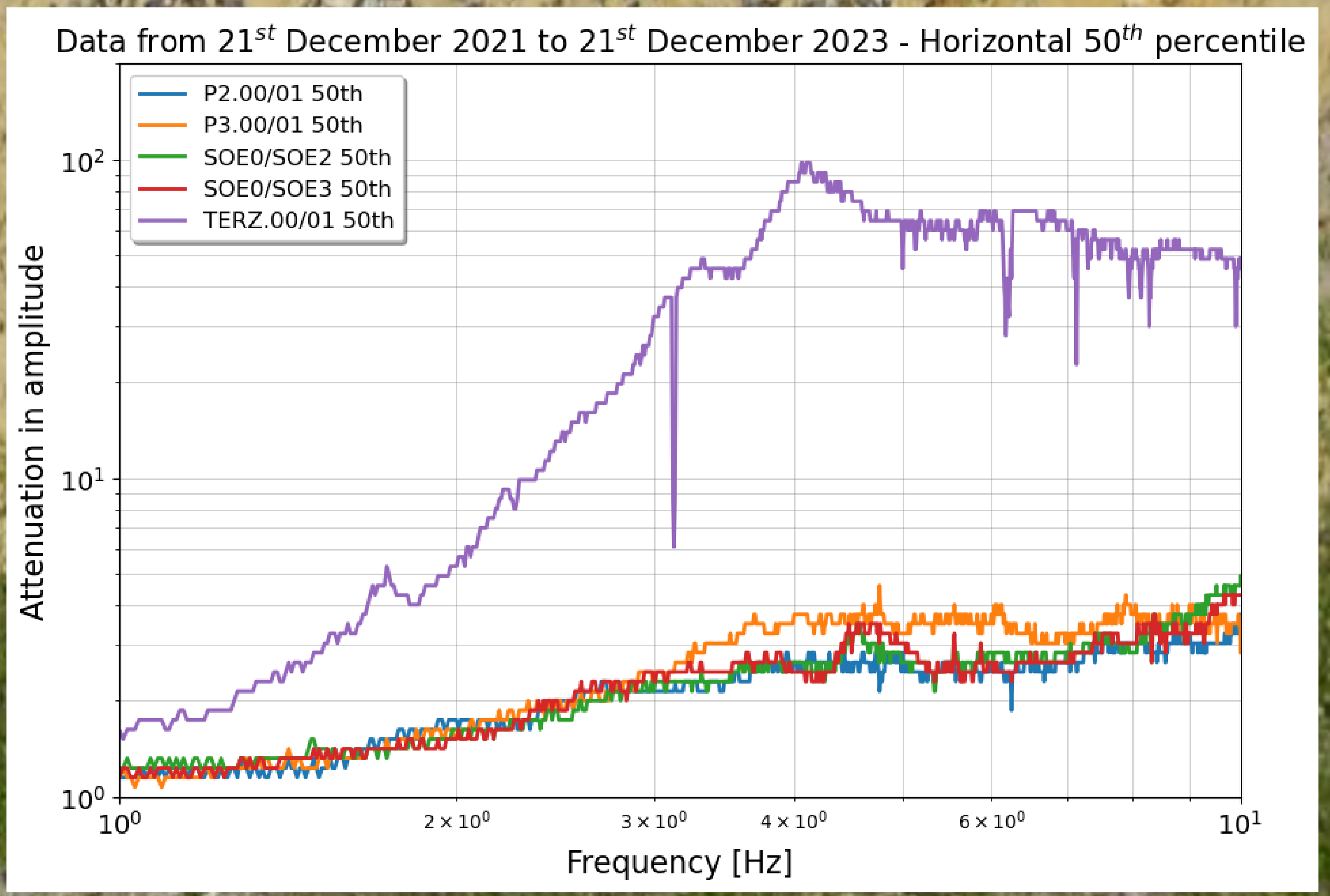
Soft Shallow Layers

Sufficient rock quality confirmed at all three corner points: Hoof, Asse and Beusdael

- In total 4.2km core analysed with internal written reports

Cretaceous top layer: soft chalk, sand- & claystone





EMR is relatively insensitive to future changes in surface activities
Important aspect for an infras that will run for >50 years!

Integral approach to Newtonian Noise

What is needed ?

See also presentation Wim Walk in WG4

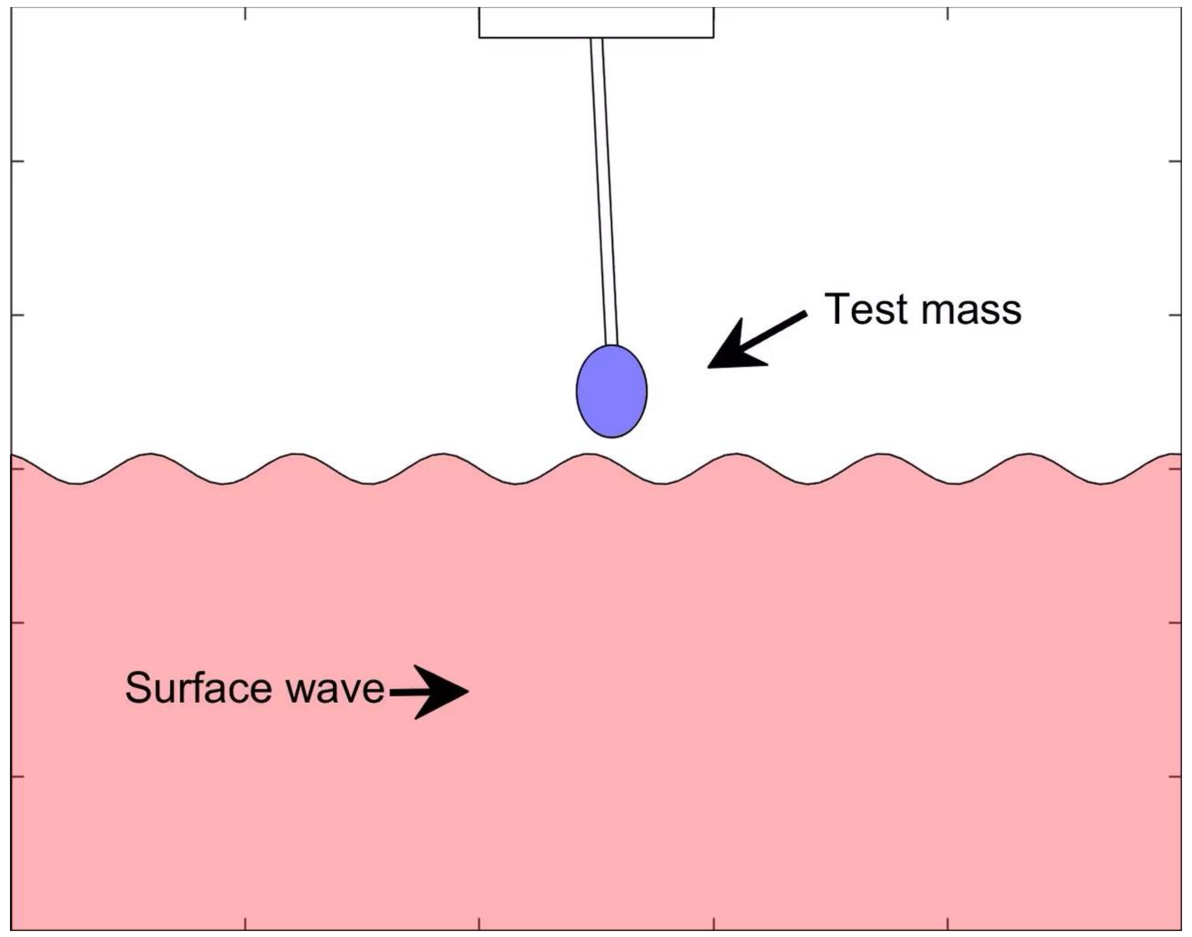
1. Seismic wavefield modeling inputs

- Source mechanism and distribution.
- Subsurface parameters like compressional, shear wave velocity, density and quality factor spatially distributed including caverns and tunnels.
- A seismic wave equation solver
- A model able to reproduce observed data

$$\delta \mathbf{a}(\mathbf{r}_0, t) = G \int \delta\rho \frac{\mathbf{r} - \mathbf{r}_0}{|\mathbf{r} - \mathbf{r}_0|^3} dV$$

2. Newtonian noise modeling inputs

- Subsurface displacement.
- Discretizing the simulation domain efficiently.
- Integration boundary



3. Newtonian noise subtraction

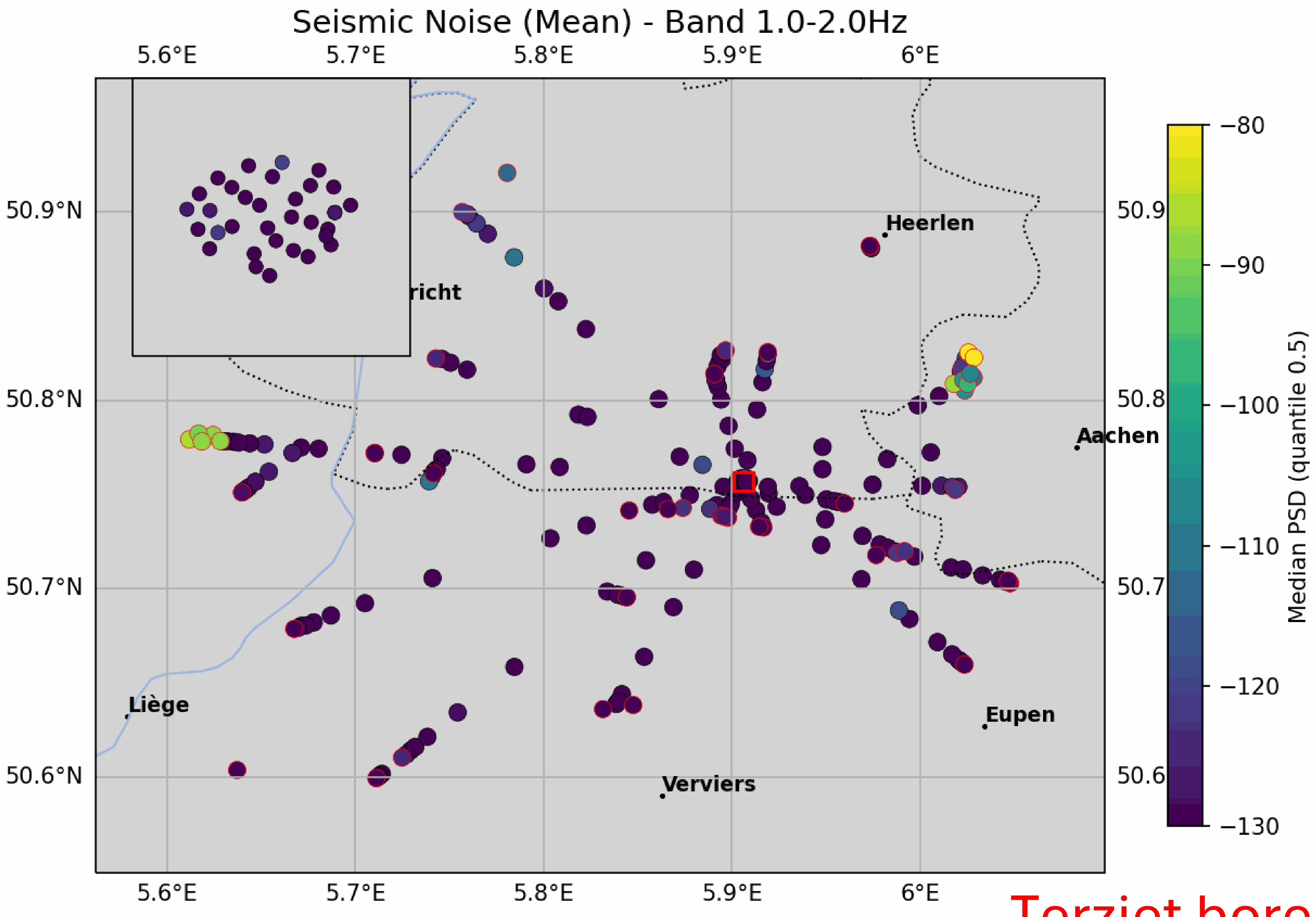
- Dense array of sensors to estimate the seismic noise level.
- Simulation environment to compute NN
- Design and test subtraction schemes.

- **Newtonian Noise: Fluctuations in the density** of a medium (air or **earth**) surrounding the antenna will create a fluctuating **gravitational force**

Integral approach to Newtonian Noise

Seismic ambient noise at Surface

- Several hundreds sensors deployment (below array 4: 230 3C 5Hz, 1 month)
  - We use data from passive seismic recordings to investigate coherence, noise sources, etc...



Terziet borehole

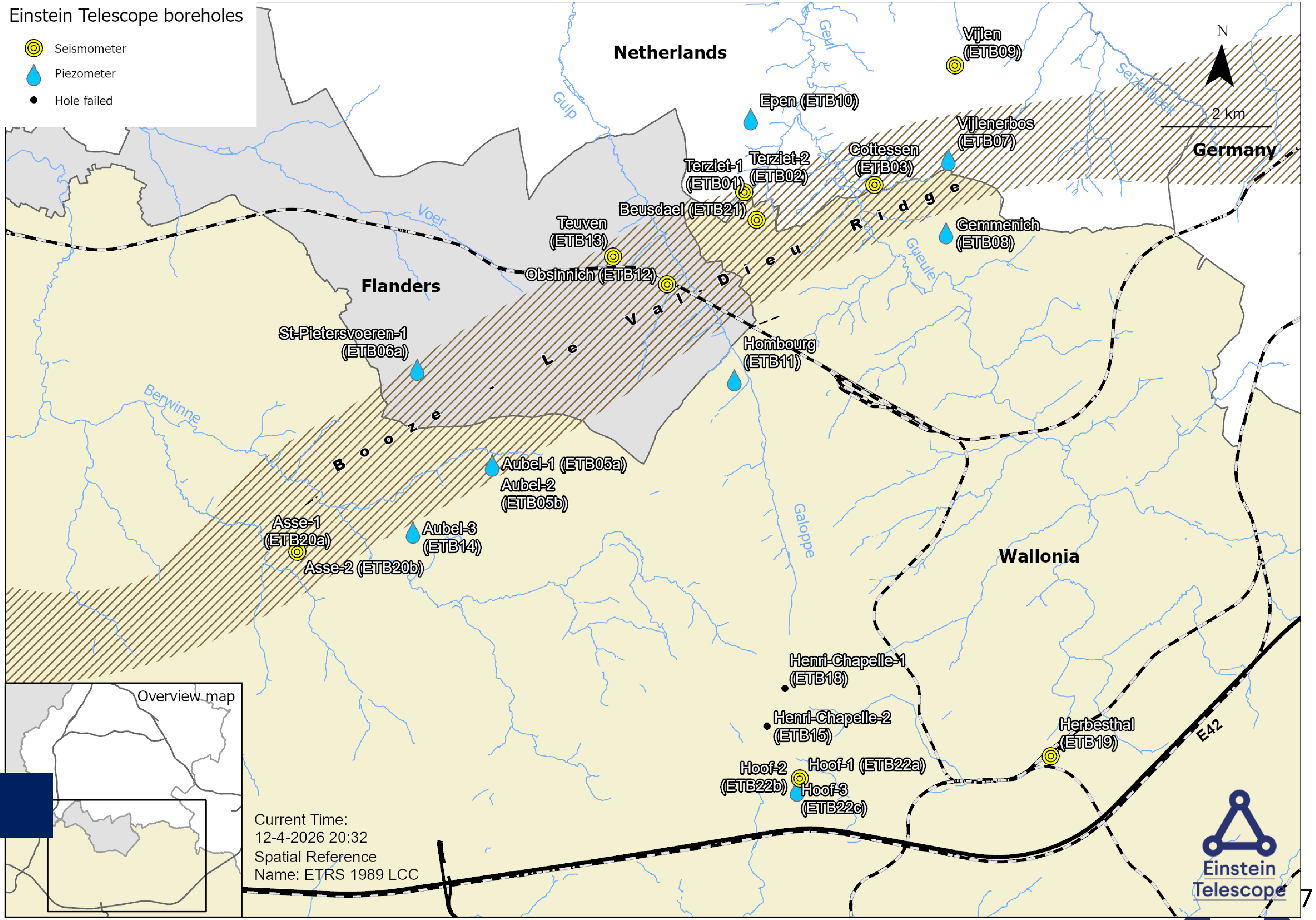
Integral approach to Newtonian Noise

Seismic ambient noise at Depth

- Drill hole campaigns ongoing

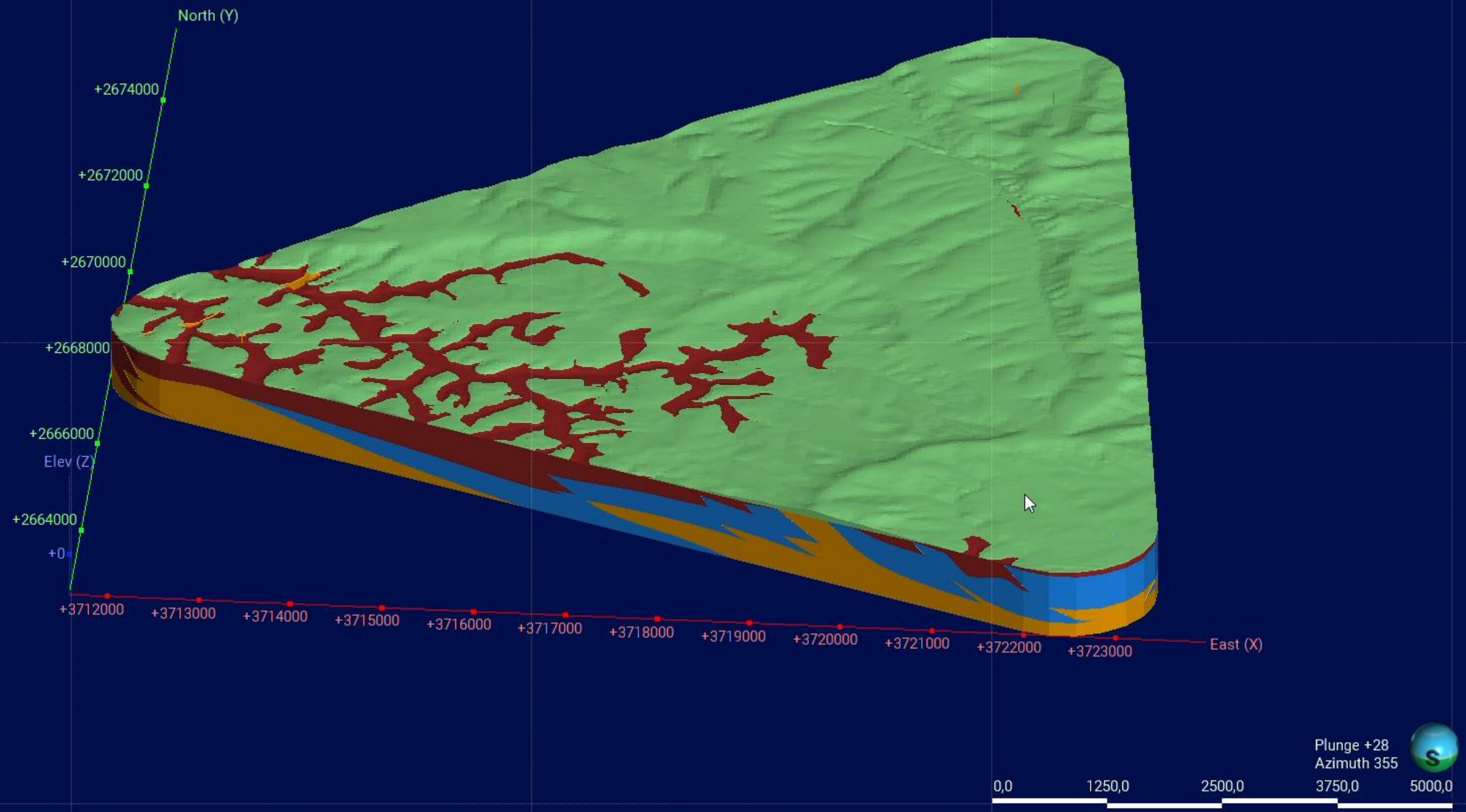
- search region protected by moratorium on windmills

24 ET boreholes | 4200 m core



Einstein Telescope

Leapfrog model



Collecting subsurface data

Intense geological surveys ongoing toward integral 3D model

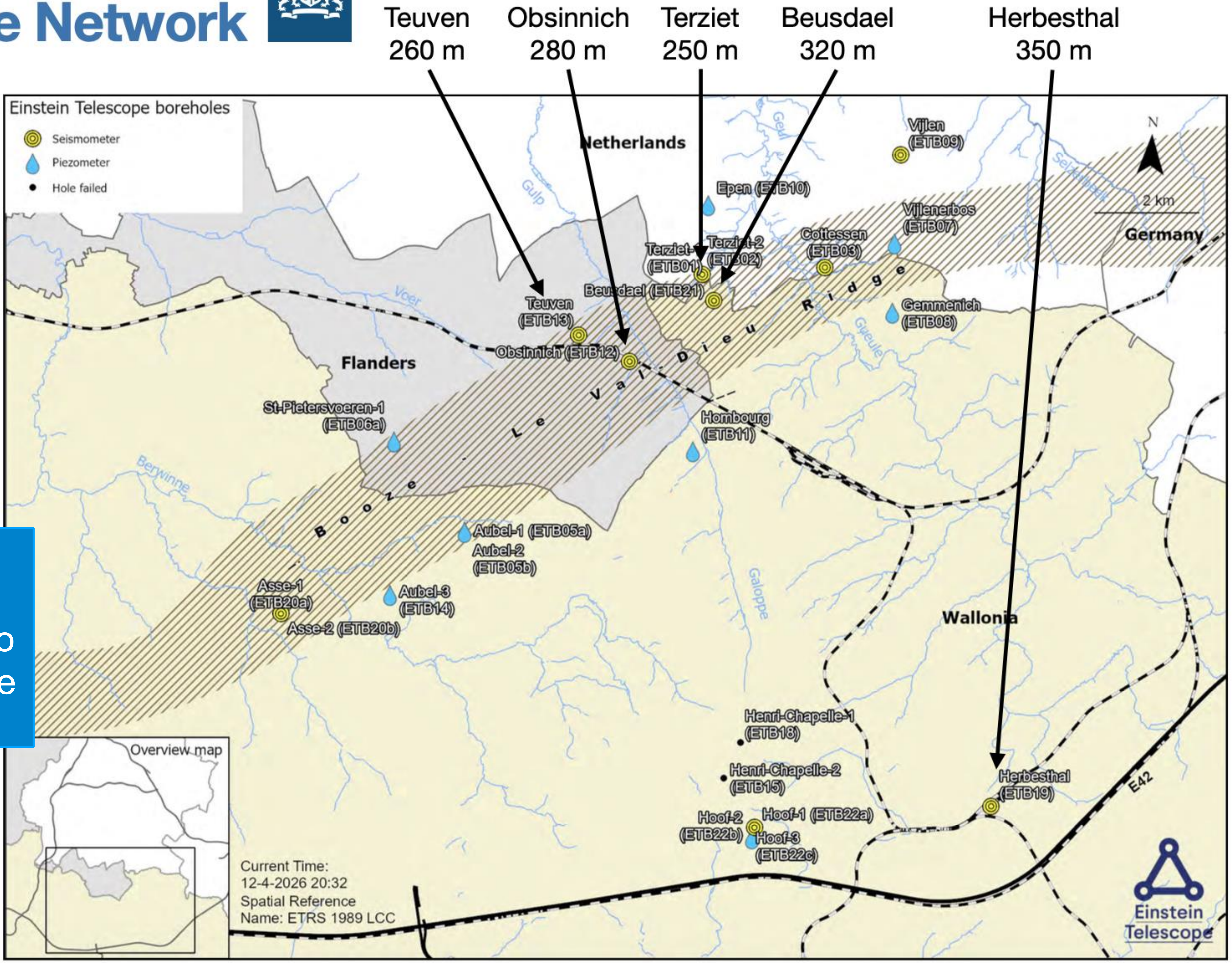
- All existing spatial datasets fed into a common geographic reference framework
  - surface and underground seismic measurements, including borehole locations
  - geological maps, structural interpretations,

Coming period is needed to install sensors and measure residual noise levels at the corner points; and determine their effect on the instrument

Borehole installation setup

The ET Seismic Borehole Network

- Borehole stations include:
  - Surface seismometer (& microbarometer)
  - Total-depth seismometer
  - Intermediate-depth seismometer (optional)

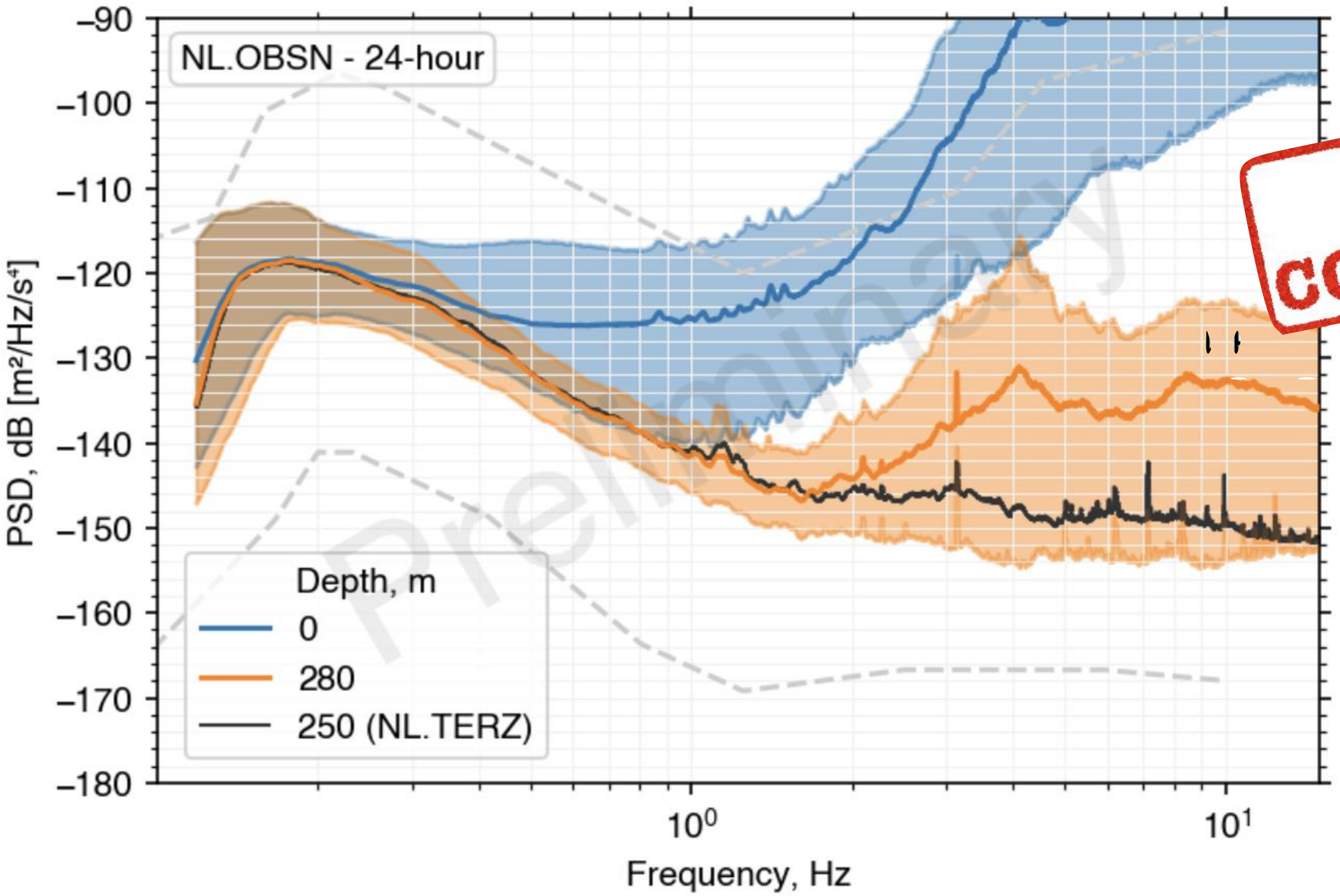


Unfortunately we do not yet have subsurface data at the corner points
So far subsurface studies available to investigate geology and biggest noise sources

Case study: Obsinnich

The borehole in Obsinnich is situated directly adjacent (~60 meters) from a railroad and a railroad bridge with significant train activity all day

- It was specifically selected to study the attenuation from the noisy surface conditions to depth.



The case of Obsinnich during peak hours of the day

- Obsinnich which is located just 70 m from a freight train track and few meters away from a road, has data marked with several transients due to road traffic and strong bursts from trains
  - During peak hours of the day (12:00:00 UTC +), road traffic dominates the surface seismic noise
  - Majority of road traffic is attenuated, however trains do leave an imprint on the underground spectrogram

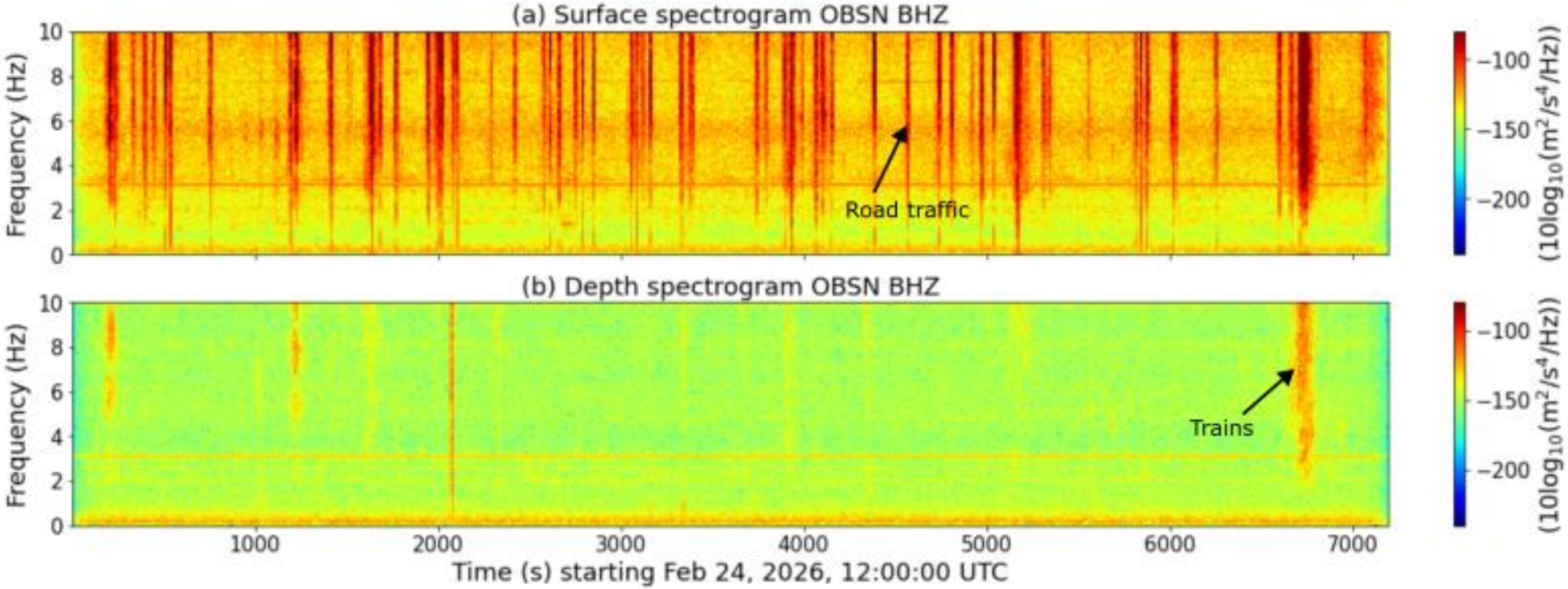
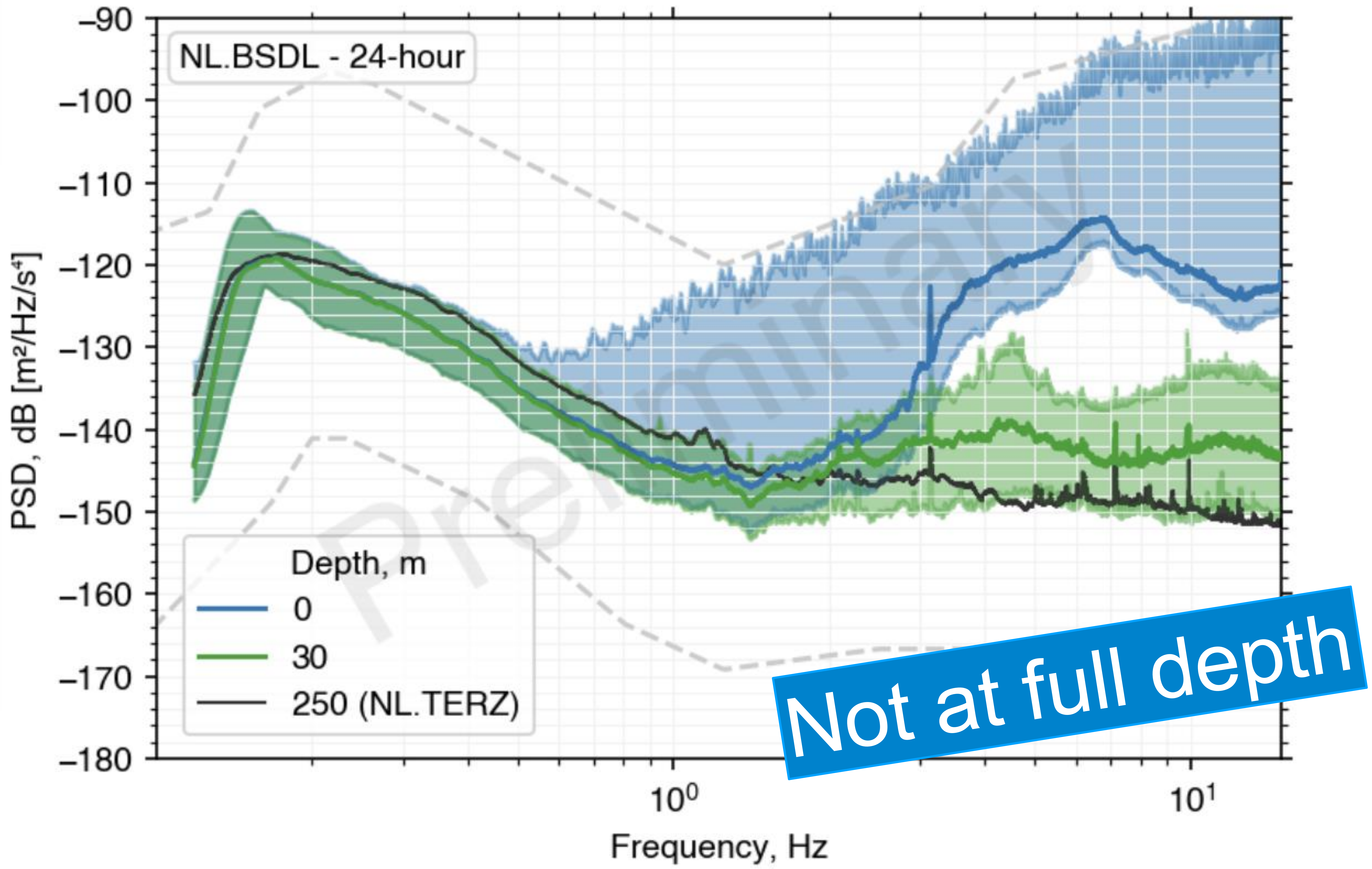


Figure 5 (a) and (b) show the spectrograms of the surface and underground seismic noise data Obsinnich corresponding to peak hours during the day on Feb 24, 2026.

Beusdael: not at full depth

Borehole to -350m

- Sensor at intermediate depth of -30m



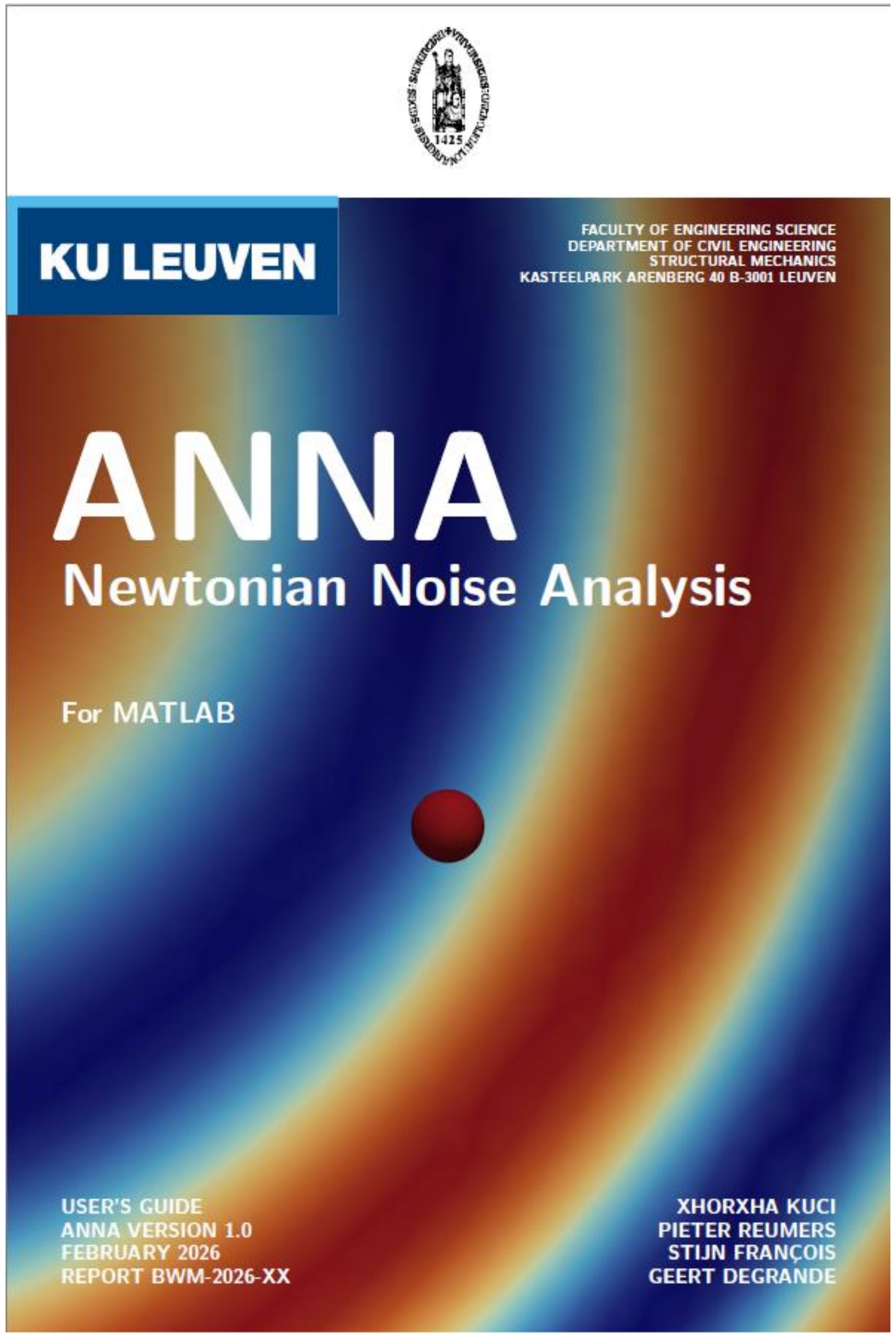
Essential data will become available in coming months

2. Newtonian noise modelling

ANNA Newtonian Noise Analysis to compute Newtonian noise from a seismic wavefield

Finite element formulation based on functionalities of the Stabil toolbox

Implementations available in MATLAB and Python



P. Reumers, X. Kuci, S. Fran.ois, and G. Degrande. ANNA: a toolbox for Newtonian Noise Analysis. https://arxiv.org/abs/2603.15157

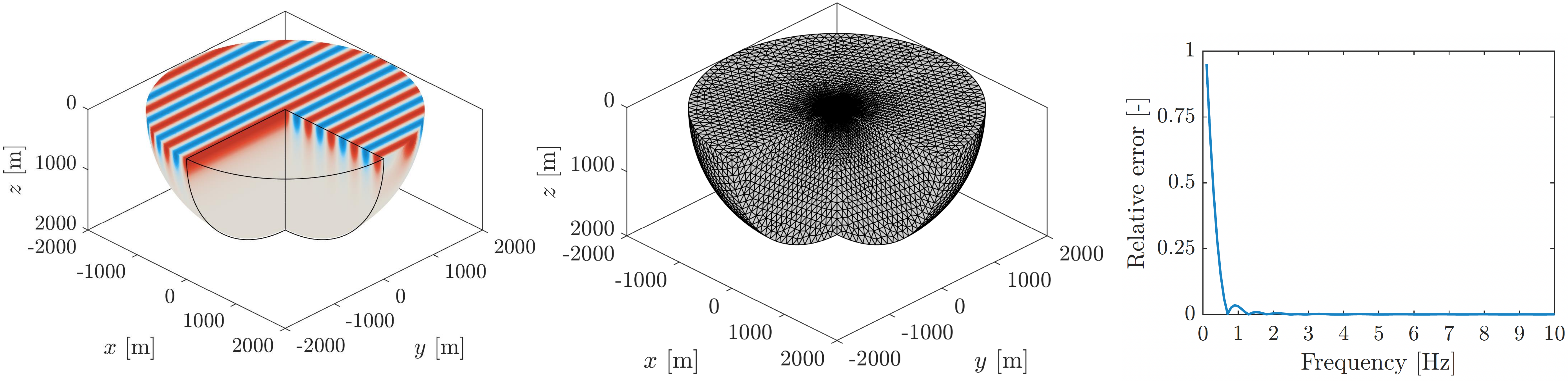
P. Reumers, S. Franxois, and G. Degrande. Validation of a numerical model of seismic Newtonian Noise for the Einstein Telescope. In 9th European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS 2024, pages 1-11, Lisbon, Portugal, June 2024.

S. Fran.çis, M. Schevenels, D. Dooms, M. Jansen, J. Wambacq, G. Lombaert, G. Degrande, and G. De Roeck. Stabil: an educational Matlab toolbox for static and dynamic structural analysis. Computer Applications in Engineering Education, 29(5):1-18, 2021.

Newtonian noise modelling with ANNA

Validation example of Numerical Tool:

- Seismic displacements at 5 Hz from Rayleigh waves (left) and 3D FE mesh tailored for the homogeneous halfspace with test mass above the surface (center), relative error with respect to analytical solution (right)



From geology+seismic to Newtonian Noise

1. FE mesh

- Generated in Gmsh.
- Enforces the three mesh criteria.
- Supports linear and quadratic tetrahedral and hexahedral elements.

2. Seismic wave field

- Computed on a coarser mesh and interpolated, or
- Evaluated directly at FE mesh nodes.
- Stored as $\underline{\hat{\mathbf{u}}}(\omega)$ $(3N \times 1)$.

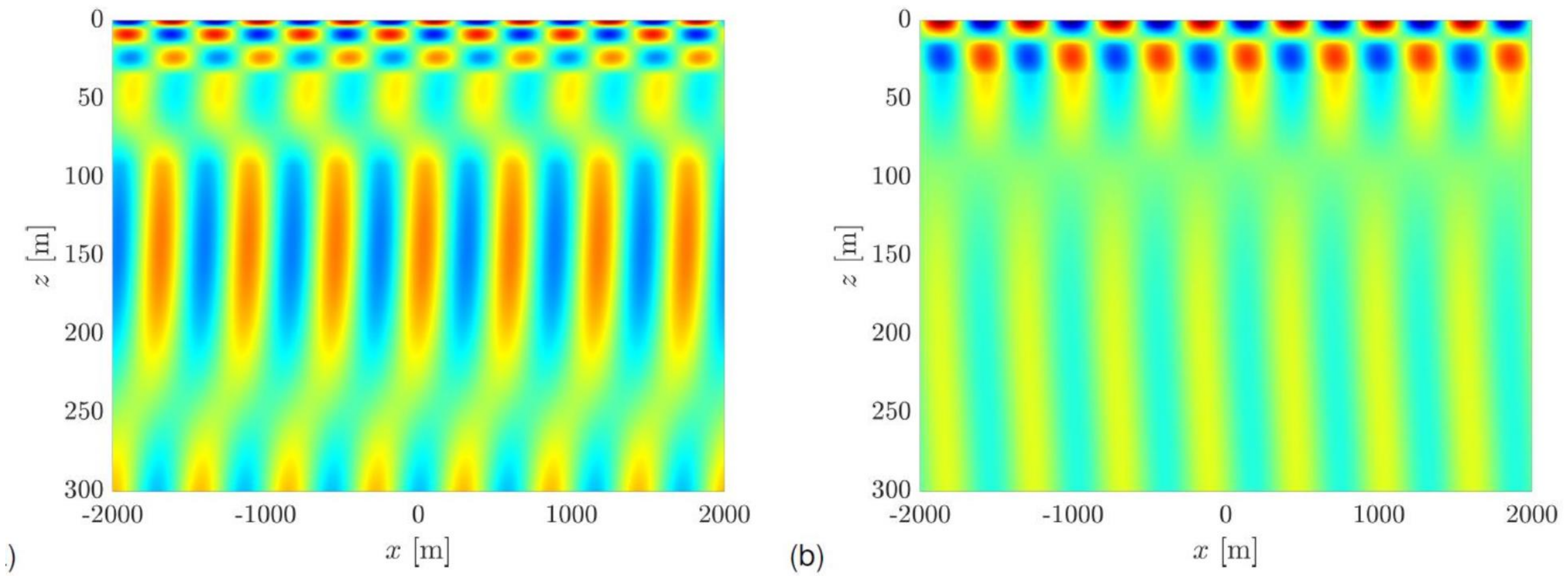
3. NN computation

- Input: FE mesh, ρ, $\mathbf{x}_0$
- Assemble NN matrices (`asmnn.m`): $\mathbf{A}_\mathrm{t}$, $\mathbf{A}_\mathrm{b}$, $\mathbf{A}_\mathrm{s}$ $(3 \times 3N)$
- Compute NN acceleration:

$$\delta\hat{\mathbf{a}}_\mathrm{i}(\omega) = \mathbf{A}_\mathrm{i}\,\underline{\hat{\mathbf{u}}}(\omega)$$

Taking advantage of the layered geometry in EMR

- Prediction of internal reflections sigma waves
- Automatic conversion to NN

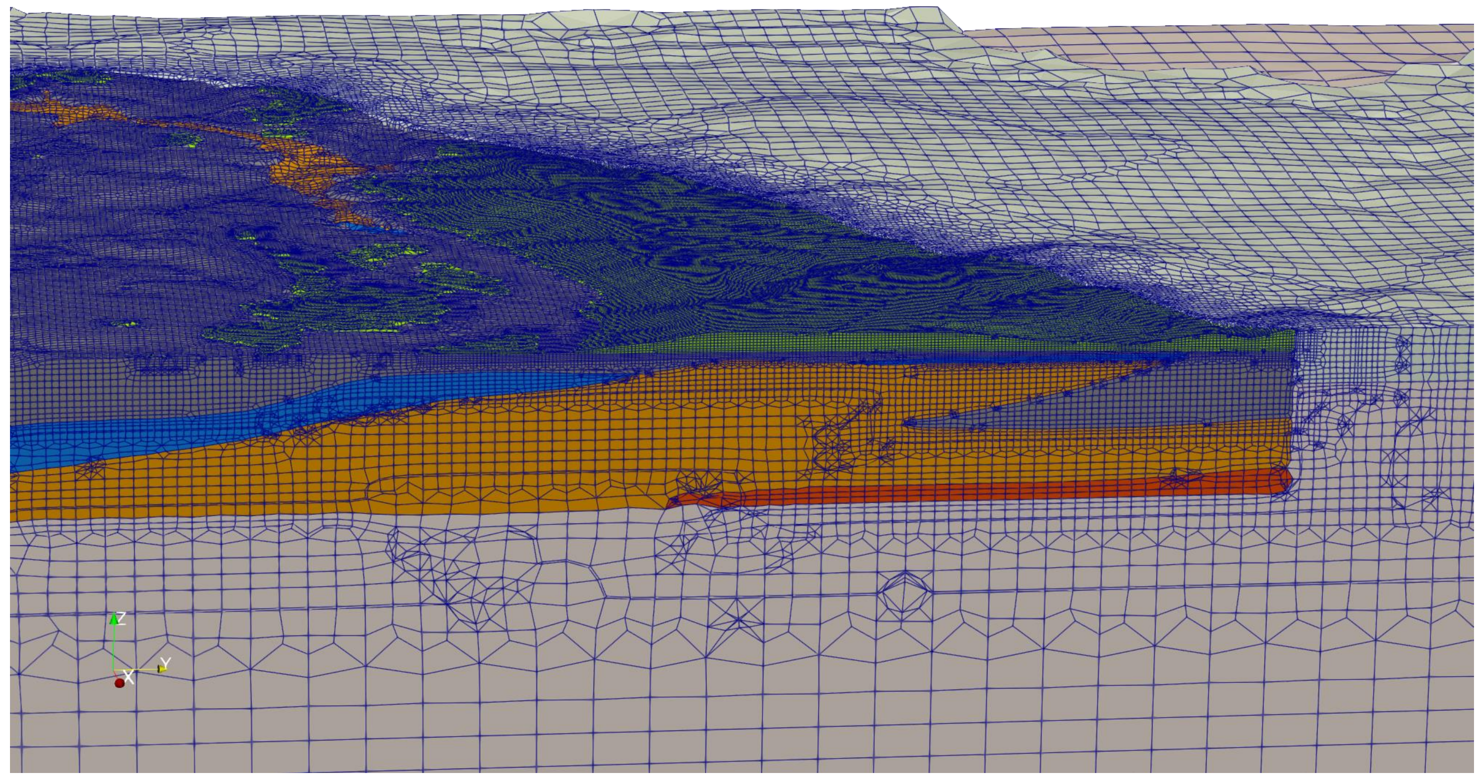


Start of many follow-up studies e.g. effect of cavern geometry

Newtonian noise modelling: 3D modelling

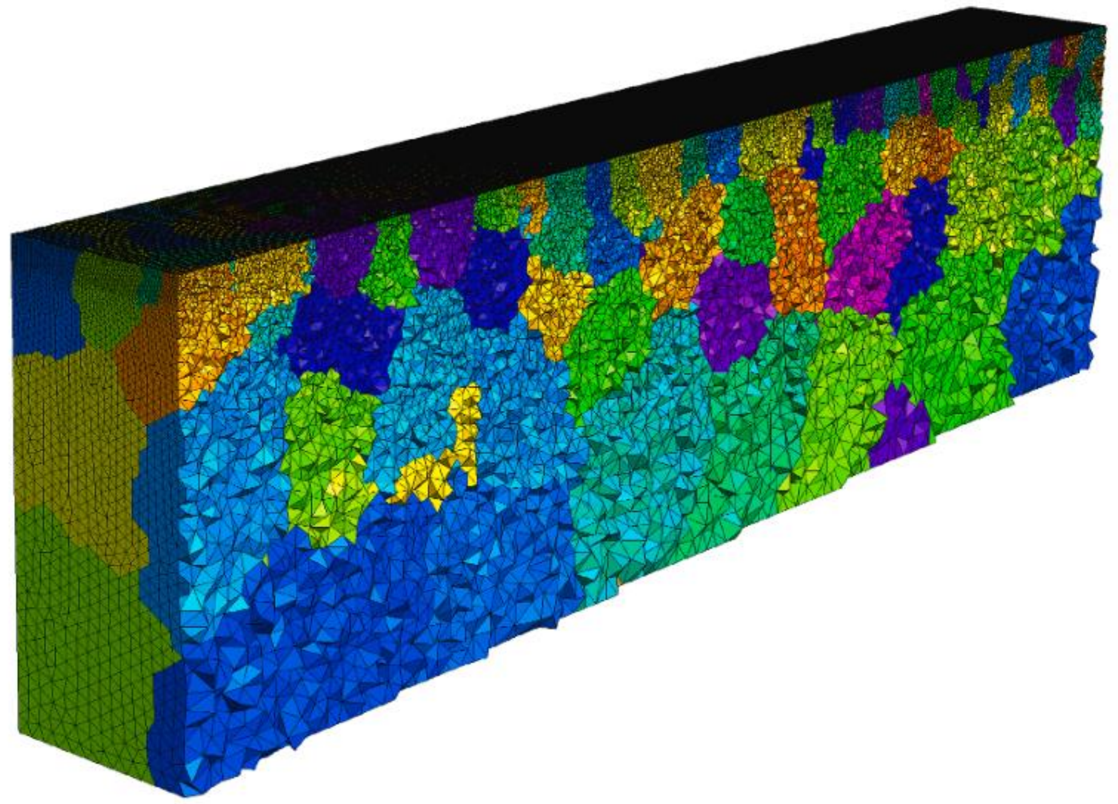
Alternative: Salvus/SPECFEM3D seismic simulation of the regional scale geological model

- Topography
- Include faults and folds



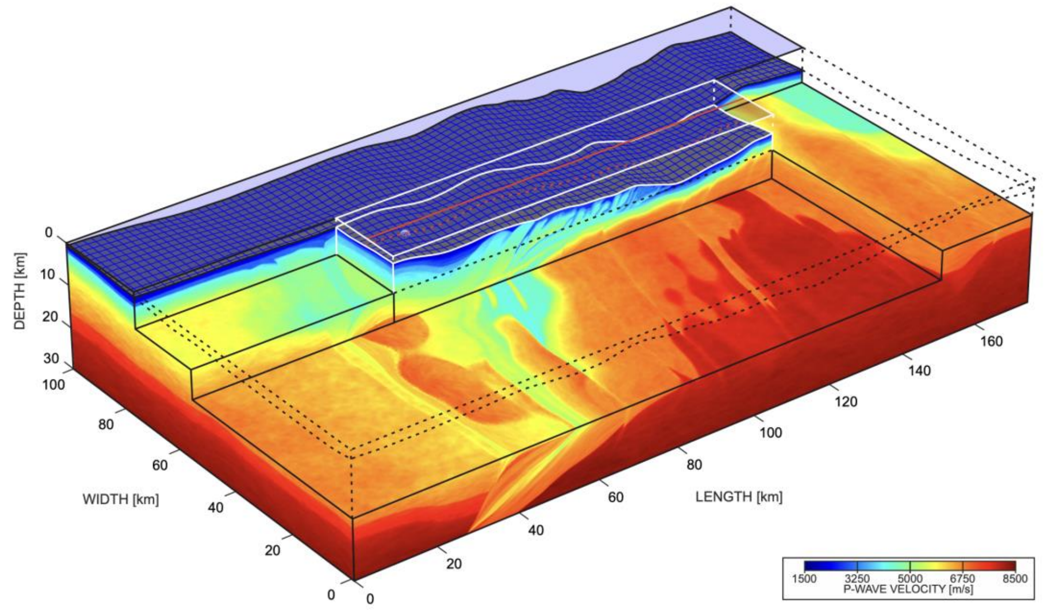
Parameters determined by multiple surveys

- Passive/active seismic, deep-ERT, microgravity, etc.



Seismic displacement simulations done with spectral finite element

- Ready to use: CUBIT + Salvus/SPECFEM3D (Elastic Hex)
- Open Source development: Gmsh + GmshFEM+GmshDDM (C. Geuzaine group)



Courtesy of ULiège team (S. Koley, H. Michel, C. Geuzaine, B. Martin)

3. Newtonian Noise mitigation

Utilize Wiener filters:

- Use the output of a number of reference traces correlated with the NN to predict the noise of a target channel
- This prediction is then subtracted from the target channel, leaving the non-correlated residual.

$$r(k) = y(k) - \sum_{m=1}^{M} (f_m * x_m)(k)$$

GW strain signal contaminated by Newtonian noise

reference data from seismometers or other sensors (correlated to NN)

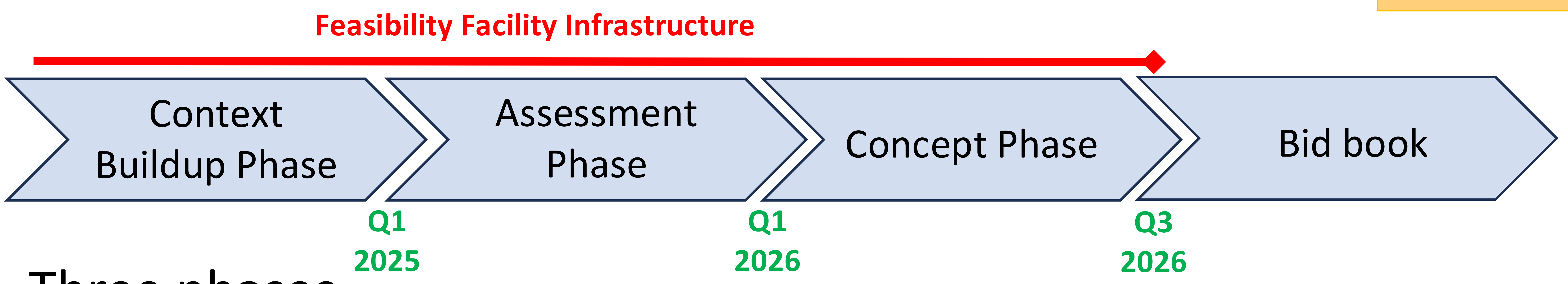
Validate Wiener cancelation with numerical solutions and compare to graph neural networks

- So far a reduction of a factor ~20 has been achieved
- We have ample time to optimize the NN mitigation (until ~2045)

Let's not forget other NN noise (HVAC) or self-inflicted!

Subsurface Infrastructure

Well defined approach and timing



Three phases

- Context Buildup phase:
  - Determine showstoppers/cost drivers/risks -> priorities & mobilization teams
- Assessment phase: 2 parallel actions resulting in a basis for concept design:
  - Design concept scenarios (expert judgement) for the relevant disciplines
  - Converging design criteria together with ETO/ETC and other stakeholders (local)
- Concept design phase after fixation of main starting points
  - Finalize concept design & feasibility Facility Infrastructure and input bid book

Facility Infrastructure

Continue Unless Civil engineering and geology *(December 2025)*:

- Evaluation of the MLT as provided by geologists
- Collect findings of different disciplines FI
  - Geotechnics
  - Civil engineering
  - Technical installations
  - Safety
  - Logistics
  - Environment and durability
  - Cost drivers
- We currently see no showstoppers
  - No reason to believe we cannot find a technical solution for creating the tunnel/cavern complexes from a civil point of view
- Review by consortium E=MC2

Topic	Data	Status
Structural Geology and Geo-mechanics.	Geo- and hydrological analysis of the first borehole campaign.	Positive outcome in Progress Report 2024 Q3 and review by TNO.
Civil engineering and geology: -feasibility of integrating the subsurface infrastructure in suitable layers from the perspective of construction engineering. -gateway showstoppers. -gateway cost drivers.	-Available analysis of Geological/ geohydrological data from first and second borehole campaigns and various geophysical campaigns. -Report evaluating suitability underground with regard to shafts/ tunnels/ caverns.	Positive outcome; as reported in this progress report and reviewed by E=mc2. CU moments

Continuation Recommendation

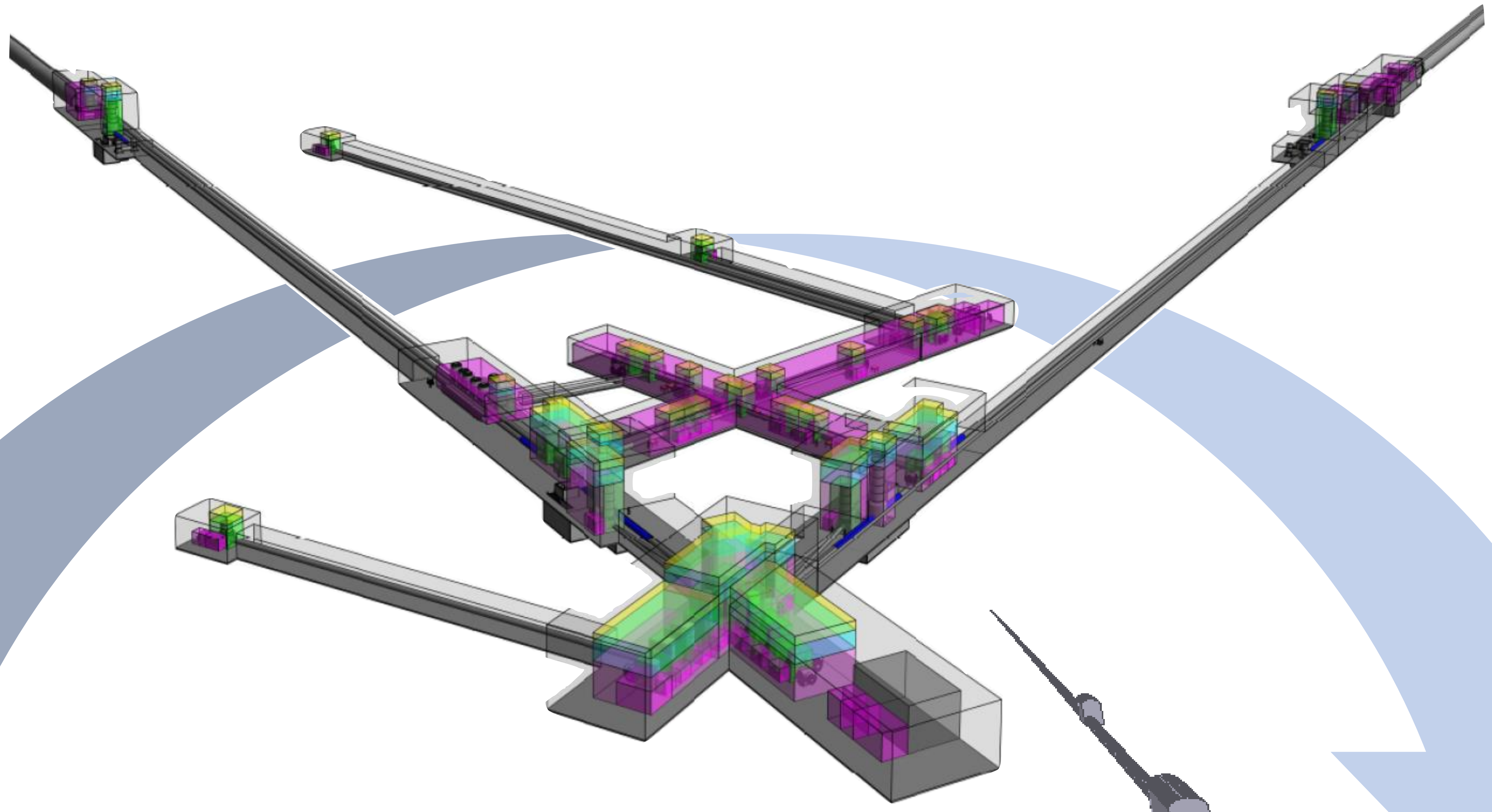
Based on the analyses completed so far, the disciplines joined in the EMR subsurface technical teams of Subsurface and Facility Infrastructure conclude that no part of the resulting updated understanding of the subsurface suggests that construction and effective operation of ET in the EMR region is not feasible. Therefore, the EMR technical teams recommend, without reservations, the EMR Project Office to continue the feasibility studies.

Subsurface Infrastructure

Detector layout with clean rooms and caverns by ETO

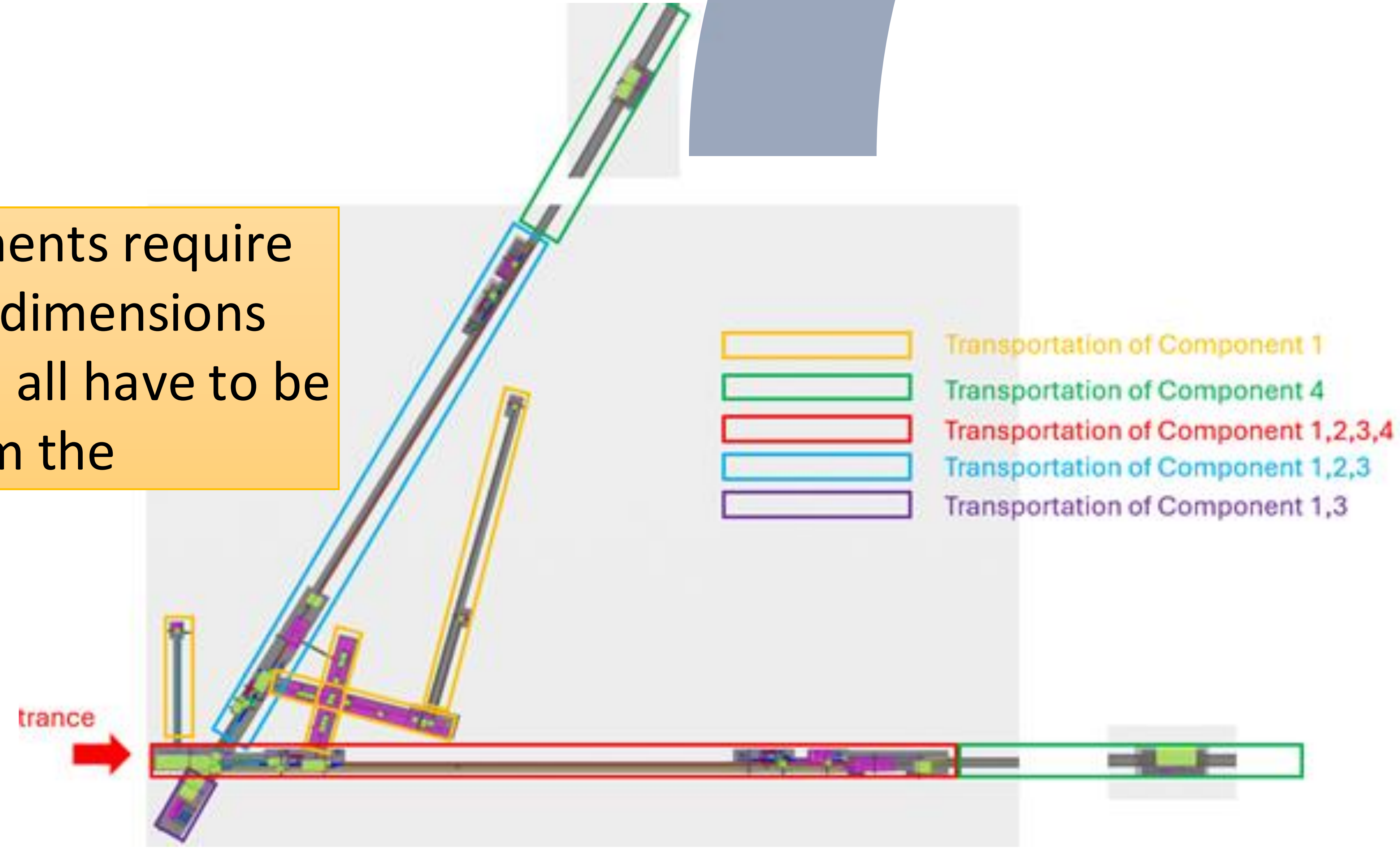
Geotechnics and civil

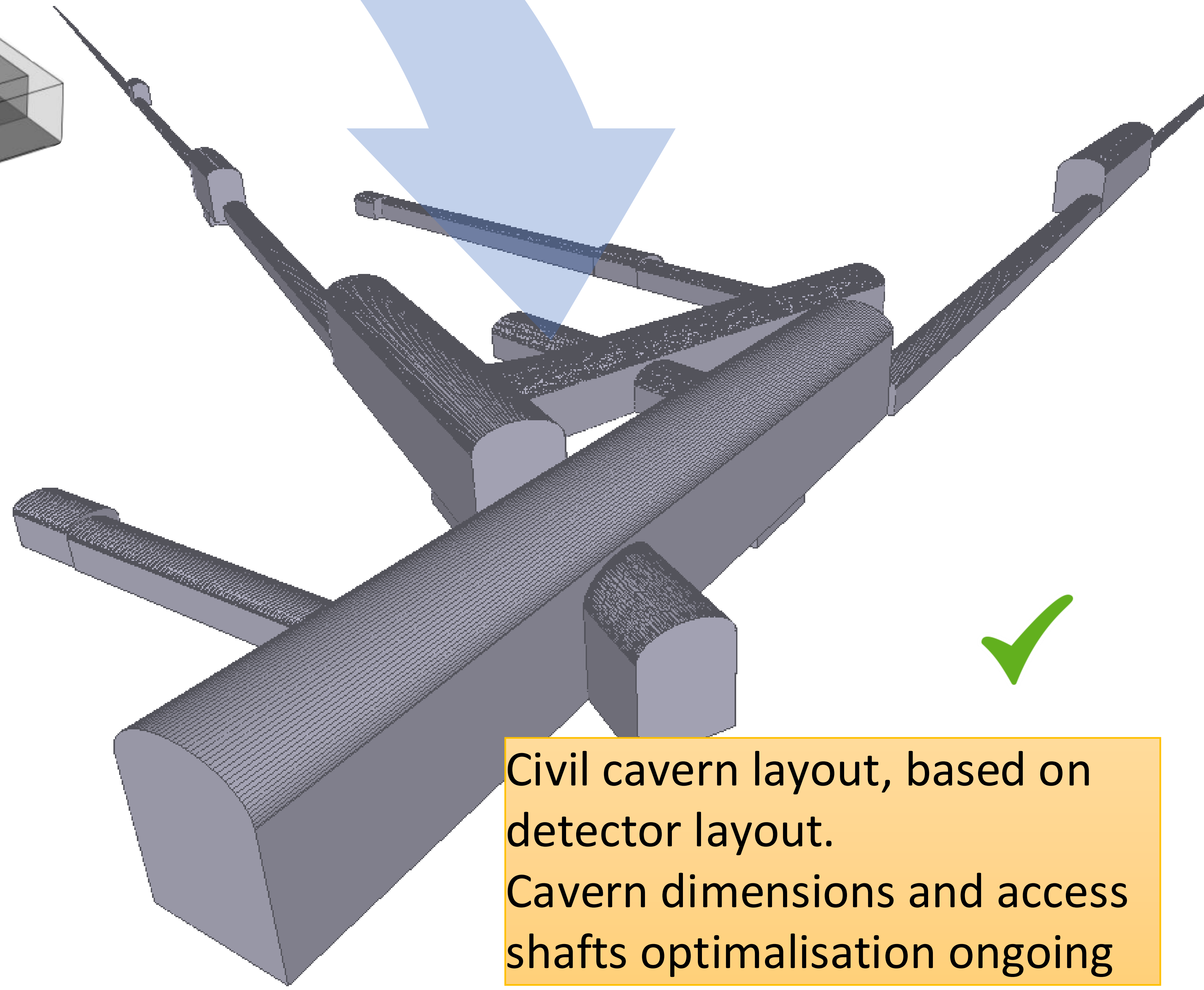
- Transfer detector layout into adequate cavern/tunnel layout



Logistics

Different components require special transport dimensions (size and weight), all have to be able to come from the entrance





Civil cavern layout, based on detector layout.
Cavern dimensions and access shafts optimalisation ongoing

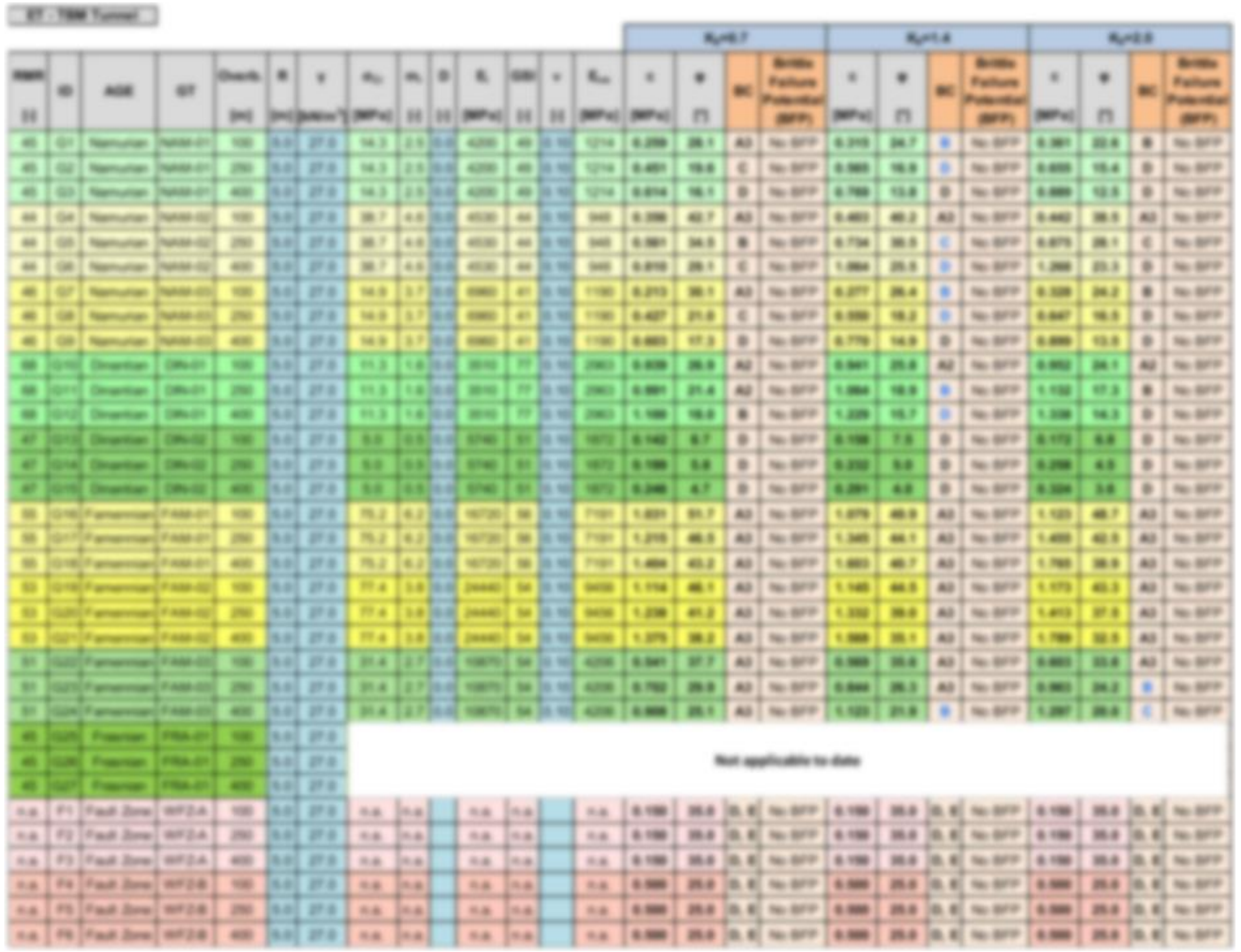
Subsurface Infrastructure

Geotechnics and civil

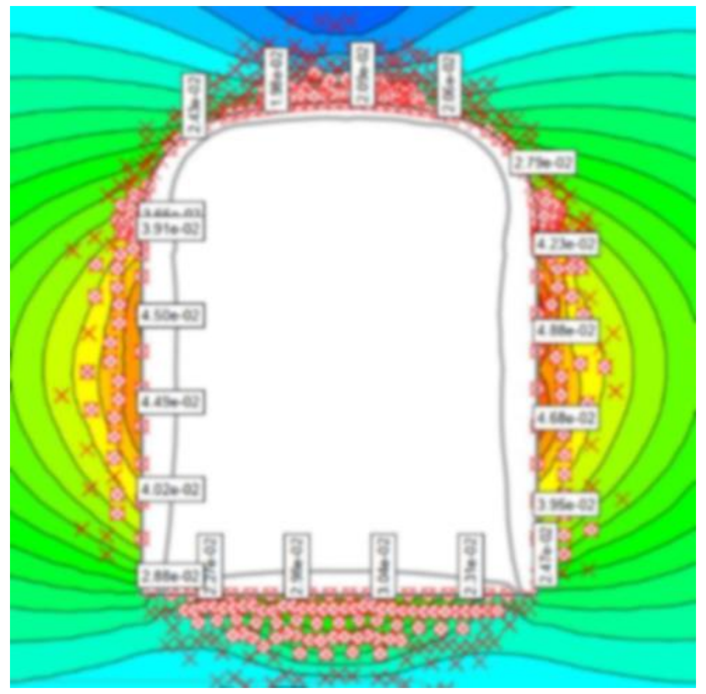
- From Geology to Tunnel/cavern design
- Evaluate subsoil conditions
- Define ground types encountered
- Determine geotechnical parameters
- Establish / calculate tunnel & cavern design concepts
- Alignment with other disciplines (ETO, local aspects)
- Fixation of layouts and requirements
- Finalize Concept design
- Cost Estimate

Ground types

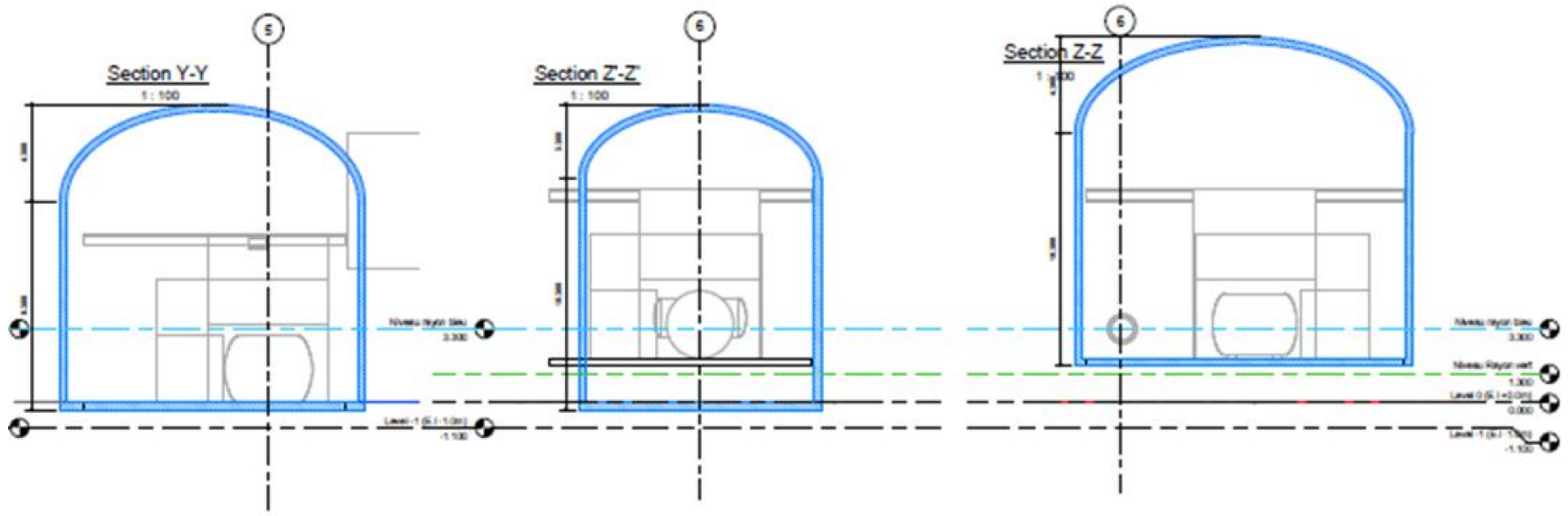
Transferring geology to usable geotechnical information



Geotechnical parameters



Tunnel & cavern concepts



Facility Infrastructure

Excellent progress of the assessment phase

- Dedicated evaluation of the EMR geology wrt the suitability to construct the infra:
  - We can find a technical solution for creating the tunnel/cavern complexes from a civil point of view
- Review by consortium E=MC2

Rigorous internal validation process in place & on time

- Results are based on a collection of internal technical reports
- Constructive meetings with ETO

Current activities

- Consultation phase with ETO to establish the principles and approach for the next phase of Concept Design.
  - We expect to complete this in March.

P3.50_101	Requirements_for_geological_data_and_conceptual_model
P3.50_102	Intermediate_Geotechnical_Interpretative_Report
P3.50_103	Requirements Hydrology
P3.50_104	Final_Geotechnical_Interpretative_Report (GIR)
P3.50_105	Geohazard Report
P3.50_107	Energy Tunnel: preliminary assessment of the heating and cooling potential
P3.50_109	Geotechnical Summary Report
P3.50_110	Longitudinal geotechnical section - MLT - Tunnel 1
P3.50_111	Longitudinal geotechnical section - MLT - Tunnel 2
P3.50_112	Longitudinal geotechnical section - MLT - Tunnel 3
P3.50_201	Cross Sections Concept
P3.50_202	Access and Excavation Works Plan
P3.50_203	Structural Design Concept
P3.50_204	Support & Lining Design
P3.50_205	Grouting and Drainage of Caverns and Tunnels
P3.50_206	Facility Infrastructure Civil Infrastructure
P3.50_301	Electrical Grid connections
P3.50_302	Electrical power supply architecture during construction
P3.50_303	Electrical power supply architecture during use
P3.50_303a	Electrical power supply Architecture during use - Consumers list
P3.50_304	Drainage system (during construction and in use)
P3.50_305	Tunnel Ventilation
P3.50_306	Ventilation during construction
P3.50_307	Vibration analysis
P3.50_307a	Equipment Catalog input
P3.50_307b	Source Vibration Level
P3.50_307c	Source Vibration Level Advanced measures
P3.50_308	Cleanrooms
P3.50_309	Cleanroom ventilation
P3.50_310	Tempertature & Humidity Control
P3.50_311	Cranes, Hoisting & Elevators
P3.50_312	Facility Infrastructure Technical Installation
P3.50_401	Initial_Environmental_Sustainability_Assessment
P3.50_402	General_Environmental_Impact_Matrix_V0.1
P3.50_403	General_Environmental_Impact_Matrix_Manual_V0.1
P3.50_404	Environmental_Assessment_Location_Alternatives_V0.1
P3.50_405	Environmental_Assessment_Location_Alternatives_V0.2
P3.50_406	Q&A_Environment_05092025
P3.50_407	Environmental_Assessment_Location_Alternatives_V0.3
P3.50_410	Safety strategy concepts and options for facility infrastructure design
P3.50_411	Terms of references Hazid assessment
P3.50_412	Hazid report
P3.50_421	Construction phase logistics feasibility study
P3.50_422	Stite visit EMR for logistics study
P3.50_423	Montzen logistical hub feasibility
P3.50_424	Drawing: Montzen hub feasibility

Environment, Sustainability and Stakeholdership

Integral approach

- Collect and assess the impact of interventions in the environment

Developing vision :

- Complying to international, national, regional and local standards
- Avoiding risks & dealing with mitigation and compensating measurements
- Satisfying support in the local area and creating added value locally

Work Packages

Environment :
- Hydrogeology
- Landscape quality
- Logistics
- Air Emissions
- Machine noise
- Mobility
- Biodiversity

Sustainability :
- Resource recovery
- Circularity of materials
- Energy providing
- Participative investigation

Stakeholder management :
- National / Regional
- Province and municipalities
- Organisations and pressure groups
- Individual citizens and companies

Communication :
- Website and socials
- News Letters
- Information Moments
- Letters to inhabitants

Plan Processes & Permit requests
- Support Permitting and Authorisations
- Spatial Planning and Permitting strategy

Environment - continue-unless

Evaluation of all available environmental issues

- Quality of the broad region where the location of the ET is planned
- Impacts of the hydrogeological data
- Impacts of the above-ground temporary constructions, machinery and infrastructures
- Impacts of the up- and downstream transport routes, logistic handling, energy
- Carbon footprint, resource recovery, circularity, energy providing and liveability for local people;

ET-EMR project on these themes is feasible: 'continue-unless passed'

Einstein

Telescope