EO for Natural and Cultural Heritage Workshop
15th to 16th October 2024

Enhancing subsurface analysis of heritage sites with synergy of muon tomography and remote sensing.

Dr Noemi Zabari

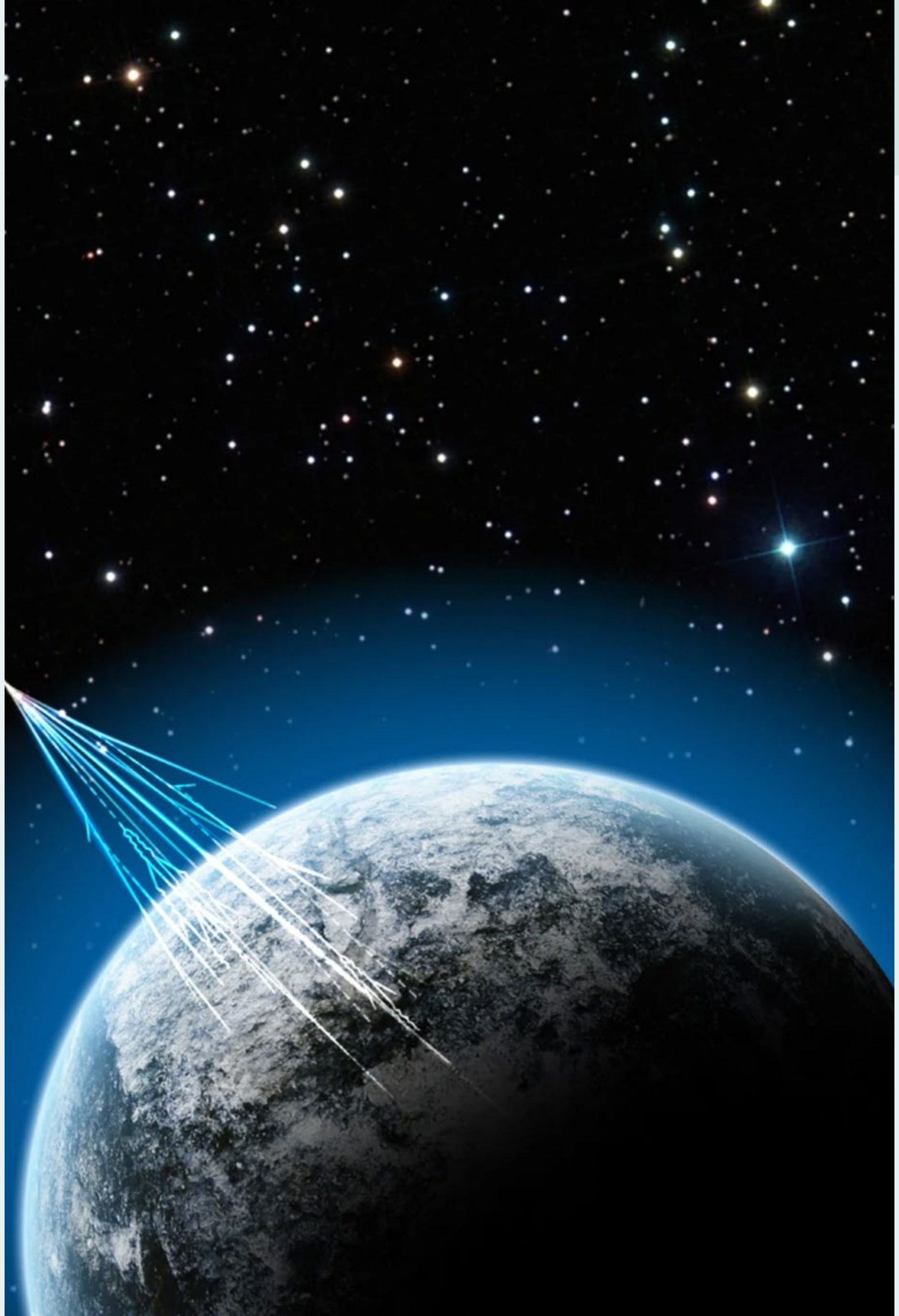
Agenda

- Muon tomography
- Applications of muon tomography
- Cosmic radiation
- Properties of cosmic muons
- Reconstruction of internal structures of objects
- Development of a simulation tool
- Remote sensing implementation
- Future development and research directions

Muon tomography

And its significance in imaging high-density objects

Imaging technique based on the use of cosmic muons, which are elementary particles produced by the interaction of cosmic radiation with the Earth's atmosphere.

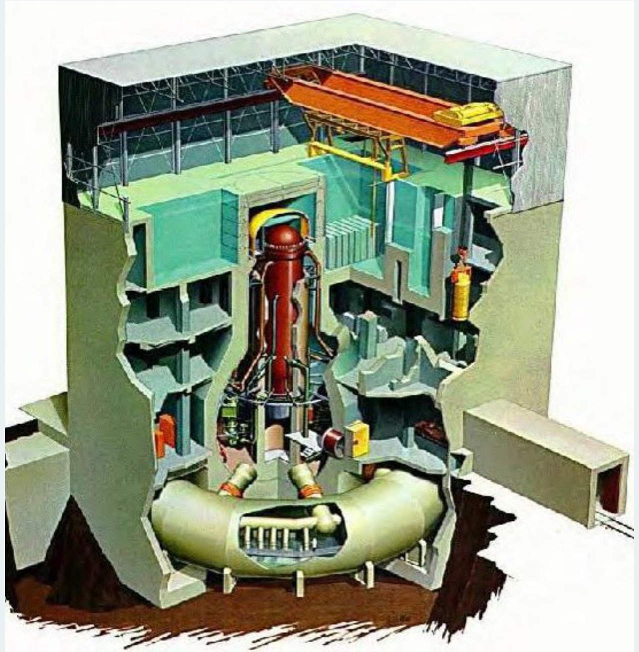


Muon tomography application till date

2015

Monitoring damaged nuclear reactors after the **Fukushima disaster.**

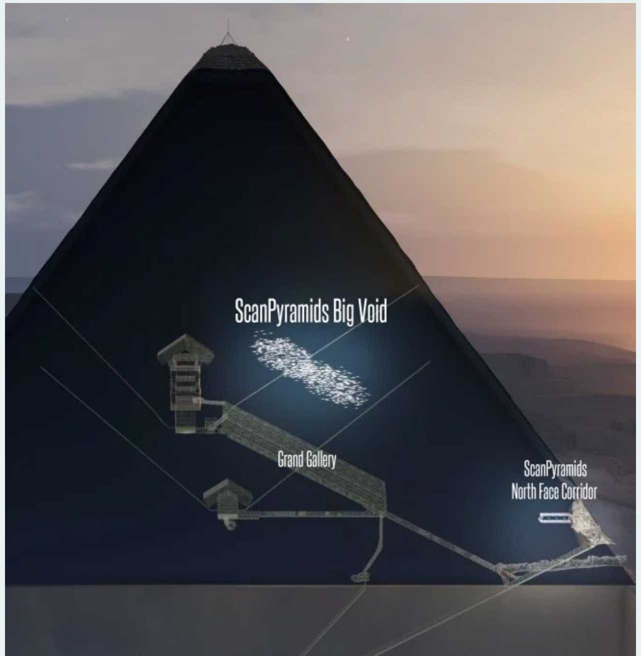
The imaging method using muons helped assess the condition of the damaged reactor cores without the need to open them.



2017

Research on the Great Pyramid of Giza as part of the **ScanPyramids project**.

In 2017, scientists discovered a large, previously unknown void called the "ScanPyramids Big Void."



2019

The ASTRI SST-2M project – generating internal images of **magma pathways in Mount Etna**.

Sequential imaging enabled the identification of the formation of a new vent.

Muon tomography application till date

2019

Imaging internal reinforcement elements in concrete and identifying damage caused by corrosion.

At the University of Glasgow, a 600 kg concrete block was analyzed, and metal reinforcement was located, with each rod being approximately **8 mm thick**.

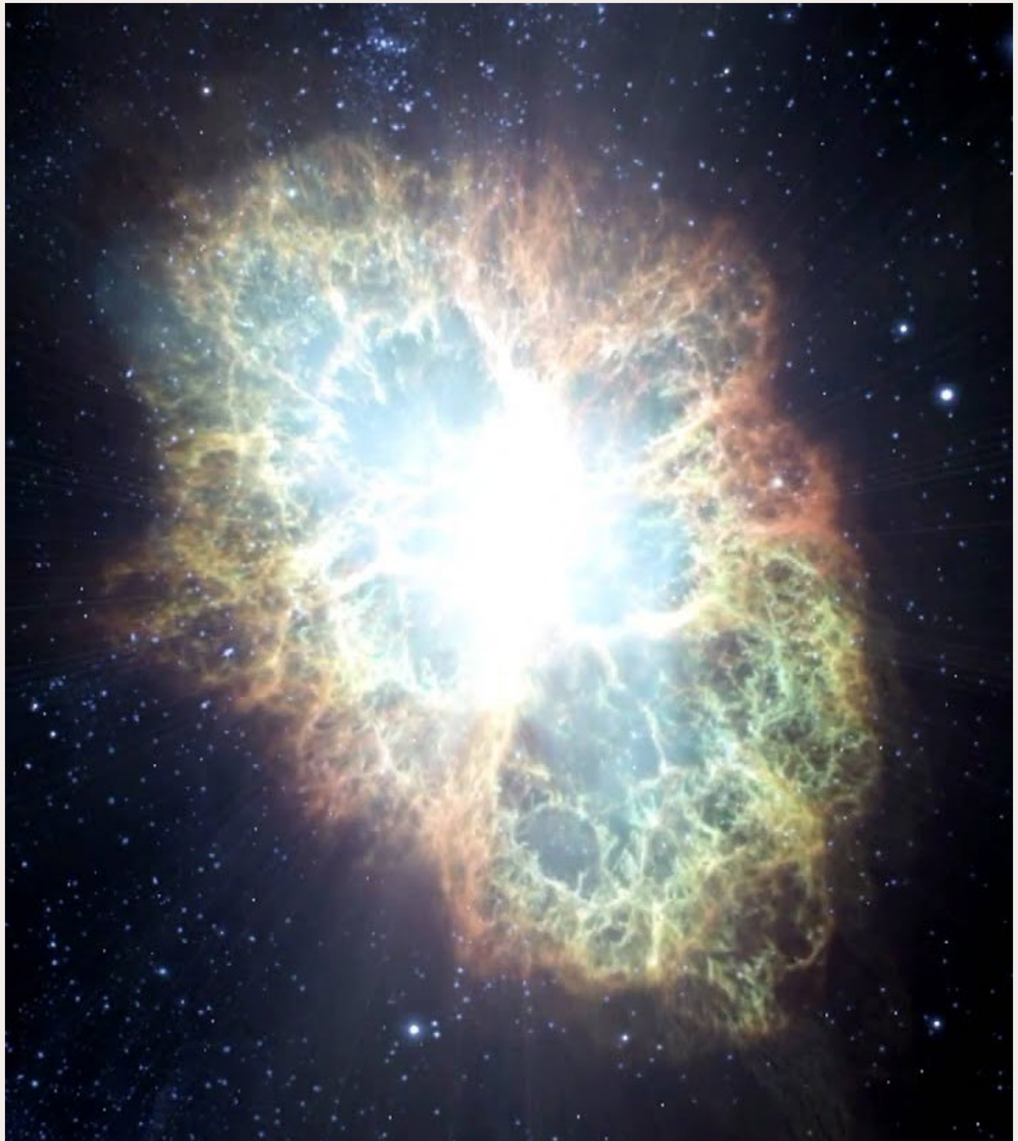
2023

In 2023, using muon radiation, a "**corridor-shaped structure**" was discovered in the Pyramid of Khufu.

It was named the "ScanPyramids North Face Corridor."

Muon tomography application till date

Cosmic radiation

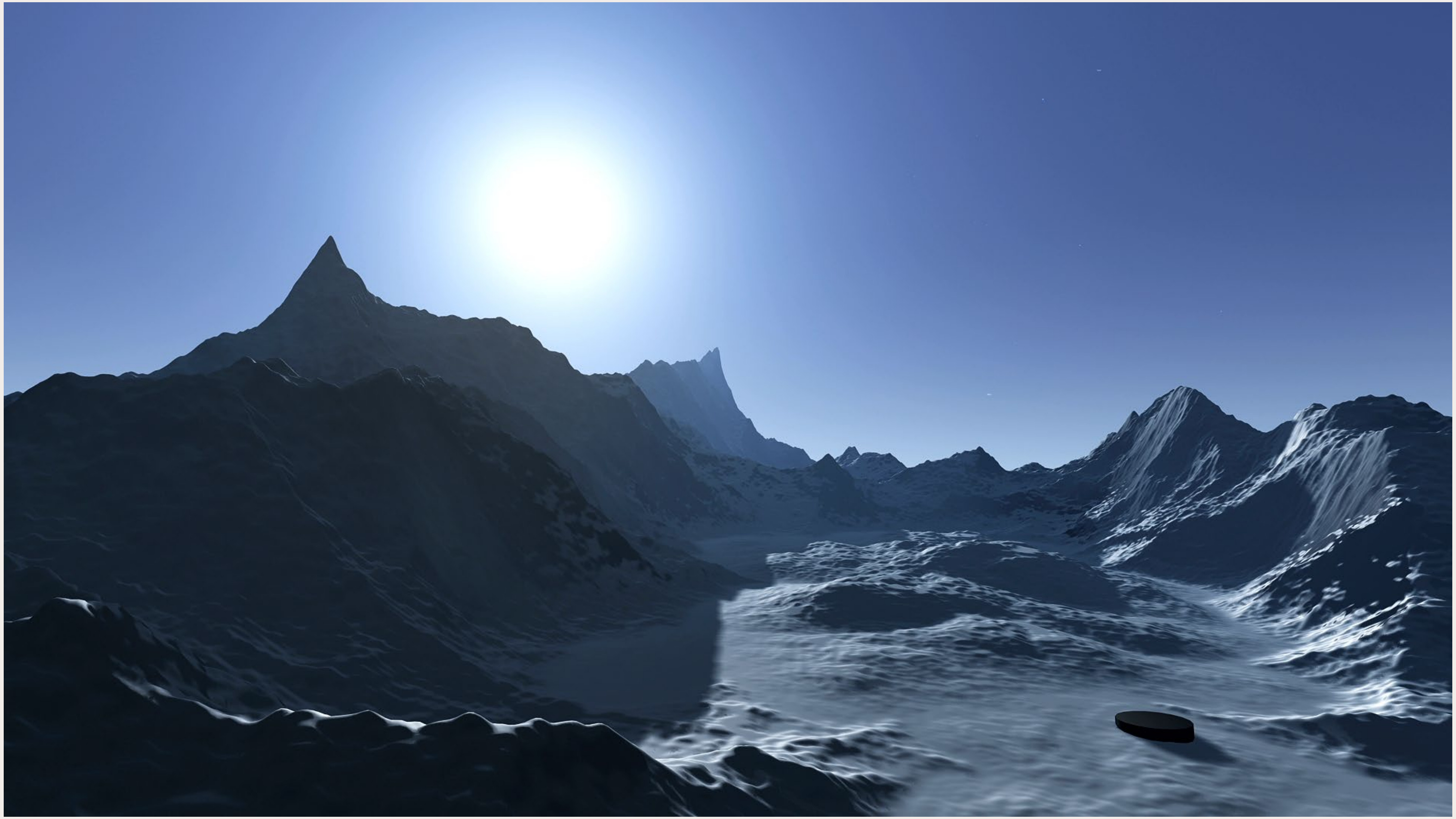


Cosmic radiation consists mainly of atomic nuclei, primarily protons (about 90%), alpha particles (helium nuclei), and electrons.

These particles travel at speeds close to the speed of light and have immense energies, reaching up to TeV.

When these high-energy particles collide with atoms in the Earth's atmosphere, a series of reactions occurs, generating new particles, known as secondary cosmic radiation particles.

Cosmic radiation



Properties of cosmic muons

- Similar to electrons, but 200 times heavier
- Approximately 10,000 particles/m^2/min
- Long lifespan (decay after ~2μs + relativistic effects)
- Penetrate up to 3 km into the Earth
- Dominant mechanisms: ionization and atomic excitation

Właściwości mionów kosmicznych

- Similar to electrons, but 200 times heavier
- Approximately 10,000 particles/m²/min
- Long lifespan (decay after ~2μs + relativistic effects)
- Penetrate up to 3 km into the Earth
- Dominant mechanisms: ionization and atomic excitation

Comparison to neutron methods:

They are not sensitive to strong nuclear interactions

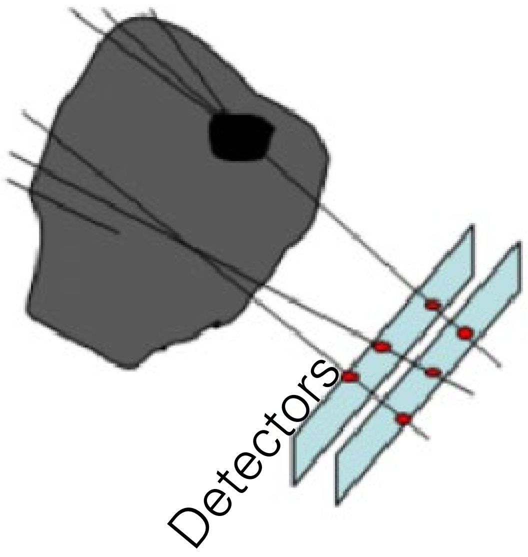
Comparison to X-ray methods:

They do not lose energy to effects such as scattering or electromagnetic cascades

Imaging of internal structures of objects

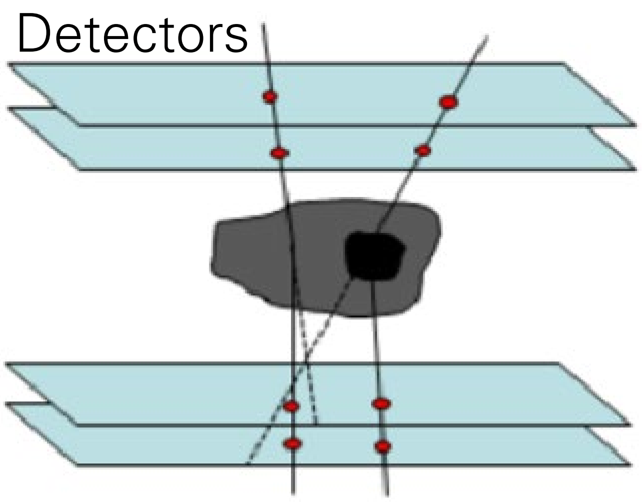
MUON RADIOGRAPHY

muon absorption

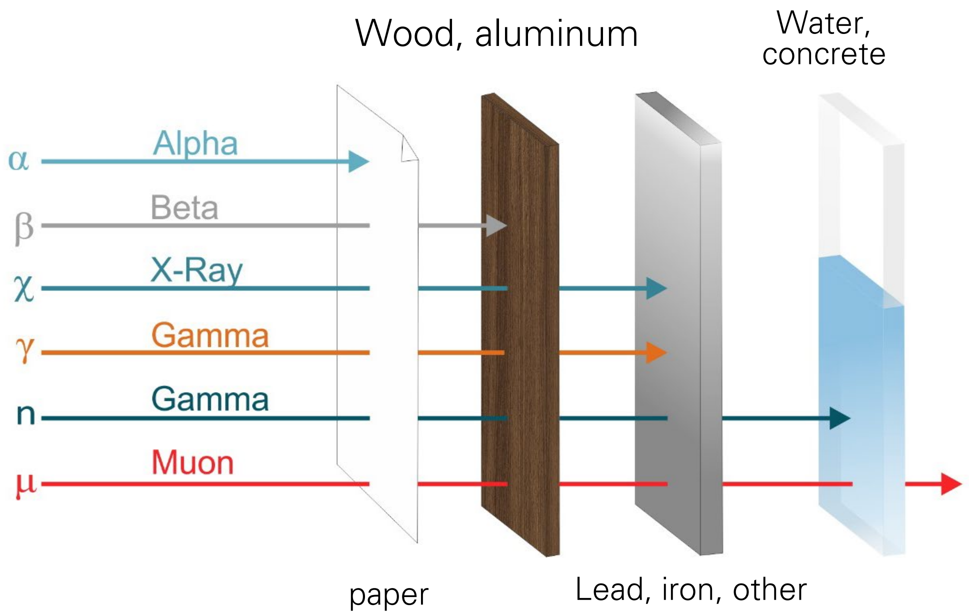


MUON SCATTERING TOMOGRAPHY

Muon scattering



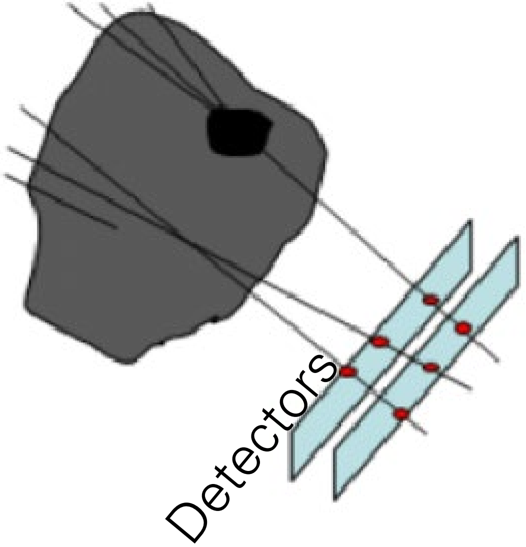
- HIGH DENSITIES
- BIG DISTANCES



Imaging of internal structures of objects

MUON RADIOGRAPHY

muon absorption



- A technique similar to X-ray imaging
- The Bethe-Bloch equation describes the relationship between energy loss and the density of matter, as well as other factors such as the particle's velocity and charge.

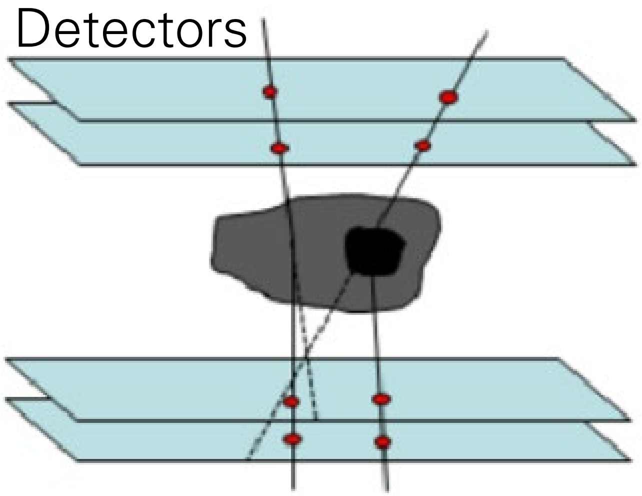
Energy loss of a particle per unit of distance → $$-\frac{dE}{dx} \approx \rho$$ ← Density

- BIG STRUCTURES ✓
- One detector for 2D, more for 3D

Imaging of internal structures of objects

MUON SCATTERING TOMOGRAPHY

muon scattering

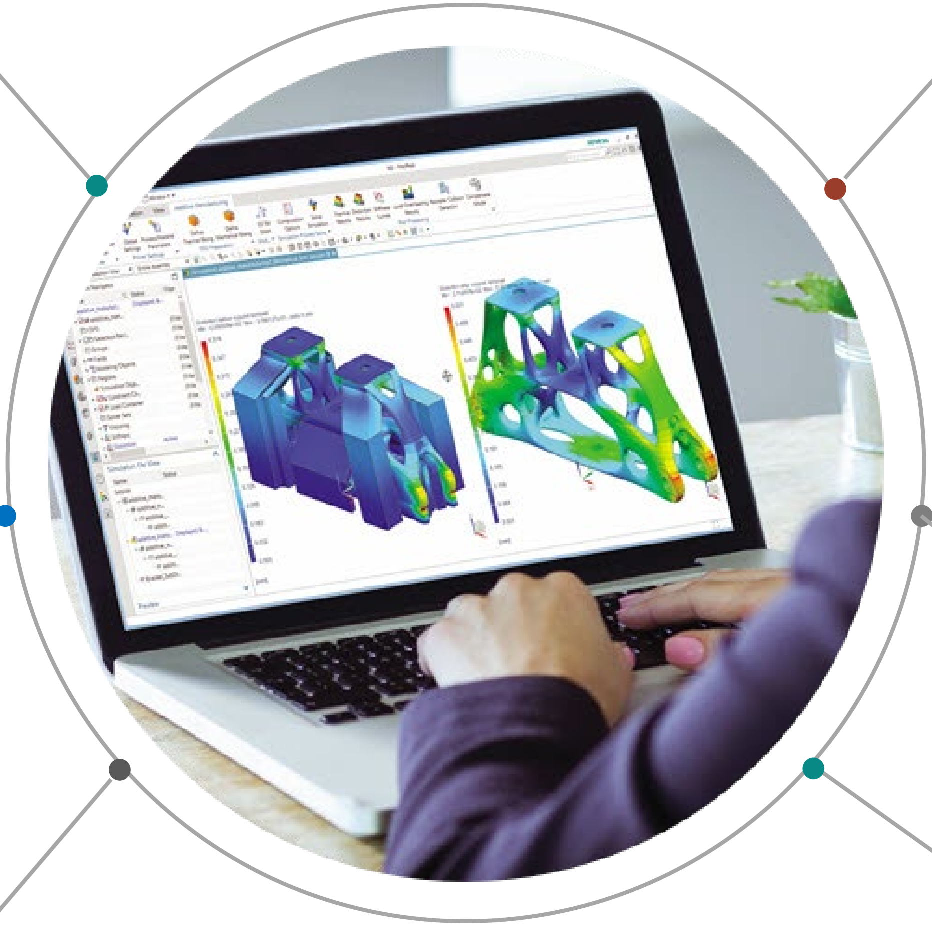


- It is based on the phenomenon of multiple Coulomb scattering
- The higher the atomic number Z, the stronger the deflection of the particle's path
- SMALL OBJECTS ✓
- Detectors placed in front of and behind the object

Development of a simulation tool

Modelling

Definition of detection setup



Optimization

Environmental conditions

Analysis

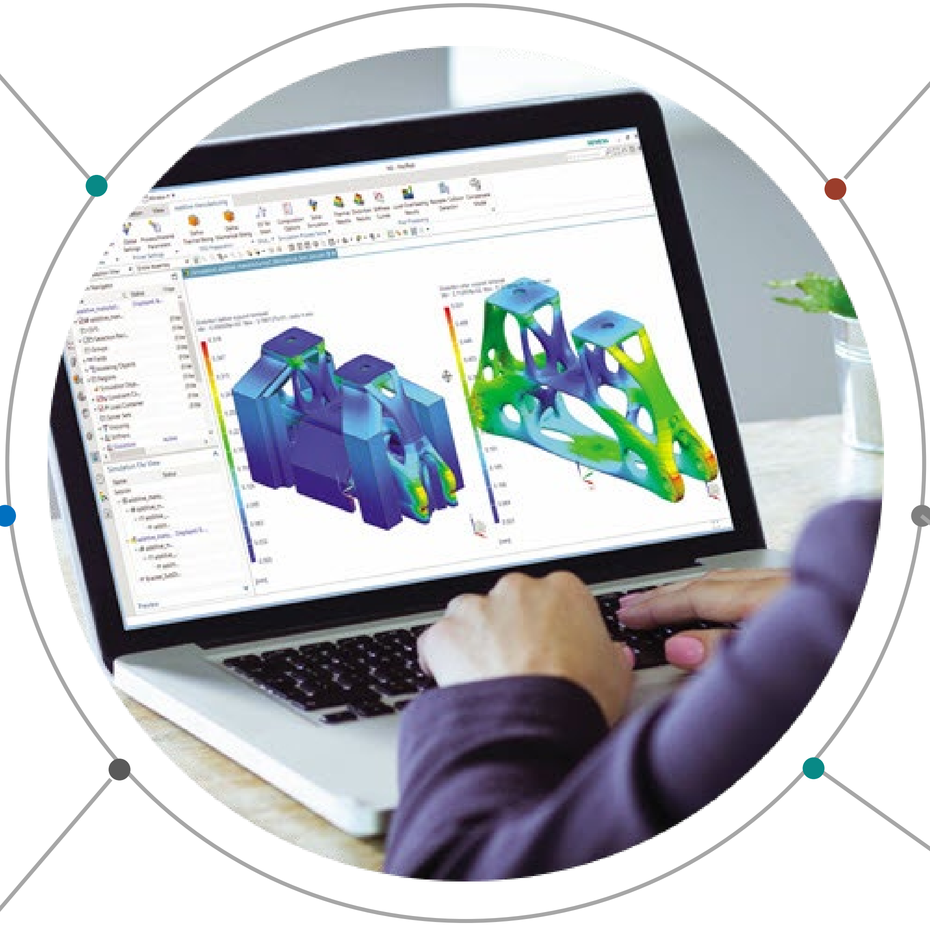
Potential parameters of objects

Development of a simulation tool

Modelling

Optimization

Analysis



Definition of detection setup

Environmental conditions

Potential parameters of objects

Development of a simulation tool

Definition of detection setup

StructoScan SENSOR

TargetScan SENSOR

Borehole SENSOR

Development of a simulation tool

Definition of detection setup

Scintillating detection

+ SiPM

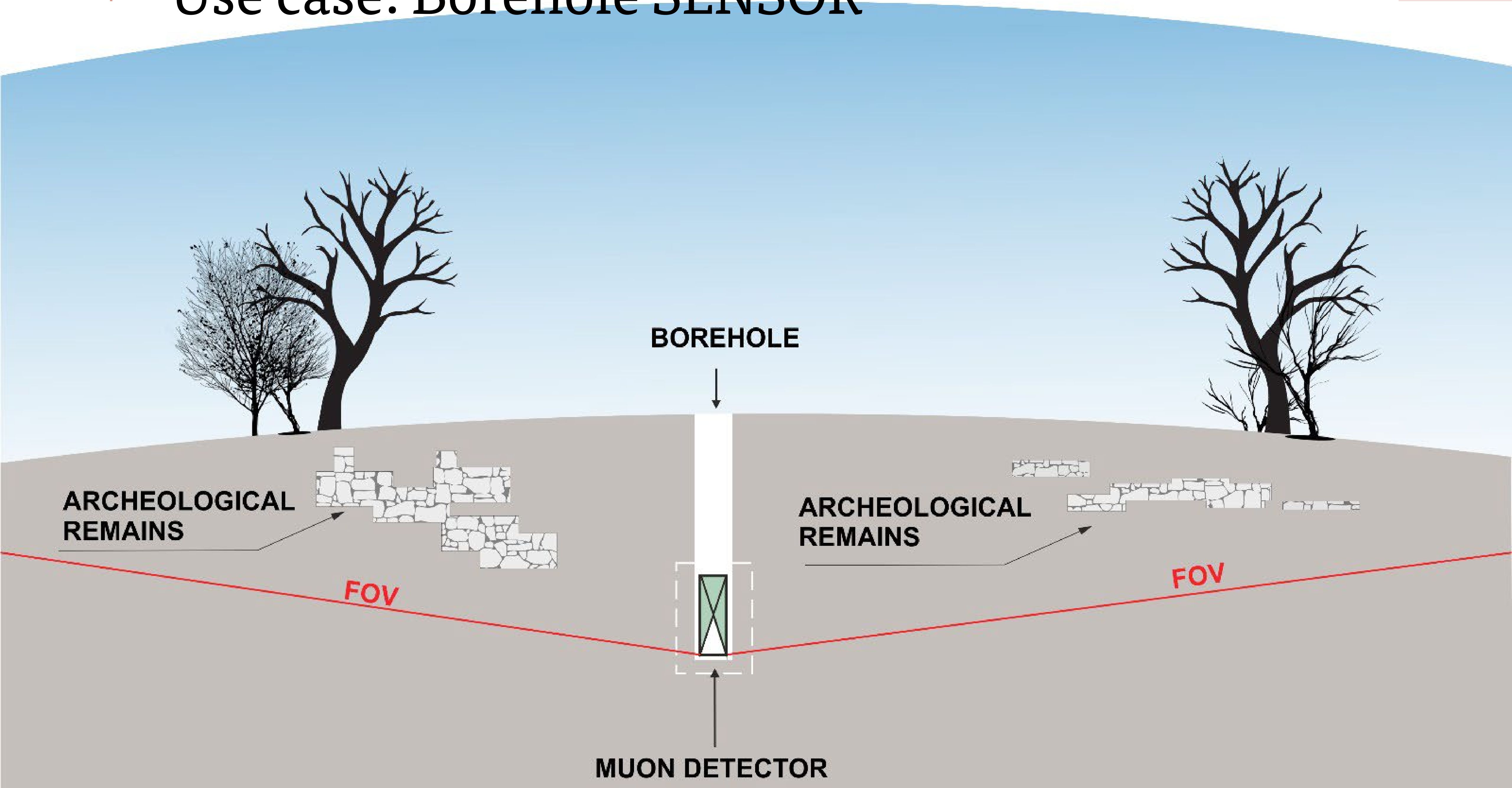
Development of a simulation tool

StructoScan SENSOR

TargetScan SENSOR

Borehole SENSOR

Use case: Borehole SENSOR

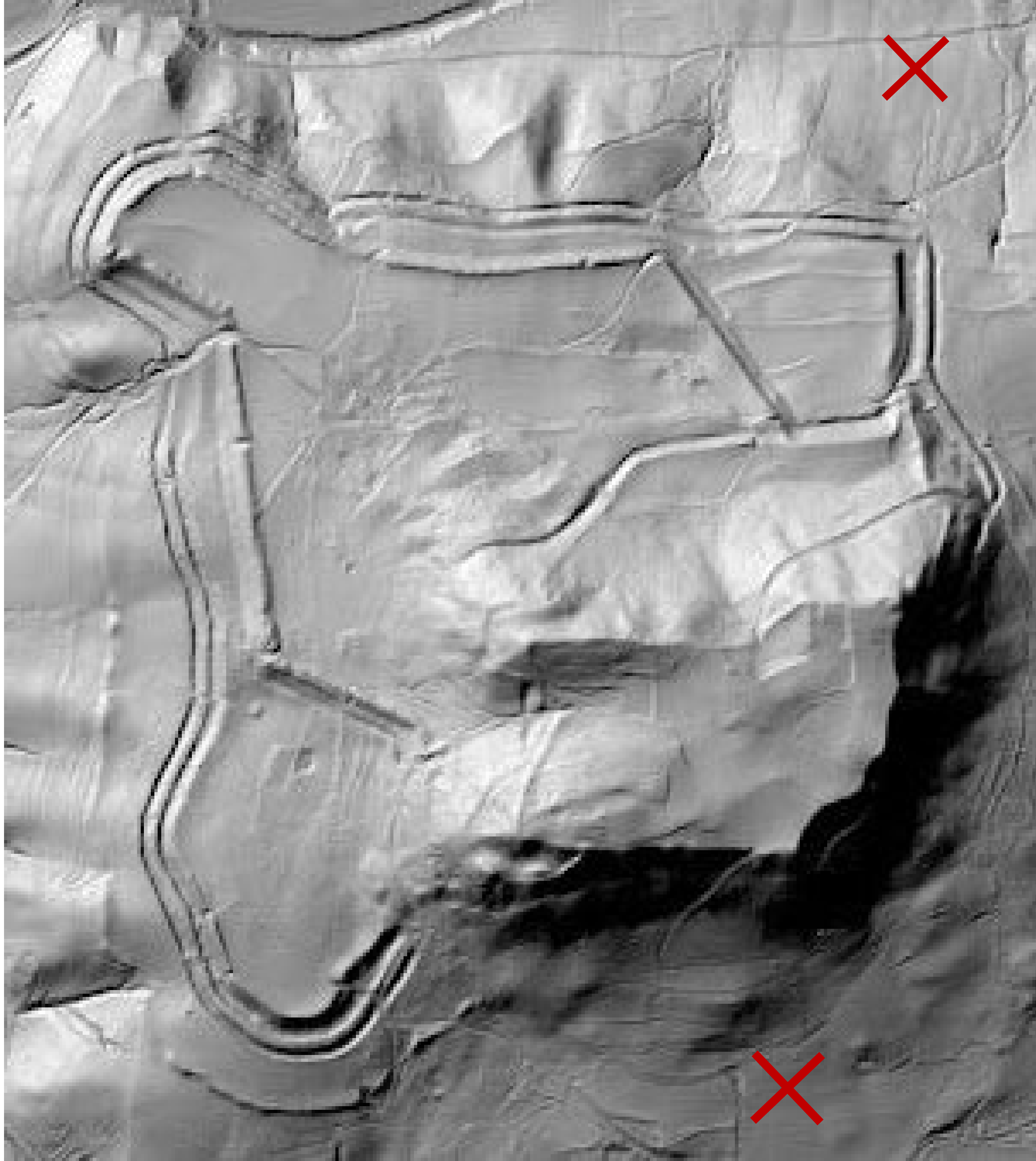


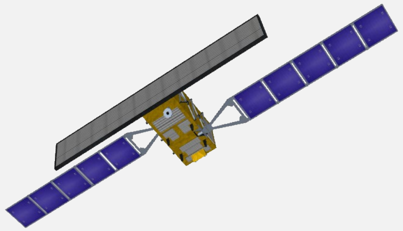
Targeted exploration

Narrowing down specific regions for the potential borehole to fully map areas of archaeological significance.

REMOTE SENSING

- Overview of the site
- Optimizing location of detector installation
- Complementary data



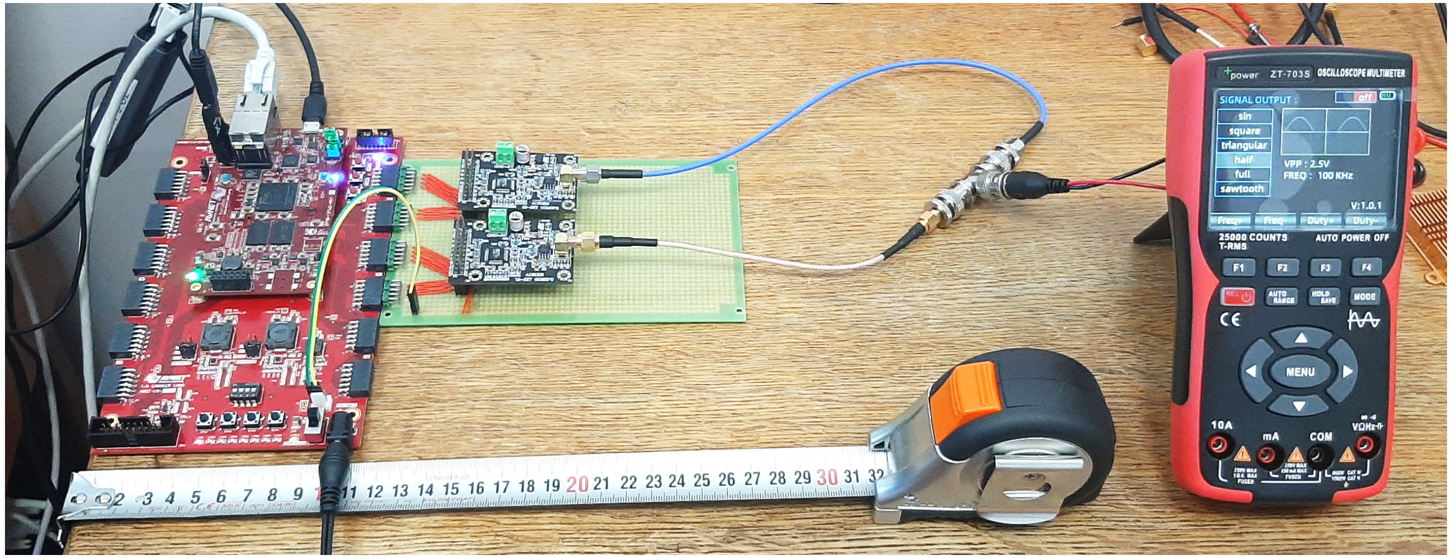


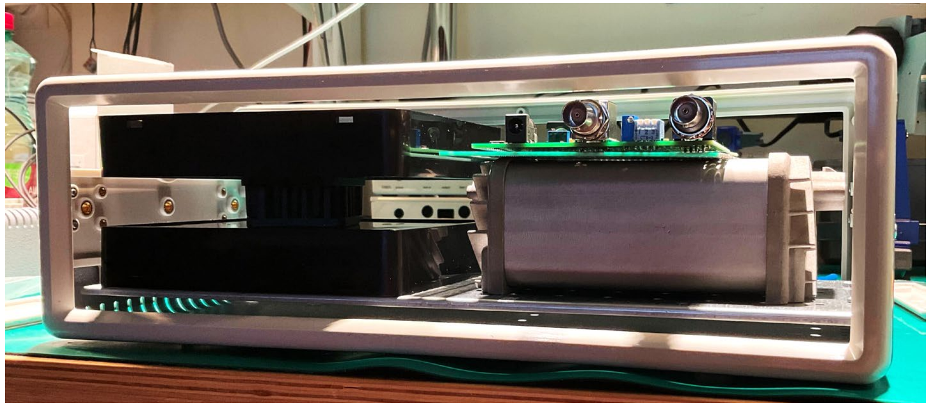
	LiDAR	Multispectral Imaging	Hyperspectral Imaging	Thermal Infrared Imaging
What we get	3D surface mapping, elevation models, can penetrate vegetation	Surface mapping based on different material properties (e.g., vegetation, soil)	Highly detailed surface material analysis, differentiating slight variations in material composition	Surface temperature variations, detecting heat retention/loss differences due to buried structures
Spatial resolution	0.1 - 1 m	0.3 - 30 m	5 - 30 m	60 - 120 m
Why it's important	Great for identifying buried ruins, roads, or structures	Identifies areas of different materials or vegetation	Detects finer material differences, which can point to specific building materials, minerals, or buried structures	Helps identify underground voids or chambers based on thermal anomalies, especially useful in dry or desert environments

Future developments and research directions

1. Finalization of the simulation tool

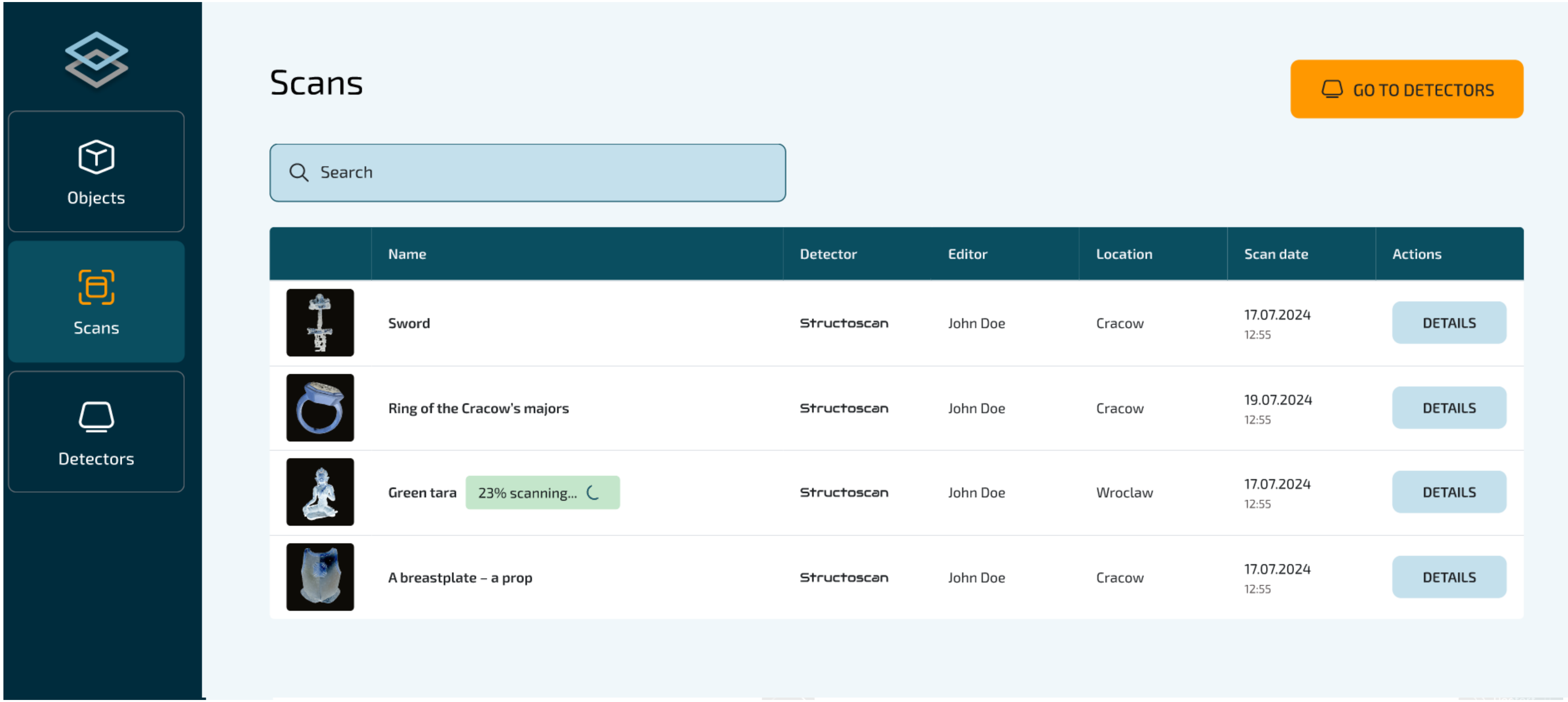
2. Prototypes building!





Future developments and research directions

3. Intuitive platform for object analysis, data storage and export



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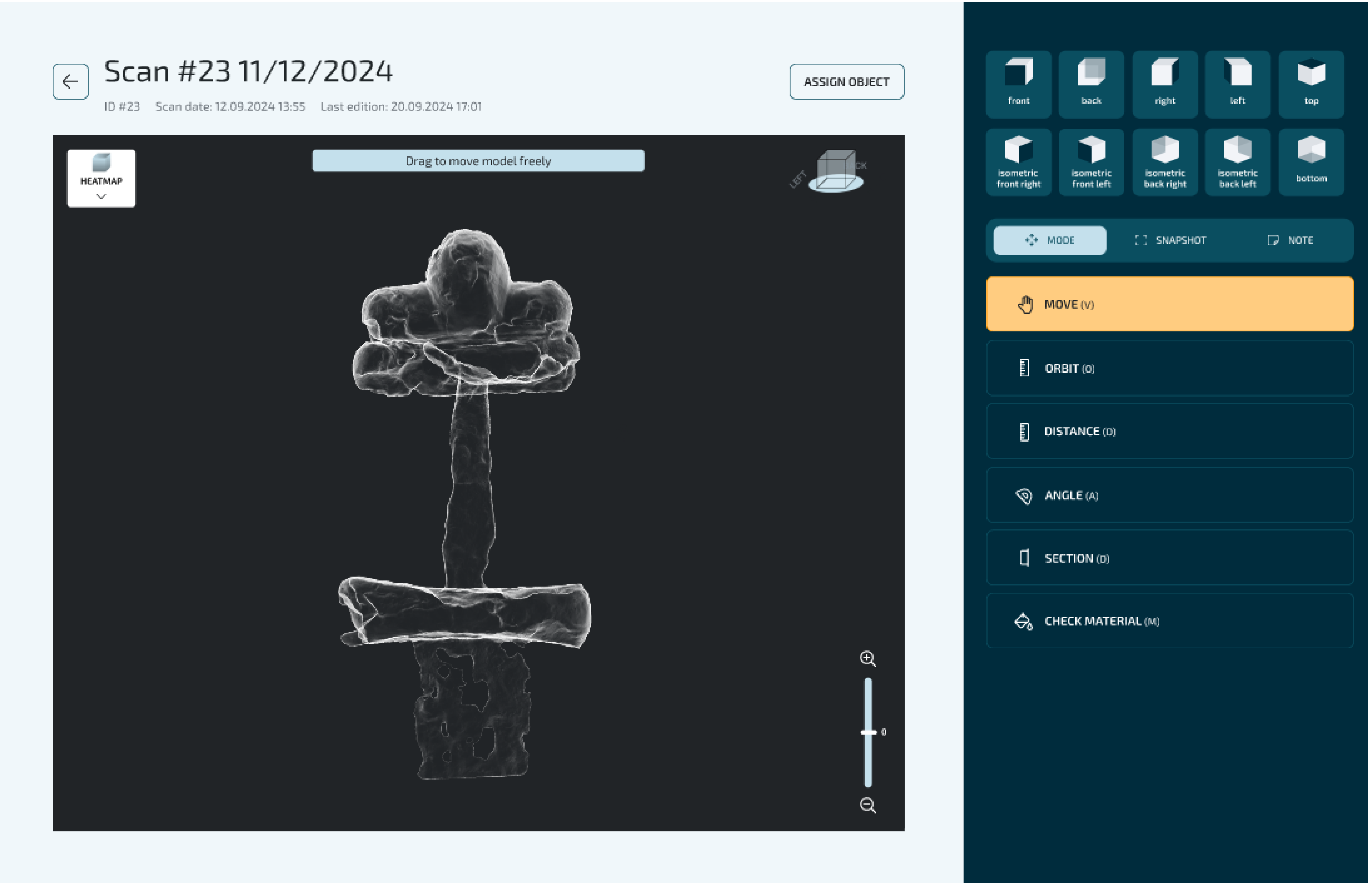

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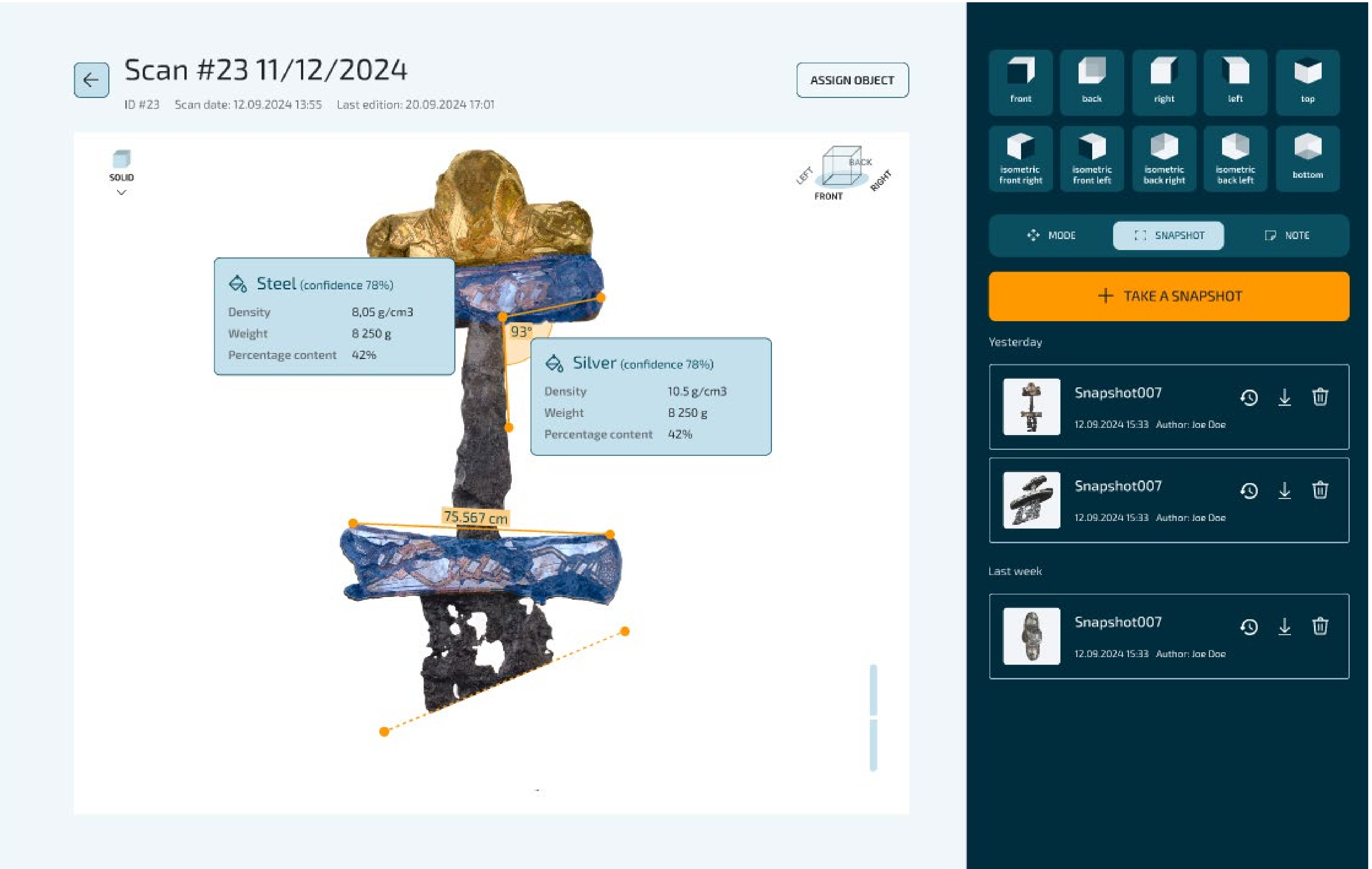

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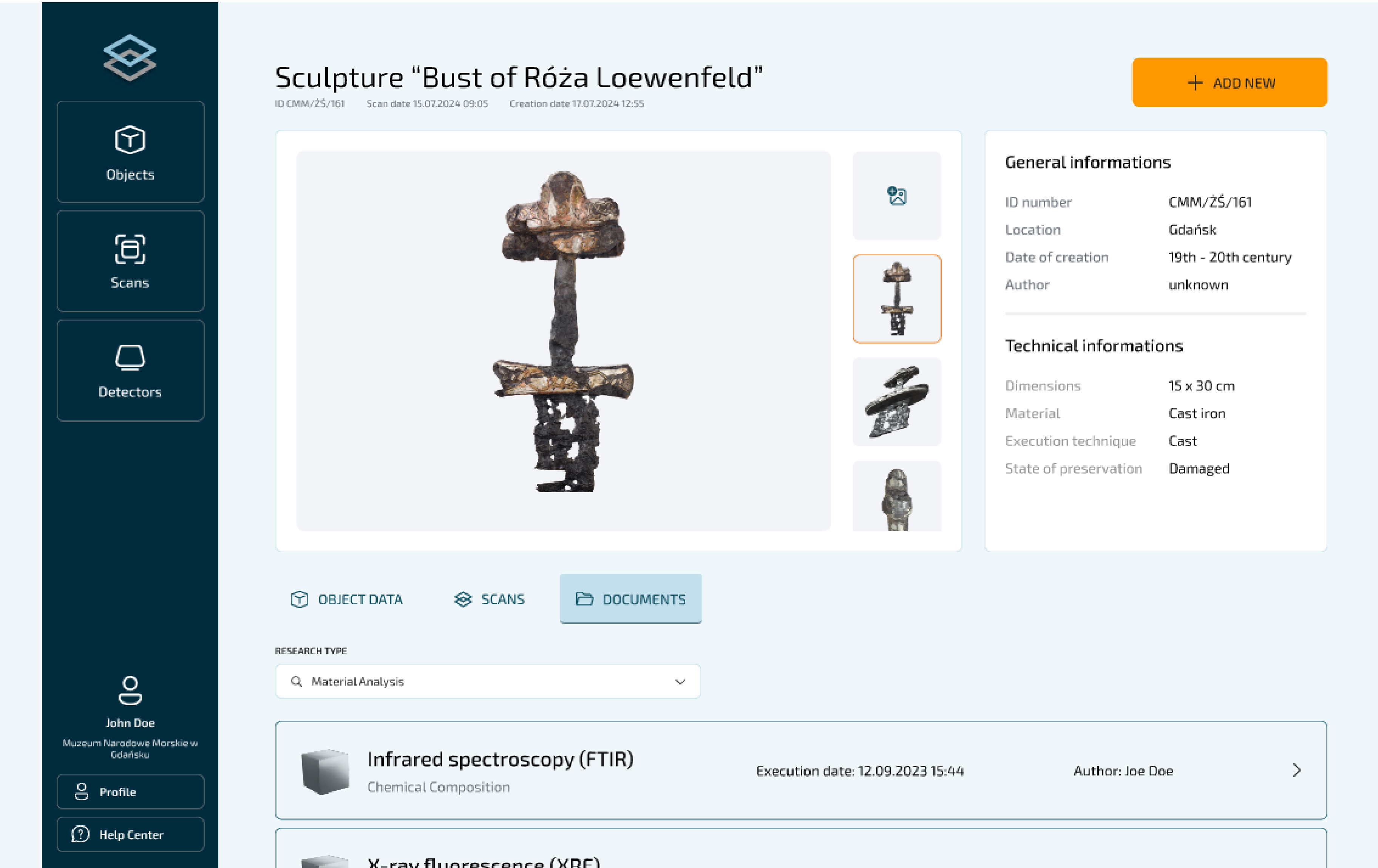

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Get in touch

MUOTECH

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