



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

Supported by



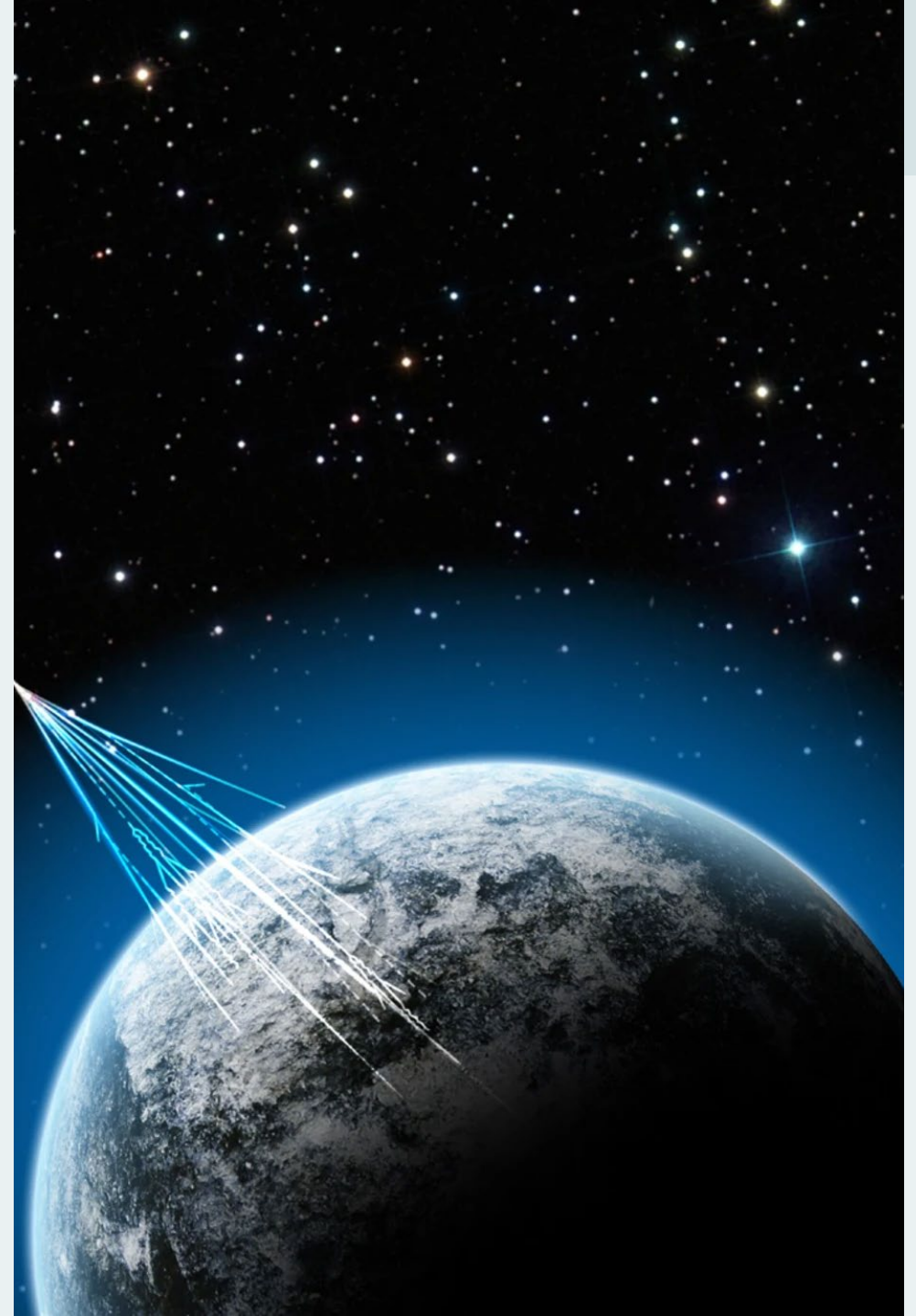
Agenda

- 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.

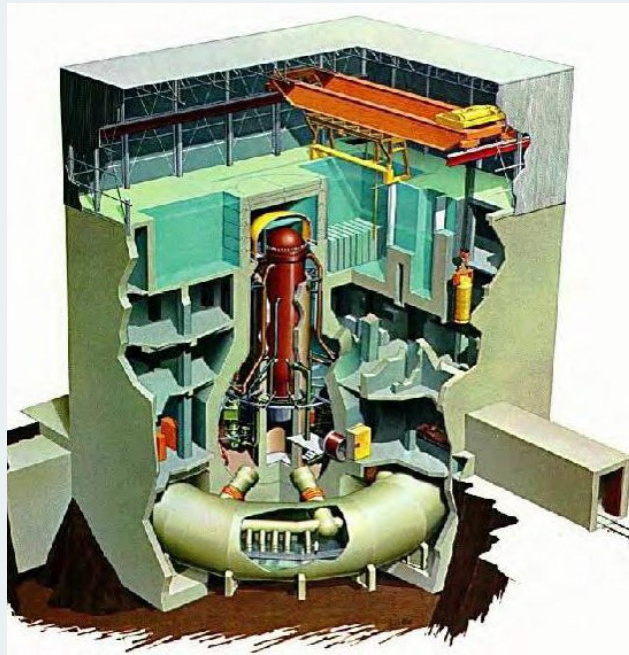


Muon tomography application till date

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.

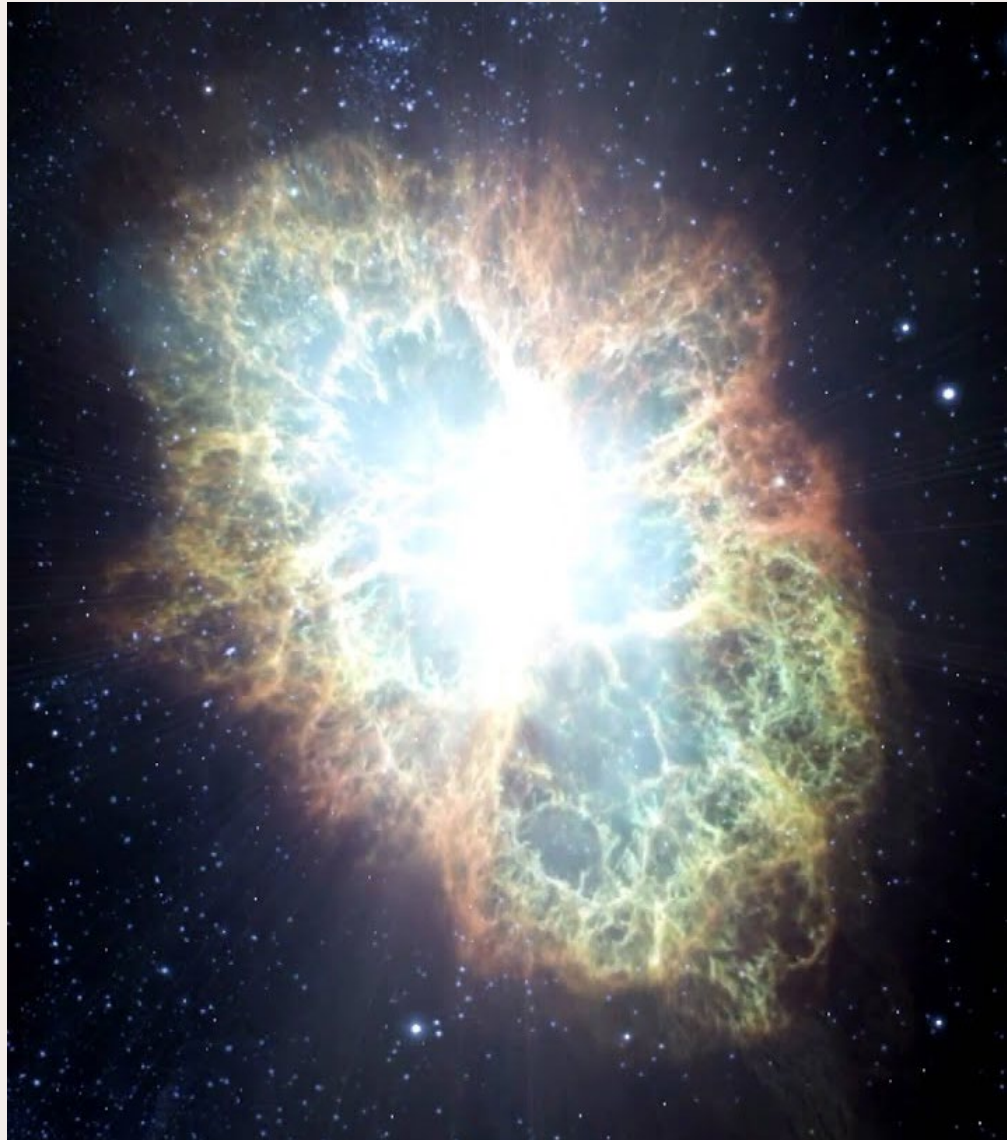
It was named the "ScanPyramids North Face Corridor."



Muon tomography application till date



Cosmic radiation

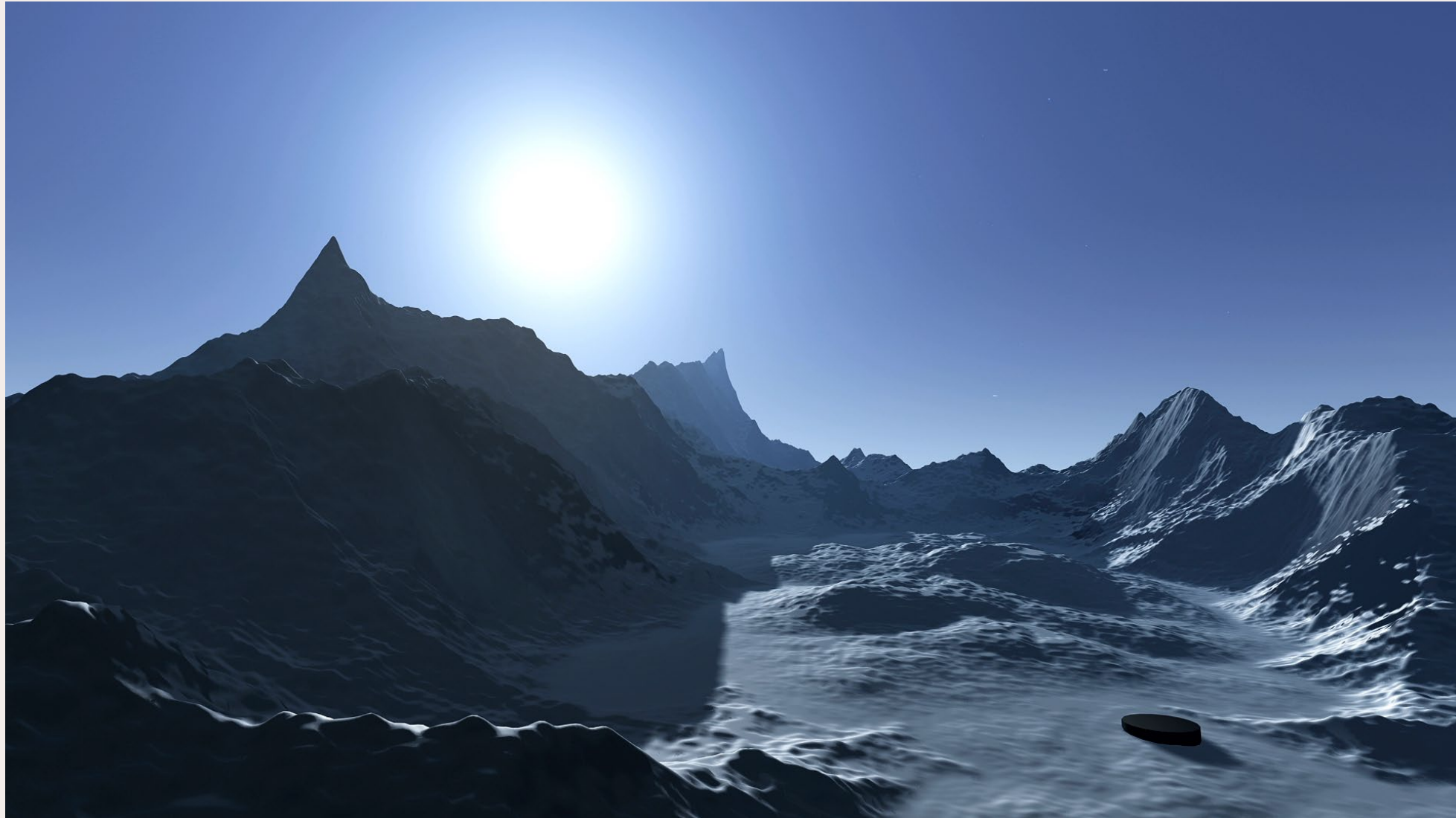


Cosmic radiation consists mainly of atomic nuclei, primarily protons (about 90%), alpha particles (helium nuclei), and electrons.

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/m²/min
- Long lifespan (decay after $\sim 2\mu\text{s}$ + 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 $\sim 2\mu\text{s}$ + 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

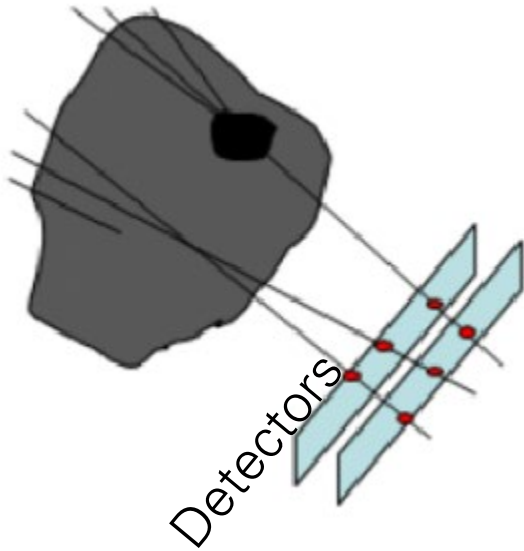
Comparison to X-ray methods:

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

Imaging of internal structures of objects

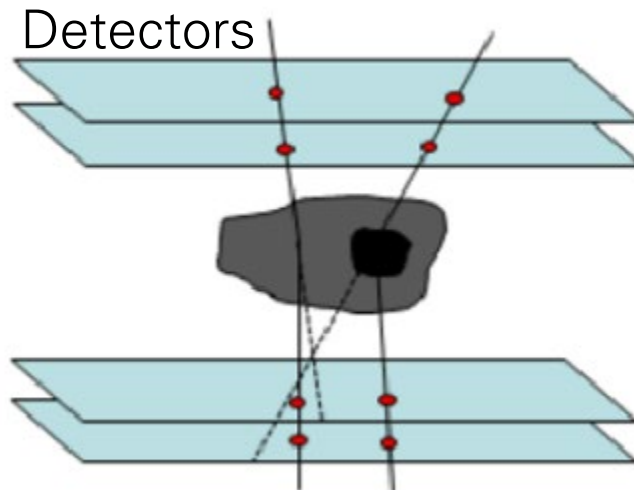
MUON RADIOGRAPHY

muon absorption

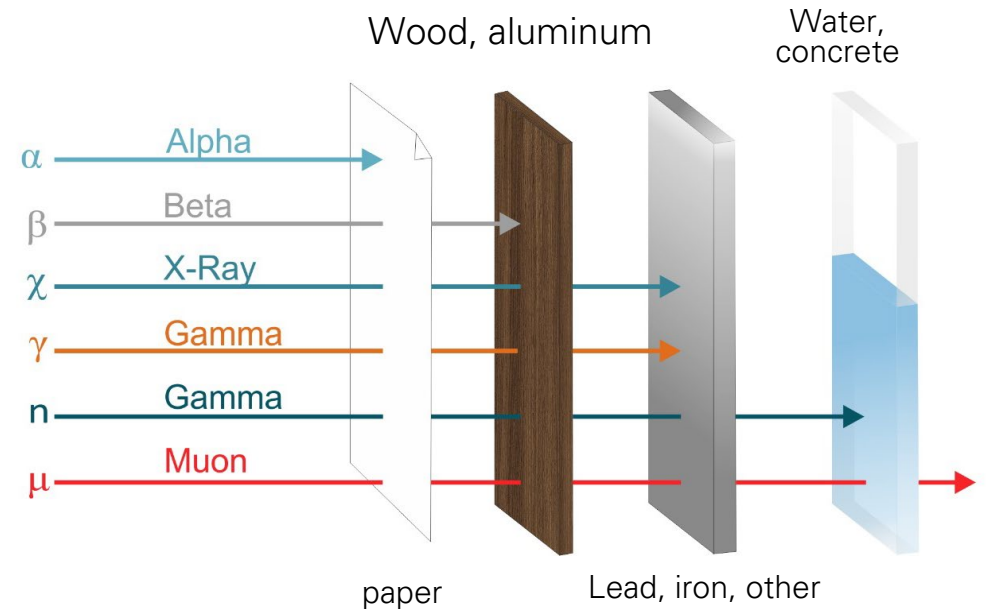


MUON SCATTERING TOMOGRAPHY

Muon scattering



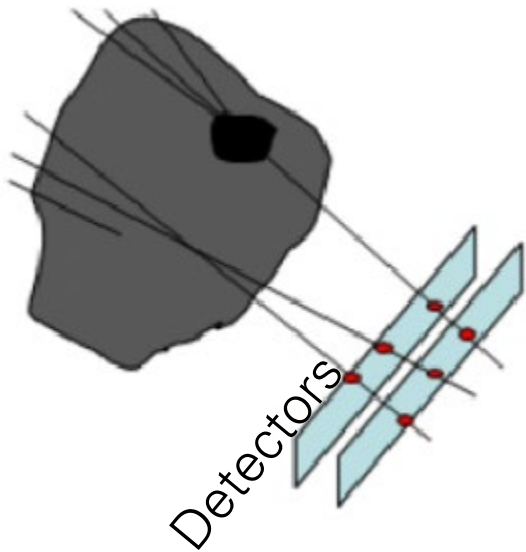
- HIGH DENSITIES
- BIG DISTANCES



Imaging of internal structures of objects

MUON RADIOGRAPHY

muon absorption

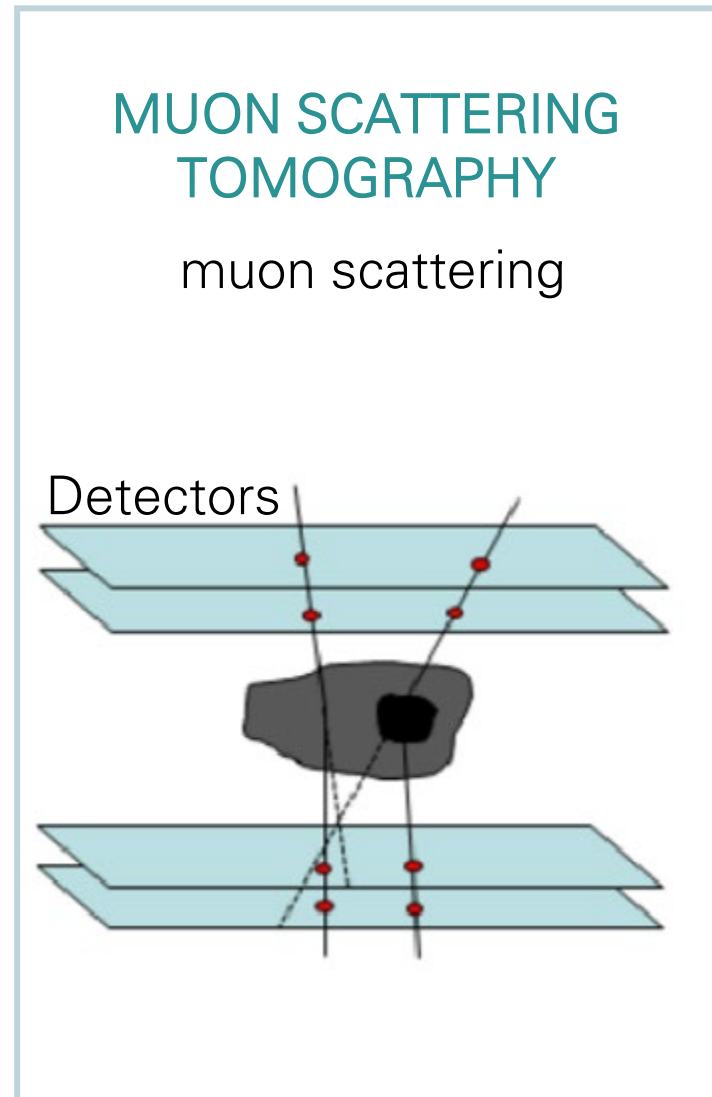


- A technique similar to X-ray imaging
- The Bethe-Bloch equation describes the relationship between energy loss and the density of matter, as well as other factors such as the particle's velocity and charge.

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

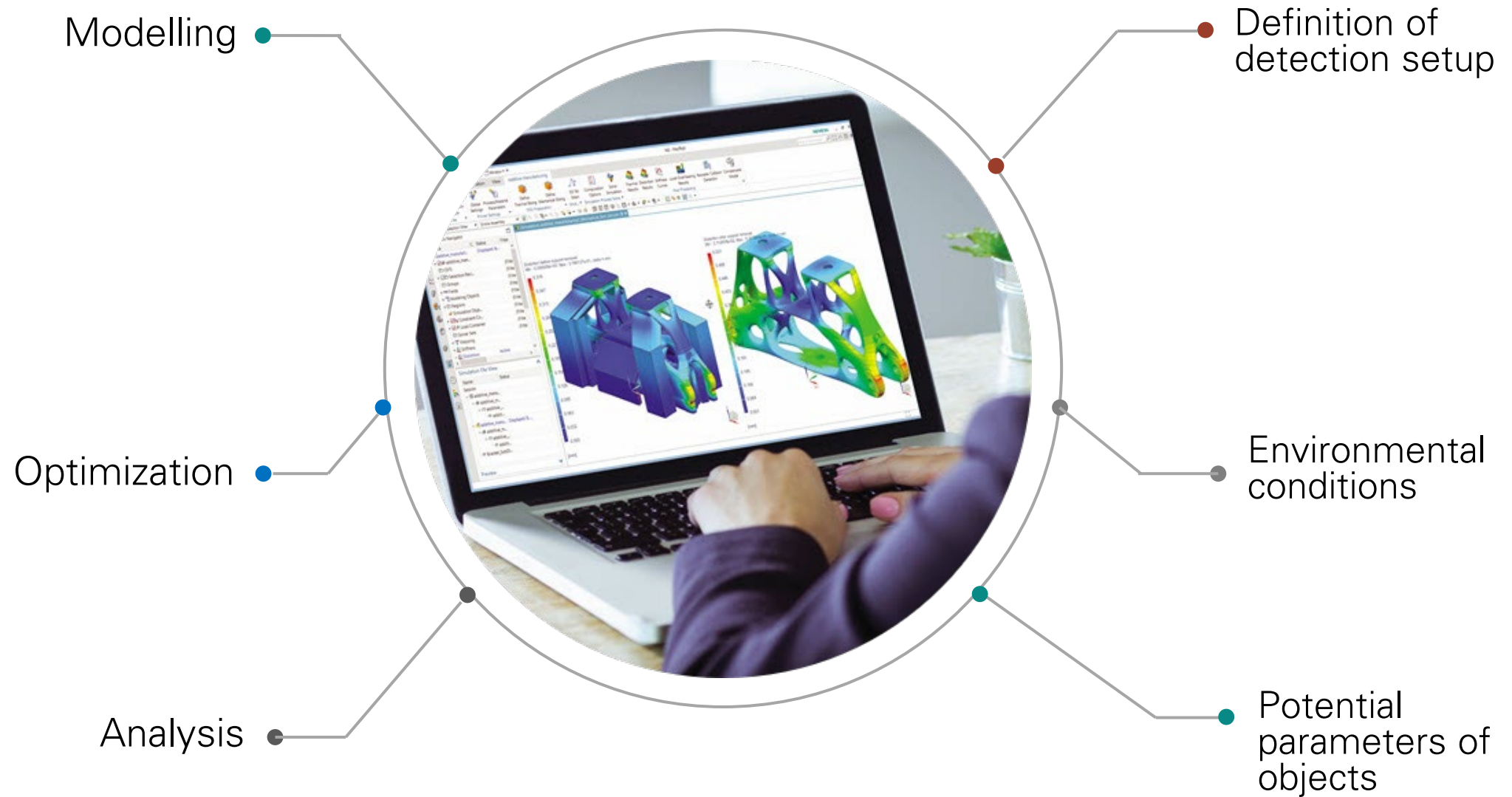
- BIG STRUCTURES ✓
- One detector for 2D, more for 3D

Imaging of internal structures of objects

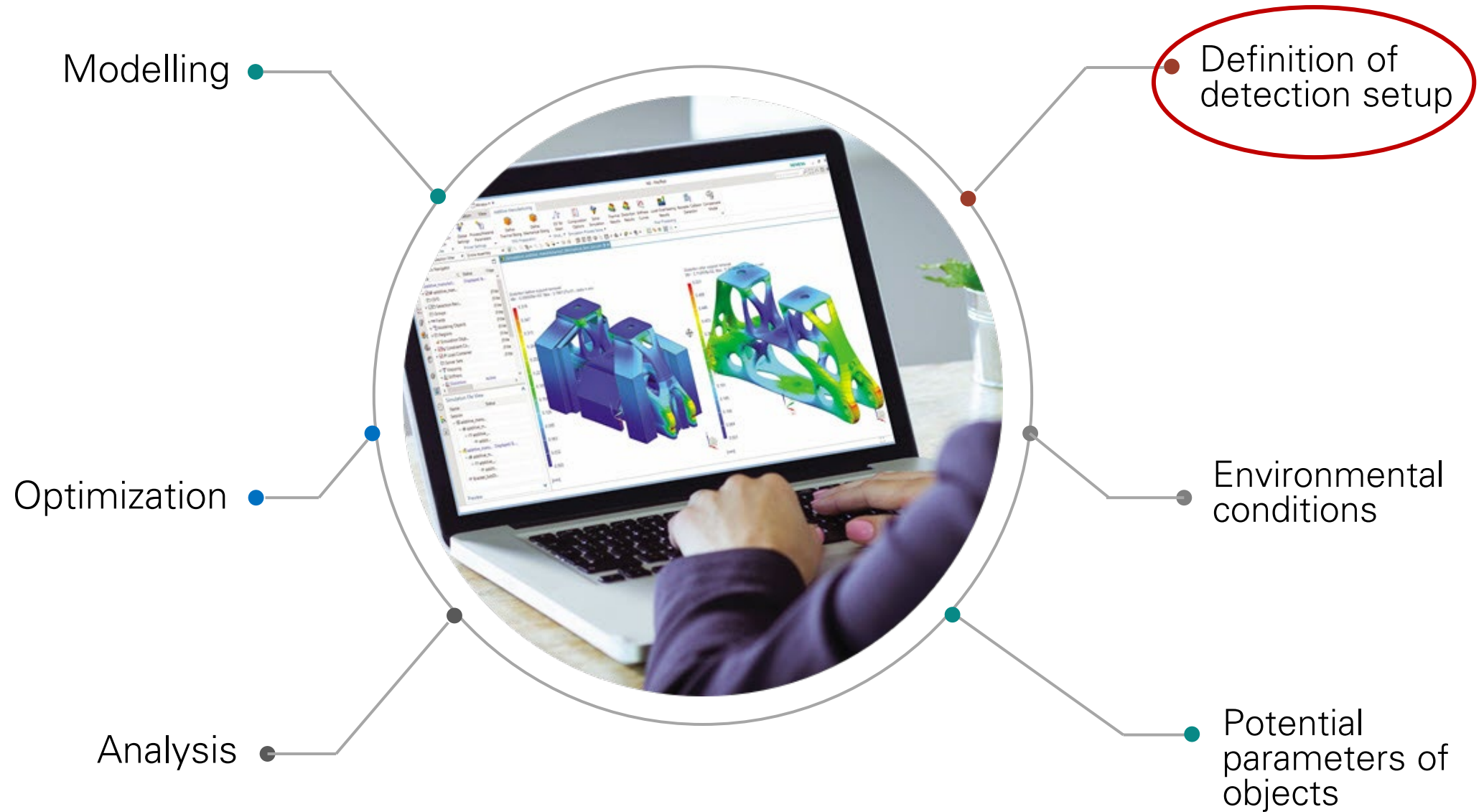


- It is based on the phenomenon of multiple Coulomb scattering
- The higher the atomic number Z , the stronger the deflection of the particle's path
- SMALL OBJECTS ✓
- Detectors placed in front of and behind the object

Development of a simulation tool



Development of a simulation tool



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



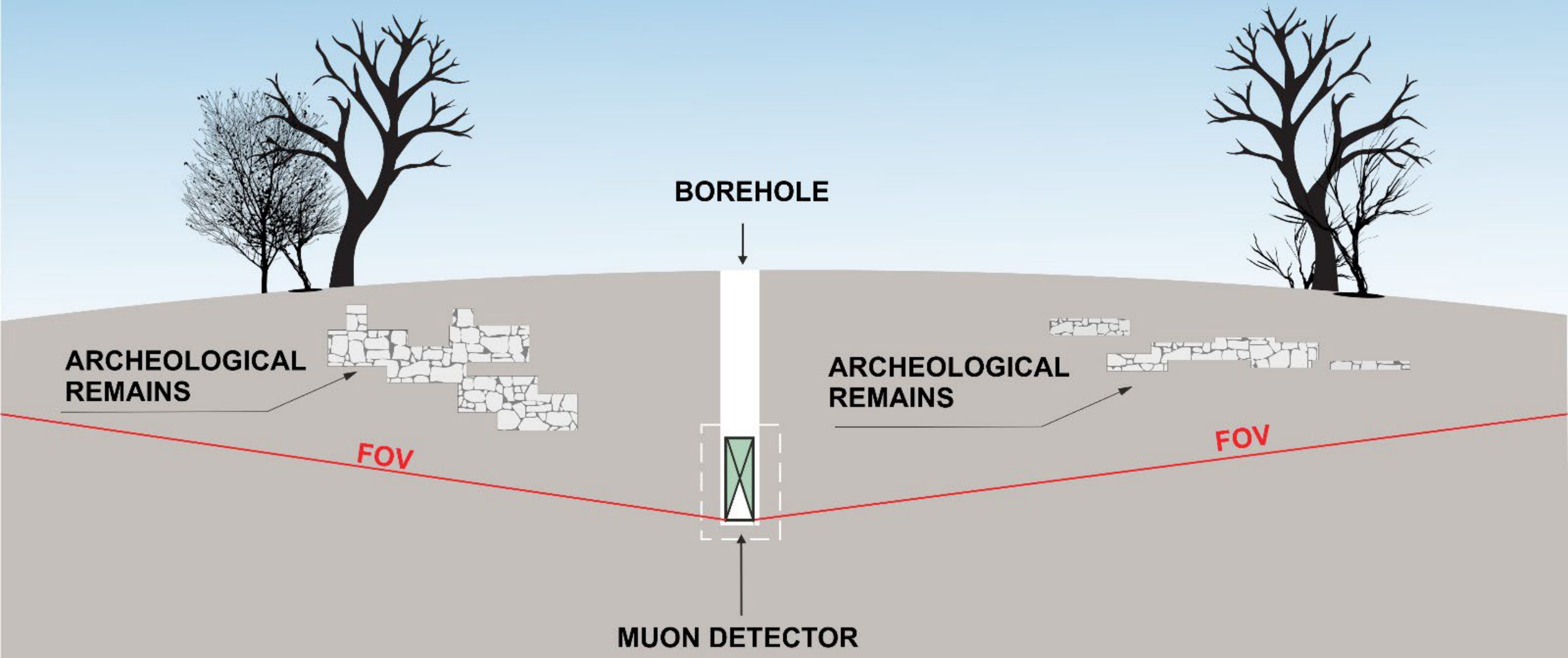
TargetScan SENSOR



Borehole SENSOR



Use case: Borehole SENSOR

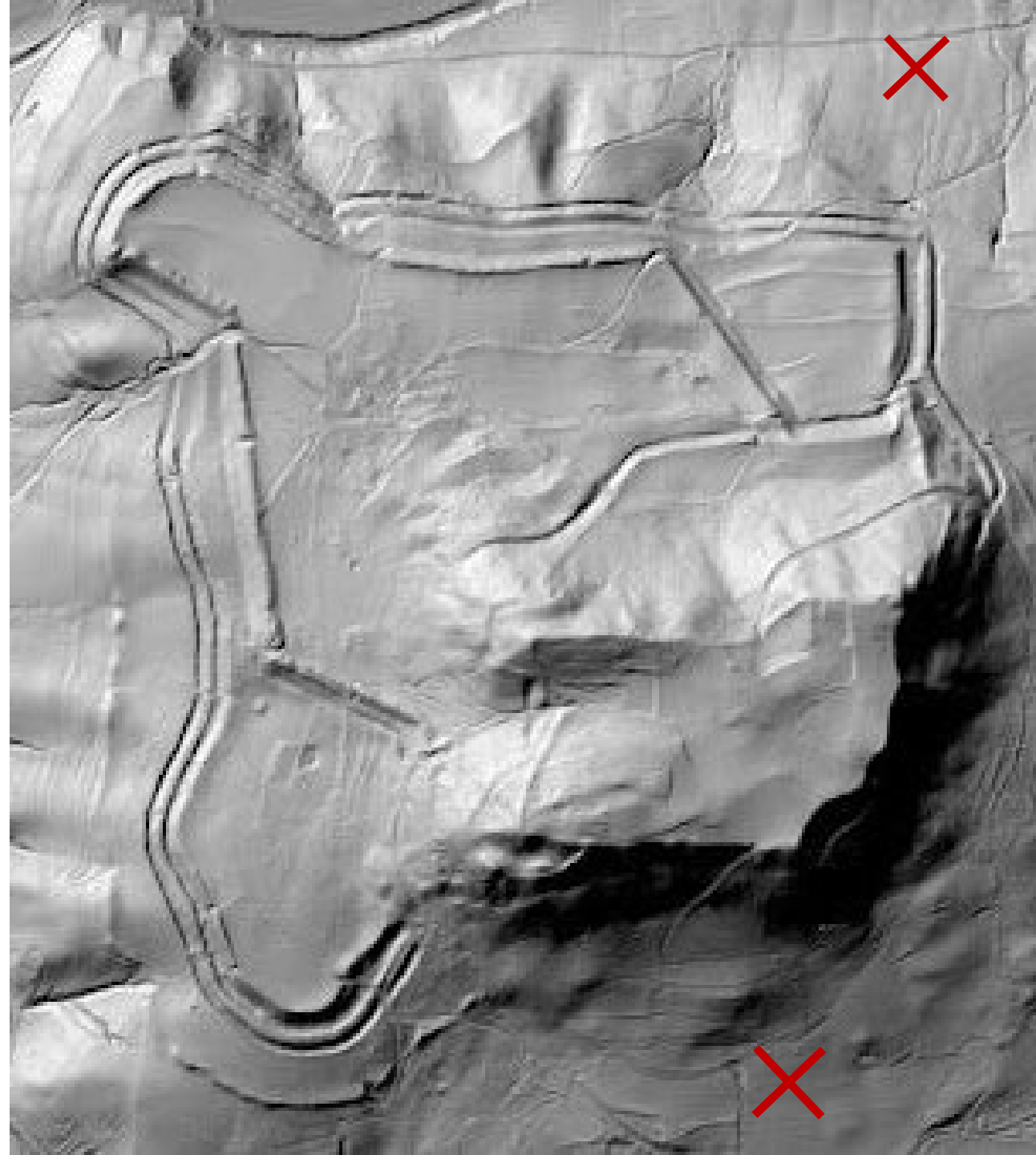


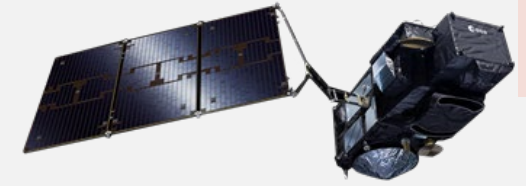
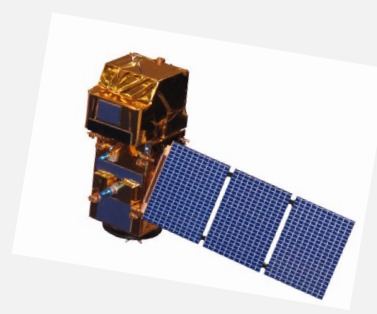
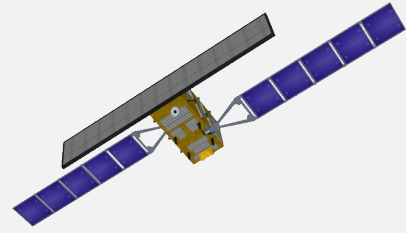
Targeted exploration

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

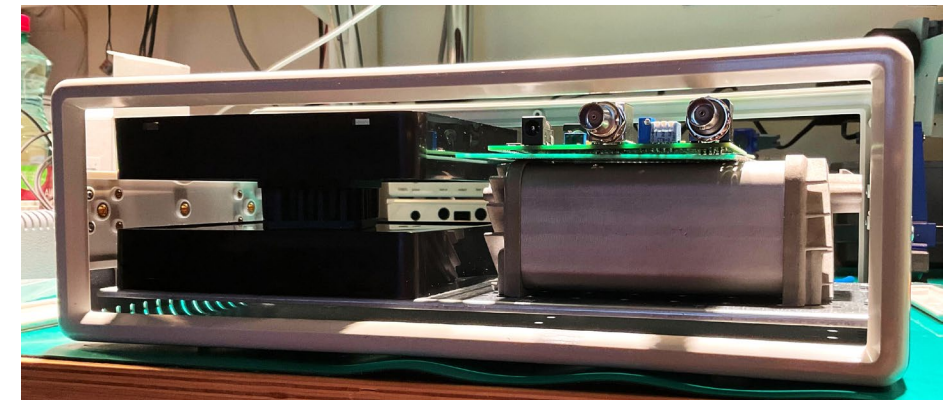
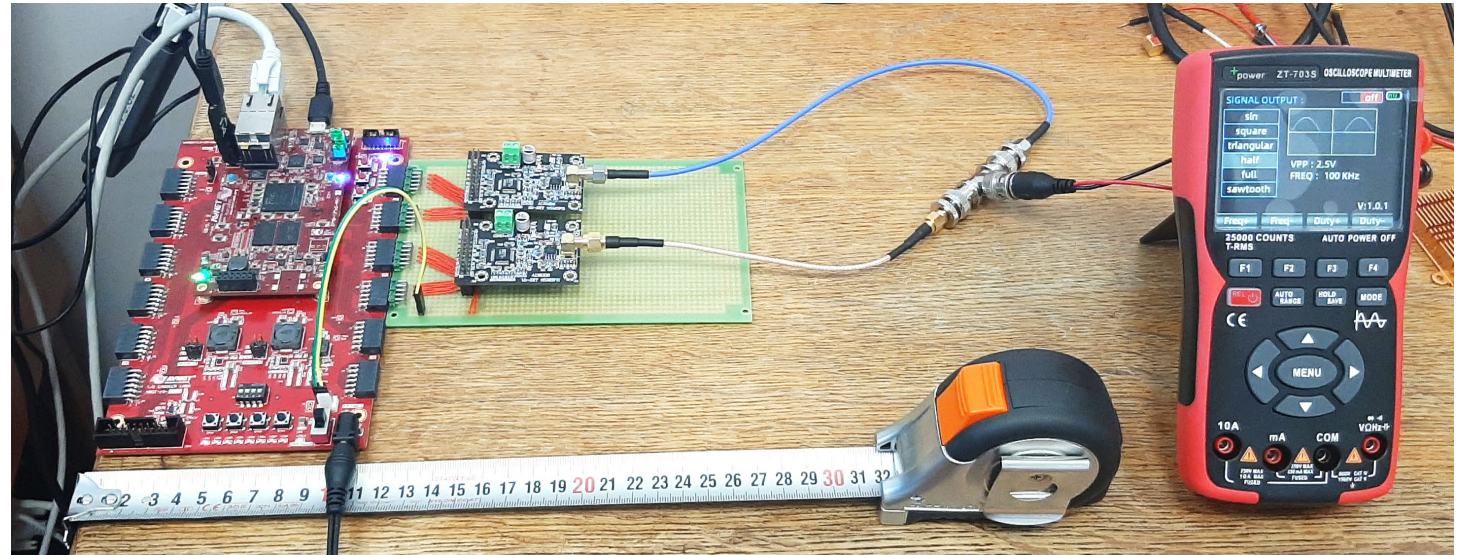




	LiDAR	Multispectral Imaging	Hyperspectral Imaging	Thermal Infrared Imaging
What we get	3D surface mapping, elevation models, can penetrate vegetation	Surface mapping based on different material properties (e.g., vegetation, soil)	Highly detailed surface material analysis, differentiating slight variations 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





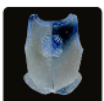
1. Finalization of the simulation tool
2. Prototypes building!



Future developments and research directions

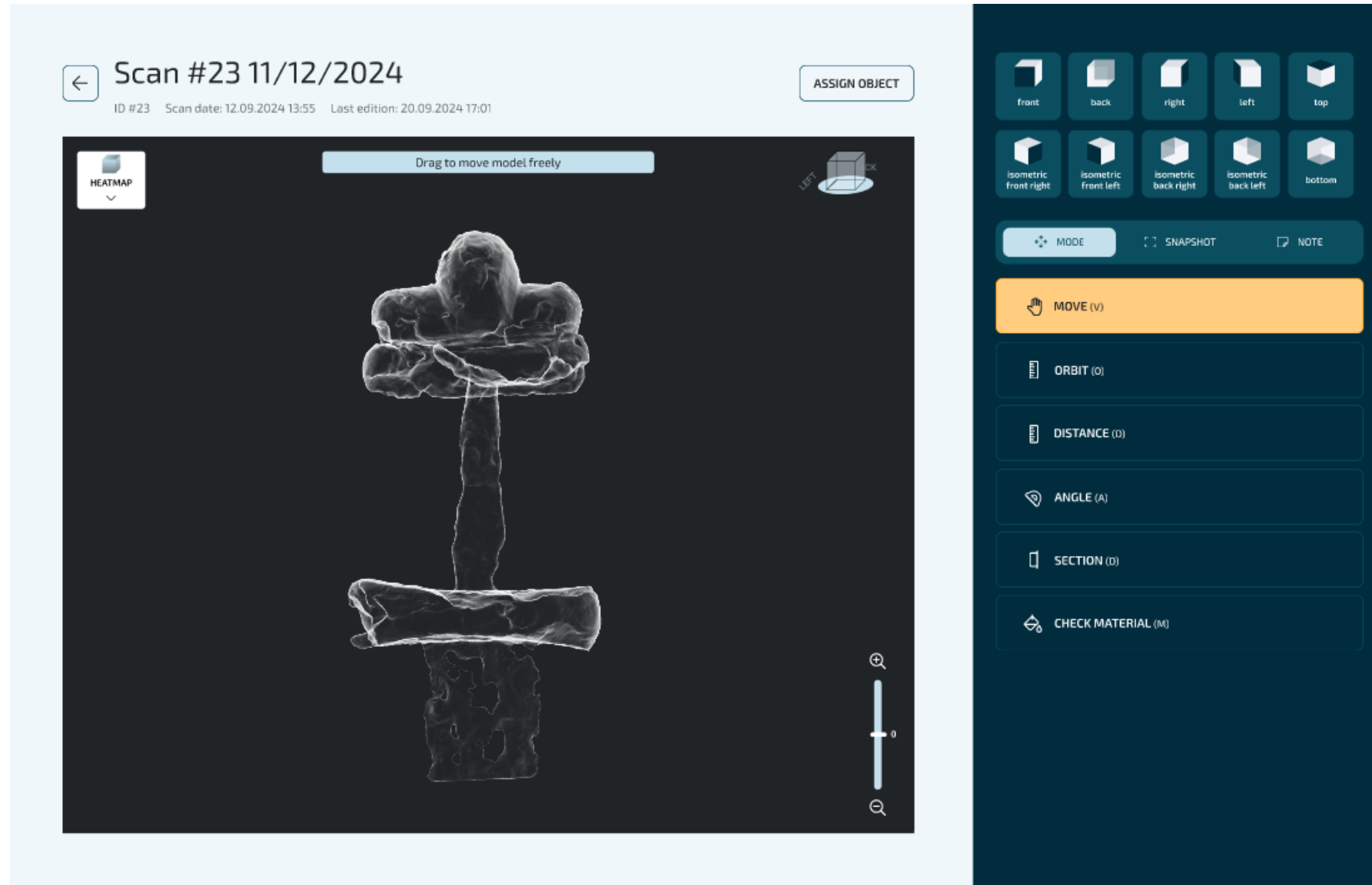
3. Intuitive platform for object analysis, data storage and export

The screenshot displays a web application interface for object analysis. On the left, a dark sidebar contains three navigation buttons: 'Objects' (with a cube icon), 'Scans' (with a camera icon), and 'Detectors' (with a monitor icon). The main content area is titled 'Scans' and features a search bar with a magnifying glass icon and the text 'Search'. In the top right corner of the main area, there is an orange button labeled 'GO TO DETECTORS' with a monitor icon. Below the search bar is a table with the following columns: Name, Detector, Editor, Location, Scan date, and Actions. The table contains four rows of scan data:

	Name	Detector	Editor	Location	Scan date	Actions
	Sword	Structoscan	John Doe	Cracow	17.07.2024 12:55	DETAILS
	Ring of the Cracow's majors	Structoscan	John Doe	Cracow	19.07.2024 12:55	DETAILS
	Green tara 23% scanning... 	Structoscan	John Doe	Wroclaw	17.07.2024 12:55	DETAILS
	A breastplate – a prop	Structoscan	John Doe	Cracow	17.07.2024 12:55	DETAILS

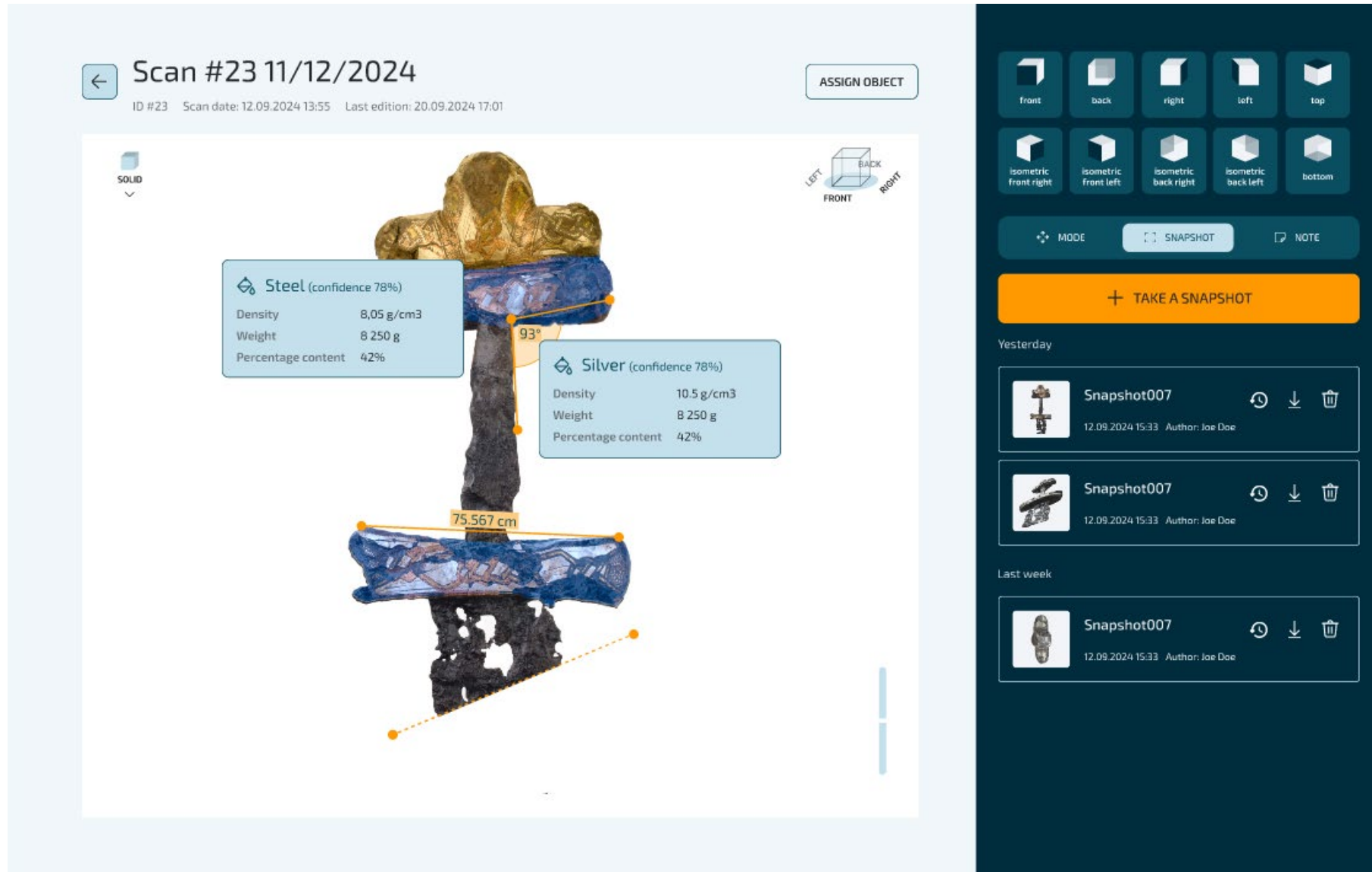
Future developments and research directions

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



Future developments and research directions

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



Future developments and research directions

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

The screenshot displays a user interface for object analysis. On the left is a dark sidebar with navigation icons for 'Objects', 'Scans', and 'Detectors', and a user profile for 'John Doe' at the 'Muzeum Narodowe Morskie w Gdańsku'. The main content area features a large image of a bust titled 'Sculpture "Bust of Róża Loewenfeld"'. Below the title are metadata fields: ID CMM/ZŚ/161, Scan date 15.07.2024 09:05, and Creation date 17.07.2024 12:55. To the right of the main image is a vertical gallery of smaller images, with the first one highlighted. Further right is a panel with 'General informations' (ID number, Location, Date of creation, Author) and 'Technical informations' (Dimensions, Material, Execution technique, State of preservation). Below the main image are tabs for 'OBJECT DATA', 'SCANS', and 'DOCUMENTS'. A 'RESEARCH TYPE' dropdown menu is set to 'Material Analysis'. At the bottom, there are cards for 'Infrared spectroscopy (FTIR)' and 'X-ray fluorescence (XRF)', each showing execution date and author.

Sculpture "Bust of Róża Loewenfeld"
ID CMM/ZŚ/161 Scan date 15.07.2024 09:05 Creation date 17.07.2024 12:55

General informations

ID number	CMM/ZŚ/161
Location	Gdańsk
Date of creation	19th - 20th century
Author	unknown

Technical informations

Dimensions	15 x 30 cm
Material	Cast iron
Execution technique	Cast
State of preservation	Damaged

OBJECT DATA **SCANS** **DOCUMENTS**

RESEARCH TYPE
Material Analysis

Infrared spectroscopy (FTIR)
Chemical Composition Execution date: 12.09.2023 15:44 Author: Joe Doe

X-ray fluorescence (XRF)

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Get in touch



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