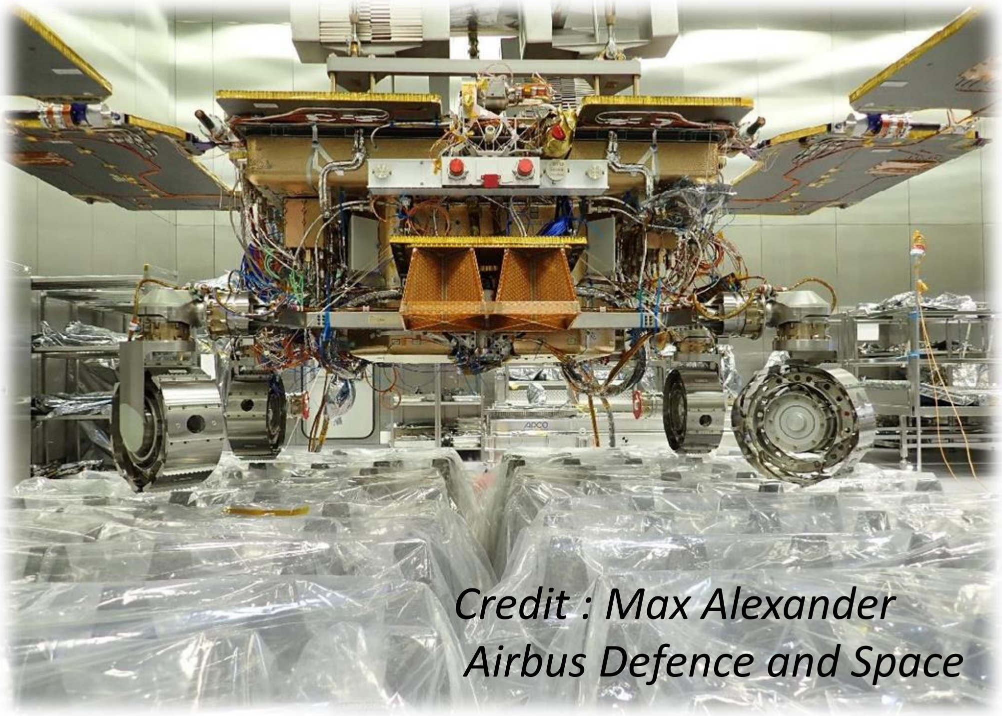


Credit : Max Alexander
Airbus Defence and Space

Identifying heterogeneity sizes in the subsurface with WISDOM

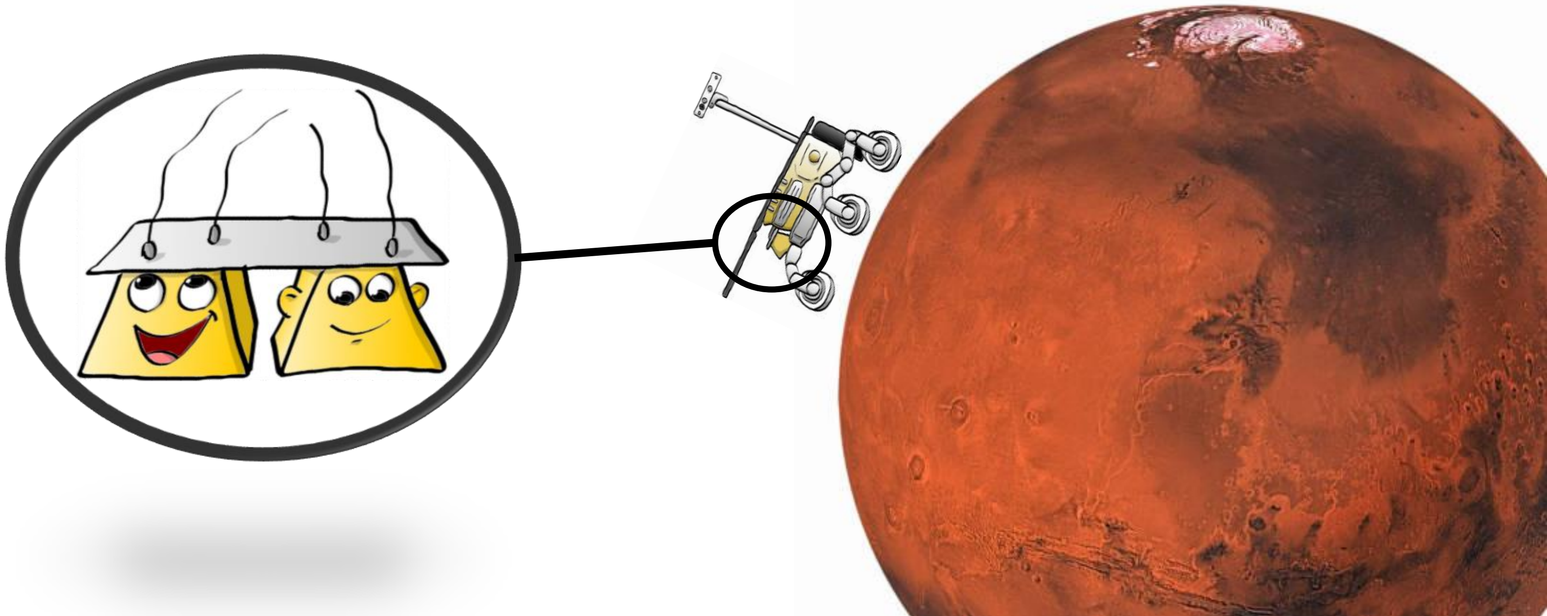
The Ground Penetrating Radar of the ExoMars Martian mission

<u>Author :</u> **Emile Brighi**

Contact *: emile.brighi@latmos.ipsl.fr*

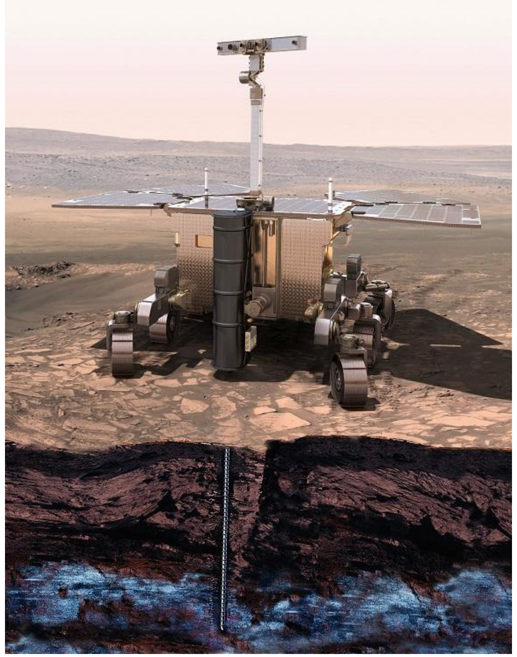
Co-authors :

- **Valérie Ciarletti**
- **Alice Le Gall**
- **Nicolas Oudart**
- **Yann Herve**



THE ROSALIND FRANKLIN / EXOMARS MISSION

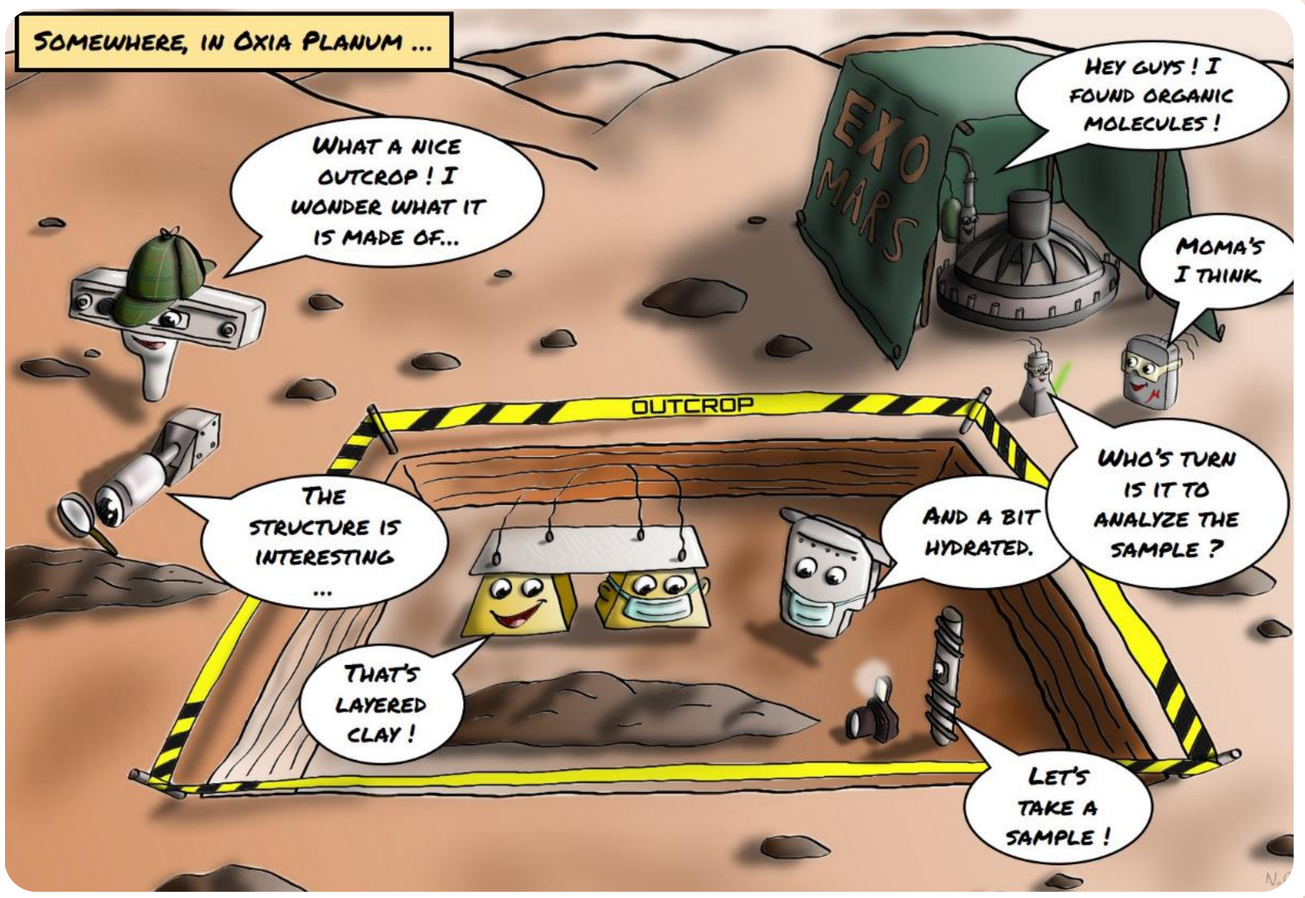
Rosalind Franklin Rover



Scientific objectives of the ExoMars mission :

- Study of the shallow subsurface (first meters)
- Seek for evidence of past life
- Study of the water distribution in the first few meters

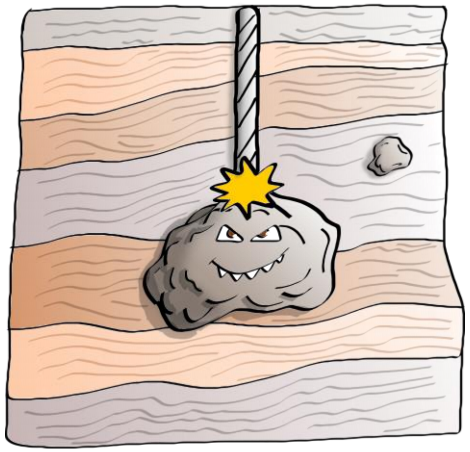
Scientific instruments collaboration for the exploration of Oxia Planum subsurface



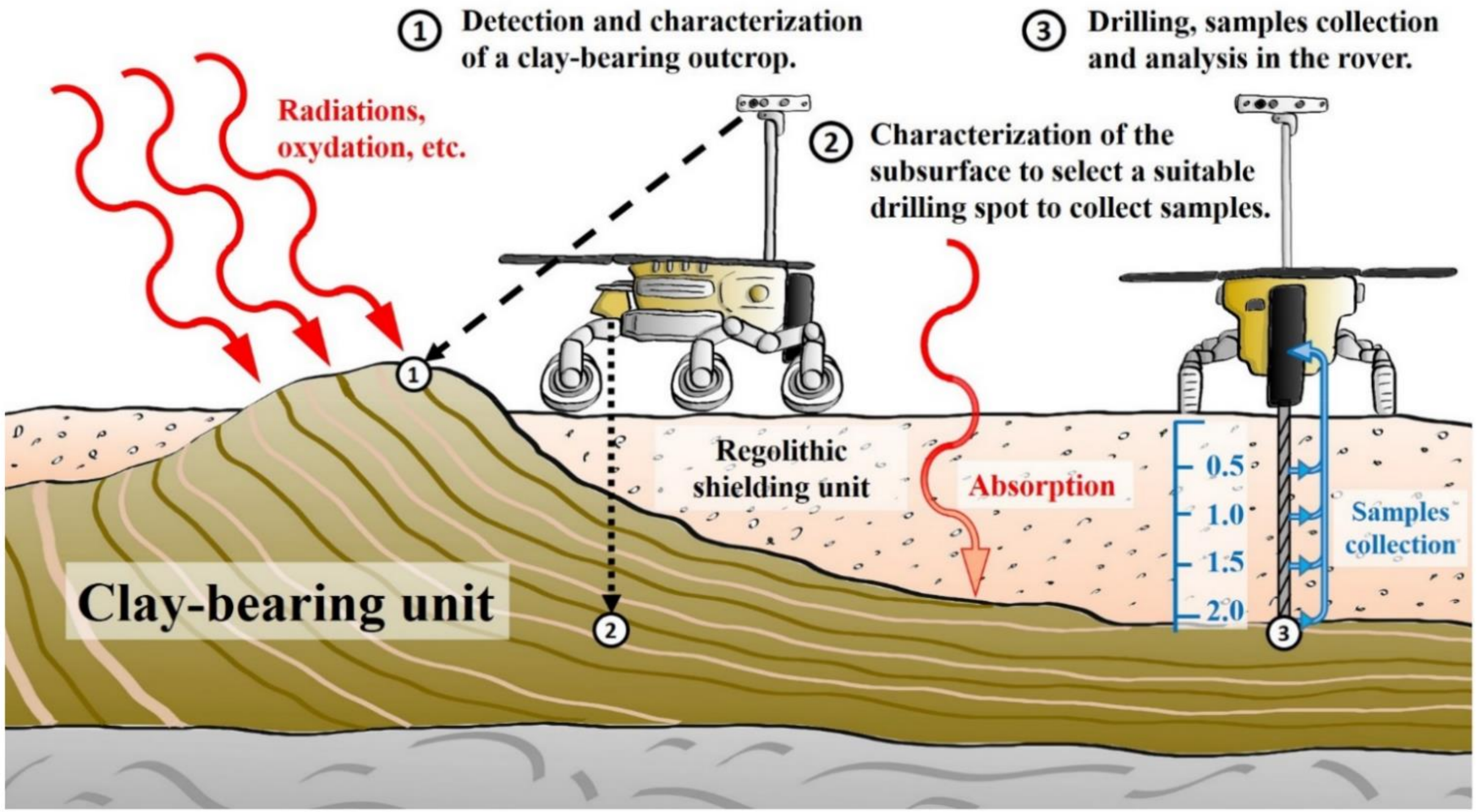
© Nicolas Oudart

WISDOM OBJECTIVES IN EXOMARS MISSION

Identify interesting and ***safe*** sites for the drill



Understanding the geological history of the landing site :
Detect and characterize buried units (rocks, interfaces, …)



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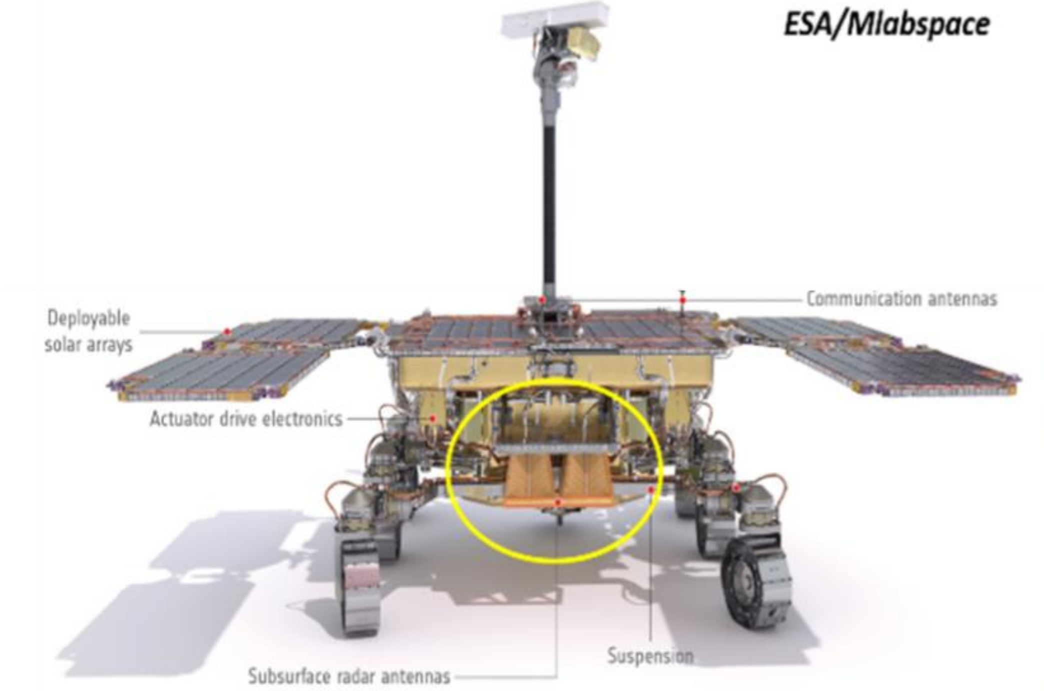
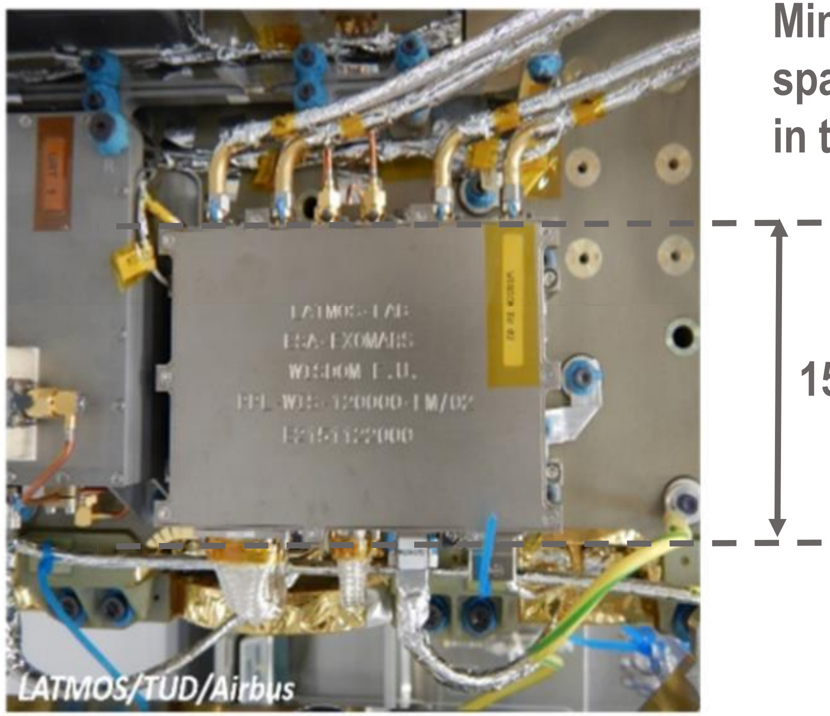
WISDOM INSTRUMENT

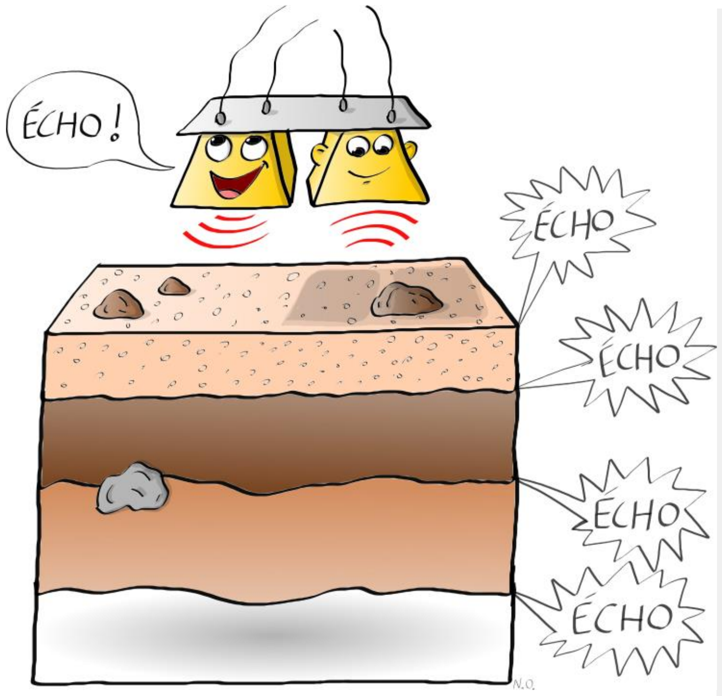




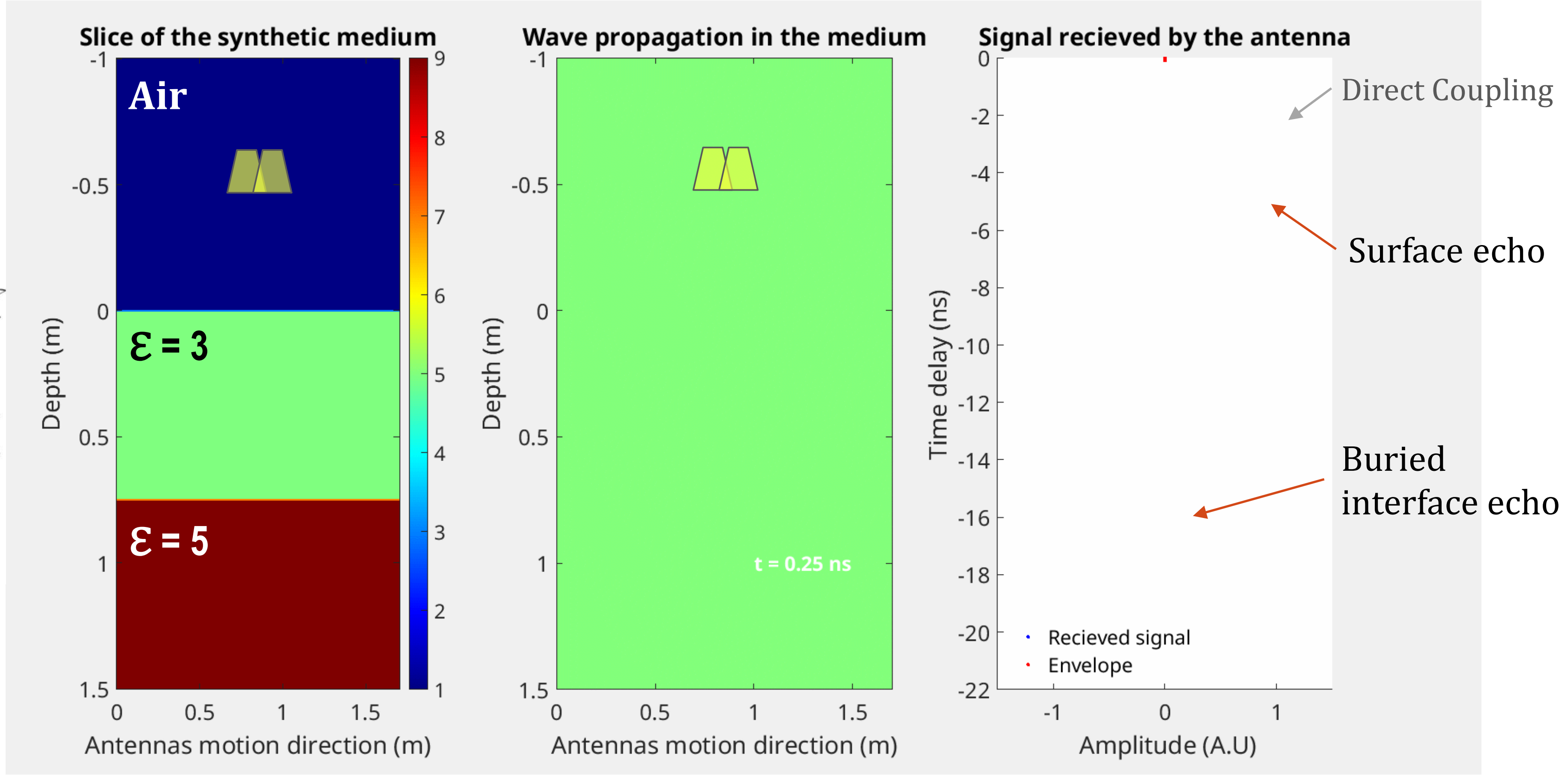
Miniaturized for space constraints in the Rover

Radar design	Antennas design	Working Frequencies	Dynamic range	Power Consumption	Emitted Power	Mass (Antennas + Electronics)
Stepped Frequency Continuous wave	Vivaldi Antennas	0.5 - 3 GHz	~ 84 dB	12.5 W (peak)	**1 mW**	**1.36 kg**

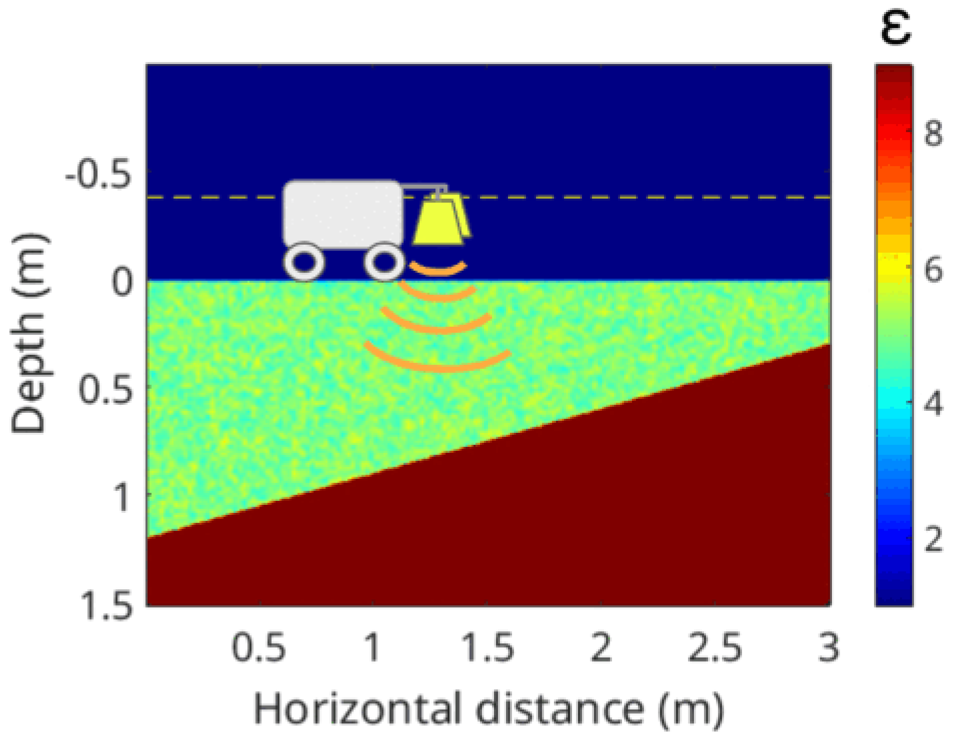
GPR OPERATIONS AND DATA PRODUCTS

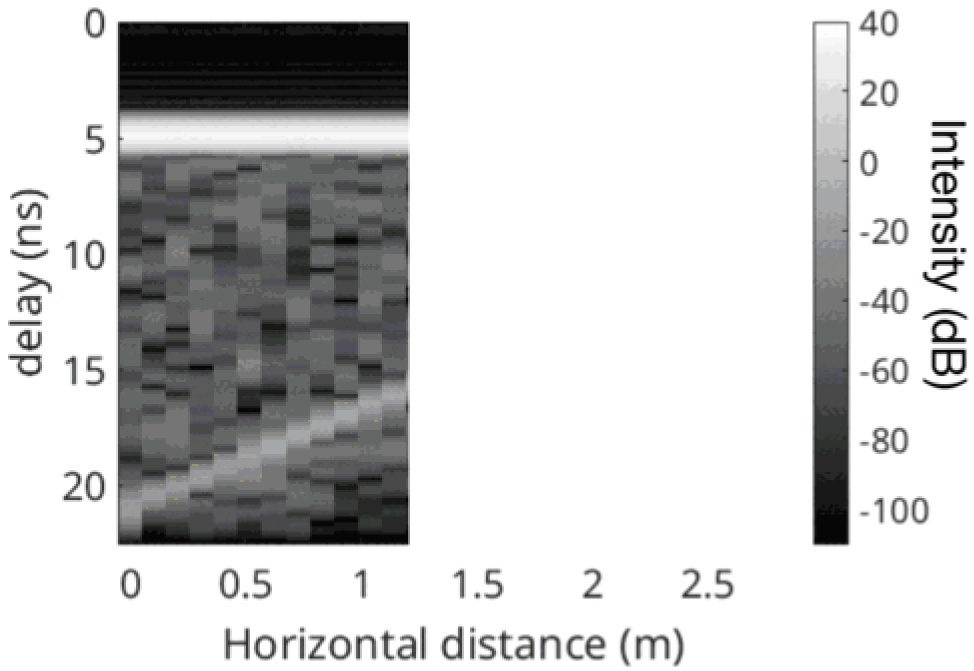


© Nicolas Oudart



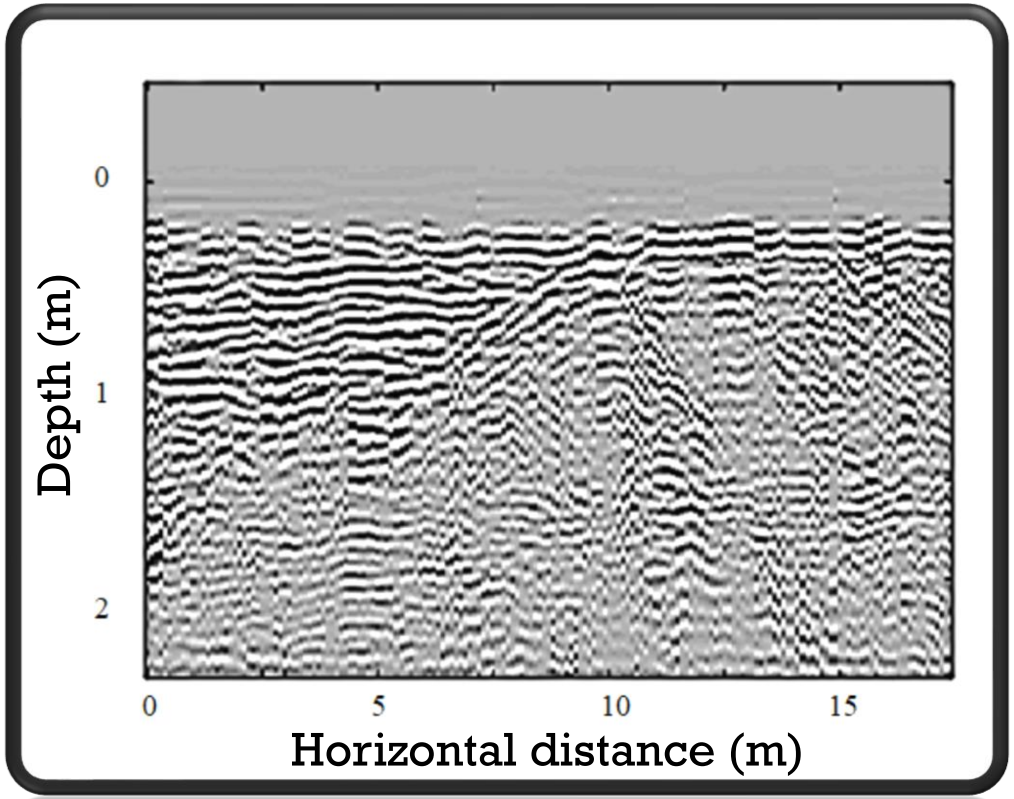
GPR OPERATIONS AND RADARGRAM



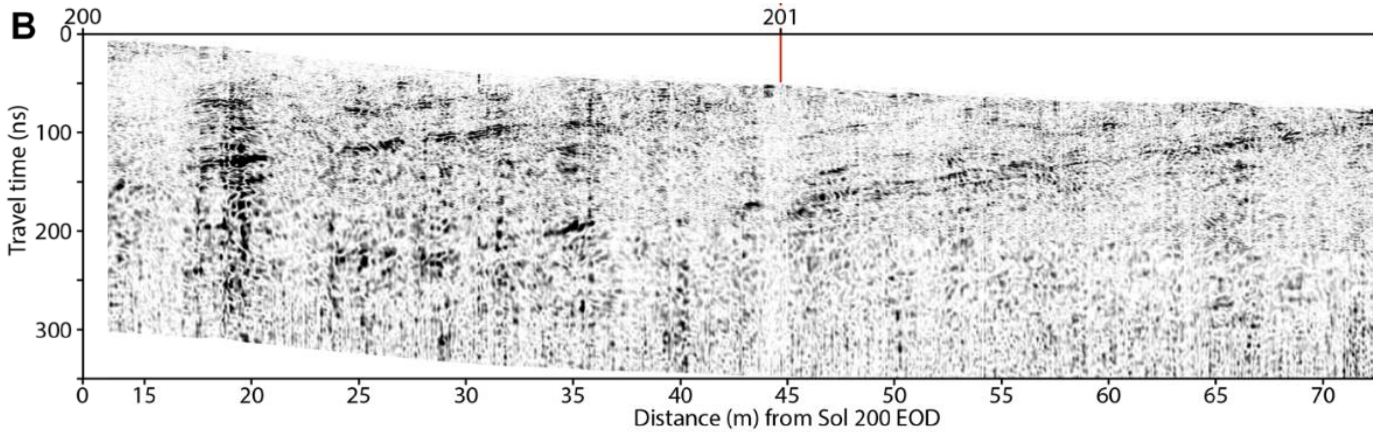


GPR OPERATIONS AND DATA PRODUCTS

Earth, Field test campaign in Colorado Provençal (France) – WISDOM Prototype



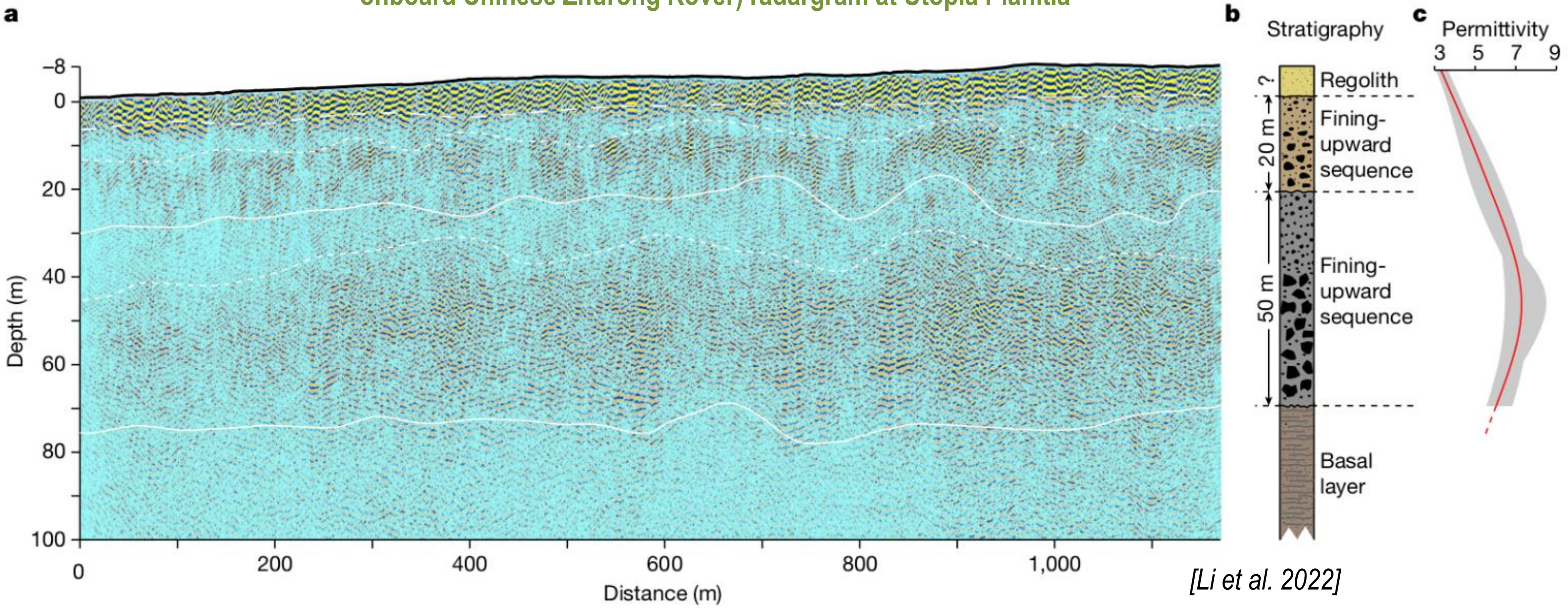
Mars, Jezero Crater – RIMFAX GPR onboard Perseverance Rover



[Hamran S. 2022]

OBJECTIVE : CHARACTERIZING HETEROGENEOUS MEDIA

Radargrams acquired in natural environments on Mars in 2022 from RoPeR (GPR onboard Chinese Zhurong Rover) radargram at Utopia Planitia

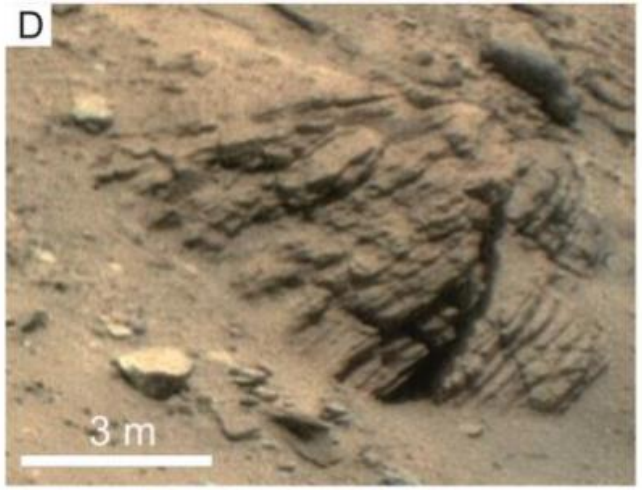


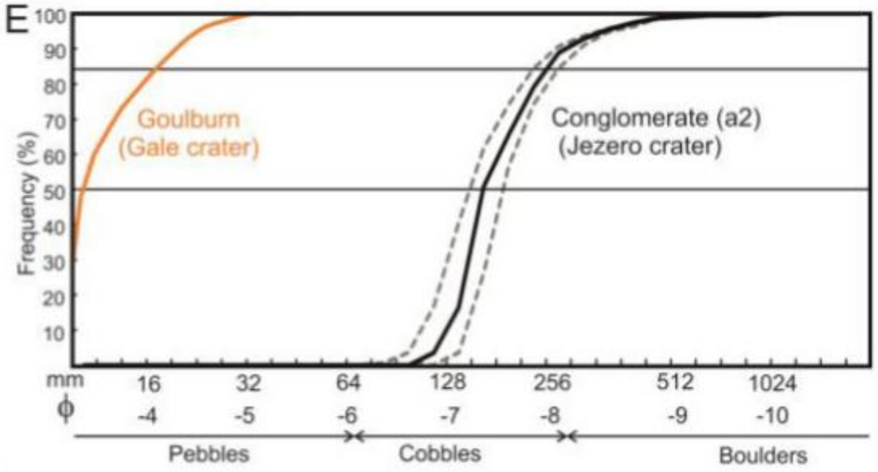
[Li et al. 2022]

MARTIAN PICTURE FROM ANOTHER ROVER ON MARS

Scatterer size distribution

Clues about past hydraulic / eolians activities





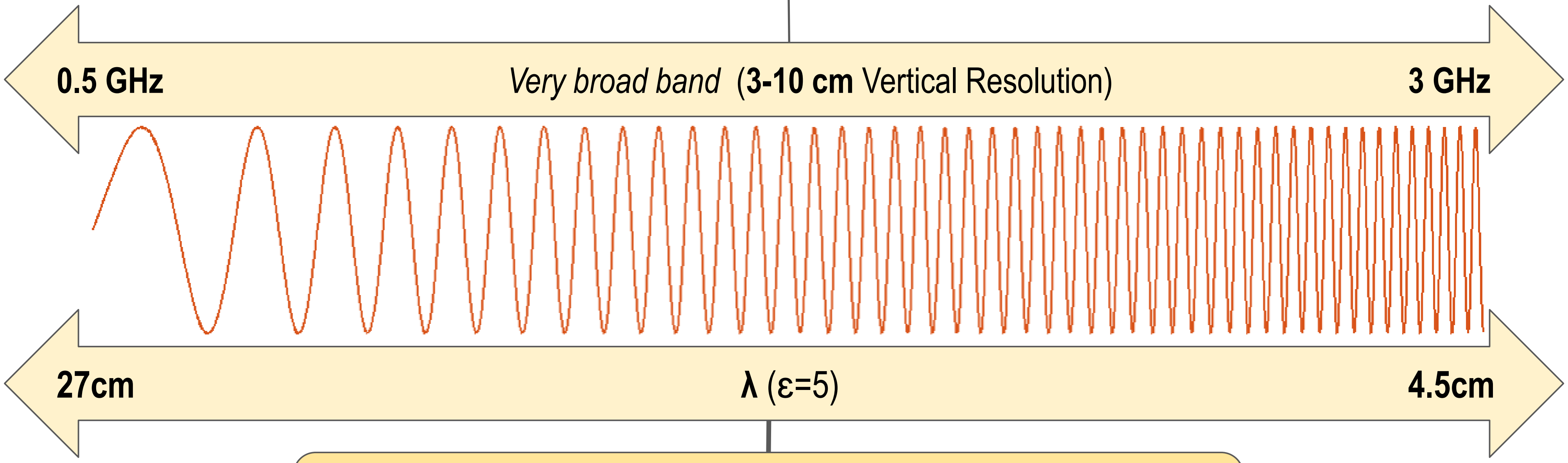
[Mangold et al. 2021]

WISDOM PERFORMANCES

WISDOM is a *polarimetric step frequency* Ground Penetrating Radar

Central frequency = 1.75 GHz

➔ Penetration depth of ***few meters***



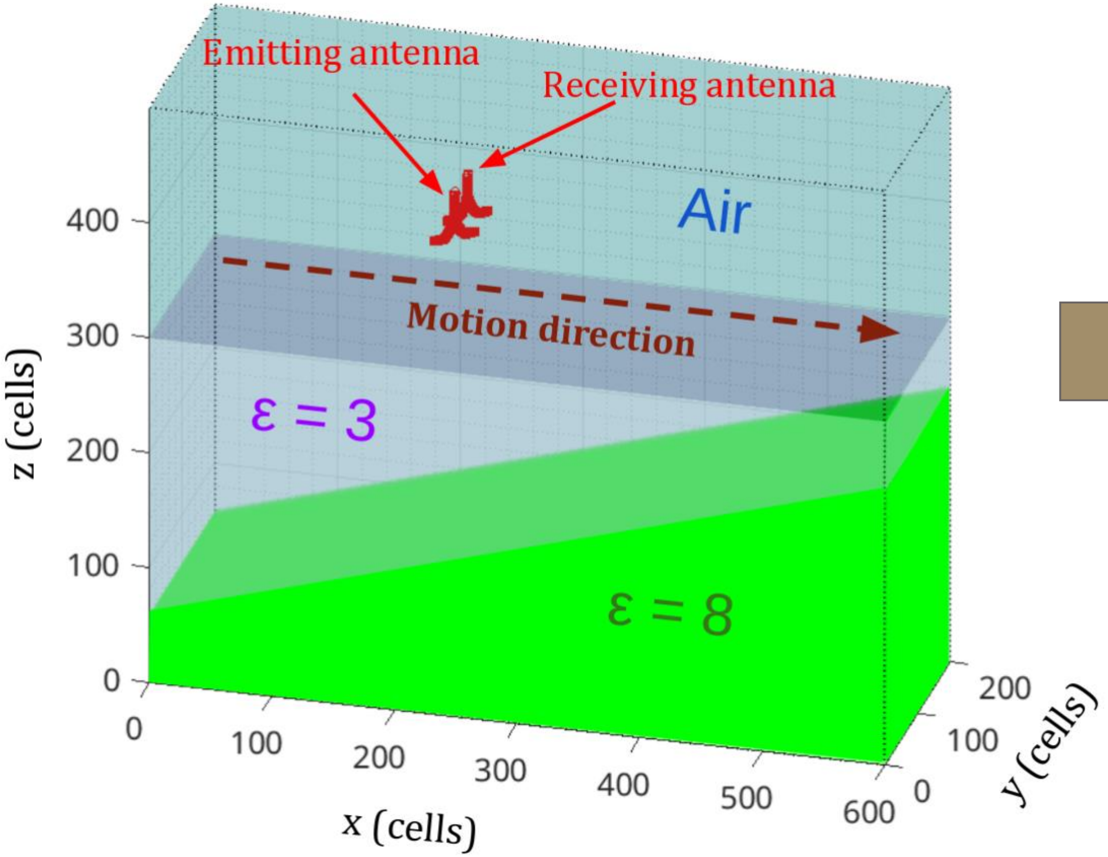
➔ Sensitive to a **large** range of scatterer sizes

Ciarletti et al. 2011 ; 2017

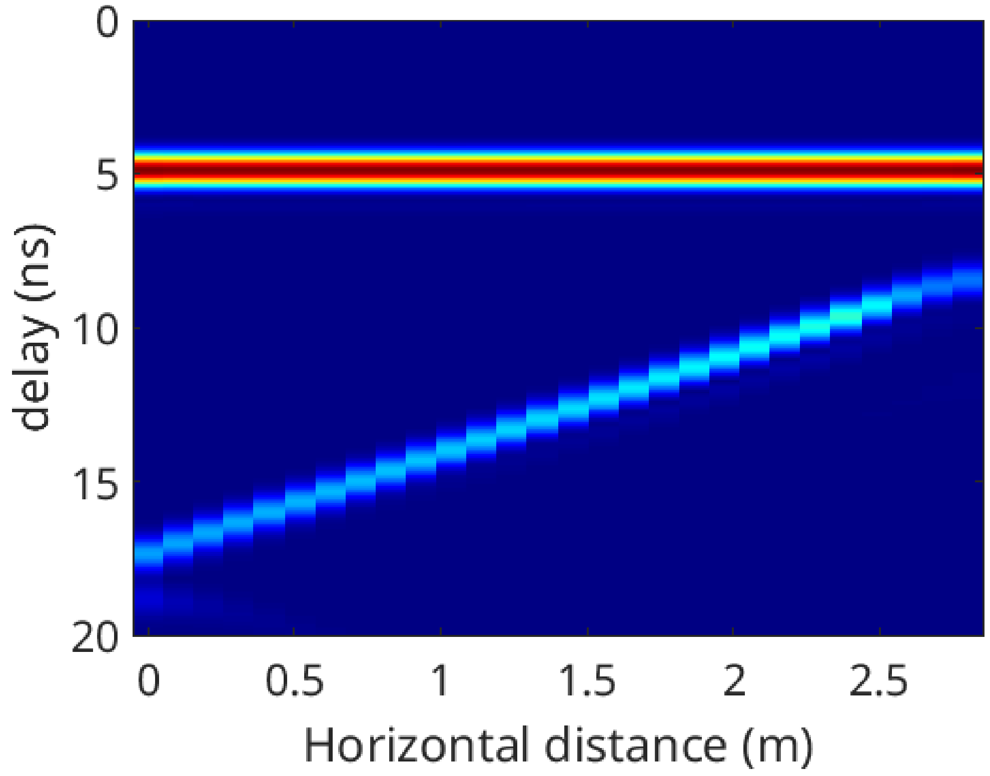
3D SIMULATIONS WITH FDTD CODE

Numerical simulations are performed with *Finite Domain Time Difference* method (TEMSI-FD, XLIM, France)

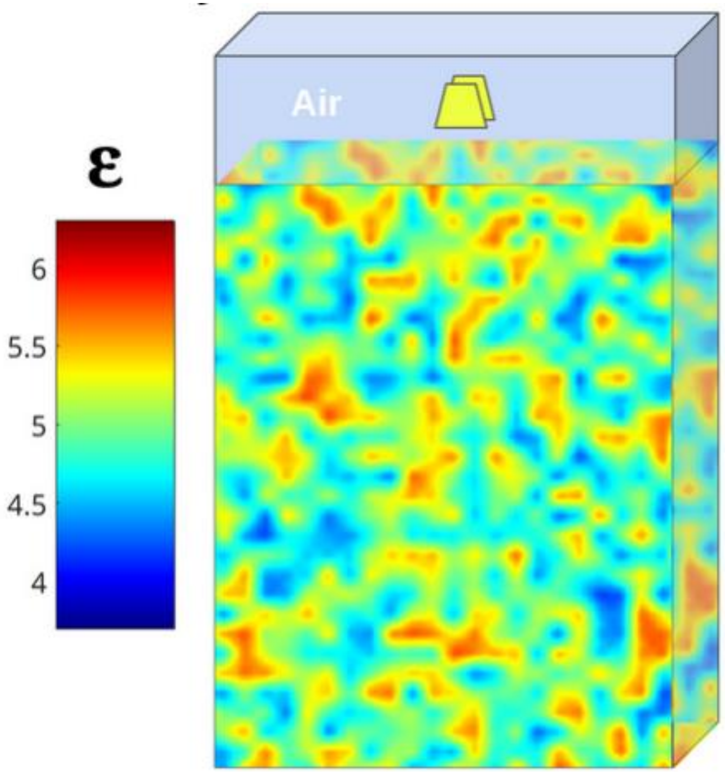
Computing synthetic volume



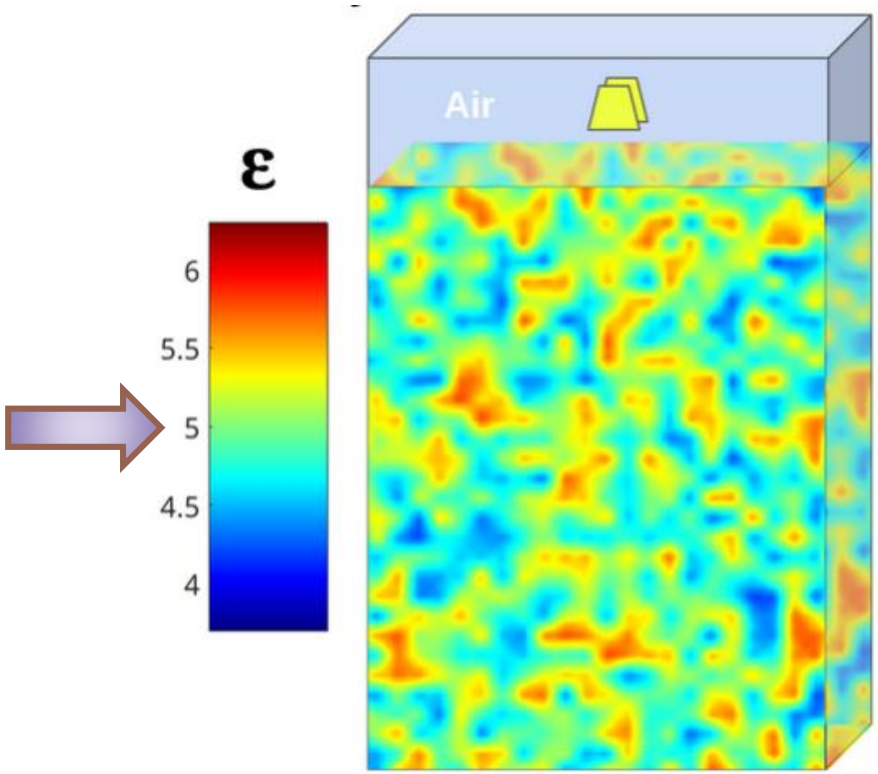
WISDOM synthetic radargram



3D SIMULATIONS OVER HETEROGENEOUS MEDIA

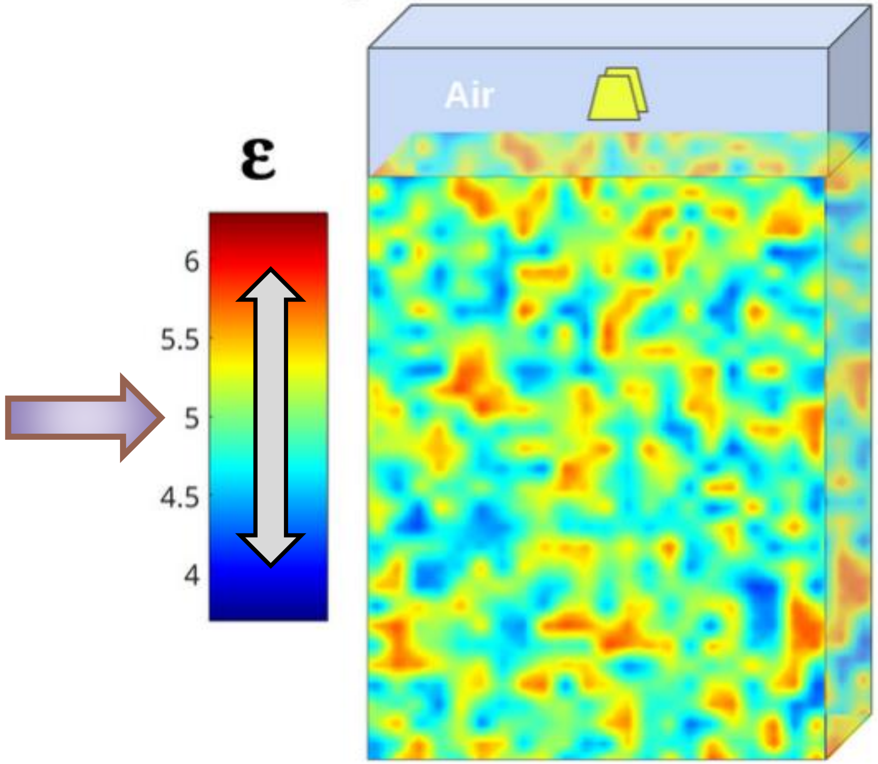


3D SIMULATIONS OVER HETEROGENEOUS MEDIA



➔ The **mean** permittivity $\bar{\varepsilon}$

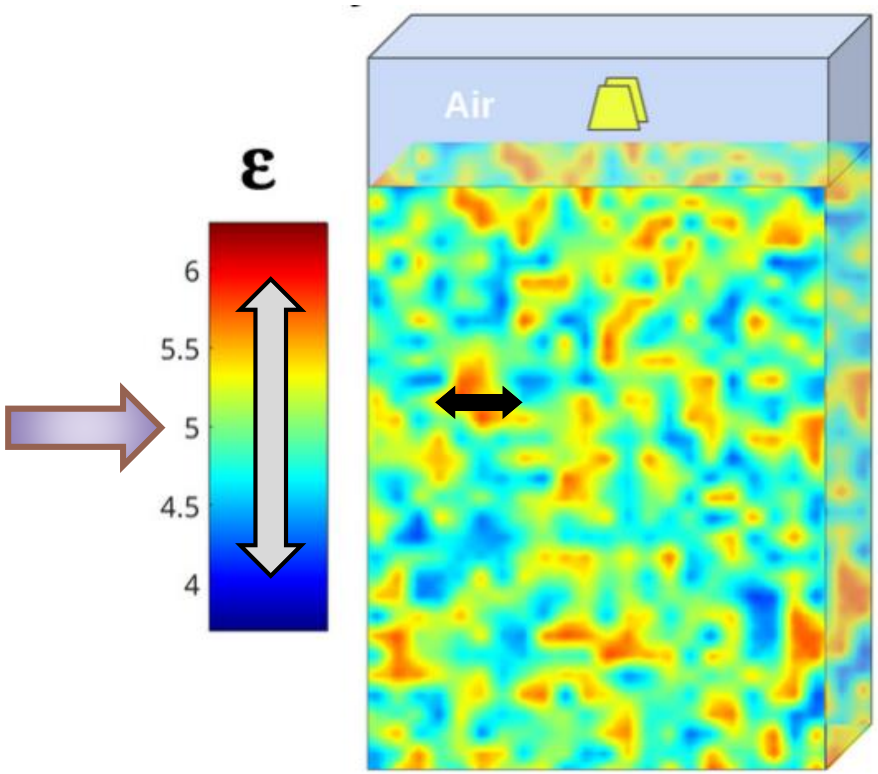
3D SIMULATIONS OVER HETEROGENEOUS MEDIA



→ The **mean** permittivity $\bar{\varepsilon}$

→ The **standard deviation** of permittivity $\Delta\varepsilon$

3D SIMULATIONS OVER HETEROGENEOUS MEDIA



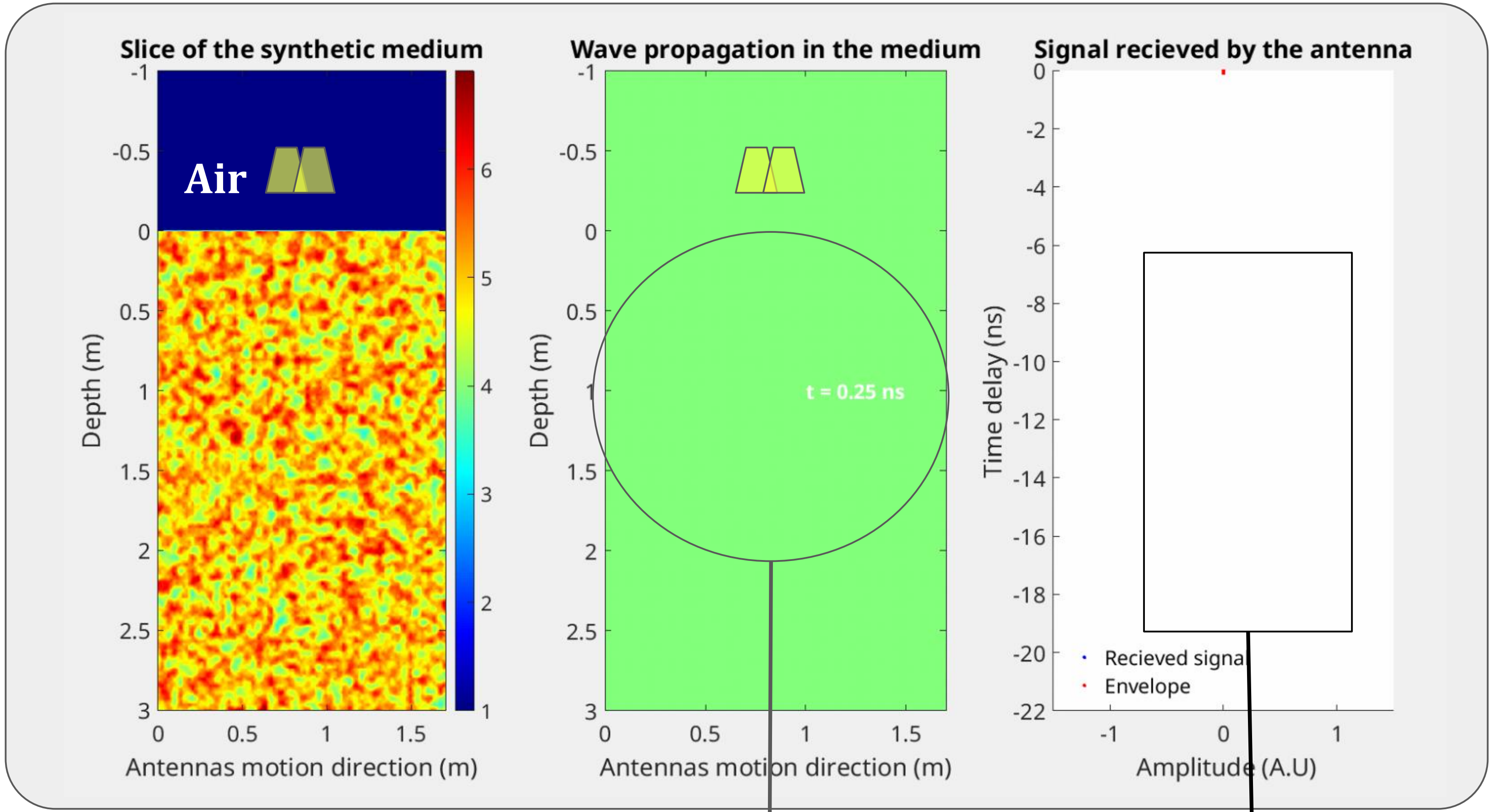
→ The **mean** permittivity $\bar{\varepsilon}$

→ The **standard deviation** of permittivity **Δε**

→ The **typical size** of heterogeneities **L**

3D SIMULATIONS OVER HETEROGENEOUS MEDIA

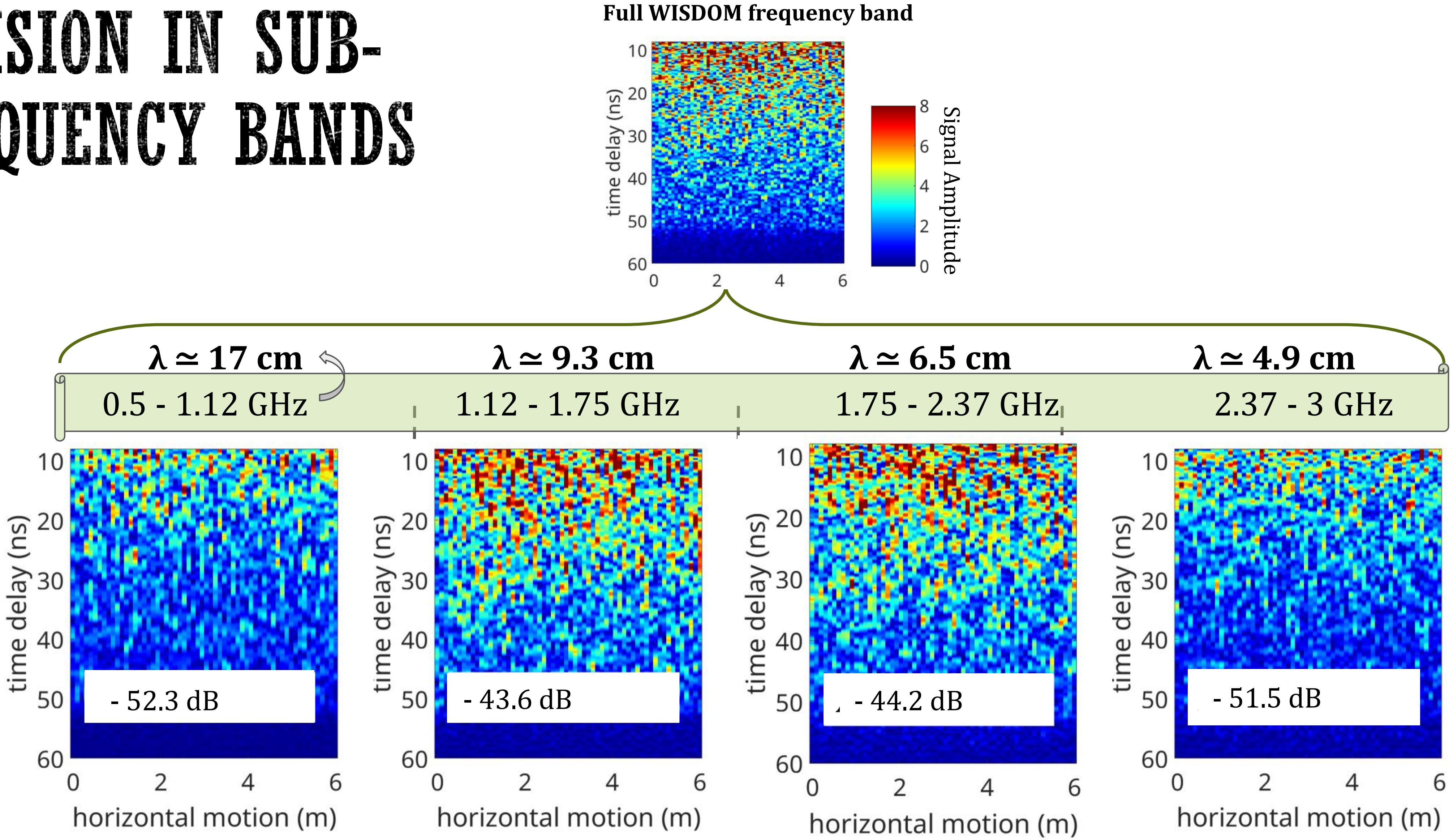
ε = 5
Δε = 0.3
L = 3.2 cm



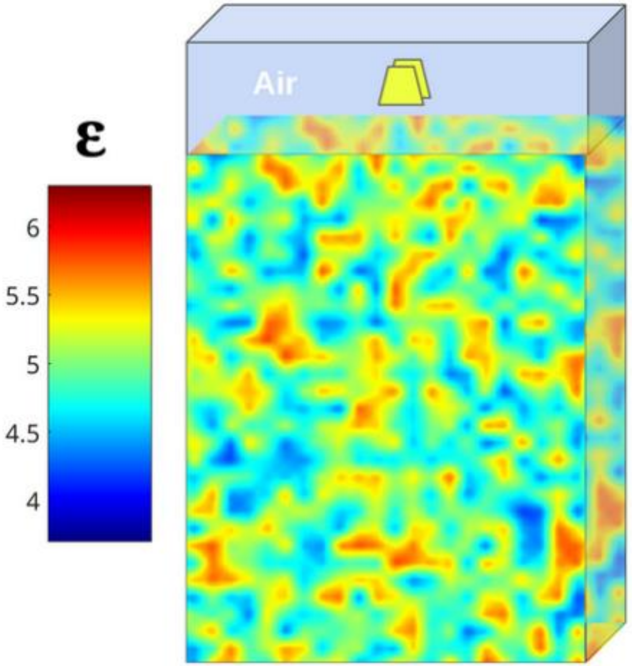
Volume scattering

Volume backscatter

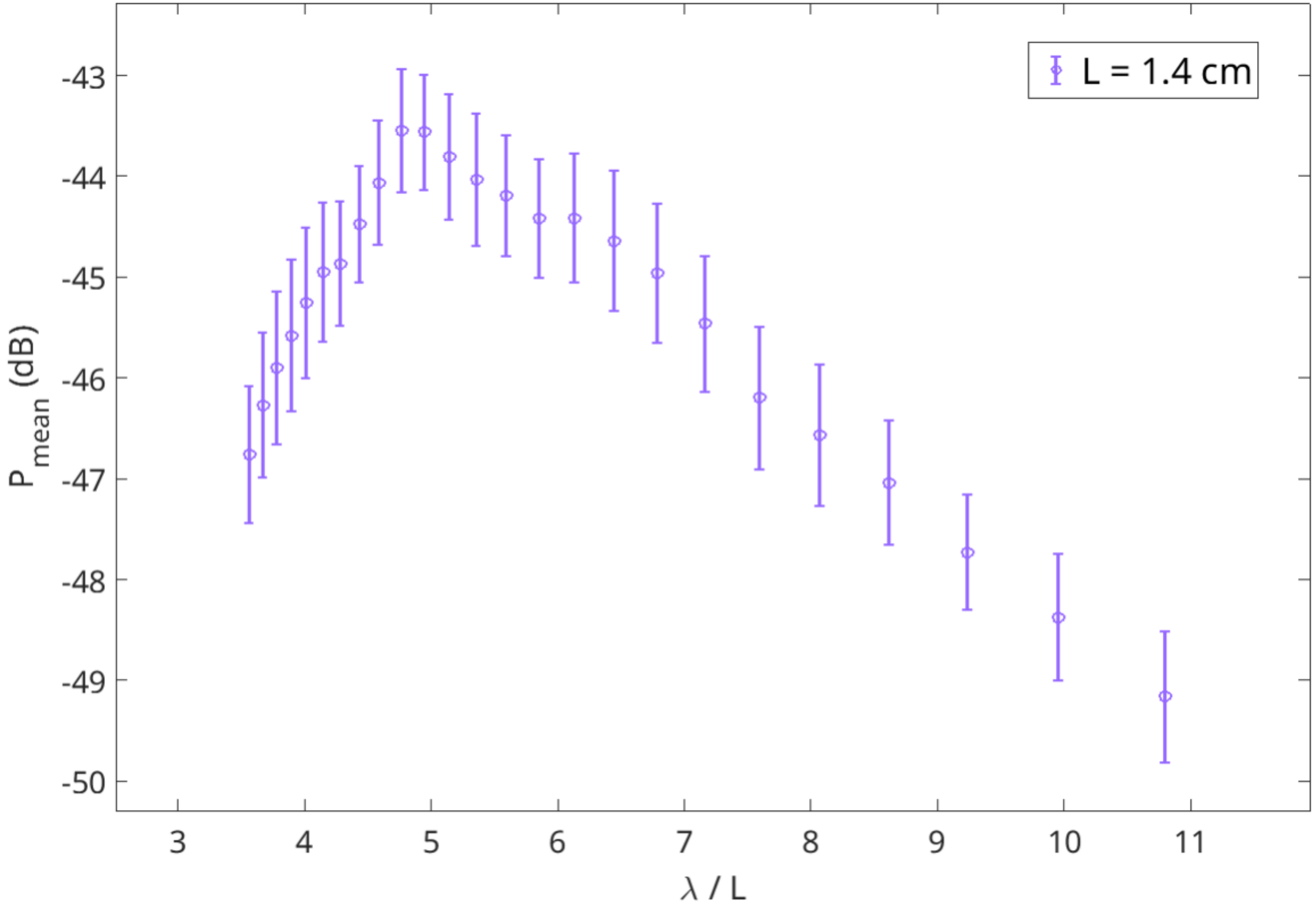
DIVISION IN SUB-FREQUENCY BANDS



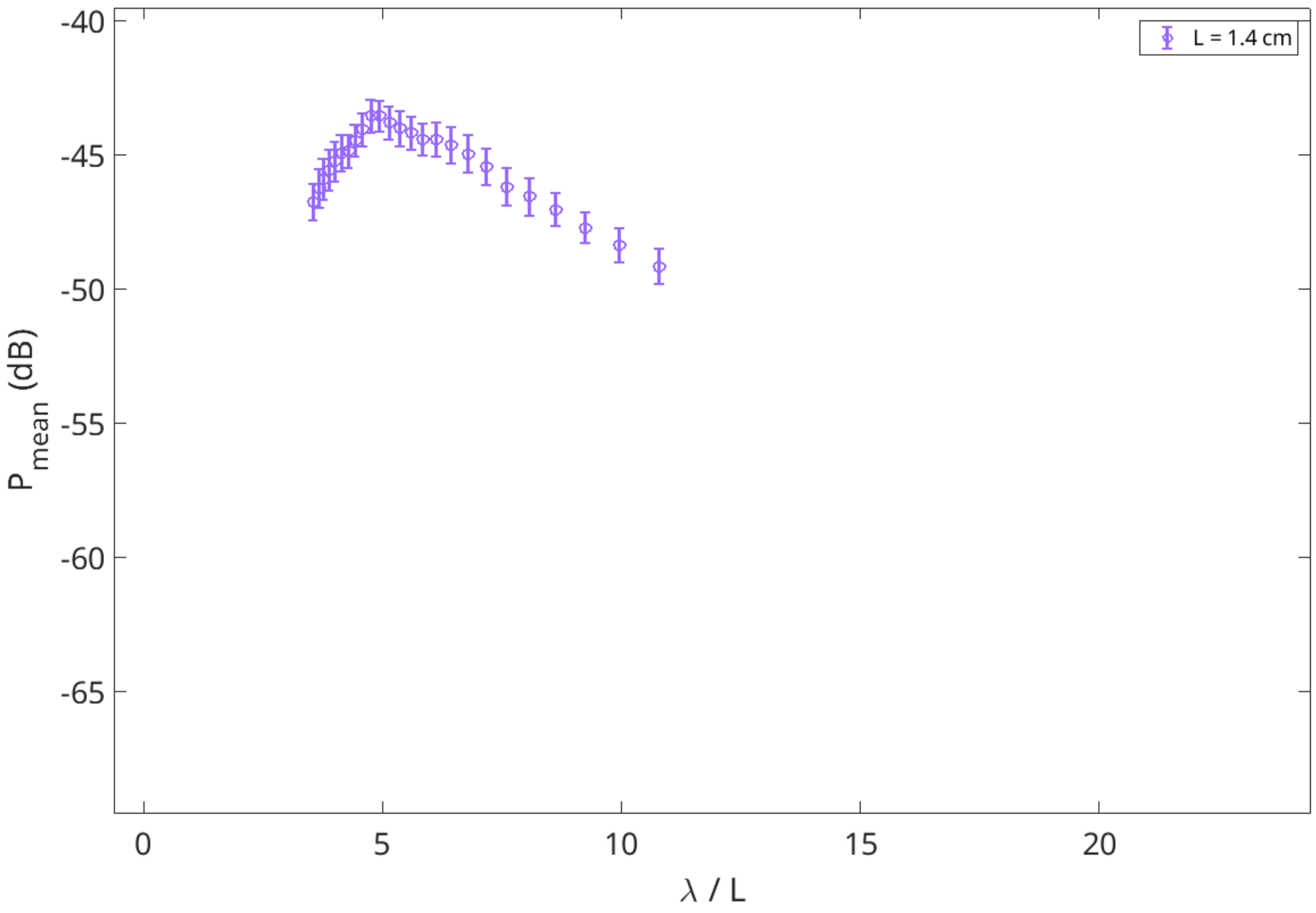
RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES



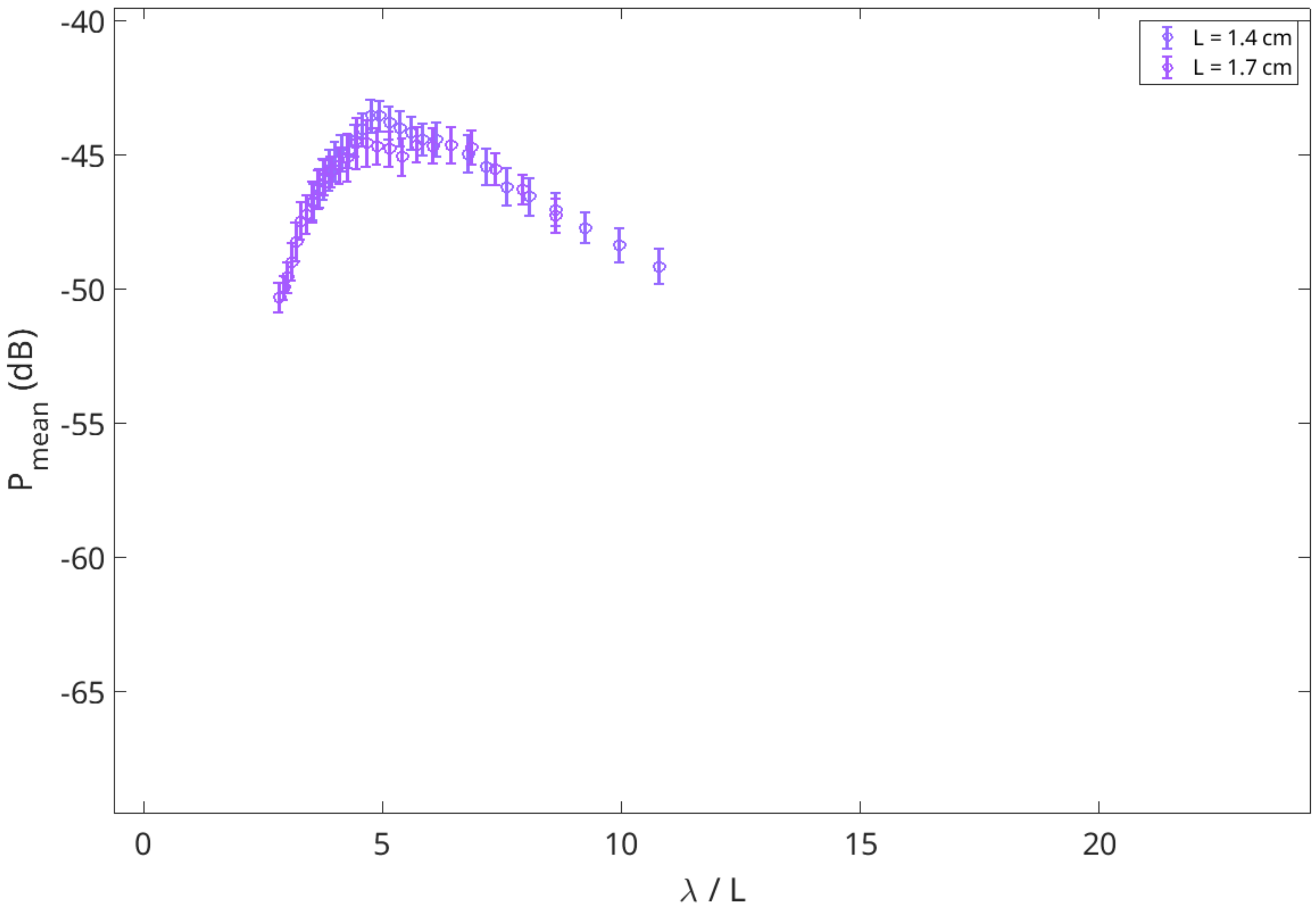
ε = 5
Δε = 0.3
L = 1.4 cm



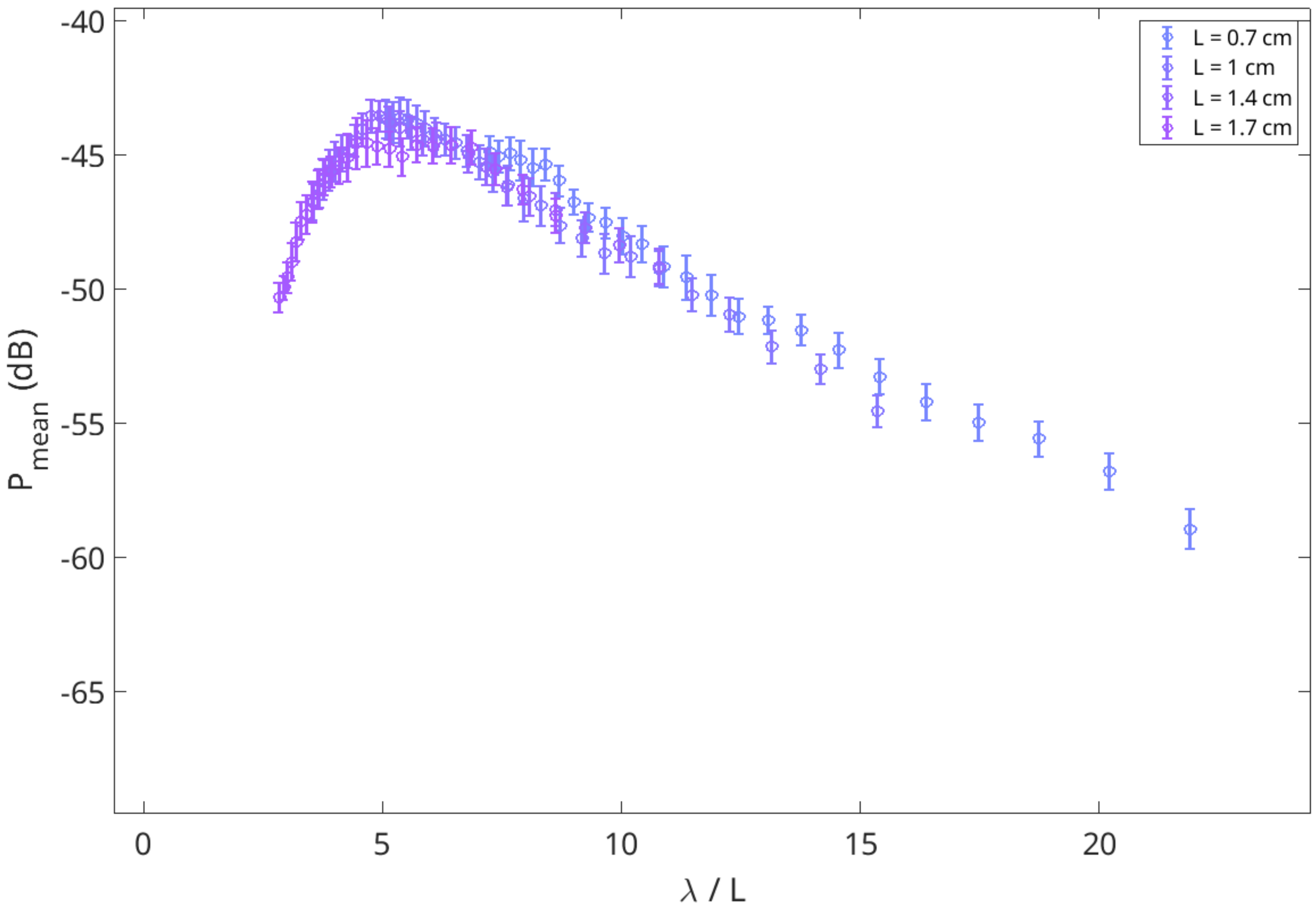
RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES



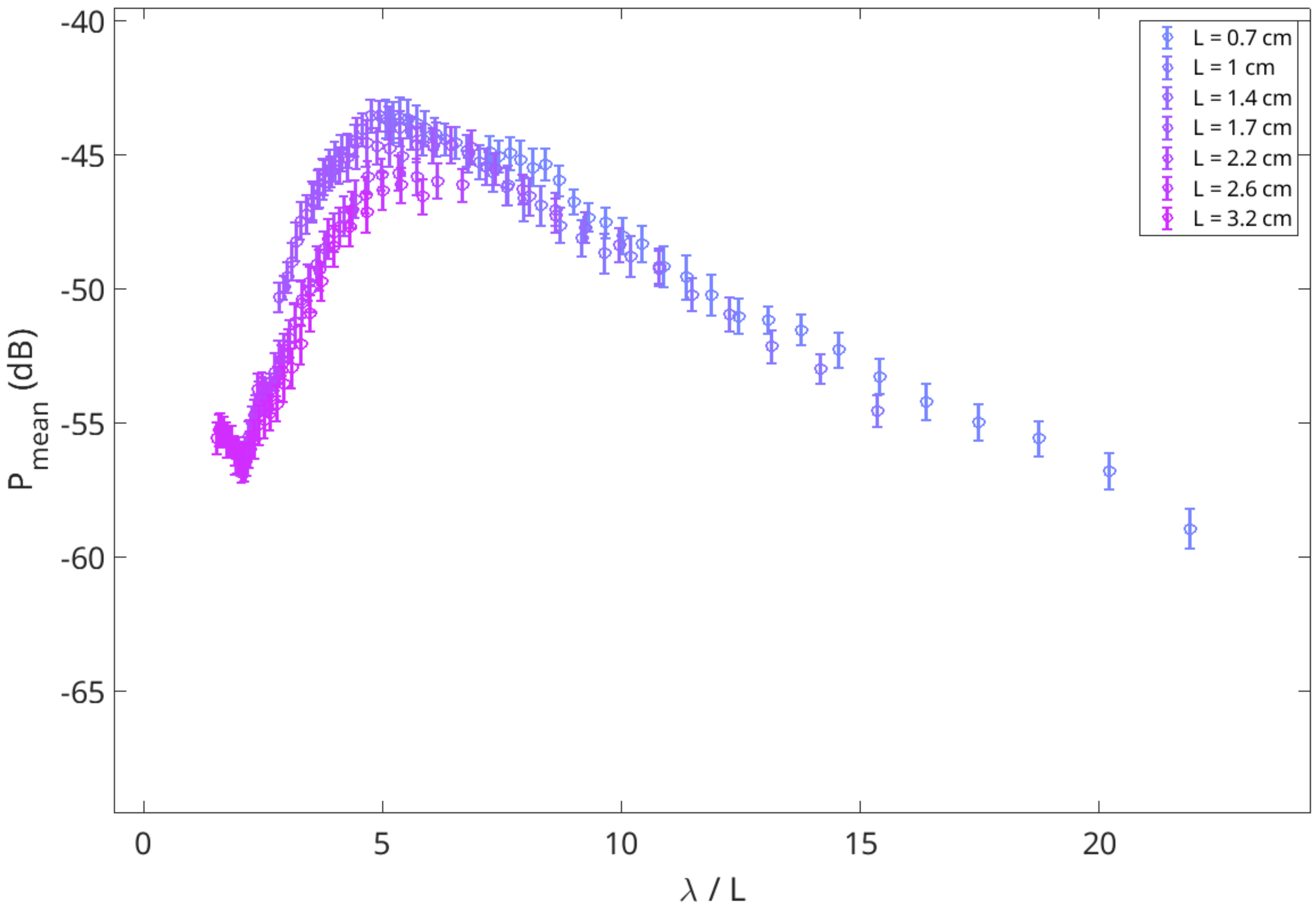
RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES



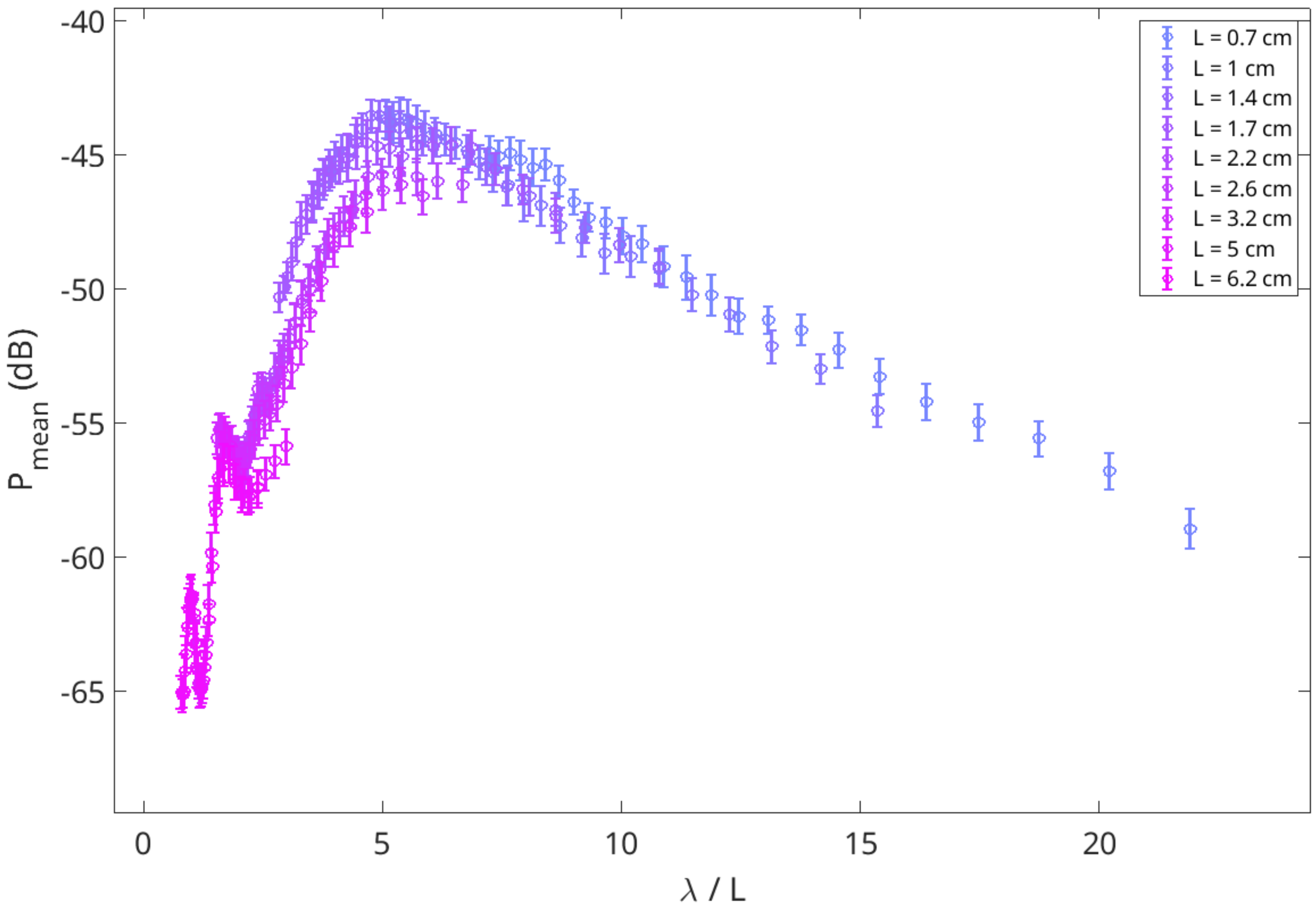
RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES



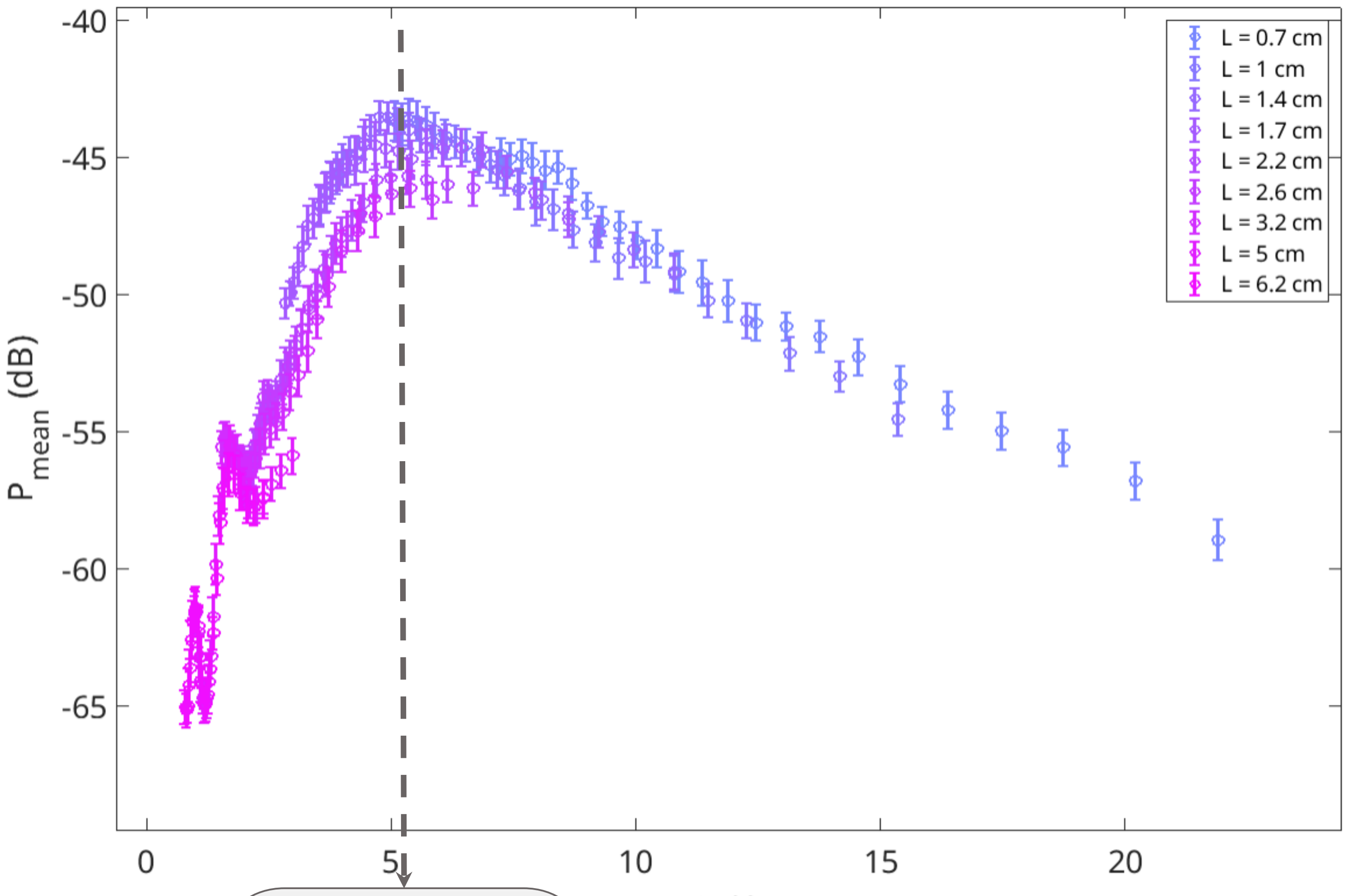
RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES



RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES



RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES



$\lambda_{peak} / L = 5$

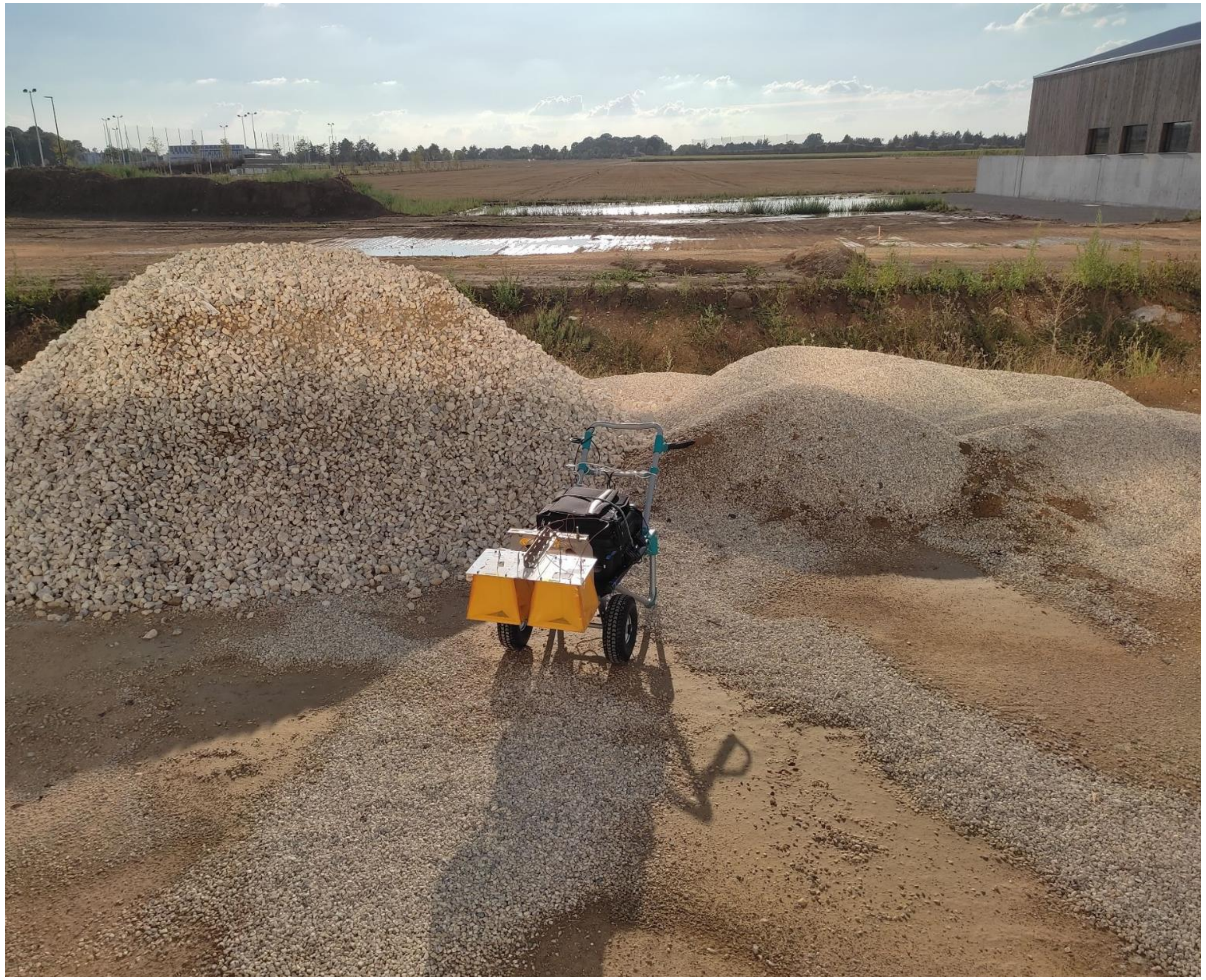
The maximum is reached for :

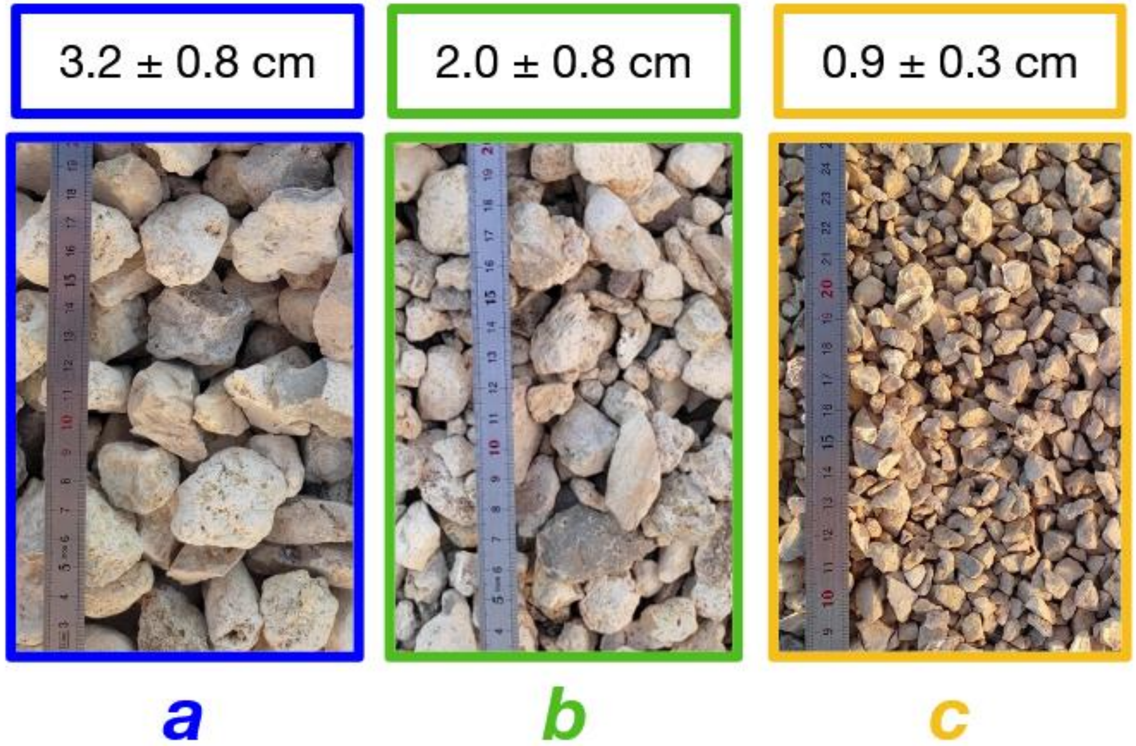
$\lambda_{peak} / L = 5$

Retrieval of L ? Determine λ_{peak} and then :

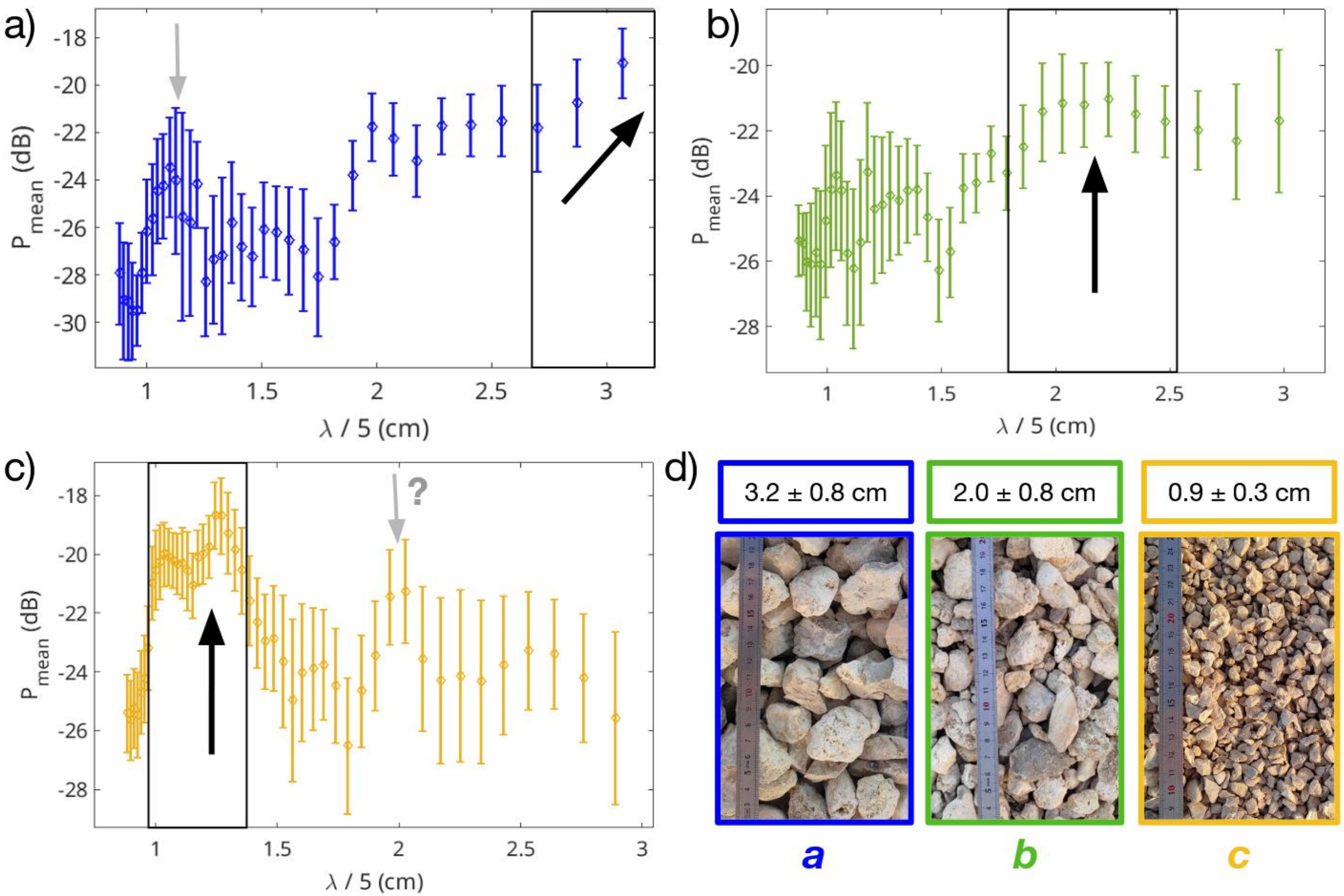
$L = \lambda_{peak} / 5$

VALIDATION ON EXPERIMENTAL DATA





VALIDATION ON EXPERIMENTAL DATA



CONCLUSION & PERSPECTIVES

- We successfully elaborated a method to retrieve the **typical size of heterogeneities** which provides information on the geological context of the site.
- The method presented still applies for different permittivity distributions and in most lossy media
- **This approach can be applied to data from any broad-band GPR**
- Preliminary analysis show promising results not only in co-polarization but also in **cross-polarization** configuration.
- The method has been preliminarily applied on real data, acquired on controlled environment.
- Ongoing study shows similar results if the scatterers are spheres.

Perspectives :

- The method could be tested on multi-layer heterogeneous subsurfaces
- Further validations on **controlled and documented environments** are warranted
- Can be applied on data collected on **Martian** and **lunar** analogs

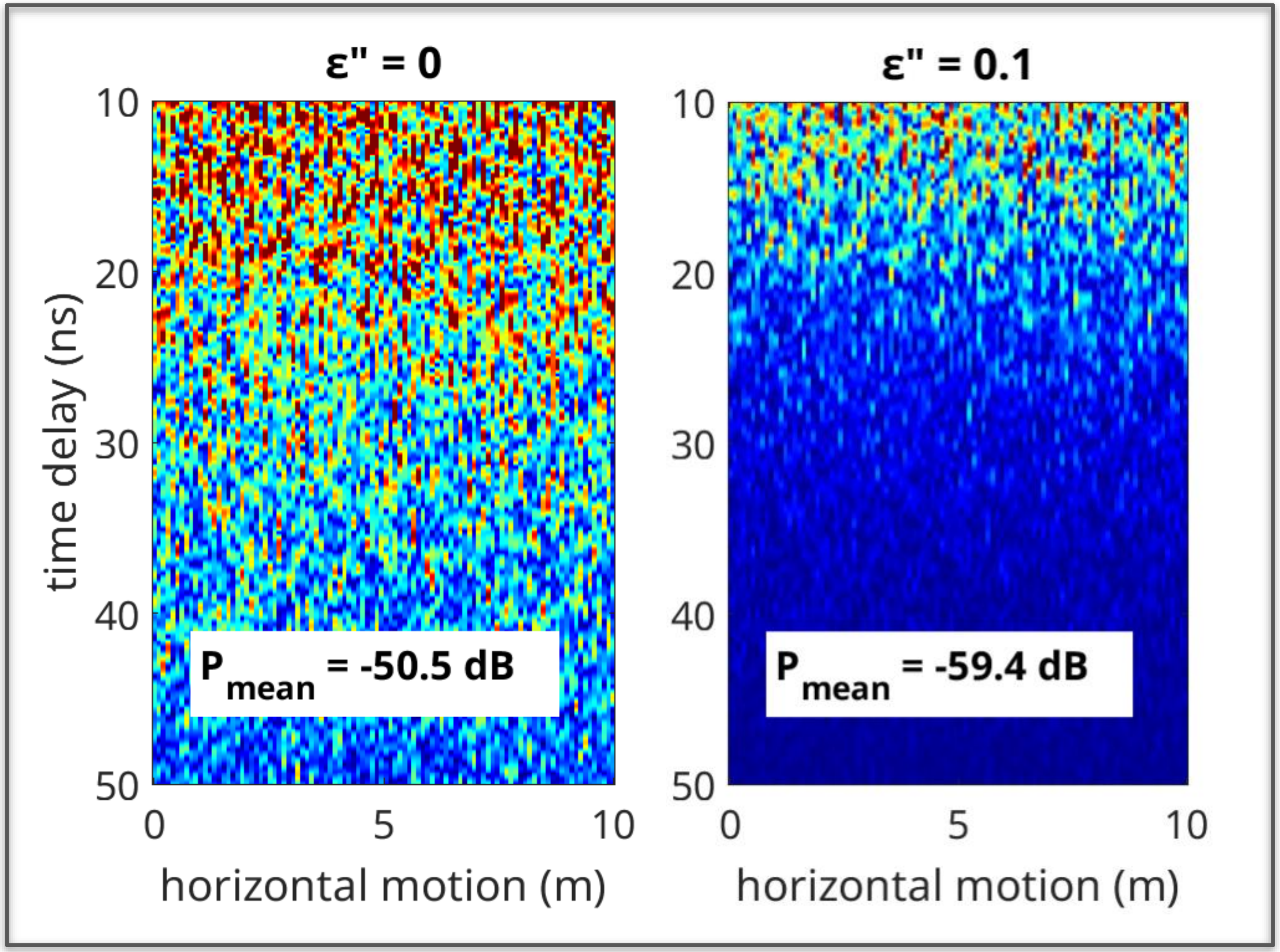
Contact *: emile.brighi@latmos.ipsl.fr*

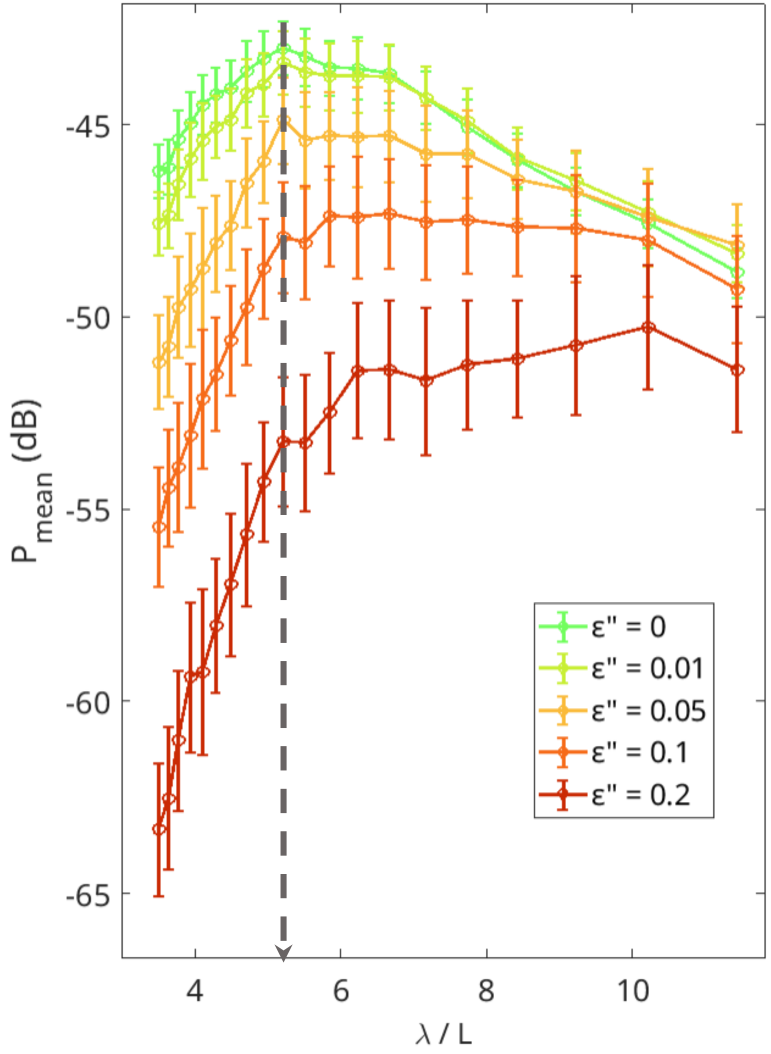
LATMOS

RESULTS

IMPACT OF DIELECTRIC LOSSES $(\varepsilon = \varepsilon' - i\varepsilon'')$

L = 1.4 cm



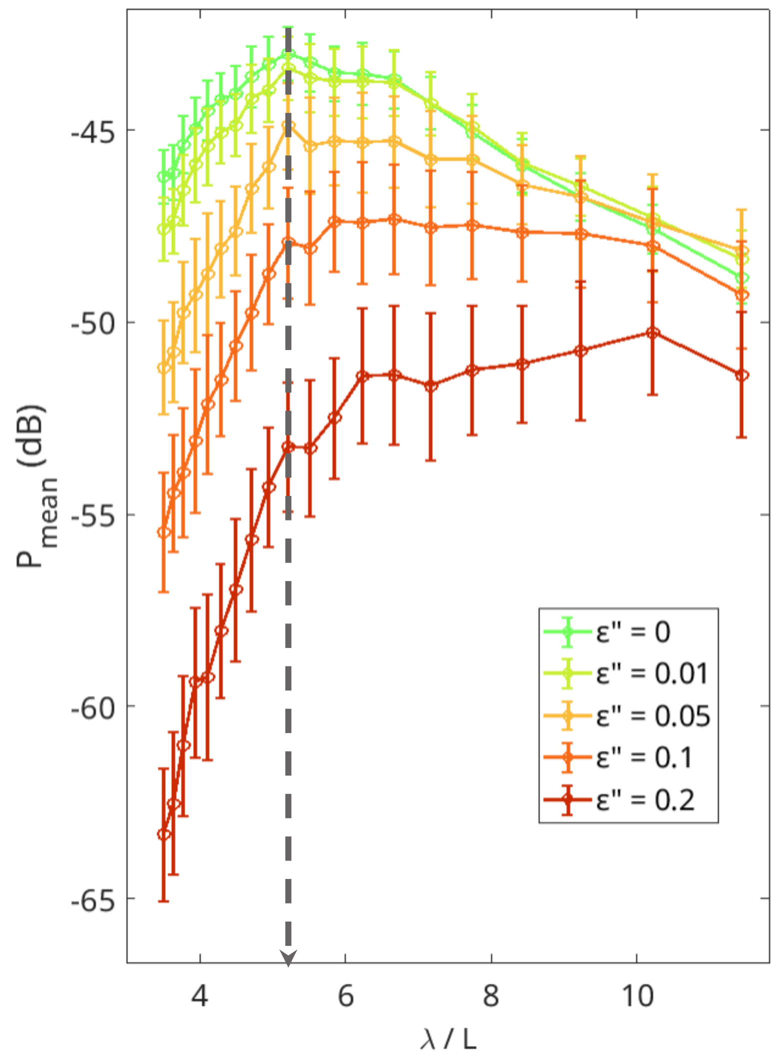


IMPACT OF DIELECTRIC LOSSES

Martian and Lunar soil analogs (color indicates the typical ε” values of the material) :

Basalt
Martian Dust
Dry sandstones
Moon regolith
Moon regolith
Mars JSC-1
Mars Jezero Crater
Dry clays
Carbon Red Clay

L = 1.4 cm

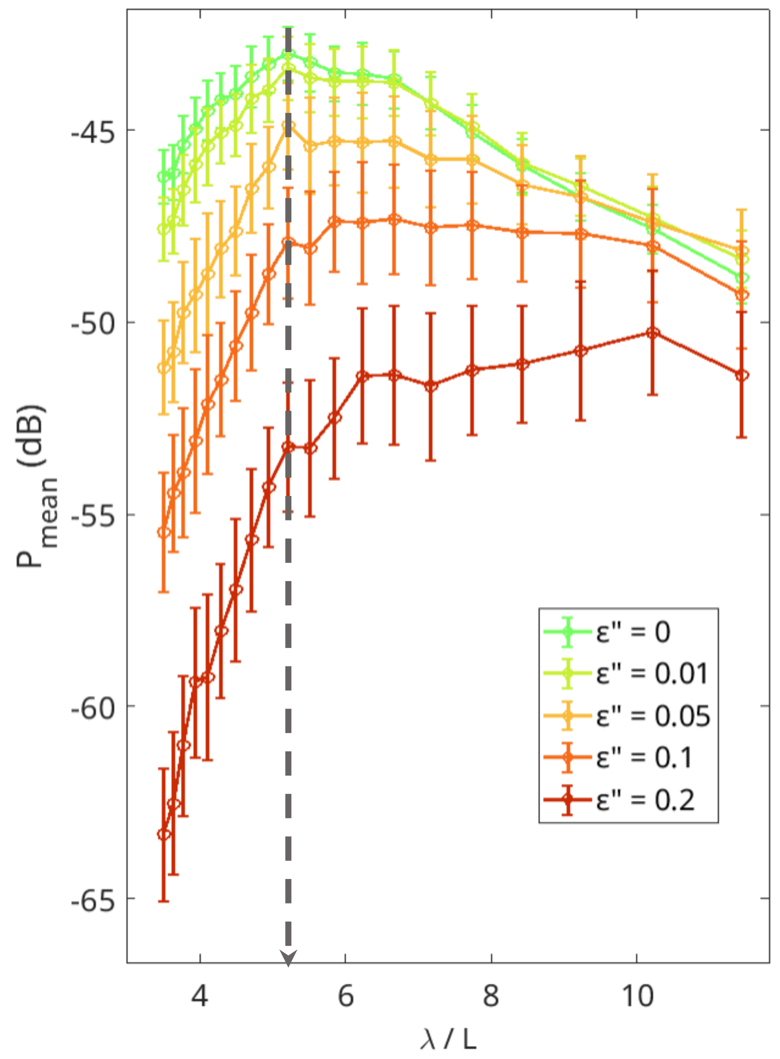


IMPACT OF DIELECTRIC LOSSES

L = 1.4 cm

<u>Martian and Lunar soil analogs (color indicates the typical ε” values of the material) :</u>

- Basalt
- Martian Dust
- Dry sandstones
- → Moon regolith (Returned samples)
- → Moon regolith (GPR estimates)
- Mars JSC-1
- → Mars Jezero Crater (RIMFAX estimates)
- Dry clays
- Carbon Red Clay

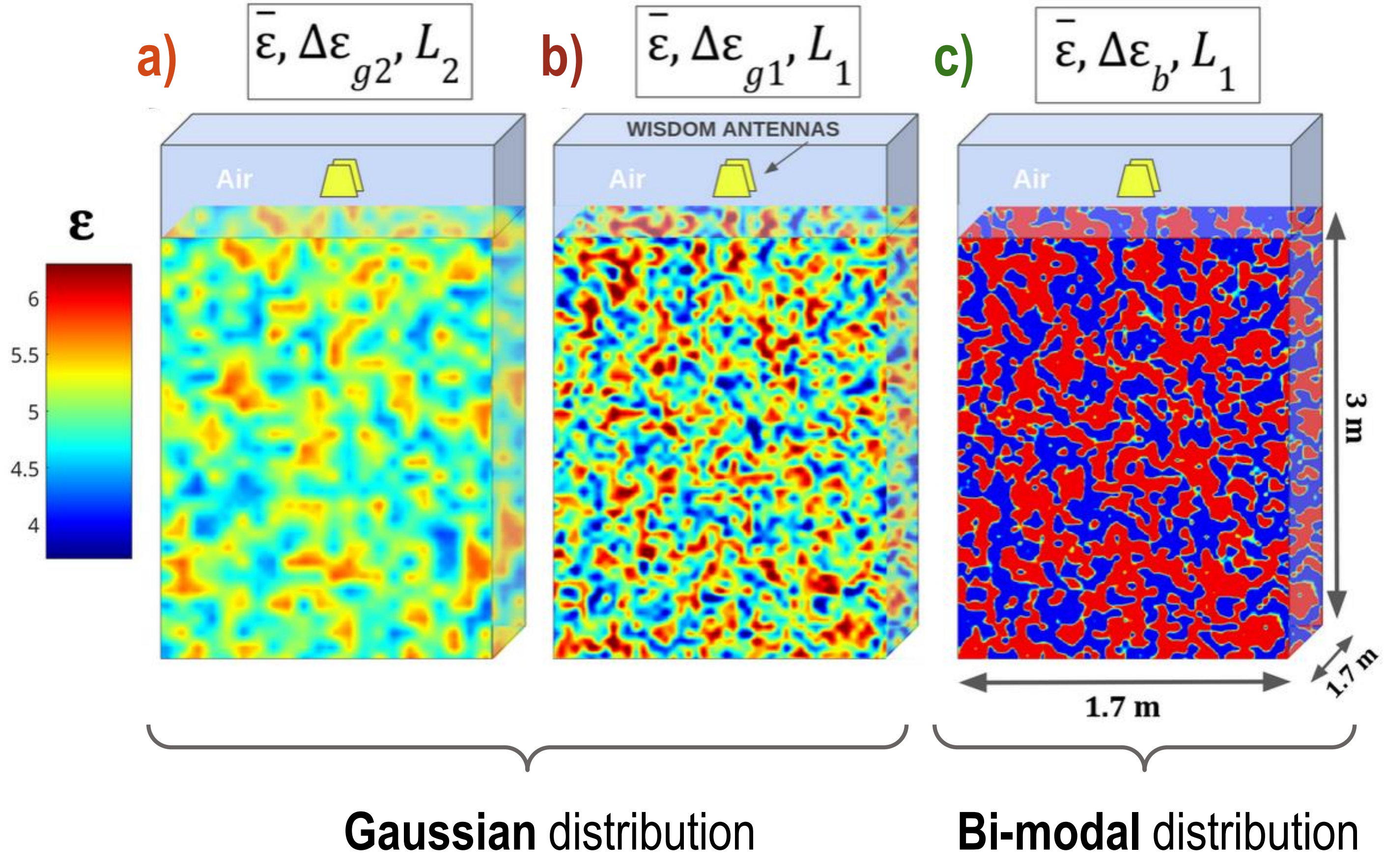


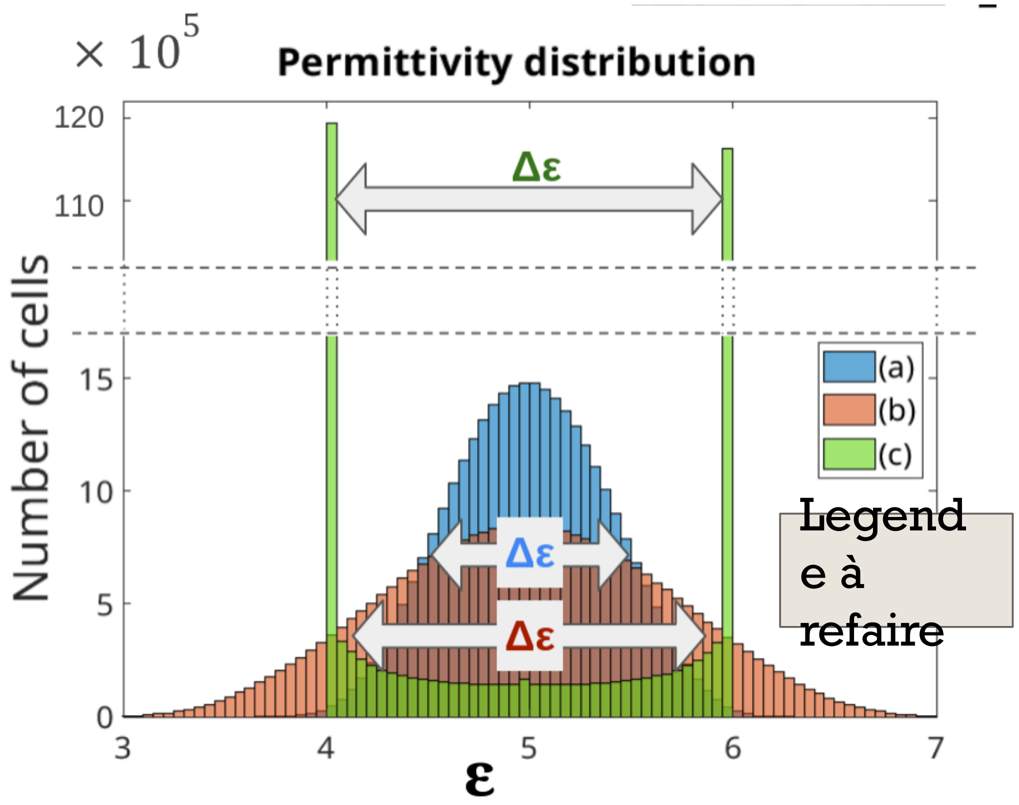
ANNEXE

Parameter of the instrument	Typical values for WISDOM
Frequency Bandwidth	0.5 to 3 GHz (2.5 GHz)
Frequency steps	2.5 MHz (1001 steps)
Repetition time	200 µs
Transmitted power	0 dBm
Noise factor	8 dB
Receiving channel gain (adjustable)	-7 to 25 dB
Antenna gain	1 to 8 dB
Effective range of the ADC (16 bits)	~84 dB
IFT gain	27 dB
Gain for 10 coherent additions	10 dB (see (Hervé, 2018))
Transmitter and receiver efficiency	0.1

[V. Ciarletti (2017) ; N. Oudart (2021)]

3D SIMULATIONS OVER HETEROGENEOUS MEDIA



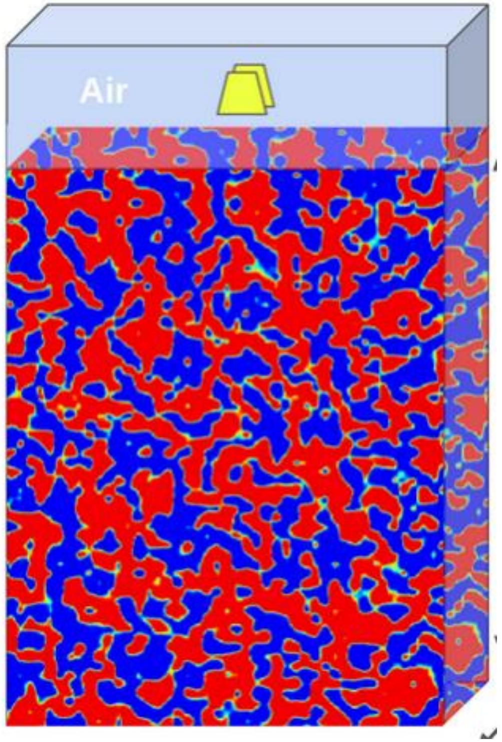


RETRIEVAL OF THE TYPICAL SIZE OF HETEROGENEITIES

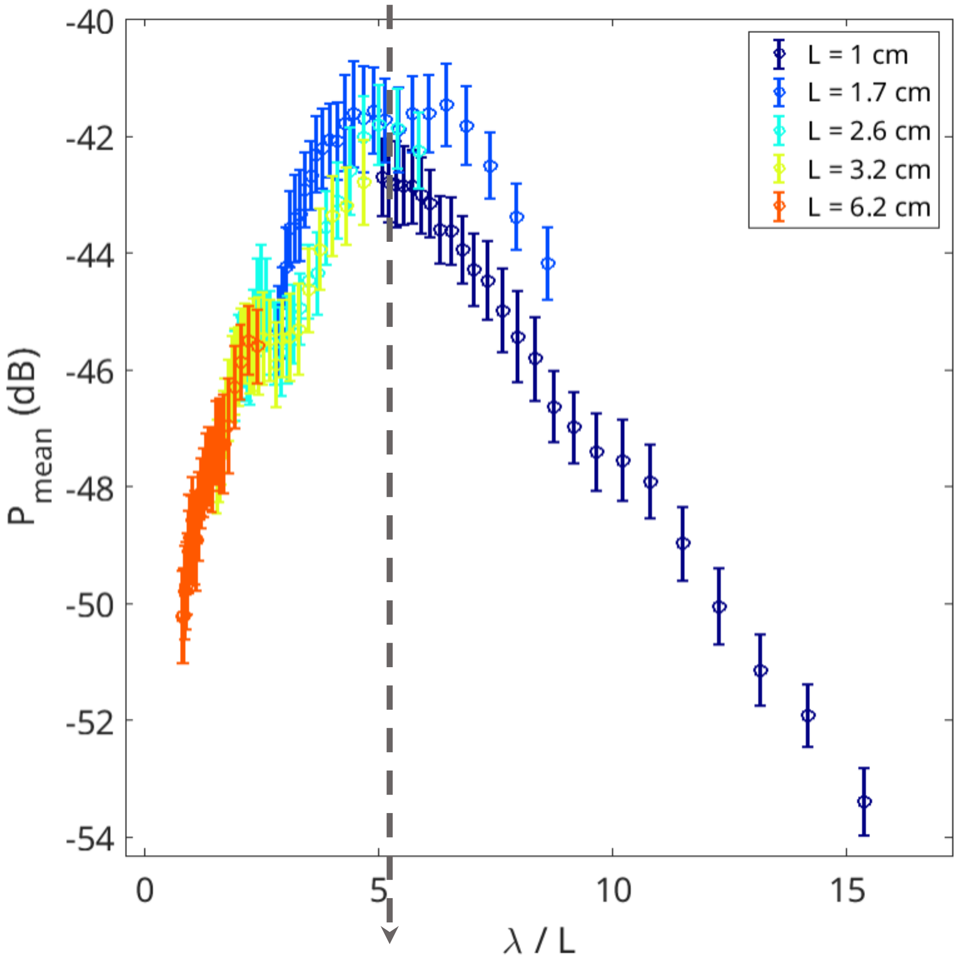
Bi-Modal distribution of permittivity

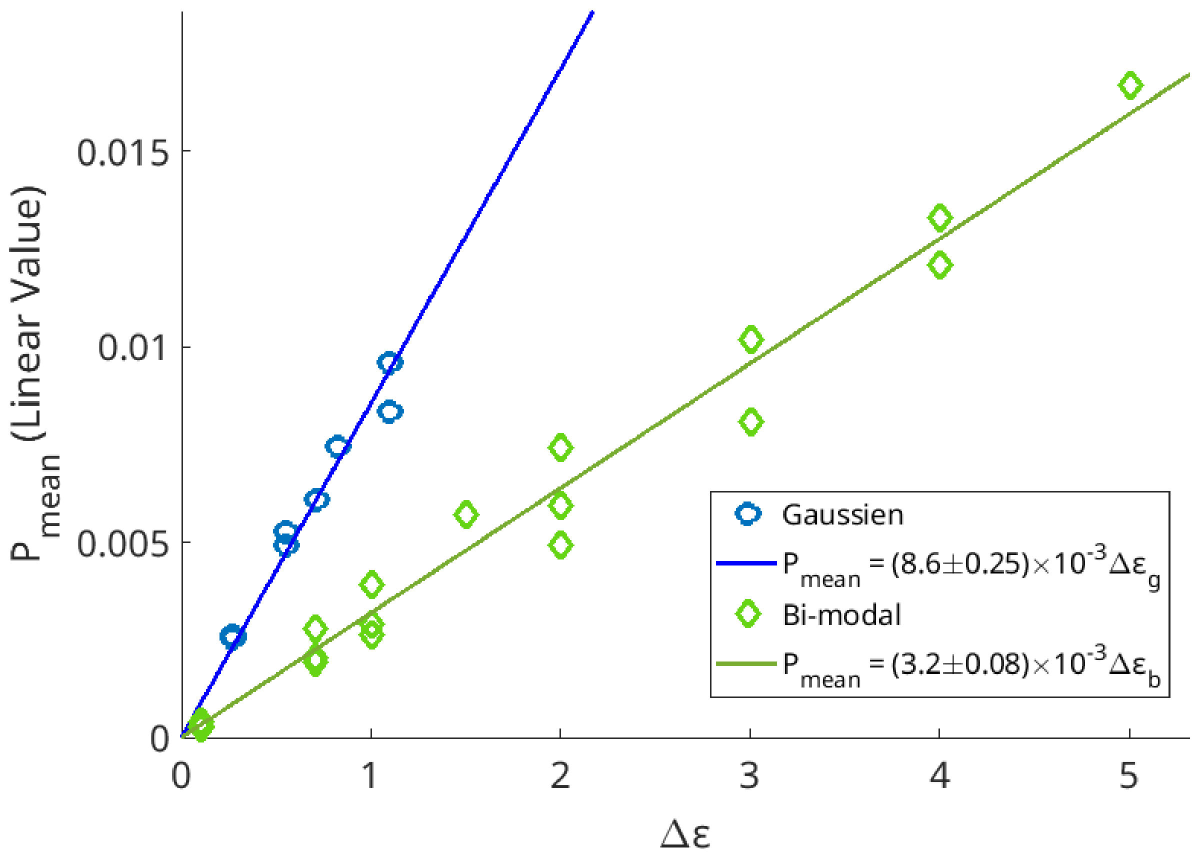
ε = 6

ε = 4

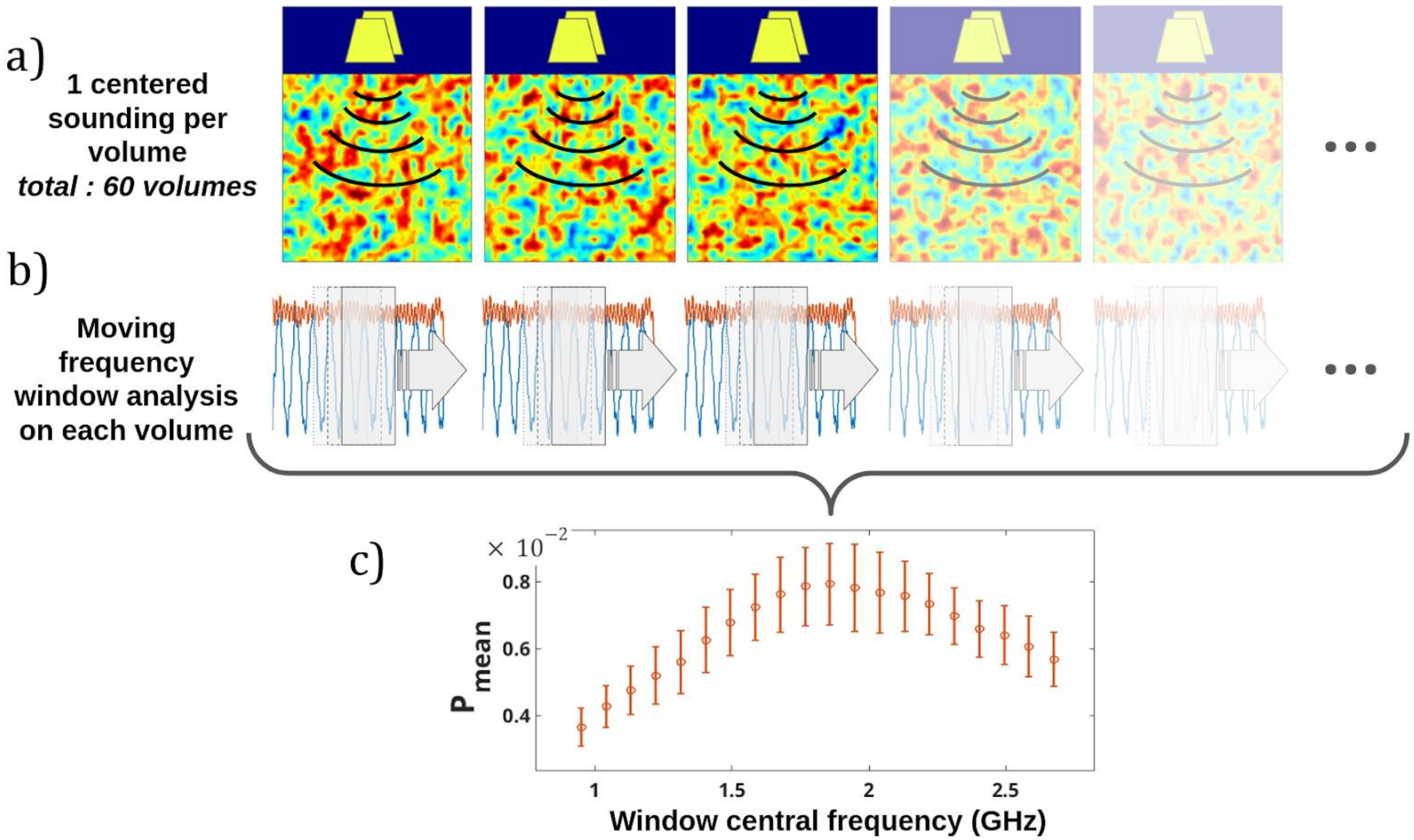


(L = 2.6 cm)

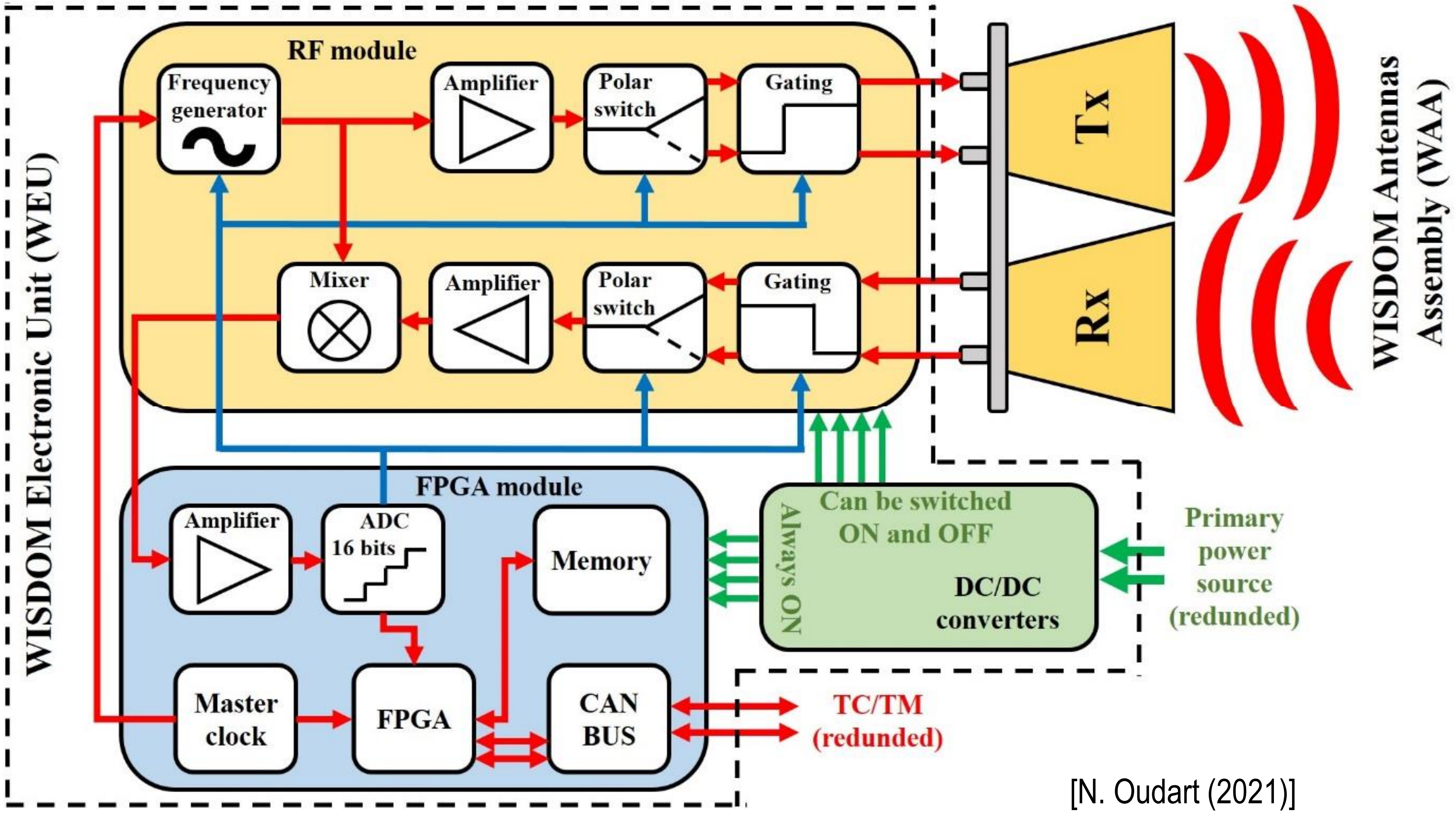




P_{mean} (Linear Value)
0.015
0.01
0.005
0
0
1
2
3
4
5
$\Delta\varepsilon$
Gaussien
$P_{mean} = (8.6 \pm 0.25) \times 10^{-3} \Delta\varepsilon_g$
Bi-modal
$P_{mean} = (3.2 \pm 0.08) \times 10^{-3} \Delta\varepsilon_b$

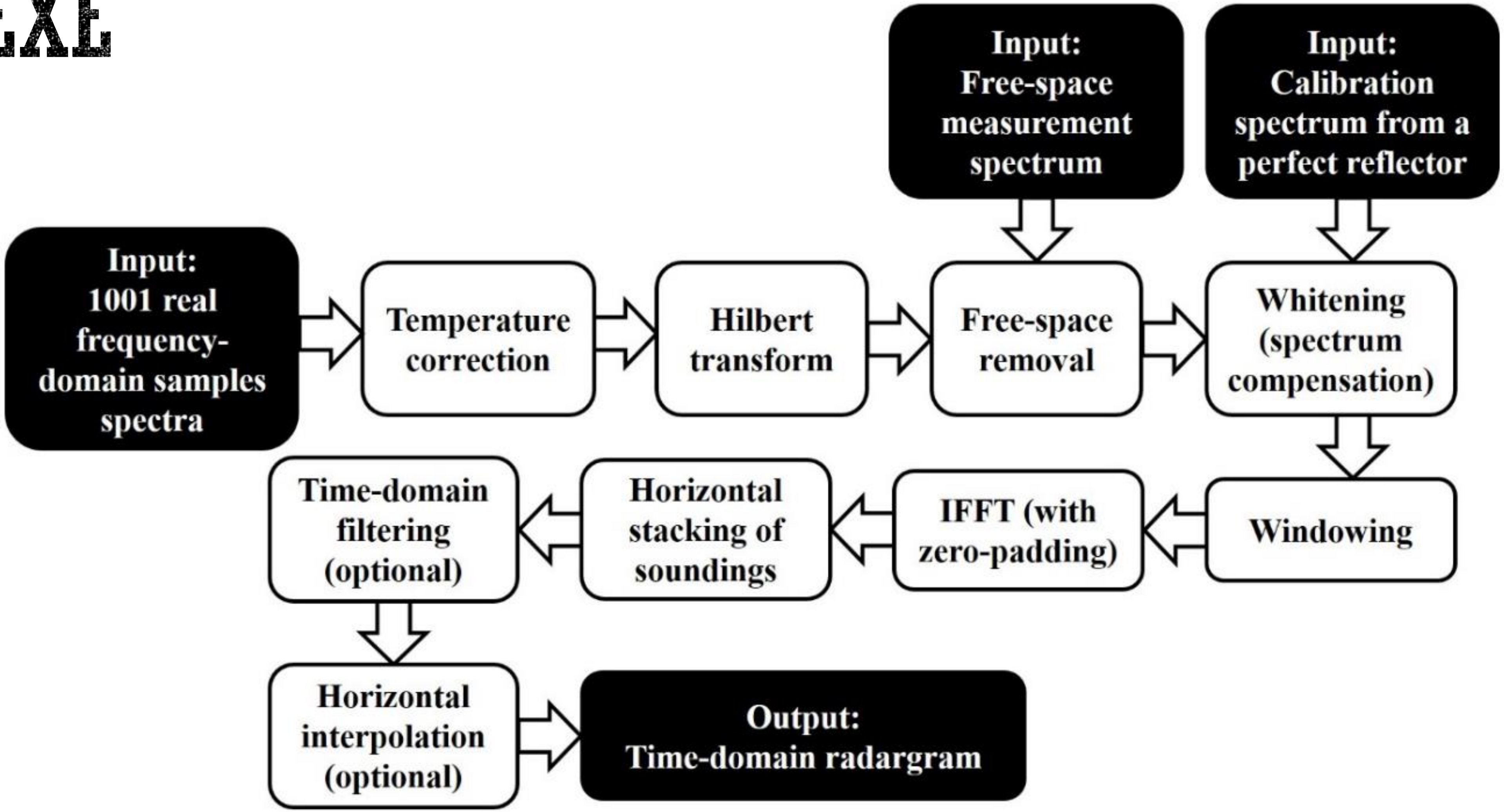

a)
1 centered sounding per volume
total : 60 volumes
b)
Moving frequency window analysis on each volume
c)
× 10^-2
0.8
0.6
0.4
P_mean
1
1.5
2
2.5
Window central frequency (GHz)

ANNEXE



[N. Oudart (2021)]

ANNEXE



[N. Oudart (2021)]

ANNEXE

	WISDOM
Radar design	Stepped Frequency Continuous Wave
Working frequencies	0.5 – 3 GHz
Antennas design	Vivaldi antennas
Free-space resolution (worst case)	6 cm
Expected penetration depth (material dependent)	3 – 10 m
Dynamic range	~84 dB of effective range
Power consumption	12.5 W
Mass	1.36 kg