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# A super resolution method applied to WISDOM Martian radar soundings

Nicolas OUDART – Elbereth – 26/02/2020

With V. Ciarletti, A. Le Gall, Y. Hervé, M. Mastrogiuseppe, W.S. Benedix



The WISDOM  
Martian  
radar

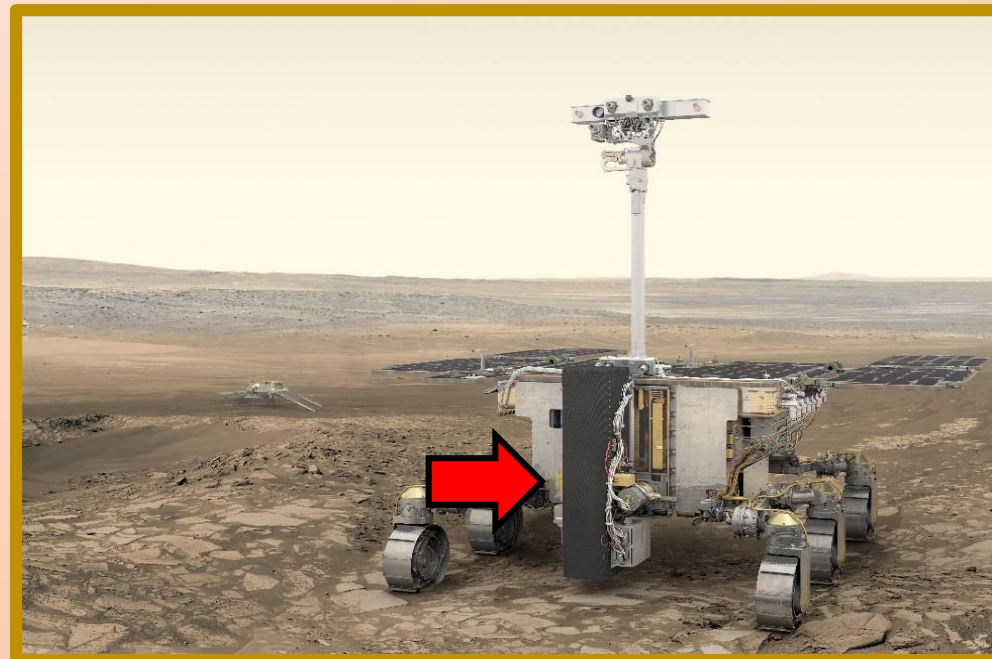
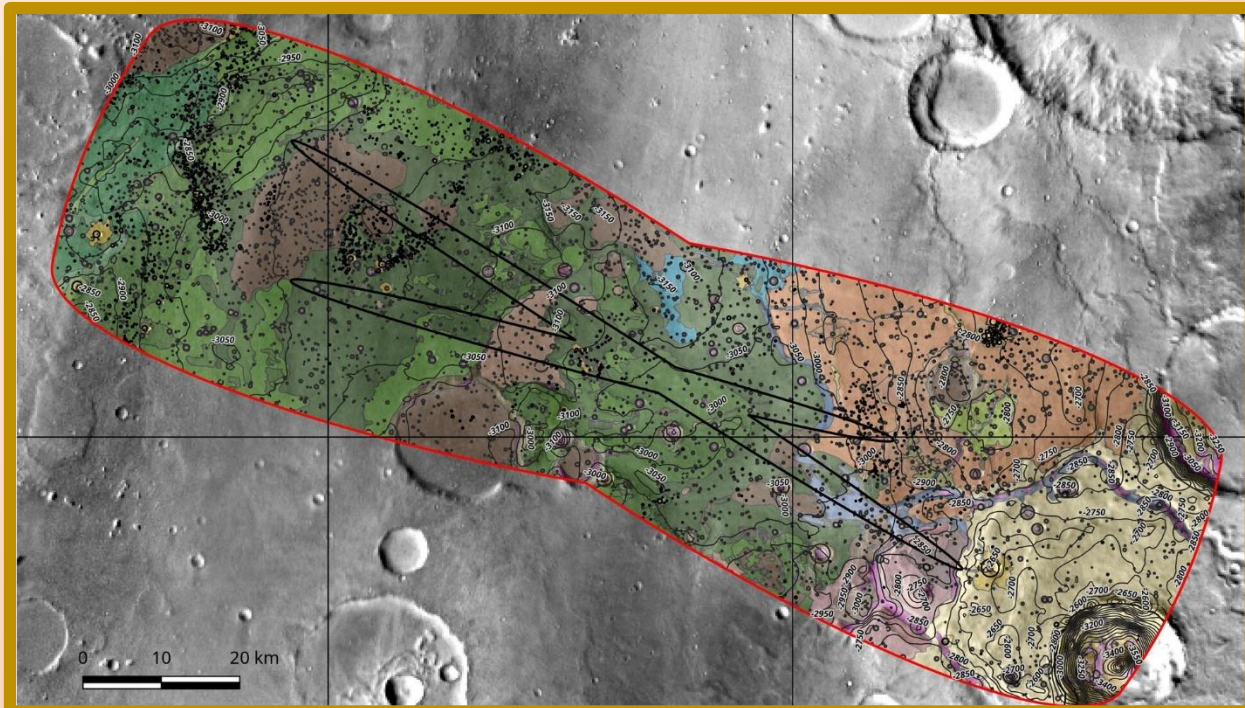
Application of  
super-resolution  
techniques

Preparing for  
Mars on Earth

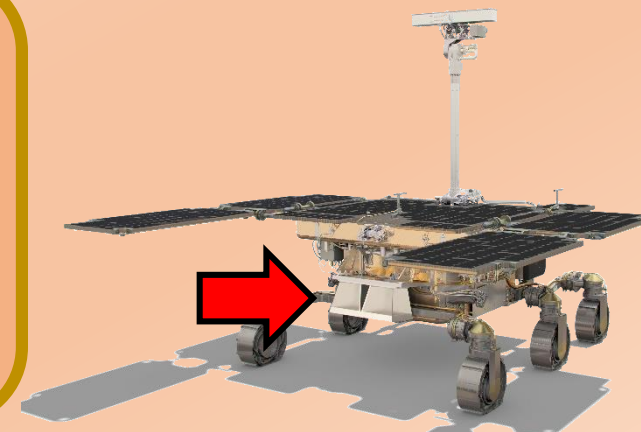
Work in  
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## The mission



The WISDOM **ground penetrating radar** will give an insight on the **structure and composition** of the subsurface prior to drilling operations.





The WISDOM  
Martian  
radar

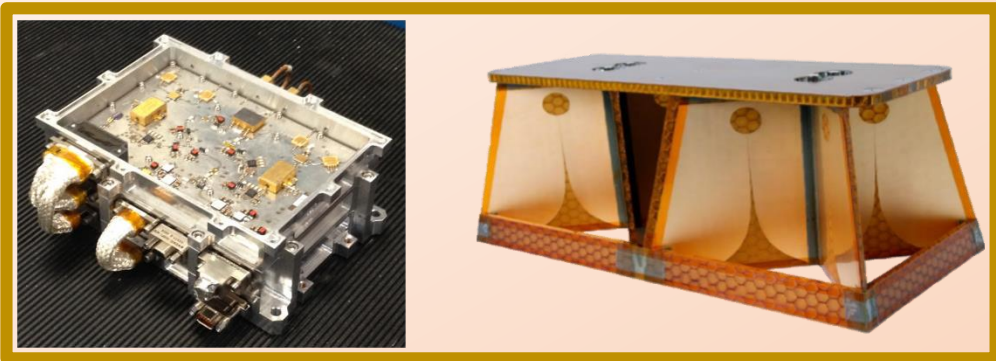
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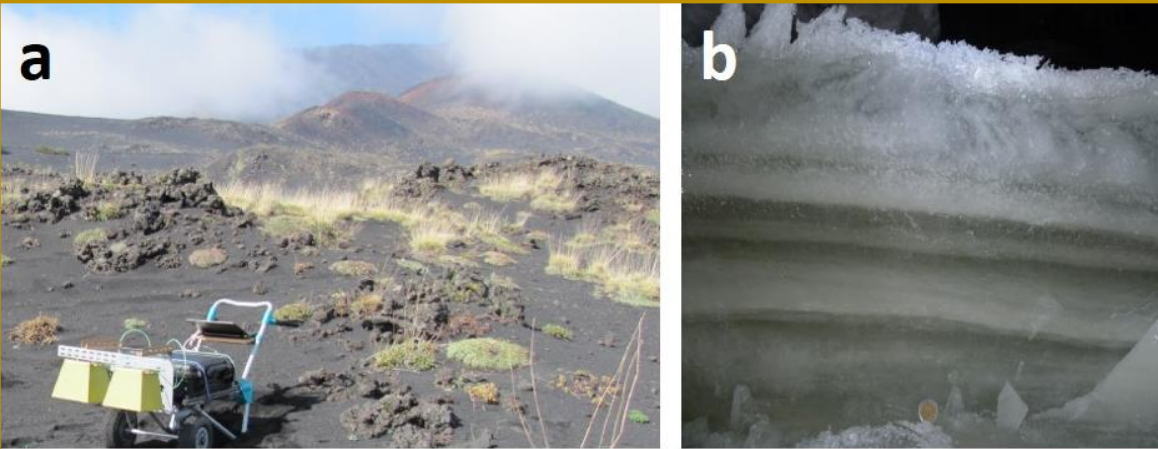


## The instrument





## Measurement campaigns



To test the processing chain of the instrument, a dataset of soundings have been acquired on natural environment in the last 10 years :

- The Etna Mt. (a) in 2010.
- The Dachstein caves (b) in 2012.



- The LATMOS « Mars Yard » (c) in 2017.
- The Atacama desert in 2019 (d).
- The TU Dresden « Mars Yard » (e) in 2019.



# The WISDOM Martian radar

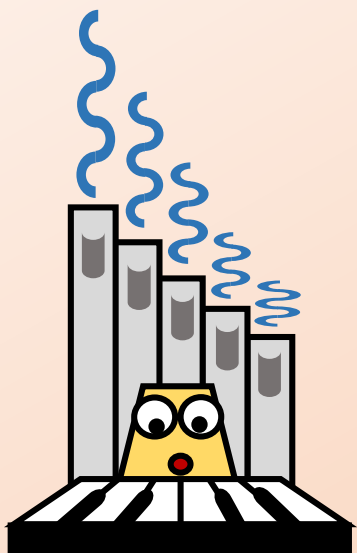
Application of super-resolution techniques

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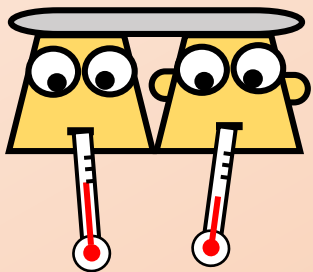


## The processing chain



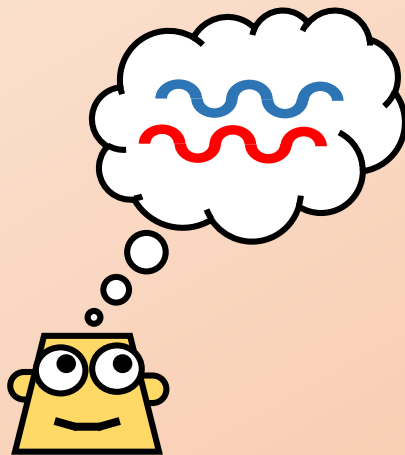
1001 frequencies spectra (0.5-3 GHz)

WISDOM transmit the equivalent of an impulse in frequency domain.



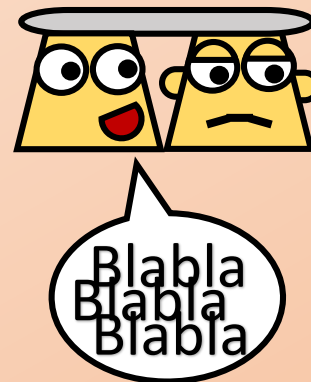
Temperature correction

(Compensate the effect of temperature on the amplitude)



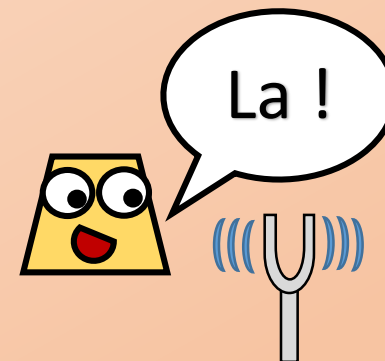
Hilbert transform

(Obtain the imaginary part of the signal)



Horizontal mean removal

(Remove constant signals: antennas coupling, internal coupling ... )



Gain corrections

(Compensate the effect of the gains of the electronics and the antennas)



# The WISDOM Martian radar

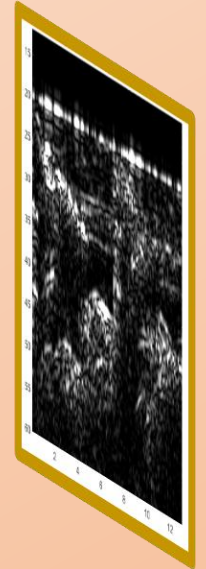
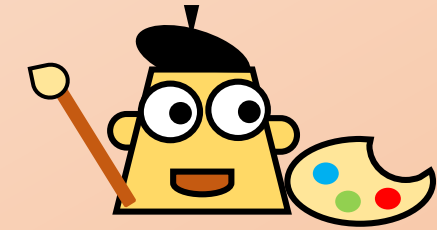
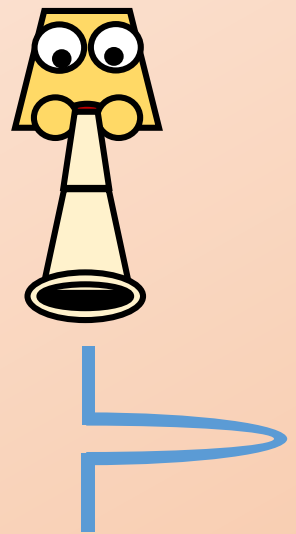
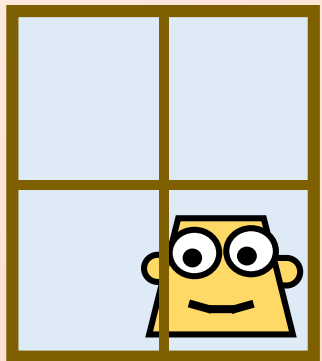
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## The processing chain



**Windowing (Hann)**

**IFFT (with zero-padding)**

**Soundings in time-domain**

**Stacking soundings horizontally to obtain an image**

**Radargram**

(To avoid side-lobes effects in time-domain)

(Inverse Fourier transform to obtain soundings in time-domain)

(The horizontal scale is the distance travelled by WISDOM, the vertical scale is the time delay of echoes)



### The resolution

The vertical resolution of WISDOM depends on its "Bandwidth" (B = 2.5 GHz):

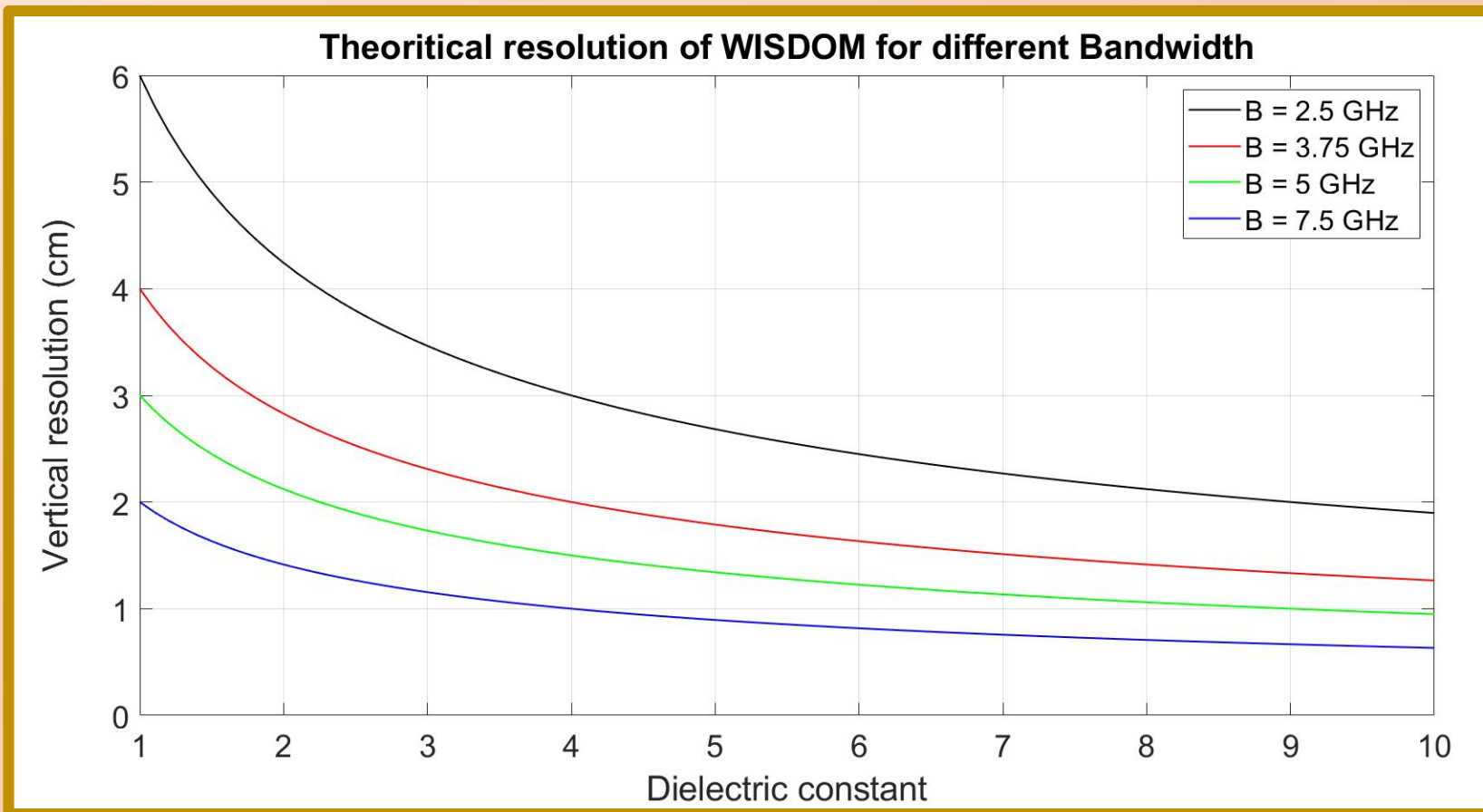
$$\delta = \frac{c}{2B\sqrt{\epsilon_r}}$$



For instance, a resolution of 3 cm can be expected in dry sand ( $\epsilon_r = 4$ ).

A larger Bandwidth would increase  $\delta$ .

➤ For this reason was applied the **Bandwidth Extrapolation** super-resolution technique (BWE).





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Martian  
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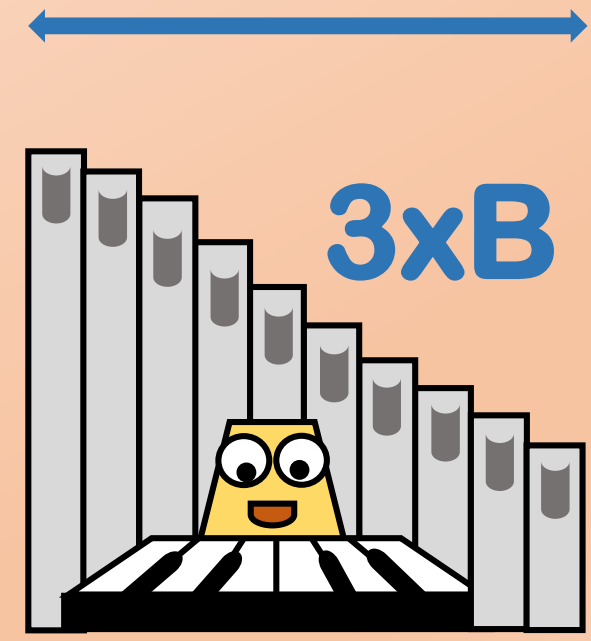
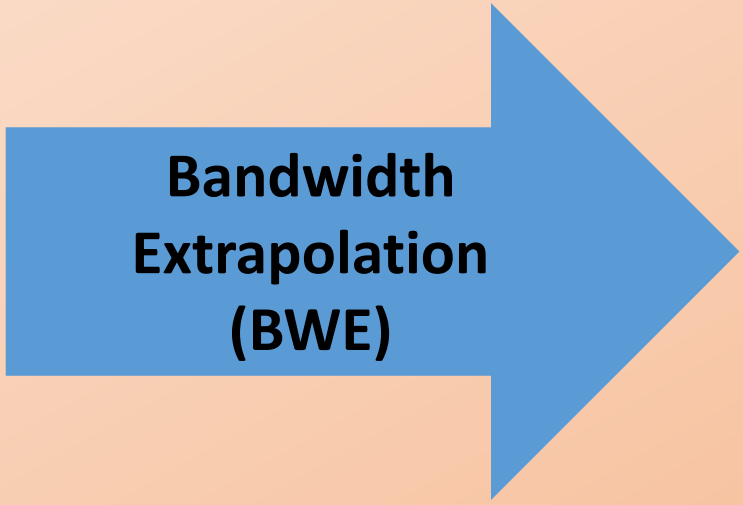
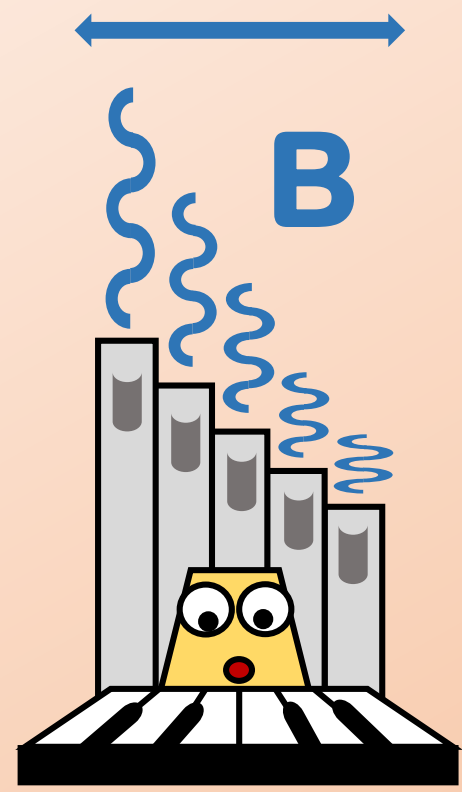
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# The resolution

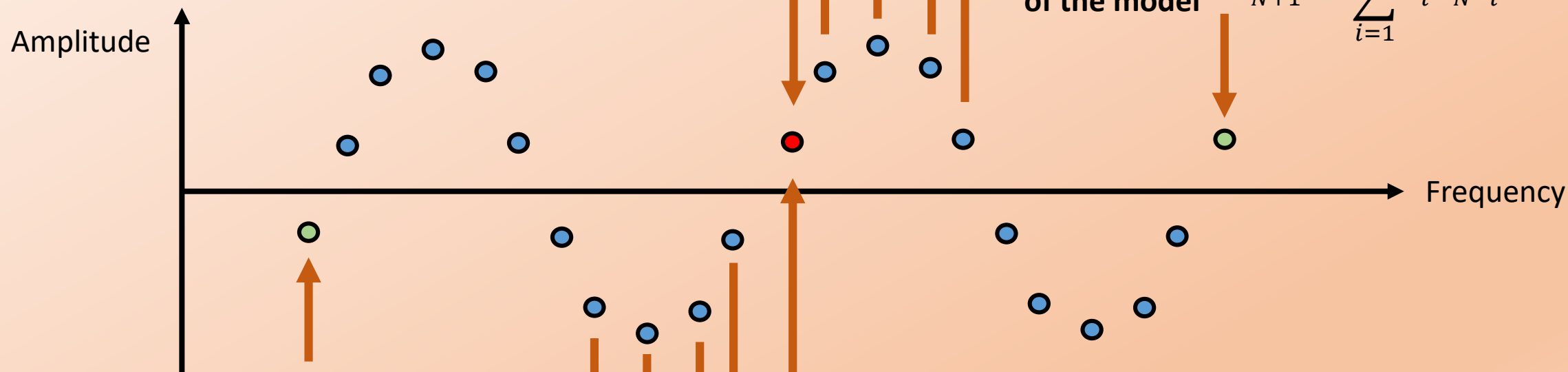






## Bandwidth Extrapolation and AR-models

A WISDOM spectrum can be modelled as a sum of sine-waves. This model can be described as an Auto-Regressive model.



$$S_n = \sum_{i=1}^p a_i S_{n+i}$$

Order of the model

Elements in the spectrum

Coefficients  
of the model

$$S_{N+1} = \sum_{i=1}^p a_i S_{N-i}$$

$$S_0 = \sum_{i=1}^p a_i S_i$$

$$S_n = \sum_{i=1}^p a_i S_{n-i}$$

The Burg algorithm returns the coefficients of a model minimizing the forward and backward errors, but needs the order as an entry.



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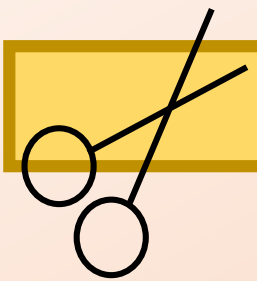
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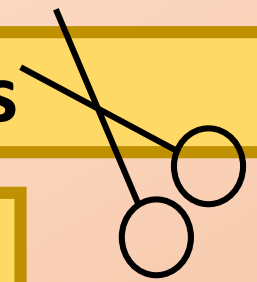
Work in  
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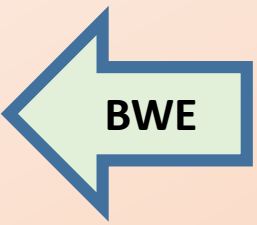
Determining the order for the model



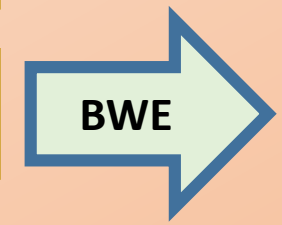
WISDOM spectrum of 1001 frequencies



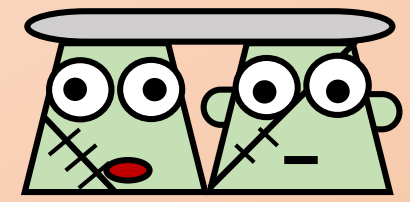
Cut WISDOM spectrum of 701 frequencies



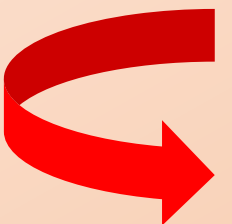
Cut WISDOM spectrum of 701 frequencies



Reconstructed WISDOM spectrum of 1001 frequencies



Compared in  
time-domain



The process is repeated  
for every possible order



For an entire  
radargram

The order corresponding  
to the best correlation is  
selected



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Application of  
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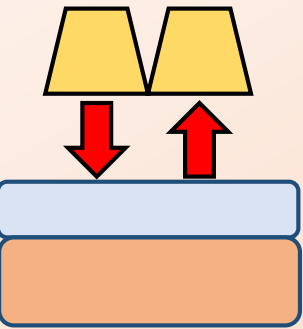
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## Determining the order for the model

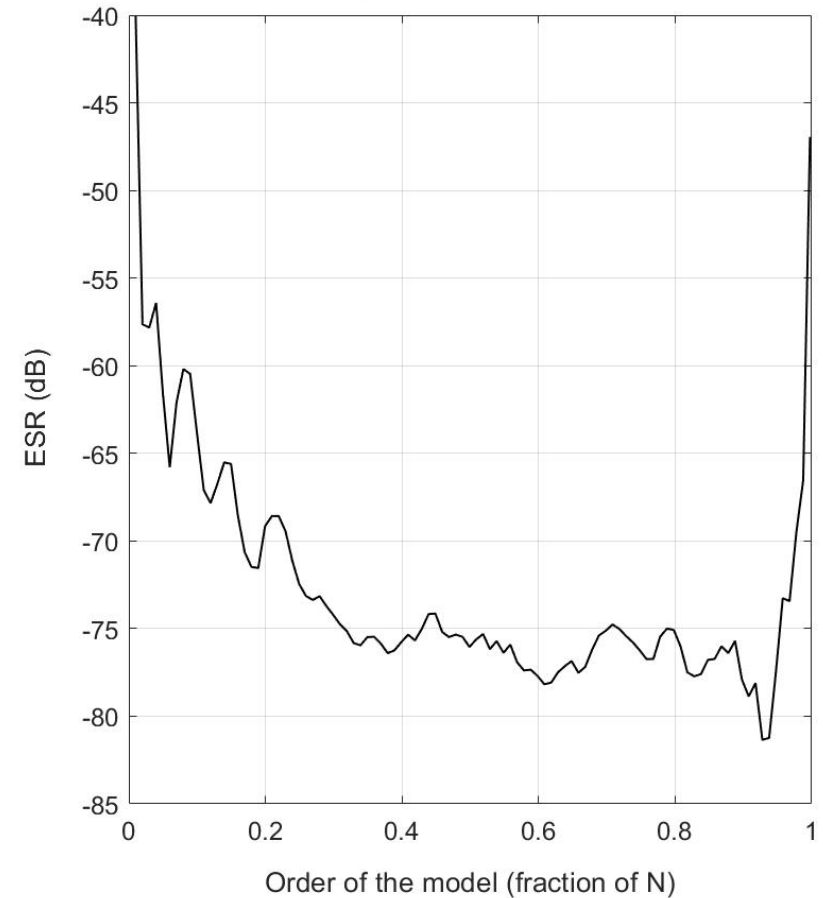
### On simulated soundings without noise



Correlation between the original and the reconstructed spectrum



ESR between the original and the reconstructed spectrum





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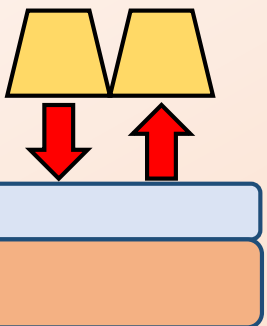
Preparing for  
Mars on Earth

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progress ...

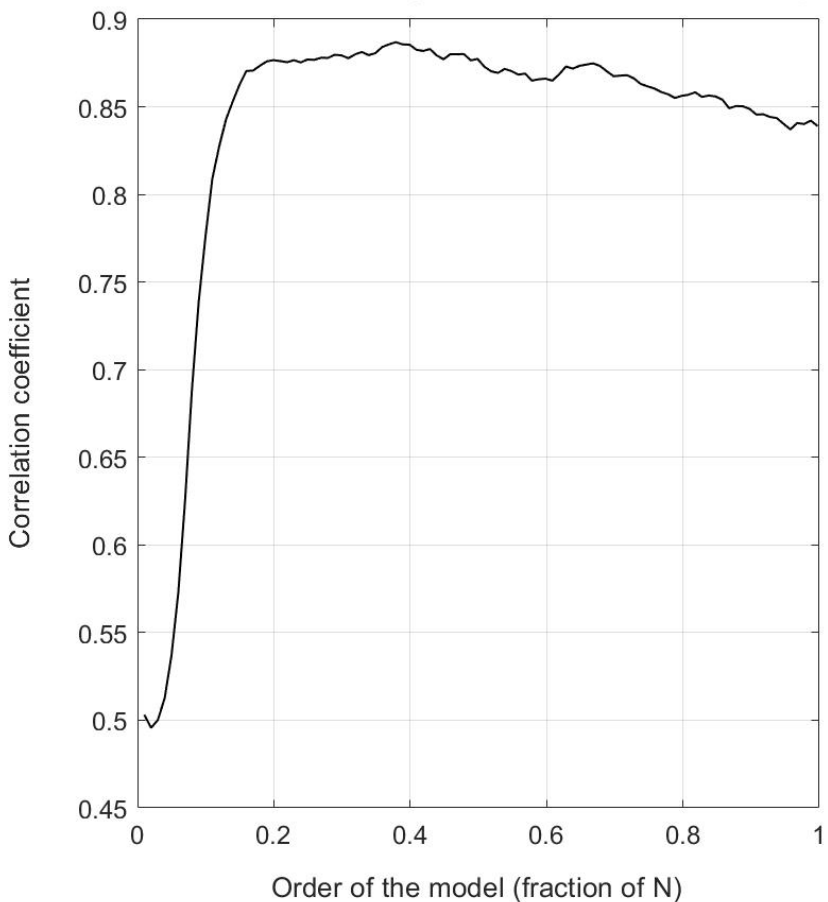


## Determining the order for the model

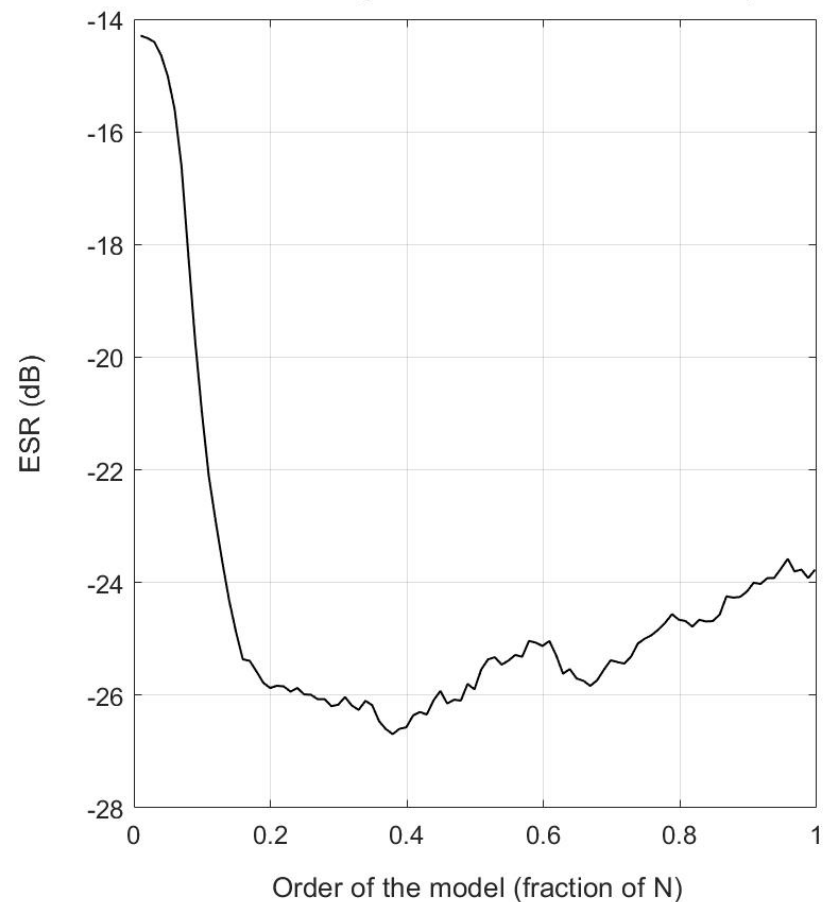
### On simulated soundings with a SNR = 20 dB



Correlation between the original and the reconstructed spectrum



ESR between the original and the reconstructed spectrum





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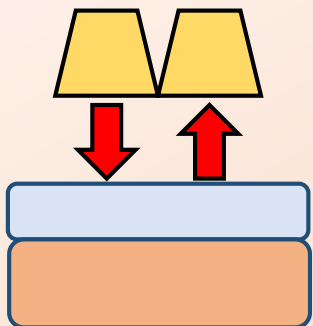
Preparing for  
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progress ...

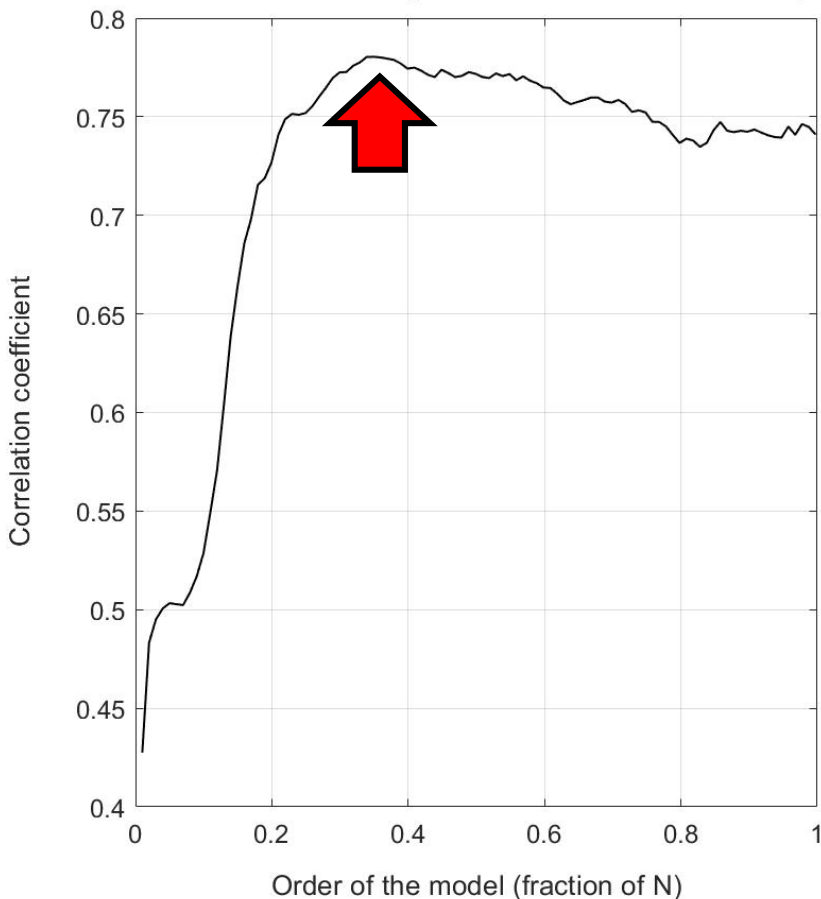


## Determining the order for the model

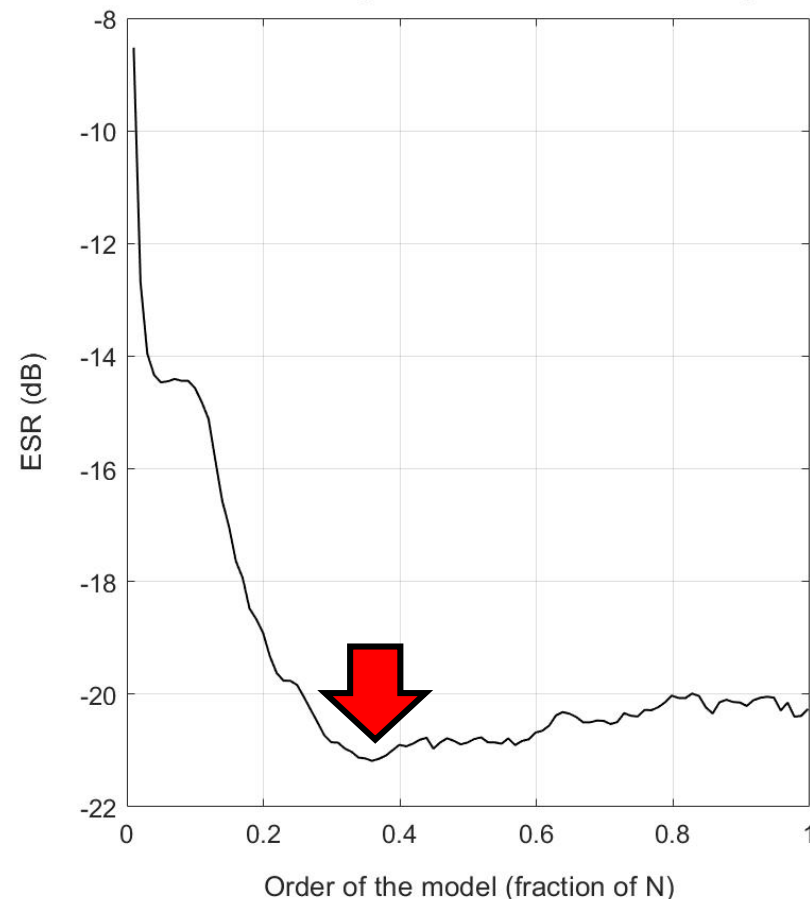
On simulated soundings with a SNR = 10 dB



Correlation between the original and the reconstructed spectrum



ESR between the original and the reconstructed spectrum





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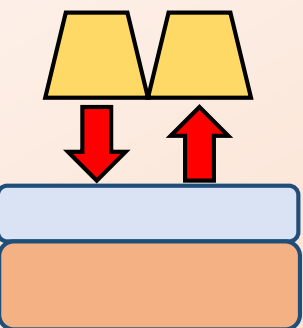
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progress ...

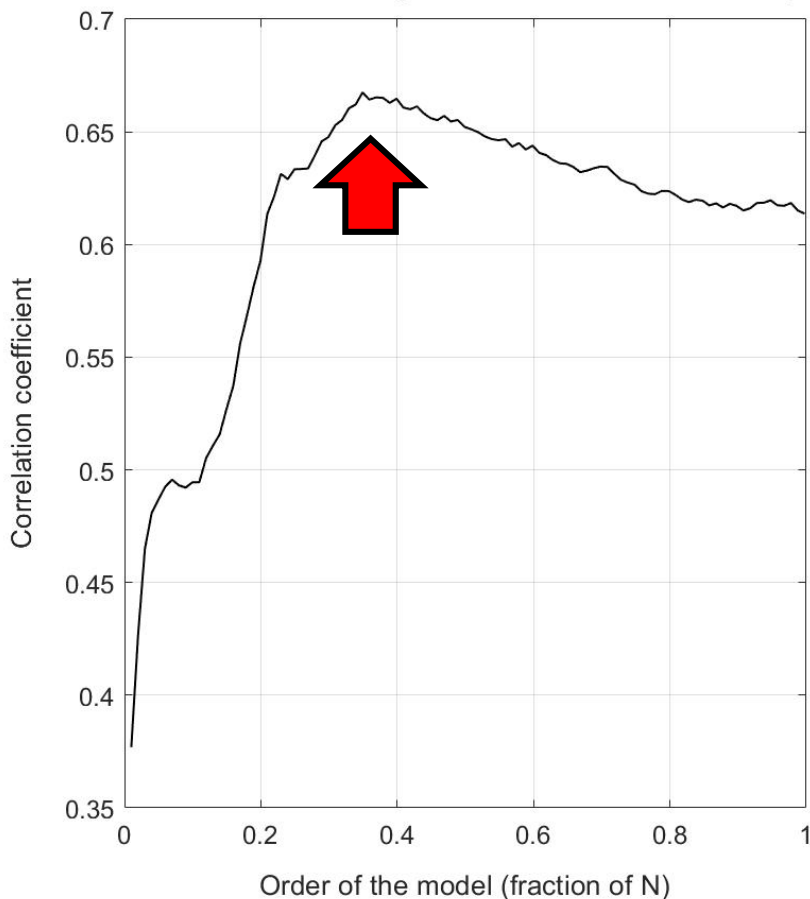


## Determining the order for the model

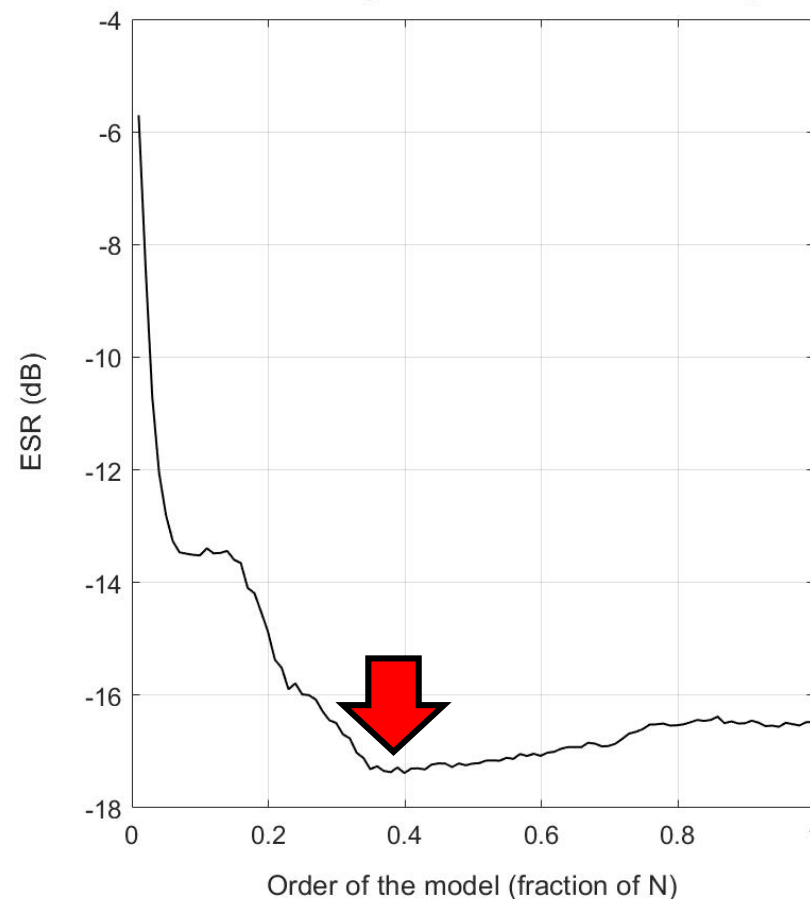
### On simulated soundings with a SNR = 5 dB



Correlation between the original and the reconstructed spectrum



ESR between the original and the reconstructed spectrum





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radar

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techniques

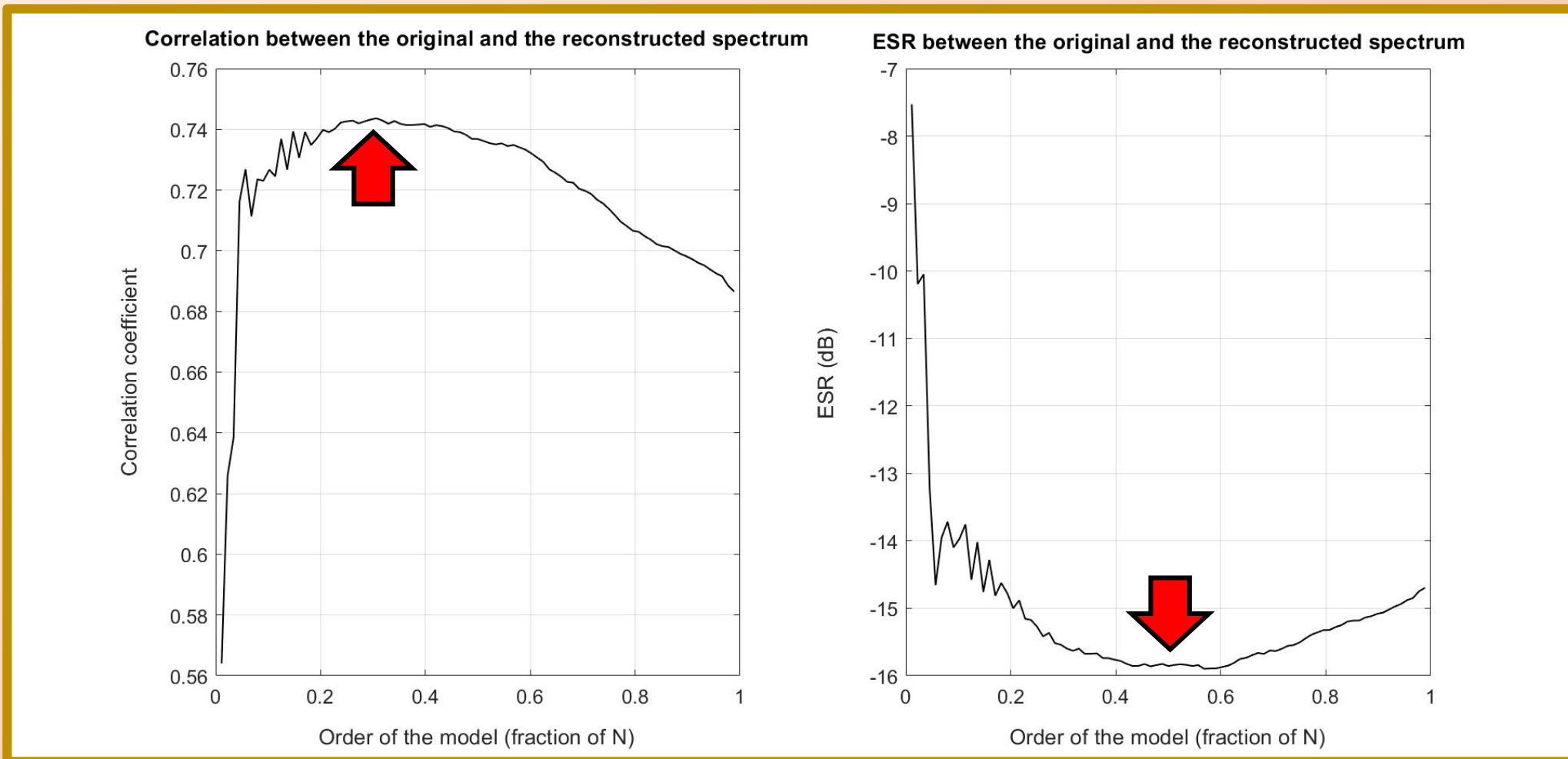
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## Determining the order for the model

### On a radargram from the Dachstein caves campaign

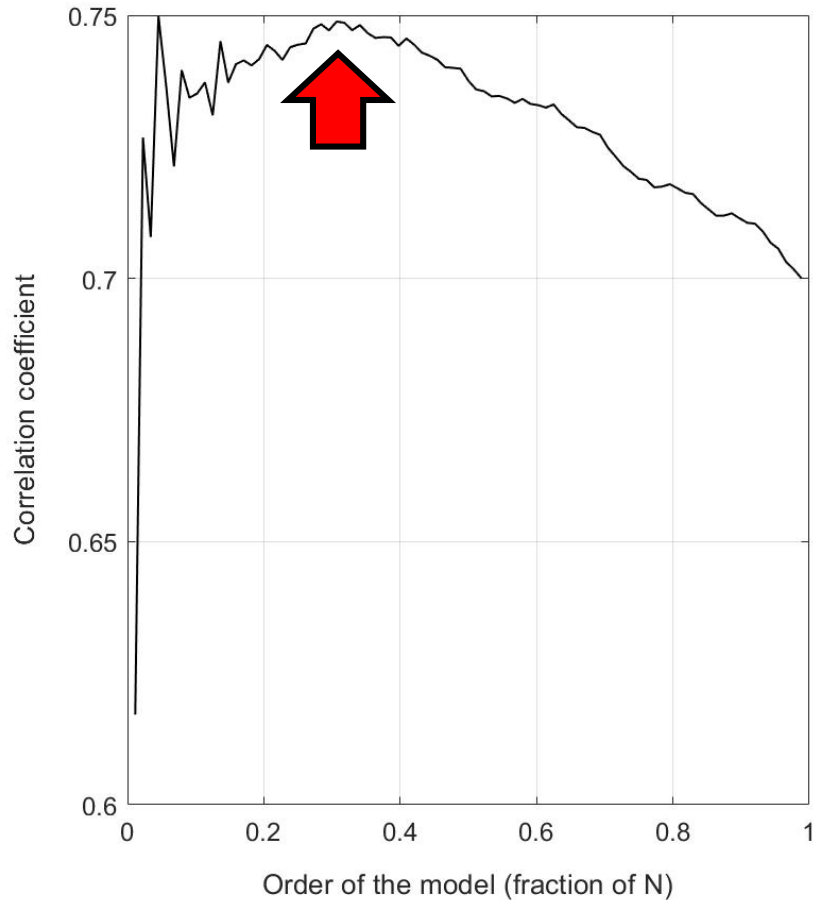




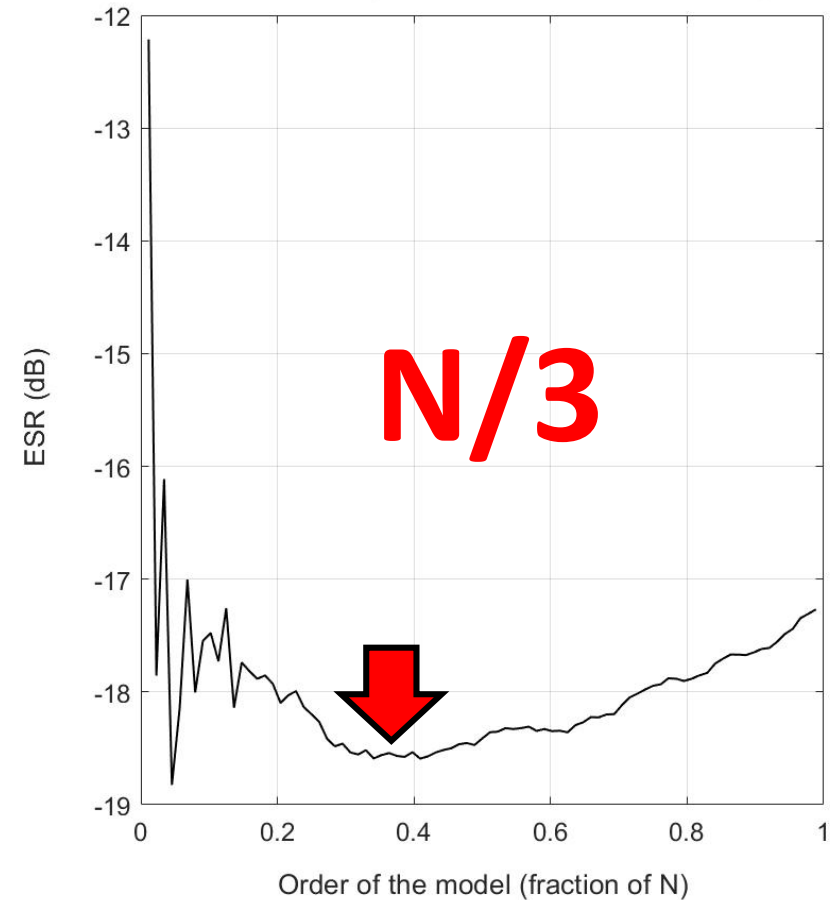
## Determining the order for the model

### On a radargram from the Etna campaign

Correlation between the original and the reconstructed spectrum



ESR between the original and the reconstructed spectrum







The WISDOM  
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radar

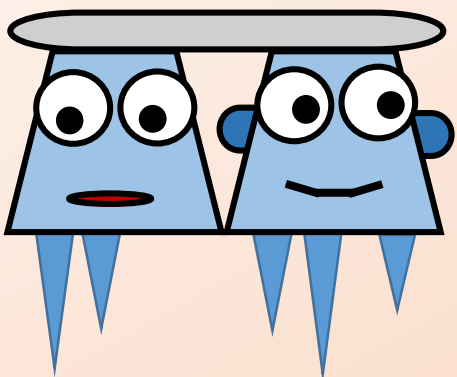
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techniques

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Mars on Earth

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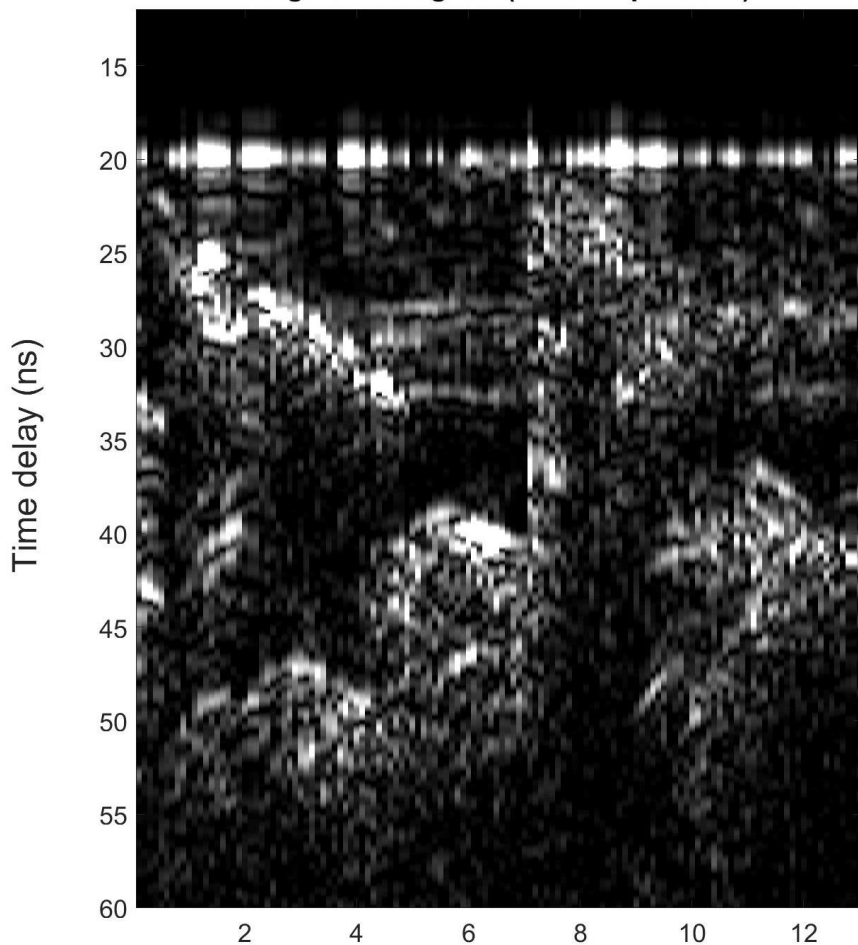


## Application to experimental radargrams

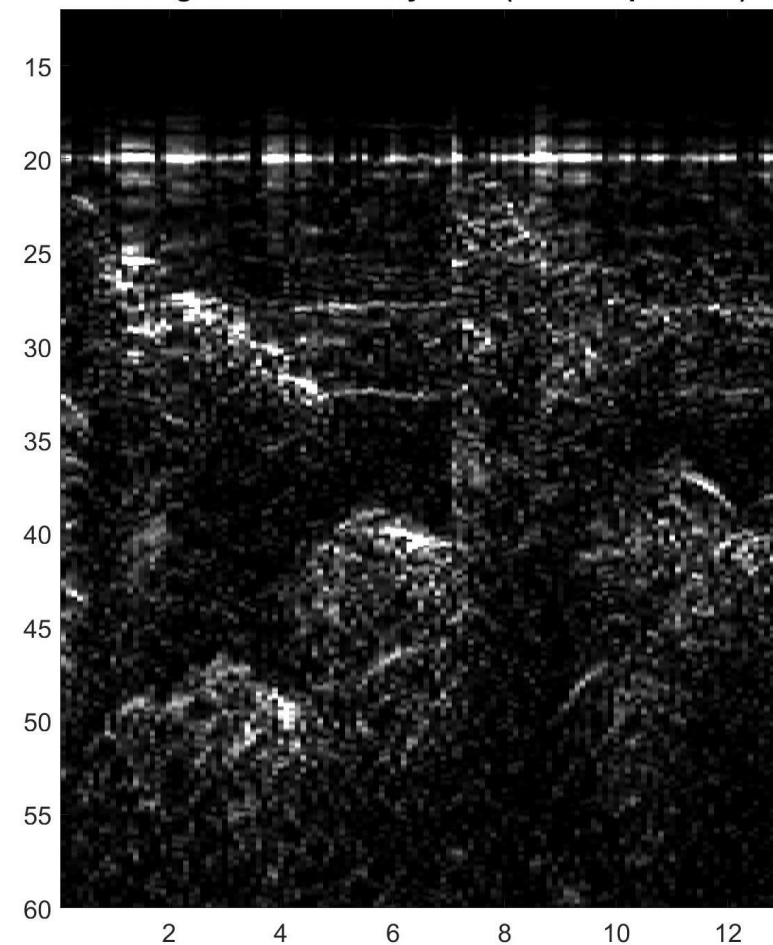


The Dachstein caves

Original radargram (1001 frequencies)



Radargram enhanced by BWE (3003 frequencies)



Distance (m)

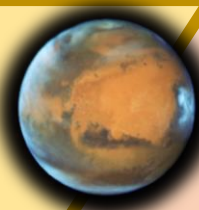


The WISDOM  
Martian  
radar

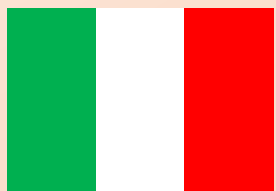
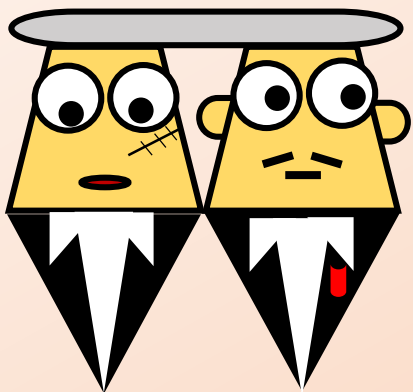
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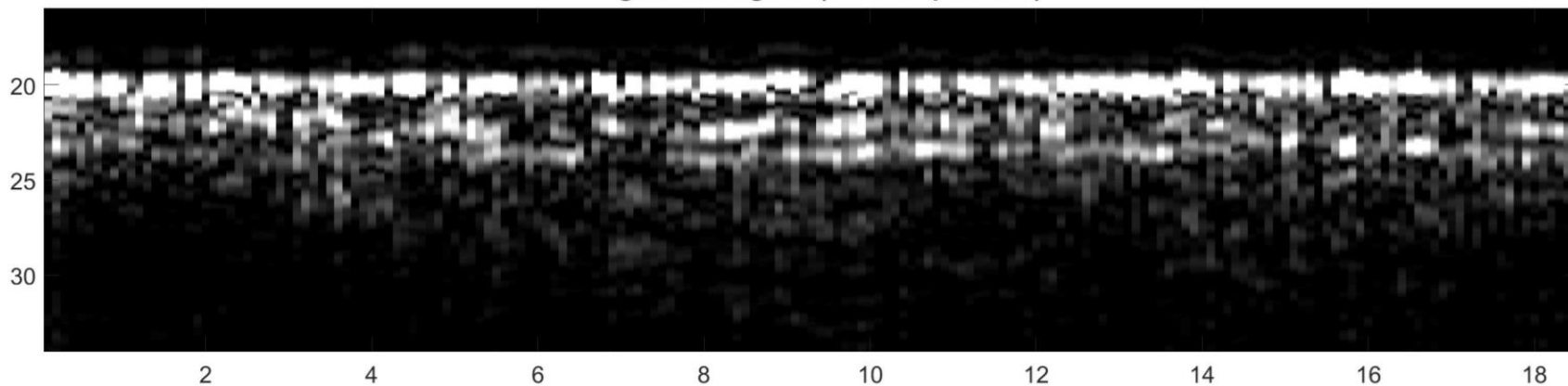
## Application to experimental radargrams



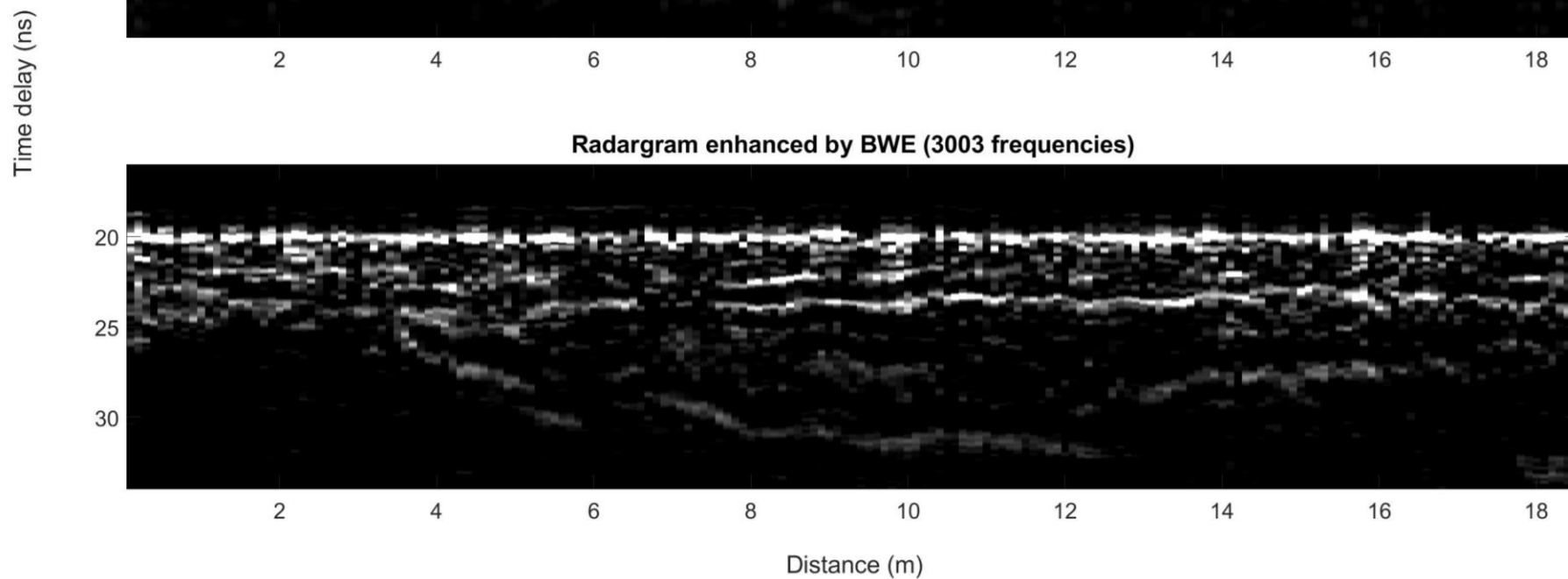
The Etna Mt.



Original radargram (1001 frequencies)



Radargram enhanced by BWE (3003 frequencies)





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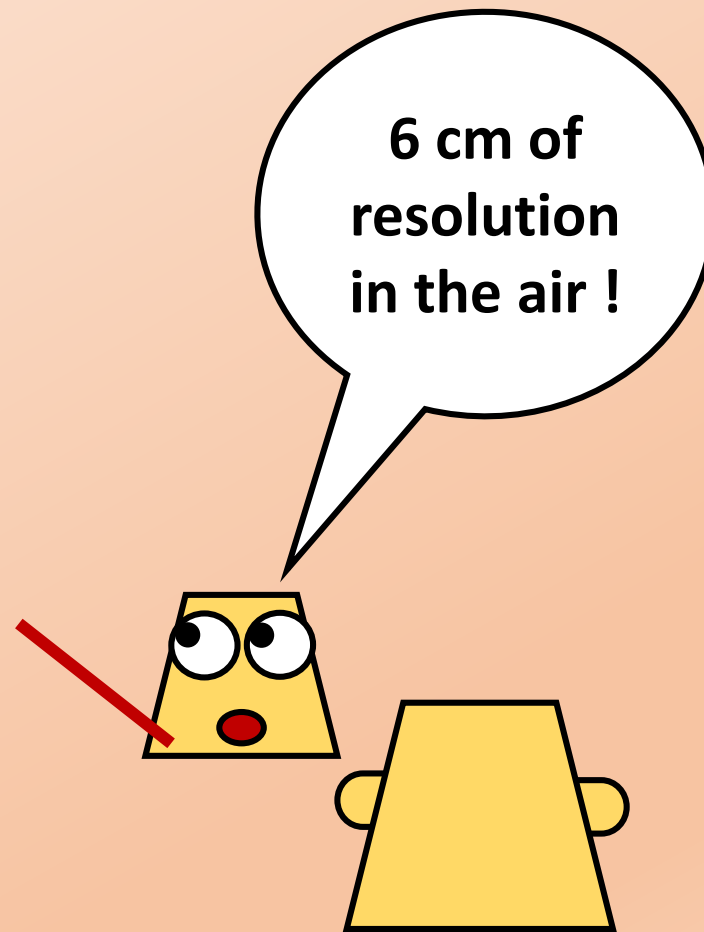
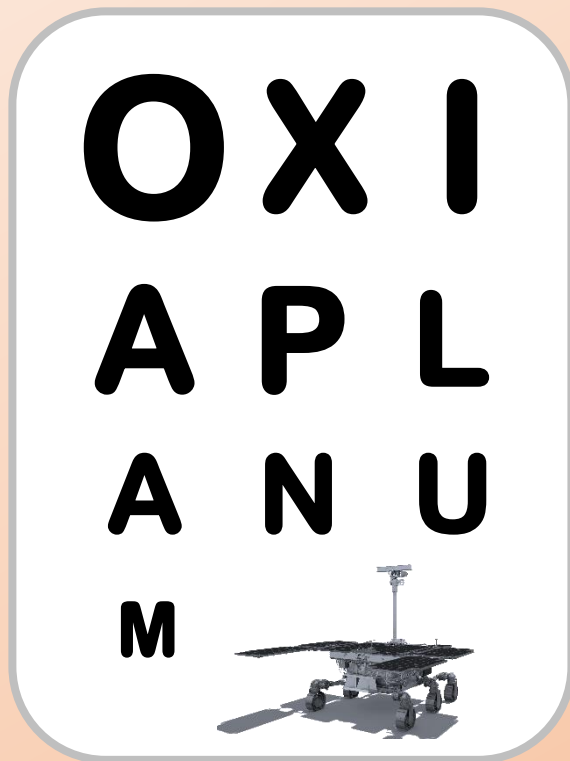
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## Measuring the improvement in resolution





The WISDOM  
Martian  
radar

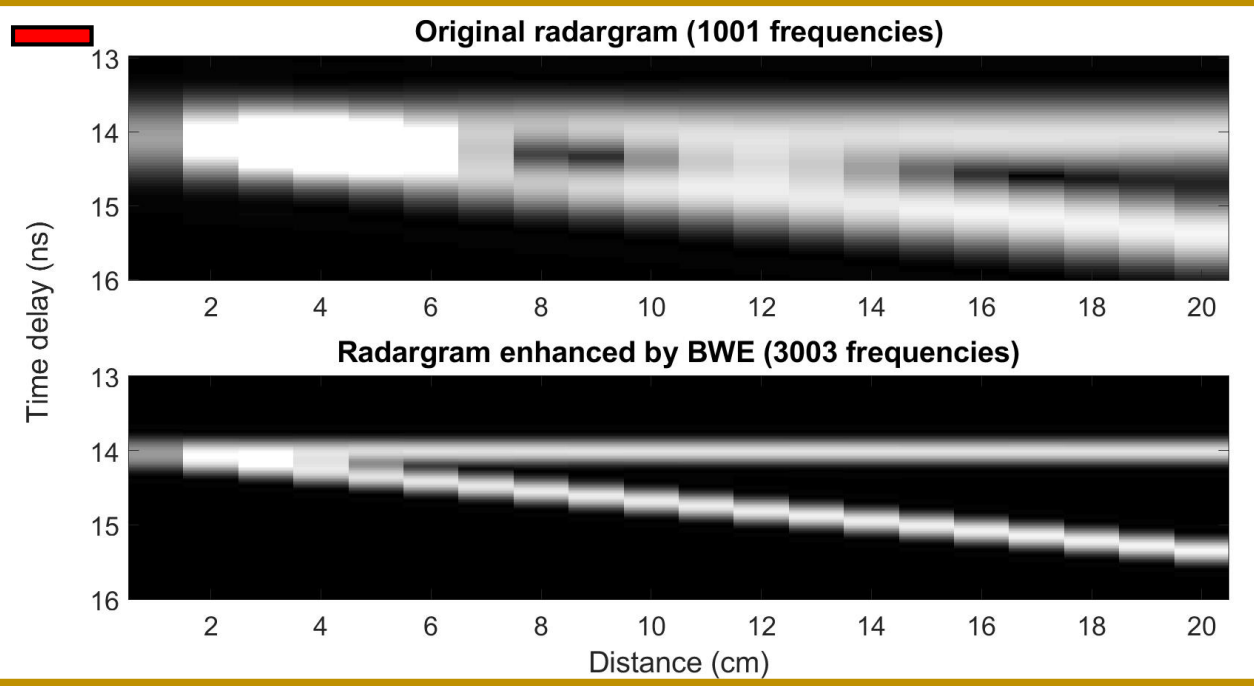
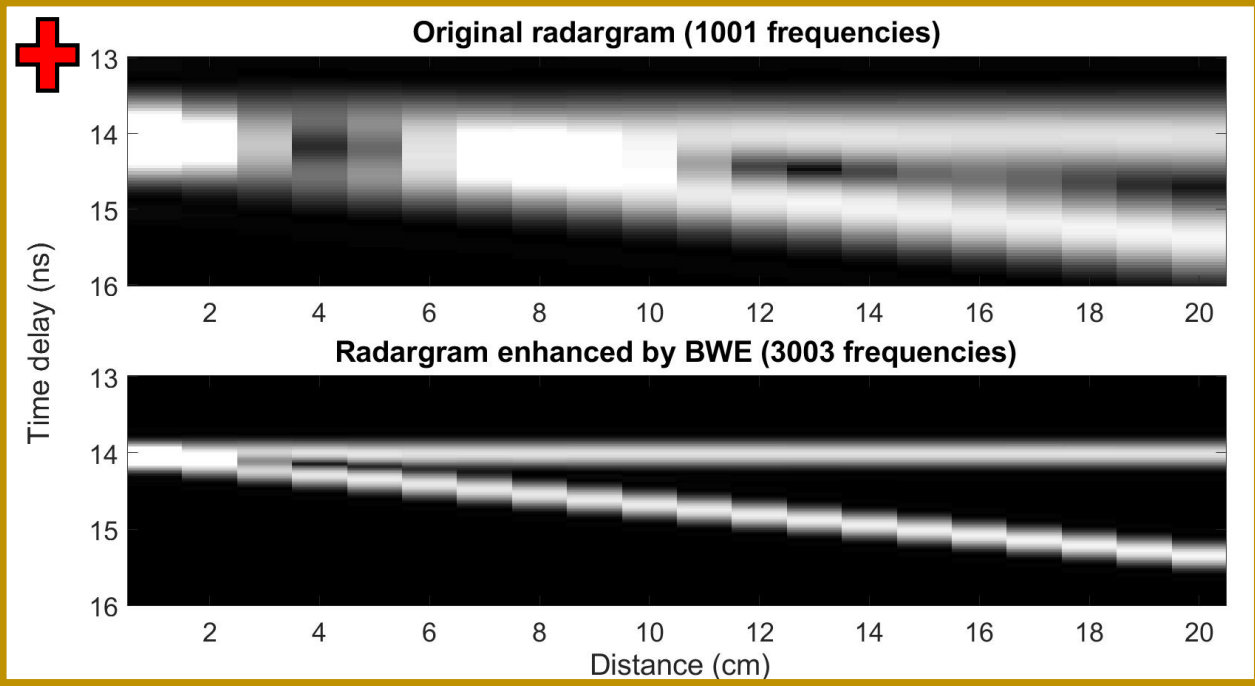
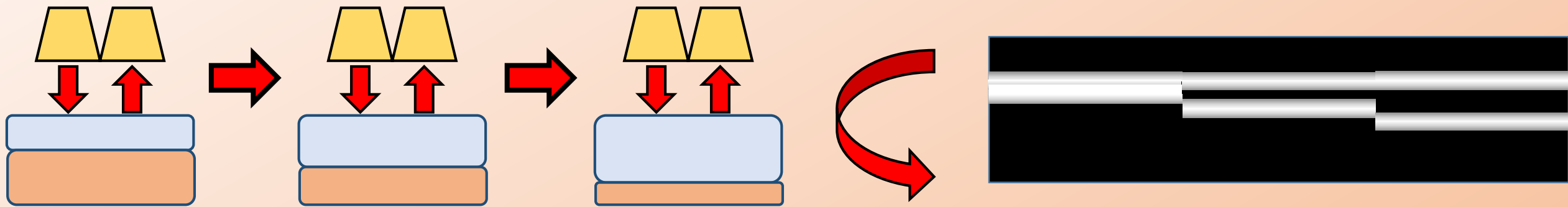
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# Measuring the improvement in resolution





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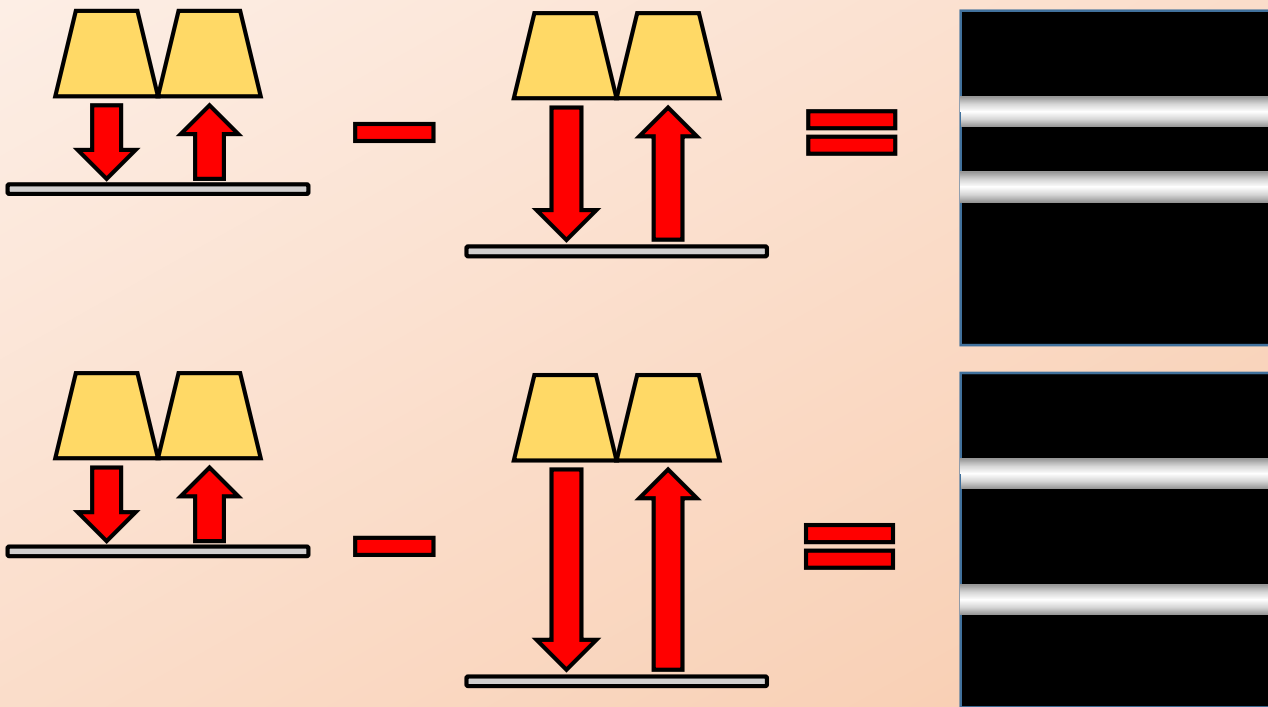
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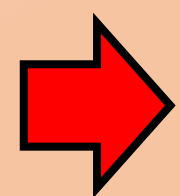
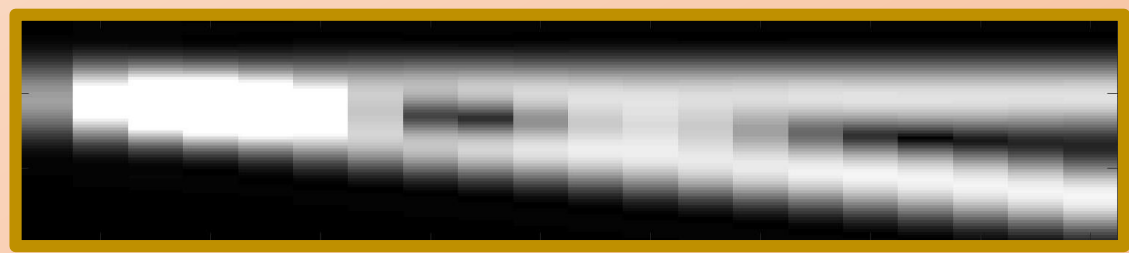
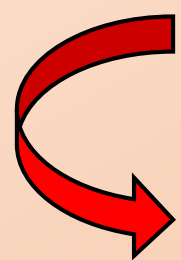
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## Measuring the improvement in resolution



TU Dresden anechoic chamber set-up



For which distance can the  
reflectors be separated ?

What is the error on the  
estimation of this distance ?



The WISDOM  
Martian  
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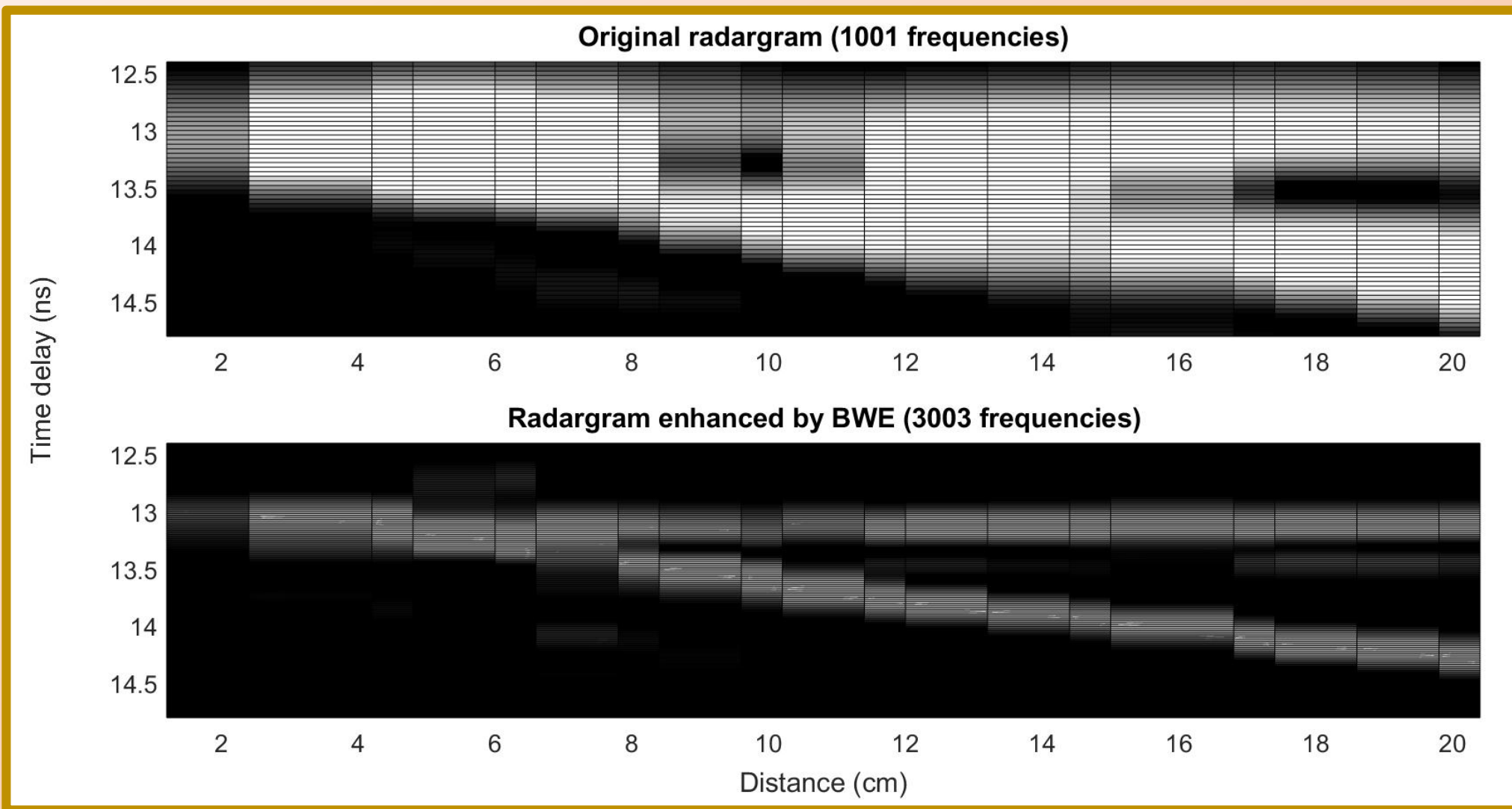
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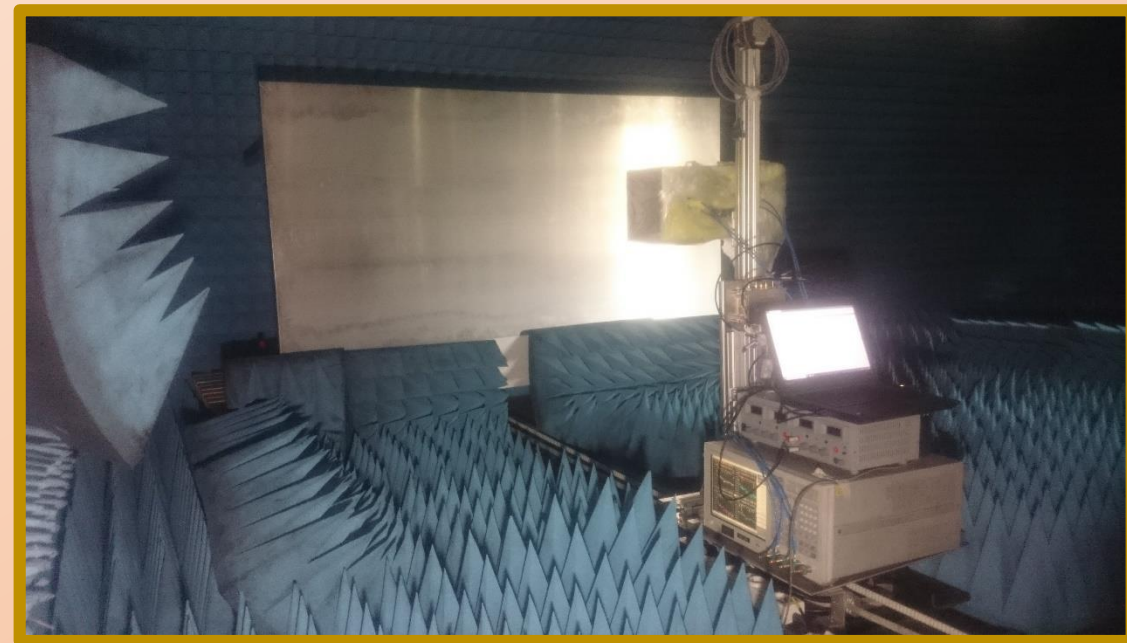
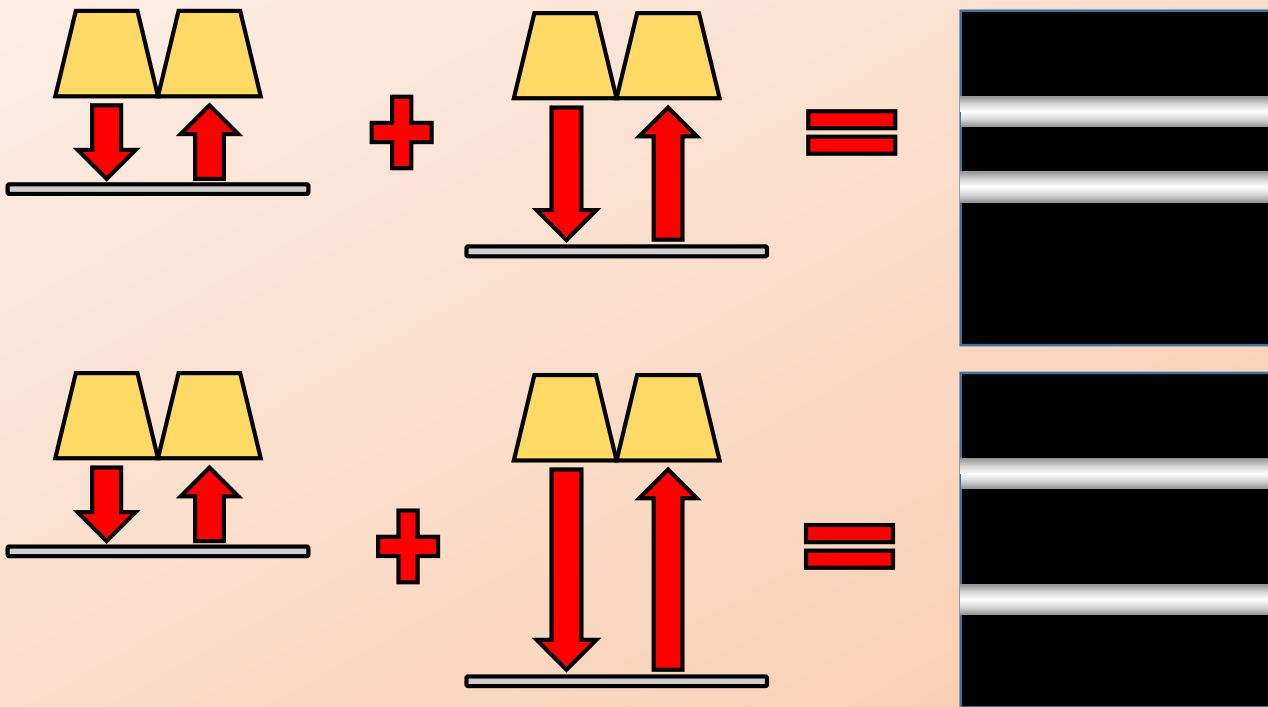
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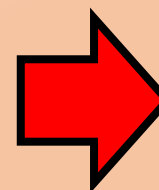
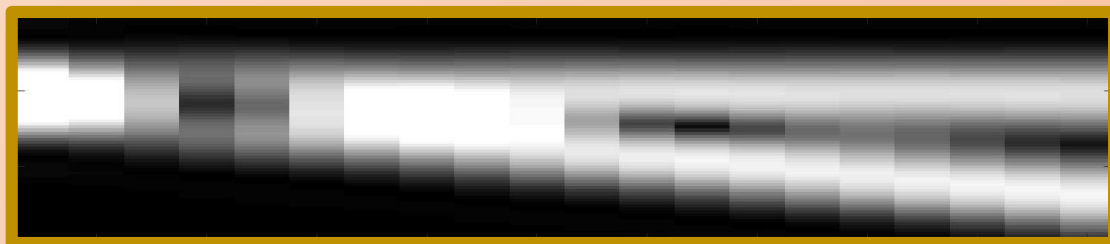
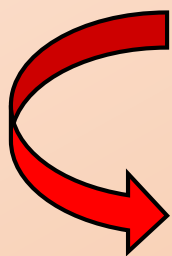
Work in  
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## Measuring the improvement in resolution



TU Dresden anechoic chamber set-up



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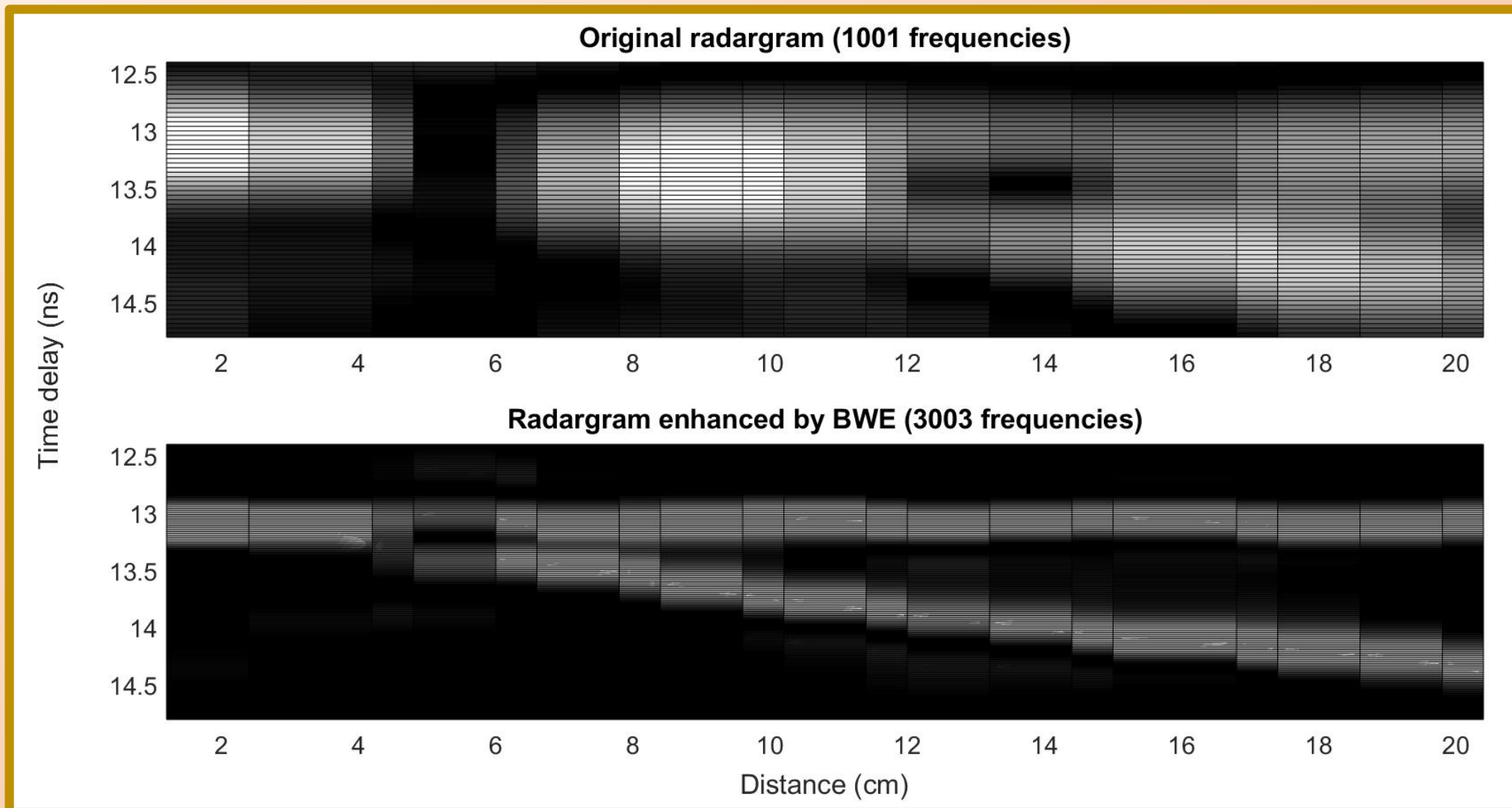
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## Measuring the improvement in resolution







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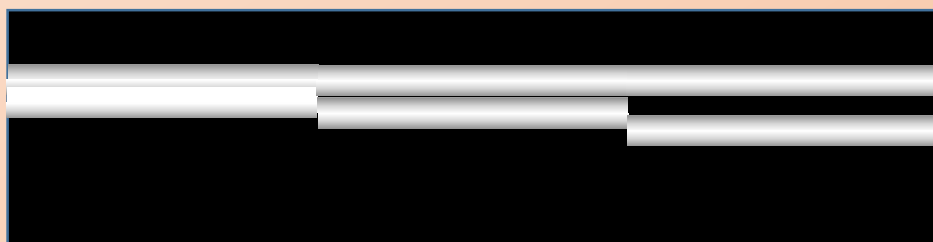
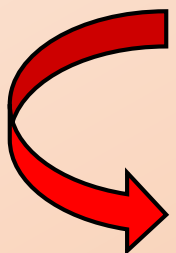
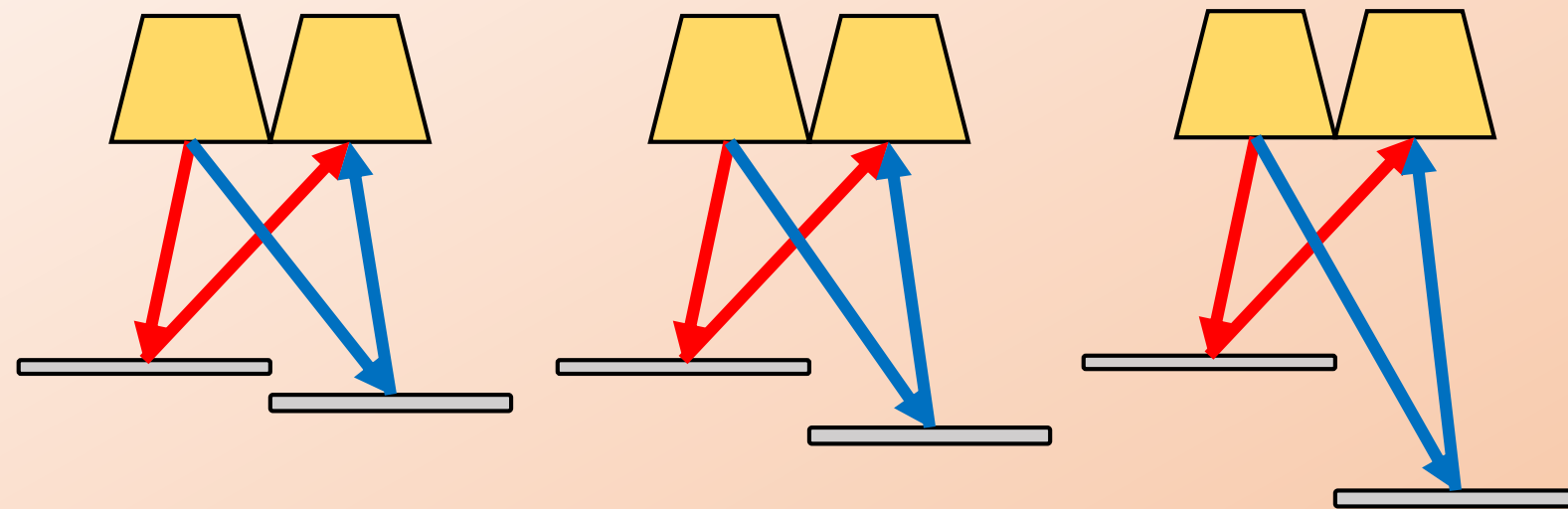
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## Measuring the improvement in resolution



LATMOS radar lab set-up

(Due to multiple reflections between the plates, this set-up is not an exact 2 reflectors situation, but is close to being one).



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radar

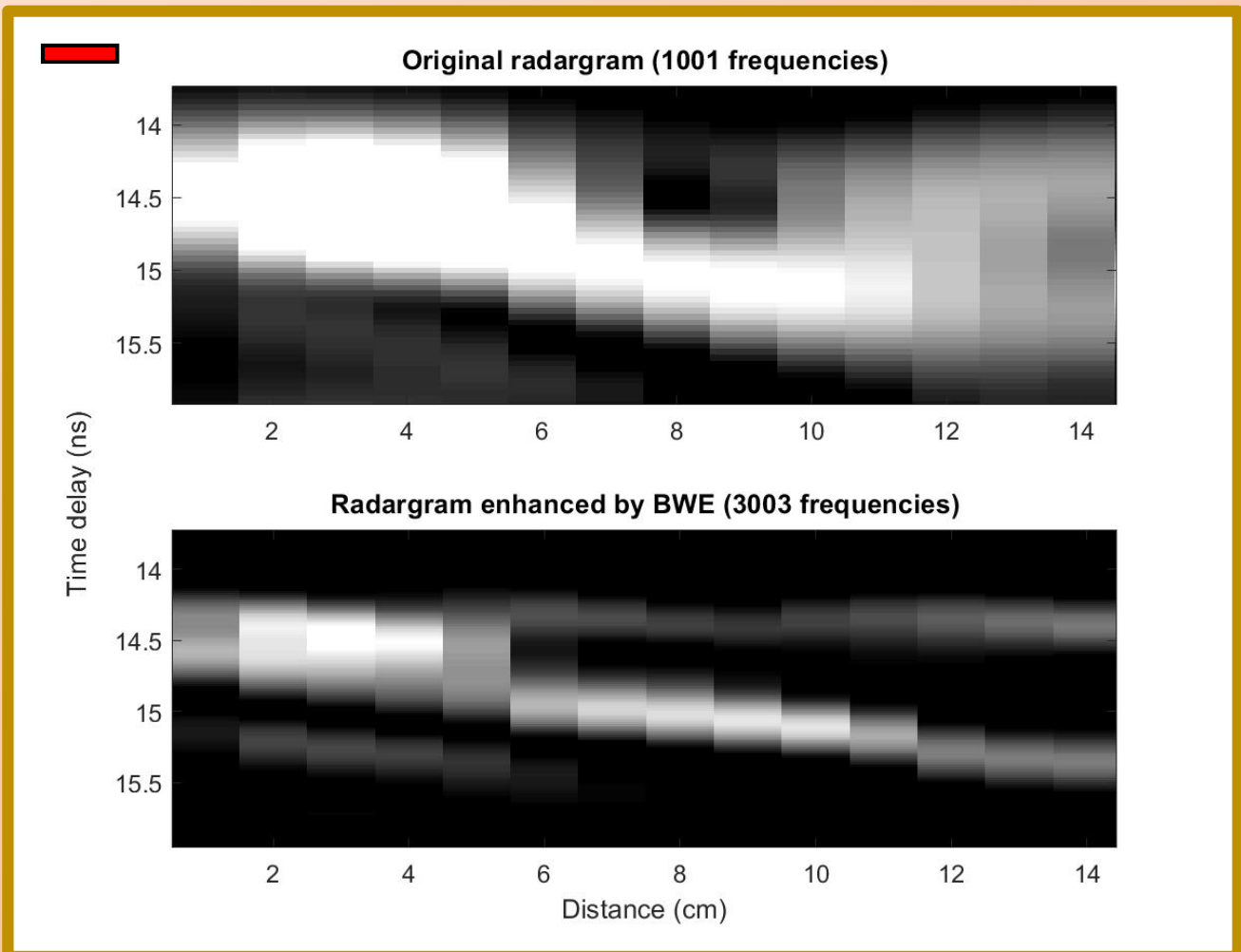
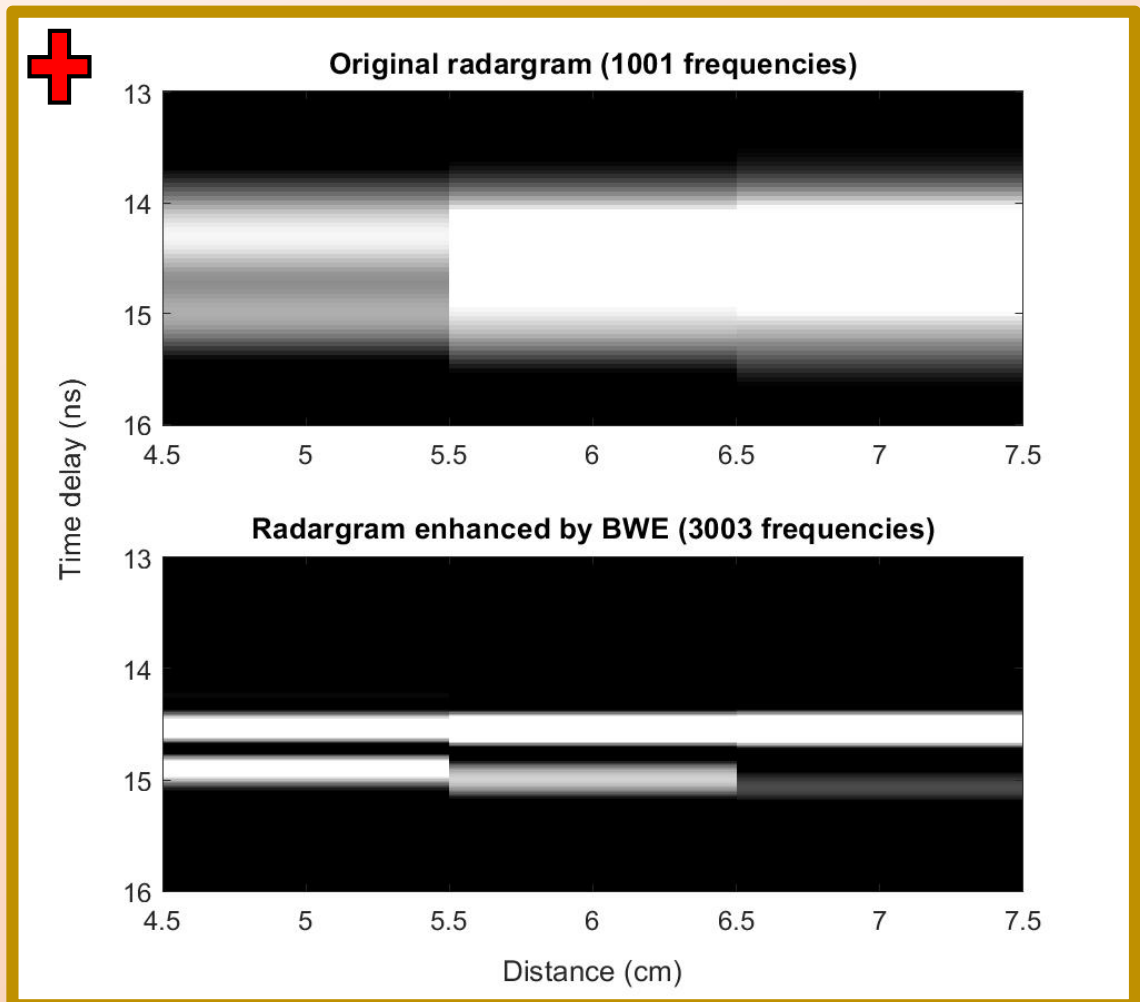
Application of  
super-resolution  
techniques

Preparing for  
Mars on Earth

Work in  
progress ...



# Measuring the improvement in resolution





The WISDOM  
Martian  
radar

Application of  
super-resolution  
techniques

Preparing for  
Mars on Earth

Work in  
progress ...



## Simulations of operations



**ESA, Harwell, UK – October 2018**  
Operation Control Center for the  
simulation of operations ExoFit  
2018, which took place in the  
Tabernas desert (Spain).



**ESO, Cerro Paranal, Chile –  
February 2019**  
Simulation of operations in the  
Atacama desert. Performing  
WISDOM soundings.





The WISDOM  
Martian  
radar

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progress ...

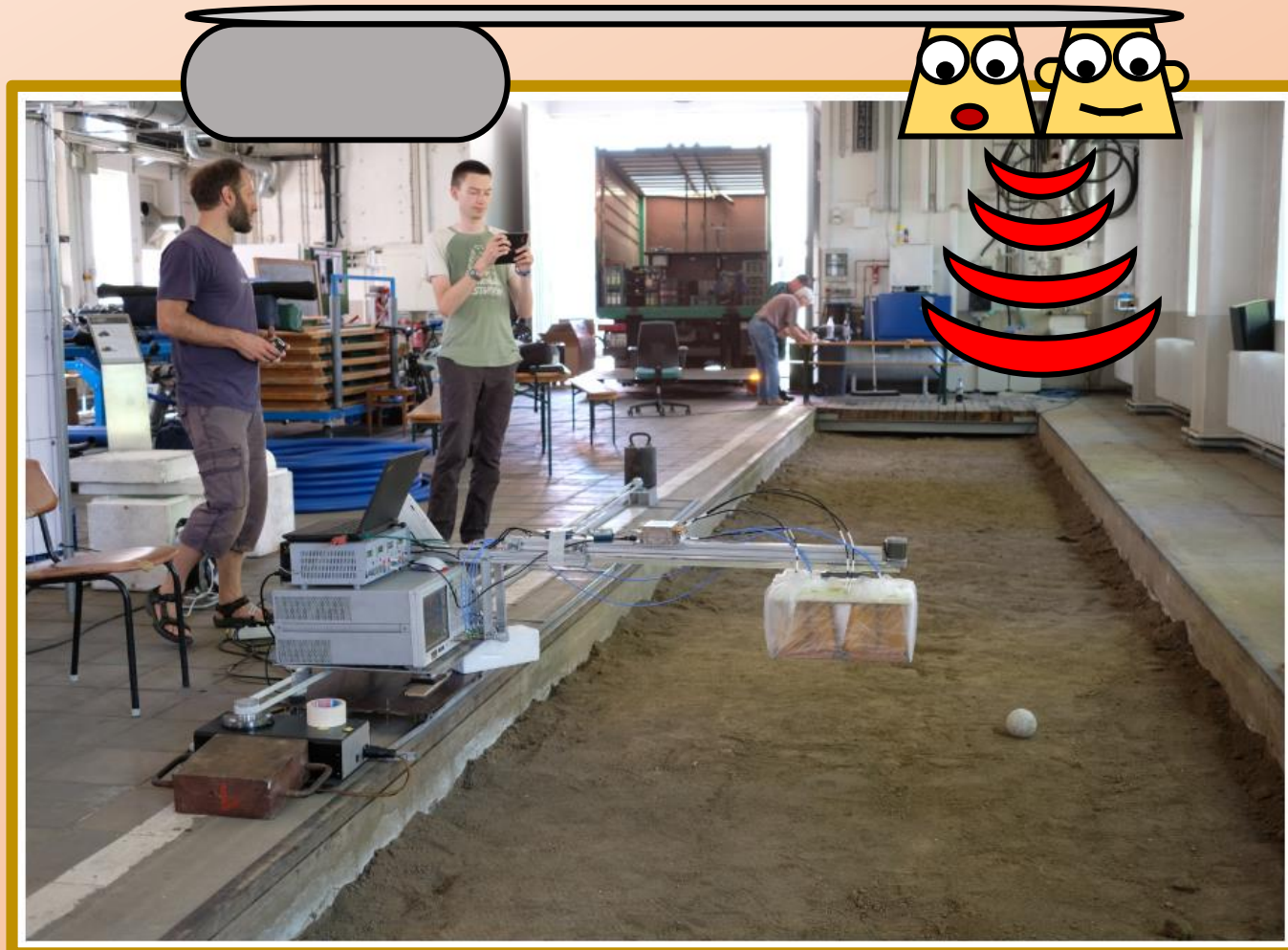


## Measurements in controlled environments



TUD, Dresden, Germany – June  
2019

Measurements on a controlled  
environment (agrarian terrain  
with buried reflectors).





The WISDOM  
Martian  
radar

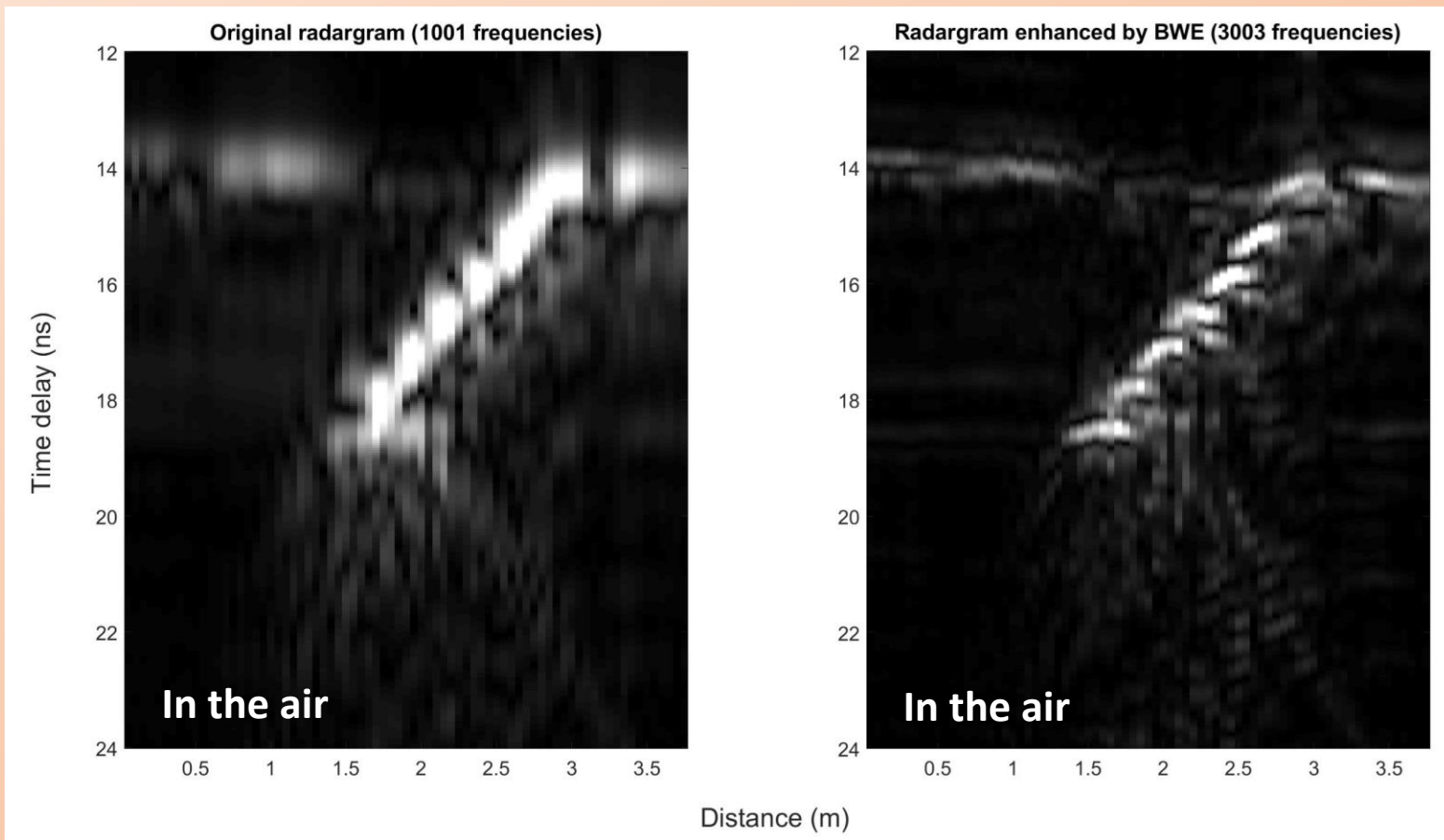
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## Examples of radargrams from the TU Dresden





The WISDOM  
Martian  
radar

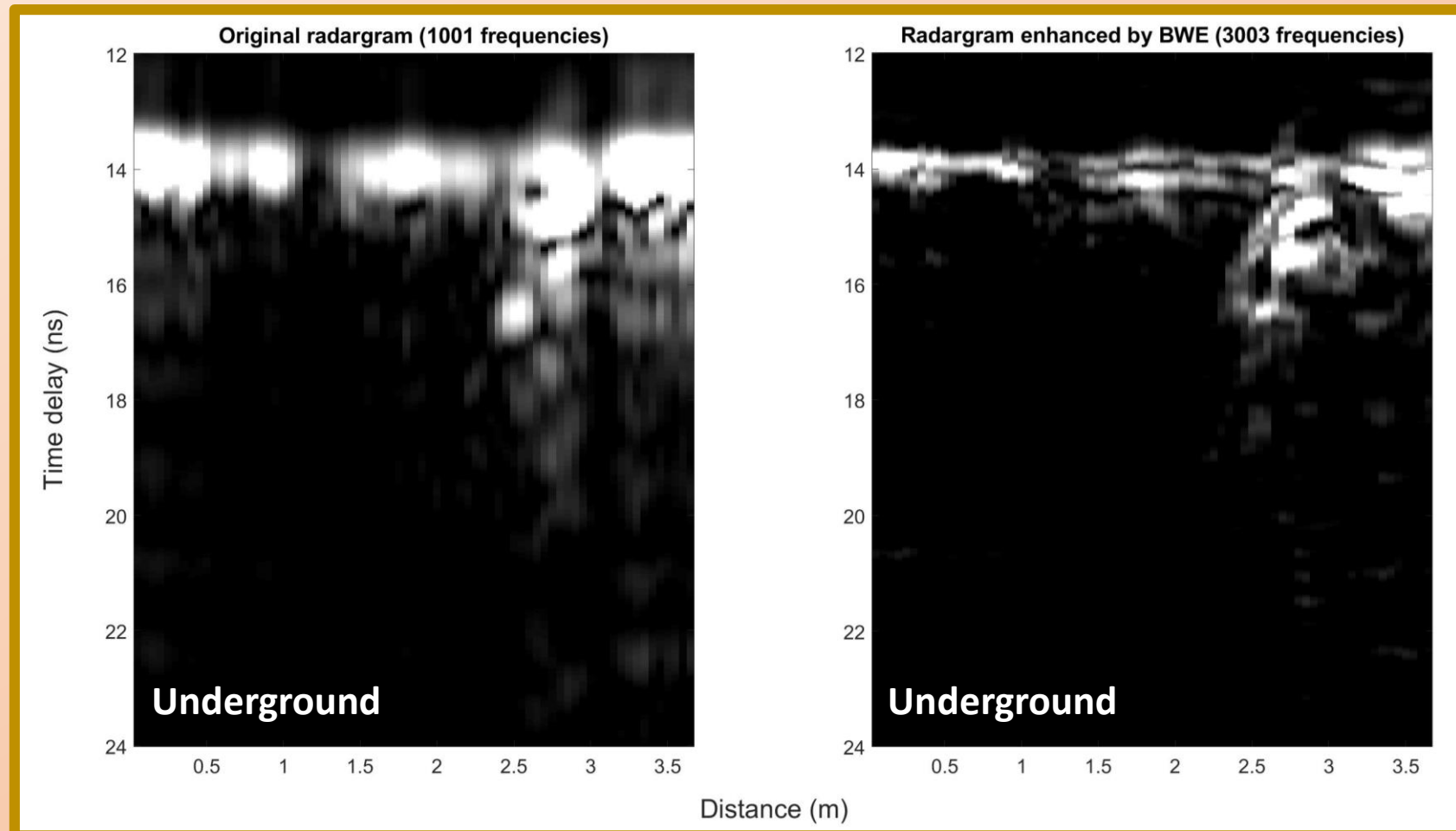
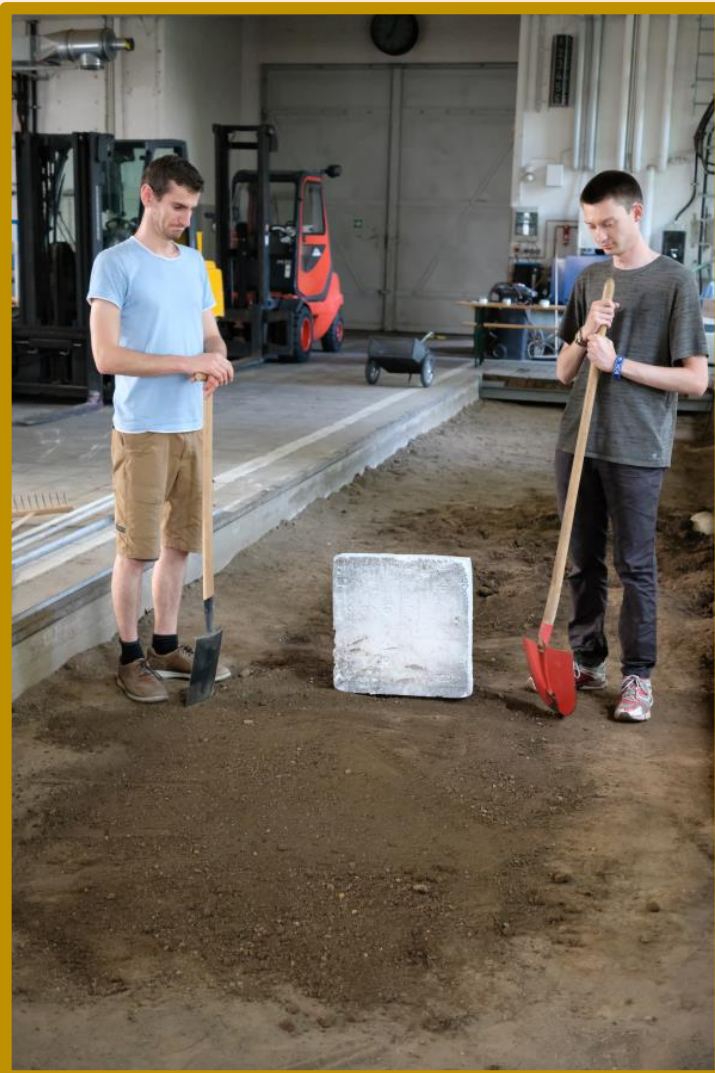
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## Examples of radargrams from the TU Dresden





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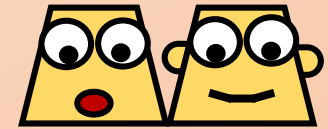
Coming soon...



*Measuring the resolution  
improvement.*

*Applying the technique to future  
measurement campaigns*

*Integrate the method to the  
processing code.*



See you on Mars !



WISDOM

