

Sound wave diffusion by the surfaces

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*Please open this PDF with Adobe Acrobat Reader to play
animations*

The work is open-source and published on my Github page
github.com/yingzi1982

Outline

Introduction

Sound diffusion efficiency of the diffuser elements

Sound scattering loss by the surfaces

Sound characteristics in the small spaces

Summary

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Summary

What is a diffuser or a diffusive surface?

a case in Blackbird Studio in Nashville



Borrowed image from Blackbird

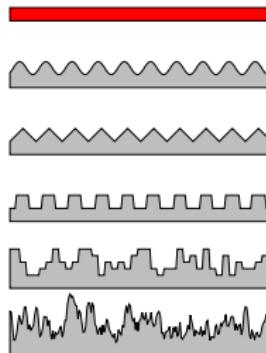
Different type of diffusers in this work

Material

- ▶ gypsum

Surface topographies

- ▶ **flat**
- ▶ *sine*
- ▶ *triangle*
- ▶ *rectangle*
- ▶ *skyline*
- ▶ *vonkarman*



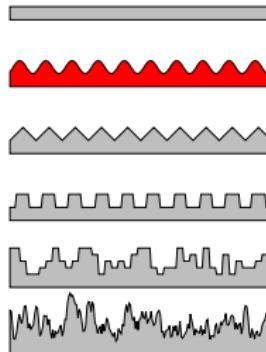
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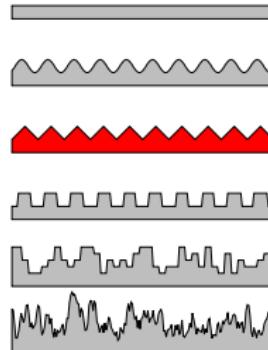
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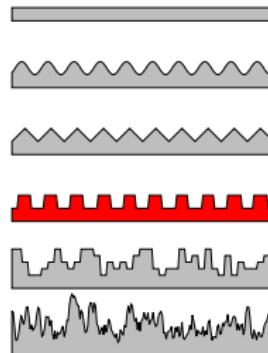
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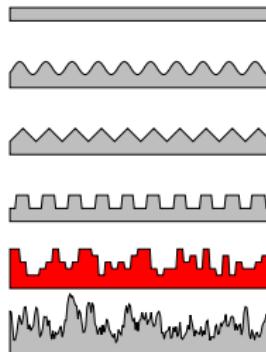
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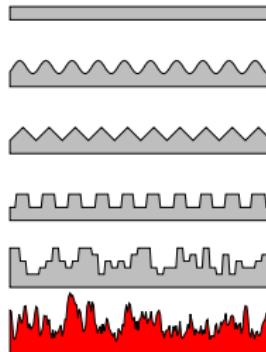
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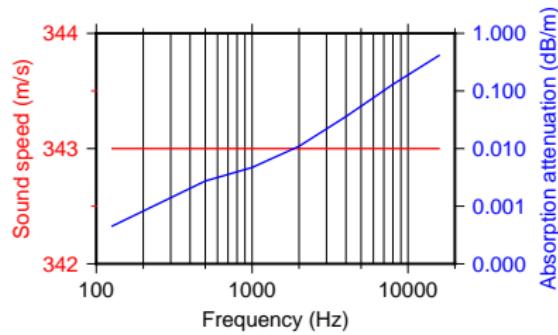
Surface topographies

- ▶ *flat*
- ▶ *sine*
- ▶ *triangle*
- ▶ *rectangle*
- ▶ *skyline*
- ▶ **vonkarman**



Sound in air

in a normal room condition, e.g., 20 °C, 1 atm, and 40% relative humidity



Numerical simulation tools

High-performance computing Linux cluster

- ▶ Fionn at the Irish Centre for High-End Computing

Simulation of coupled acoustic and elastic wave propagation

- ▶ SPECFEM2D (github.com/geodynamics/specfem2d)
- ▶ based on the spectral element method

Outline

Introduction

Sound diffusion efficiency of the diffuser elements

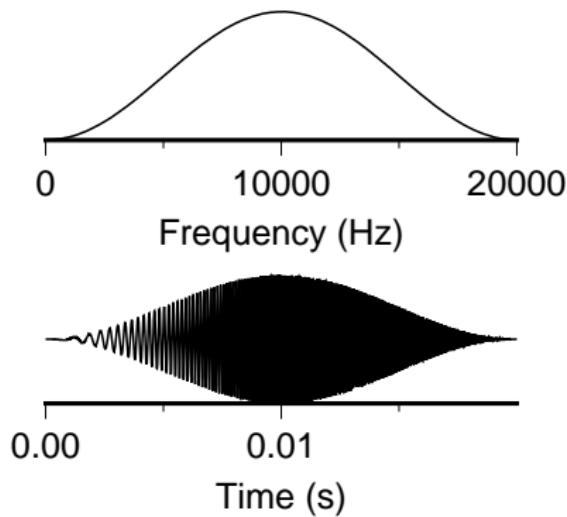
Sound scattering loss by the surfaces

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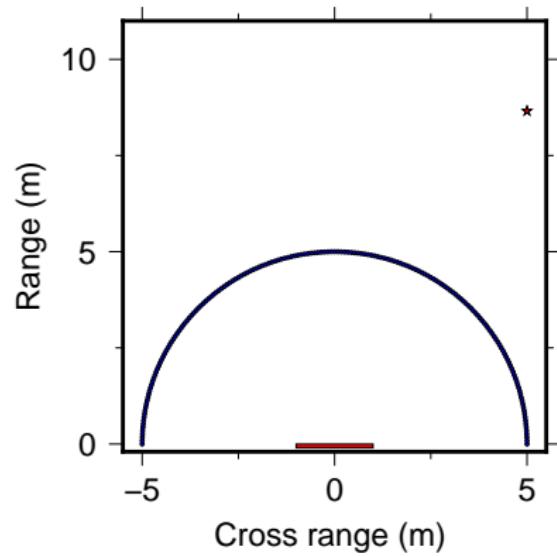
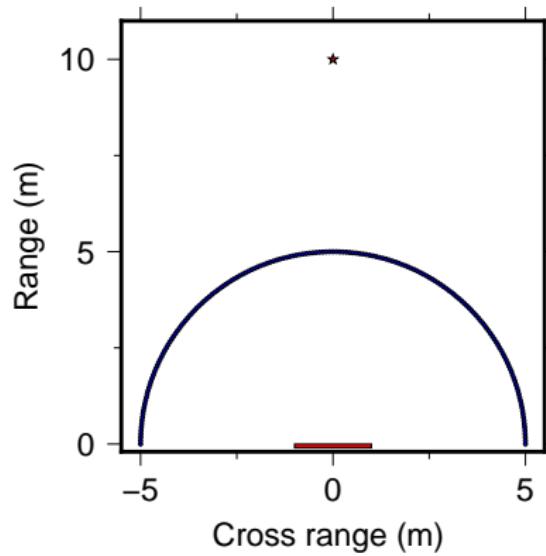
Probing source waveform and spectrum

Chirp signal added with Hanning window, linearly sweep over the audible frequency range



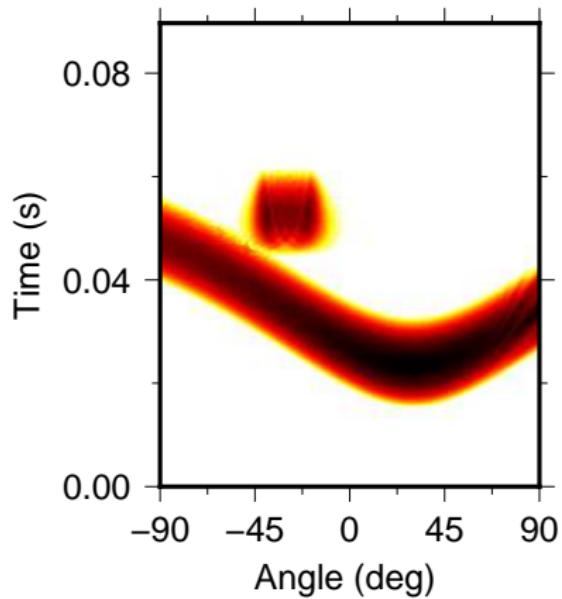
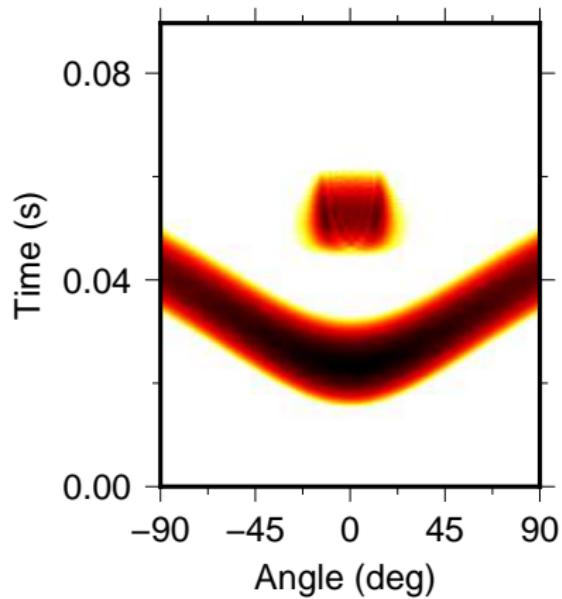
Deployments for measuring diffuser performance, following AES-4id-2001 Standard

diffuser type: *flat*; source incident angles: 0° v.s. 30°



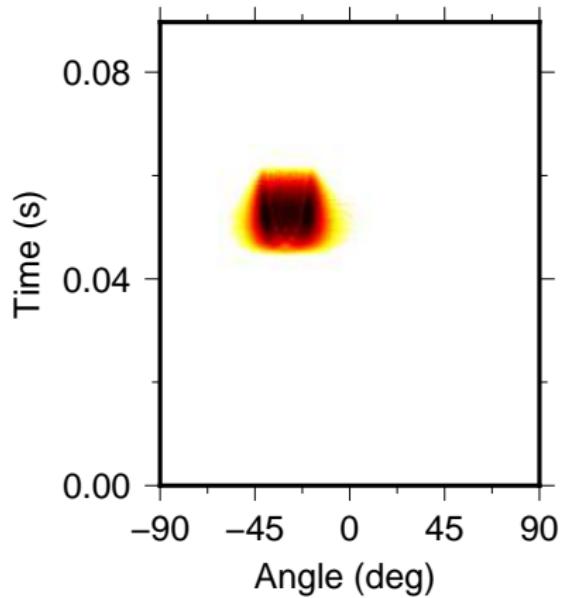
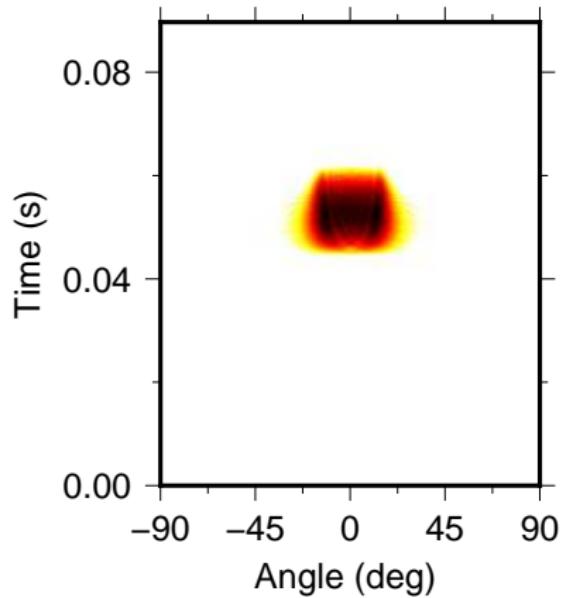
Sound pressure signals I

total recorded traces



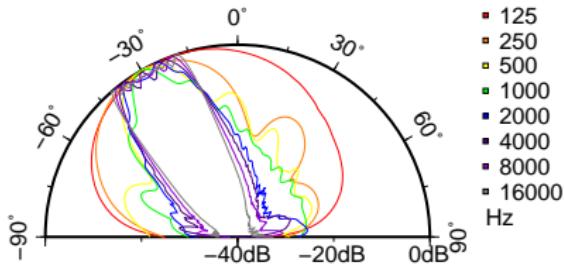
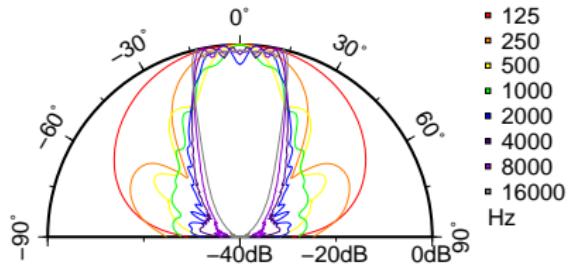
Sound pressure signals II

separated scattering components



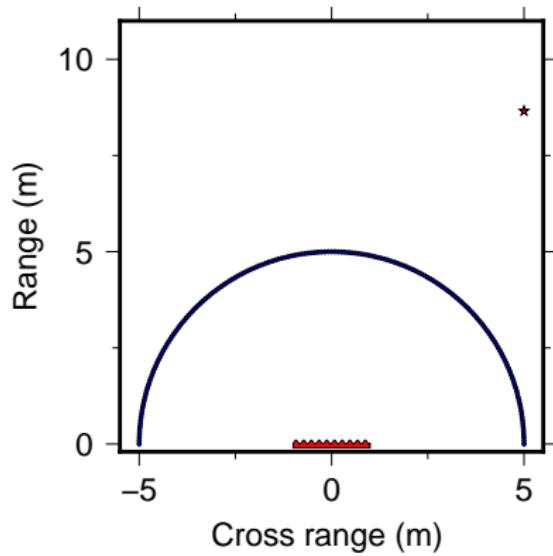
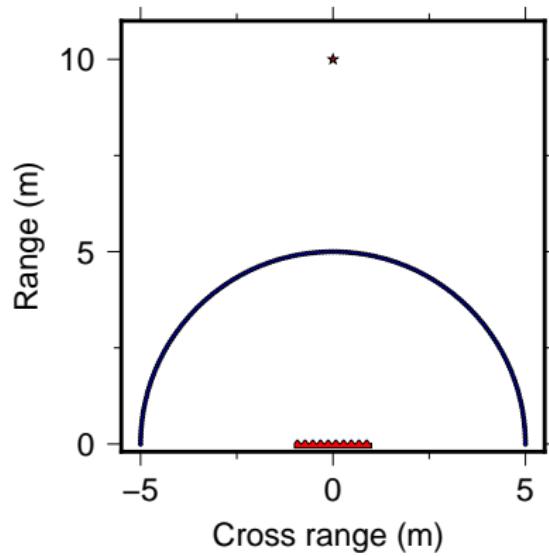
Scattering polar response patterns

calculated within one third Octave bands



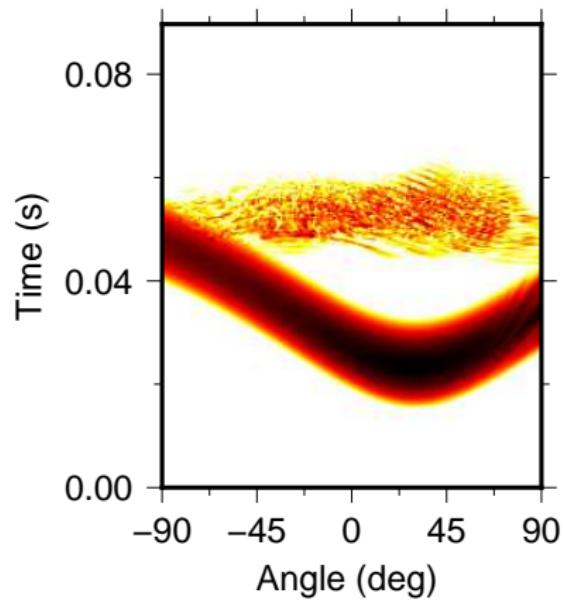
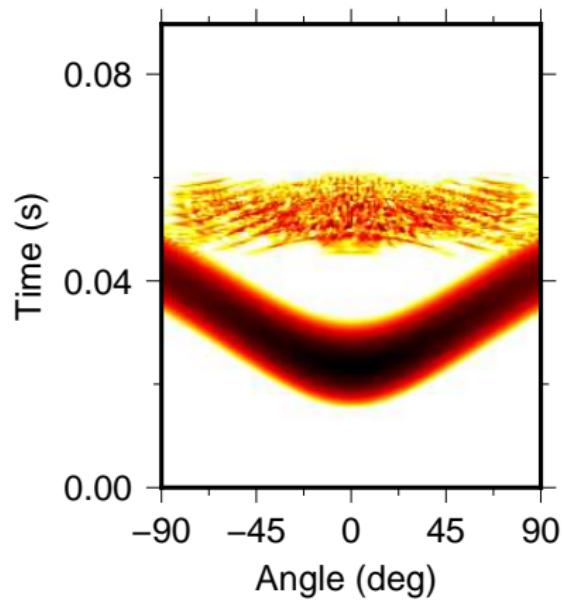
Deployments for measuring diffuser performance, following AES-4id-2001 Standard

diffuser type: *sine*; source incident angles: 0° v.s. 30°



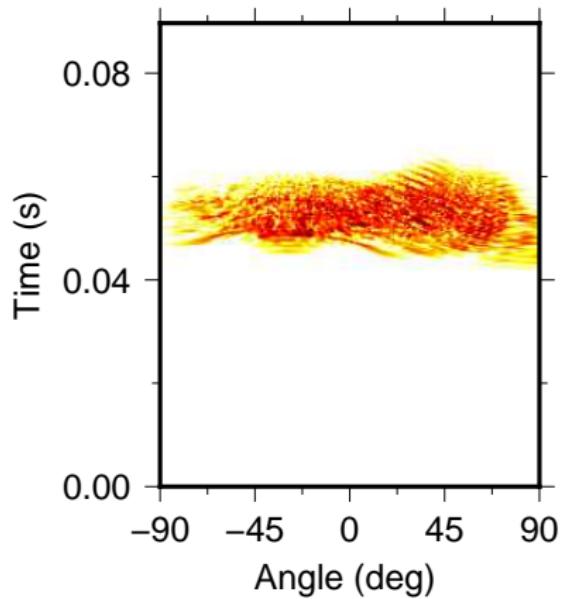
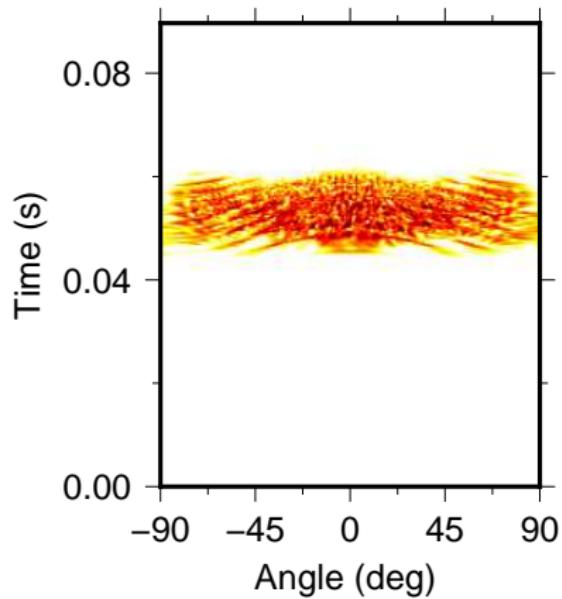
Sound pressure signals I

total recorded traces



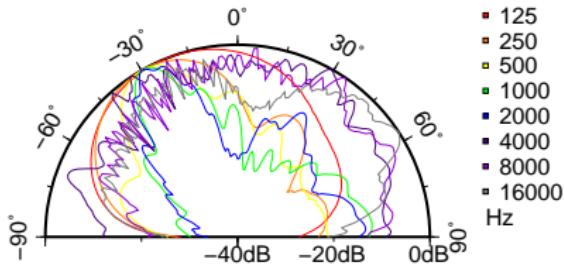
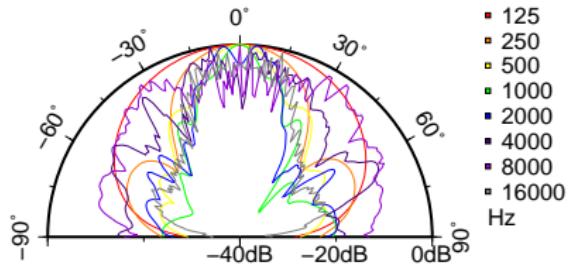
Sound pressure signals II

separated scattering components



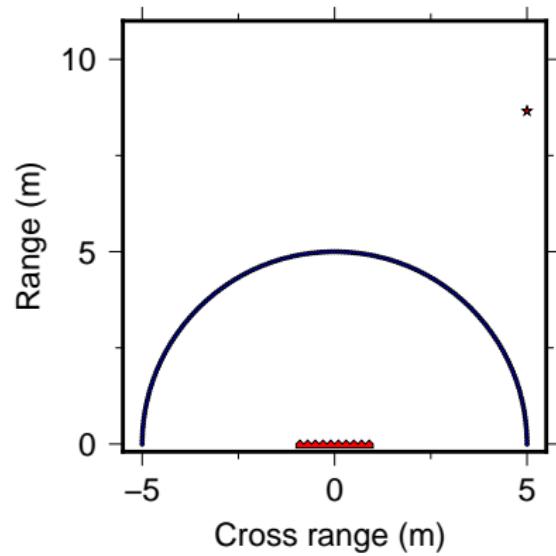
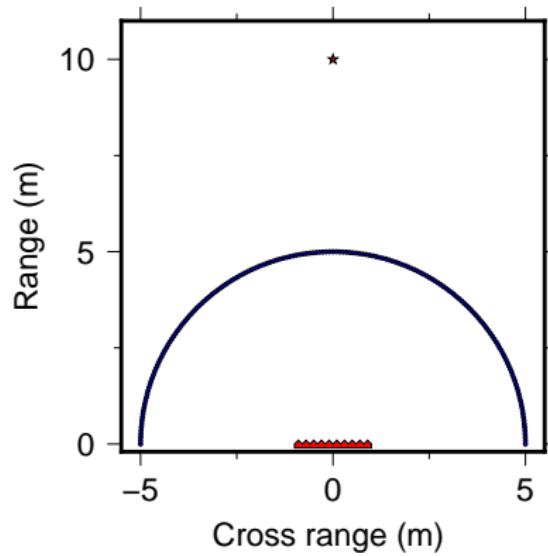
Scattering polar response patterns

calculated within one third Octave bands



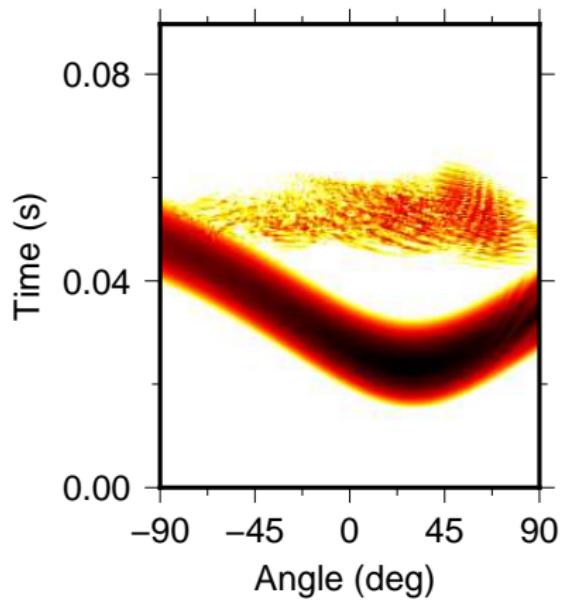
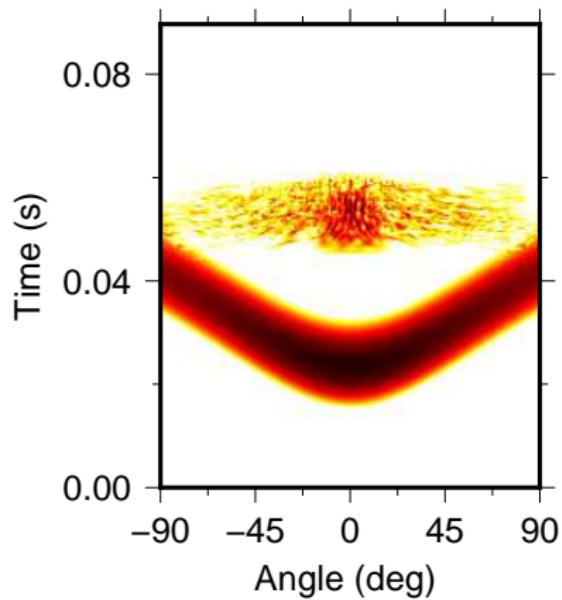
Deployments for measuring diffuser performance, following AES-4id-2001 Standard

diffuser type: triangle; source incident angles: 0° v.s. 30°



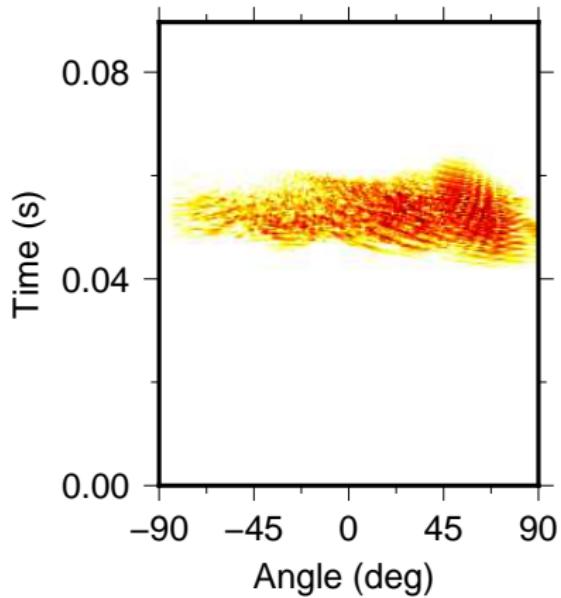
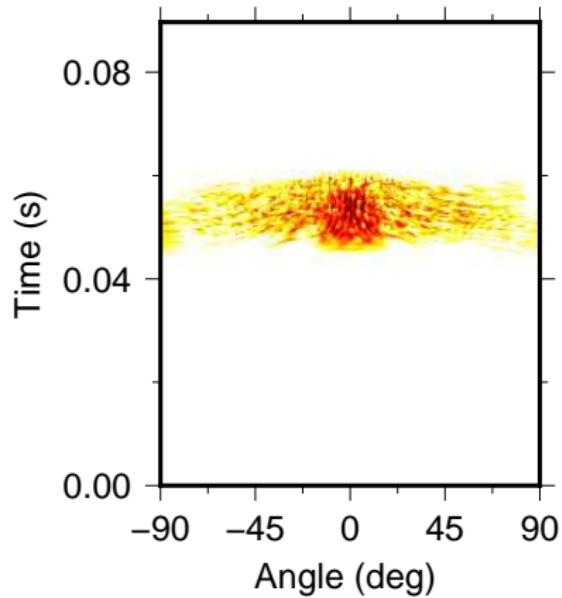
Sound pressure signals I

total recorded traces



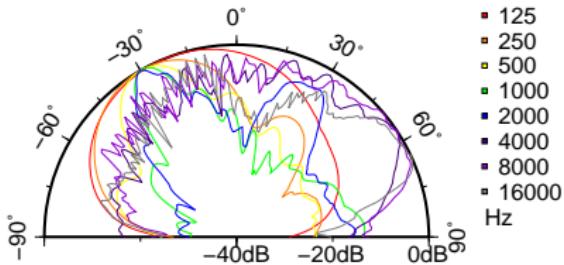
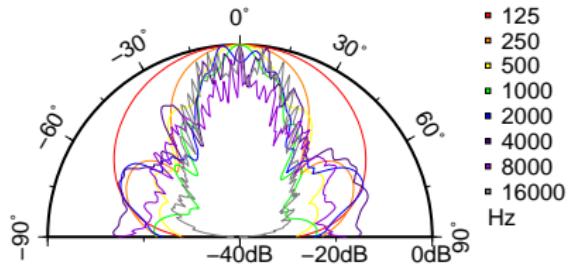
Sound pressure signals II

separated scattering components



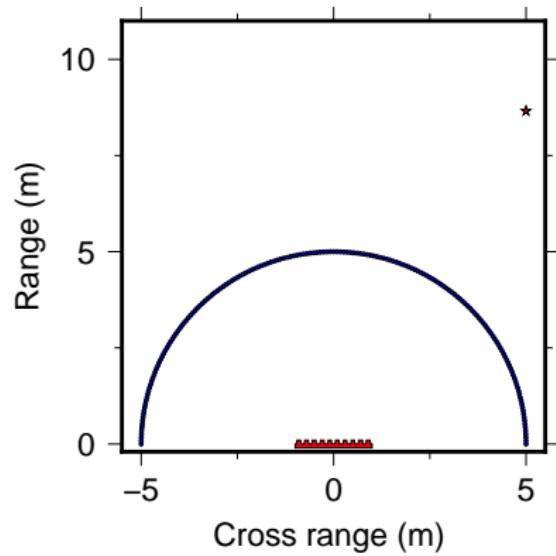
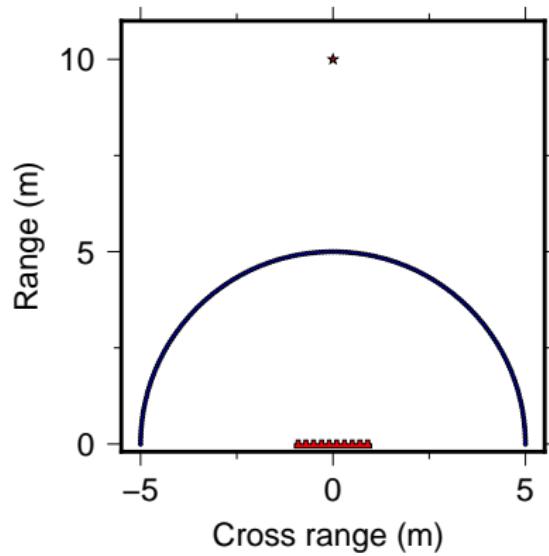
Scattering polar response patterns

calculated within one third Octave bands



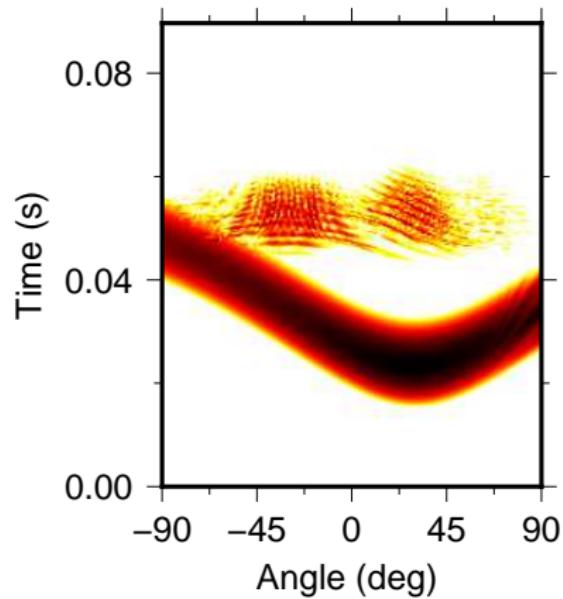
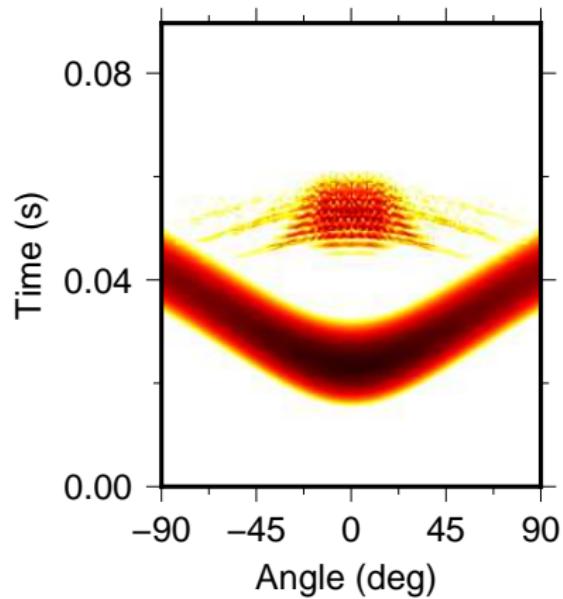
Deployments for measuring diffuser performance, following AES-4id-2001 Standard

diffuser type: *rectangle*; source incident angles: 0° v.s. 30°



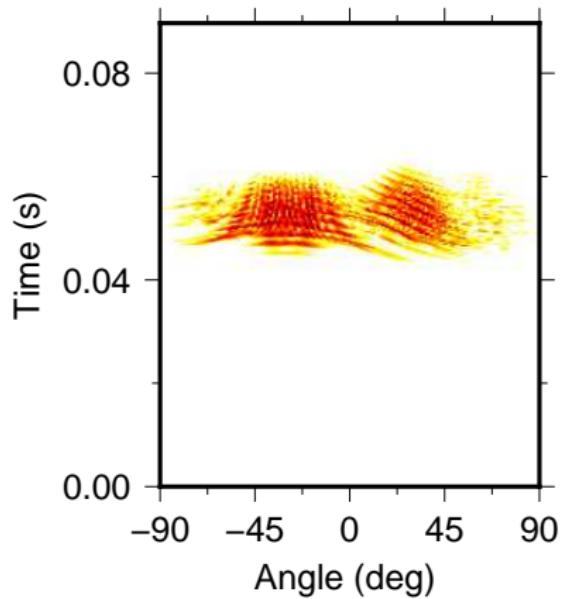
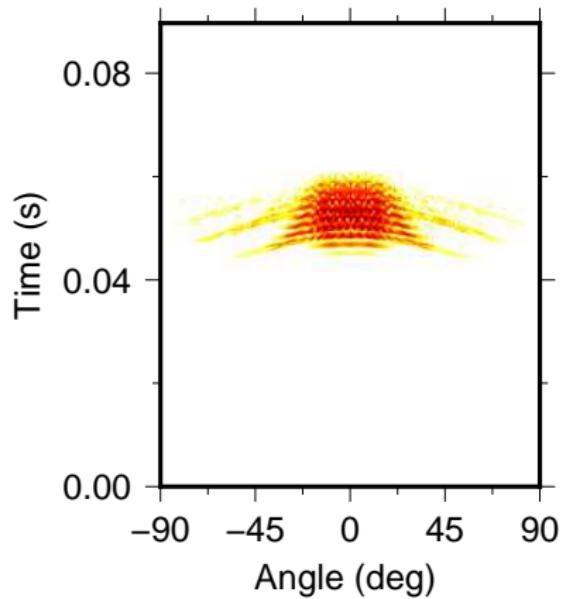
Sound pressure signals I

total recorded traces



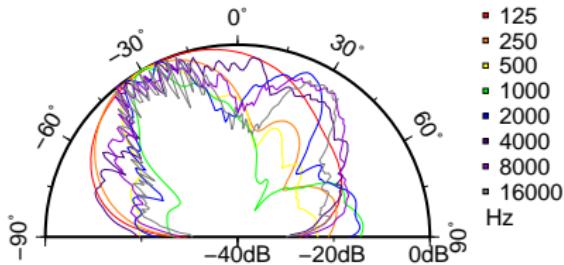
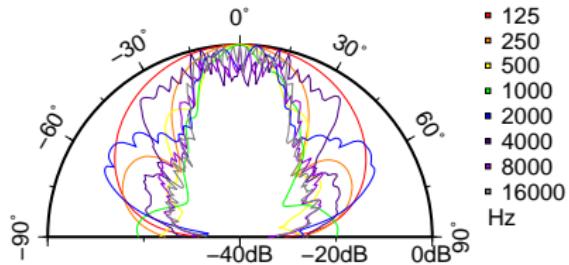
Sound pressure signals II

separated scattering components



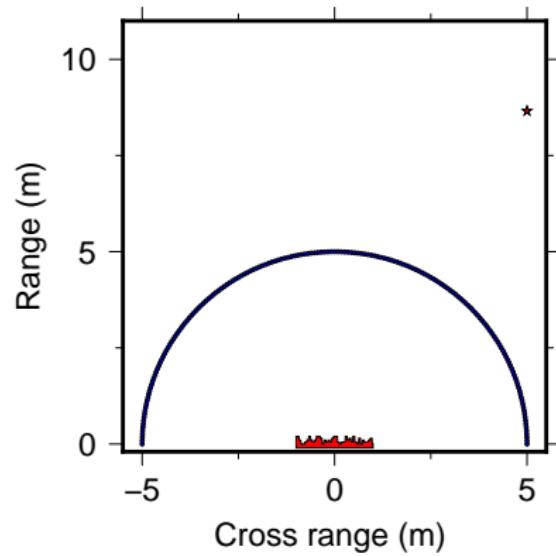
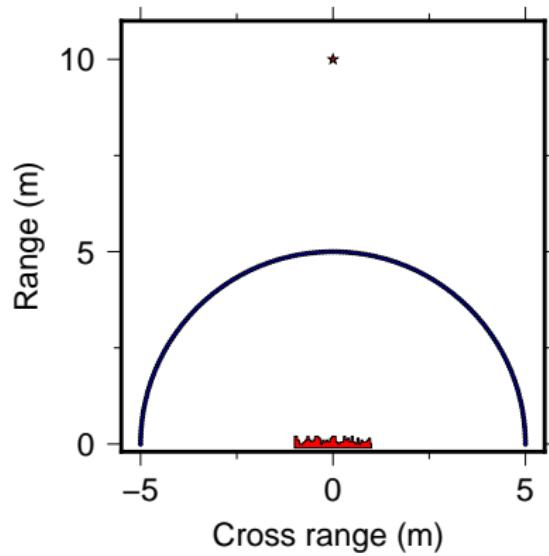
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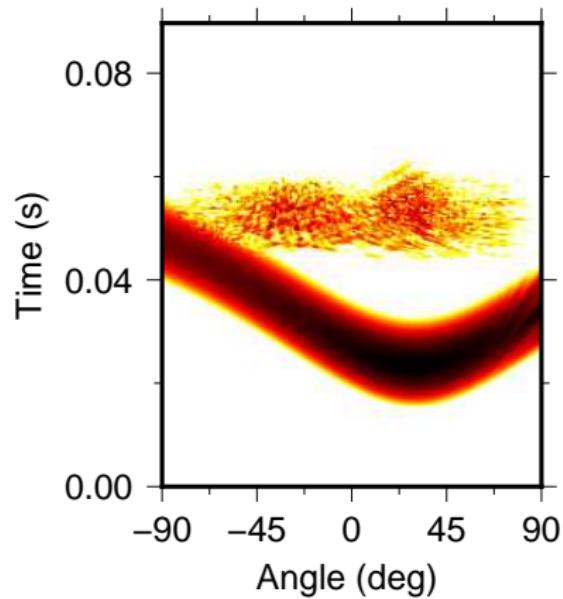
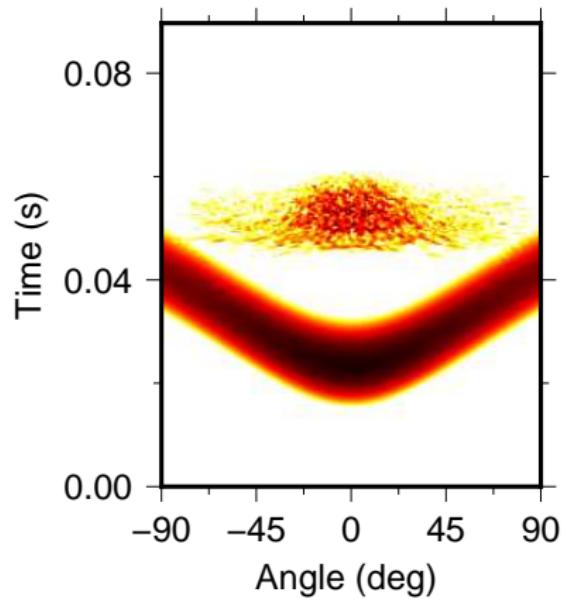
Deployments for measuring diffuser performance, following AES-4id-2001 Standard

diffuser type: *skyline*; source incident angles: 0° v.s. 30°



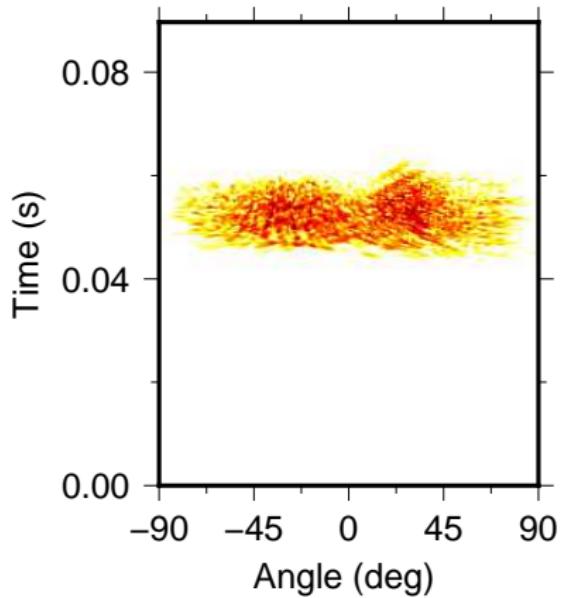
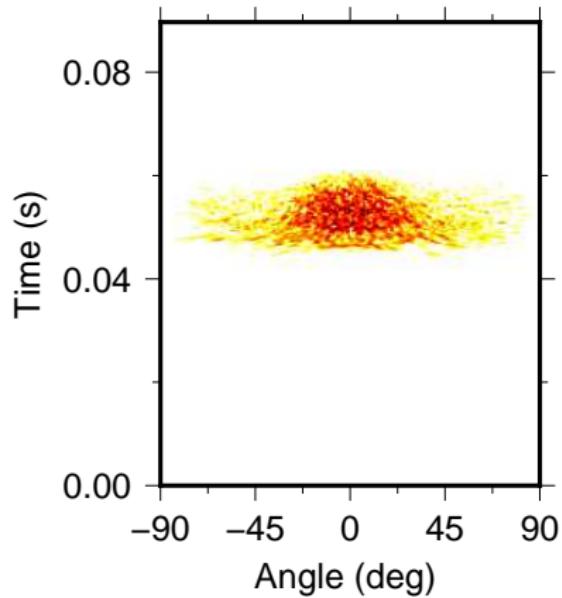
Sound pressure signals I

total recorded traces



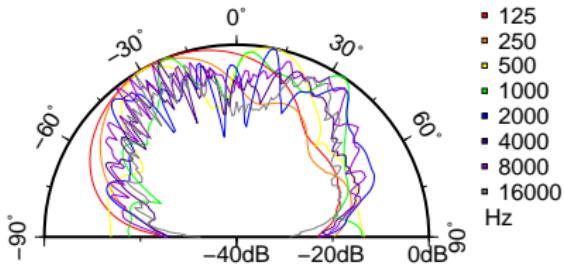
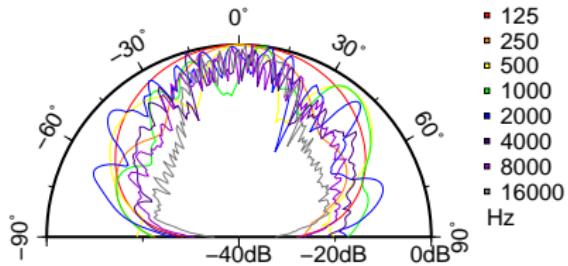
Sound pressure signals II

separated scattering components



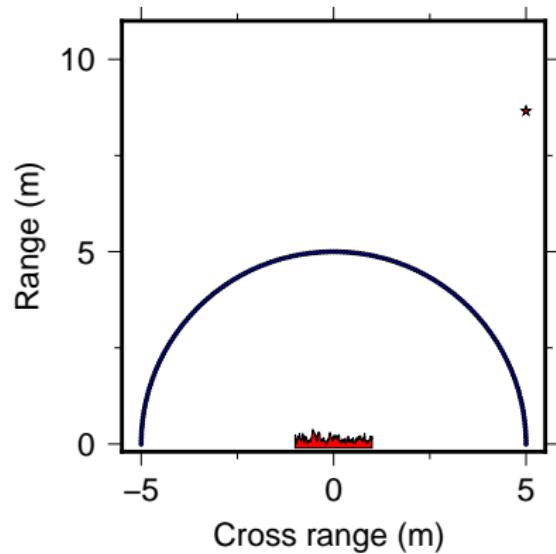
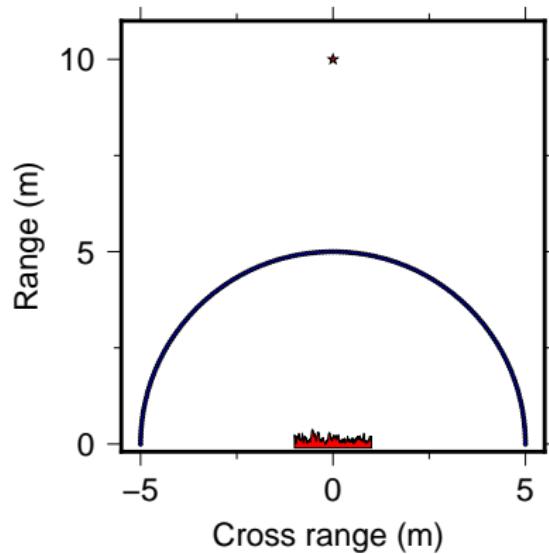
Scattering polar response patterns

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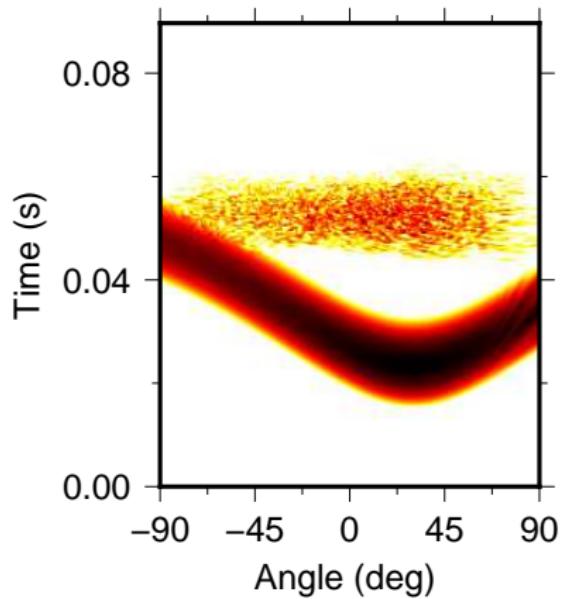
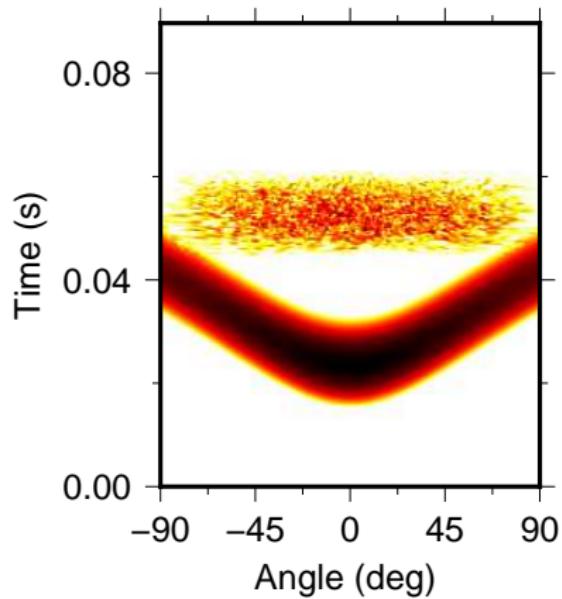
Deployments for measuring diffuser performance, following AES-4id-2001 Standard

diffuser type: *vonkarman*; source incident angles: 0° v.s. 30°



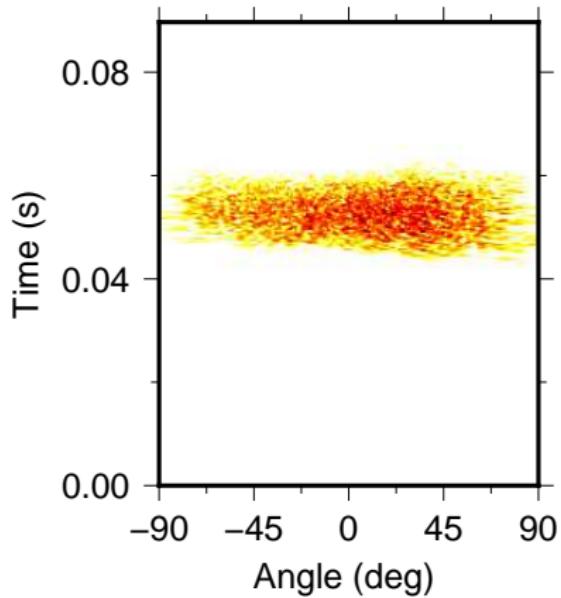
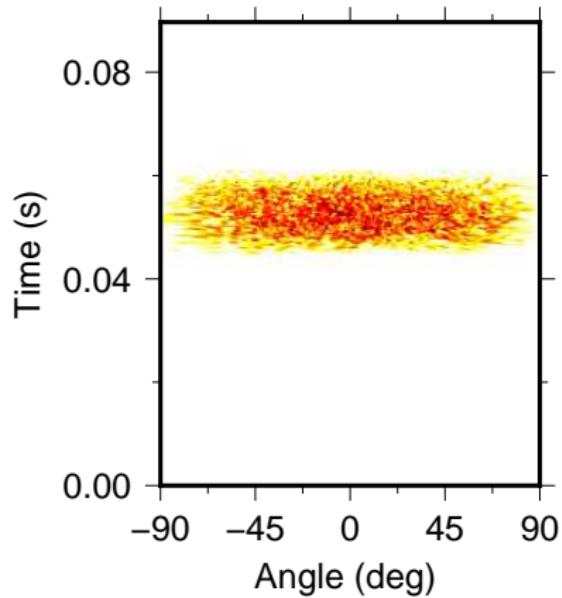
Sound pressure signals I

total recorded traces



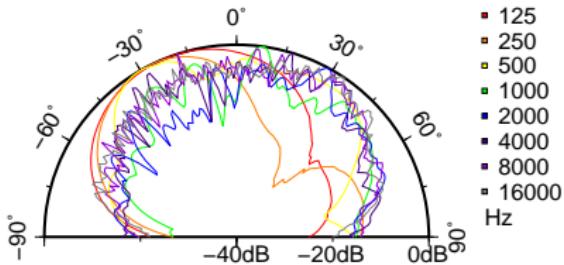
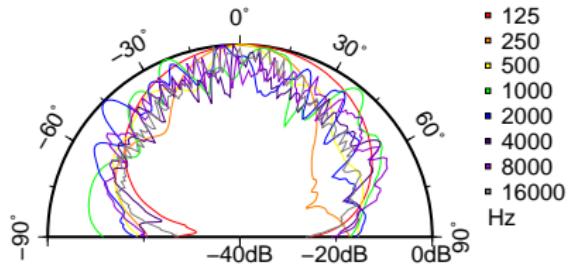
Sound pressure signals II

separated scattering components



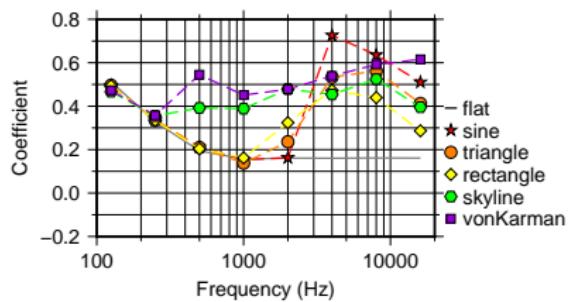
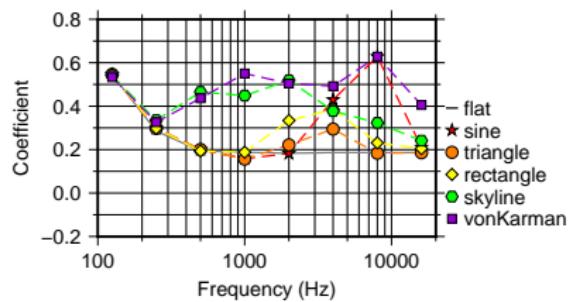
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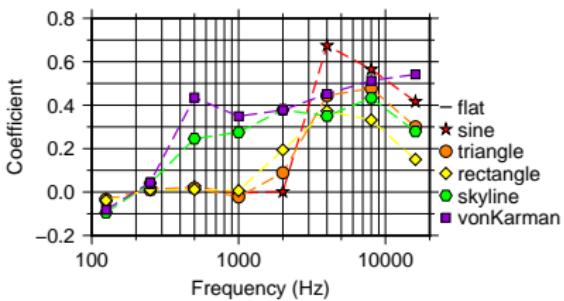
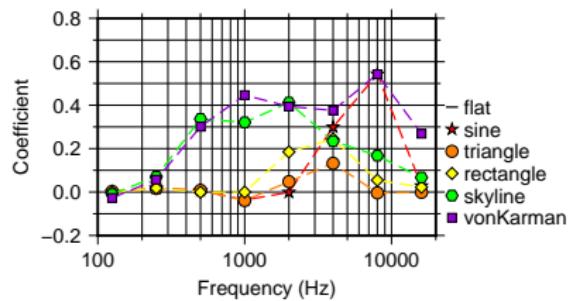
Diffusion efficiency I

diffusion coefficient: characterizing the spatial uniformity of scattering response



Diffusion efficiency II

normalized diffusion coefficient, with the flat one as reference, to remove cutting effect



Outline

Introduction

Sound diffusion efficiency of the diffuser elements

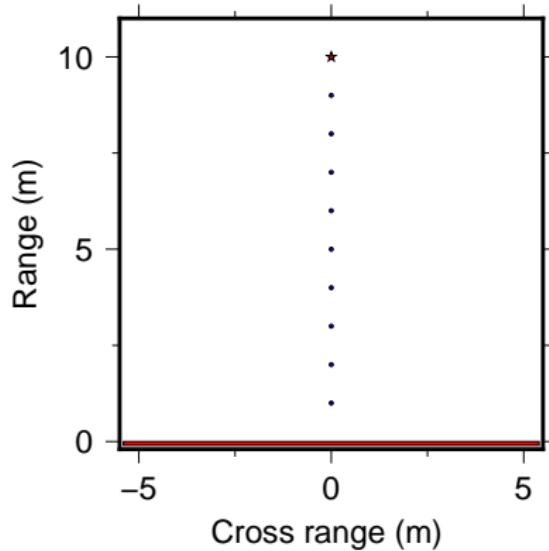
Sound scattering loss by the surfaces

Sound characteristics in the small spaces

Summary

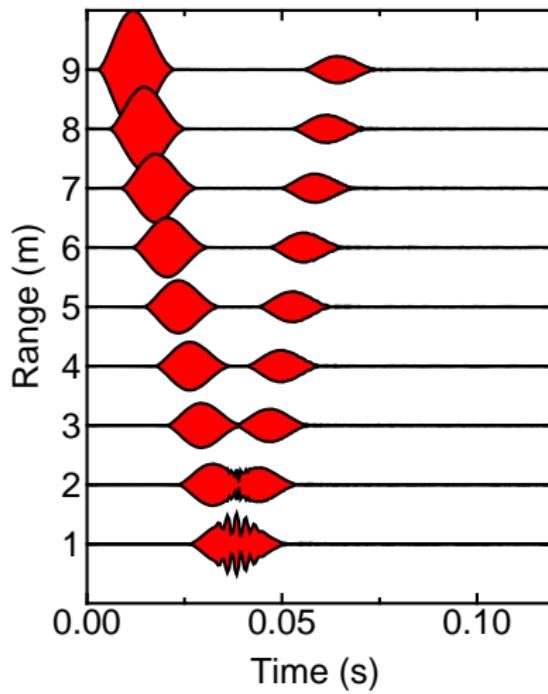
Deployment

wall topography type: *flat*; the receivers are deployed with 1m step away from the source



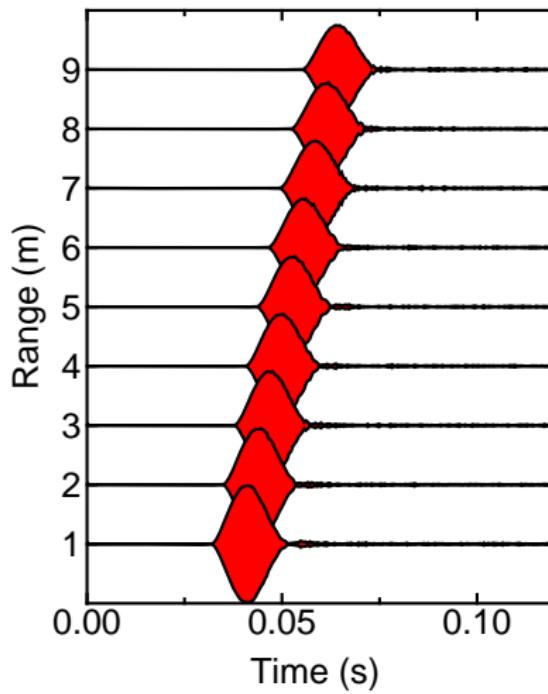
Sound pressure signals I

total recorded traces



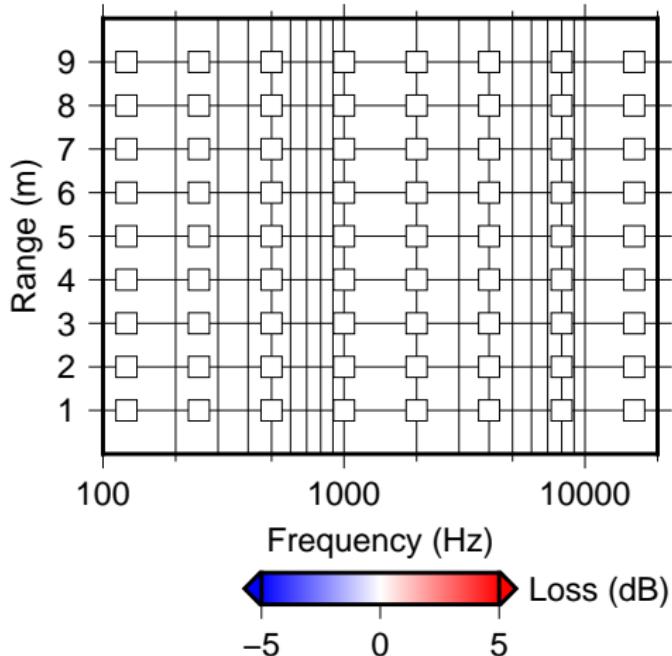
Sound pressure signals II

separated scattering components



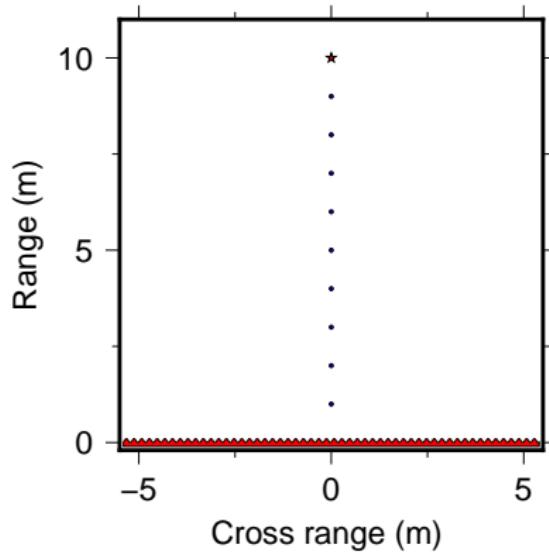
Scattering loss

calculated within one third Octave bands, with the specular reflection as reference



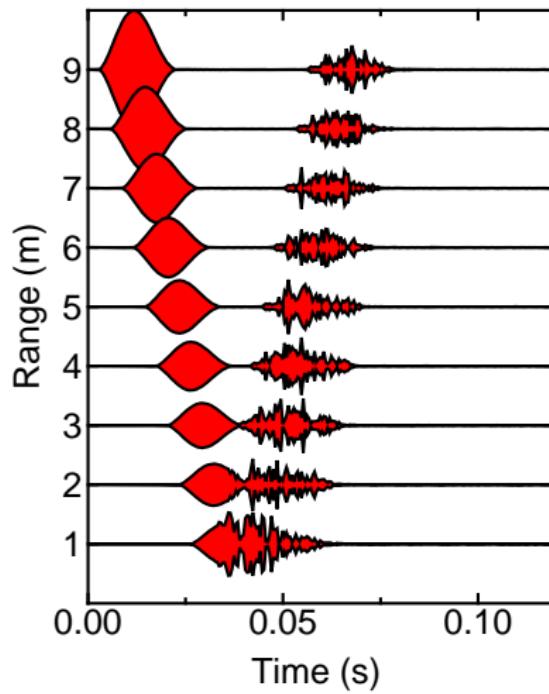
Deployment

wall topography type: *sine*; the receivers are deployed with 1m step away from the source



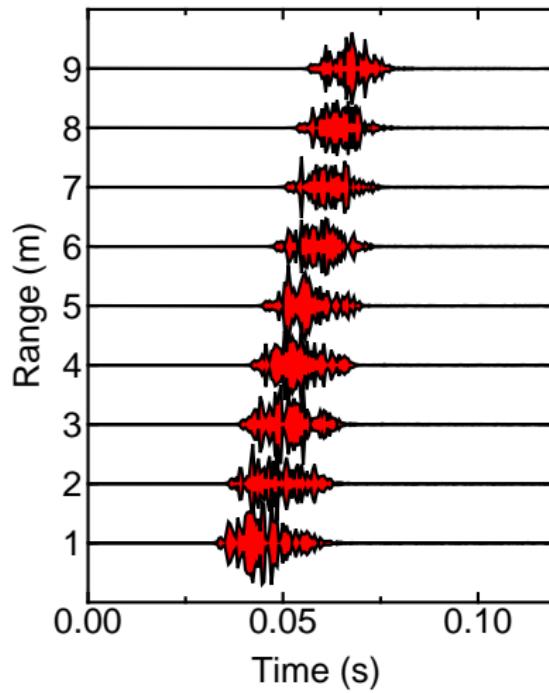
Sound pressure signals I

total recorded traces



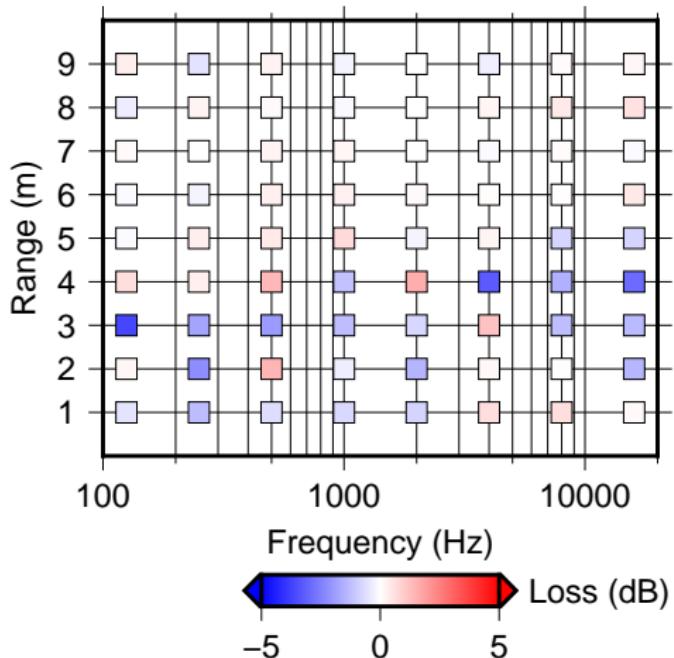
Sound pressure signals II

separated scattering components



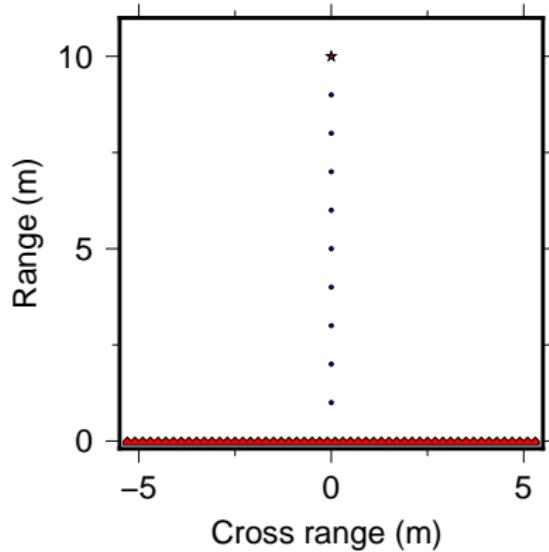
Scattering loss

calculated within one third Octave bands, with the specular reflection as reference



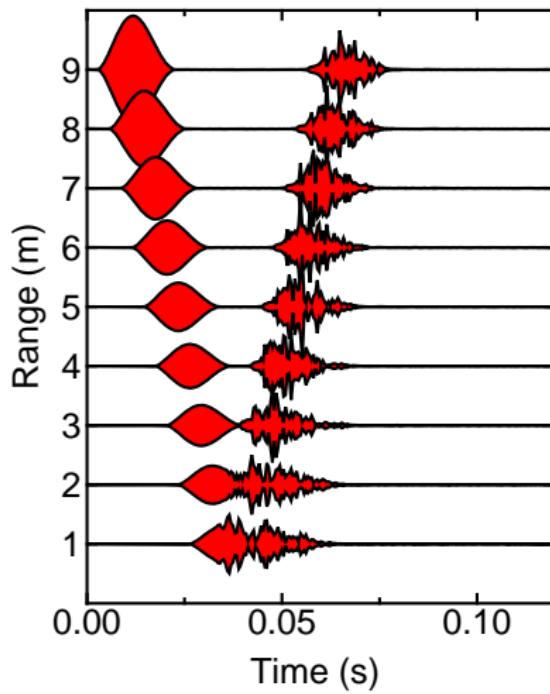
Deployment

wall topography type: *triangle*; the receivers are deployed with 1m step away from the source



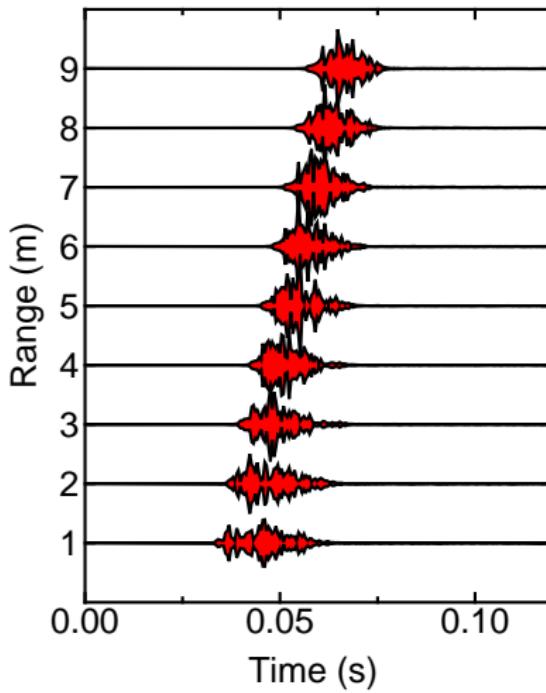
Sound pressure signals I

total recorded traces



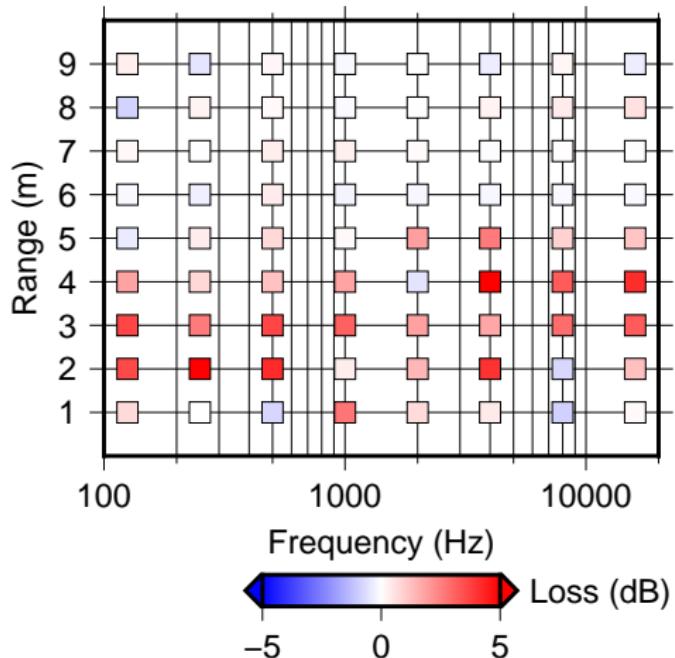
Sound pressure signals II

separated scattering components



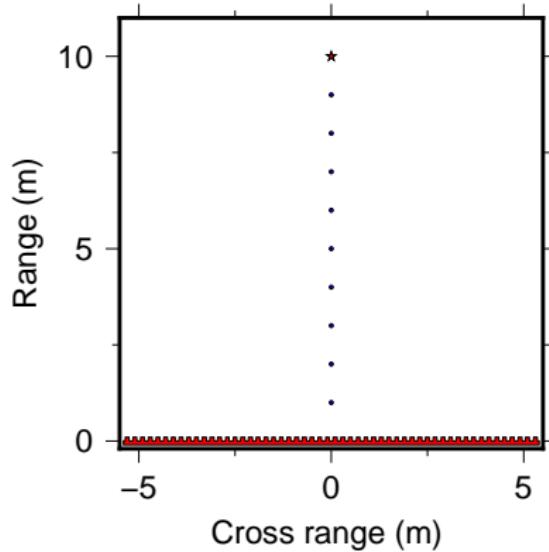
Scattering loss

calculated within one third Octave bands, with the specular reflection as reference



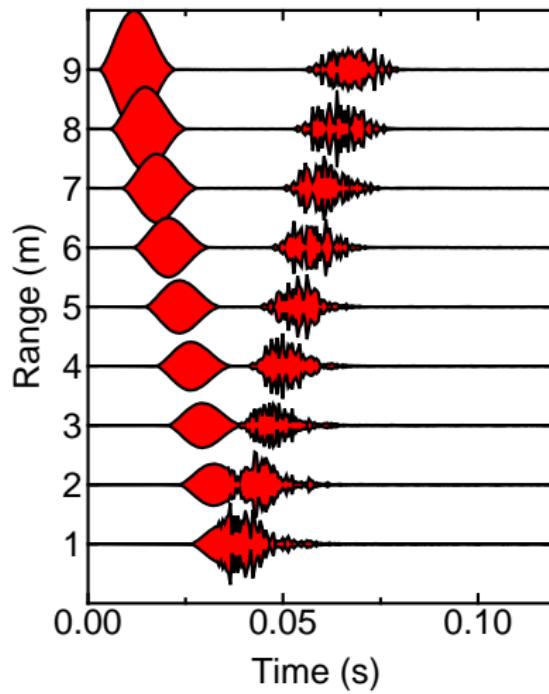
Deployment

wall topography type: *rectangle*; the receivers are deployed with 1m step away from the source



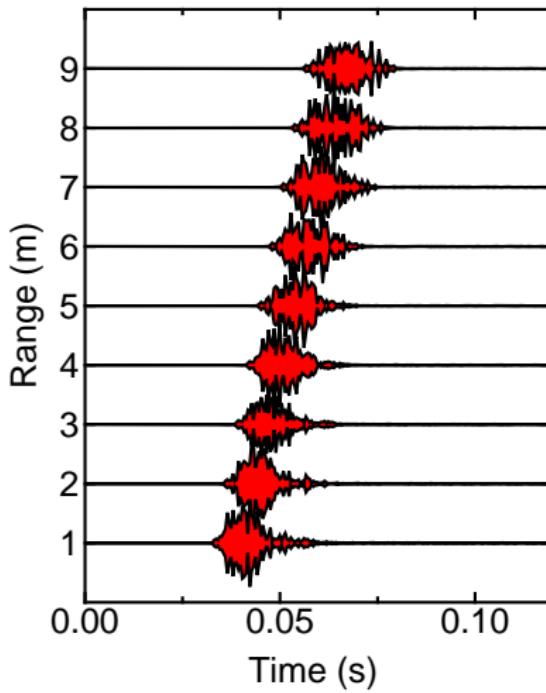
Sound pressure signals I

total recorded traces



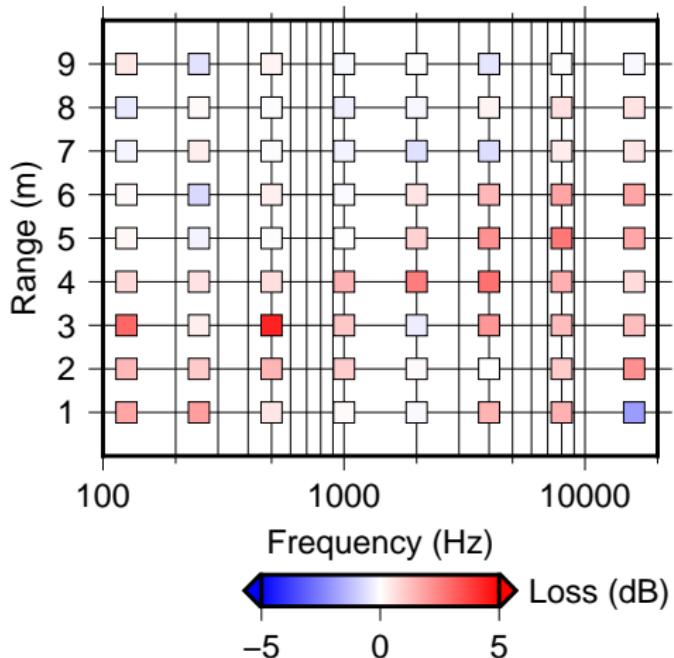
Sound pressure signals II

separated scattering components



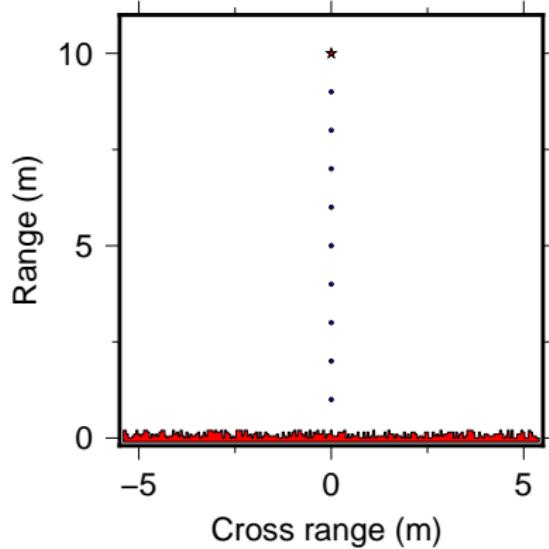
Scattering loss

calculated within one third Octave bands, with the specular reflection as reference



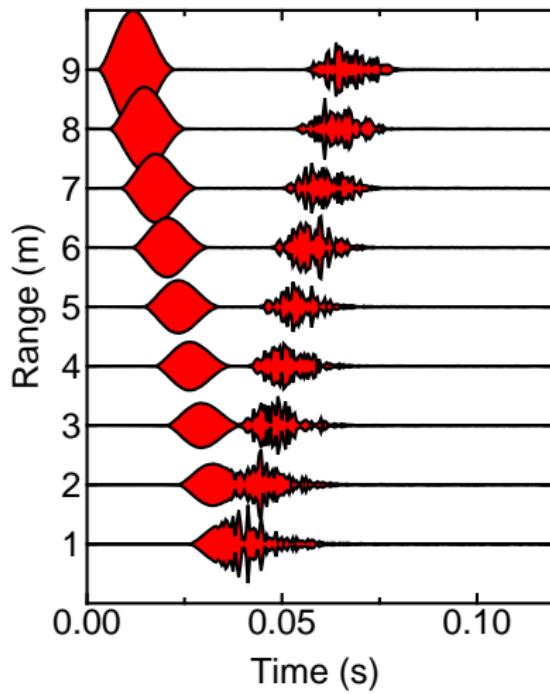
Deployment

wall topography type: *skyline*; the receivers are deployed with 1m step away from the source



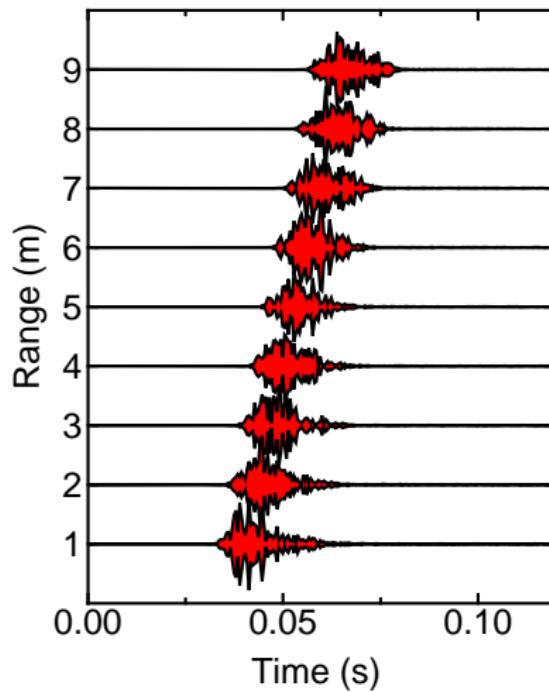
Sound pressure signals I

total recorded traces



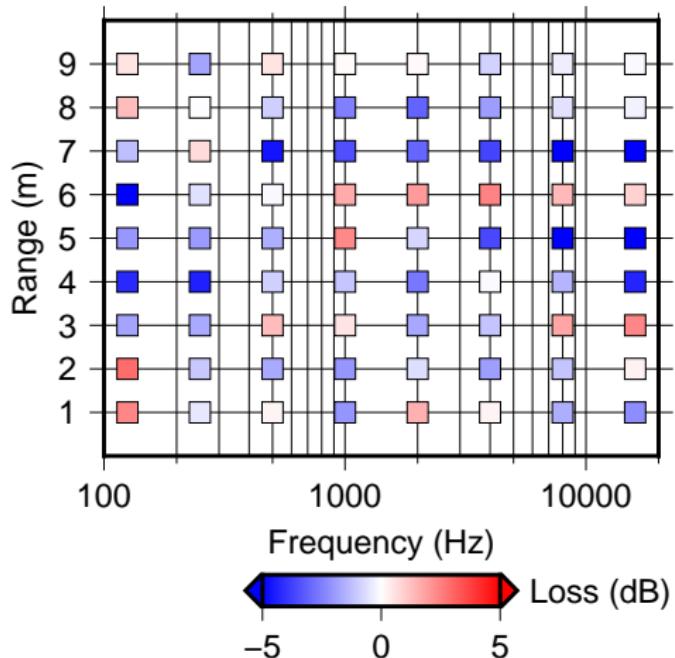
Sound pressure signals II

separated scattering components



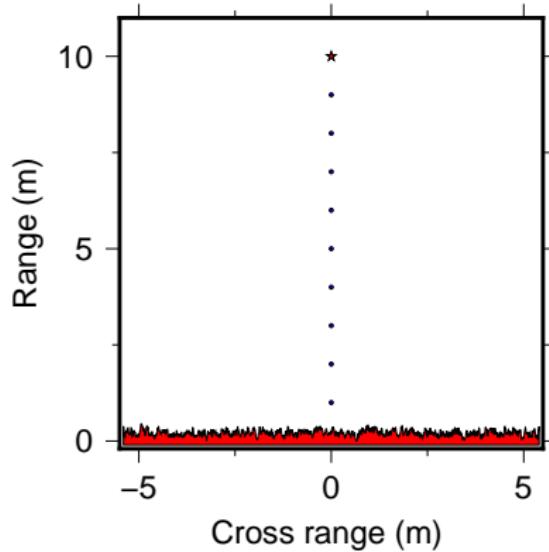
Scattering loss

calculated within one third Octave bands, with the specular reflection as reference



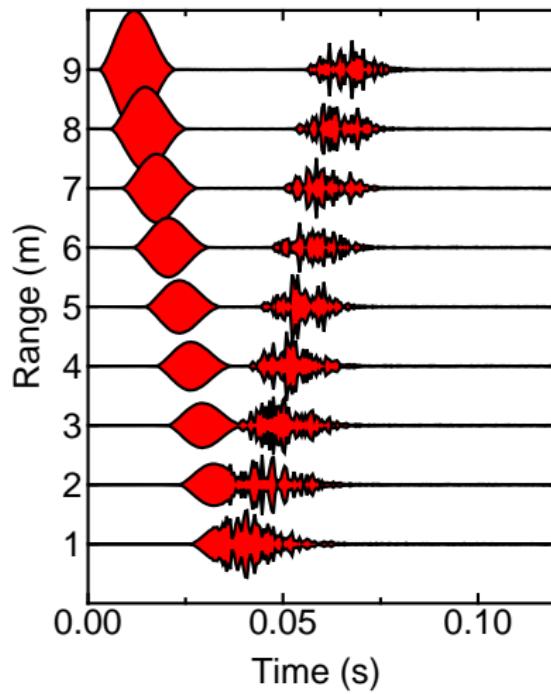
Deployment

wall topography type: *vonkarman*; the receivers are deployed with 1m step away from the source



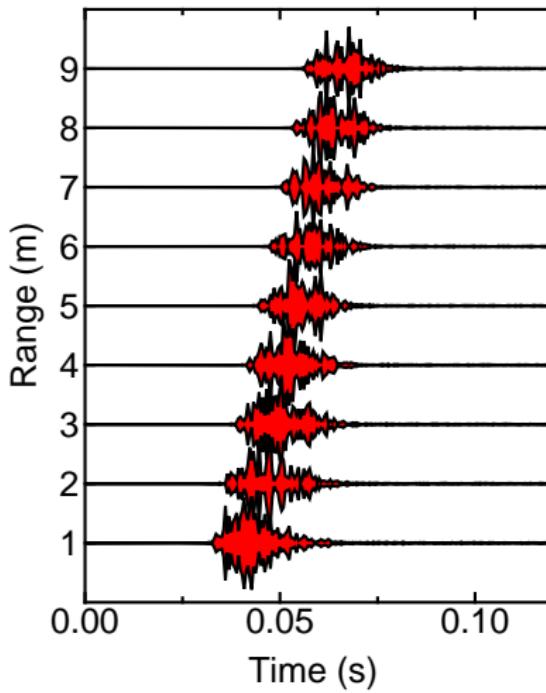
Sound pressure signals I

total recorded traces



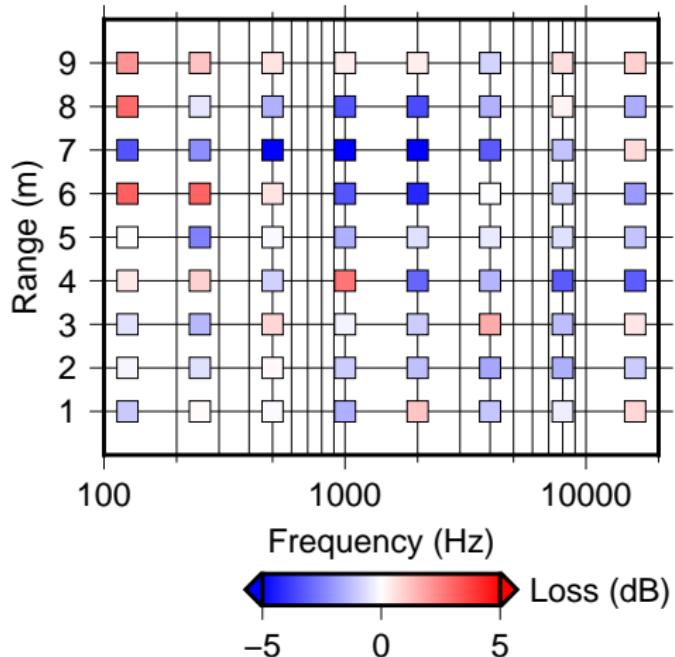
Sound pressure signals II

separated scattering components



Scattering loss

calculated within one third Octave bands, with the specular reflection as reference



Outline

Introduction

Sound diffusion efficiency of the diffuser elements

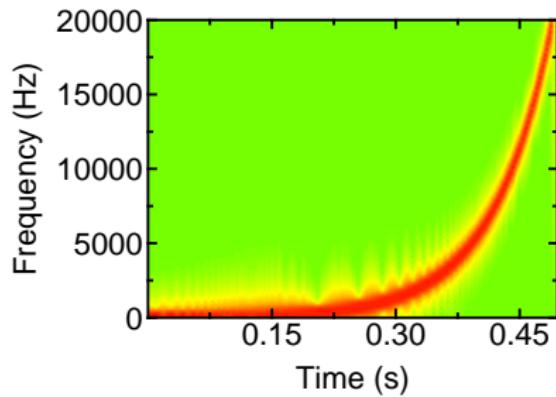
Sound scattering loss by the surfaces

Sound characteristics in the small spaces

Summary

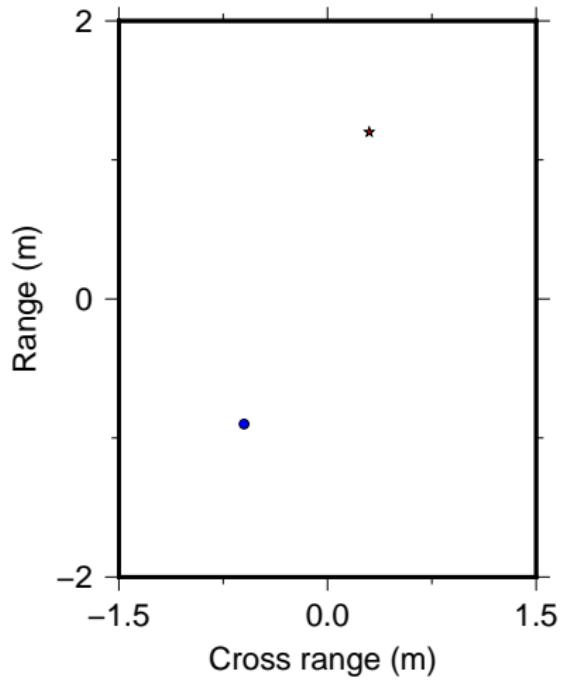
Source spectrogram

measure channel impulse response between the source-receive pair with the Exponential Sine Sweep method



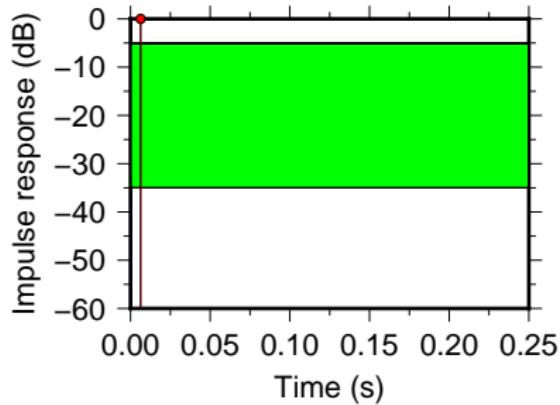
Deployment for the free space

wall topography type: *none*



Impulse response

acoustical signature of the room

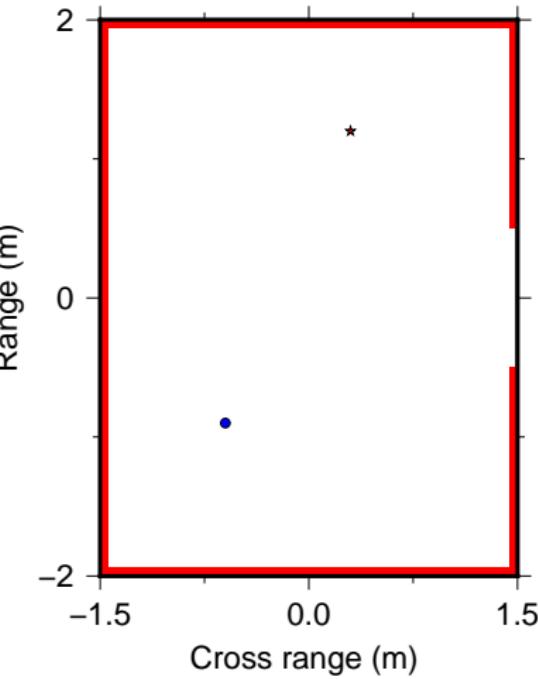
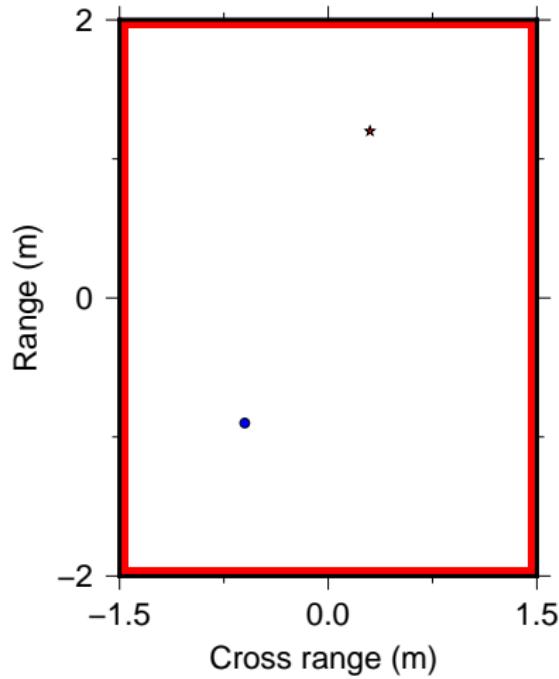


Wave animation (*view with Acrobat Reader*)

probing source: 2k Hz Ricker wavelet; 20 snapshots are taken with 0.5ms time step

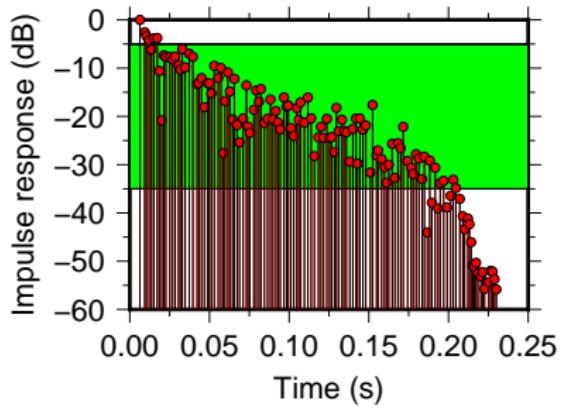
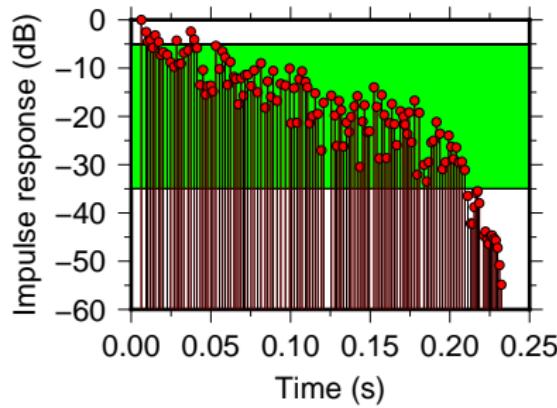
Deployments for the *fully* and *partially* closed rooms

wall topography type: *flat*



Impulse responses

acoustical signatures of the rooms

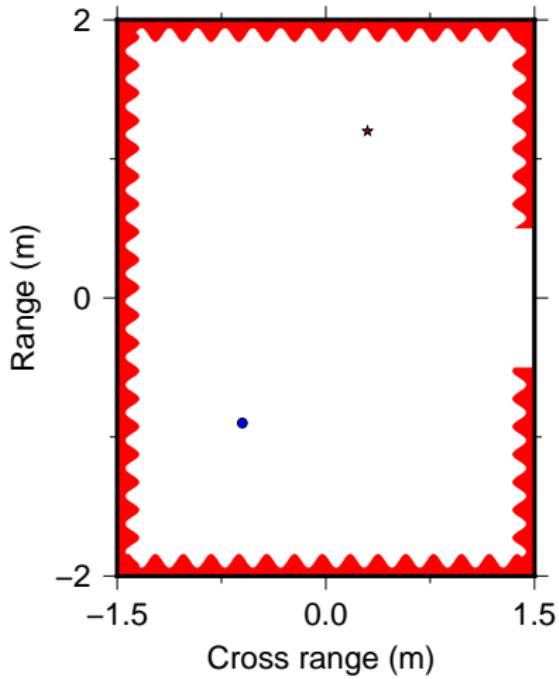
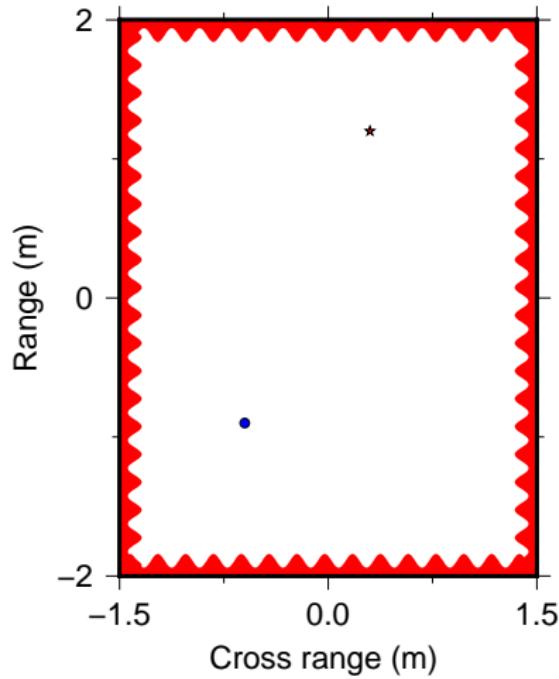


Wave animations (*view with Acrobat Reader*)

probing source: 2k Hz Ricker wavelet; 20 snapshots are taken with 0.5ms time step

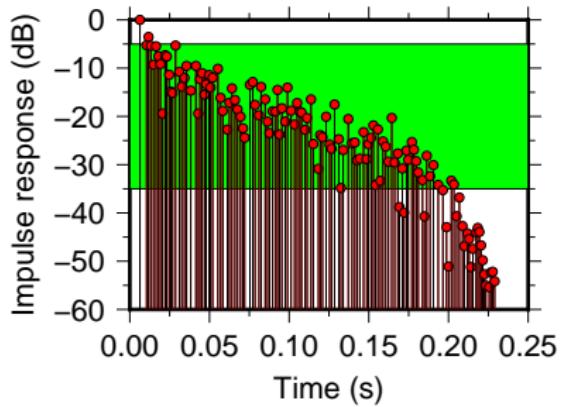
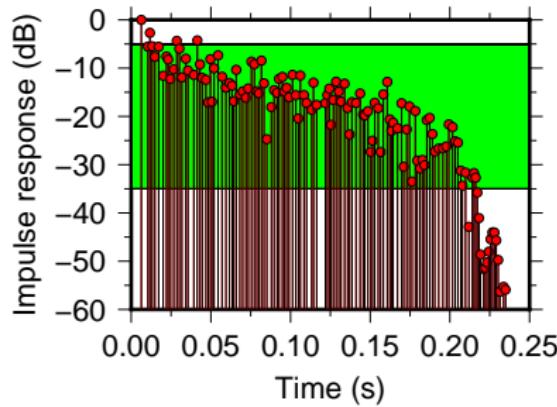
Deployments for the *fully* and *partially* closed rooms

wall topography type: *sine*



Impulse responses

acoustical signatures of the rooms

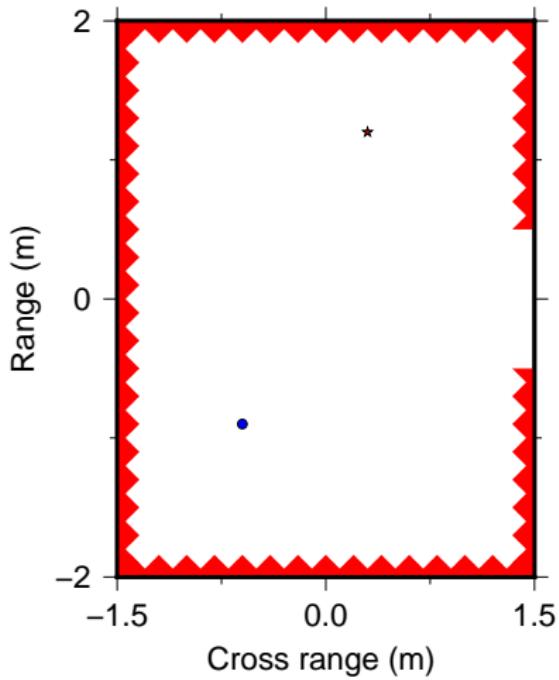
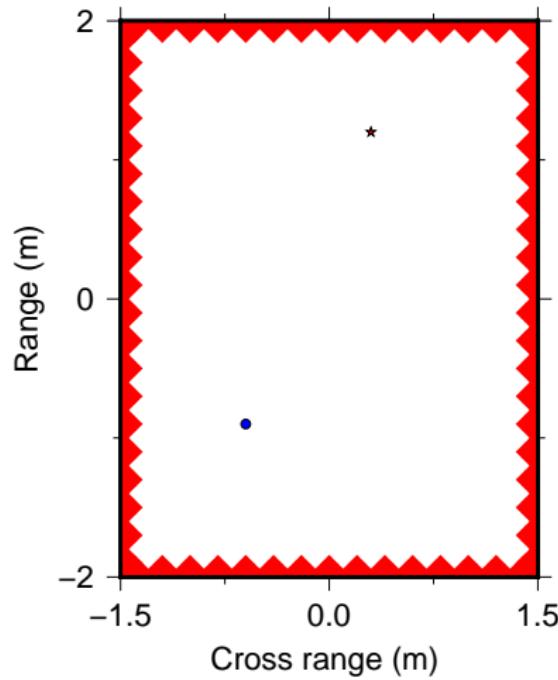


Wave animations (*view with Acrobat Reader*)

probing source: 2k Hz Ricker wavelet; 20 snapshots are taken with 0.5ms time step

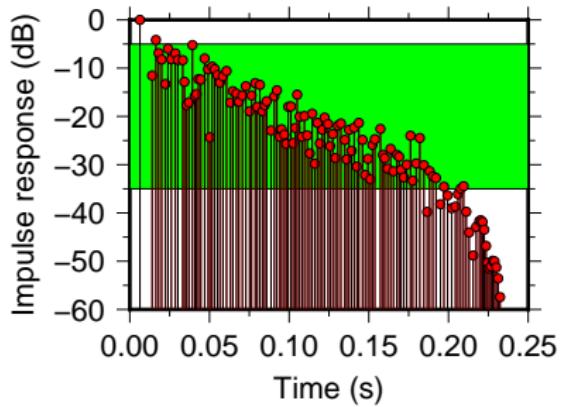
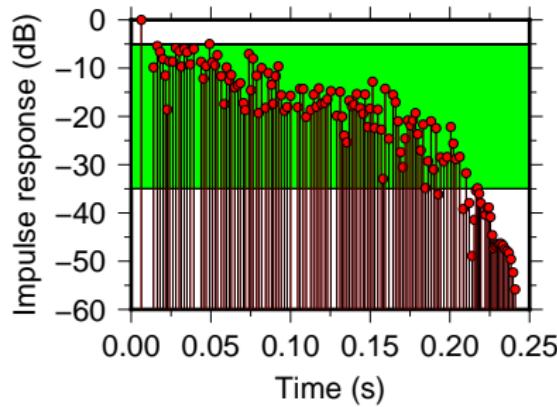
Deployments for the *fully* and *partially* closed rooms

wall topography type: *triangle*



Impulse responses

acoustical signatures of the rooms

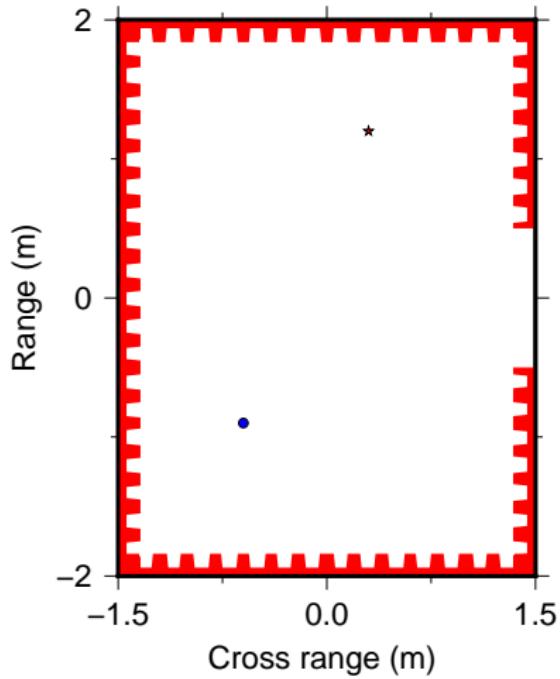
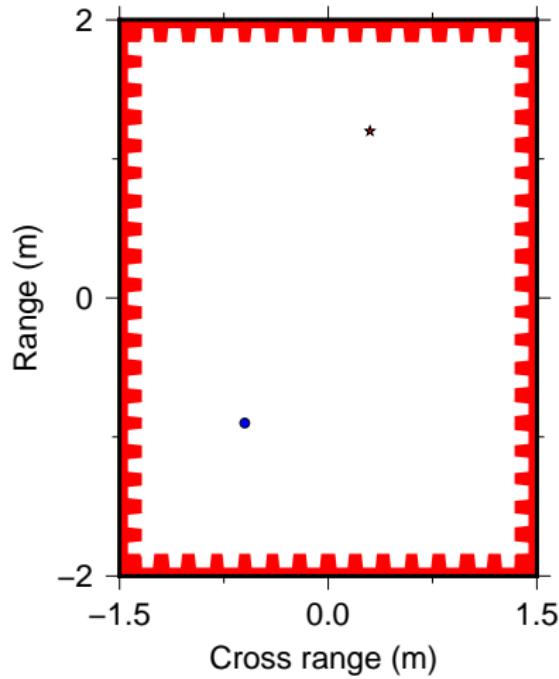


Wave animations (*view with Acrobat Reader*)

probing source: 2k Hz Ricker wavelet; 20 snapshots are taken with 0.5ms time step

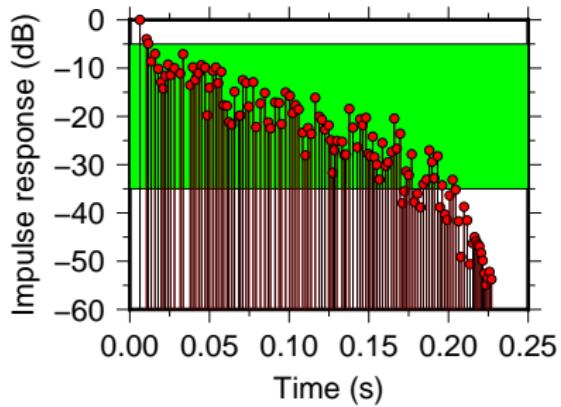
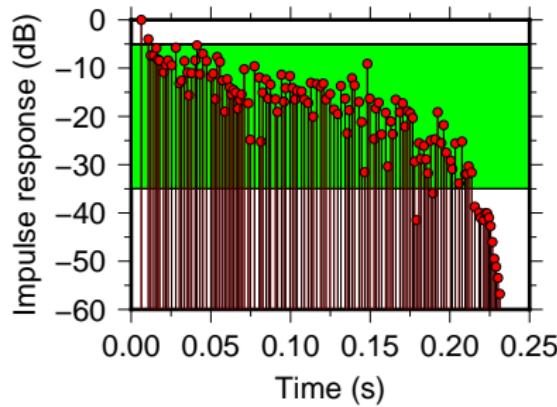
Deployments for the *fully* and *partially* closed rooms

wall topography type: *rectangle*



Impulse responses

acoustical signatures of the rooms

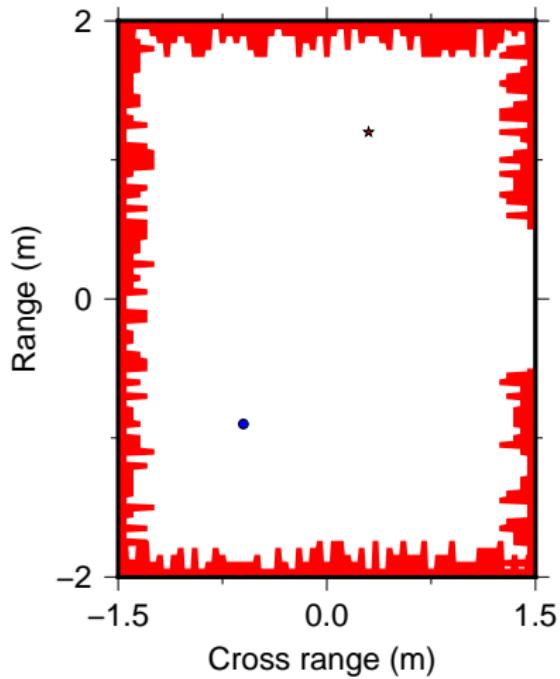
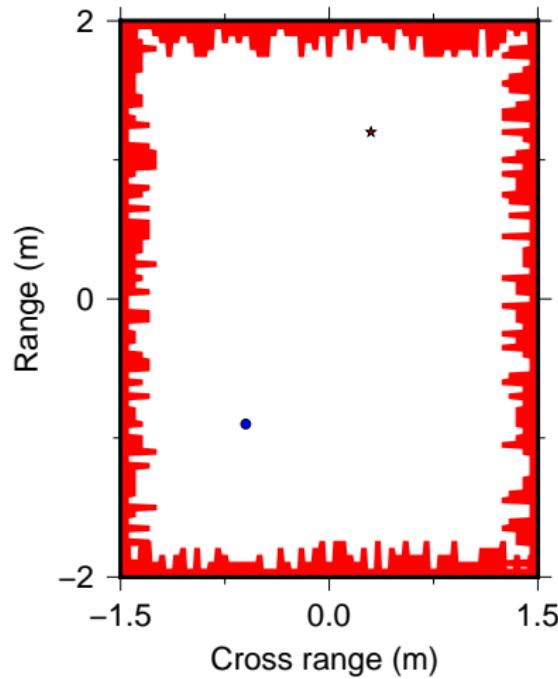


Wave animations (*view with Acrobat Reader*)

probing source: 2k Hz Ricker wavelet; 20 snapshots are taken with 0.5ms time step

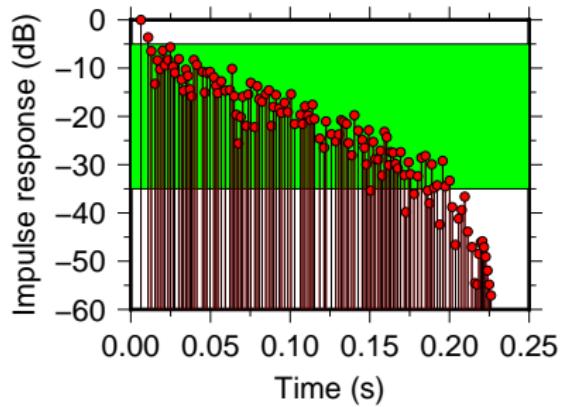
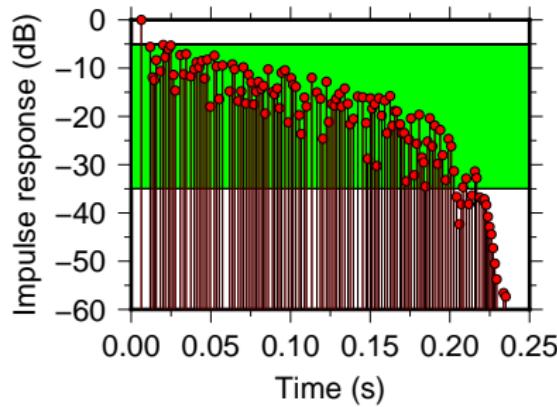
Deployments for the *fully* and *partially* closed rooms

wall topography type: *skyline*



Impulse responses

acoustical signatures of the rooms

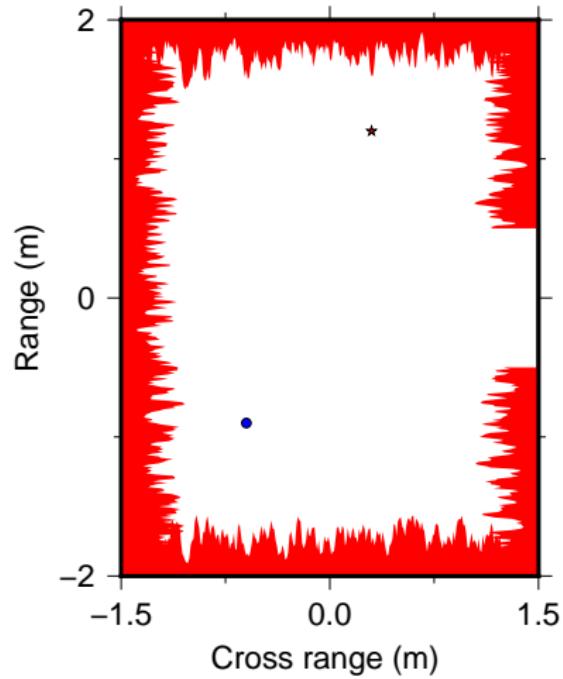
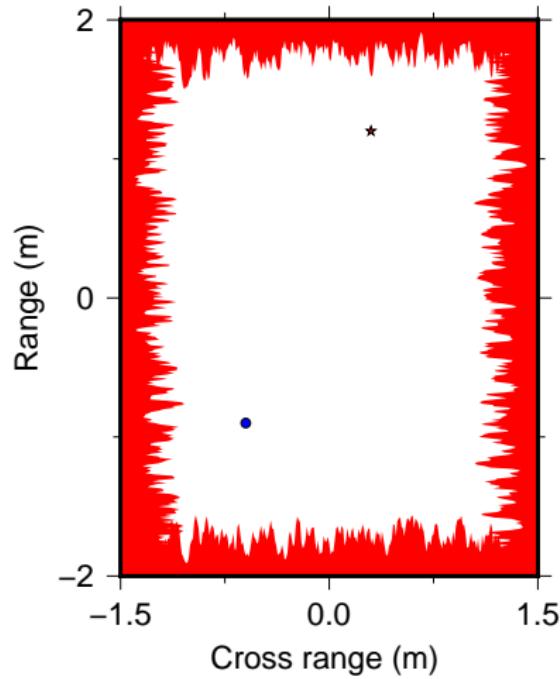


Wave animations (*view with Acrobat Reader*)

probing source: 2k Hz Ricker wavelet; 20 snapshots are taken with 0.5ms time step

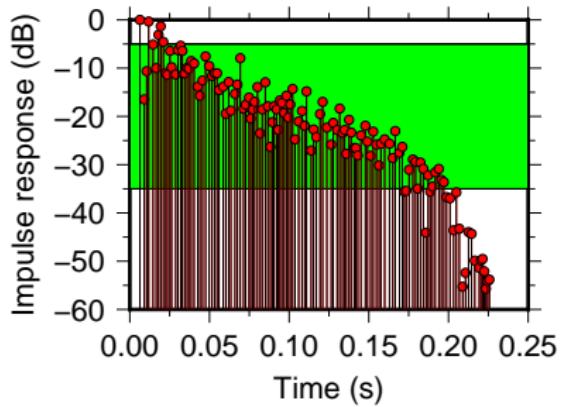
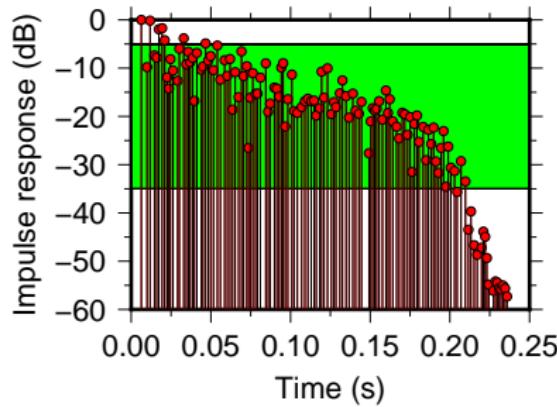
Deployments for the *fully* and *partially* closed rooms

wall topography type: *vonkarman*



Impulse responses

acoustical signatures of the rooms



Wave animations (*view with Acrobat Reader*)

probing source: 2k Hz Ricker wavelet; 20 snapshots are taken with 0.5ms time step

Outline

Introduction

Sound diffusion efficiency of the diffuser elements

Sound scattering loss by the surfaces

Sound characteristics in the small spaces

Summary

A brief summary

- ▶ More rough, more diffusive
- ▶ Preserve, or in other words, not reduce sound energy
- ▶ Spread out sound field coverage
- ▶ Eliminate disturbing flutter echoes

Thank you!