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A glimpse on acoustic metamaterials and black holes

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with
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Índex

Acoustic metamaterials: Bragg scattering and local resonances

Metamaterials

- Possible definition? A material with ‘on-demand’ effective properties, without

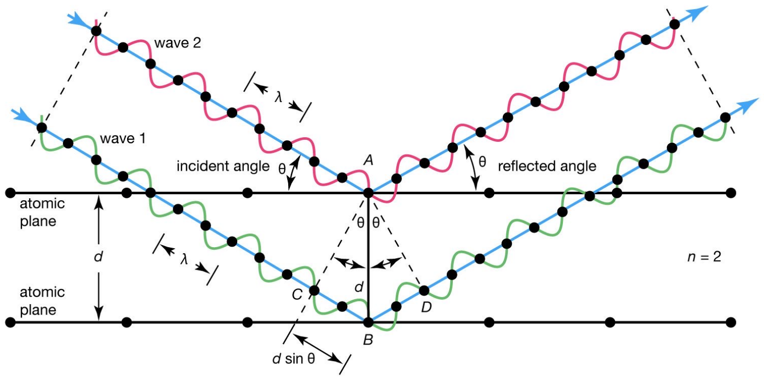
the constraints imposed by what nature provides.

S.A. Cummer, J. Christensen and A. Alù (2016). Controlling sound with acoustic metamaterials. Nat. Rev. Mat., 1(3), 1-13.

- Metamaterials can exhibit negative effective mass and stiffness. How is that possible? Manufacturing inner structure.

Two mechanisms: Bragg scattering and local resonances

Bragg scattering (wavelength)



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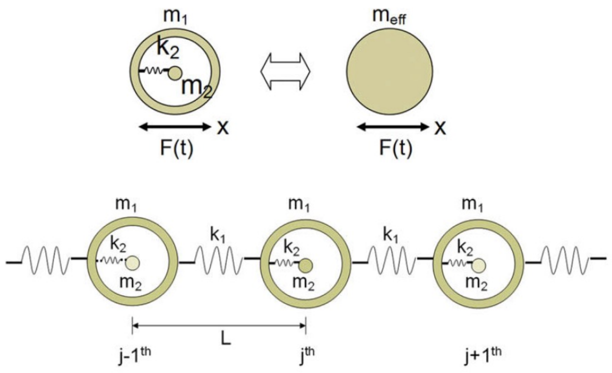
Local resonances (subwavelength)



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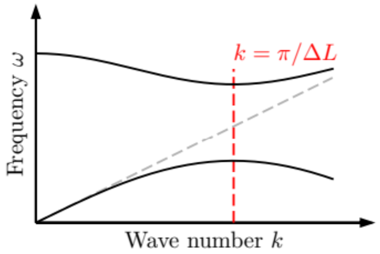
Acoustic metamaterials: examples

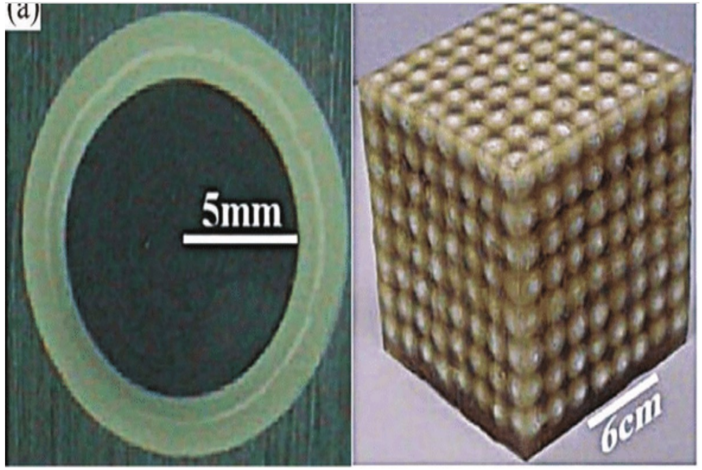
Two emblematic examples:

Bragg scattering

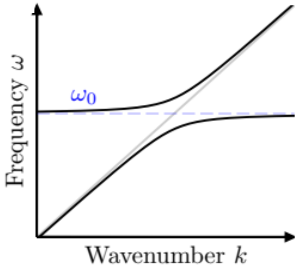
Artwork "Órgano" by sculptor Eusebio Sempere, designed to attenuate waves at 1670 Hz.



Local resonances



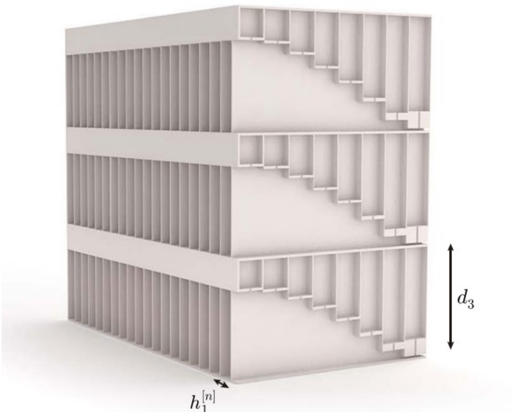
Z. Liu, X. Zhang, Y. Mao, Y.Y. Zhu, Z. Yang, C.T. Chan, & P. Sheng (2000). Locally resonant sonic materials. Science, 289(5485), 1734-1736.

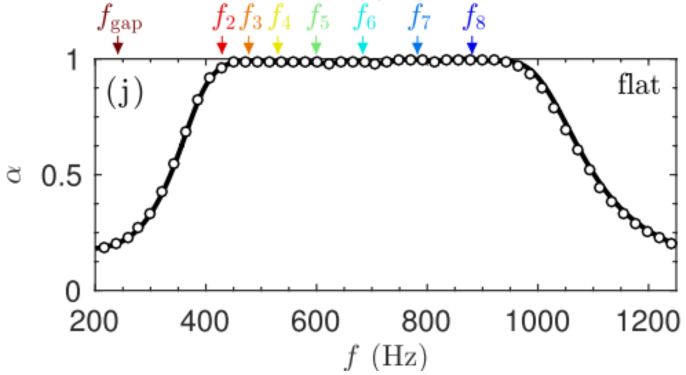


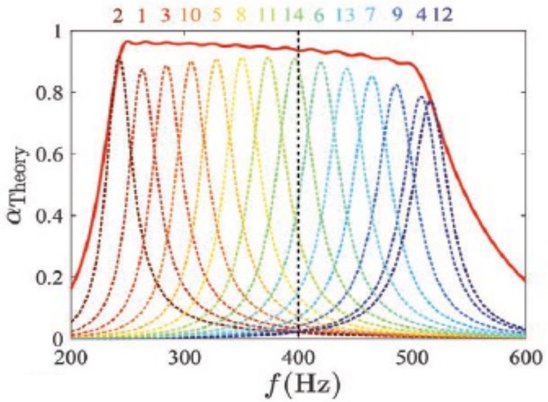
BANDGAP FORMATION

Acoustic metamaterials: examples

The Rainbow Trapper Absorber



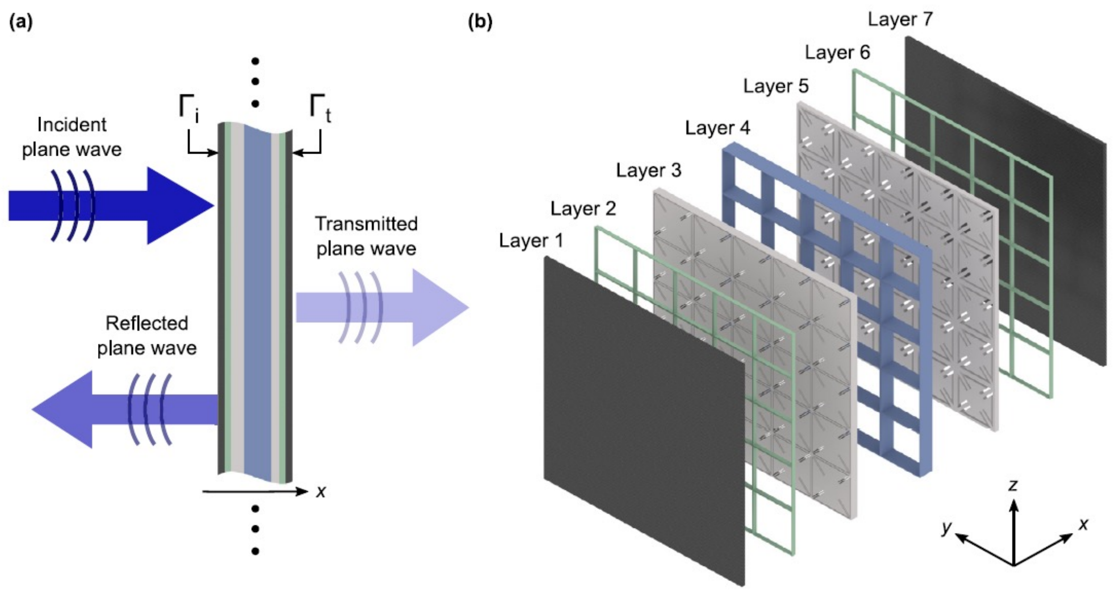


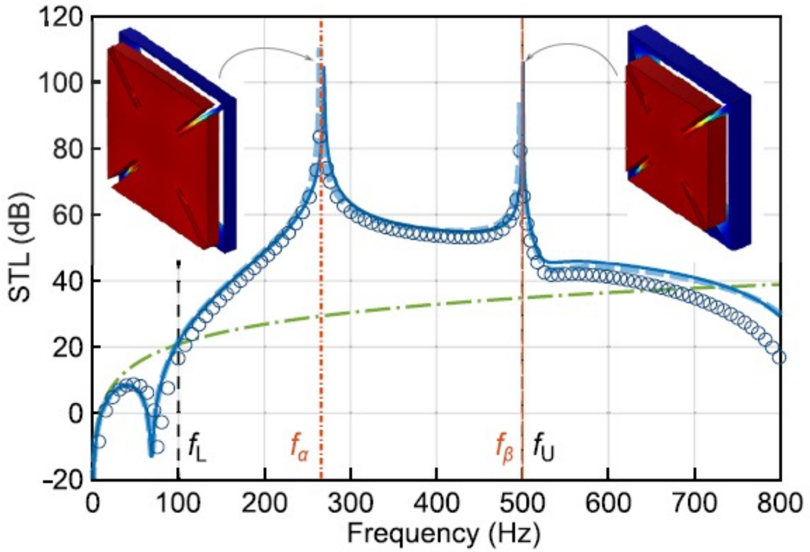


N. Jiménez, V. Romero-García, V. Pagneux, and J.P. Groby, J. P. (2017). Rainbow-trapping absorbers: Broadband, perfect and asymmetric sound absorption by subwavelength panels for transmission problems. Sci. Rep., 7(1), 13595.

Acoustic metamaterials: examples

Improving Transmission Loss at low frequencies

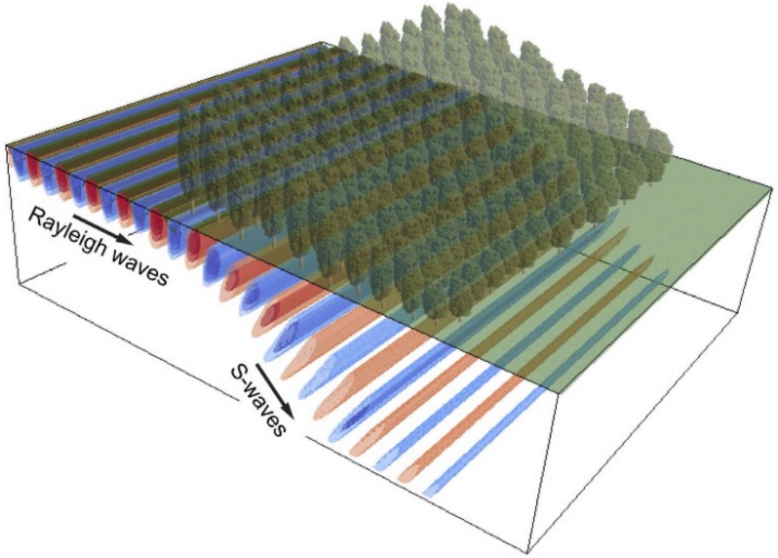


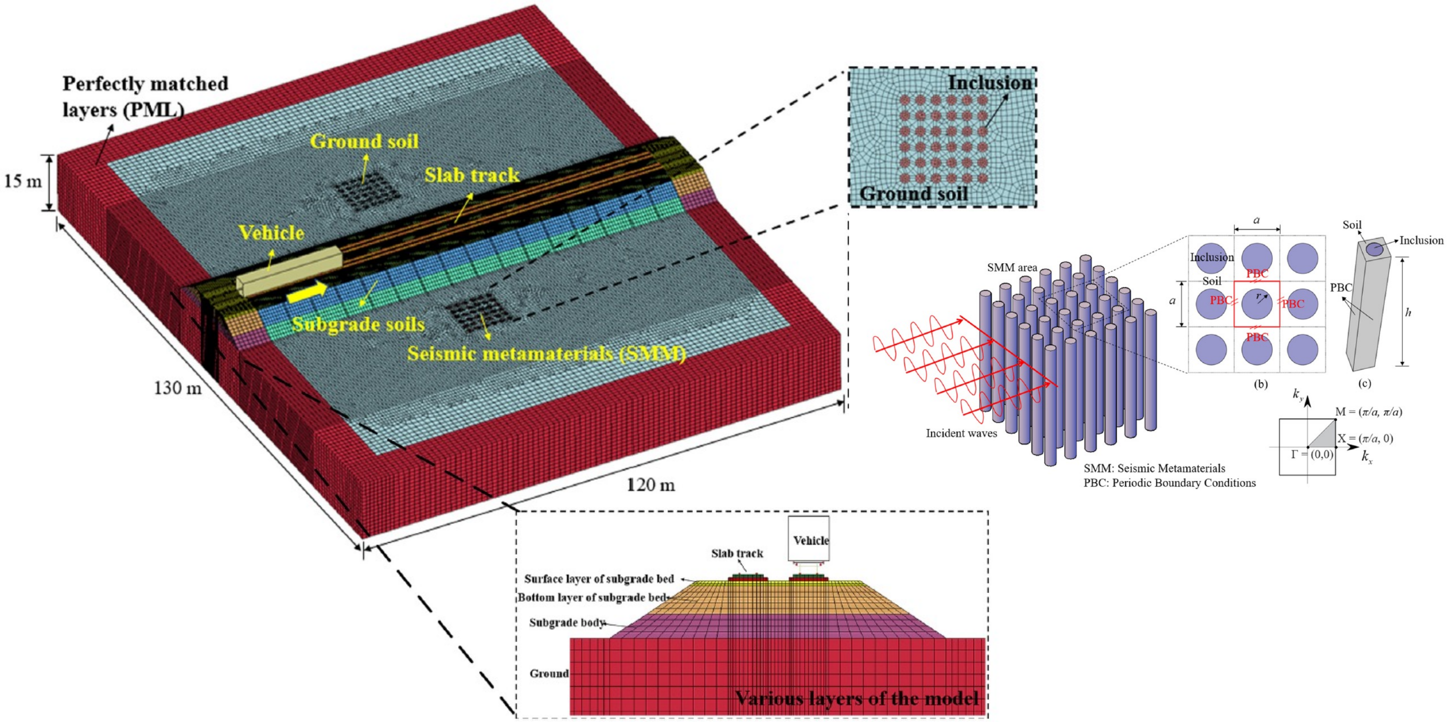


G. Sal-Anglada, D. Yago, J. Cante, J. Oliver, and D. Roca (2023). Optimal design of Multiresonant Layered Acoustic Metamaterials (MLAM) via a homogenization approach. Eng. Struct., 293, 116555.

Acoustic metamaterials: examples

Seismic metamaterials

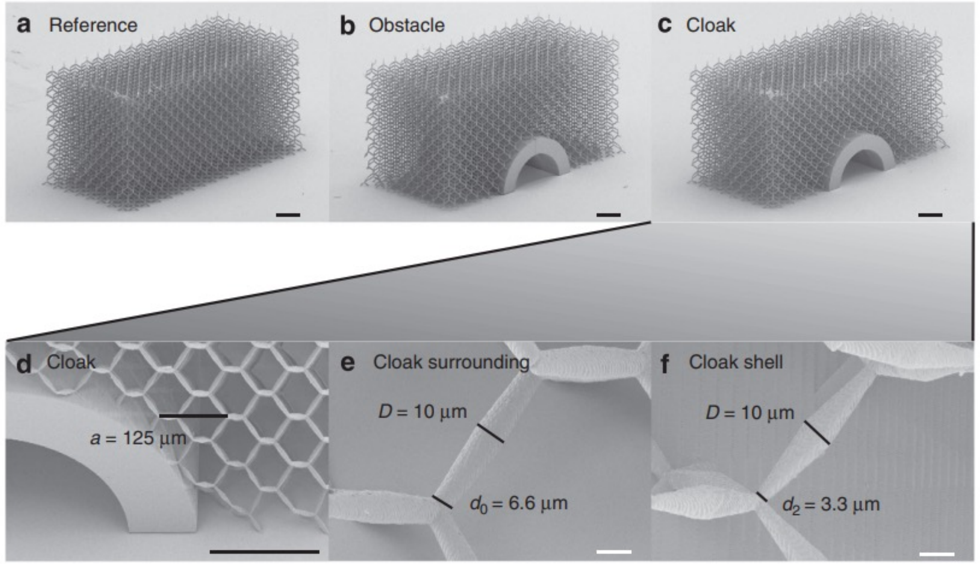


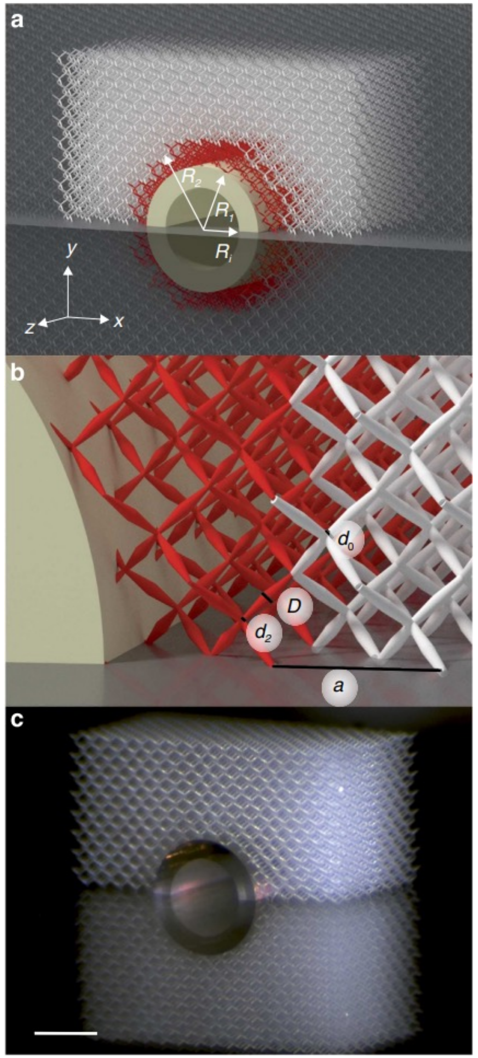


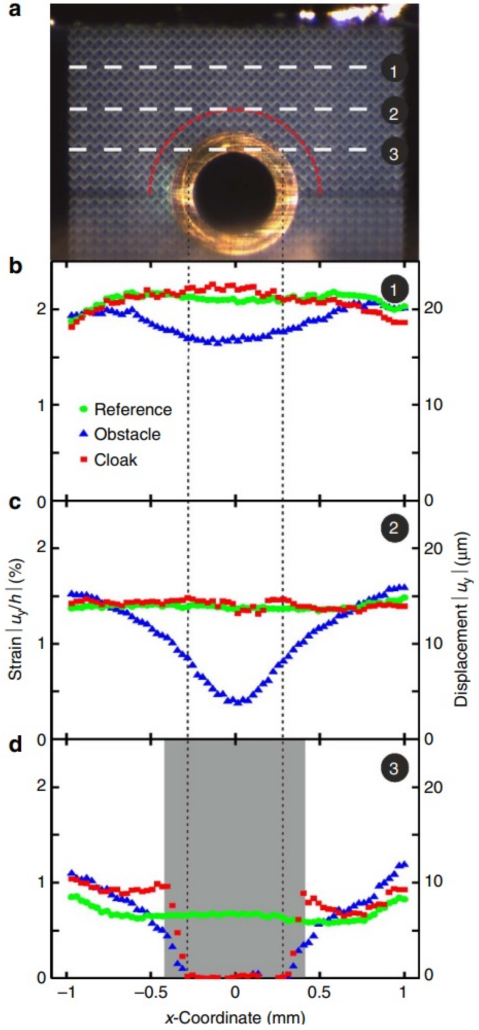
A. Colombi, D. Colquitt, P. Roux, S. Guenneau, and R.V Craster (2016). A seismic metamaterial: The resonant metawedge. Sci. Rep. 6(1), 27717.
T. Li, Q. Su, and S. Kaewunruen (2020). Seismic metamaterial barriers for ground vibration mitigation in railways considering the train-track-soil dynamic interactions. Constr. Build. Mat., 260, 119936.

Acoustic metamaterials: examples

Elasto-mechanical cloaking (invisibility)



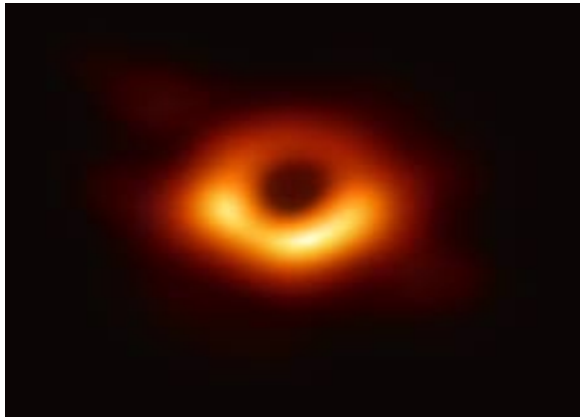




T. Bückmann, M. Thiel, M. Kadic, R. Schittny and M. Wegener (2014). An elasto-mechanical unfeelability cloak made of pentamode metamaterials. Nat. Comm., 5(1), 4130.

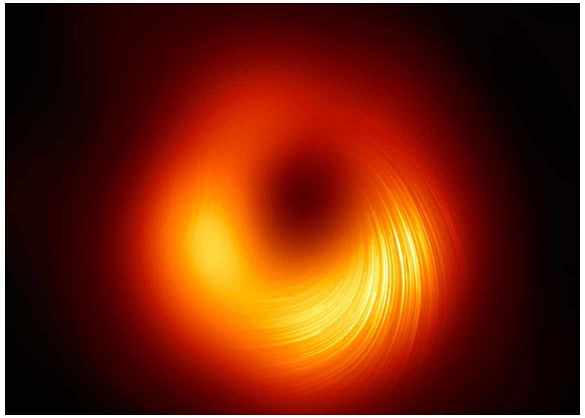
Black holes in astrophysics

- What are black holes in astrophysics?



year 2019. First photo.

First picture of a real supermassive BH at the center of the M87 galaxy having 7 billion times the mass of the Sun.



year 2021. Polarized light.

There exist different types of BHs. Stellar black holes were the first ones to be conjectured and occur at the collapse of a neutron star.

The term **black hole** is a catchy name made popular by J.A Wheeler. Nobody except experts would know about BHs if they were still known as totally collapsed neutron stars!!!

Acoustic Black Holes in structures

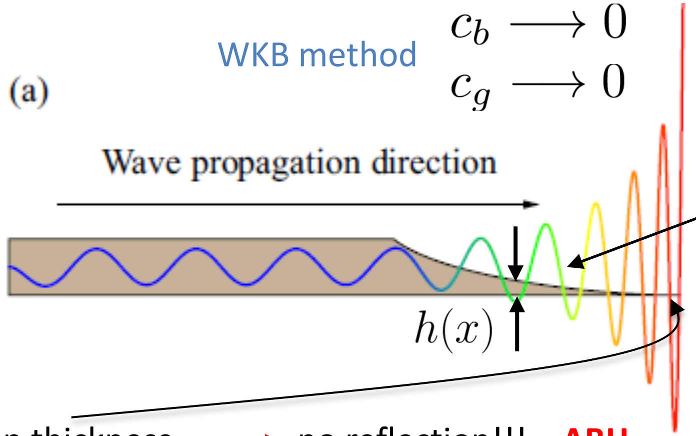
- Acoustic black holes (ABH) in mechanics is also a catchy name to account for some curious wave phenomena in structures. Essentially there exist two types of ABHs, those essentially dealing with waves propagating in beams, plates and shells, and those dealing with acoustic waves in duct terminations.
- First type: original ABH for beams

Power-law profile (m>2)

$$h(x) = \varepsilon x^m$$

WKB method

$$c_b \longrightarrow 0$$
$$c_g \longrightarrow 0$$



Zero truncation thickness → no reflection!!! = **ABH**

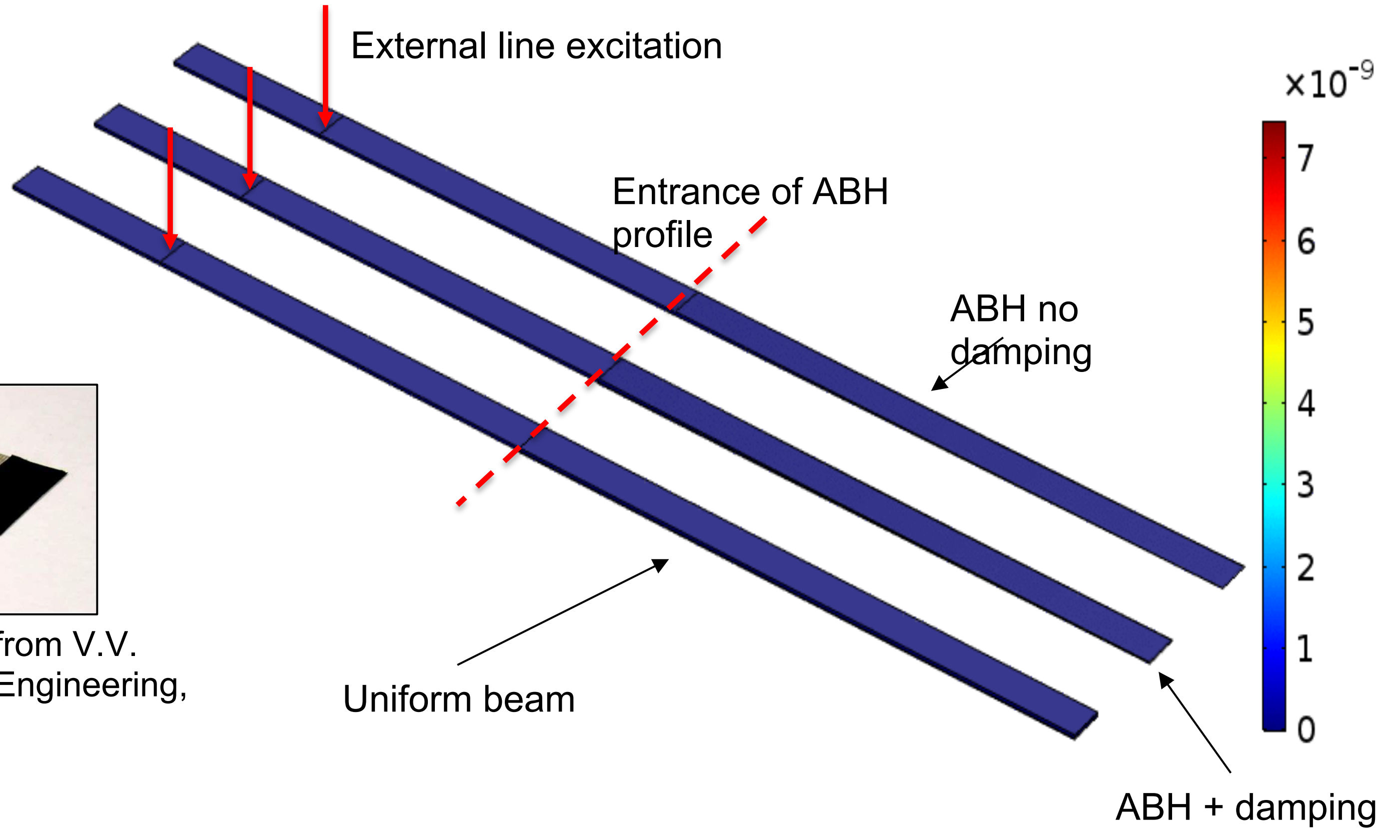
M. Mironov (1988), Propagation of a flexural wave in a plate whose thickness decreases smoothly to zero in a finite interval, Sov. Phys. Acoust. 34.

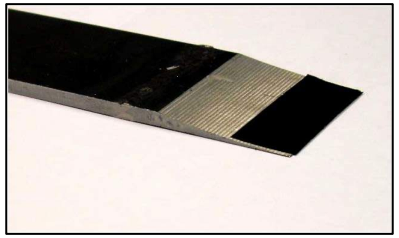
Mironov's work went unnoticed until:

V.V. Krylov, F. Tilman (2004), Acoustic black holes for flexural waves as effective vibration dampers, J. Sound Vib. 274.

Acoustic Black Holes in beams

- Finite element method (FEM) simulations

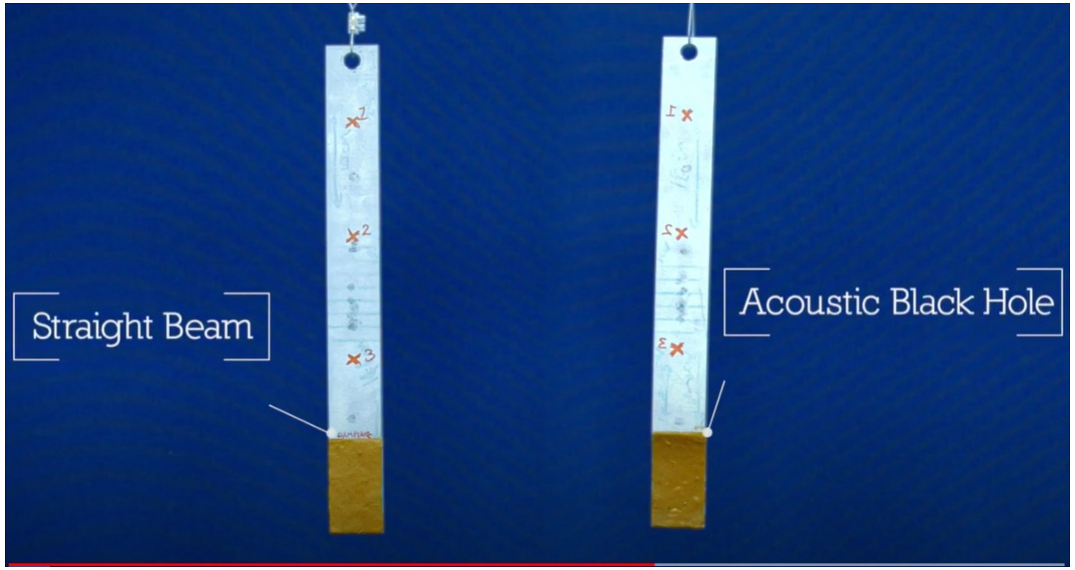




ABH termination from V.V. Krylov. Procedia Engineering, 199 (2017)

Acoustic Black Holes in beams

- We have seen that the ABH can be very effective for vibration reduction at mid-to high frequencies. But, what about noise? Some parts of the structure (outside the ABH region) have less vibration while others (inside the ABH region) exhibit large deflections. How does this affect noise generation?
- Let us first listen to it and then explain the underlying phenomena

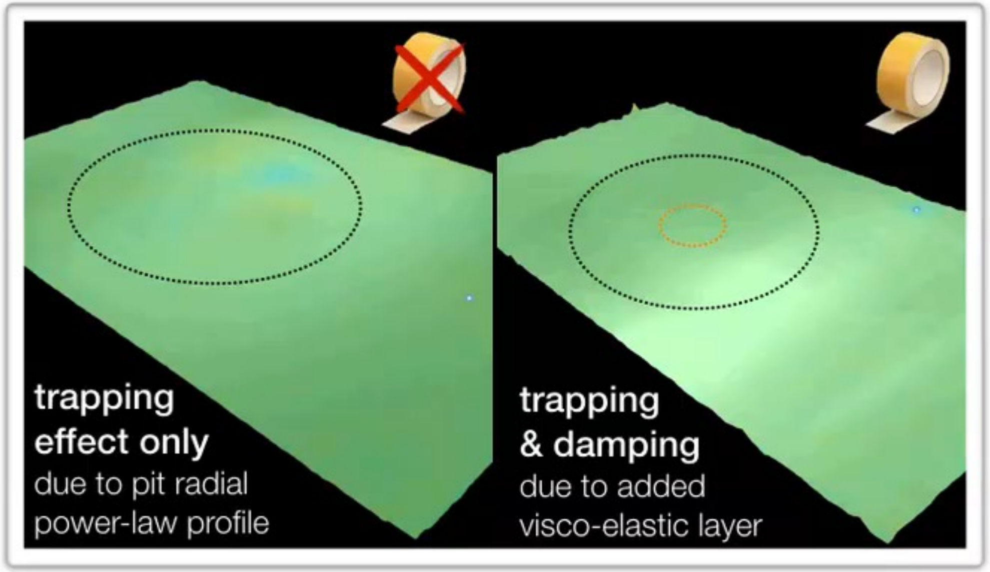


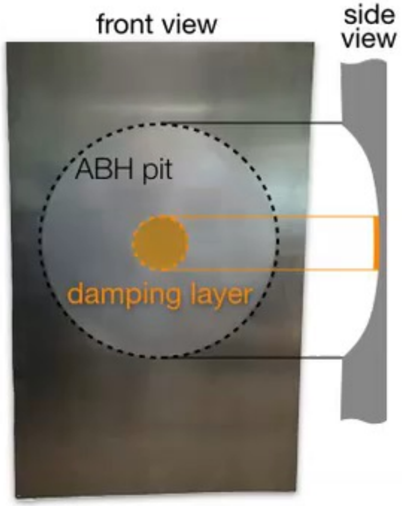
From ISVR video (2021) (t=51 s) at:
https://www.youtube.com/watch?v=Im8FHXLQJMU

Acoustic Black Holes in plates

Wave Trapping effect in 2D circular ABH

- **experimental time scan** of a transient wave field on an **embedded ABH pit**





A. Pelat, F. Gautier, F. Semperlotti, S.C Conlon, *The Acoustic Black Hole : A review of theory and applications*, Journal of Sound and Vibration, 2020

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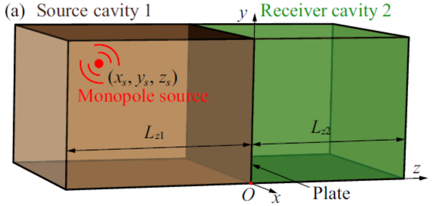
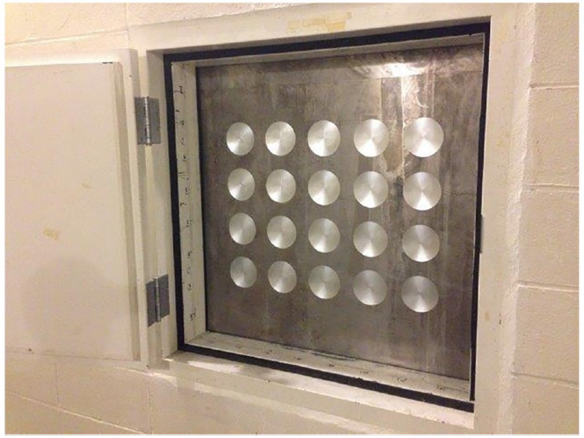
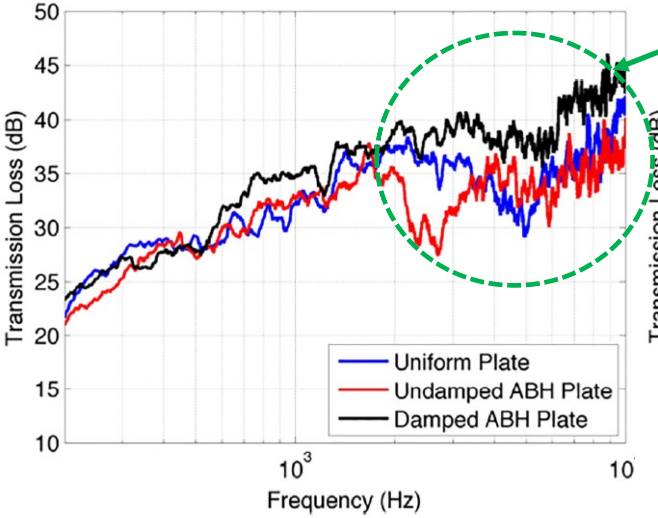
ABHs for Transmission Loss

- ABHs can improve the Transmission Loss dip of walls near the critical frequency.

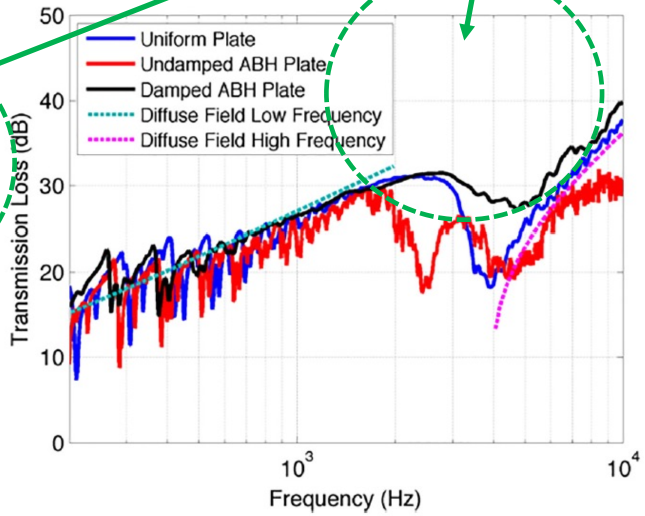




Tested sample



Measured TL



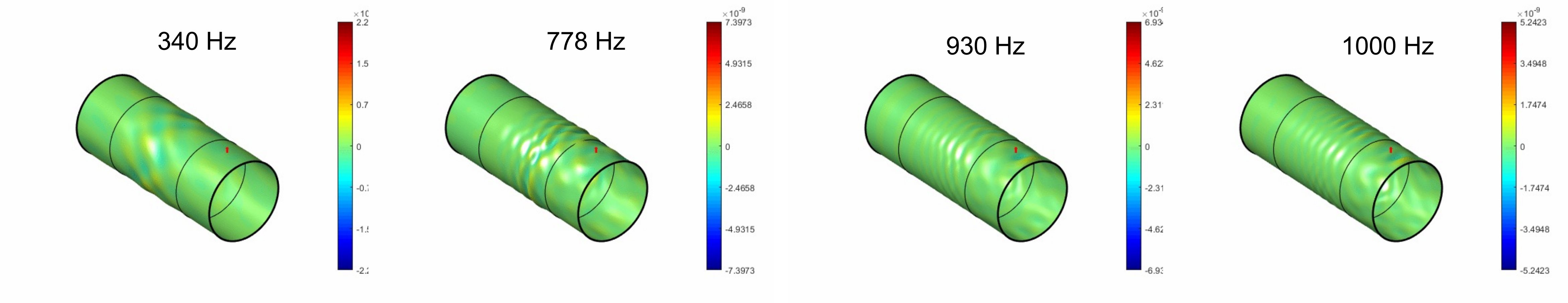
FEM/BEM simplified model

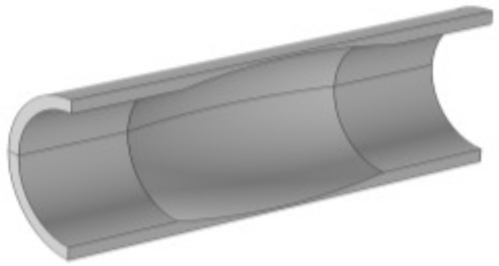
P. A Feurtado and S.C. Conlon (2017), Transmission loss of plates with embedded acoustic black holes, J. Acoust. Soc. Am., 142.

J. Deng, O. Guasch, L. Maxit and L. Zheng (2021), Transmission loss of plates with multiple embedded acoustic black holes using statistical modal energy distribution analysis, Mech. Sys. Signal Proc. 150.

ABHs in cylindrical shells

- Annular ABHs for vibration reduction in cylindrical shells





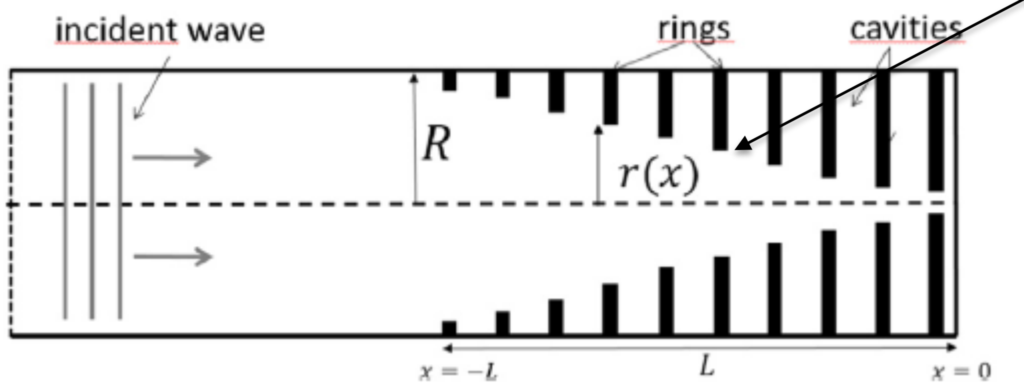
J. Deng, O. Guasch, L. Maxit and L. Zheng (2021), *Vibration of cylindrical shells with embedded annular acoustic black holes using the Rayleigh-Ritz method with Gaussian basis functions*. Mech. Syst. Signal Process., 150, 107225.

J. Deng, O. Guasch, L. Maxit and L. Zheng (2021), *Annular acoustic black holes to reduce sound radiation from cylindrical shells*. Mech. Syst. Signal Process., 158, 107722

Acoustic Black Holes in ducts

- Second type: original ABH for duct terminations

Power-law profile



The acoustic wave slows down inside the ABH termination and ideally should not get reflected. A singularity occurs at the end and absorption material becomes necessary.

M. Mironov and V. Pislyakov (2002), One-dimensional acoustic waves in retarding structures with propagation velocity tending to zero, Acoust. Phys. 48.

Mironov's work went unnoticed until:

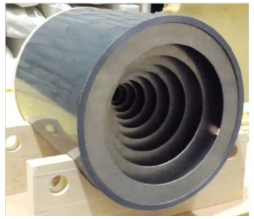
V. A. El-Ouahabi, V. Krylov and D. O'Boy (2015), Investigation of the acoustic black hole termination for sound waves propagating in cylindrical waveguides, in: INTER-NOISE and INCE Proceedings, San Francisco, USA.

O. Guasch, M. Arnela and P. Sánchez-Martín (2017), Transfer matrices to characterize linear and quadratic acoustic black holes in duct terminations, J. Sound Vib. 395.

O. Guasch, P. Sánchez-Martín and D. Ghilardi (2020), "Application of the transfer matrix approximation for wave propagation in a metafluid representing an acoustic black hole duct termination". Appl. Math. Model., 77 (2), pp. 1881-1893.

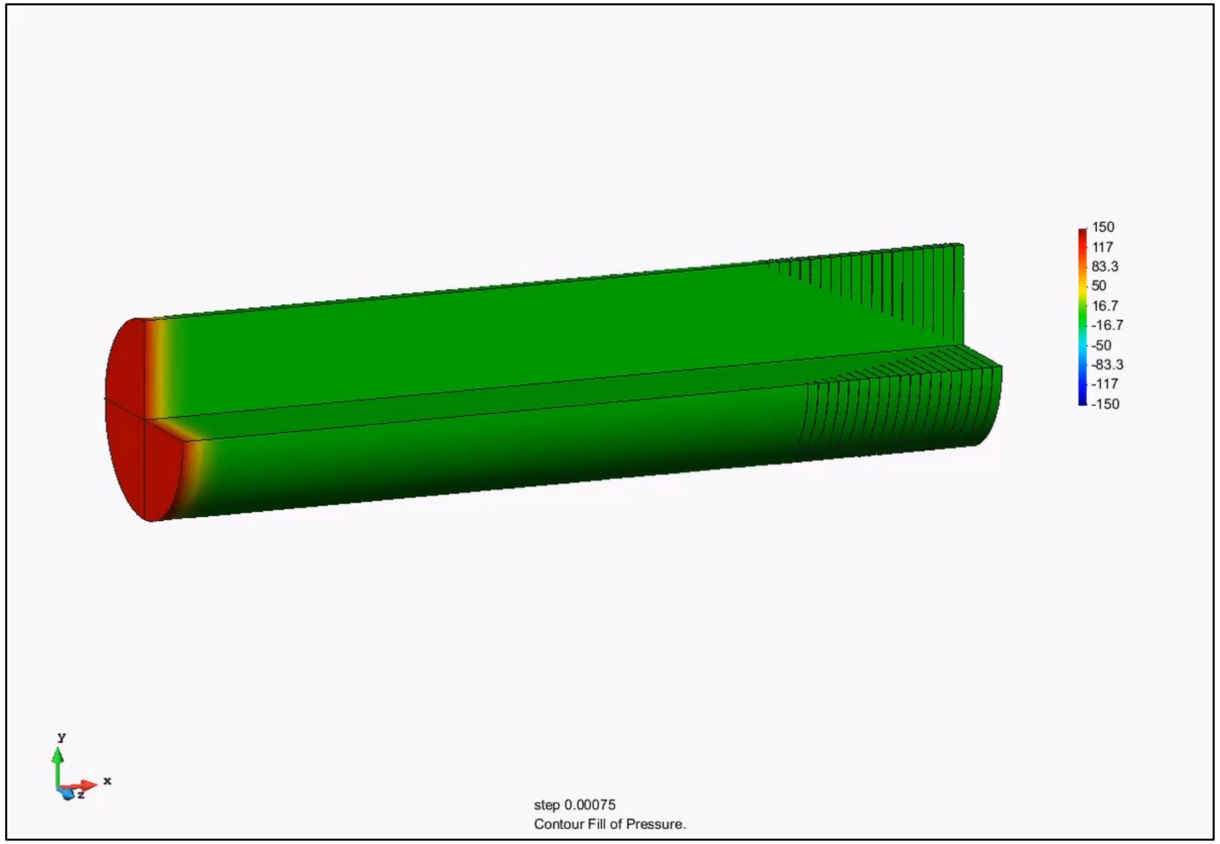
Acoustic Black Holes in ducts

- FEM simulation



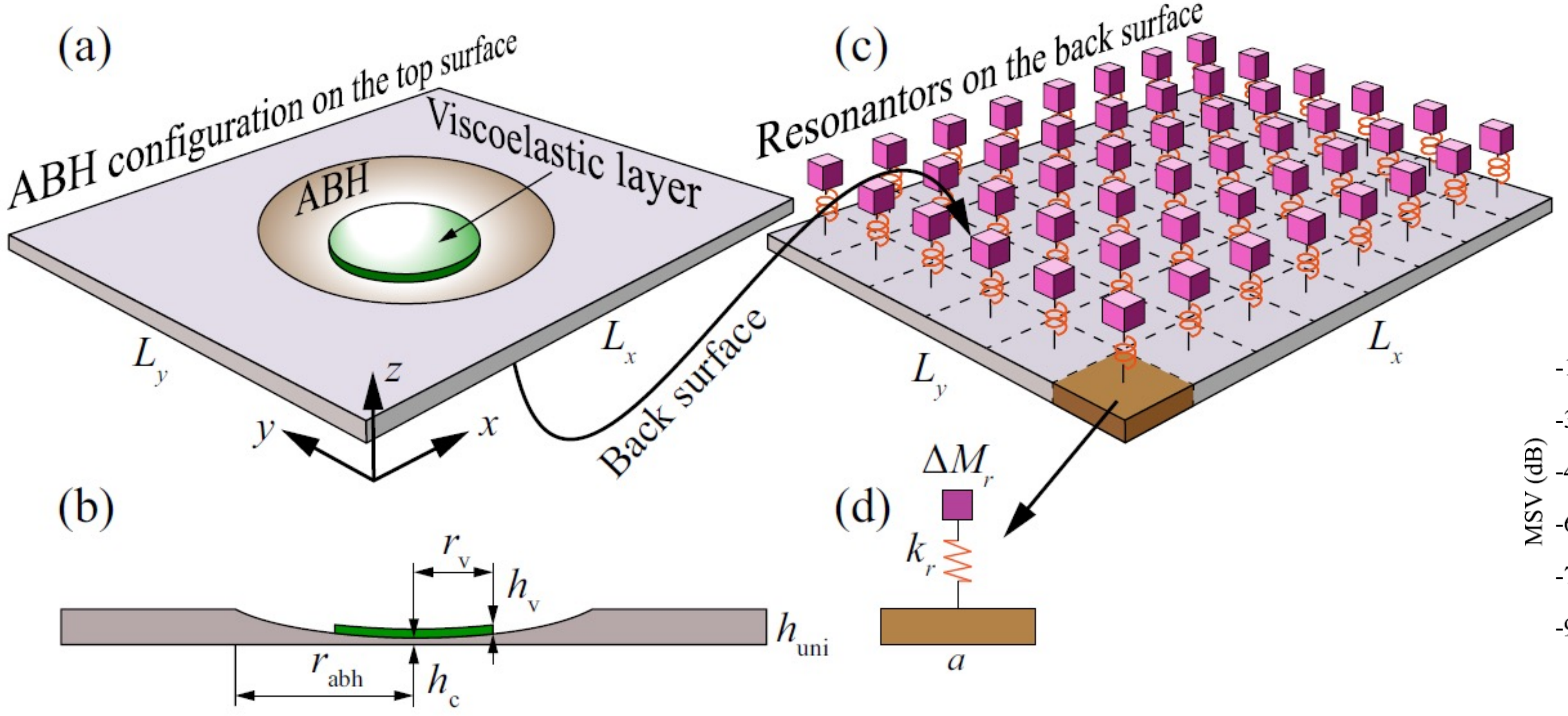
ABH termination from V. A. El-Ouahabi et al. ICSV (2015)

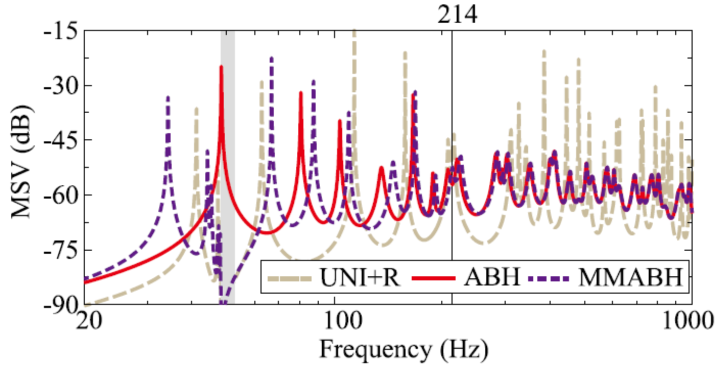
3D printed ABH termination from Mi et al. Appl. Phys. Lett. 118, 114101 (2021)



Jie Deng and Oriol Guasch (2023), "Sound waves in continuum models of periodic sonic black holes". Mech. Syst. Signal Process., 205, 110853.
Jie Deng, Oriol Guasch and Davide Ghilardi (2024), "Solution and analysis of a continuum model of sonic black hole for duct terminations". Appl. Math. Model., 129, pp. 191-206.

Combination of Acoustic metamaterials and black holes





J. Deng, O. Guasch, L. Maxit and N. Gao (2022), A metamaterial consisting of an acoustic black hole plate with local resonators for broadband vibration reduction. J. Sound Vib., 526, 116803.
J. Deng, O. Guasch, L. Maxit and N. Gao (2023), Sound radiation and non-negative intensity of a metaplate consisting of an acoustic black hole plus local resonators. Comp. Struct., 304, 116423.

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Conclusions i preguntes

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