MISS – Project

Minderung der Störwirkung von Windenergieanlagen auf seismologische Stationen

Gefördert durch:

EFRE.NRW
Investitionen in Wachstum und Beschäftigung

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

Teilprojekt WWU:
Mitigation of effects on the travel path – a theoretical approach

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MISS: Mitigation of induced seismic signals

Trying to avoid or reduce windturbine noise

- at the station (filters)
- at the source (metamaterials)
- on the way (metamaterials)

Photos from Simon Kremers

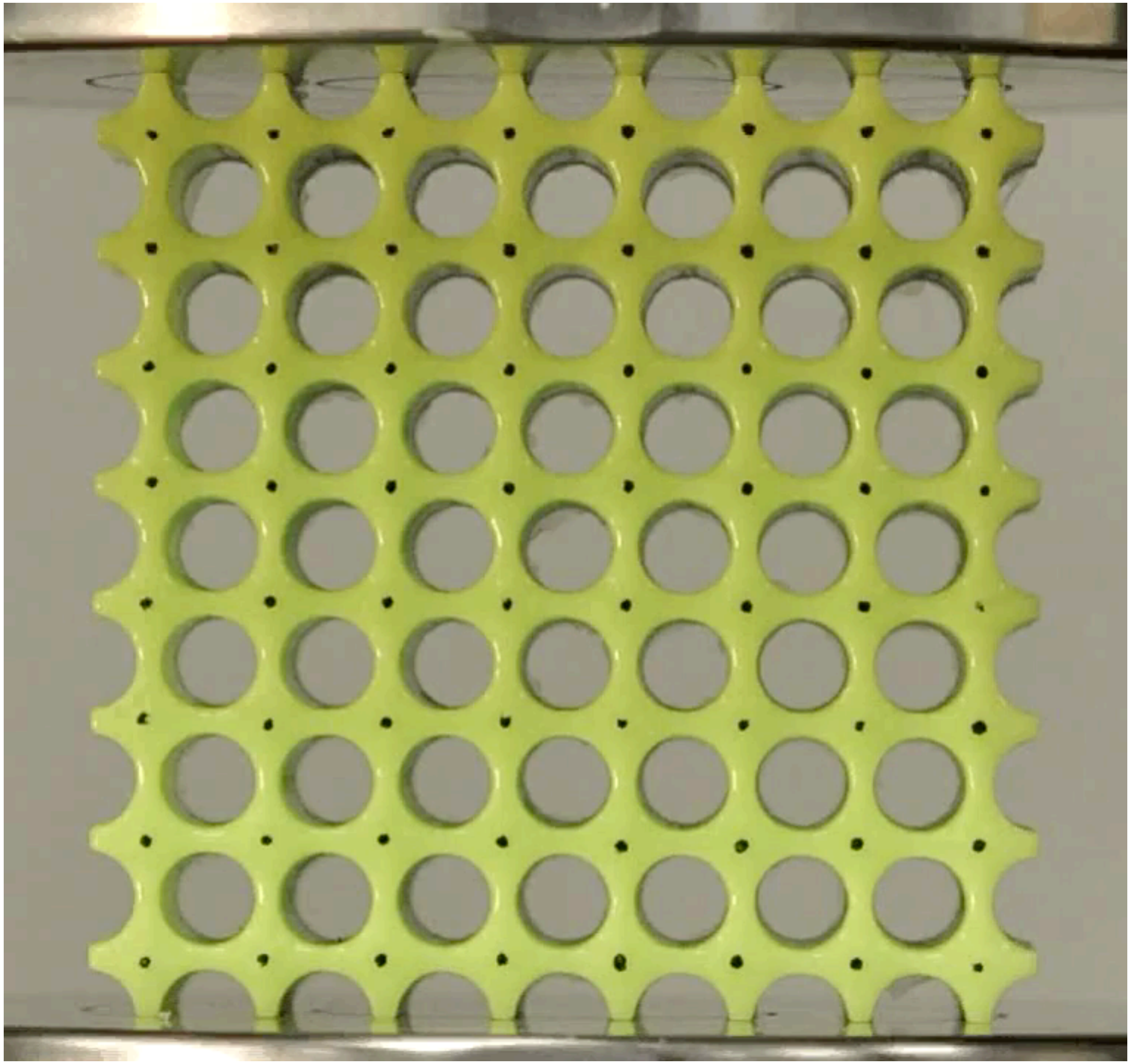
What are metamaterials?

Engineered materials that have unique properties **not found in nature**

Types of metamaterials

- ✓ **Electromagnetic**
- ✓ **Acoustic**
- ✓ **Elastic**

Elastic metamaterials

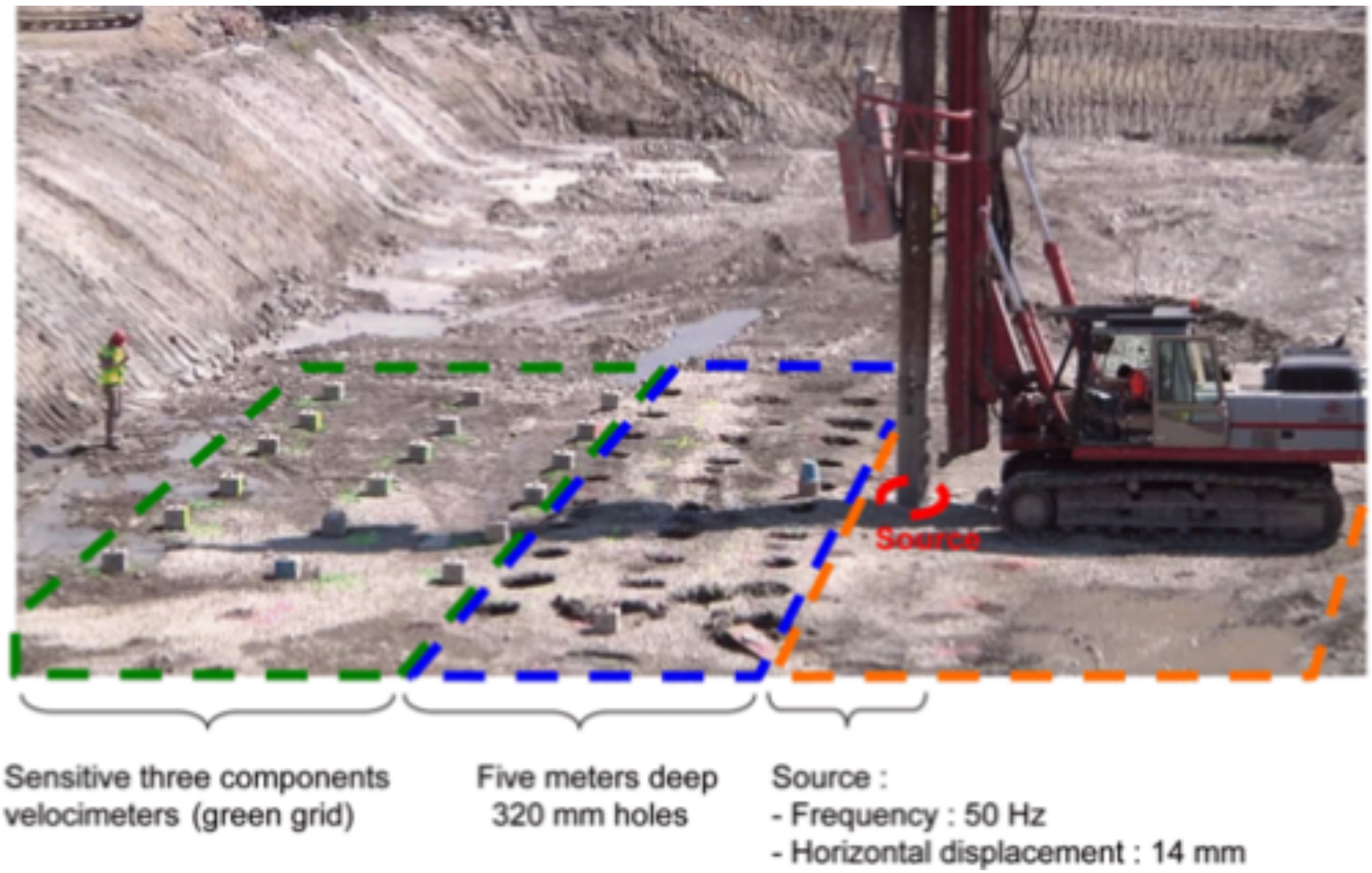


Types of seismic metamaterials

- **Seismic soil metamaterials**
- **Above surface resonators**
- **Buried mass resonators**

Seismic soil metamaterials

Previous experiments near the alpine city of Grenoble (France) August 2015

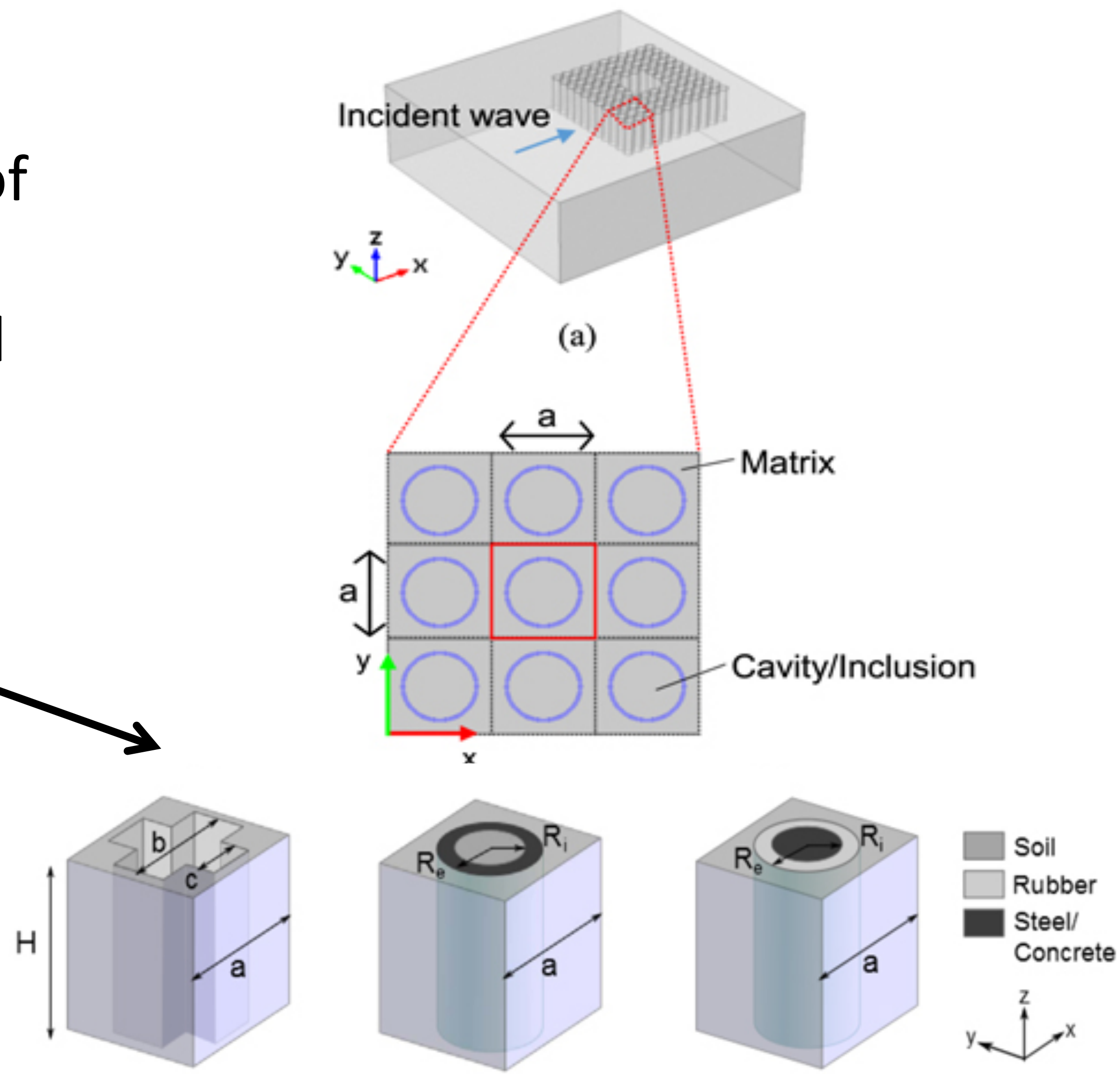


First realistic numerical experiment

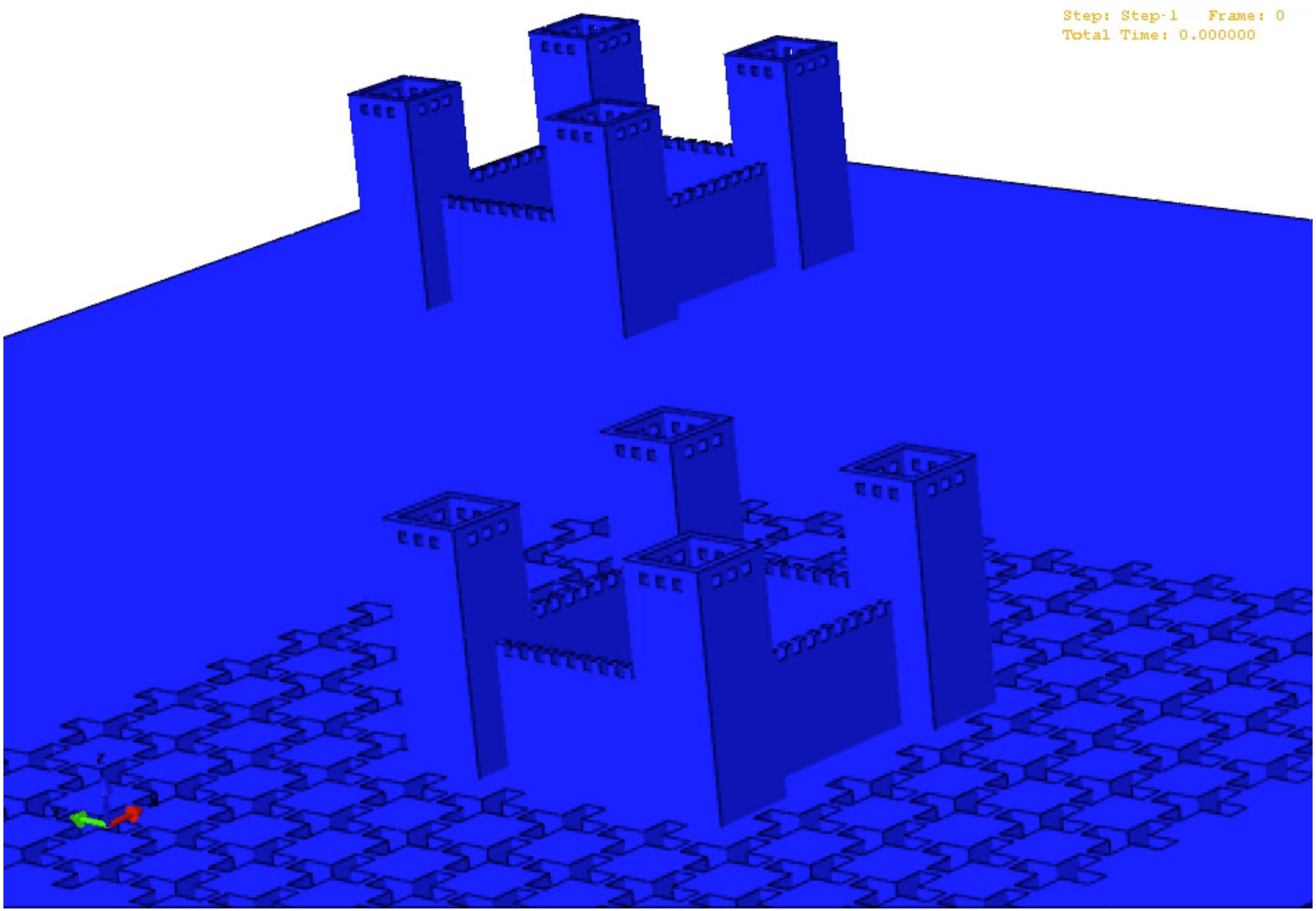
Miniacci et al. (2016). Large scale mechanical metamaterials as seismic shields

To study the combination of different materials and shapes

different shapes and materials



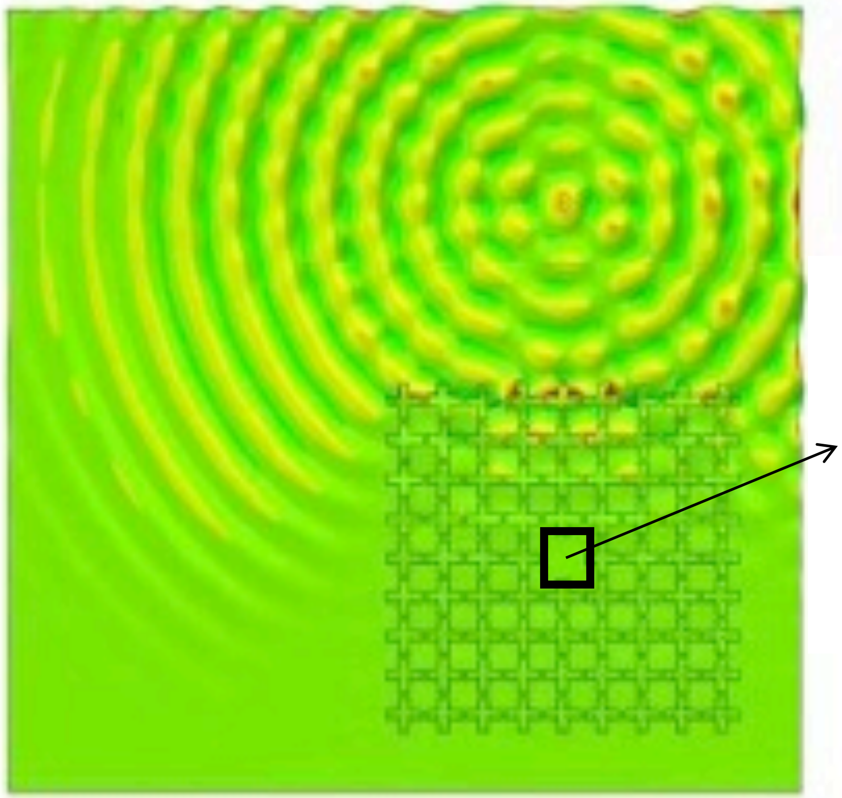
Seismic soil-metamaterials

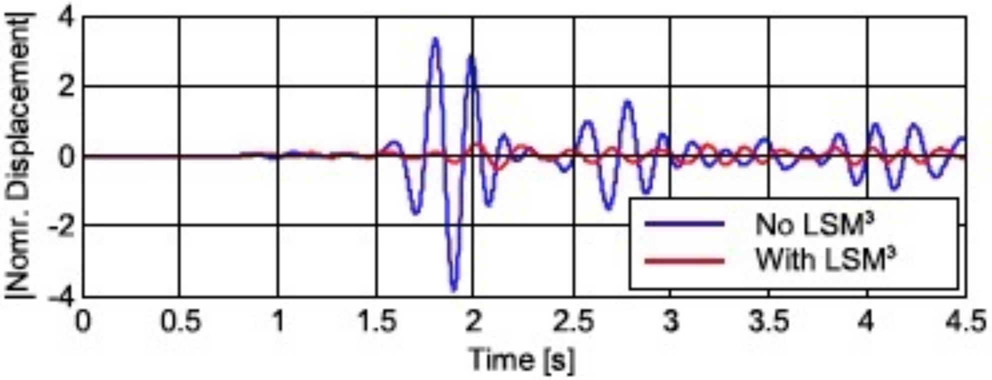


Miniaci et al. 2016

RESULTS

Finite element simulation at 5Hz





LSM- Large Scale Metamaterial

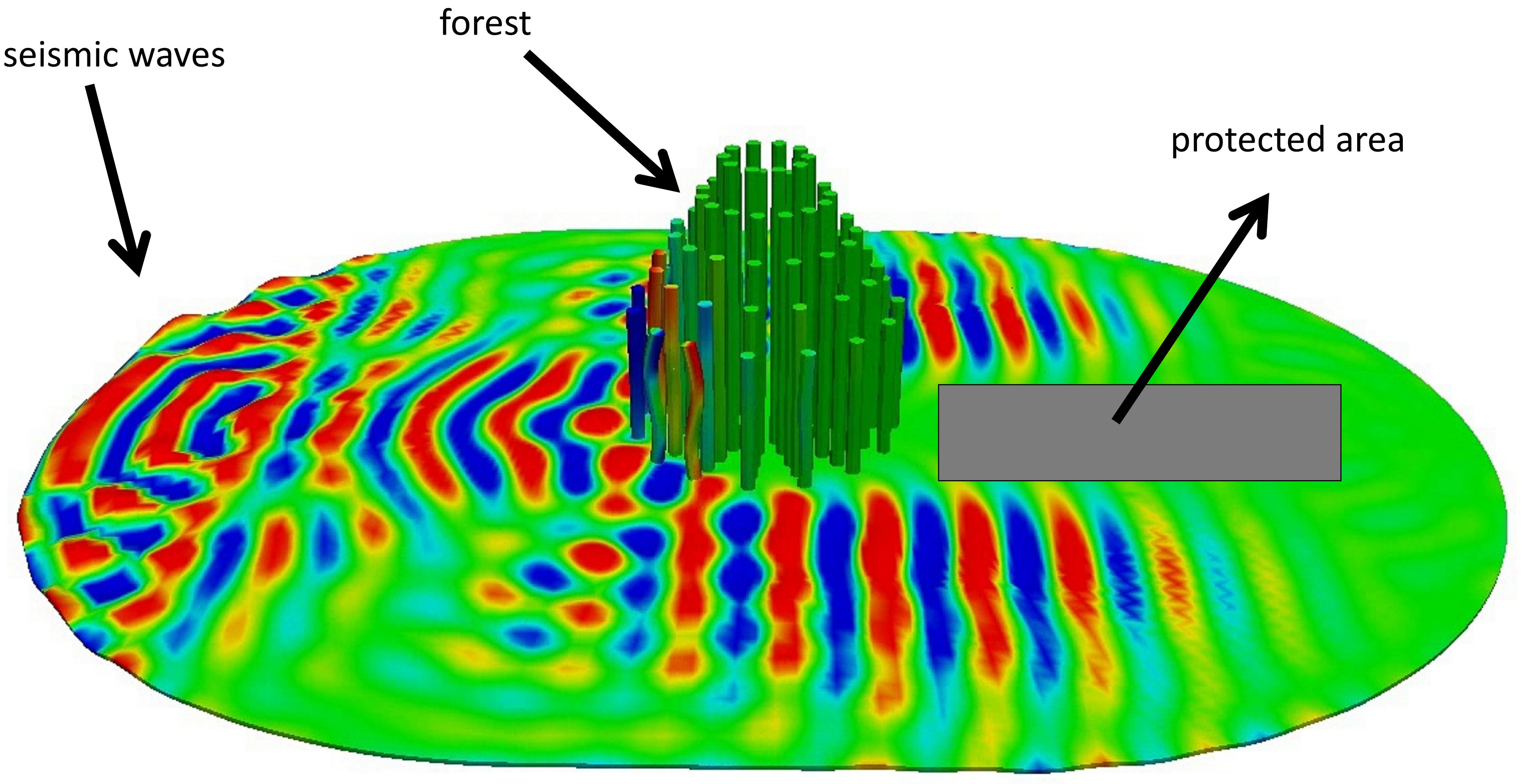
Dimensions of 200 x 200 x 100 m^3

9x9 grid of metamaterials of 10m deep

Miniaci et al. 2016

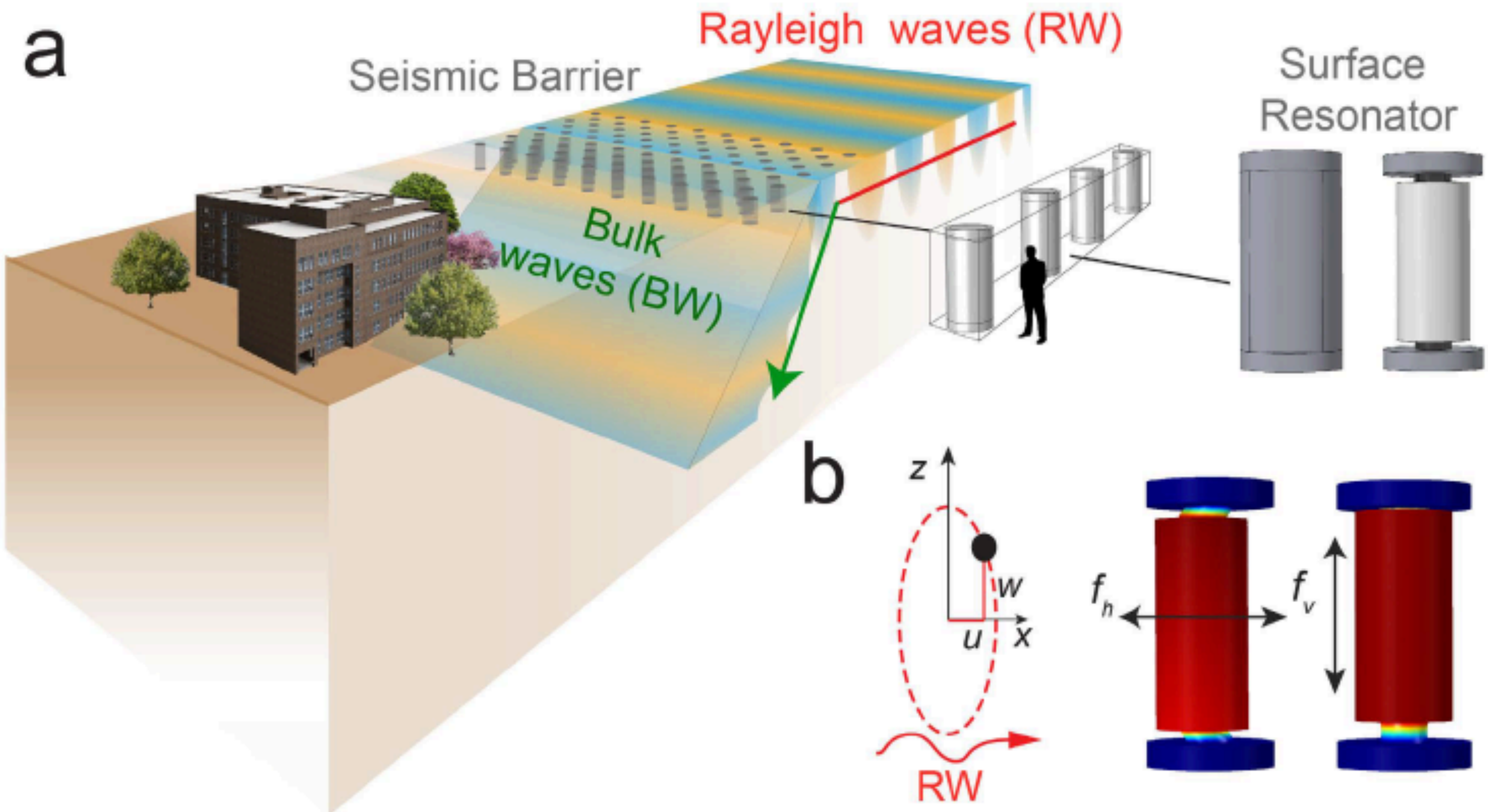
Above surface resonators

Colombi et al. (2016) Forests as a natural seismic metamaterial.

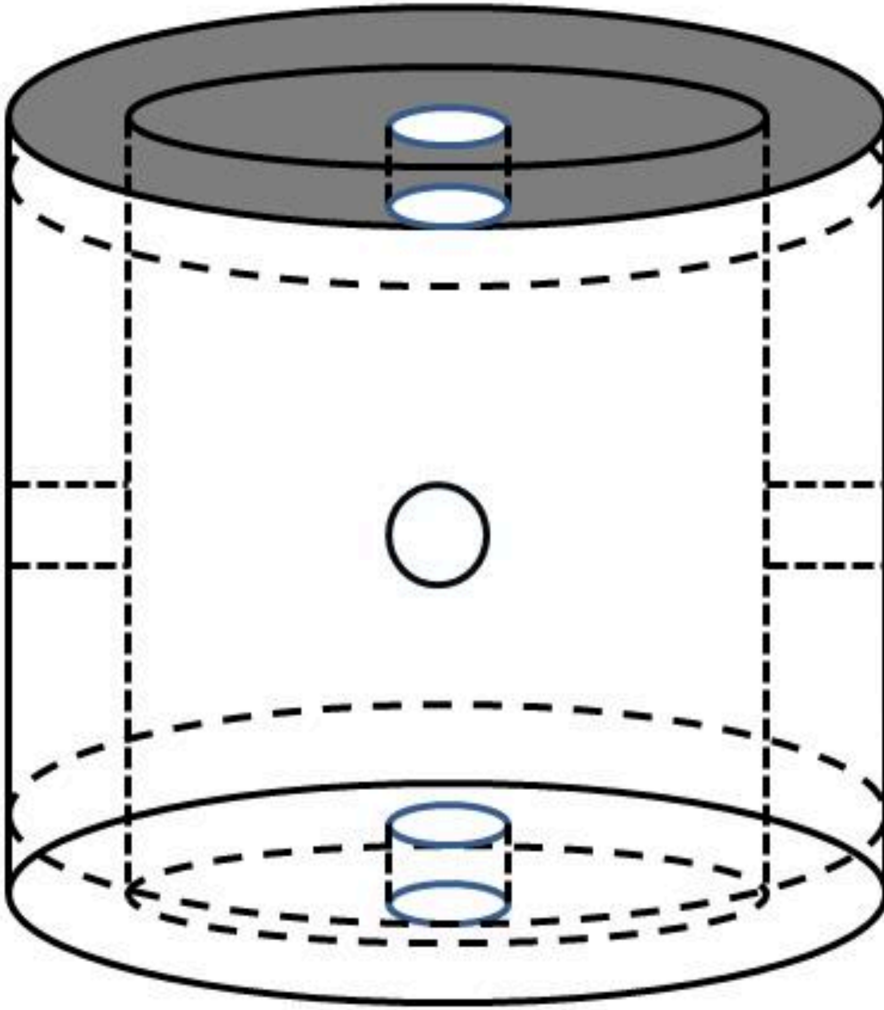


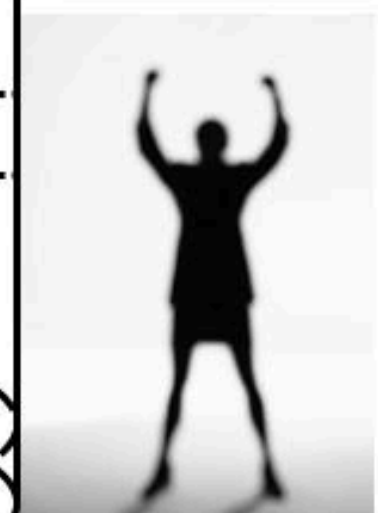
Forests as seismic metamaterials

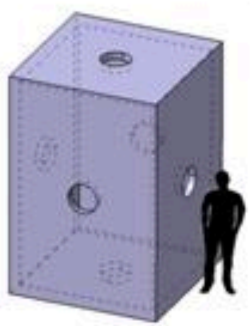
Buried mass resonators

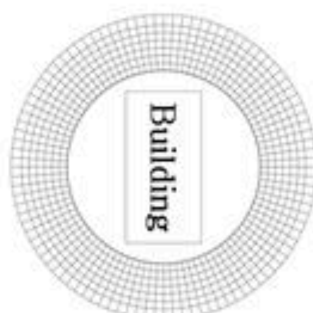


From Palermo et al. 2016

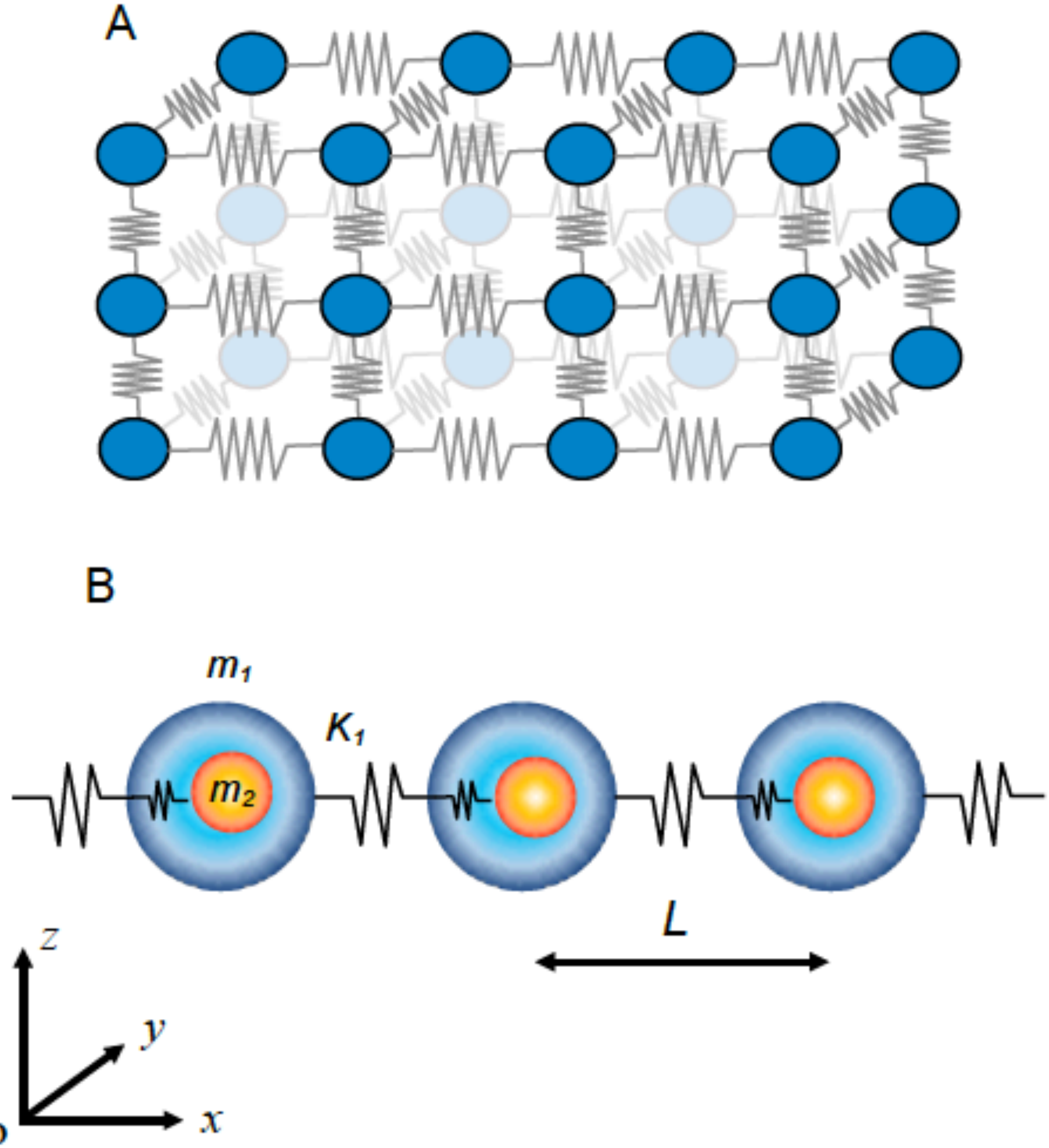








http://acoustics.org/pressroom/httpdocs/163rd/Kim_2aEA8.html



From Brûlé et al. 2018

How do we numerically design metamaterials?

- ✓ **Base your design on a theory of wave propagation** (electromagnetic, acoustic, elastic,…)
- ✓ **Perform numerical simulations**
- Code installation (development)
- Mesh generation
- Parameter selection
- Run simulations
- ✓ **Predictions** (and most probably redesign)

Theory of wave propagation: Conventional elasticity

$$\rho \frac{\partial^2 u}{\partial t^2} = \nabla \cdot \sigma$$

$$\sigma = C : \epsilon$$

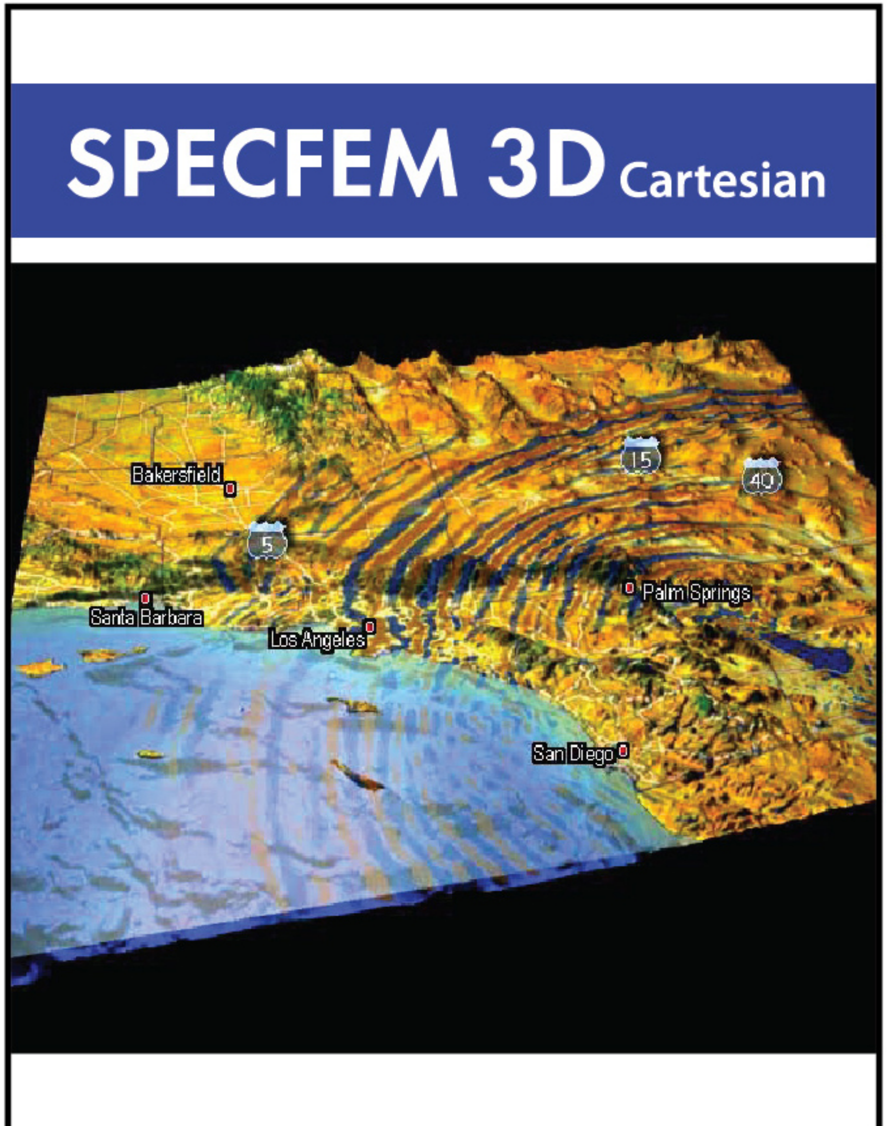
$$\epsilon = \frac{1}{2}(\nabla u + (\nabla u)^T)$$

u = displacement field

ϵ = strain tensor

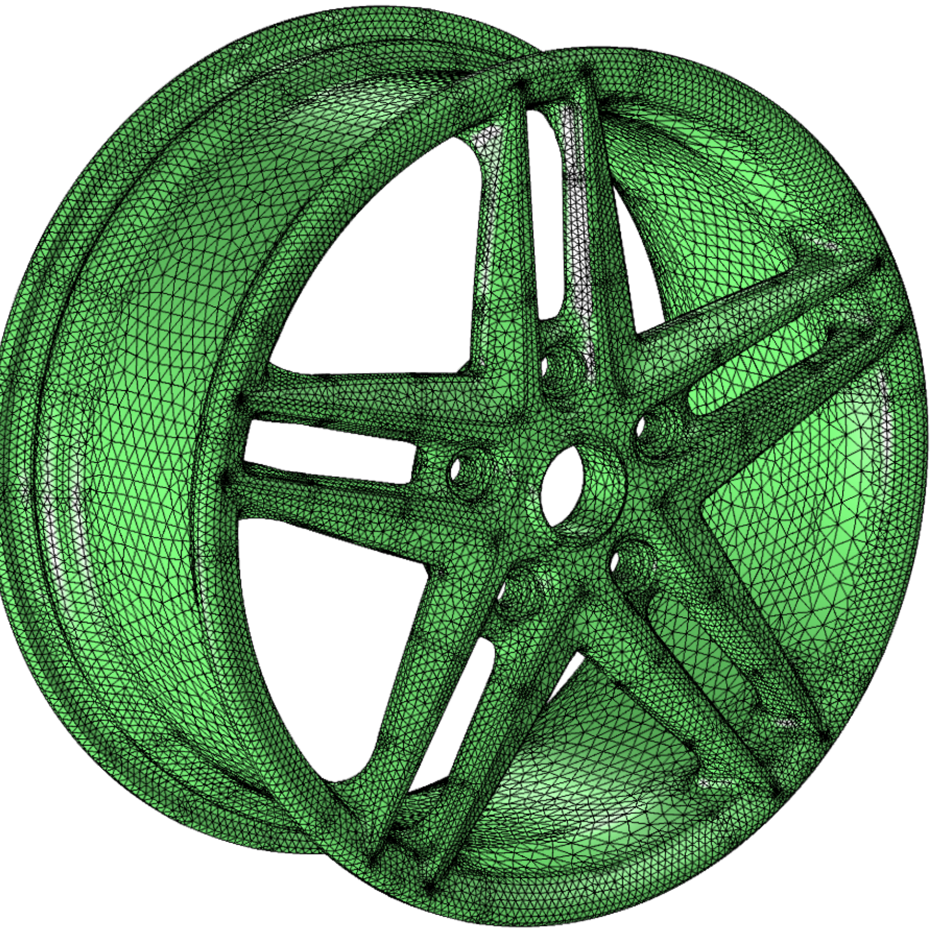
σ = stress tensor

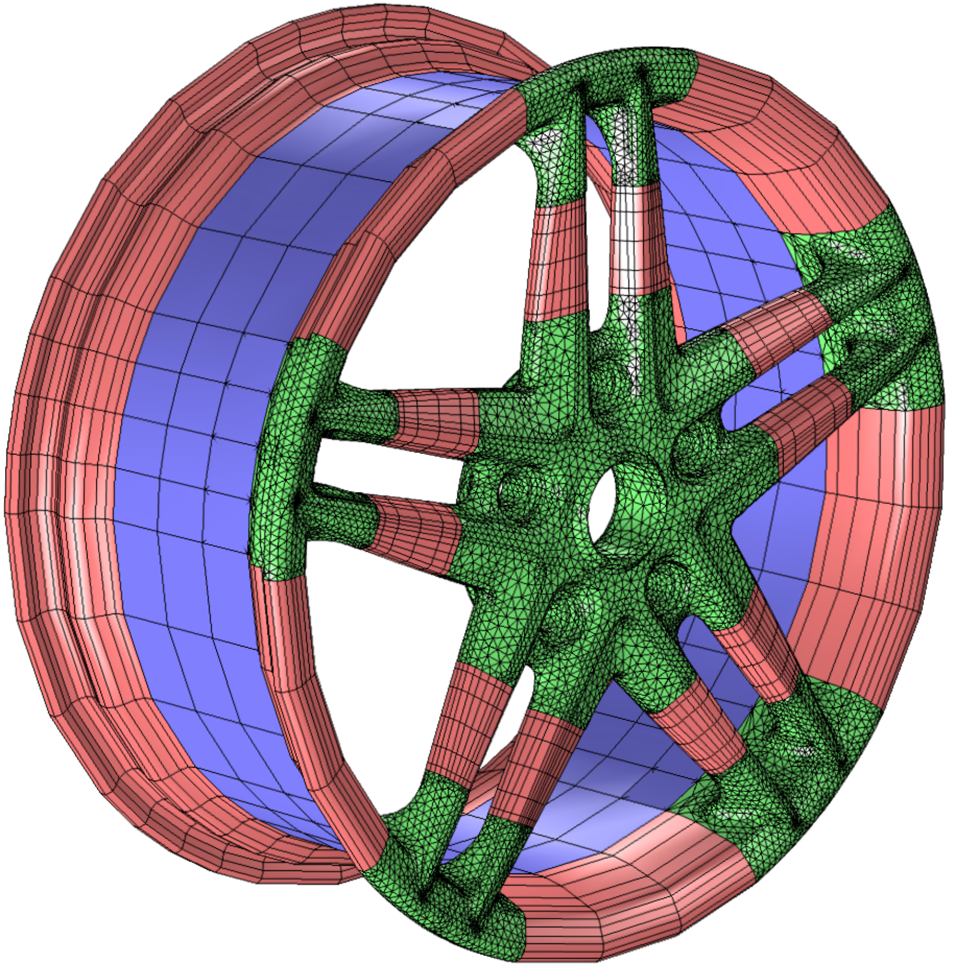
Code selection and installation



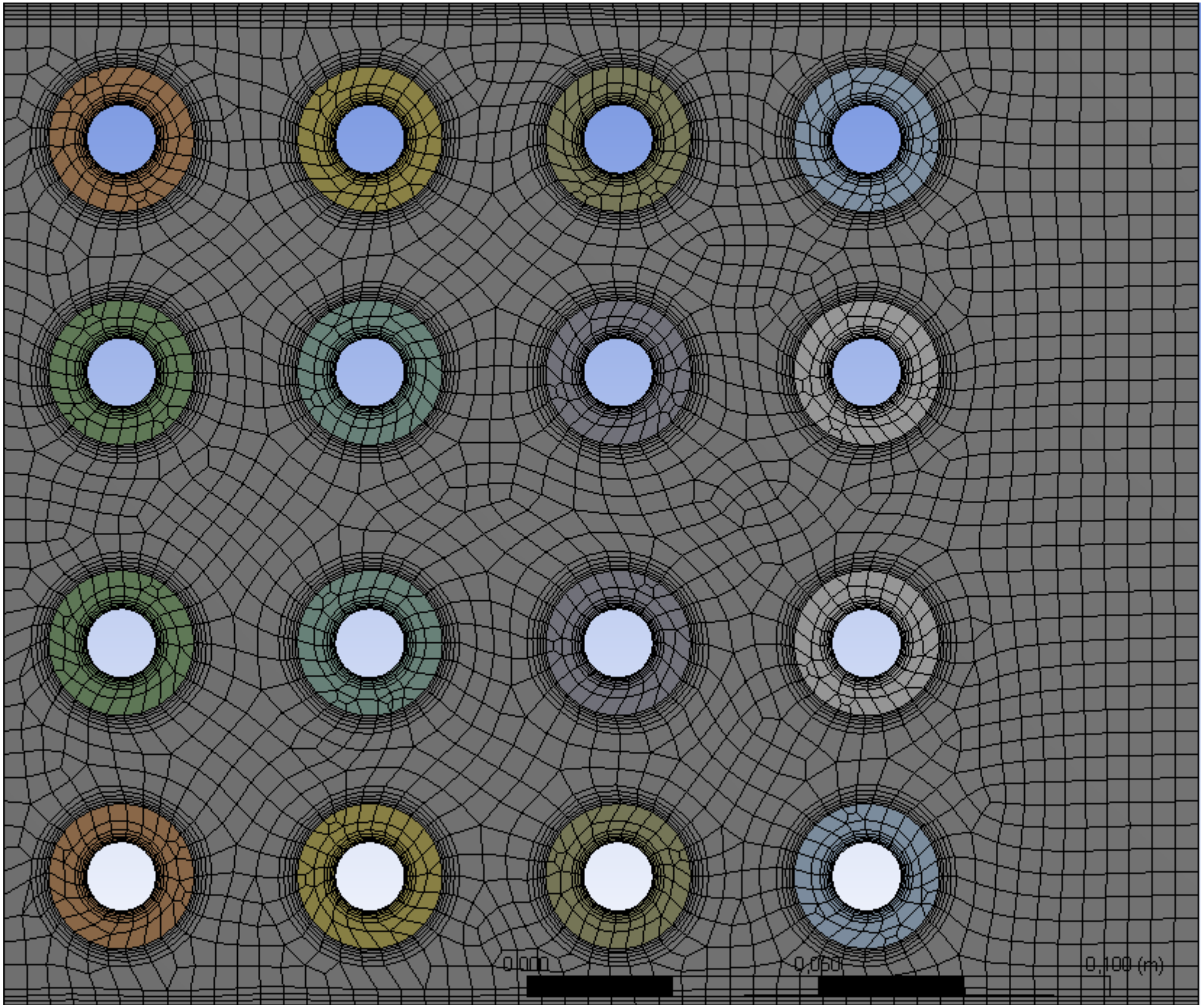
- ✓Elastic, acoustic and poroelastic media.
- ✓Installation of the code in the University cluster and in personal PC.
- ✓First tests simulations running properly.
- ✓Mesh generation ….

What is a numerical mesh?



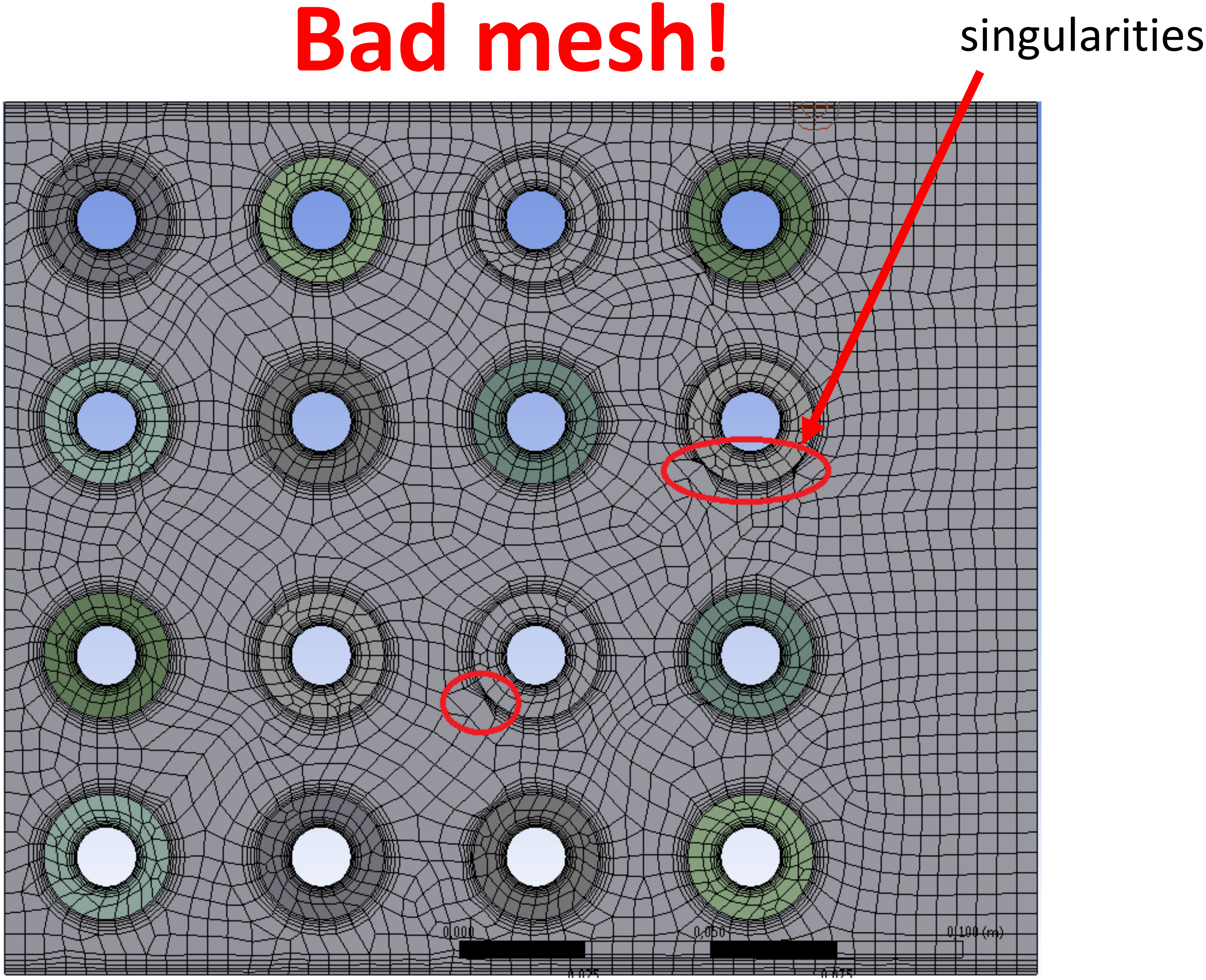


Good mesh!

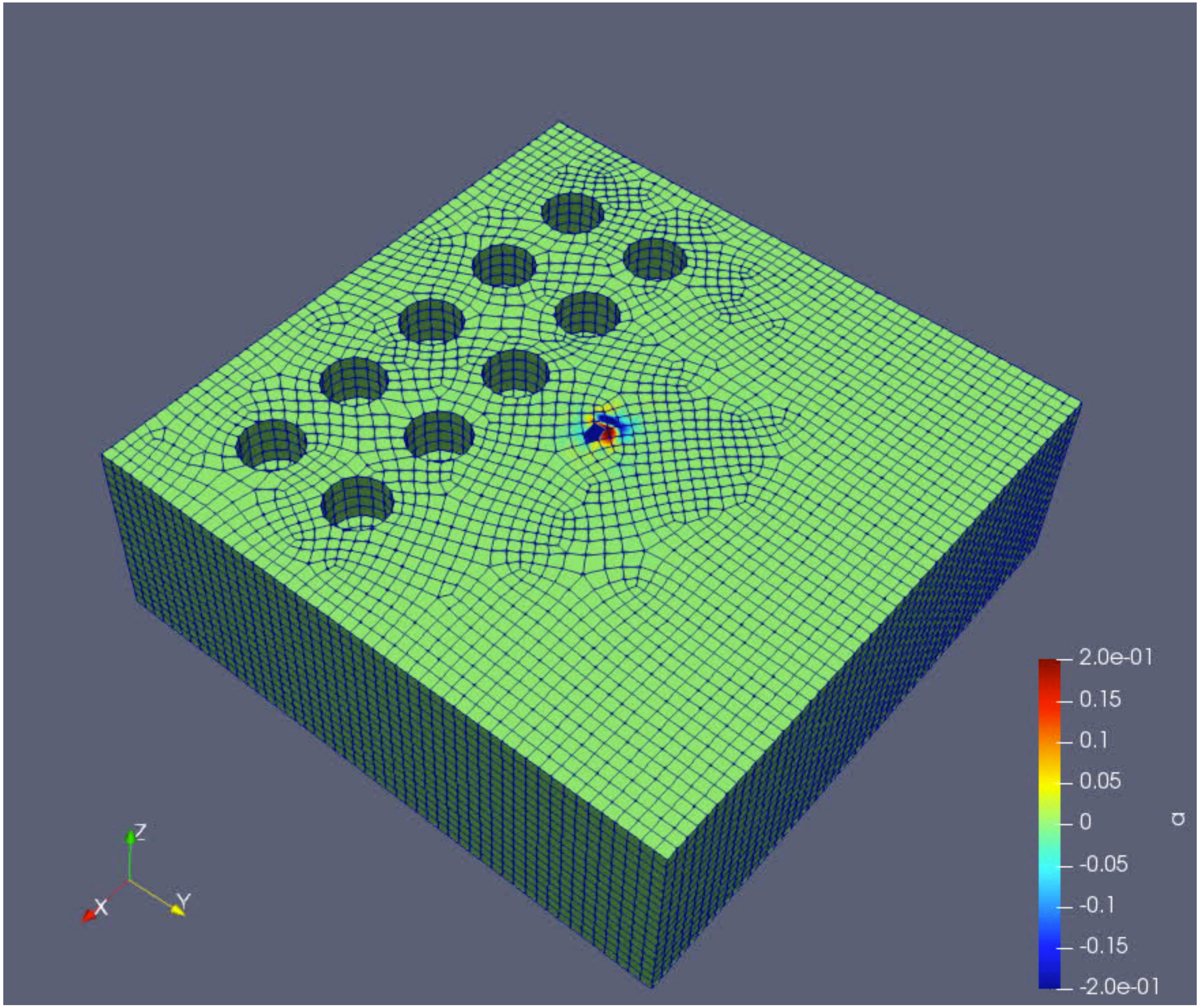


Not very distorted elements

Bad mesh!

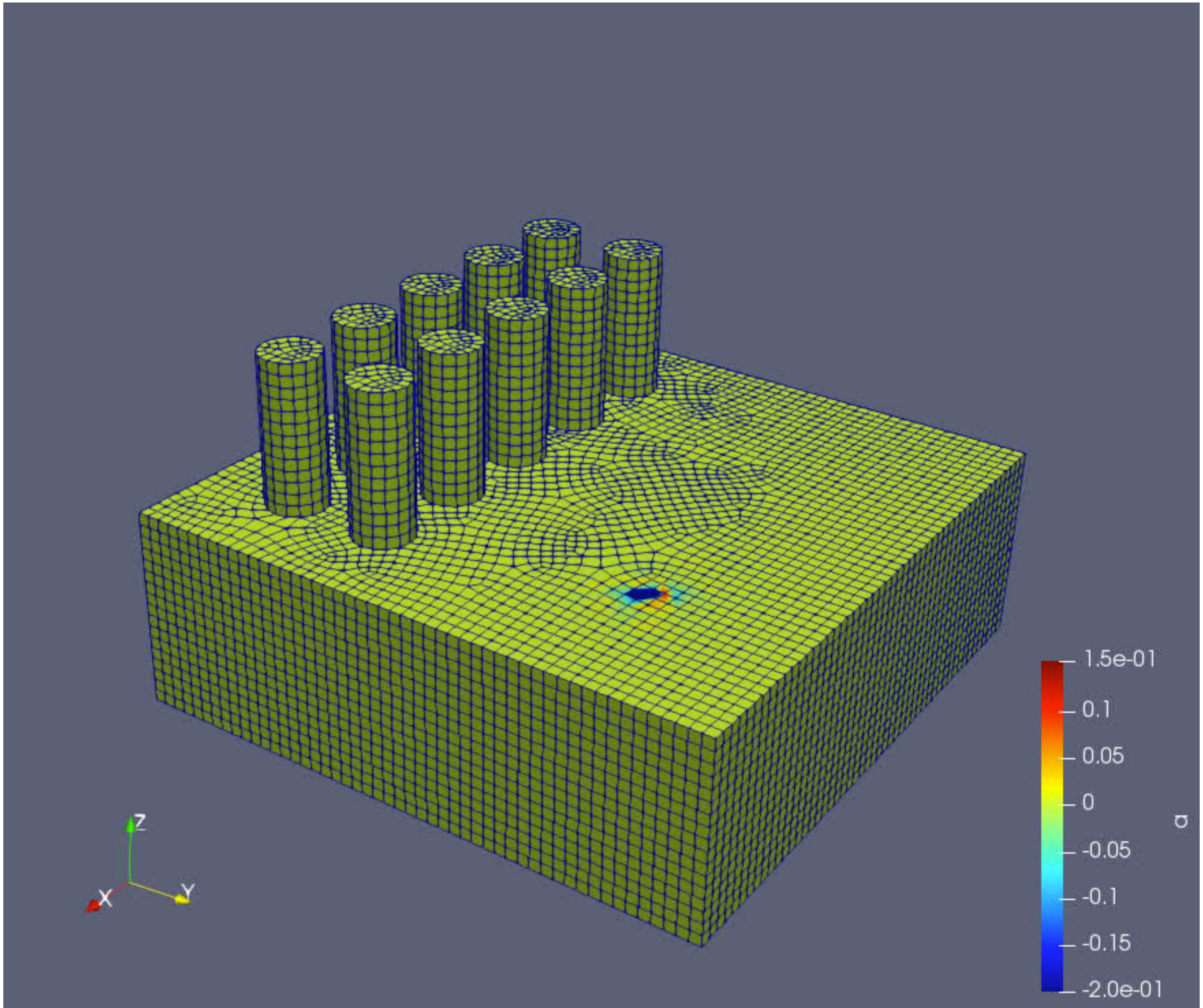


Simulations with SPECFEM3D

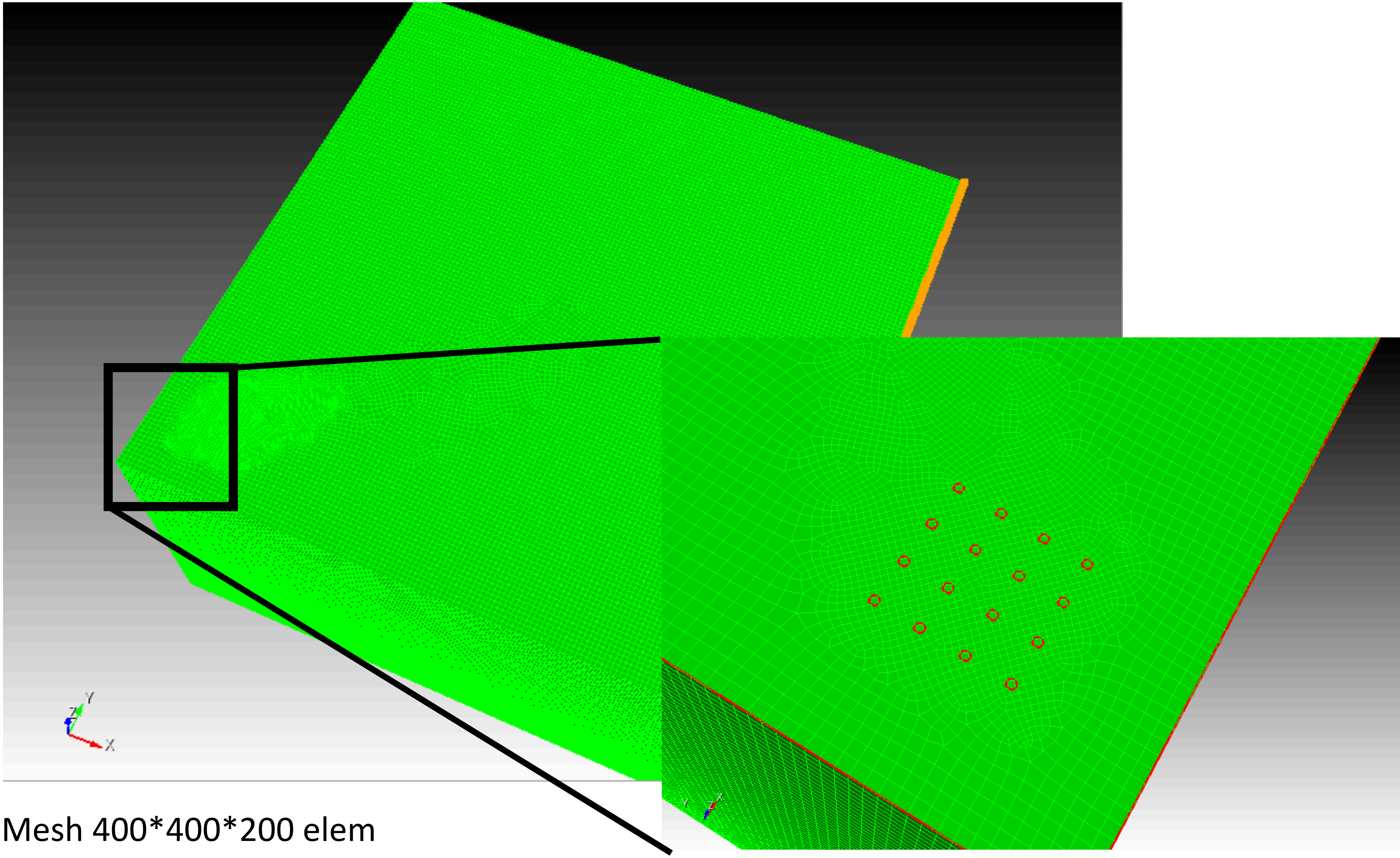


Mesh 50x50x17
approx 42500 elem
approx 1062500
nodes

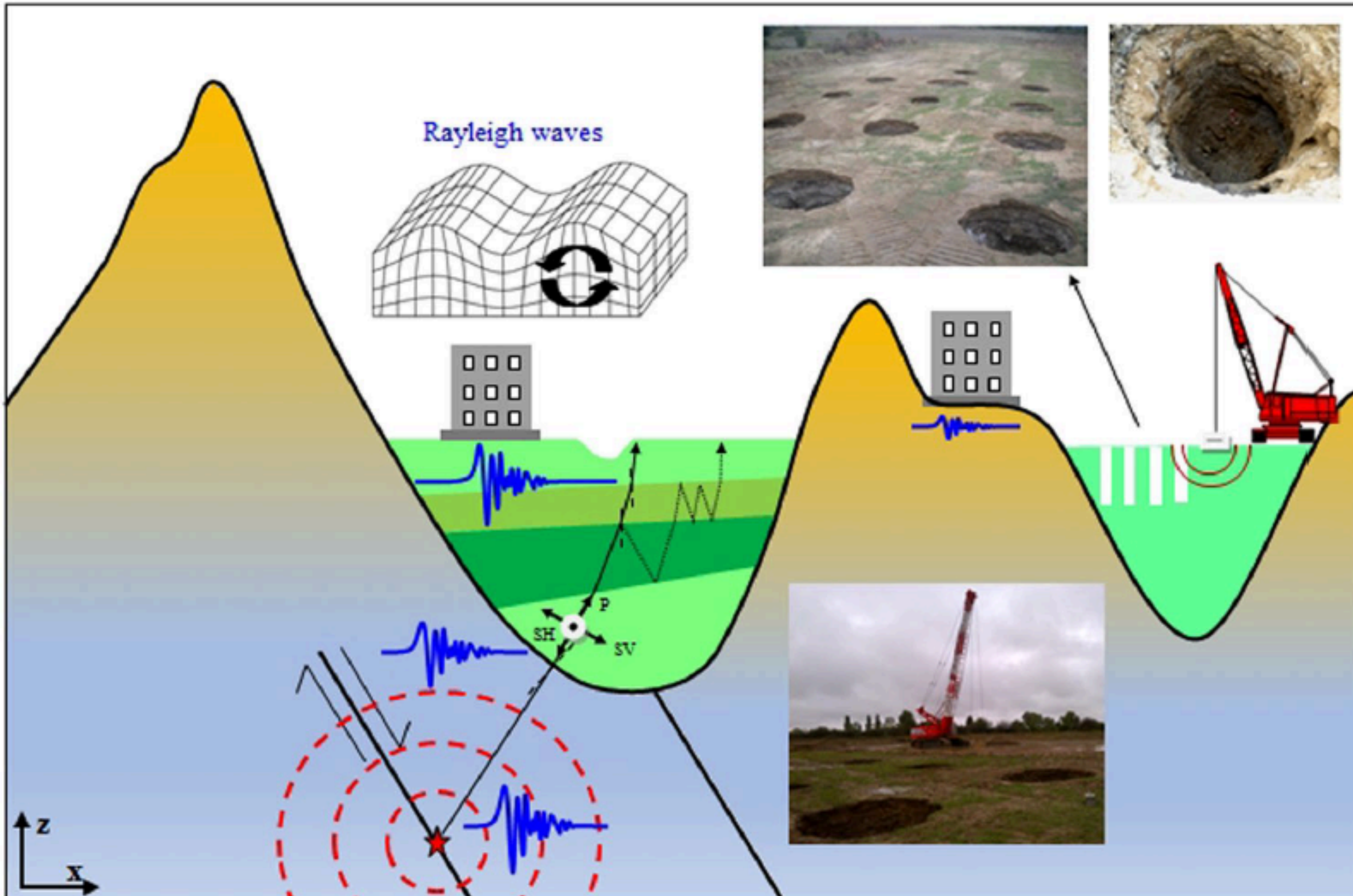
Simulations with SPECFEM3D



Realistic mesh 40 x 40 x 20 km



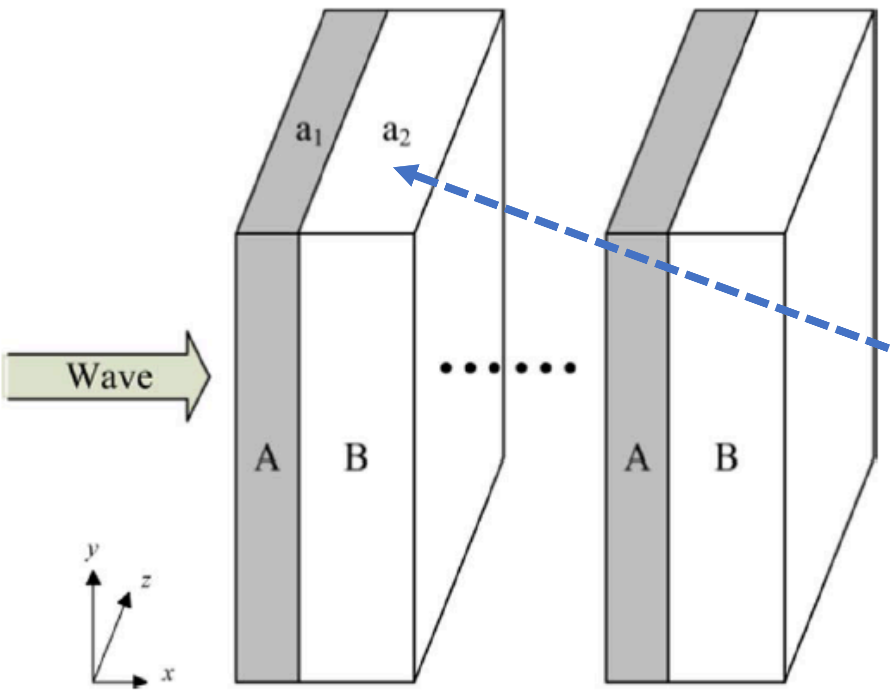
Mesh 400*400*200 elem
800 million nodes



Brûlé et al. 2018

Metamaterials size prediction

1D metamaterials



(Geng et al. 2018)

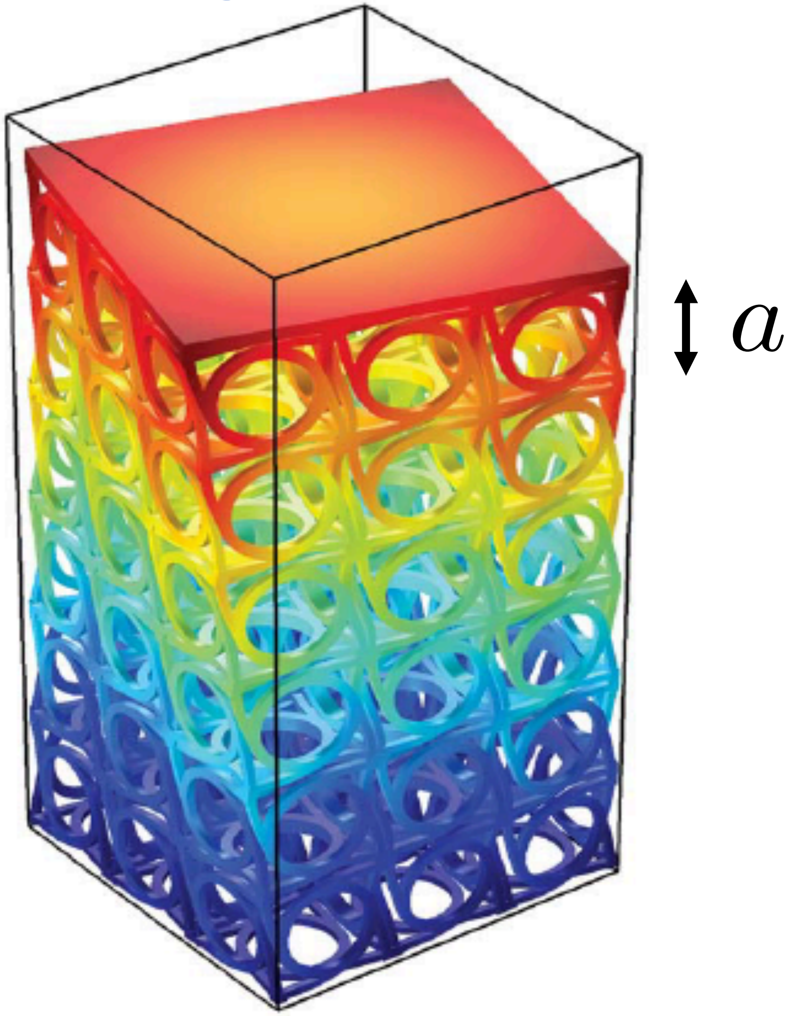
$$\lambda < 15.5a$$

$$\lambda = \text{wavelength}$$

$$a = a_1 + a_2$$

For a soil with v=900 m/s if one look for attenuating waves with frequencies larger than 1Hz, we must have **a> 58 m**

Use of generalized continuum models



(Frenzel et al. 2017)

No wave propagation (frequency bad gap) at

$$\frac{a}{\lambda} \approx 0.035$$

$$\lambda = \text{wavelength}$$

For a soil with v=900 m/s if one look for attenuating waves with frequencies larger than 1Hz, we must have **a> 31.5 m**

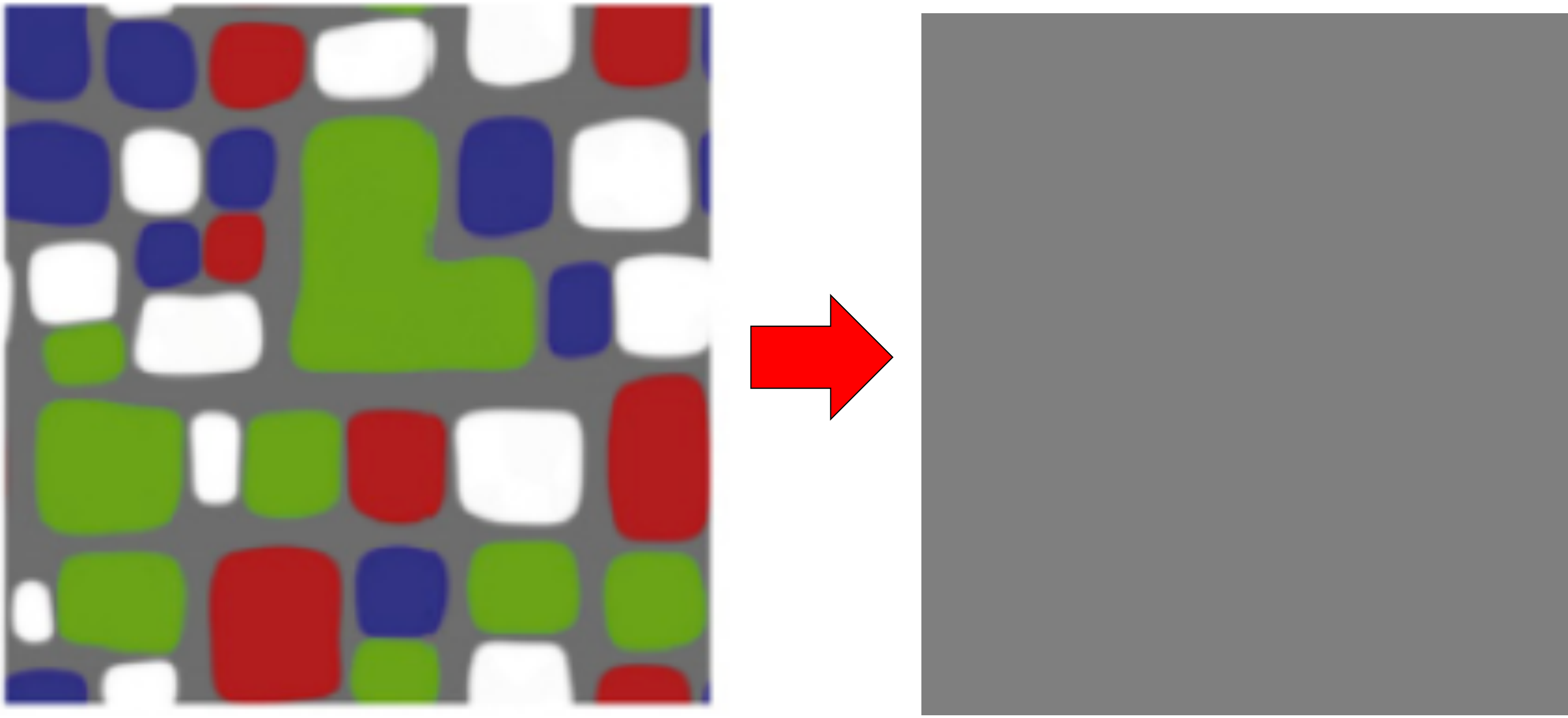
HALF the size of 1D metamaterials

Generalized continuum models

Generalized continuum models

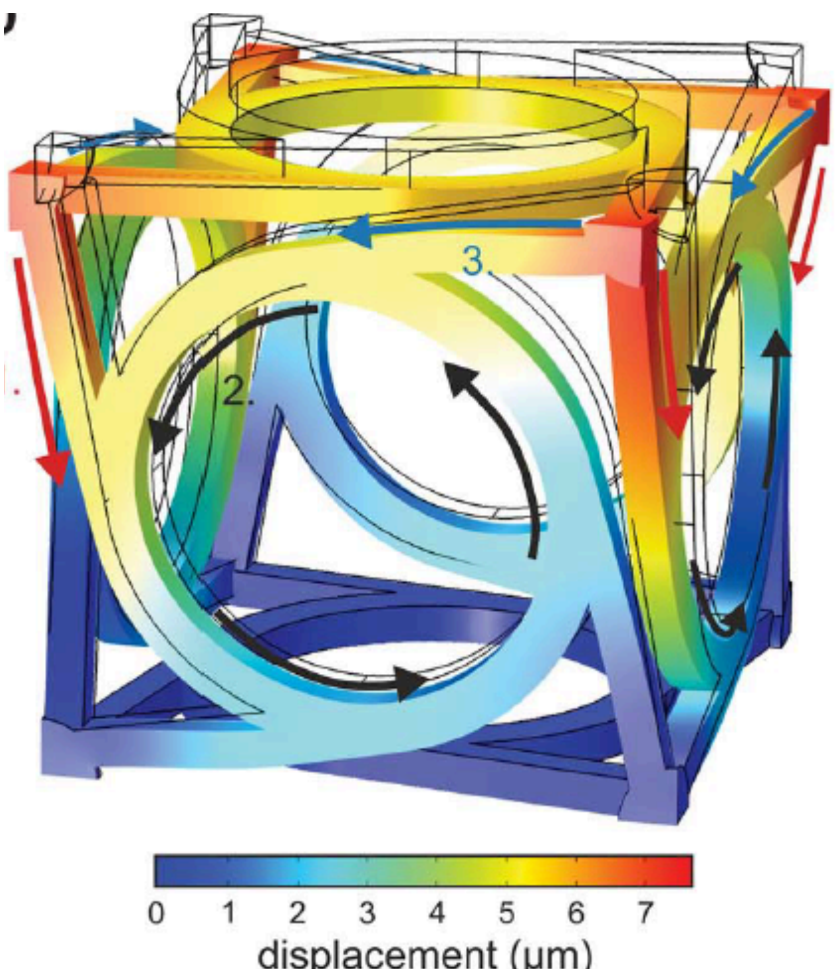
Conventional elasticity

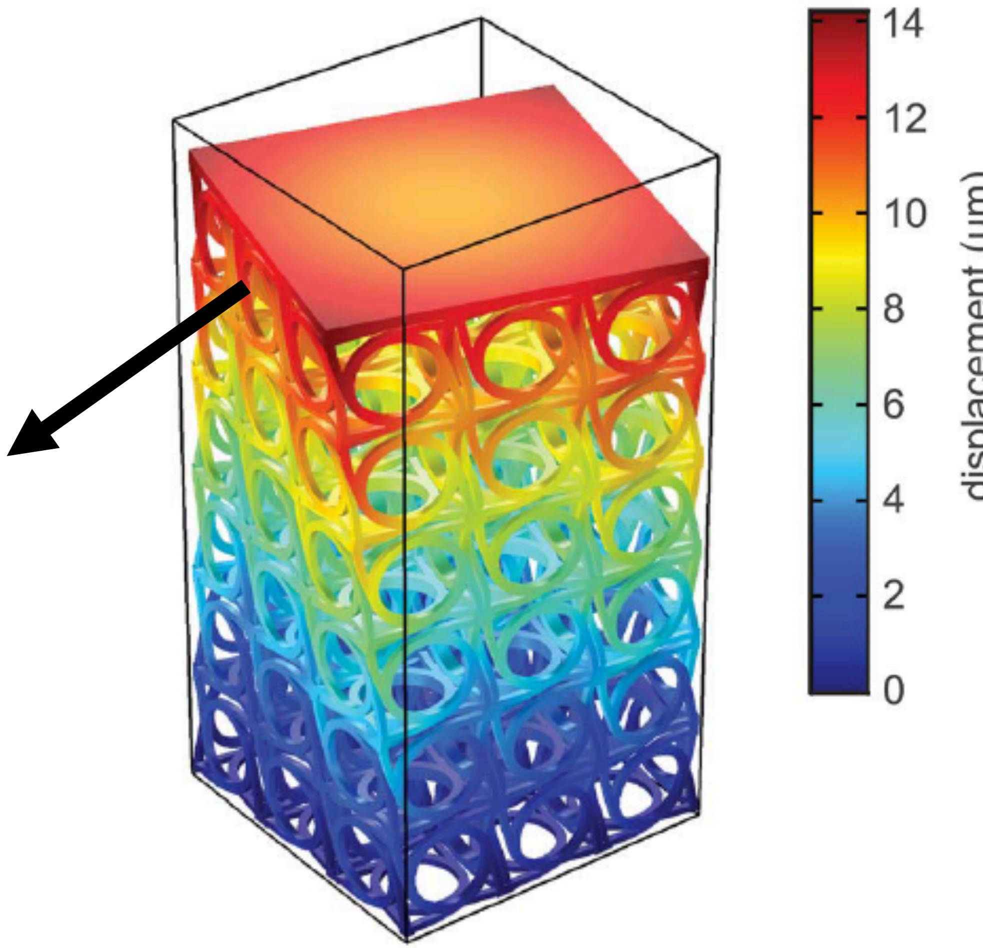
Micropolar elasticity



The micropolar model incorporates intrinsic rotational degrees of freedom

Conventional Elasticity?

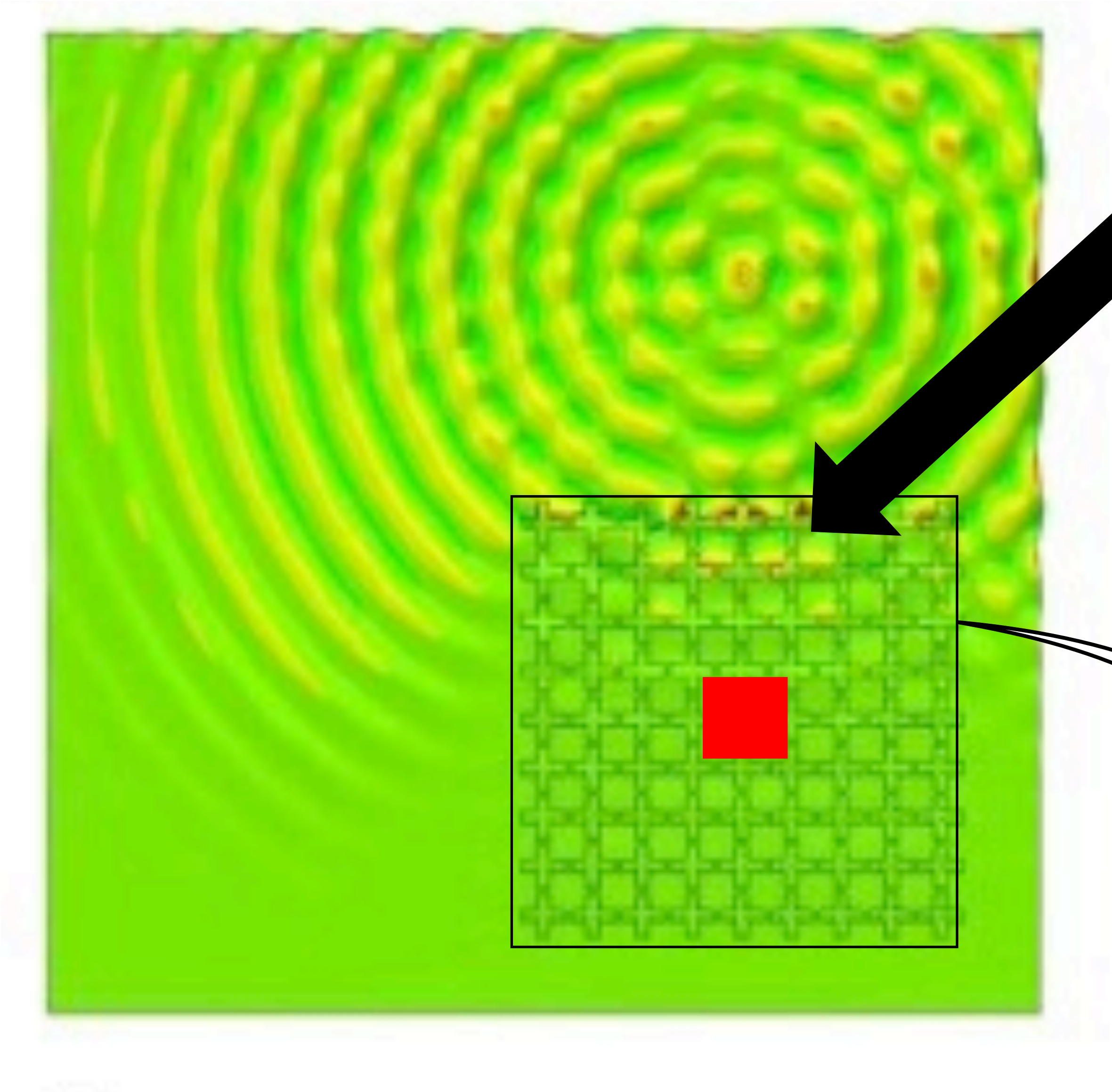


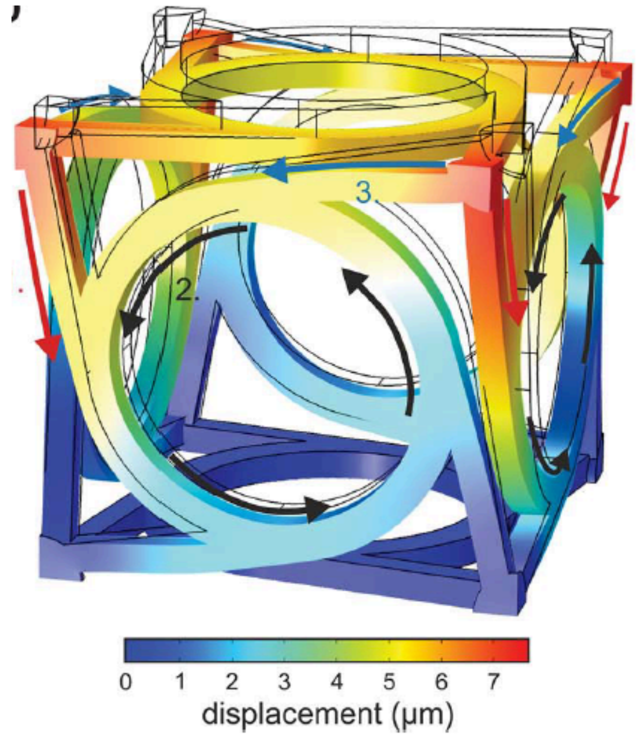


Bloch-Flocket analysis

Frenzel et el. 2017

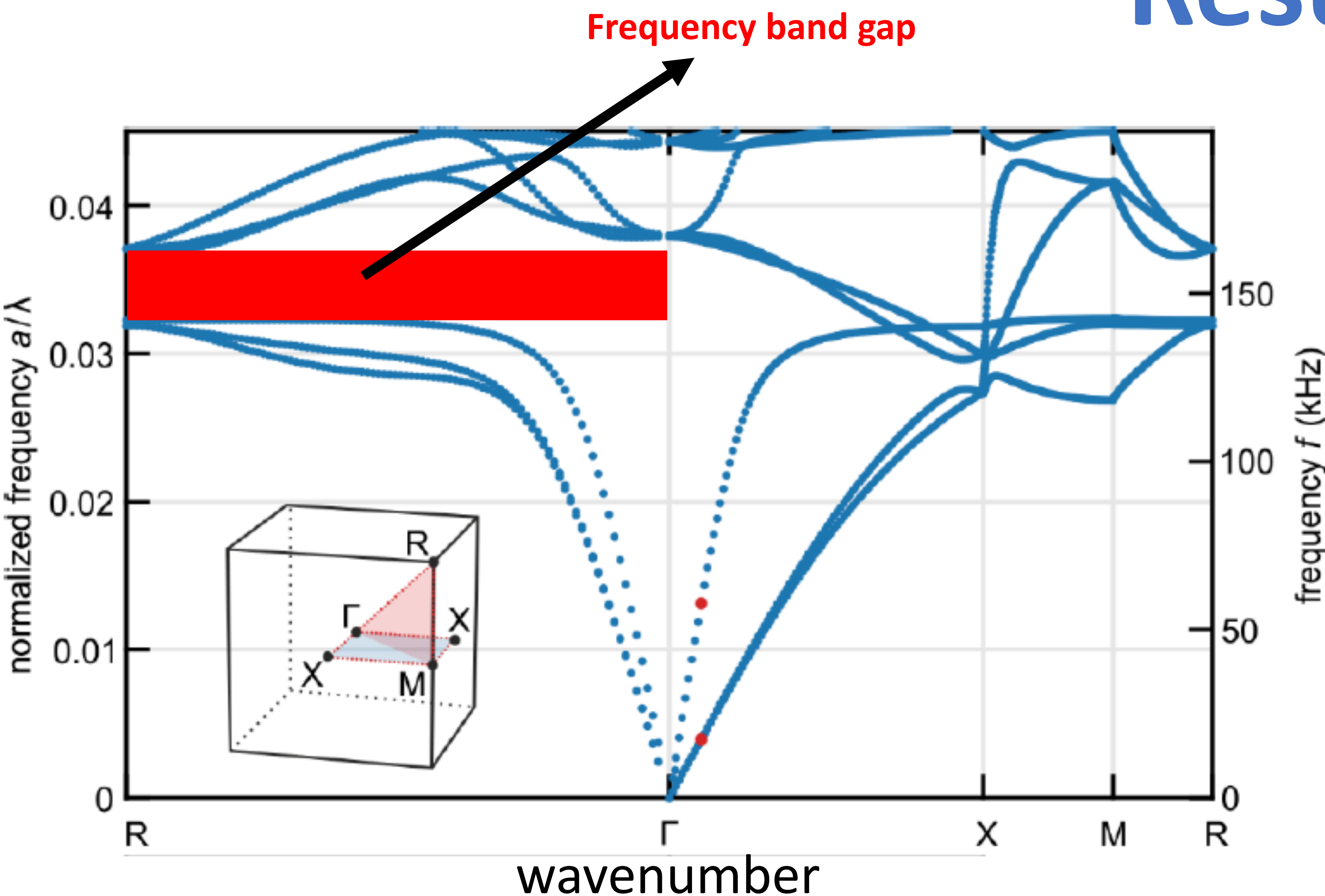
THE IDEA





Micropolar elasticity

Results



Possibility to filter to certain frequencies!!

lattice constant a and the wavelength λ

SUMMARY

- ✓ **Setting up simulation with SPECFEM3D.**
- ✓ **Mesh generation with Cubit/Trelis.**
- ✓ **Installation of SPECFEM3D in the cluster.**
- ✓ **Currently running: realistic setup without metamaterials.**
- ✓ **Understanding effects of metamaterials and micropolar media (for less cost intensive option).**

NEXT TASKS

- Studying wind-park effects as seismic sources.
- Comparing measured data to simulated data using SPECFEM3D.
- Studying dispersion relations of the micropolar model.
- Writing 2D and 3D code in Fortran for running micropolar simulations.

Conventional elasticity

$$\frac{\partial^2 u_y}{\partial t^2} = \frac{\mu}{\rho}\frac{\partial^2 u_y}{\partial x^2} \quad \text{with} \quad v_s = \sqrt{\frac{\mu}{\rho}}$$

Conventional elasticity

$$\frac{\partial^2 u_y}{\partial t^2} = \frac{\mu}{\rho}\frac{\partial^2 u_y}{\partial x^2} \qquad \text{with} \qquad v_s = \sqrt{\frac{\mu}{\rho}}$$

Micropolar elasticity

$$\frac{\partial^2 u_y}{\partial t^2} = \frac{\mu + \mu_c}{\rho}\frac{\partial^2 u_y}{\partial x^2} - \frac{2\mu_c}{\rho}\frac{\partial \theta_z}{\partial x}$$

$$\frac{\partial^2 \theta_z}{\partial t^2} = \frac{2\mu_c}{\eta}\frac{\partial u_y}{\partial x} - \frac{4\mu_c}{\eta}\theta_z$$

θ = spin

μ_c = Cosserat couple modulus

η = micro-inertia density