Acoustics of porous media

Lecture 1: Overview

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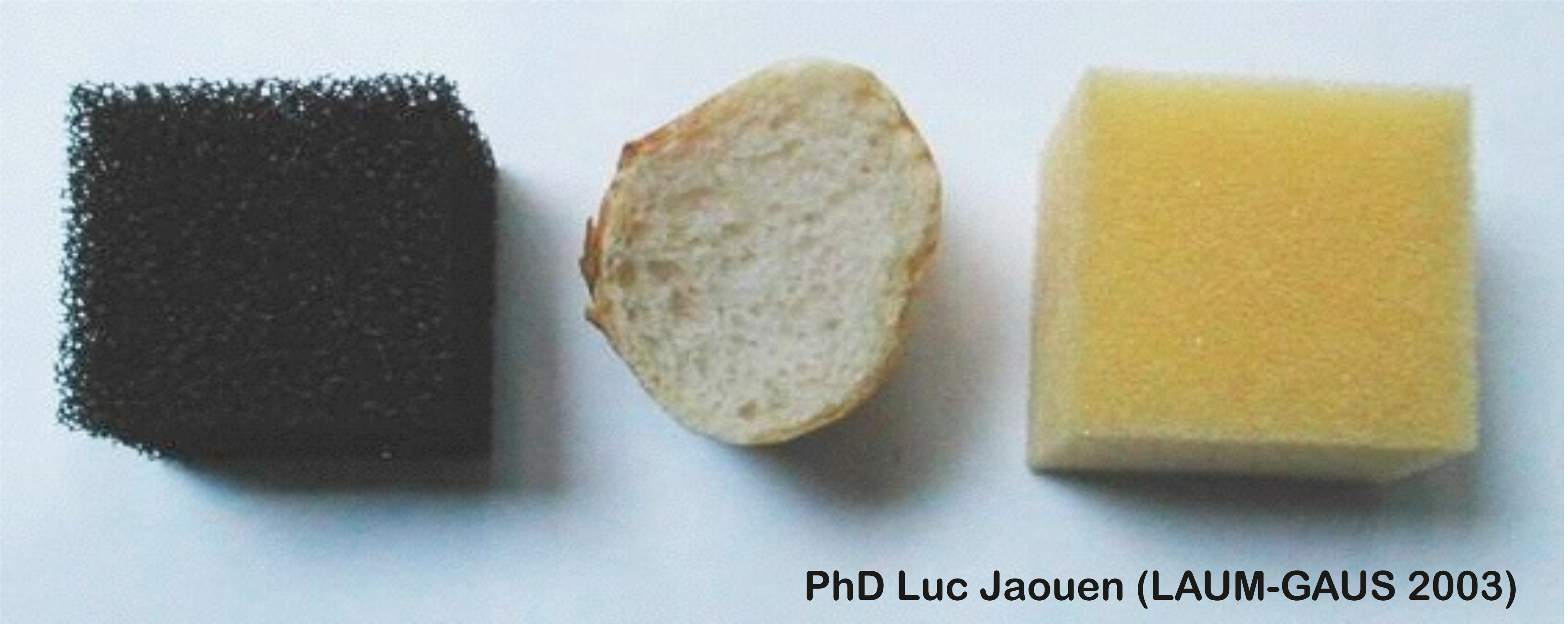
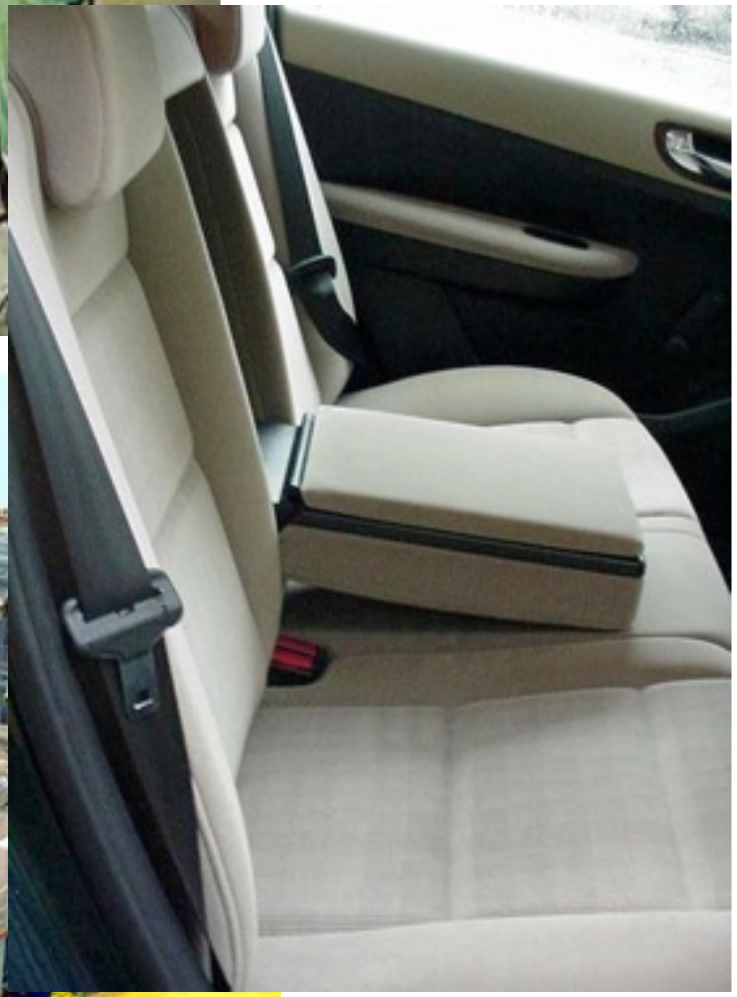
Context of sound absorbing materials

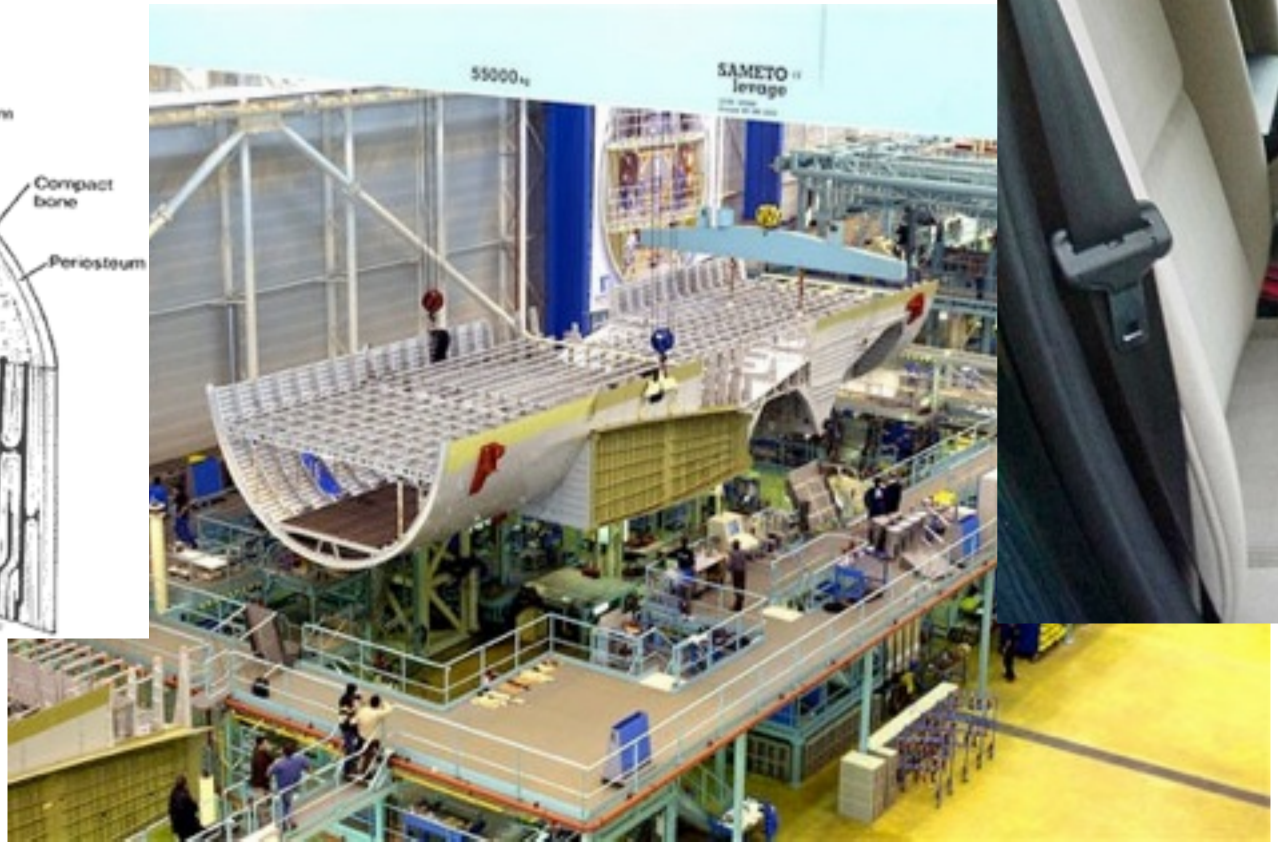


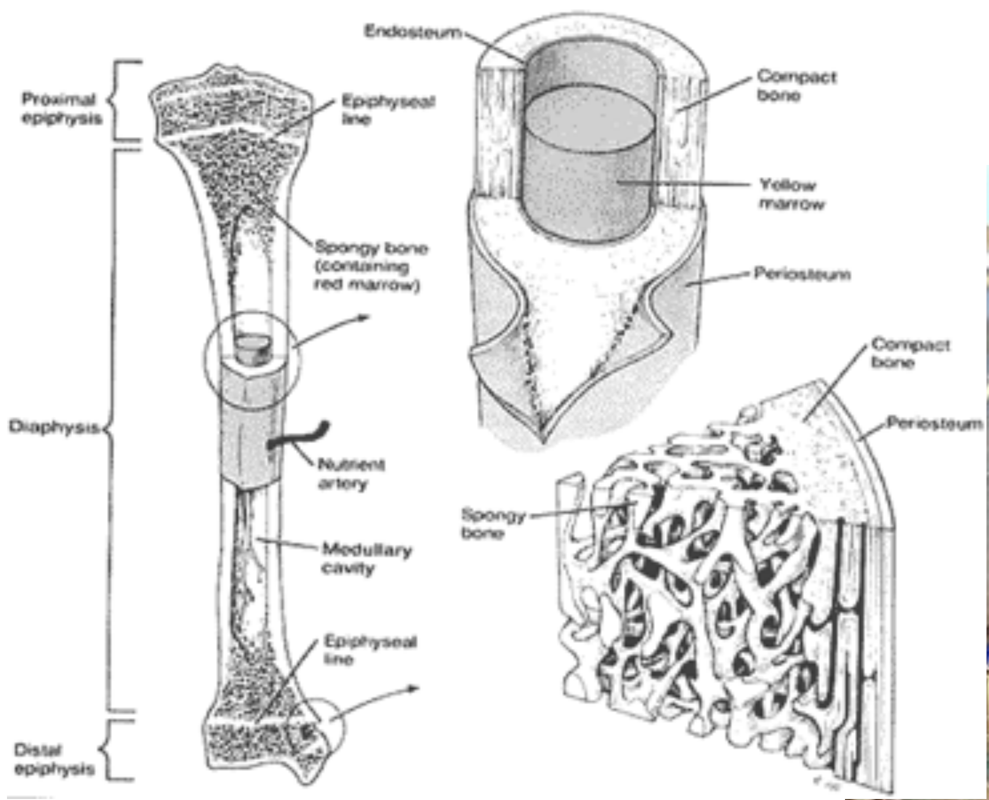
- Interesting properties for sound absorption
- A complex physics due to a complex microstructure
- At the intersection of Theoretical/Applied science/ Engineering

Fields of applications

- Automative
- Aeronautics
- Building
- Geophysics
- Medical (bones)

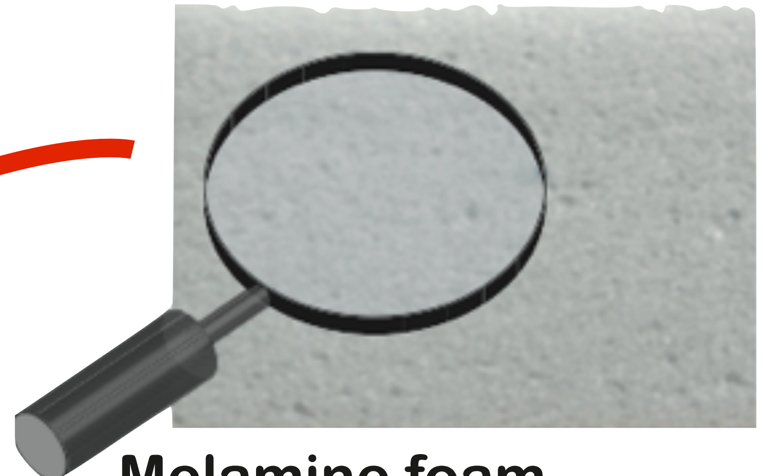




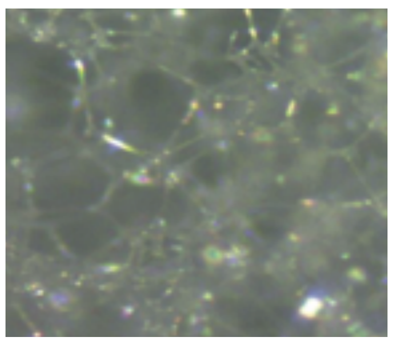


What are porous materials ?

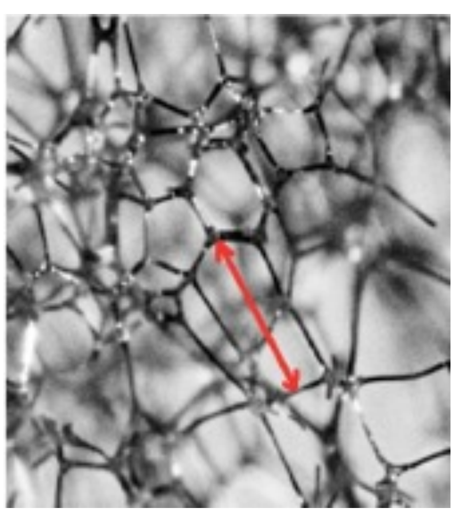
A solid skeleton saturated by a fluid



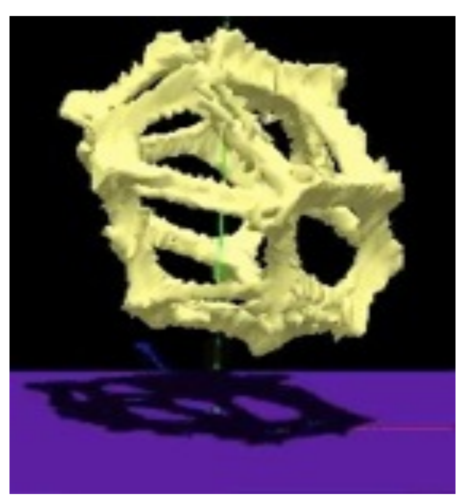
Melamine foam
(Anechoic chamber LAUM)



PhD A. Geslain (LAUM 2011)



PhD R. Guastavino (MWL 2007)



PhD C. Perrot (GAUS-INSA Lyon 2006)

Two separate continua

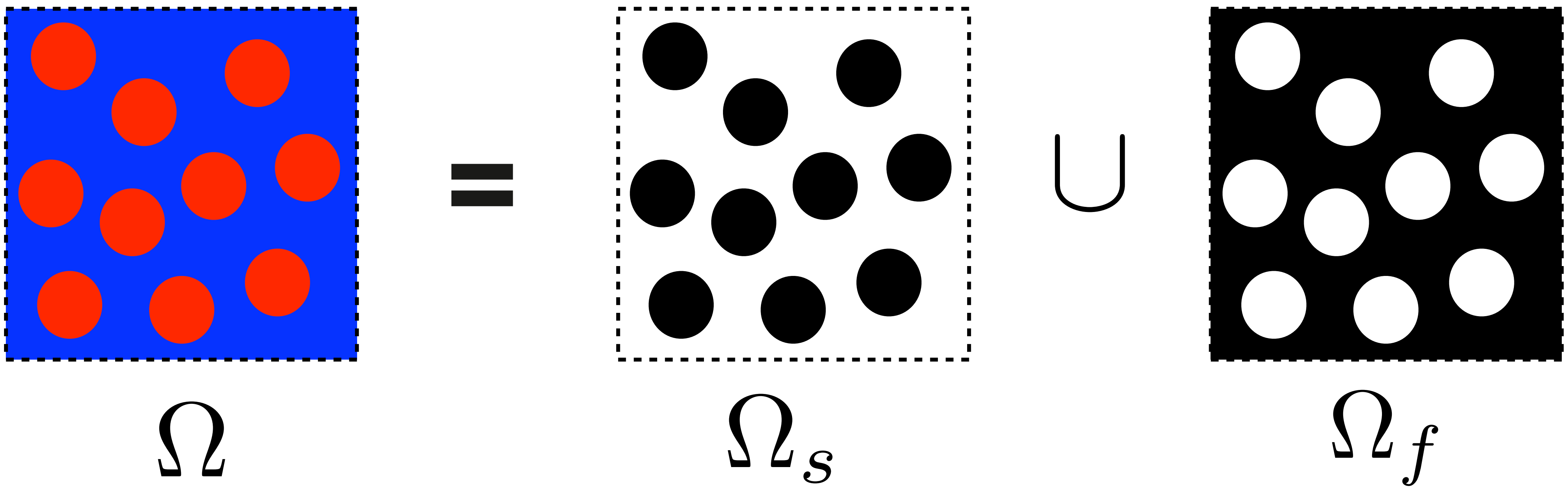
Skeleton

- ✓ Cellular foam
- ✓ Fibrous material
- ✓ Recycled / hemp …

Saturating fluid

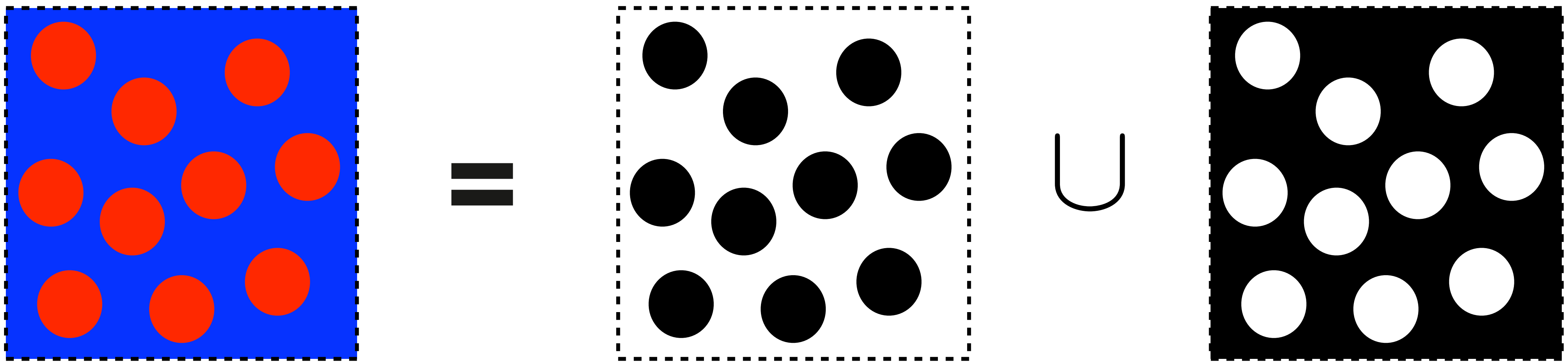
- ✓ Air (viscothermal fluid)
- ✓ Water

Superposition of 2 continua



For sound absorbing materials

Superposition of 2 continua



$$\Omega = \Omega_s \cup \Omega_f$$

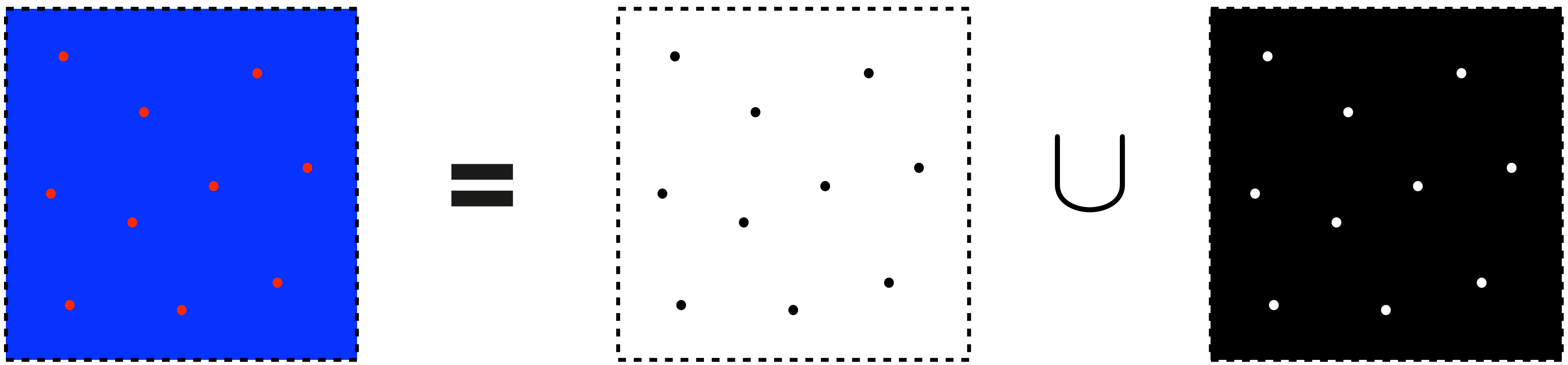
Porosity

$$\phi = \frac{V(\Omega_f)}{V(\Omega)}$$

For sound absorbing materials

Only open porosity is considered

Superposition of 2 continua



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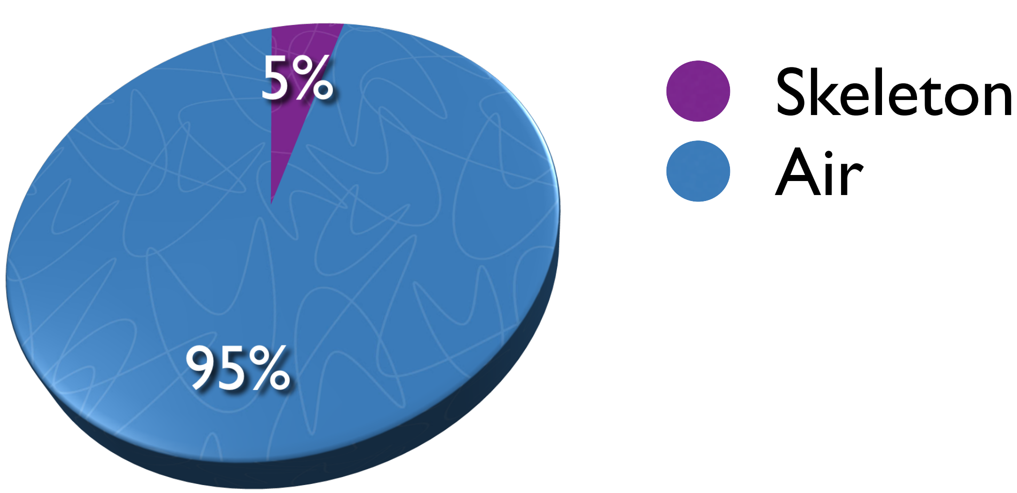
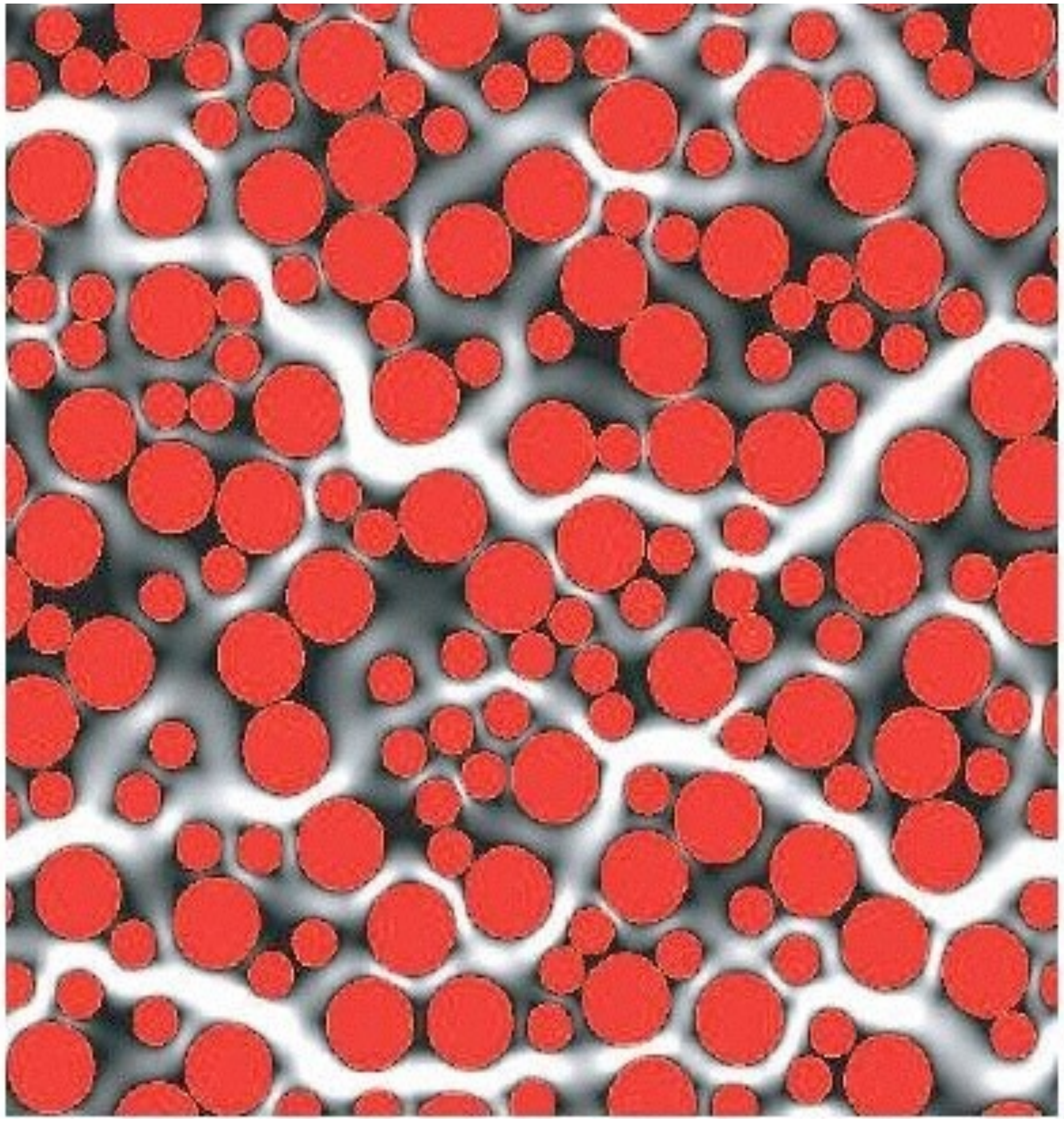
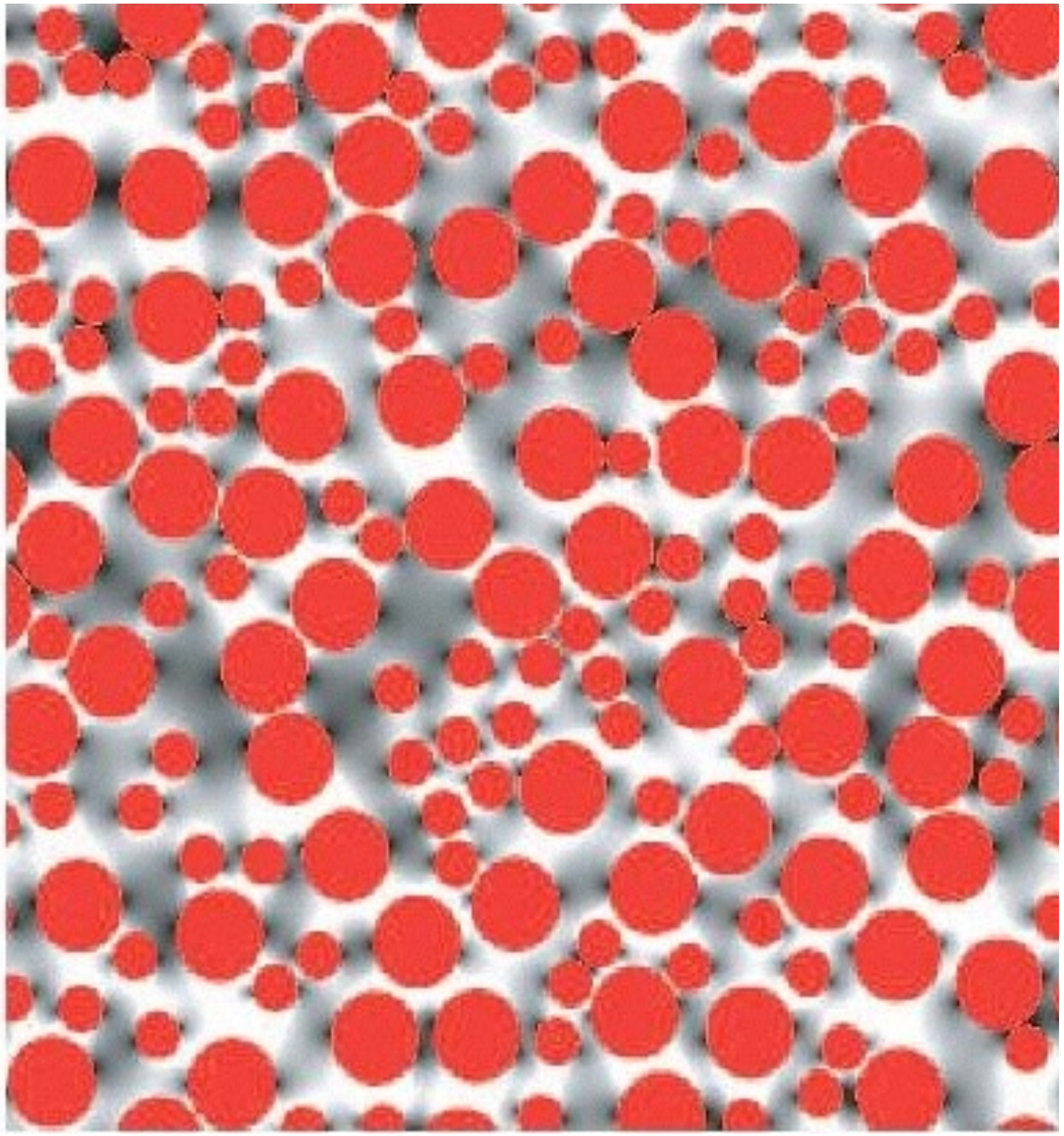


Complexity at microscopical scale



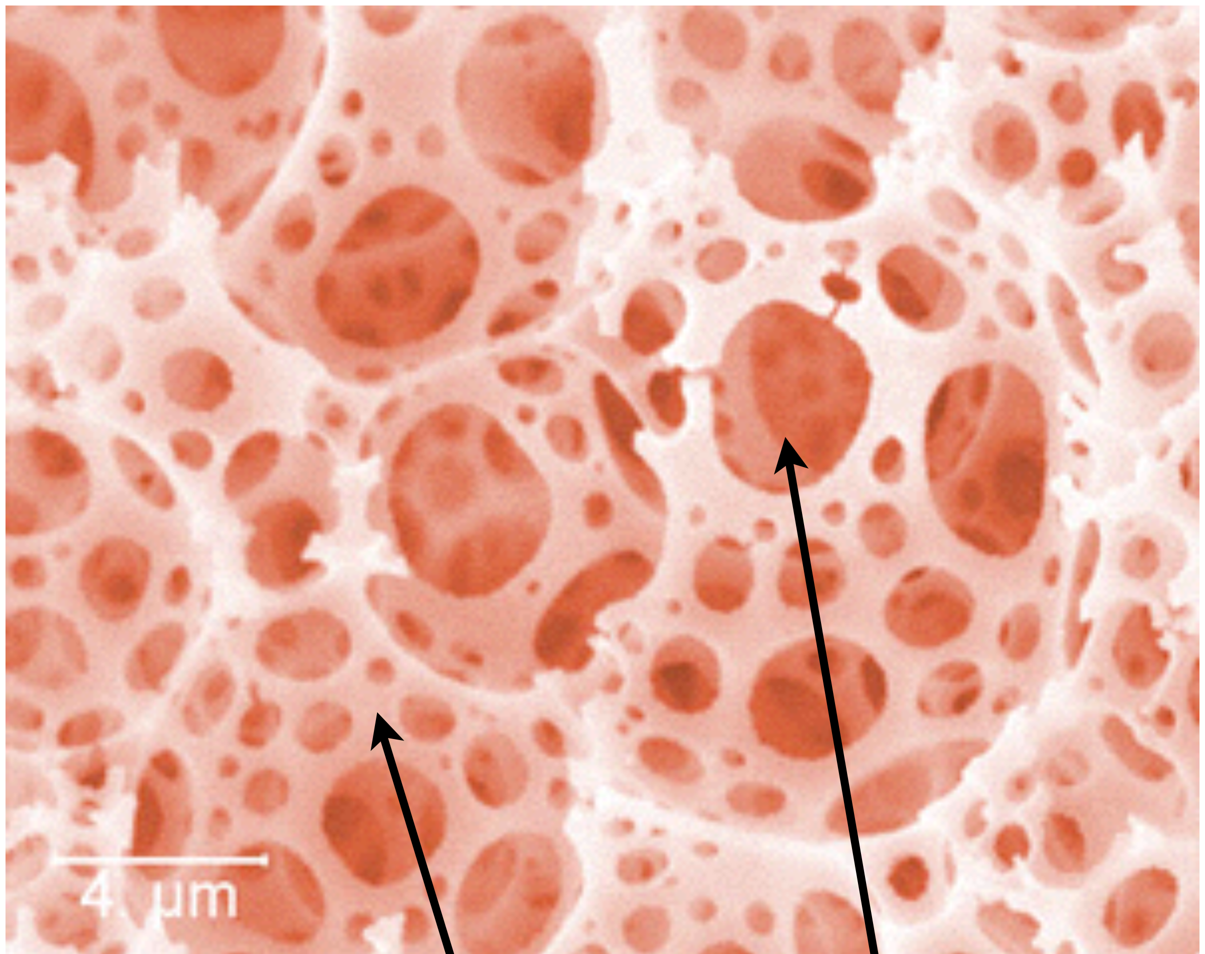
Low frequency



High frequency range

http://ciks.cbt.nist.gov/~garbocz/paper32/

Homogenization



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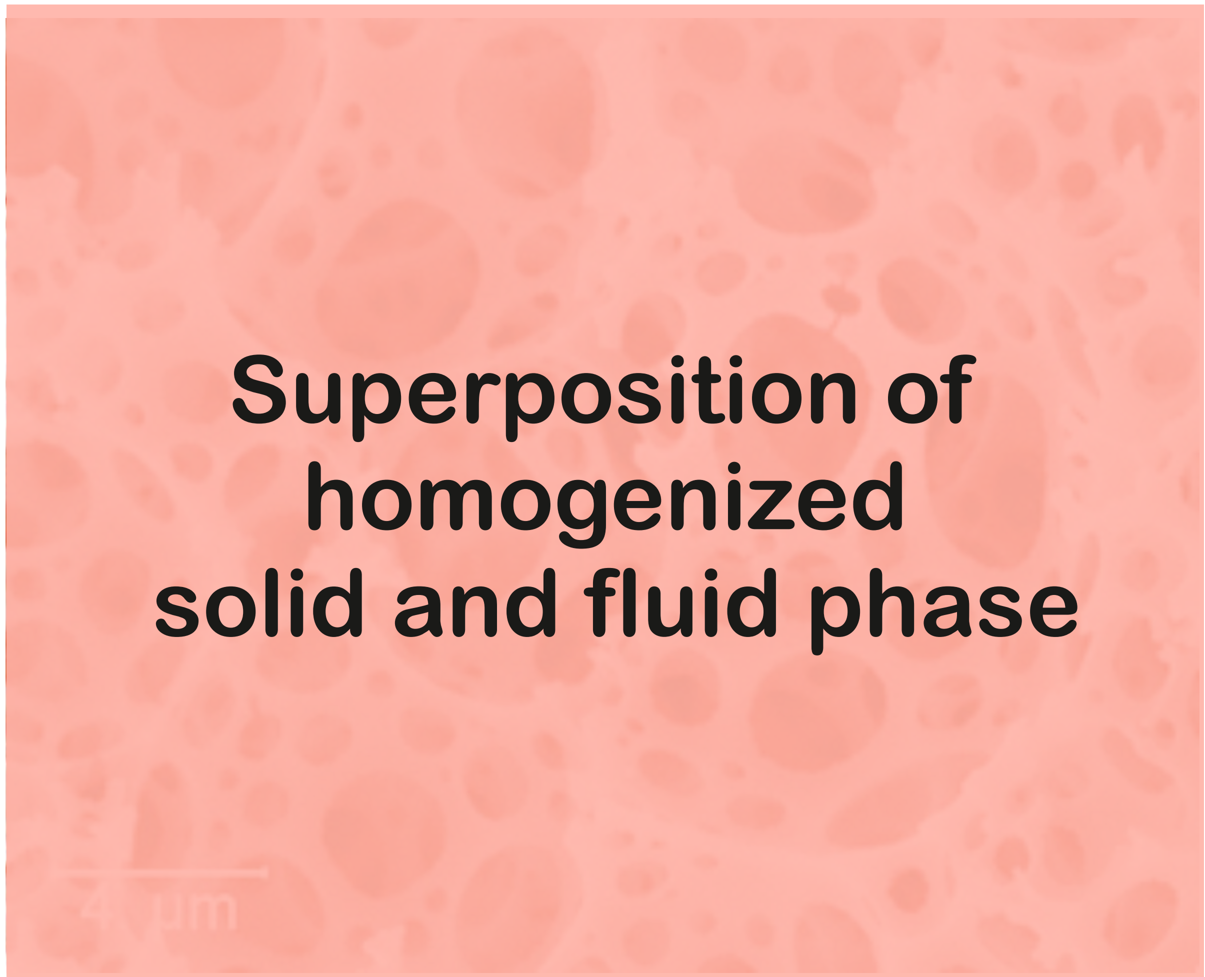
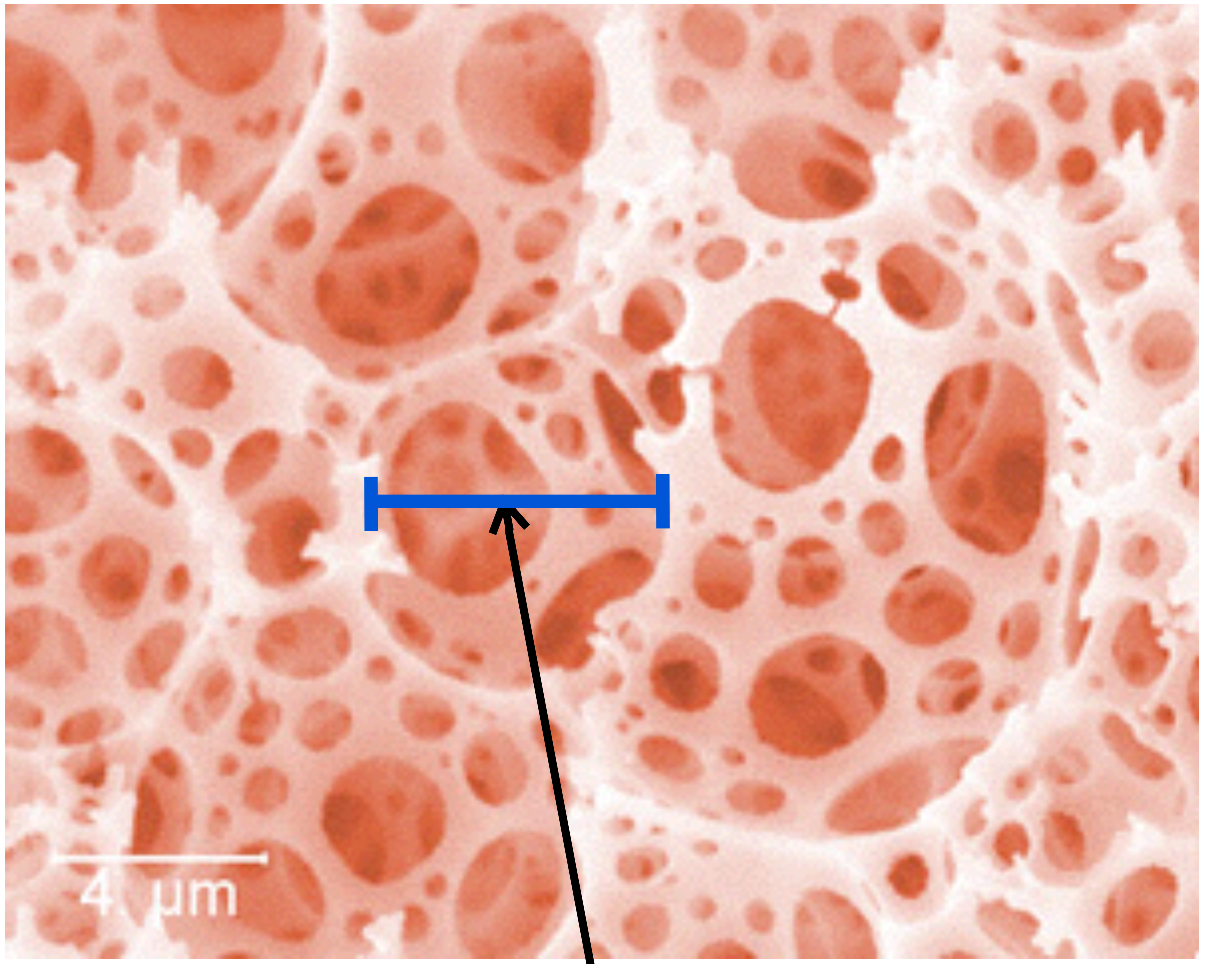


Homogenization of REV

↓

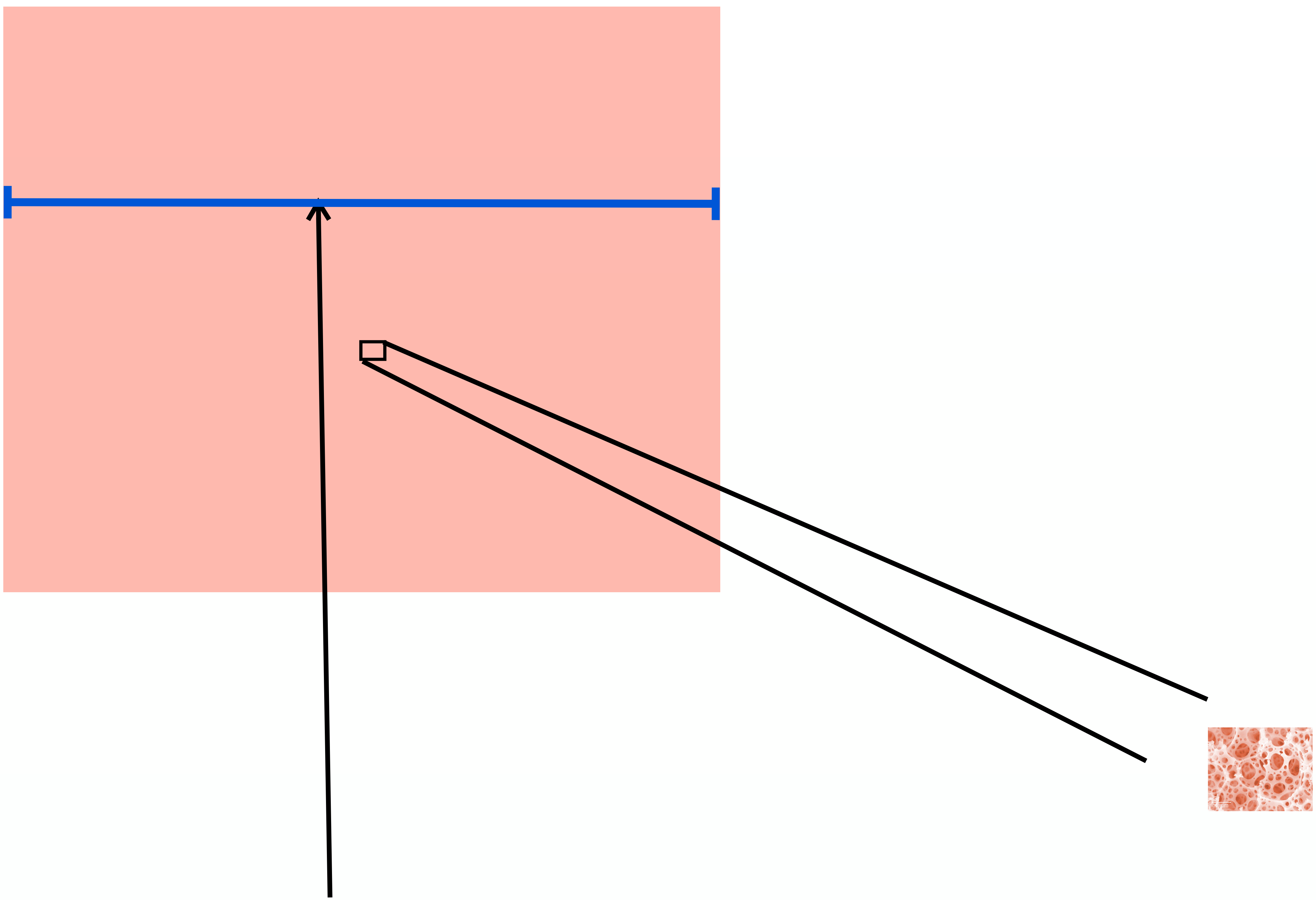
Continuum Mechanics

The scale separation hypothesis



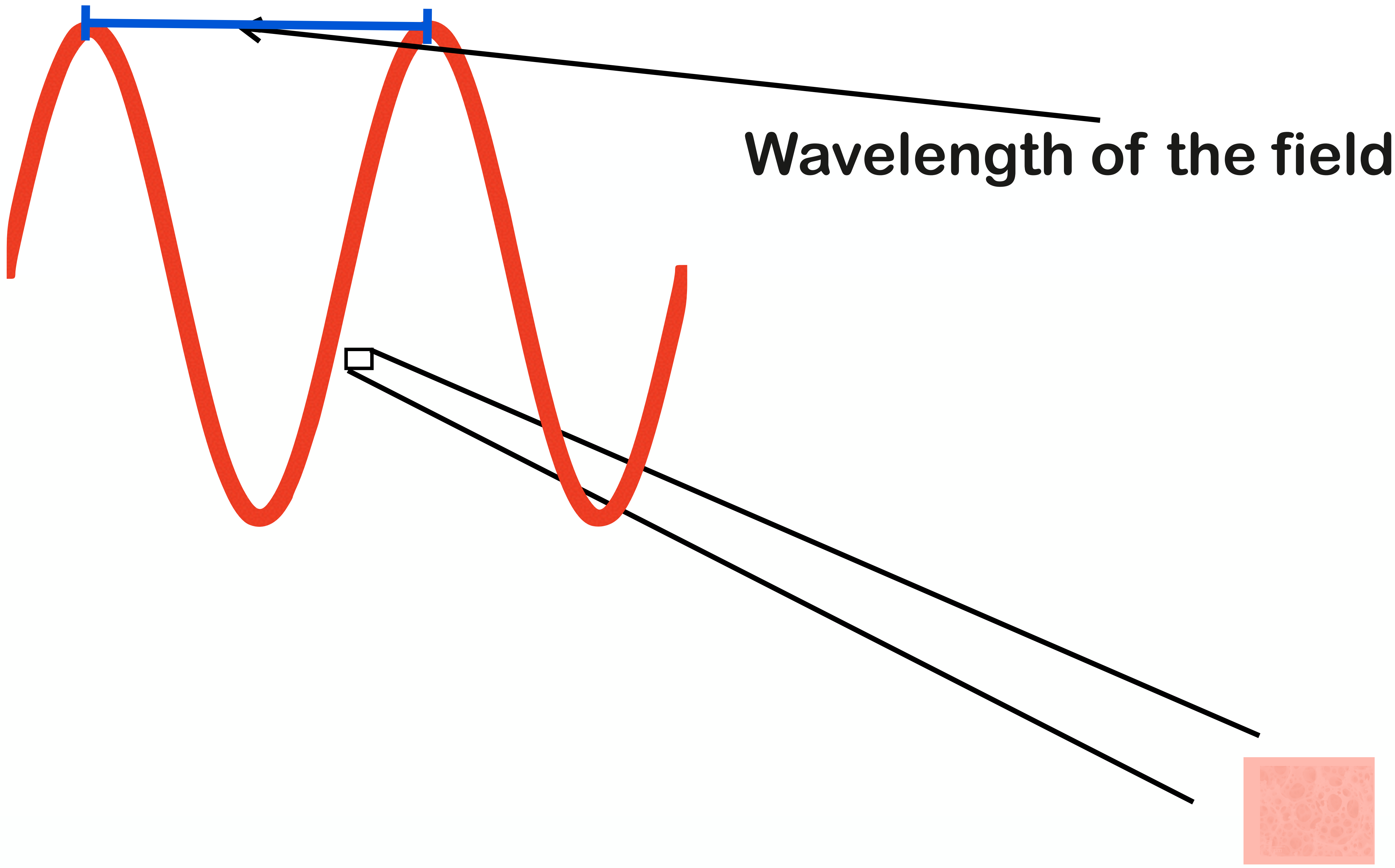
Microstructure
typical length

The scale separation hypothesis



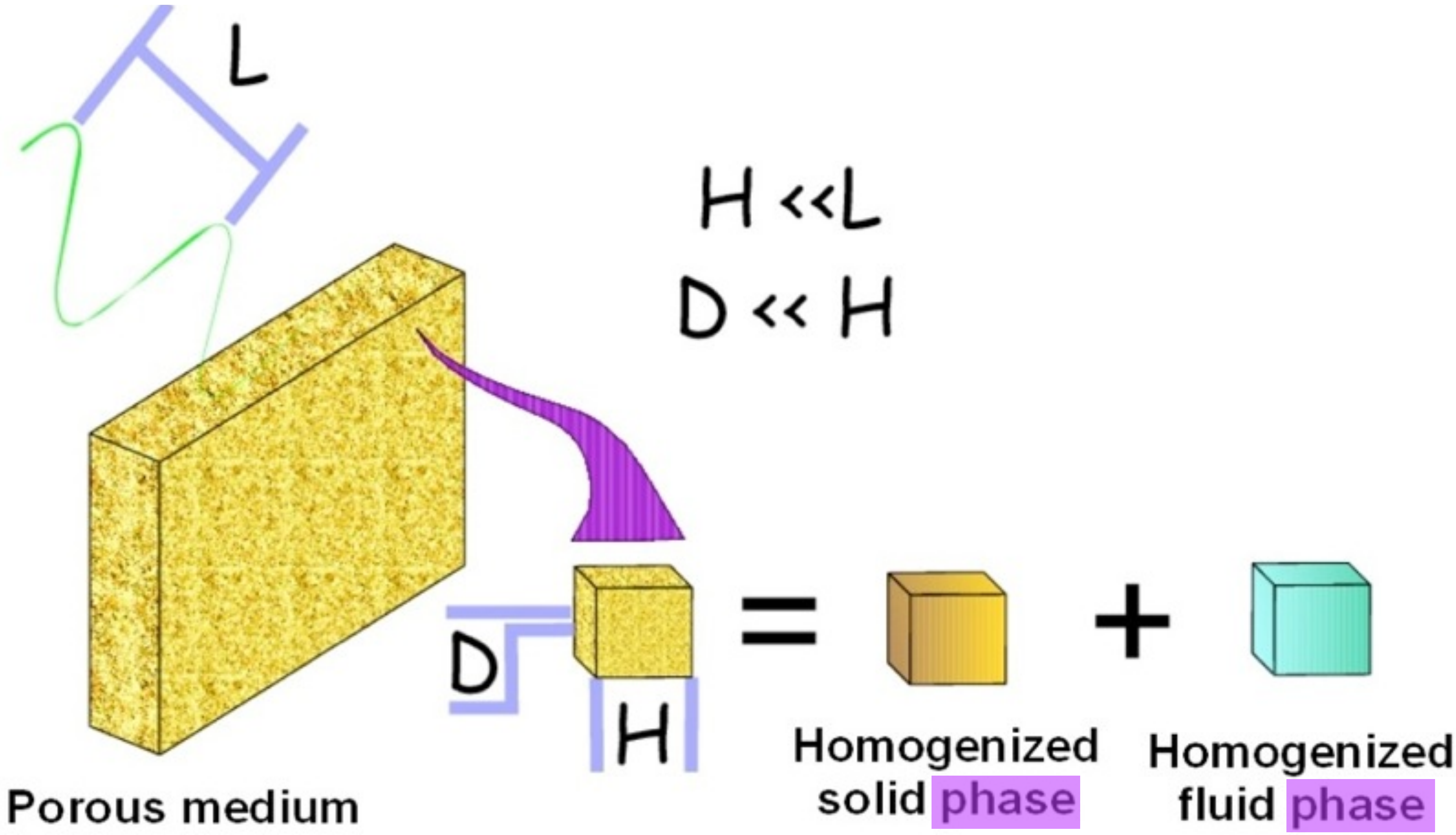
Dimension of the REV

The scale separation hypothesis

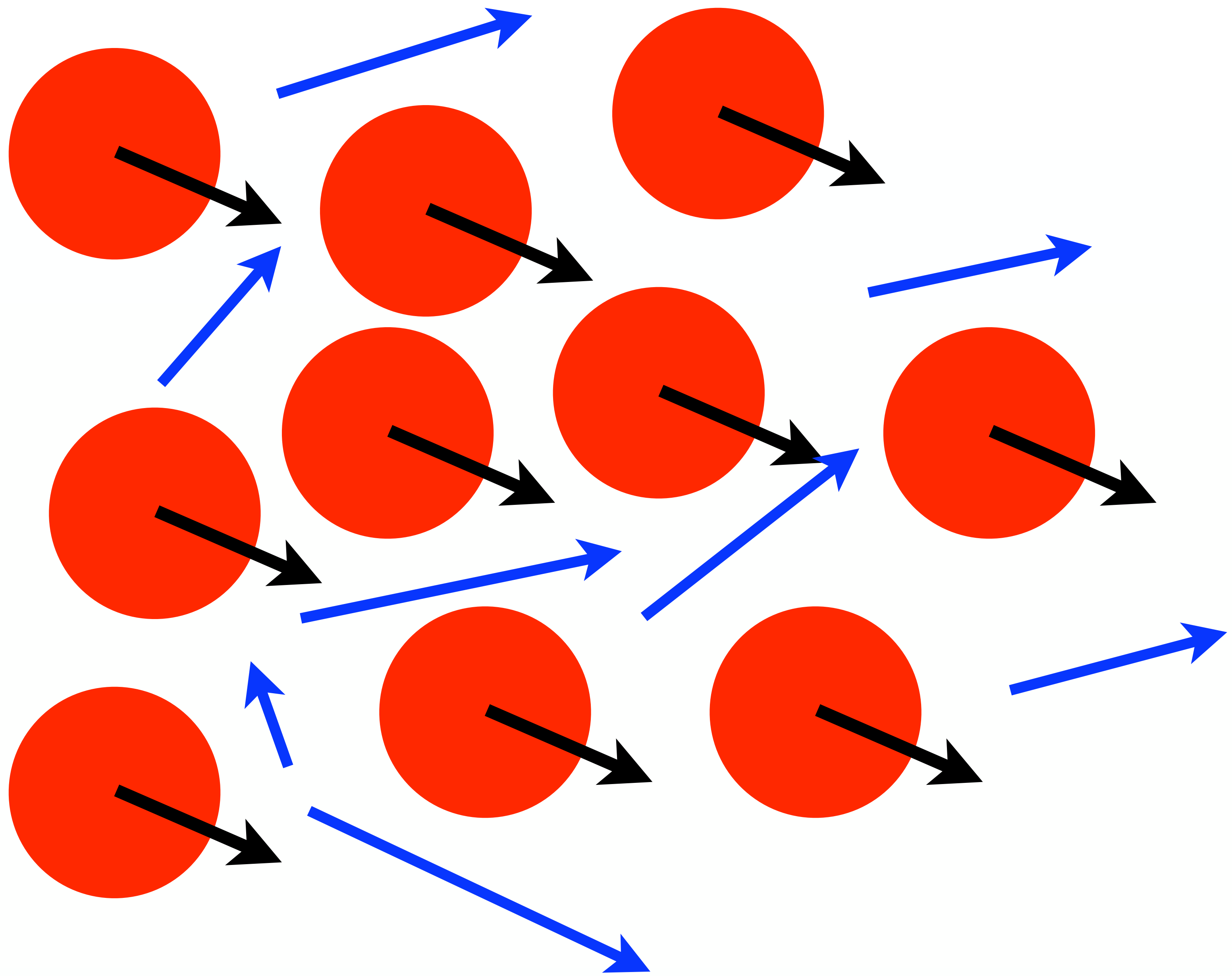


Three scales

- Macroscopical : Excitation / Sample
- Mesoscopical : REV / Particle
- Microscopical : Pore/ Heterogeneities

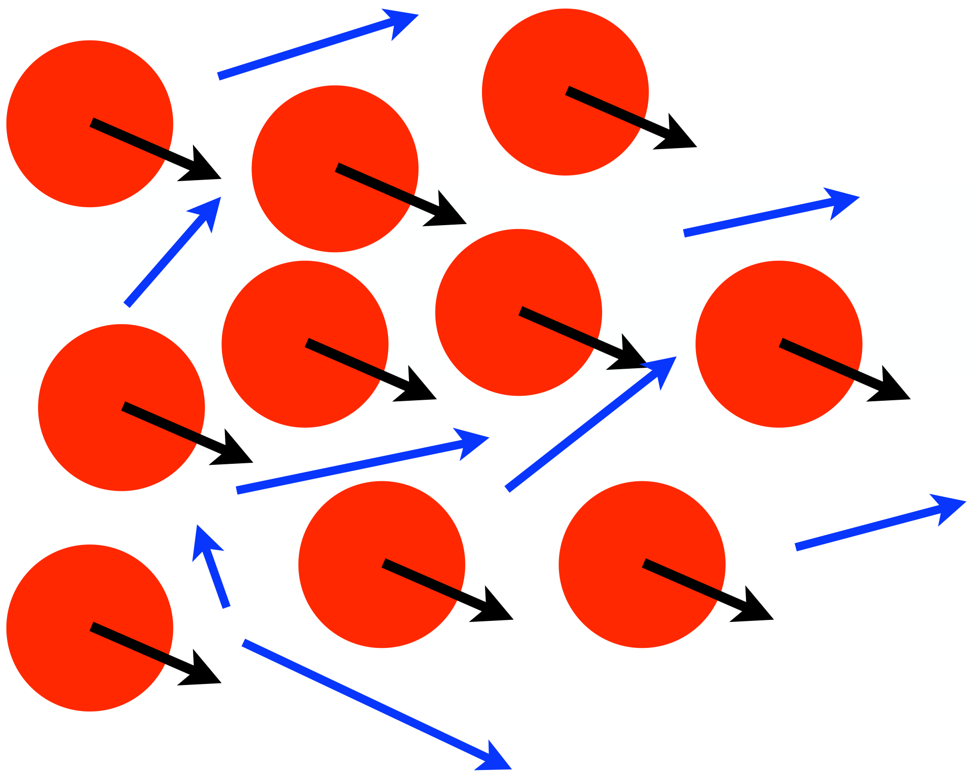


Spatial variation of disp. on a REV



Uniform solid displacement at local scale

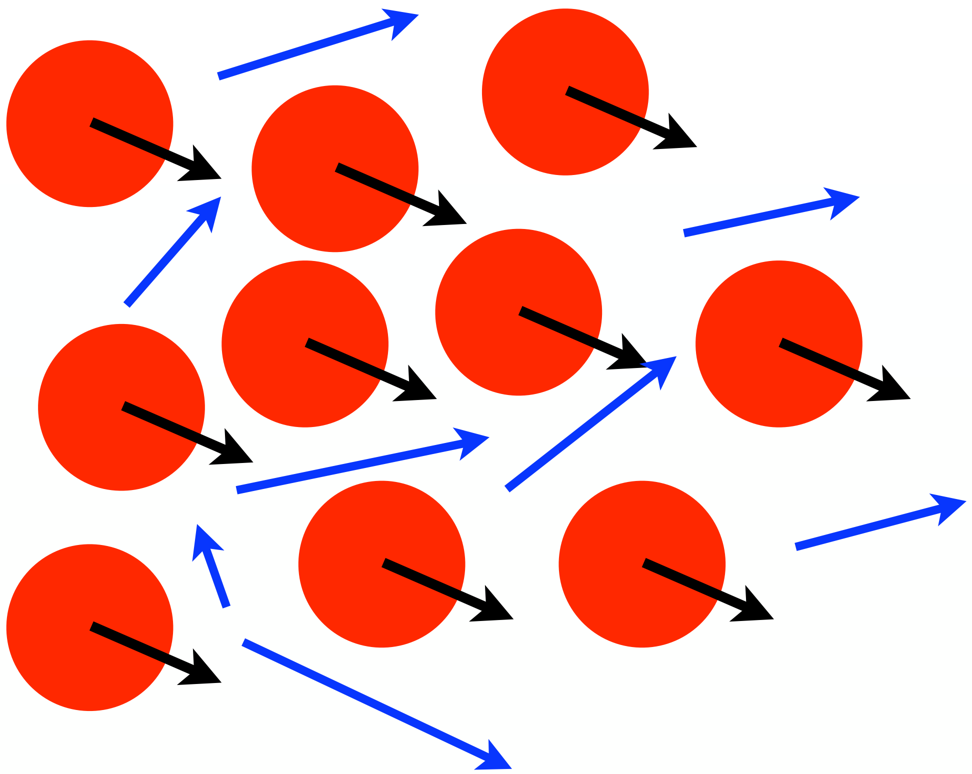
Spatial variation of disp. on a REV



Uniform solid displacement
at local scale

Consequences

Spatial variation of disp. on a REV

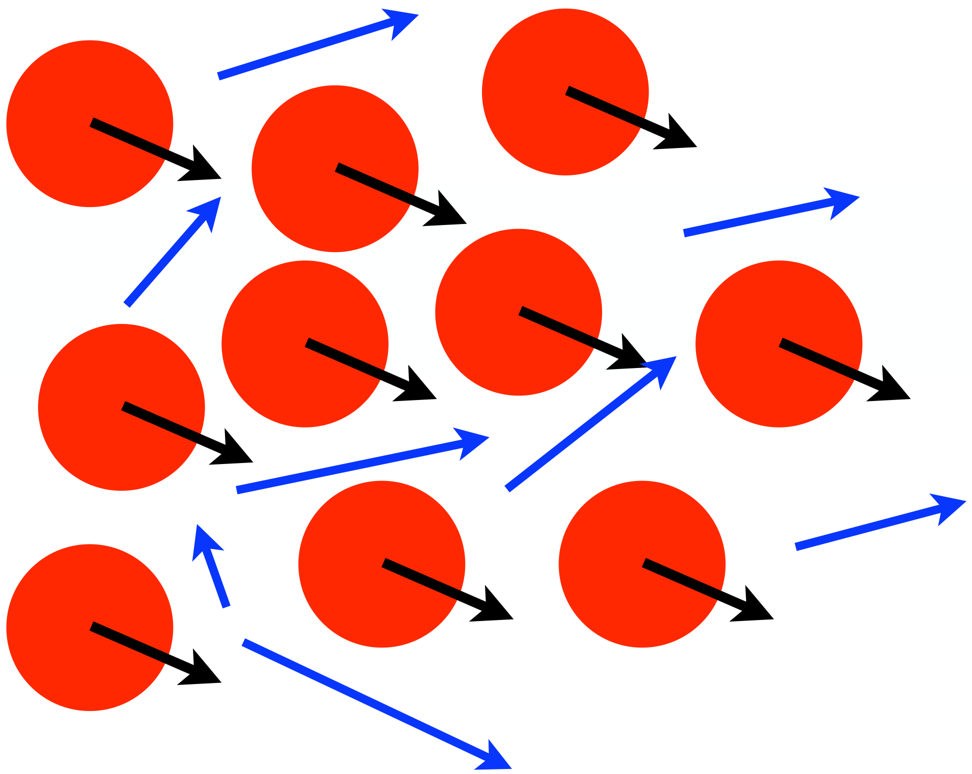


Uniform solid displacement
at local scale

Consequences

•Conservation of the fluid volume at micro scale

Spatial variation of disp. on a REV

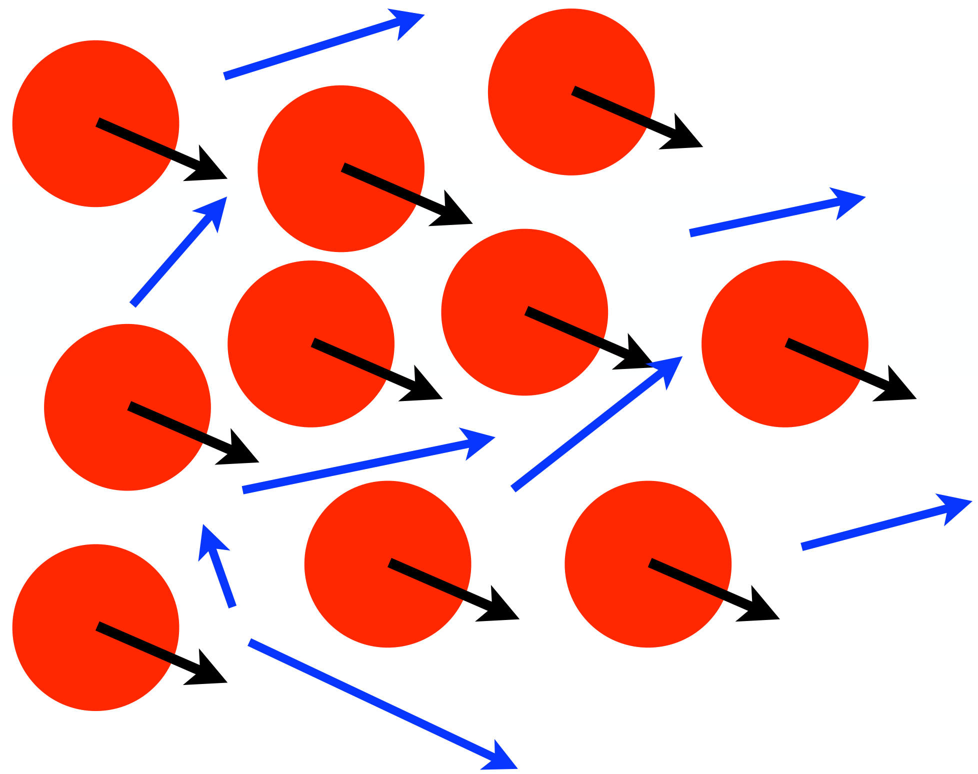


Uniform solid displacement at local scale

Consequences

- Conservation of the fluid volume at micro scale
- Incompressible fluid at micro scale

Spatial variation of disp. on a REV



Uniform solid displacement
at local scale

Consequences

- Conservation of the fluid volume at micro scale
- Incompressible fluid at micro scale
- At macro scale: No shear stress in the fluid

Different classes of models

Models= Systems of PDE + boundary conditions

Class	Solid phase	Fluid phase
In-vacuo		
Equivalent fluid		
Limp Model	Motion without deformation energy	
Biot model		

Starting point : fields of representation

Homogenized quantities

$$\mathbf{X} = < x_\mu >_V$$

Macroscopic field

Microscopic field

Averaging volume

Homogenized quantities

$$\mathbf{X} = < x_\mu >_V$$

Macroscopic field

Microscopic field

Averaging volume

- Assumption of statistic homogeneity
- Which averaging volume?
  - Skeleton
  - Pore
  - Total volume
- Several methods (but same value !)
- For our models
  - Displacements
  - Stresses

Homogenized displacements

Solid displacement

$$\mathbf{u}^s = \langle u^s_\mu \rangle_{\Omega_s}$$

Fluid displacement

$$\mathbf{u}^f = \langle u^f_\mu \rangle_{\Omega_f}$$

Homogenized displacements

Solid displacement

$$\mathbf{u}^s = \langle u^s_\mu \rangle_{\Omega_s}$$

Fluid displacement

$$\mathbf{u}^f = \langle u^f_\mu \rangle_{\Omega_f}$$

Total displacement

$$\mathbf{u}^t = \langle u^s_\mu \rangle_{\Omega} + \langle u^f_\mu \rangle_{\Omega} = (1-\phi)\mathbf{u}^s + \phi\mathbf{u}^f$$

Homogenized displacements

Solid displacement

$$\mathbf{u}^s = \langle u_\mu^s \rangle_{\Omega_s}$$

Fluid displacement

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Total displacement

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Flow of the fluid /solid per unit area of bulk medium.

$$\mathbf{w} = \langle u_\mu^f - \mathbf{u}^s \rangle_{\Omega} = \phi(\mathbf{u}^f - \mathbf{u}^s)$$

Homogenized displacements

Solid displacement

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Fluid displacement

$$\mathbf{u}^f = \langle u_\mu^f \rangle_{\Omega_f}$$

Total displacement

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Flow of the fluid /solid per unit area of bulk medium.

$$\mathbf{w} = \langle u_\mu^f - \mathbf{u}^s \rangle_\Omega = \phi(\mathbf{u}^f - \mathbf{u}^s)$$

Case of equivalent fluid models

$$\mathbf{u}^s = \mathbf{0} \implies \mathbf{w} = \mathbf{u}^t = \mathbf{u}^{eq}$$

Homogenized stresses

Average force per unit area of a surface

Solid partial stress tensor

$$\boldsymbol{\sigma}^s = < \boldsymbol{\sigma}^s_\mu >_\Omega$$

Fluid partial stress tensor

$$\boldsymbol{\sigma}^f = < \boldsymbol{\sigma}^f_\mu >_\Omega$$

Homogenized stresses

Average force per unit area of a surface

Solid partial stress tensor

$$\boldsymbol{\sigma}^s = <\boldsymbol{\sigma}_\mu^s>_\Omega$$

Fluid partial stress tensor

$$\boldsymbol{\sigma}^f = <\boldsymbol{\sigma}_\mu^f>_\Omega$$

For the fluid phase, no shear force can be restored at macroscopic scale

$$\boldsymbol{\sigma}_\mu^f = -p_\mu \boldsymbol{\delta} + \boldsymbol{\sigma}_\mu^{f\,\prime}$$

$$<\boldsymbol{\sigma}_\mu^{f\,\prime}>_{\Omega_f} \approx 0$$

$$\boldsymbol{\sigma}^f = -\phi p \,\boldsymbol{\delta}$$

$$p = <p_\mu>_{\Omega_f}$$

Macroscopic (or interstitial) pressure

Homogenized stresses

Average force per unit area of a surface

Solid partial stress tensor

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Fluid partial stress tensor

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$$p = < p_\mu >_{\Omega_f}$$

Macroscopic (or interstitial) pressure

$$\boldsymbol{\sigma}^t = \boldsymbol{\sigma}^s + \boldsymbol{\sigma}^f$$

Total stress tensor

Modelling porous materials

Model (PDE)

Modelling porous materials

Interaction with environment

Parameters

Boundary conditions

✓ Loadings

✓ Continuity relations

Characterization techniques

Model (PDE)

Modelling porous materials

Interaction with environment

Boundary conditions
- ✓ Loadings
- ✓ Continuity relations

Parameters

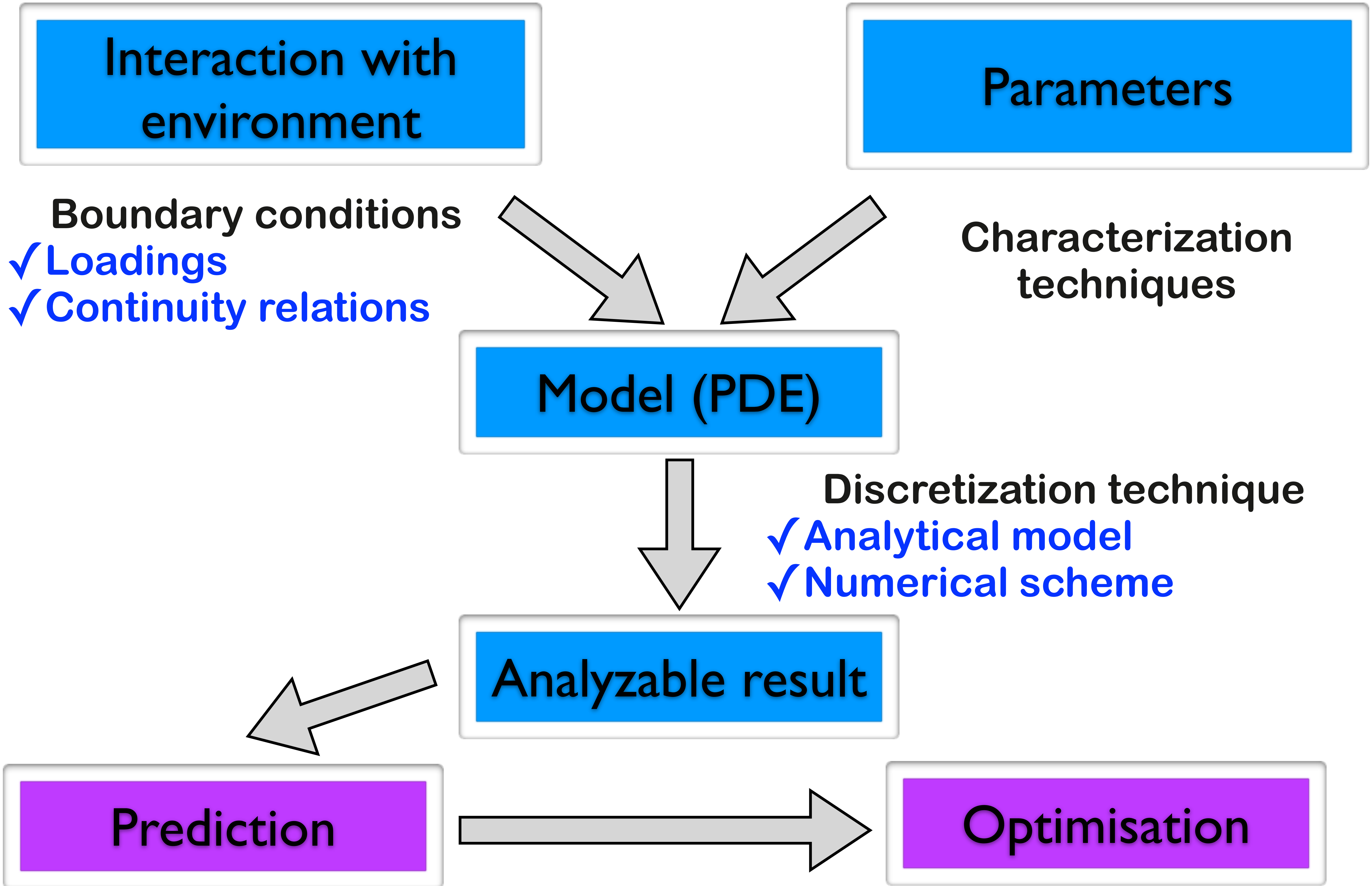
Characterization techniques

Model (PDE)

Discretization technique
- ✓ Analytical model
- ✓ Numerical scheme

Analyzable result

Modelling porous materials



State of Art

- 1949: Zwikker and Kösten (Cylindrical tubes)
- 1956: Biot theory (Motion of the solid phase)
- 1987: Johnson (Viscous effects)
- 1991: Stinson / Champoux / Allard (Thermal effects)

- 199-: Caracterization of acoustical parameters
- 200-: Caracterization of mechanical parameters

- 1989: Analytical and first numerical methods
- 2000: Advanced numerical techniques