On the characterization of acoustical porous media

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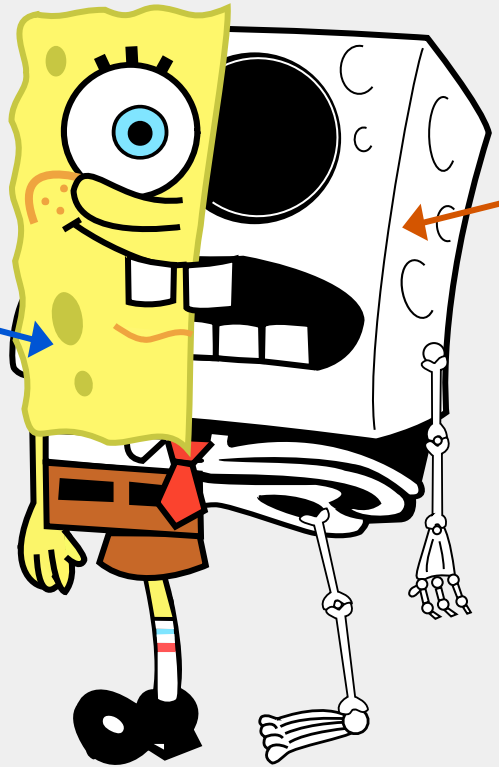
MATELYS
Research Lab

I focus on porous materials...

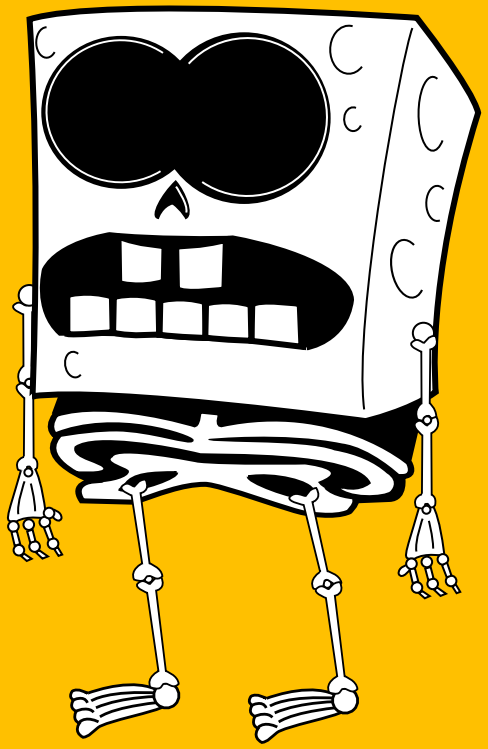
I focus on porous materials... composed with 2 phases

ACOUSTIC characterization
provides parameters
describing
visco-thermal dissipation
in fluid phase.



VISCO-ELASTIC characterization
provides parameters
describing
the skeleton motion

Visco-elastic Characterization



See APMR on the web (Acoustical Porous Materials Recipes),

Forthcoming Inter-laboratory test on elastic characterization:

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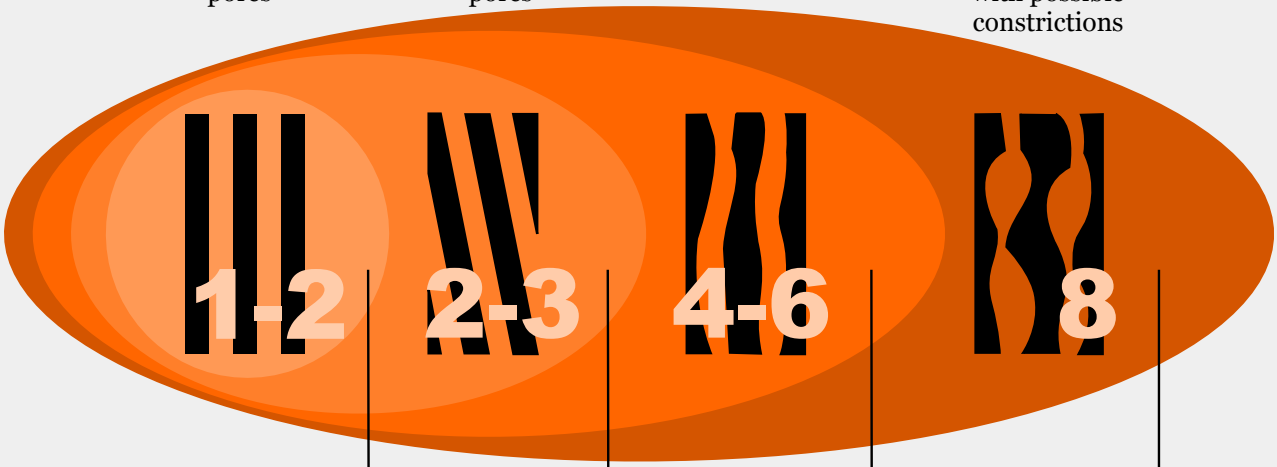
Acoustic Characterization

One issue : Many acoustic parameters



Material morphology and number of parameters

Model and parameter examples

Zwikker-Kosten
$\phi\ \sigma = \eta/k_0$

Miki
$\phi\ \sigma\ \alpha_\infty$

Attenborough
$\phi\ \sigma\ \alpha_\infty\ b$

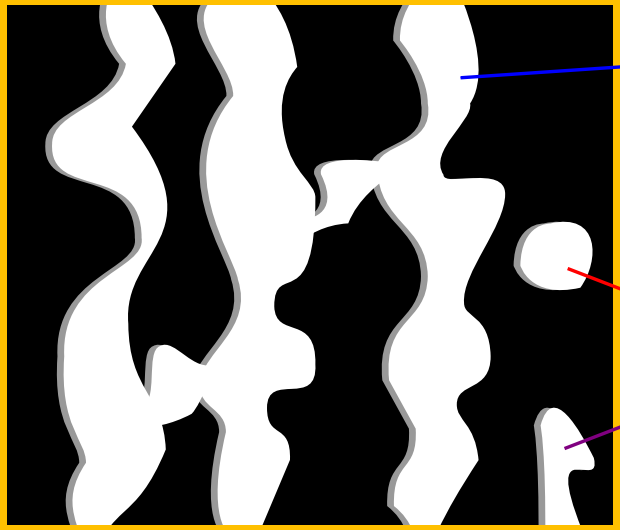
Wilson
$\rho_\infty\ \tau_{\mathrm{vor}}\ \ K_\infty\ \tau_{\mathrm{ent}}$

Johnson-Champoux-Allard-Lafarge
$\phi\ \sigma\ \alpha_\infty\ \Lambda\ \ \Lambda'\ k_0'$

Johnson-Champoux-Allard-Pride-Lafarge
$\phi\ \sigma\ \alpha_\infty\ \Lambda\ \alpha_0\ \Lambda'\ k_0'\ \alpha_0'$

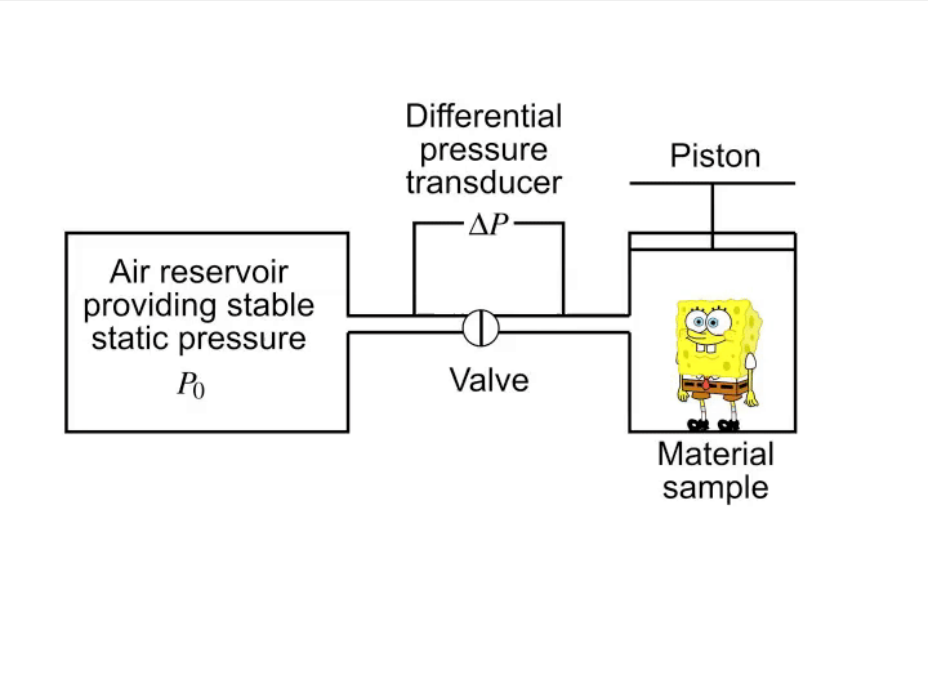
→ Most descriptive models need 5 to 8 acoustic parameters

Open porosity ϕ



Range of values:
less than 0.01 (for facings)
to more than 0.99

Open porosity - Pressure difference (~pycnometer)



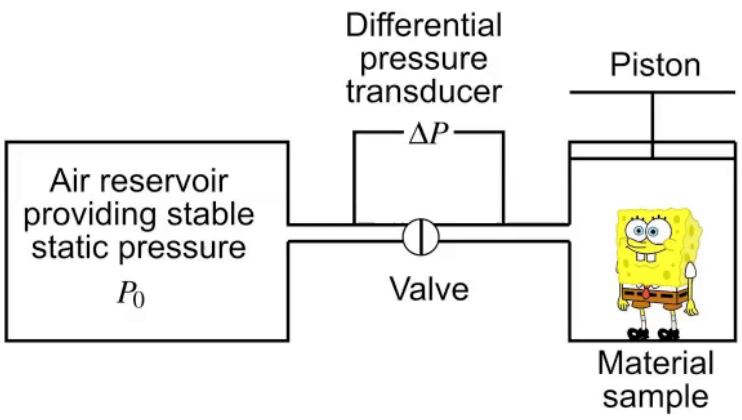
L. L. Beranek 1942, DOI: 10.1121/1.1916172

Champoux et al. 1990, DOI: 10.1121/1.1894653

ISO 4590 (2002), Link: www.iso.org

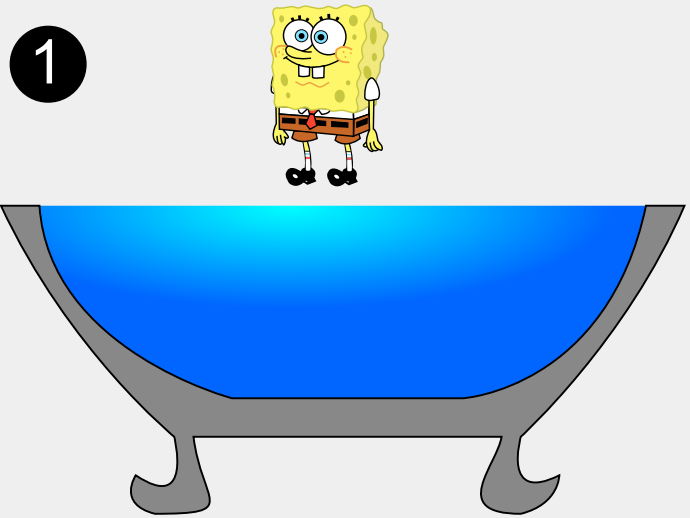
Leclaire et al. 2003, DOI: 10.1063/1.1542666

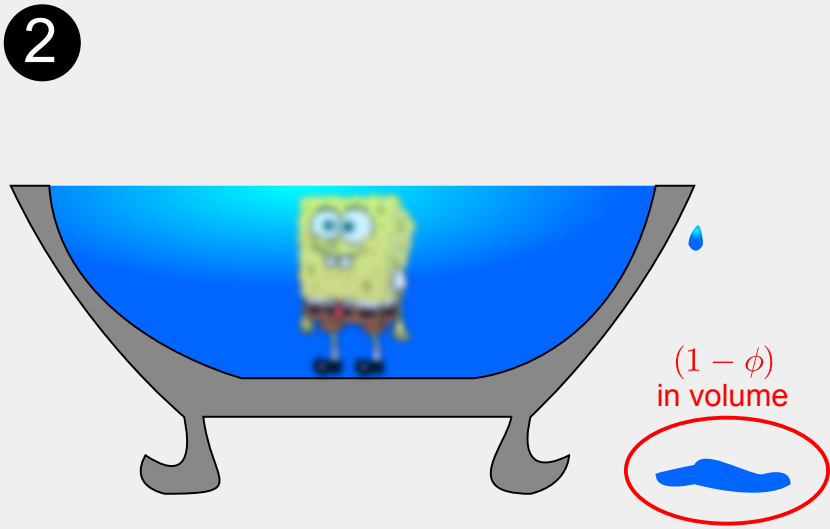
Open porosity - Pressure difference (~pycnometer)



PROS	CONS
Applied on all types of materials Accuracy of 0.01	Requires large samples for accurate results

Open porosity - Archimedes' principle / Fluid saturation

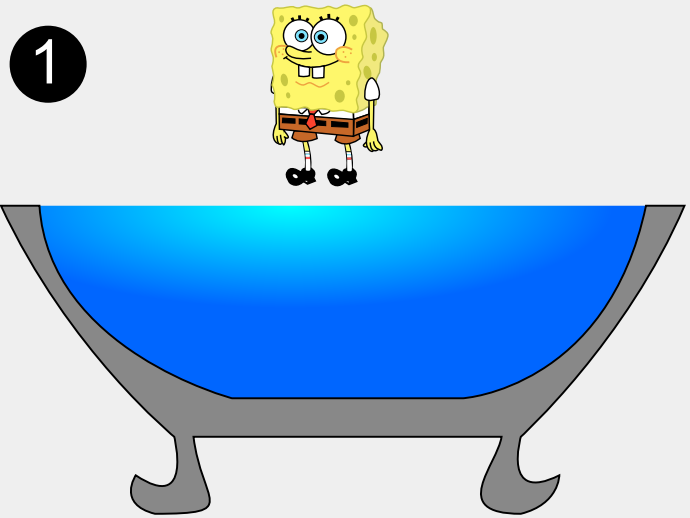


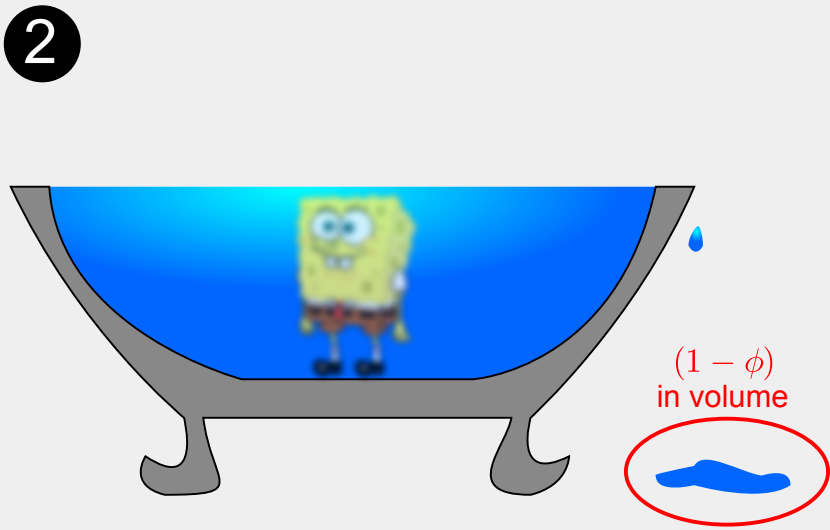


Panneton & Gros 2005 Link: www.ingentaconnect.com

Salissou & Panneton 2007, DOI: 10.1063/1.2749486

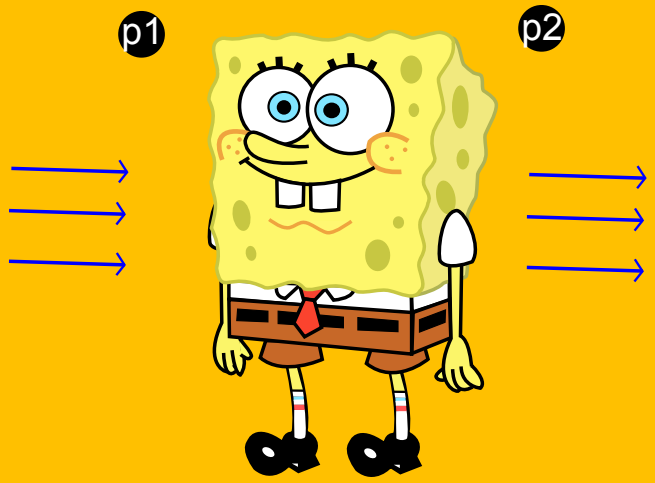
Open porosity - Archimedes' principle / Fluid saturation





PROS	CONS
Easy set-ups unless use of fluids other than air or water	Usually lower accuracy compared to pressure difference (saturate the pore network can be difficult)

Static air flow resistivity σ

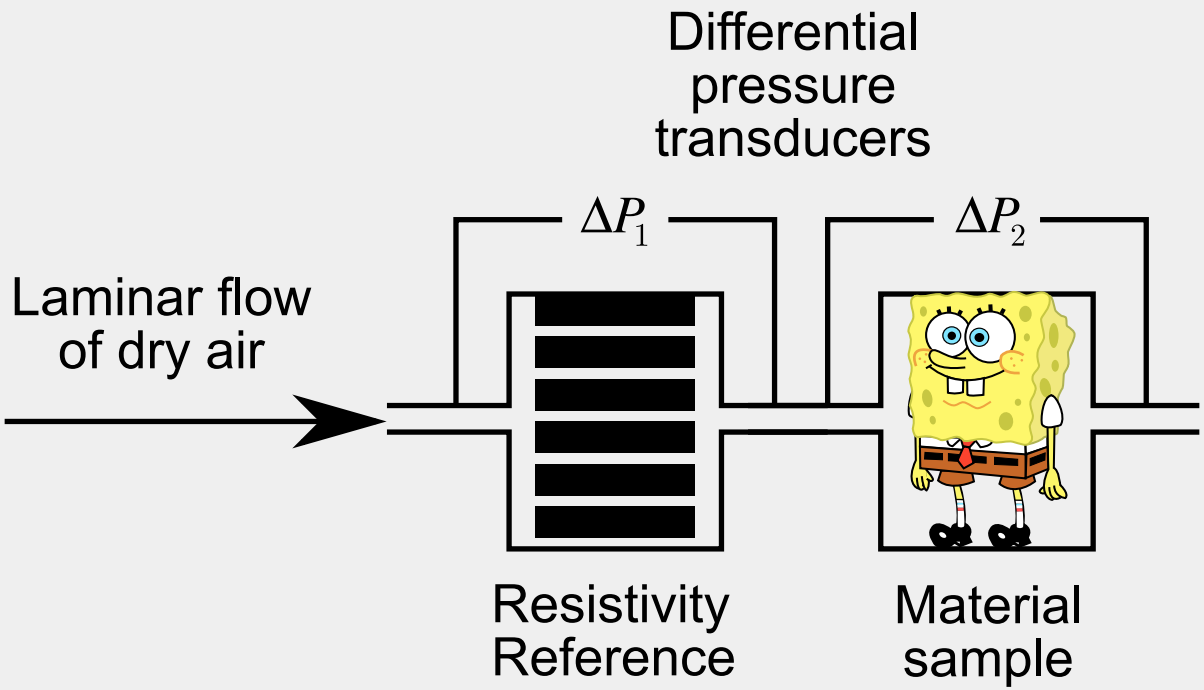


$$\phi\vec{v} = -\frac{1}{\sigma}\vec{\nabla}p$$

Range of values:

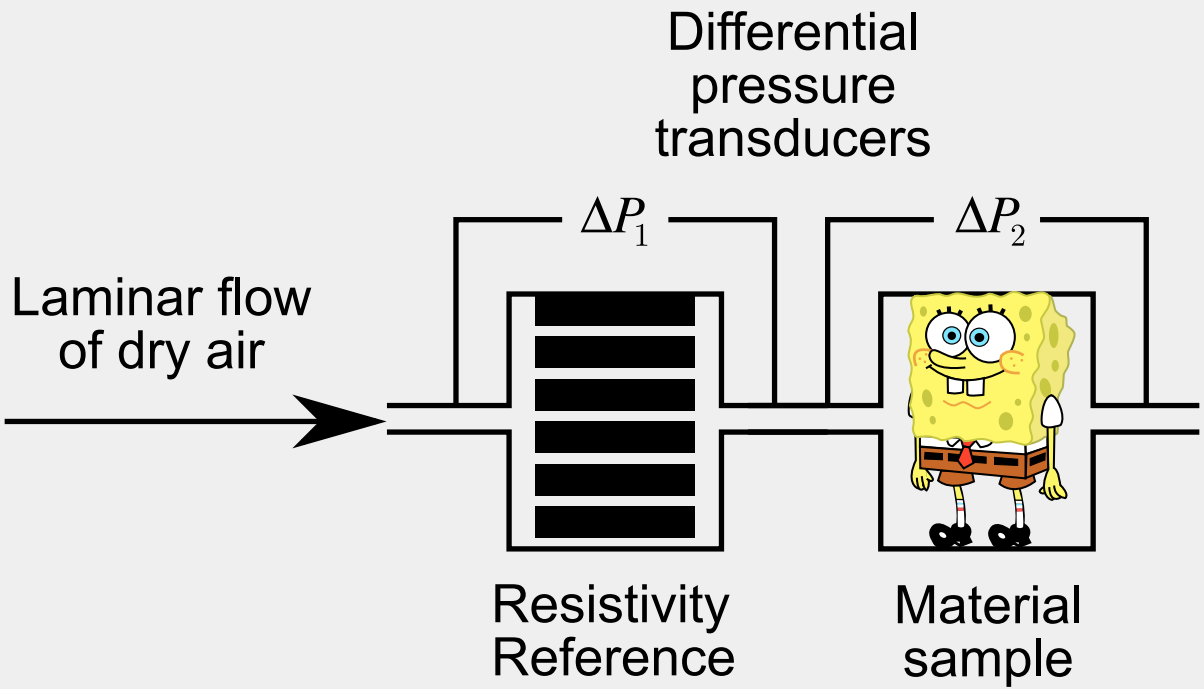
$[\,0 \quad - \quad +\infty\,[\qquad \mathrm{N.s.m^{-4}}$

Static air flow resistivity - Pressure difference



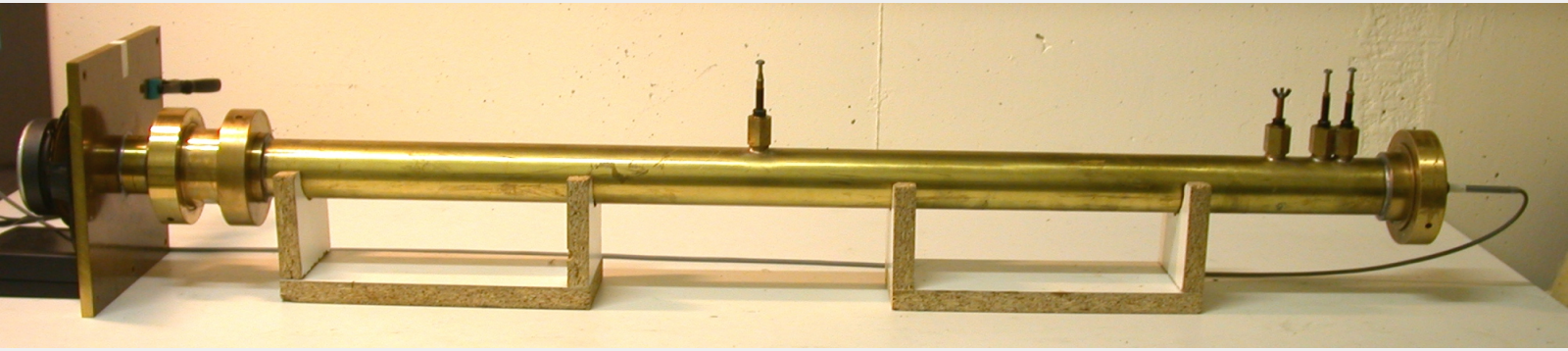
ISO 9053 (1991), Link: www.iso.org
(currently under revision, send comments to luc.jaouen@matelys.com)

Static air flow resistivity - Pressure difference



PROS	CONS
Direct measurement	Boundary conditions can highly impact the results

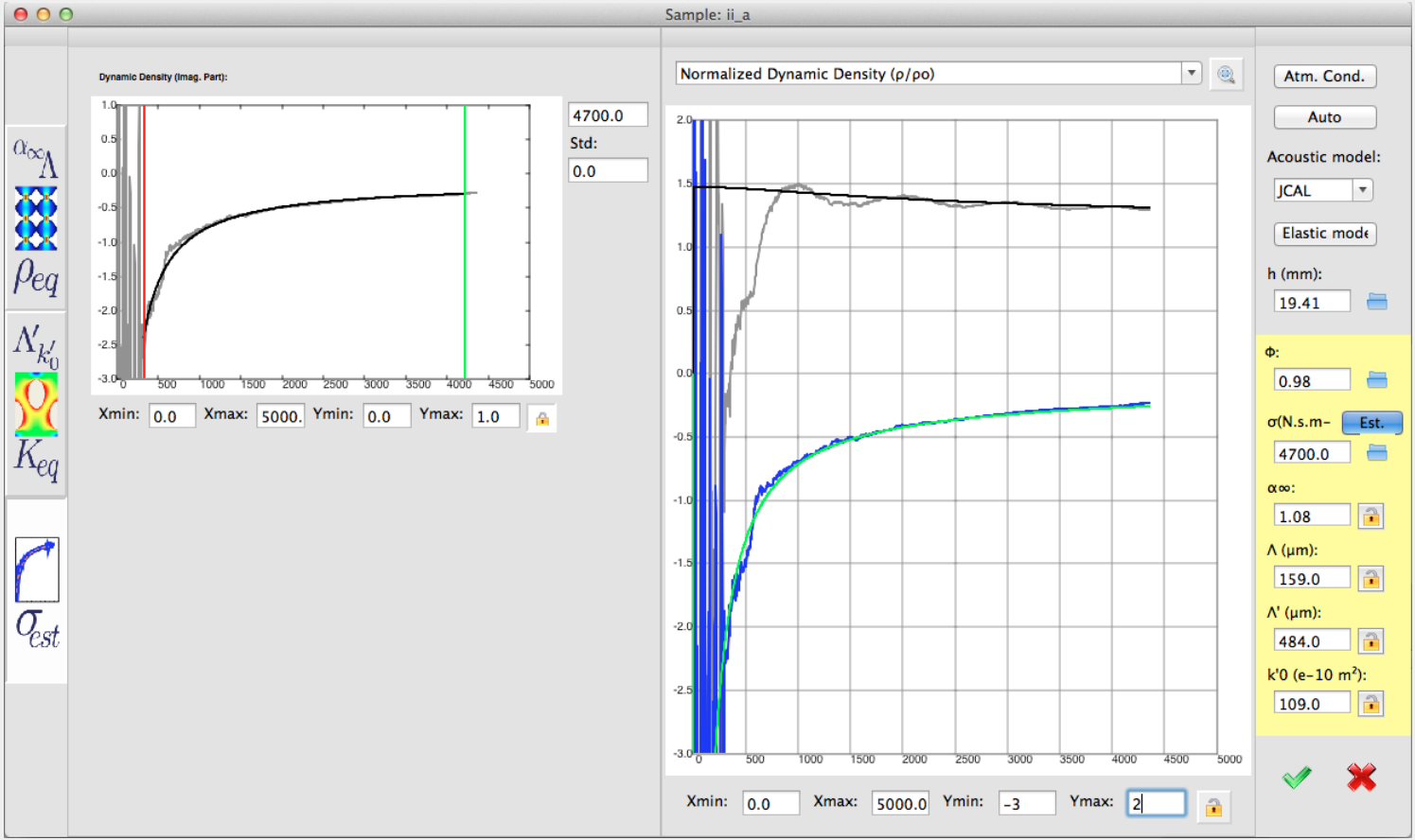
Static air flow resistivity - Low freq. asymptote of $\mathrm{Im}(\tilde{\rho})$



Set-up at ENTPE / Matelys

Panneton & Olny 2006, DOI: 10.1121/1.2169923

Static air flow resistivity - Low freq. asymptote of $\mathrm{Im}(\tilde{\rho})$



PROS	CONS
Measurements with an impedance tube at audible frequencies.	Asymptote can be difficult to identify.

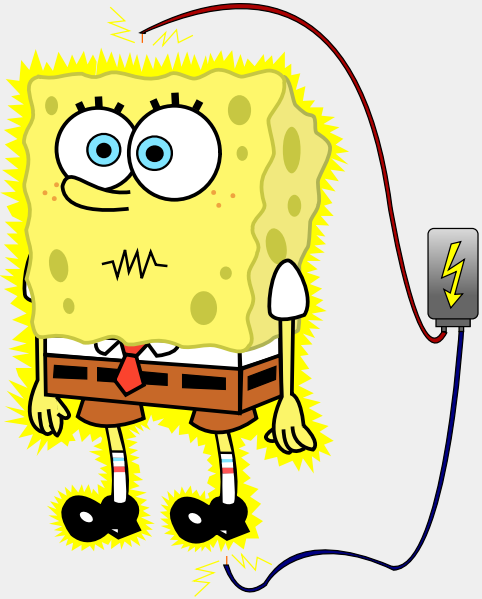
HF limit of the dynamic tortuosity α_∞

" We shall consider the value of α_∞ to be
a measure of the disorder in the sytem. "

D. L. Johnson, J. Koplik, R. Dashen

Range of values:
[1 – 3]

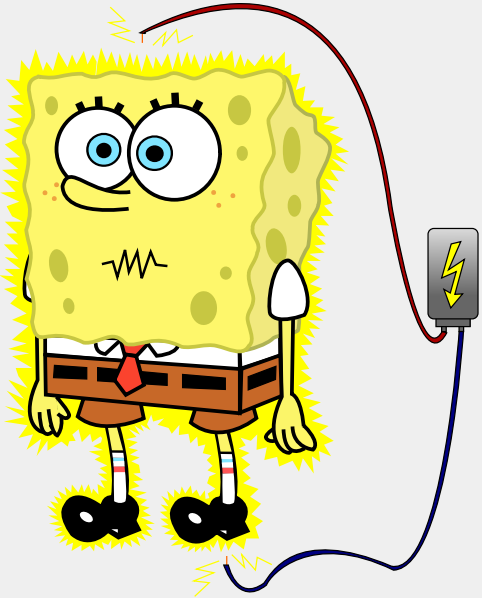
HF limit of dynamic tortuosity - Electric liquid saturation



R. J. S. Brown 1980, DOI: 10.1190/1.1441123

Johnson et al. 1982, DOI: 10.1103/PhysRevLett.49.1840

HF limit of dynamic tortuosity - Electric liquid saturation



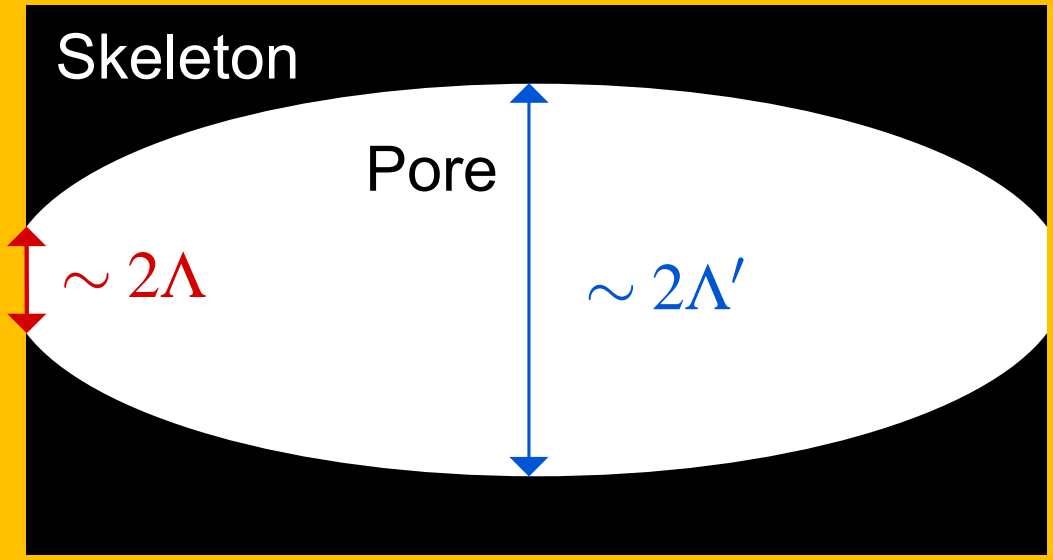
PROS	CONS
Direct measurement.	Skeleton must be an electrical insulator. Open-porosity is required.

HF limit of dynamic tortuosity - 2 other methods

- Ultrasound waves:
  Give estimations for α_∞ and Λ, Λ', (ϕ)

- Impedance tube:
  Give estimations for α_∞ and Λ, Λ', k_0'.

Viscous (Λ) & thermal (Λ') characteristic lengths

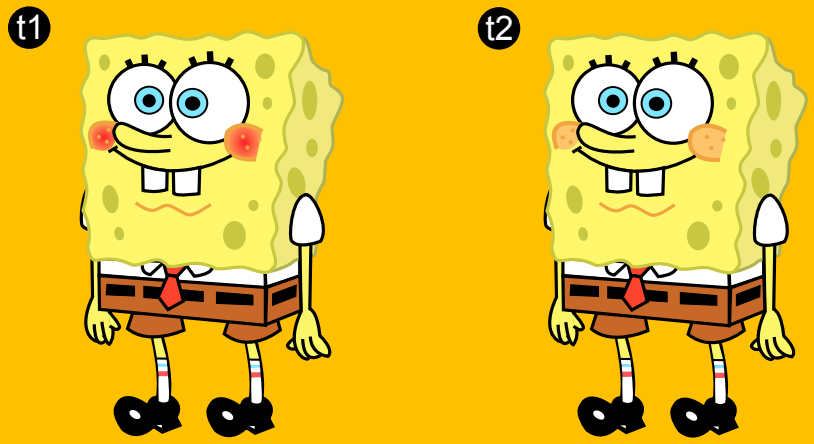


Range of values:

$[\ 10 \quad - \quad 1\,000\ ]\ \mu\text{m}$

$(\boldsymbol{\Lambda} \leq \boldsymbol{\Lambda'})$

Static thermal permeability k'_0



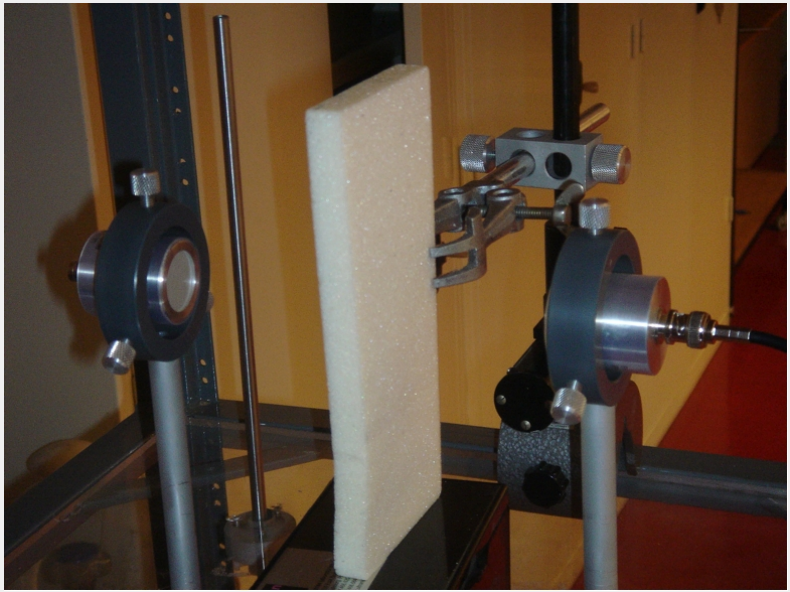
$$\phi\tau = k'_0 \alpha \frac{\partial p}{\partial t}$$

Range of values:

$[\,0 \quad - \quad +\infty\,[\ m^2$

with $k'_0 \geq k_0$

$\alpha_\infty, \Lambda, \Lambda', (\phi)$ - Ultrasounds



Picture courtesy of W. Lauriks

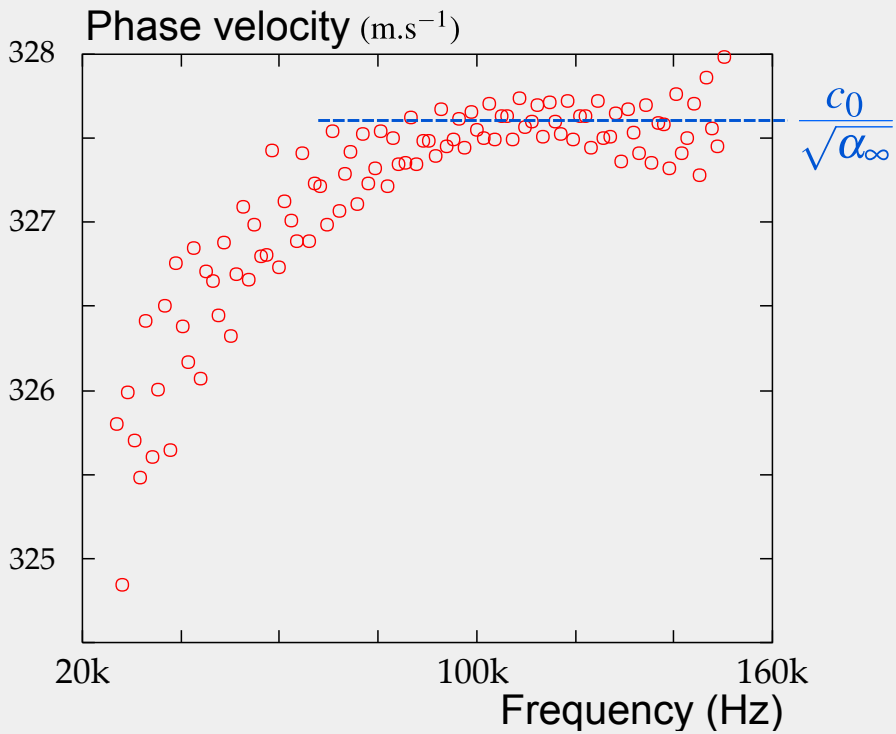
Allard et al. 1994, DOI: 10.1063/1.1145097

Leclaire et al. 1996, DOI: 10.1121/1.415378

Leclaire et al. 1996, DOI: 10.1063/1.363817

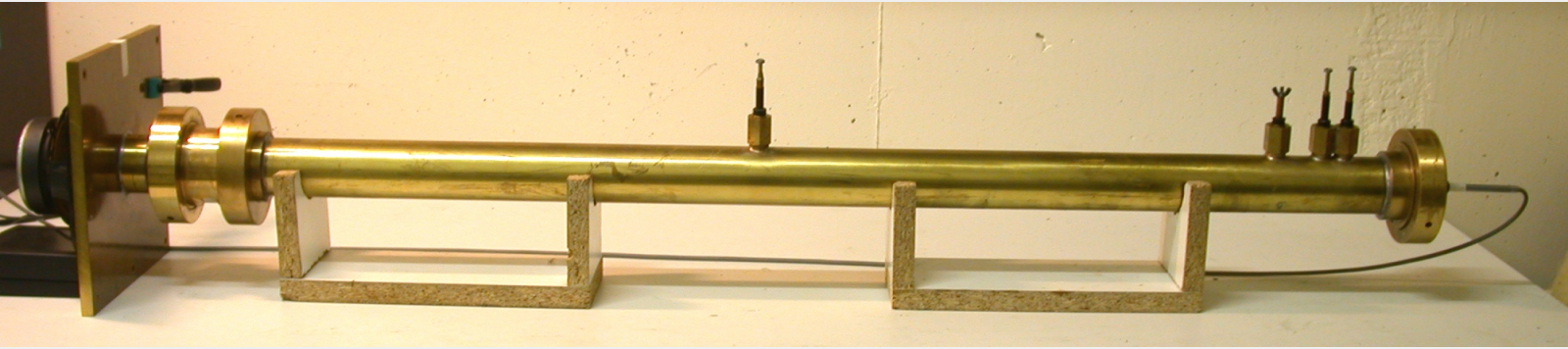
Groby et al. 2010, DOI: 10.1121/1.3283043

$\alpha_\infty, \Lambda, \Lambda', (\phi)$ - Ultrasounds



PROS	CONS
Can quickly mapped heterogenity	Multiple scattering can occur (measurements with 2 fluids thus needed)

$\alpha_\infty, \Lambda, \Lambda', k_0'$ - Impedance tube

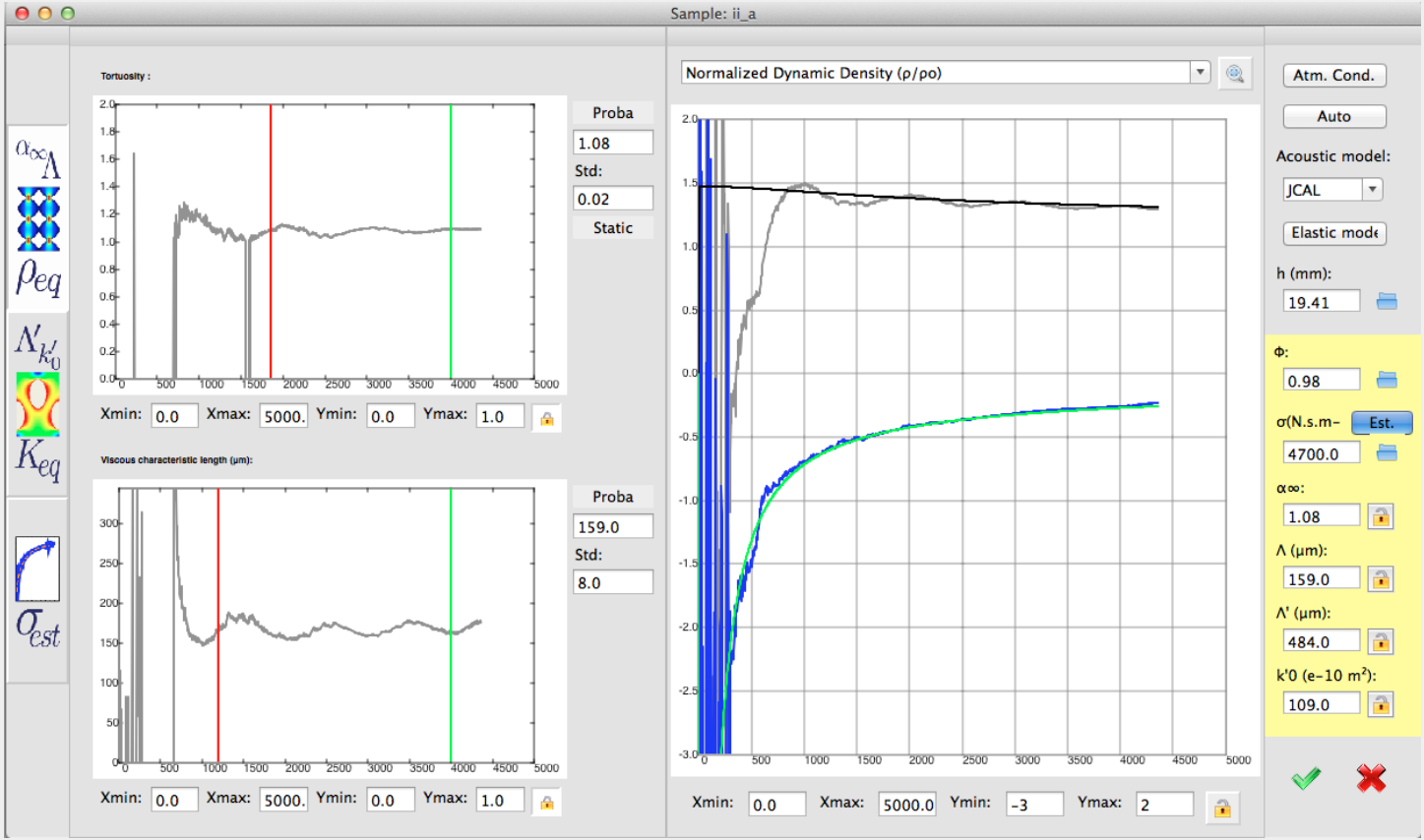


Set-up at ENTPE / Matelys

Panneton & Olny 2006, DOI: 10.1121/1.2169923

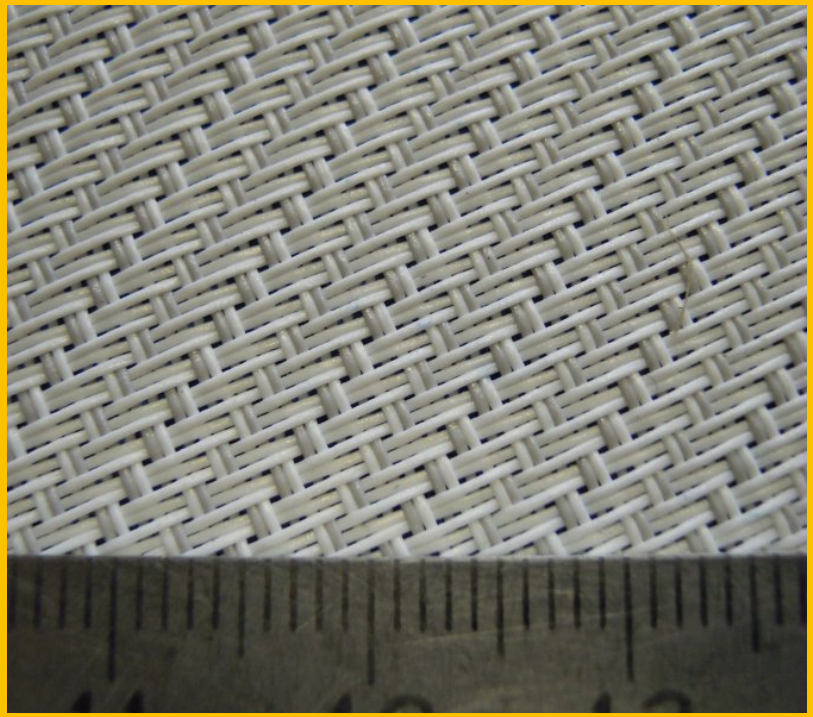
Olny & Panneton 2008, DOI: 10.1121/1.2828066

$\alpha_\infty, \Lambda, \Lambda', k'_0$ - Impedance tube



PROS	CONS
Estimations at audible frequencies	Porosity and resistivity must be known
Analytical inversions (no fit)	Sensible to frame vibrations, air leakages

A note about perforated facings



Jaouen & Bécot 2011, DOI: 10.1121/1.3552887

Conclusions & perspectives

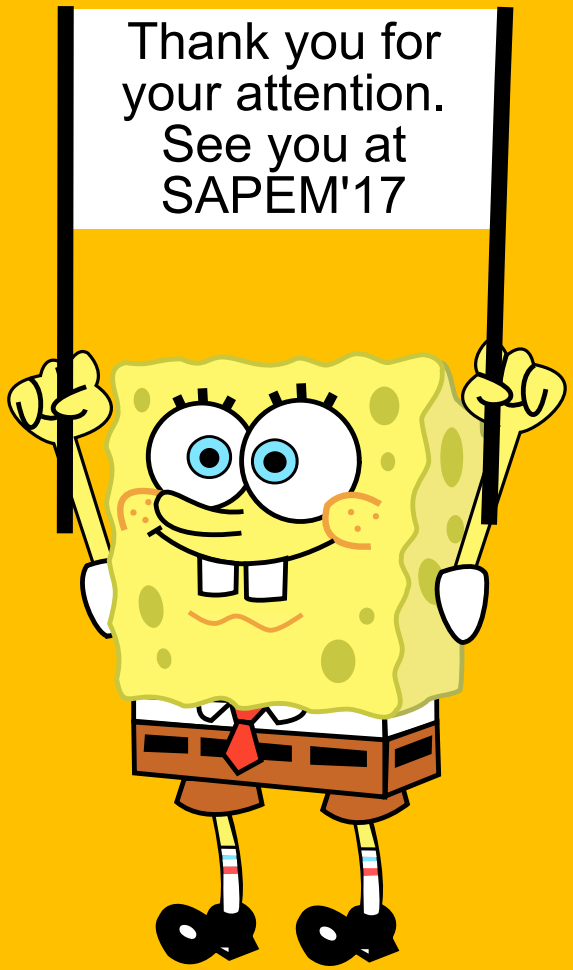
There is and will be **no perfect method**
but a bundle of **complementary methods**.

Acoustic characterization

- Many methods exist,
- still α_0 and α'_0 are not characterized.
  (perspectives at low freq. with long impedance tube).

Visco-elastic characterization

- Broadband characterization is still the exception.
- Too few work on anisotropy.


Thank you for
your attention.
See you at
SAPEM'17