# Latest advances of in-situ (PU) absorption measurements

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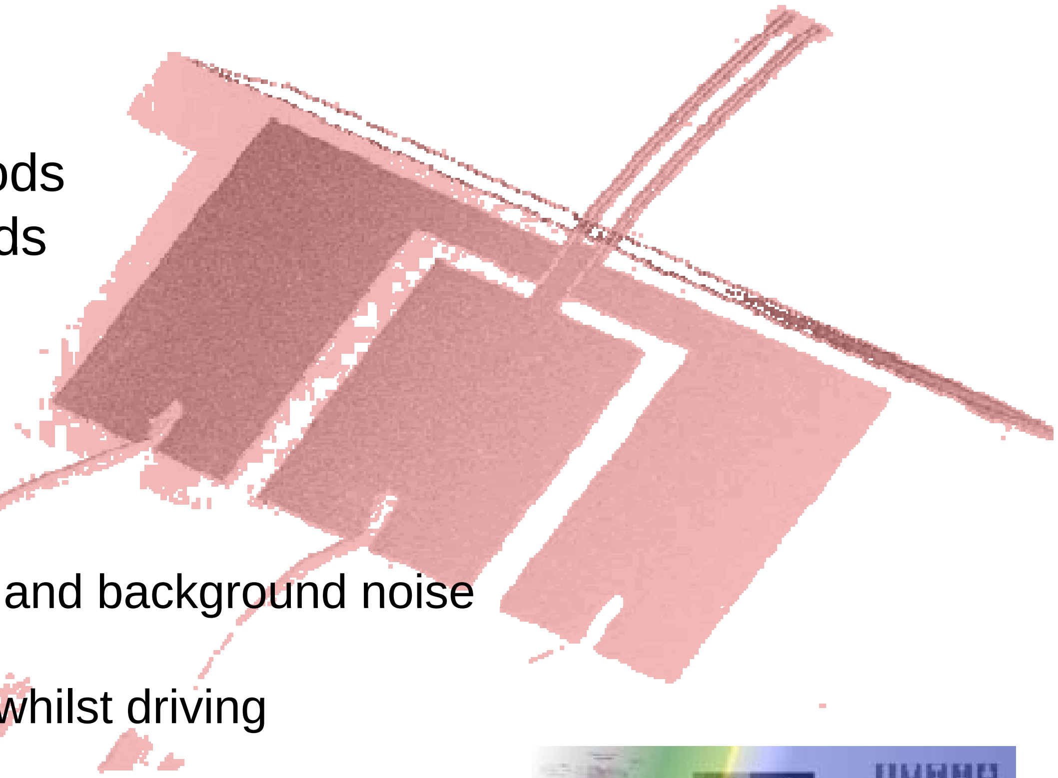
# Contents

- Standardized laboratory based methods:
  - Reverberant room & alpha cabin
  - Kundt’s tube
- *in situ* methods
  - Single microphone methods
  - Impedance based methods
    - Sound field models
    - Experienced problems
    - Extrapolation method
  - PU *in situ* method
    - Setup
    - Low influence reflection and background noise
    - Spatial resolution
    - Asphalt measurements whilst driving
- Conclusion



# Standardized laboratory based methods
## Reverberant room & alpha cabin

- Main principle
  - An acoustic absorbing sample will reduce the pressure amplitude in time. The decay rate is a measure for the absorption

- Advantages
  - Standardized under ISO 354 & ASTM C423

- Disadvantages
  - Large, expensive facilities required
  - Large sample size: several square meters
  - Only absorption is measured (not the complex impedance)
  - “Diffuse” field is changed by the material
  - Absorption values higher than 100% are experienced, because of finite sample size and edge effects.

# Standardized laboratory based methods
## Kundt's tube

- Main principle
  - Measurement of the impedance with one or multiple microphones or by PU probes

- Advantages
  - Standardized
  - Straight forward equations
  - Small sample size

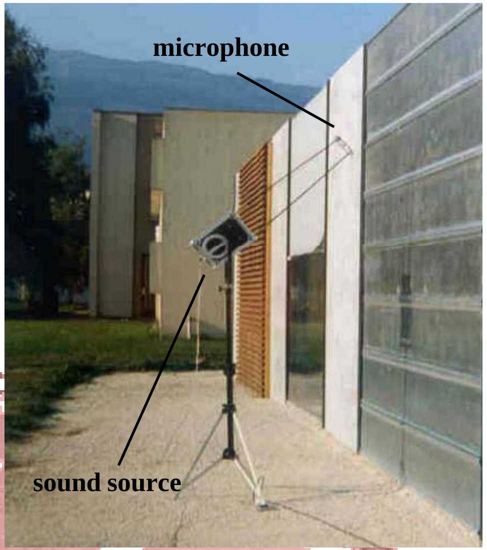
- Disadvantages
  - Sample cut-out: acoustic properties are affected
  - Sound leakage due to mounting problems
  - Only normal incidence
  - Cannot be used on materials with a high flow resistivity and a low stiffness
    (like many multi-layer materials)
  - Only uniform samples

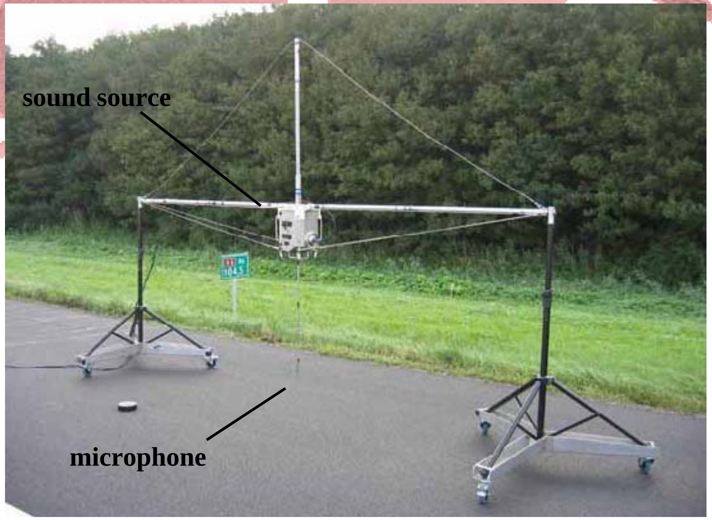
# *in situ* methods
# single microphone methods

- Main principle
  - Direct and reflected sound wave are separated by subtraction- and/or time window techniques

- Advantages
  - *in situ*
  - Adrienne / Extended surface method standardized (ISO 13472-1)

- Disadvantages
  - Frequency limitations
  - Large sample size
  - Background noise
  - For road measurements: cannot be used while moving

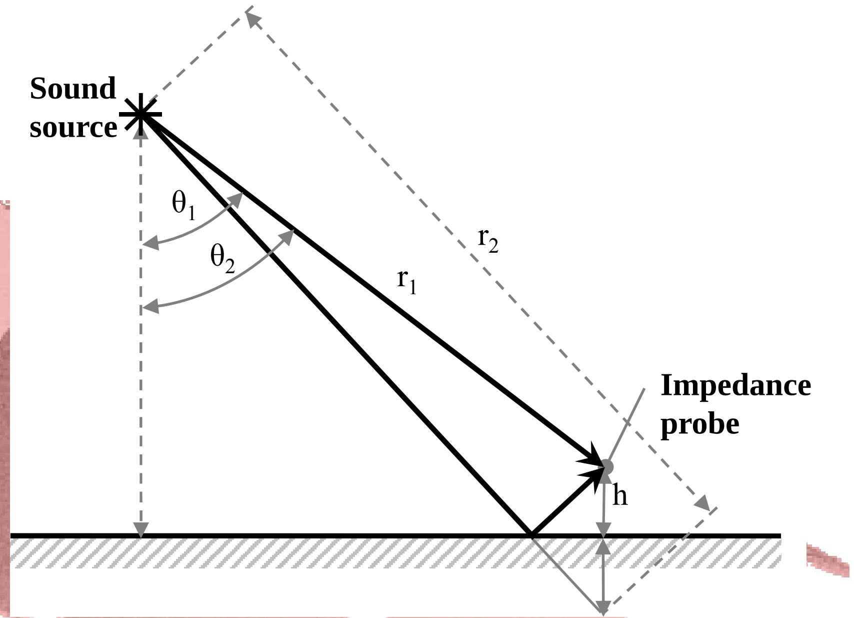


# *in situ* methods
## impedance based: sound field models

- Plane wave model

$$R = \frac{Z_s \cos\theta - \rho c}{Z_s \cos\theta + \rho c} \qquad a = 1 - |R|^2$$




- Mirror source model

$$R = \frac{\frac{Z_m}{Z_{ff}}\cos\theta_1 - 1}{\frac{Z_m}{Z_{ff}}\frac{r_1}{r_2}\frac{ik_0 r_2 + 1}{ik_0 r_1 + 1}\cos\theta_2 + 1}\,\frac{e^{-ik_0 r_1} r_2}{e^{-ik_0 r_2} r_1}$$

# *in situ* methods
# impedance based: sound field models

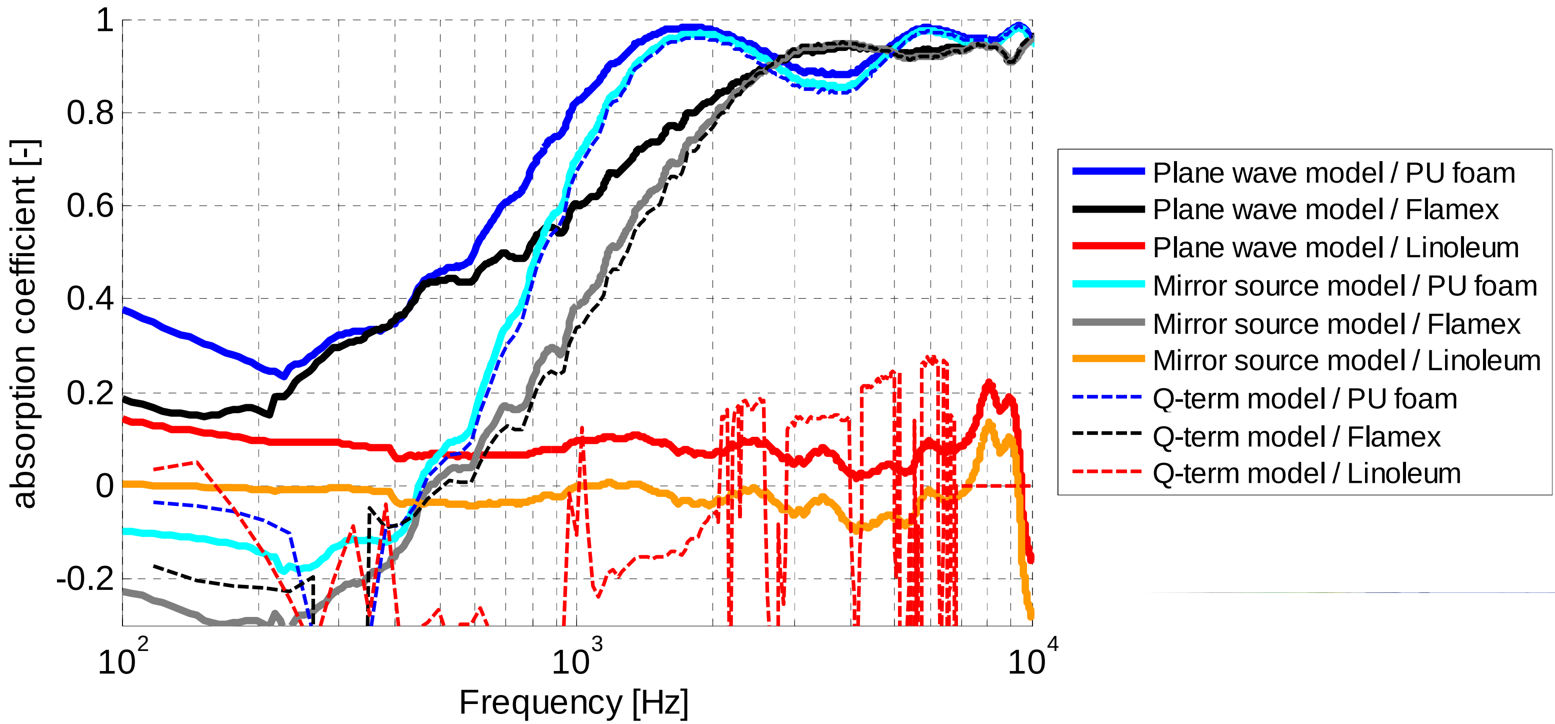
The Q-term model: an example of an exact solution for a point source above an infinitely thin impedance layer:

$$Z_e = \frac{\dfrac{e^{-ik_0 h_1}}{r_1} + \dfrac{e^{-ik_0 h_2}}{r_2} - \dfrac{2k_0}{Z'}\displaystyle\int_0^\infty e^{-q\frac{k_0}{Z'}} \frac{e^{-ik_0(r_2 - iq)}}{r_2 - iq}\,dq}{\dfrac{e^{-ik_0 r_1}}{r_1}\dfrac{ik_0 r_1 + 1}{ik_0 r_1} - \dfrac{e^{-ik_0 r_2}}{r_2}\dfrac{ik_0 r_2 + 1}{ik_0 r_2} + \dfrac{2k_0}{Z'}\displaystyle\int_0^\infty e^{-q\frac{k_0}{Z'}} \frac{e^{-ik_0(r_2 - iq)}}{r_2 - iq}\,\frac{ik_0(r_2 - iq) + 1}{ik_0(r_2 - iq)}\,dq}$$

*Ref: J. Alvarez, F. Jacobsen, "An Iterative Method for Determining the Surface Impedance of Acoustic Materials In Situ", Internoise, 2008*

# *in situ* methods
# impedance based: experienced problems

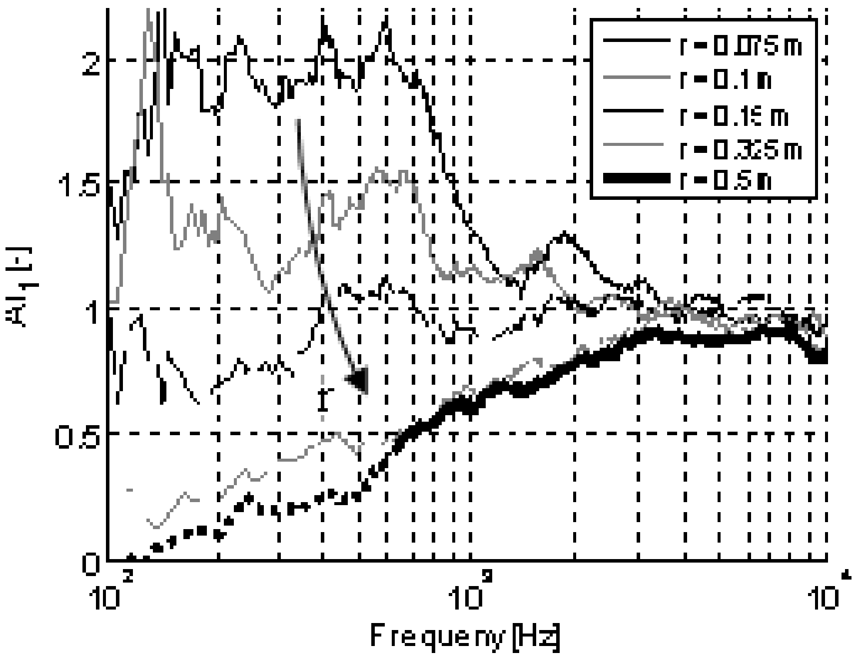
- Low frequency deviations with plane wave models
- Results form the mirror source- and Q-term model are often similar
- Negative absorption values are found because no correction for spherical waves inside the sample is made (the sample is assumed to be infinitely thin).
- Both the complex material impedance and wavenumber need to be known.



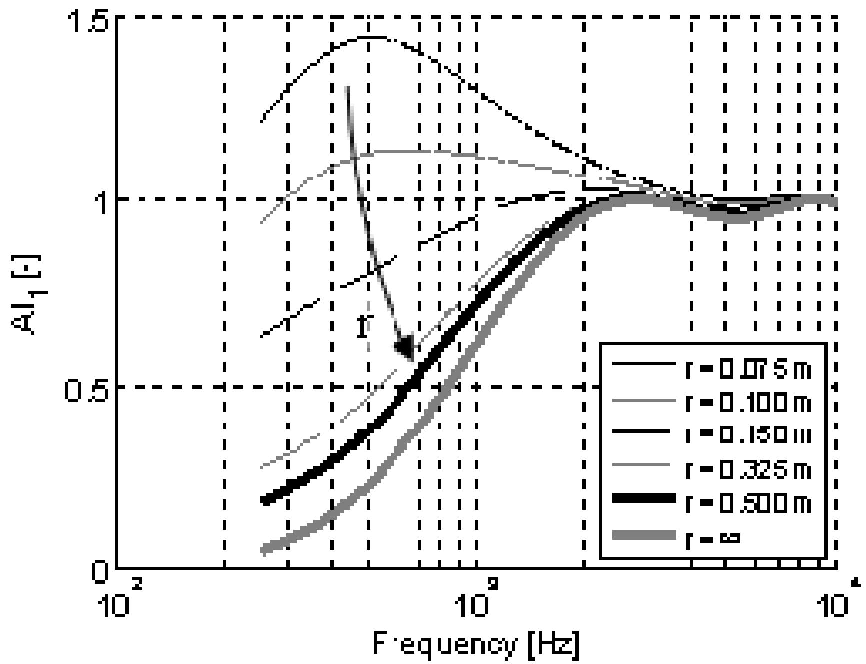
# *in situ* methods
## intensity: extrapolation model

$$\alpha(r) = \frac{re\left(I_{incident} - I_{reflected}\right)}{re\left(I_{incident}\right)} = \frac{re\left(I_1\right)}{re\left(I_0\right)}$$

Intensity based absorption for several source-probe distances *r*:




Measured

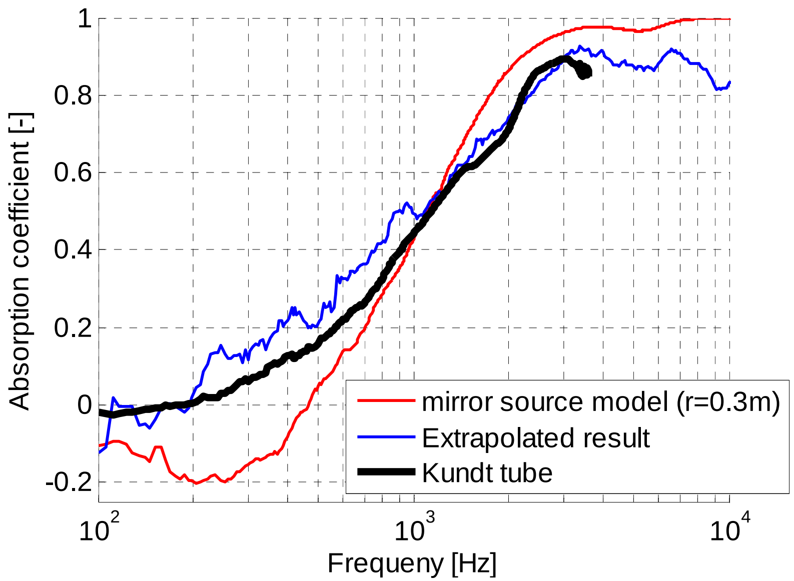



Simulated

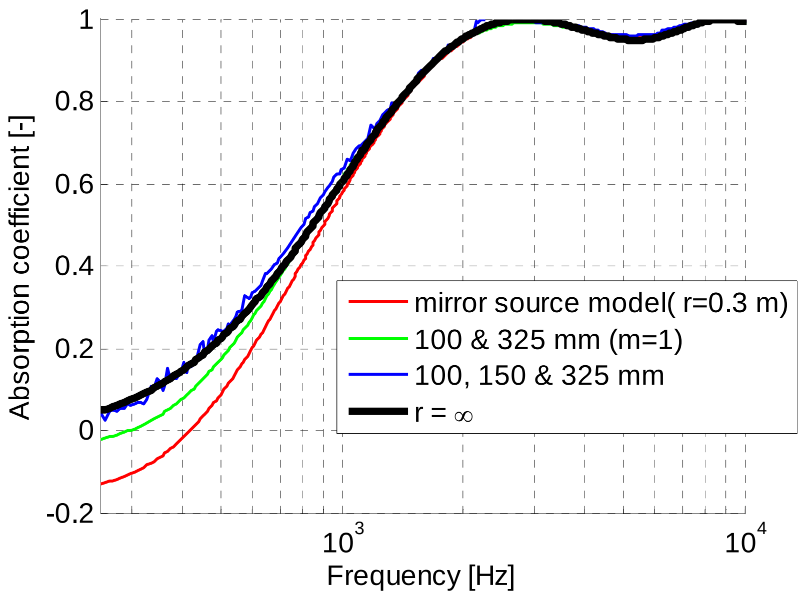
# *in situ* methods
# intensity: extrapolation model

Three (or more) measurements with nearfield effects are combined to solve *B*, *m* and *α*:

$$\alpha(h) = \frac{B}{r^m} + \alpha(r \to \infty)$$




Flamex



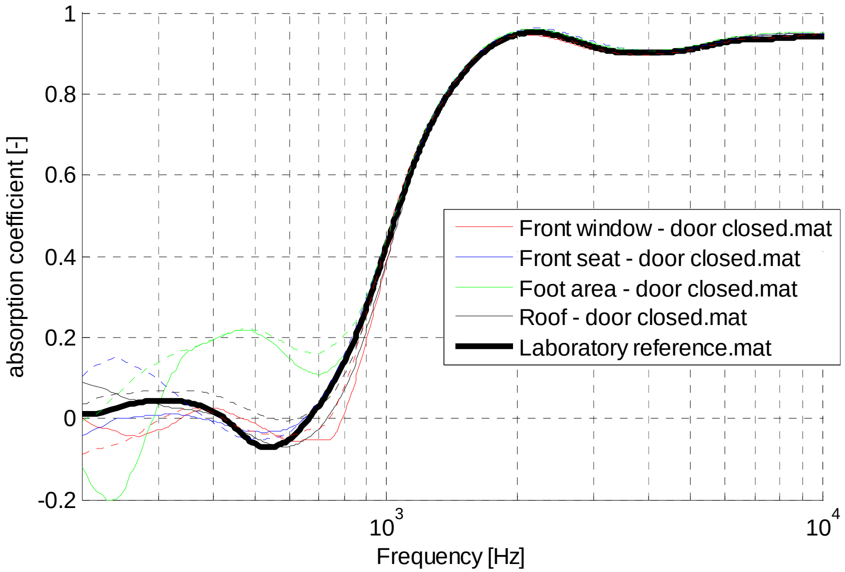

PU foam

# PU in situ method
# Setup

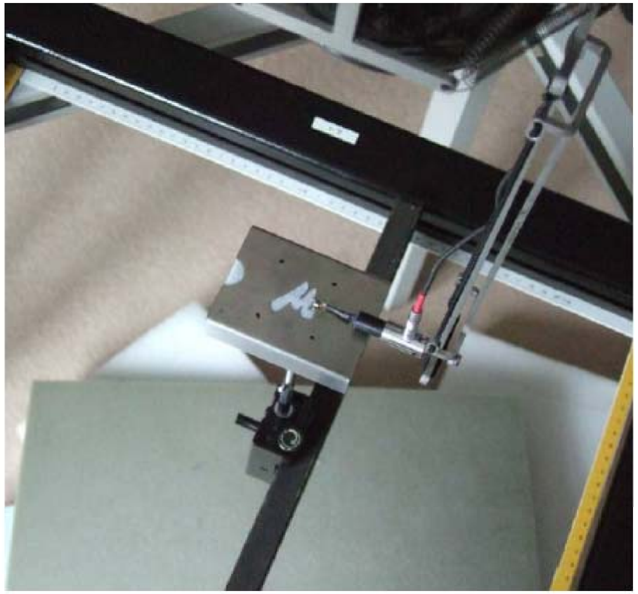
- Small probe-sample and probe-source distance
- Broad banded
- Fast
- Small sample size
- Extremely small spatial resolution
- Low susceptibility to background noise
- Impedance and absorption coefficient

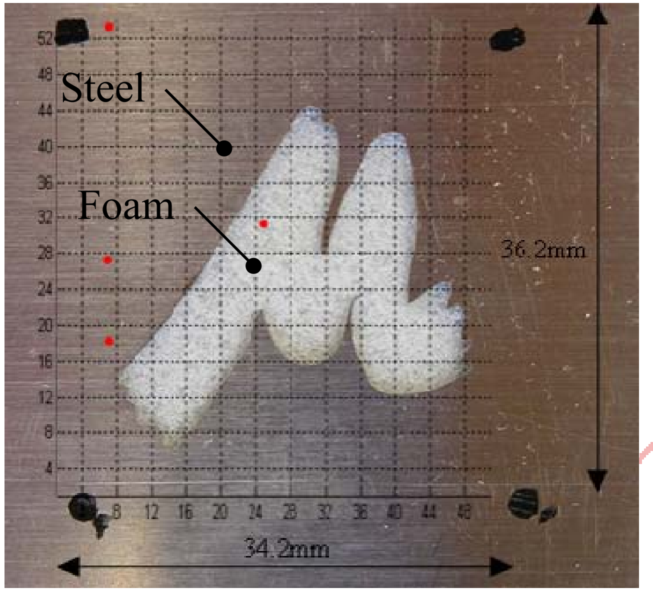
# PU in situ method

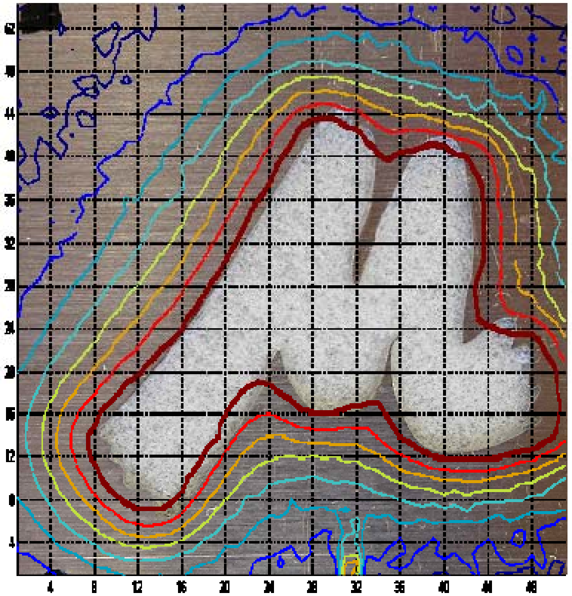
## Low influence reflection and background noise



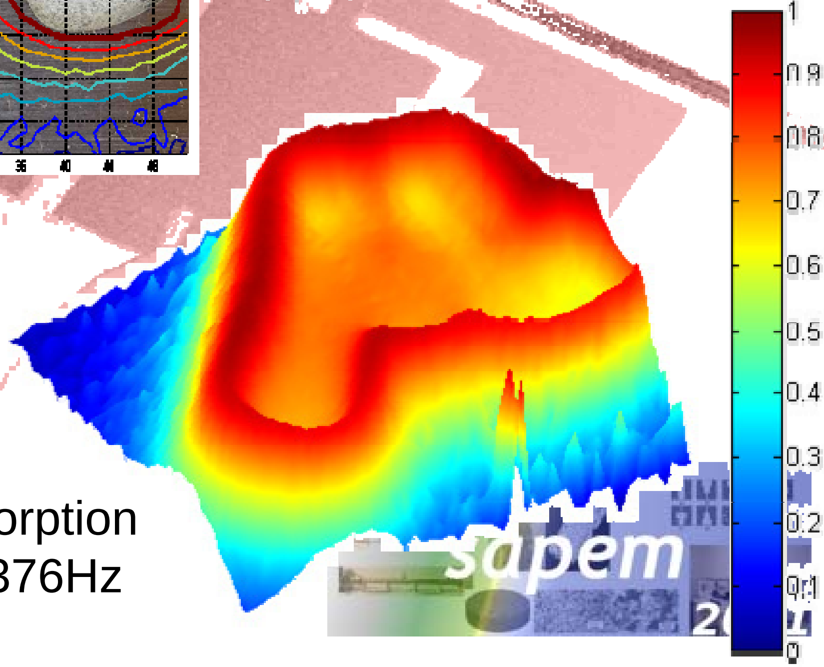
# PU in situ method
## Small spatial resolution





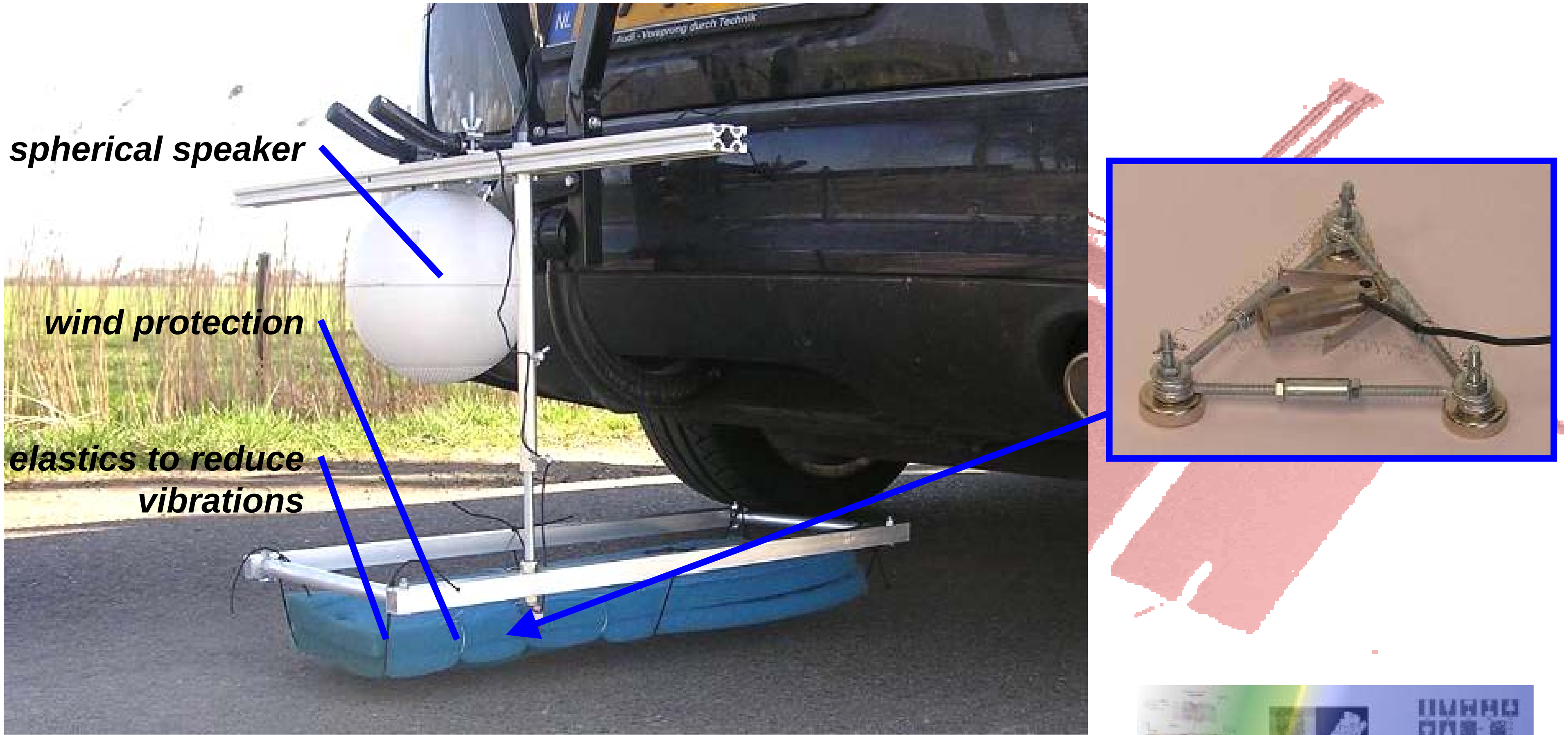



Velocity contour plot @2253Hz




Absorption @2376Hz

# PU in situ method
## Asphalt measurements whilst driving



# Conclusions

- There are several methods to measure the acoustic absorption of materials, but these have their specific weaknesses. Some of them are only laboratory based. Single microphone *in situ* techniques have limitations in terms of band width, sample size and signal to (background) noise ratio.
- Throughout the years increasingly advanced models have been proposed to correct for a monopole above an impedance layer. However, errors are found for small sample-source distances because of spherical waves inside the sample
- An intensity based extrapolation method has recently been proposed that combines several measurements with near field effects in order to obtain the plane wave absorption coefficient.
- Advantages of using small PU probes are the small sample size requirement, the high spatial resolution and the low influence to background noise and reflections.