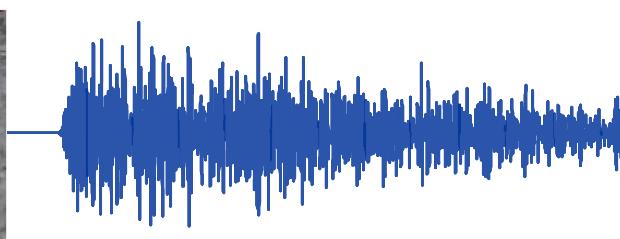


# Diffusion ultrasound cracks imaging: application to concrete evaluation

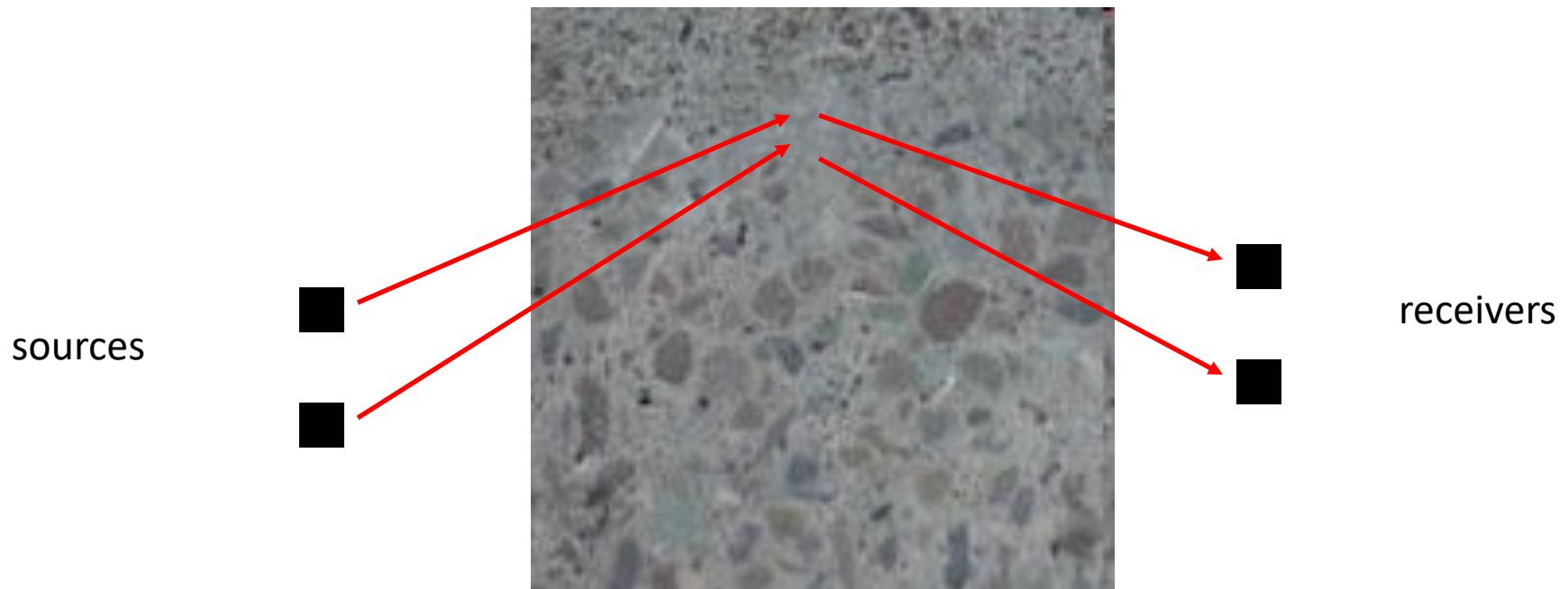
Eric LAROSE, Y. ZHANG,  
T. PLANES, L. MOREAU, Q.  
XUE...

ISTerre,

CNRS & Université Grenoble Alpes

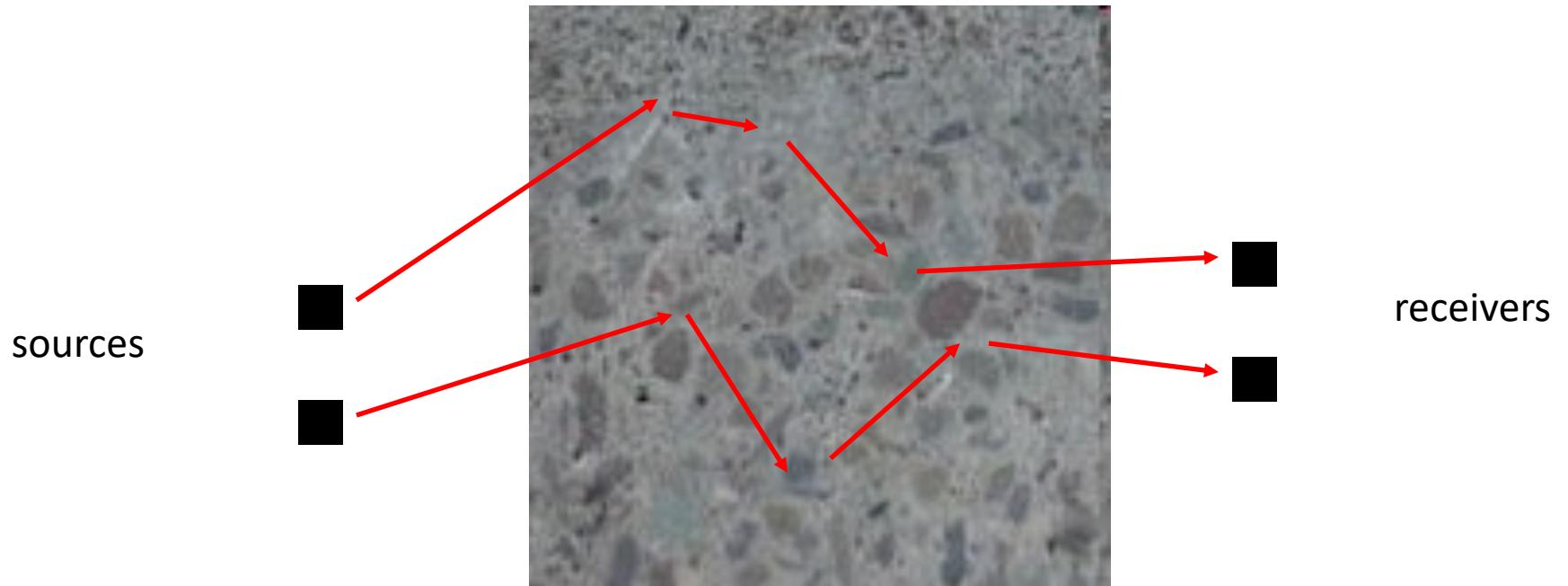


# → ultrasonic coda waves



Transition at 50-100 kHz : simple scattering

# → ultrasonic coda waves

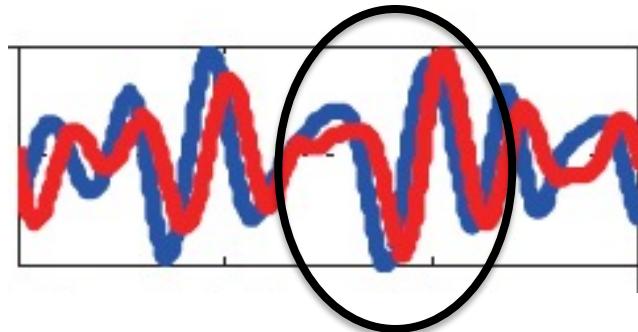


Transition at 50-100 kHz : simple → multiple scattering

$\lambda <$  grain size

Anugonda et al (2001)  
Becker et al (2003)

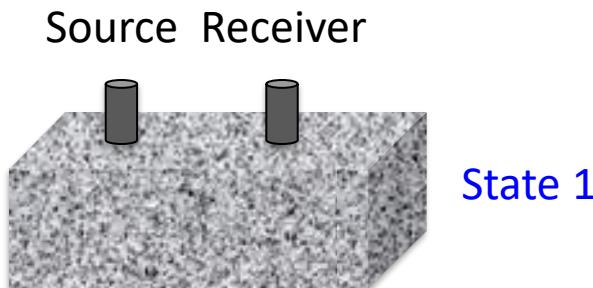
# 1) Relative velocity changes $dV/V$



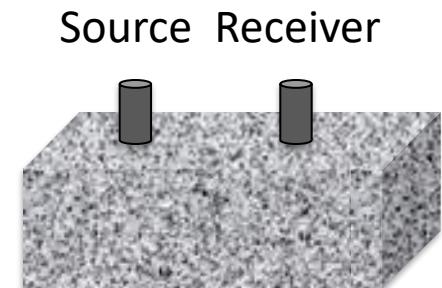
**Stress cartography**

Elastic modulus

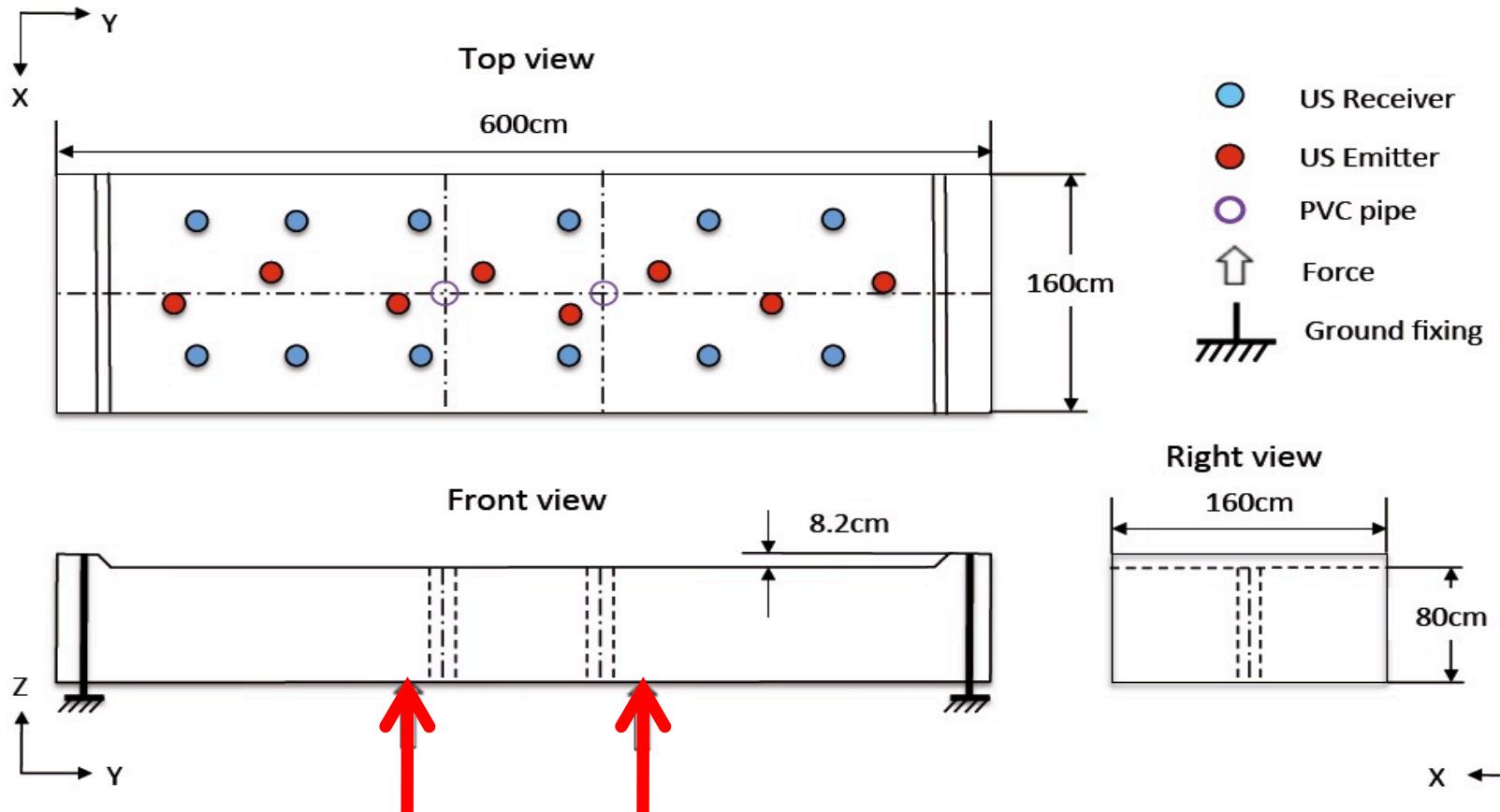
Coda wave Interferometry



State 2

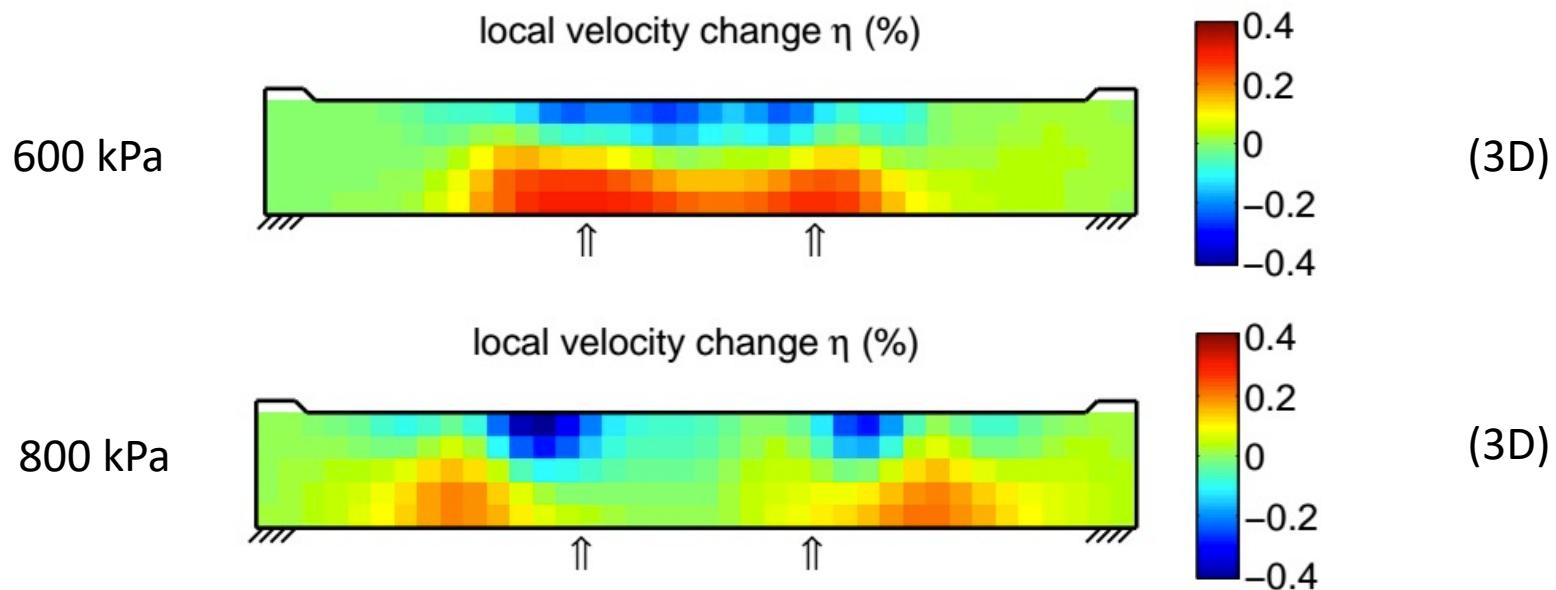


## 4 points bending test on a 16 tons concrete beam

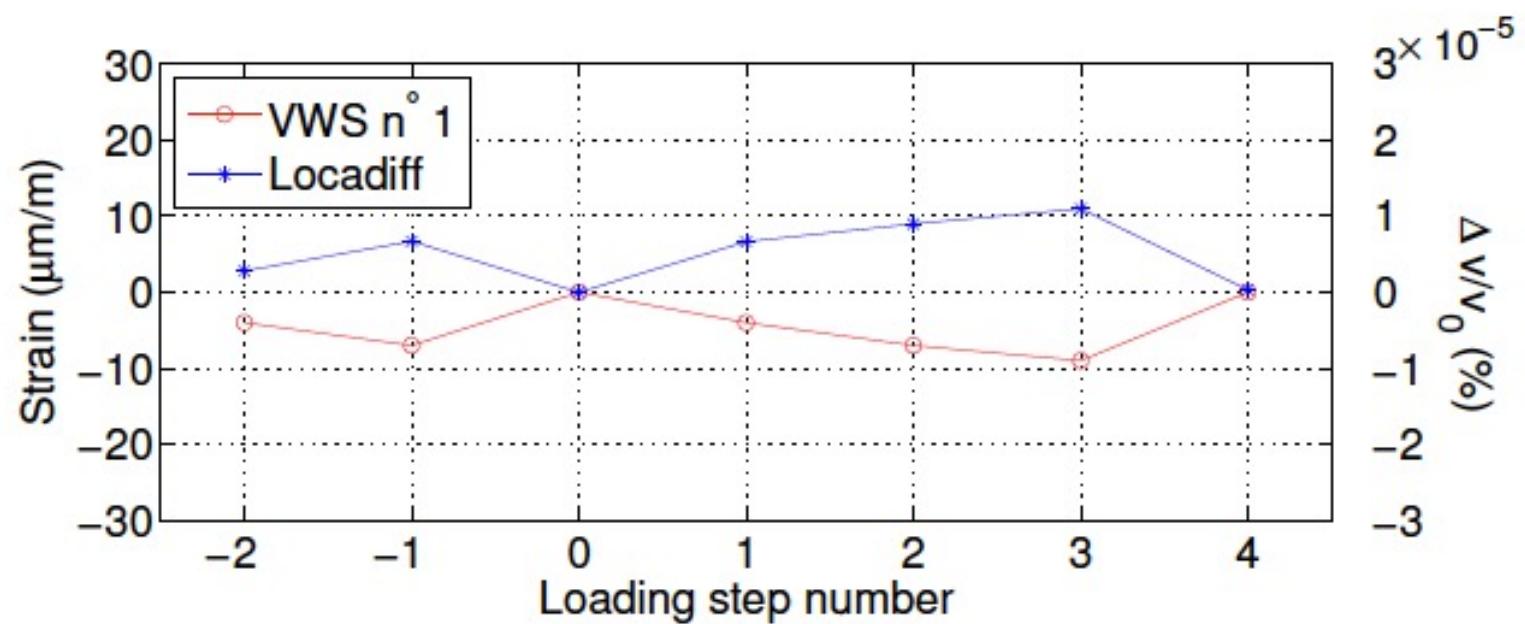


# Stress map (3D)

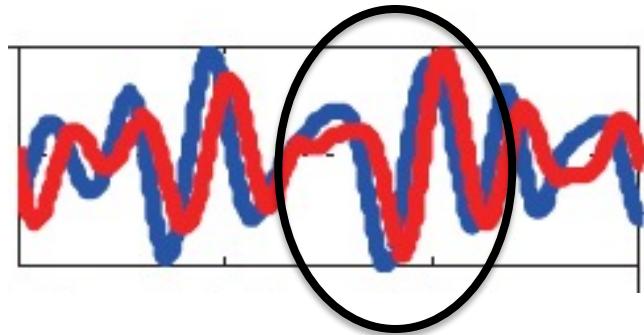
## *In Situ & non-destructif*



# Calibration $dV/V \leftrightarrow$ strain

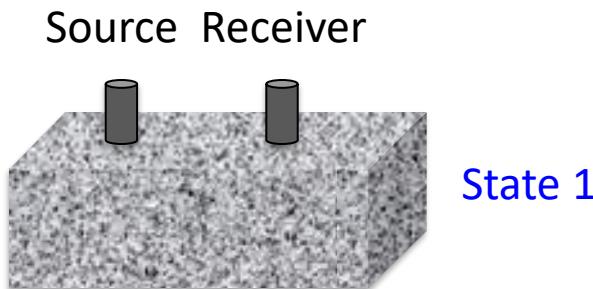


## 2) Coda Wave Decorrelation

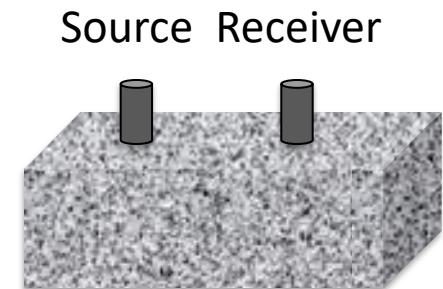


Change of structure

**Crack density ( $\text{m}^2/\text{m}^3$ )**

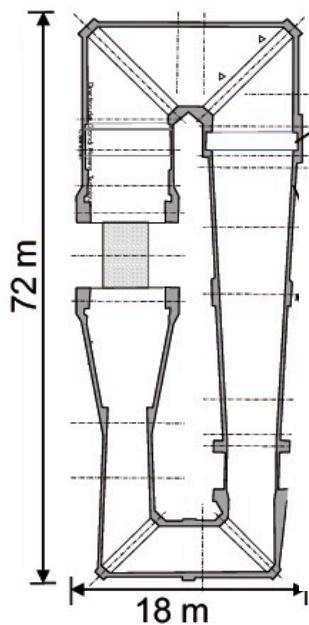


→ State 2



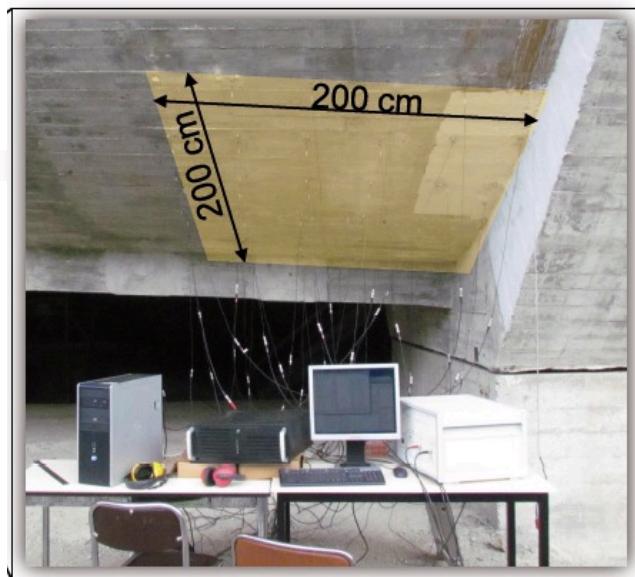
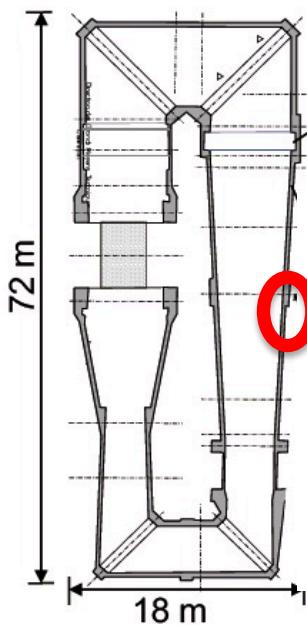
**ONERA**

THE FRENCH AEROSPACE LAB

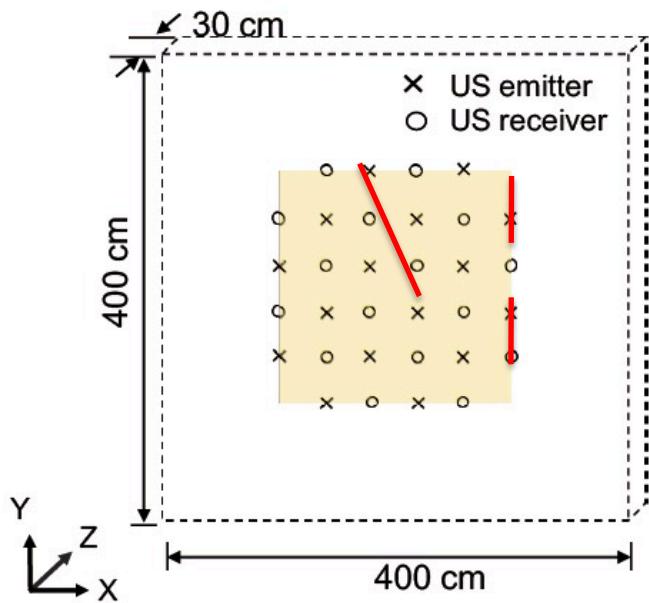
**ANR ENDE**

ONERA

THE FRENCH AEROSPACE LAB

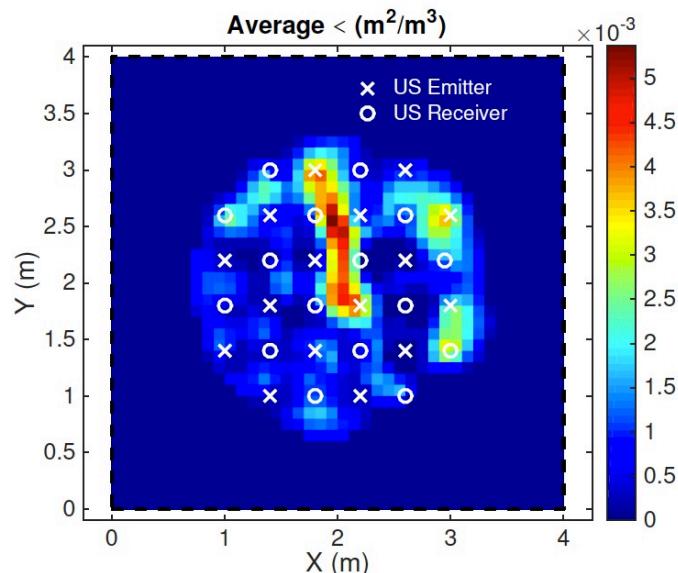
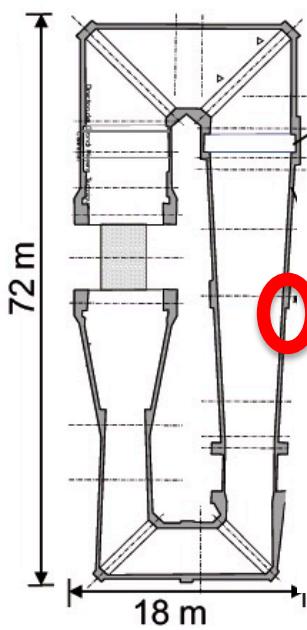


# Wind tunnel

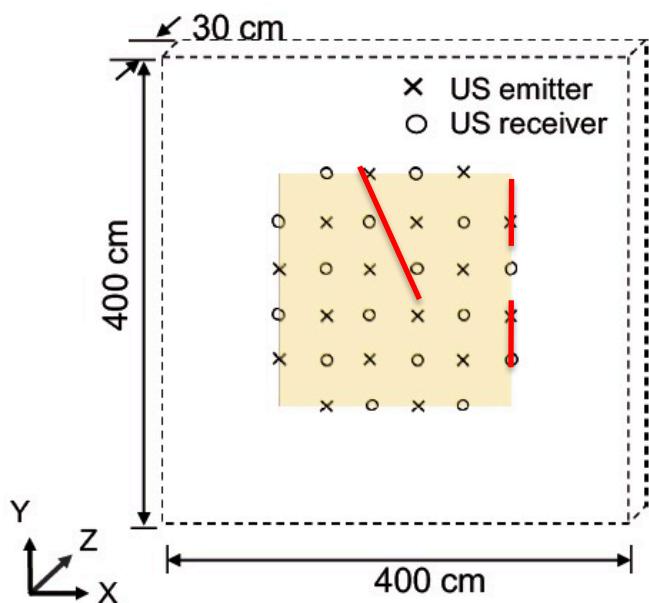


ONERA

THE FRENCH AEROSPACE LAB

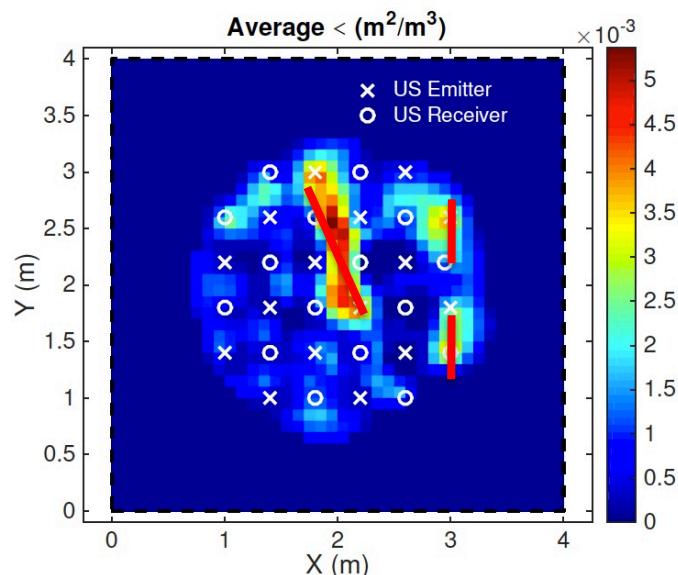
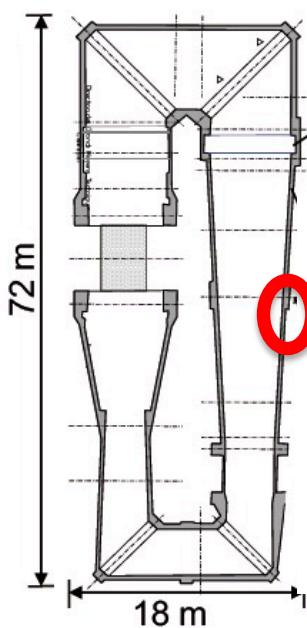


# Wind tunnel



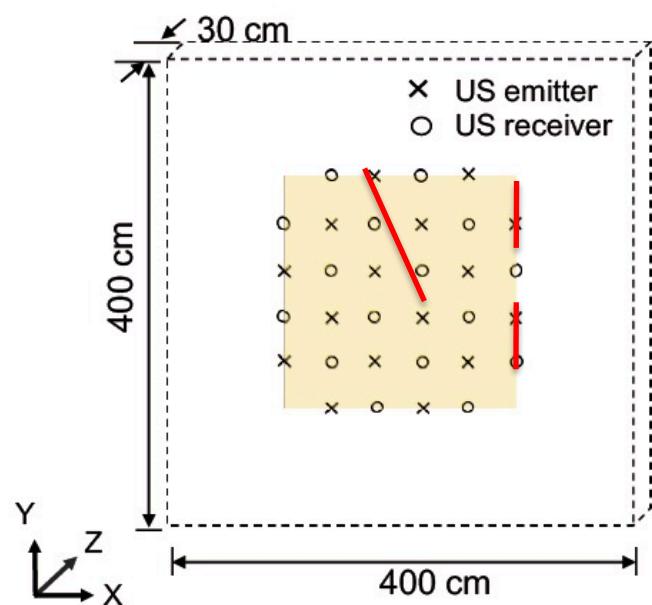
ONERA

THE FRENCH AEROSPACE LAB

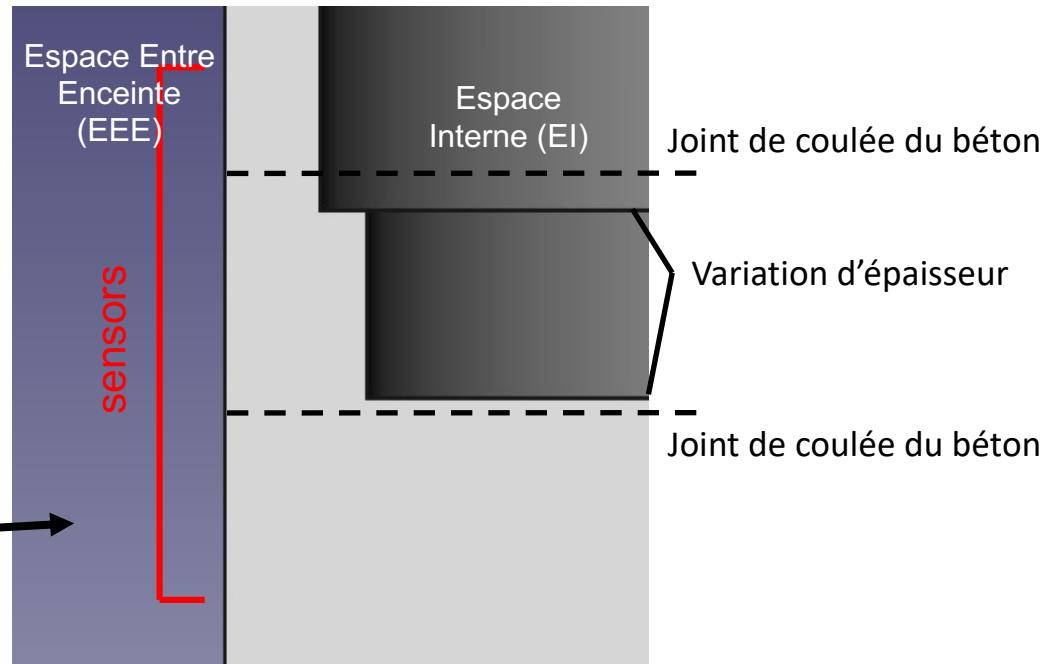
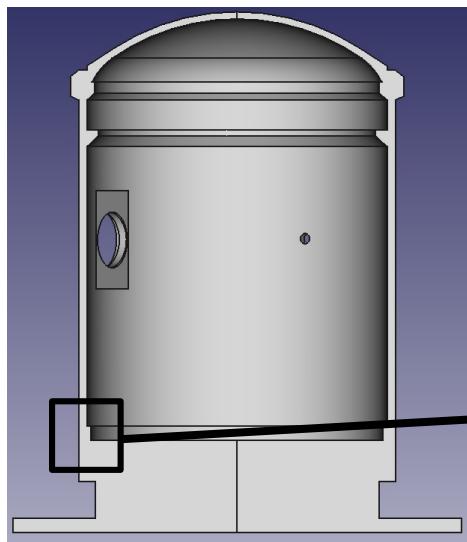


at 15 cm depth

# Wind tunnel



Zone d'étude :  
Le Gousset

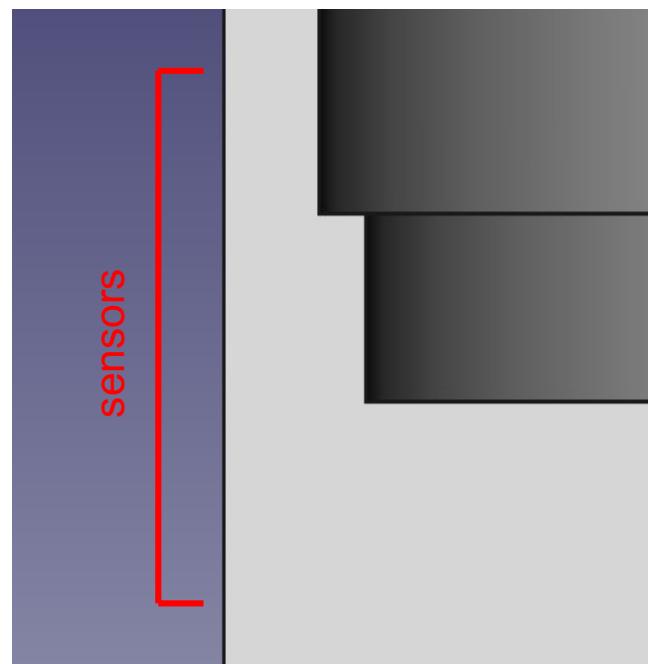
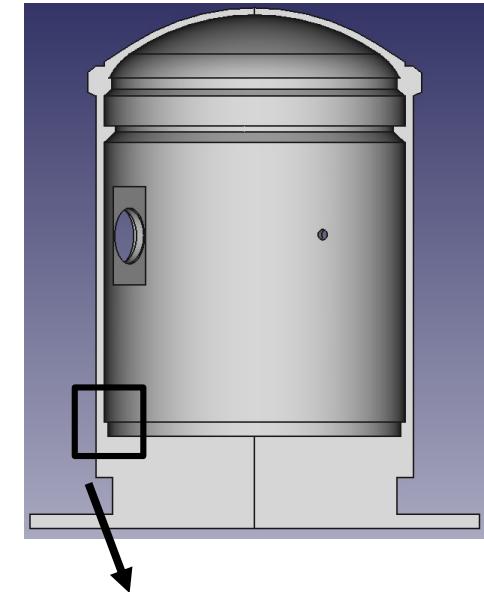
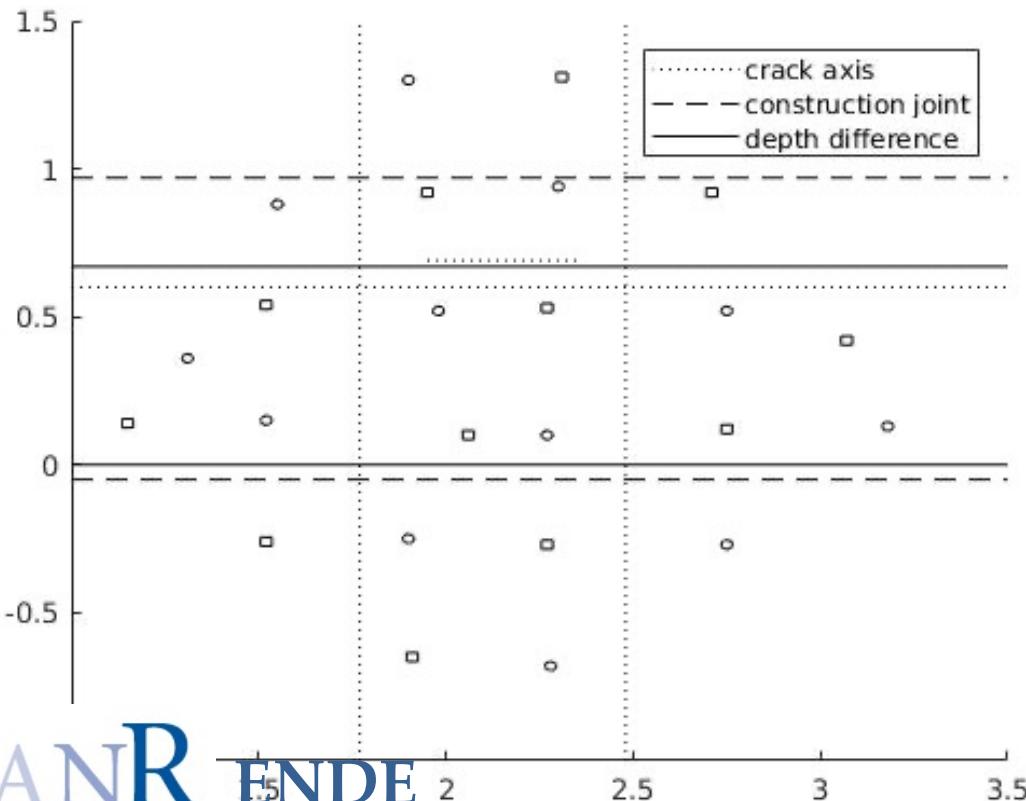


ANR ENDE (2014-2021) :  
Evaluation Non Destructive des Enceintes de confinement

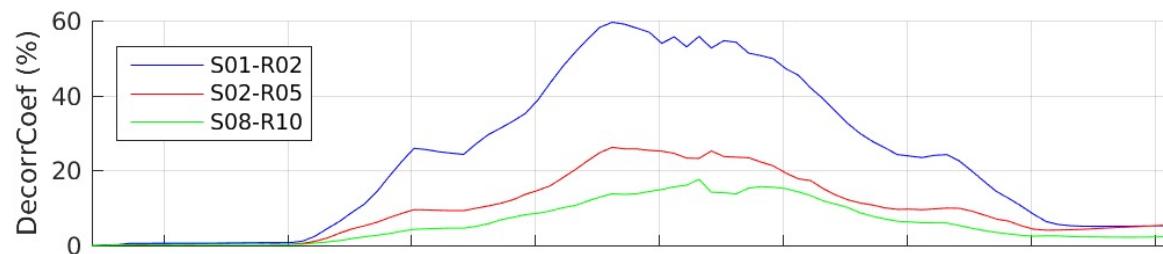
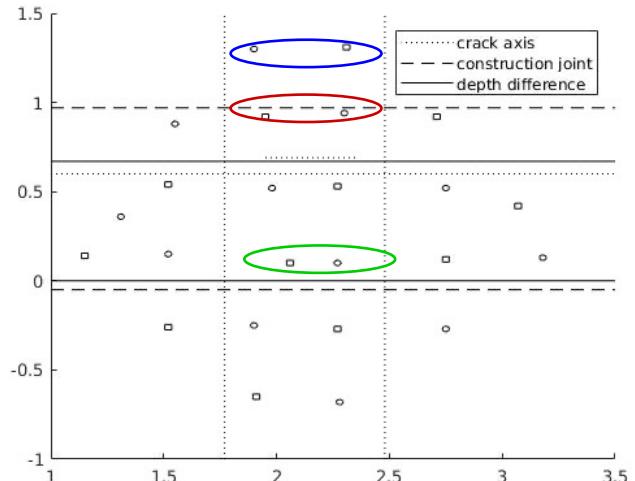
# LOCADIFF

- Application a Vercors

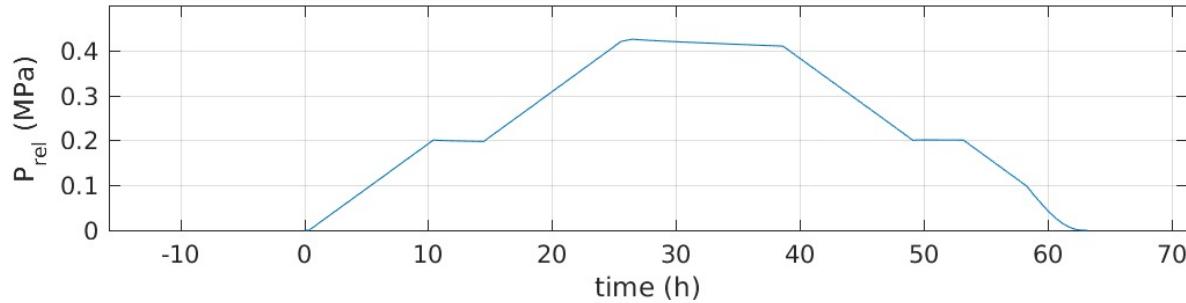
Zone d'étude :  
Le Gousset



# Évolution de dV/V et DC avec la pression, pour 3 couples de capteurs

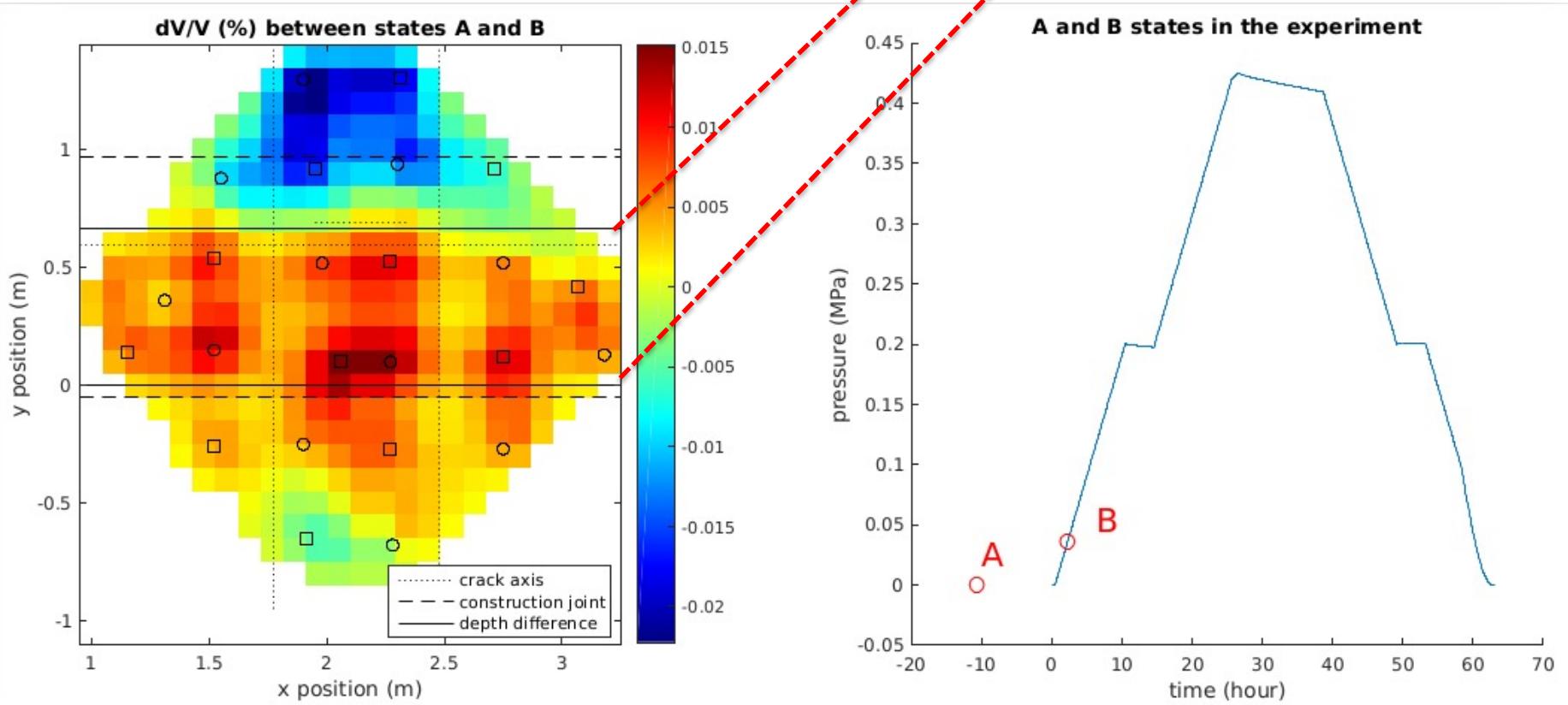
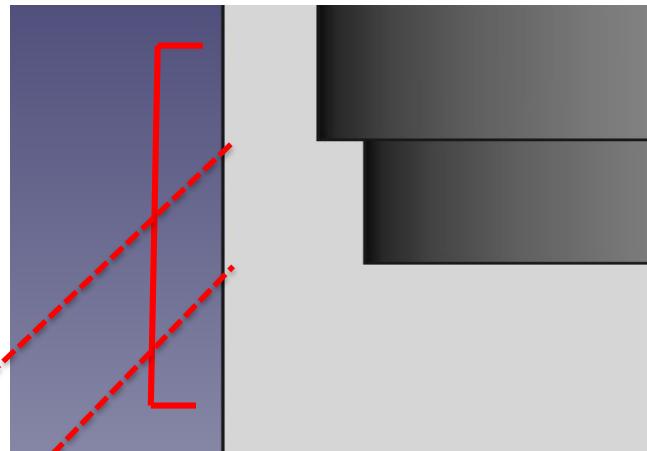


⇒ notions de localisation



# Résultat d'imagerie en dV/V (manip 2017-semaine 2)

ANR ENDE



# Advantages

- Fully 3D, in the bulk of concrete
- Sensors glued on the surface only
- Temporary or permanent instrumentation
- Versatile & flexible instrumentation
- Sensitive to mechanical changes
- Non-destructive, non-invasive

# Performances

- Spatial resolution :
  - down to a few centimeters... and less\*
- Sensitivity/ability to detect :
  - Cracks of 10 µm opening... and less\*
  - Cracks of a few cm<sup>2</sup> ... and less\*
  - Stress change of a few kPa

\*Resolution and sensitivity can be improved by switching to higher US frequencies, which results in reducing the depth penetration and probed area to ~10 cm x 10 cm x 10 cm

# Complementary to

- Acoustic emission (same sensors!)
- Surface visual inspection
- Surface photo-image correlation
- Bubbling

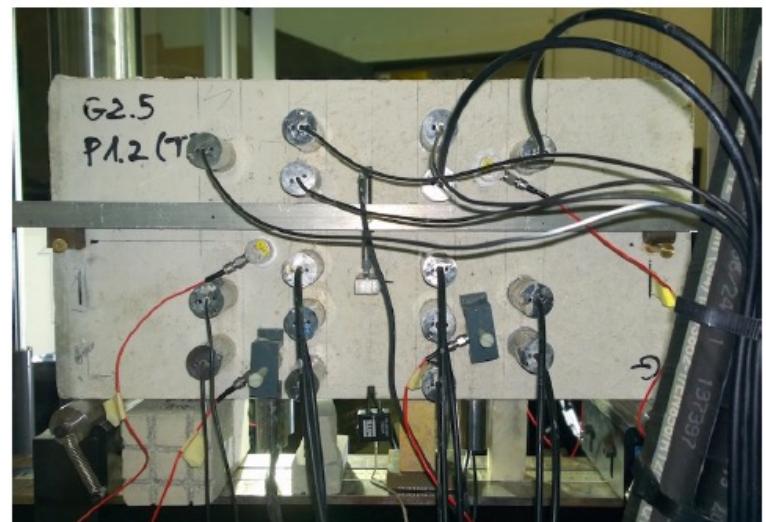
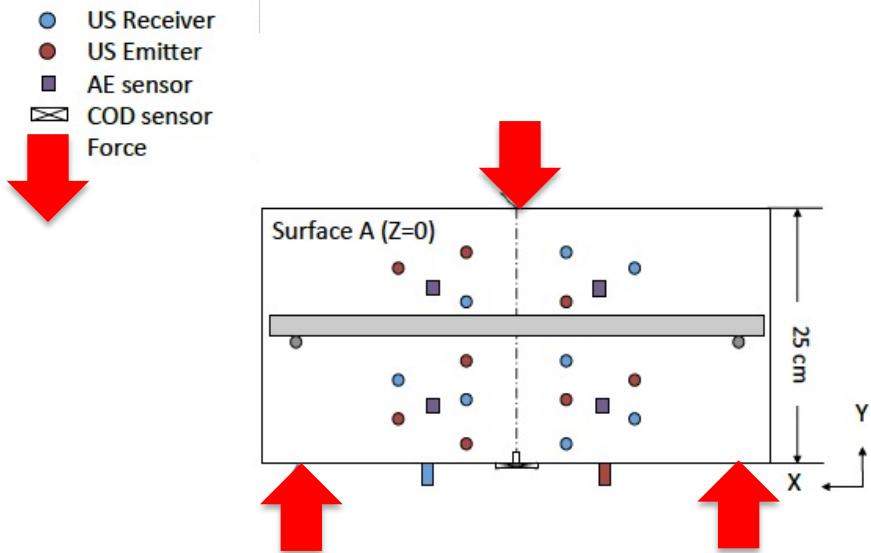
# Thank you !!

[eric.larose@univ-grenoble-alpes.fr](mailto:eric.larose@univ-grenoble-alpes.fr)

- Q. Xue, E. Larose, L. Moreau : *Locating structural changes in a multiple scattering domain with an irregular shape*, J. Acoust. Soc. Am., **146**, 595-602 (2019).
- F. Xie, E. Larose, L. Moreau, Y. Zhang, T. Planes : *Characterizing extended changes in multiple scattering media using Coda Wave Decorrelation : numerical simulations*, Waves Rand. Media **28** 1-14 (2018).
- Y. Zhang, E. Larose, L. Moreau, G. d'ozouville : *3D in-situ imaging of cracks in concrete using diffuse ultrasound*, Structural Health Monitoring **17** 279-284 (2018).
- Y. Zhang, T. Planes, E. larose, A. Obermann, C. Rospars, and G. Moreau : *Diffuse ultrasound monitoring of stress and damage development on a 15-ton concrete beam*, J. Acoust. Soc. Am. **139** 1691-1701 (2016).
- E. larose, A. Obermann, A. Digulescu, T. Planes, J-F Chaix, F. Mazerolle, and G. Moreau *Locating and characterizing a crack in concrete with diffuse ultrasound : a four-point bending test*, J. Acoust. Soc. Am, **138** 232 (2015).
- T. Planes, E. Larose, V. Rossetto, and L. Margerin , *Imaging multiple local changes in heterogeneous media with diffuse waves*, J. Acoust. Soc. Am., **137**, 660,(2015).
- E. Larose, T. Planes, V. Rossetto and L. Margerin : *Locating a small change in a multiple scattering environment*, Appl. Phys. Lett. **96** (20), 204101 (2010).

# Laboratory experiment

3D image of the state of stress at different loading levels on a 12 cm x 25 cm x 50 cm sample



# Laboratory experiment

Restrictions :

- Access to two sides only,
- Fully 3D, in the bulk
- resolution down to  $\sim$ cm

## 15-to-18 cm high crack

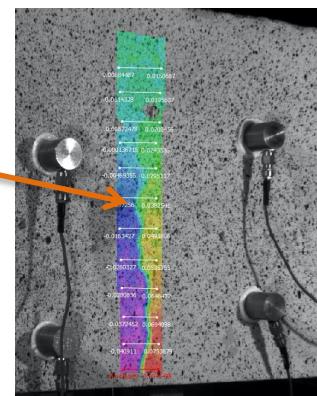
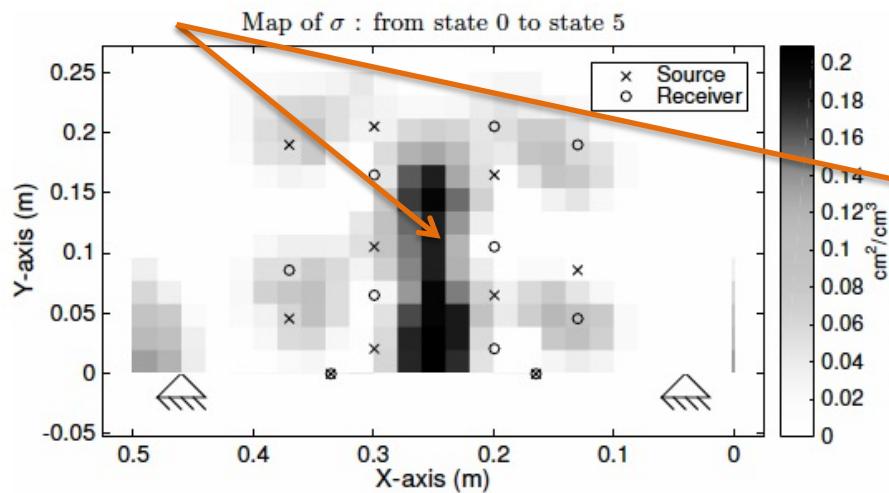


Image correlation (DIC)

LOCADIFF

ANR ENDE