



# Thesis Report of the: Ongoing experimental research on seismo-electromagnetic fields generated at saturated porous media interfaces

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# Overview

## Introduction

### Experiments: What has been done

### Open questions I will focus

*Known questions*

*Questions we have ourselves*

### Experiments to be conducted

### Where am I at?

*General view*

*Automation*

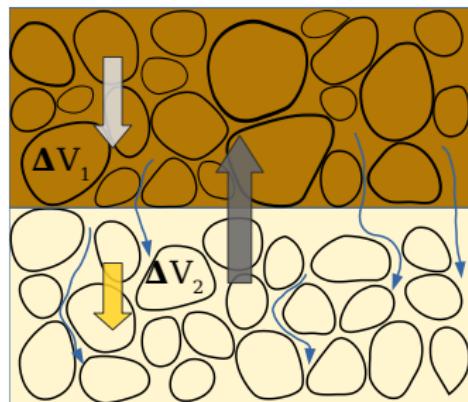
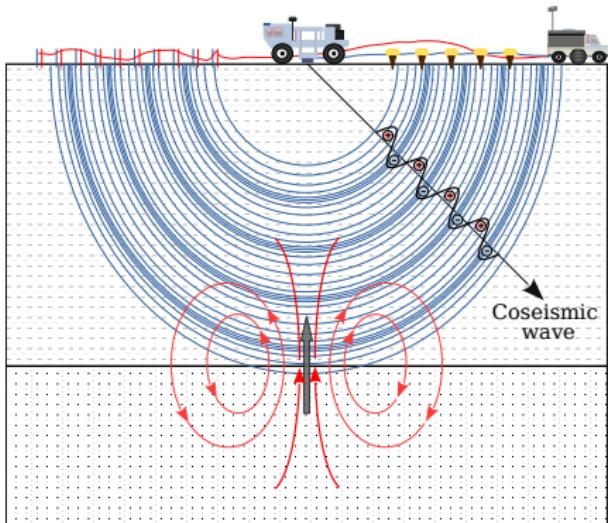
*Validation of set-up*

*Planning validation and automation*

*Perspectives*

# Introduction

## Seismo-electromagnetic phenomena



# Introduction

## Interface response :

- ▶ Synchronous
- ▶ Arrival time is equal to travel time of P-wave to the interface
- ▶ Max amplitude in receivers whise offset is equal to help the interface depth
- ▶ Different polarity in source sides

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**Physical properties :** Porosity ( $\phi$ ), Permeability ( $k_0$ ), Bulk modulus ( $K_s, K_f, K_{fr}$ ), frame's Shear modulus, densities ( $\rho_s, \rho_f$ ), fluid's electrical conductivity ( $\sigma$ ), fluid's viscosity ( $\eta$ ), molarity, temperature, solid and fluid's relative permittivity and tortuosity.

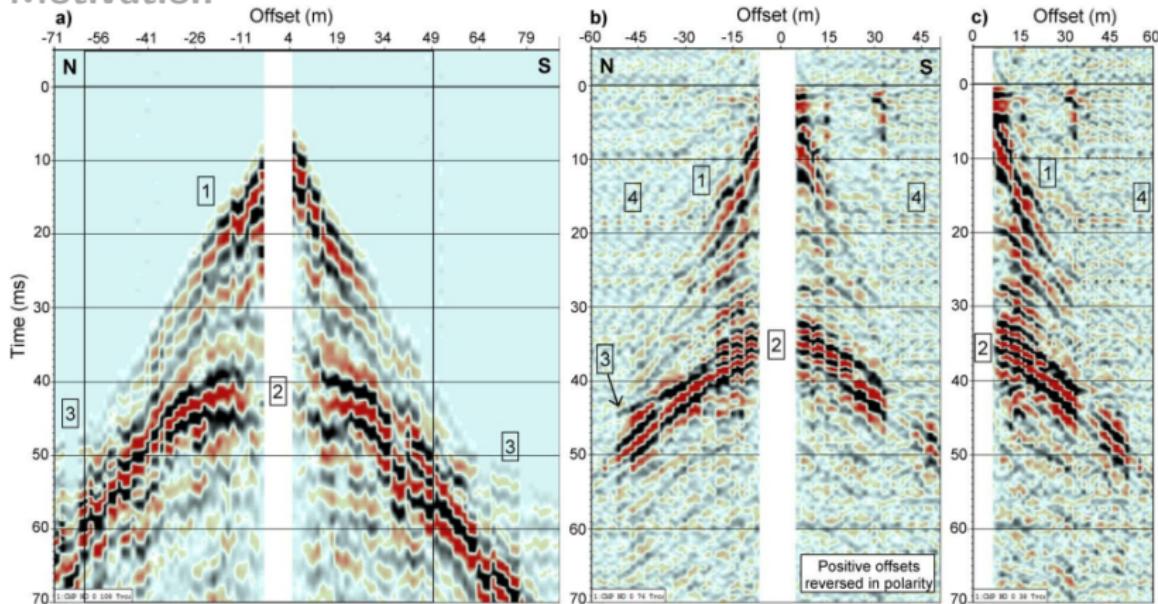
# Introduction

## Motivation

- ▶ Hydrocarbon
- ▶ Bedrock
- ▶ Water
- ▶ Water table
- ▶ CO<sub>2</sub> storage
- ▶ Borehole and surface

# Introduction

## Motivation



Butler et al., 2018

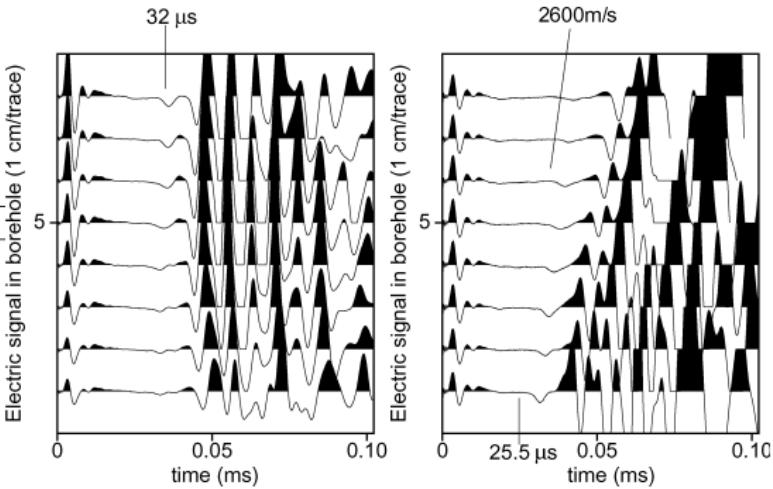
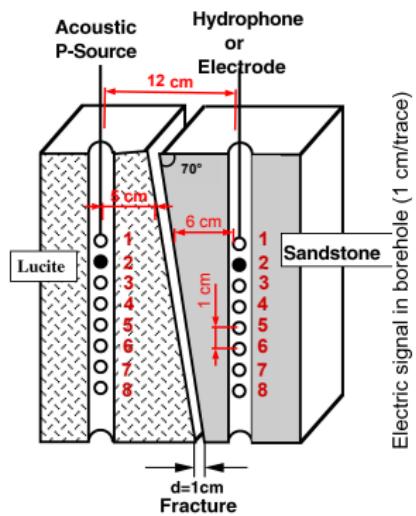
# Experiments: What has been done

## Summary

1. Zhu and Toksöz (2003)
2. Chen and Mu (2005)
3. Zu et al. (2008)
4. Schakel et al. (2011)
5. Peng et al. (2017)
6. Ellouz (2017)

# Experiments: What has been done

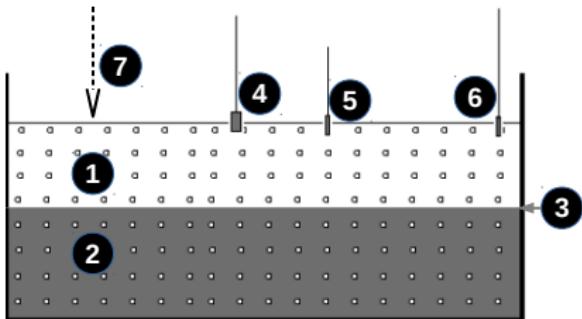
## Zhu and Toksöz (2003)



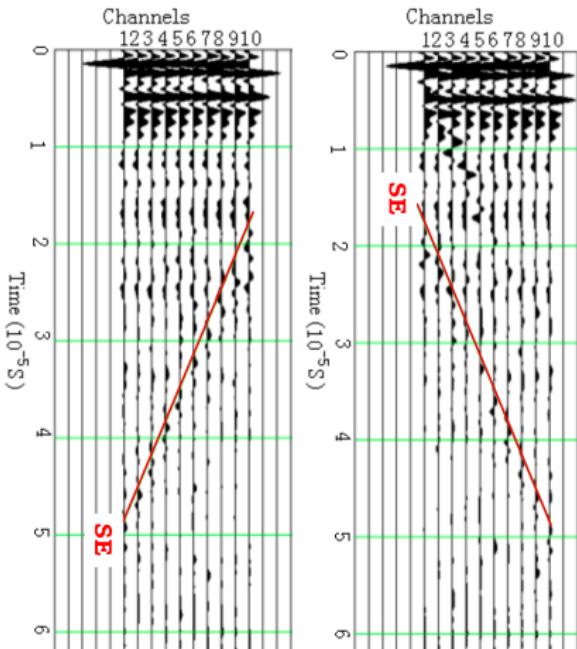
- ▶ Crosshole w/ water filled fracture
- ▶ Study fracture aperture vs amplitude
- ▶ Geometrical parameters of dipping fractures

# Experiments: What has been done

Chen and Mu (2005)

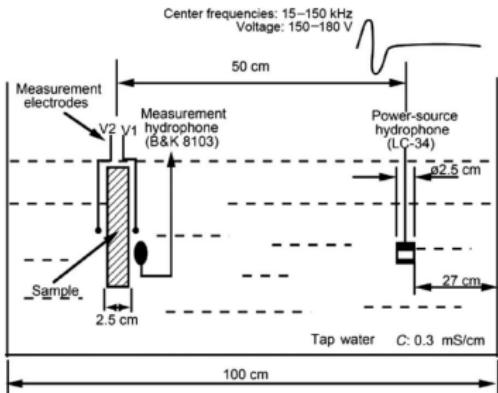


- ▶ NaCl-saturated sand
- ▶ Salt-water/Water/Oil saturated layers
- ▶ Conductivity behaviour
- ▶ converted EM is sensitive to Oil/salt-water

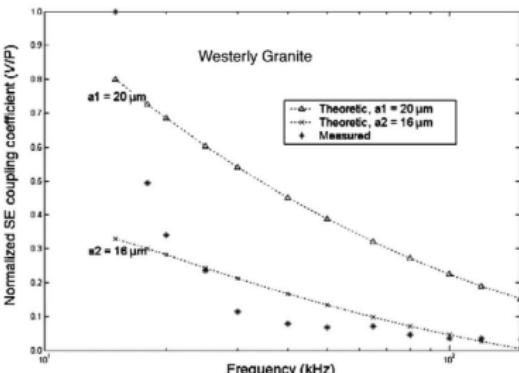
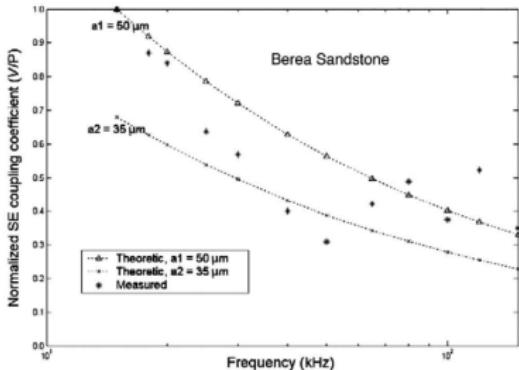


# Experiments: What has been done

## Zhu et al. (2008)

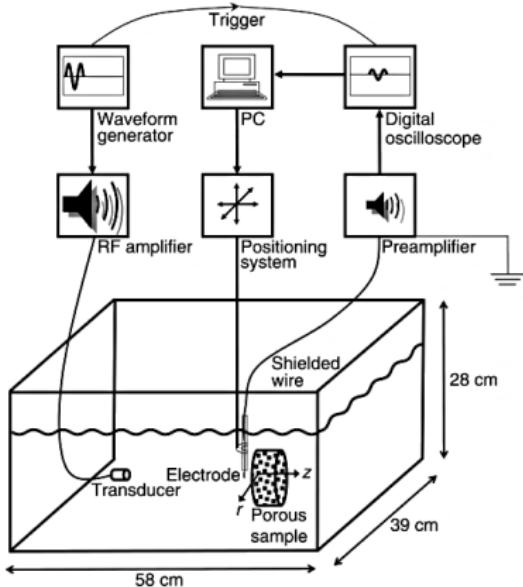


- ▶ Sandstone and Granite
- ▶ Coup Coef for 15 – 150 kHz
- ▶ Coup Coef for Capillary model
- ▶ Similar in frequency
- ▶ Converted energy  $\propto$  Permeability and Porosity

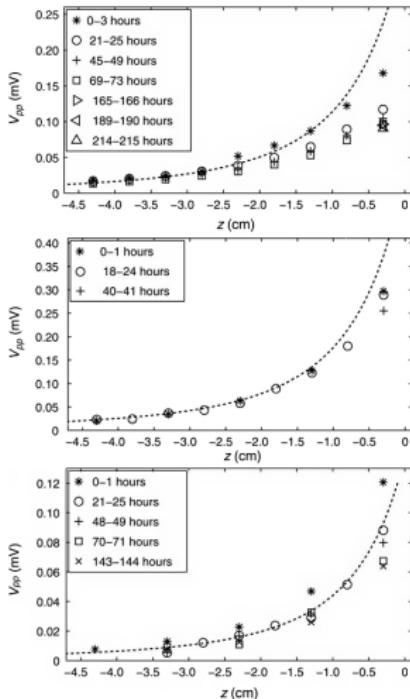


# Experiments: What has been done

Schakel et al. (2011)

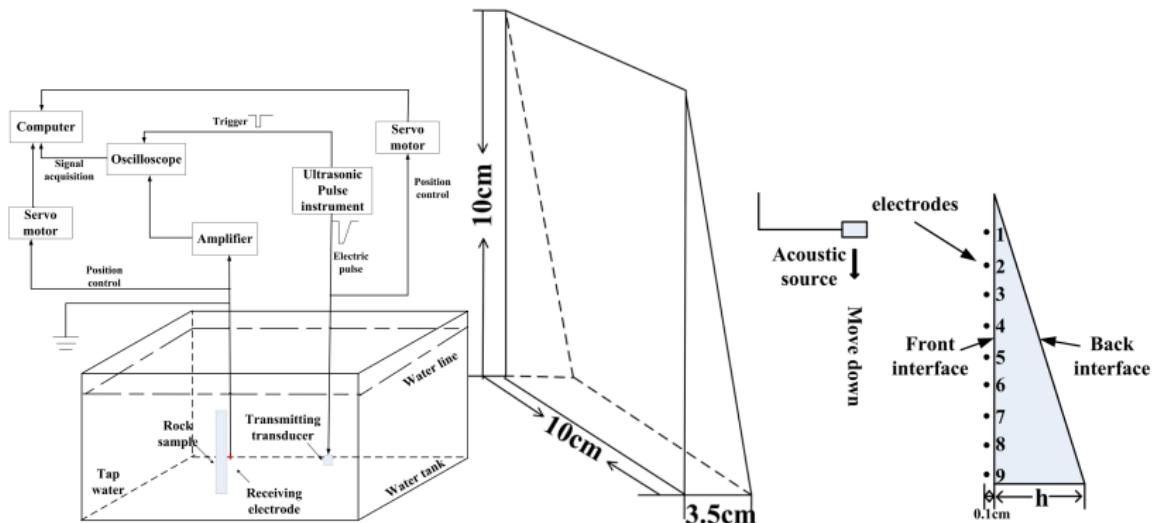


- ▶ Amp vs. Conductivity
- ▶  $\sigma = 1.27\text{e-}3$  (up),  $1.20\text{e-}2$  (middle),  $1.01\text{e-}1$  (bottom)



# Experiments: What has been done

Peng et al. (2017)

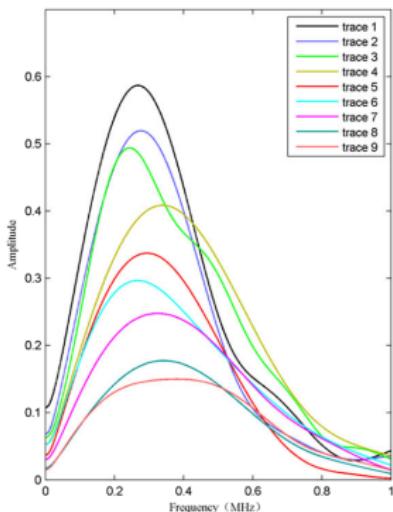
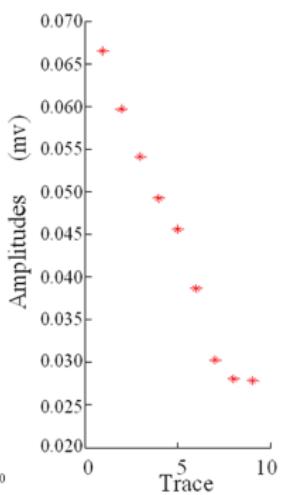
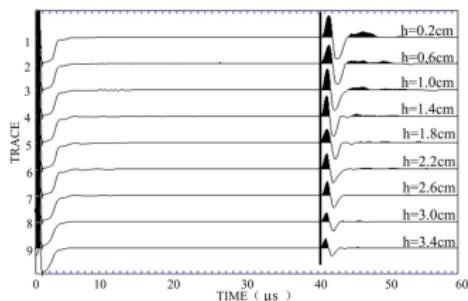


►  $\lambda=0.9\text{cm}$

# Experiments: What has been done

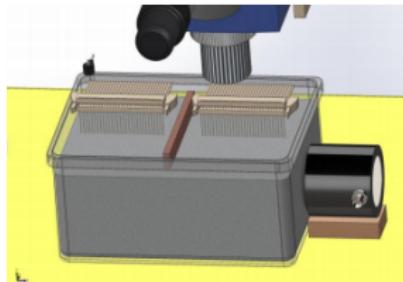
Peng et al. (2017)

Continue :



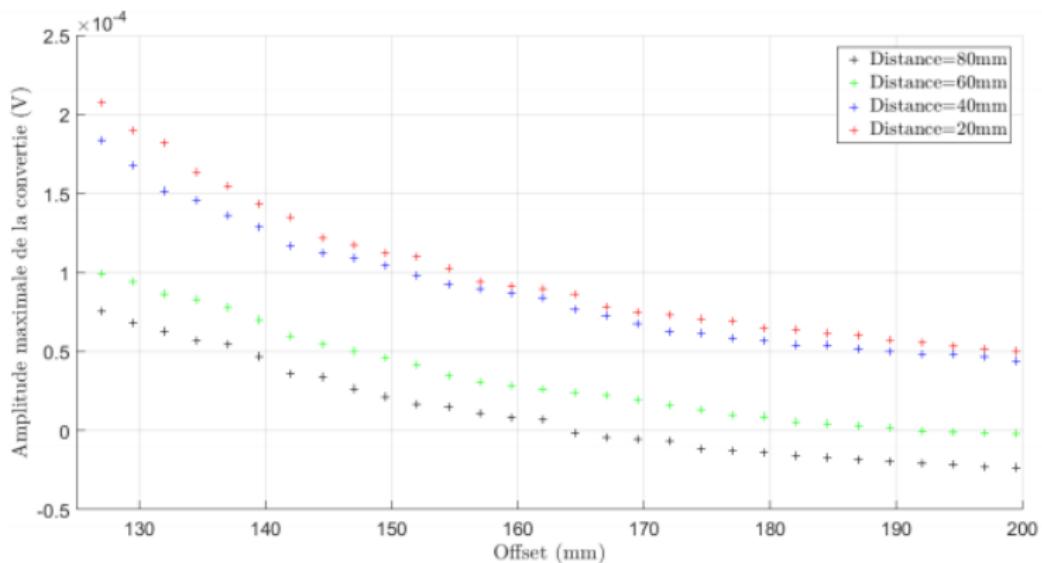
- ▶ Experimentally confirmed that thin-layers can enhance the interface response.

- ▶ Investigated the effect of various acquisition and geometry-related model parameters to amplitude of converted-EM:
  - ▶ Thickness
  - ▶ Electrode distance to layer
  - ▶ Excitation frequency
- ▶ Layer with widths as small as  $\lambda/6$  could be identified



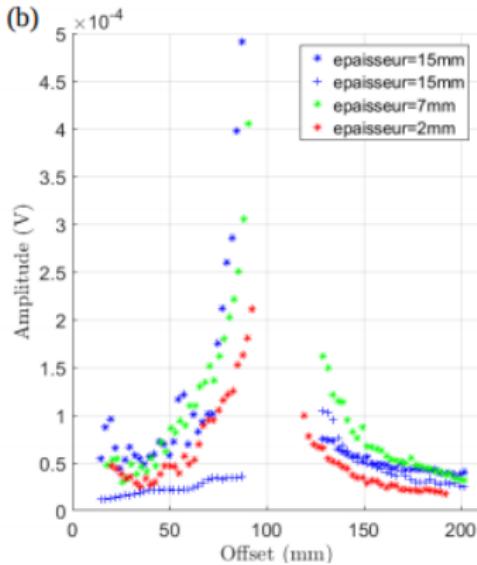
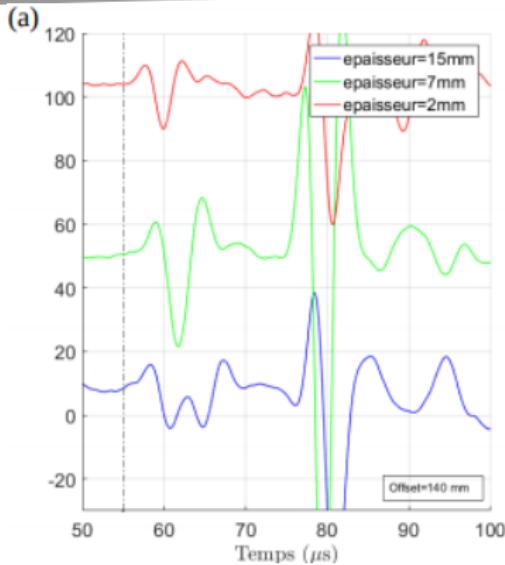
# Experiments: What has been done

## Ellouz (2017)



# Experiments: What has been done

## Ellouz (2017)



- ▶  $\lambda \approx 7\text{mm}$
- ▶ Thin-layer amplitude enhancement was not seen for 2mm thickness

- ▶ Extend what was experimentally done in Schakel et al. (2012), Peng et al. (2017) and Ellouz (2017)
- ▶ Change in thickness and physical properties:
  - ▶ Wetting fluid/Salinity
  - ▶ Permeability/Porosity
- ▶ Try to keep up with numerical studies (Grobbe et al., 2016)

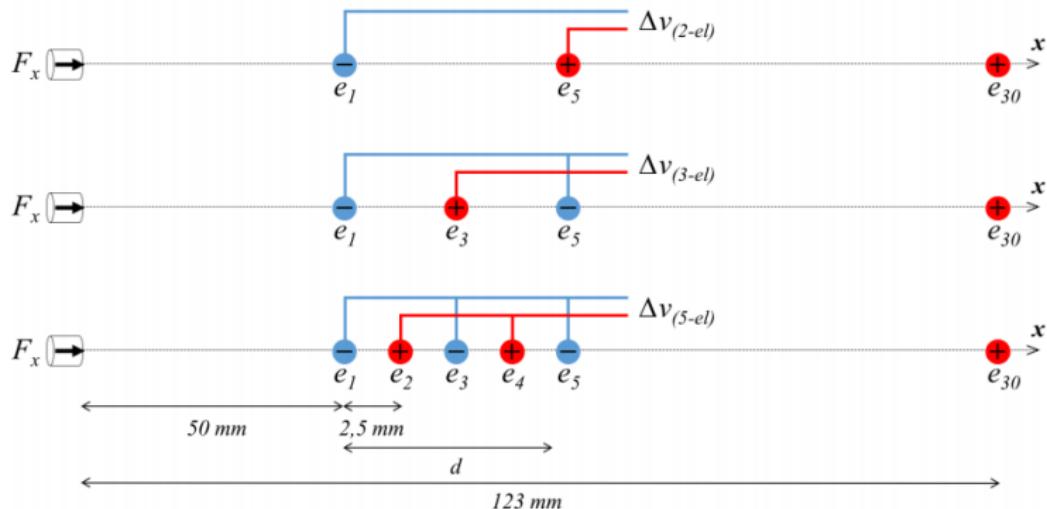
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**Thin-layers** : those smaller than the wavelength

# Open questions

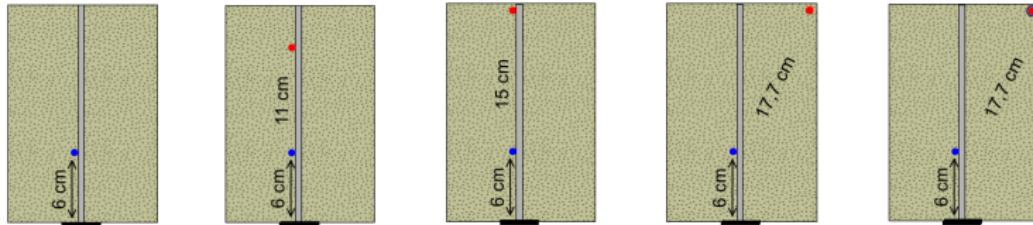
## Multi-electrode arrangement

- ▶ Devi (2017)
- ▶ 3 and 5-electrodes configuration to reduce noise and amplify EM-waves



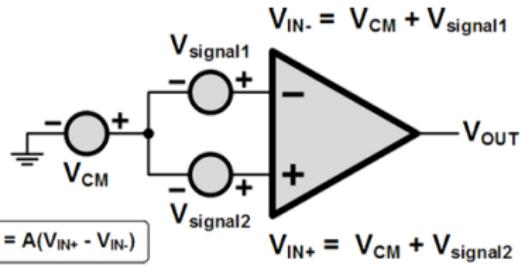
## Questions we have ourselves

### Reference electrode



Ellouz (2017)

### Differential amplifier – Common mode rejection ratio

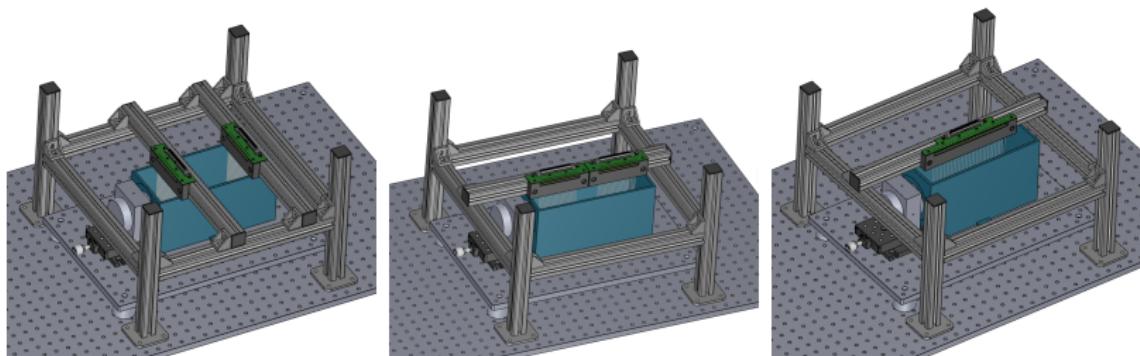


# Experiments to be conducted

- ▶ Test:
  - ▶ Reference electrode (which configuration, are there improvements?, etc.)
  - ▶ Common mode rejection (does it improve our signal? Is it worthy to use it?)
  - ▶ Multi-electrode configuration
- ▶ Parallel and perpendicular (to layer) measurements
- ▶ Change rocks /rock properties (heating to change porosity?)
- ▶ Change wetting fluid ( $\mu$ m plastic to seal fluid in?)

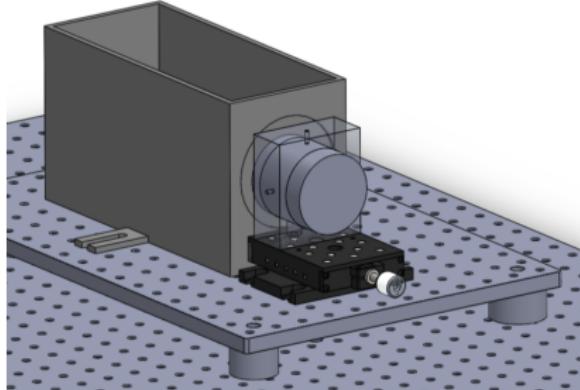
# New experimental set-up

- ▶ Conceived thanks to Federico
- ▶ With the help of Clarice and Daniel



# New experimental set-up

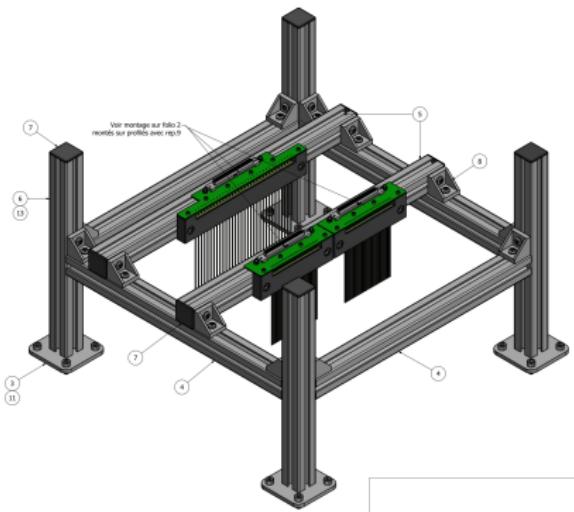
## Acoustic-related



- ▶ Thorlabs equipments
- ▶ Support for Piezo
- ▶ Sandbox

# New experimental set-up

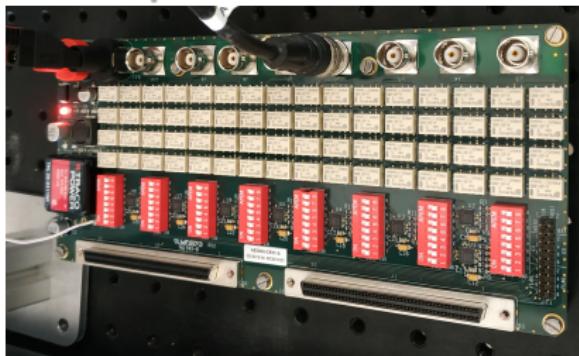
## EM-related



- ▶ Thicker and longer electrodes
- ▶ More rigid -> Better positioning
- ▶ Metallic support for moving

# New experimental set-up

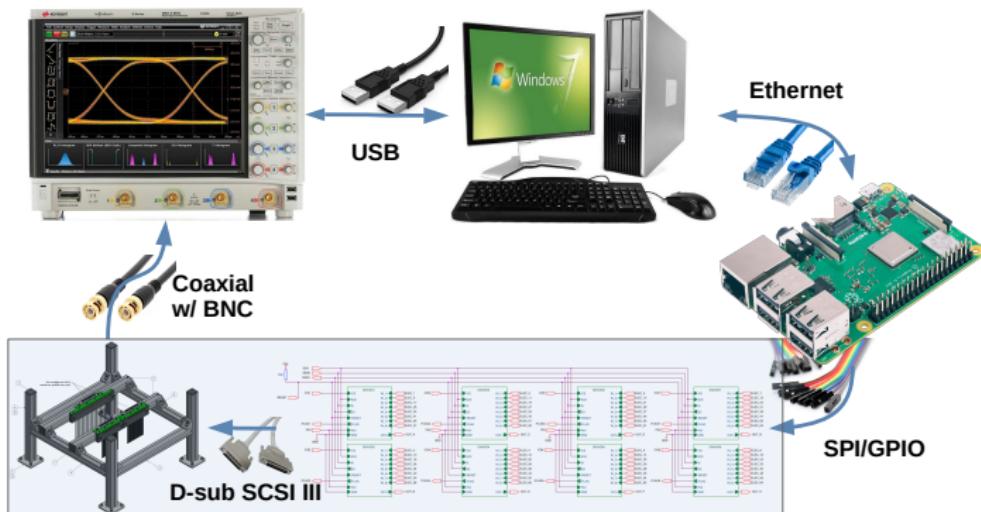
## EM Acquisition-related



- ▶ Easily make measurements manually or in an automated way using SPI
- ▶ Faster acquisitions
- ▶ Less human influence

# Automation – general view

## Schema

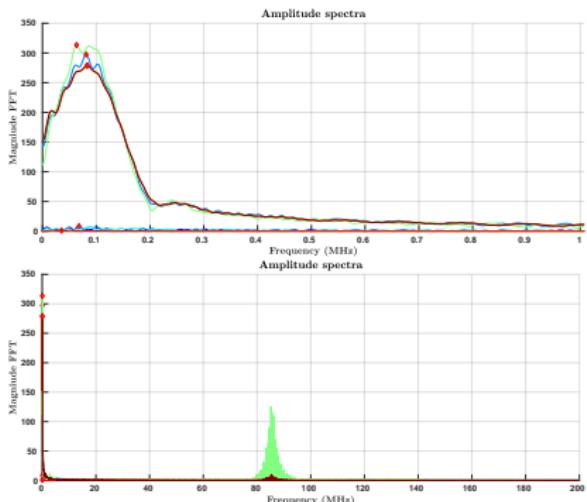
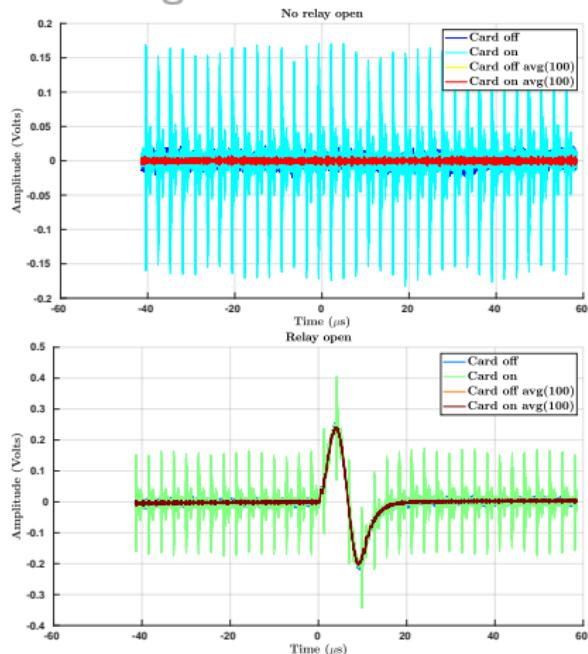


# Automation – general view

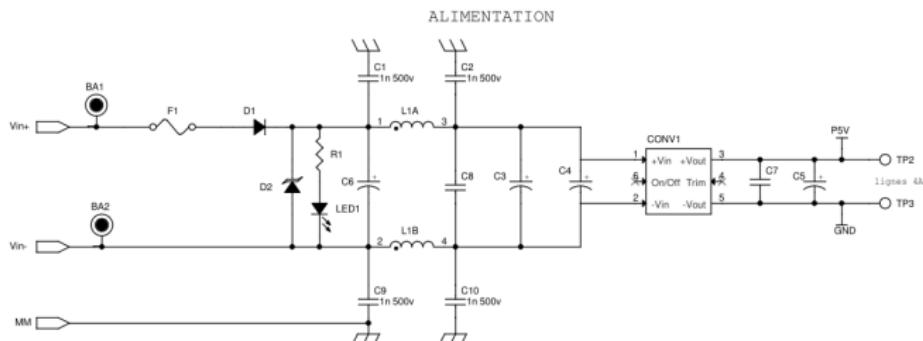
## Main points

- ▶ Python-based routines and interface to control the electric acquisition
- ▶ Quicker and simpler acquisition
- ▶ Less human interaction
- ▶ Towards reproductibility

### Testing the card

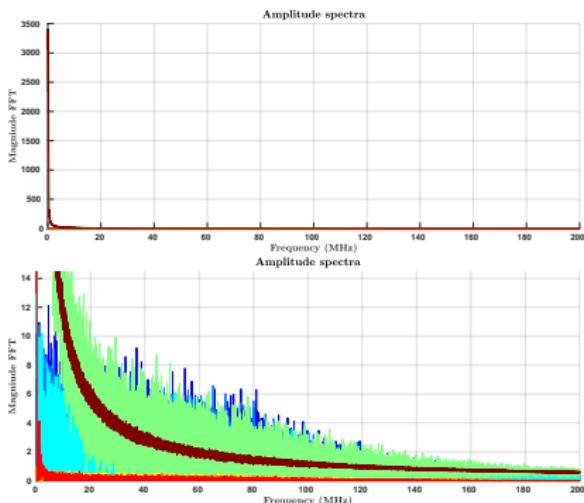
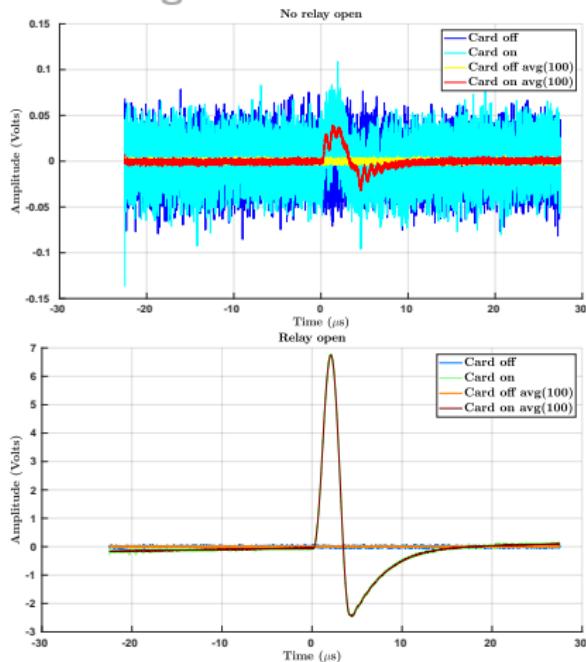


### Testing the card

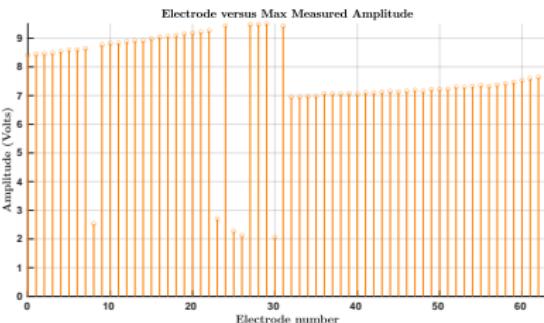
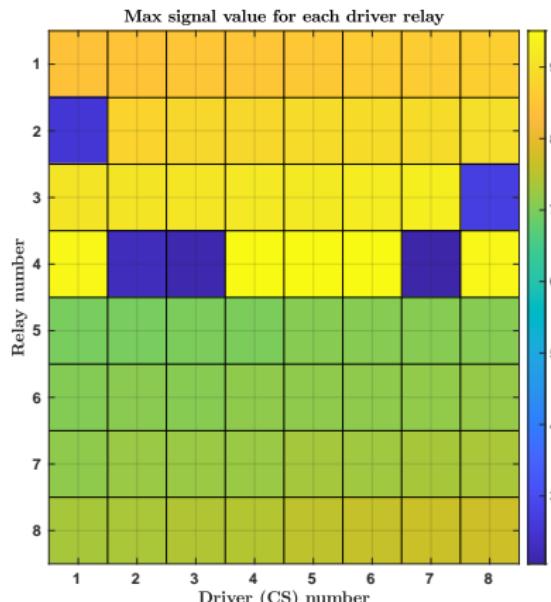


- ▶ Problem in switching regulator
- ▶ Solution: remove it

### Testing the card

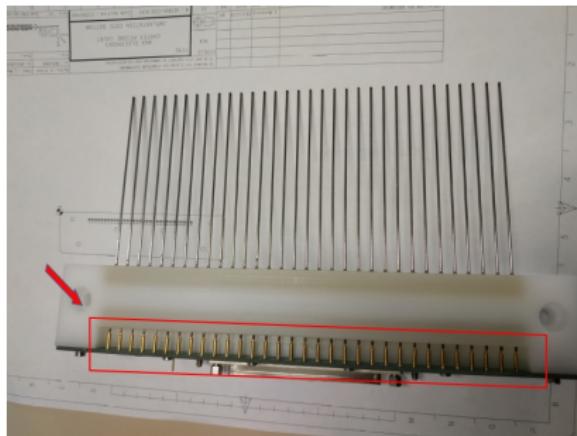


### Testing electrodes



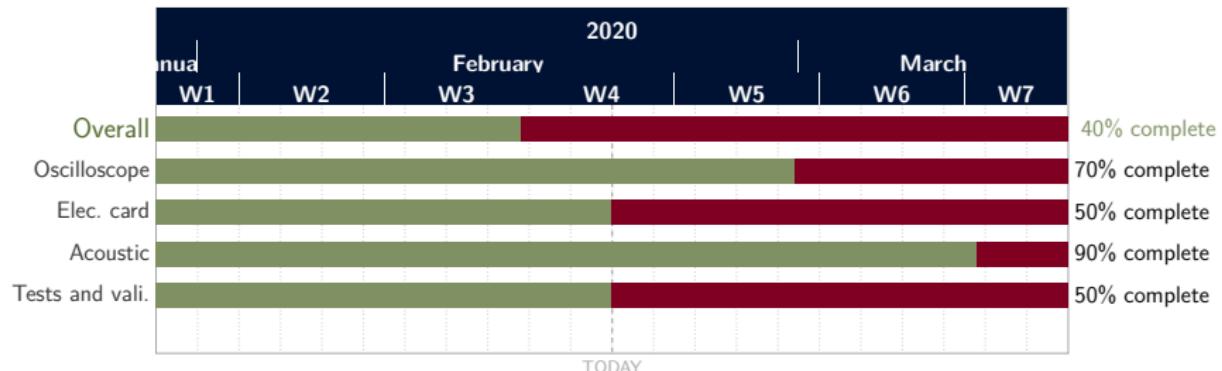
## Testing electrodes

- ▶ Some defectuous electrodes in two combs
- ▶ Long comb (2,5,7,18 and 24)
- ▶ Short comb (9,24,26,27 and 31)
- ▶ Not yet solved



# Automation and validation Planning

From : 2020-01-30 until 2020-03-13



► **Proposed at 2020-02-20**

# Automation and validation Planning

## Today



## Tests yet to be performed

- ▶ Test box attenuation/plastic velocity/etc **ONGOING**
  - ▶ Better characterize measurements
  - ▶ More measurements
- ▶ Sand-filled box
- ▶ Sensitivity to the Layer response
- ▶ Check for improvements (acoustic and electric-wise) from previous experiment

# Perspectives to new experimentl setup

## General :

1. Greater SNR
2. Faster acquisition
3. Greater spatial precision of electric measurements due to more rigid electrodes
4. Ensure repeatability
5. More precision when studying the converted wave

# Perspectives to new experimentl setup

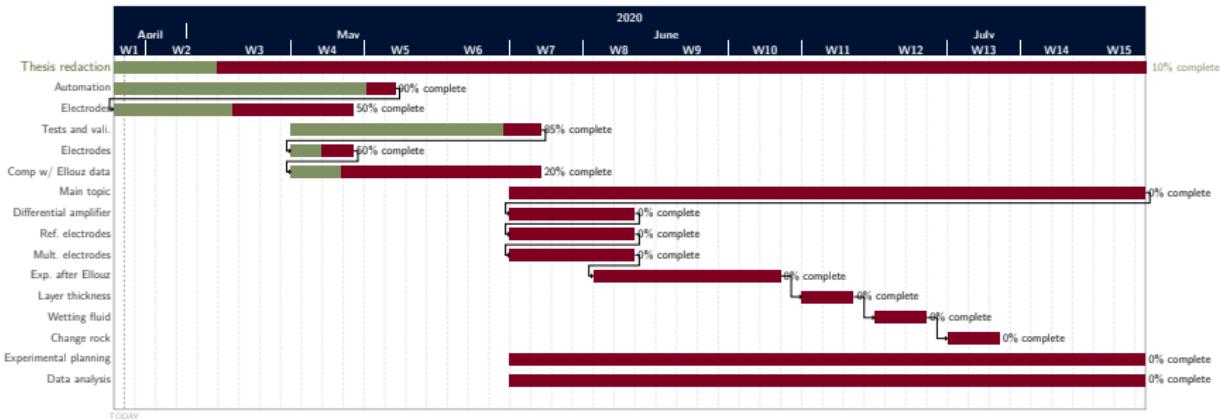
General :

1. Greater SNR
2. Faster acquisition
3. Greater spatial precision of electric measurements due to more rigid electrodes
4. Ensure repeatability
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In the end : A robust and easily reproducible seismoelectric experiment.

# Automation and validation Planning

## Today



# Thank you for your attention!

