Earthquake Source Spectra Analyses:
from Laboratory Micro-Scale to Volcano-Tectonic Seismicity

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Why study Earthquake Source Spectra Parameters?

Self-similarity of earthquakes proposed by Aki, 1967:

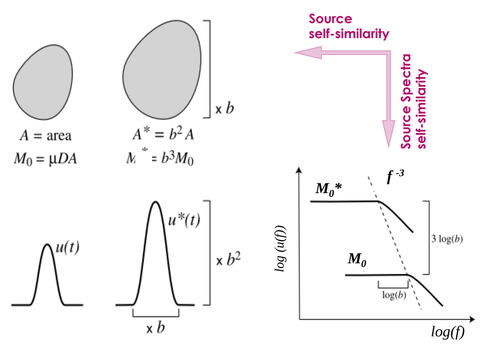
$$\Delta\sigma = const$$
$$M_0 \sim \frac{\Delta\sigma}{f_c^3} \sim f_c^{-3}$$

Slip-source model:

$M_0 = \mu\bar{D}S \sim \mu\bar{D}$ – seismic moment

$\Delta\sigma = \frac{\mu\bar{D}}{L}$ – stress-drop

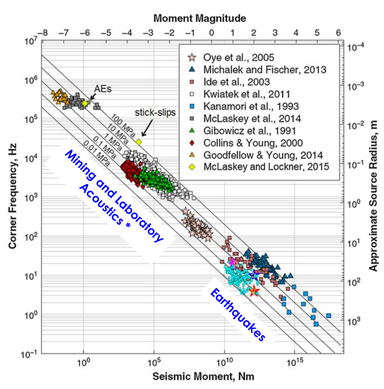
$f_c \sim \frac{v}{L}$ – corner frequency



Modified from Prieto et al, 2004

Questions:

- Are Laboratory Acoustic Events self-similar?
- Are VT Earthquakes self-similar? What is the stress-drop?
- How Source Parameters depend on Loading Conditions or Seismic Regimes?



Why using Coda-Waves?

source radiation propagation instrument

$$Y(f) = S(f)R(\theta, f)M(r, f)I(f)$$

Radiated Signal in Frequency Domain

Under special conditions:

$$SR = \frac{Y_1(f)}{Y_2(f)} = \frac{S_1(f)}{S_2(f)}$$

For Small-Earthquakes:

- Mechanisms are hard to determine
- Hard to find co-located events with same mechanisms
- Highly inhomogeneous medium

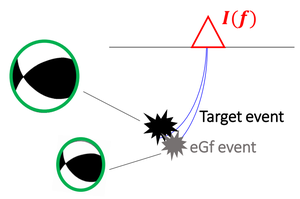
For Acoustic Emission:

- Clipped amplitudes
- P and S waves indistinguishable (uniaxial sensors)
- Direct waves indistinguishable from reflected
- Dramatically changing medium

Direct waves (P or S)

? ?

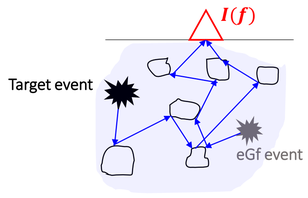
$$SR = \frac{S_1(f)R_1(\theta_2, f)M_1(r, f)\cancel{I(f)}}{S_2(f)R_2(\theta_2, f)M_2(r, f)\cancel{I(f)}}$$



Coda waves (usually of S)

Averaged during propagation ✓ same path for all local events ✓

$$SR = \frac{S_1(f)\cancel{R_1(\theta_2, f)}M(r, f)\cancel{I(f)}}{S_2(f)\cancel{R_2(\theta_2, f)}M(r, f)\cancel{I(f)}}$$



For Small-Earthquakes:

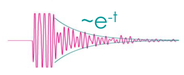
- Coda produced by diffusive **backscattering** on local inhomogeneties **

Coda Amplitudes | EQ source + Scattering | Geometrical Spreading | Inelastic Attenuation

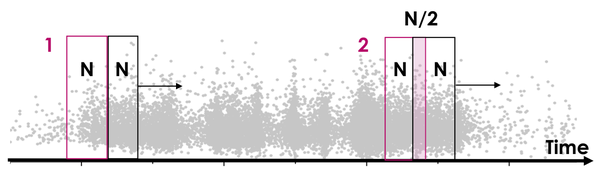
$$A(\omega|t) = \boxed{C(\omega)} \cdot t^{-m} \cdot e^{-\omega t/2Q}$$

For Acoustic Emission:

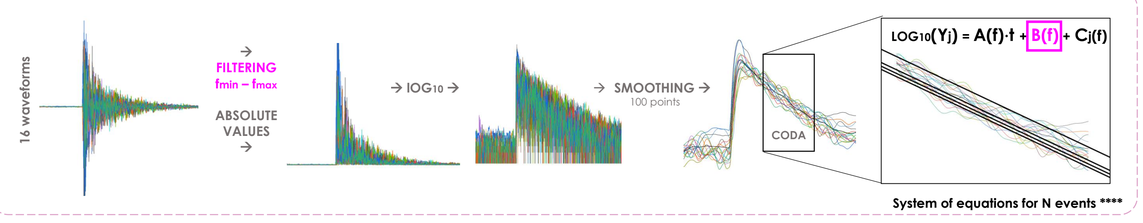
- Coda produced by diffusive **reverberation** (reflections on sample boundaries) ***



Data processing

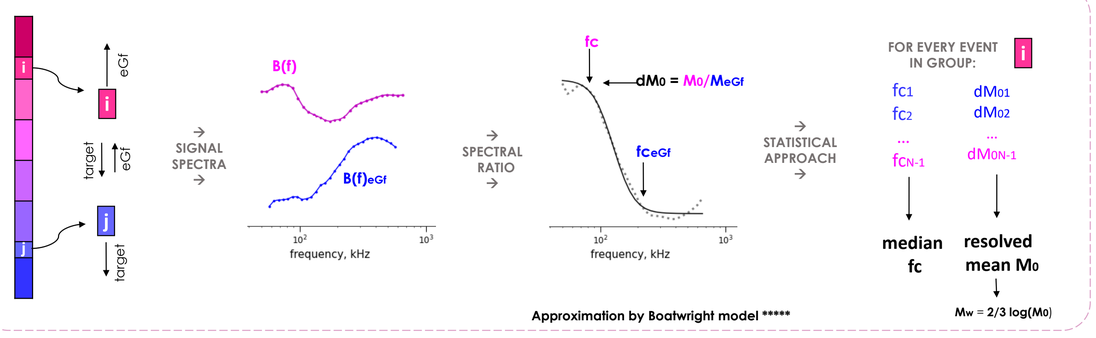


1: Coda parameters estimation



System of equations for N events ****

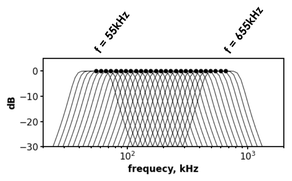
2: Spectra parameters estimation

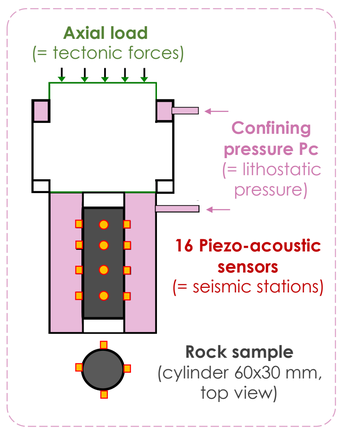


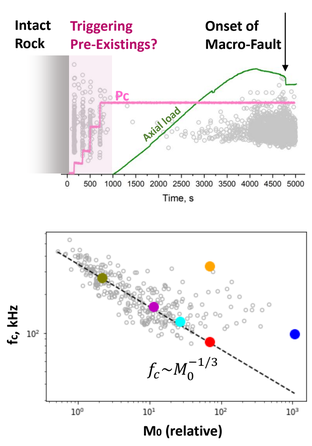
Approximation by Boatwright model *****

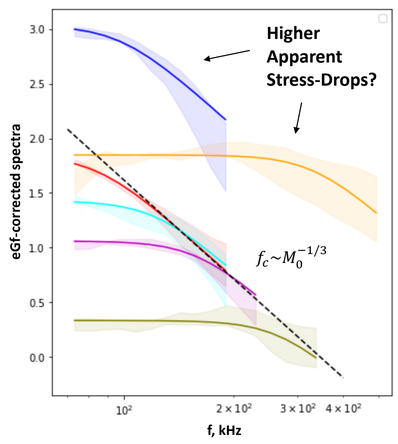
Laboratory Earthquakes

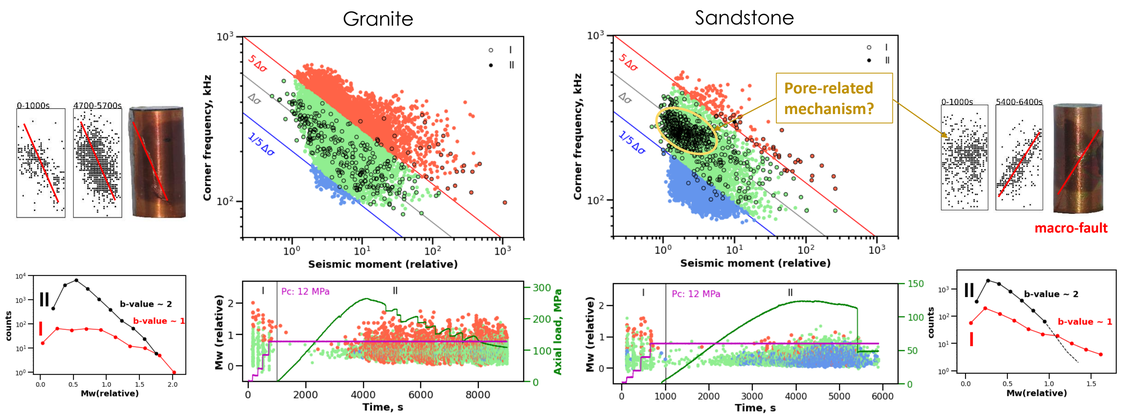
Or Acoustic-Emission Events registered during Rock-Physics Experiment









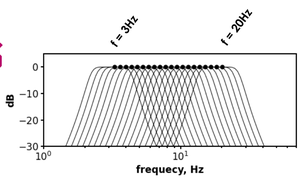


Key points:

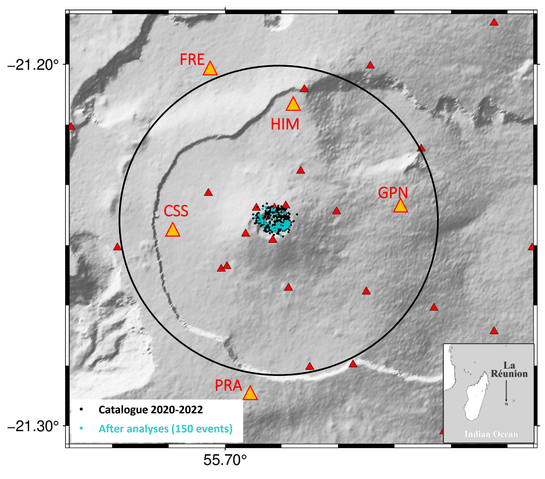
- Generation of **tectonic-like lab-earthquakes (M ~ f_c^{-3}, b-value ~ 1)** is possible under certain conditions: hydrostatic loading of pre-existing cracks
- **Diagrams fc vs M0** depend on **rock structure** and **loading regime**
- Coda-based method well applicable to laboratory earthquakes

Volcano-Tectonic Earthquakes

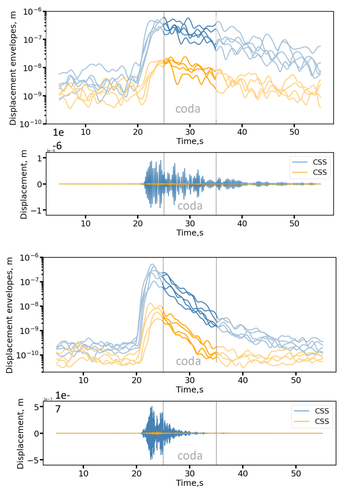
Earthquakes occurring in the summit of Piton de la Fournaise volcano on La Réunion

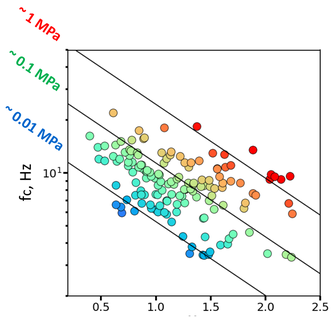


Available catalogue 2020-2022
(730 events)

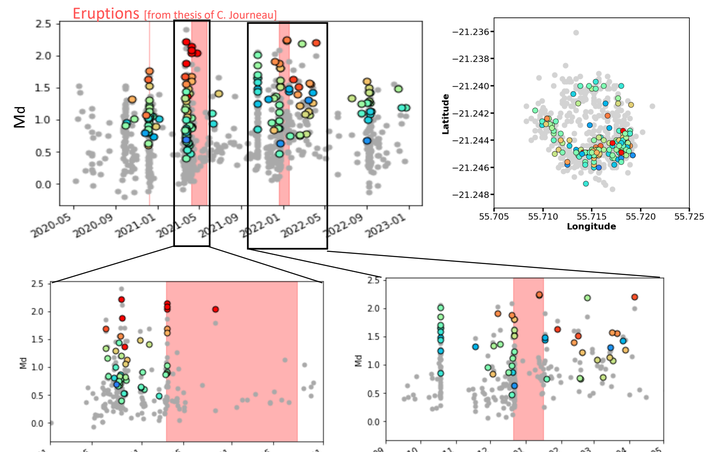


Envelopes from stations:
CSS, FRE, PRA, HIM, GPN





Eruptions [from thesis of C. Journeau]



Next:

- Should we complicate model describing coda?
- Analyzing larger catalogues in combination of eruption types

*** Studies of AE Source Parameters:**

Harrington & Benson, 2011
Yoshimitsu et al, 2014
McLaskey & Lockner, 2016
Blanke et al, 2021
Marty et al, 2021

**** Nature of coda-waves and application to Source Spectra Study:**

Aki & Chouet, 1975
Rautian & Khalturin, 1978
Mayeda et al, 2003

***** Coda-waves in limited space ("room acoustics")**

Weaver, 1984
Kanev, 2011
Farin et al, 2016

****** System of equations for N events:**

$$Y(f) = A(f) \cdot T + \sum_{i=1}^{N} B_i(f) \cdot X_i + \sum_{j=1}^{16} C_j(f) \cdot S_j$$

******* Boatwright model [Boatwright, 1980]**

$$u(f) = \frac{const \cdot M_0}{\left(1 + \left(\frac{f}{f_c}\right)^{\gamma n}\right)^{1/\gamma}} \quad (\gamma = 2, n = 3)$$

$u(f)$ - displacement spectrum

γ, n – coefficients controlling form of spectrum after f_c, ($\gamma = 1, n = 2$ - Brune)