ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT ET PHYSIQUE DE L'UNIVERS, PARIS

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Subject title:	**Global determination of reliable earthquake source parameters via probabilistic spectral ratios and artificial intelligence**
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Funding:	**Doctoral contract funded 50% by INGV**

Context and Problem Definition

In 1967, Keiiti Aki proposed that earthquake amplitude spectra are scale-invariant, suggesting self-similarity across magnitudes. James Brune (1970) later identified static stress drop—the change in shear traction during rupture—as the key scaling parameter. Since then, numerous studies across magnitudes and tectonic settings have yielded mixed results (see Abercrombie, 2021). While some research supports scale invariance, others report increasing stress drop with event size, with depth and tectonic context also proposed as influencing factors.

This ongoing lack of consensus raises concerns about the reliability of stress drop estimates and their value in earthquake rupture modelling. Reported stress drop values vary by over five orders of magnitude (e.g., Cocco et al., 2016; see figure below), potentially reflecting both real variability and methodological inconsistencies. In particular, estimates for smaller events (M < 4) are often affected by wave propagation and attenuation uncertainties (e.g., Shearer et al., 2024).

The spectral ratio method (e.g., Uchide & Imanishi, 2016) helps mitigate these effects. As amplitude spectra are shaped by both corner frequency (fc) and attenuation (Q), estimating fc is challenging when Q is unknown. The spectral ratio method addresses this by comparing displacement spectra of nearby earthquakes with similar mechanisms, cancelling out propagation and radiation effects. This isolates source-specific signals, enabling more accurate fc and stress drop estimation.
While this method has proven effective in regional studies, it has yet to be systematically applied to a global dataset encompassing a wide range of magnitudes and tectonic settings.

Meanwhile, machine learning approaches are increasingly being adopted in earthquake seismology as powerful tools for spectral analysis, feature extraction, event classification, amongst other applications (Mousavi & Beroza, 2023). These advancements offer promising opportunities to speed up and possibly enhance the estimation of earthquake source parameters.

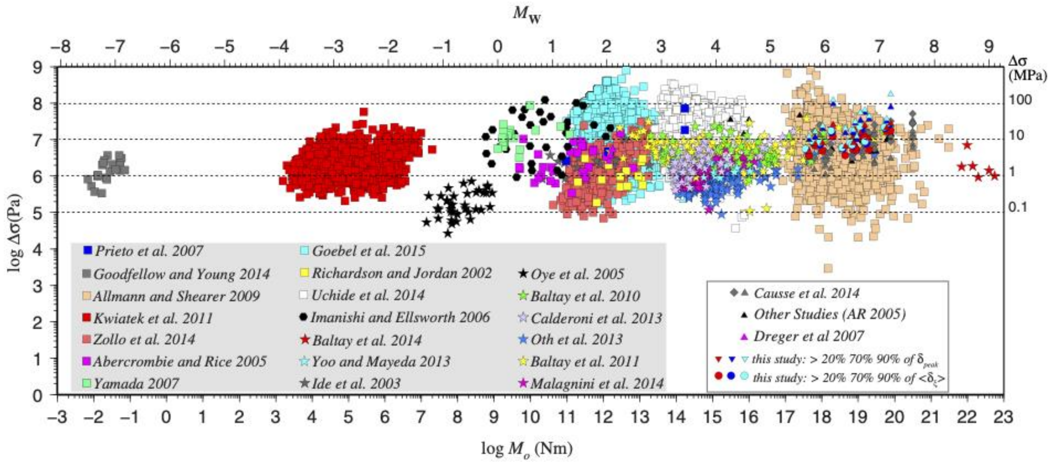

Figure: Stress drop scaling with seismic moment for different earthquakes in different tectonic settings. Figure and data compilation by Cocco et al. (2016).

Goals and Organization

The primary objective of this PhD project is to develop and apply modern methodologies to build and analyze a high-quality global dataset of earthquake source parameters. This dataset will encompass a wide range of seismic events, including small earthquakes recorded by near-fault observatories, large earthquakes occurring at plate boundaries, and low-frequency earthquakes. The potential integration of Distributed Acoustic Sensing (DAS) data from various experimental deployments will also be investigated.

Source parameter estimates will be primarily derived using a non-conventional implementation of the spectral ratio method, incorporating a probabilistic Bayesian framework to better quantify uncertainties. Additionally, the project will explore the application of Artificial Intelligence (AI) techniques to enhance spectral inversion and parameter estimation processes.

The project is divided into four main phases, to be run in parallel for validation and consistency:

1. Global Dataset Compilation

Event catalogues and waveform data will be gathered from:

- European Near-Fault Observatories (TABOO, INFO – Italy; CRL – Greece)
- Seismic networks in Southern and Northern California
- Crustal and subduction events in Japan and Chile
- Low-frequency earthquakes from the University of Tokyo’s Slow Earthquake Database
- DAS experiments in different regions (Italy, Chile)

2. Spectral Ratio Method Validation

A new probabilistic spectral ratio code, extending the SPAR framework (Supino et al., 2019), is under development at IPGP and INGV. It will undergo further testing before global application. In parallel, the use of AI for fast (near real-time) spectral inversions will be explored.

3. Dataset Analysis

Earthquake families will be identified using the Requake code (Satriano, 2024). Spectral ratios will then be computed to derive seismic moment, fc, source radius, and stress drop.

4. Statistical Analysis

The resulting database will be analysed to assess scaling laws across magnitudes, depths, and tectonic settings. Deep learning-based clustering methods will also be explored to identify hidden trends and refine event classification.

Environment

The PhD project is co-financed by INGV (Italy) and IPGP (France). A six-month stay at INGV is expected. Collaboration with Japanese partners is also planned.

Candidate Profile

Background in Geophysics or Physics with interest in programming (Python preferred), signal processing, and data analysis. Professional-level English required. Open to candidates with disabilities.

References

Abercrombie, R. E. (2021). Resolution and uncertainties in estimates of earthquake stress drop and energy release. https://doi.org/10.1098/rsta.2020.0131

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Supino, M., Festa, G., & Zollo, A. (2019). A probabilistic method for the estimation of earthquake source parameters from spectral inversion: application to the 2016–2017 Central Italy seismic sequence. https://doi.org/10.1093/gji/ggz206

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