CORTEX

Core monitoring techniques and experimental validation and demonstration

Necessary signal processing

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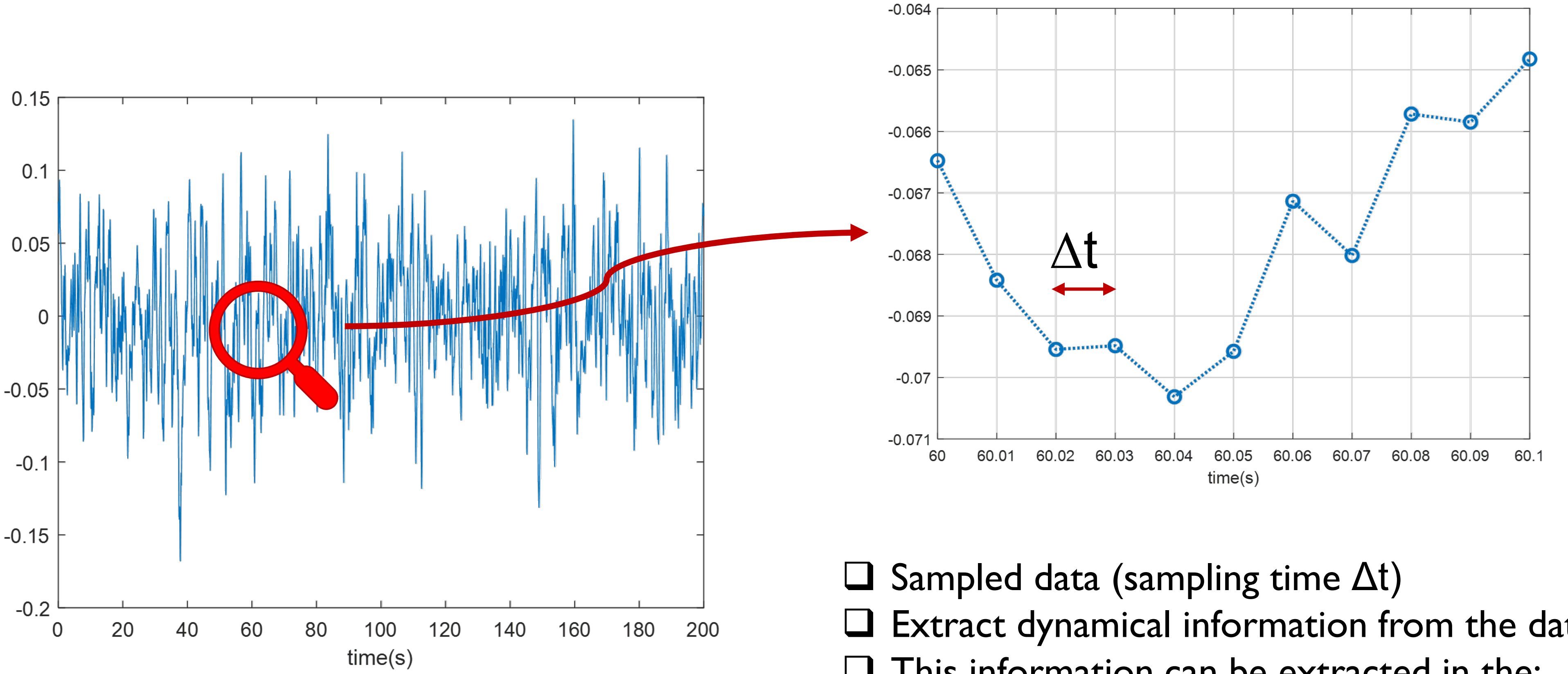
Noise analysis

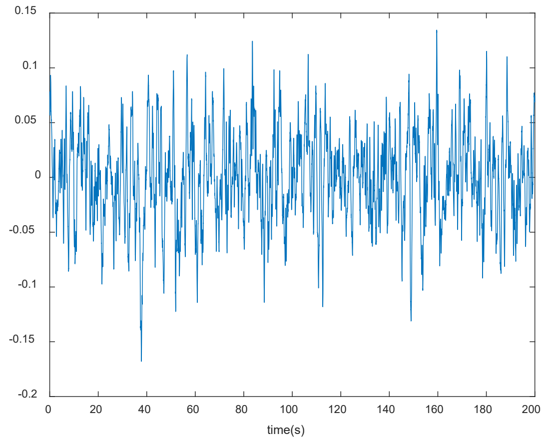
Measurement data



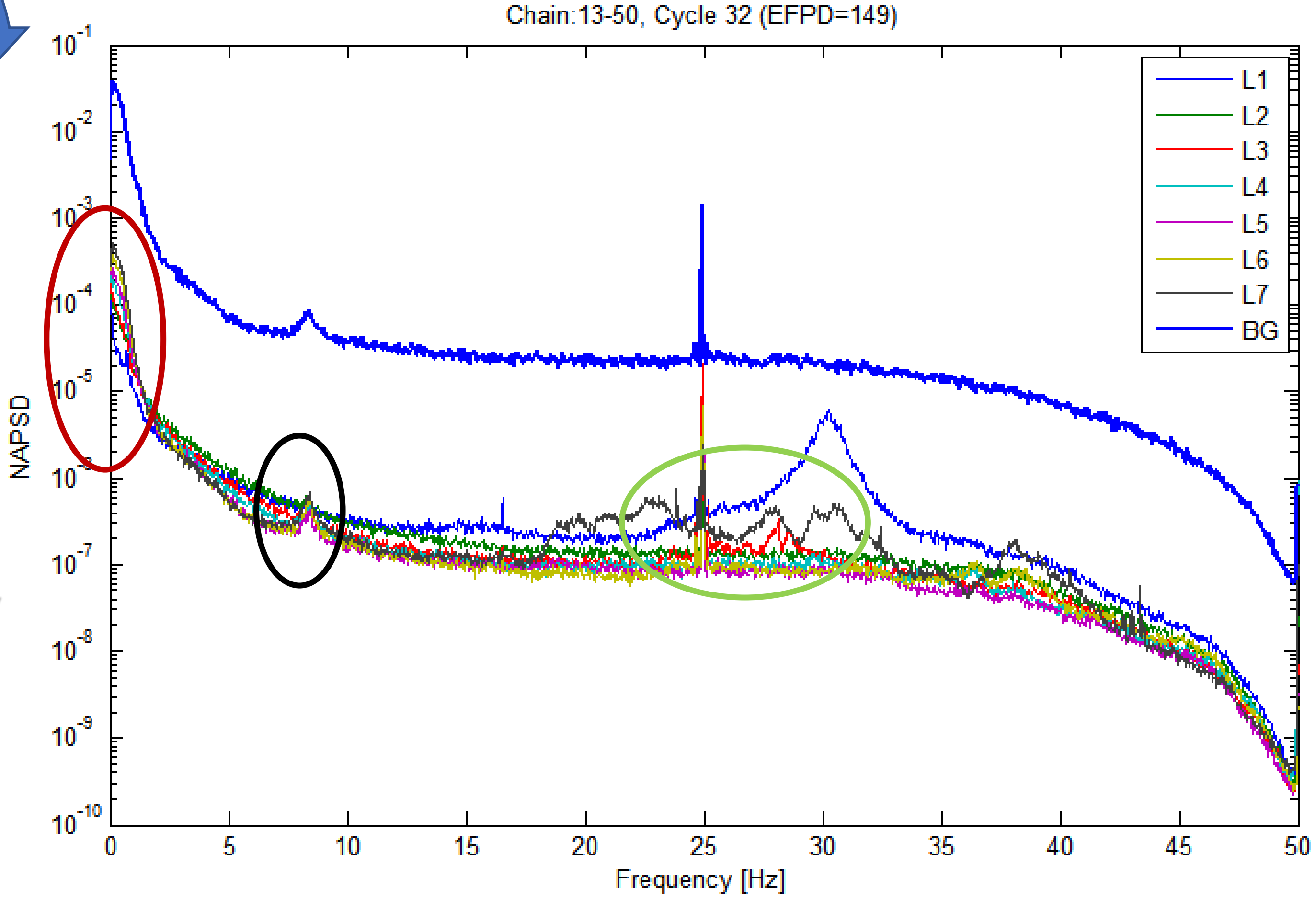
- ❑ Sampled data (sampling time Δt)
- ❑ Extract dynamical information from the data
- ❑ This information can be extracted in the:
  - Frequency domain (Fourier Transform)
  - Time domain (correlations, time series models)

Example spectra of the detectors of a selected chain

TIME DOMAIN



FREQUENCY DOMAIN



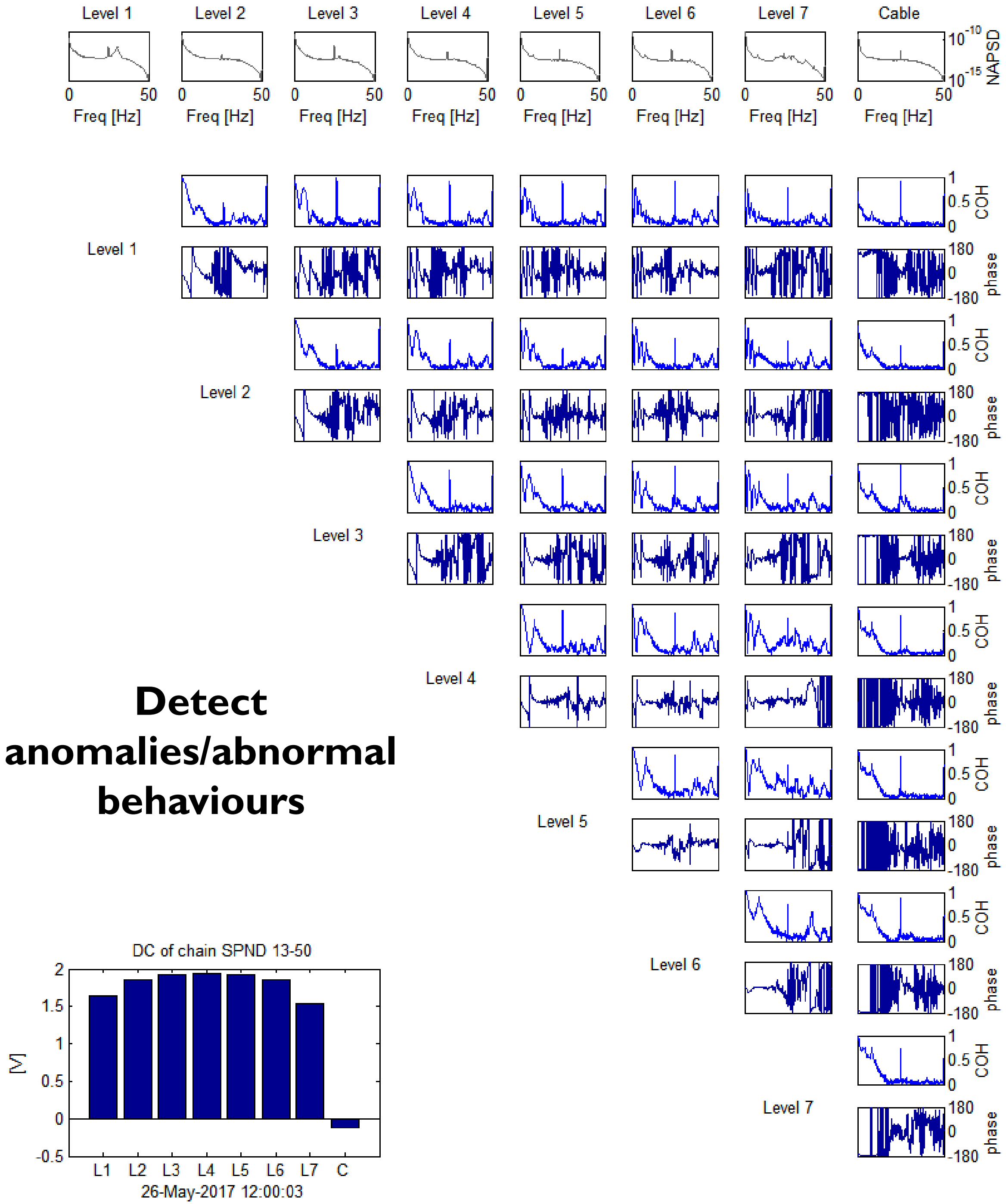
High amplitude in the low frequency part

Resonances (due to vibrations or other phenomena)

There are differences between detectors

Correlation between detectors

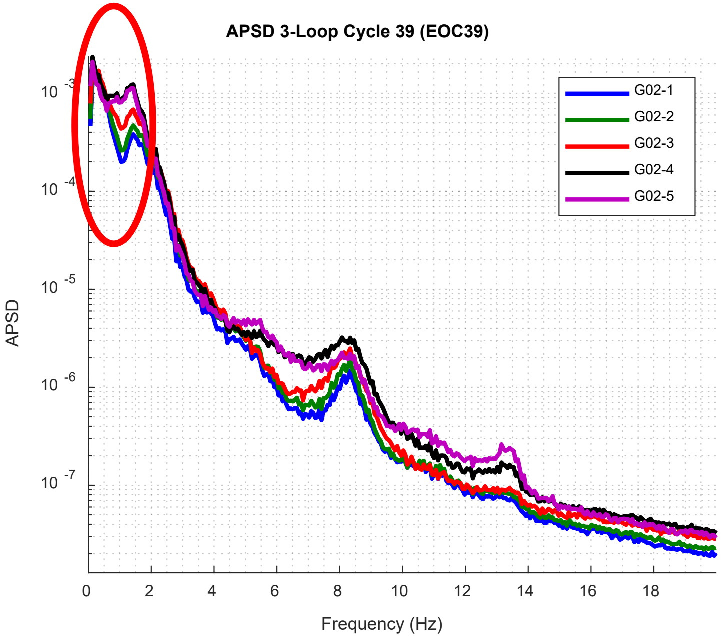
- Correlation between detectors through Cross Spectra (CPSD)
- COHERENCE: statistical similarity in the frequency domain
- PHASE: phase difference between detectors
  - Out of pase : pendular motion
  - In phase: pressure oscillations
  - Linear phase: transport phenomena



Detect anomalies/abnormal behaviours

Some spectral characteristics found in real data and simulations

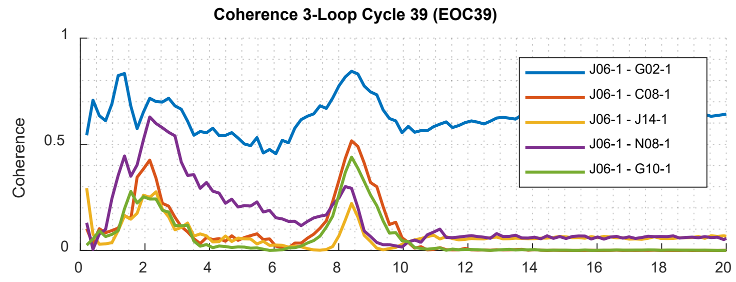
High amplitude at low frequencies

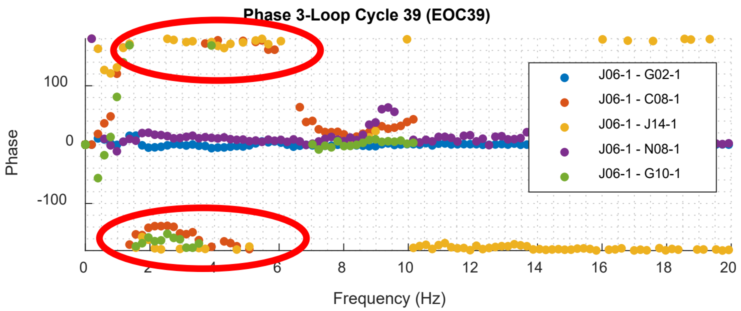


High amplitude below 1 Hz

Temperature fluctuations

Out of phase relationship

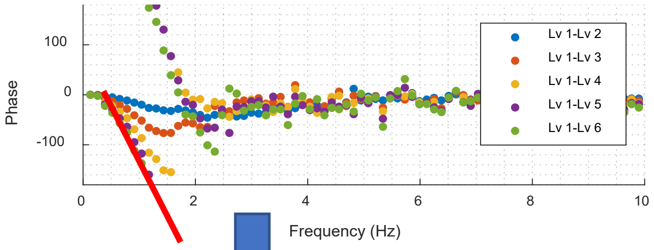




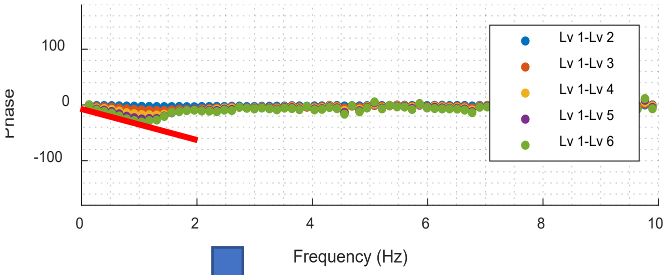
Out of phase between oposite detectors.

Mechanical vibrations

Linear phase



Temperature fluctuations



Flow fluctuations

Monitoring of time varying signals by JTFS

JFTS: Joint Frequency Time Spectrum

When the characteristics of the time series do not change, noise analysis techniques are valid but….

When there are transients and the frequency content change with time…

We need methodologies that can obtain Amplitude and Frequency of our signals at every time step to be able to monitor time-varying signals

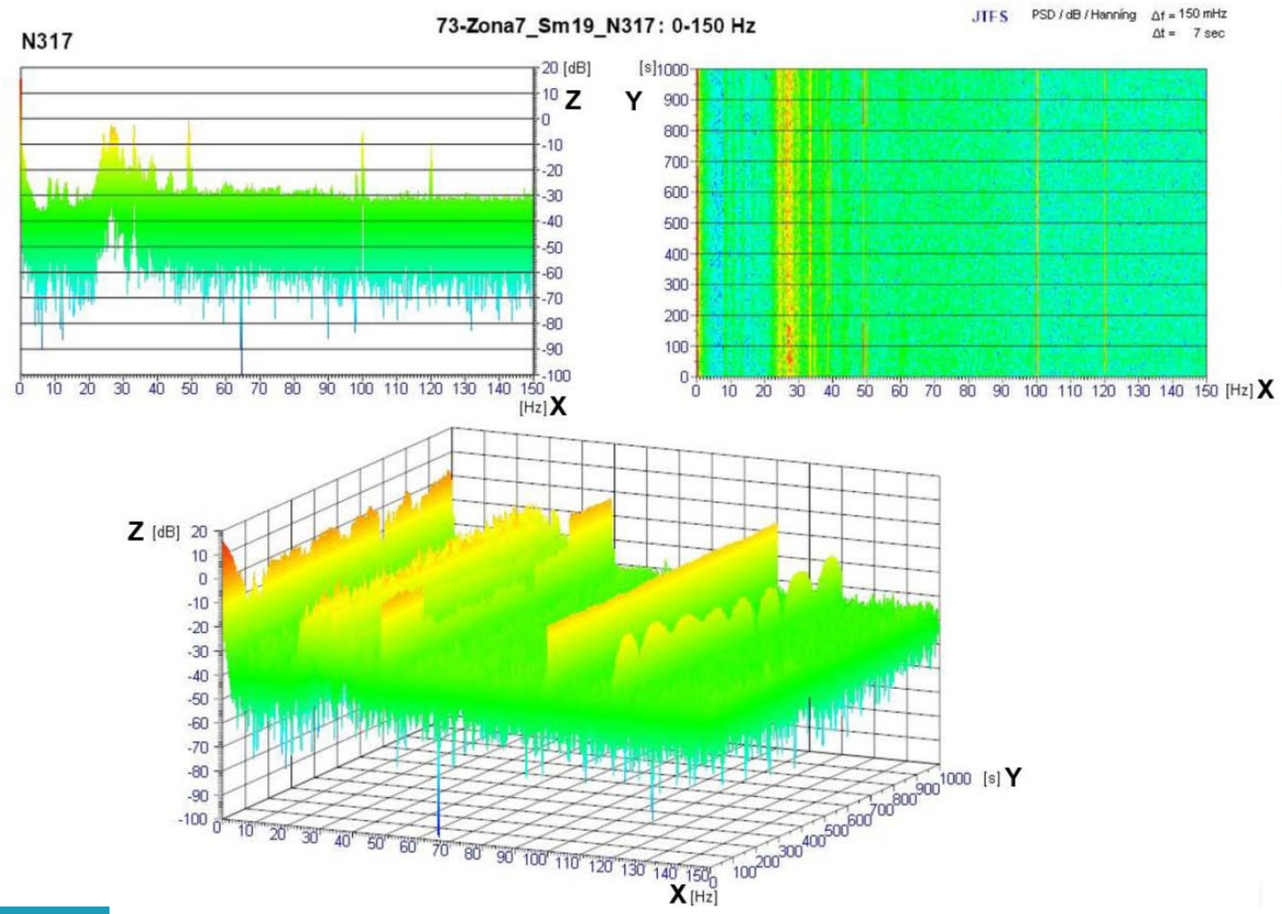
JFTS spectrograms have XYZ coordinates,

i. **in [Hz] for frequency**
ii. **in [s] for time**
iii. **PSD amplitude in [1/Hz^2] given in dB.**

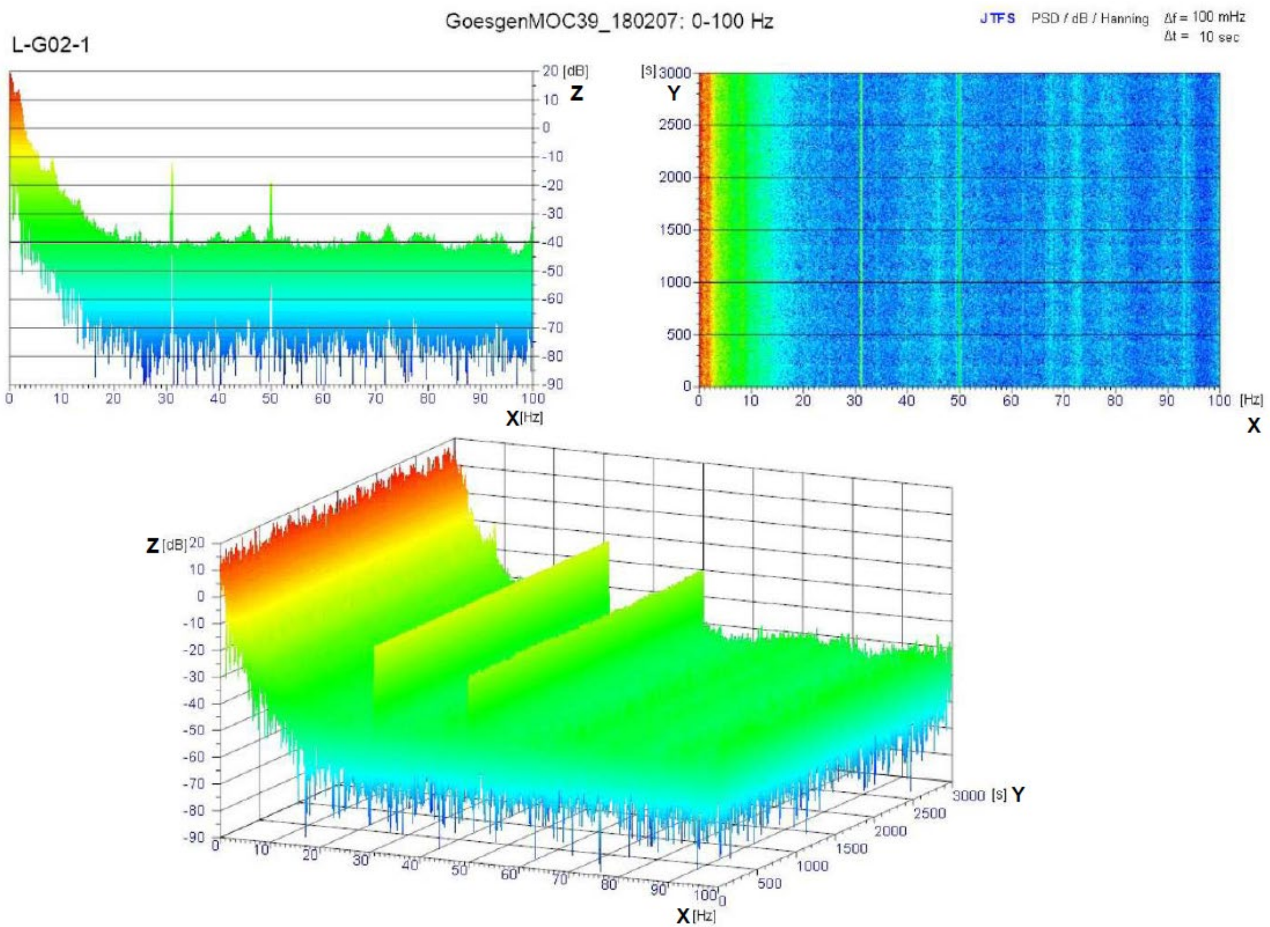
Plant data results

JTFS spectrograms

Temelin



Gösgen



Conclusions

- JFTS spectrograms can quickly show the spectral dynamics of the core behavior on an effective basis.
- The lowermost axial level shows the largest number of neutron field transients due to thermal and hydrodynamic conditions at the entrance to the core.
- This space can thus be a source of perturbations that are further moving along the height of the axial neutron field profile of the reactor.
- JFTS spectrograms allows observing transient phenomena during certain measurement intervals.
- All this knowledge can be taken into account for DNN training and AI algorithms.

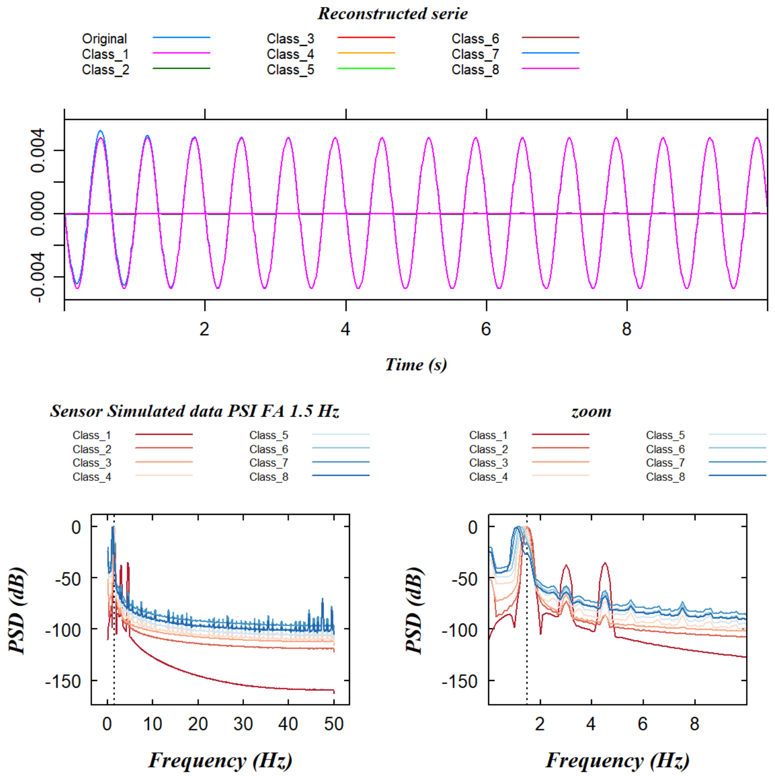
Singular Spectral Analysis on VVER-1000 measurements

Principle of the Singular Spectral Analysis (SSA)

Signal processing by principal component analysis

- **Phase 1:** **Signal decomposition in order to identify and analyse its different components**
- **Phase 2:** **Obtain Spectrum from the different componets**
- **Phase 3:** **Classification of these components according to their frequency content**
- **Phase 4:** **Signal Reconstruction as the sum of those components of interest. We can remove the components we are not interested in:**
  - **Trend**
  - **Certain harmonics**
  - **Noise**

Simulated data analysis

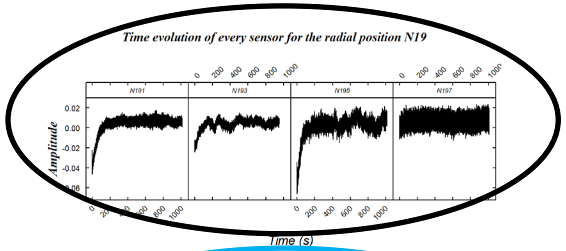


Outputs for each signal

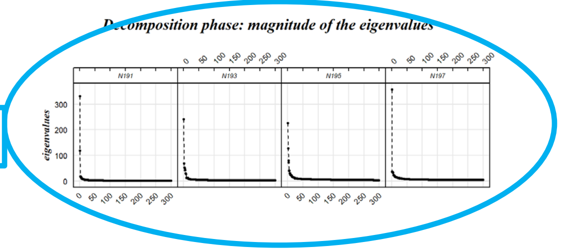
➢ *Spectral exploratory analysis by Singular Spectrum Analysis (SSA)*

Example : a rhodium SPND (cycle U1C09) for the 4 axial positions at the N19 radial position

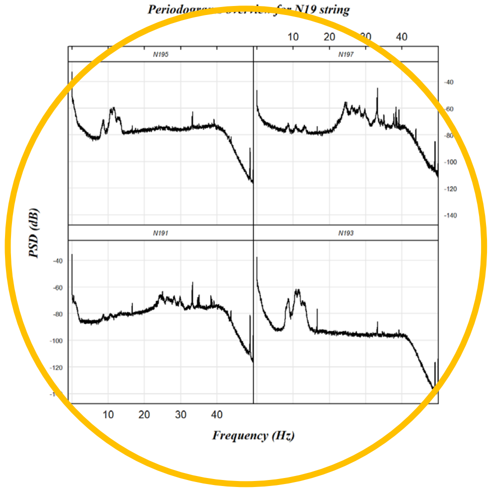
Original Signal



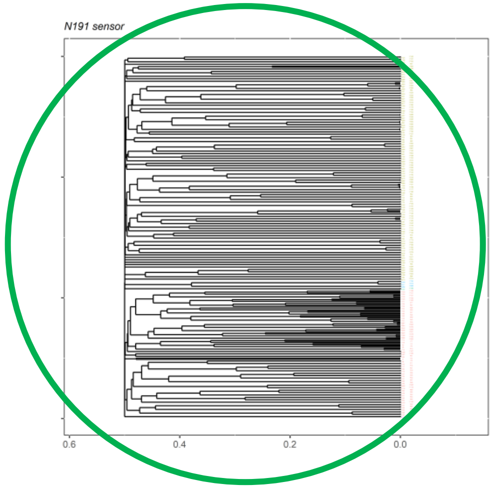
Decomposition phase



Spectrum estimation of each signal



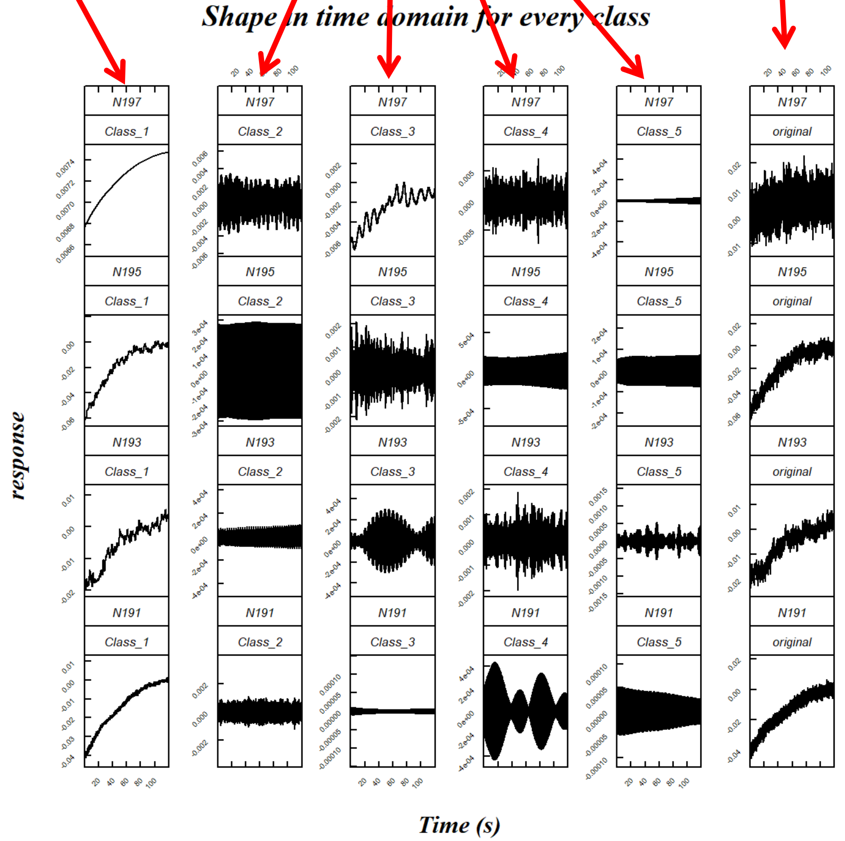
Classification



Important Oscillations found in the signal

Trend

Raw signal



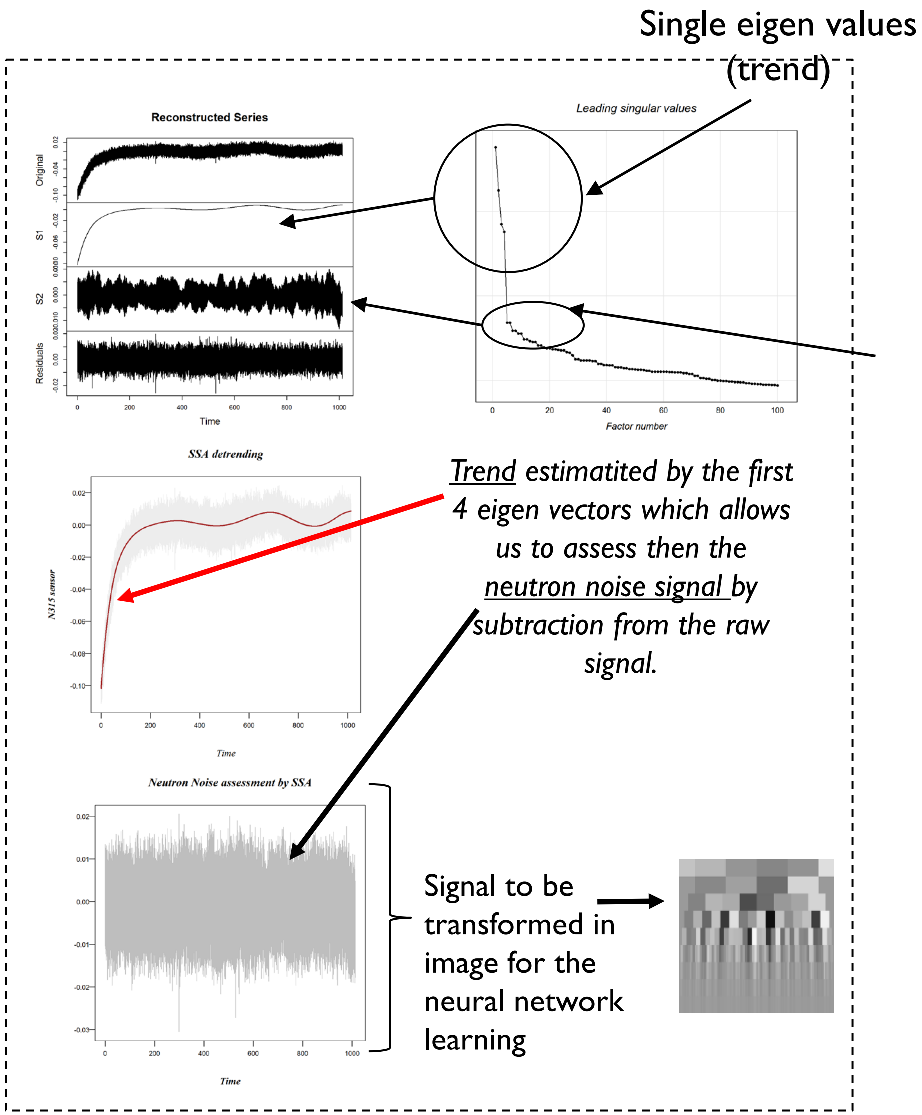
SOME PRELIMINARY CONCLUSIONS

- SSA is a powerful tool to extract the trend from the signals

- SSA extract the important components of the signals

- These components can be later used for AI methods

- A construction of a database is on-going



Operational Modal Analysis on KWU plant data

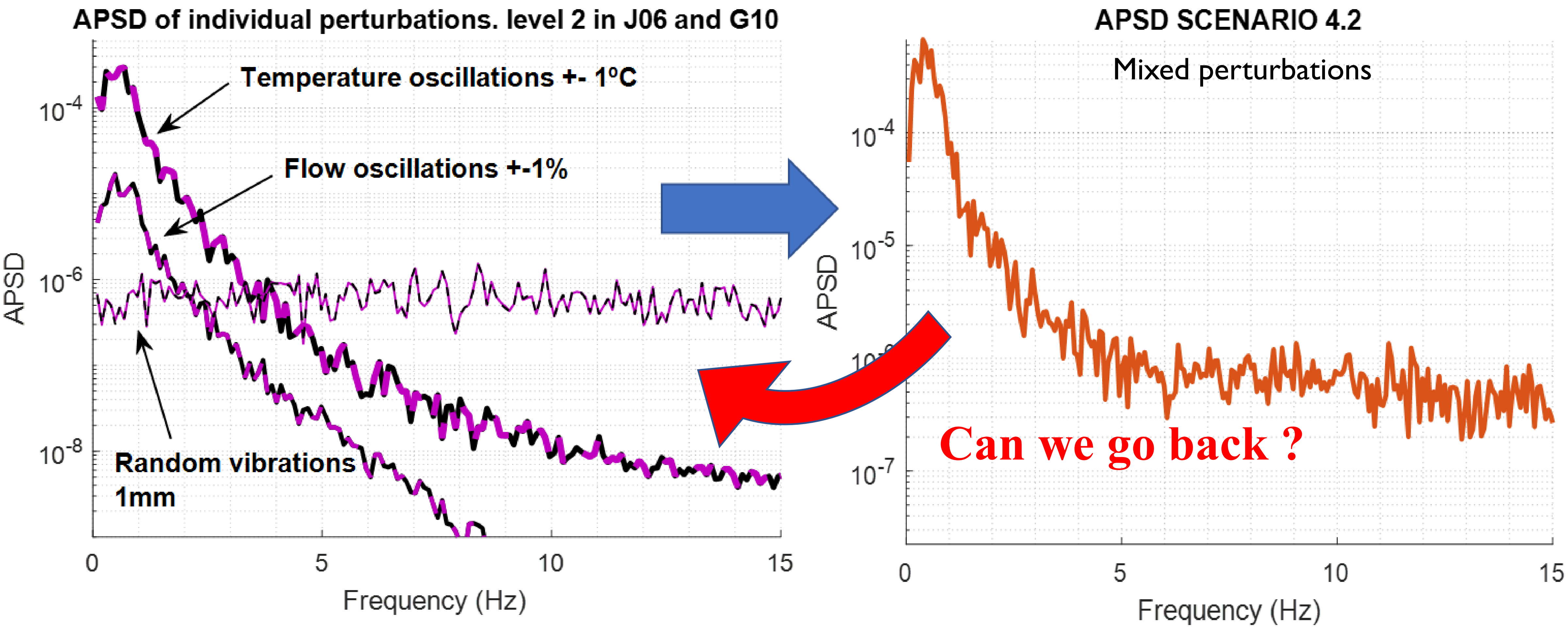
Can we separate the different phenomena?

- Which source/physical phenomena is responsible for the spectral characteristics of our data?
- When a particular feature of the time series has changed, are we able to identify the physical cause of this change?
- Nuclear reactors are very complex systems where several phenomena thermal-hydraulic, mechanical vibrations and others are acting simultaneously
- Signal processing methods can be useful to decompose the signal and being able to "see" the contribution in the data from different sources (mechanical, temperature, Flow…)

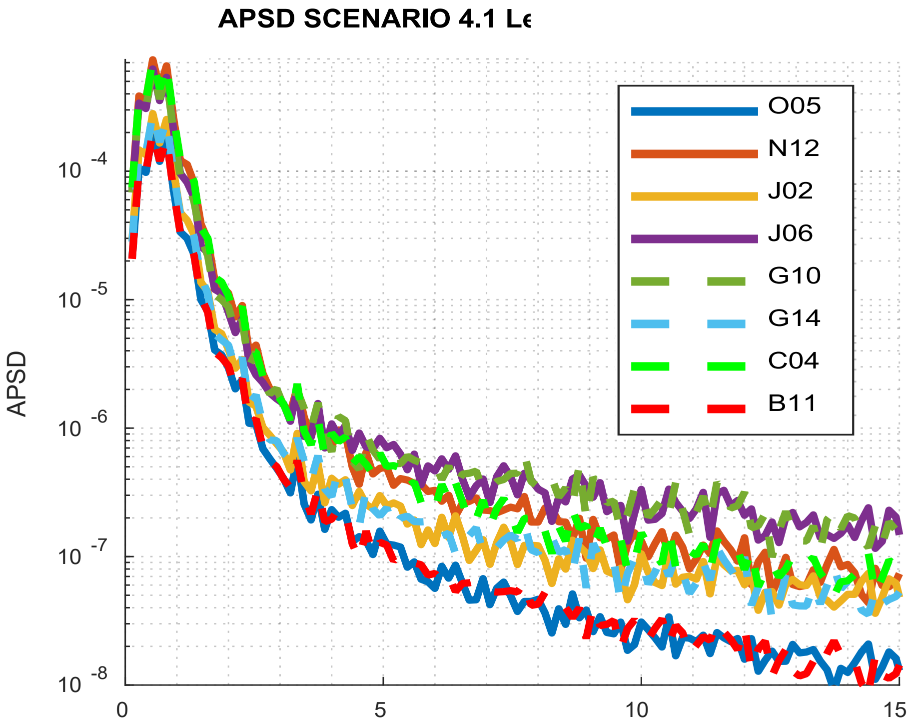
Operational Modal Analyis

Enhanced Frequency Domain Decomposition

Searching for a decomposition methodology



EFDD performance in simulated data

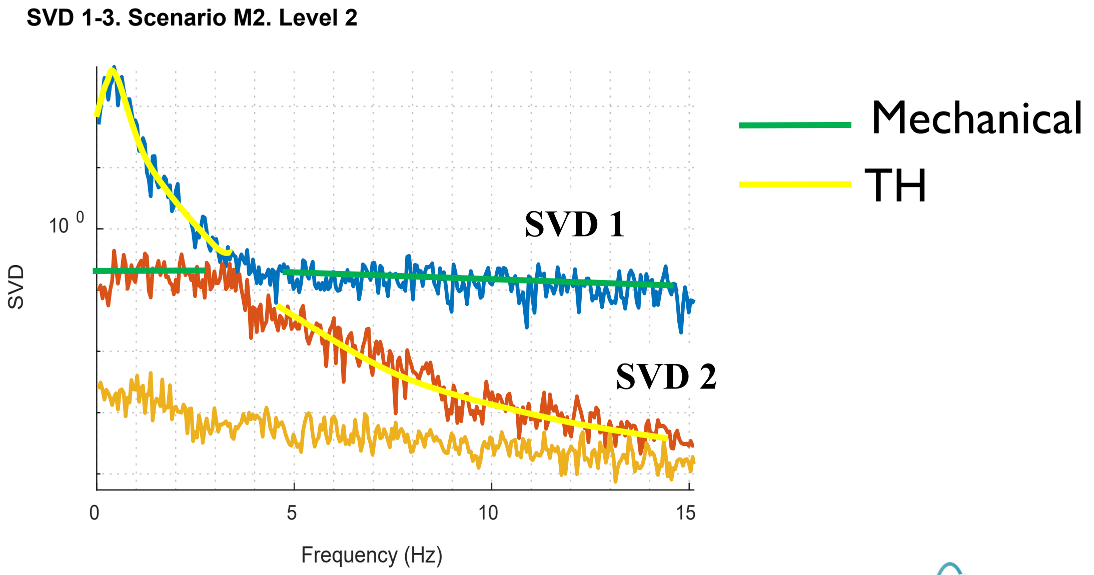


Phase 0: Selecting the sensors for the analysis.

Phase1: Decomposing the spectra into different components (**SVD_i**)

Phase2: Identify which phenomena is behing every **SVD_i**

Phase 3: Estimating modal parameters



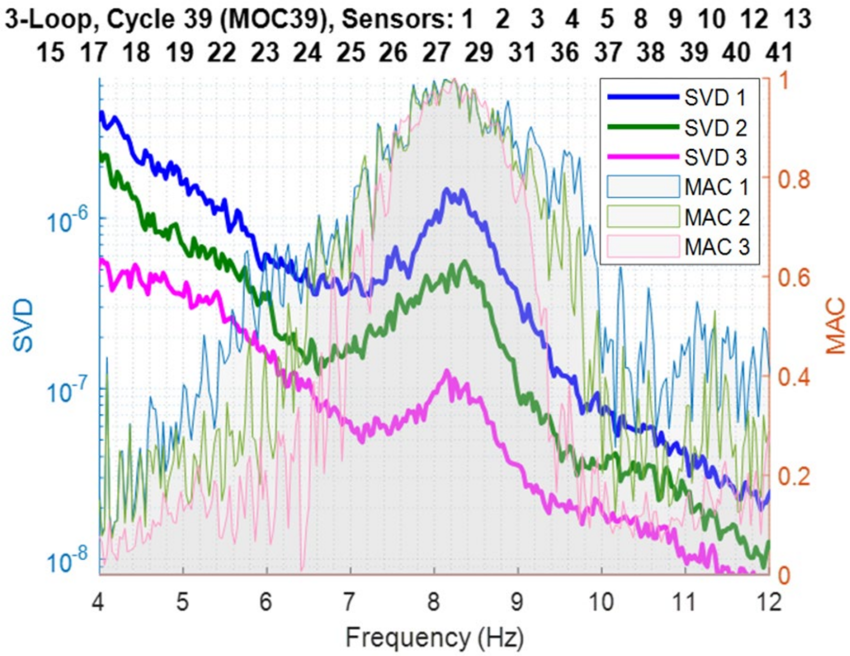
EFDD performance in real data

Including all the sensors available

EFDD

Characteristics of the methodology

- -It divides the spectra into different components: the highest components are dominant **(Monitoring)**
- All the sensors can be analyzed simultaneously. **(Operative monitoring)**
- The method gives spatial information on how every component is manifesting in each detector **(Infer sources of noise)**
- For certain regions of interest or resonances, we can estimate more parameters such as: amplitude, frequency and damping **(Parameters estimation)**



Instead of 41 spectra per detector, you get 3 "dominant spectra"

Conclusions

- Noise analysis is a powerful tool for stationary data and preliminary assessment of the measurements
- For transients and time-varying signals it is necessary to use JTFS or any other similar method
- SSA and EFDD are methodologies which decompose the signal into different components which can be related to physical phenomena
- All the knowledge gained from signal processing is essential for:
    - Surveillance and monitoring
    - Detecting anomalies/abnormal behaviours
    - Better development and improvement of AI algorithms

Thank you