CORTEX

Core monitoring techniques and
experimental validation and demonstration

Analysis of the experimental data

Validation workshop, 12-13.03.20

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Outline: Quantities of Interest

- Following the validation meetings:

  QoI are CPSD relative power & phase

- Using exp. 20 on CROCUS reactor at ±1.5 mm/1Hz
  - 30 min measurement
  - Dwell time 0.004 s
  - $\sim 4.5 \cdot 10^5$ samples
- Post-processing
  - Signal Coherence (checking data validity)
  - Power density estimate
  - Uncertainty estimates

Outline: analysis steps

- Detrending: removal of low frequency shifts (e.g. reactor power change) and normalization by removing moving average
  - Requirement: mean=0

Impacted by detrending window size

- PSD estimates using Welch averaging

Impacted by both detrending and Welch sample window size

- Coherence determination

Are signals biased or not?

- Determination of PSD peak frequency and area
- Effects of Welch averaging (windowing) on peak area
- Uncertainty estimates using bootstraping
- Using power ratios

Experimental data

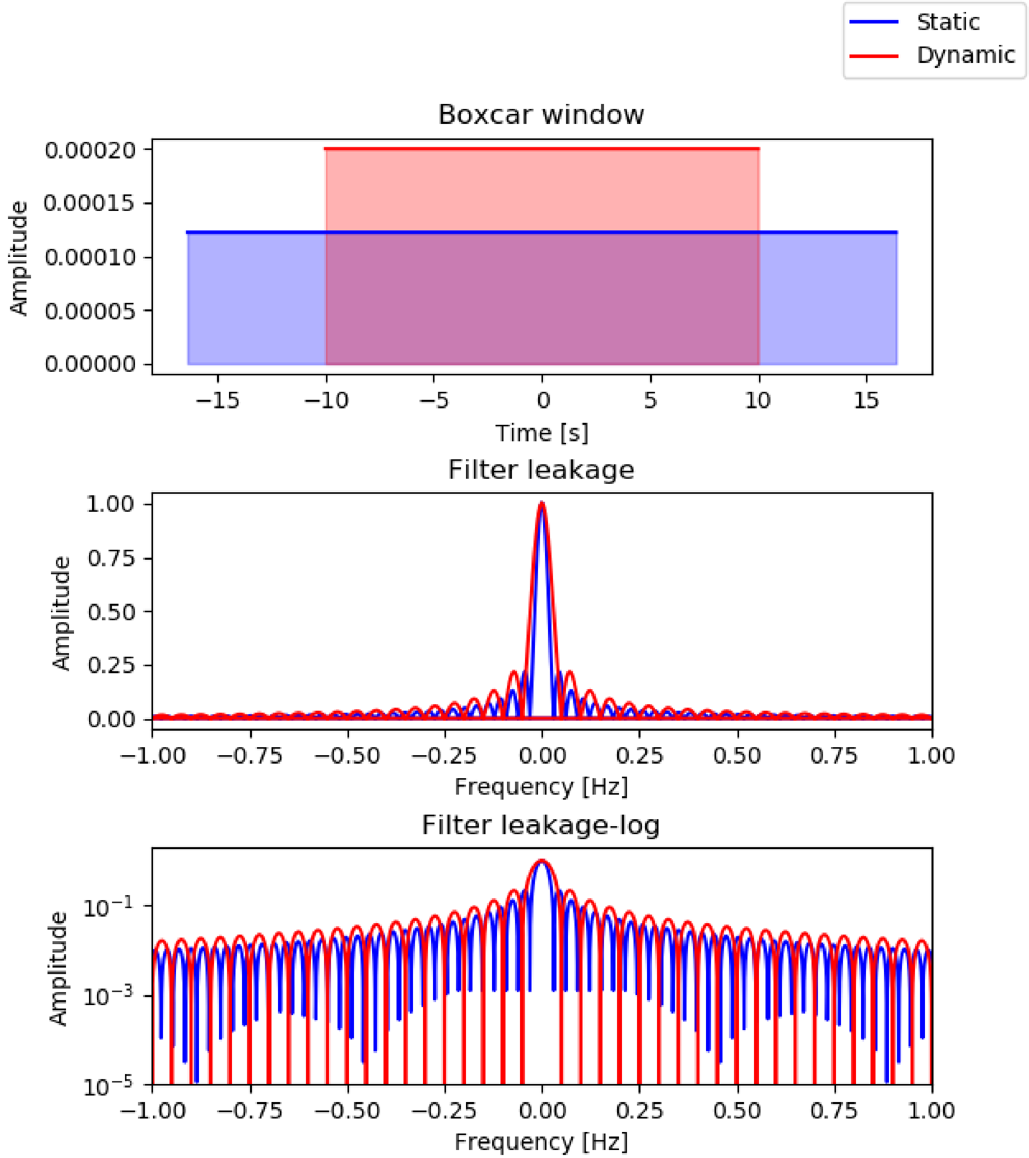
For both 1st campaigns, the neutron detection time series arise from:

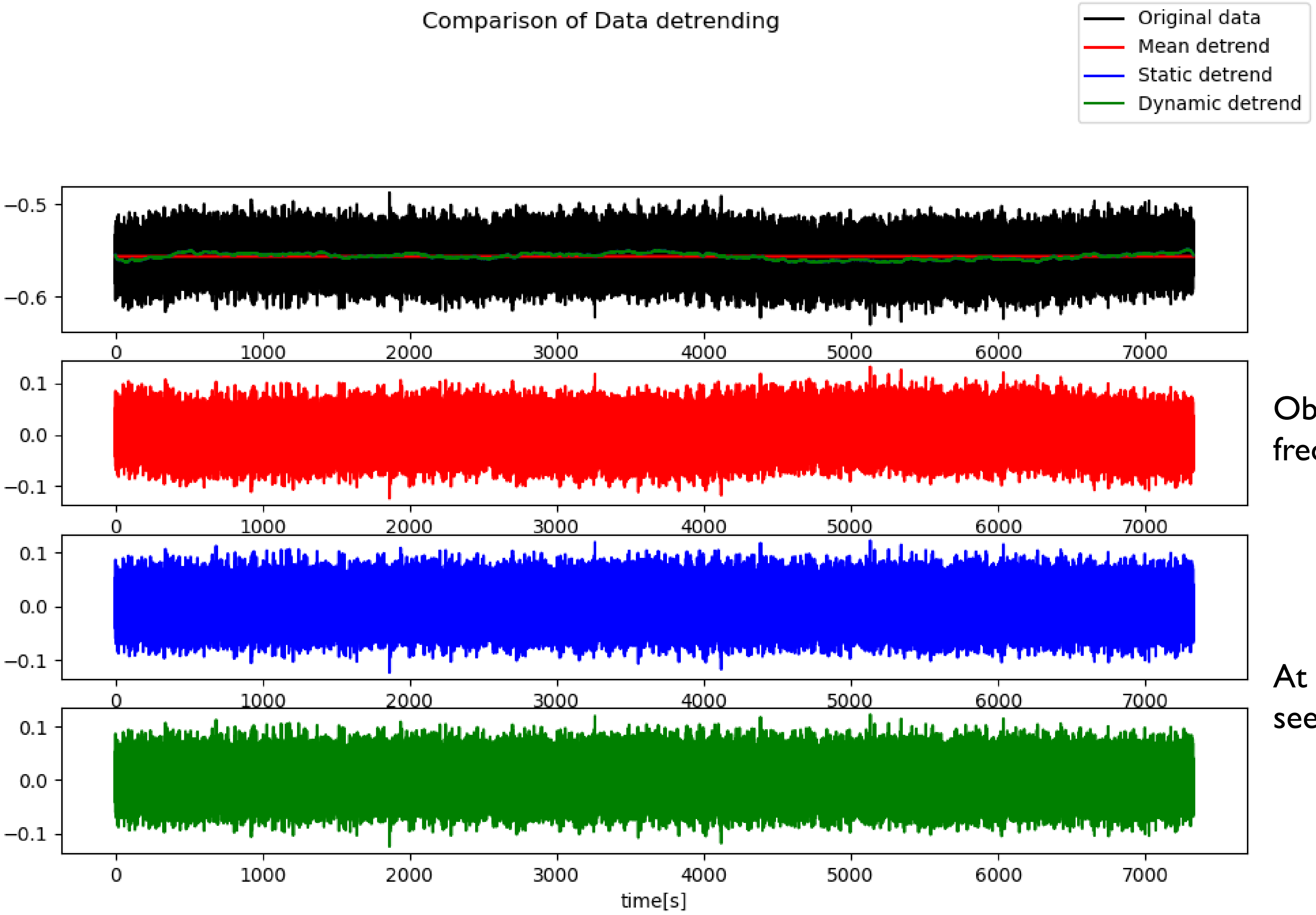
- Measuring various reactions rates: ^{235}U, ^{3}He, ^{10}B
- Various detectors' types
  - ^{235}U fission chambers
  - $^{3}He/BF_3$ proportional counters
  - ^{10}B-coated compensated ionisation chambers
- Various electronics' types
  - Pulse mode, i.e. counting detection events
  - Current mode, i.e. measuring energy deposits
- One acquisition system as of now: ISTec SIGMA
  - Pulses are converted in current using Robotron devices

Please refer to deliverable D2.1!

Detrending

- Motivation:
  - Need of data with 0 mean for analysis
  - Removal of low frequency data shifts, not induced by the oscillator (e.g. reactor power change)
- Methods:
  - Mean removal
  - Moving average removal, static or dynamic
- Effects of averaging window size:
  - Static: use the window size used for PSD estimate
  - Dynamic: use the window size of 2x the wavelength of estimated base frequency by the initial PSD estimate.





← *Our selection*

Observable low frequency trend

At this stage, series seem fine

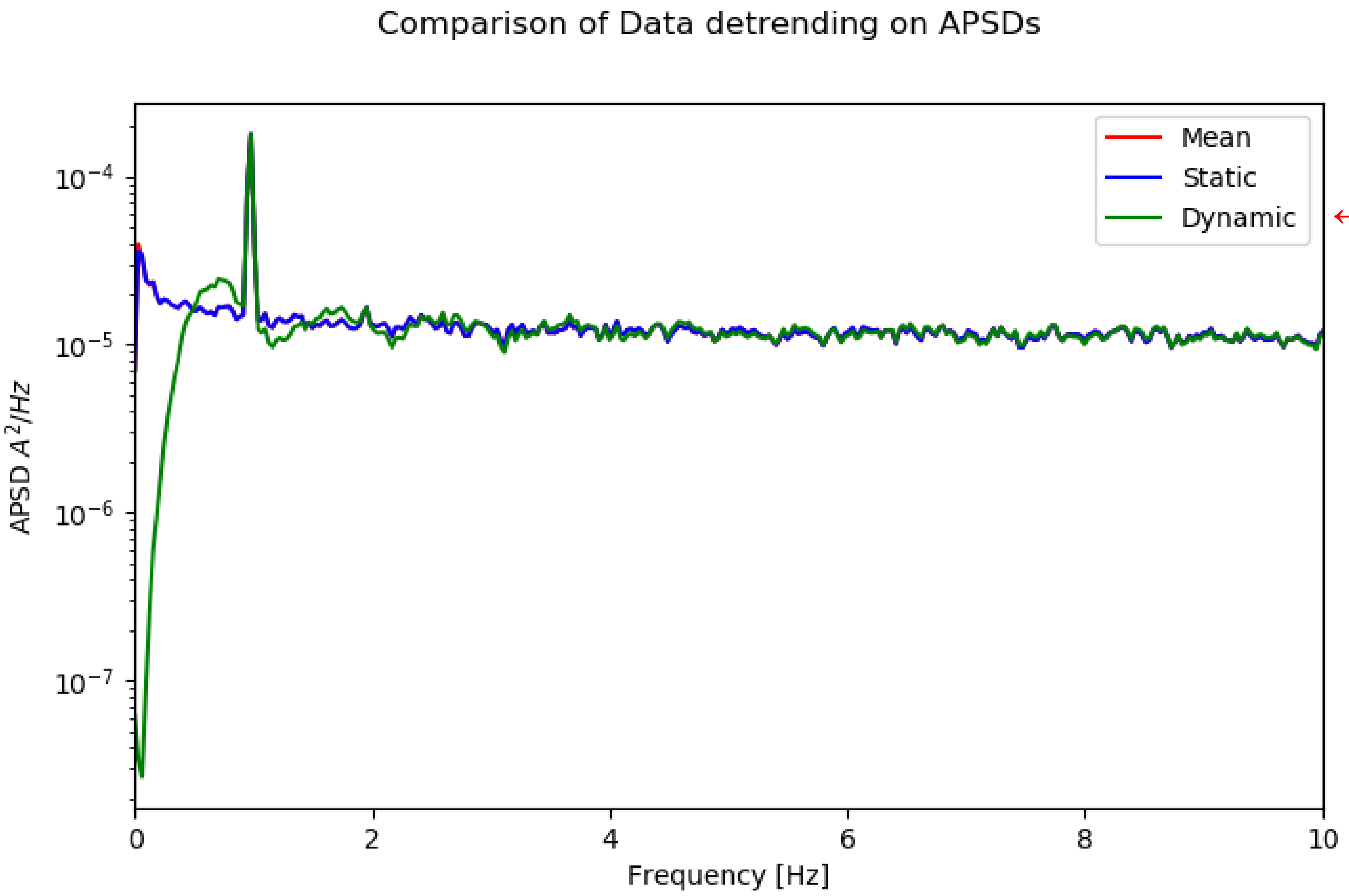
PSD estimates using Welch

- Averaging periodograms ($|FFT|^2$) of several signal sections (W window size samples), here without overlapping
- Lowering the spectral resolution compared to periodogram

$$\Delta f = \frac{1}{\Delta t \cdot W}$$

With Δt the sampling time or dwell time

- Unwanted noise is averaged out
- Smart window selection: *removing noise* ***and*** *keeping the peak!*



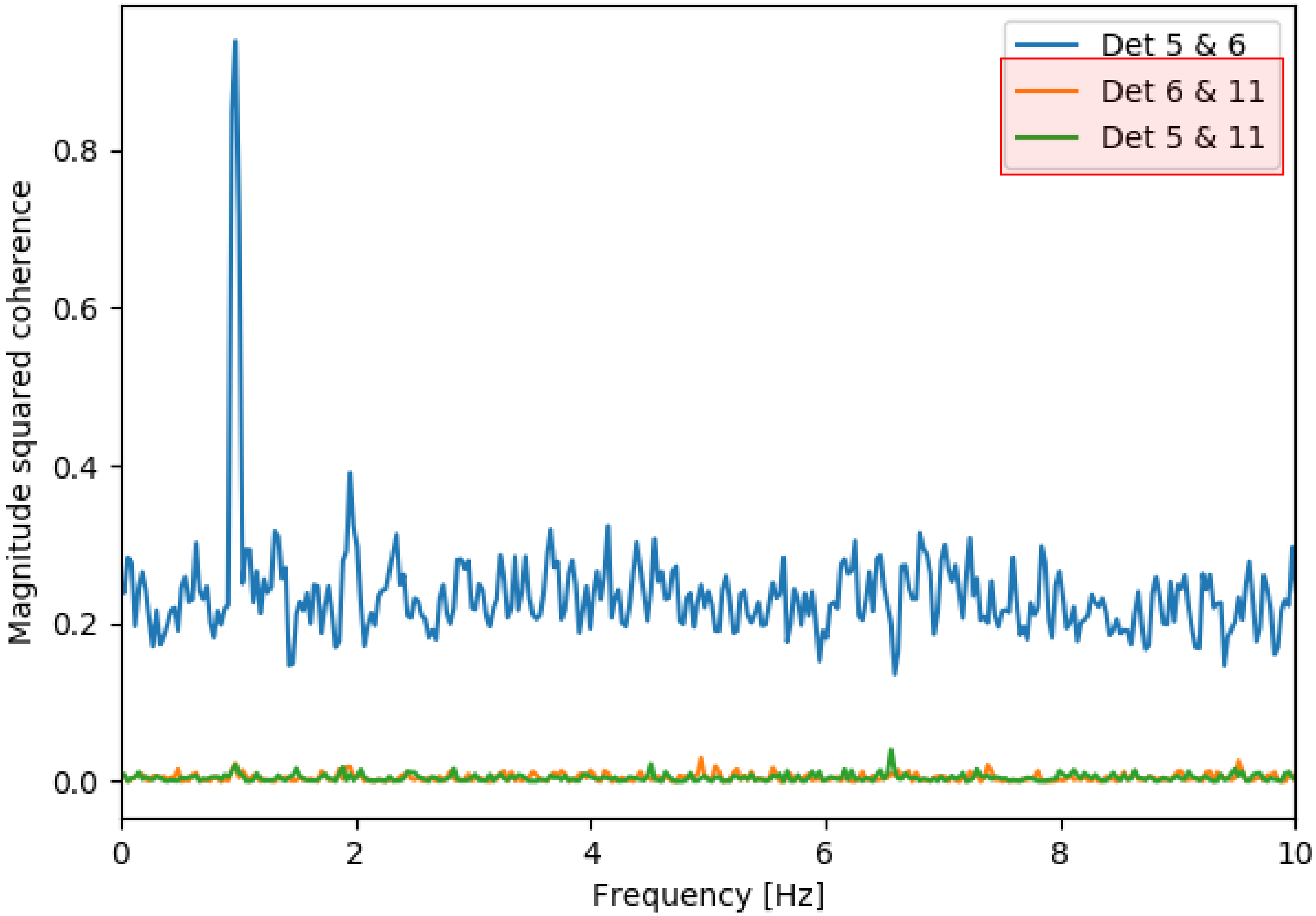
← Our selection

Coherence determination

- Measure of relation between two signals.
- Calculated by $C_{i,j}(f) = \frac{\left|CPSD_{i,j}(f)\right|^2}{APSD_i(f) \cdot APSD_j(f)}$
- Valued at $C_{i,j}(f) = [0,1]$
  - Higher the coherence, the more can signal i be predicted from signal j and vice-versa.
  - If $C_{i,j}(f) \sim 0$ at non-induced frequency: uncorrelated noise.
  - If $C_{i,j}(f) \sim 0$ at the induced frequency: biased data.

Even with a coherence issue, the CPSD can have a peak at the induced frequency!

Coherence between different detectors



To be discarded…

…although they still present a peak

Effect of the CPSD window size

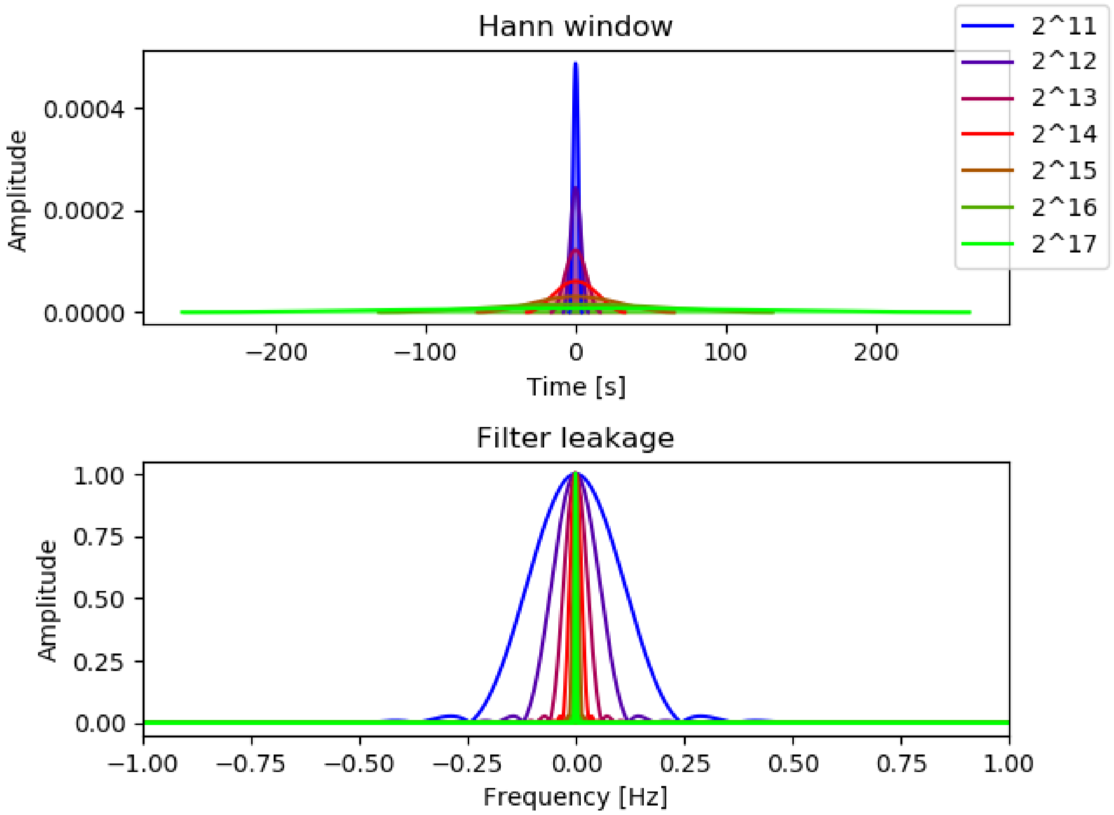
- Frequency resolution:

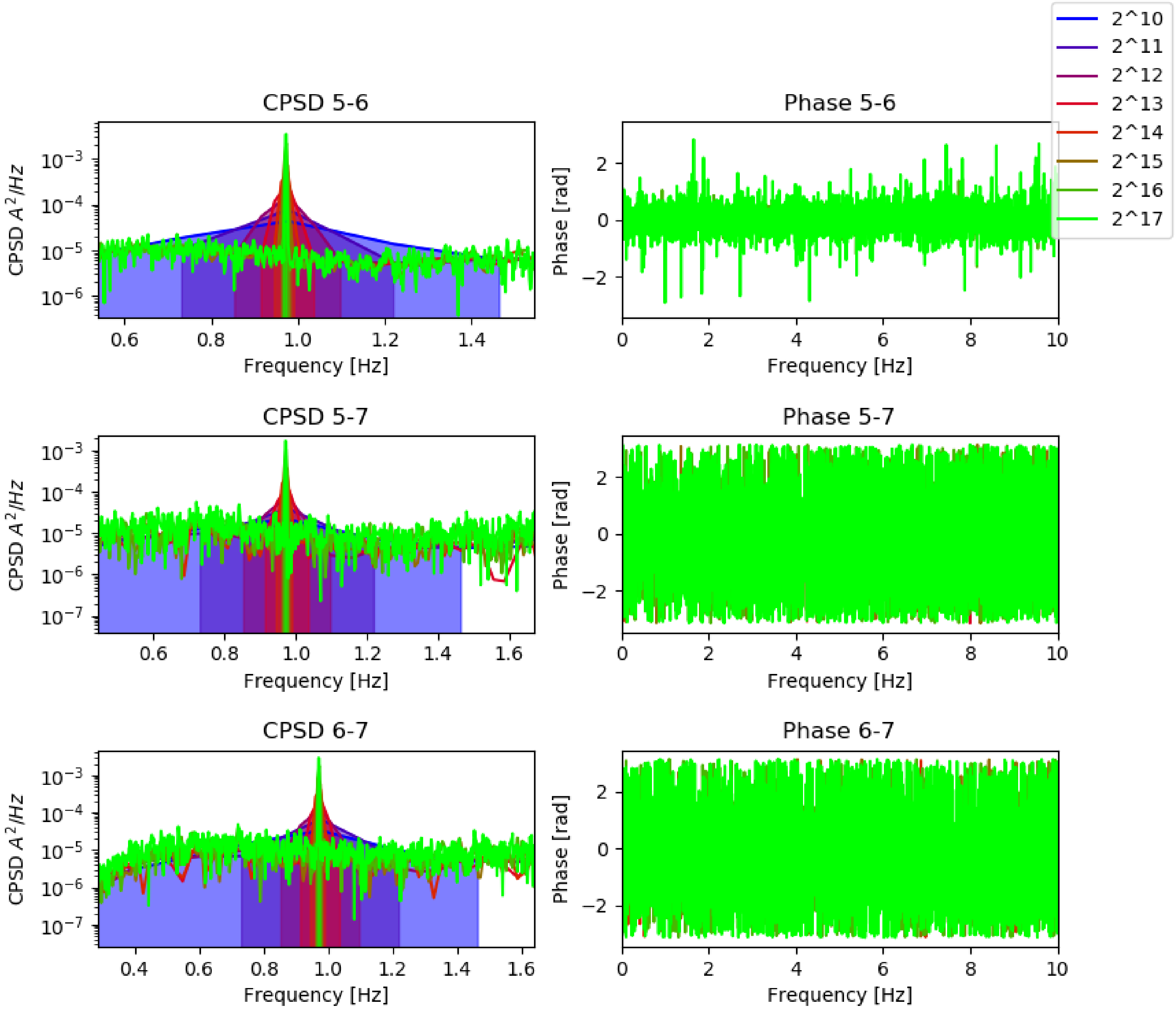
$$\Delta f_{min} = \frac{1}{\Delta t * W}$$

with:

  - $\Delta t = 4$ ms in our case
  - W to be adapted

- Trade-off between bias elimination and spectral resolution.
  - Large W : no averaging, no noise elimination, coming back to periodogram
  - Small W: *how much of the neighbouring PSD is considered to be in peak area using a smaller window (illustrated in the exercises)?*
- Angle dependence: not observed at all
  - Phase shifts vs. Time → timeseries analysis will be performed in the future





← *Our selection*

Window length is ~30s:

- *i.e. ~30 cycles*
- *30 min: ~60 samples*

For the PSD

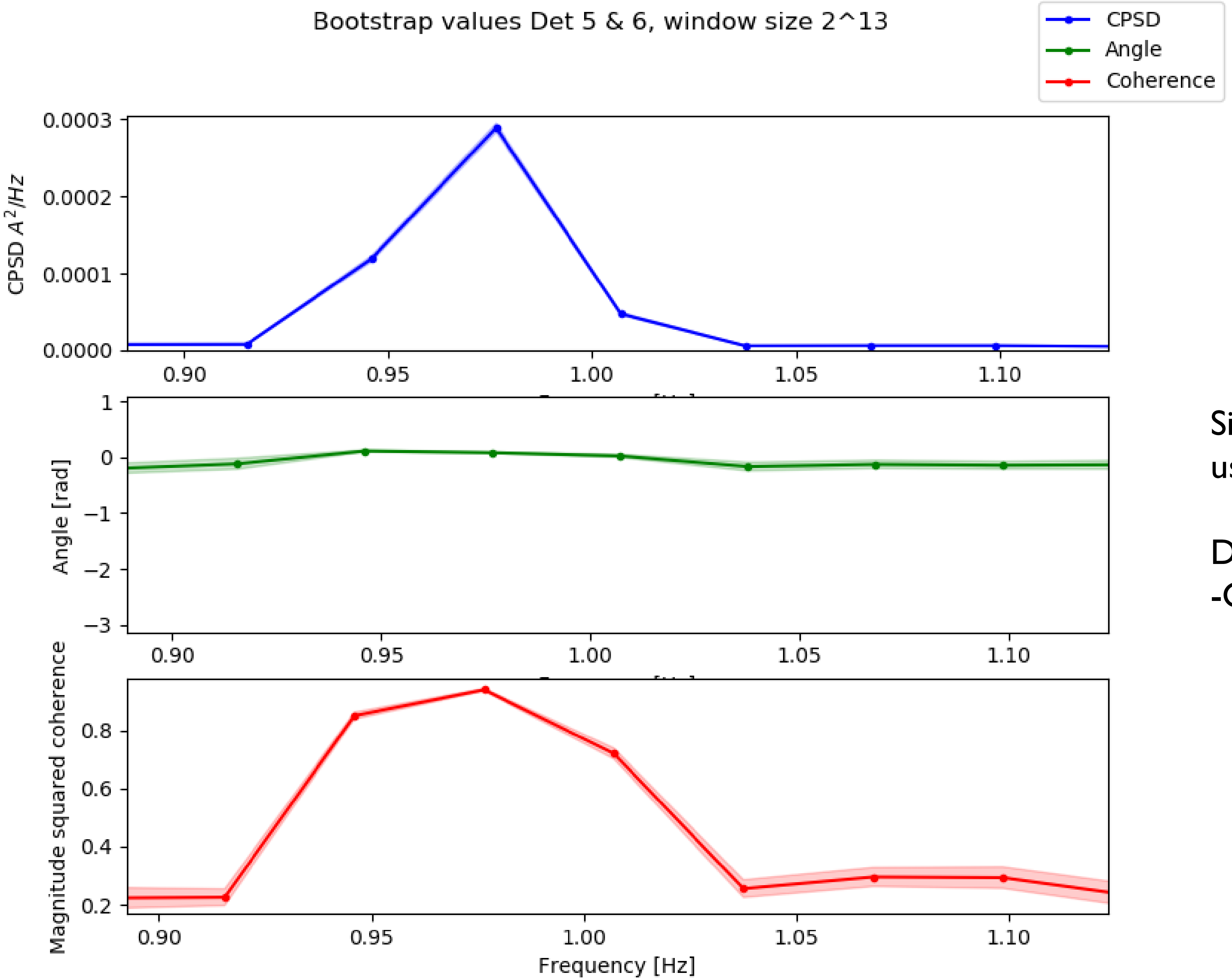
- *Enough samples for noise averaging*
- *Not too many samples for peak area estimate*

For bootstrapping

- *enough samples for statistical significance*

Bootstrapping

- One could directly use the standard deviation of the PSD estimate, but:
  - Problem of statistical significance
  - Forcing sensitivity to local variations and biases, i.e. hidden temporal correlations
- Bootstrapping:
  - Principle:
    - signal is chopped into (in our case equal) sections, which are resampled with replacement allowing random repetitions, for the same final length
    - timeseries are sampled multiple times using this method
    - values of interest are estimated for each combination.
  - If n sections, n^n possible combinations
- Currently:
  - Both signals are resampled in the same way, otherwise coherence is lost
    - Future developments: sections of size of peak frequency $\pm$ frequency spread will be used for bootstraping to observe coherence uncertainty.



Significant spread not observed using 100 boostrap samples.

Deviations:

-Check for distributions

Uncertainty quantification

- One could directly use the standard deviation of the PSD estimate, but:
  - Not enough sections for statistical significance
  - Forcing sensitivity to local variations and biases, i.e. hidden temporal correlations
- Bootstrapping:
  - Principle:
    - signal is chopped into (in our case equal) sections, which are reordered with random repetitions for the same final length
    - timeseries are sampled multiple times using this method
    - values of interest are estimated for each combination.
  - If n sections, $n!$ possible combinations
- Currently:
  - Both signals are reordered in the same way, otherwise coherence is lost
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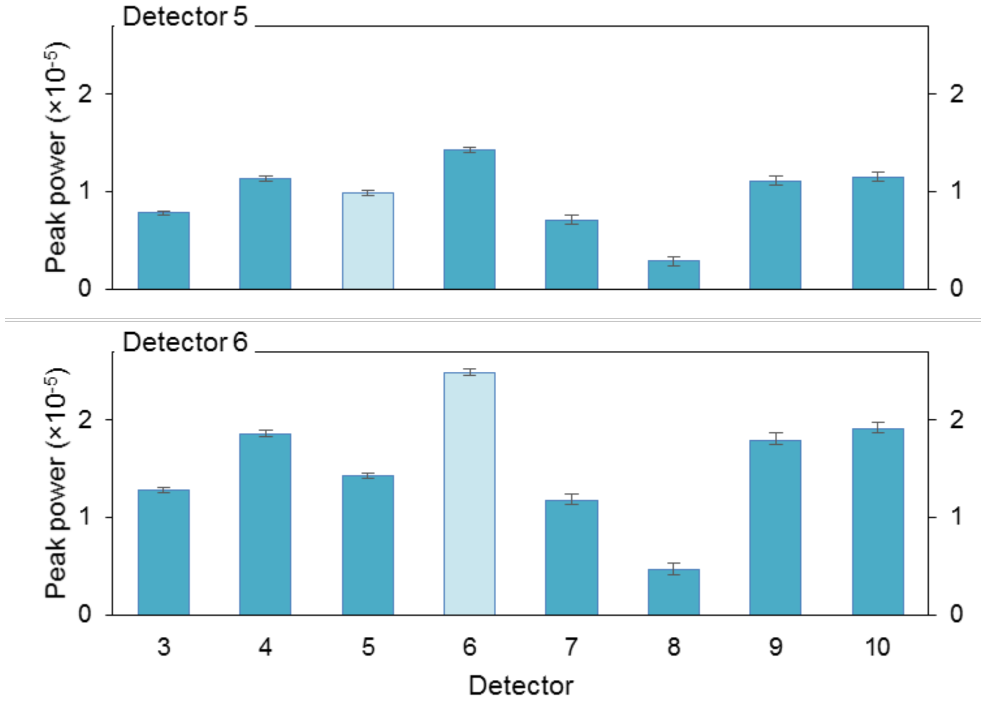
Using power ratios



Using power ratios

- We define the following ratio:

$$R_{ij5}(A,f) = \frac{P_{i-j}}{P_{5-j}}$$

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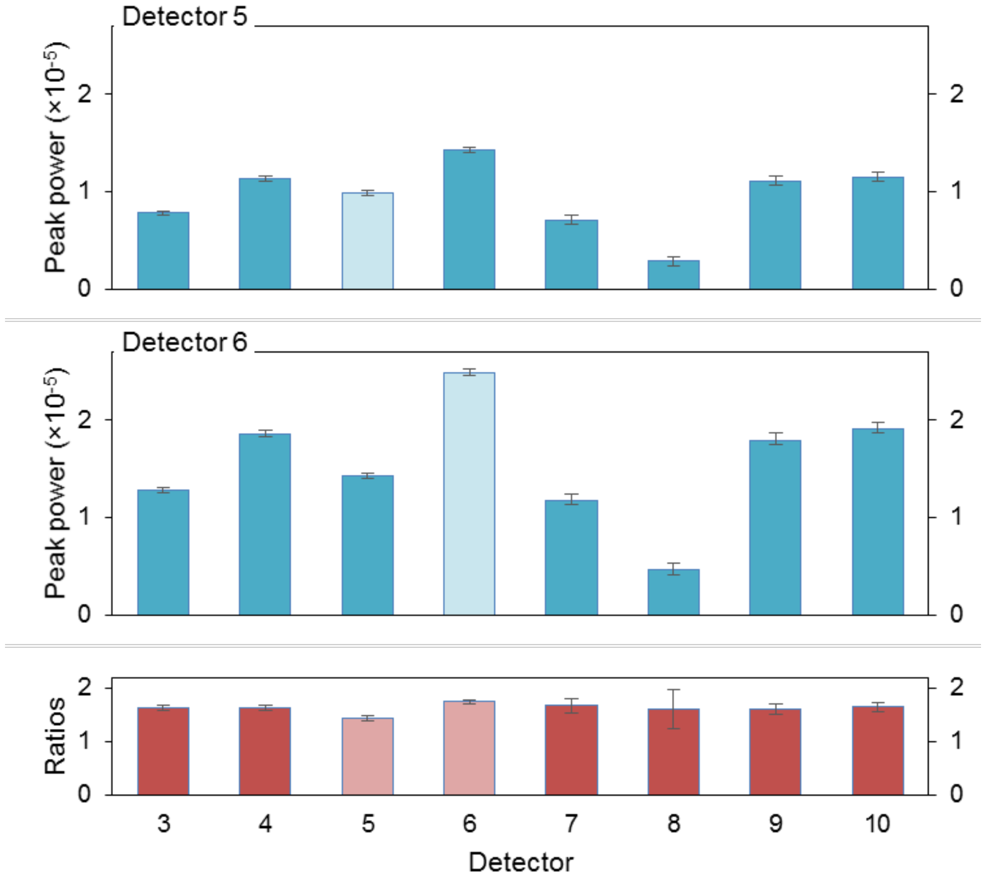

Here $R_{ij5}(A,f) = \frac{P_{6-j}}{P_{5-j}}$

Using power ratios

- For one full experiment

Power P_{ij}

Detector j	Detector i: 3	4	5	6	7	8	9	10
3	7.11E-06	1.01E-05	**7.80E-06**	1.28E-05	6.22E-06	2.47E-06	9.83E-06	1.03E-05
4	1.01E-05	1.51E-05	**1.14E-05**	1.86E-05	9.15E-06	3.77E-06	1.43E-05	1.51E-05
5	7.80E-06	1.14E-05	**9.90E-06**	1.43E-05	7.11E-06	2.85E-06	1.11E-05	1.15E-05
6	1.28E-05	1.86E-05	**1.43E-05**	2.49E-05	1.17E-05	4.64E-06	1.79E-05	1.91E-05
7	6.22E-06	9.15E-06	**7.11E-06**	1.17E-05	2.57E-05	1.40E-05	8.42E-06	8.98E-06
8	2.47E-06	3.77E-06	**2.85E-06**	4.64E-06	1.40E-05	0.00E+00	4.33E-06	4.10E-06
9	9.83E-06	1.43E-05	**1.11E-05**	1.79E-05	8.42E-06	4.33E-06	3.38E-05	1.45E-05
10	1.03E-05	1.51E-05	**1.15E-05**	1.91E-05	8.98E-06	4.10E-06	1.45E-05	3.36E-05

Ratios R_{ij5}

Detector j	Detector i: 3	4	5	6	7	8	9	10
3	0.911	1.30	1	1.64	0.7.97	0.317	1.26	1.32
4	0.890	*1.33*	1	1.63	0.804	0.331	1.25	1.32
5	*0.789*	*1.15*	*1*	*1.44*	*0.718*	*0.288*	*1.12*	*1.16*
6	0.896	1.30	1	1.74	0.820	0.325	1.26	1.34
7	0.874	1.29	1	1.65	3.61	1.96	1.18	1.26
8	0.866	1.32	1	1.62	4.89	0	1.52	1.44
9	0.883	1.28	1	1.61	0.756	0.389	3.03	1.30
10	0.894	1.31	1	1.66	0.781	0.357	1.26	2.92
Ratios R_{i5}	0.896	1.31	1	1.64	0.797	0.339	1.25	1.32
Difference with 5	-10%	31%	0%	64%	-20%	-66%	25%	32%
Uncertainty	1.5%	1.6%	-	1.8%	3.2%	7.1%	2.5%	2.3%
$\langle P_{i-5} \rangle$	$7.82 \cdot 10^{-6}$	$1.14 \cdot 10^{-5}$	$8.72 \cdot 10^{-6}$	$1.43 \cdot 10^{-5}$	$6.95 \cdot 10^{-6}$	$2.95 \cdot 10^{-6}$	$1.09 \cdot 10^{-5}$	$1.15 \cdot 10^{-5}$

Using power ratios

- Identification of biases
- Multiple estimates allows computing a standard deviation
- Reducing uncertainties

Detector j	**Ratios R_{ij5}**							
	Detector i							
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Conclusion

- General outline of all steps for estimating power, phase, and associated uncertainties
- Currently developing more advanced methods, e.g.:
  - True estimate of peak area and corresponding uncertainty
  - Comparing to alternative methods, such as using autocorrelation and time-domain analysis
  - Preparation of phase analysis, using data of campaign #2 in CROCUS

Thank you!
Any question?