pyBOAT
A Biological Oscillations Analysis Toolkit

December 2020

Gregor Mönke
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Oscillations and Rhythms in Nature

- Astrophysics: Pulsar, …
- Meteorology: El Niño, …
- Chemistry: BZ reaction, …
- Economics: "Business cycles", …
- Biology: Circadian rhythms, **Genetic oscillators, …**

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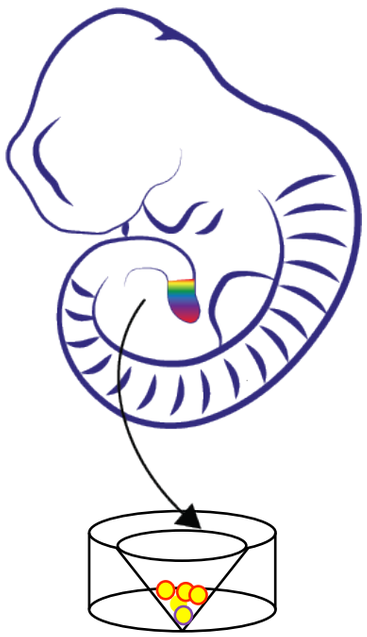
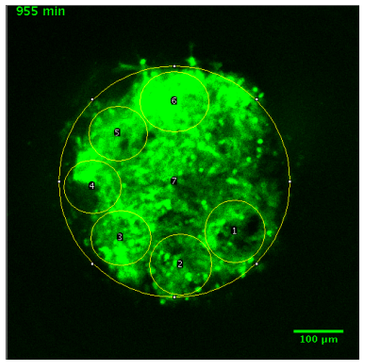
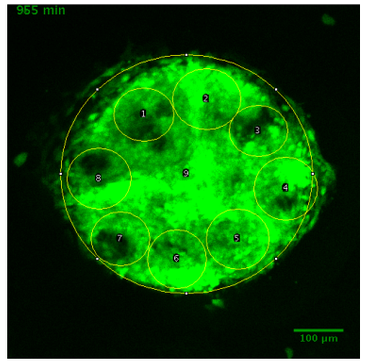
Lunatic fringe reporter line (LuVelu)

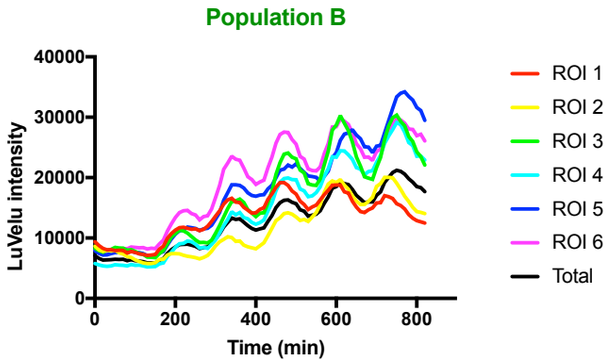
Aulehla et al., 2008

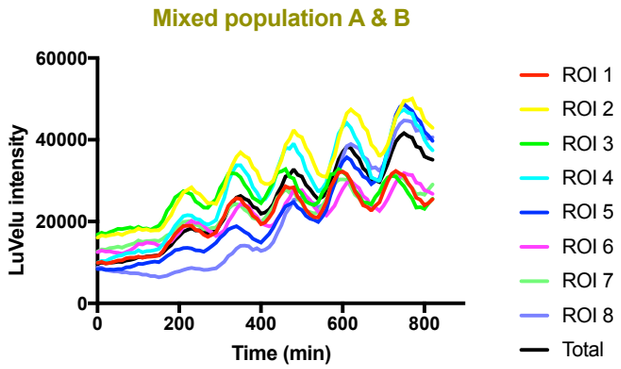
Mouse embryo





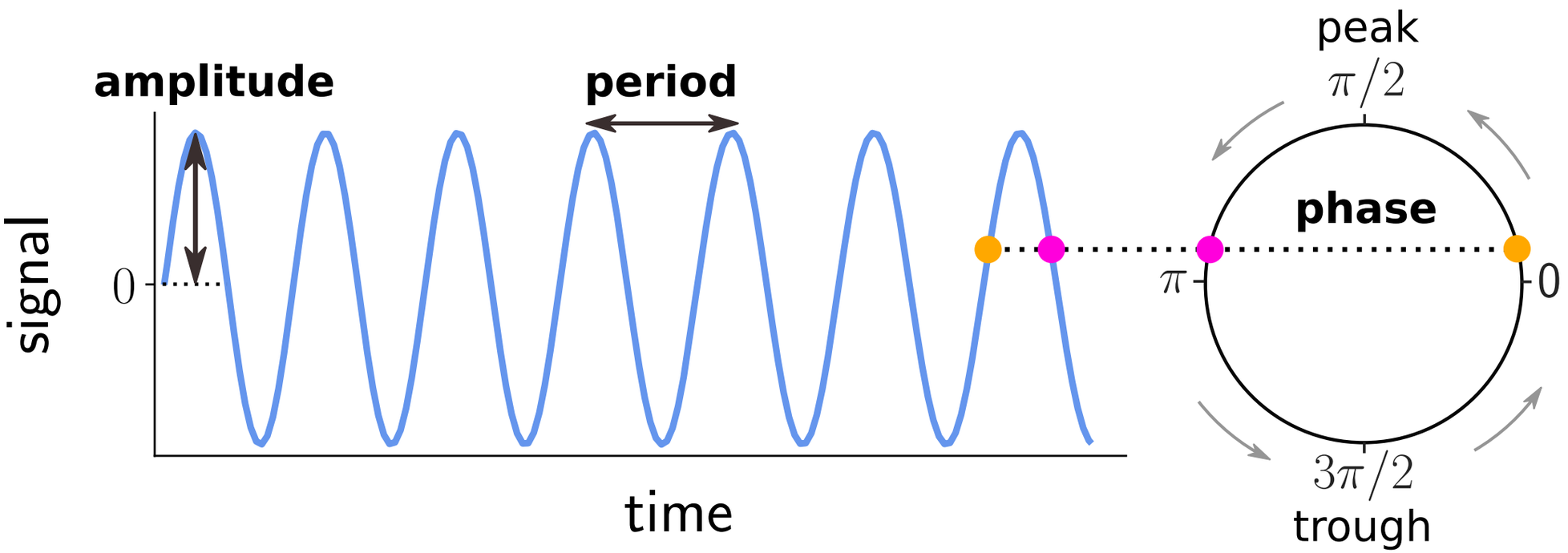






Experiments by C. Ho, EMBL Heidelberg

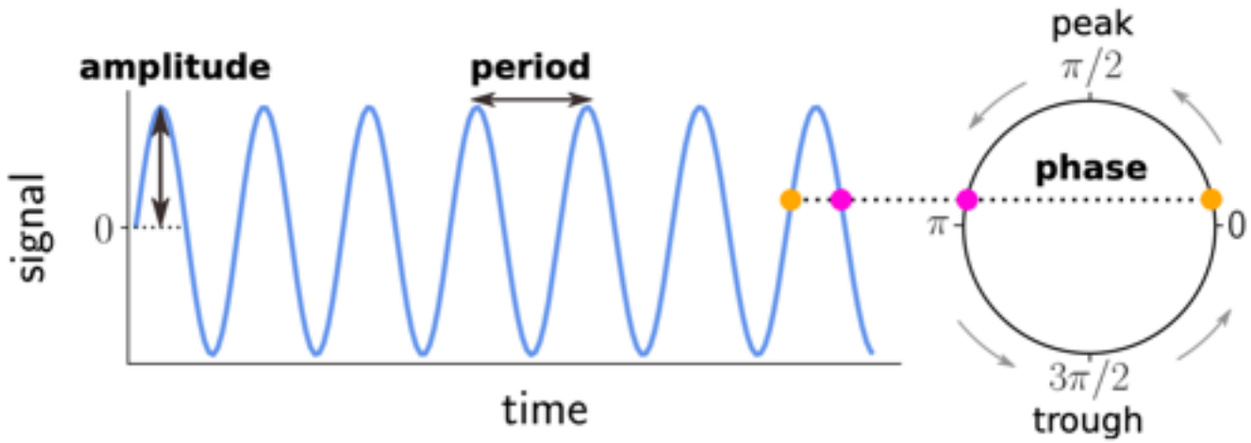
Problem Setting



- Amplitude and period potentially time-dependent!
- Uniquely characterize an **analytic signal**

$$A(t)\ cos[\phi(t)],\ \omega(t) = \frac{d\phi}{dt},\ \omega = \frac{2\pi}{T}$$

Why Does It Matter?



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- Phase encoding: lunch at 12pm, sleep at 12am
- Frequency encoding: Heart Rate
- Amplitude encoding: NfKb signalling pathway

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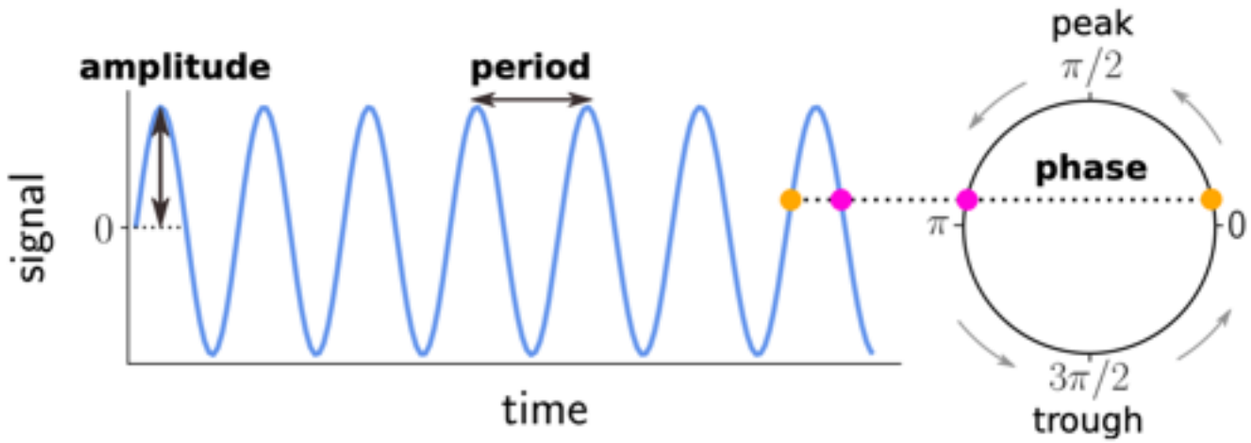

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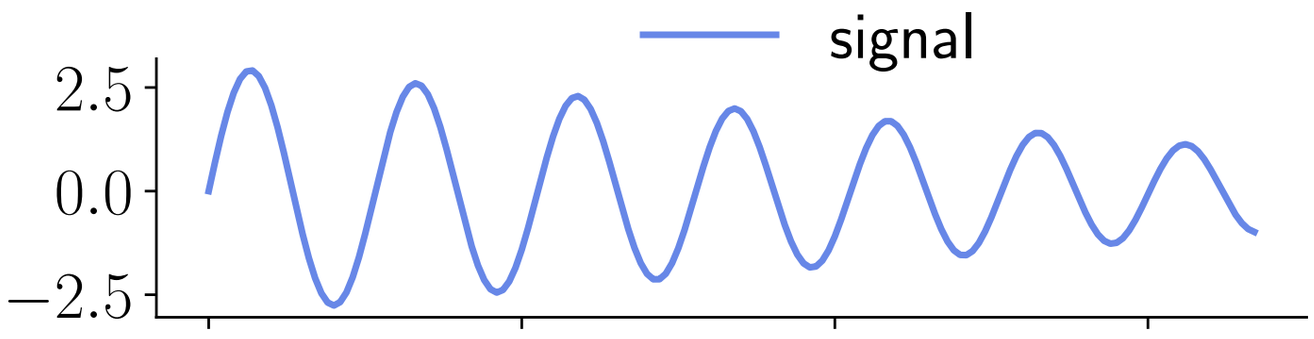
- aaand mix it :)

Problem Setting



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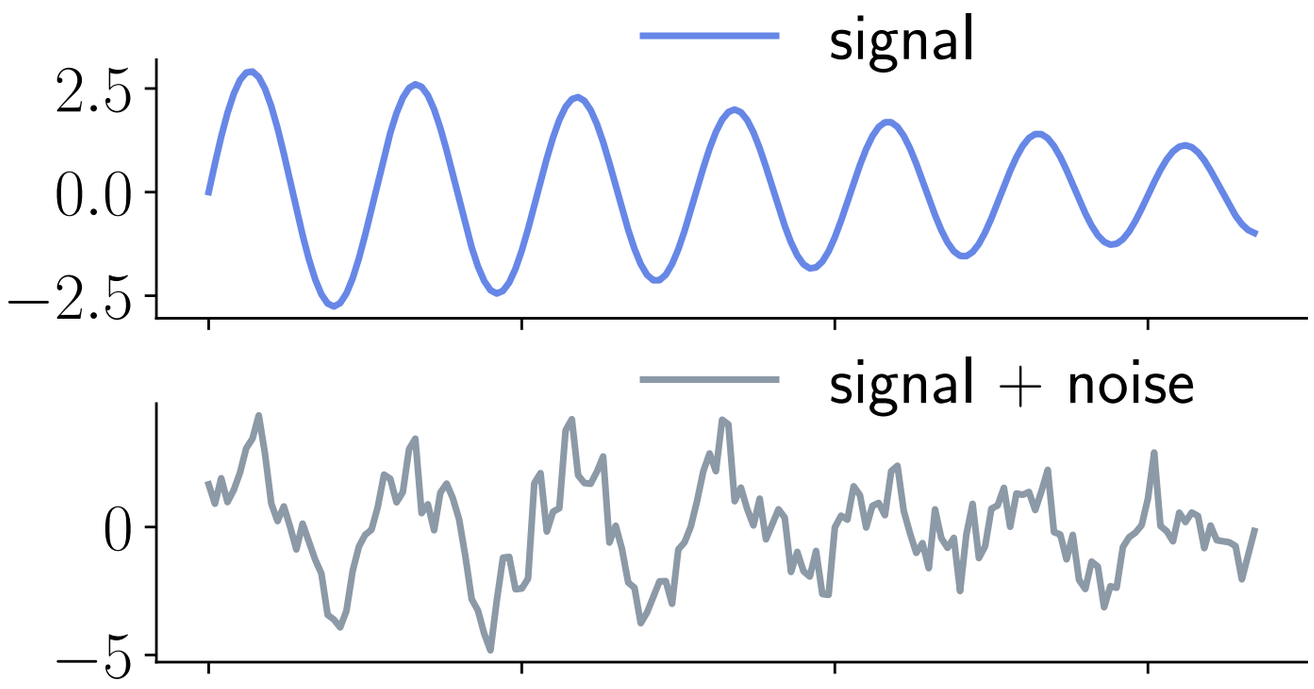

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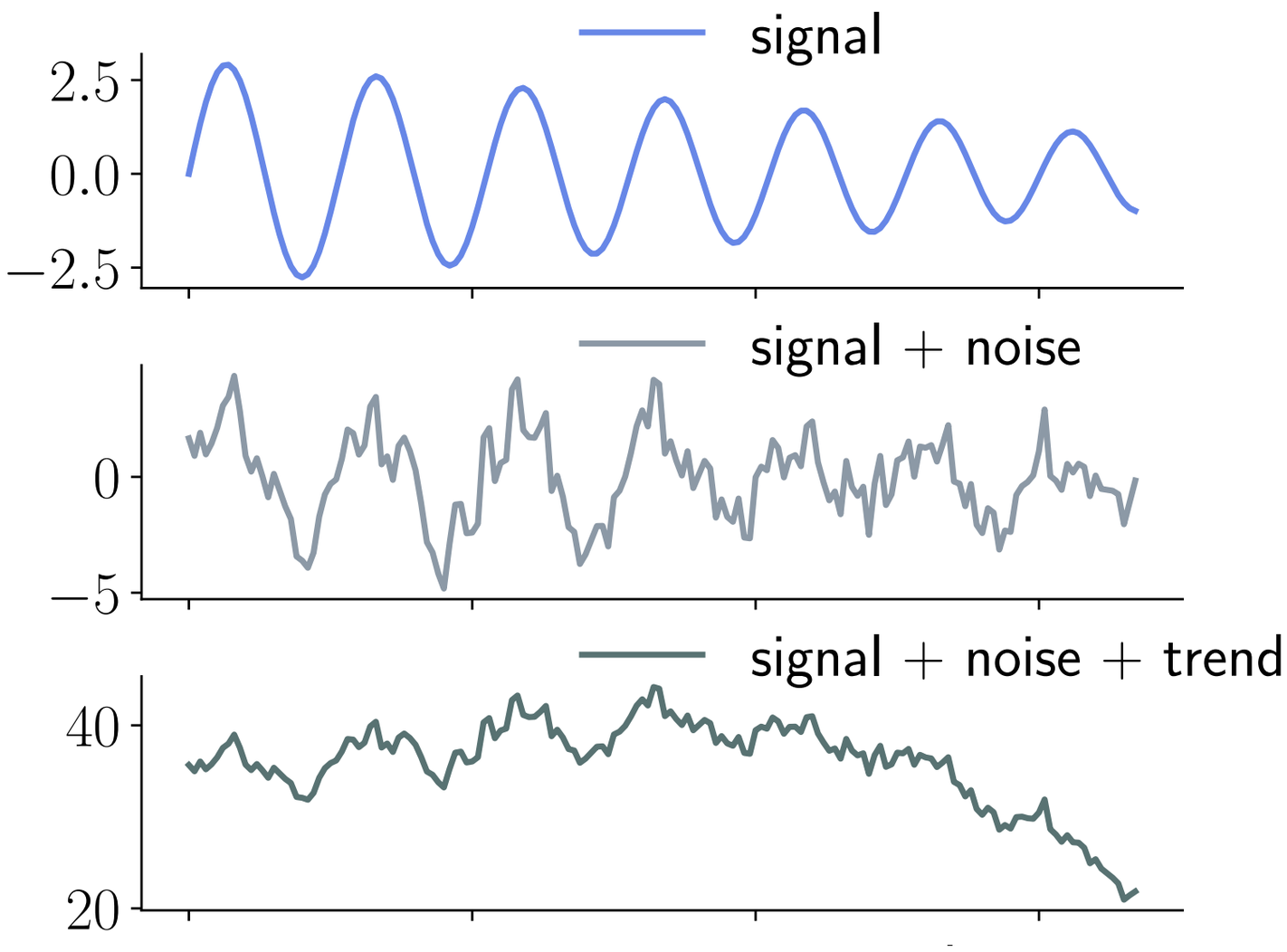

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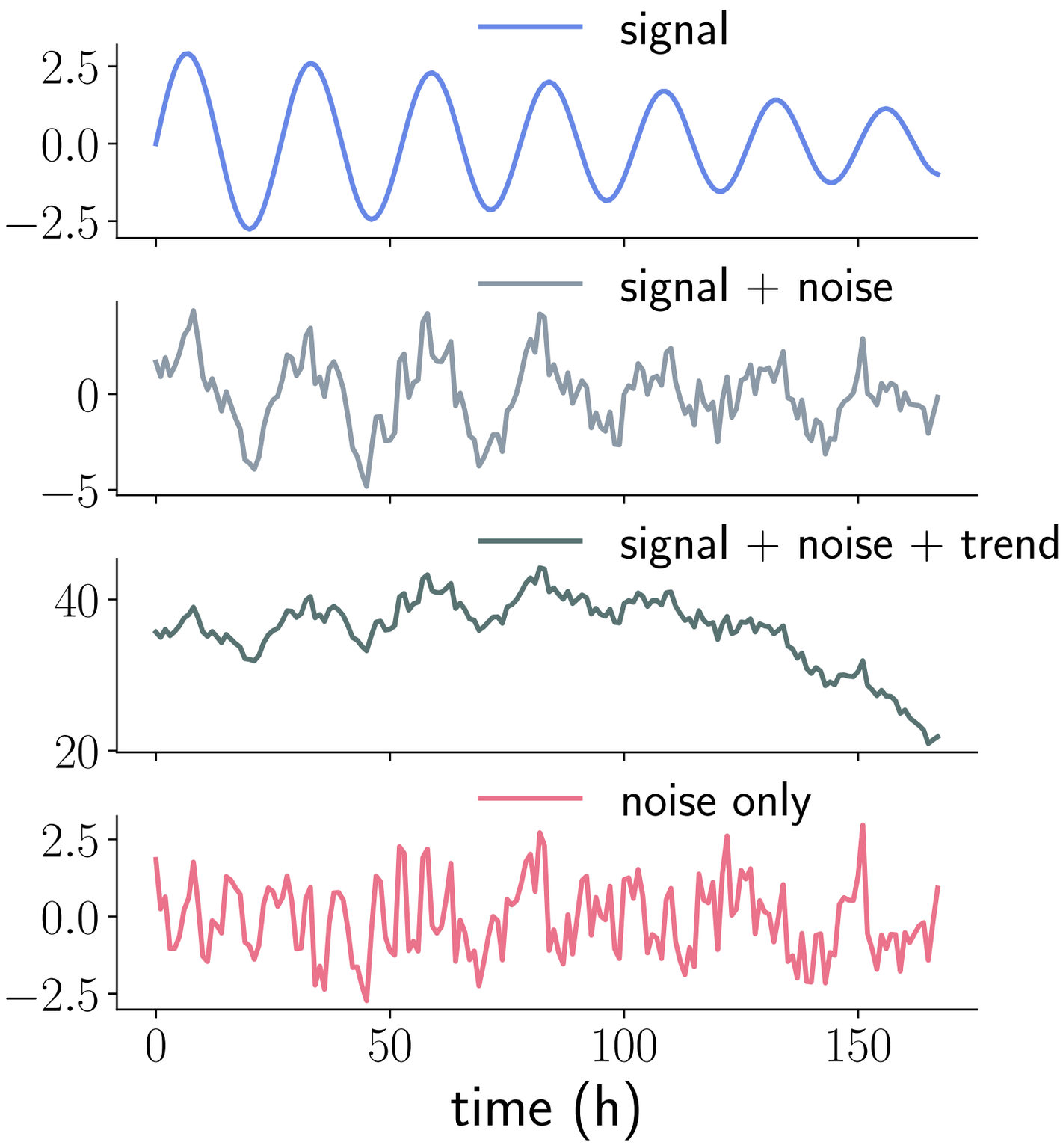
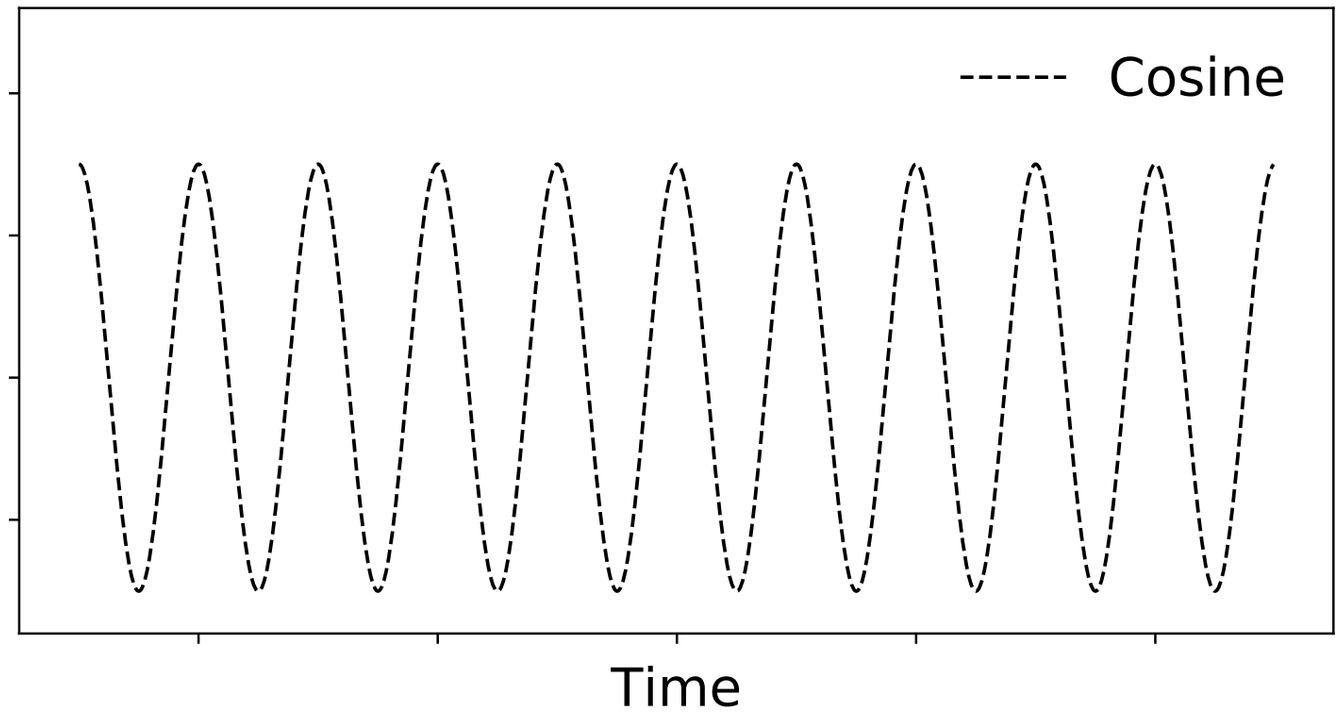


The Task:

- bias free estimation of period, phase and amplitude
- no spurious results

What are Wavelets?

- Fourier modes have no time localization



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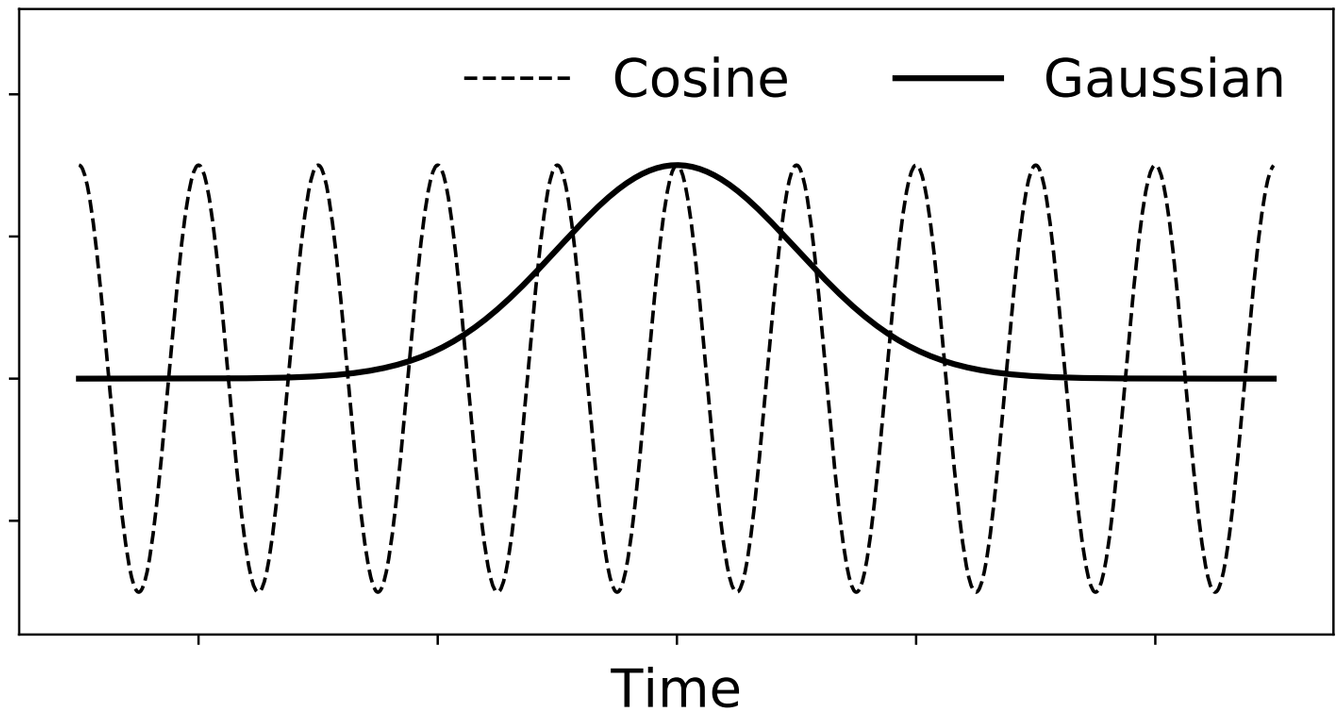
- Idea from Gabor 1947: Localize them with a Gaussian



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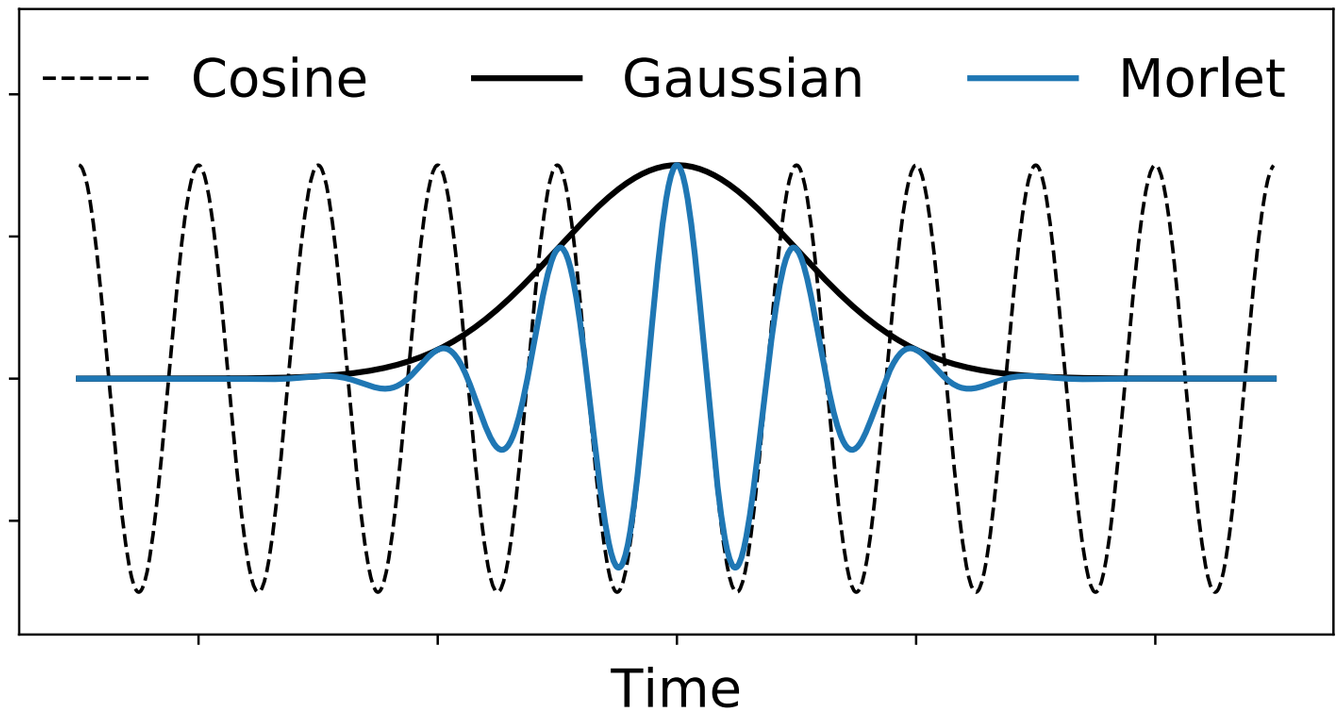

Morlet Mother Wavelet: $$\psi(t) = \pi^{1/4}\ e^{i\omega_0 t}\ e^{-\frac{1}{2}t^2}$$

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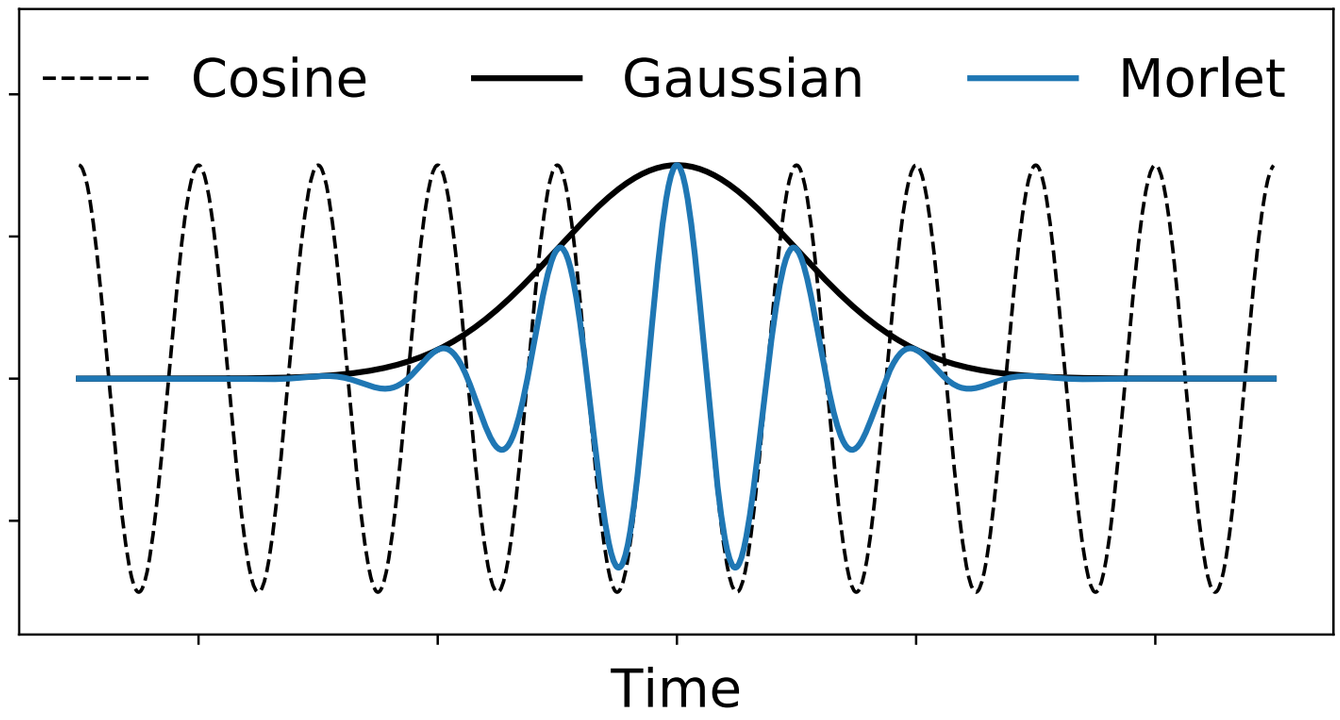

Morlet Mother Wavelet: $\psi(t) = \pi^{1/4} \left[cos(\omega_0 t) + isin(\omega_0 t)\right] e^{-\frac{1}{2}t^2}$

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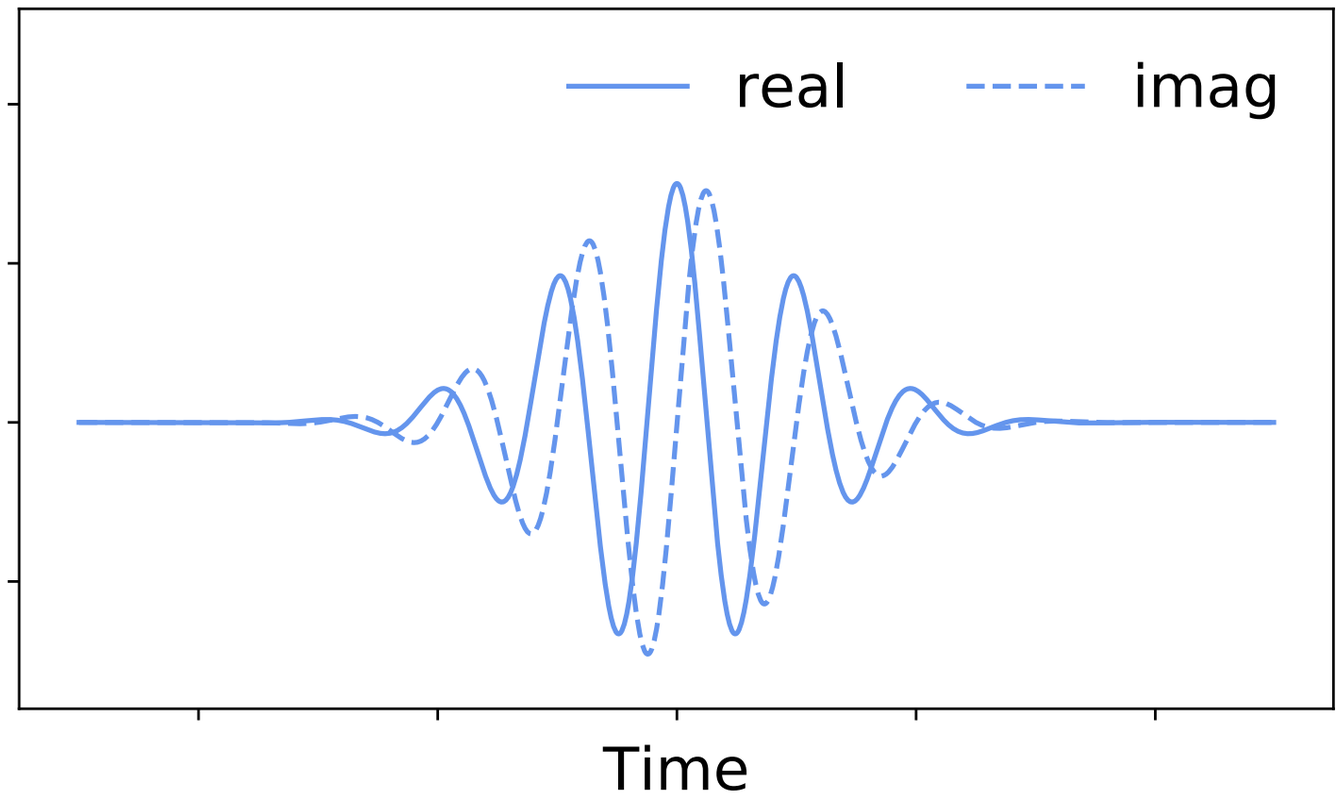
Complex Function!



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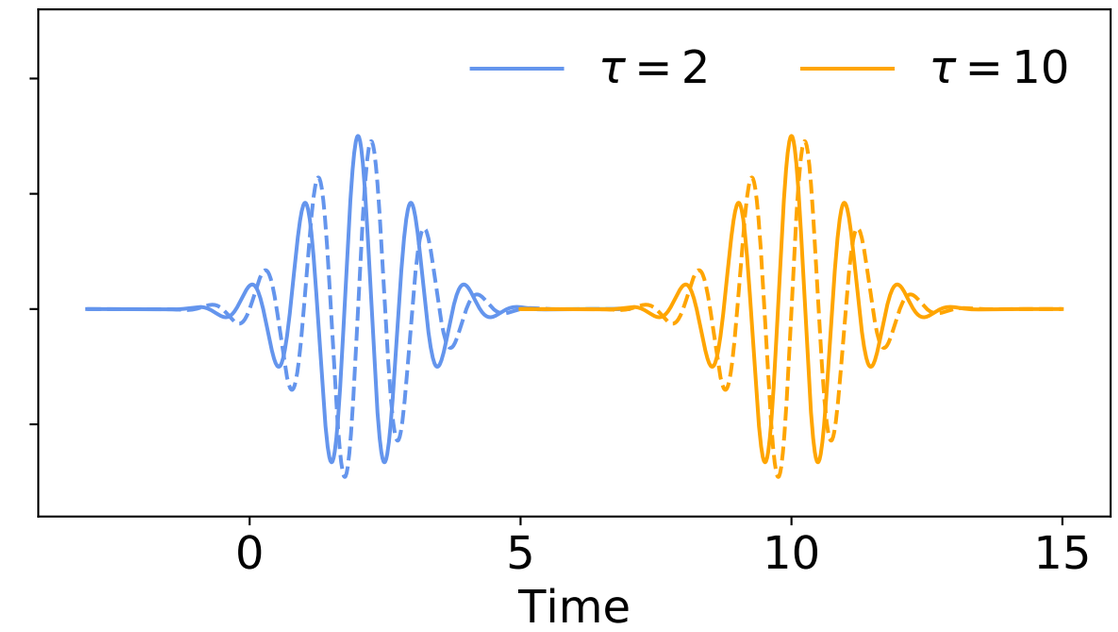
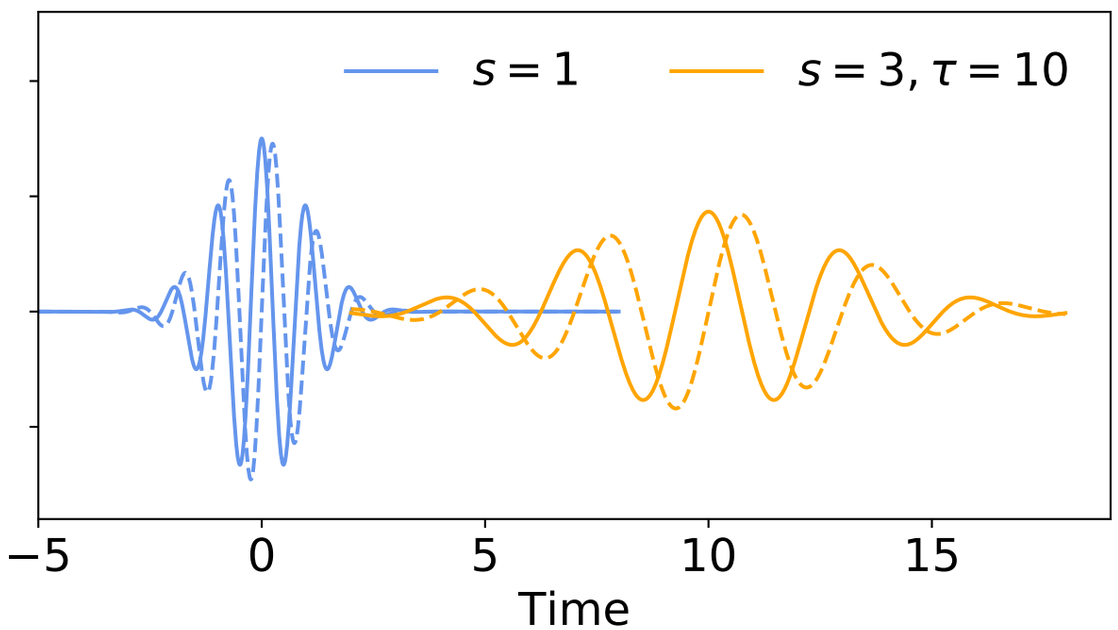
Translation and Dilation: We have a Family!

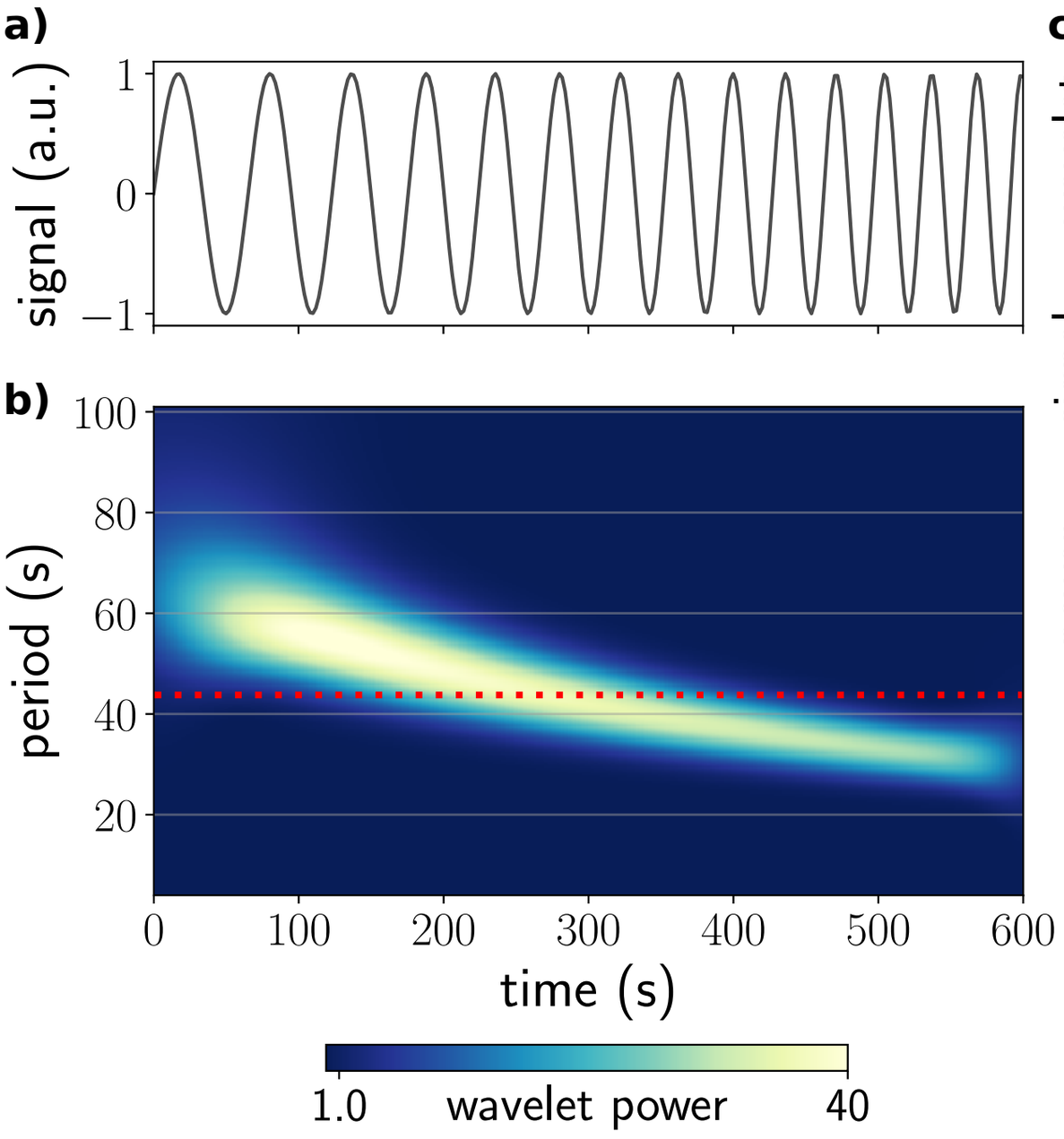
Shift in time: Translation

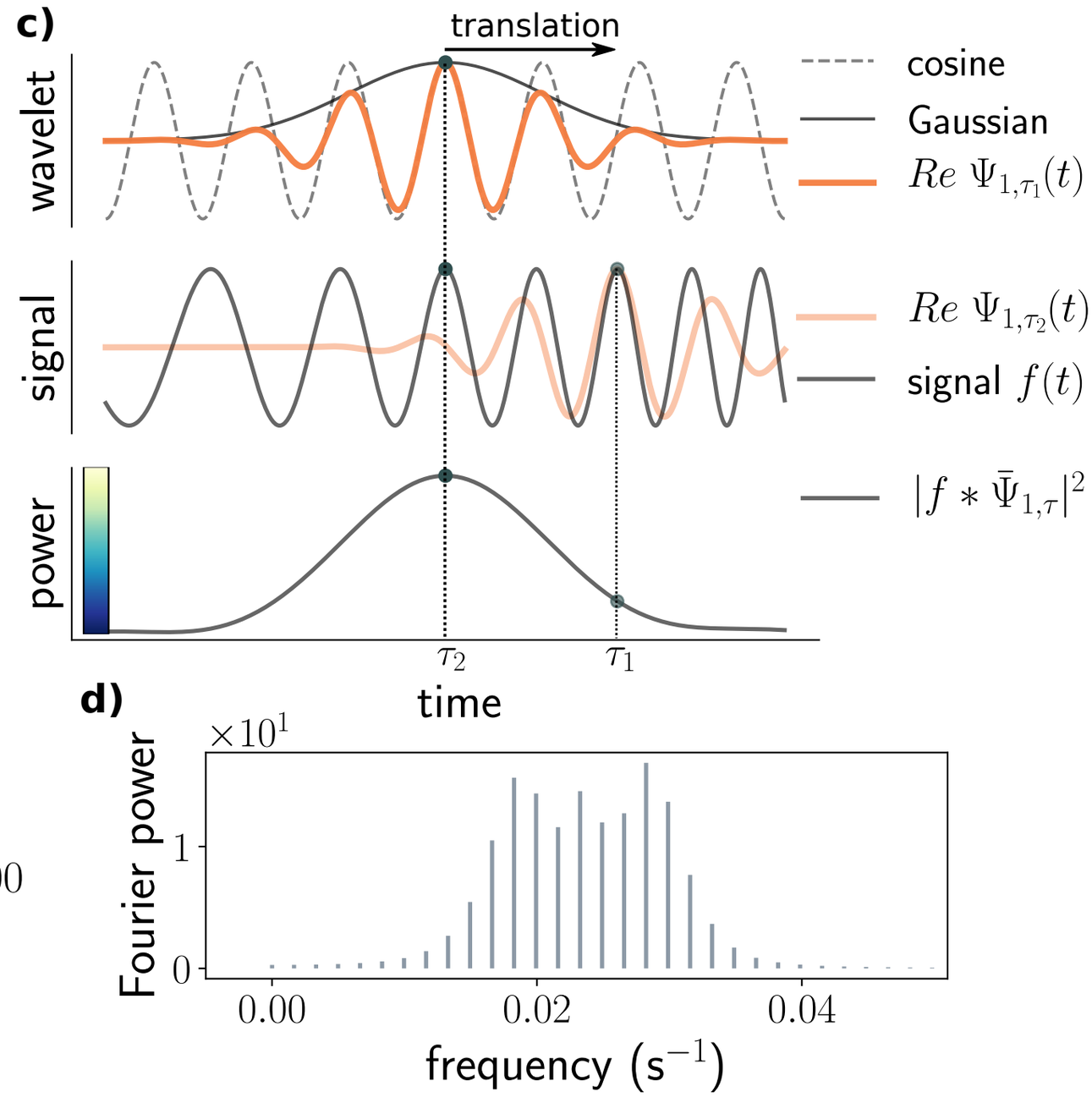


Change of wavelength: Dilation

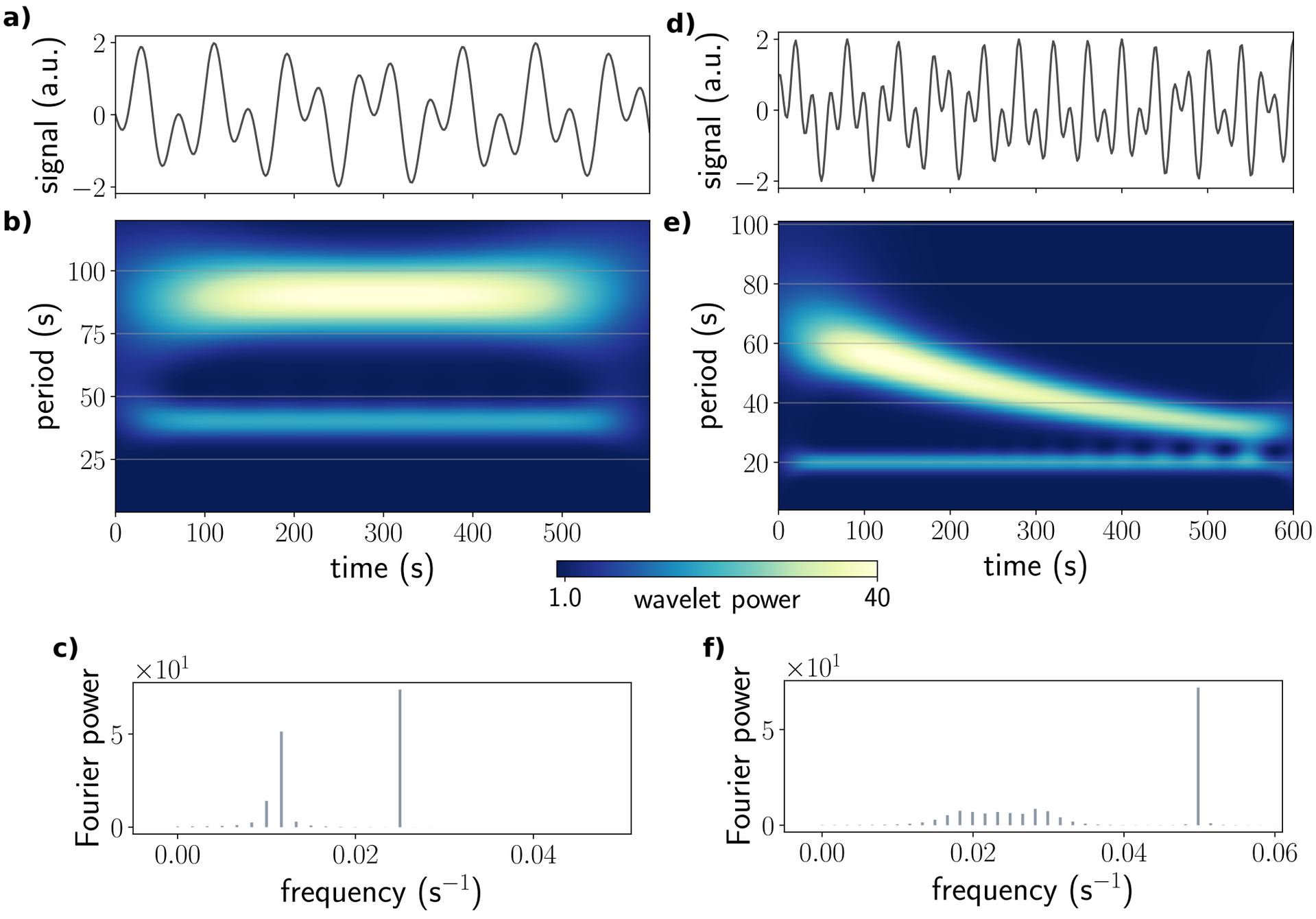


Wavelet Analysis and Power Spectrum



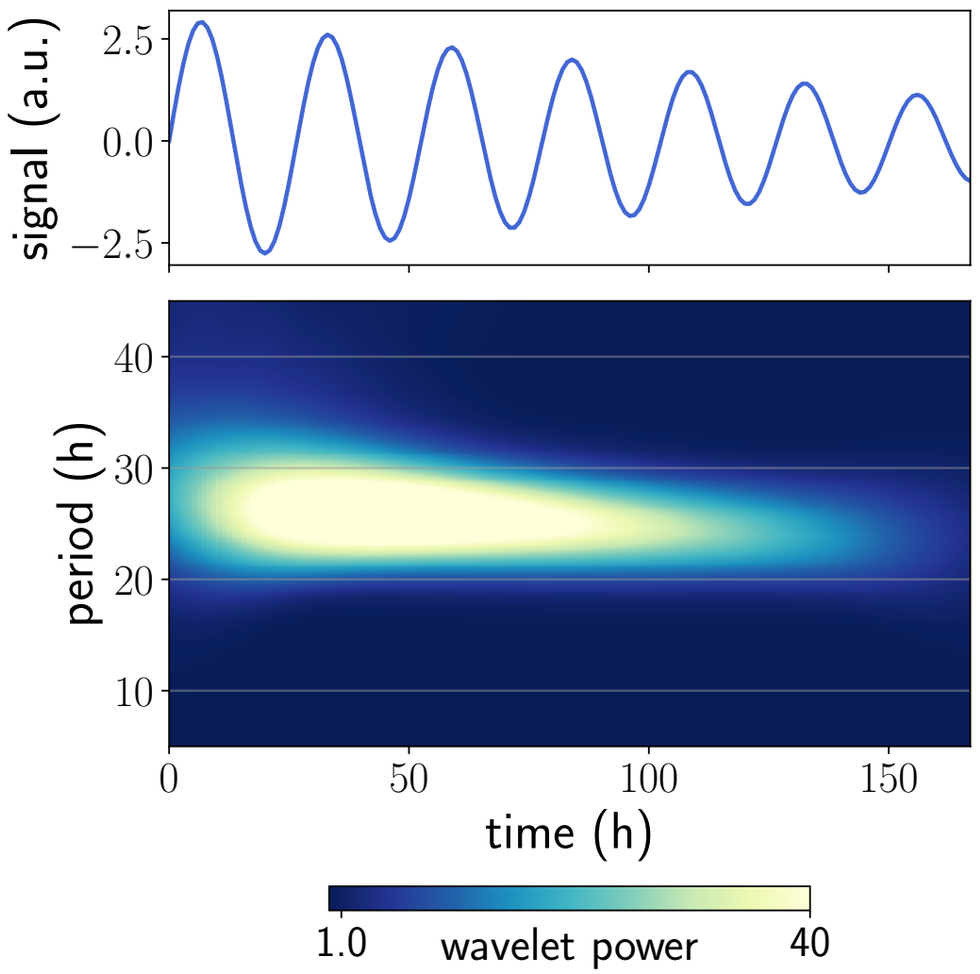


Asymptotic Wavelet Spectrum



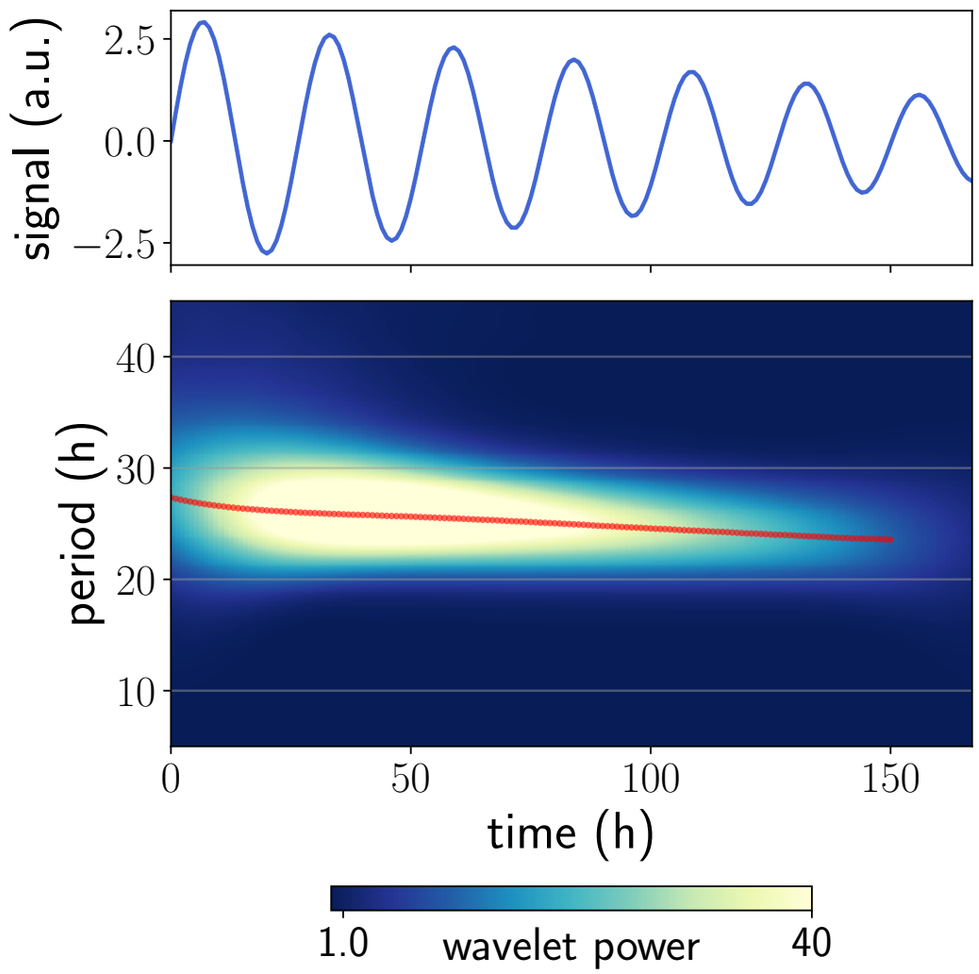
Time averaged Wavelet Spectrum is (optimal) estimate for the Fourier Spectrum!

Ridge Extraction

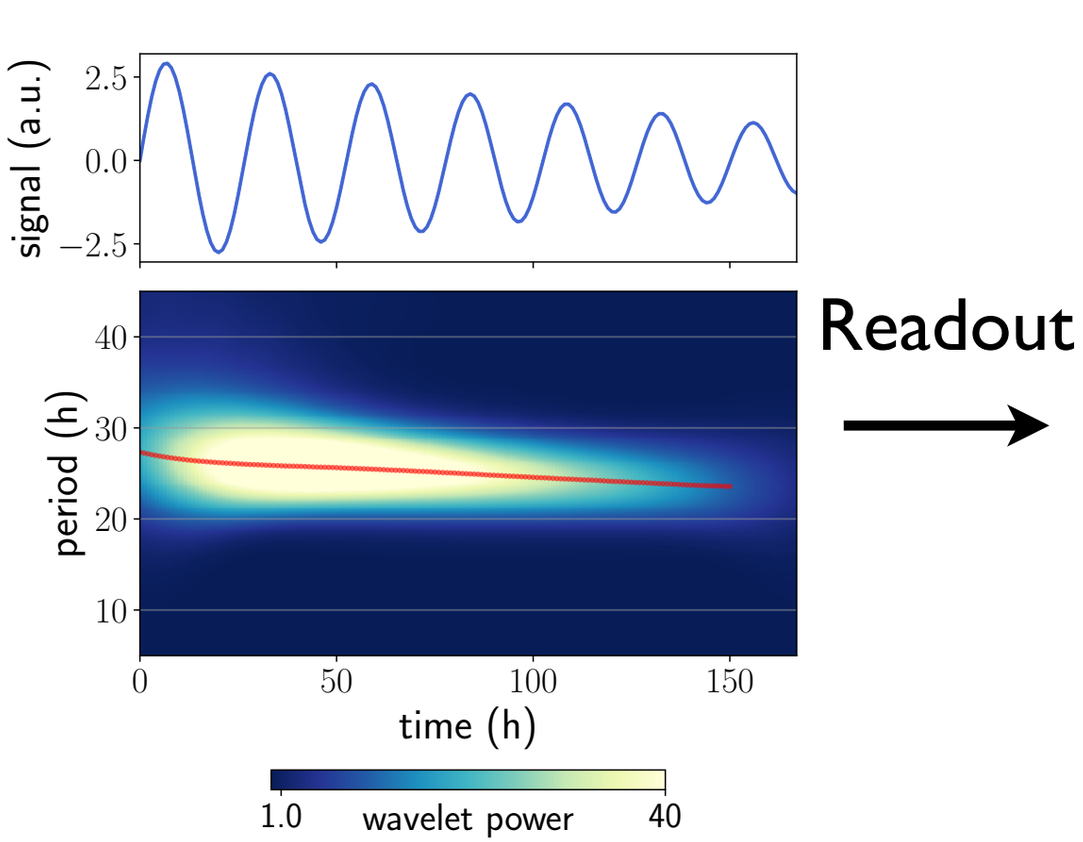


Trace Power Maxima

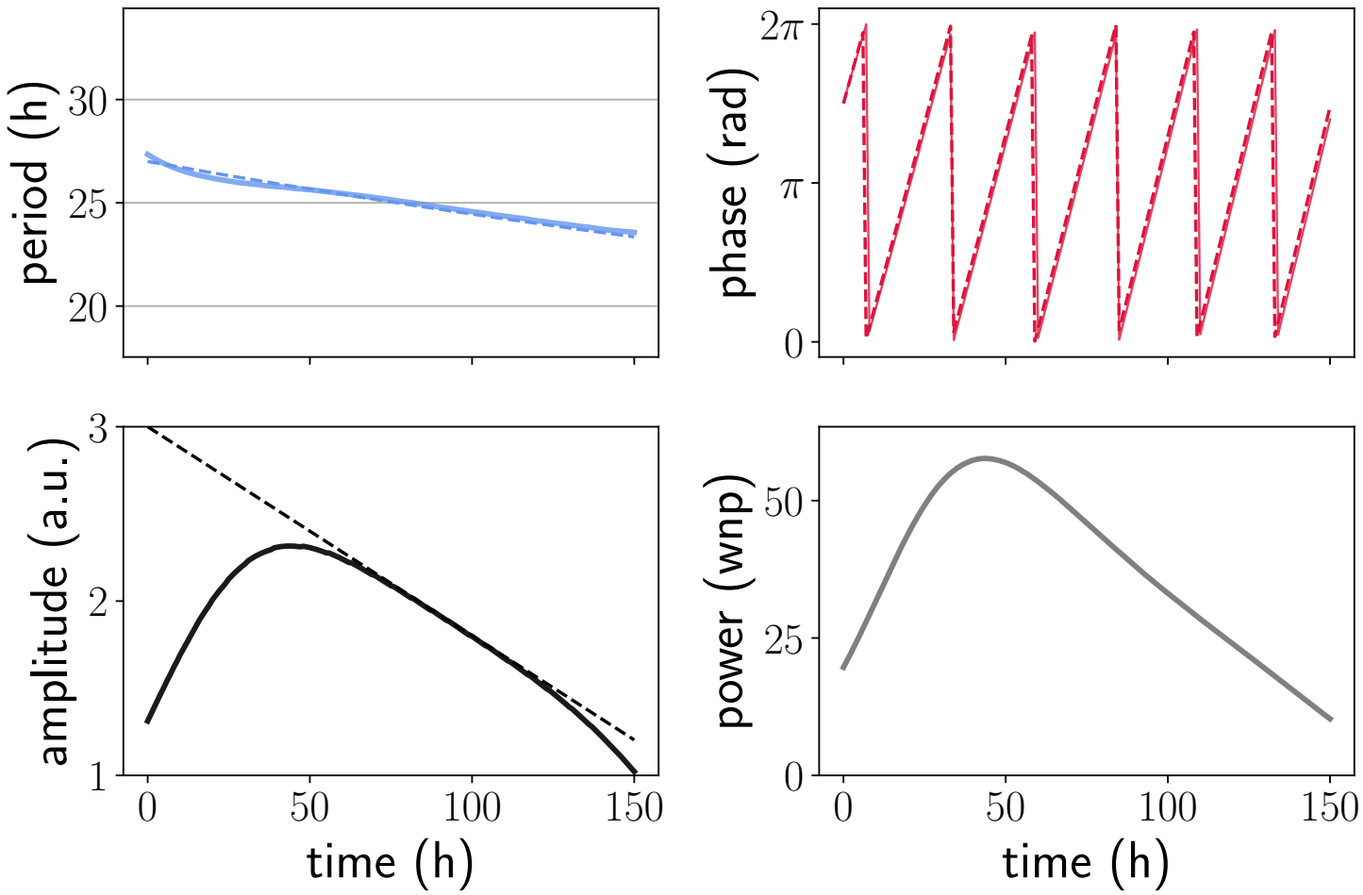
Threshold



Ridge Evaluation



Readout



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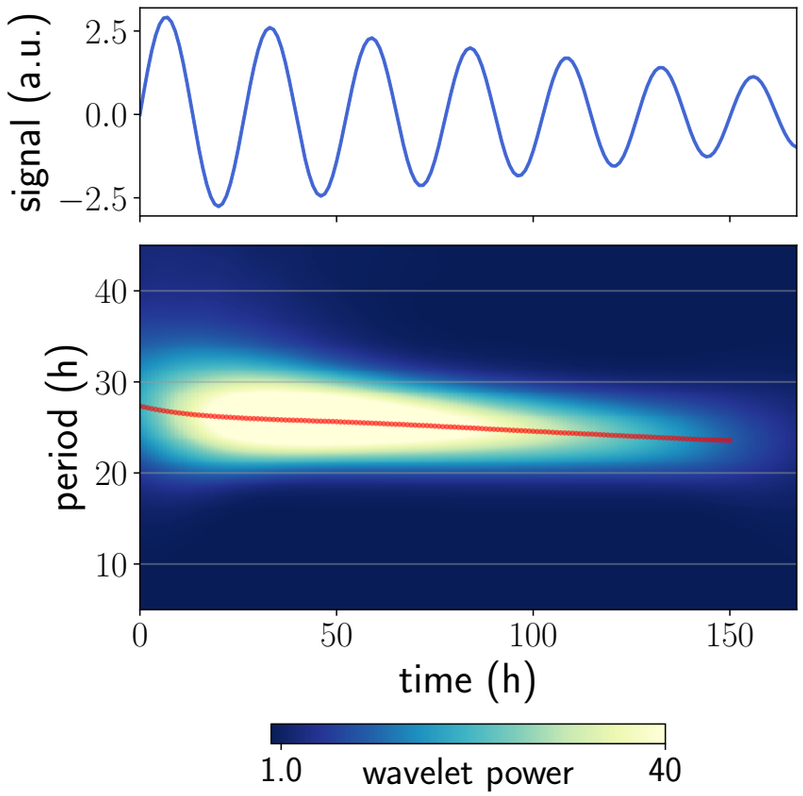

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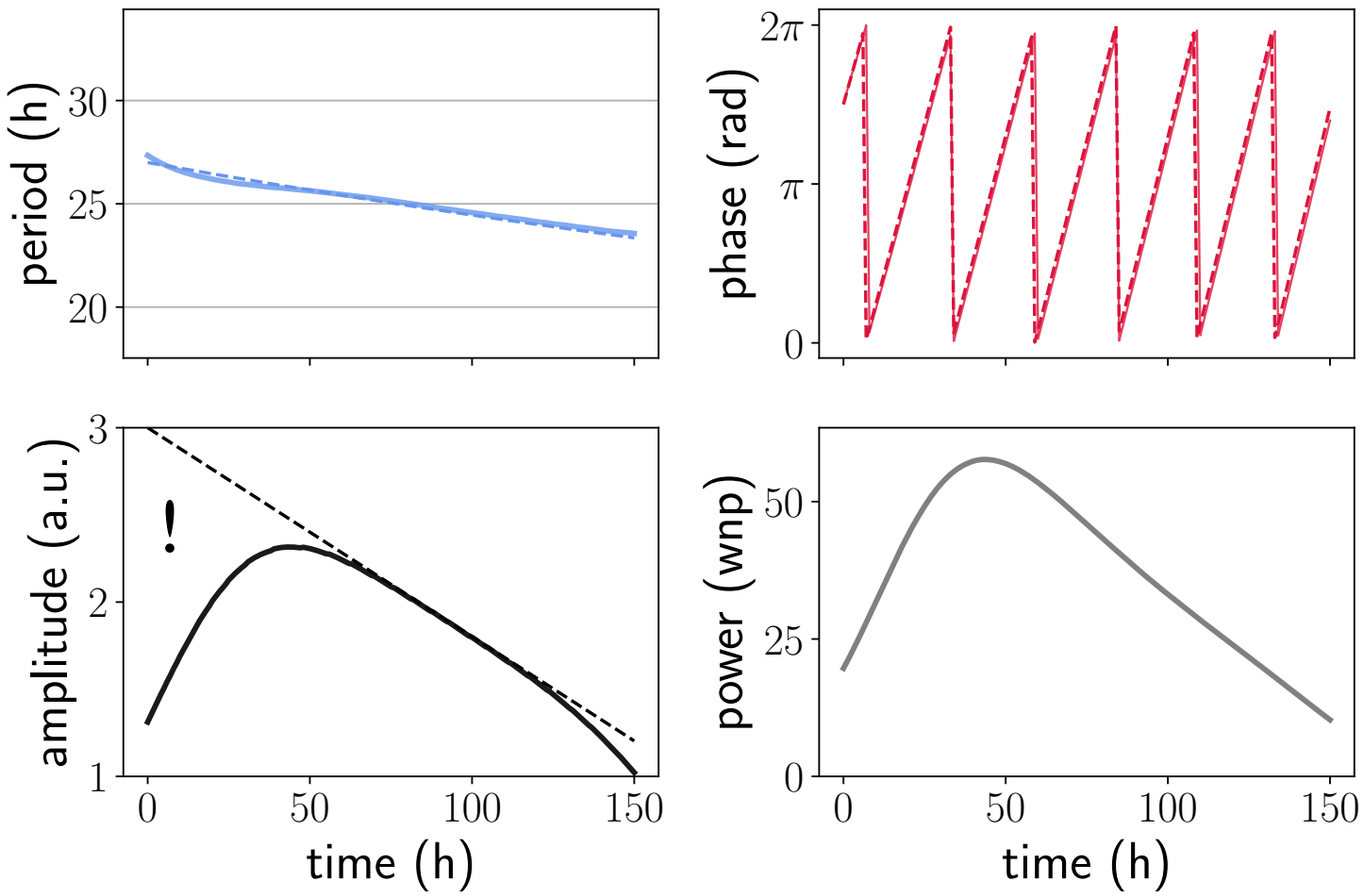
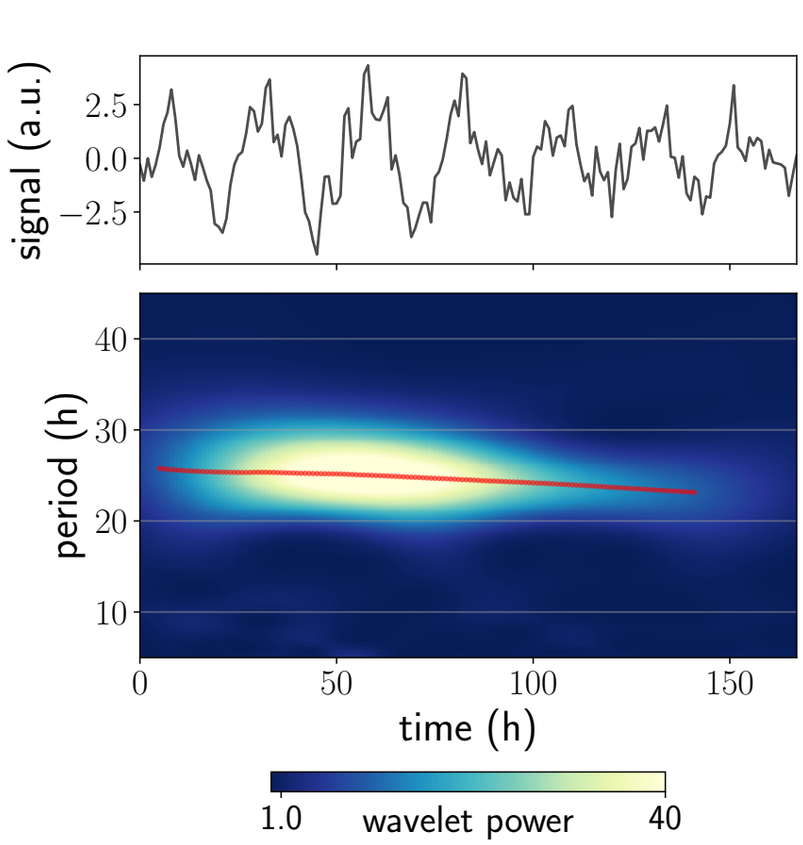
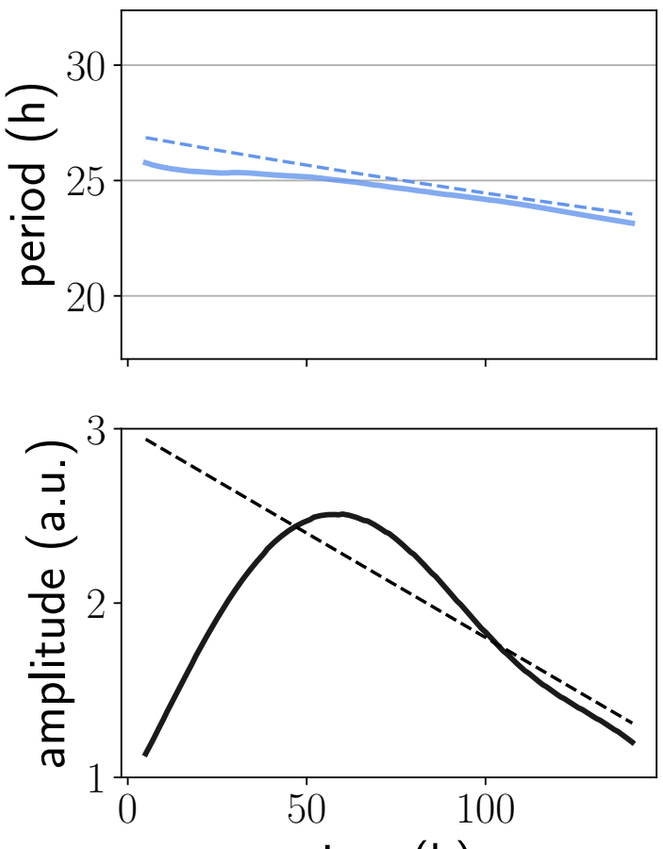


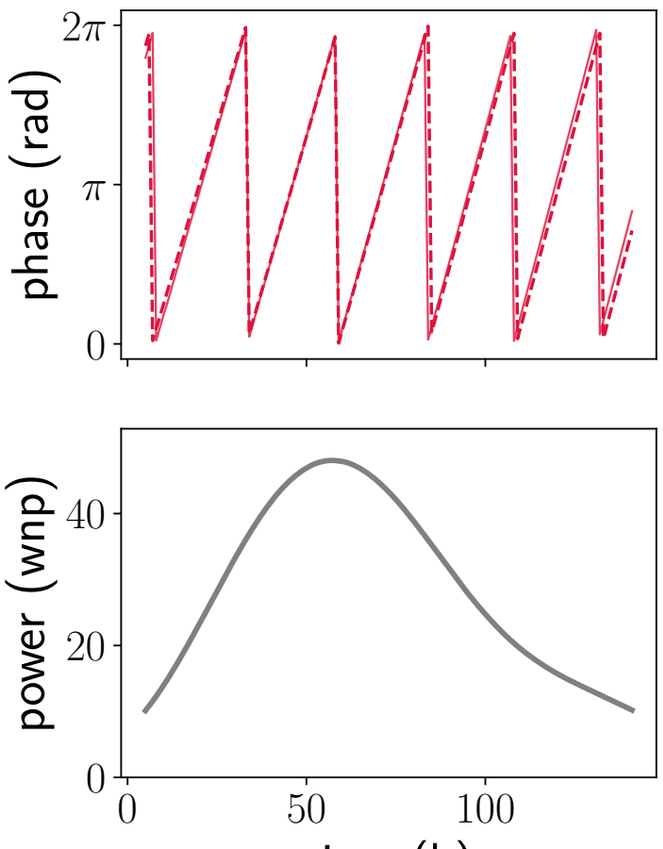
Edge effects of convolutions most prominent for amplitude estimation

Noise Robustness



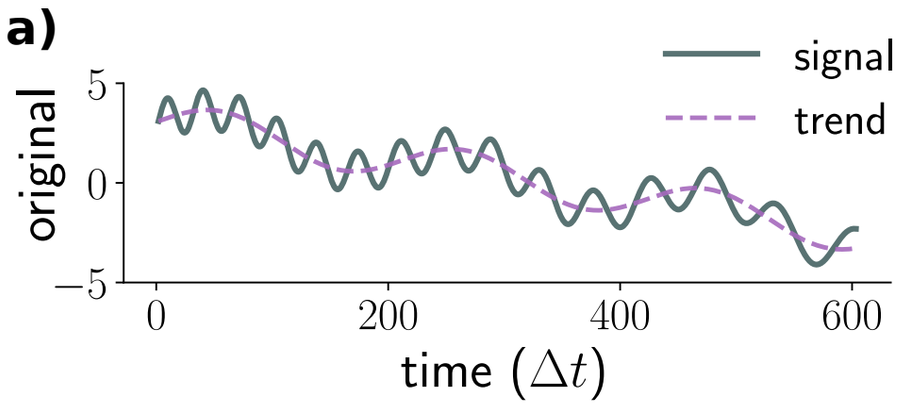
Readout

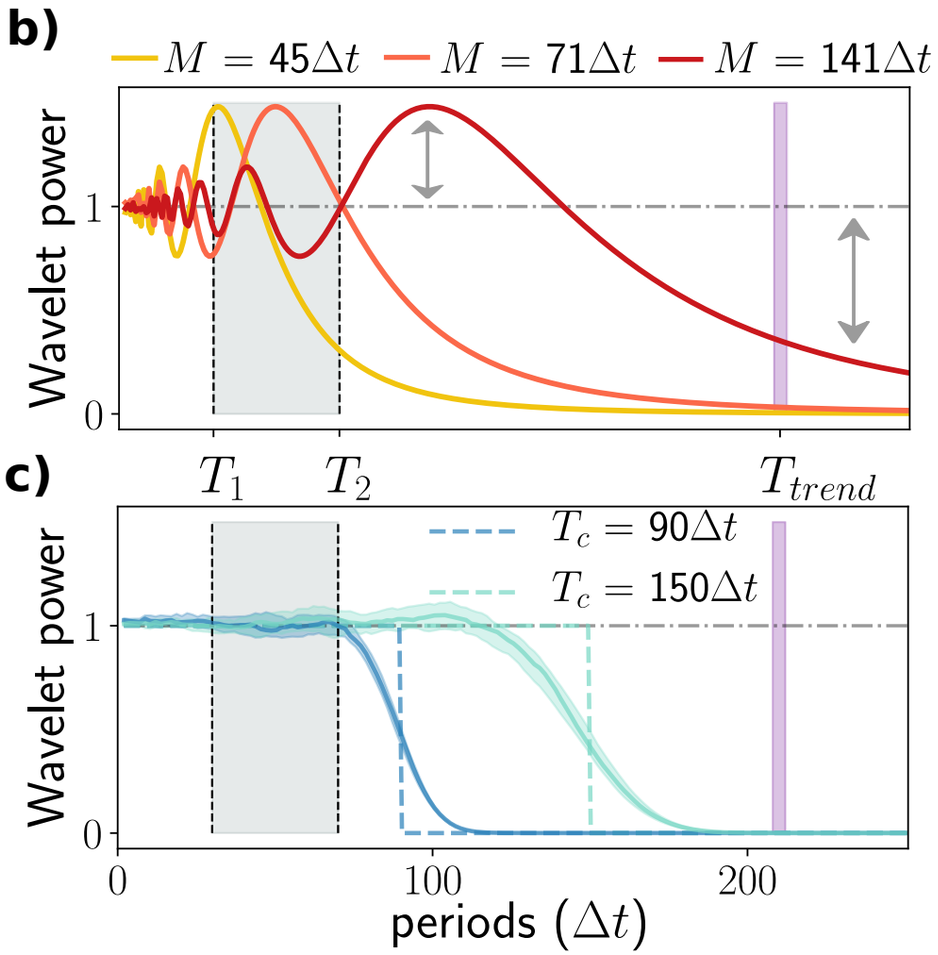


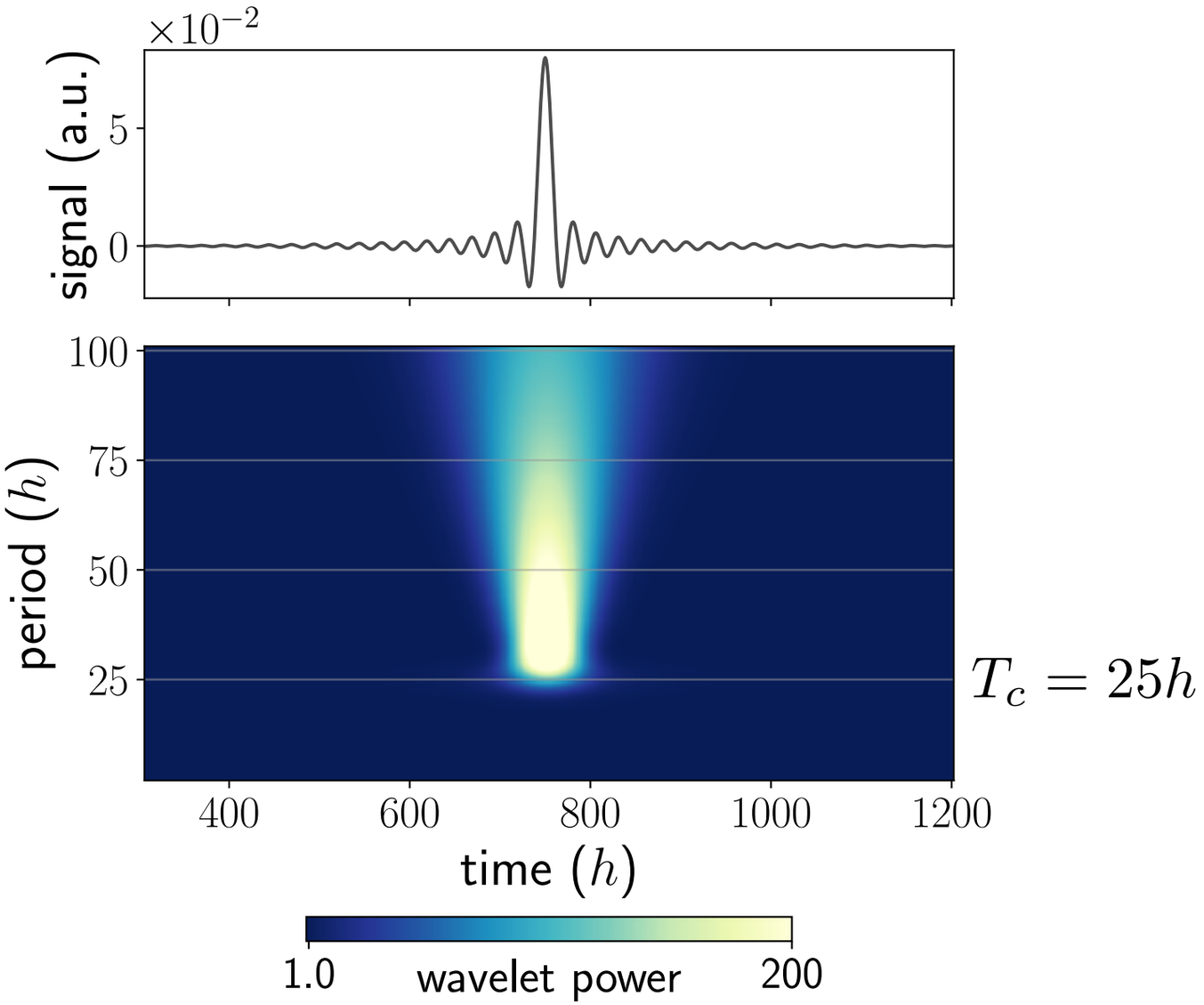


Wavelet analysis has a built-in noise robustness!

Detrending with optimal Sinc Filter



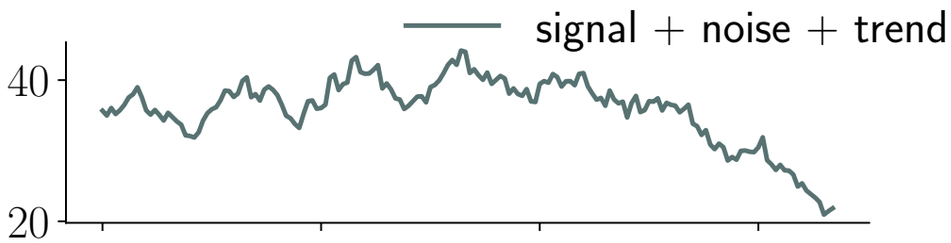


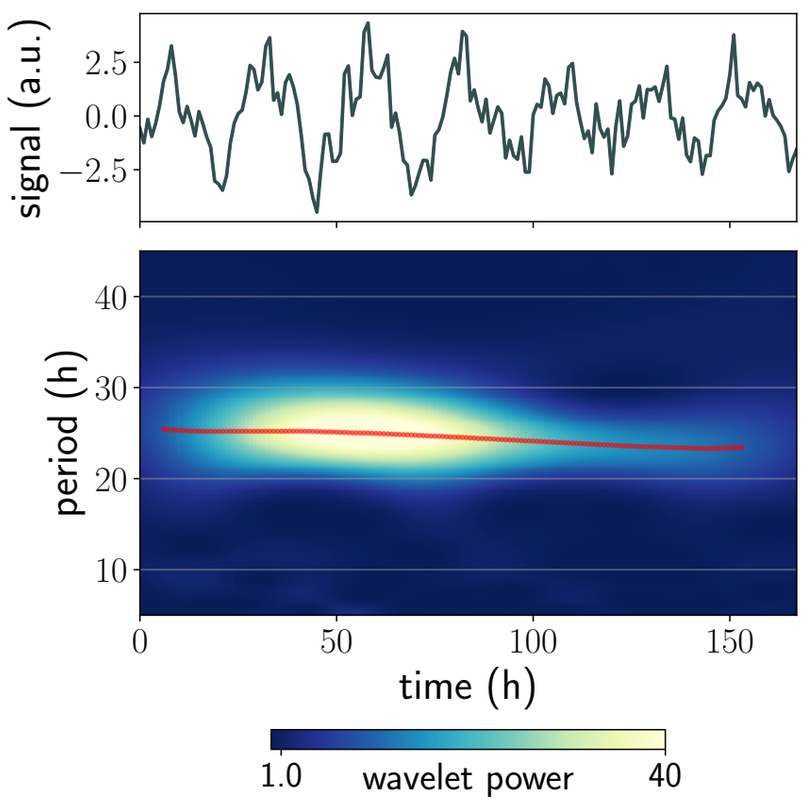


Cut-off period divides
pass- and stopband of the filter
without amplification or attenuation

$$1.5\,T_c \geq T_{max}$$

Noise + Trend





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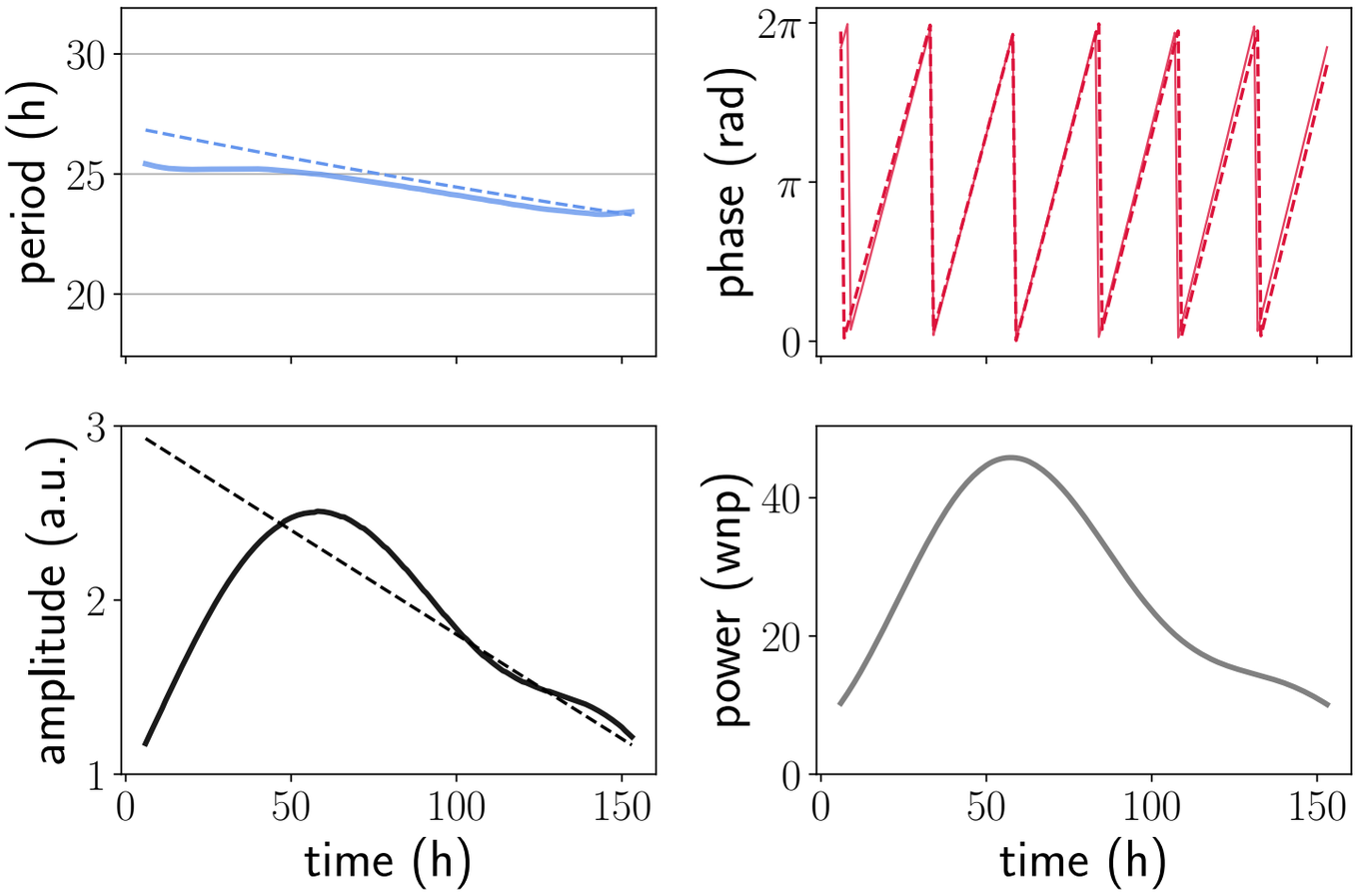
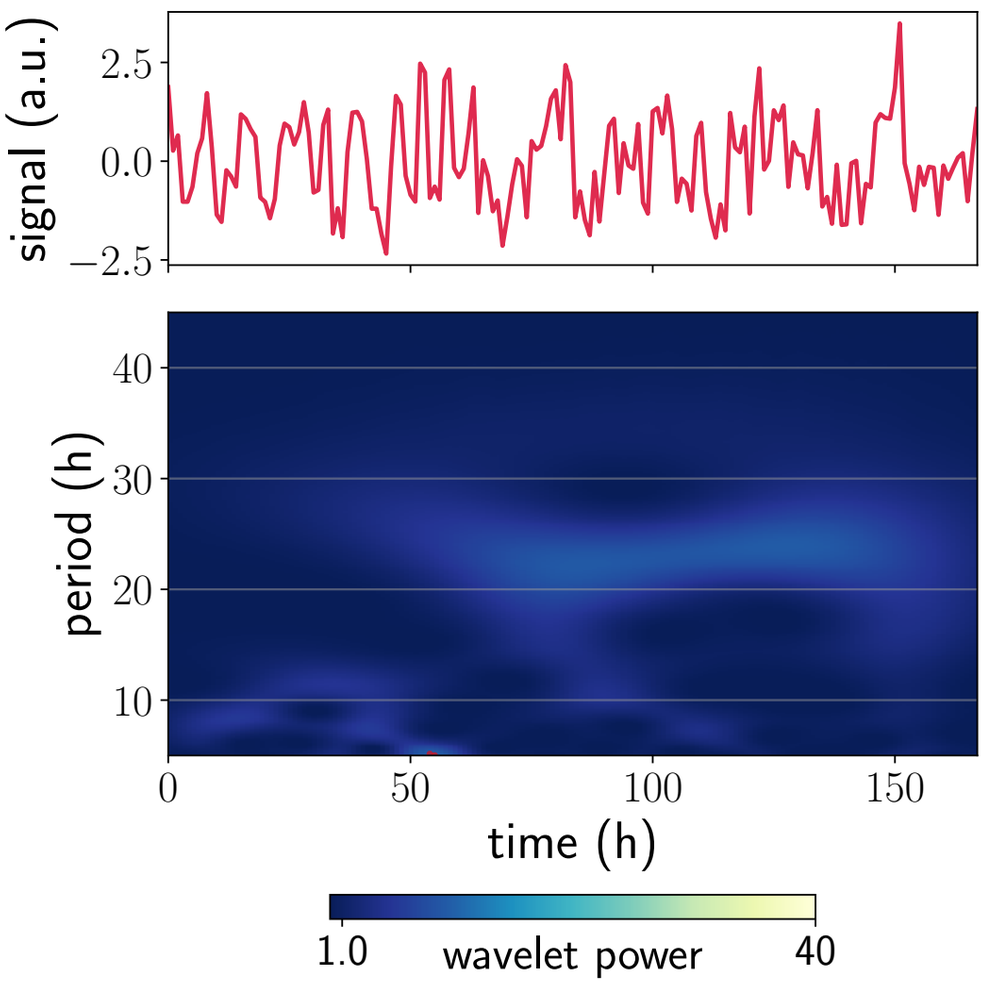


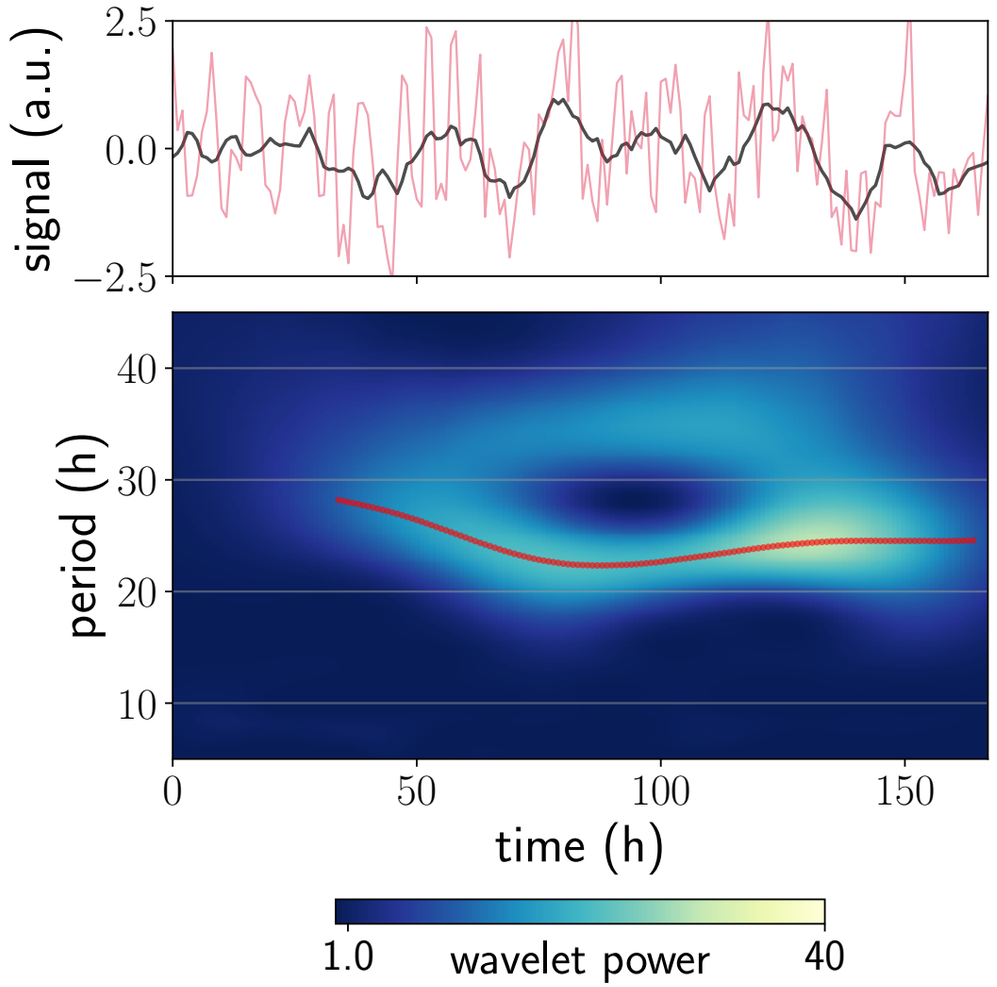
Detrending is practically perfect here

Smoothing Noise

unfiltered

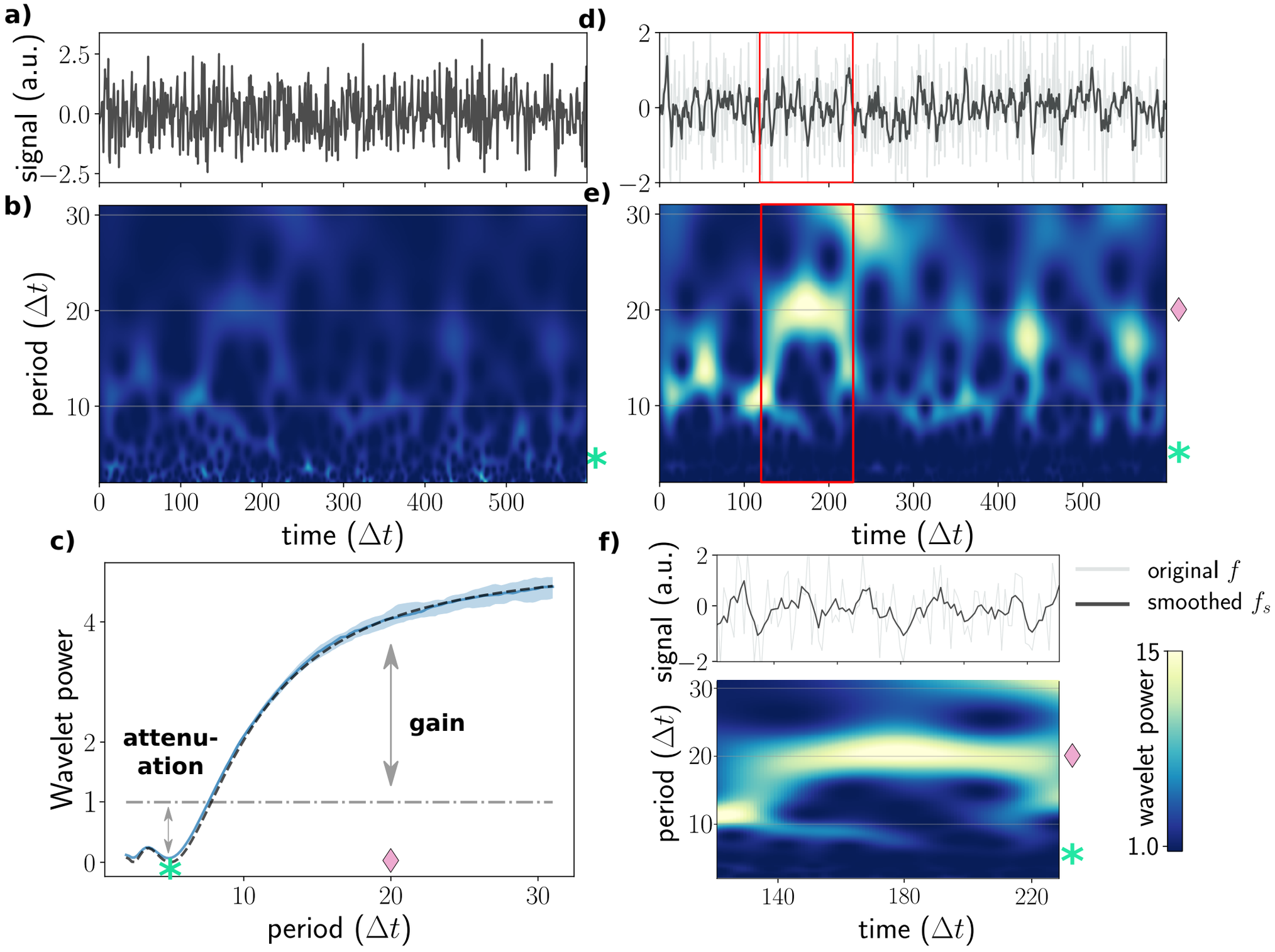


smoothed

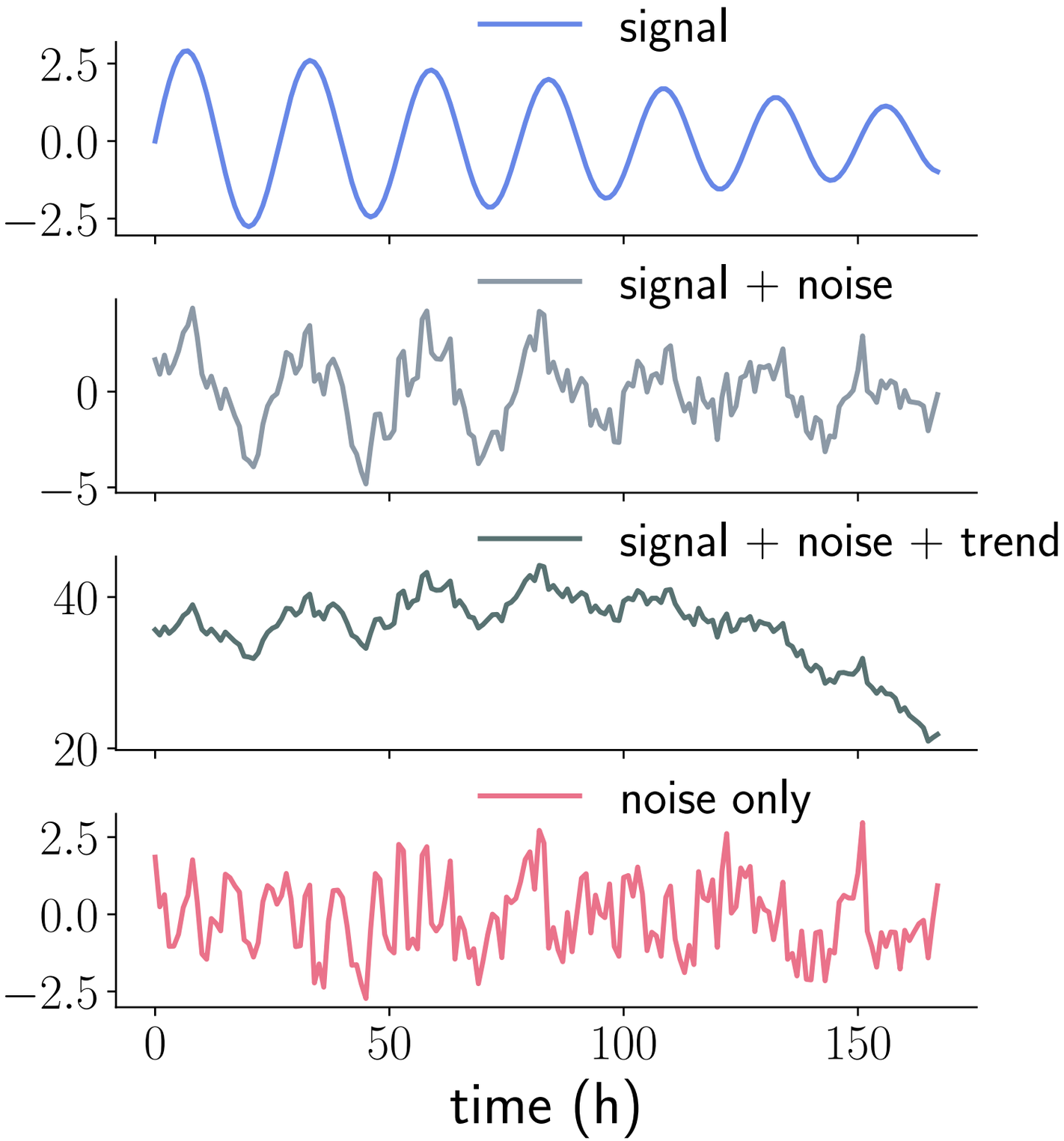


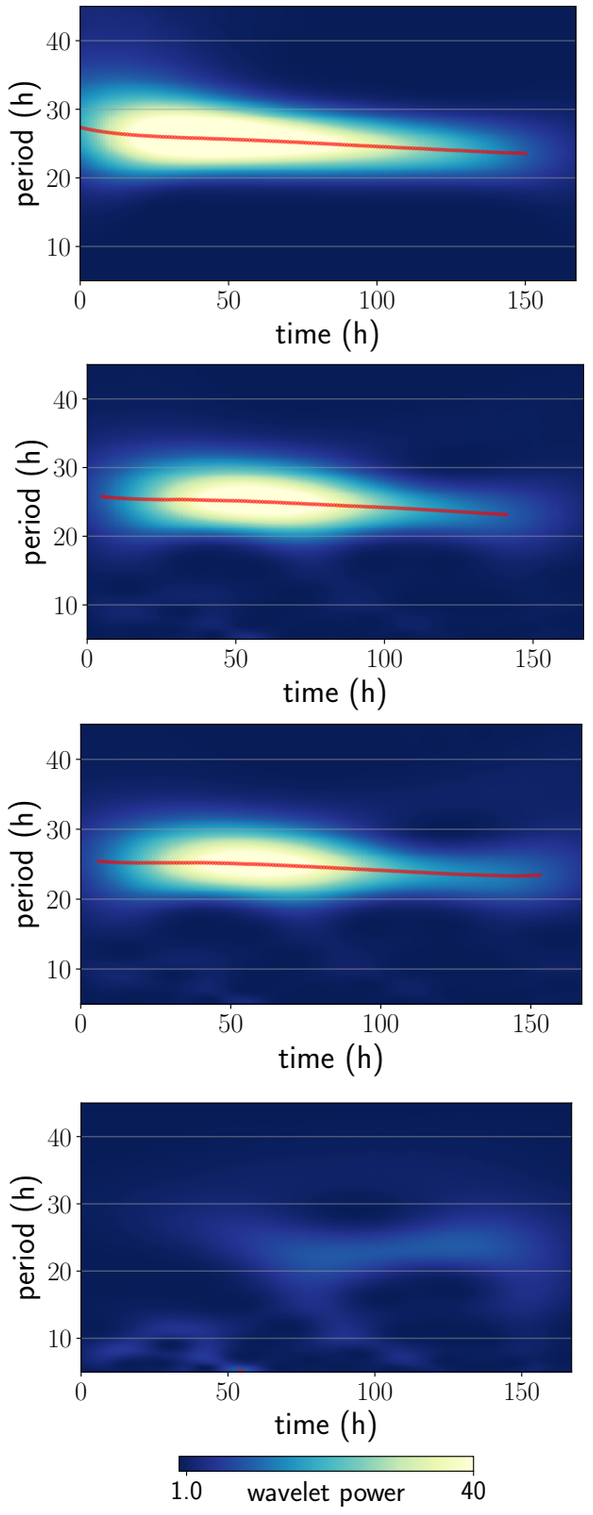
Wavelet analysis has a built-in
noise robustness: smoothing is not needed!

Smoothing Noise



Wrapping up Time Series analysis





pyBOAT

README.md

pyBOAT - A Biological Oscillations Analysis Toolkit

Current Version	Conda Downloads
conda-forge v0.8.22	downloads 9.6k

Tools for time-frequency analysis of noisy time series. The accompanying manuscript "Optimal time frequency analysis for biological data - pyBOAT" can be found here. Questions, comments etc. please to gregor.moenke@embl.de.

Features

- Optimal sinc filter
- Fourier analysis
- Wavelet analysis
- Ridge detection
- Phase extraction
- Amplitude estimation
- Synthetic signal generator

Optimal time frequency analysis for biological data - pyBOAT

Gregor Mönke, Frieda A. Sorgenfrei, Christoph Schmal, Adrián E. Granada
doi: https://doi.org/10.1101/2020.04.29.067744

https://www.biorxiv.org/content/10.1101/2020.04.29.067744v3

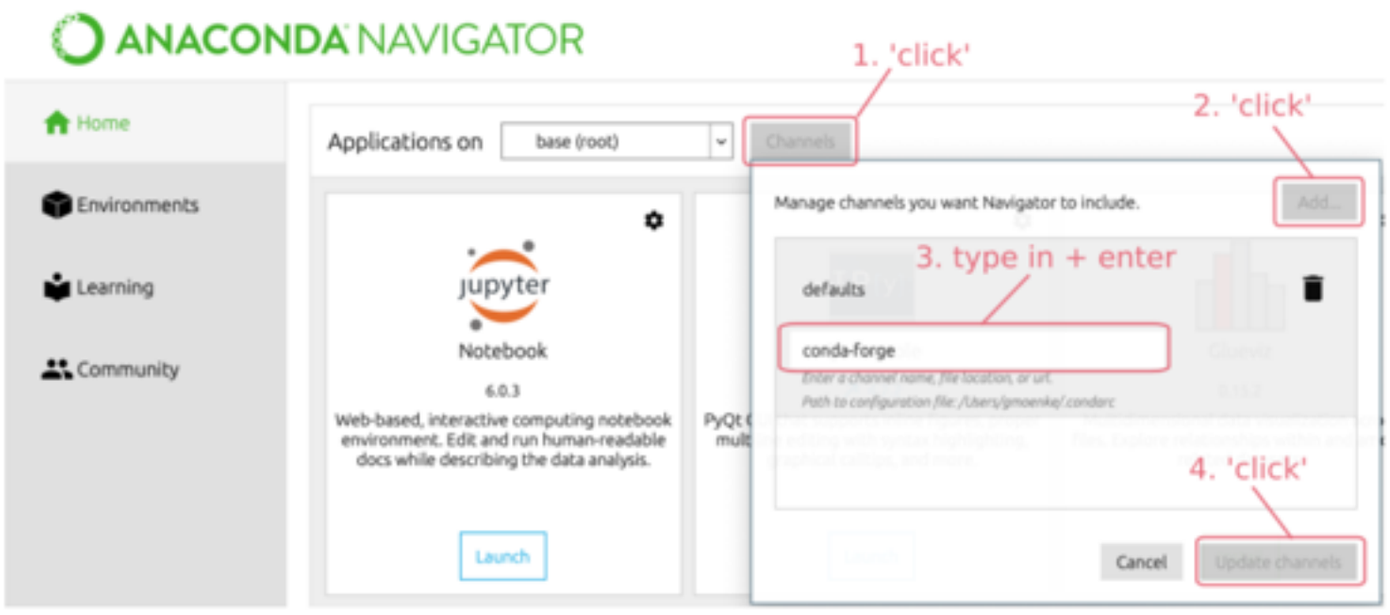
https://github.com/tensionhead/pyBOAT

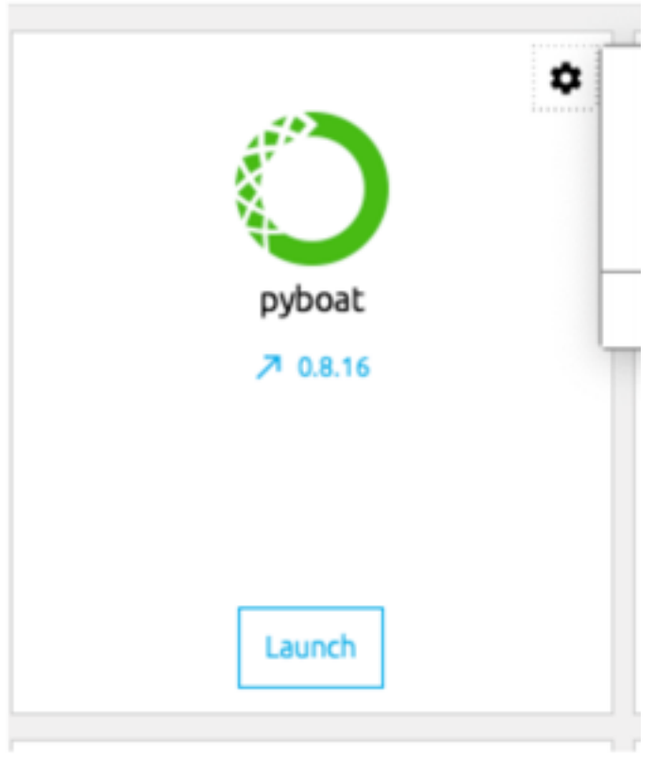
pyBOAT

Installation with Anaconda Navigator

pyBOAT is written in Python and therefore requires Python to be present on the system. An easy way to install a cross-platform scientfic Python environment is to use the freely availabe Anaconda Distribution. Installation instructions can be found here: https://docs.anaconda.com/anaconda/install/, a Python 3.x version is needed.

Once the Anaconda installation is complete, starting up the `Anaconda Navigator` will show an interface like this:





- ‘click installable’ PyQT GUI - Navigator App (no commandline needed)
- Python package ‘import pyboat’ - OOP API

https://github.com/tensionhead/pyBOAT

Spatial pyBOAT - SpyBOAT

SpyBOAT - Spatial pyBOAT

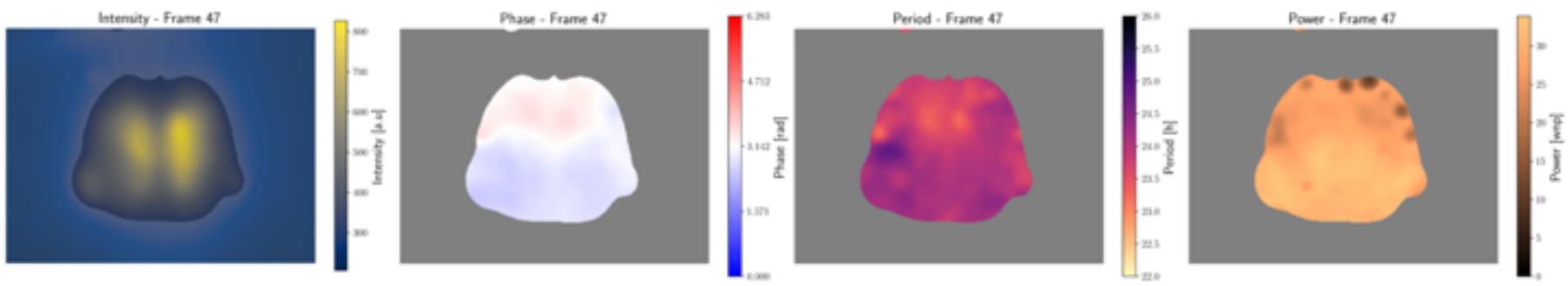
conda-forge v0.1.1 usegalaxy .eu

Small pipeline to wavelet analyze spatially extended oscillatory systems, represented as 3D-Image Stacks (time,Y,X). The analyis is based on the tools provided by pyBOAT. The supplied input movie gets analyzed pixel by pixel along the time axis, yielding up to four output movies:

- phase movie
- period movie
- amplitude movie
- power movie

A snapshot of a typical output of the pipeline might look like this:

Example data graciously provided by Jihwan Myung, GIMBC Taipei Medical University



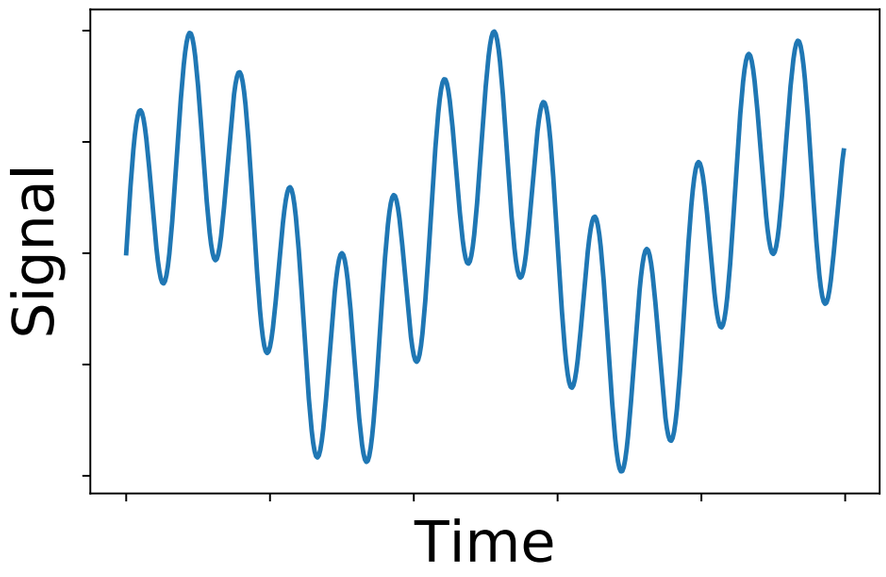
From left to right: Intensity of the blurred and down-sampled input; Phases; Periods and Powers

- Galaxy web UI
- Python package ‘import spyboat’

https://github.com/tensionhead/SpyBOAT

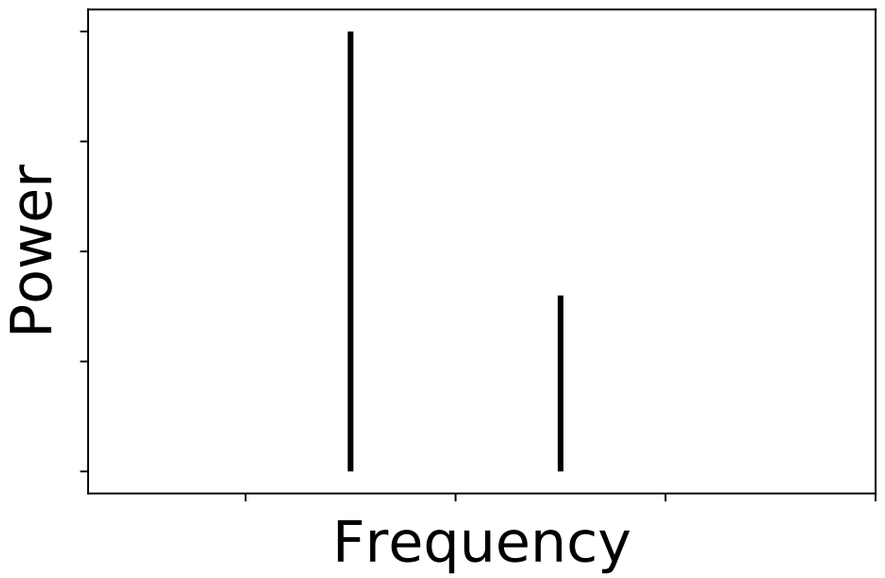
Recap: Frequency Analysis with Fourier

Time domain



$\mathcal{F}: \ t \rightarrow \omega$

Frequency domain



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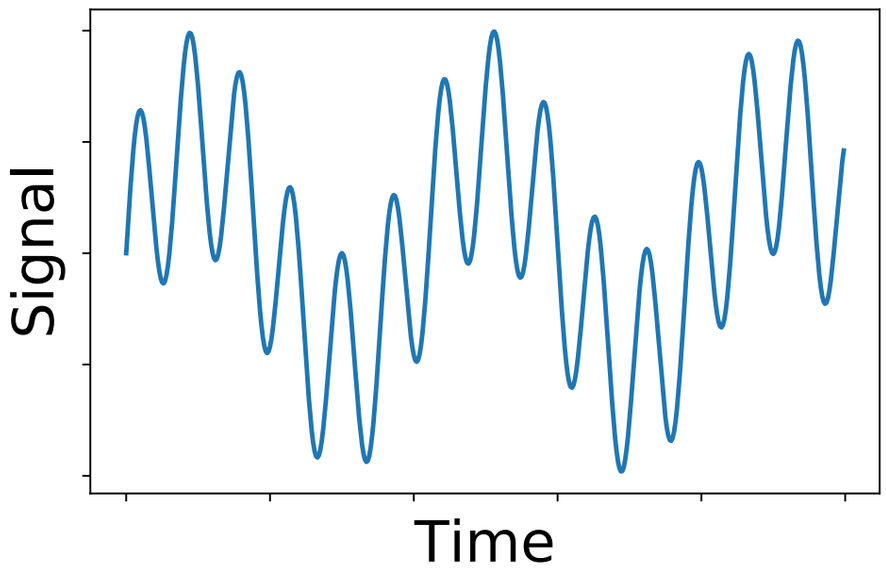
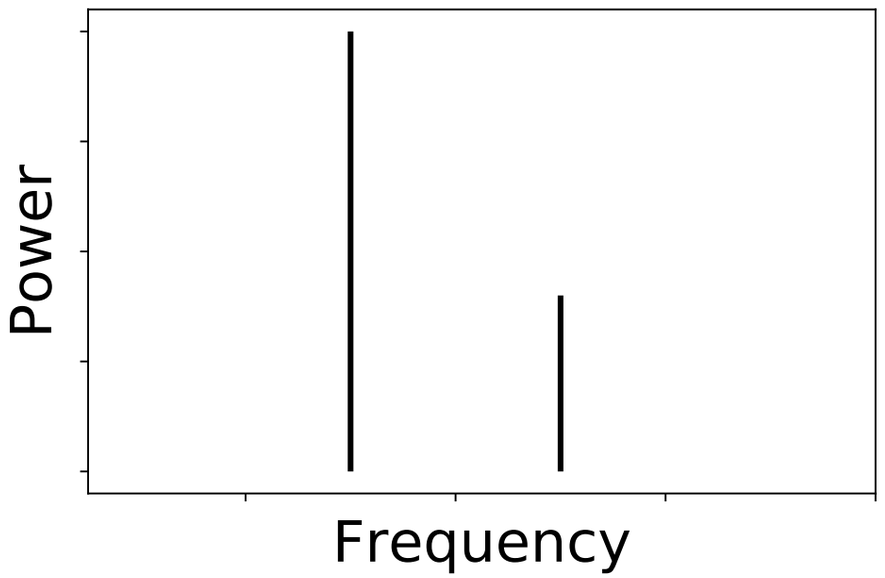


$\mathcal{F}: \ t \rightarrow \omega$

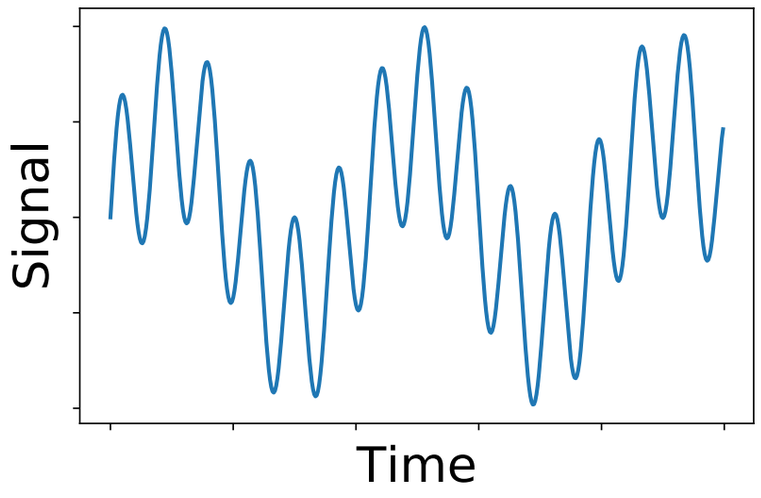
Frequency domain



Both representations contain
the same energy/information
(e.g. jpeg compression)

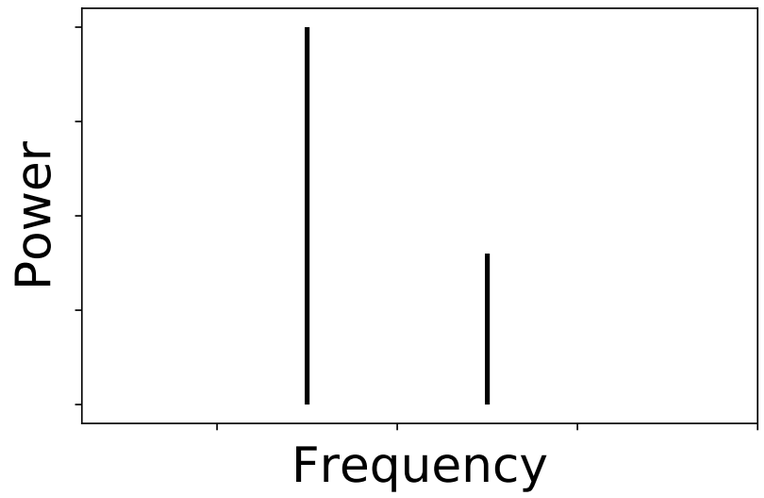
Discrete and Continuous Spectra

harmonic signal

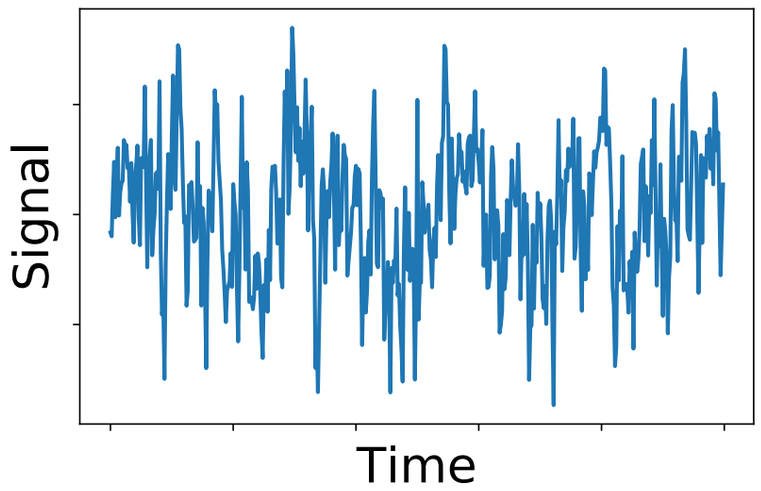


$$\mathcal{F}: \ t \rightarrow \omega$$

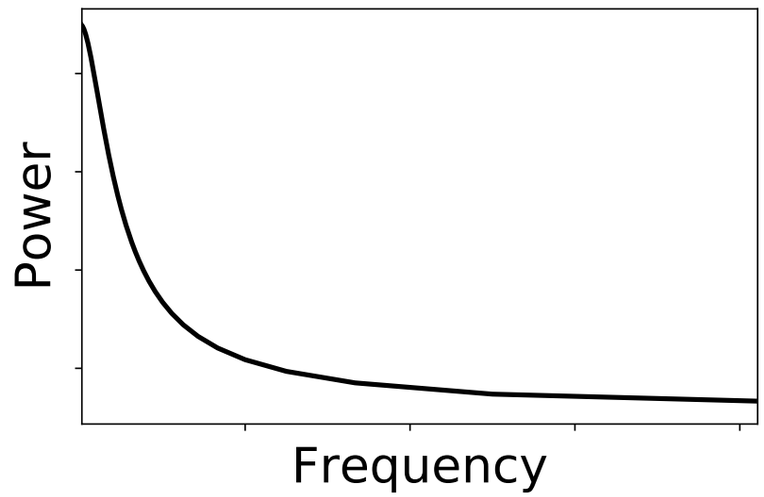
discrete spectrum



stochastic/chaotic signal



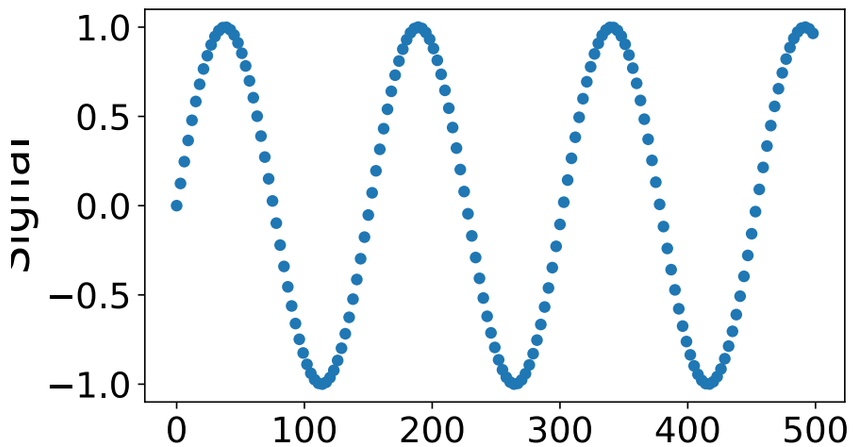
continuous spectrum



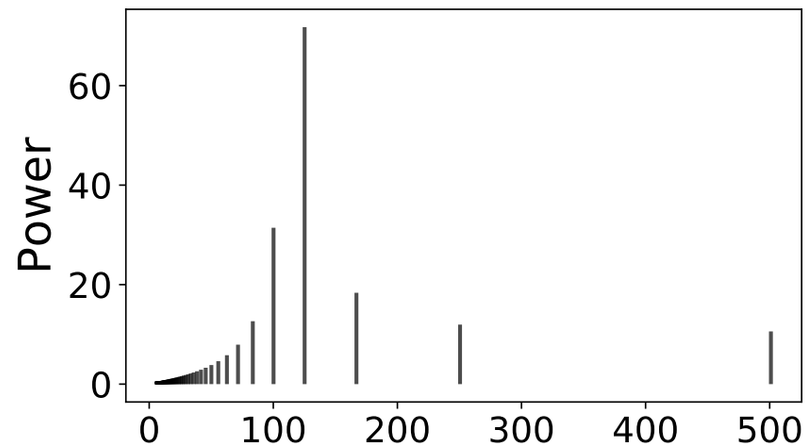
Most "real world" signals have both components!

Fourier Limitations

Short signal

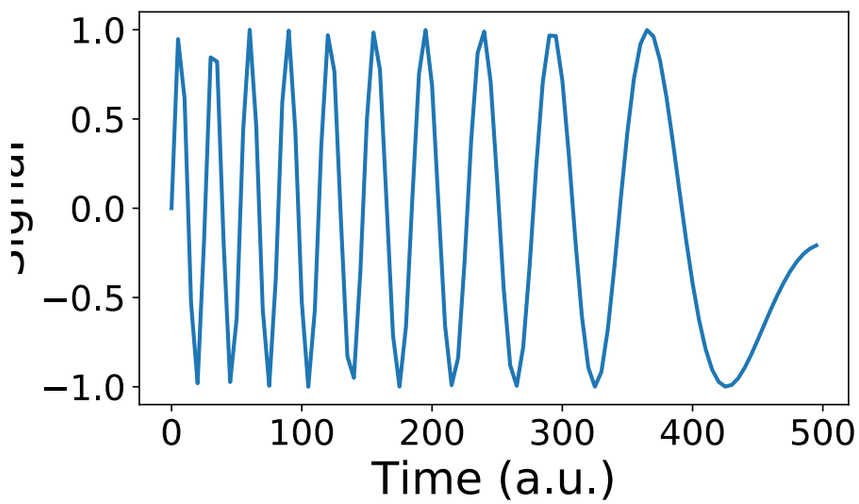


Poor spectral resolution



$$\mathcal{F}: t \rightarrow \omega$$

Non-stationary signal



No time-resolution