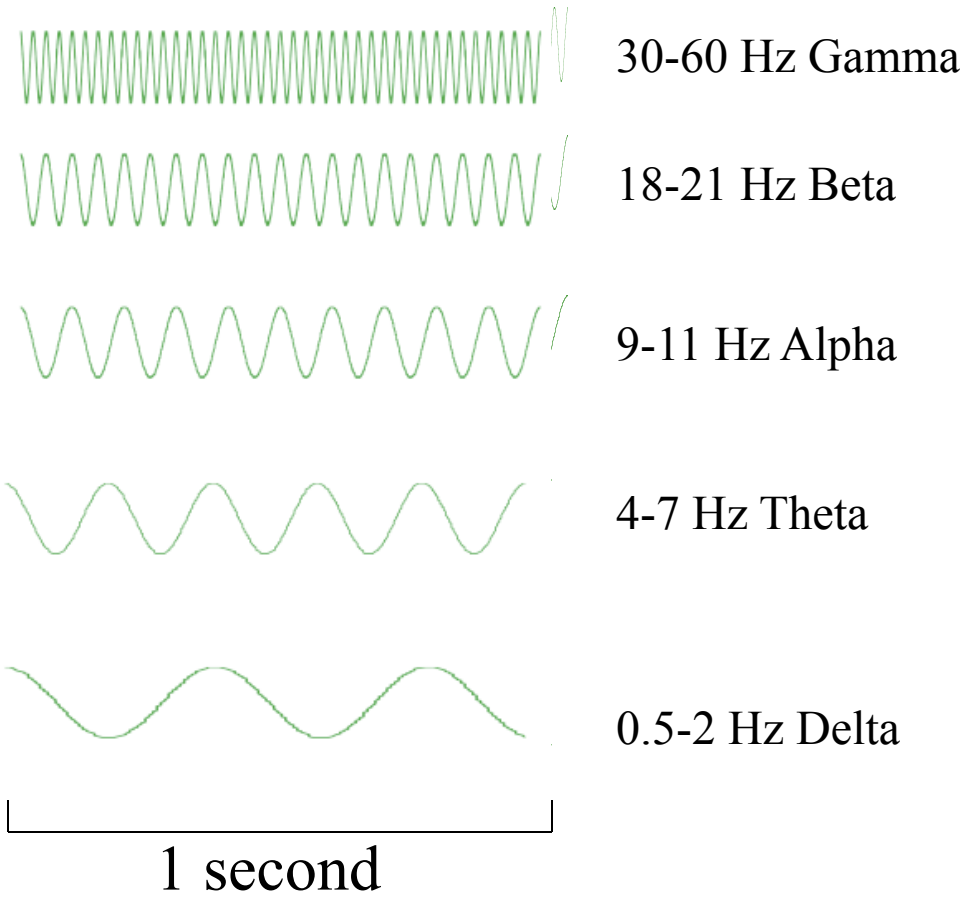
Time-Frequency analysis of biophysical time series

Sept 9th 2010, NCTU, Taiwan

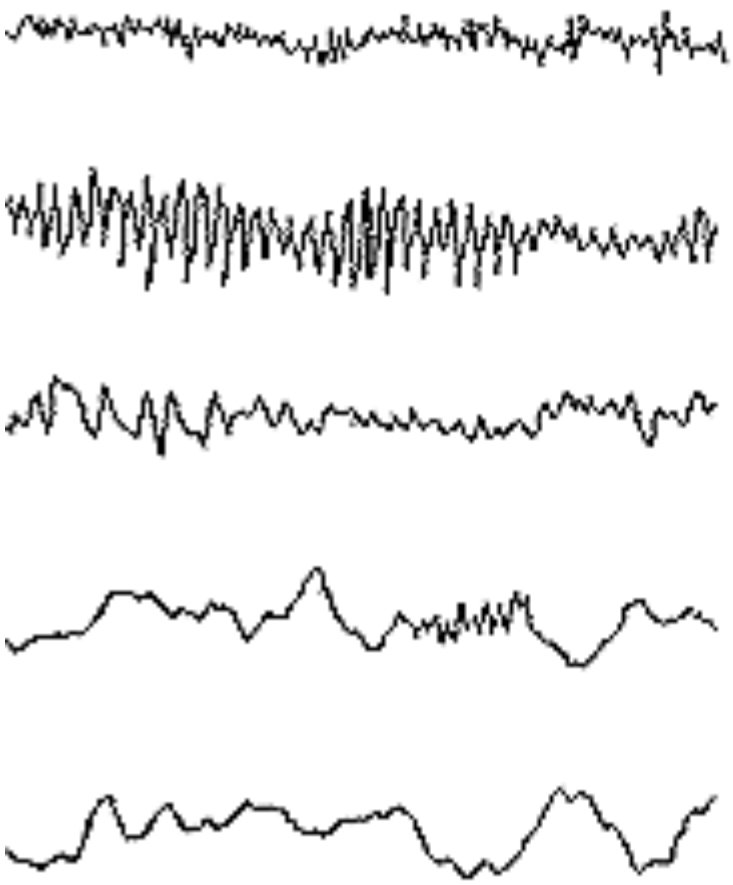
Arnaud Delorme

Frequency analysis

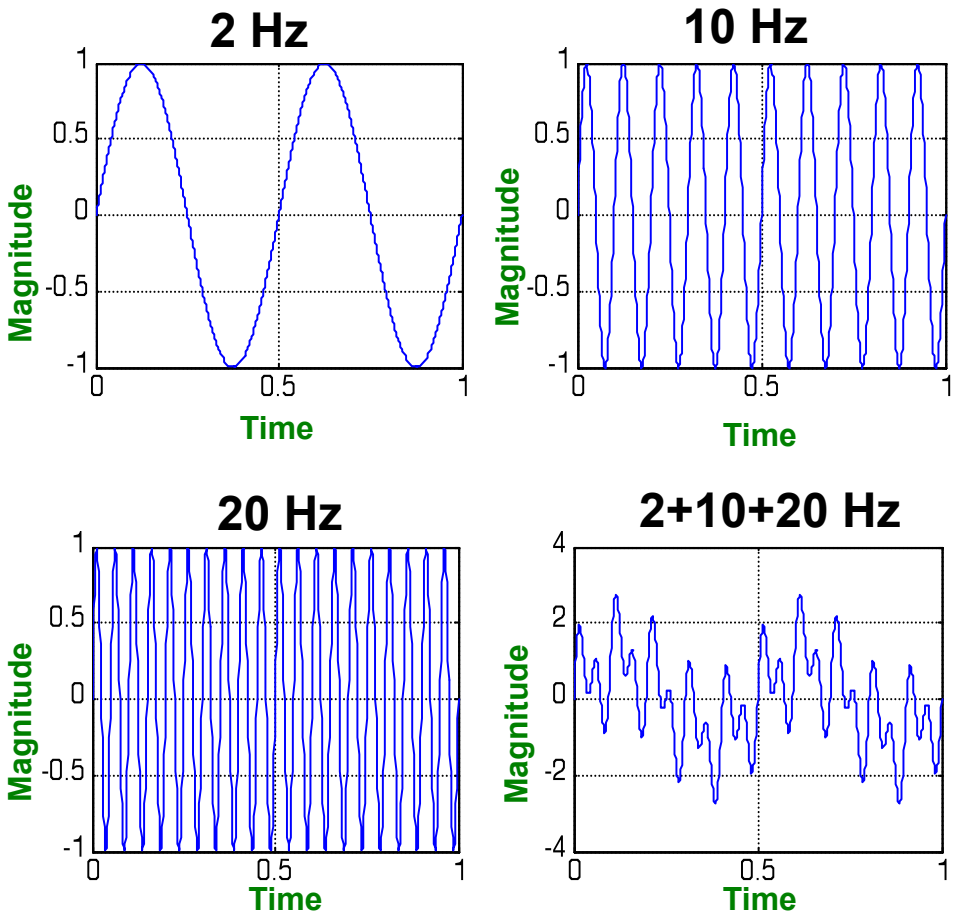
synchronicity of cell excitation determines amplitude and rhythm of the EEG signal



Frequency analysis



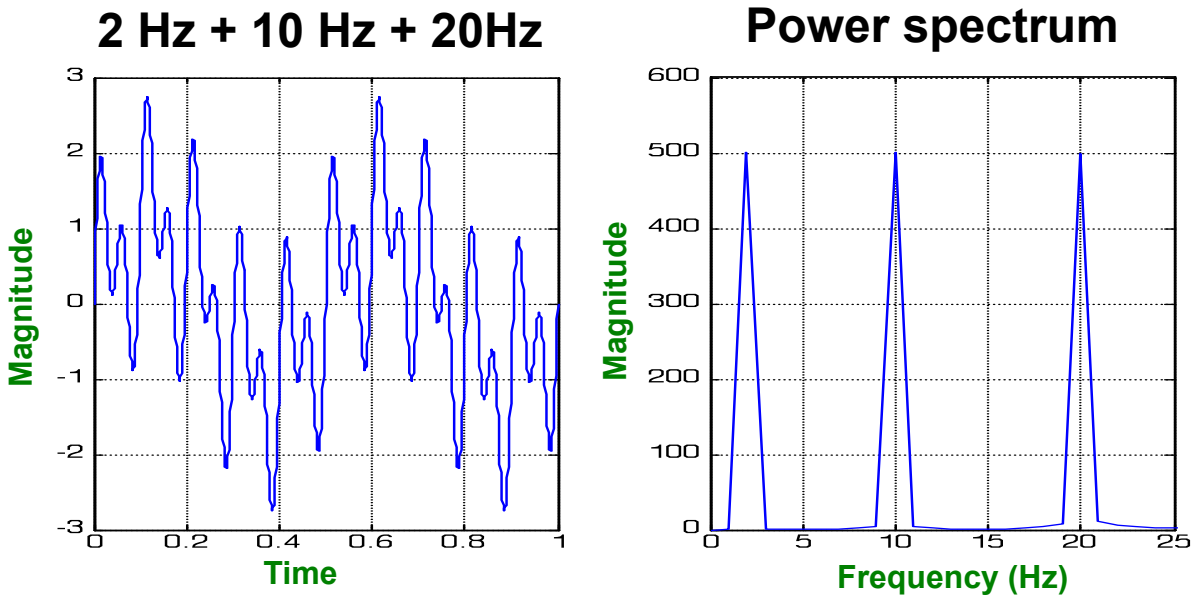
Stationary signals



Slide courtesy of Petros Xanthopoulos, Univ. of Florida

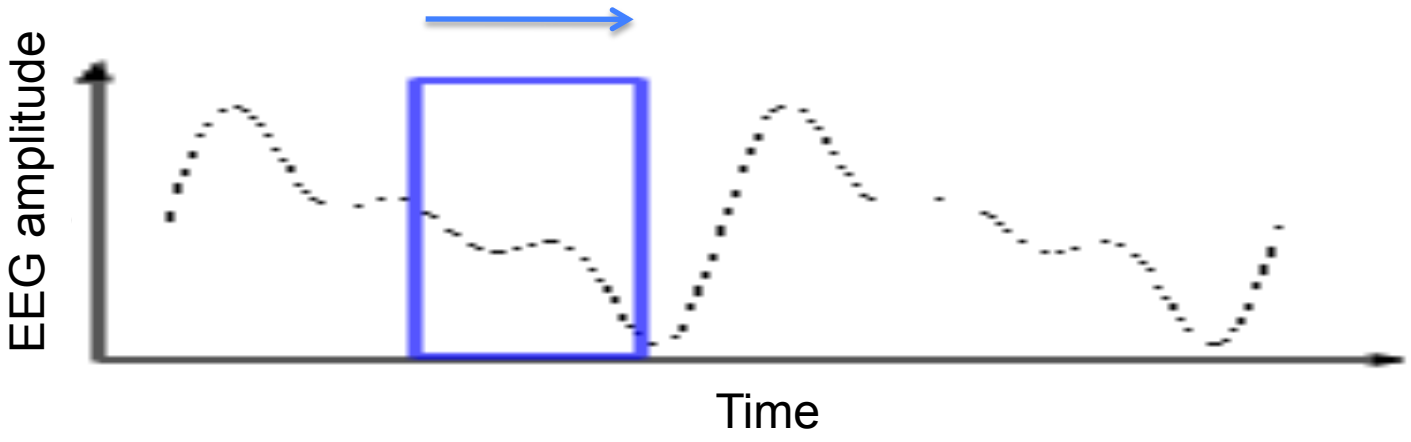
Stationary signal

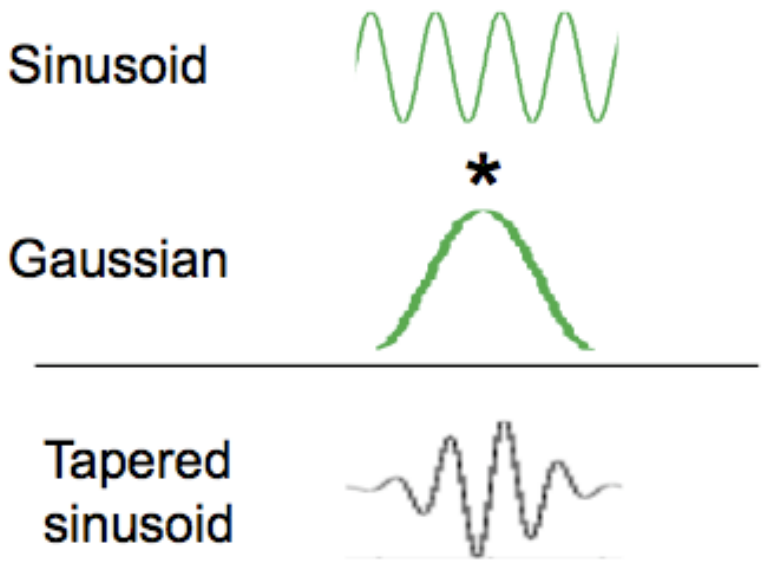
Stationary



By looking at the Power spectrum of the signal we can recognize three frequency Components (at 2,10,20Hz respectively).

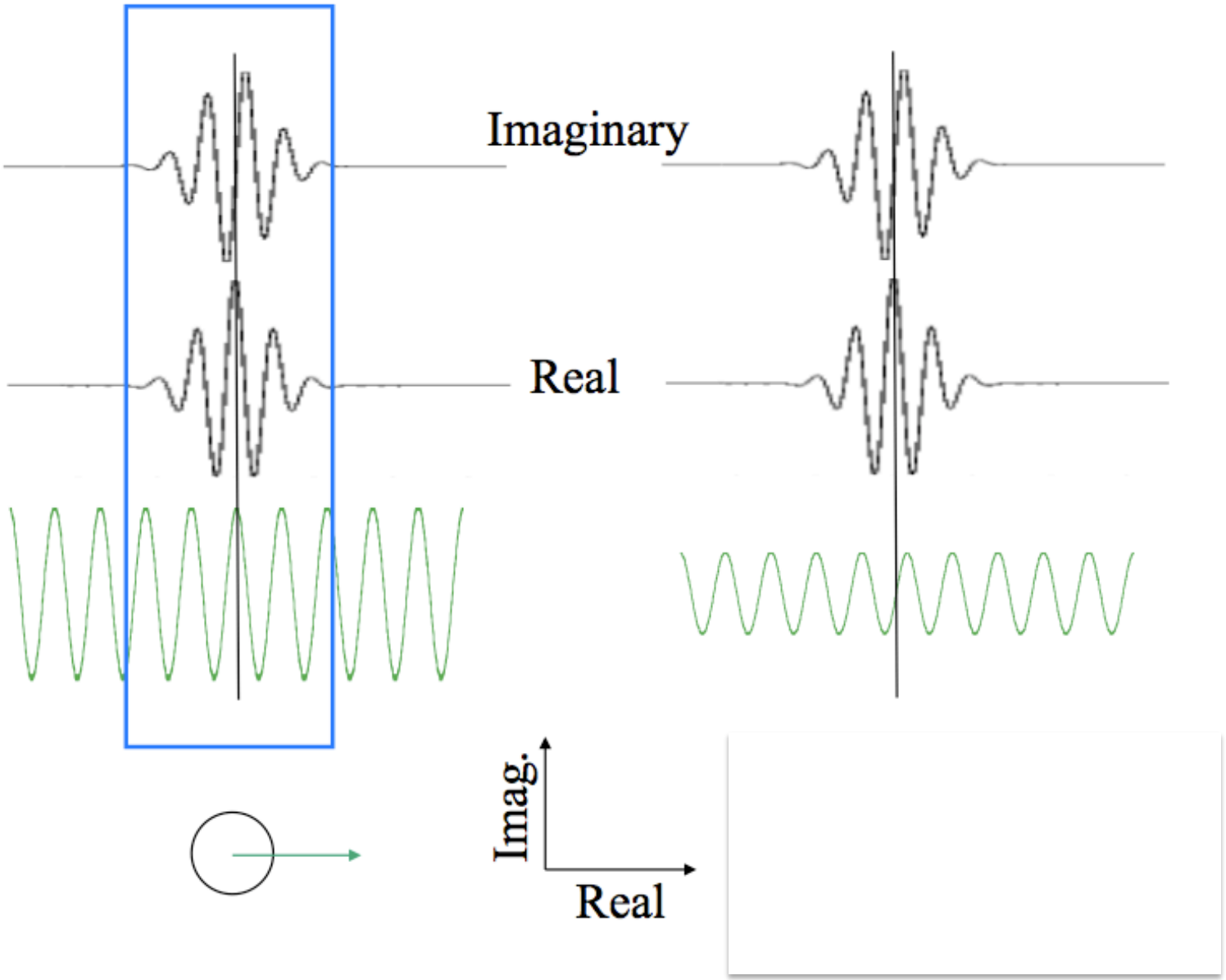
Slide courtesy of Petros Xanthopoulos, Univ. of Florida



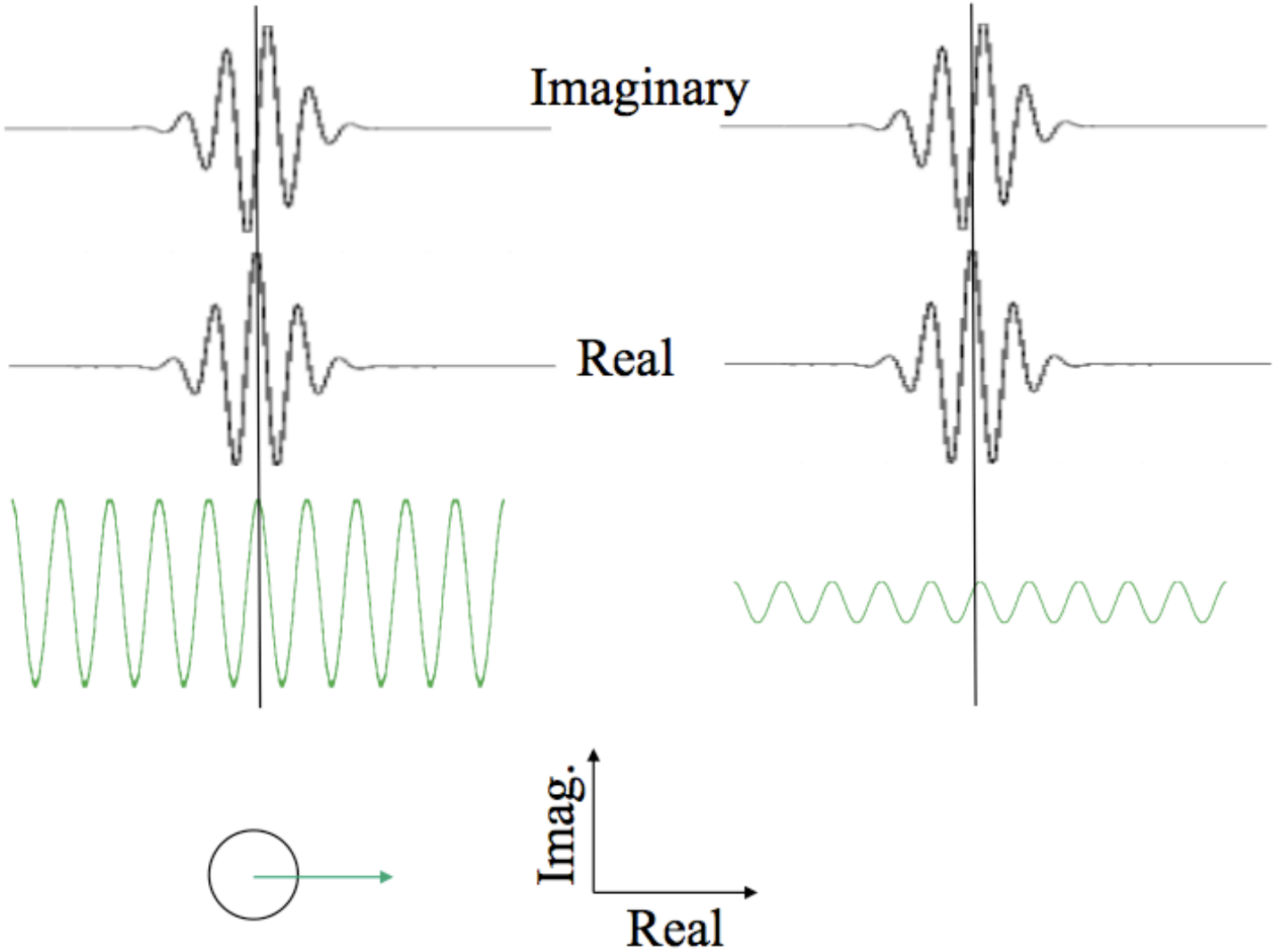


Performing Fourier transform by using a time moving window

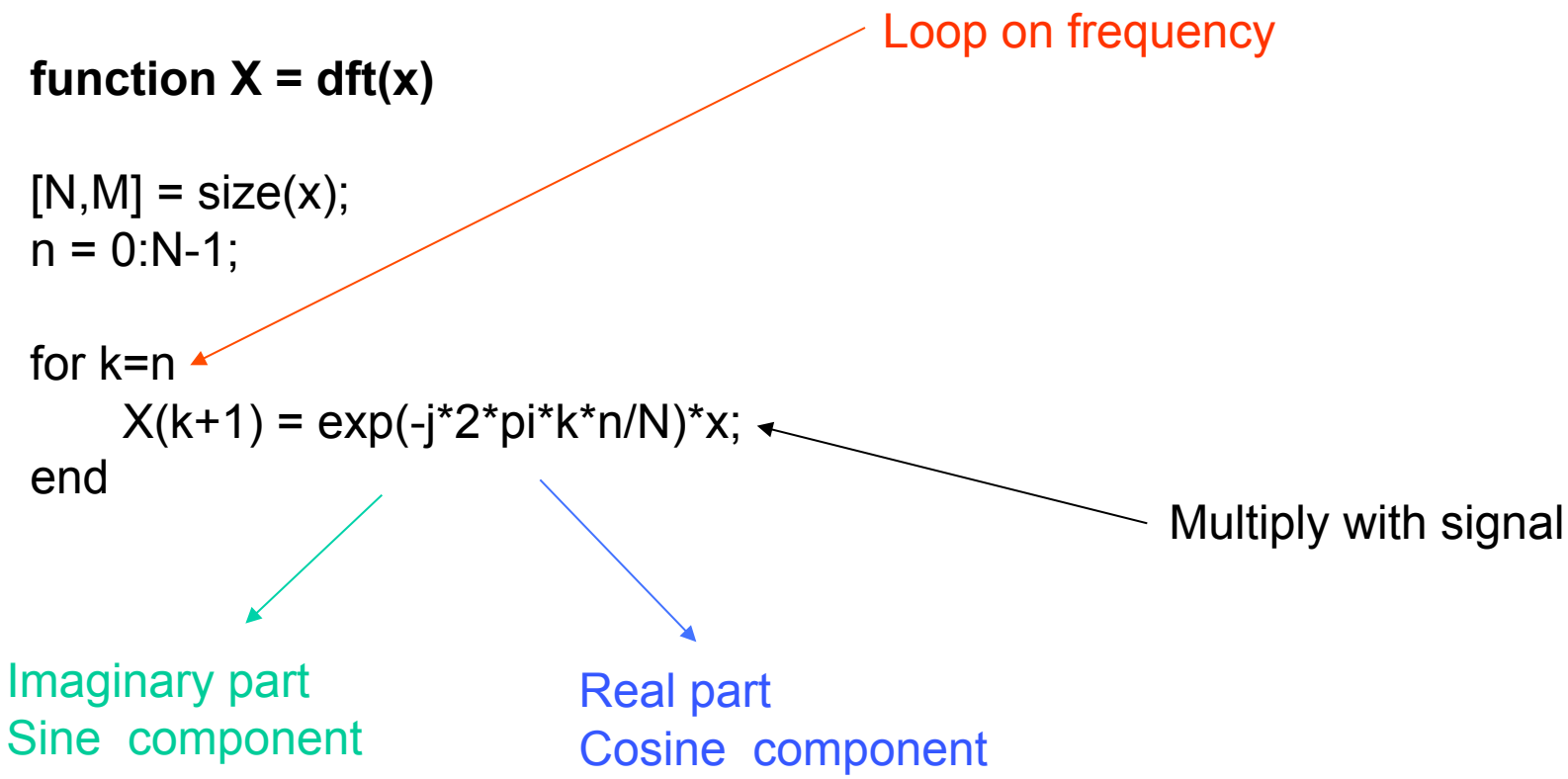
Spectral phase and amplitude

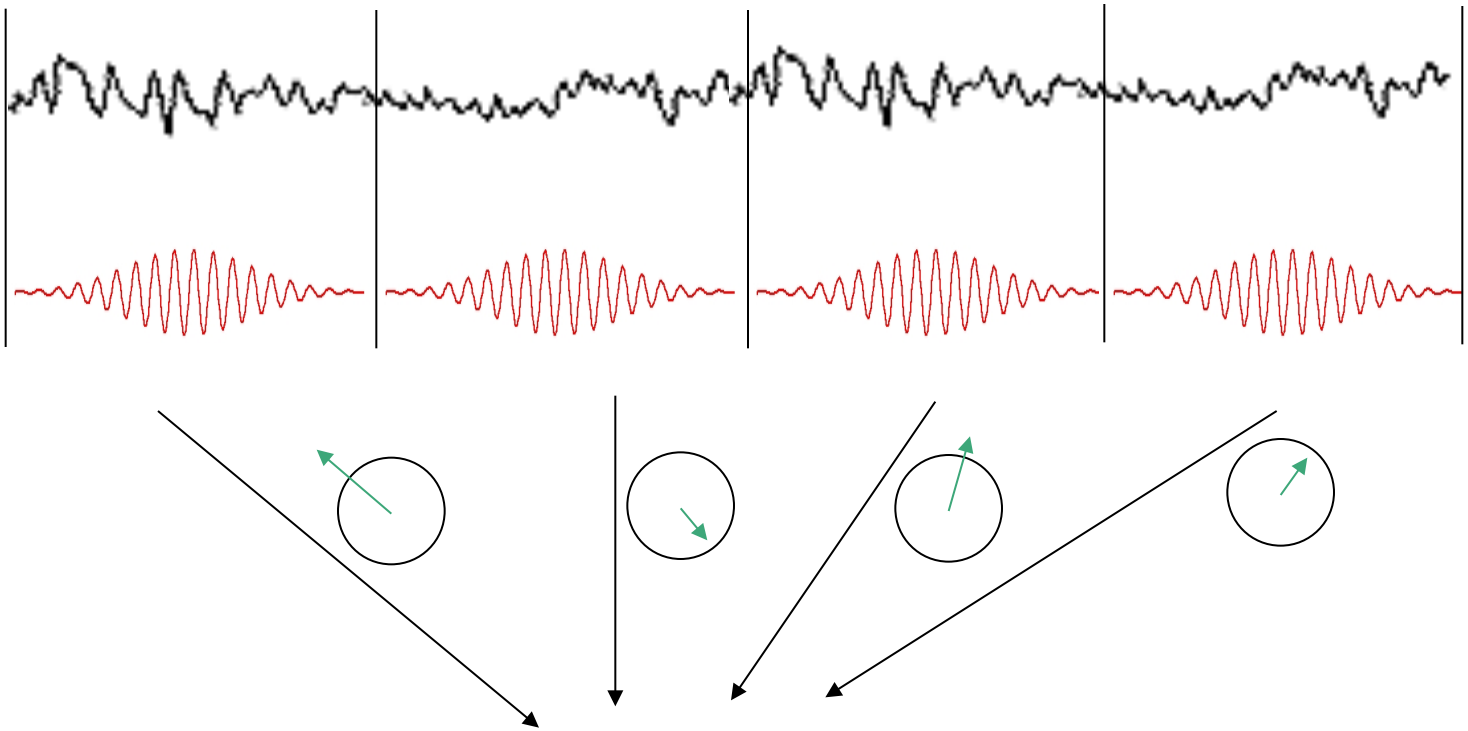


Spectral phase and amplitude

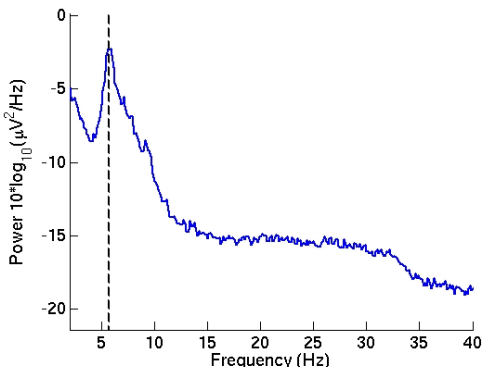


Discrete Fourrier Transform function

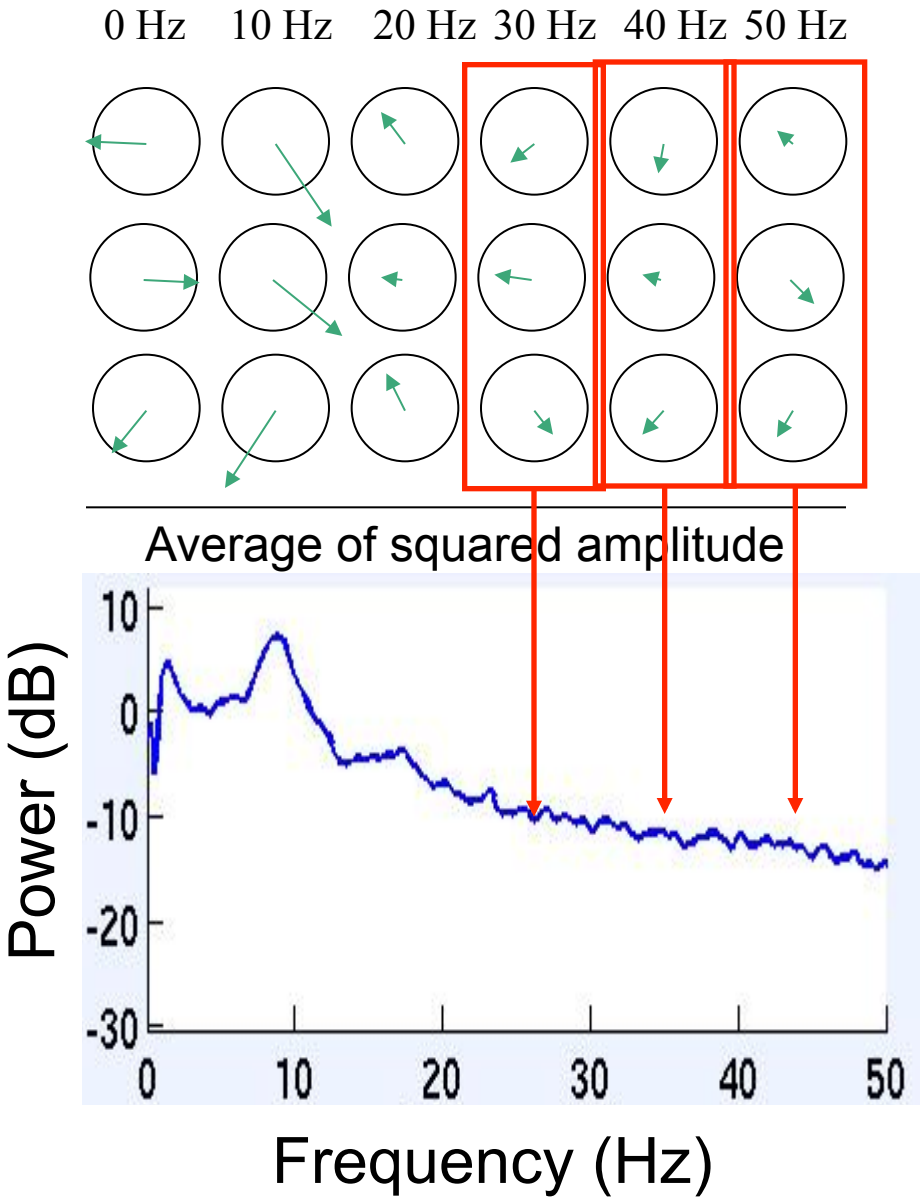


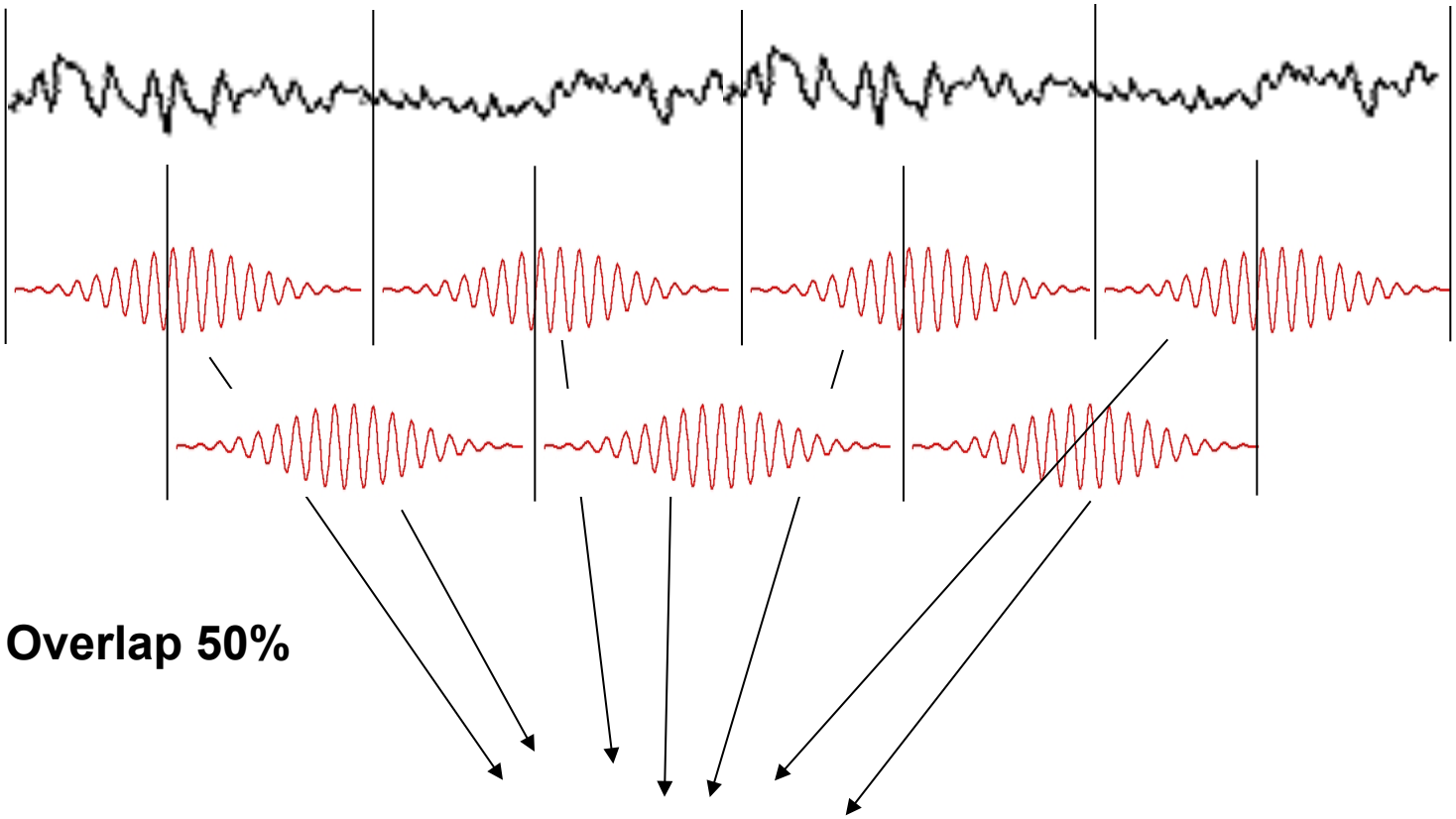


Average of squared absolute values



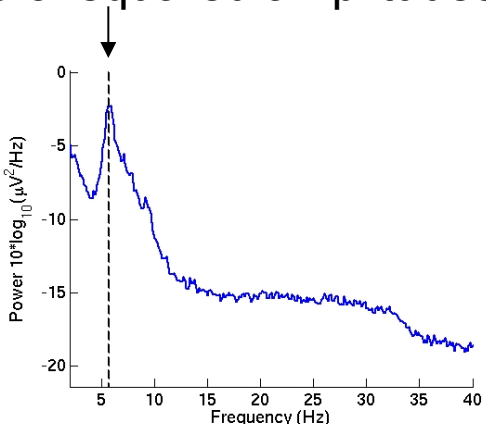
Spectral power

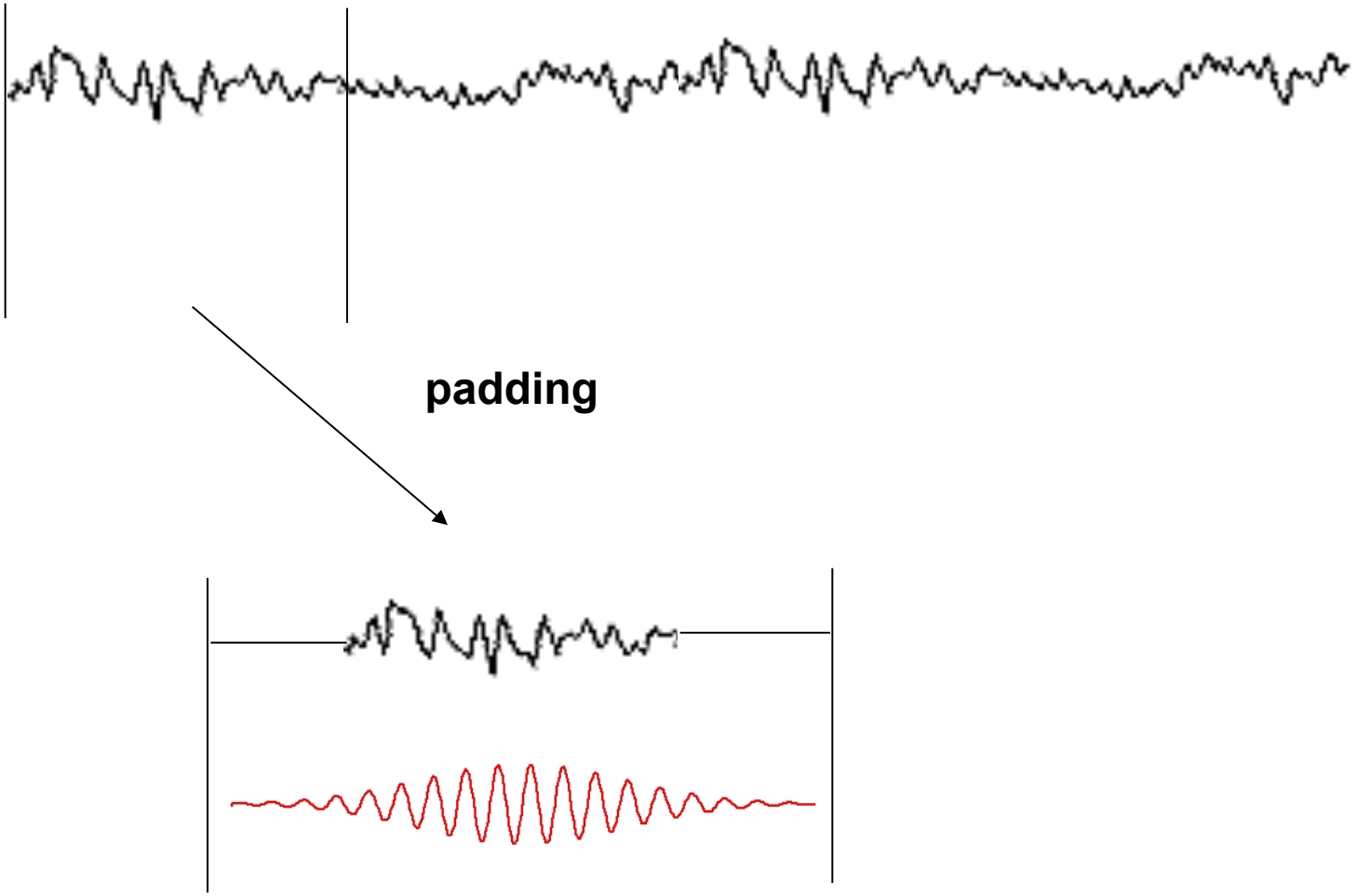




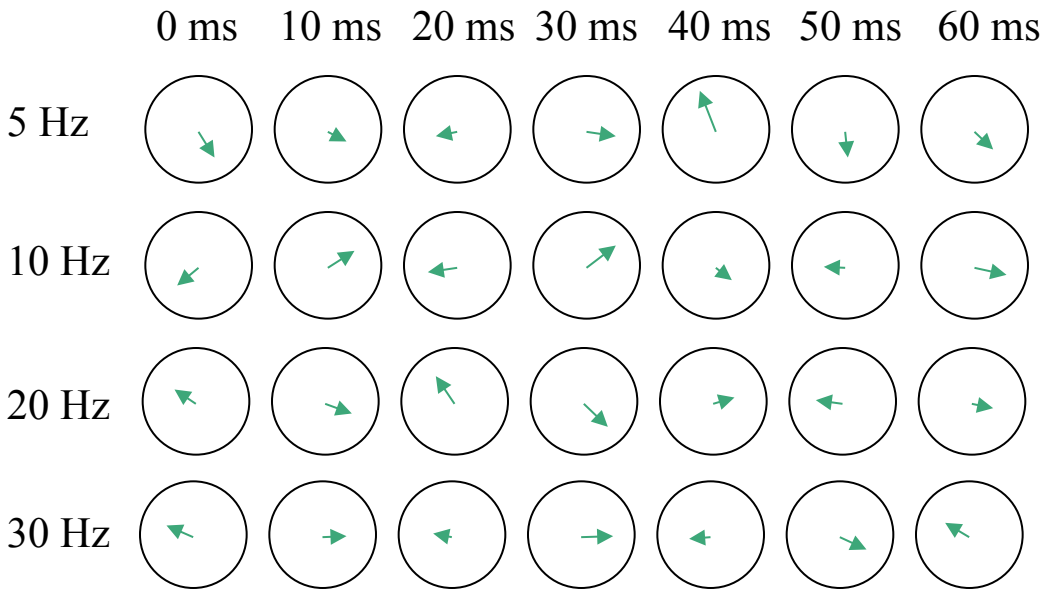
Overlap 50%

Average of squared amplitudes

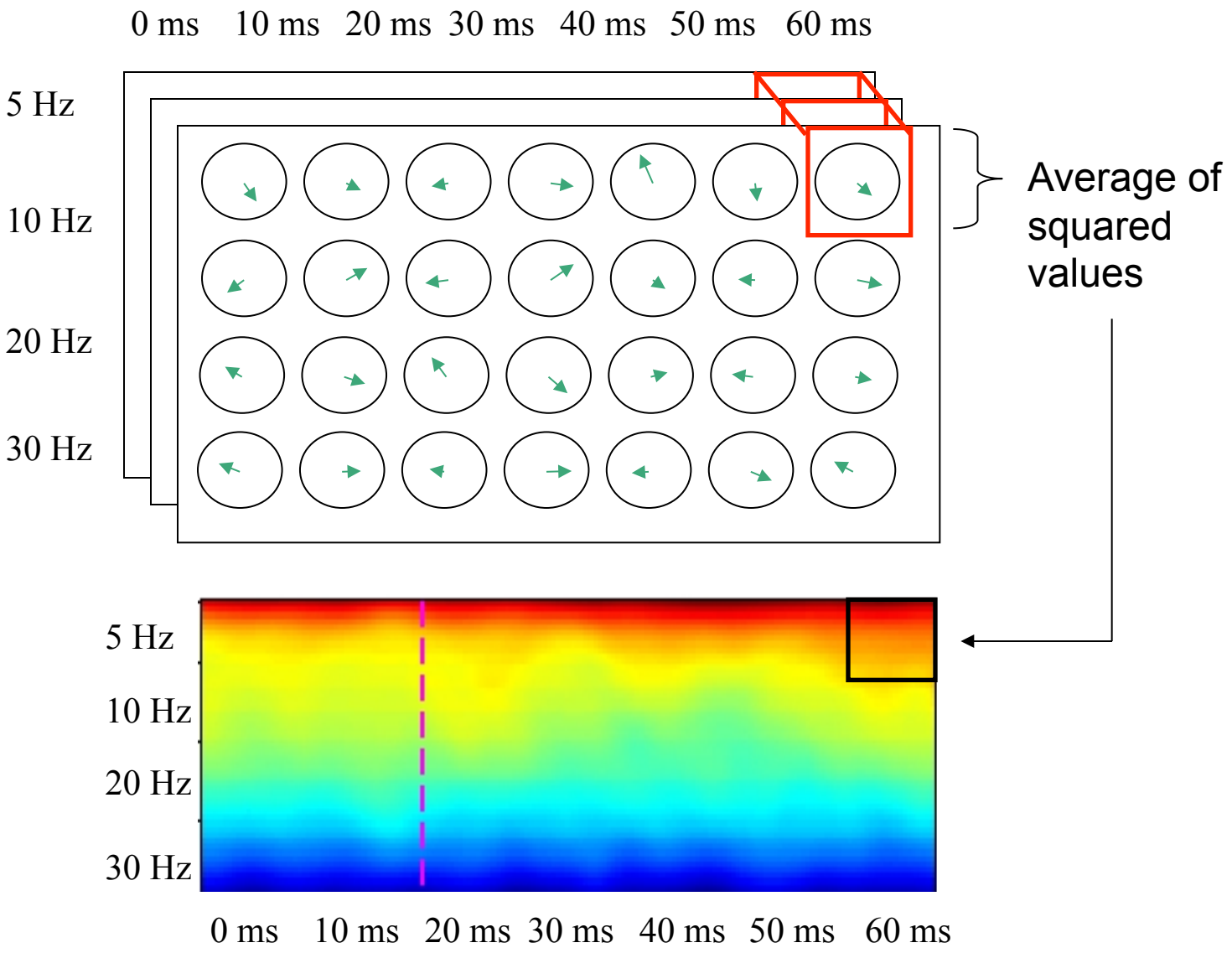



padding

Spectrogram or ERSP



Spectrogram or ERSP



Power spectrum and event-related spectral perturbation

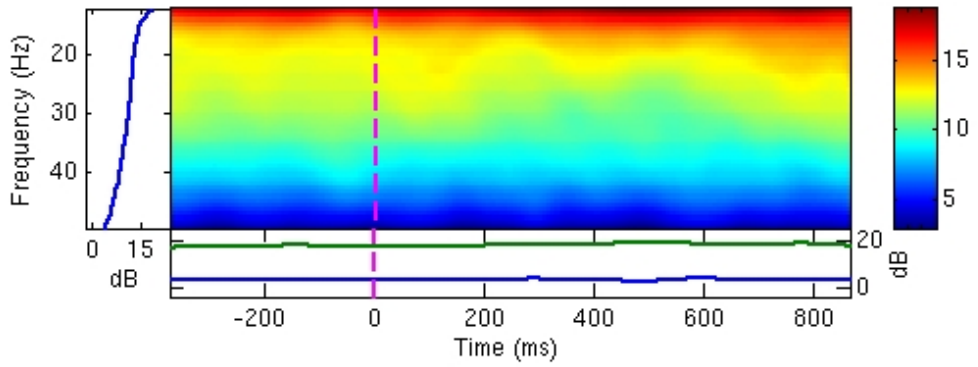
$$ERS\ (f,t) = \frac{1}{n}\sum_{k=1}^{n}\left|F_k(f,t)\right|^2$$

Complex number

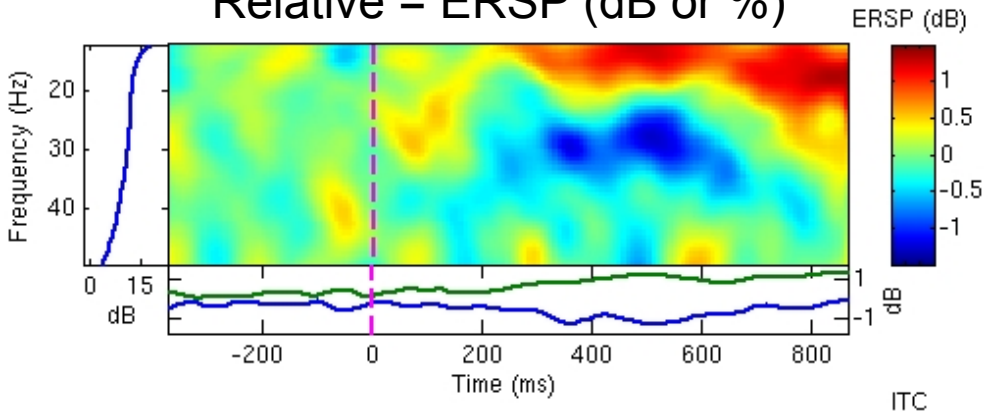
Scaled to dB $10\mathrm{Log}_{10}(\mathrm{ERSP})$

Absolute versus relative power

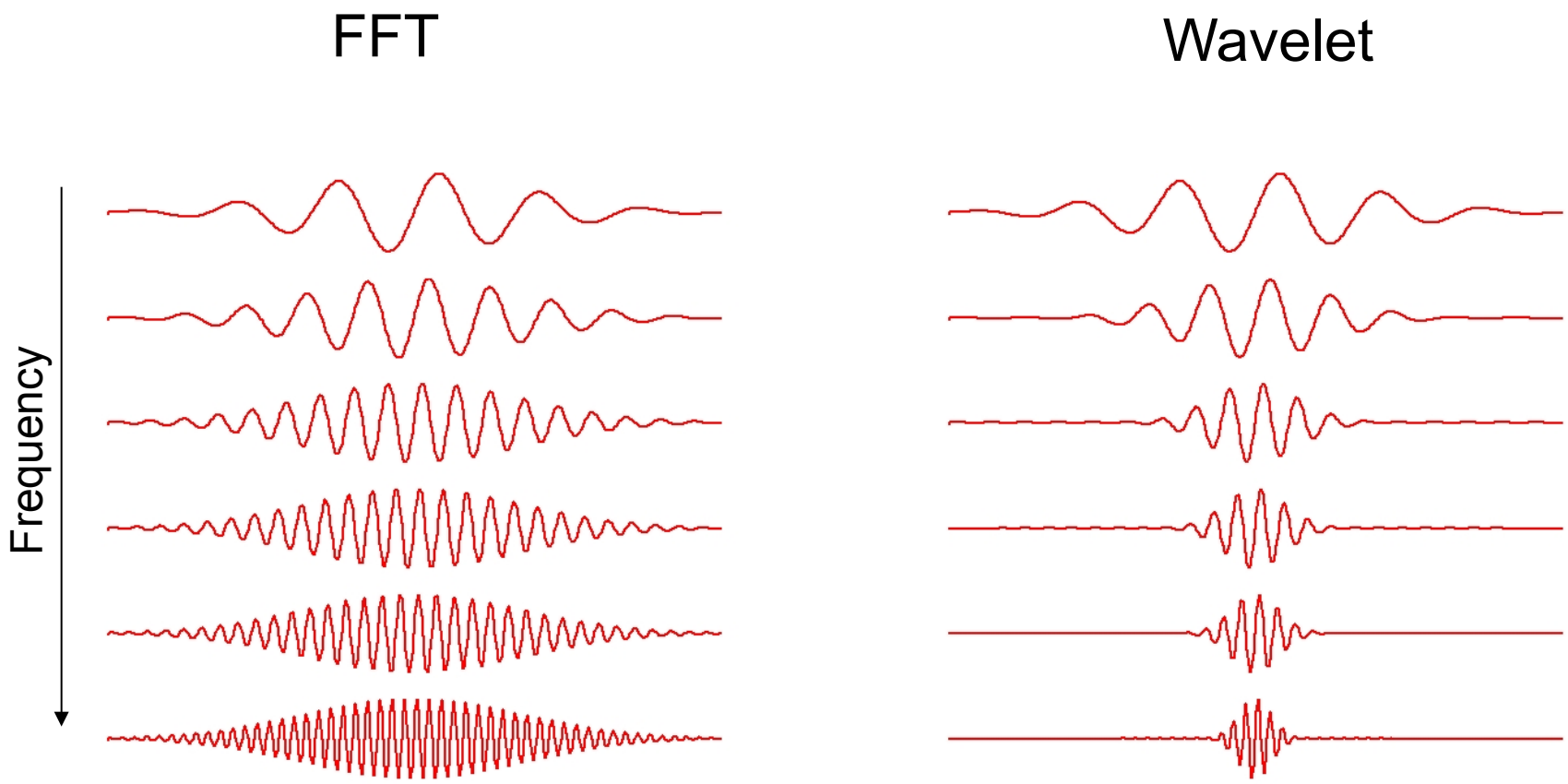
Absolute = ERS



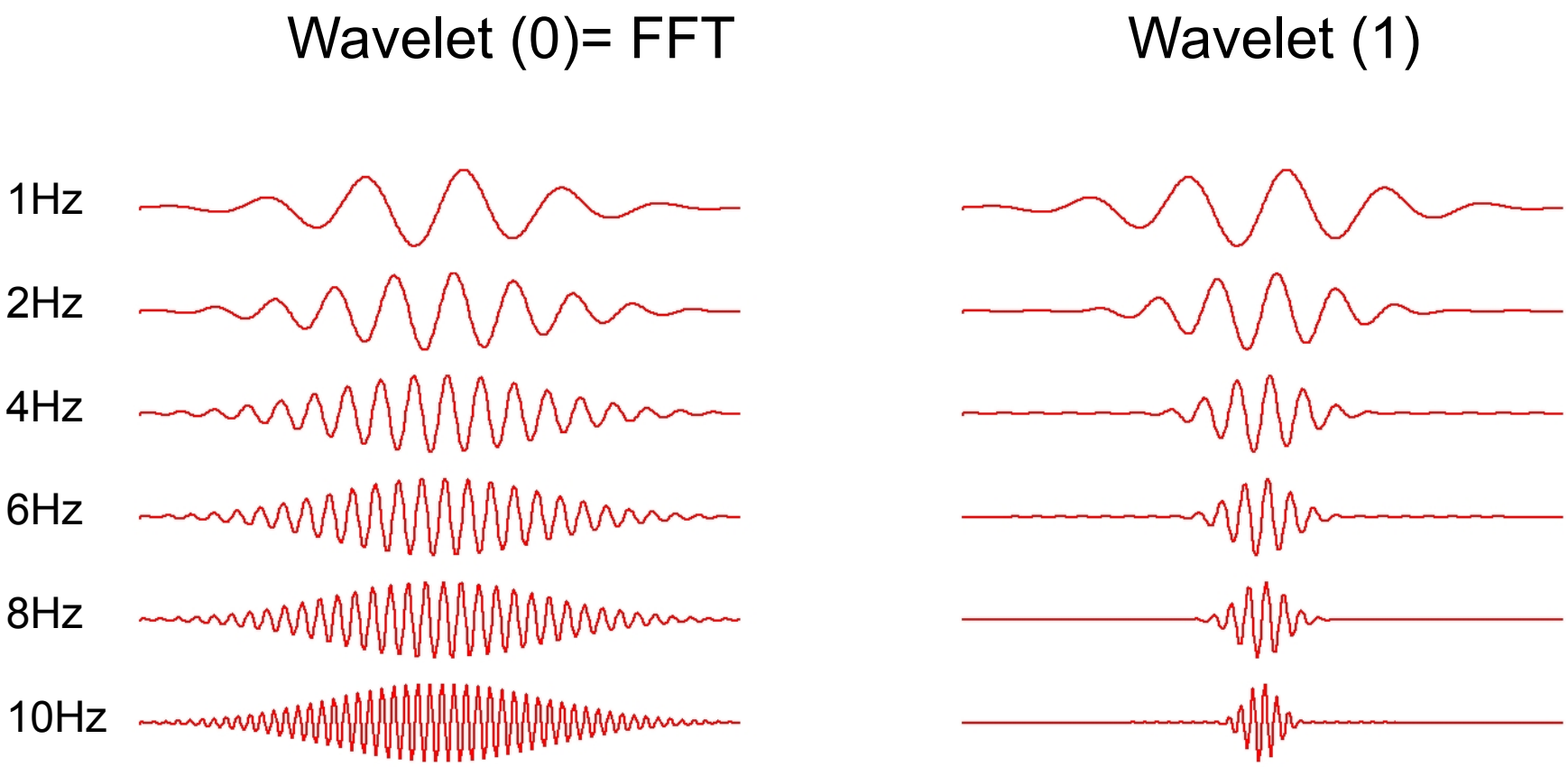
Relative = ERSP (dB or %)



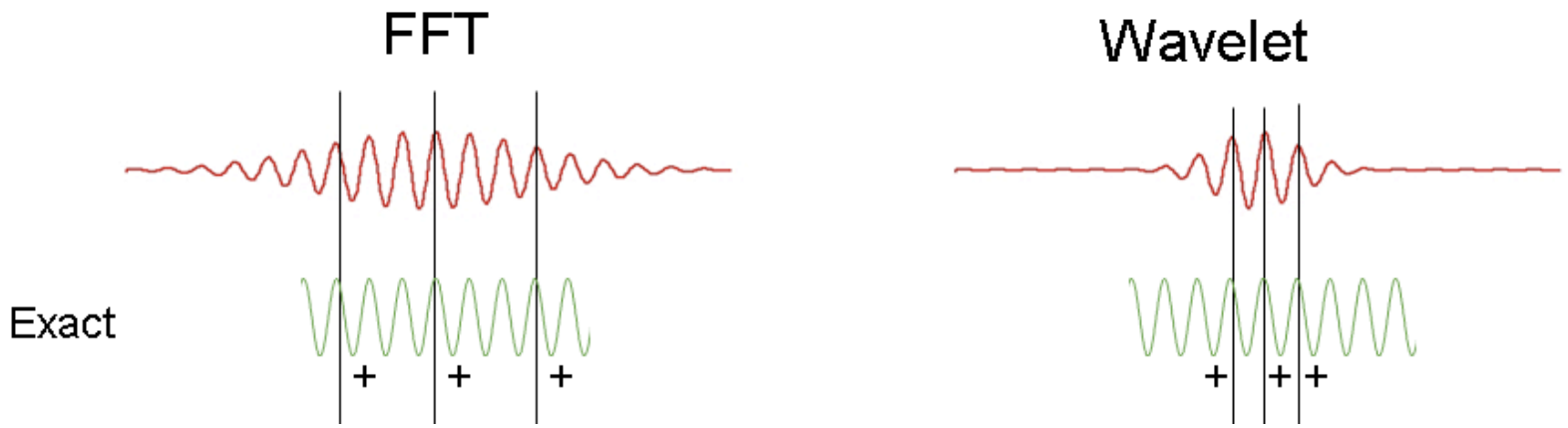
Difference between FFT and wavelets



Wavelets factor



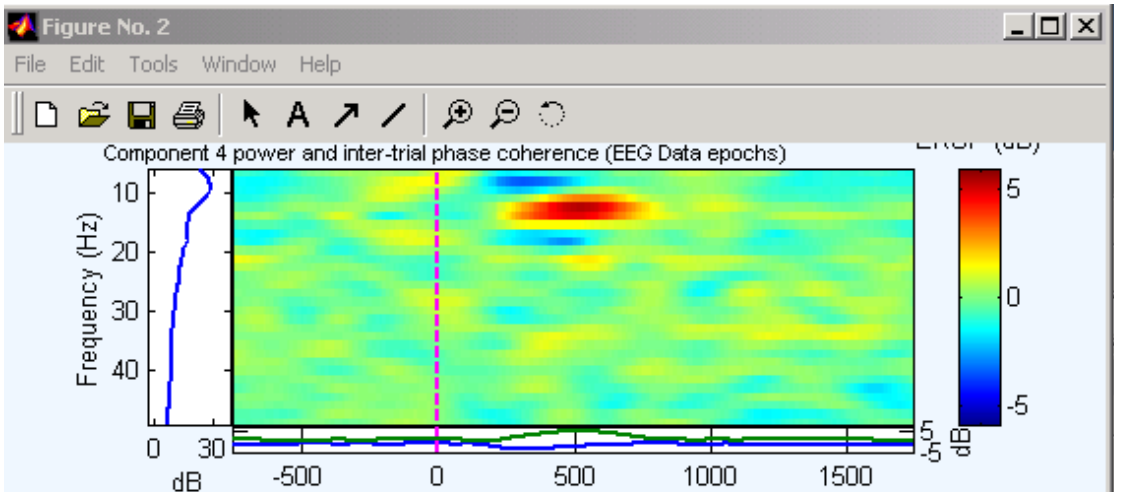
Time-frequency resolution trade off



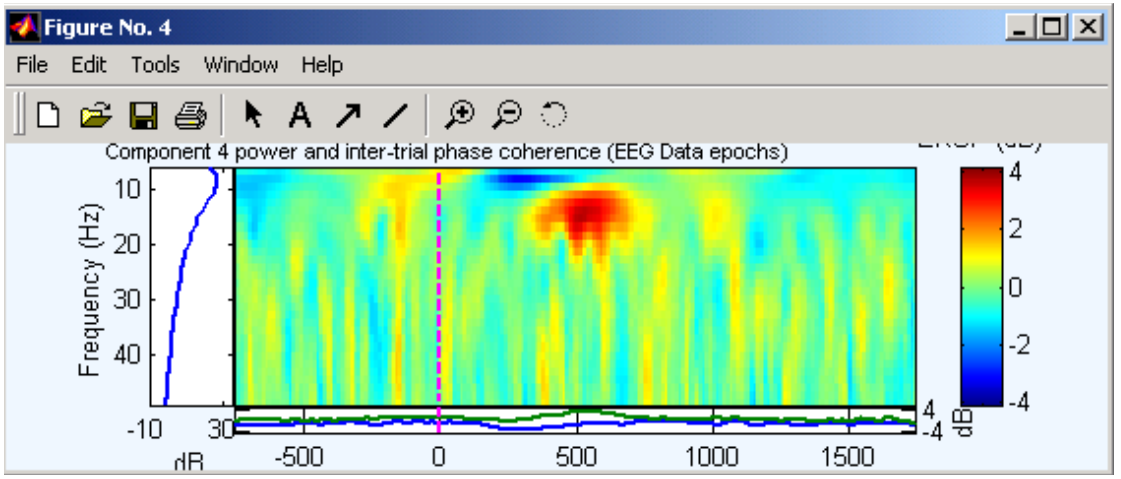
High freq. resolution
low time-resolution

Low freq. resolution
high time-resolution

FFT



Pure wavelet



The Uncertainty Principle

A signal cannot be localized arbitrarily well both in time/ position and in frequency/ momentum.

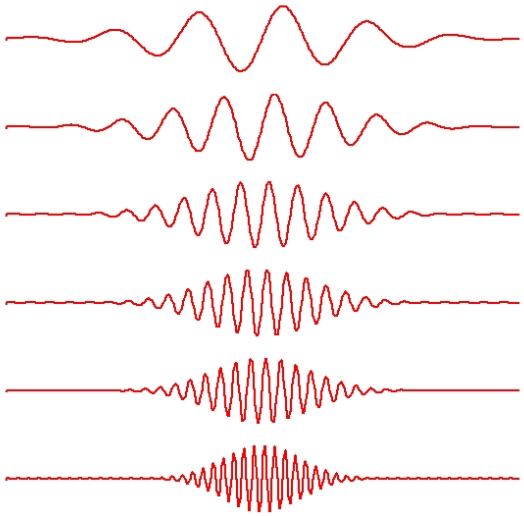
There exists a lower bound to the *Heisenberg's product*:

$$\Delta t \, \Delta f \geq 1/(4\pi)$$

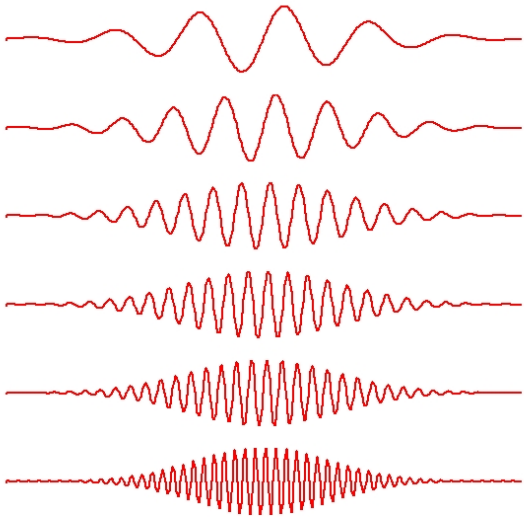
Δf = 1Hz, Δt = 80 msec or Δf = 2Hz, Δt = 40 msec

Modified wavelets

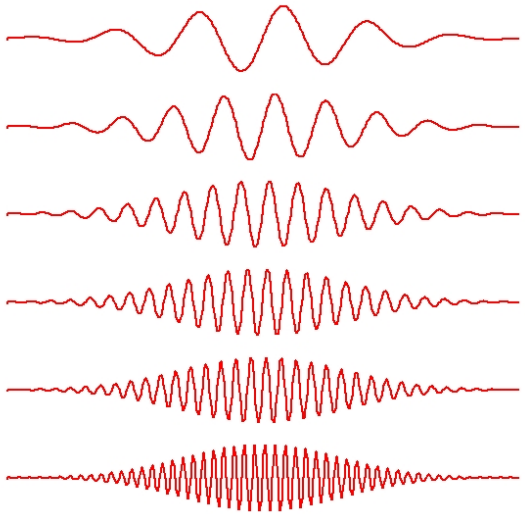
Wavelet (0.8)



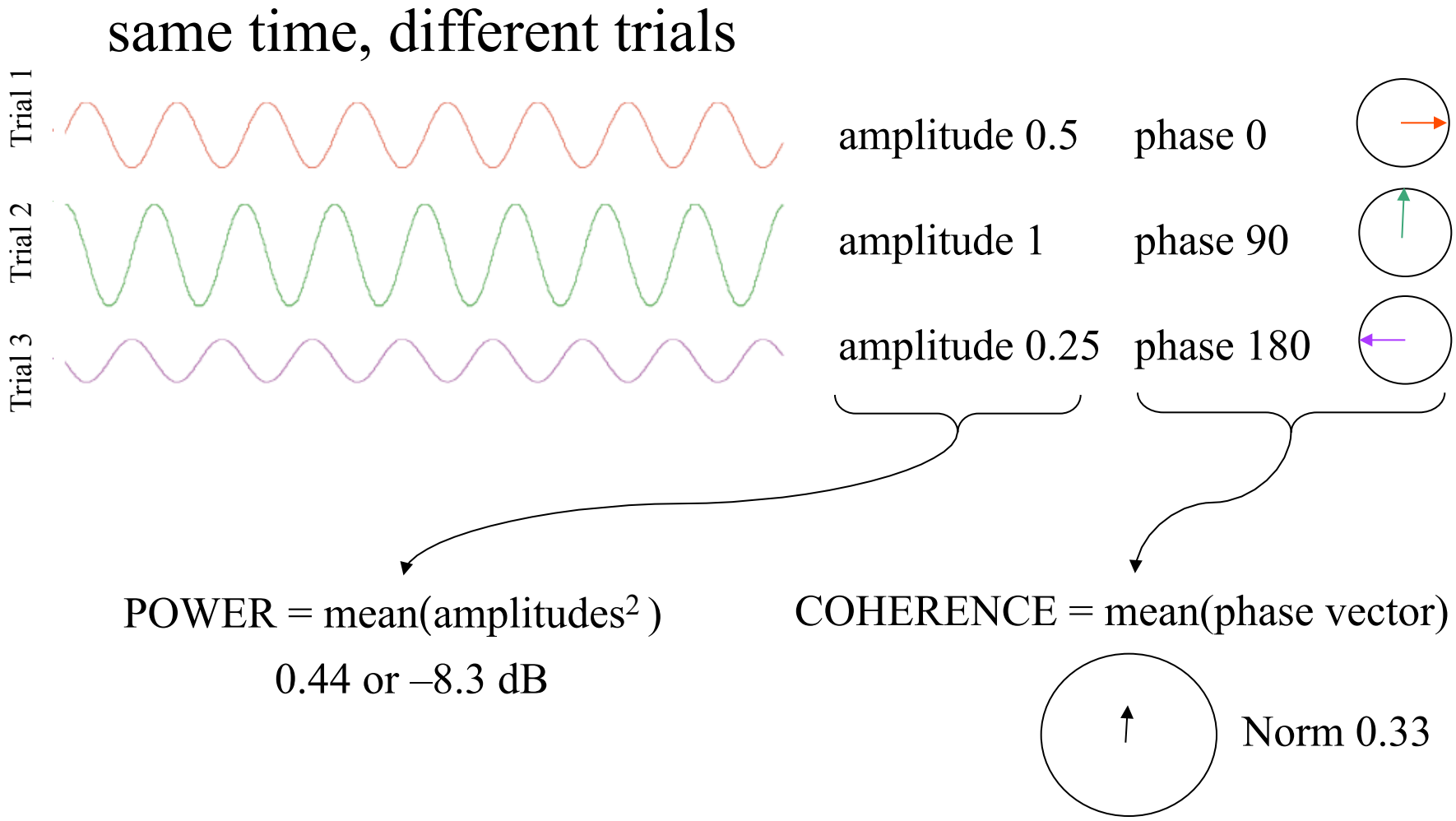
Wavelet (0.5)

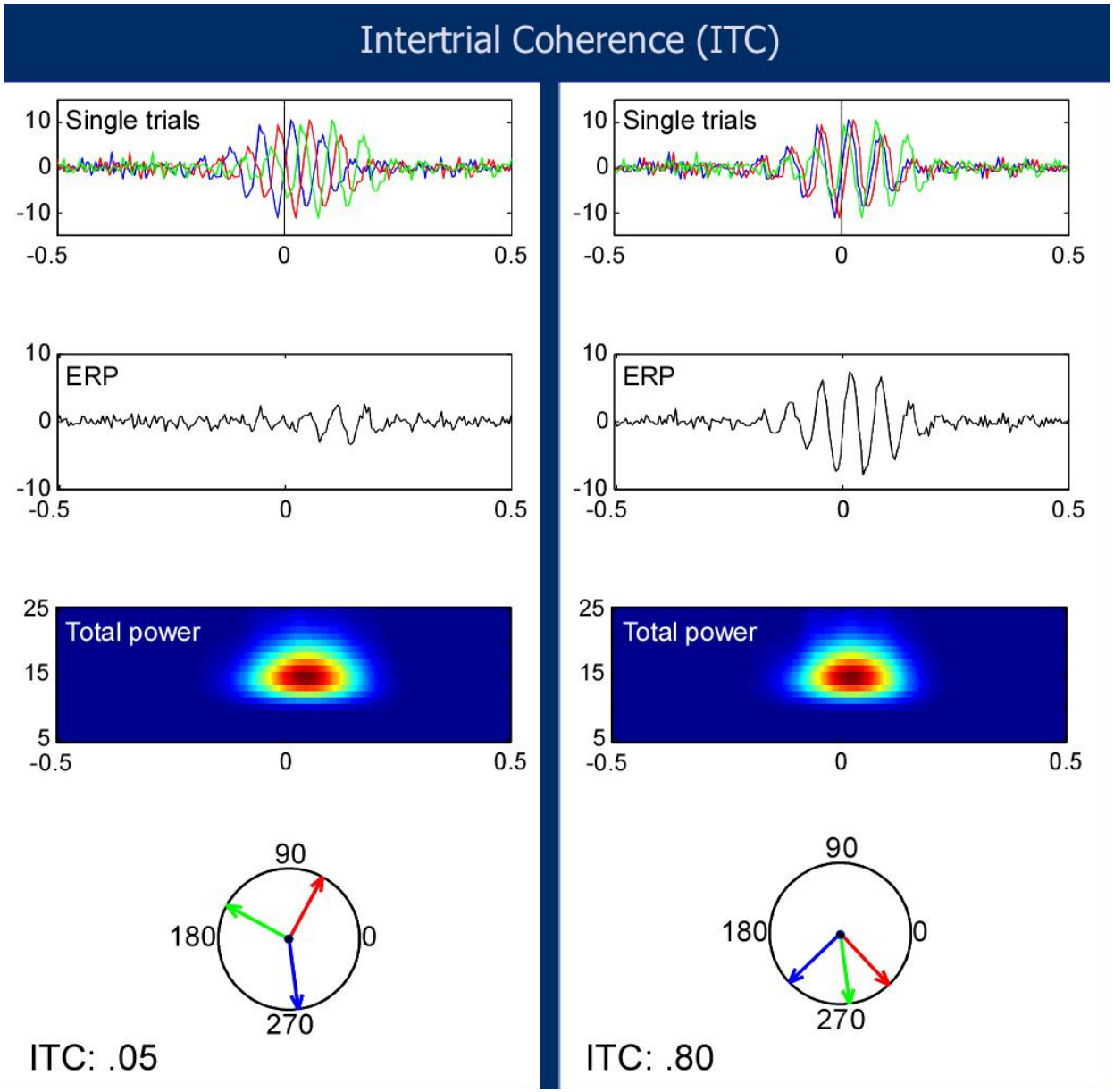


Wavelet (0.2)



Inter trial coherence





Slide courtesy of Stefan Debener

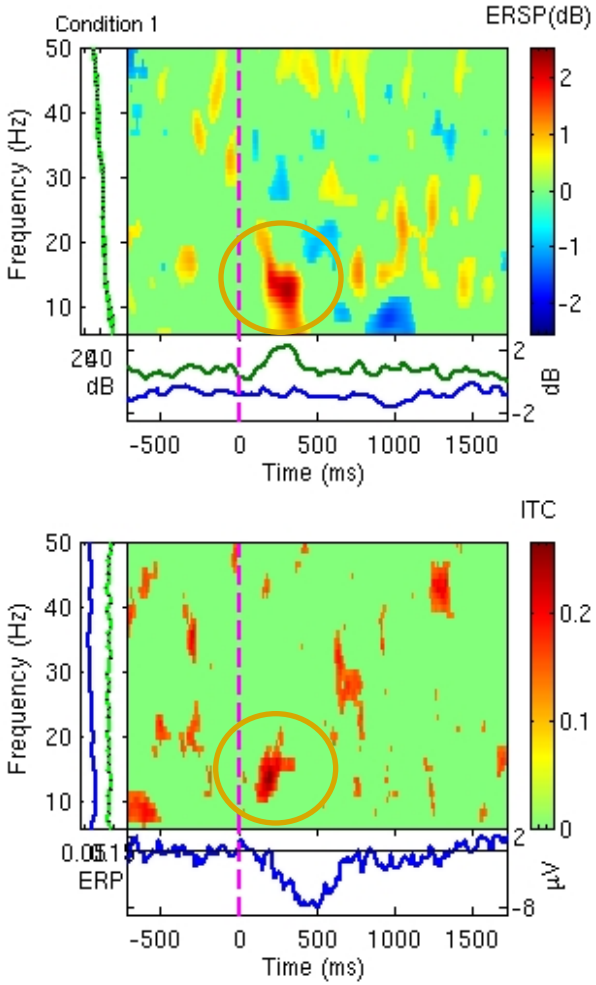
Phase ITC

$$ITPC(f,t) = \frac{1}{n}\sum_{k=1}^{n}\underbrace{\frac{F_k(f,t)}{\left|F_k(f,t)\right|}}$$

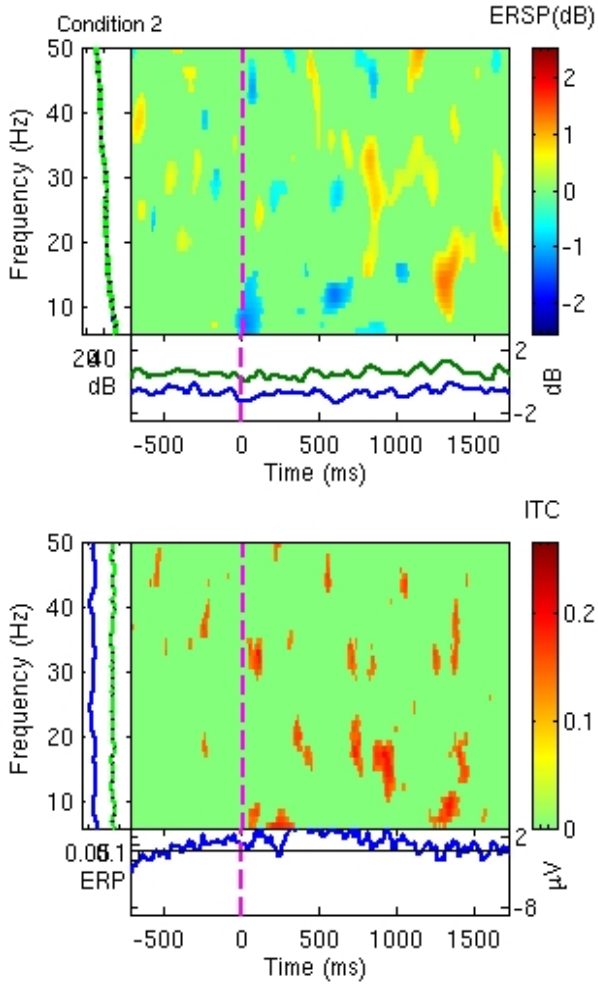
Normalized
(no amplitude information)

Power and inter trial coherence

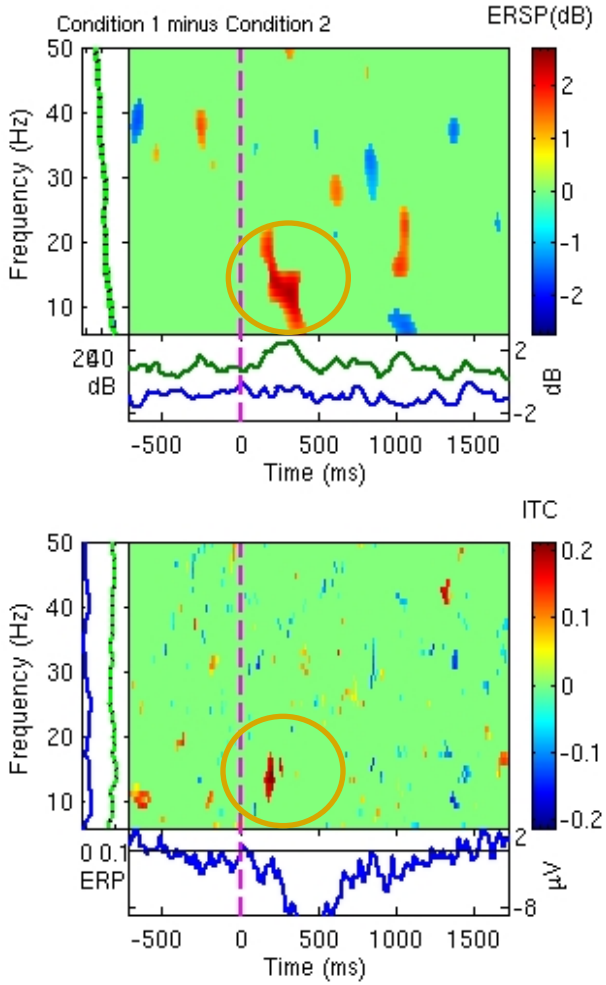
Attend left-stim left

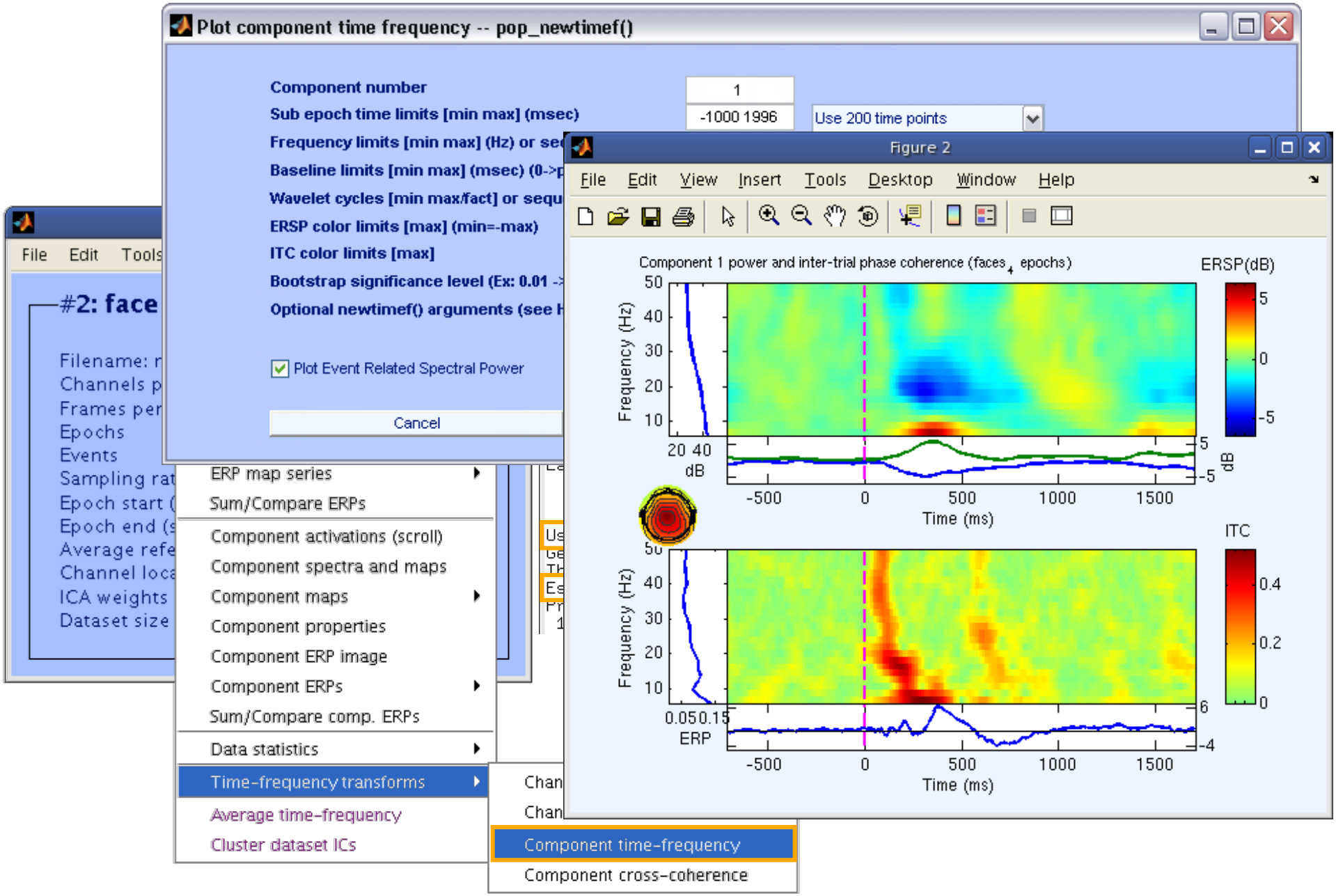


Attend left-stim right



Difference




Plot component time frequency -- pop_newtimef()
Component number
1
Sub epoch time limits [min max] (msec)
-1000 1996
Use 200 time points
Frequency limits [min max] (Hz) or se
Baseline limits [min max] (msec) (0->p
Wavelet cycles [min max/fact] or sequ
ERSP color limits [max] (min=-max)
ITC color limits [max]
Bootstrap significance level (Ex: 0.01 ->
Optional newtimef() arguments (see H
Plot Event Related Spectral Power
Cancel
File Edit Tools
#2: face
Filename: r
Channels p
Frames per
Epochs
Events
Sampling rat
Epoch start (
Epoch end (s
Average refe
Channel loca
ICA weights
Dataset size
ERP map series
Sum/Compare ERPs
Component activations (scroll)
Component spectra and maps
Component maps
Component properties
Component ERP image
Component ERPs
Sum/Compare comp. ERPs
Data statistics
Time-frequency transforms
Average time-frequency
Cluster dataset ICs
Chan
Chan
Component time-frequency
Component cross-coherence
Figure 2
File Edit View Insert Tools Desktop Window Help
Component 1 power and inter-trial phase coherence (faces, epochs)
ERSP(dB)
Frequency (Hz)
50
40
30
20
10
20 40
dB
5
0
-5
-500
0
500
1000
1500
Time (ms)
ITC
0.4
0.2
0
0.05 0.15
ERP
6
-4

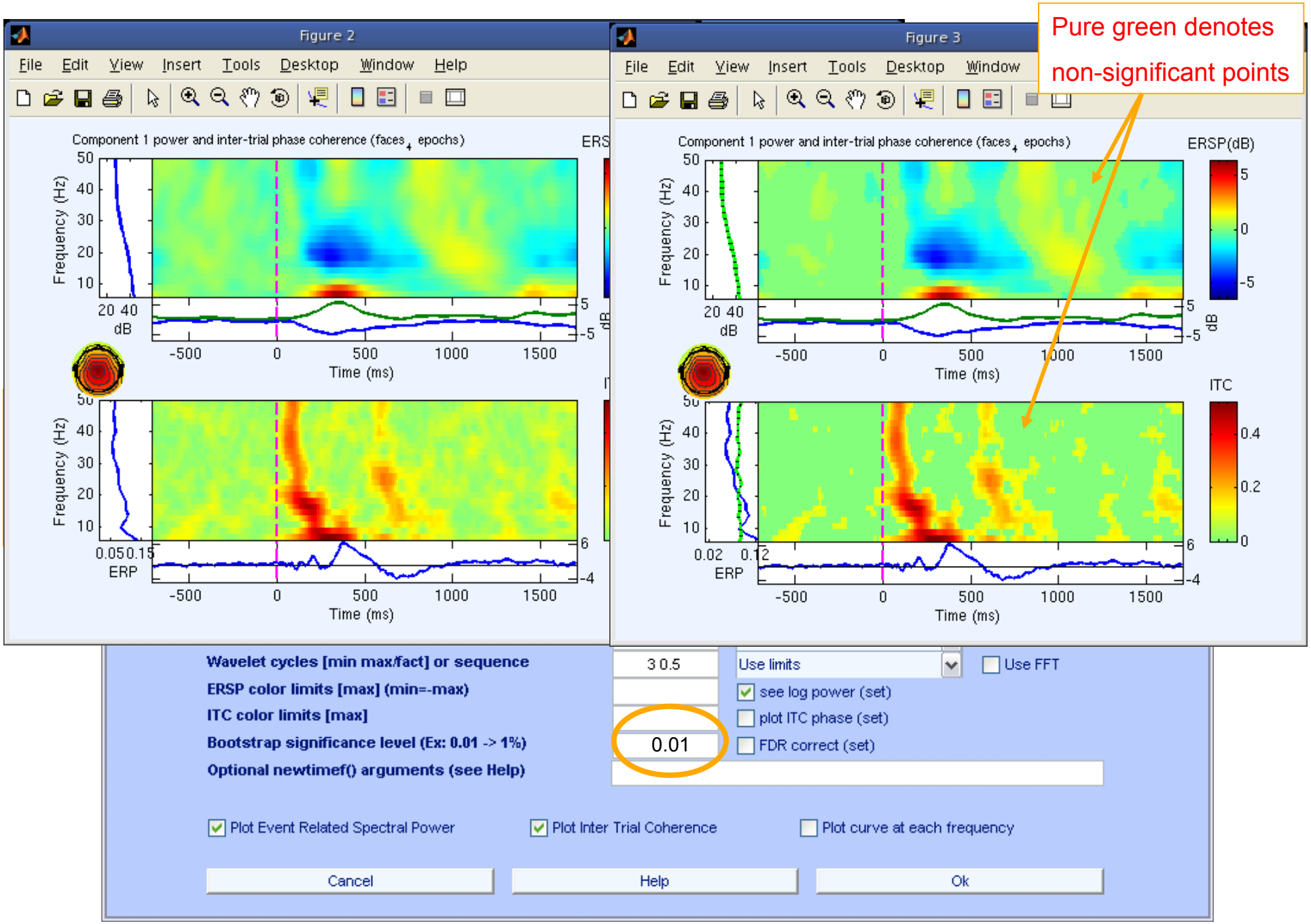
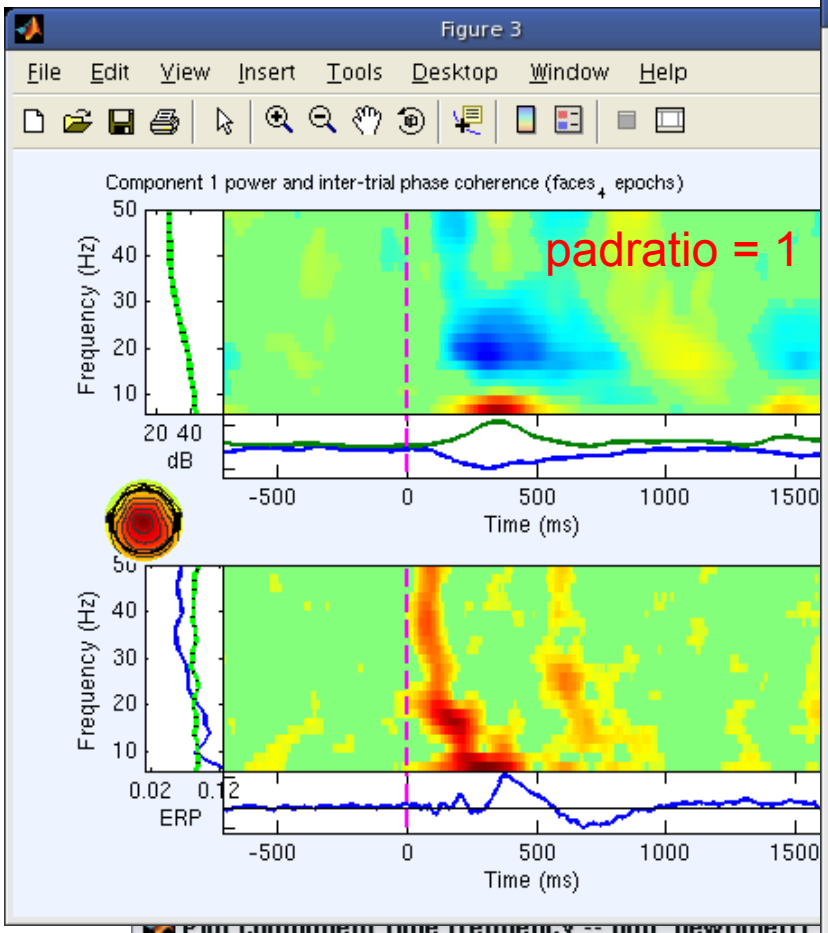
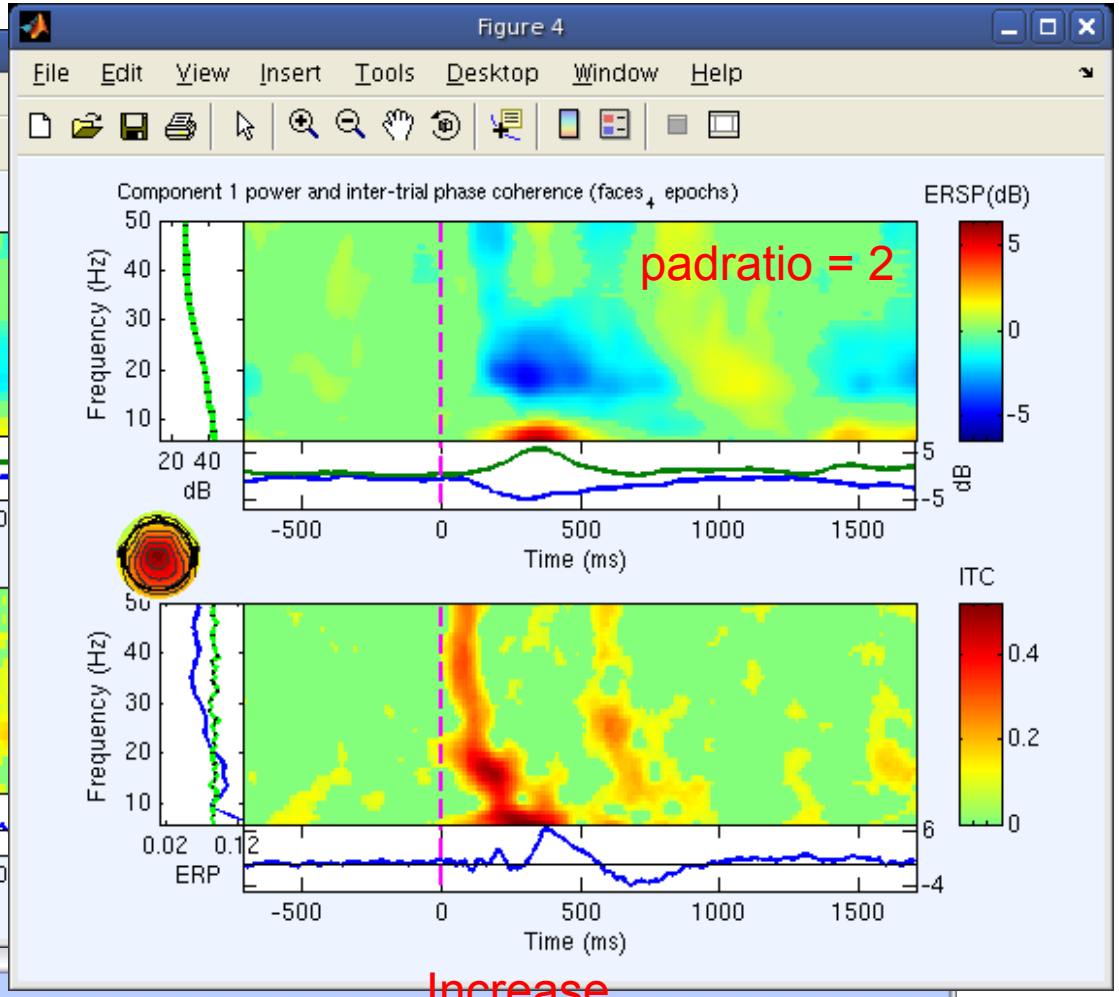
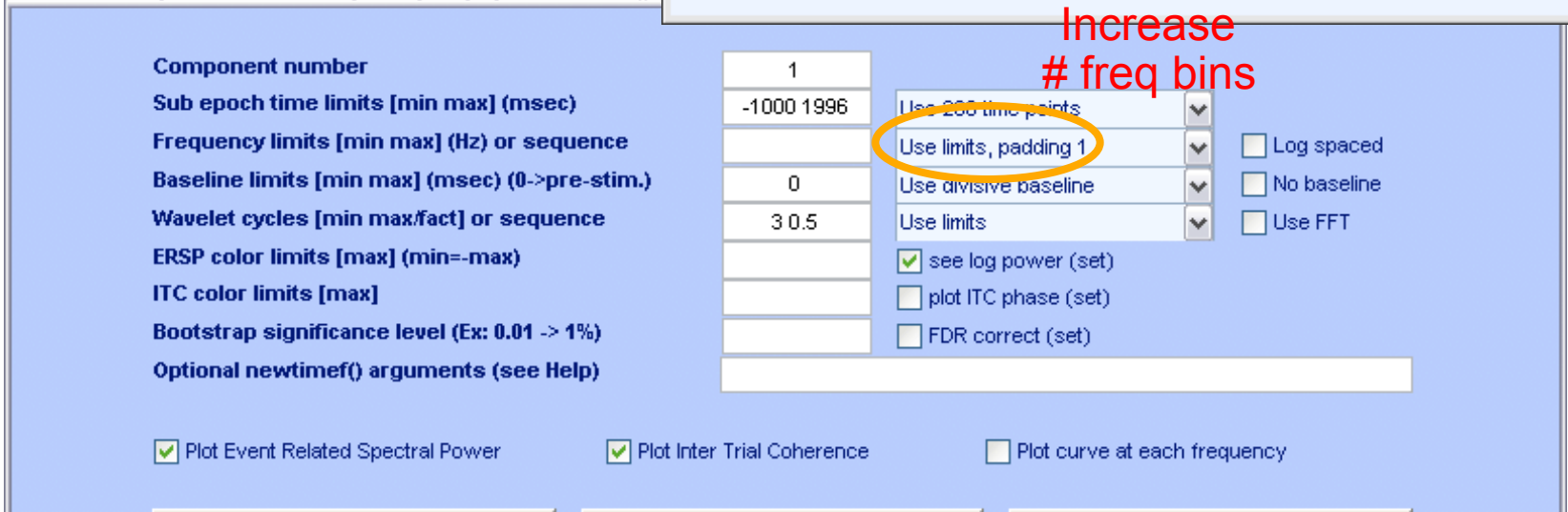


Figure 2
File Edit View Insert Tools Desktop Window Help
Component 1 power and inter-trial phase coherence (faces4 epochs)
Frequency (Hz)
Time (ms)
ERP
dB
Figure 3
File Edit View Insert Tools Desktop Window
Component 1 power and inter-trial phase coherence (faces4 epochs)
ERSP(dB)
ITC
Pure green denotes non-significant points
Wavelet cycles [min max/fact] or sequence
3 0.5
Use limits
Use FFT
ERSP color limits [max] (min=-max)
see log power (set)
ITC color limits [max]
plot ITC phase (set)
Bootstrap significance level (Ex: 0.01 -> 1%)
0.01
FDR correct (set)
Optional newtimef() arguments (see Help)
Plot Event Related Spectral Power
Plot Inter Trial Coherence
Plot curve at each frequency
Cancel
Help
Ok

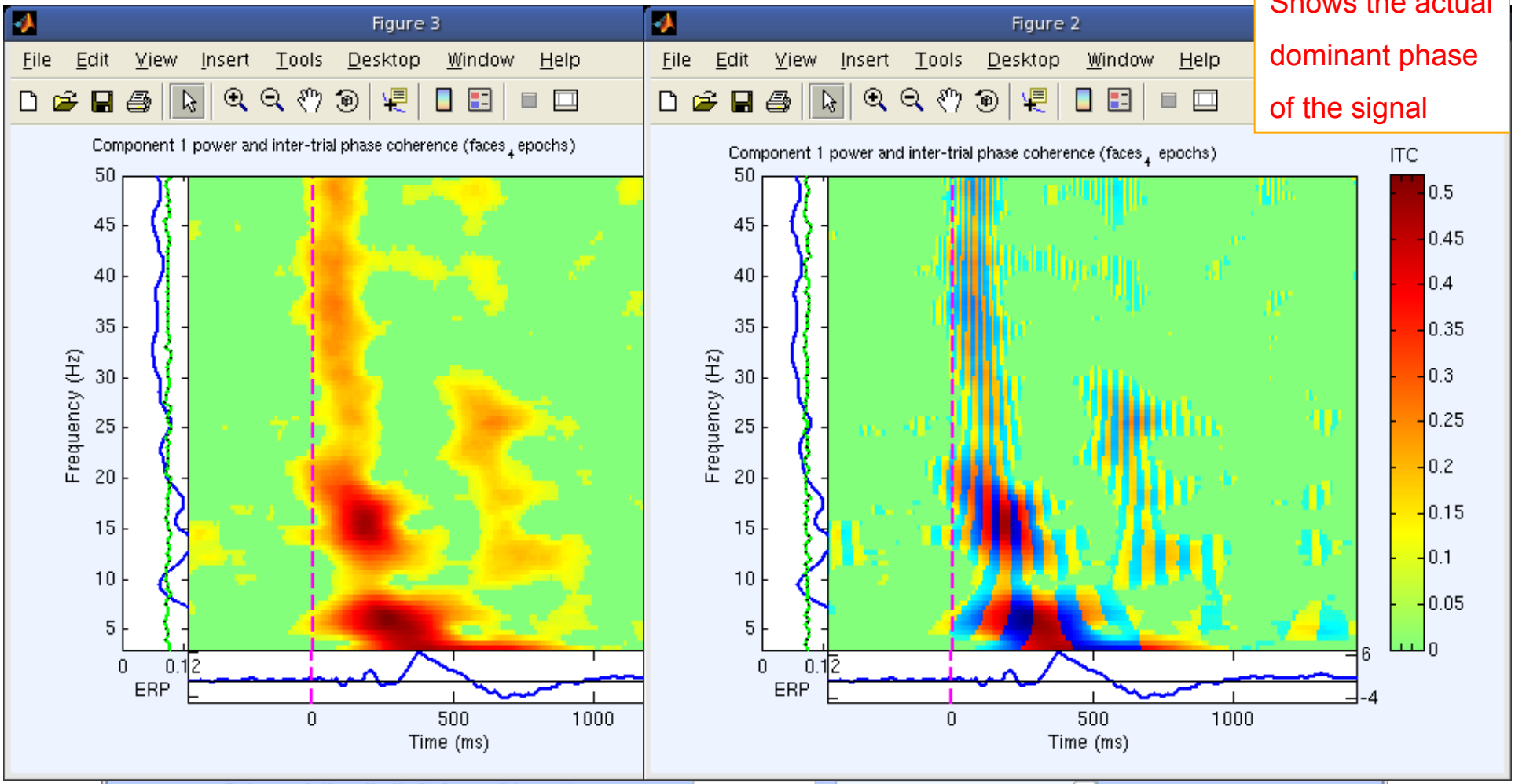




Increase
freq bins



Shows the actual dominant phase of the signal

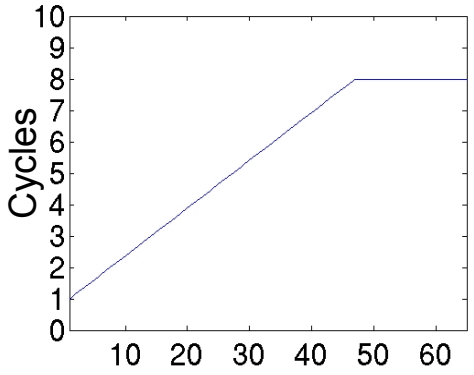


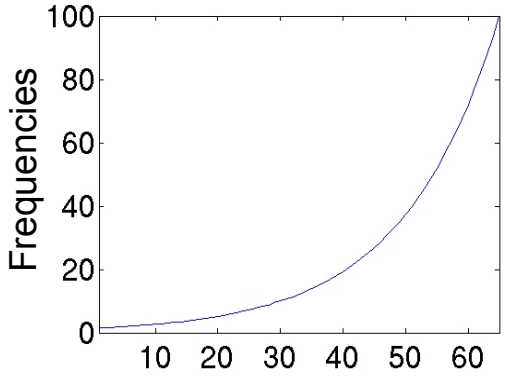
Sub epoch time limits [min max] (msec)	-1000 1996	Use 200 time points	
Frequency limits [min max] (Hz) or sequence		Use limits, padding 1	Log spaced
Baseline limits [min max] (msec) (0->pre-stim.)	0	Use divisive baseline	No baseline
Wavelet cycles [min max/fact] or sequence	3 0.5	Use limits	Use FFT
ERSP color limits [max] (min=-max)		see log power (set)	
ITC color limits [max]		plot ITC phase (set)	
Bootstrap significance level (Ex: 0.01 -> 1%)		FDR correct (set)	
Optional newtimef() arguments (see Help)	'plotphase', 'on'		

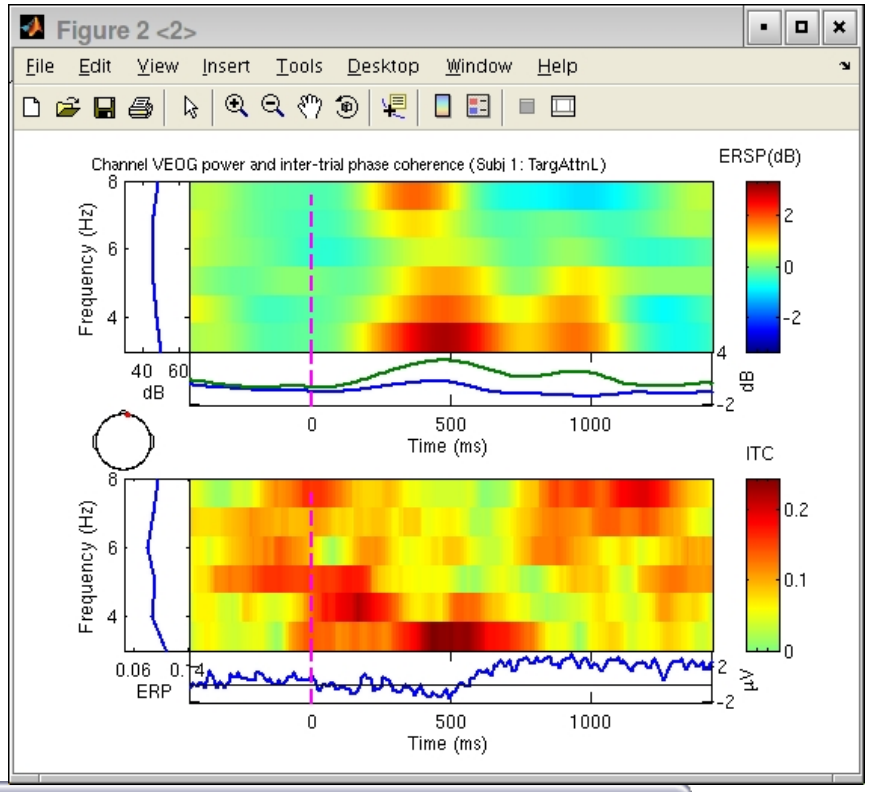
Plot Event Related Spectral Power Plot Inter Trial Coherence Plot curve at each frequency

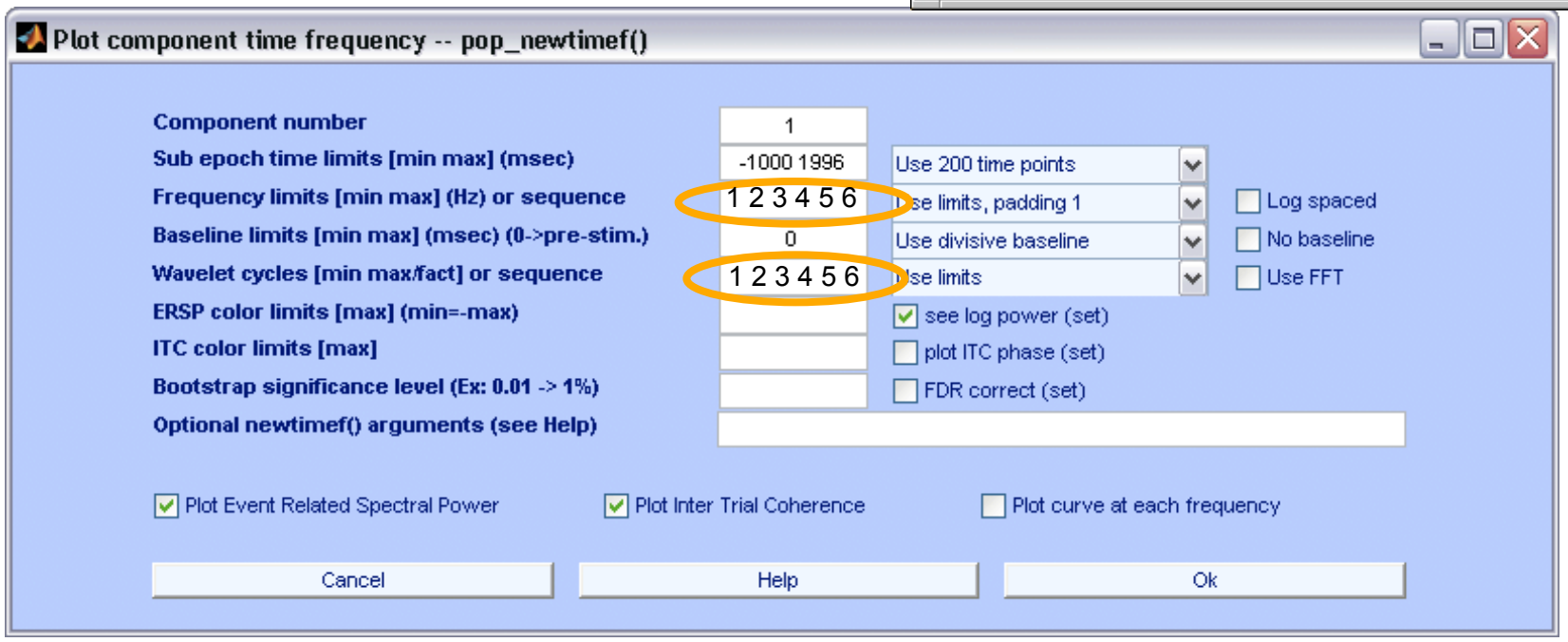
To visualize both low and high frequencies

freqs = exp(linspace(log(1.5), log(100), 65));
cycles = [linspace(1, 8, 47) ones(1,18)*8];

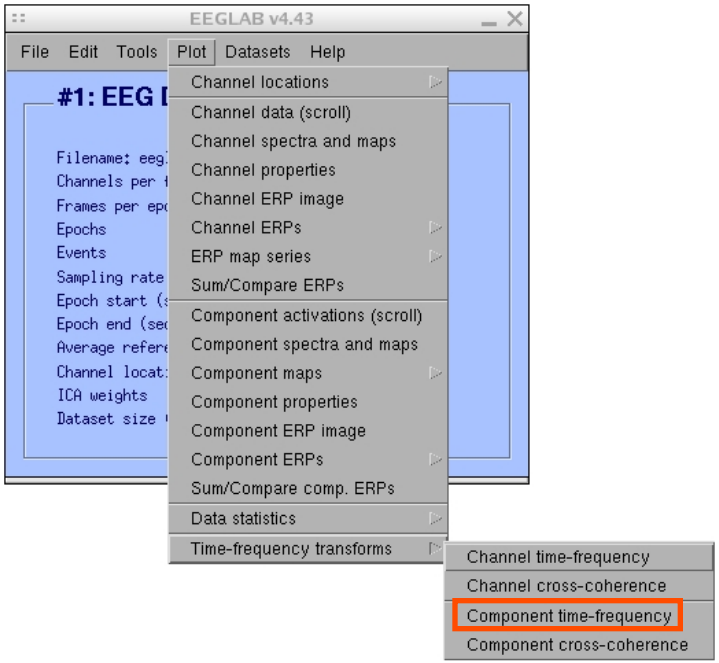


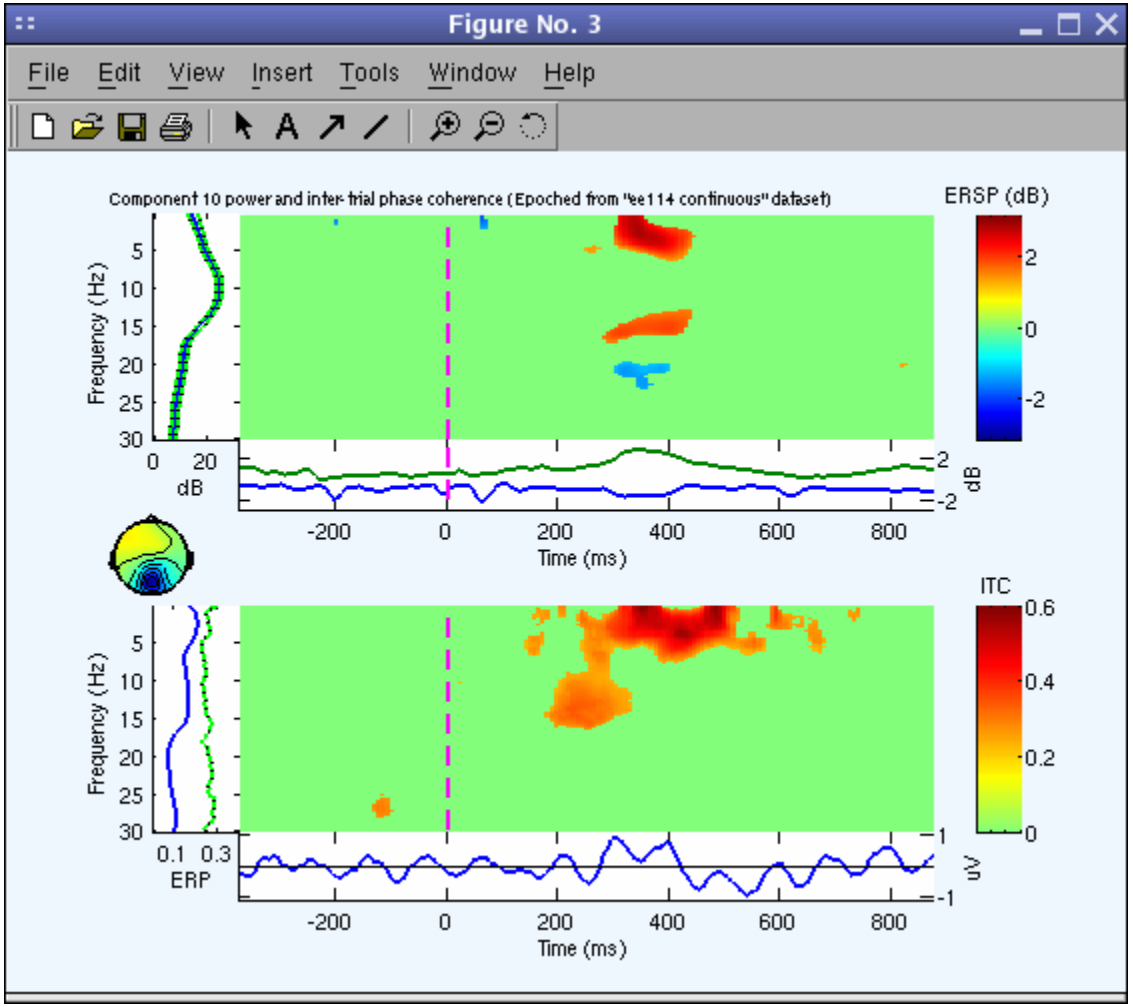




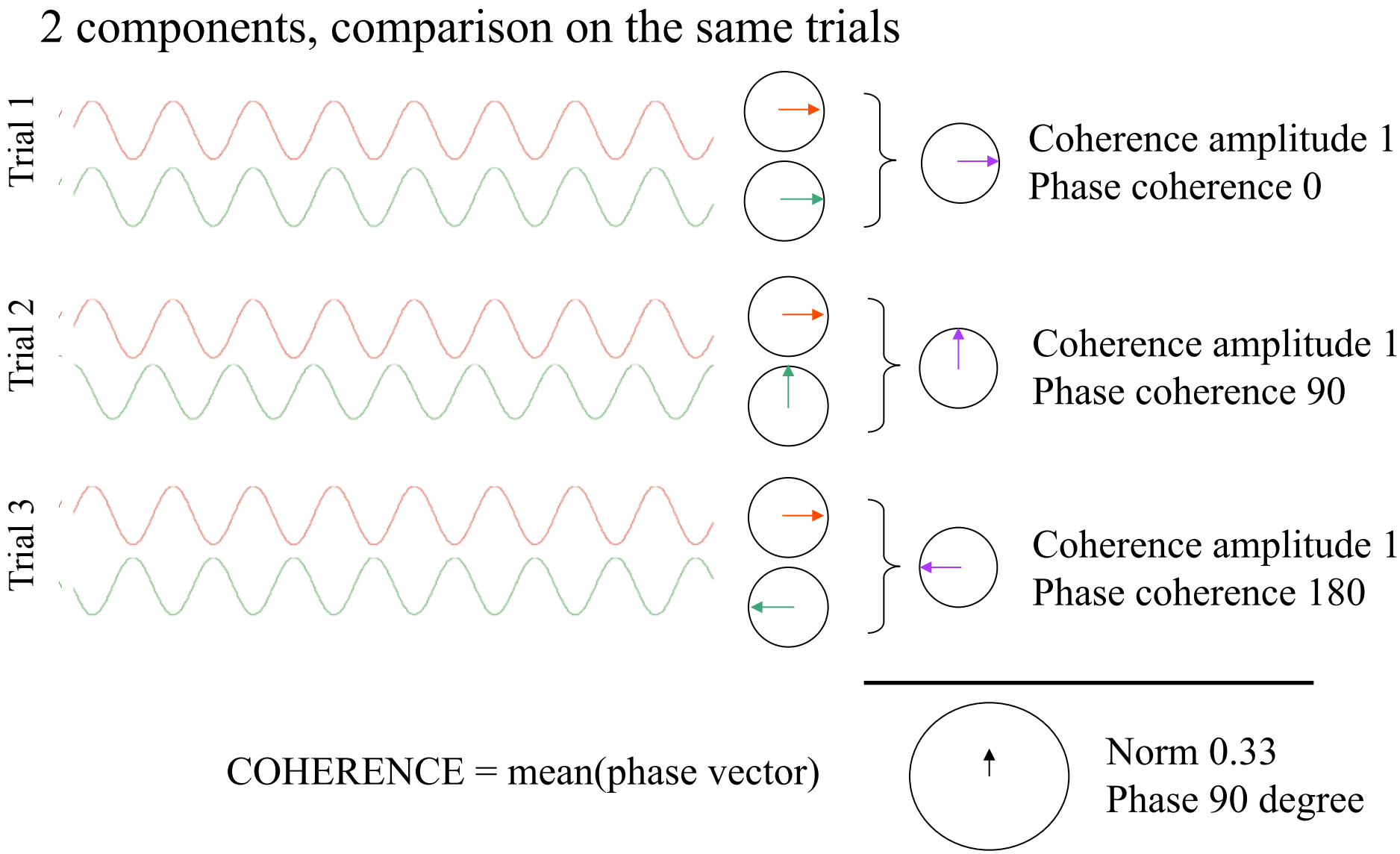


Component time-frequency





Cross-coherence amplitude and phase



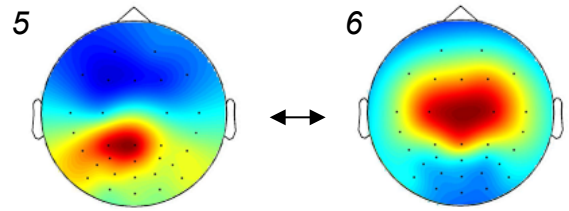
Phase coherence (default)

$$ERPCOH^{a,b}(f,t) = \frac{1}{n}\sum_{k=1}^{n}\frac{F_k^a(f,t)F_k^b(f,t)^*}{\left|F_k^a(f,t)\right|\left|F_k^b(f,t)\right|}$$

Only phase information component b

Only phase information component a

Cross-coherence amplitude and phase

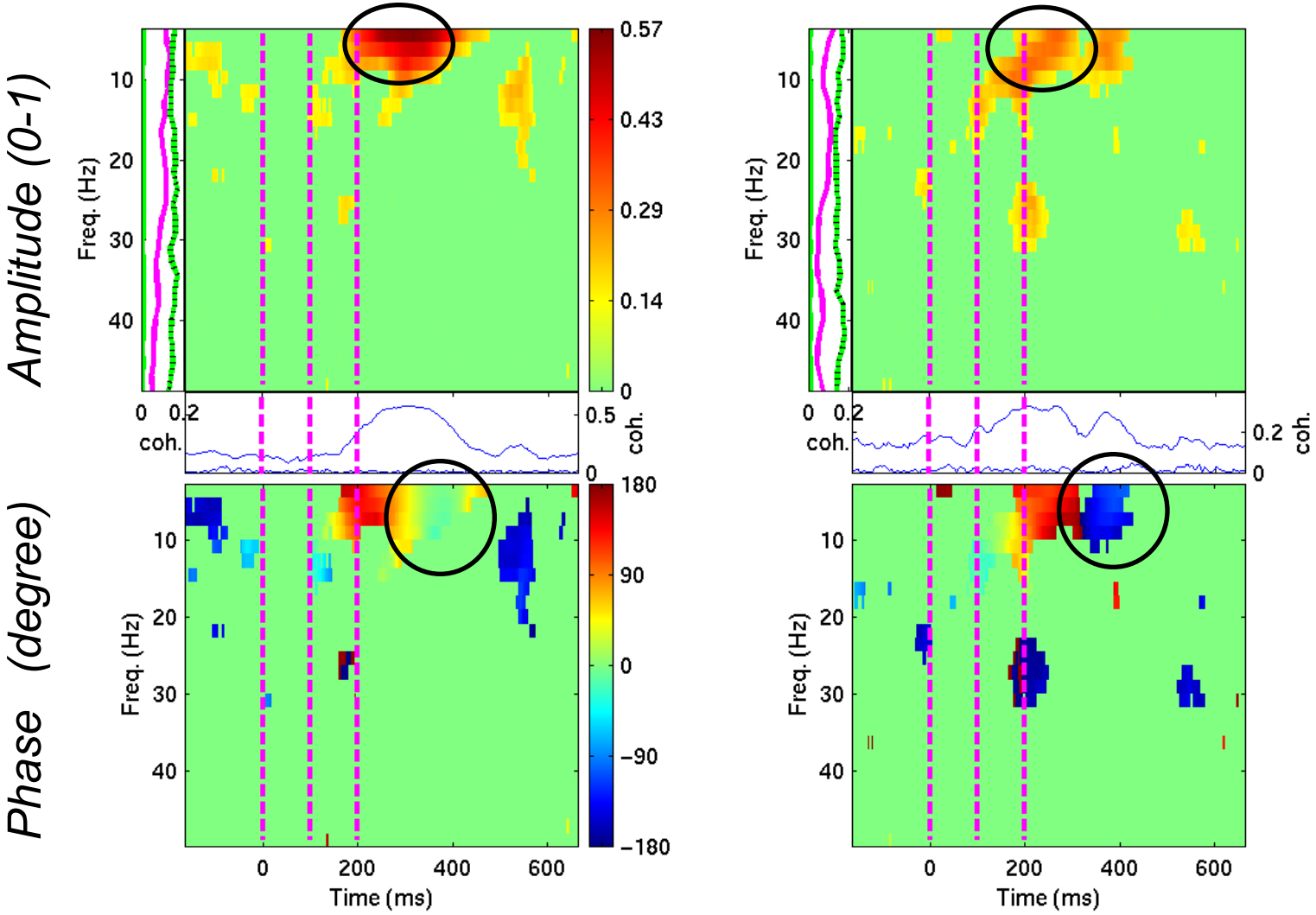


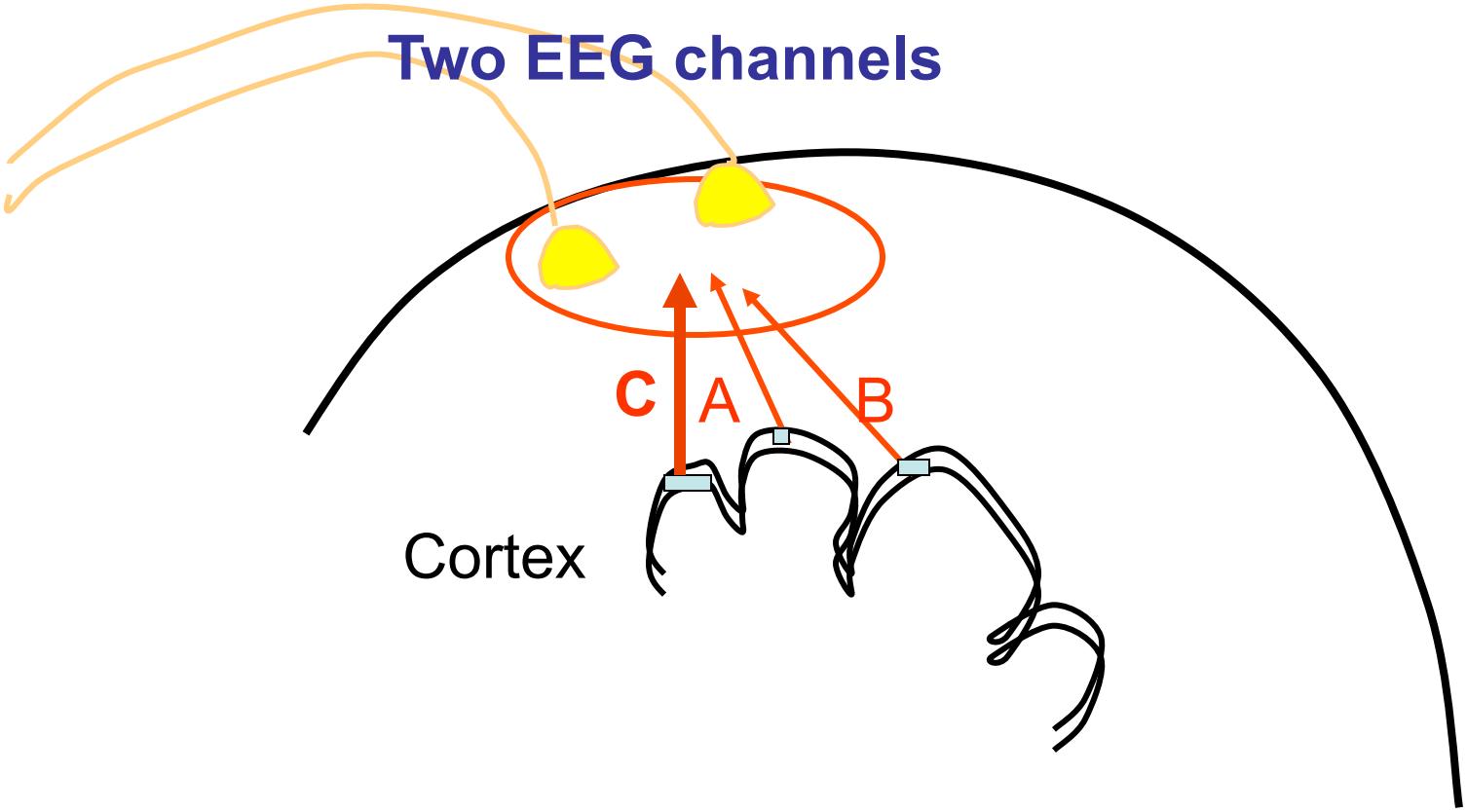
Animal picture

Distractor picture

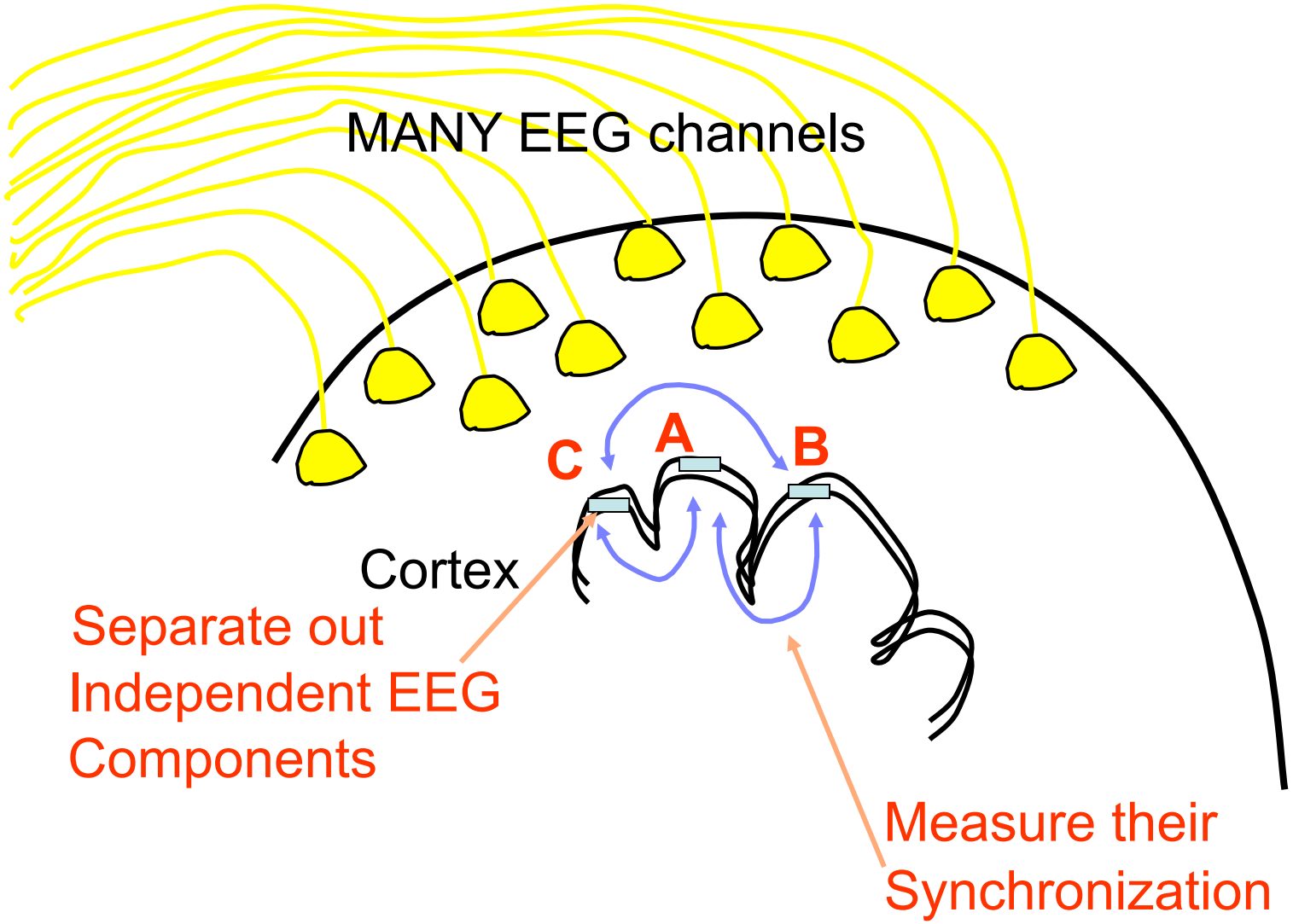
Amplitude (0-1)

Phase (degree)



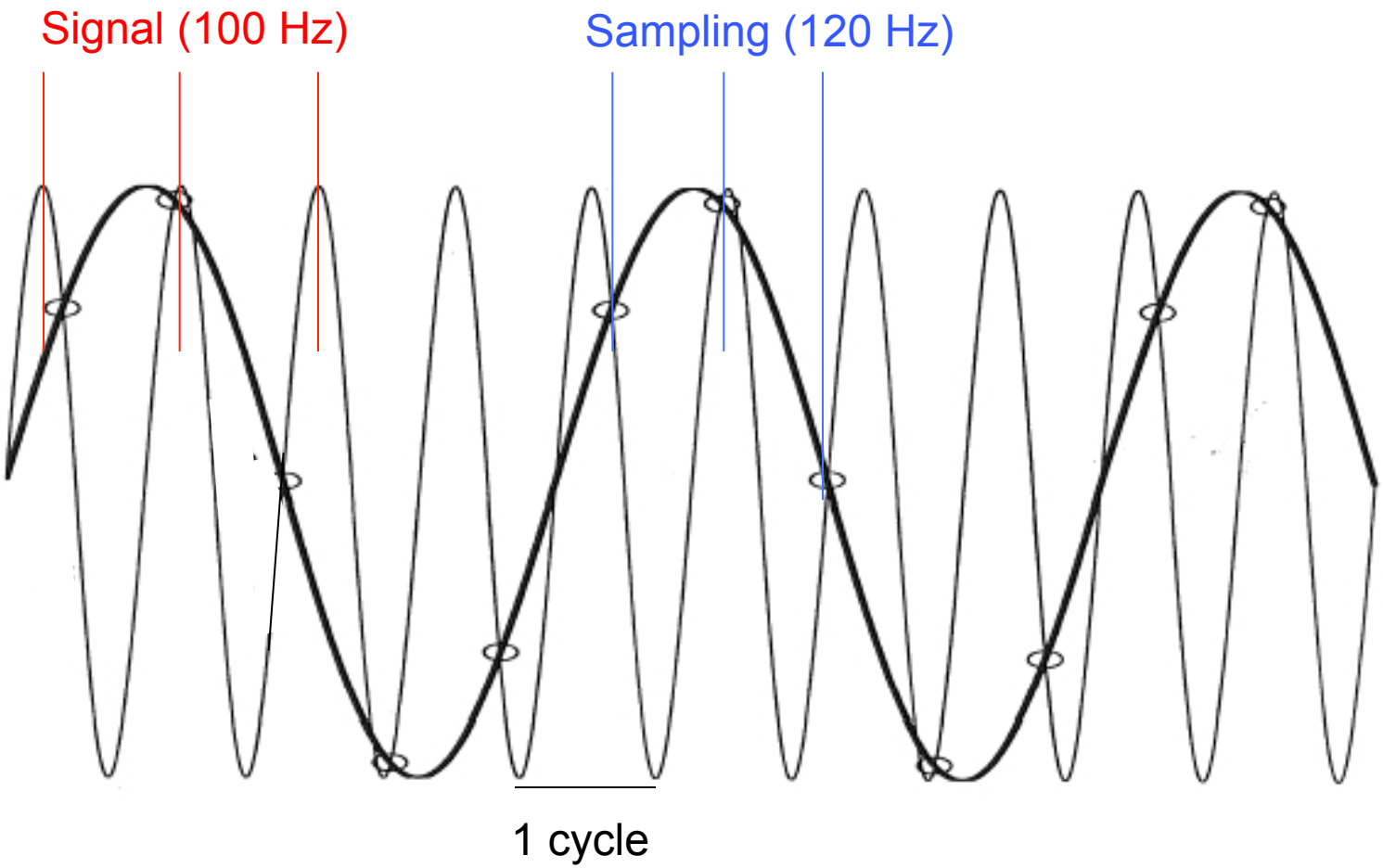


Scalp channel coherence → source confounds!



source dynamics!

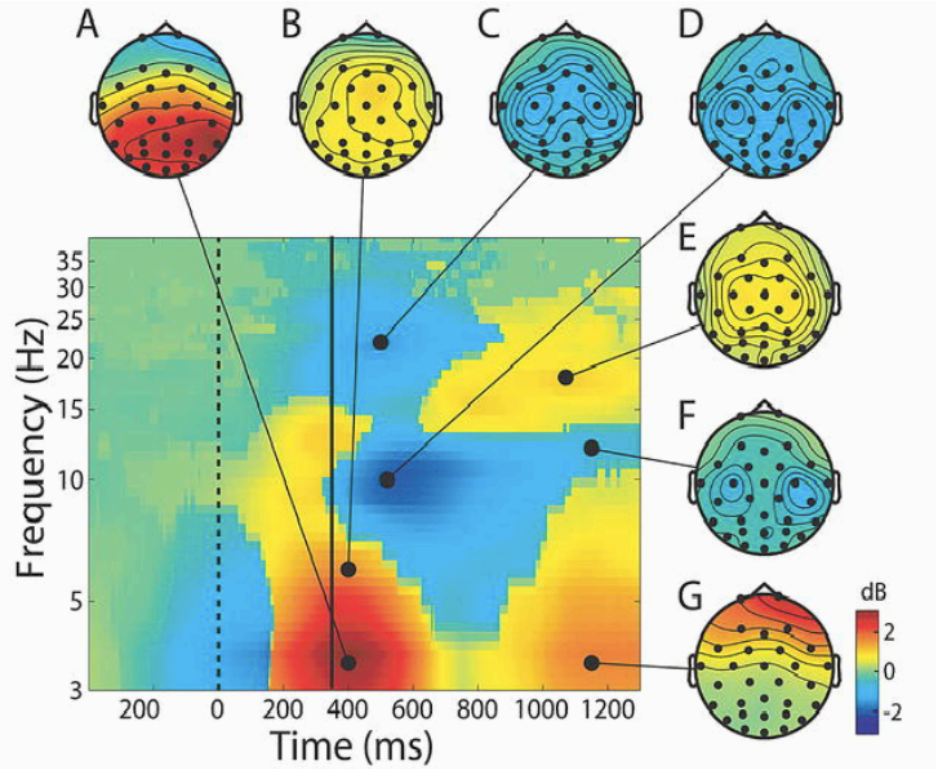
Niquist frequency: Aliasing



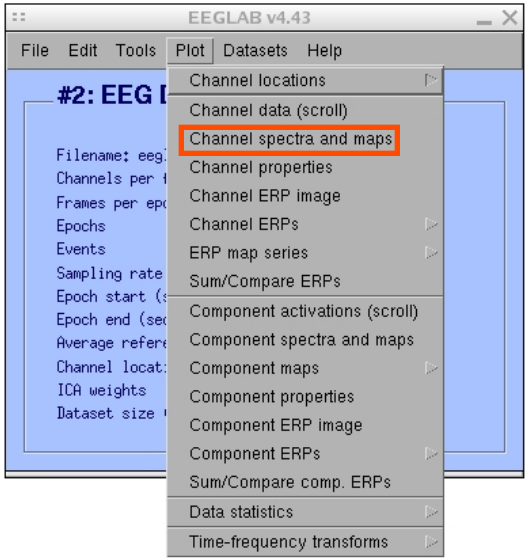
e.g. 100 Hz sampled at 120 Hz

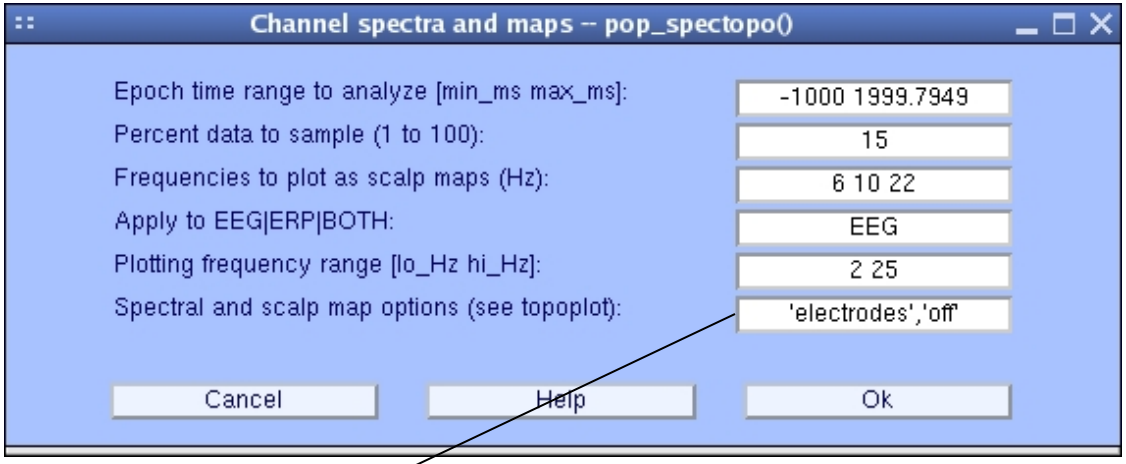
Advanced time-frequency functions

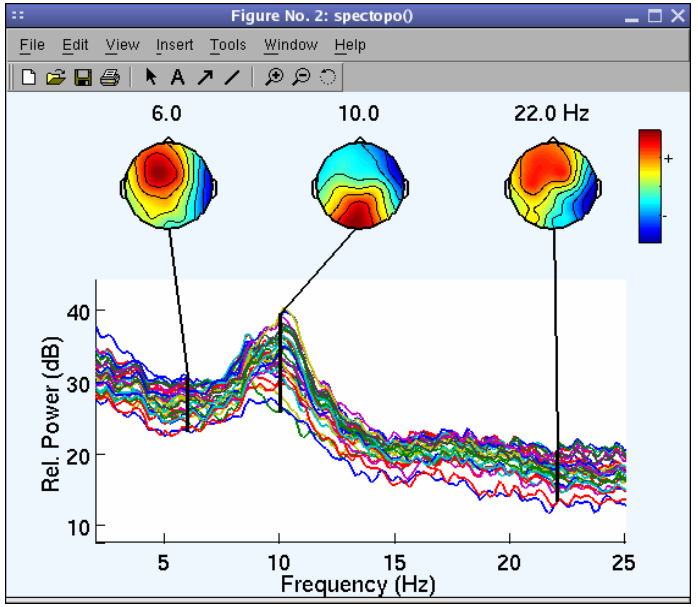
- Tftopo(): allow visualizing time-frequency power distribution over the scalp



Plot data spectrum using EEGLAB







'winsize', 256 (change FFT window length)
'nfft', 256 (change FFT padding)
'overlap', 128 (change window overlap)

Exercise

- **ALL**

  Start EEGLAB, from the menu load *sample_data/eeglab_data_epochs_ica.set* or your own data (epoch, reject noise if not done already)

- **Novice**

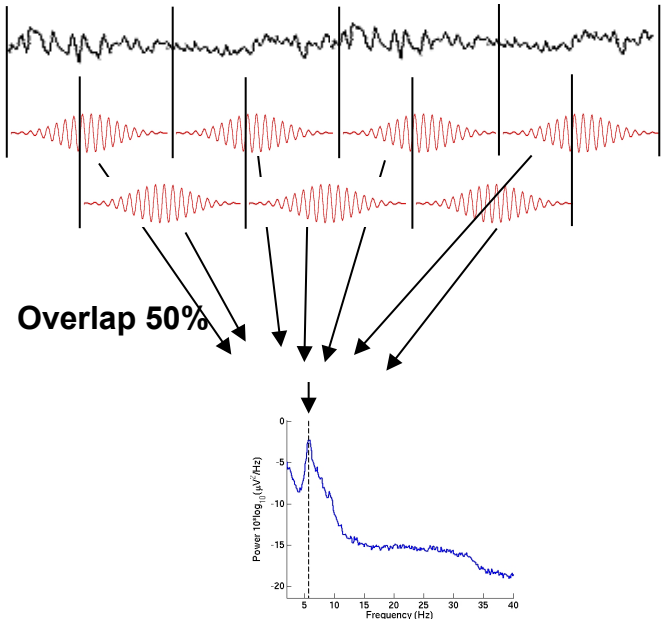
  From the GUI, Plot spectral decomposition with 100% data and 50% overlap ('overlap'). Try reducing window length ('winsize') and FFT length ('nfft')

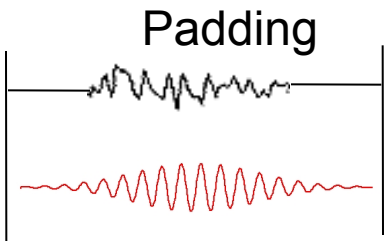
- **Intermediate**

  Same as novice but using a command line call to the *pop_spectopo()* function. Use GUI then history to see a standard call ("eegh").

- **Advanced**

  Same as novice but using a command line call to the *spectopo()* function.





Exercise - newtimef

- **Novice**

  From the GUI, pick an interesting IC and plot component ERSP. Try changing parameters window size, number of wavelet cycles, padratio,

- **Intermediate**

  From the command line, use newtimef() to tailor your time/ frequency output to your liking. Look up the help to try not to remove the baseline, change baseline length and plot in log scale. Enter custom frequencies and cycles (2 slides back).

- **Advanced**

  Compare FFT, the different wavelet methods (see help), and multi-taper methods (use timef function not newtimef). Enter custom frequencies and cycles. Look up newtimef help to compare conditions. Vizualise single-trial timef-frequency power using erpimage.