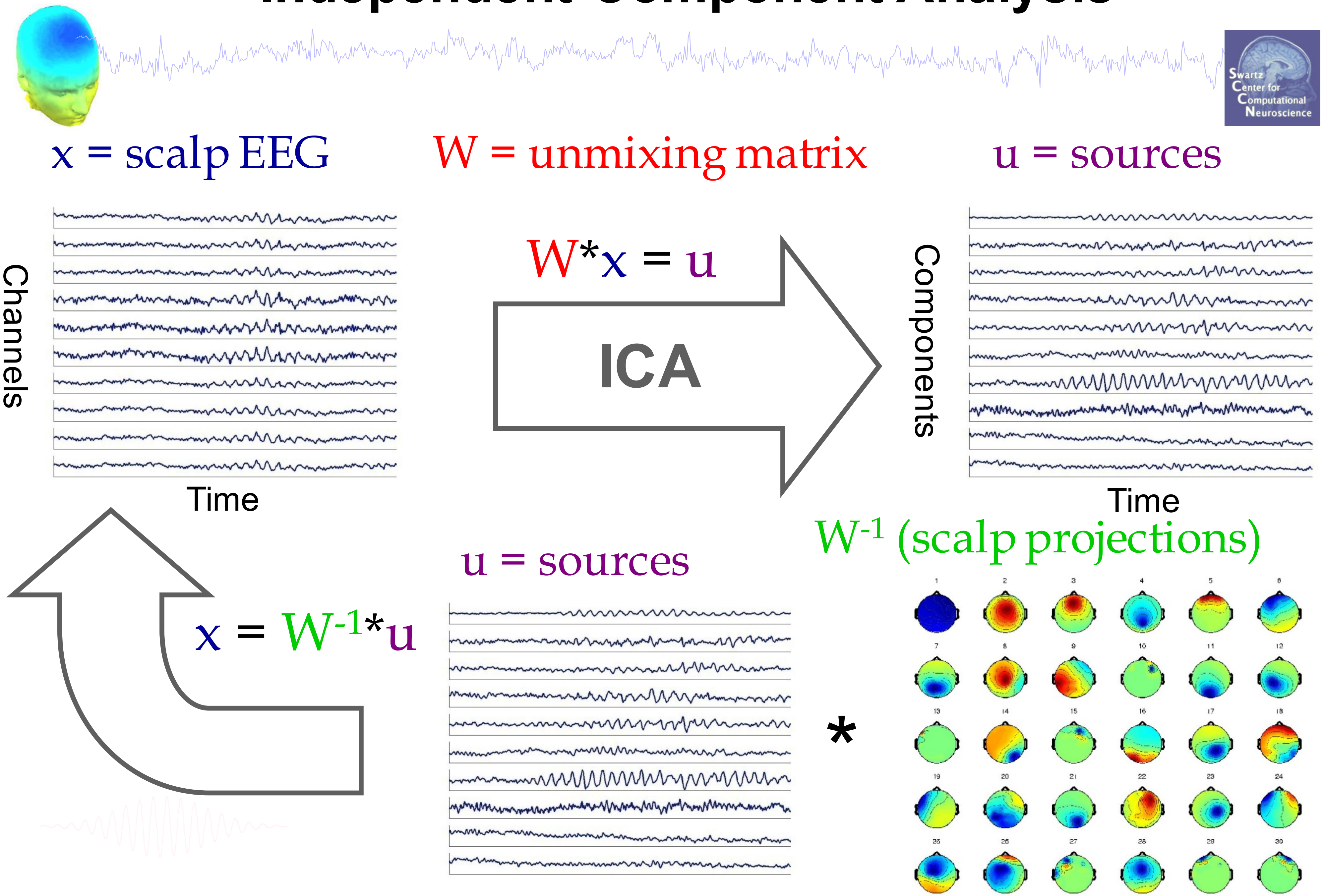
ICA Decomposition of EEG Data & Evaluating ICA Components

EEGLAB Workshop XXI

Santa Margherita Ligure, Italy

Day 1

Independent Component Analysis



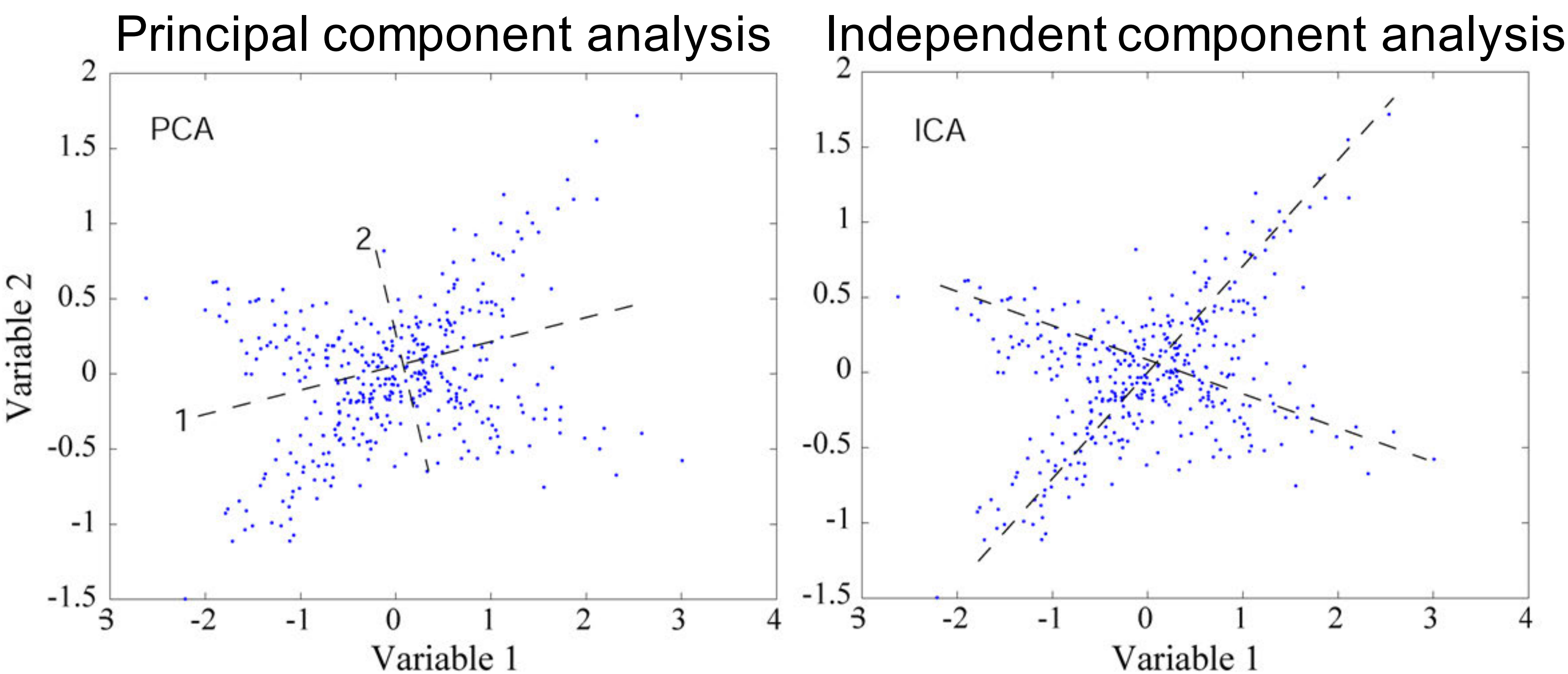
Review: ICA in Plain English

Source activation = unmixing * Channel data

Channel data = mixing (topo) * Source activation

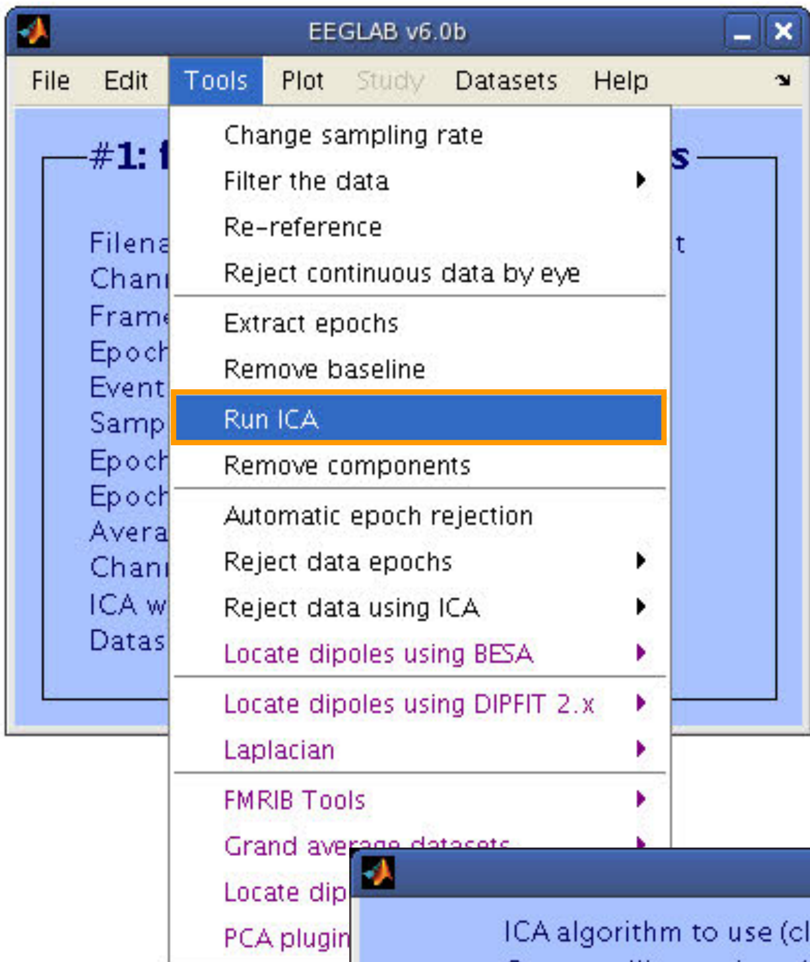
ICA and PCA

ICA is a method to recover a version of the original sources by multiplying the data by a unmixing matrix,



While PCA simply decorrelates the outputs (using an orthogonal mixing matrix), ICA attempts to make the outputs **statistically independent**, while placing no constraints on the mixing matrix.

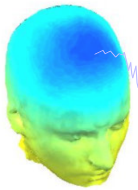
Finally: ICA options



Option	Default	Comments
'extended'	0	1 is recommended to find sub-gaussians
'stop'	1e-7	final weight change → stop
'lrate'	determined from data	too small → too long… too large → wts blow up
'maxsteps'	512	more channels → more steps
'pca'	0 or EEG.nbchan	Decompose only a principal data subspace

Other algorithms: binica, amica, cudaica, beamica

Runica progress…



Press Button to interupt runica

Interupt

csh

```
Input data size [33,133175] = 33 channels, 133175 frames/nFinding 33 ICA components using extended ICA.
Kurtosis will be calculated initially every 1 blocks using 6000 data points.
Decomposing 122 frames per ICA weight ((1089)^2 = 133175 weights, Initial learning rate will be 0.001, block size
Learning rate will be multiplied by 0.98 whenever angledelta >= 60 deg.
More than 32 channels: default stopping weight change 1E-7
Training will end when wchange < 1e-07 or after 512 steps.
Online bias adjustment will be used.
Removing mean of each channel ...
Final training data range: -171.806 to 179.094
Computing the sphering matrix...
Starting weights are the identity matrix ...
Sphering the data ...
Beginning ICA training ... first training step may be slow ...
step 1 - lrate 0.001000, wchange 16.85061324, angledelta  0.0 deg
step 2 - lrate 0.001000, wchange 0.26760405, angledelta  0.0 deg
step 3 - lrate 0.001000, wchange 0.79058323, angledelta 104.0 deg
step 4 - lrate 0.000980, wchange 0.66700031, angledelta 147.2 deg
step 5 - lrate 0.000960, wchange 0.62849071, angledelta 146.5 deg
step 6 - lrate 0.000941, wchange 0.73967955, angledelta 150.7 deg
step 7 - lrate 0.000922, wchange 0.73727229, angledelta 151.6 deg
step 8 - lrate 0.000904, wchange 0.74051387, angledelta 137.9 deg
step 9 - lrate 0.000886, wchange 0.74536137, angledelta 156.0 deg
step 10 - lrate 0.000868, wchange 0.72101402, angledelta 143.7 deg
step 11 - lrate 0.000851, wchange 0.14690114, angledelta 102.5 deg
step 12 - lrate 0.000834, wchange 0.11822100, angledelta 114.3 deg
step 13 - lrate 0.000817, wchange 0.75552966, angledelta 100.6 deg
step 14 - lrate 0.000801, wchange 0.26739750, angledelta 109.1 deg
step 15 - lrate 0.000785, wchange 0.12123251, angledelta 94.2 deg
step 16 - lrate 0.000769, wchange 0.10285606, angledelta 110.7 deg
step 17 - lrate 0.000754, wchange 0.09770499, angledelta 118.6 deg
step 18 - lrate 0.000739, wchange 0.09544428, angledelta 117.1 deg
```

csh

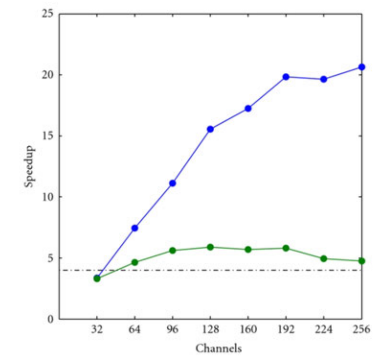
```
step 241 - lrate 0.000002, wchange 0.00000082, angledelta 101.5 deg
step 242 - lrate 0.000001, wchange 0.00000061, angledelta 96.1 deg
step 243 - lrate 0.000001, wchange 0.00000057, angledelta 97.5 deg
step 244 - lrate 0.000001, wchange 0.00000054, angledelta 93.7 deg
step 245 - lrate 0.000001, wchange 0.00000055, angledelta 100.3 deg
step 246 - lrate 0.000001, wchange 0.00000047, angledelta 96.9 deg
step 247 - lrate 0.000001, wchange 0.00000046, angledelta 91.3 deg
step 248 - lrate 0.000001, wchange 0.00000045, angledelta 101.5 deg
step 249 - lrate 0.000001, wchange 0.00000041, angledelta 103.1 deg
step 250 - lrate 0.000001, wchange 0.00000036, angledelta 95.5 deg
step 251 - lrate 0.000001, wchange 0.00000033, angledelta 92.1 deg
step 252 - lrate 0.000001, wchange 0.00000029, angledelta 97.4 deg
step 253 - lrate 0.000001, wchange 0.00000030, angledelta 95.8 deg
step 254 - lrate 0.000001, wchange 0.00000023, angledelta 94.2 deg
step 255 - lrate 0.000001, wchange 0.00000023, angledelta 97.6 deg
step 256 - lrate 0.000001, wchange 0.00000023, angledelta 97.1 deg
step 257 - lrate 0.000001, wchange 0.00000021, angledelta 92.0 deg
step 258 - lrate 0.000001, wchange 0.00000020, angledelta 99.1 deg
step 259 - lrate 0.000001, wchange 0.00000019, angledelta 95.0 deg
step 260 - lrate 0.000001, wchange 0.00000015, angledelta 98.3 deg
step 261 - lrate 0.000001, wchange 0.00000014, angledelta 99.0 deg
step 262 - lrate 0.000001, wchange 0.00000014, angledelta 94.3 deg
step 263 - lrate 0.000001, wchange 0.00000013, angledelta 95.4 deg
step 264 - lrate 0.000001, wchange 0.00000012, angledelta 94.1 deg
step 265 - lrate 0.000001, wchange 0.00000011, angledelta 96.1 deg
step 266 - lrate 0.000001, wchange 0.00000010, angledelta 94.8 deg
step 267 - lrate 0.000001, wchange 0.00000010, angledelta 94.5 deg
step 268 - lrate 0.000001, wchange 0.00000010, angledelta 97.7 deg
step 269 - lrate 0.000001, wchange 0.00000008, angledelta 95.1 deg
Sorting components in descending order of mean projected variance ...
Permuting the activation wave forms ...
>>
>>
```

Alternatives to runica

Infomax ICA

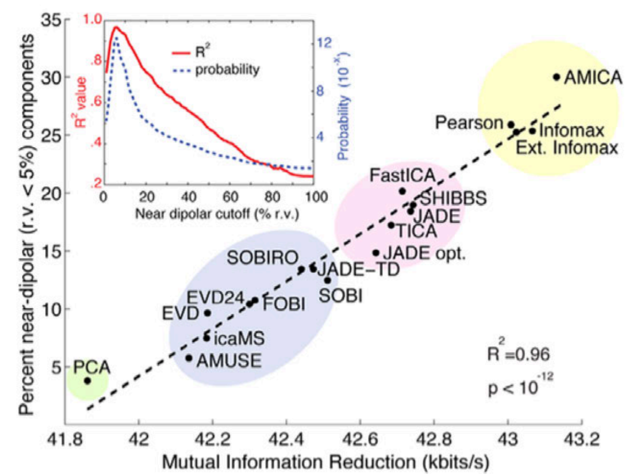
- `runica` matlab implementation
- `binica` compiled version; fast
- `cudaica` GPU version

Raimondo, et al, 2012, `https://liaa.dc.uba.ar/node/13`



AMICA

- Best at extracting dipolar ICs
- Multiple-model support



Now what…?

Part 1
Getting an overview of your ICs

Part 2
Classifying/Evaluating ICs

Part 3
Detailed look at IC properties

- ERP
- Spectrum
- ERP images
- ERSP

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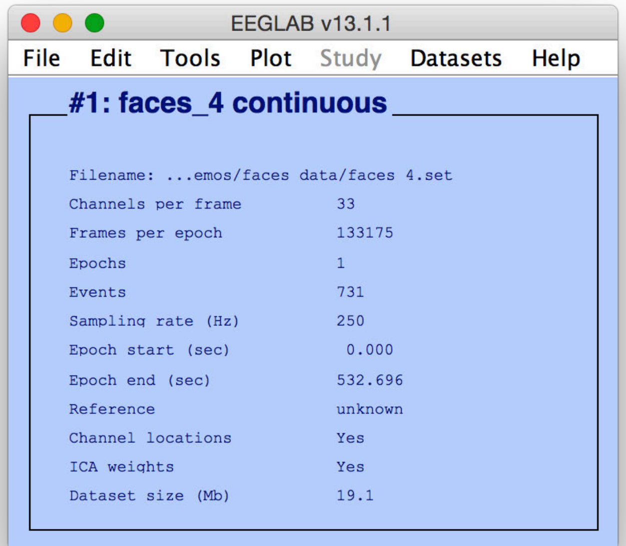
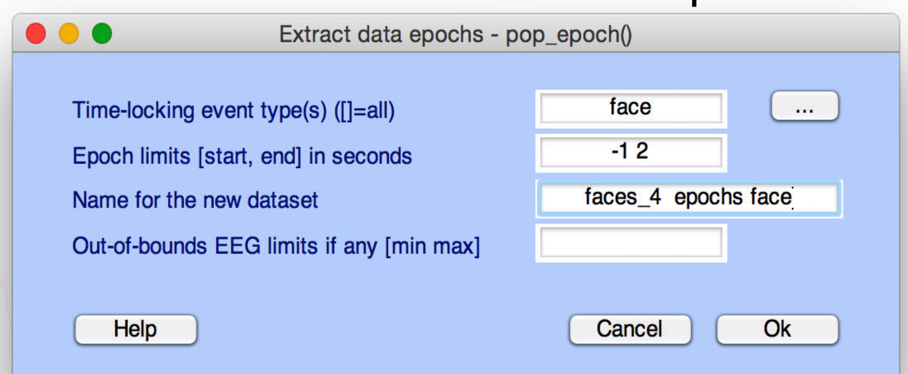
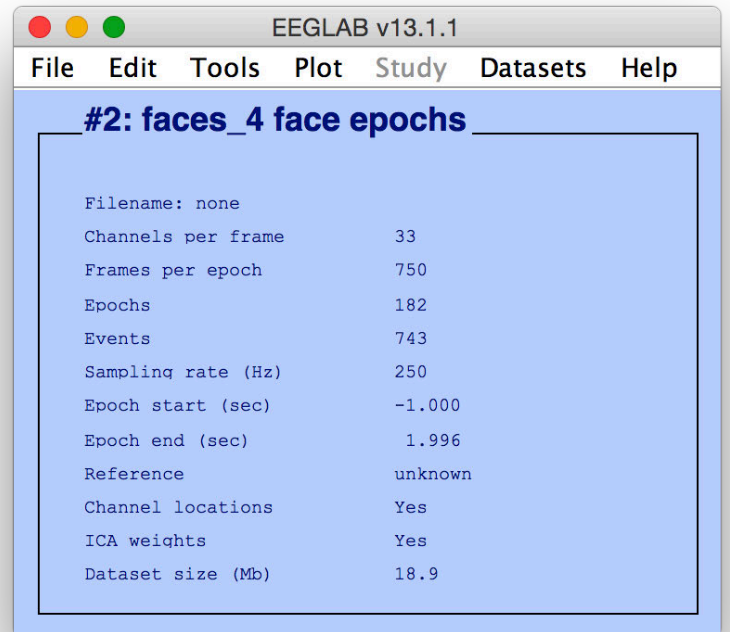
(Example Datasets)

Load: EEG_data/faces_4.set



Tools → Extract Epochs

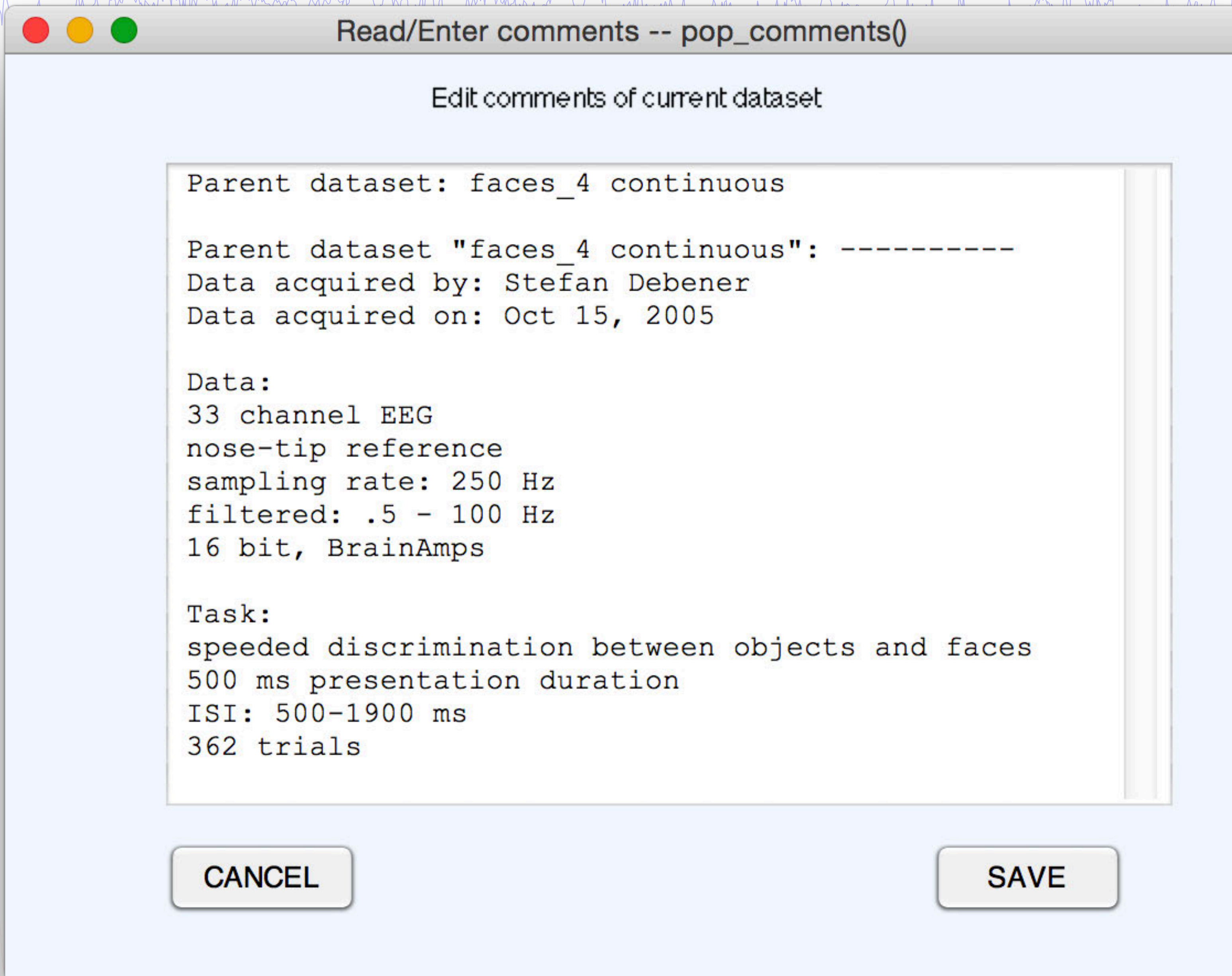




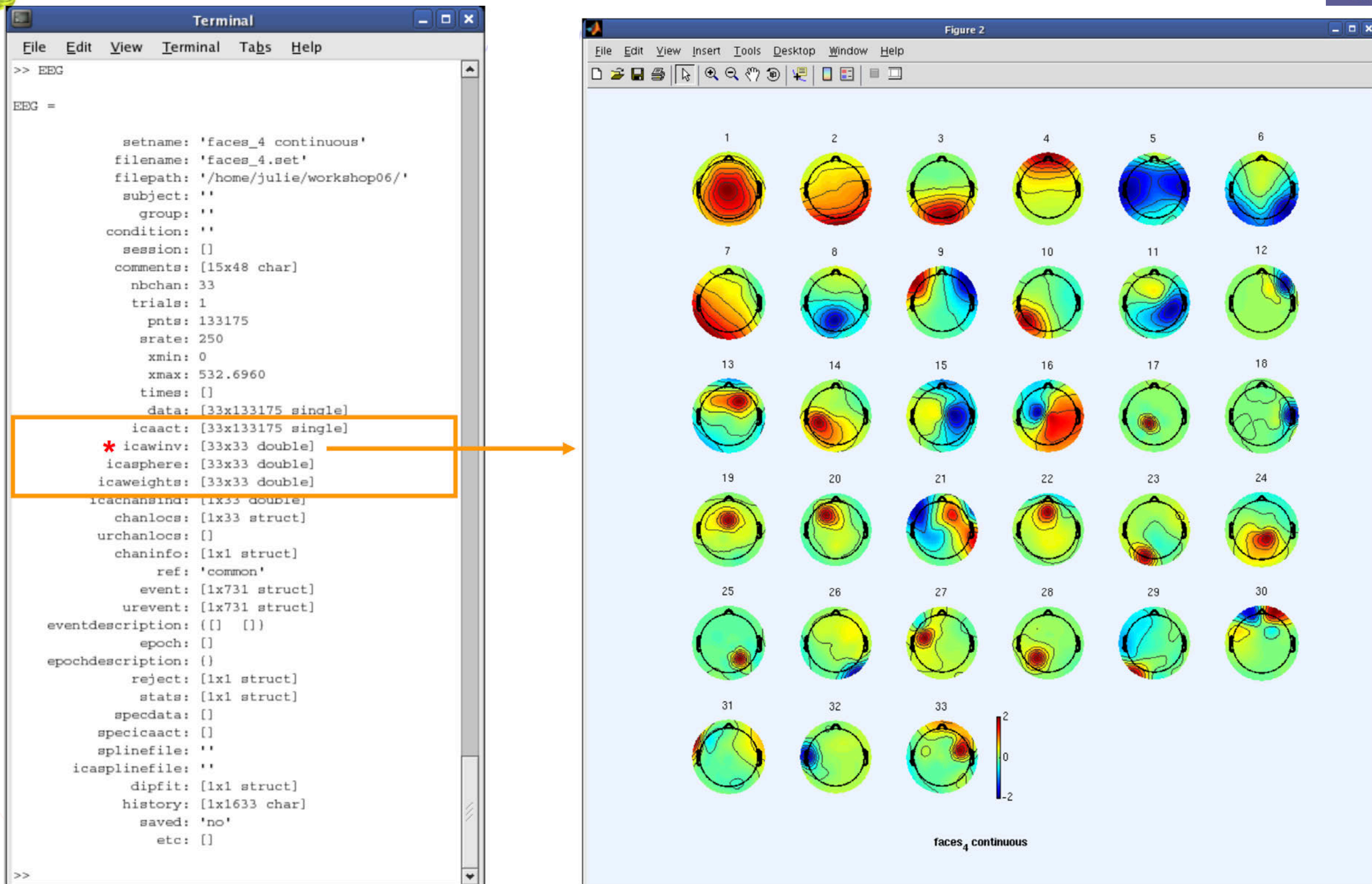
Subtract Baseline [-1000 0]

(Some other examples use stern_125Hz.set)

Edit → Dataset Info → Enter Comments



Results of ICA Decomposition in EEG struct



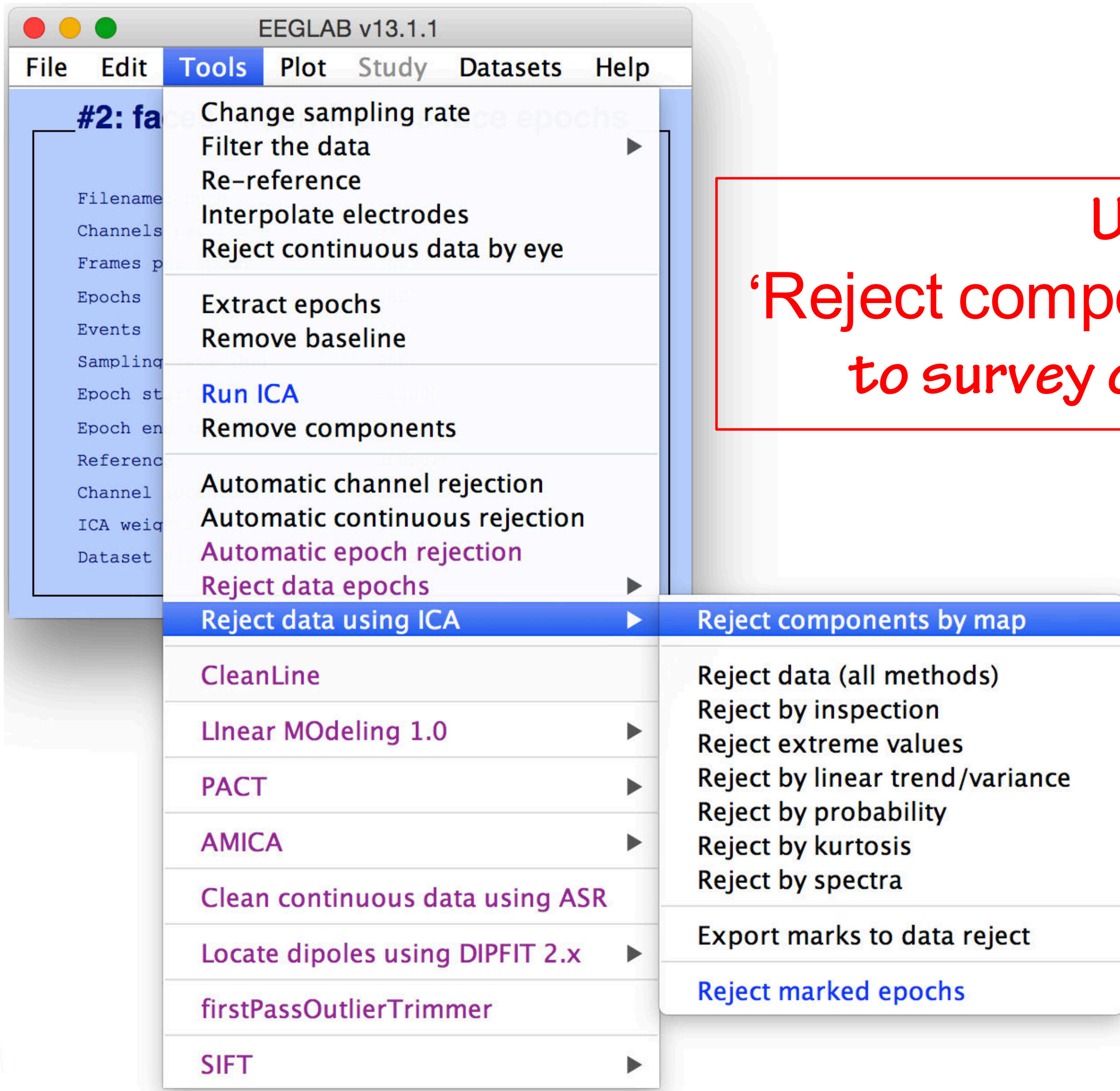
English → MATLAB

Source activation = unmixing * Channel data

Channel data = mixing (topo) * Source activation

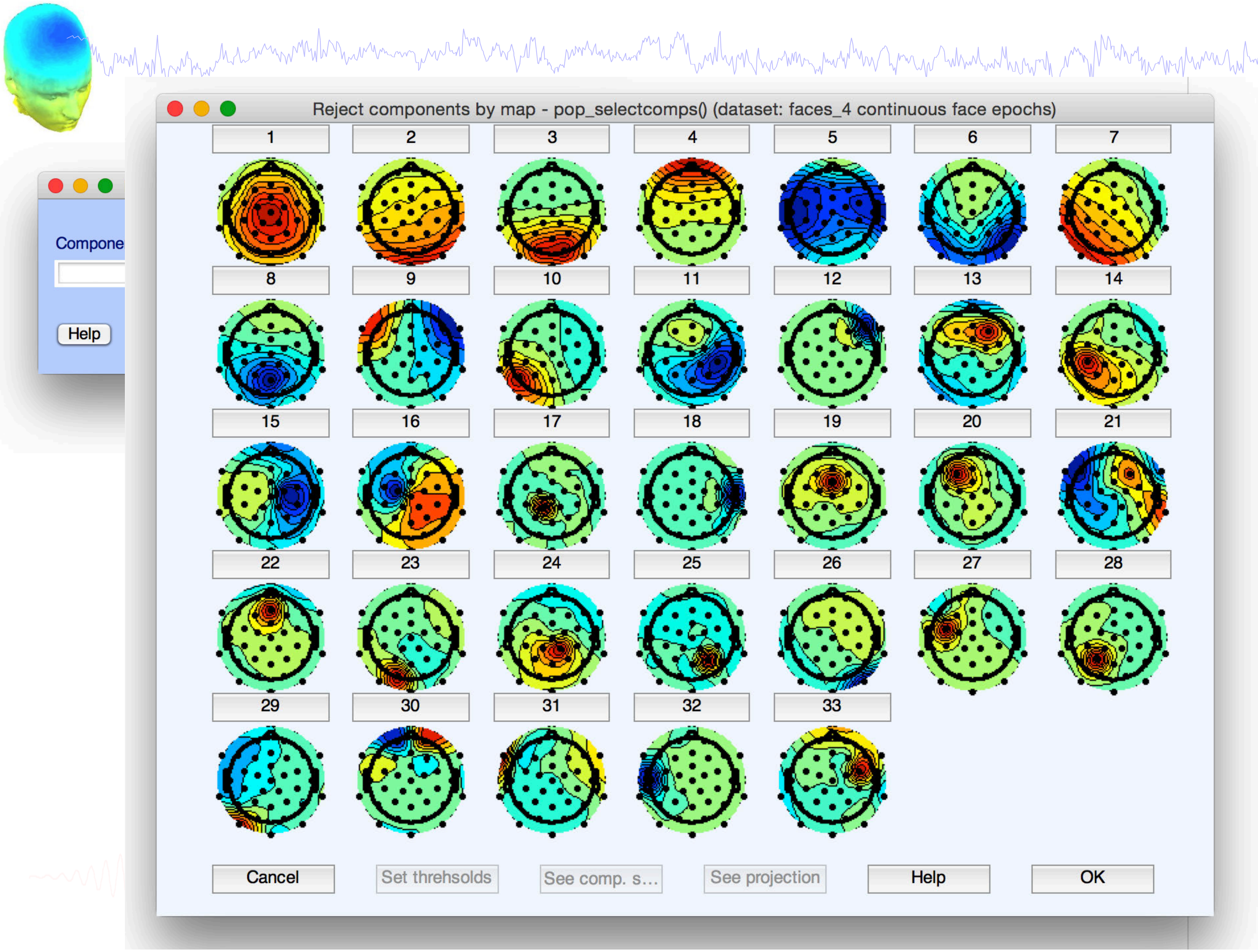
```
EEG.icaact = (EEG.icaweights*EEG.icasphere) * EEG.data

EEG.data = EEG.icawinv * EEG.icaact
```

A convenient 'trick'…

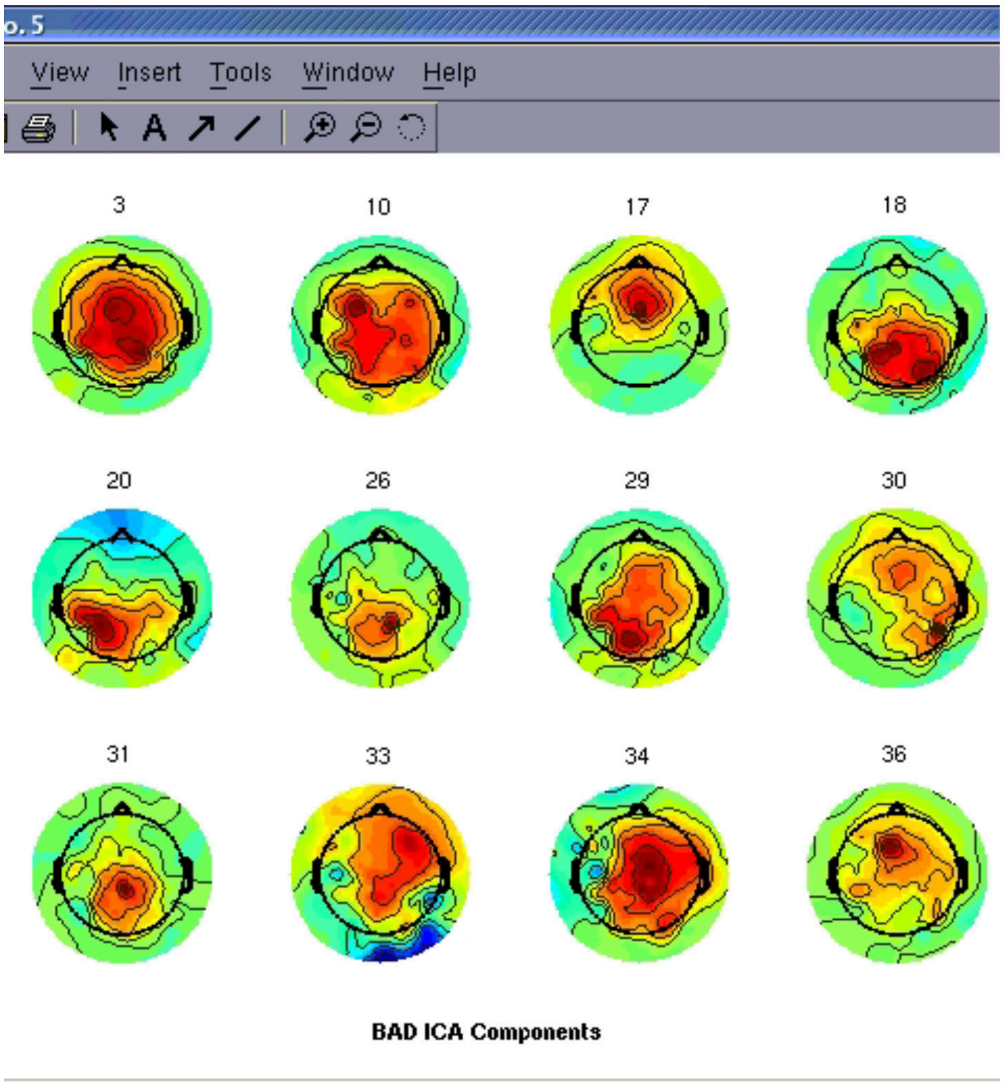


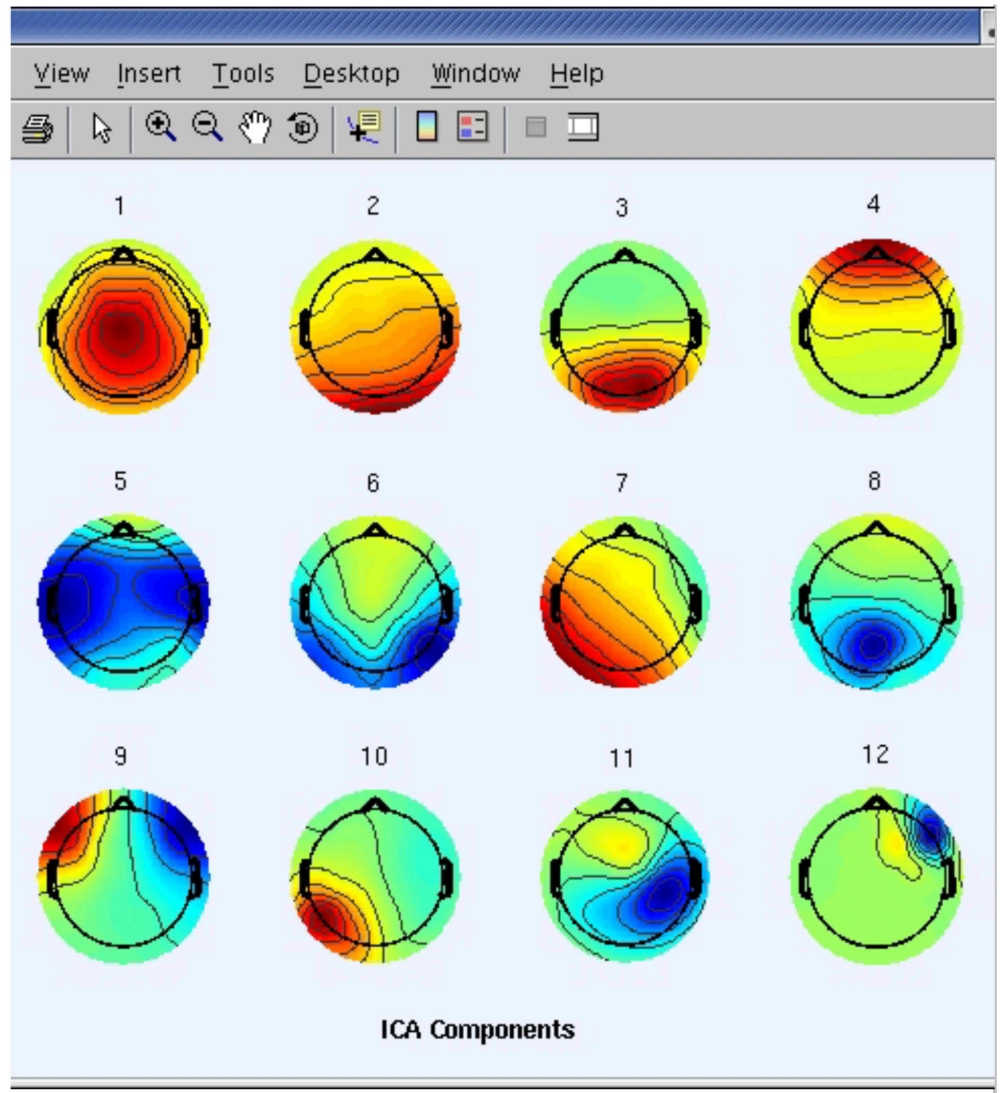
Use
'Reject components by map'
to survey components

An interactive overview of ICs

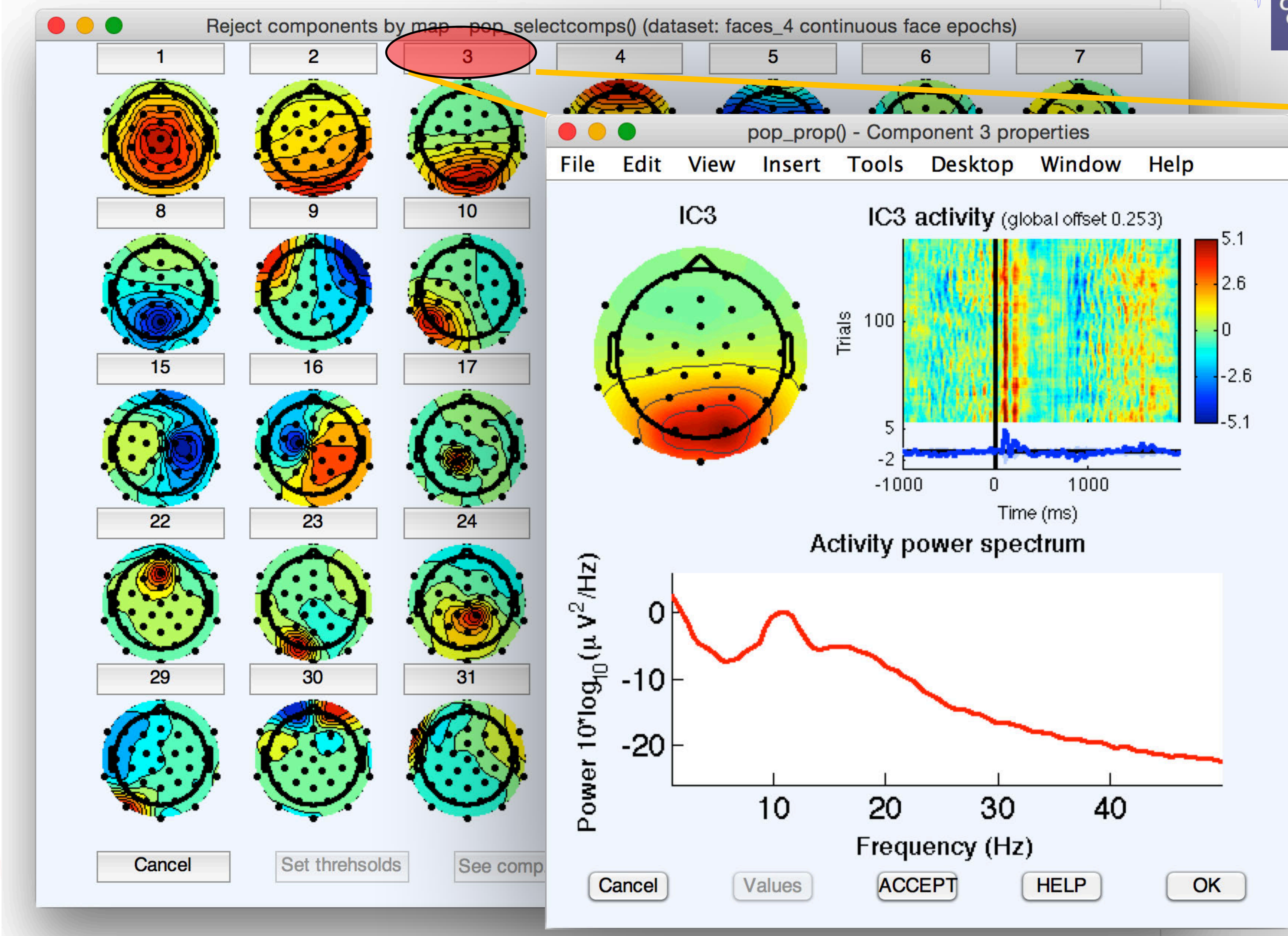


Step 0: Quality of Decomposition

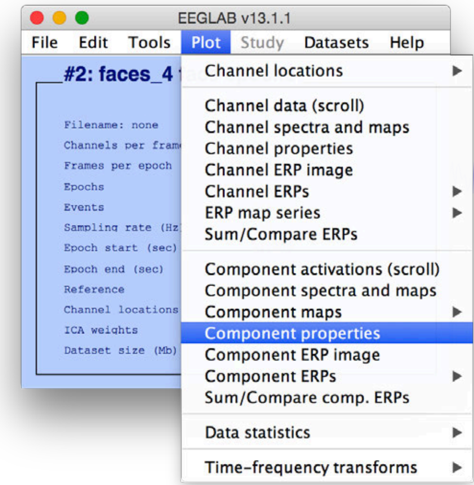




Examining IC Properties

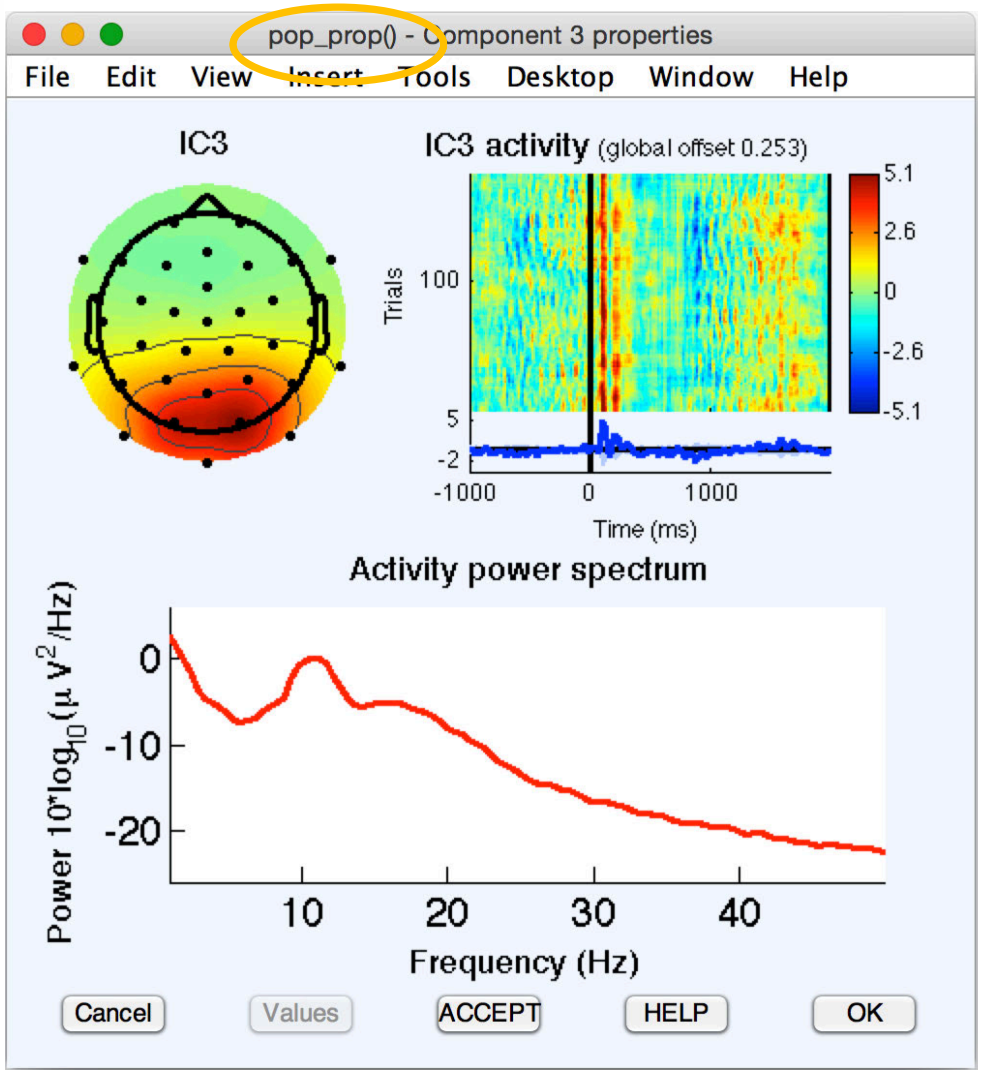


IC Properties



IC Topography

`topoplot()`



ERP Image

&

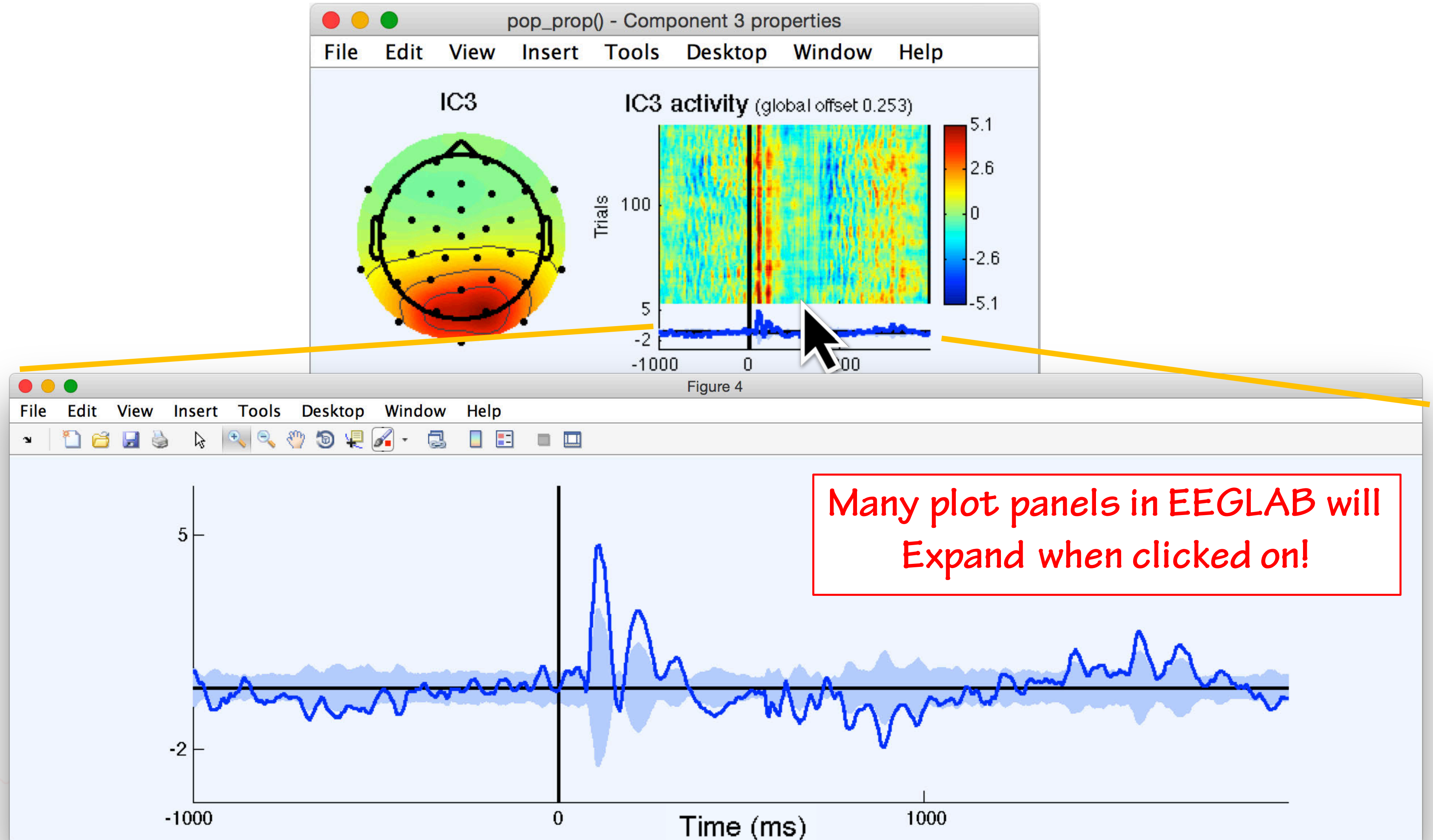
ERP

`erpimage()`

Power Spectrum

`spectopo()`

Click to expand…



Part 1

Getting an overview of your ICs

Part 2

Classifying/Evaluating ICs

- Eye Artifacts
- Muscle Artifacts
- Other Artifacts
- Brain ICs

Part 3

Detailed look at IC properties

- ERP
- Spectrum
- ERP images
- ERSP

Evaluating ICs

Over time, most EEGLAB users develop a heuristic sense of which ICs might be brain vs. artifact.

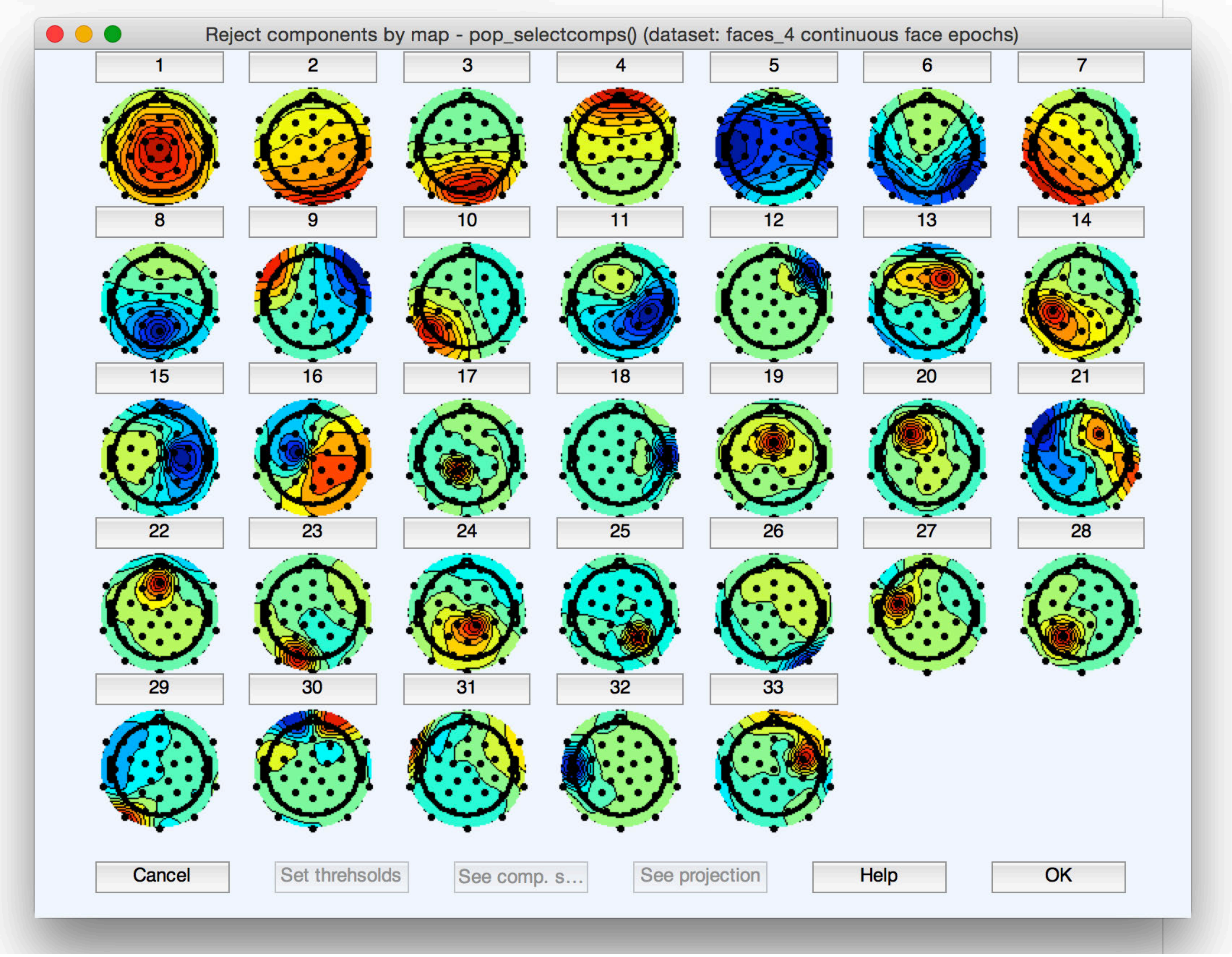
Heuristics are generally based on:

- Topography
- Component Activities (scroll)
- ERP
- Power Spectrum

IC Classification is typically used to 'clean' data—study likely brain activity without artifacts

There are some efforts to automate this process, but doing it by hand is a good place to start to build intuition

Topography


Reject components by map - pop_selectcomps() (dataset: faces_4 continuous face epochs)
1
2
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12
13
14
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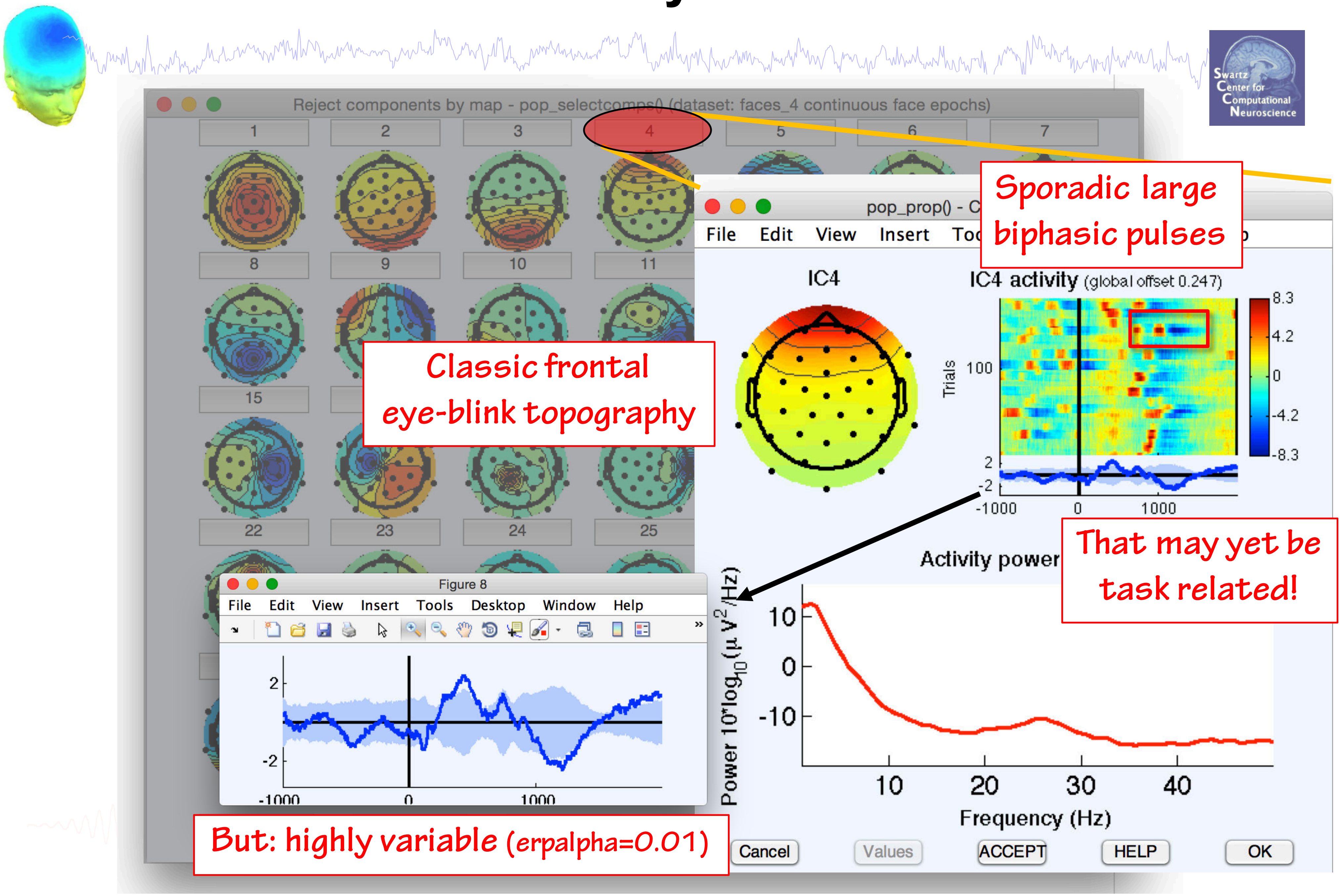
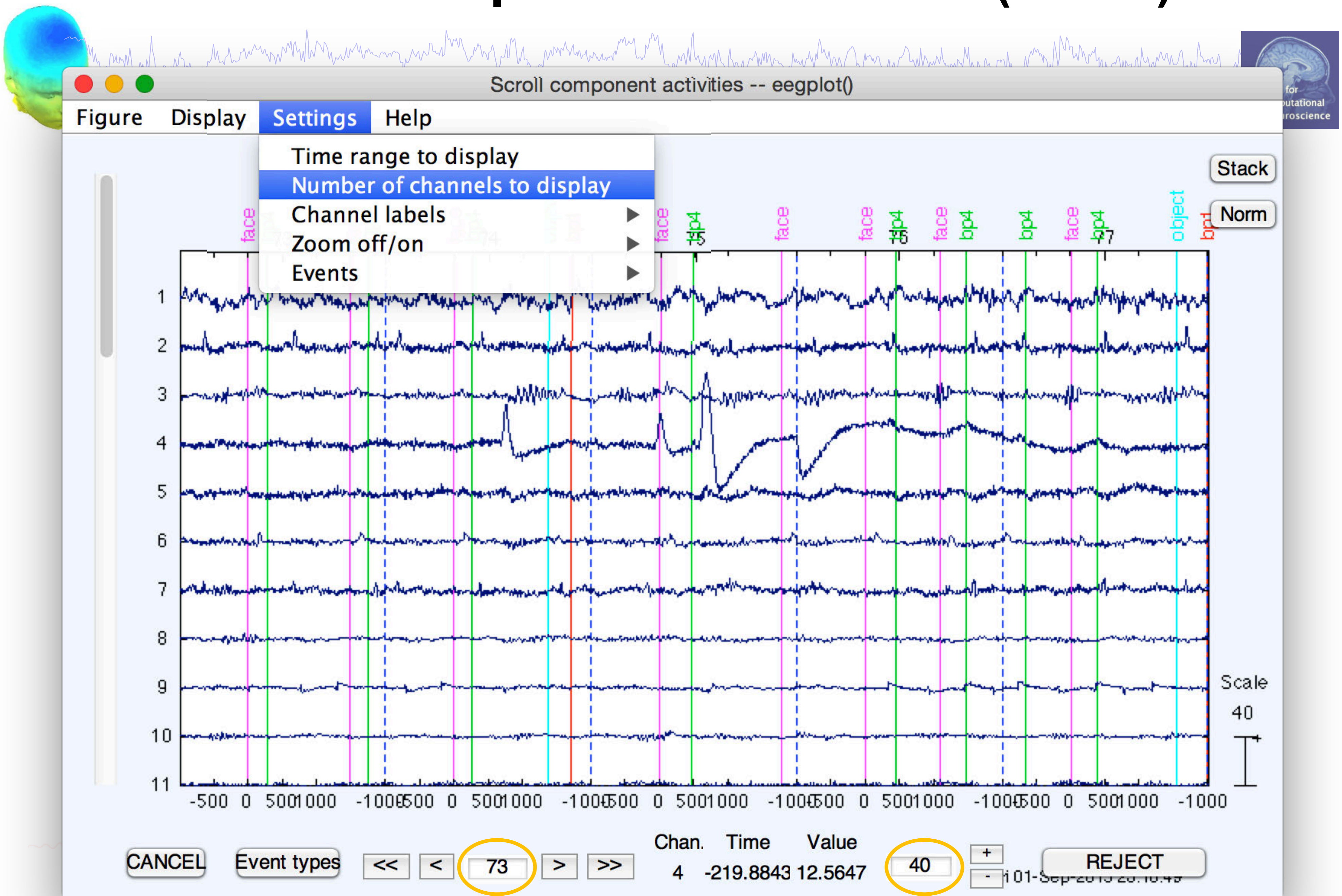
24
25
26
27
28
29
30
31
32
33
Cancel
Set threhsolds
See comp. s...
See projection
Help
OK

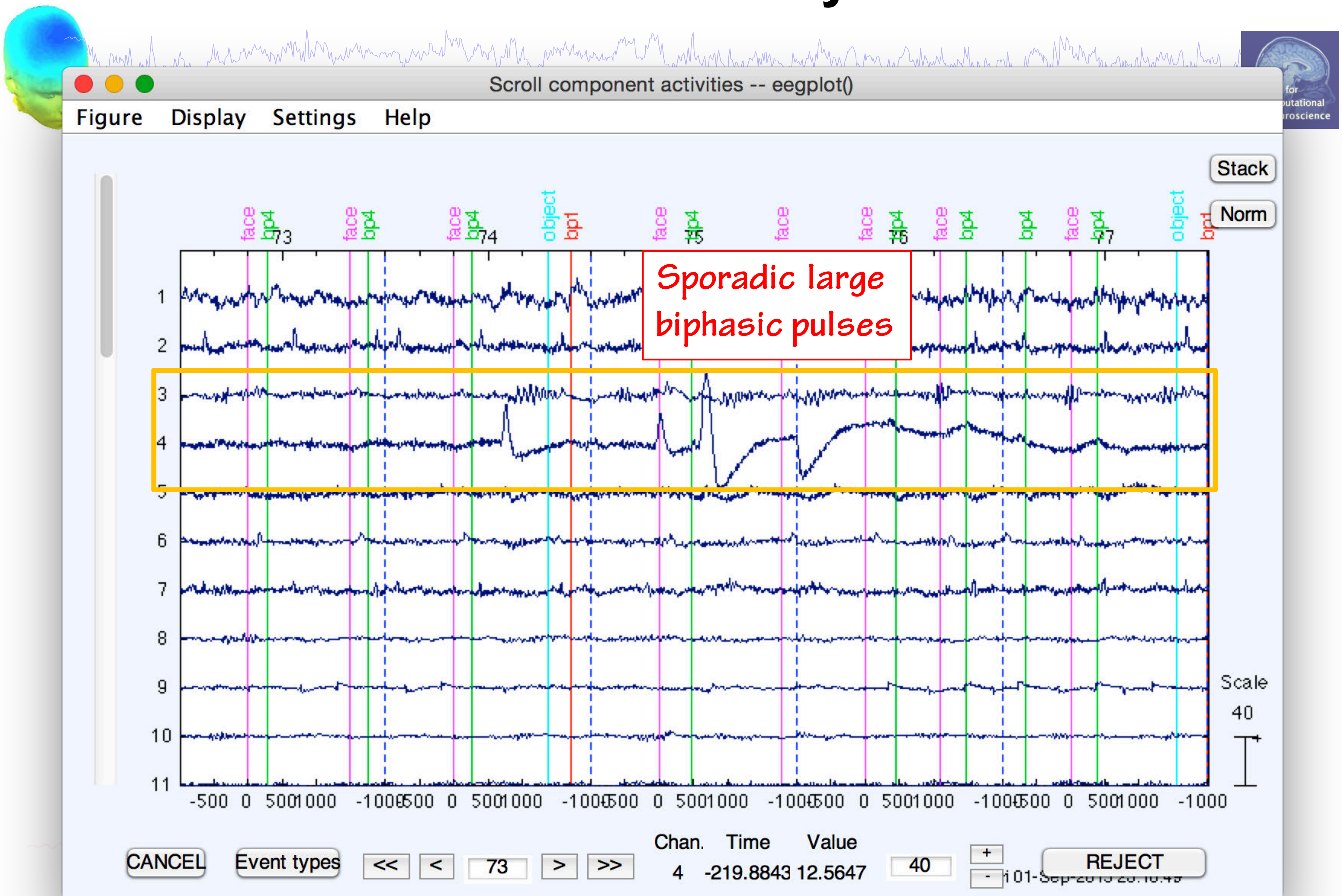
IC 4 – eyeblink



Plot → Component Activations (scroll)

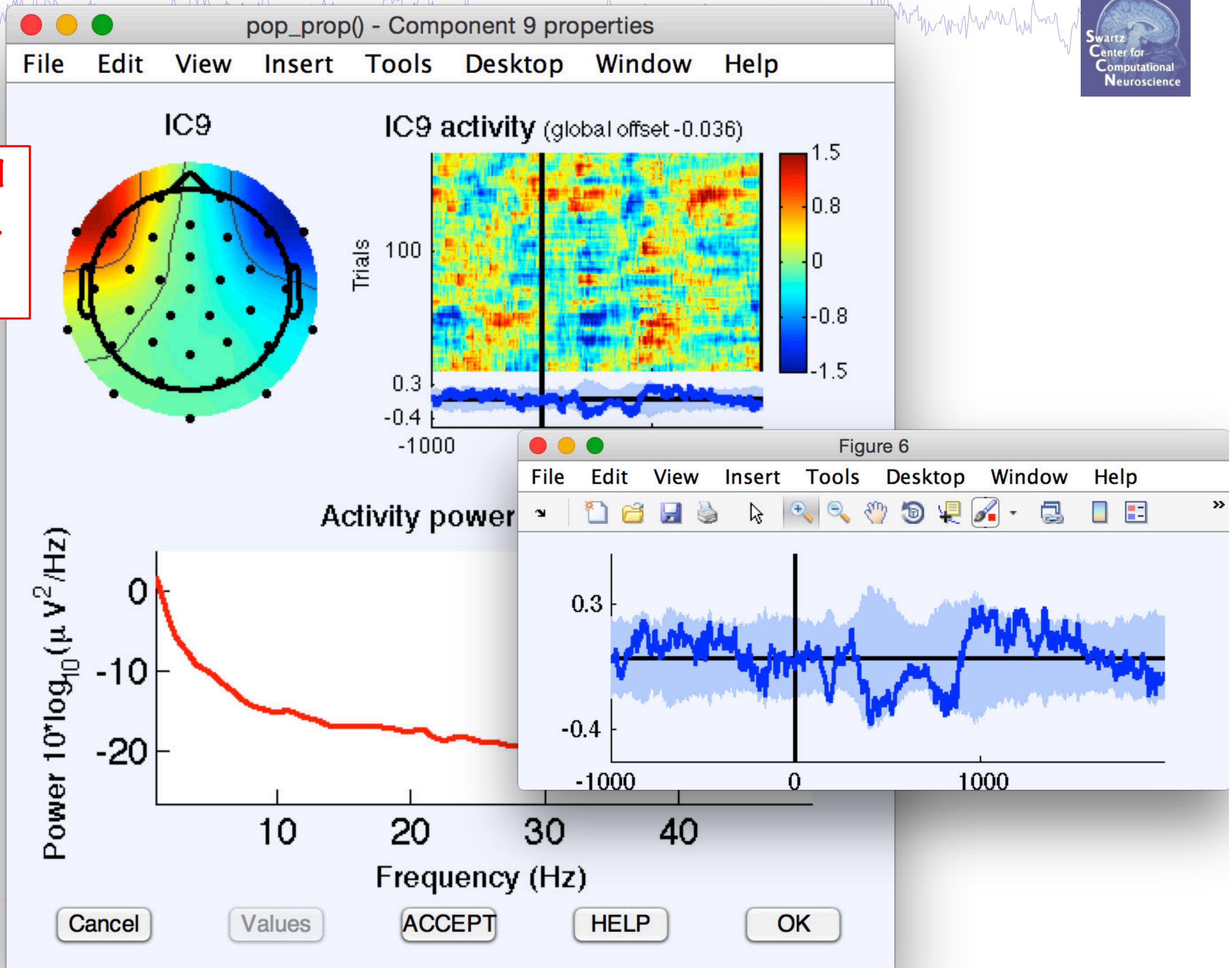


IC 4 Activation – eyeblink

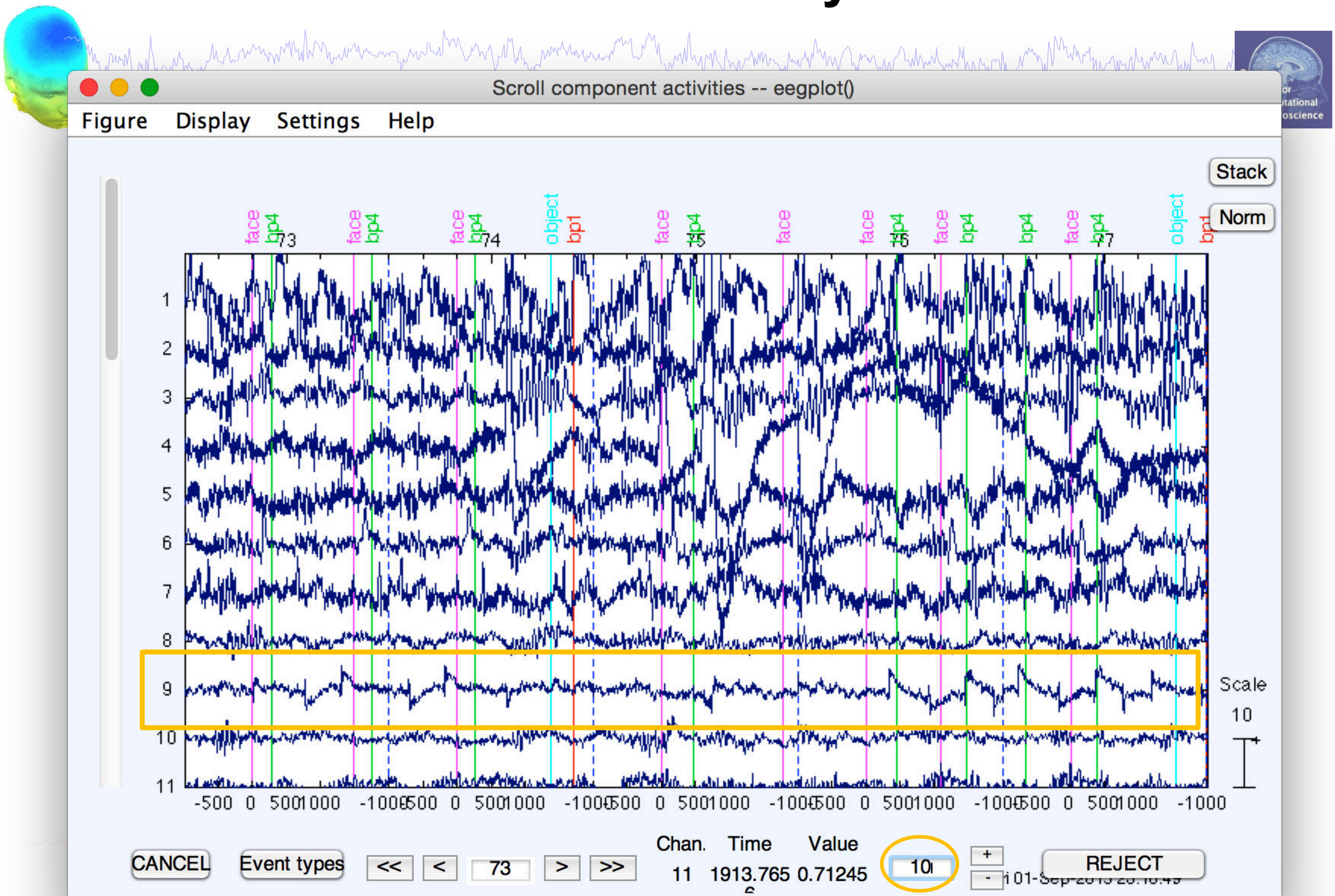


IC 9 – lateral eye movement

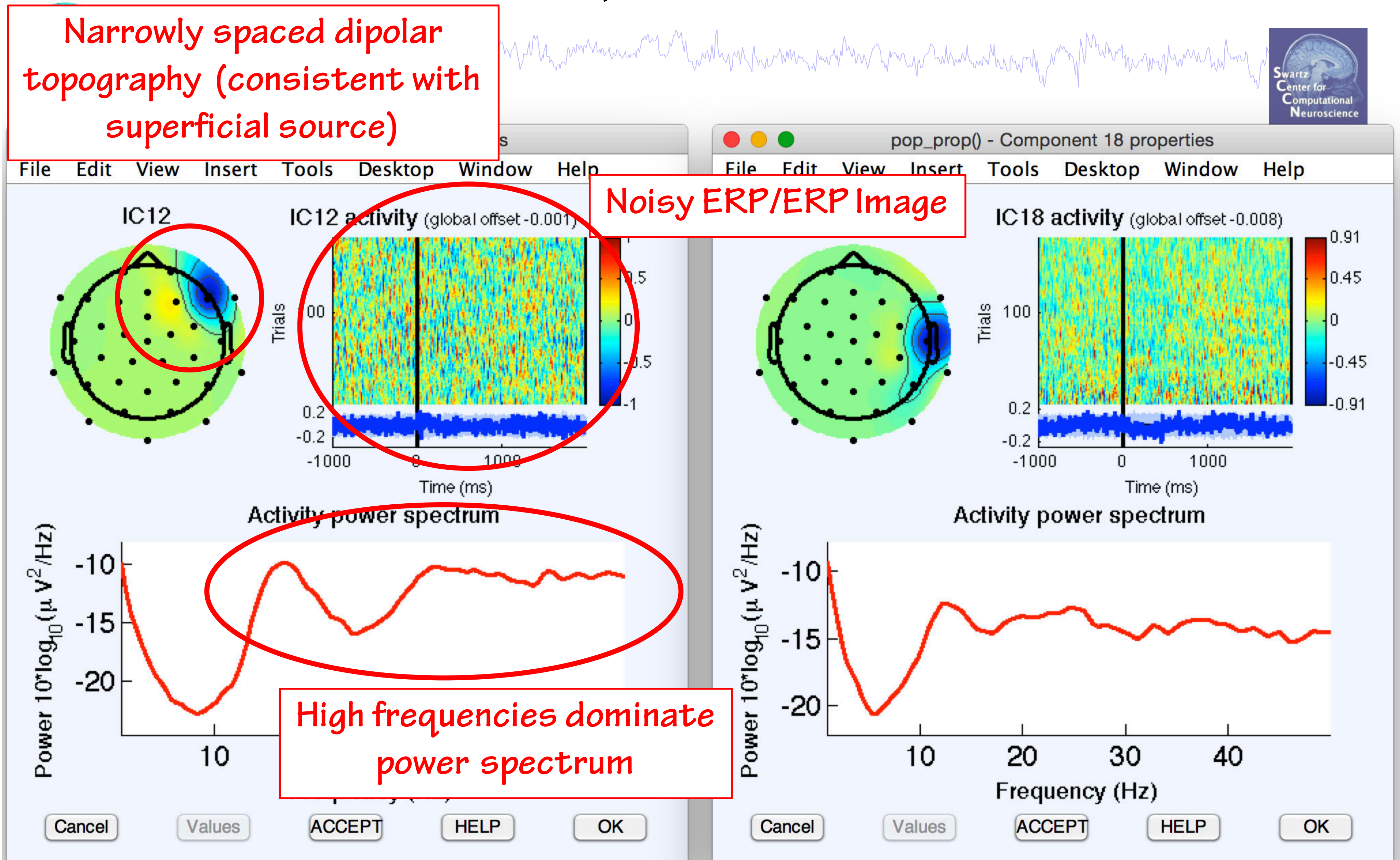
Classic frontal eye-movement topography



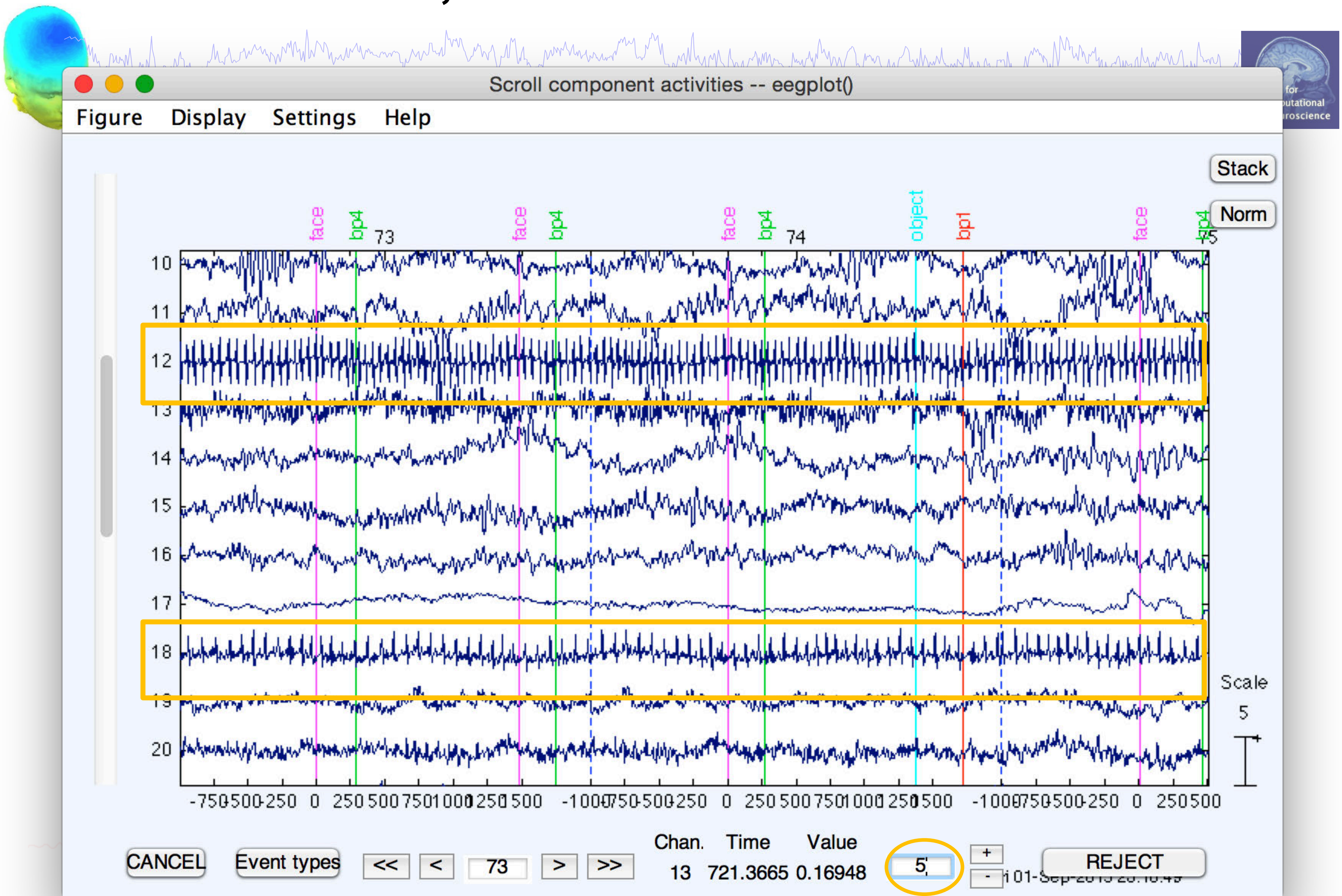
IC 9 Activation – lateral eye movement



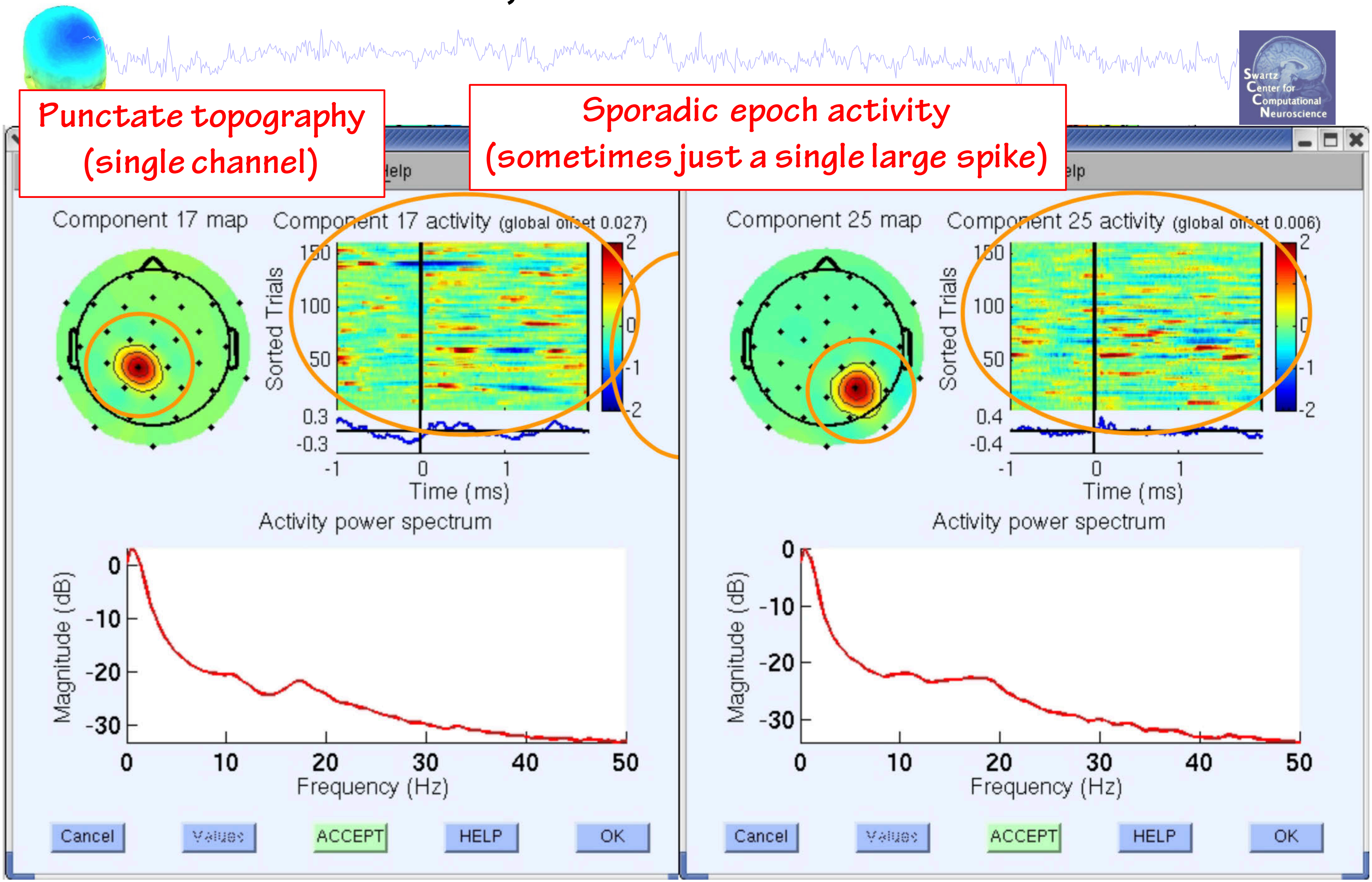
IC 12, 18 – Muscle



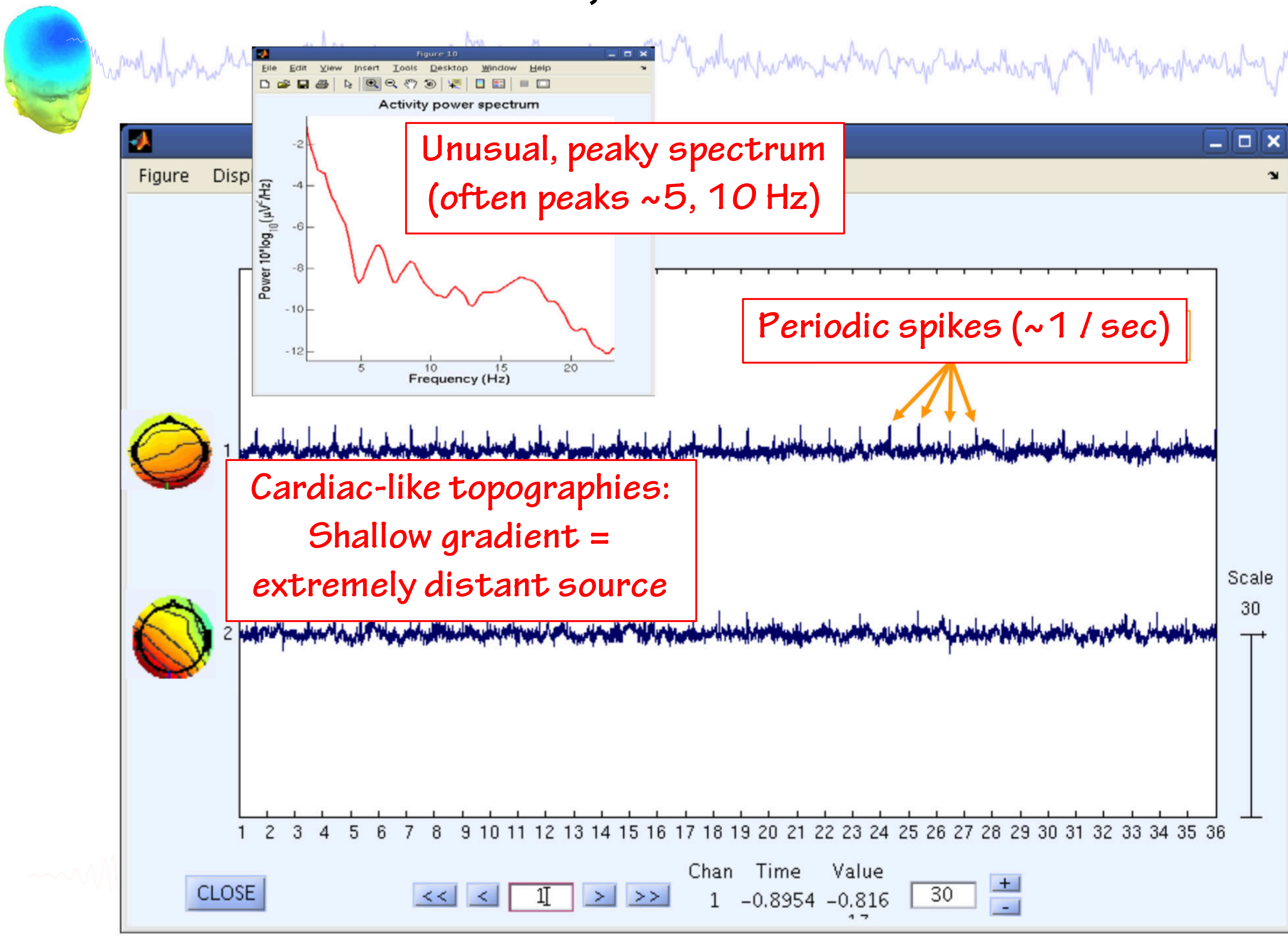
IC 12, 18 Activation – Muscle



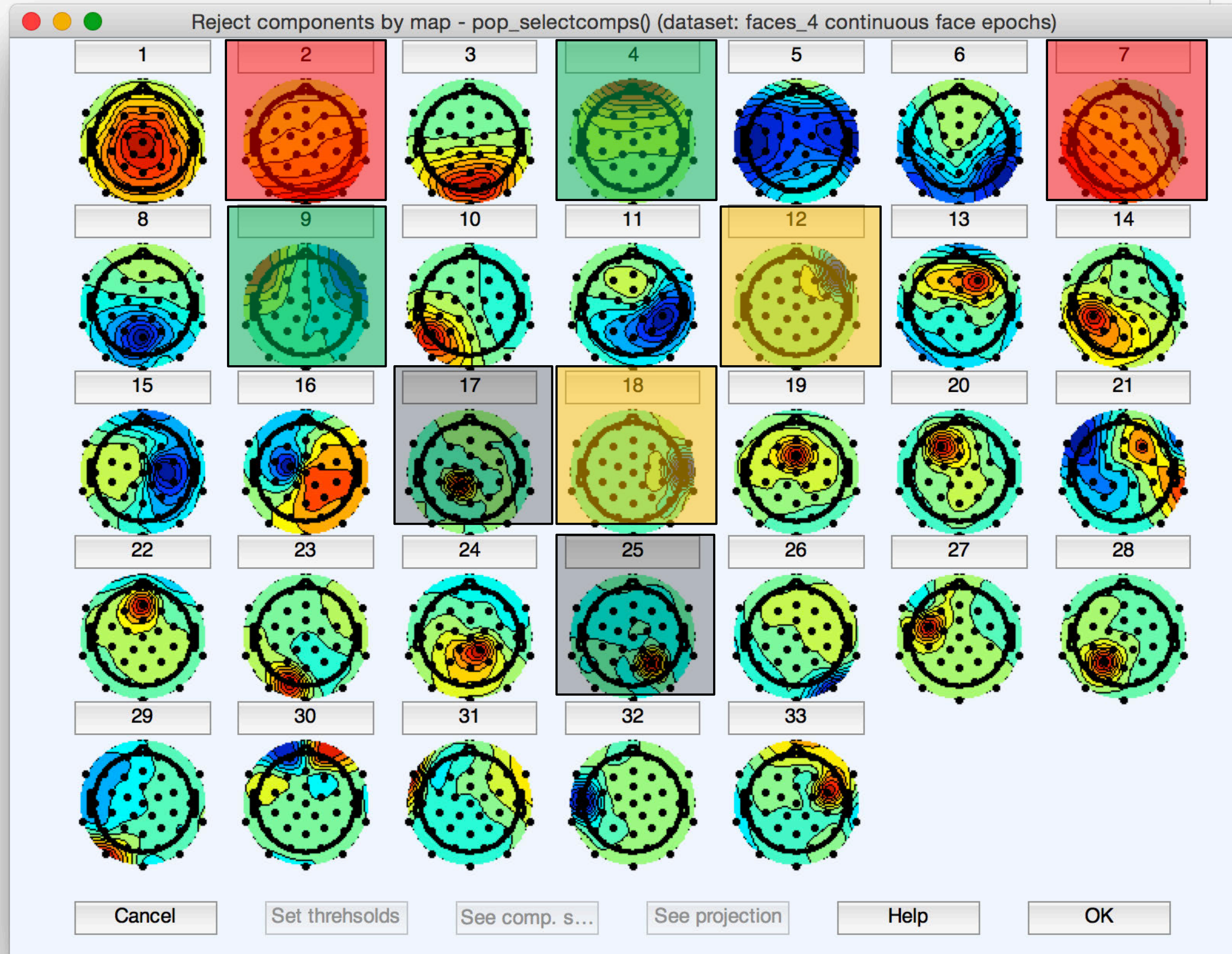
IC 17, 25 – Bad channels



IC 2, 7 – Cardiac

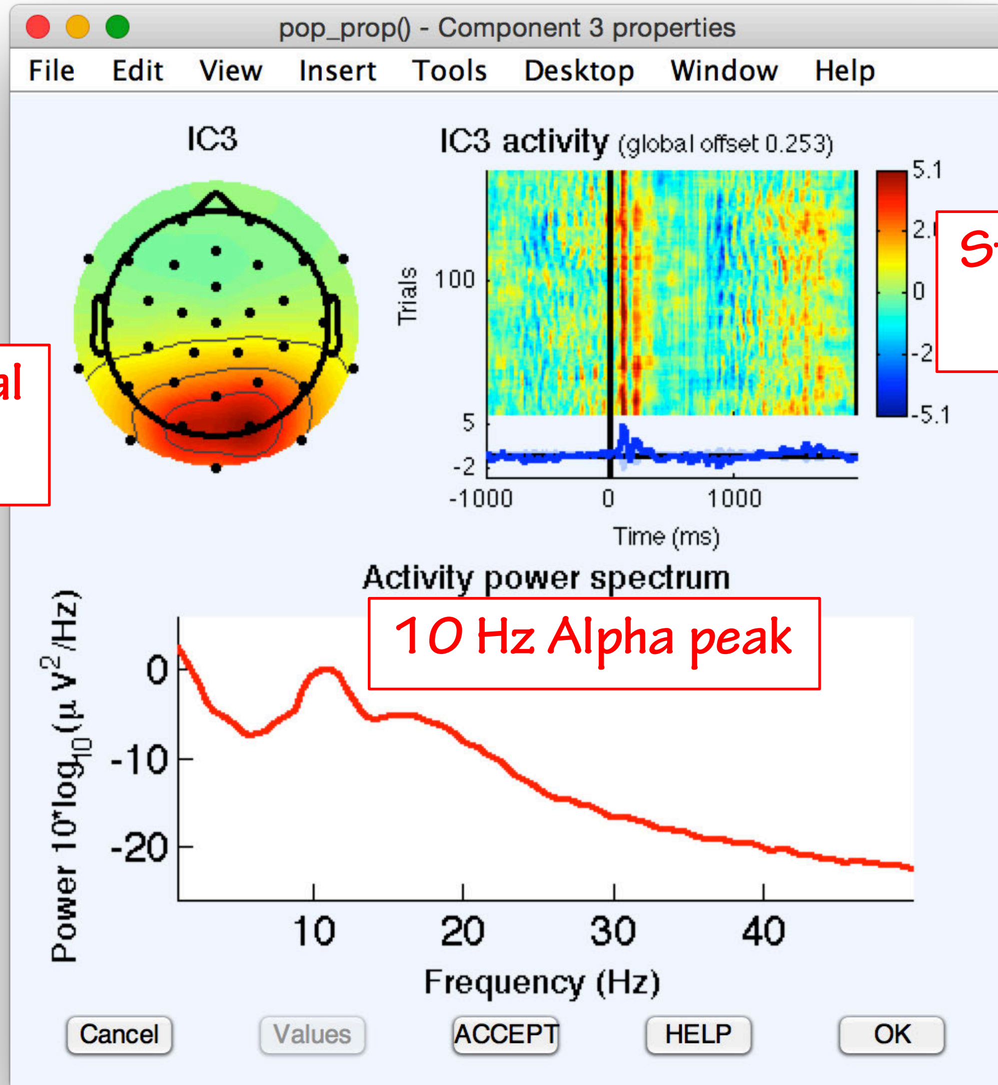


Artifacts



Eye
Muscle
Cardiac
Badchan

Brain ICs



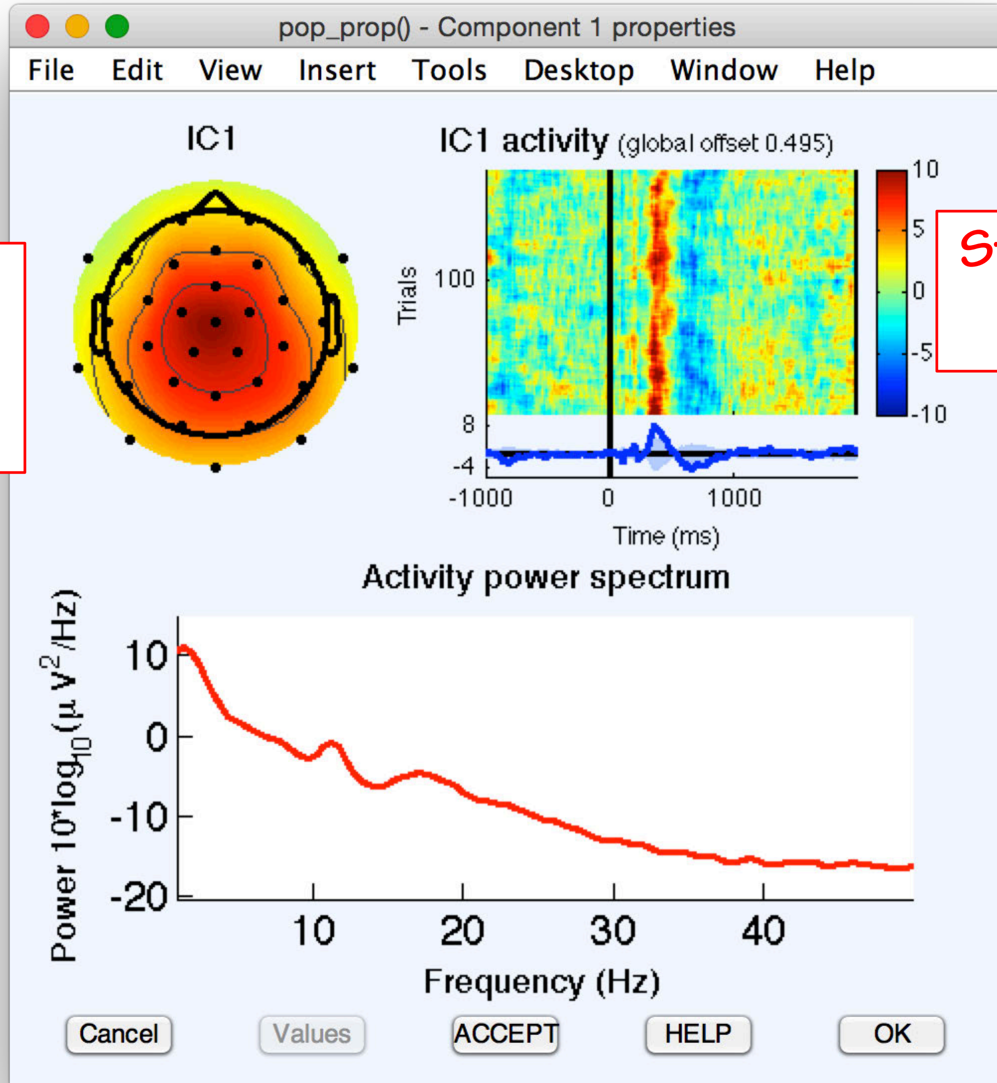
Strongly task-related ERP Image & ERP

Classic occipital topography

10 Hz Alpha peak

Dipole orientation matters

Brain ICs



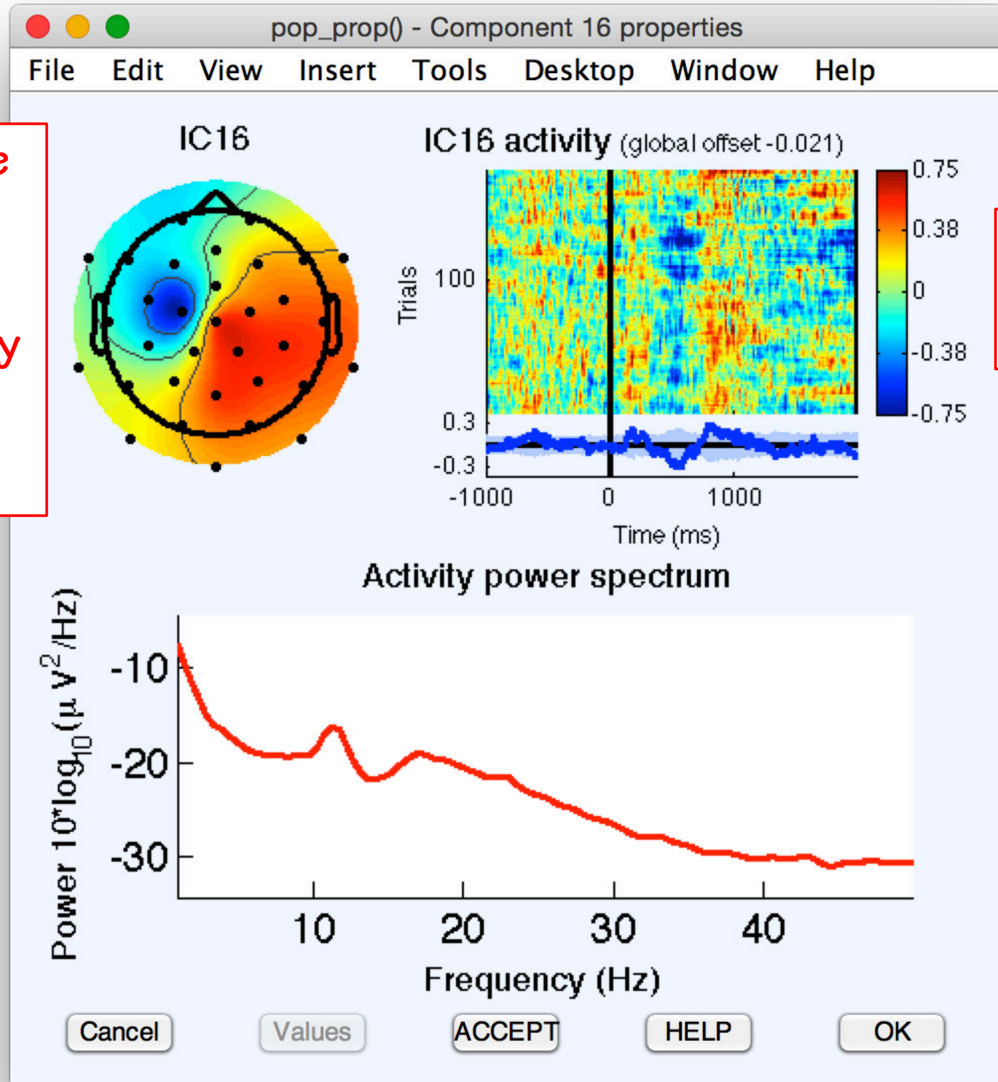
Classic radial-dipole source topography

Strongly task-related ERP Image & ERP

Brain ICs

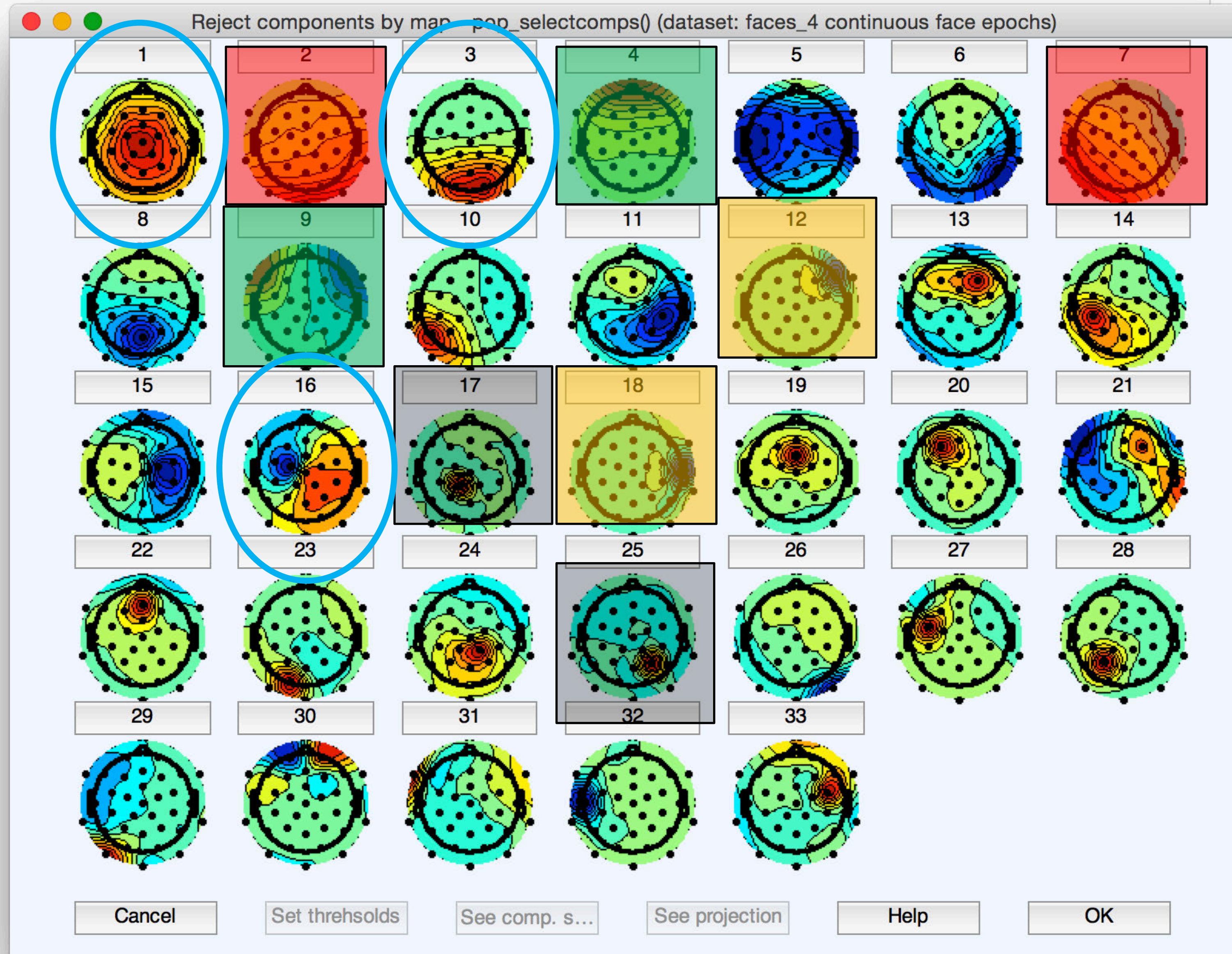
Classic <u>tangential</u>-dipole source topography

two peaks, not as closely spaced as muscle: deeper



Task-related ERP Image & ERP

IC Classification…so far



Eye
Muscle
Cardiac
Badchan
Brain

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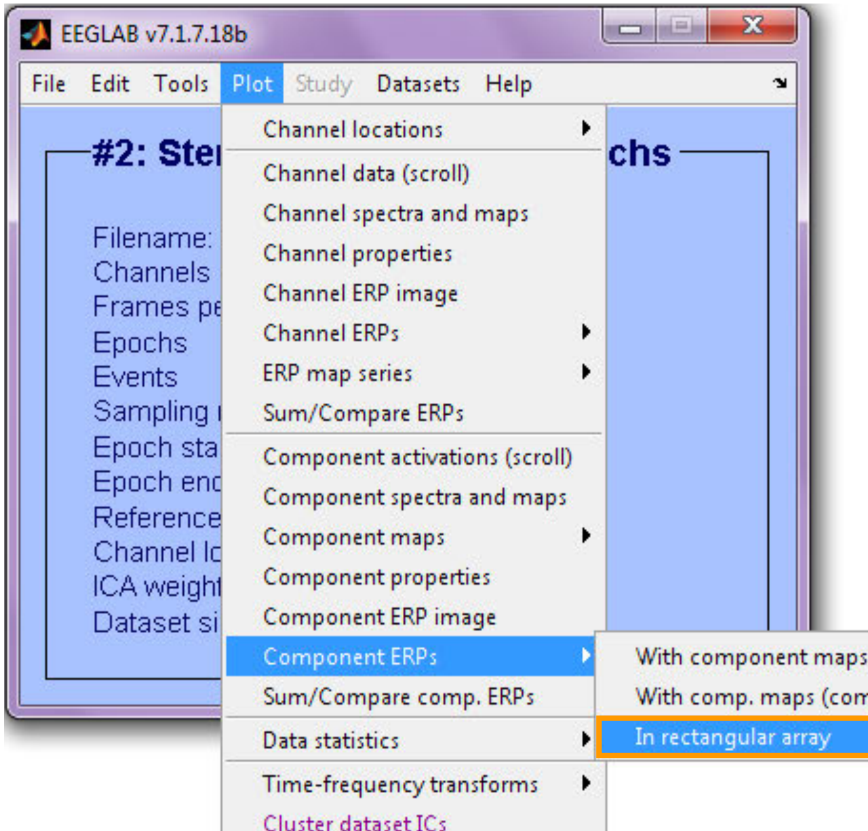
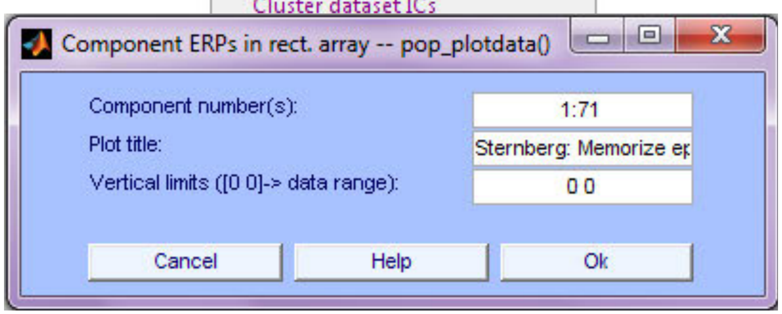
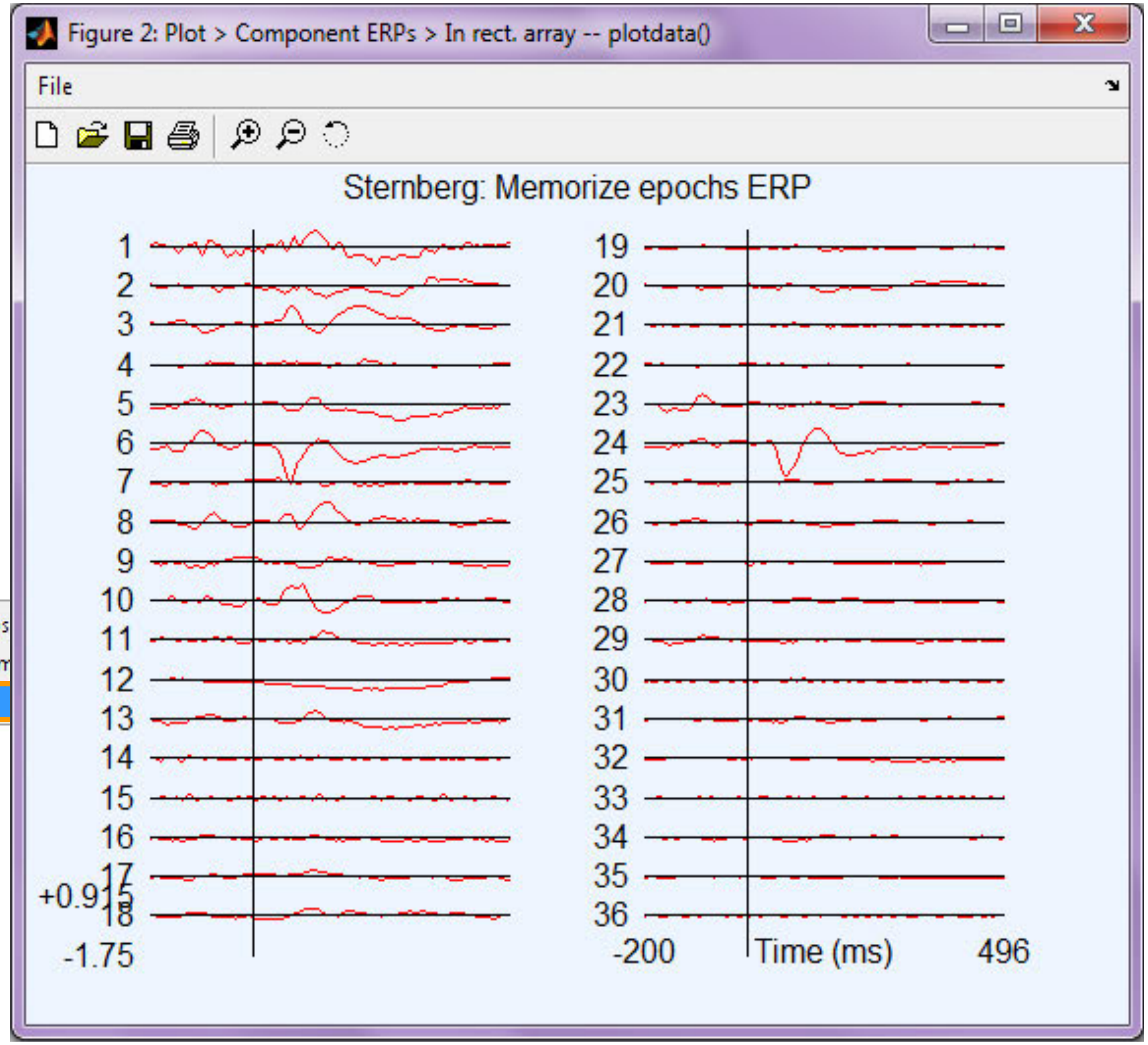
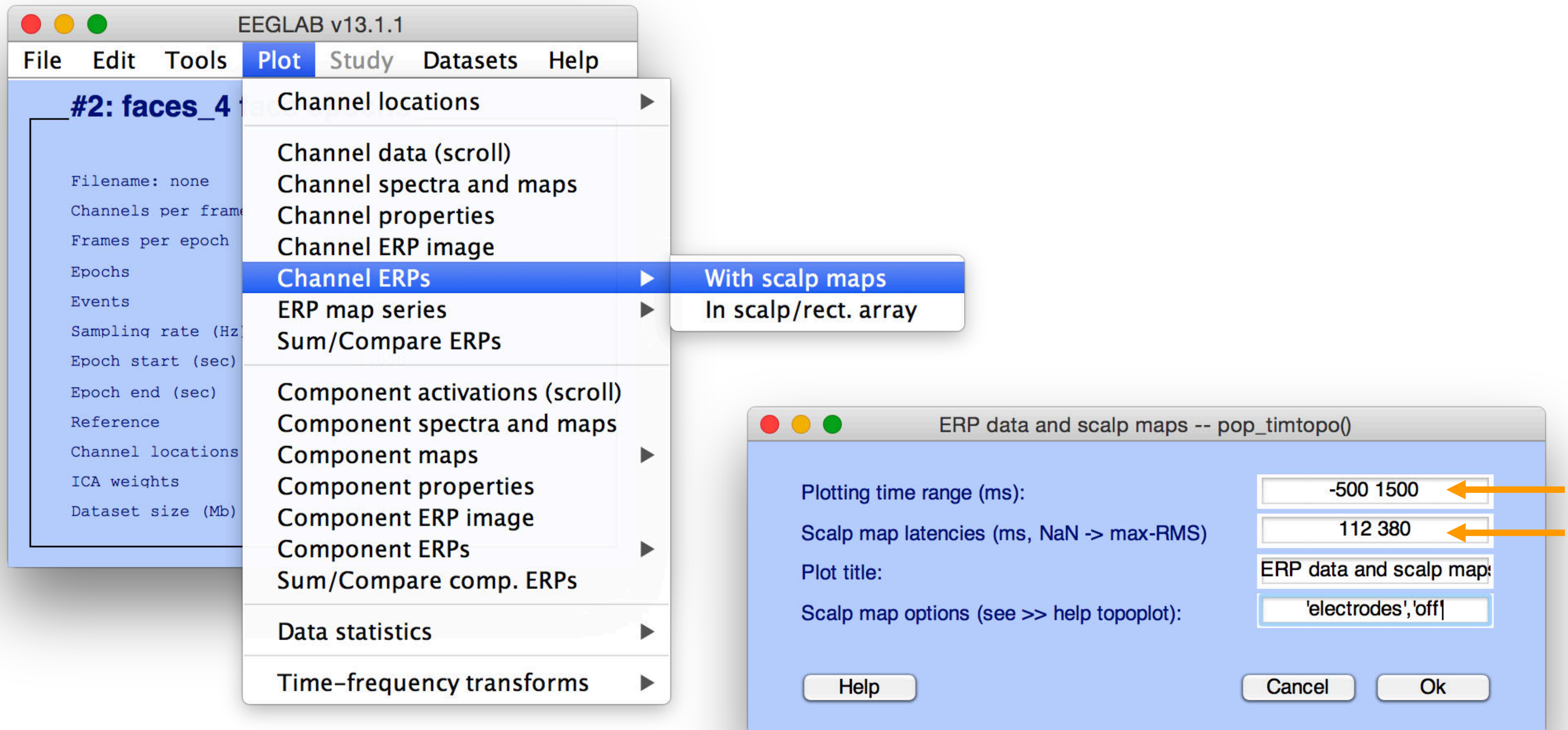
Component ERPs



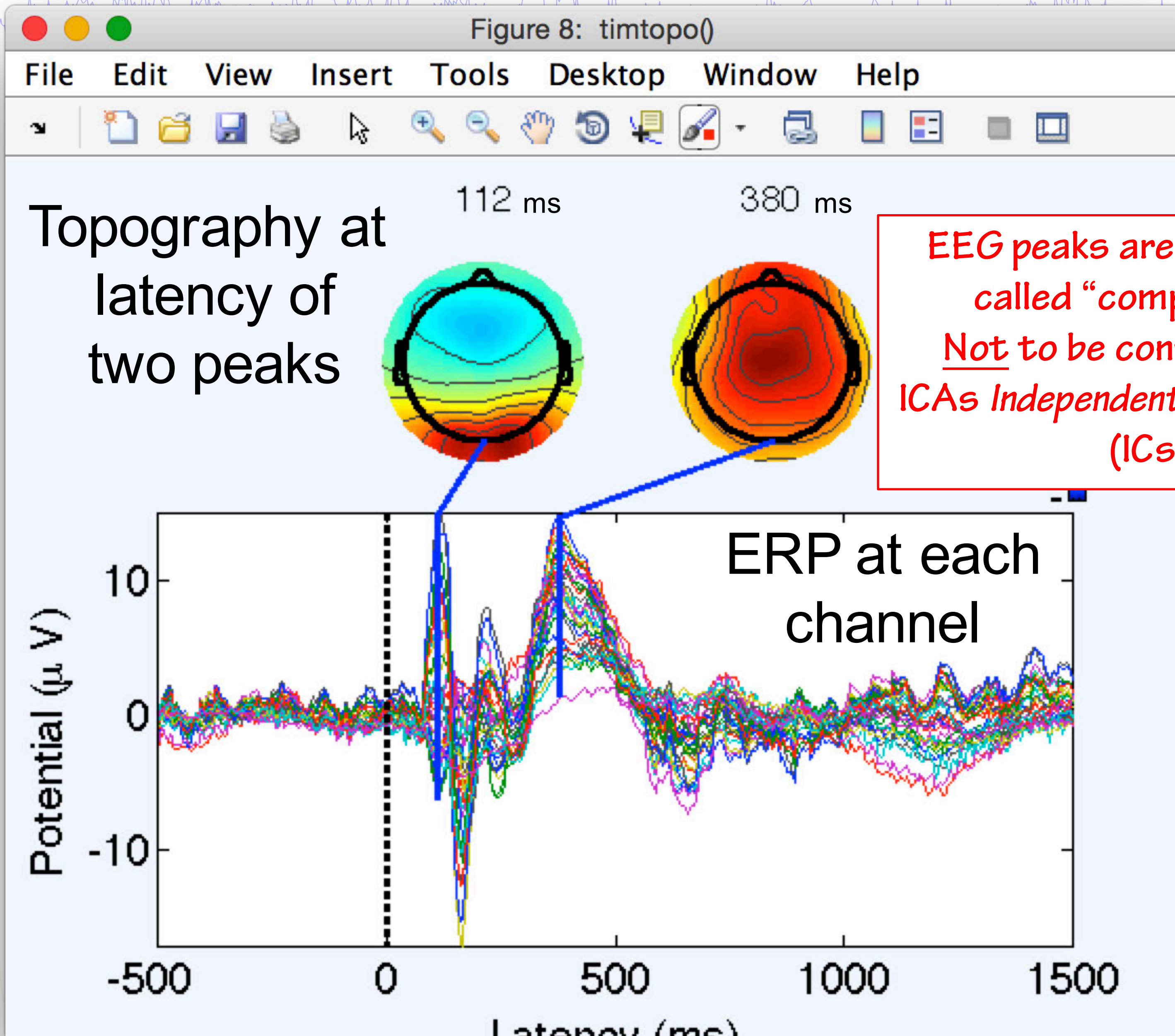




A step back: Electrode-level ERP

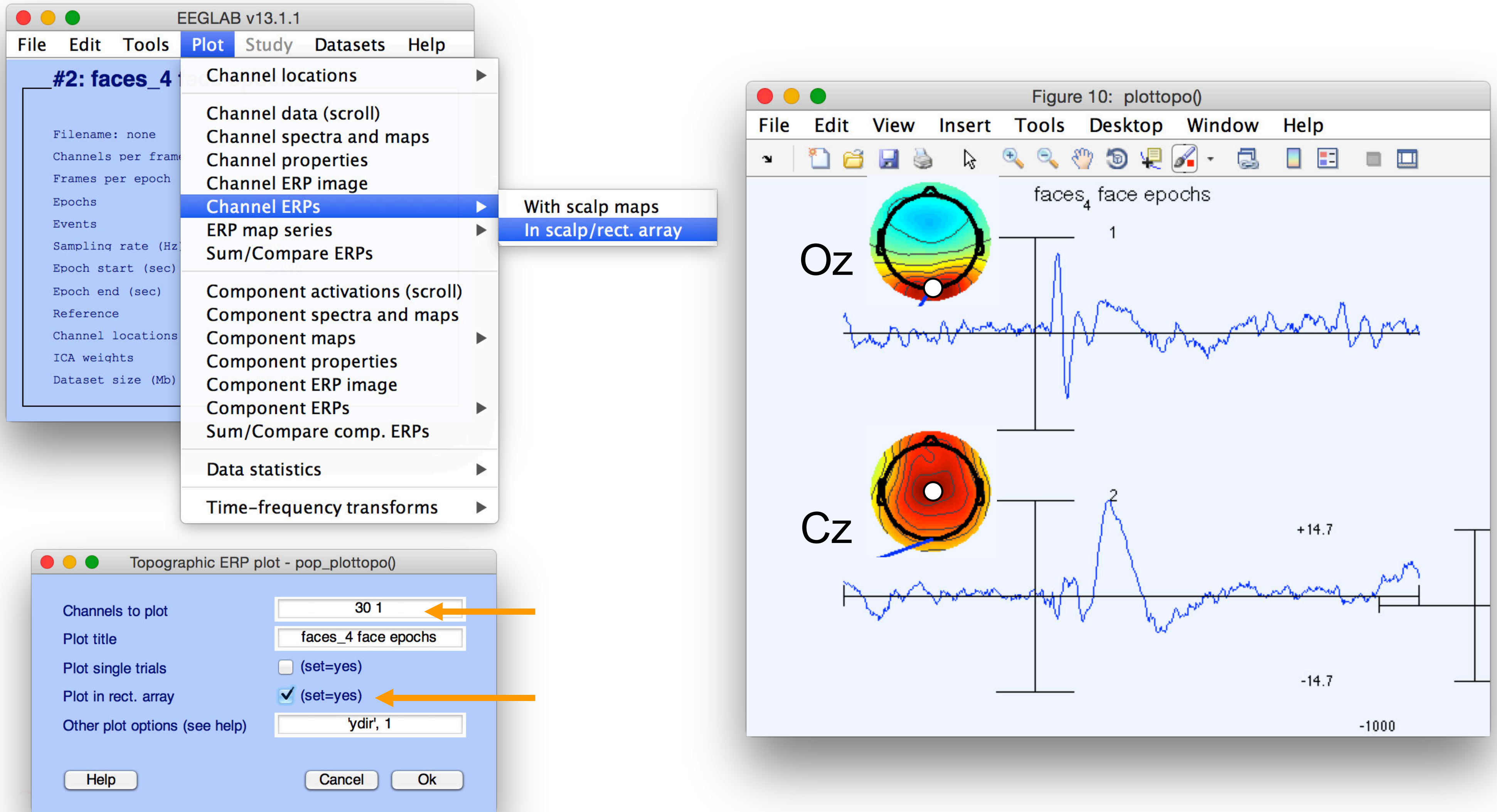


Traditional ERP: Time-locked activity at each channel

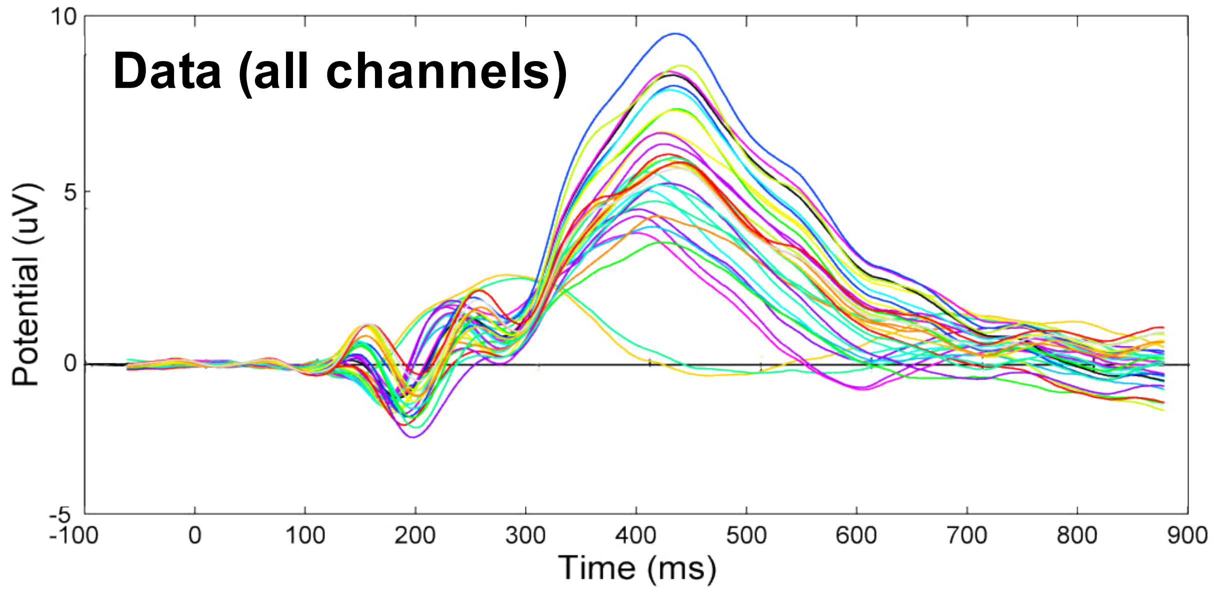


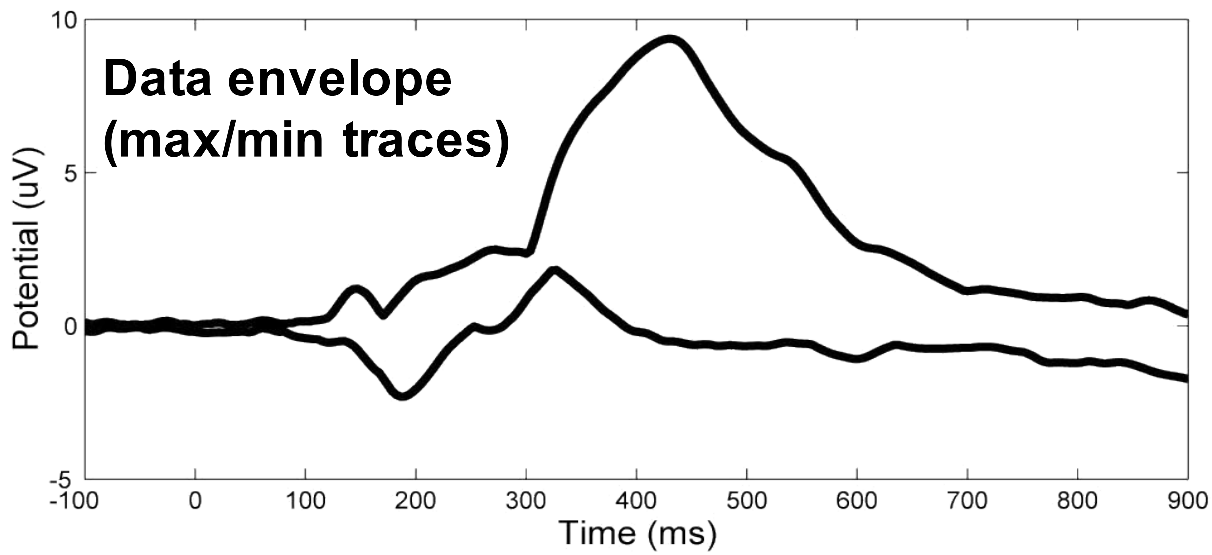
EEG peaks are sometimes called "components."
Not to be confused with ICAs *Independent Components* (ICs)!

ERP at two channels

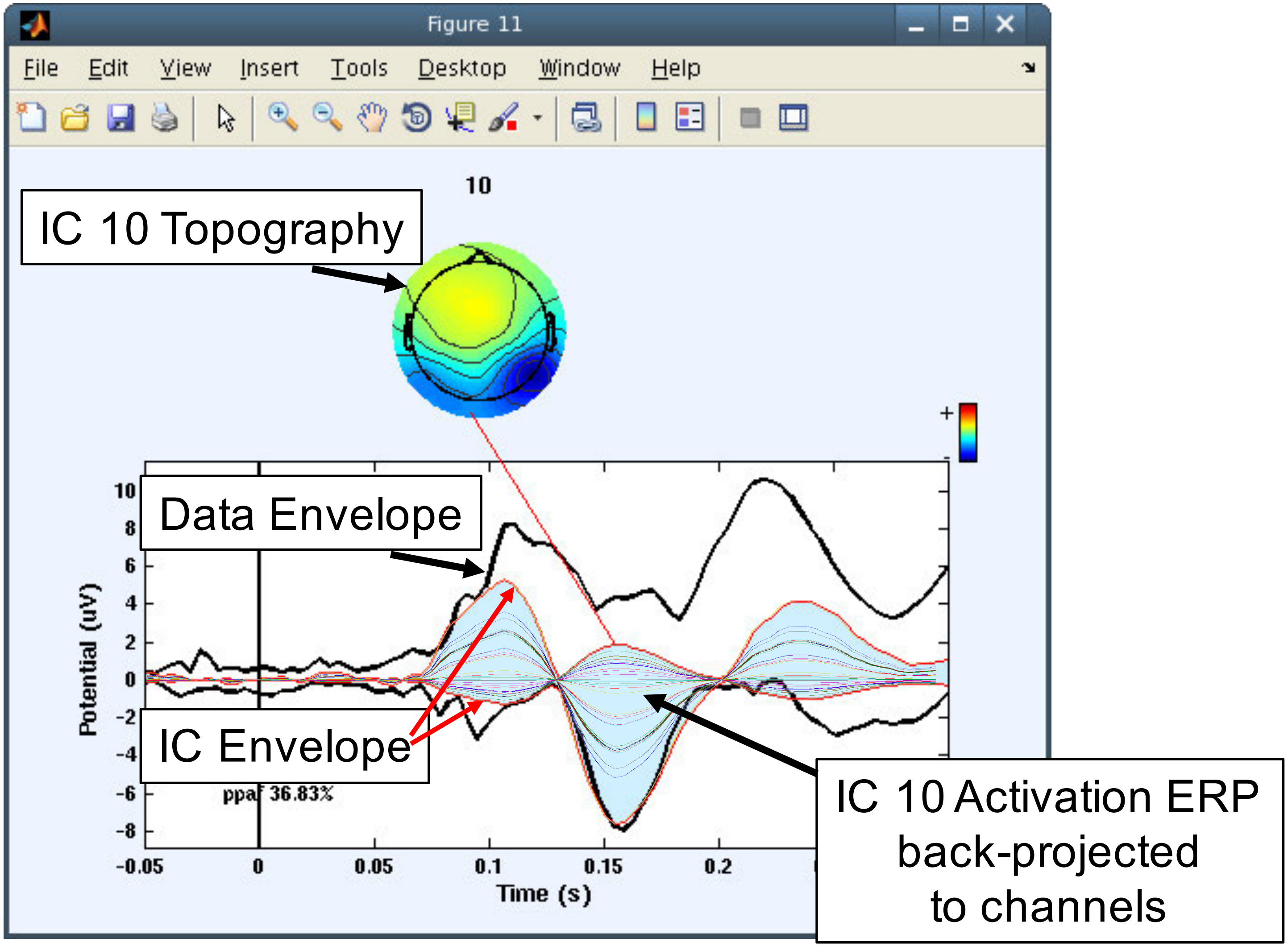


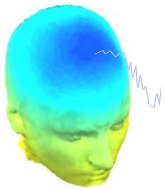
Definition: The data envelope



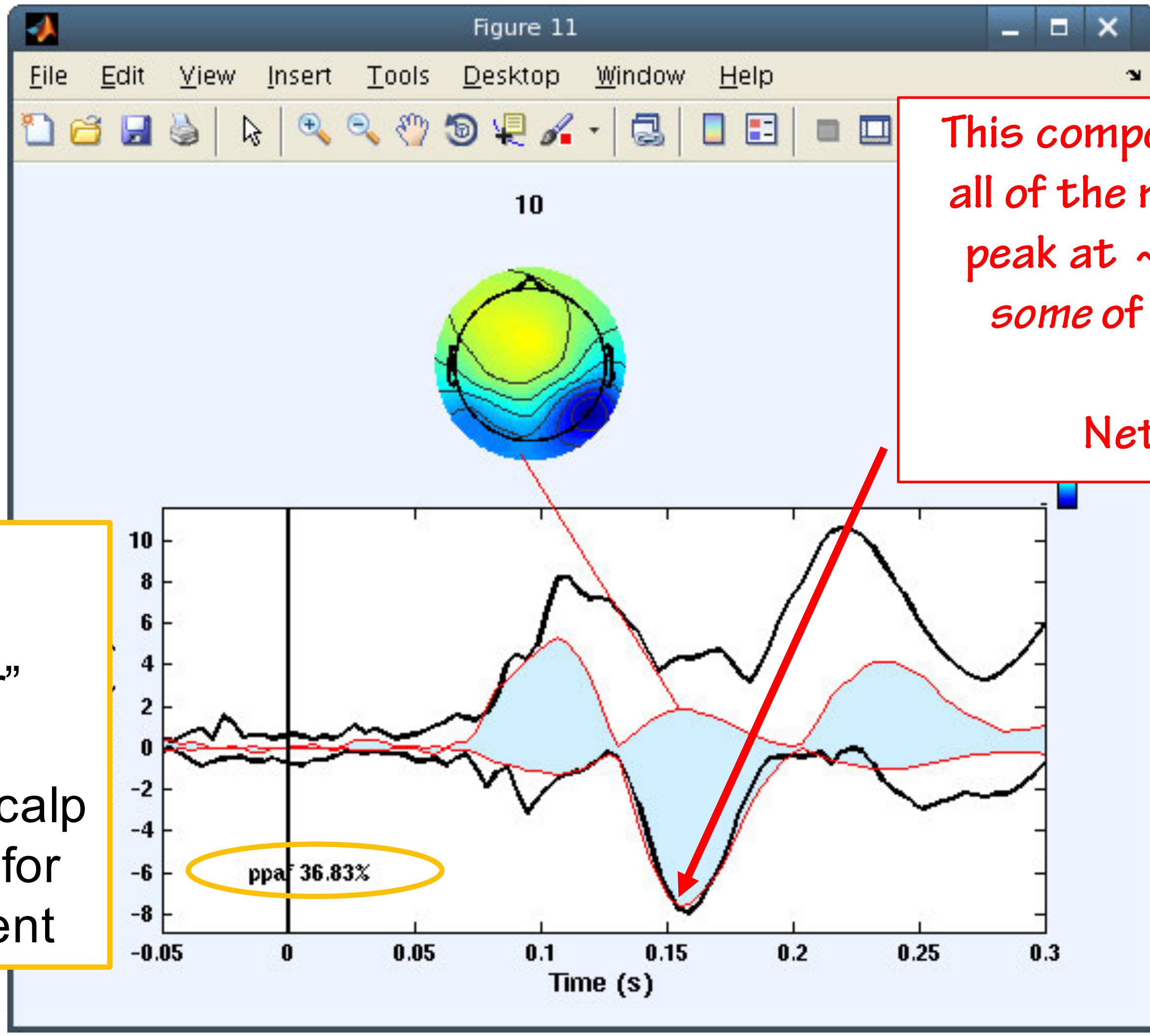


Definition: IC Envelope





Key: Scalp ERP peaks are often the sum of multiple independent source processes



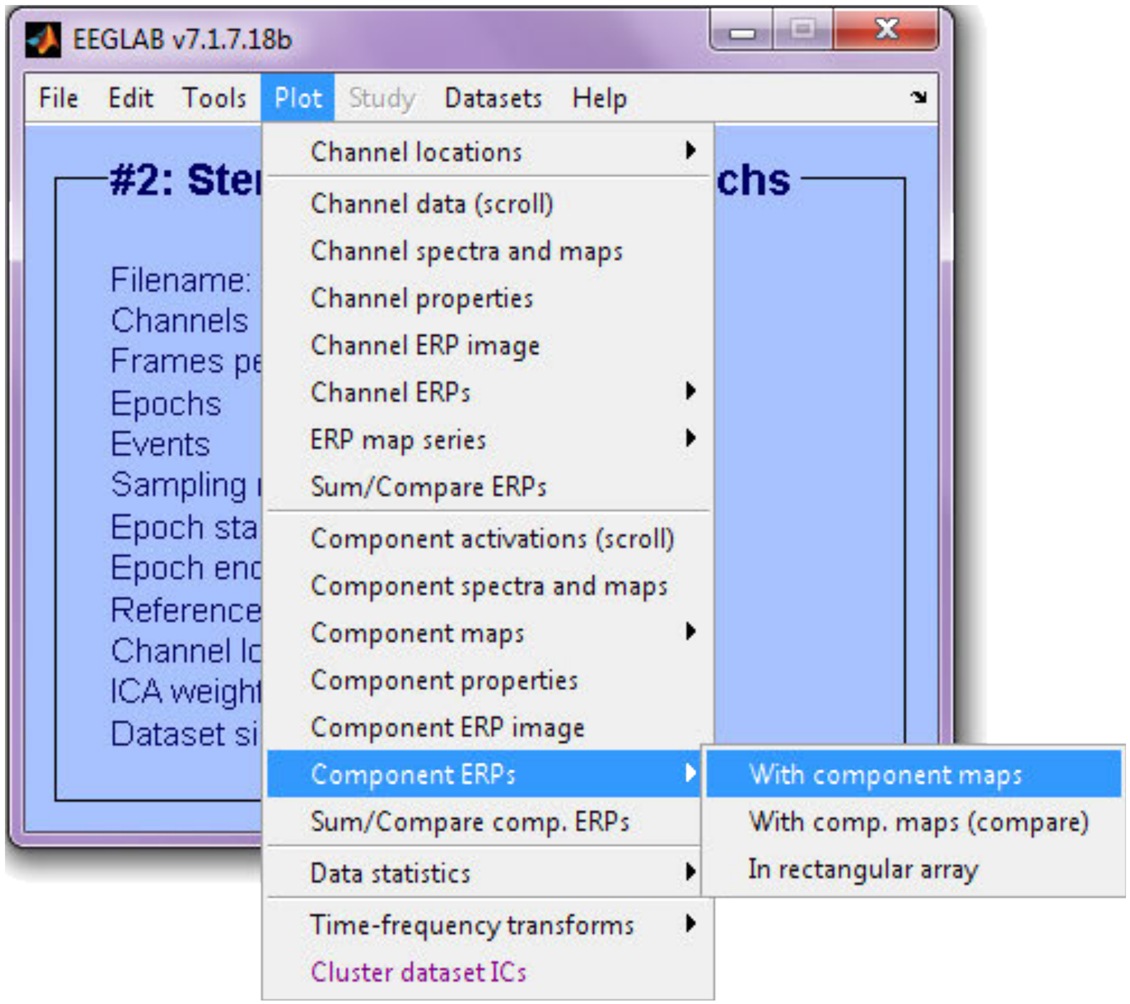
This component accounts for all of the negative scalp ERP peak at ~150 ms, but only some of other ERP peaks

Net PVAF: 37%

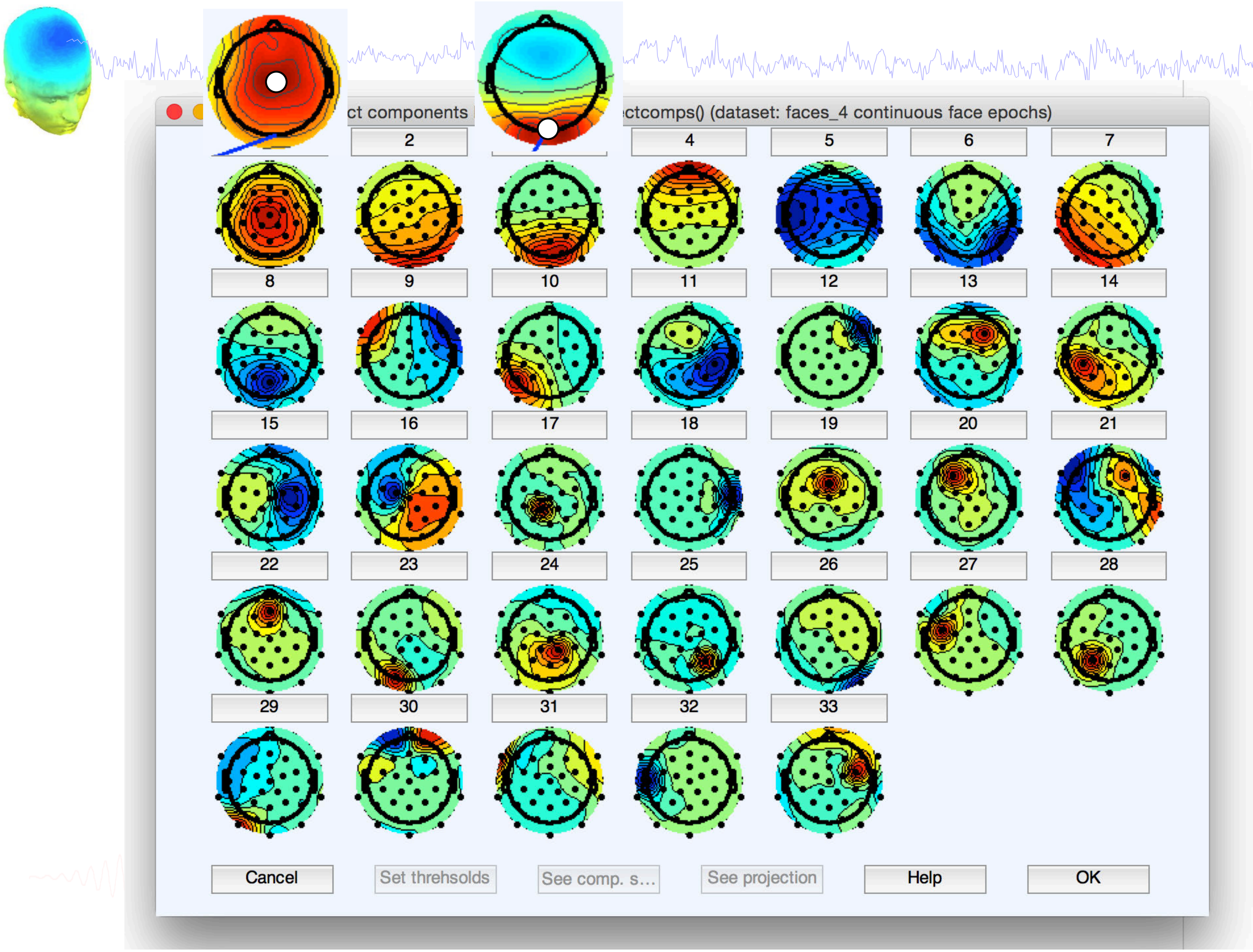
PPAF/PVAF
"% Variance Accounted For"

The variance of scalp EEG accounted for by this component

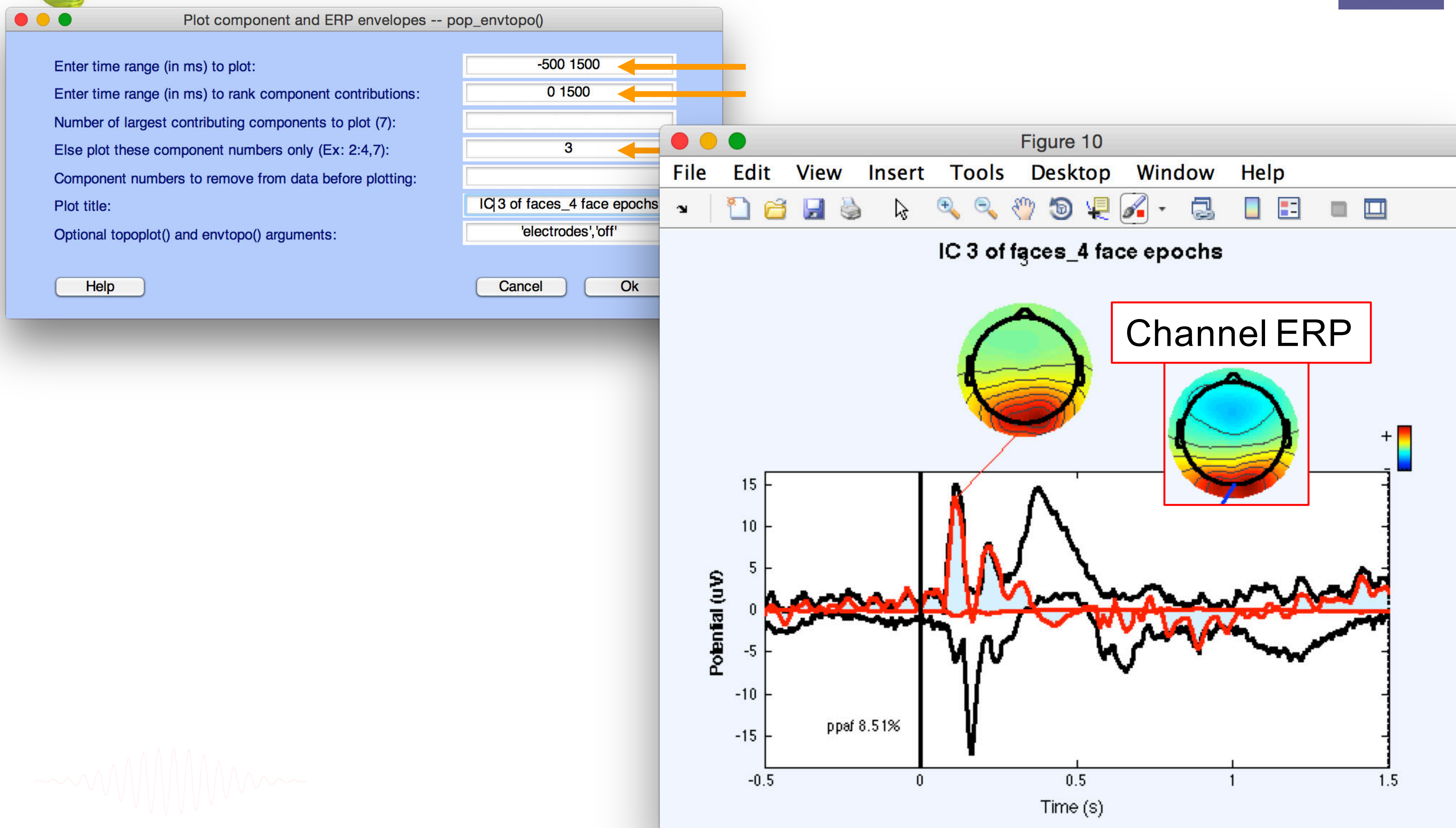
Component ERP envelope



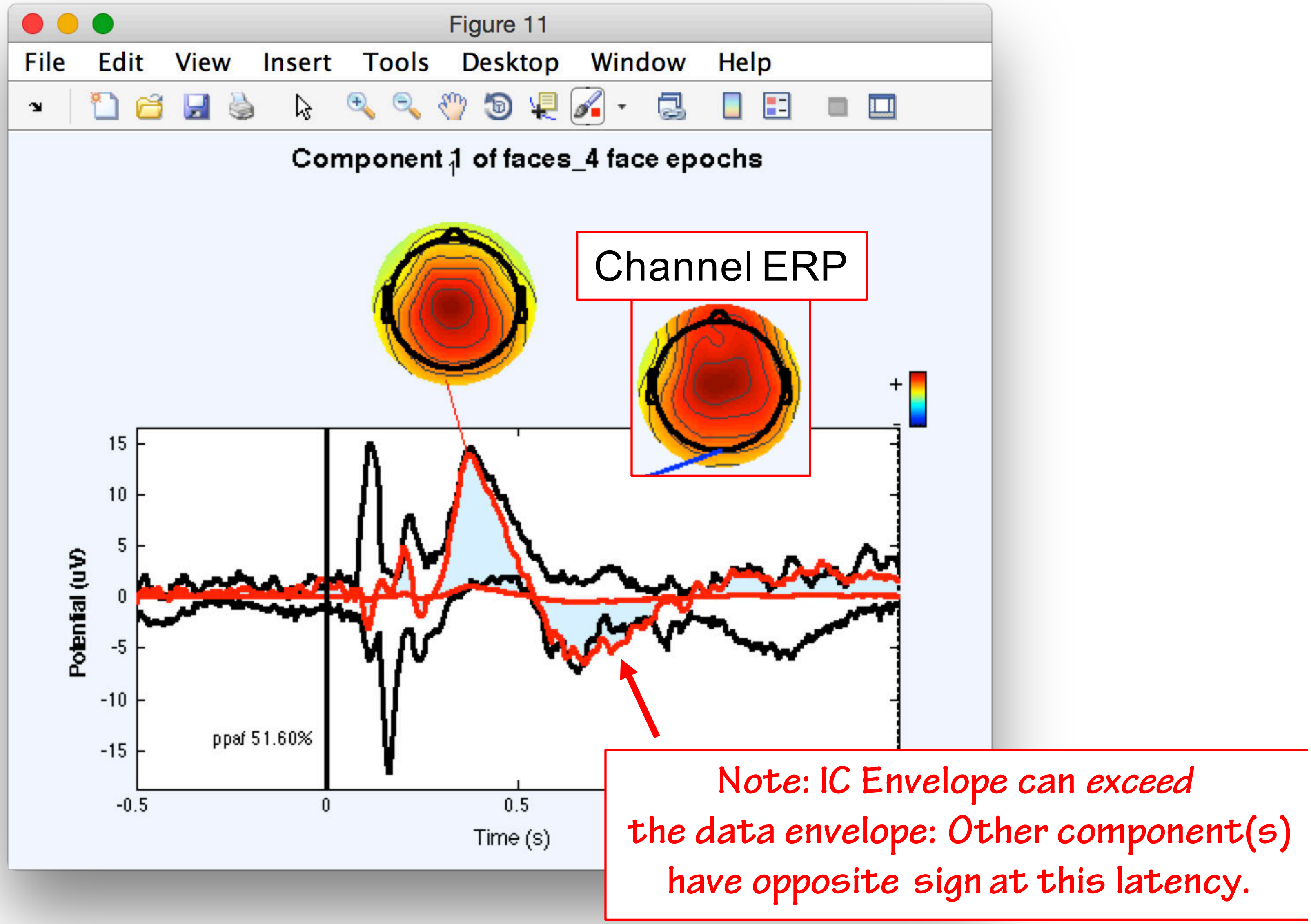
ERP peak- and IC Component-topographies



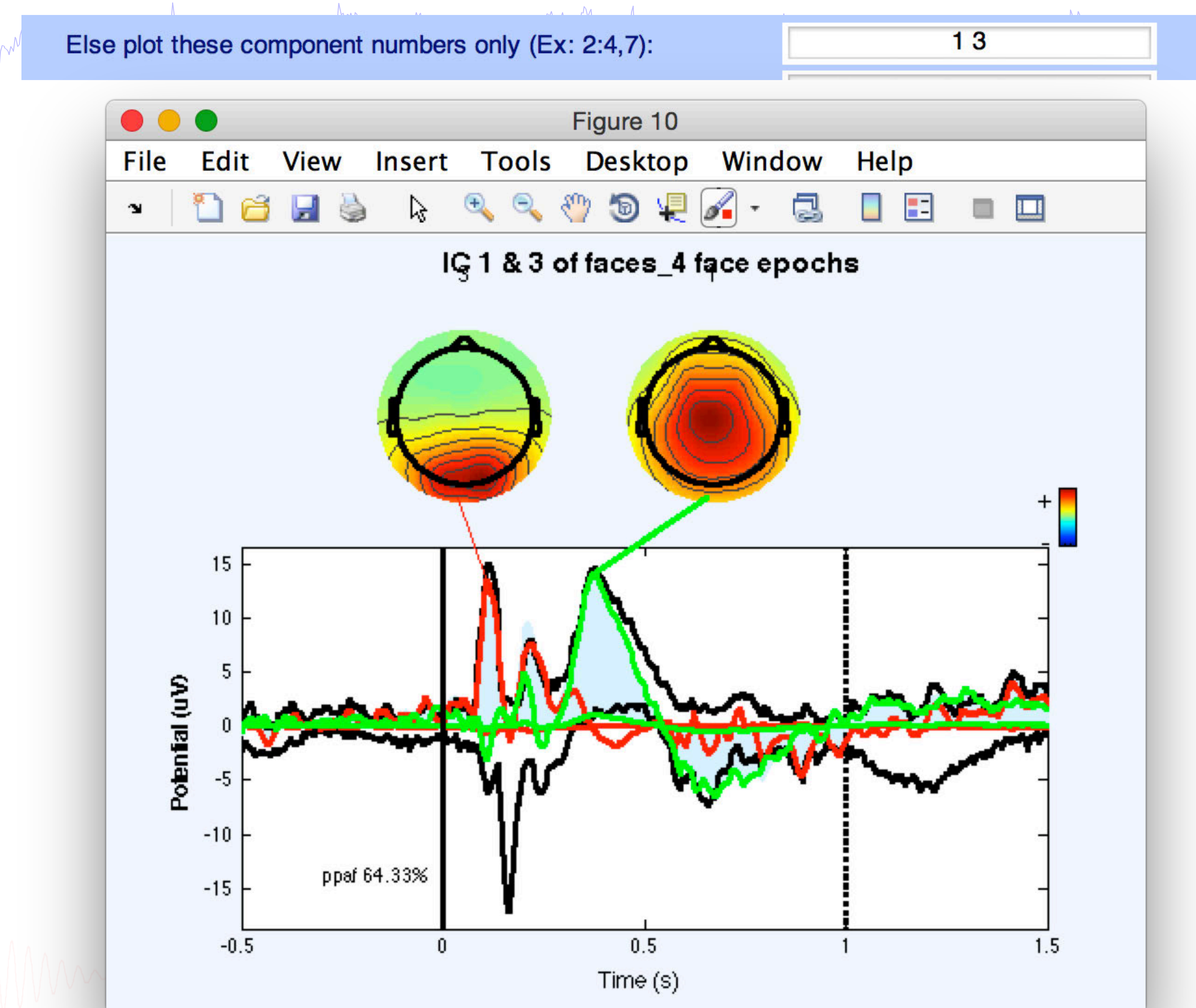
Component 3 ERP envelope



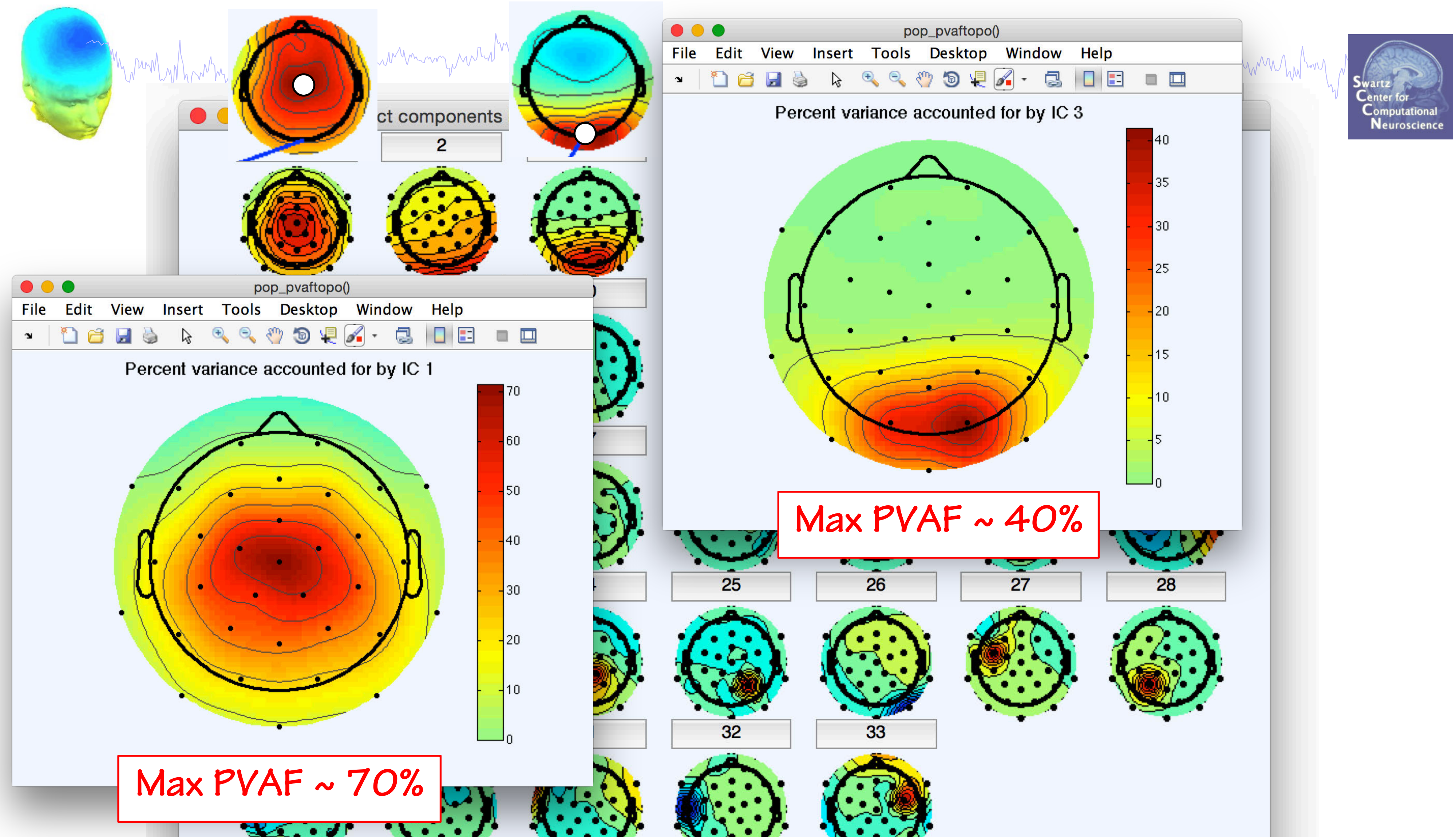
Component 1 ERP envelope



Component 1 + 3 ERP envelope

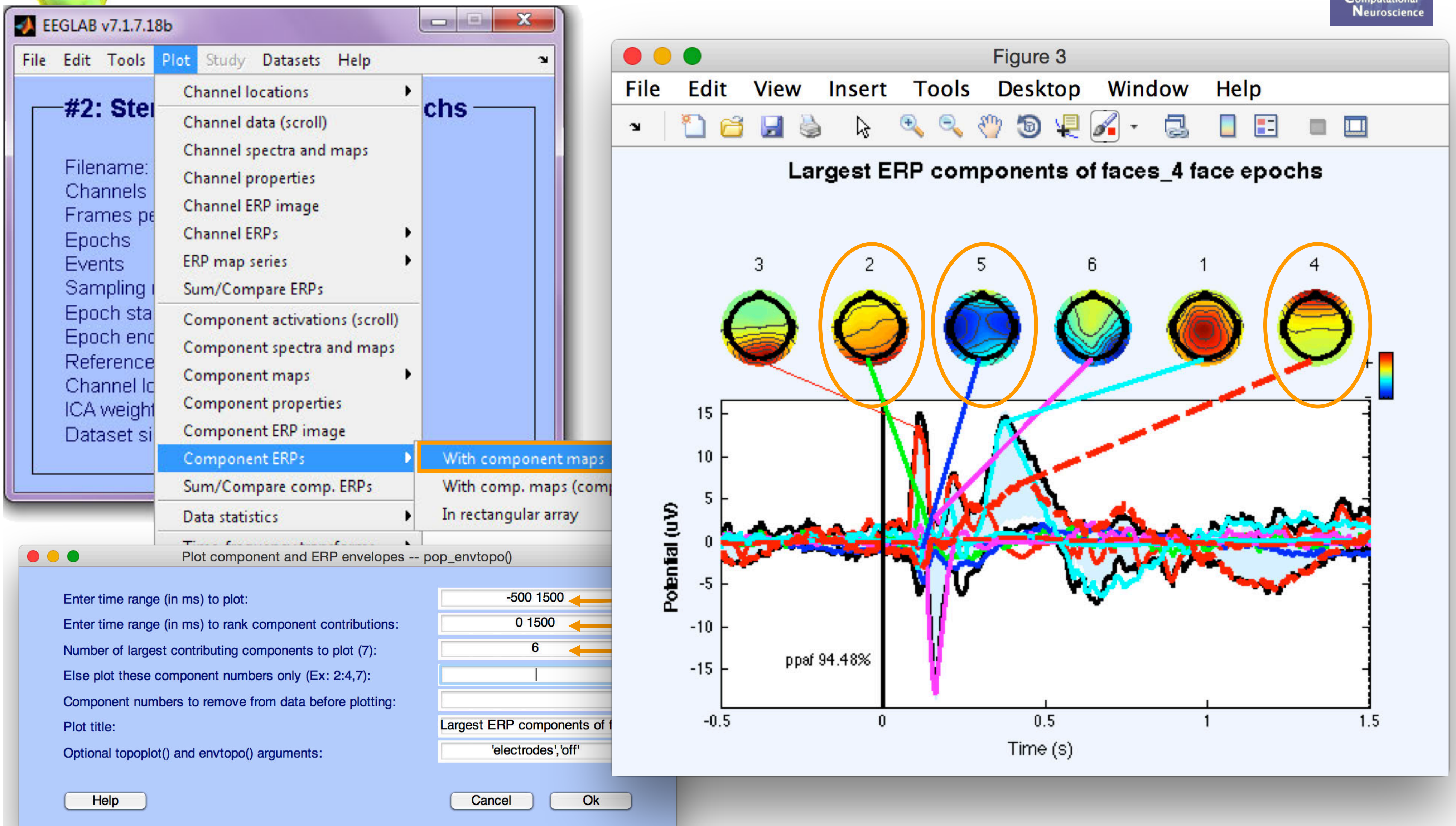


pvaftopo plugin (Makoto Miyakoshi)

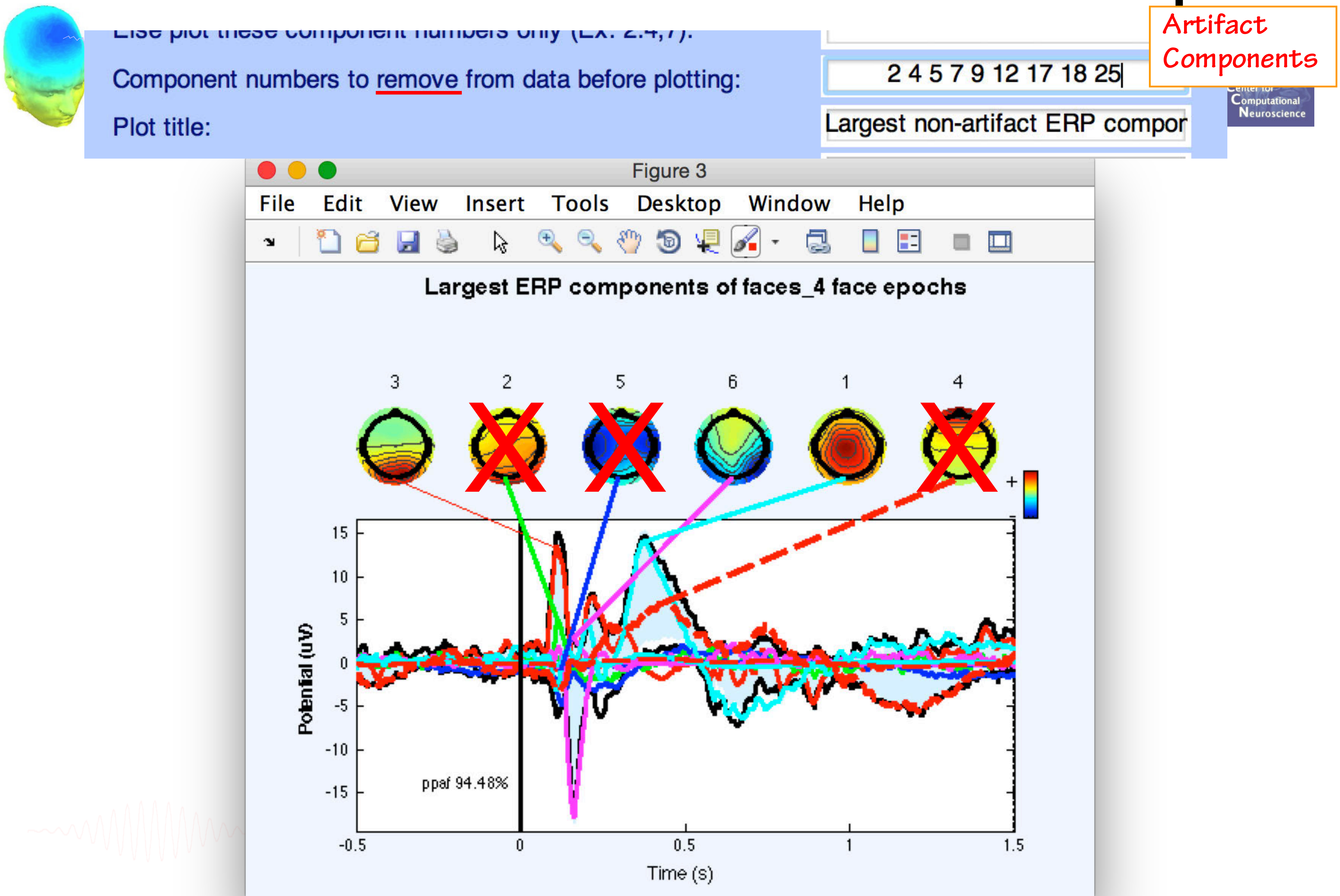


Note: However, PVAF is calculated over *entire* signal duration.
PVAF at times of peaks often higher, but still typically not 100%.

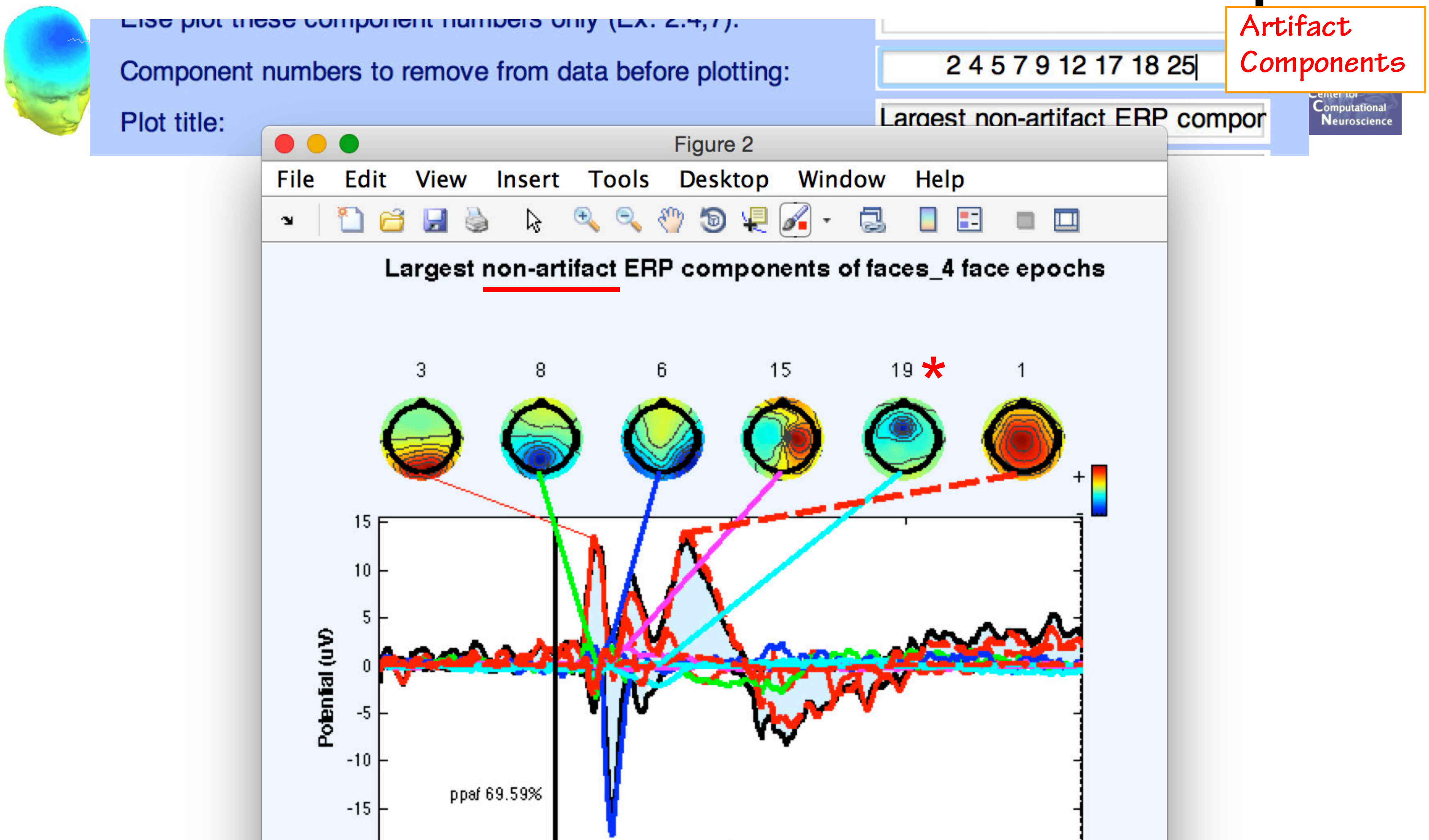
Top 6 IC contributions to data ERP envelope



Non-artifact IC contrib. to data ERP envelope

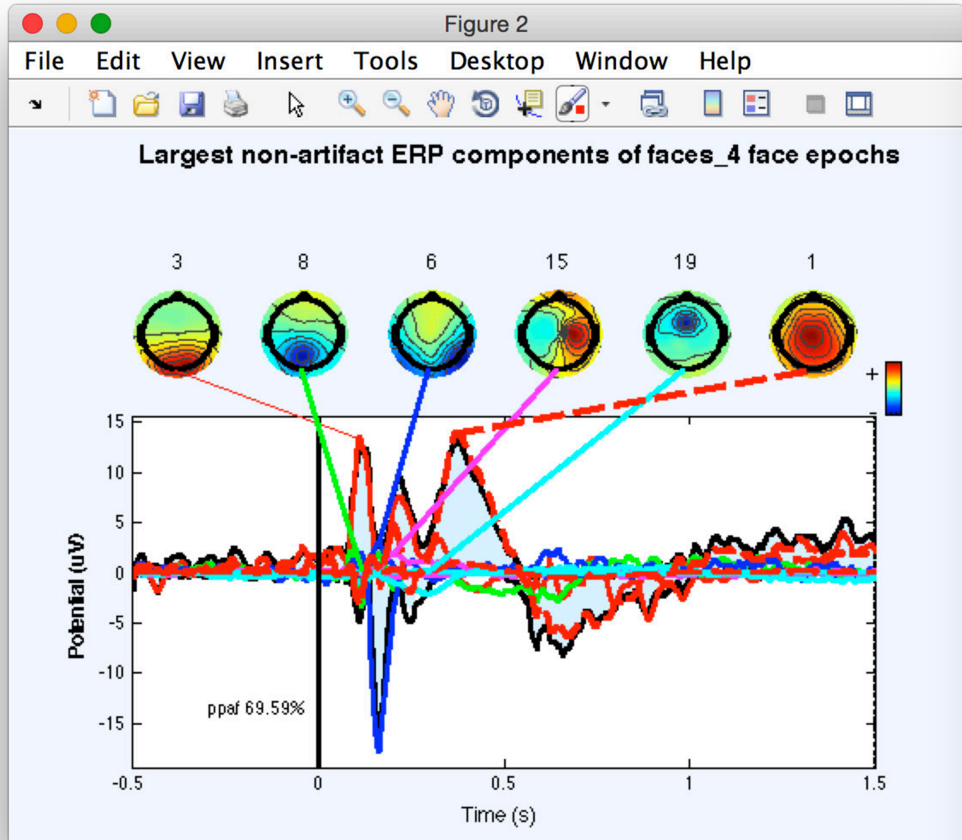


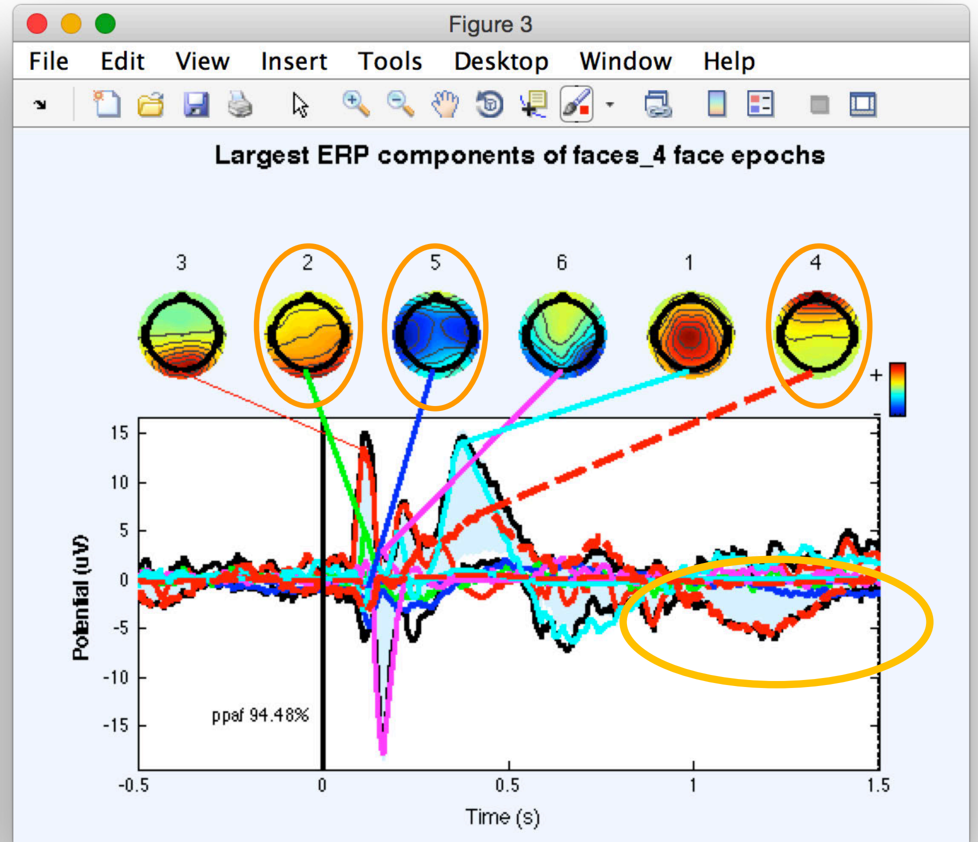
Non-artifact IC contrib. to data ERP envelope




```
pop_envtopo(EEG, [-500  1500] ,'limcontrib', [0 1500], ...
'compsplot',[6],'subcomps',[2 4 5 7 9 12 17 18 25], ...
'title', 'Largest non-artifact ERP components of faces_4 face epochs',...
'electrodes','off');
```

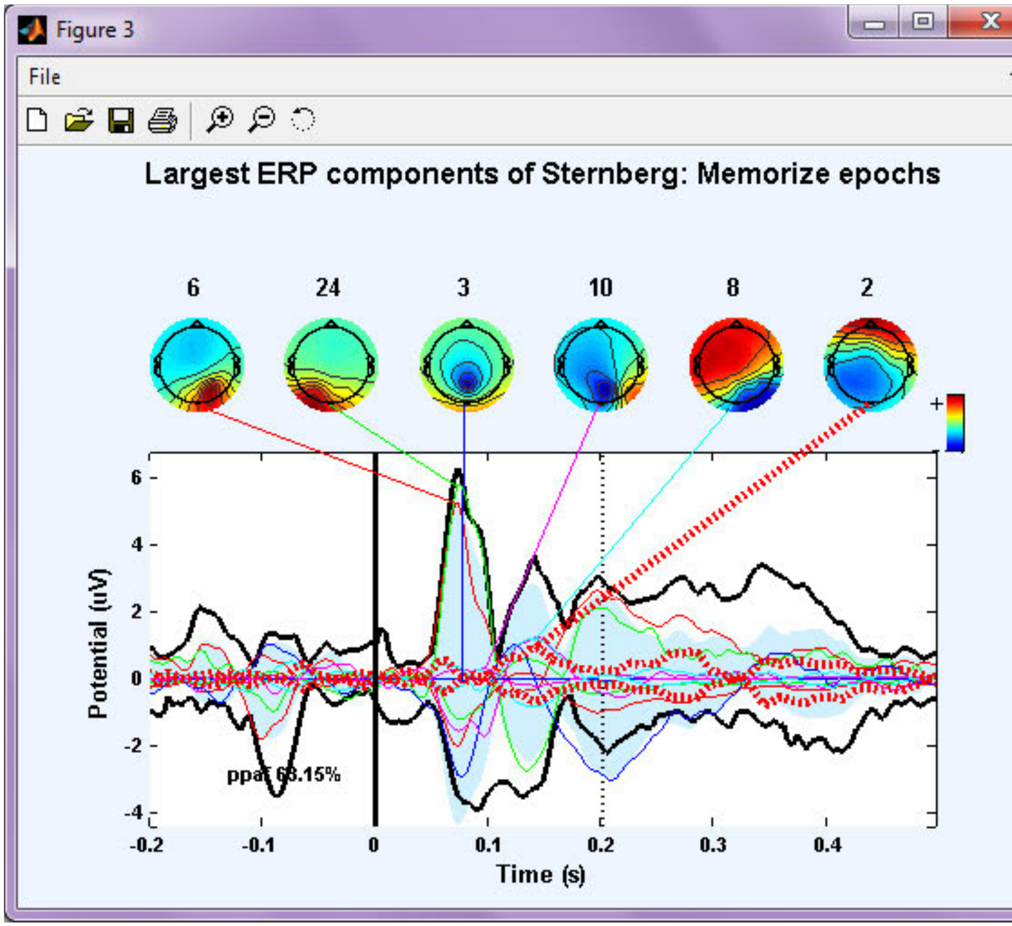
Compare: Effect of removing artifacts

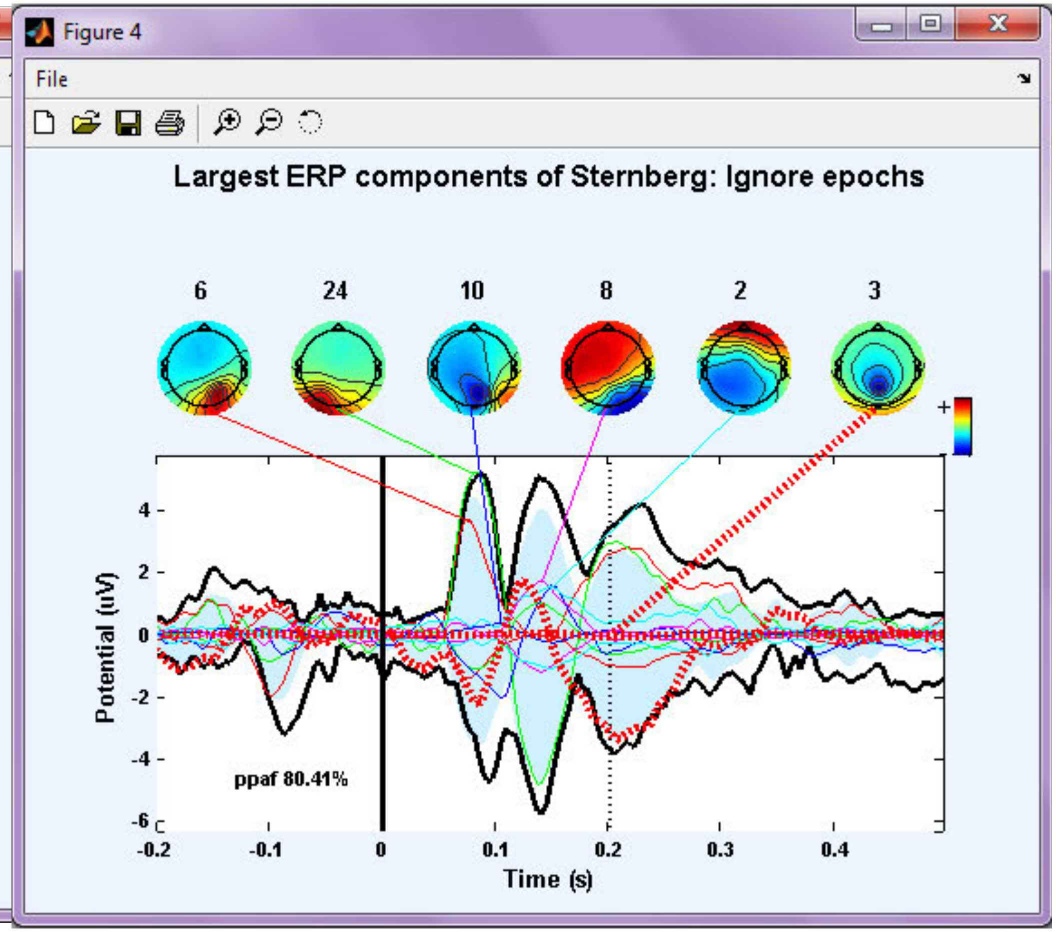




IC ERP difference

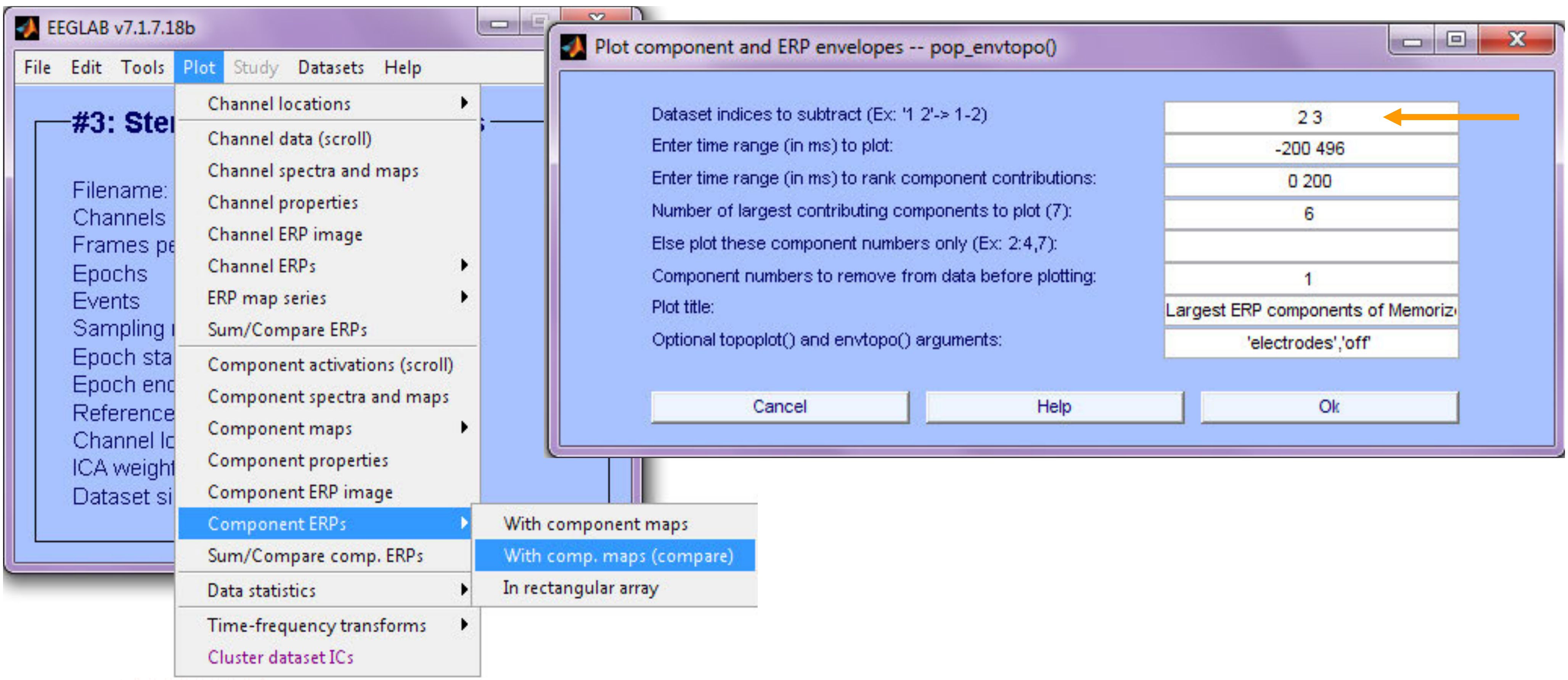
What is the IC ERP difference between these 2 conditions?



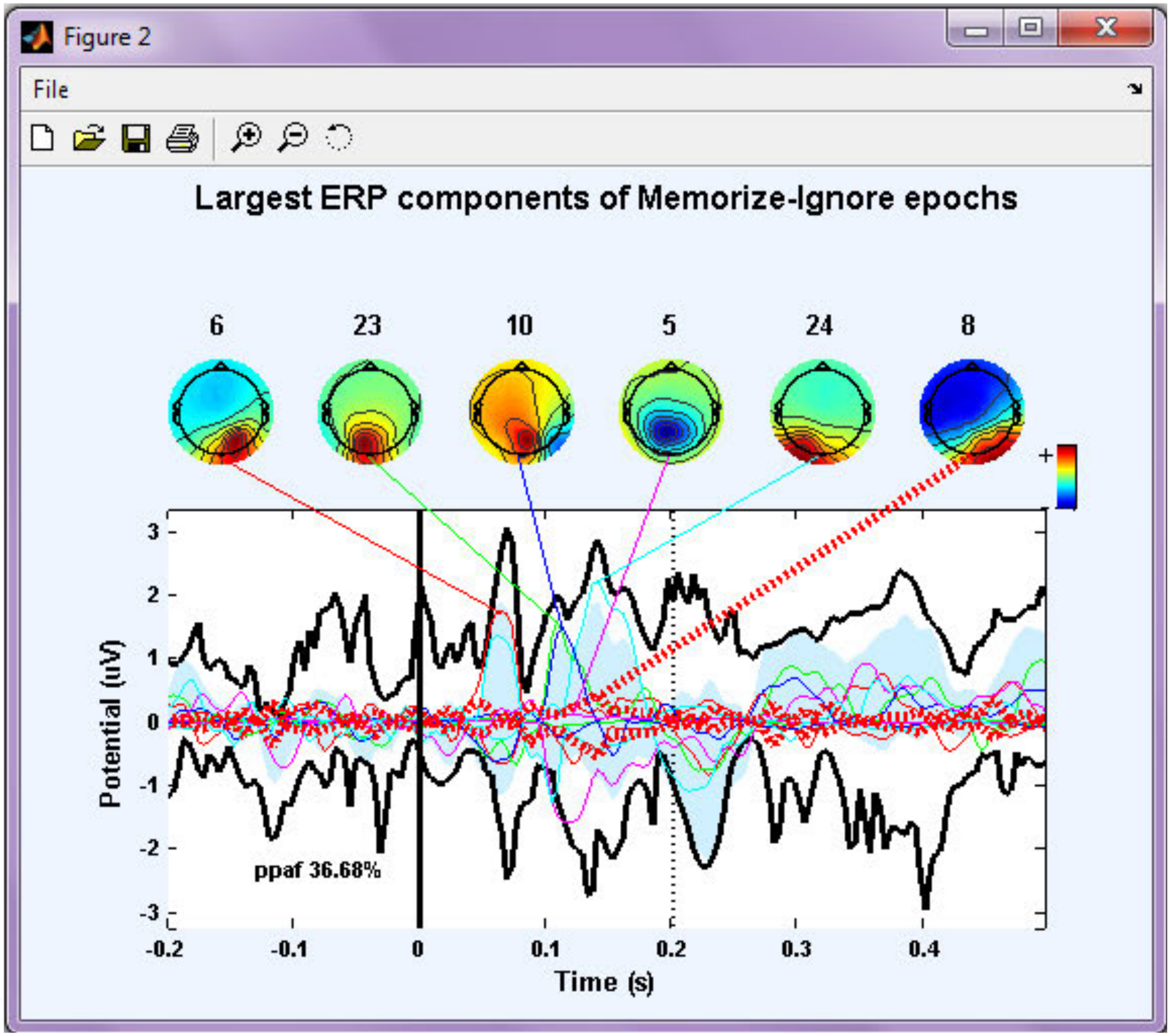


(Data: stern_125Hz.set)

IC ERP difference



IC ERP difference



Now what…?

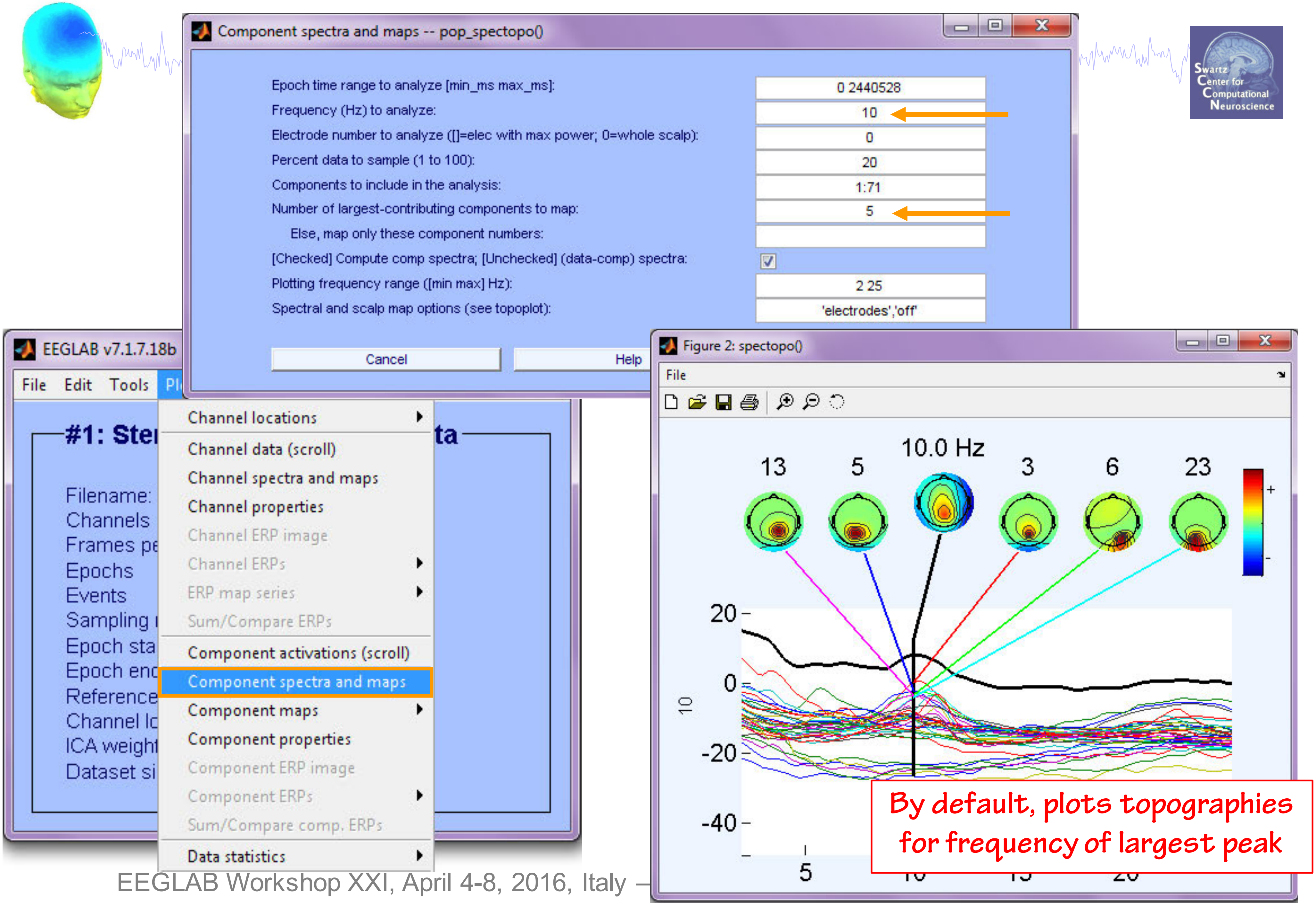
Part 1
Getting an overview of your ICs

Part 2
Classifying/Evaluating ICs

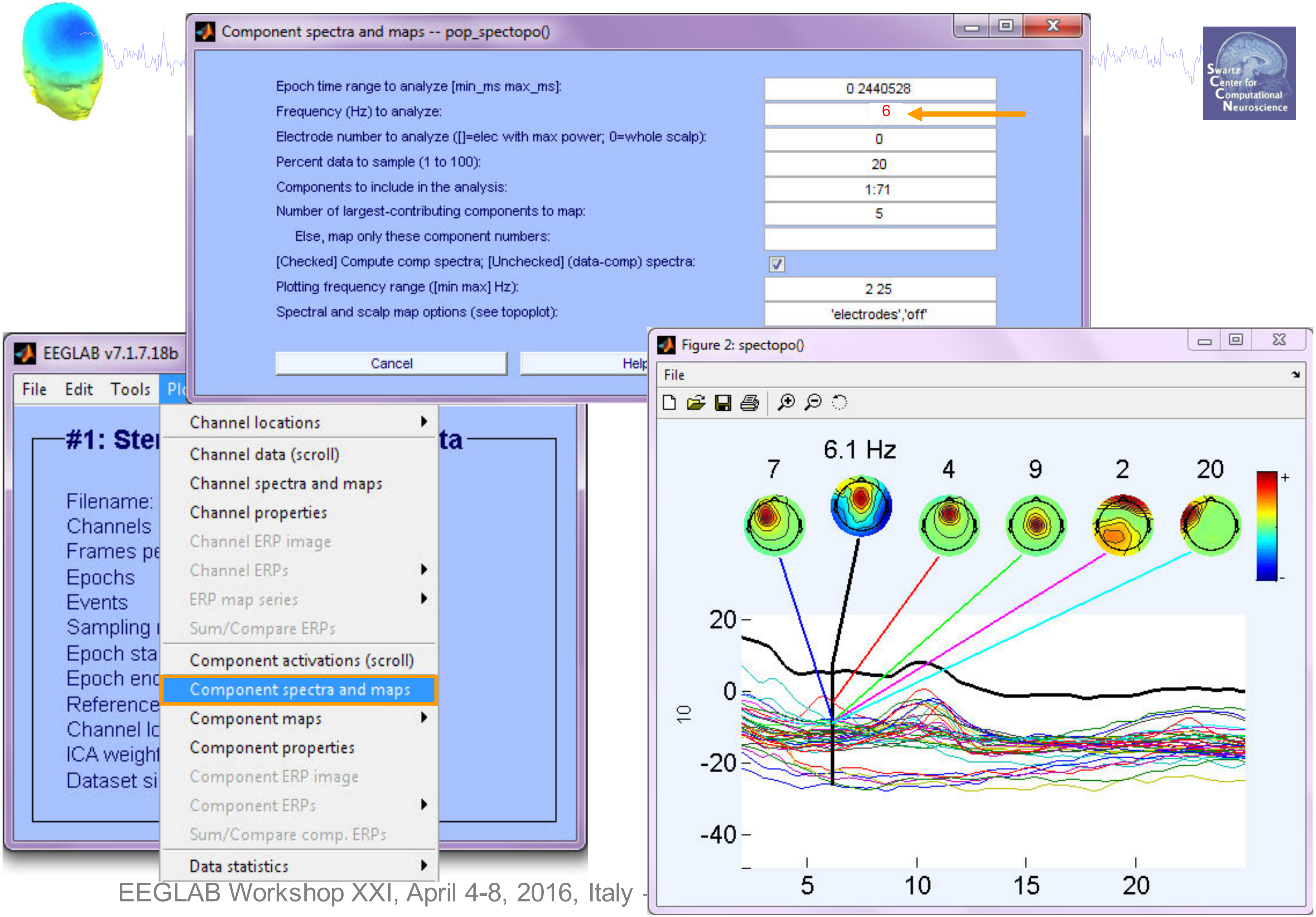
Part 3
Detailed look at IC properties

- ERP
- Spectrum
- ERP images
- ERSP

Plot component power spectrum



Select the frequency for topographies



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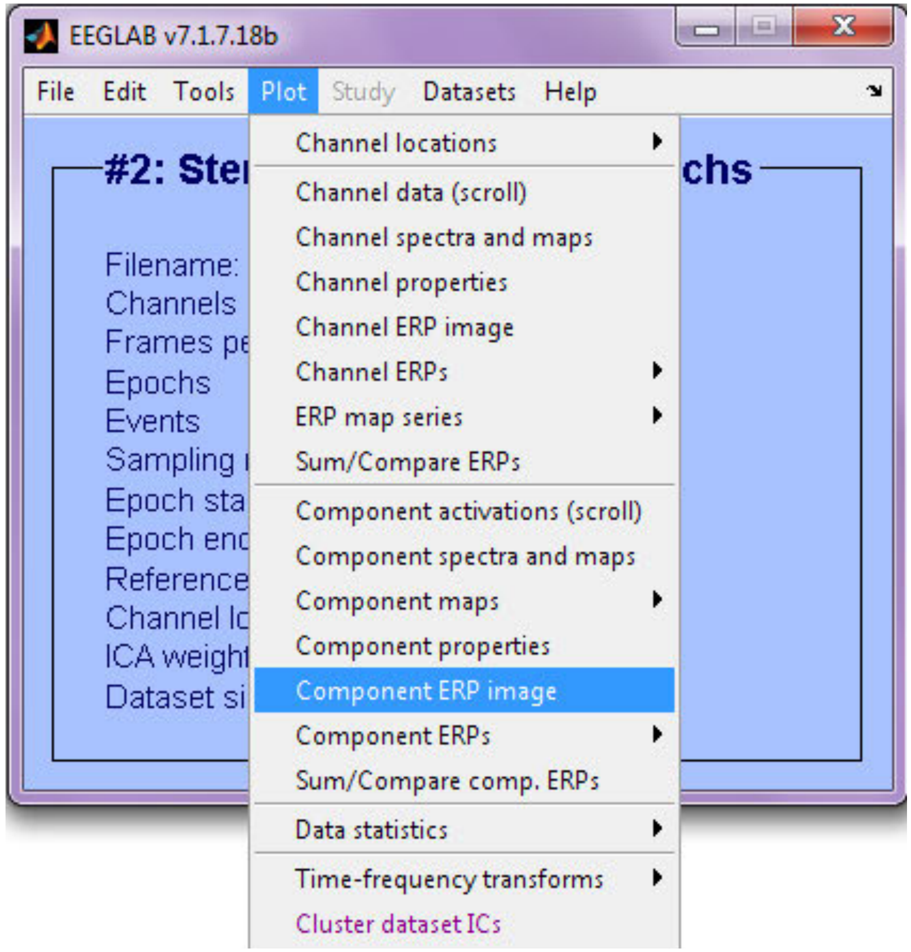
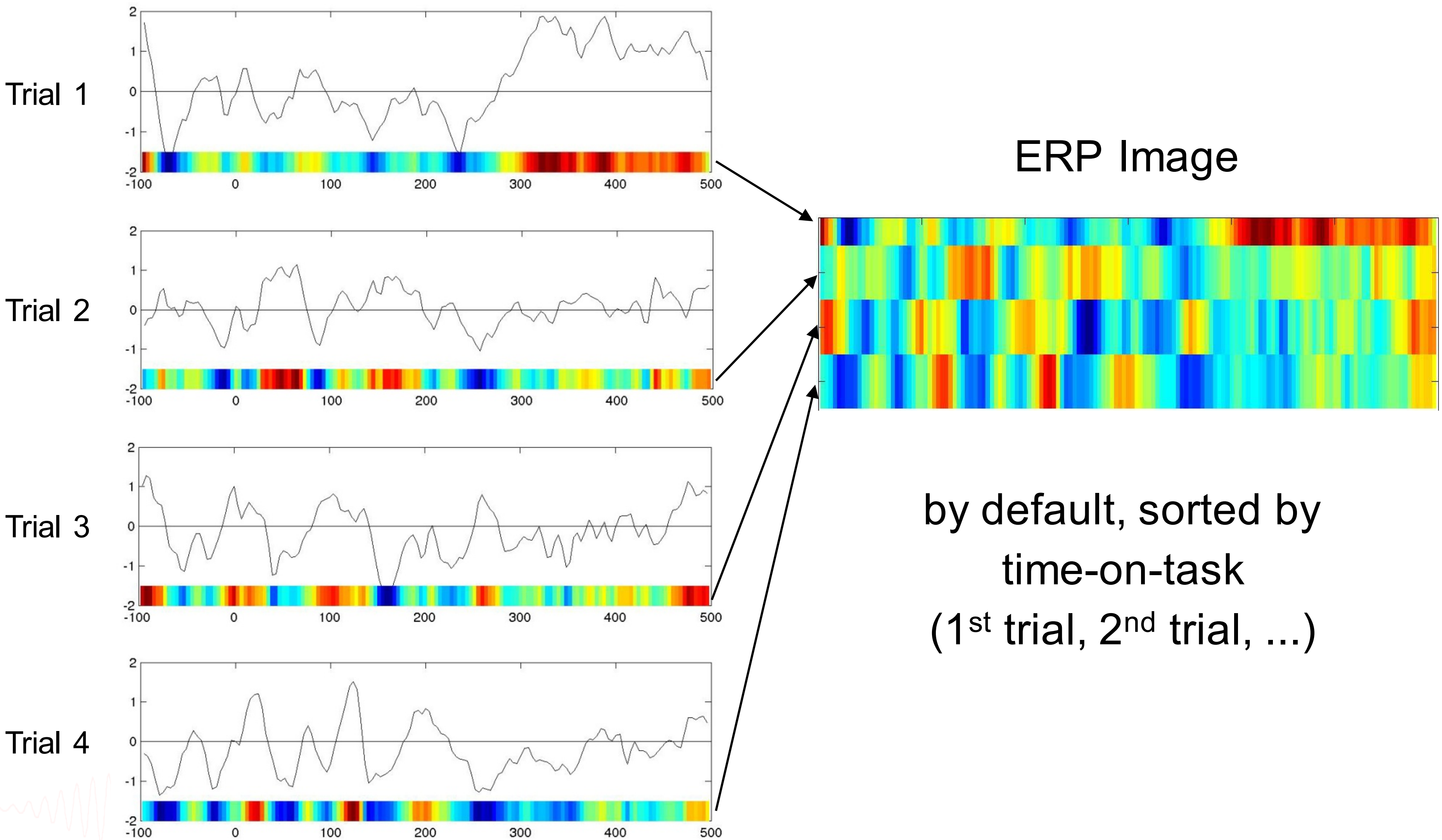
Component ERP image

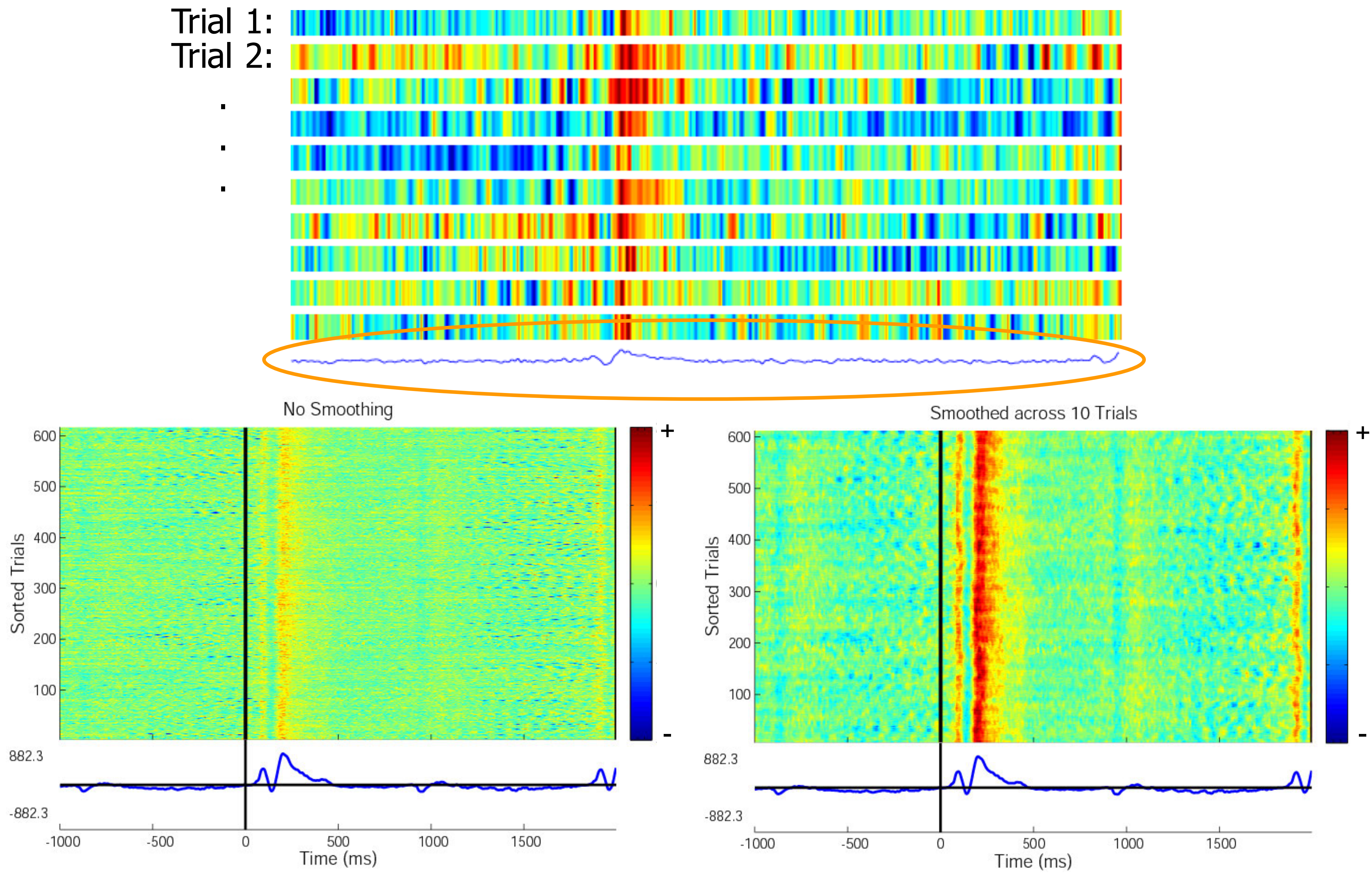


ERP Image basics

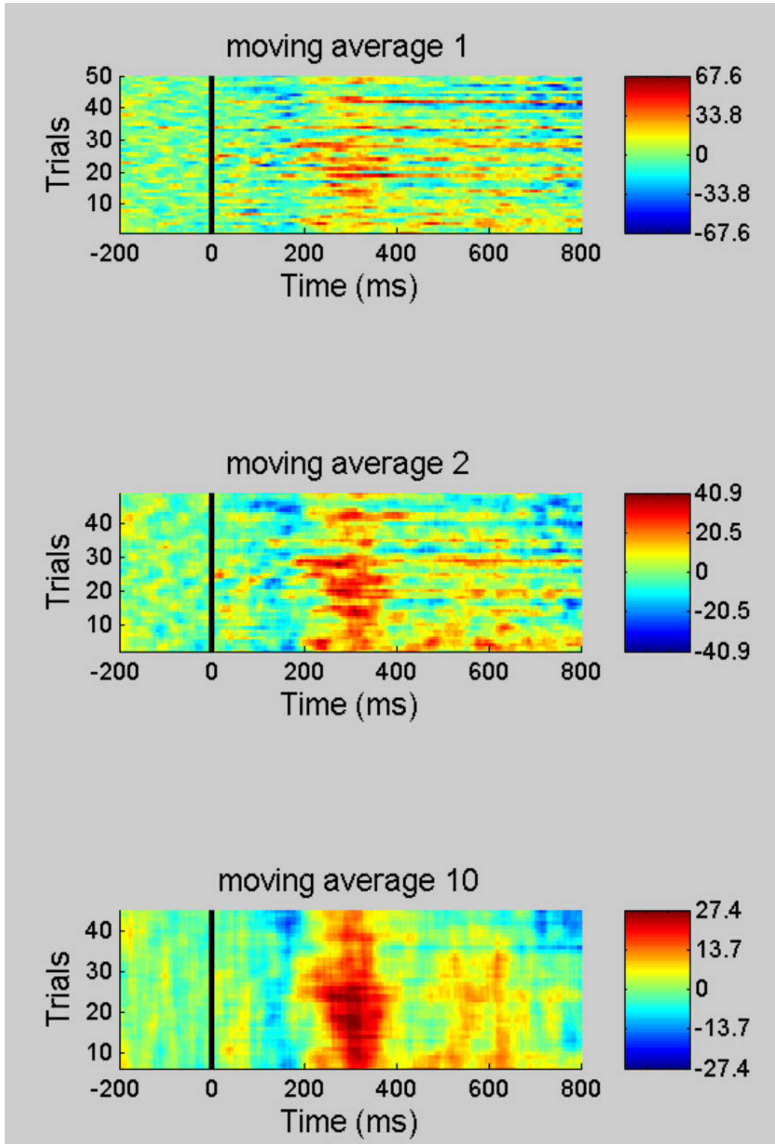


by default, sorted by time-on-task (1st trial, 2nd trial, ...)

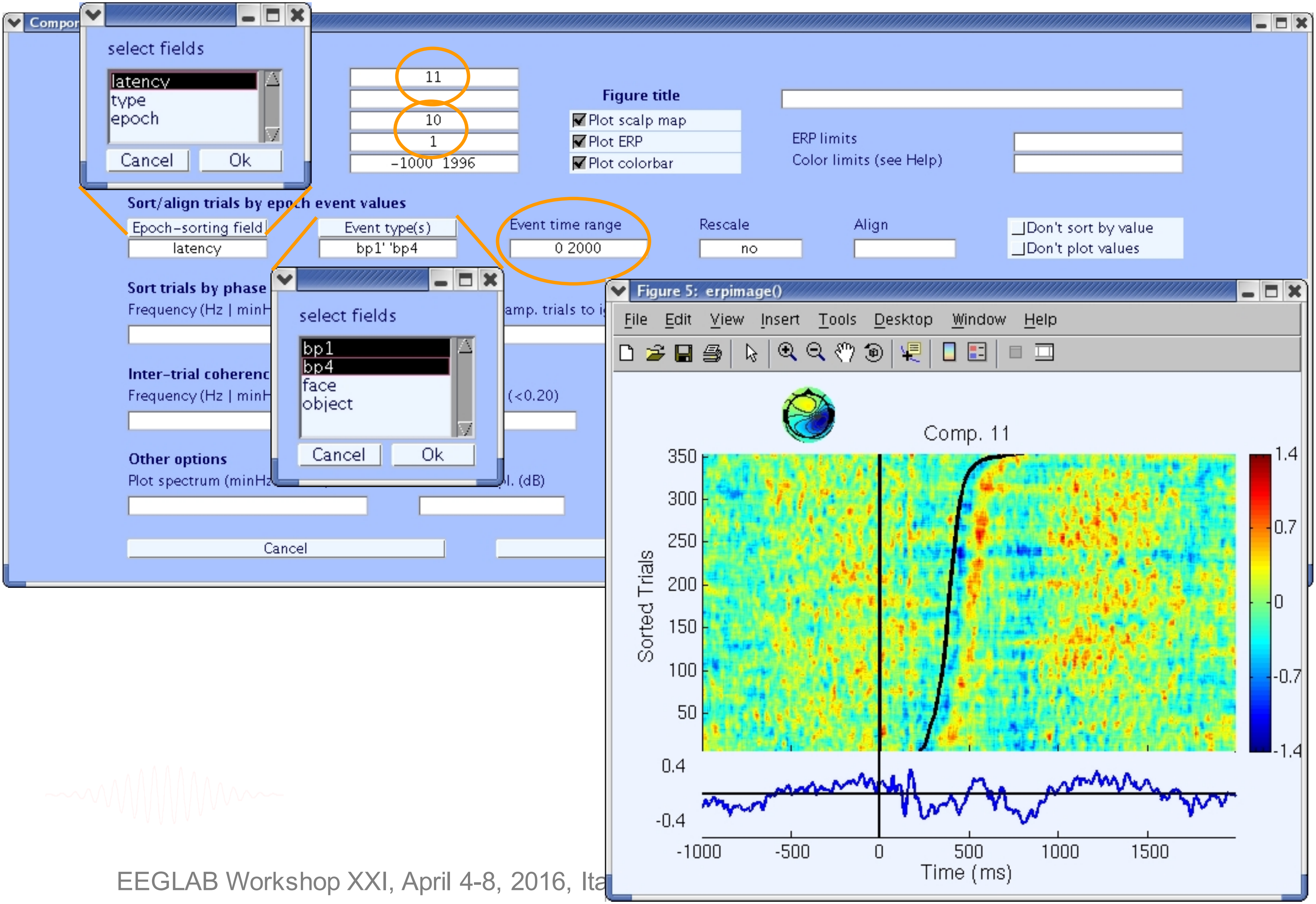
ERP Image basics



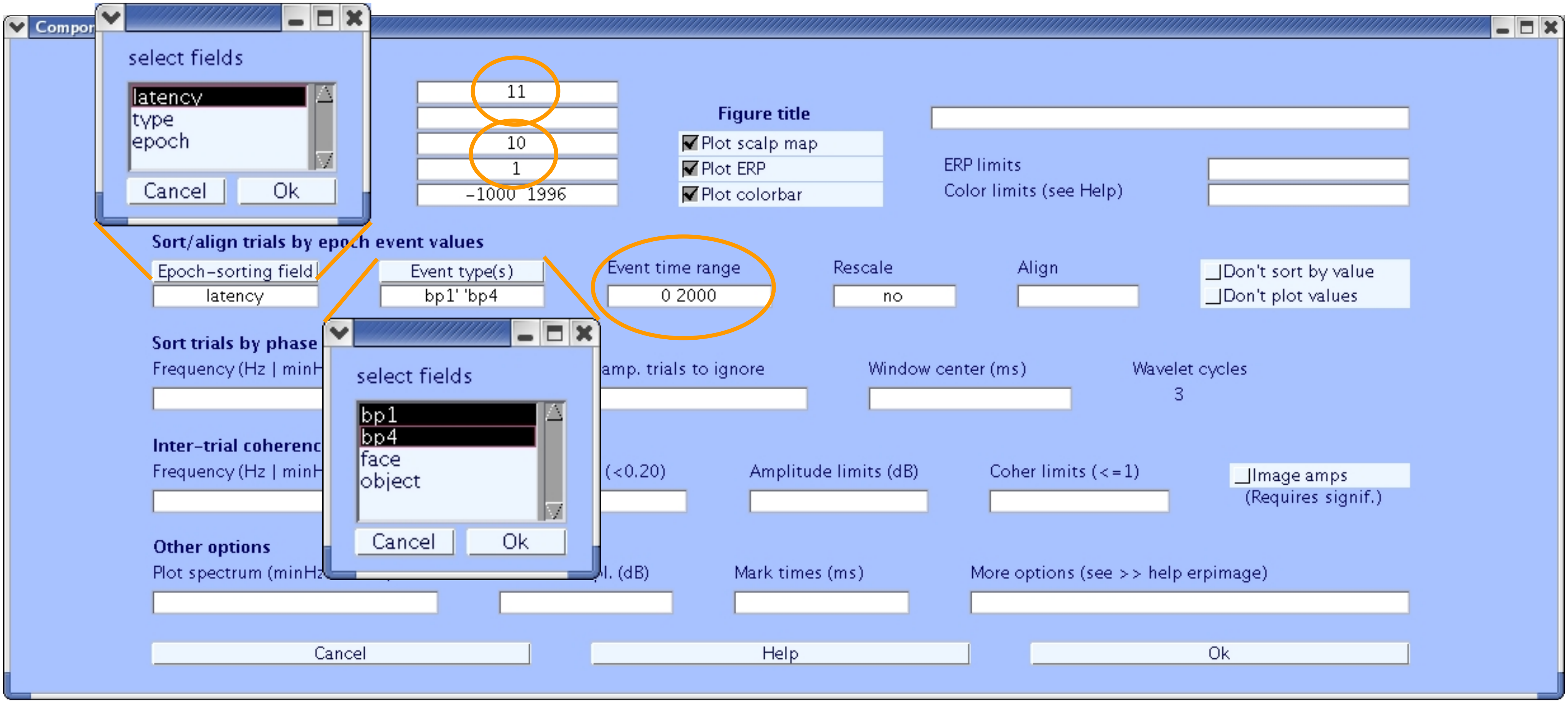
ERP Images: smoothing across trials



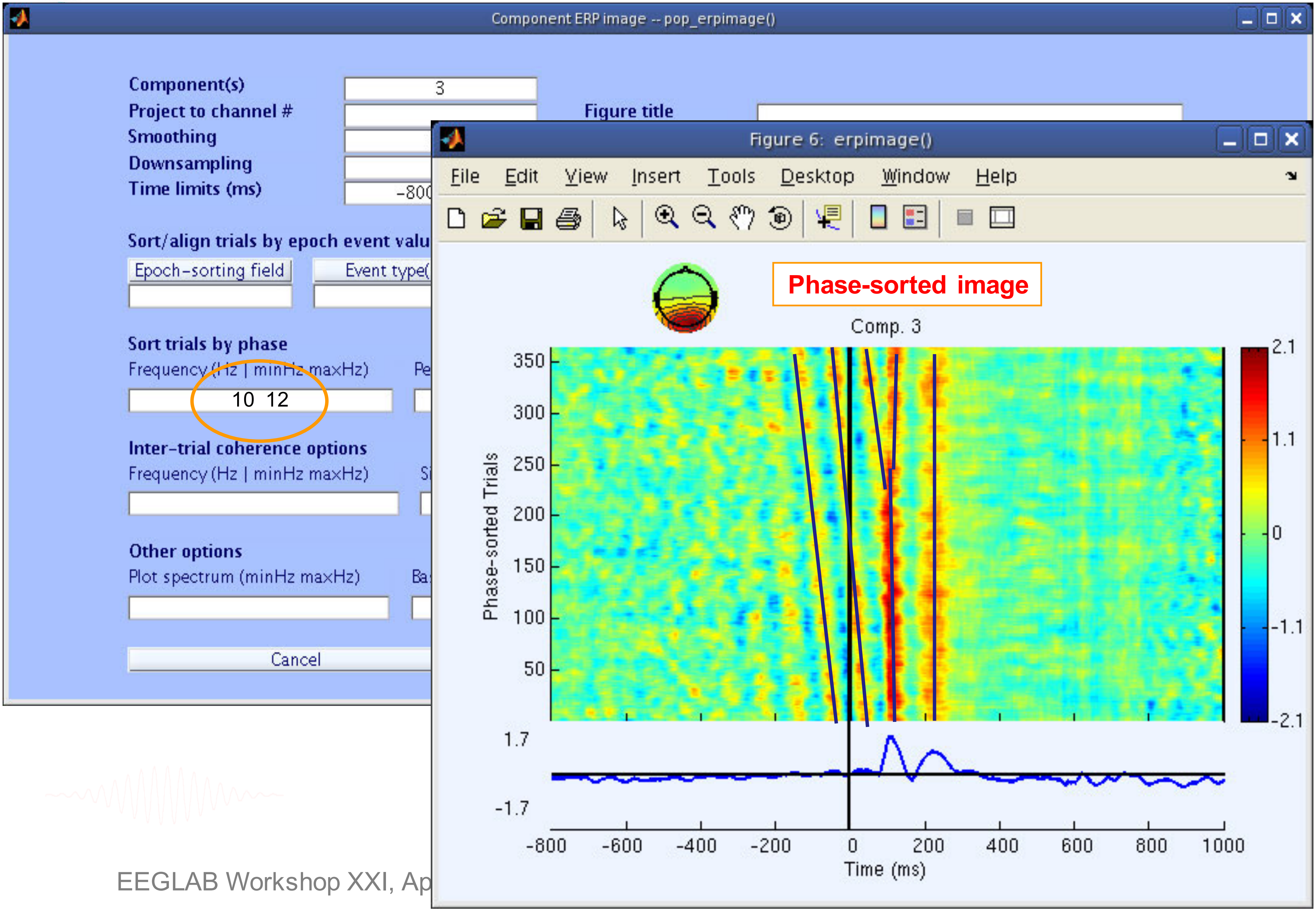
Component ERP Image: Sort by RT



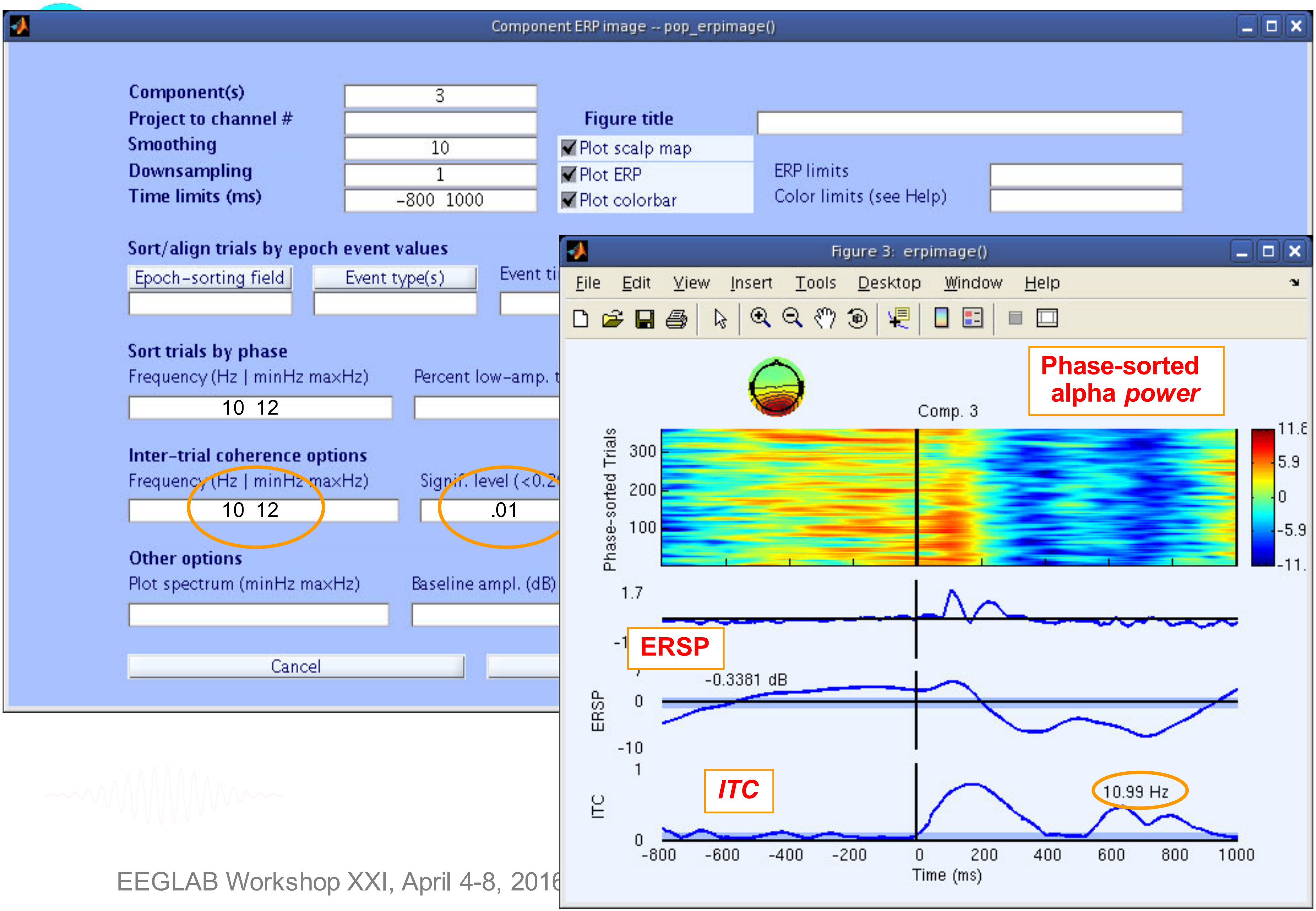
Component ERP Image: Sort by RT



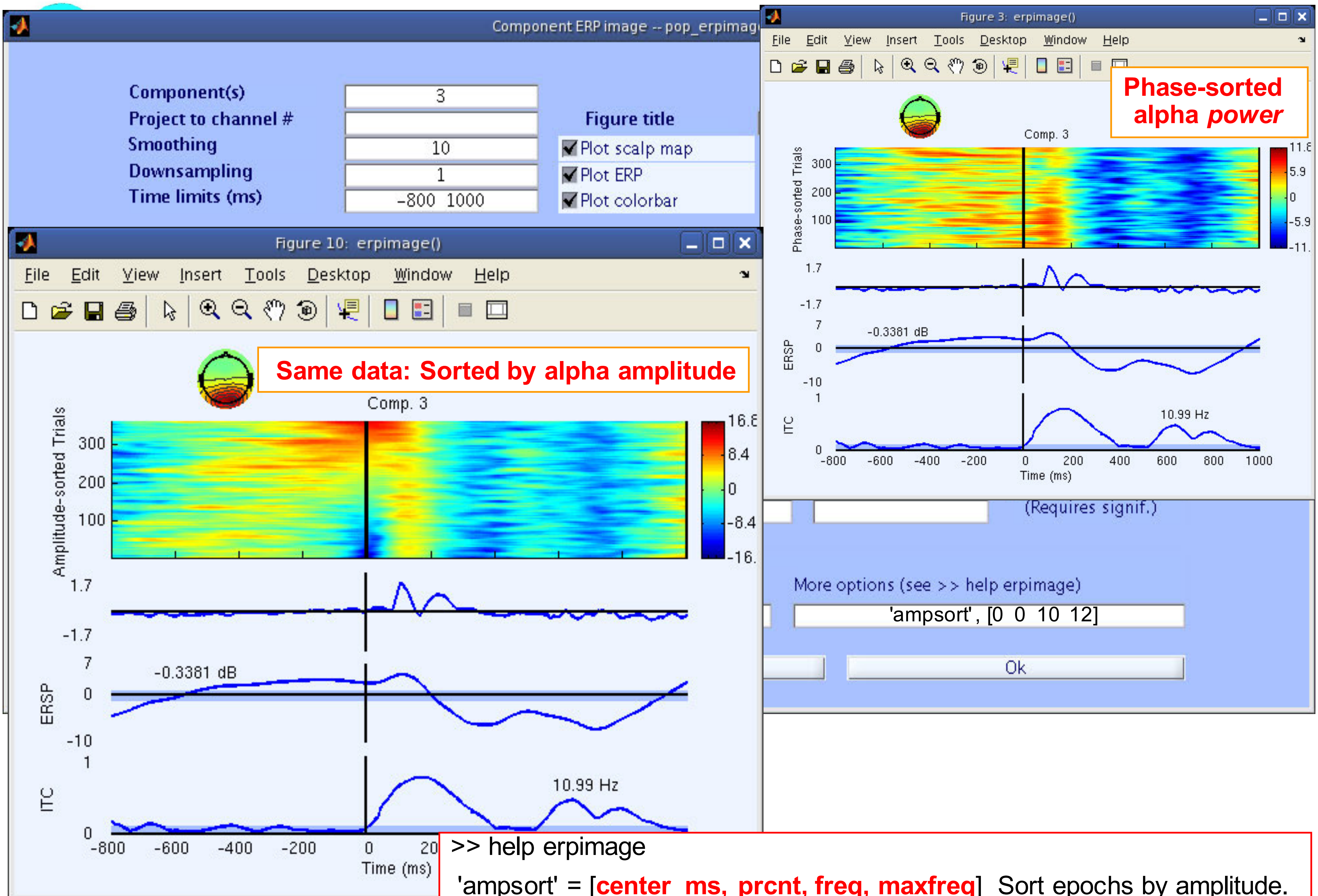
Component ERP Images: Sort by phase



Component ERP Images: ITC



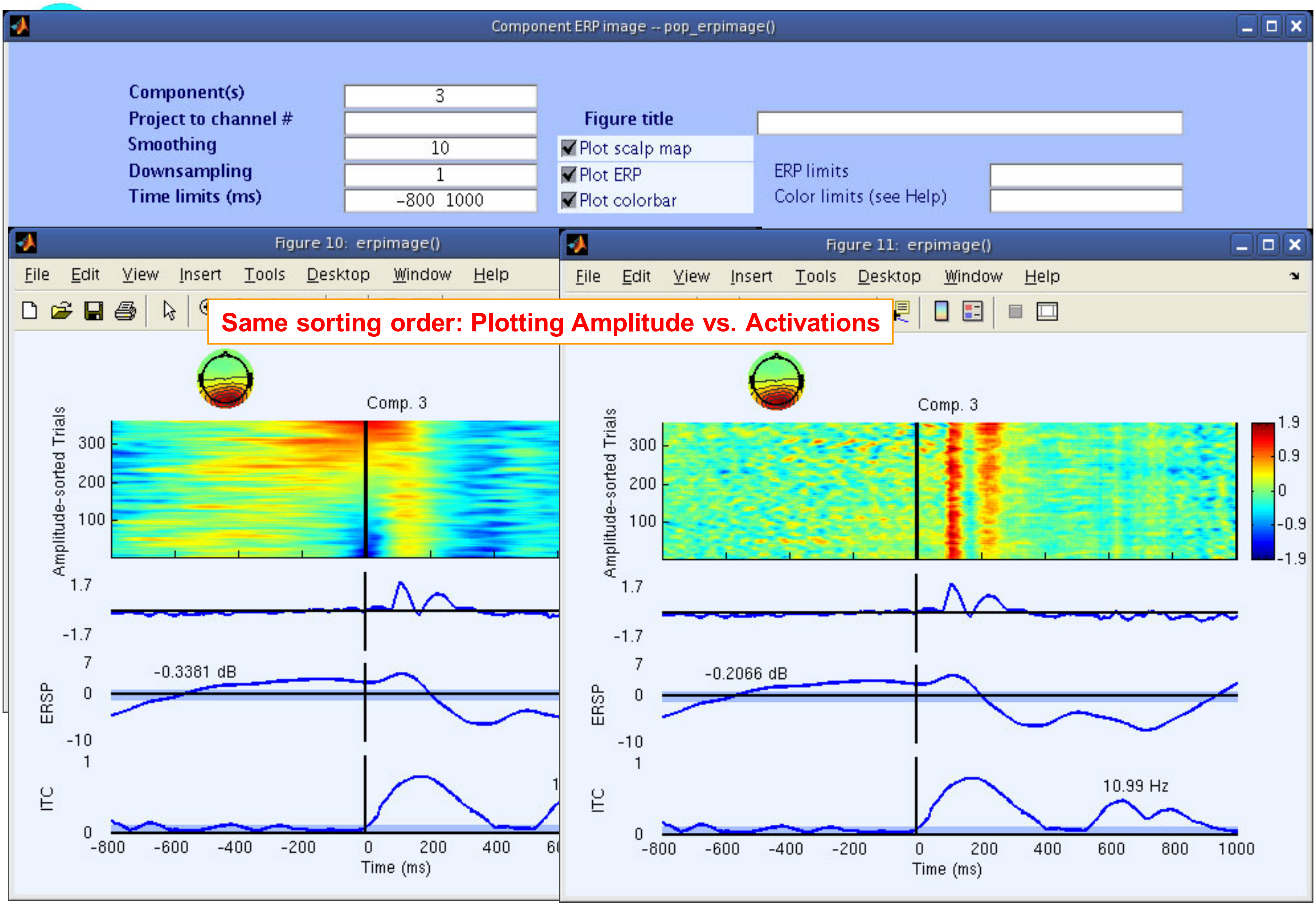
Component ERP Images: Sort by amplitude



>> help erpimage

'ampsort' = [**center_ms, prcnt, freq, maxfreq**] Sort epochs by amplitude.

Component ERP Images: Amplitude vs. Activations



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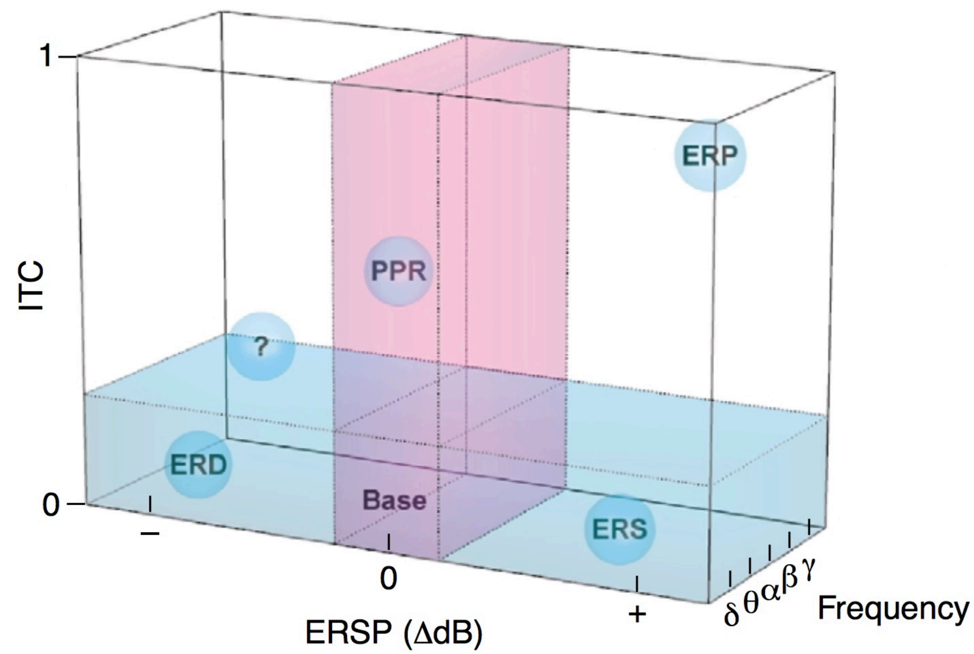
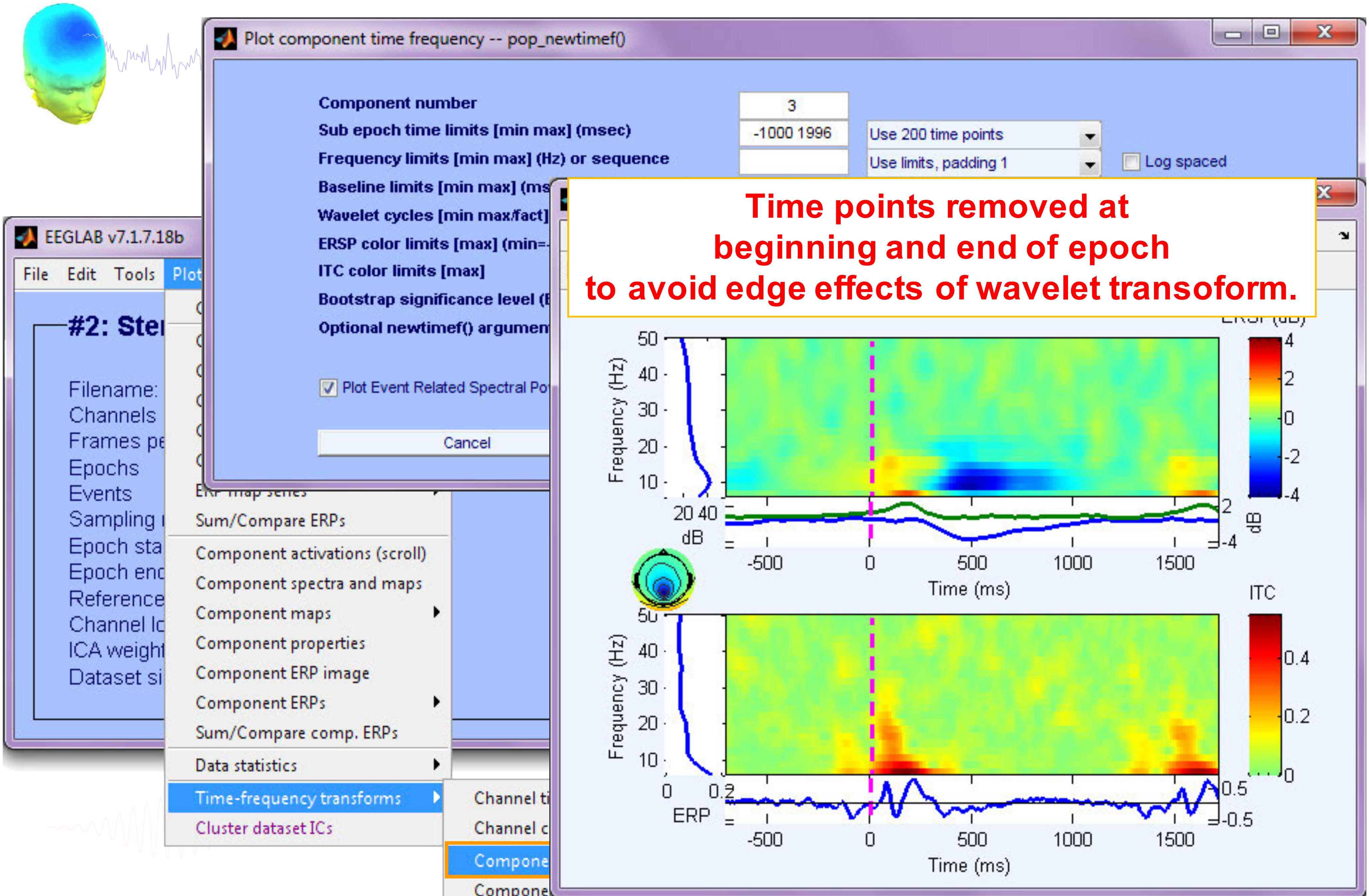
Definition: ERSP

Event Related Spectral Perturbation

Change in power in different frequency bands relative to a baseline. ERS , ERD

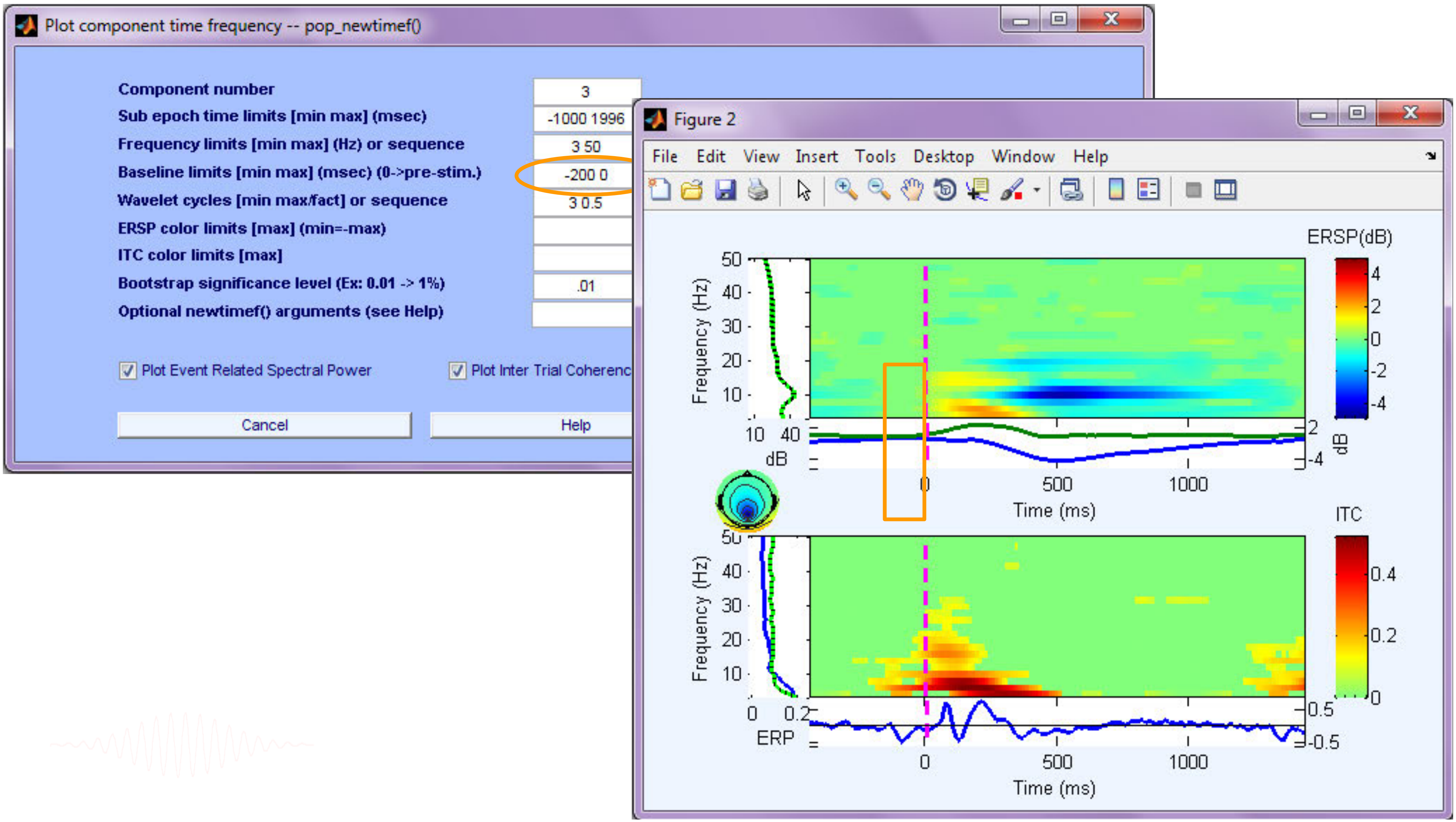


Plot IC ERSP



Plot component time frequency -- pop_newtimef()
Component number
3
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] (ms
Wavelet cycles [min max/fact]
ERSP color limits [max] (min=-
ITC color limits [max]
Bootstrap significance level (
Optional newtimef() argumen
Plot Event Related Spectral Po
Cancel
EEGLAB v7.1.7.18b
File Edit Tools Plot
#2: Ste
Filename:
Channels
Frames pe
Epochs
Events
Sampling
Epoch sta
Epoch enc
Reference
Channel lo
ICA weight
Dataset si
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
Cluster dataset ICs
Channel ti
Channel c
Compone
Compone
Time points removed at
beginning and end of epoch
to avoid edge effects of wavelet transoform.
Frequency (Hz)
Time (ms)
dB
ERP
ITC

Plot IC ERSP



Plot component time frequency -- pop_newtimef()
Component number
3
Sub epoch time limits [min max] (msec)
-1000 1996
Frequency limits [min max] (Hz) or sequence
3 50
Baseline limits [min max] (msec) (0->pre-stim.)
-200 0
Wavelet cycles [min max/fact] or sequence
3 0.5
ERSP color limits [max] (min=-max)
ITC color limits [max]
Bootstrap significance level (Ex: 0.01 -> 1%)
.01
Optional newtimef() arguments (see Help)
Plot Event Related Spectral Power
Plot Inter Trial Coherenc
Cancel
Help
Figure 2
File Edit View Insert Tools Desktop Window Help
ERSP(dB)
Frequency (Hz)
dB
Time (ms)
ITC
ERP

Further Resources

Some attempts to automate the IC classification:

"Automatic Classification of Artifactual ICA-Components for Artifact Removal in EEG Signals"

Irene Winkler, Stefan Haufe and Michael Tangermann (2011)

http://www.behavioralandbrainfunctions.com/content/7/1/30

Bigdely-Shamlo's EyeCatch (2013)

https://www.researchgate.net/publication/257602145_EyeCatch_Data-mining_over_half_a_million_EEG_independent_components_to_construct_a_fully-automated_eye-component_detector

Luca Pion-Tonachini (ongoing)

Crowd-sourcing heuristic knowledge about IC components to build automatic classifier

We'll play the game later: http://reaching.ucsd.edu:8000