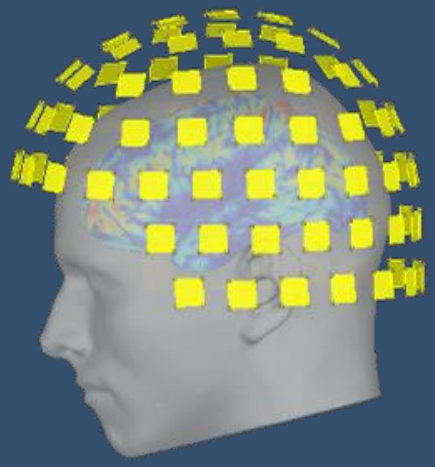
MEG and EEG analysis using

Brainstorm

http://neuroimage.usc.edu/brainstorm



USC UNIVERSITY OF SOUTHERN CALIFORNIA

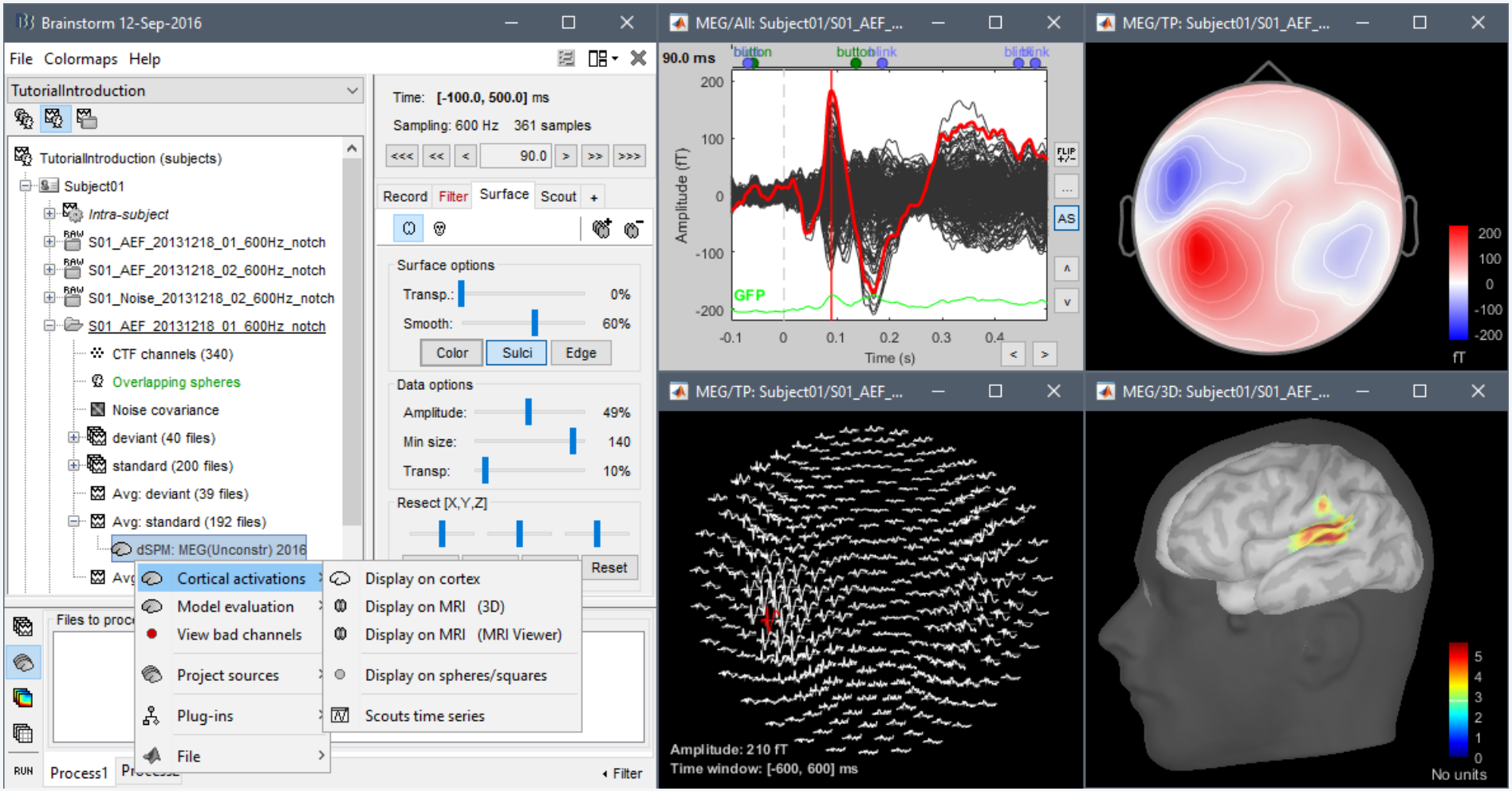
Cleveland Clinic

McGill

neuro

April 2017

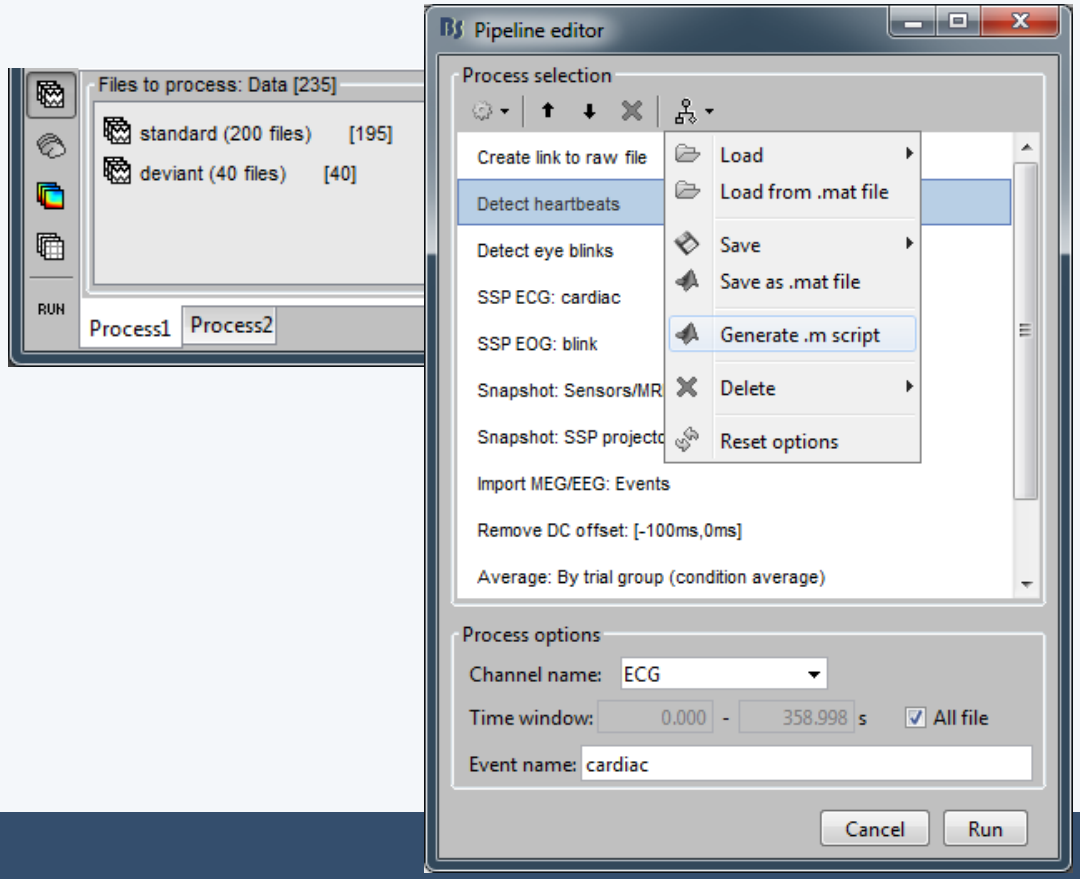
Graphic interface



Brainstorm

Scripting environment

- Rapid selection of files and processes to apply
- Automatic generation of Matlab scripts
- Plug-in structure: easy to add custom processes



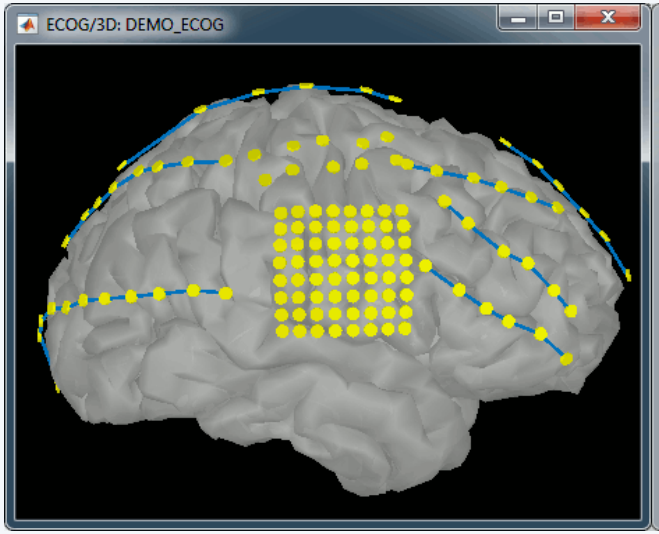

```
% Script generated by Brainstorm v3.1 (17-Dec-2010).
FileNamesA = {'Subject01\Left\data_average_101213_1558.mat', ...
              'Subject01\Right\data_average_101213_1559.mat'};
FileNamesB = [];

% Process: Detect bad trials: Peak-to-peak  MEGGRAD(0-2000)
sFiles = bst_process(...
    'CallProcess', 'process_detectbad', ...
    FileNamesA, FileNamesB, ...
    'timewindow', [-0.0998, 0.3000], ...
    'meggrad', {[0, 2000], 'fT/cm (x 0.04)', 1e-015}, ...
    'rejectmode', 2);

% Process: Remove baseline: [-100ms,-1ms]
sFiles = bst_process(...
    'CallProcess', 'process_baseline', ...
    sFiles, [], ...
    'baseline', [-0.09983, -0.00056], ...
    'overwrite', 1);

% Process: Band-pass filter: 1Hz - 80Hz
sFiles = bst_process(...
    'CallProcess', 'process_bandpass', ...
    sFiles, [], ...
    'f1', 1, ...
    'f2', 80, ...
    'overwrite', 1);

% Process: Average by condition
sFiles = bst_process(...
    'CallProcess', 'process_average', ...
    sFiles, [], ...
    'avgtype', 3, ...
    'isstd', 0);
```

Brainstorm

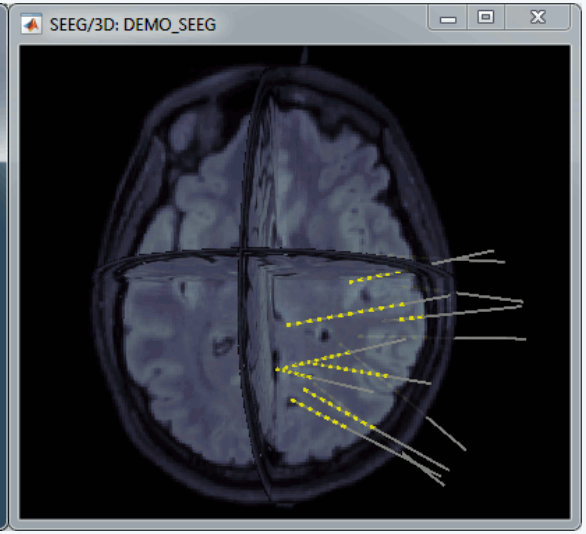
- Free and open-source application
- Matlab & Java: Platform-independent
- Designed for Matlab
- Stand-alone version available
- Interface-based: click, drag, drop
- No programming experience required
- Daily updates of the software
- Supports most common file formats

Multi-modal imaging

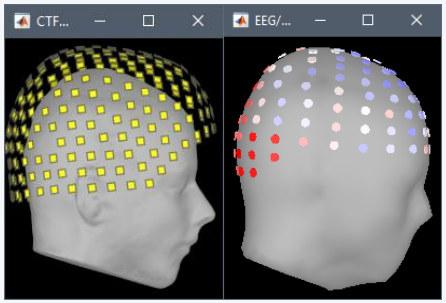
ECoG



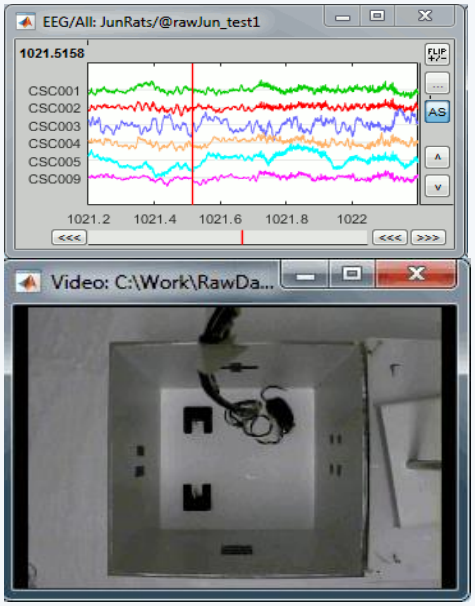
Depth electrodes



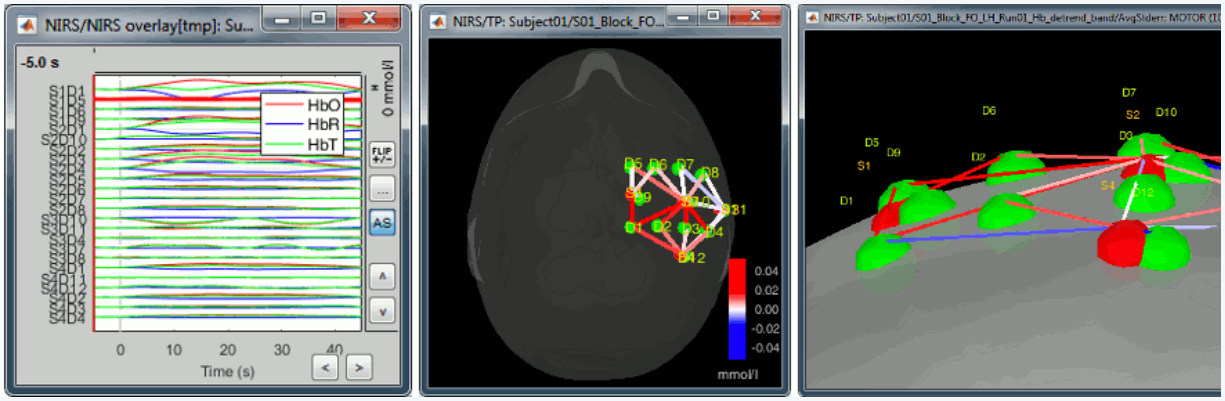
MEG/EEG



Electrophysiology



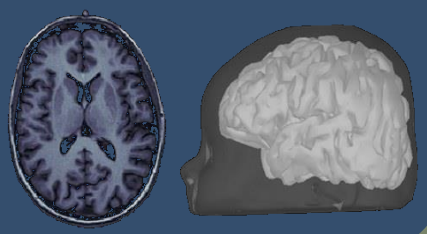
fNIRS



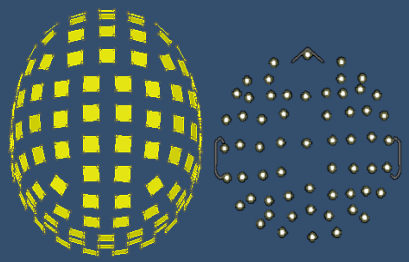
Brainstorm

Workflow

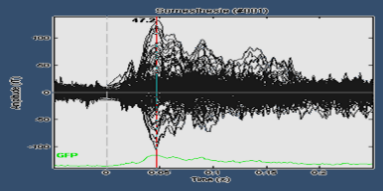
Anatomy



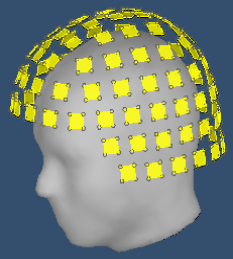
Sensors



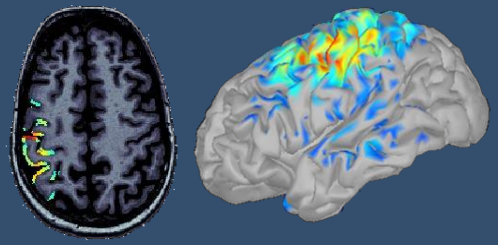
EEG/MEG



Co-registration



Source estimation



Analysis

Averages
Contrasts
Group analysis
Time-frequency
Connectivity

Single subject

Anatomy
Link recordings
MRI registration

Importing

PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Pre-processing

Markers
Epoching
Averaging
Sources
Time-frequency

Analysis of the experimental data

Loop:
all acquisition runs
all subjects

Import

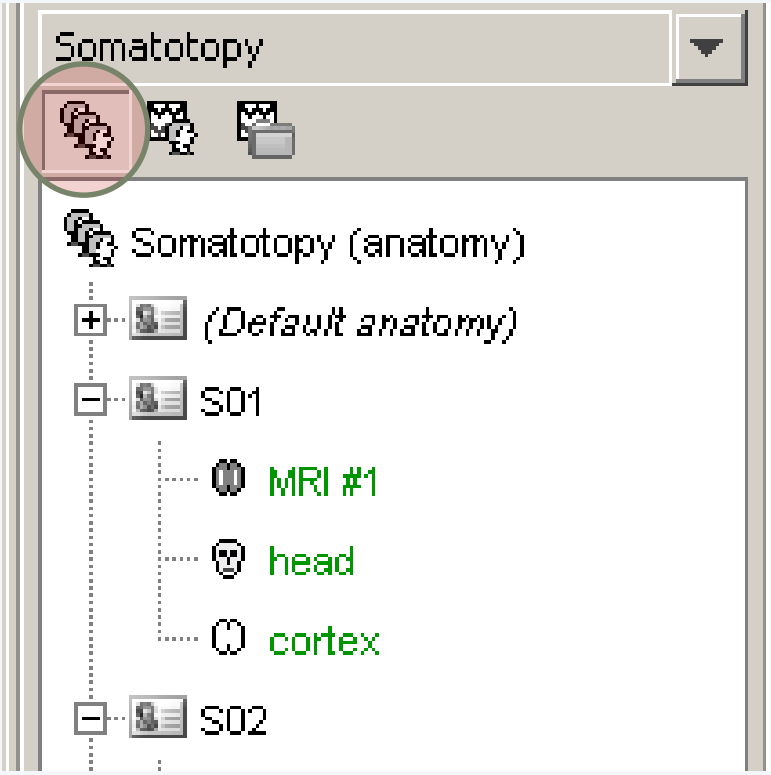
Anatomy
Link recordings
MRI registration

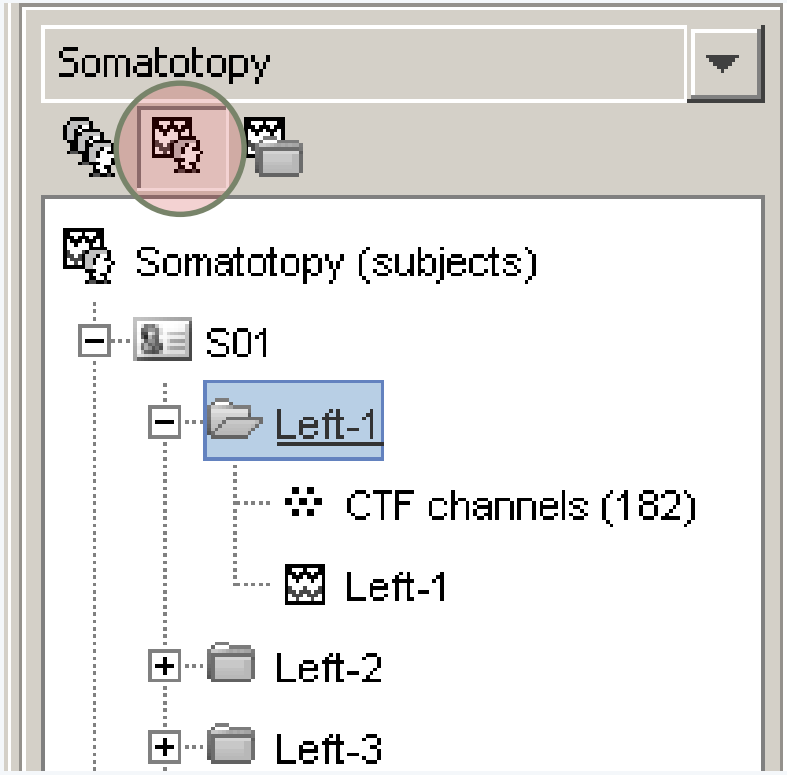
PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

- One-click import of the T1 segmentation: FreeSurfer, BrainSuite, BrainVISA, CIVET
- Import and place fiducials in the MRI (N,L,R)

Database





- Three levels:
  - Protocol
  - Subject
  - Condition
- Popup menus
- All files saved in Matlab .mat
- Same architecture on the disk

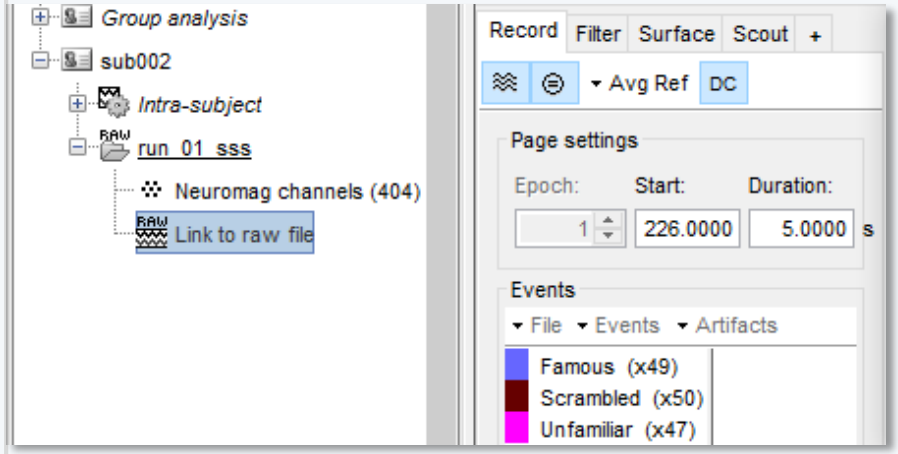
Import

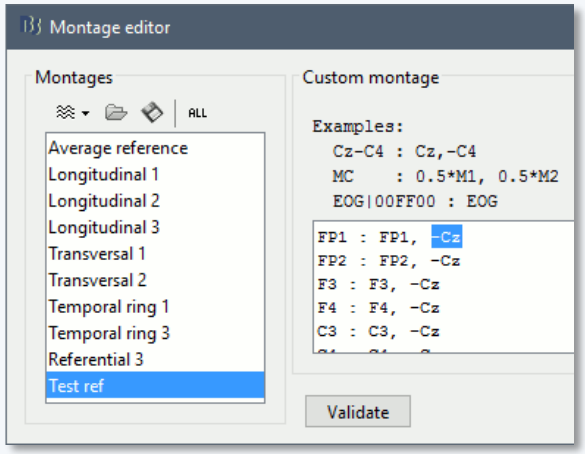
Anatomy
Link recordings
MRI registration

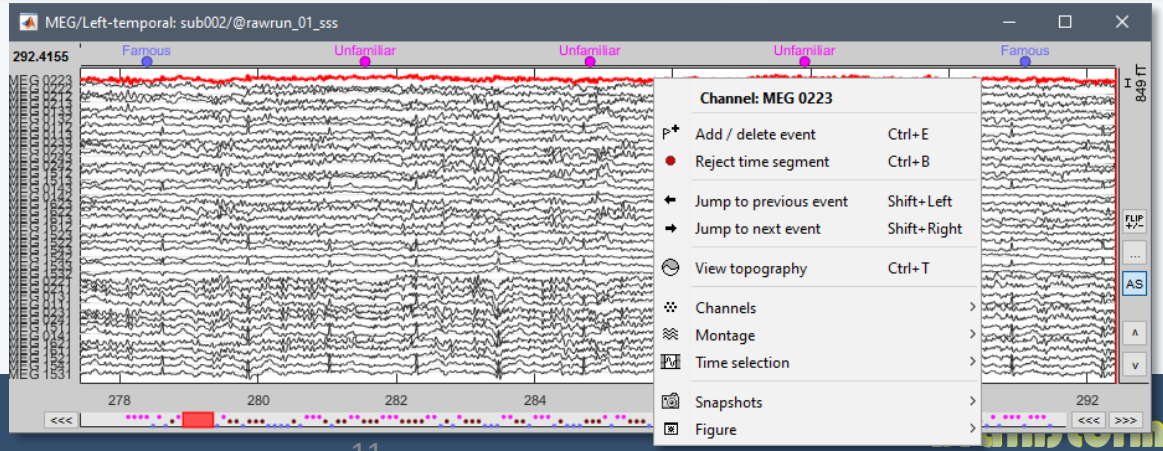
PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

- Original files linked to the database (no copy)
- Rich data viewer with flexible montage editor
- Optimized reading functions



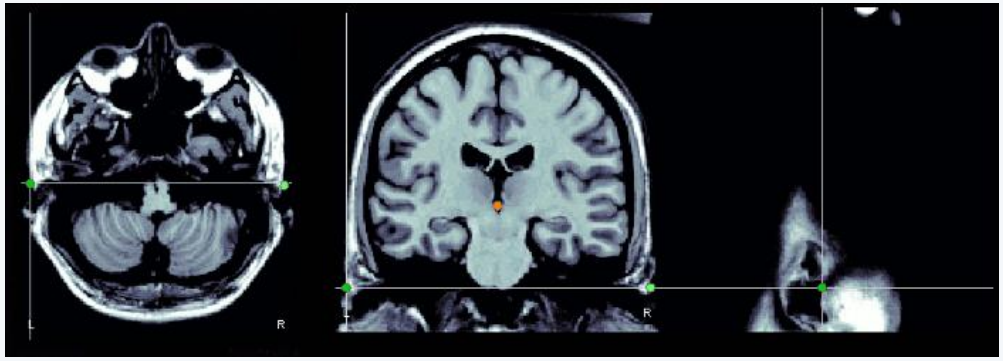




Co-registration MEG / MRI (I)

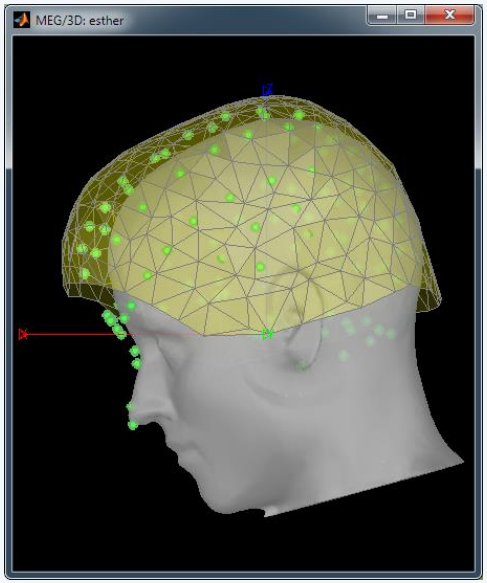
- Basic estimation based on three points: Nasion (NAS), Left ear (LPA), Right ear (RPA)

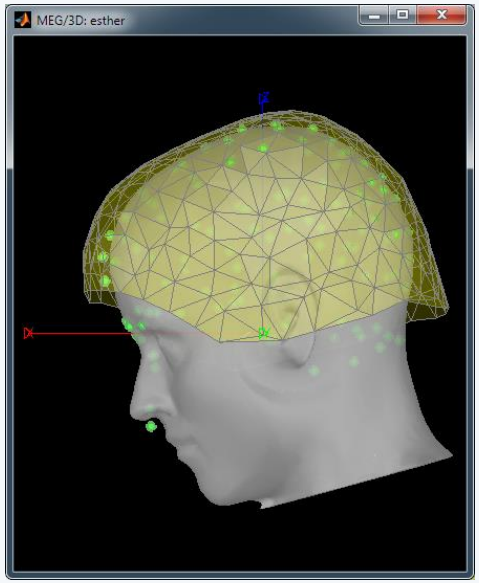
- MRI: Marked in the volume with the MRI Viewer
- MEG: Obtained with a tracking system (Polhemus)



Co-registration MEG / MRI (2)

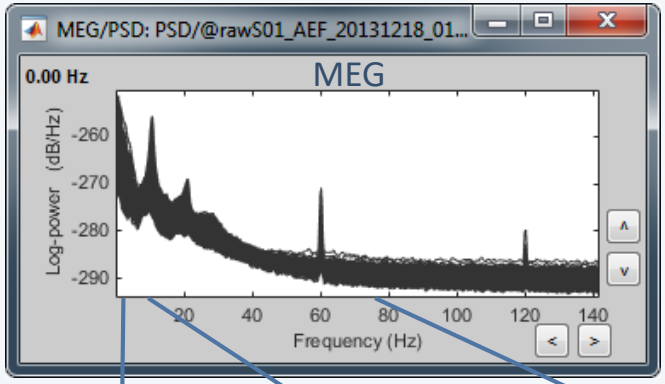
- Automatic adjustment based on head shape: Fitting Polhemus points on the MRI head surface
- Final registration must be checked manually
- Polhemus driver included in Brainstorm

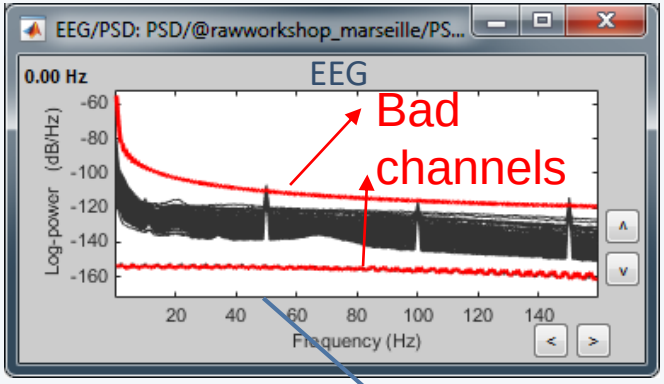


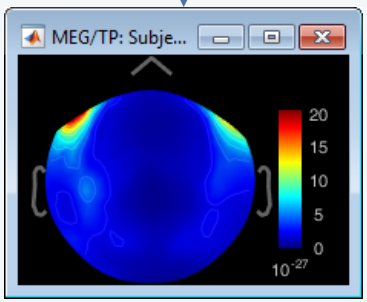


Quality control

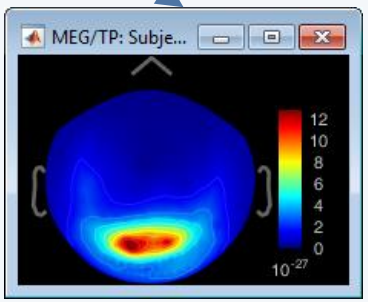
- Power spectrum density for quality control



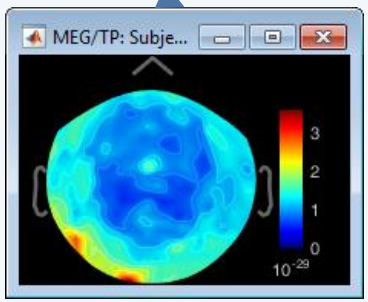




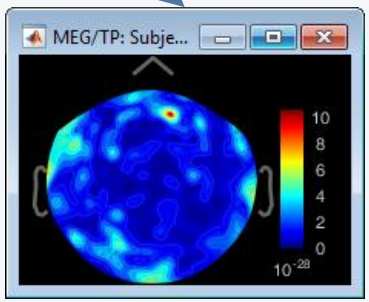
< 3Hz: Eyes



10Hz: Alpha



> 40Hz: Muscle

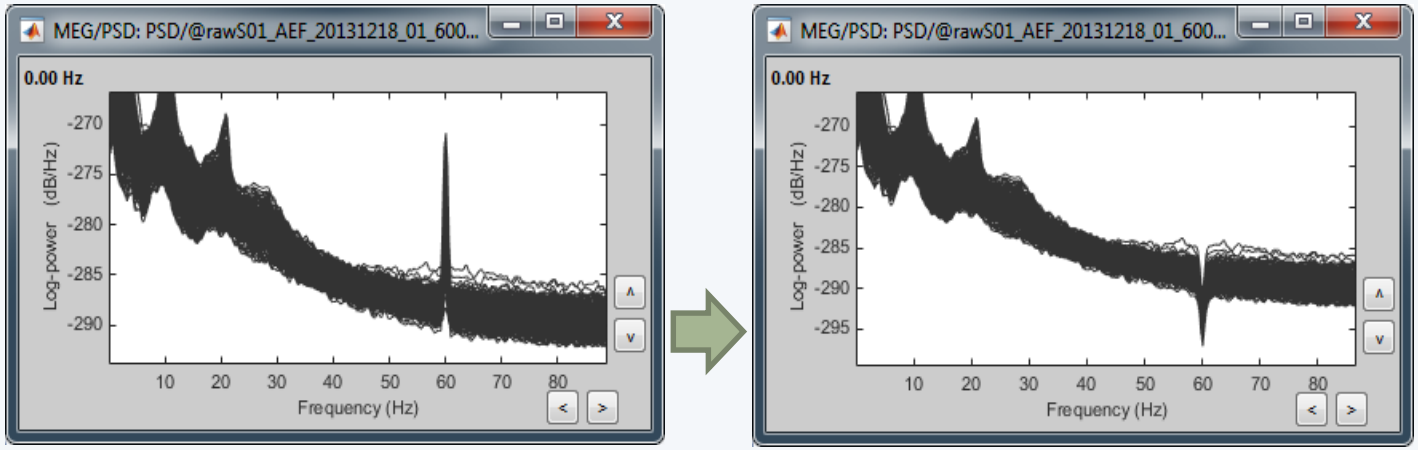


50/60Hz

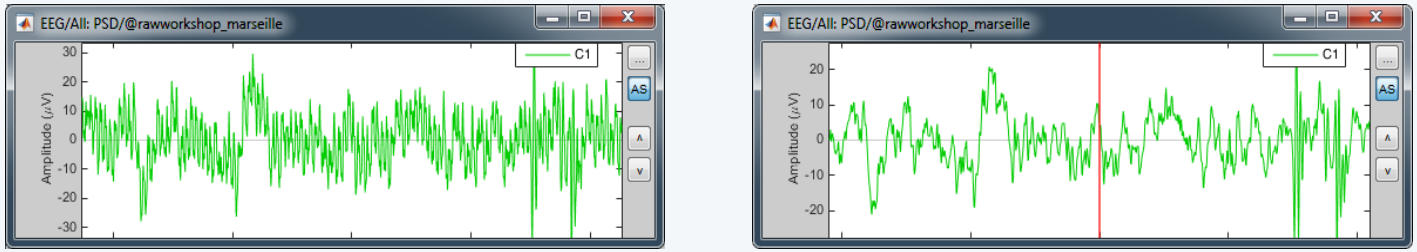
Pre-processing

- Notch filter: Removes 50Hz/60Hz power line noise (and harmonics)

PSD

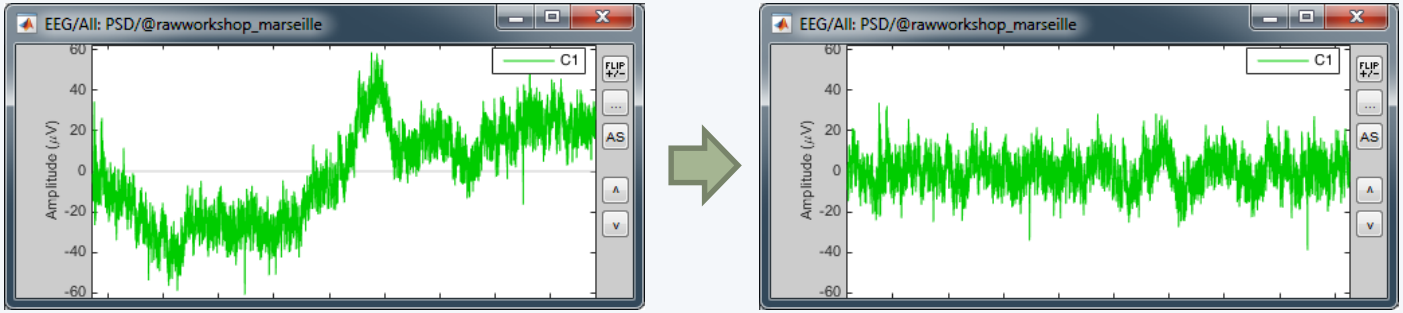


Signal

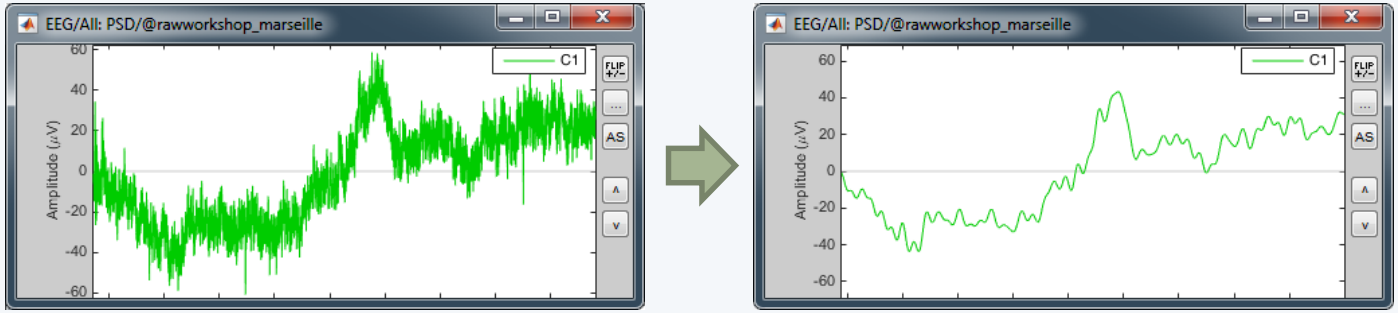


Pre-processing

- High-pass filter: Removes slow components (eye movements, breathing, sensor drifts…)

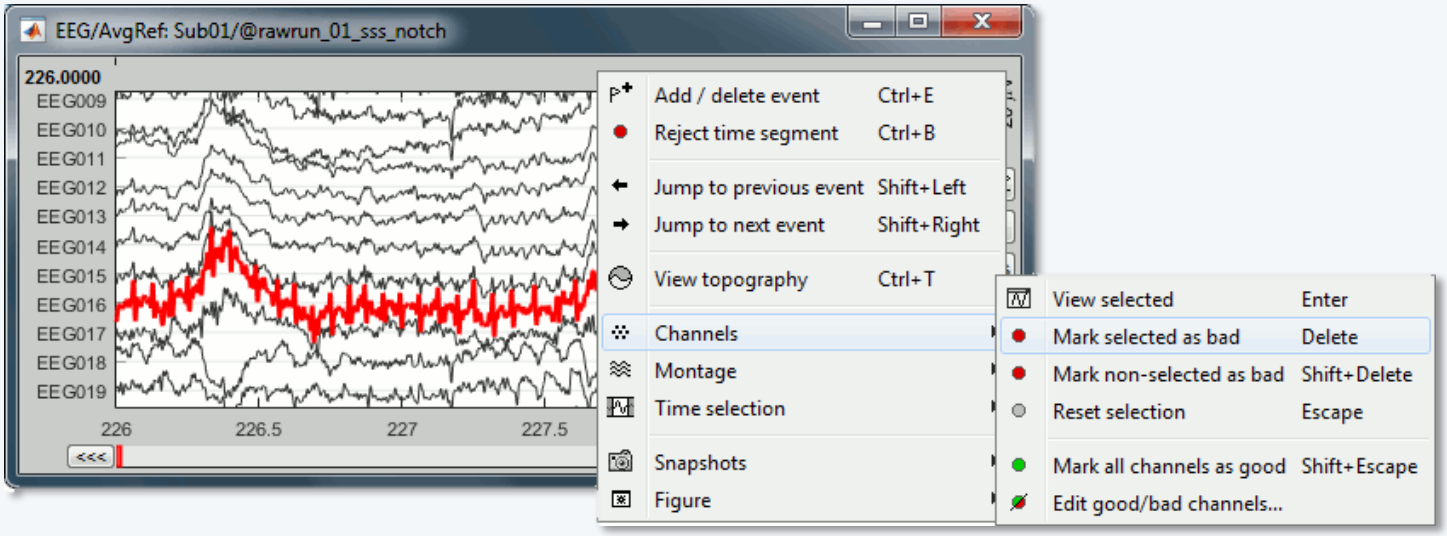


- Low-pass filter: Remove high-frequencies



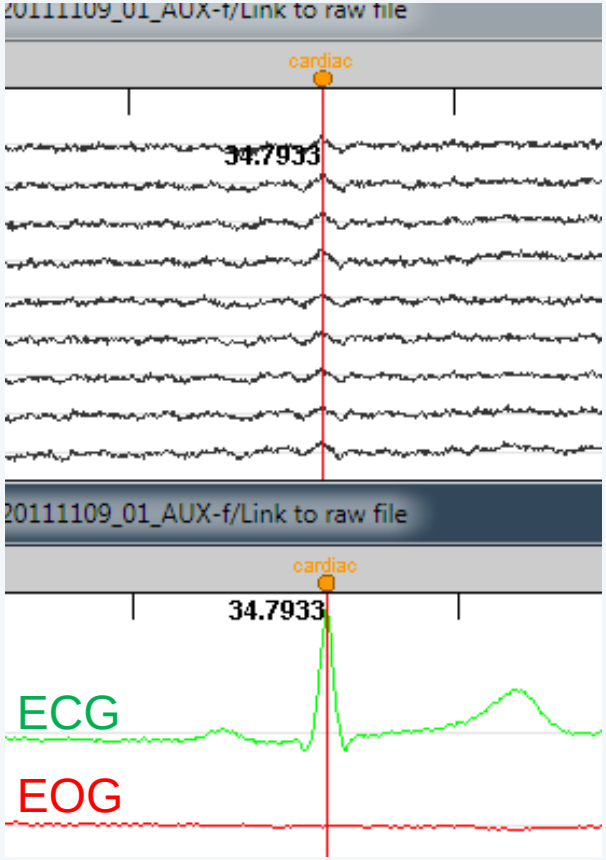
Pre-processing

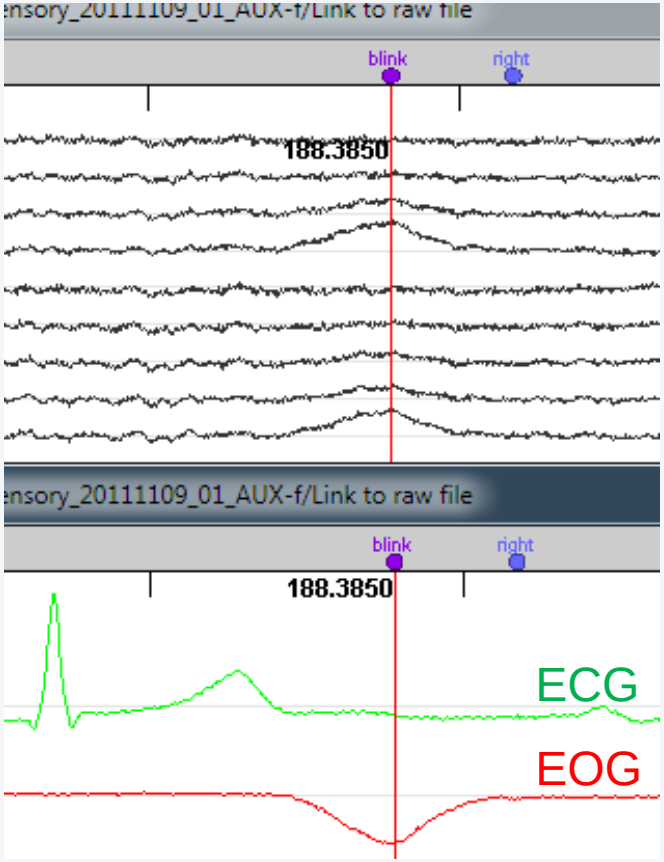
- Manual inspection of the recordings
- Interactive selection of bad channels
- Re-reference the EEG if necessary (Average ref)



Pre-processing

- Automatic detection of blinks and heartbeats (peak detection, or explicit amplitude threshold)

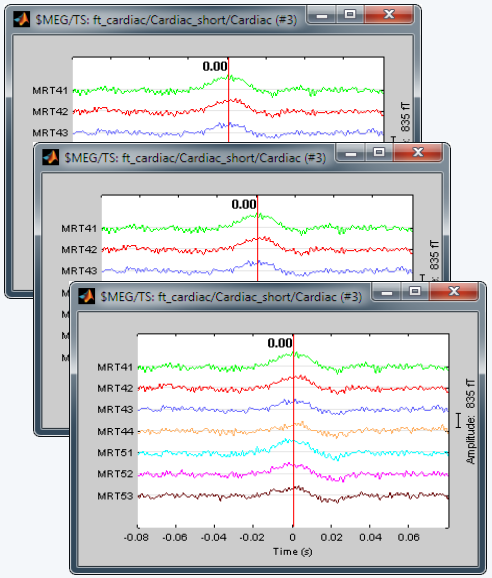




Pre-processing

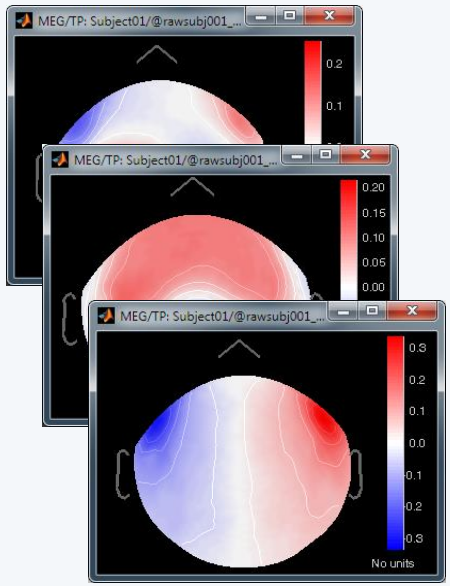
- Correction with Signal Space Projections (SSP)

Detect artifacts



PCA

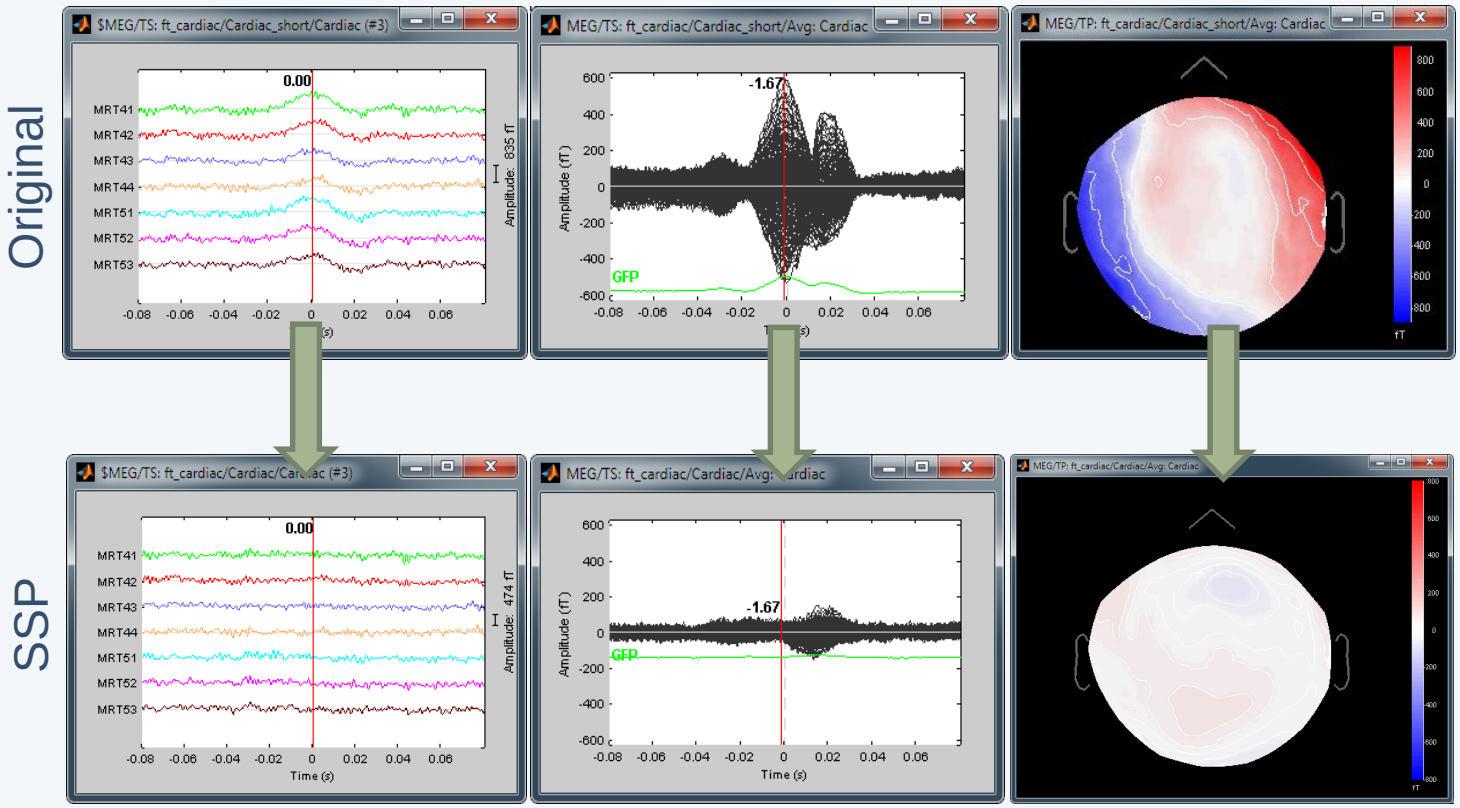
Spatial components



Select components and compute a linear projector to remove their contribution from the recordings

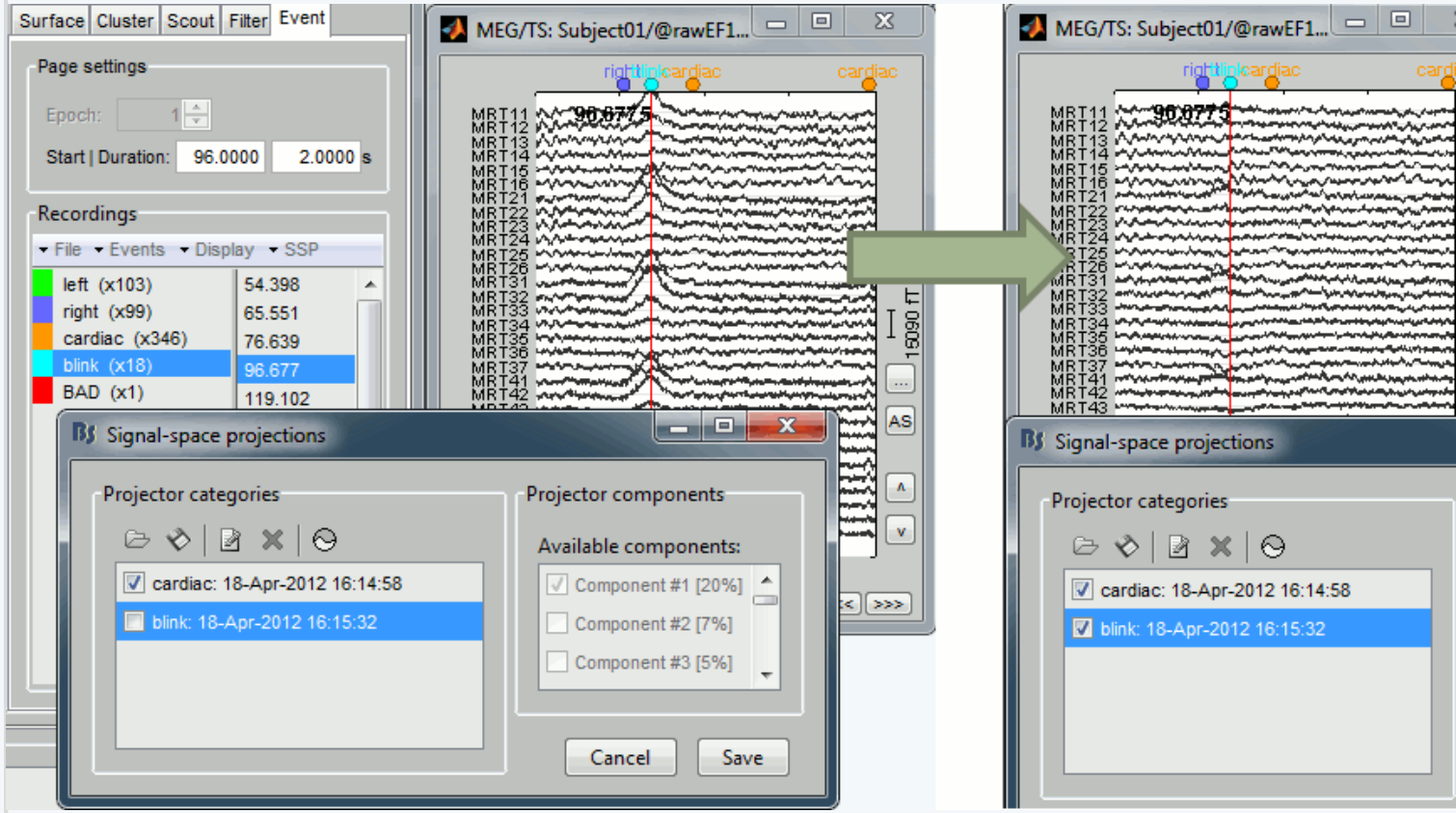
Brainstorm

- Example: Cardiac artifact



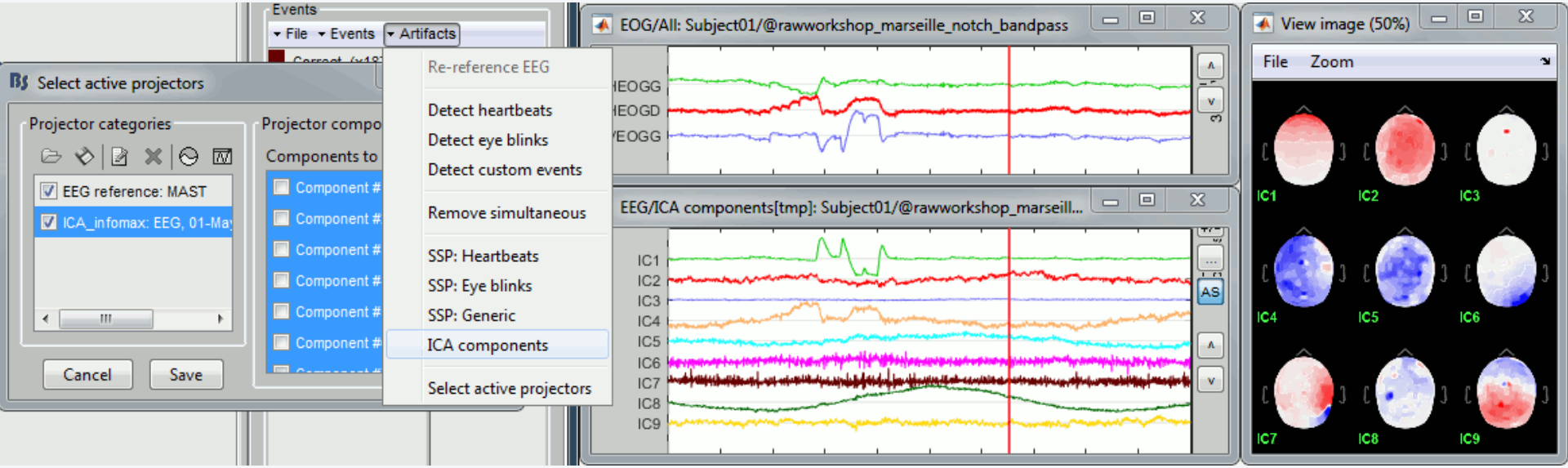
Pre-processing

- Example: Blink



Pre-processing

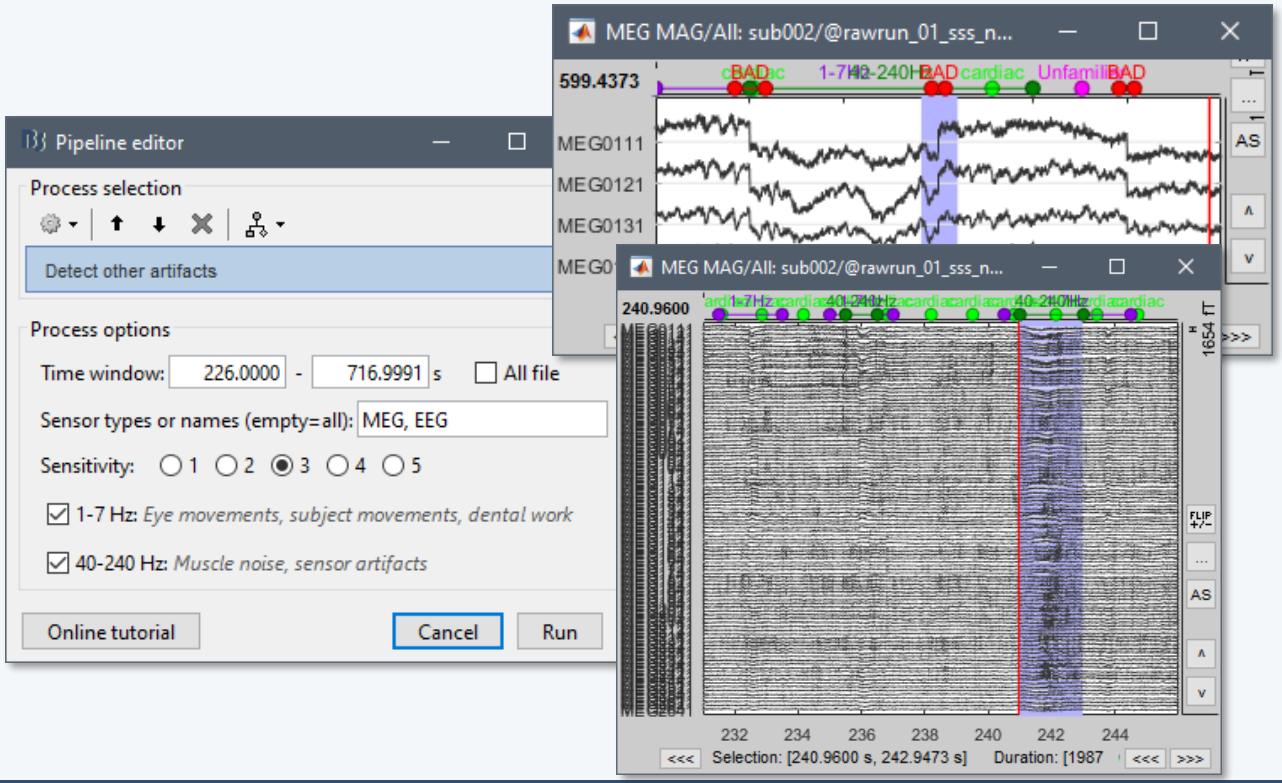
- Independent component analysis (ICA):
  - Popular in the EEG literature
  - Alternative to SSP for low number of sensors
  - Already implemented: Infomax and JADE (EEGLAB)



Brainstorm

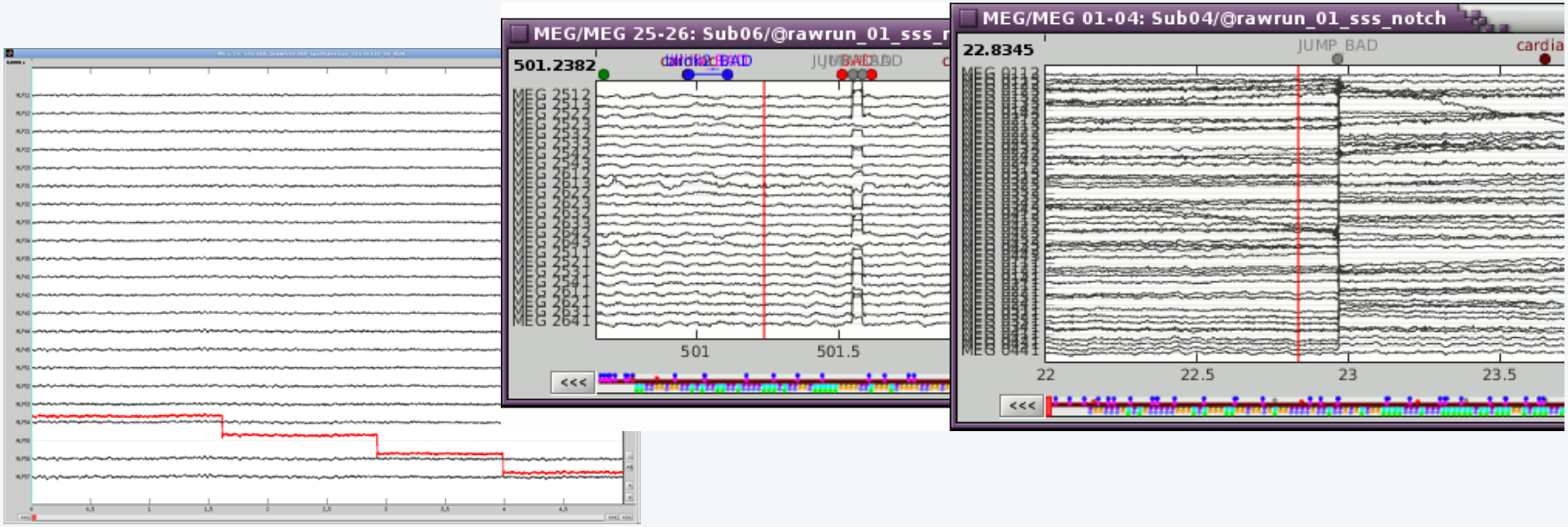
Pre-processing

- Automatic detection of artifacts (RMS-based)
- Manual screening of all the recordings is advised (scroll all the sensors by pages of 10-20s)
- Exclude: Blinks, movements, SQUID jumps



Elekta-Neuromag SQUID jumps

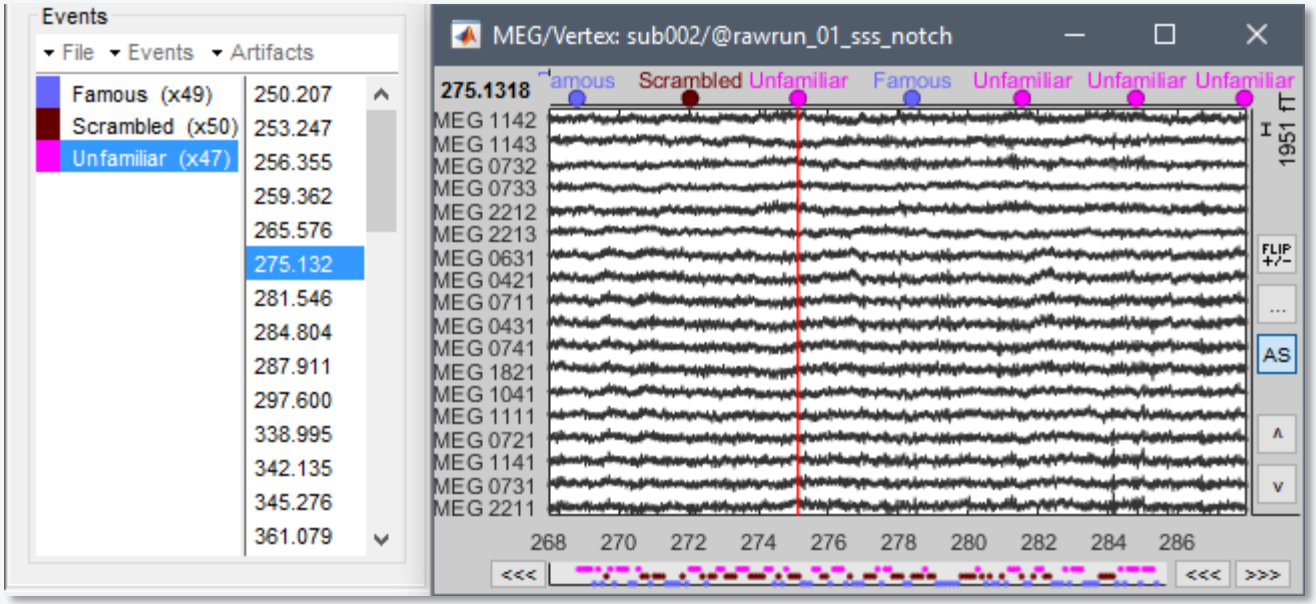
- Sharps steps followed by a change of baseline value
- Mark the channels as bad before running MaxFilter
- Or mark the segments as bad in Brainstorm



Epoching

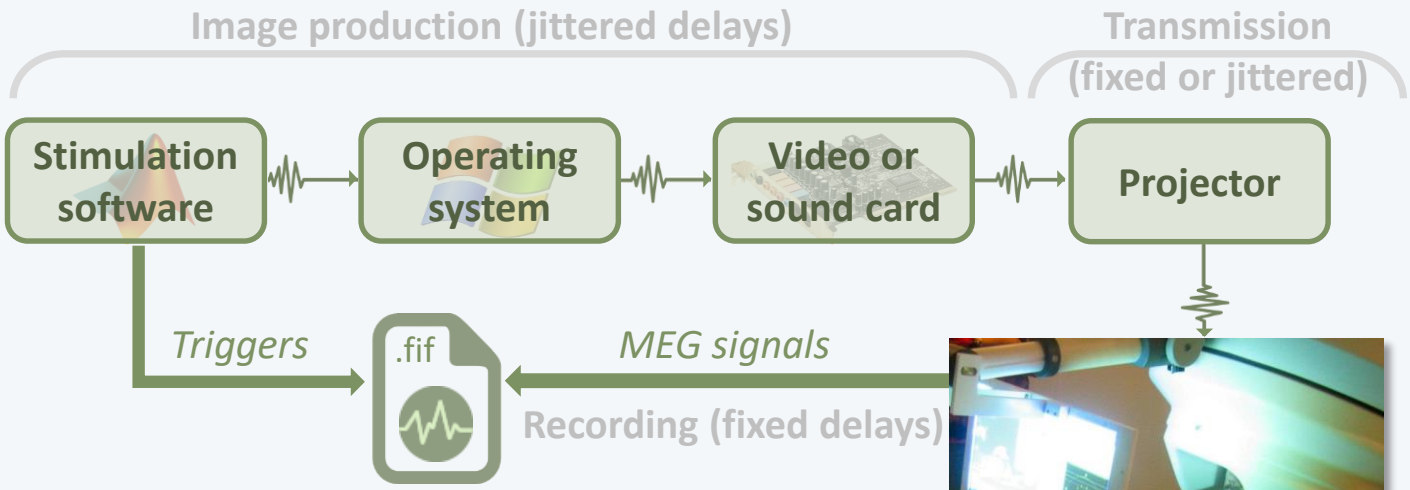
- Two types of experiments:
  - Steady-state or resting-state (ongoing activity)
  - Event-based (stimulus, response, spike…)

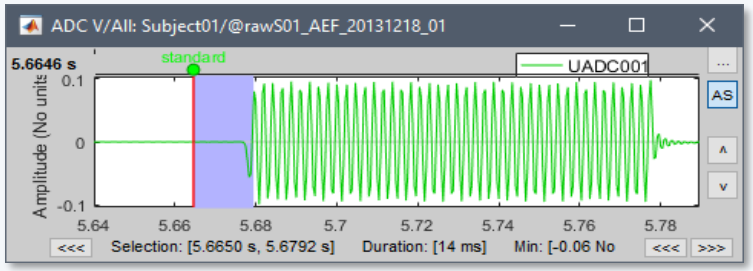
- How to get event markers in the recordings?



Epoching

- Reading the triggers saved by the presentation software (includes jittered OS delays)

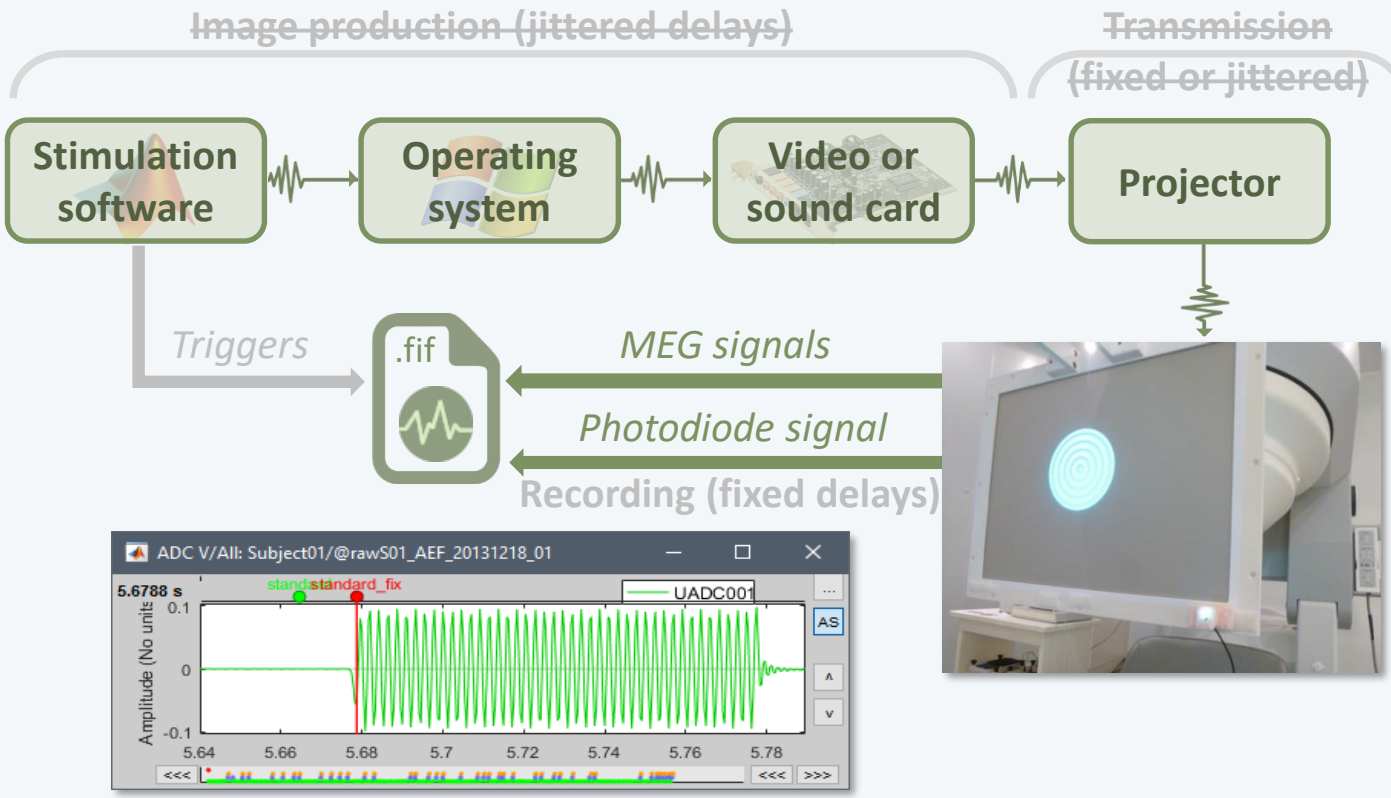




- File triggers are never aligned with the real stim

Epoching

- Reading information recorded on the subject side (photodiode, microphone, response box…)

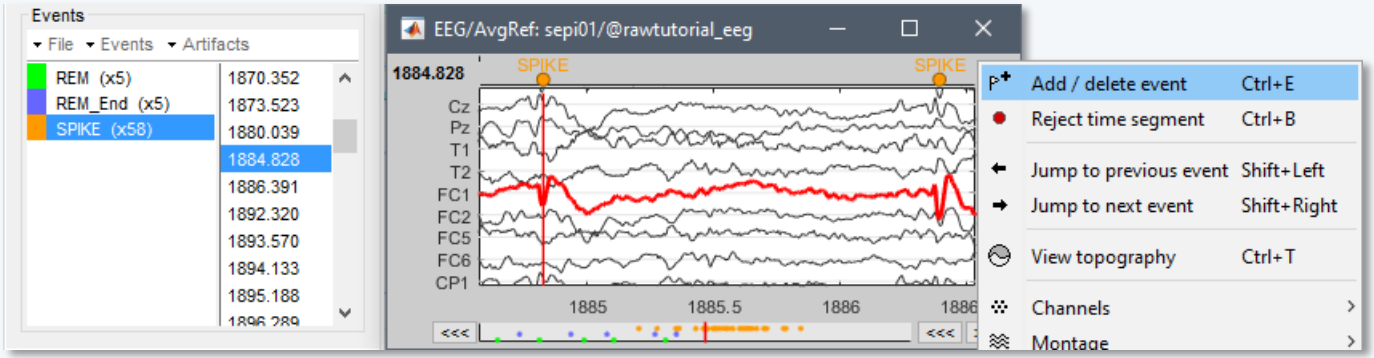


- Avoids most uncontrollable jittered delays

Epoching

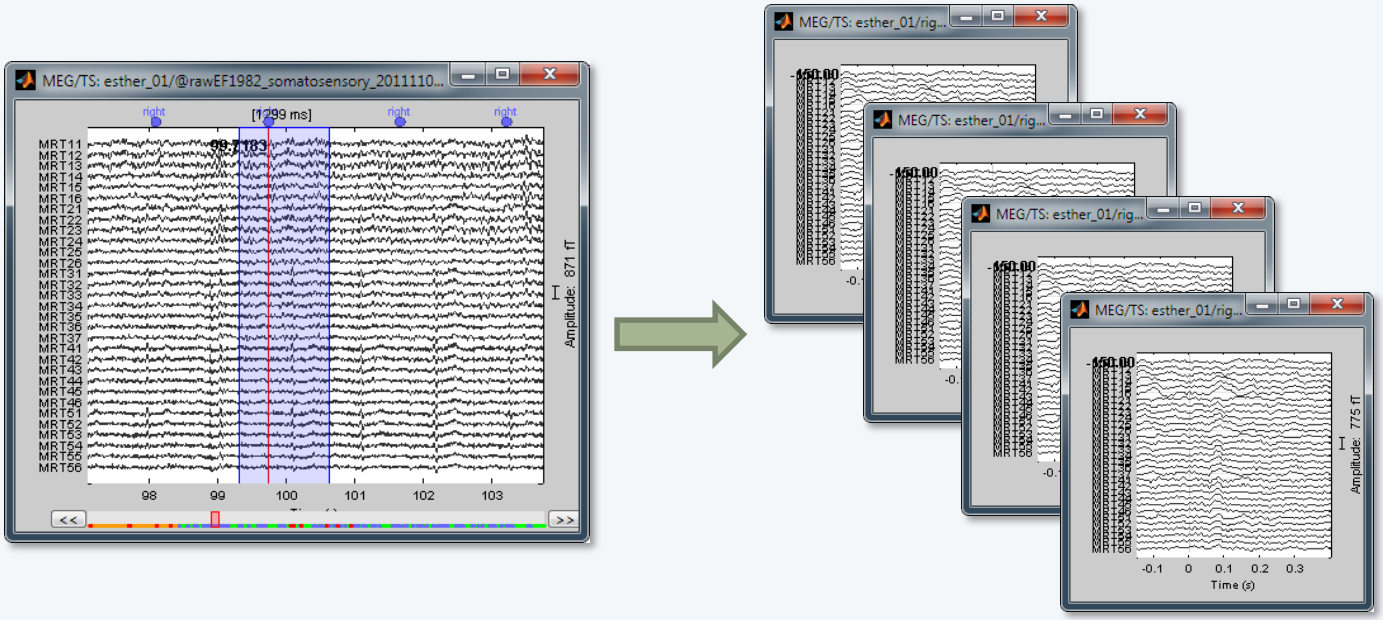
- Manual or automatic marking of biological or behavioral events, post-acquisition (epileptic spikes, sleep spindles, rat position in a box…)

- Optimized workflow for clinicians (keyboard and mouse shortcuts, workspace…)



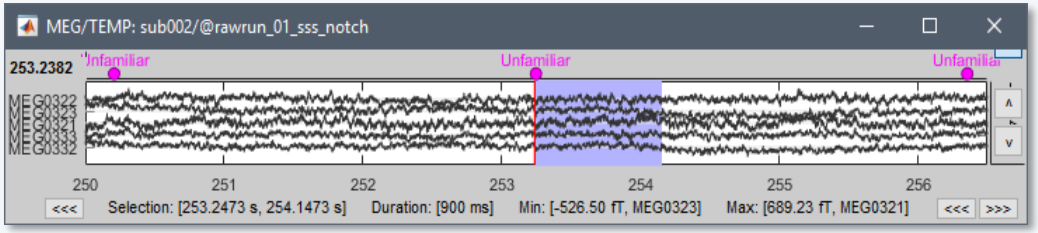
Epoching

- Epochs = Trials = Short blocks of recordings around an event of interest.
- Epoching = Extracting epochs from the continuous recordings and saving them.



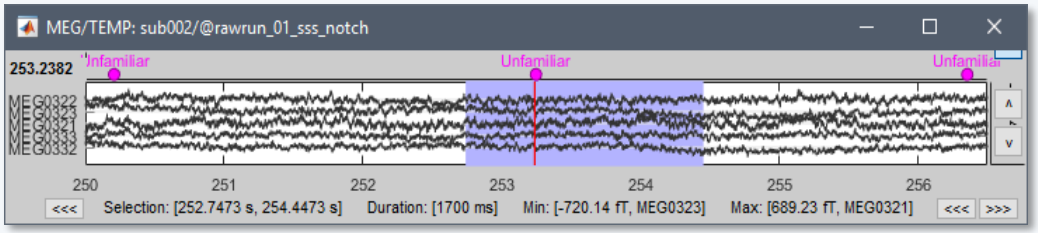
Epoching

- How to define the optimal epoch length ?
- Experimental design:
  Expected effect duration, inter-stimulus interval



[0,900] ms

- Analysis: Frequency filters and amplitude normalizations may require longer epochs



+ 200ms baseline
+ 300ms filters

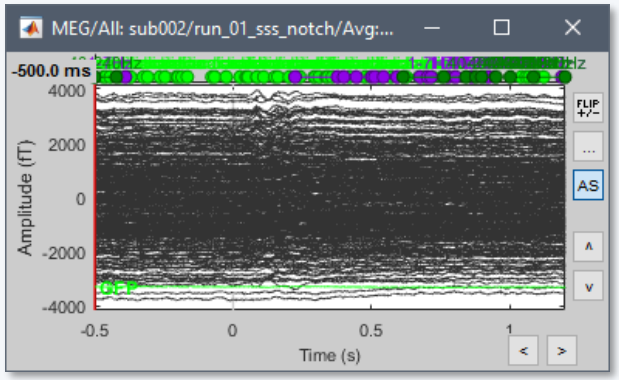
= [-500, 1200] ms

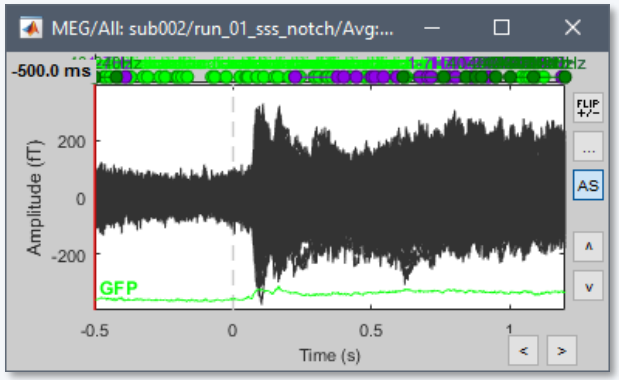
- Computational limitations: Size and time

Brainstorm

Epoching

- Processing steps that can be applied on epochs:
  - **DC offset correction**: Subtract the average estimated over a baseline period
  - **Detrending**: Subtract a linear trend estimated over a reference period
  - **Resampling**: Decrease the sampling rate
- This dataset: DC correction, baseline=[-500,0]ms

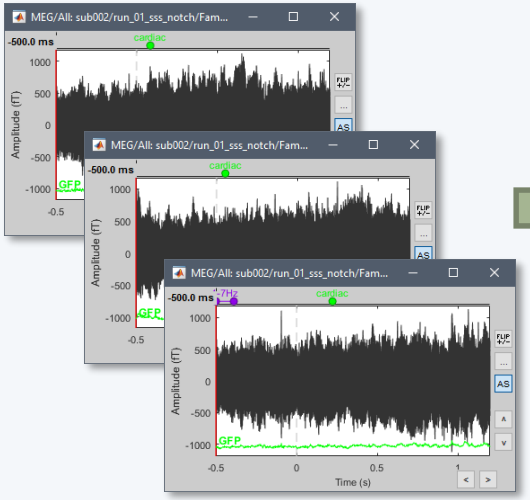


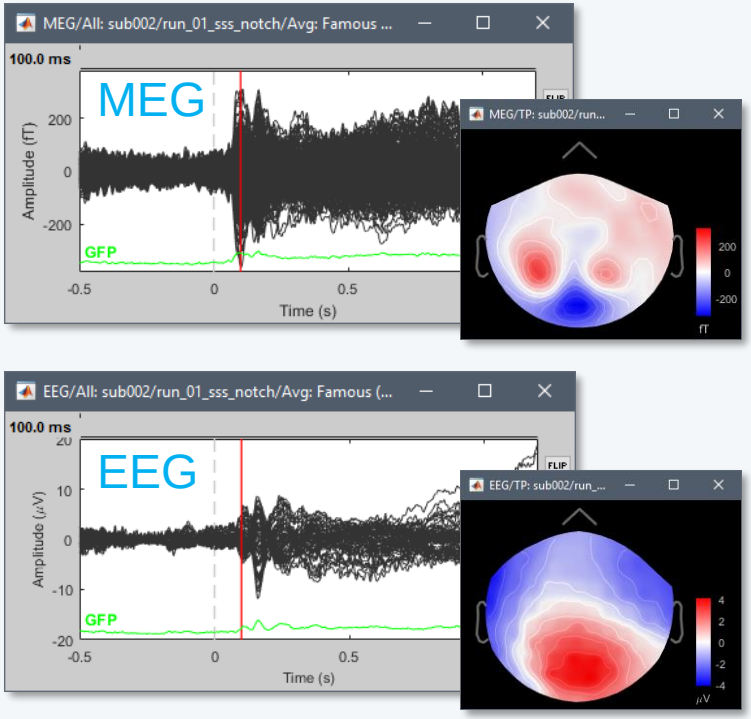


Single subject

- Averaging the trials: Reveals the features of the signals that are locked in time to a given event

  = Event-related field / potential
  = Evoked response
  = ERF/ERP



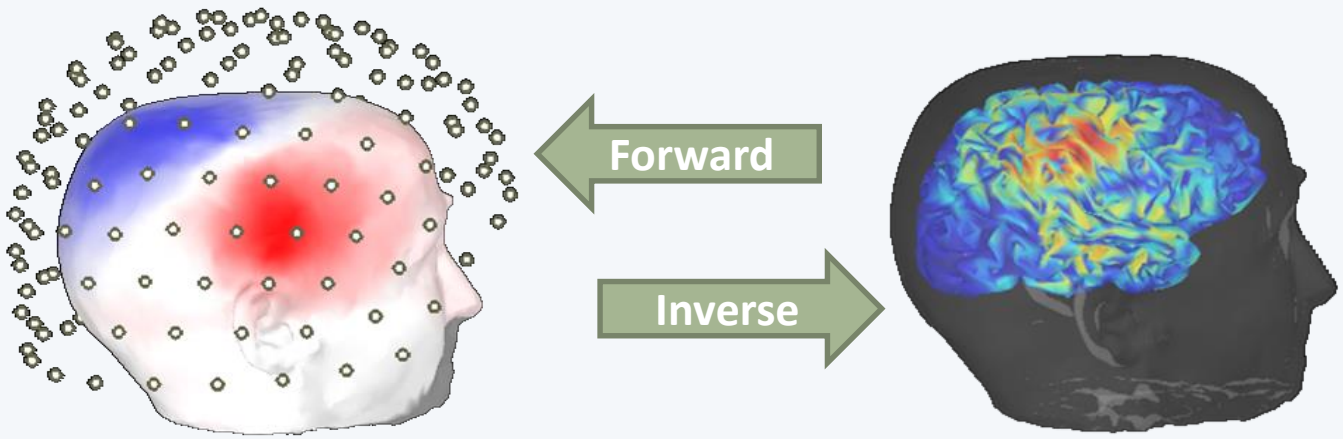


Single subject

- **EEG**: Averaging data across runs and subjects OK.
- **MEG**: Averaging across runs is not always accurate
  - Head shapes differ between subjects.
  - Head positions different between runs.
  - One sensor does not record the same thing in two different runs.
  - Coregistration of runs with Elekta MaxFilter helps but modifies a lot the recordings. Never use this to average across subjects.
  - Recommended: Estimate the sources for each run separately, then average in source space.

Single subject

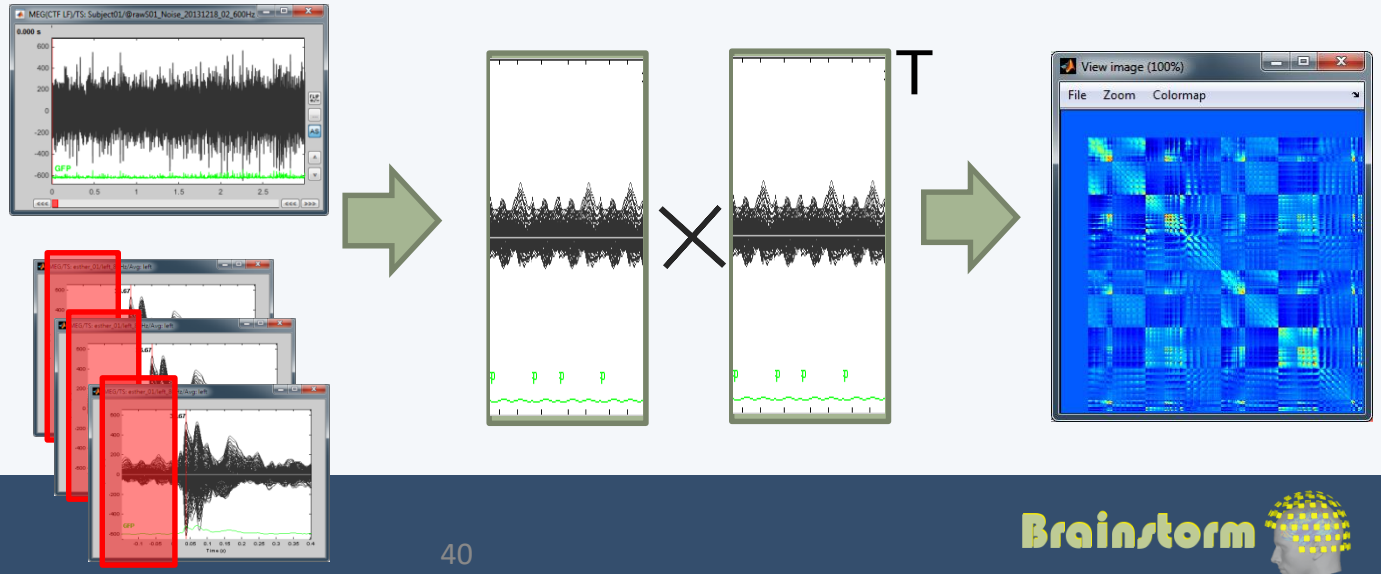
- Source space: Cortex or full head volume
- Forward model: Overlapping spheres (MEG)
  OpenMEEG BEM (EEG)
- Inverse model: **Minimum norm estimates**
  Beamformers
  Separately for MEG and EEG



Sensor space *Source space*

Single subject

- The MNE model requires an estimation of the level of noise of the sensors
- Noise covariance matrix = covariance of segments that do not contain any "meaningful" data
- Empty room, pre-stim baseline, resting



Brainstorm

Single subject

Anatomy
Link recordings
MRI registration

PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

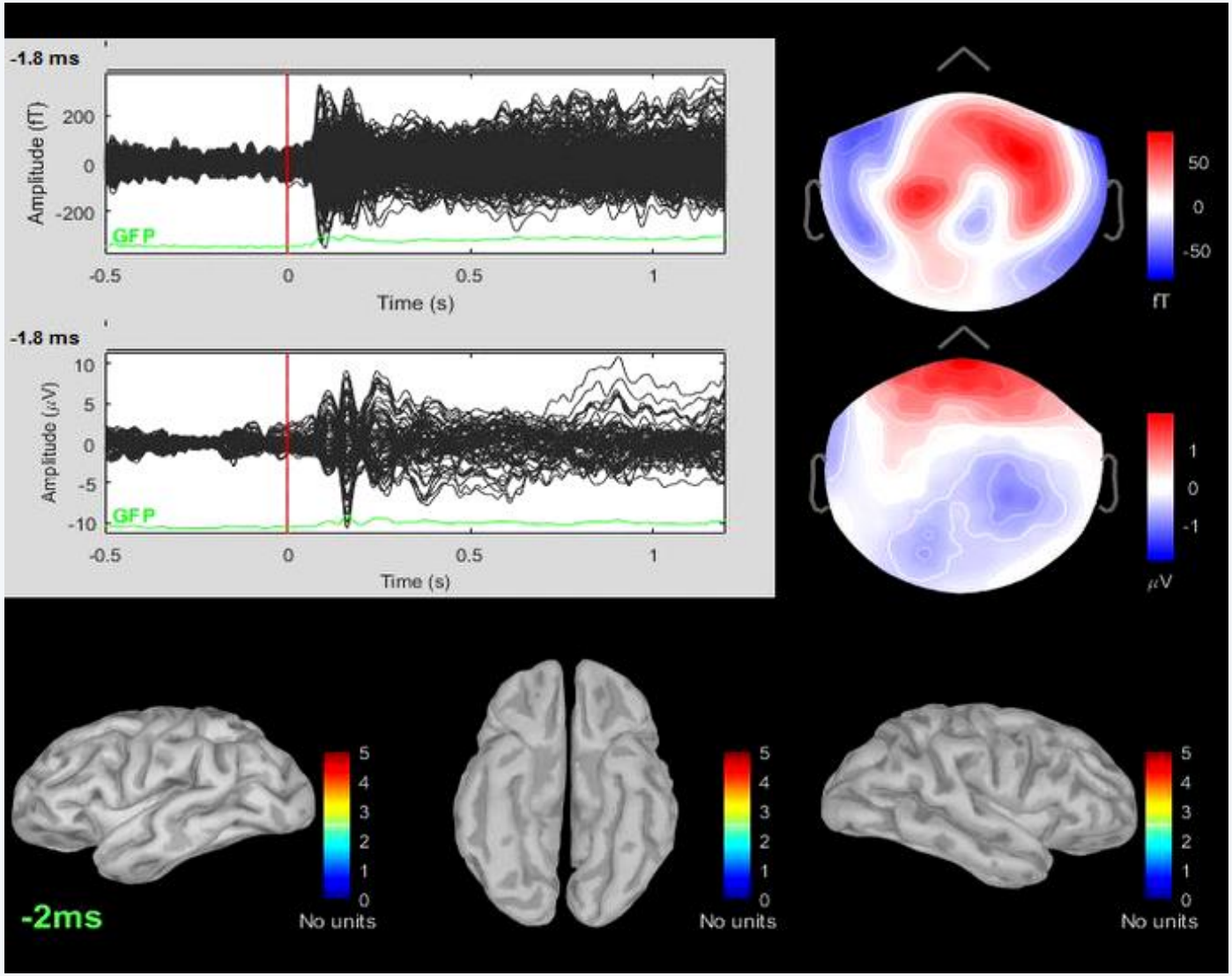
Markers
Epoching
Averaging
Sources
Time-frequency

Famous faces

MEG

EEG

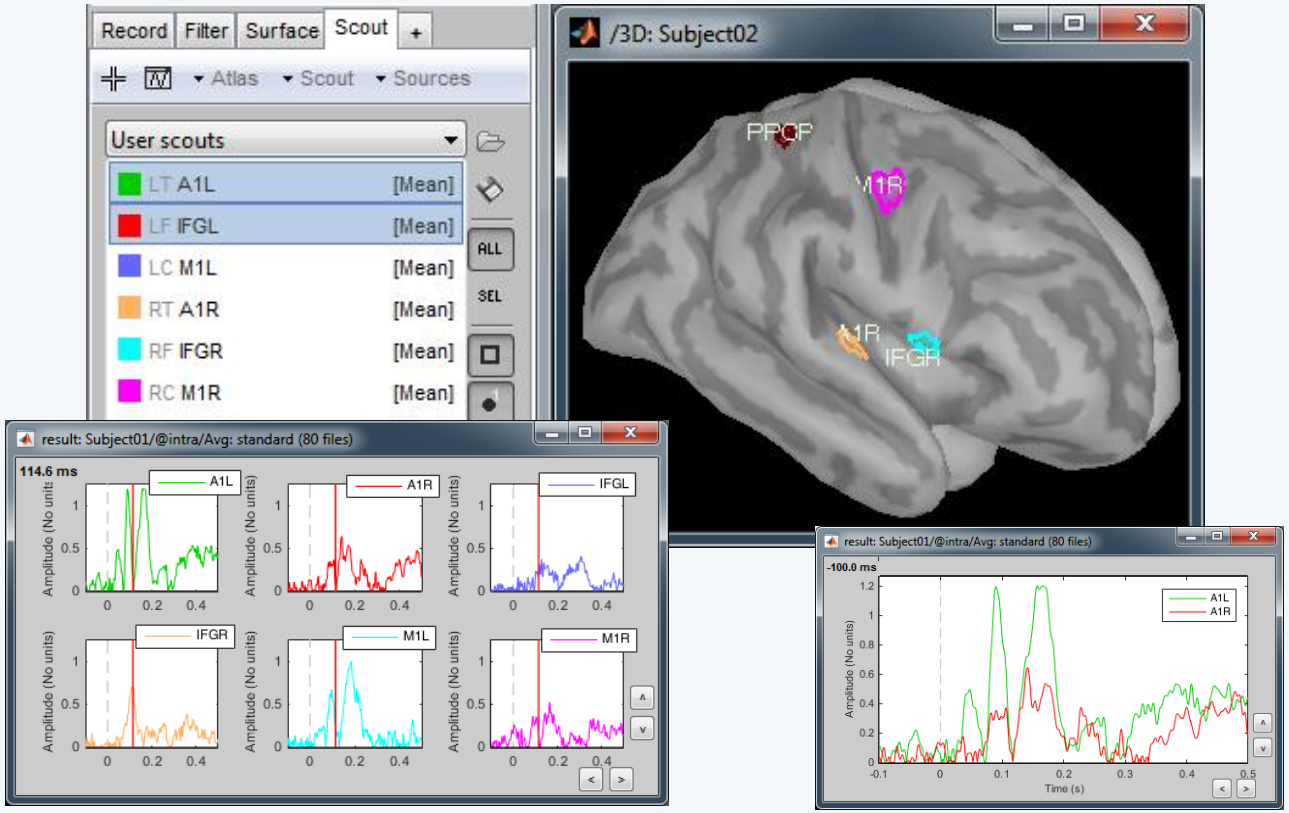
MEG sources



Brainstorm

Single subject

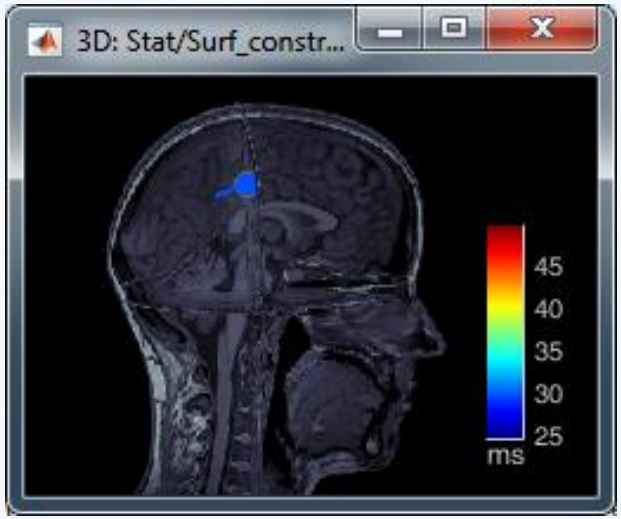
- Regions of interest at cortical level (scouts)
  = Subset of a few dipoles in the brain
  = Group of vertices of the cortex surface

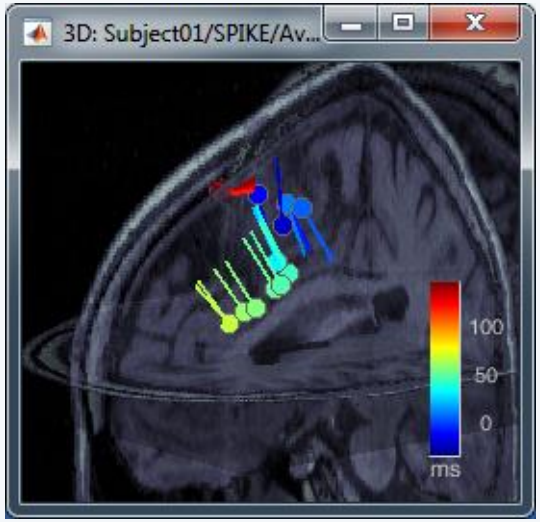


Single subject

- Dipole scanning
  Compute a distributed source model, then find the most significant dipole at each time sample.

- Dipole fitting (FieldTrip)
  Non-linear search of the dipoles that minimizes the residuals (data explained - recordings)

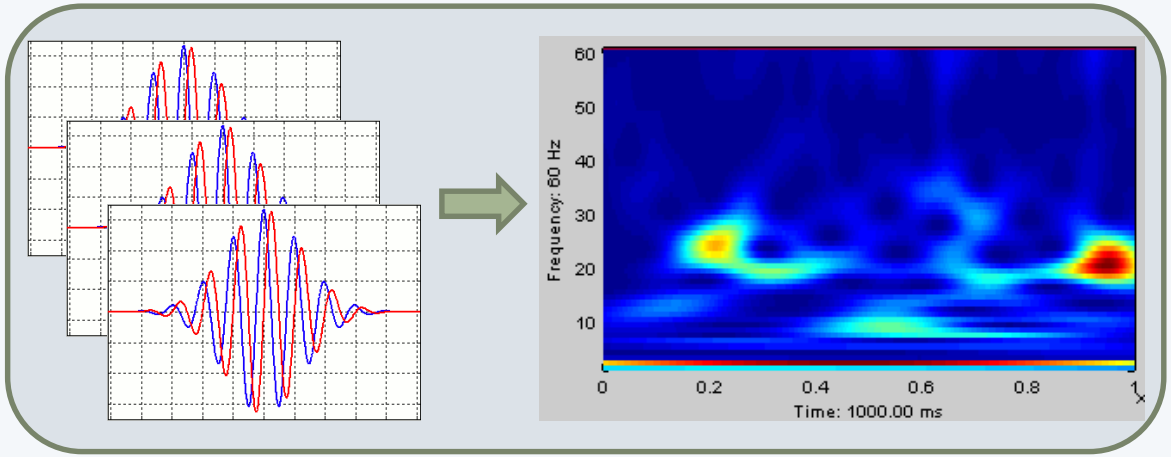


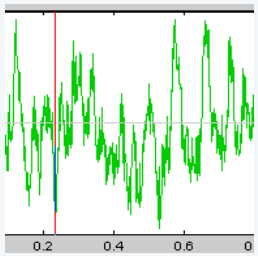


Brainstorm

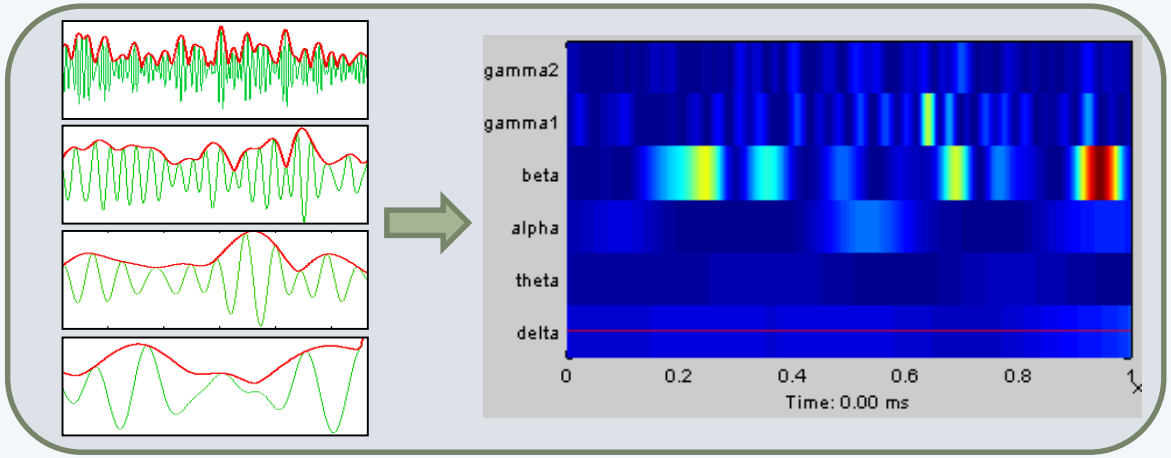
Single subject

Morlet wavelets



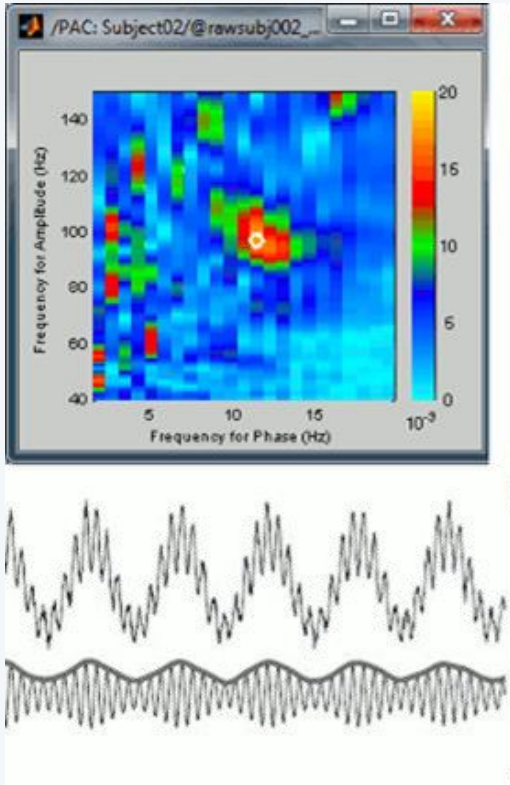


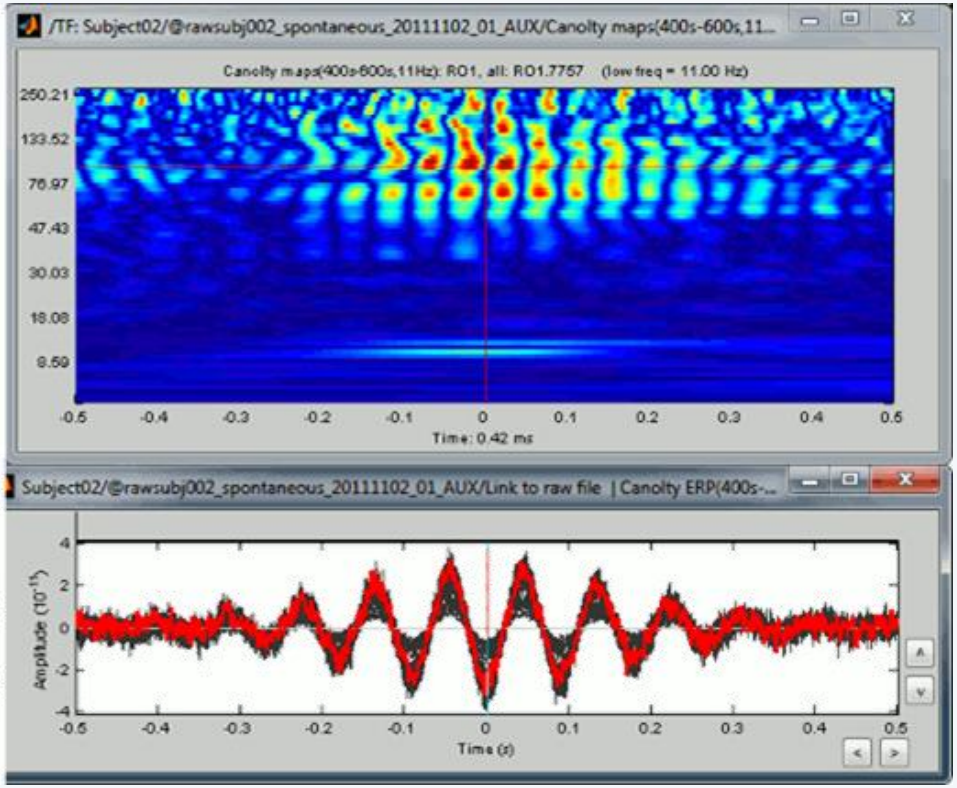
Hilbert transform + band-pass filter



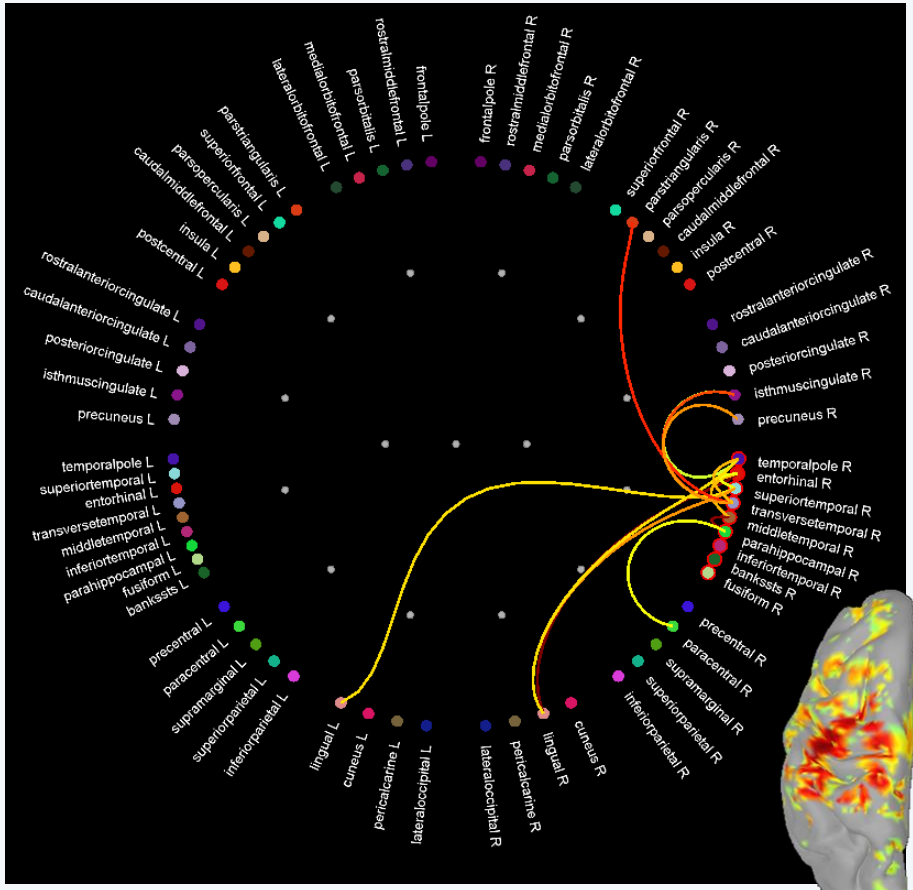
Brainstorm

- Phase-amplitude coupling

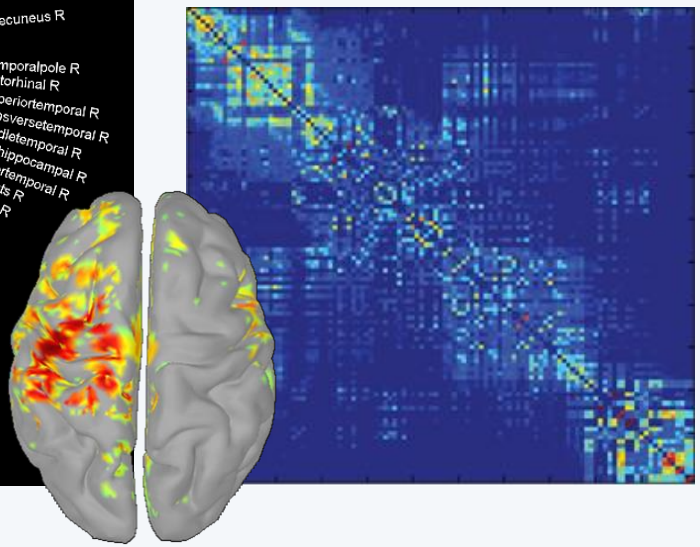




- Connectivity measures



- Correlation
- Coherence
- Phase locking value
- Granger causality

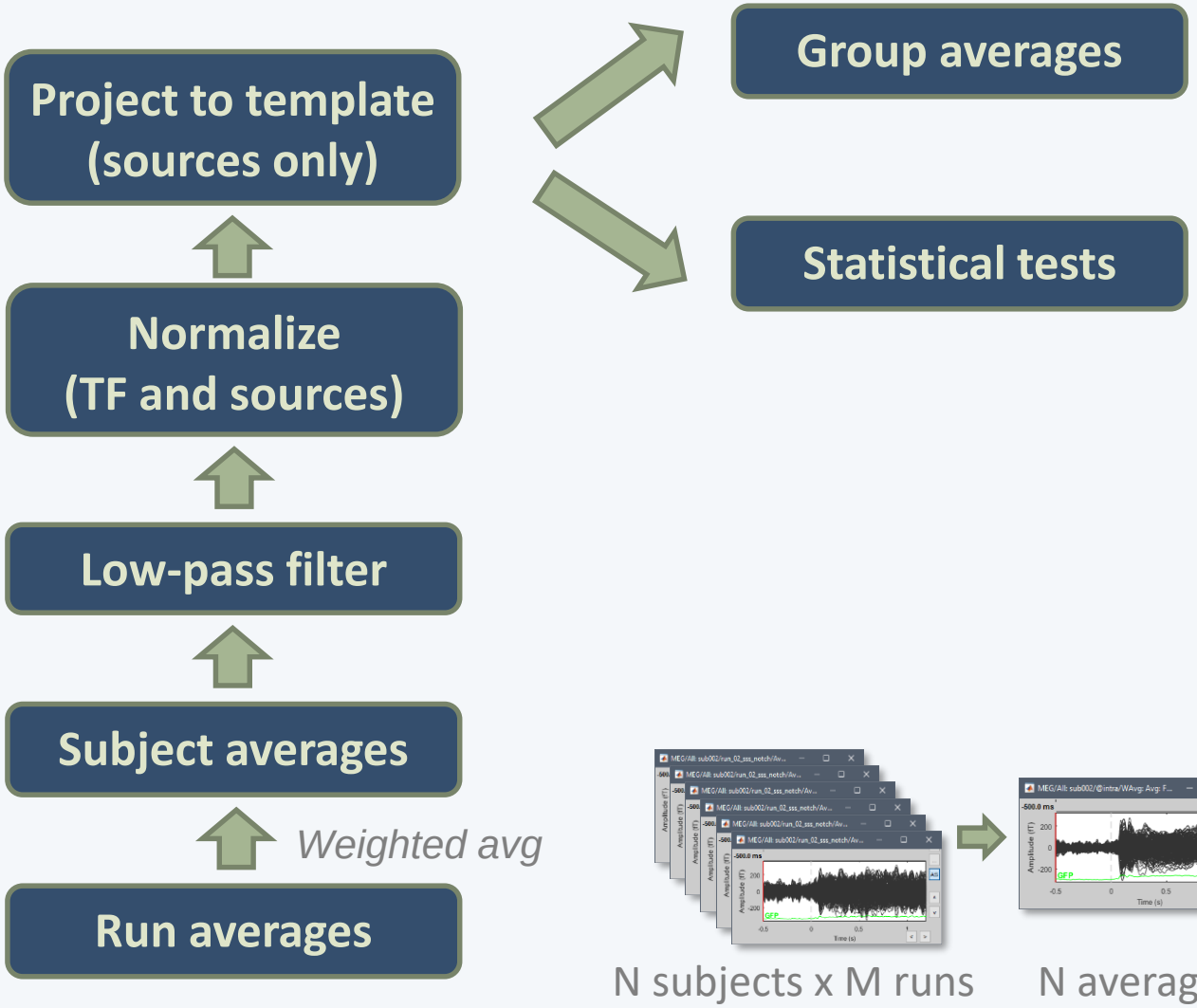


Group analysis

Anatomy
Link recordings
MRI registration

PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency



Brainstorm

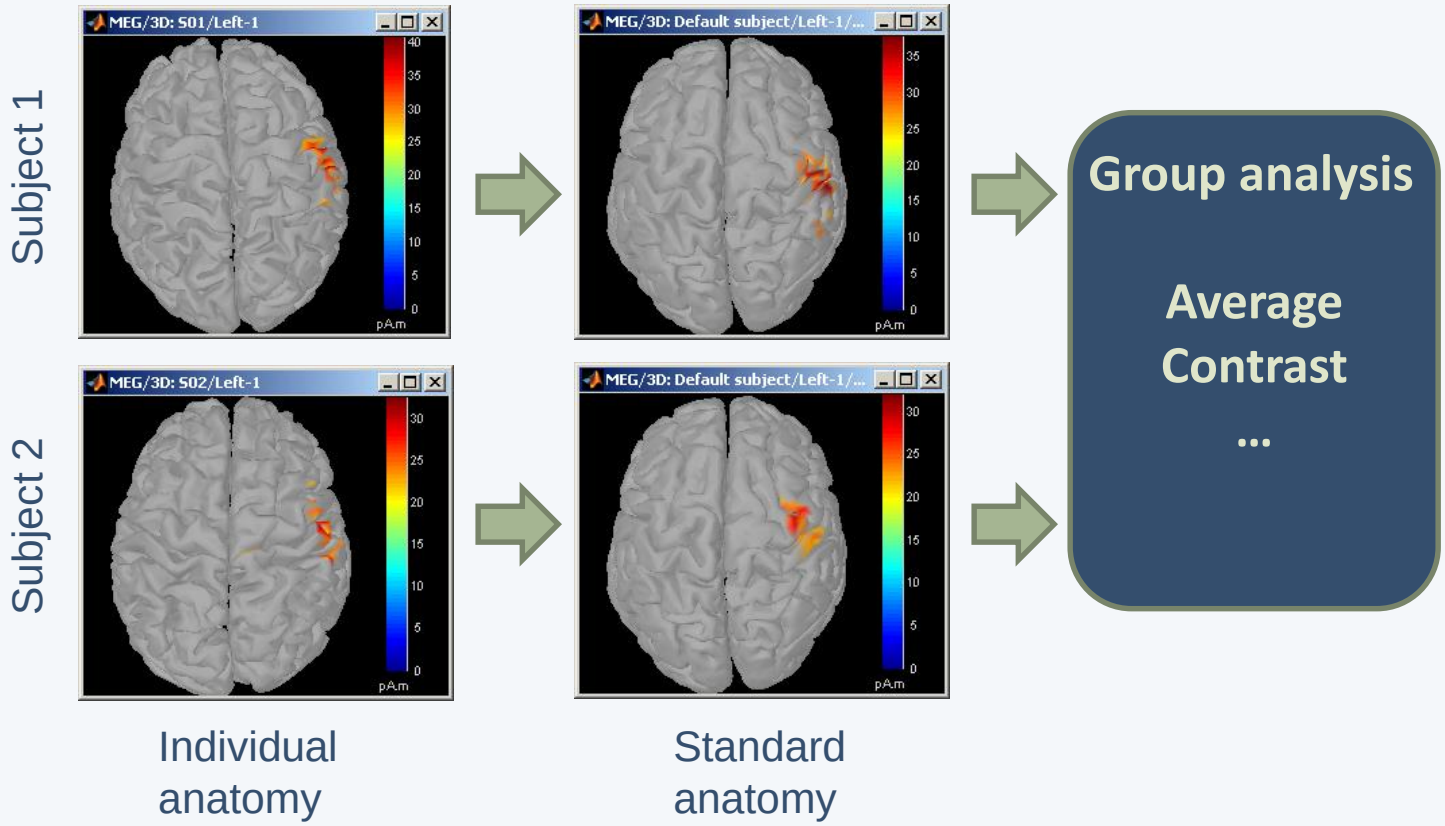
Group analysis

Subject averages
Low-pass
Normalize
Project

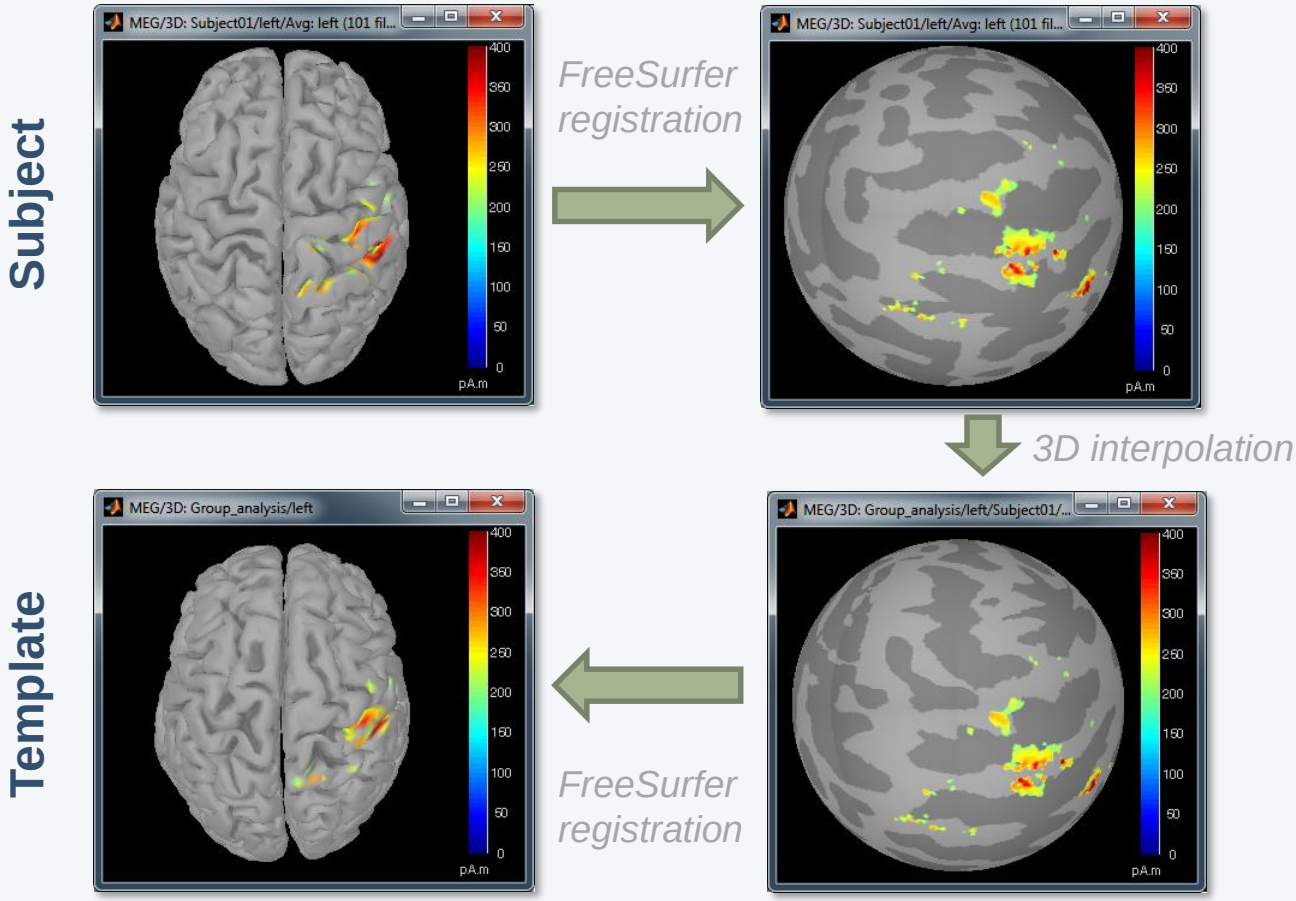
Group averages
Group statistics

Quality control
Workflow

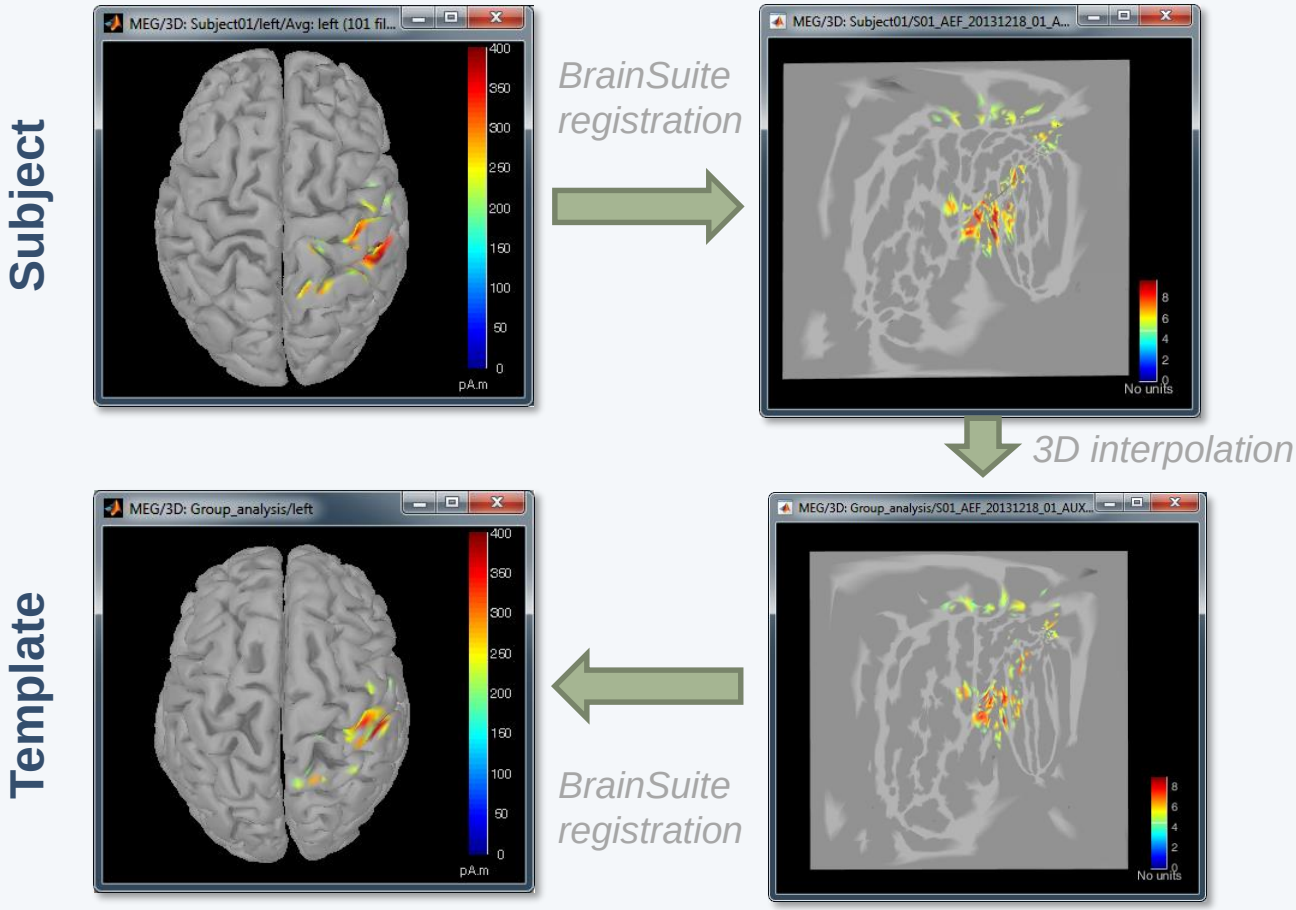
- Registration of individual sources on a template
  (ICBM152, Colin27, DNI, infants…)



- Using FreeSurfer registration



- Using BrainSuite registration



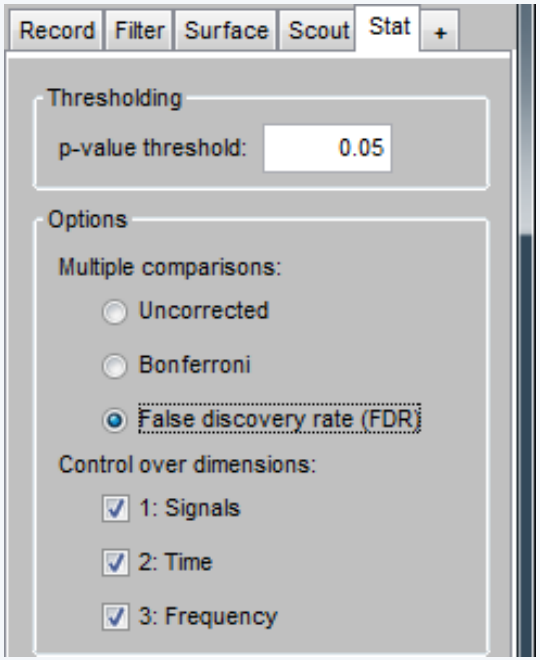
Group analysis

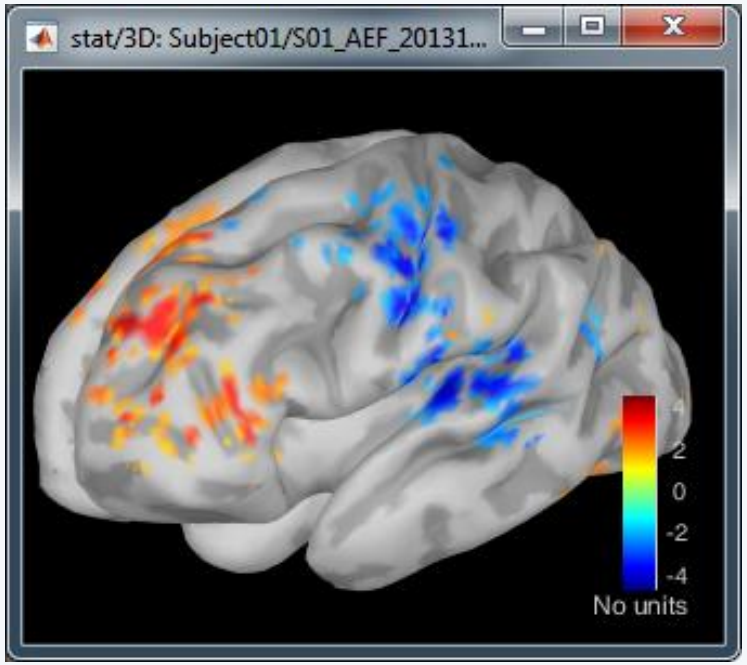
Subject averages
Low-pass
Normalize
Project

Group averages
Group statistics

Quality control
Workflow

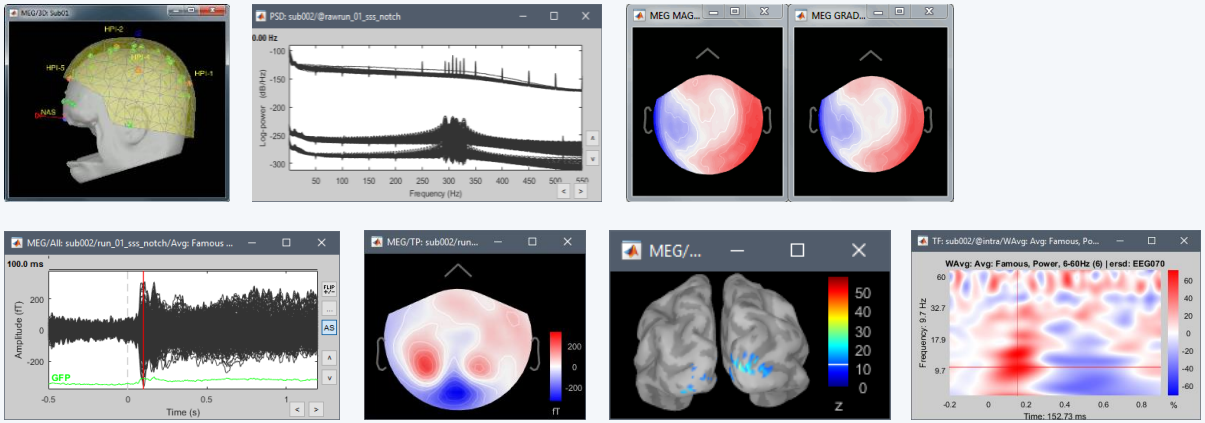
- Contrasts between subjects or conditions
- Parametric t-test
- Cluster-based non-parametric tests
- Export to: **SPM**, R, Excel, SPSS, Matlab…





Group analysis

- When scripting the analysis, we recommend you always check visually the following items for each run separately:
  - MRI/sensors registration
  - PSD before and after filters
  - SSP and ICA component topographies
  - ERP/ERF: Sensors time series
  - ERP/ERF: Sensors topo of primary response
  - ERP/ERF: Sources of primary response
  - Any other metric of interest



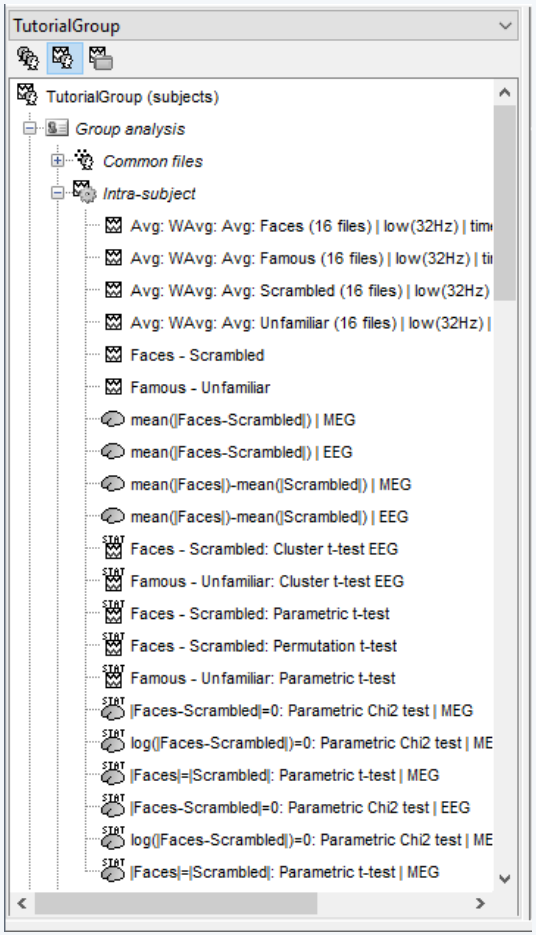
Group analysis

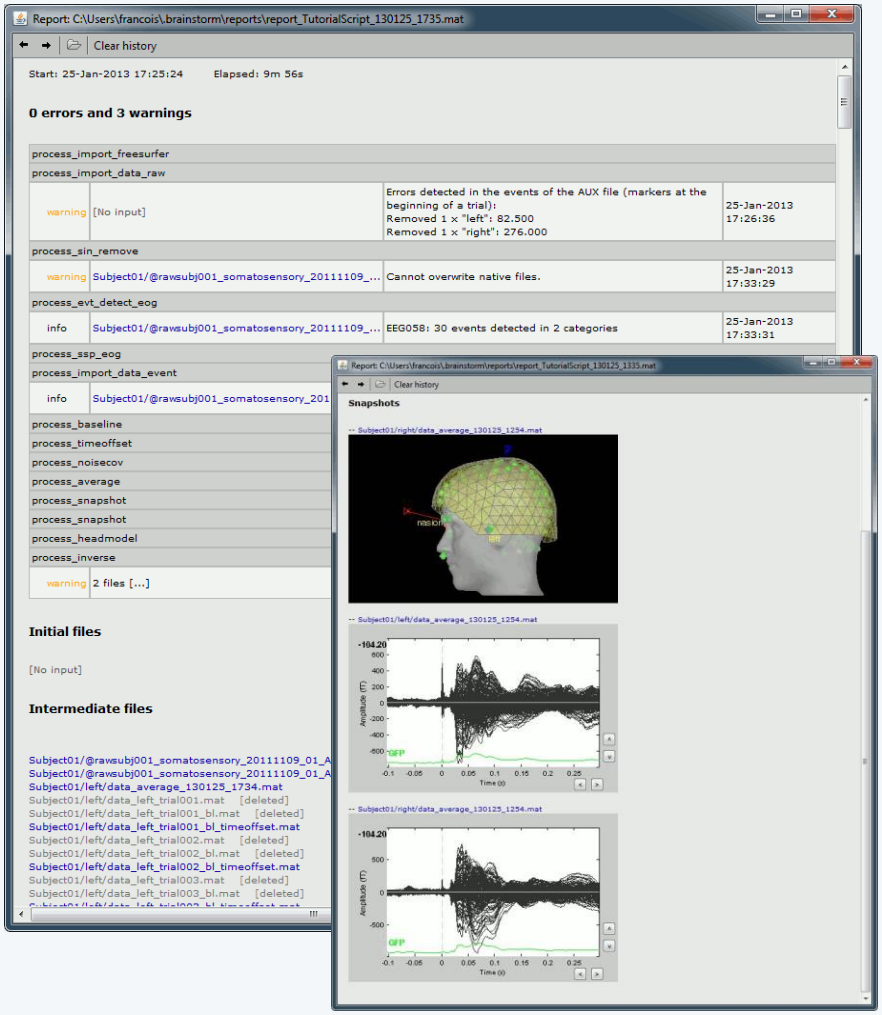
Subject averages
Low-pass
Normalize
Project

Group averages
Group statistics

Quality control
Workflow

- Execution reports with snapshots saved in HTML





Add your code to Brainstorm

- Direct manipulation of the files in Matlab
- Use the menu “Run Matlab command”
- Write a plugin:
  - Well documented API
  - Lots of example (170 functions written as plugins)
- Examples of recent external contributions:
  - MVPA decoding (Oliva, MIT)
  - Microstate segmentation (Cacioppo, UChicago)
  - Eyetracker/EEG synchronization (Uni Freiburg)

User community

- 15,500 users registered on the website

Find users next to you

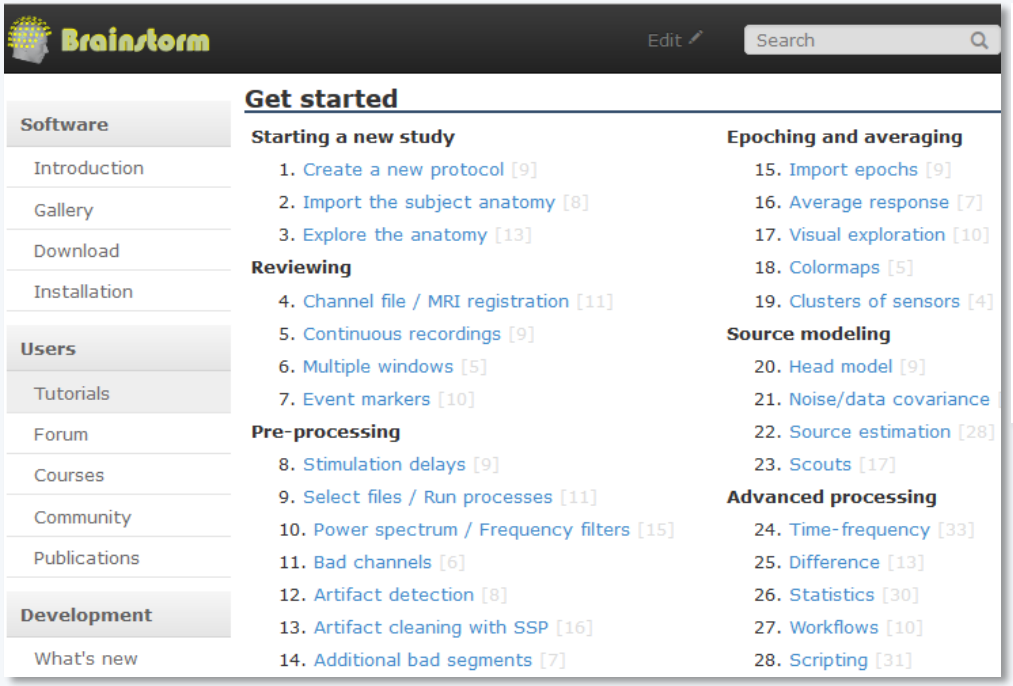
Location: montreal

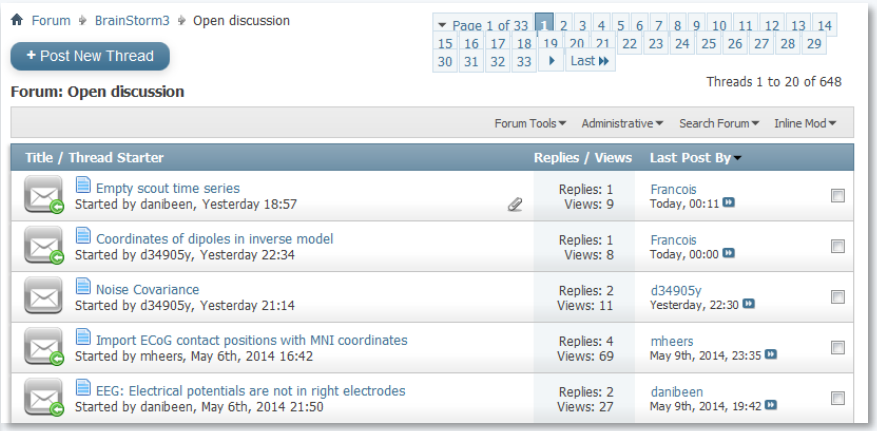
josieannebertrand	UQAM, Montreal	EEG	post-doc	2013
timothynest	Montreal, McGill	MEG, fNIRs	research	2013
Clara Moreau	Montreal	MEG	stagiare	2013

Brainstorm

User support

- Online tutorials: 30-hour self-training program
- Active user forum: 150 posts/month
- Daily updates: 750 downloads/month





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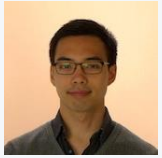

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Rey Ramirez
UW

Sample data

Oddball auditory task (Dec 2013, MNI, McGill)

- Binaural stimulation with intra-aural earphones
- 200 standard beeps (400Hz) + 40 deviant (554Hz)
- Inter-stimulus interval: Random in [0.7 - 1.7] s
- Subject taps the right index when a deviant is heard

- Acquisition at 2400 Hz - Downsampled at 600Hz
- Recorded on CTF 275 MEG sensors
  + 2 EEG (Pz,Cz) + 26 MEG reference sensors
  + EOG + ECG + STIM + … = 302 channels
- 6 minutes of recordings
- MRI processed with FreeSurfer 5.3