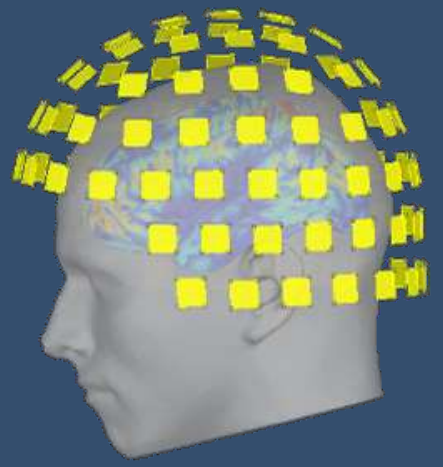
MEG and EEG analysis with

Brainstorm

http://neuroimage.usc.edu/brainstorm

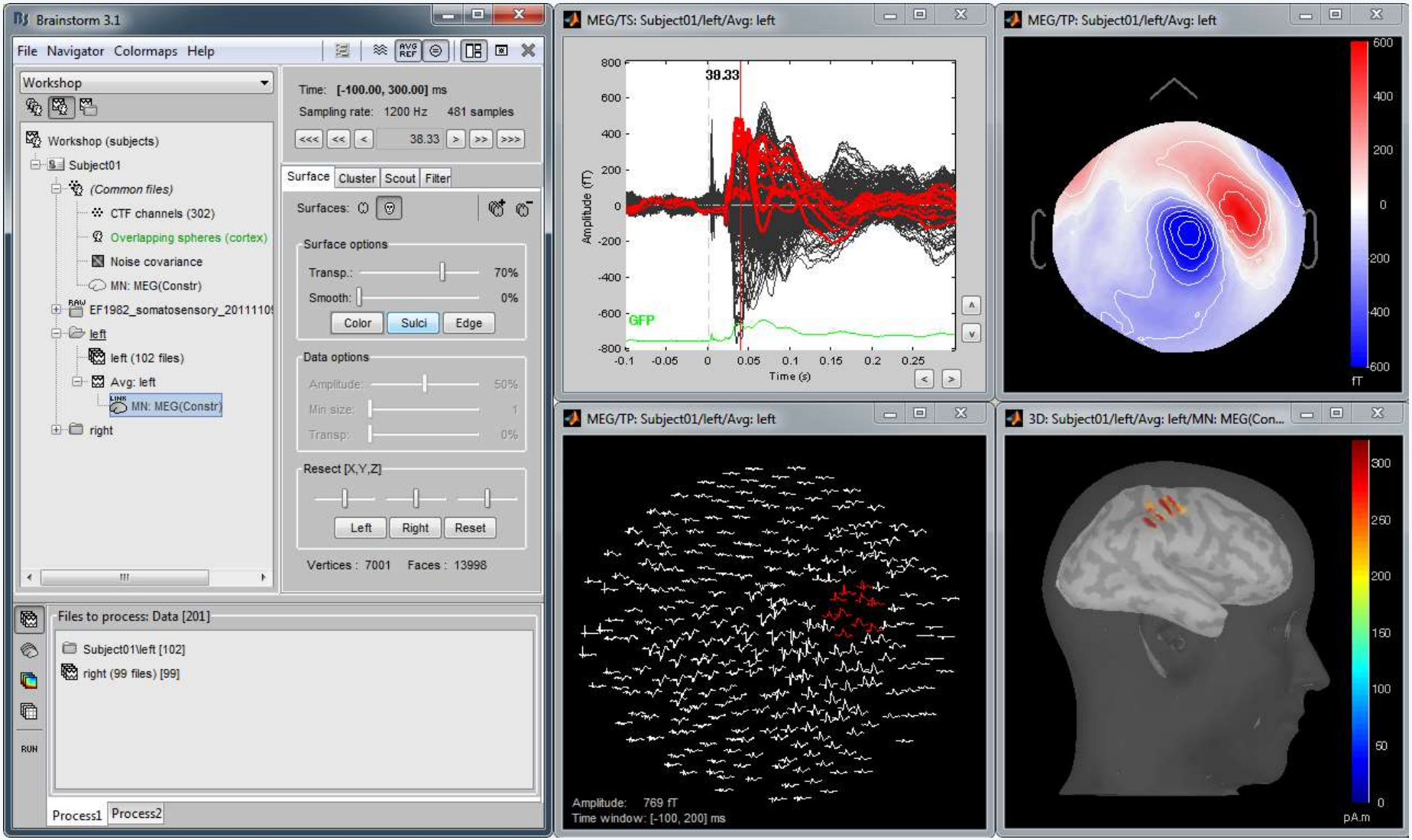


Grenoble, December 2015

Francois Tadel
Sylvain Baillet
Anne-Sophie Dubarry

USC University of Southern California · Cleveland Clinic · McGill · neuro

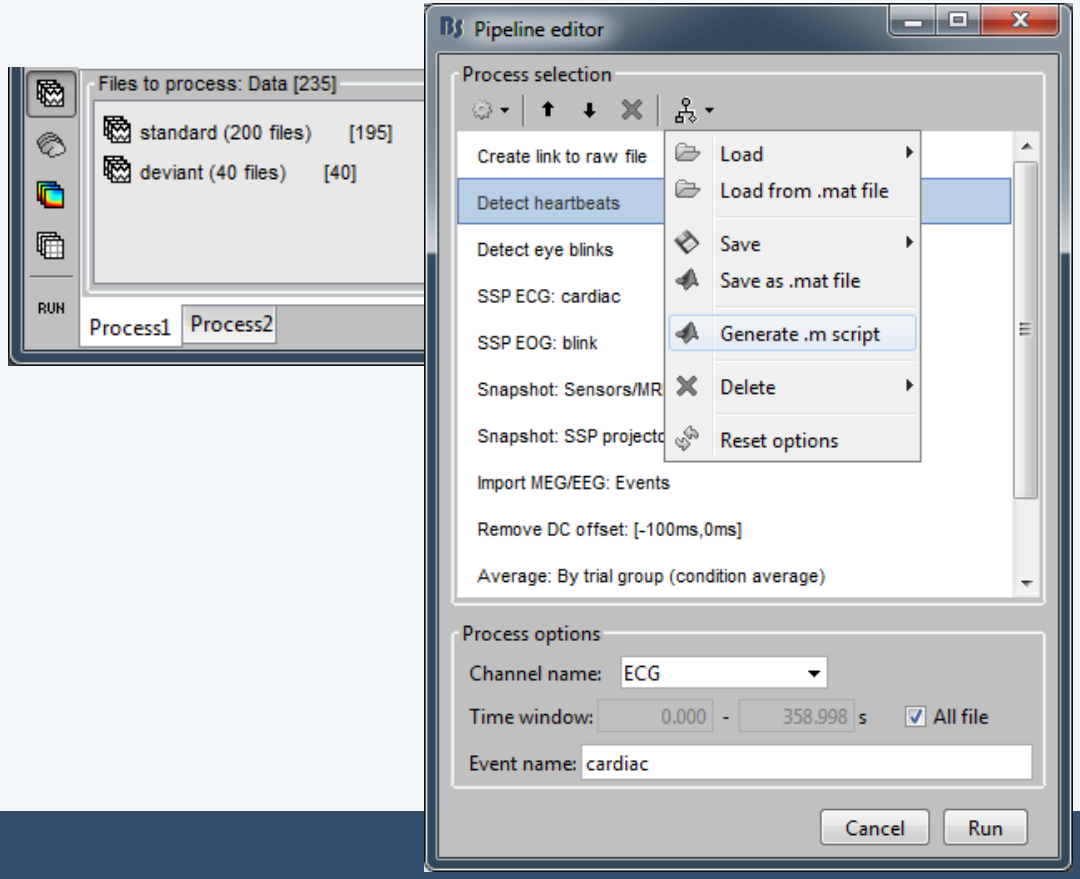
Graphic interface



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);
```

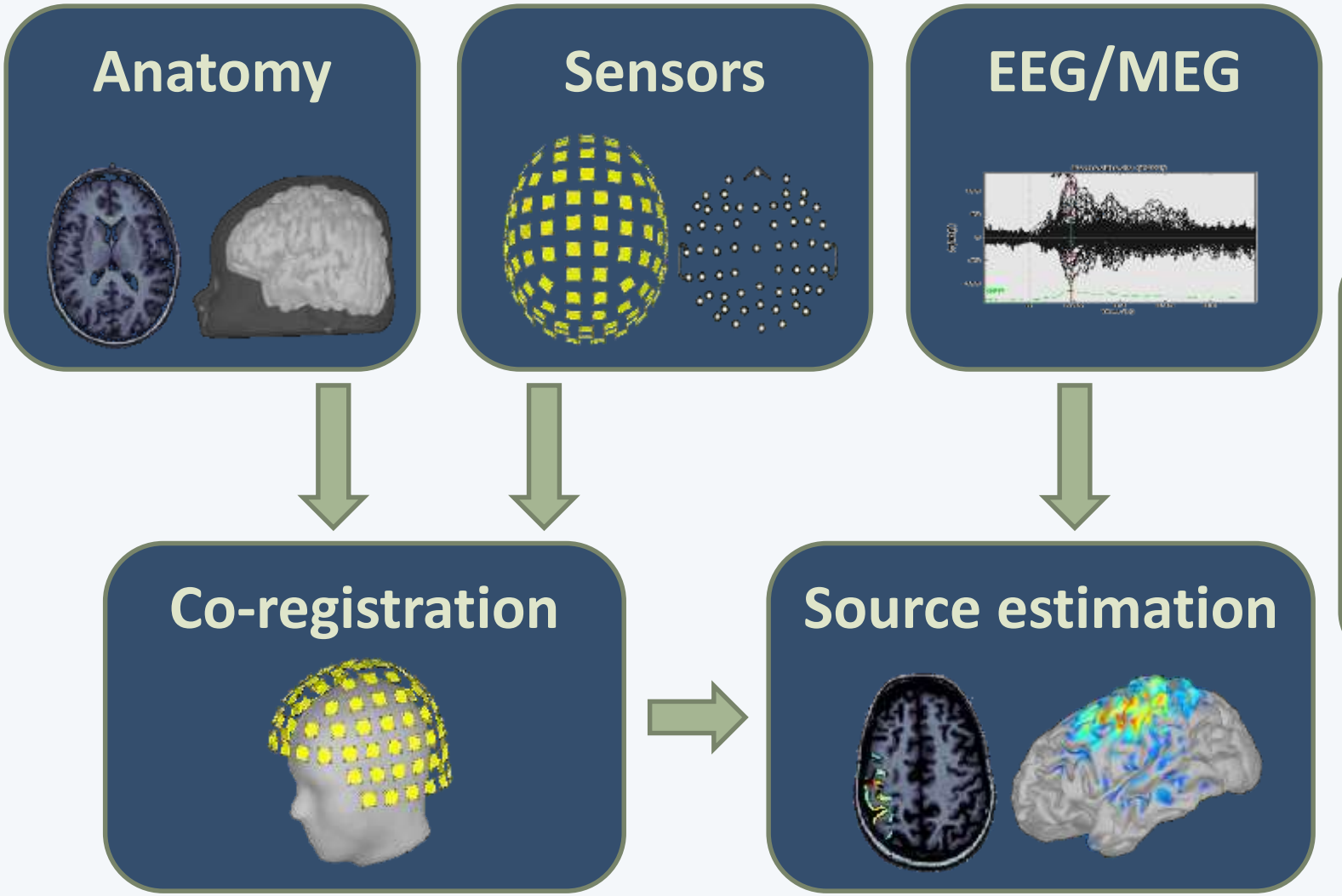
Brainstorm is...

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

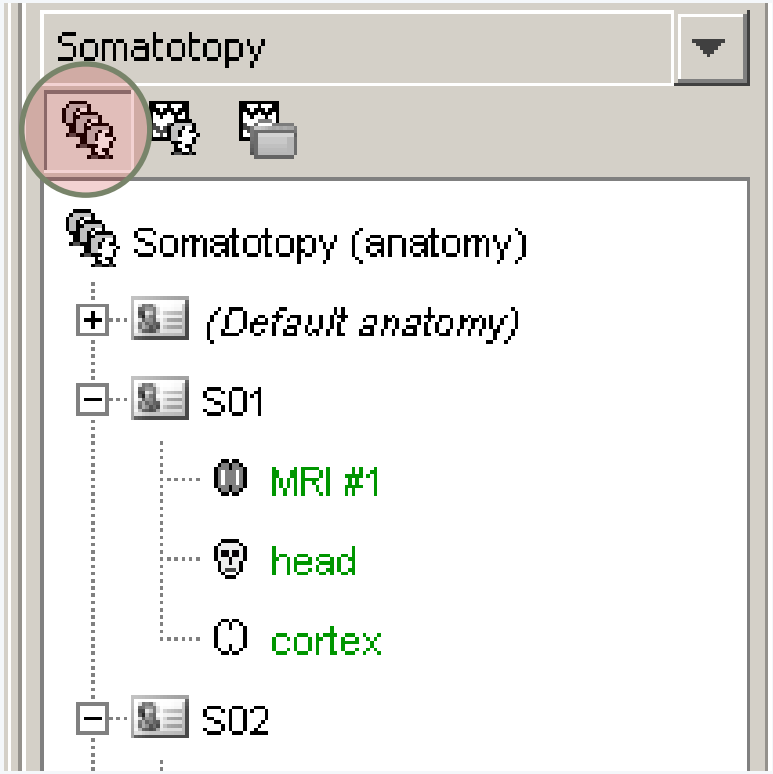


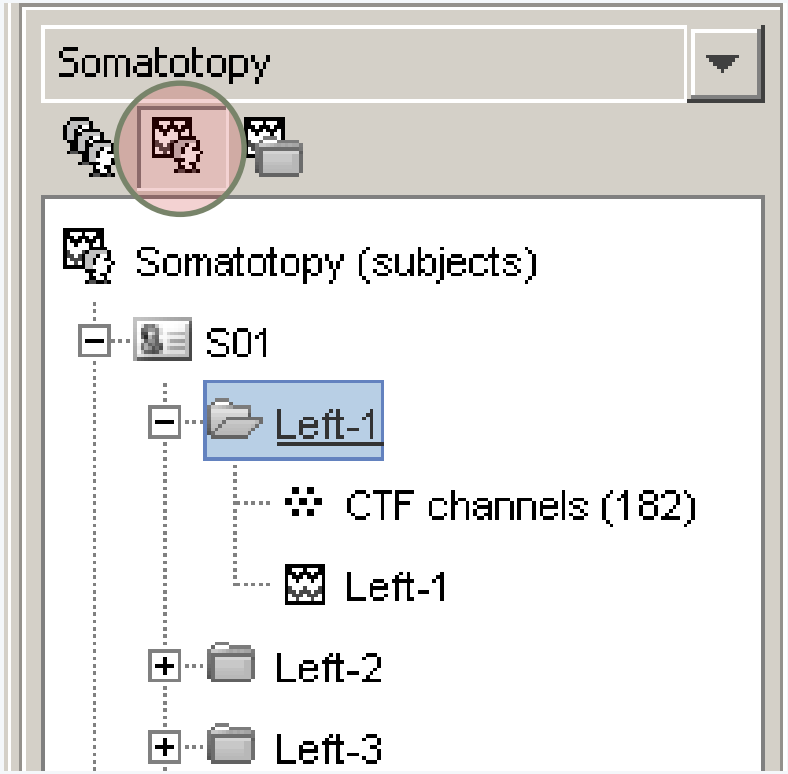


Workflow


Anatomy
Sensors
EEG/MEG
Analysis
Averages
Contrasts
Group analysis
Time-frequency
Connectivity
Co-registration
Source estimation

Database





- Three levels:
  - Protocol
  - Subject
  - Condition

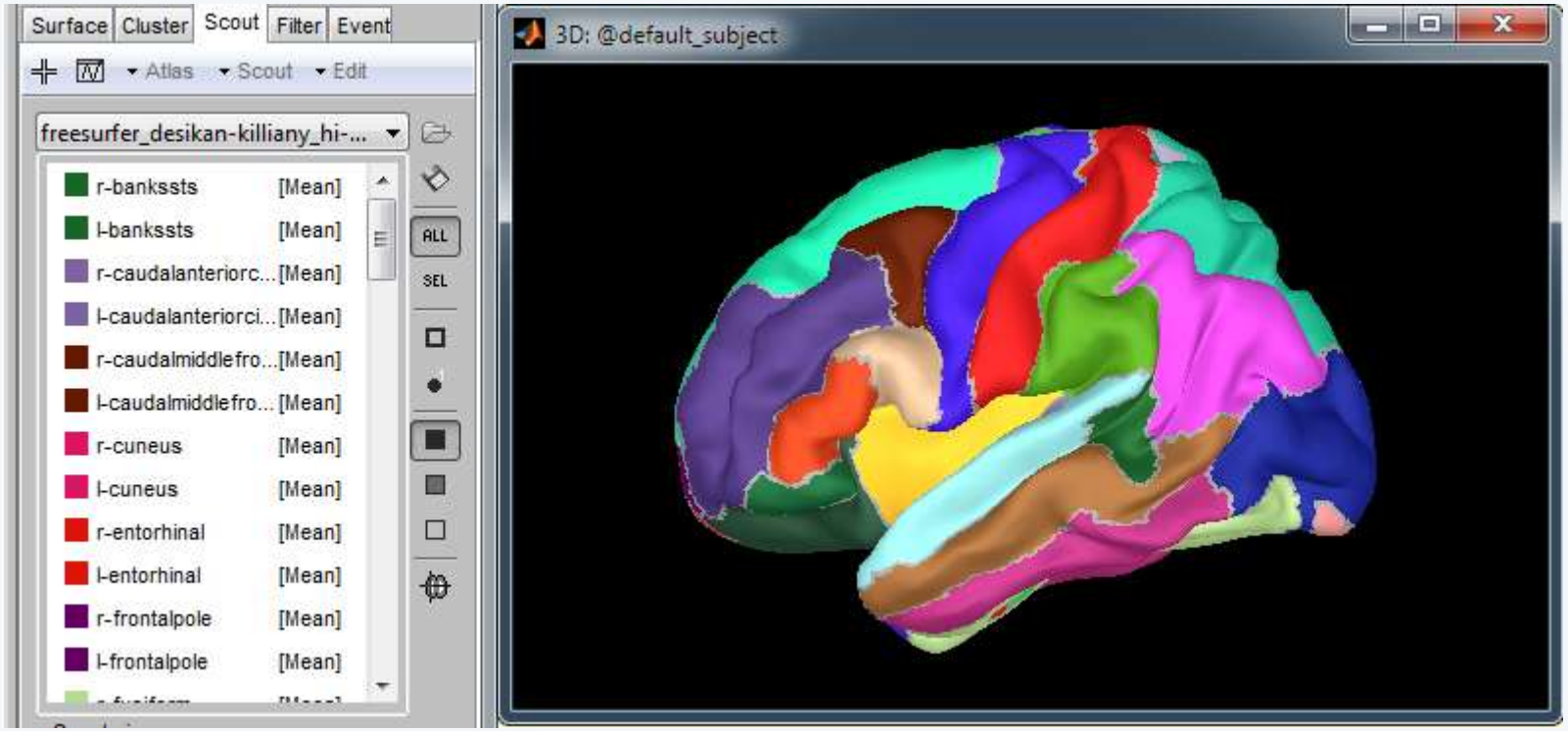
- Popup menus
- All files saved in Matlab .mat
- Same architecture on the disk

Anatomy

- One-click import of the T1 segmentation:
  FreeSurfer, BrainSuite, BrainVISA, CIVET

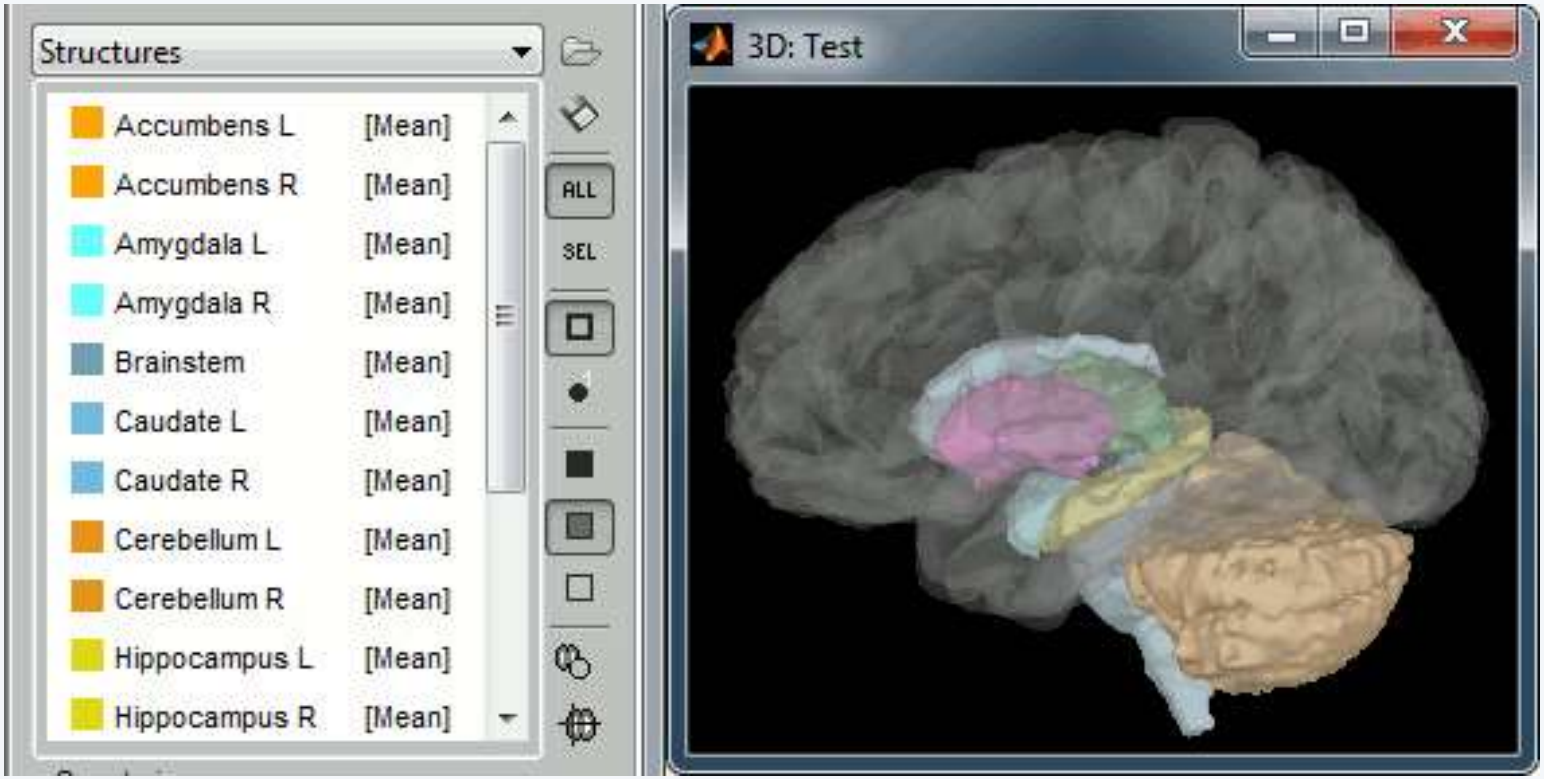
Atlases

- Support for the surface-based atlases generated automatically by FreeSurfer and BrainSuite



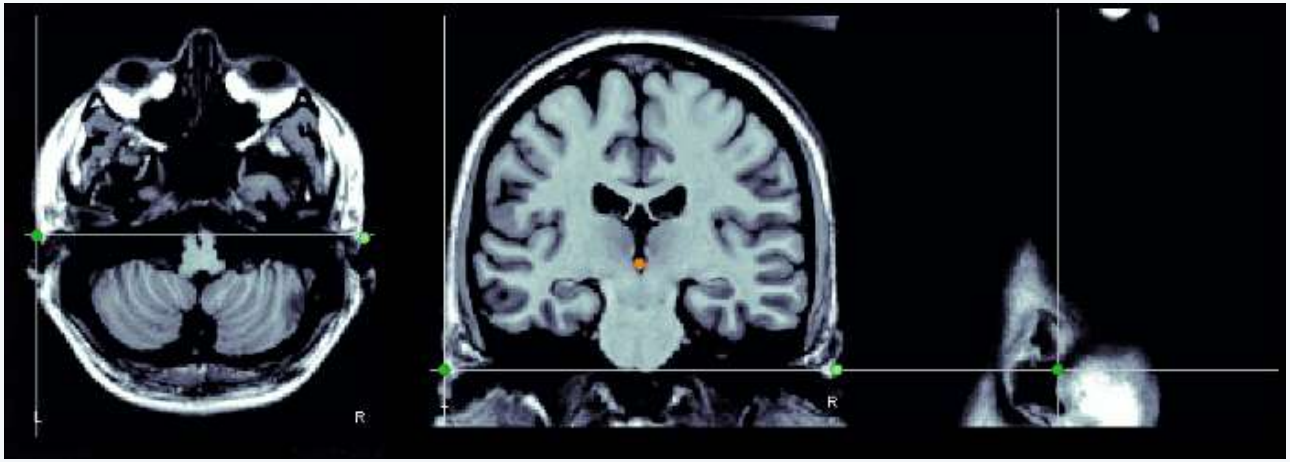
Brainstorm

- Support for the subcortical atlases generated automatically by FreeSurfer



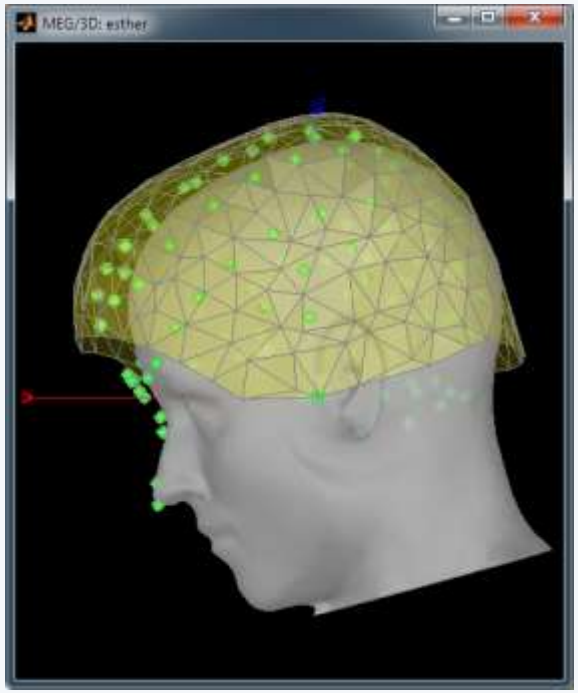
Co-registration MEG / MRI (1)

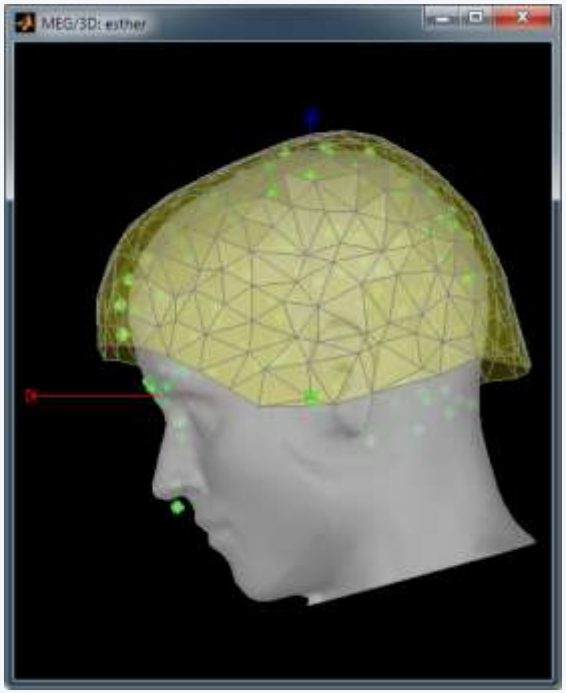
- Basic estimation based on three points (NAS,LPA,RPA)
  - MRI: Marked in the volume with the MRI Viewer
  - MEG: Obtained with a tracking system (Polhemus)



Co-registration MEG / MRI (2)

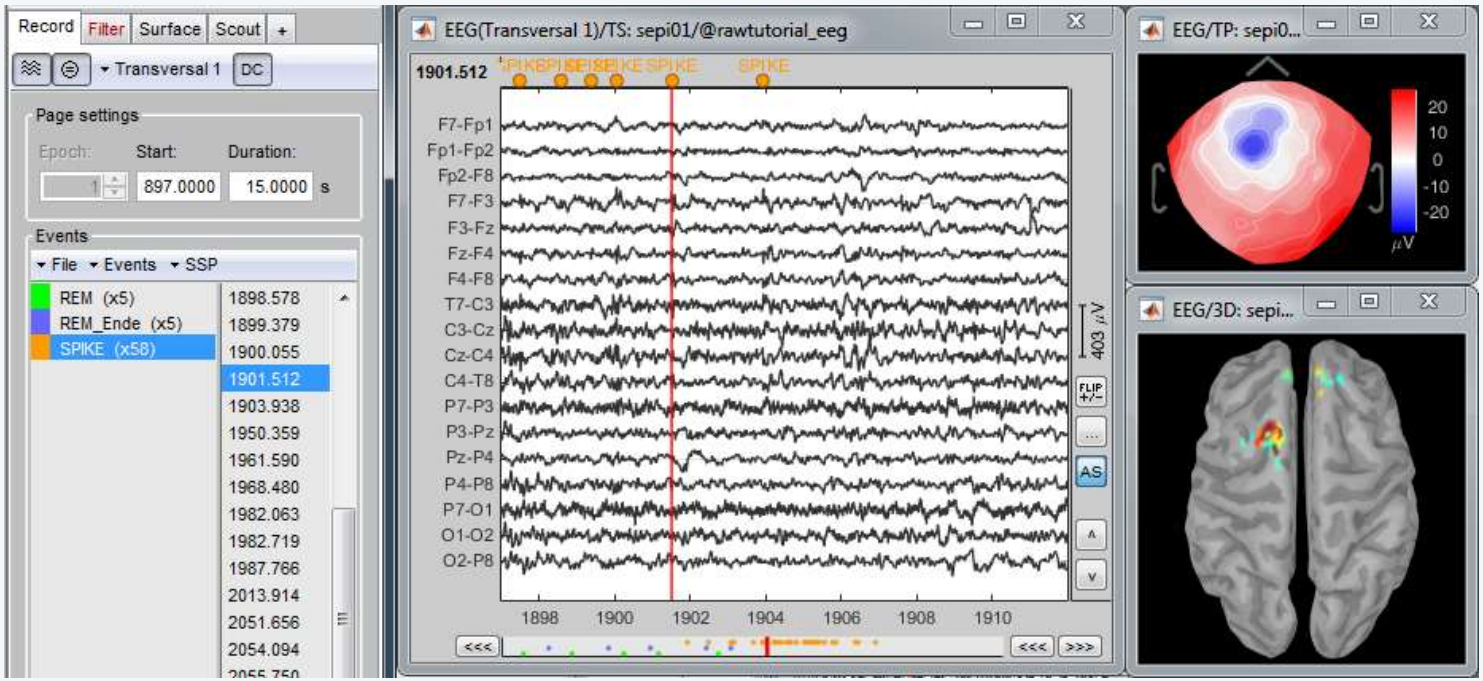
- Automatic adjustment based on head shape:
  Fitting the Polhemus points with the MRI head surface
- Final registration must be checked manually
- Polhemus driver included in the software





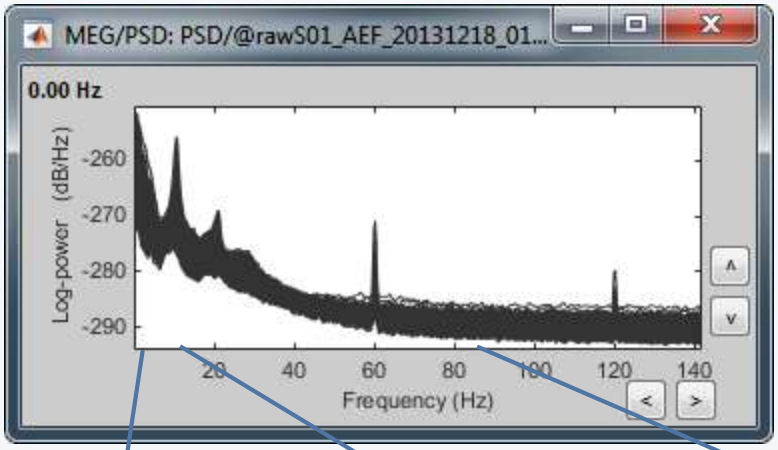
Continuous recordings

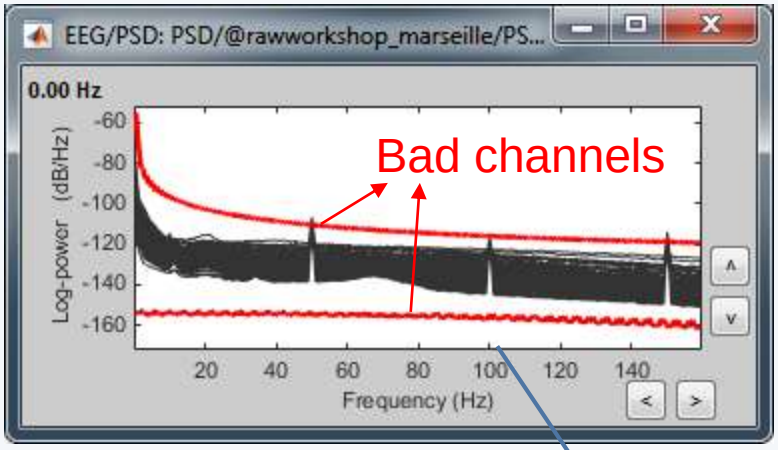
- Manual inspection of the recordings
- Identify noise sources, mark bad segments
- Check stimulus markers, add custom events
- Optimized workflow for clinicians (shortcuts, workspace…)

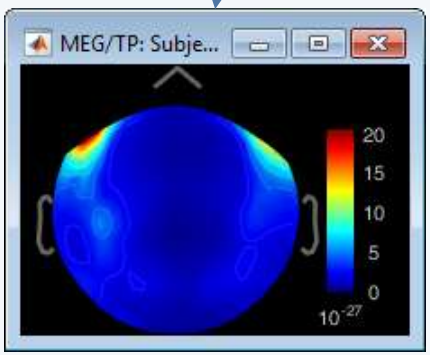


Brainstorm

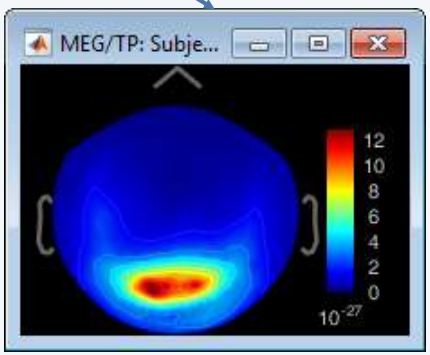
Quality control — Spectral density



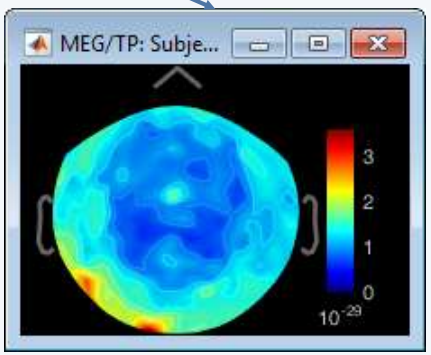




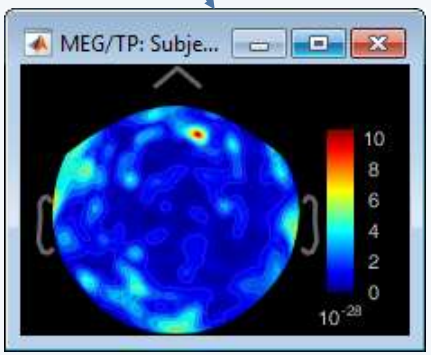
< 3Hz: Eyes



10Hz: Alpha



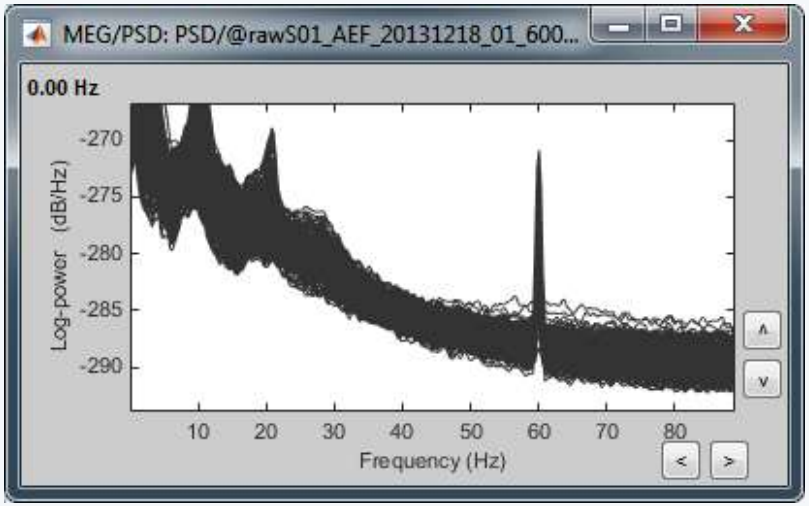
> 40Hz: Muscle

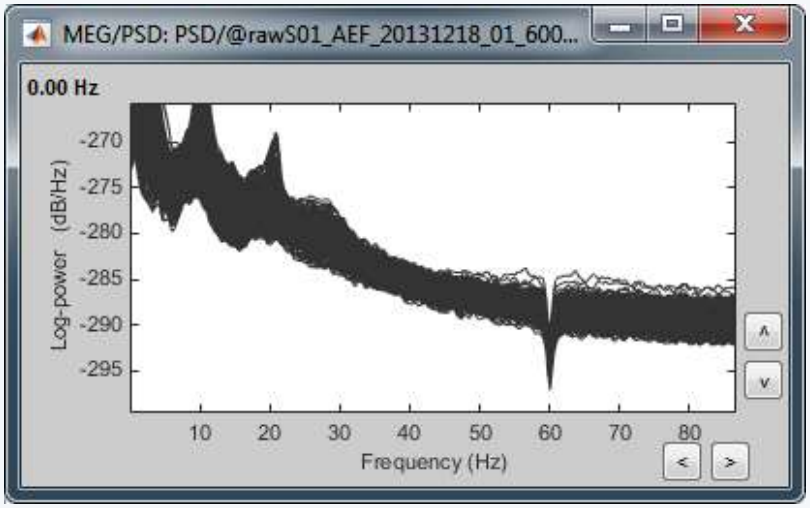


50/60Hz: Power

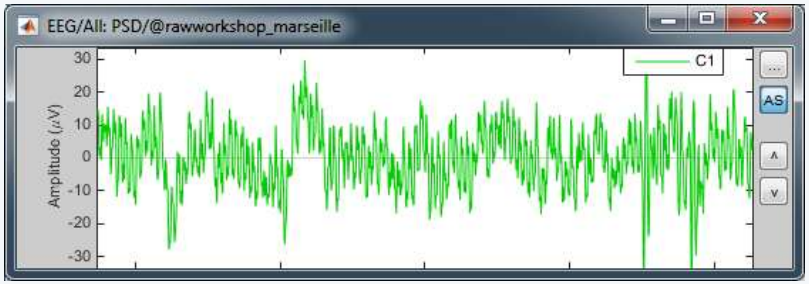
- Notch filter
  Removes 50Hz/60Hz power line noise (and harmonics)

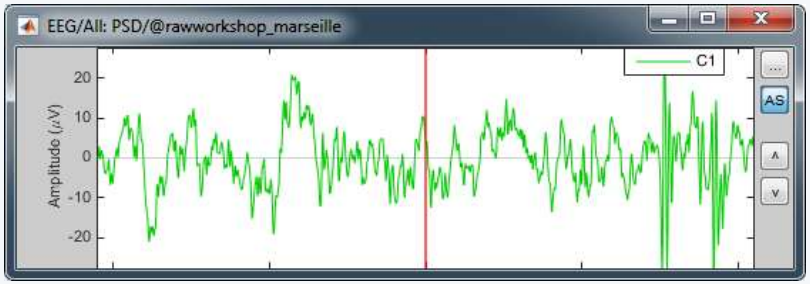
PSD



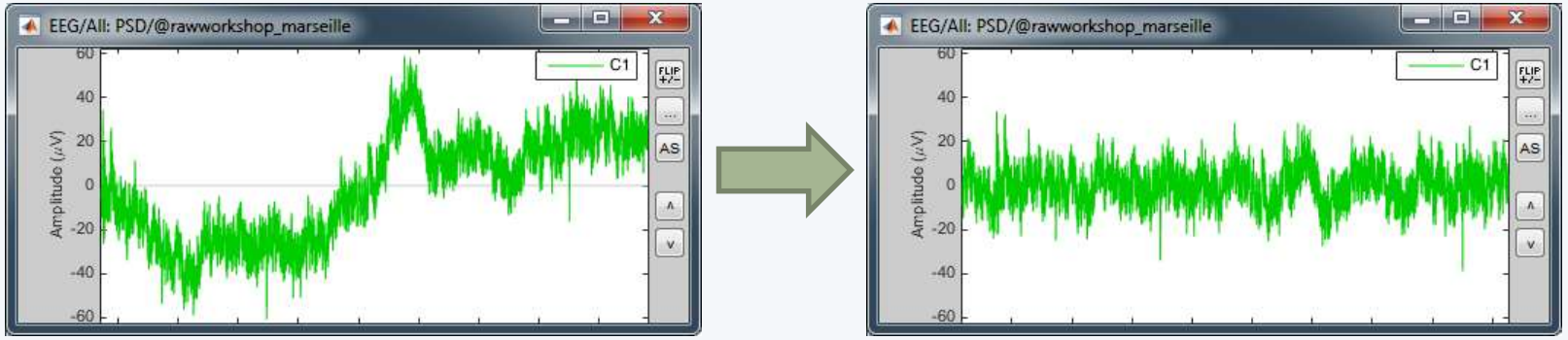


Signal

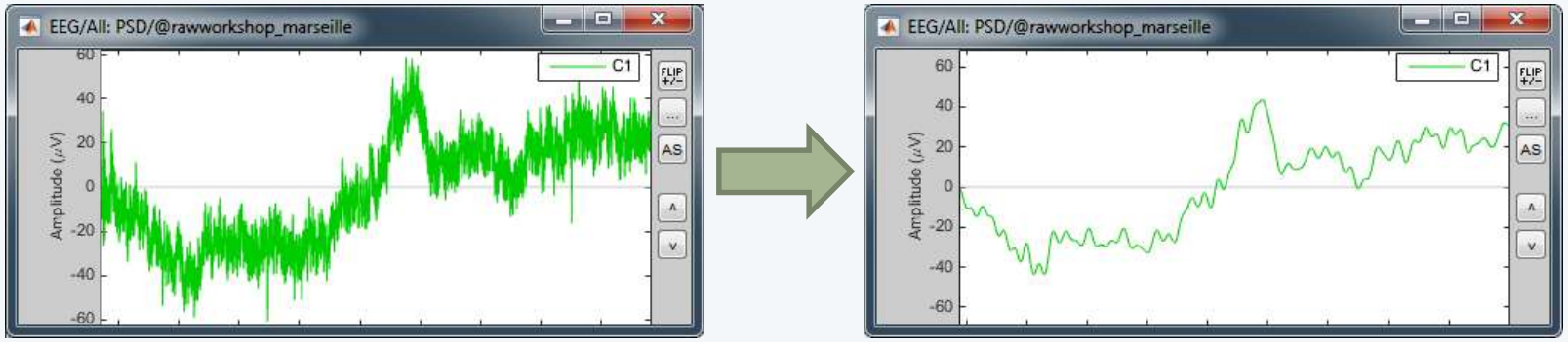




- High-pass filter: Removes slow components (eye movements, breathing, sensor drifts…)

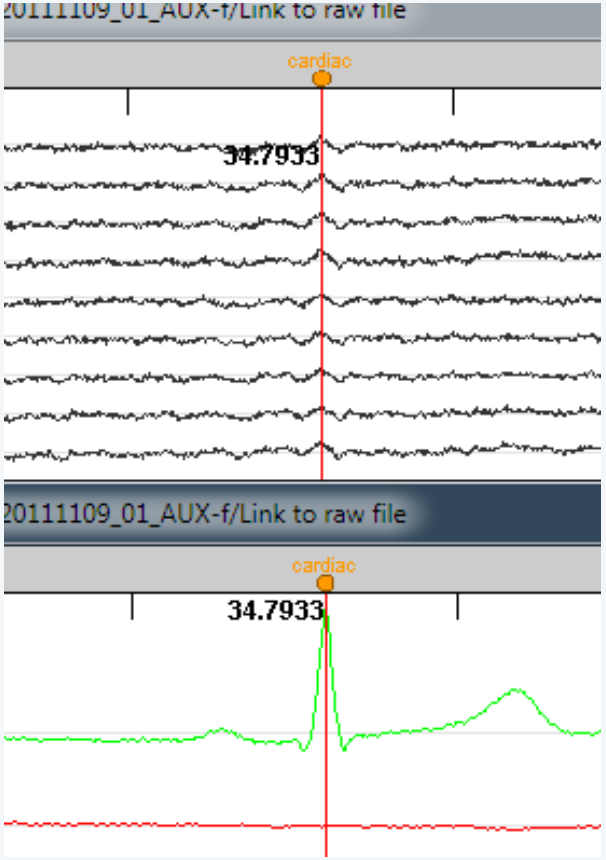


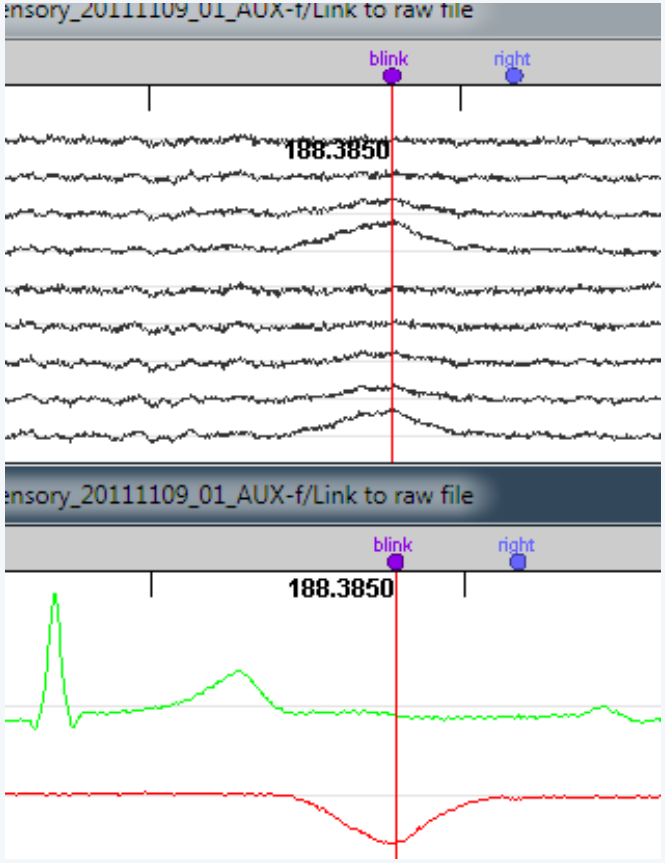
- Low-pass filter: Remove high-frequencies



Artifact correction

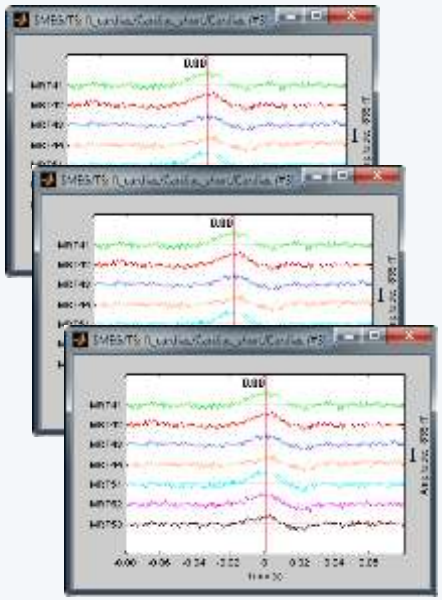
- Artifact detection and removal:
  - heartbeats, eye blinks, movements, …





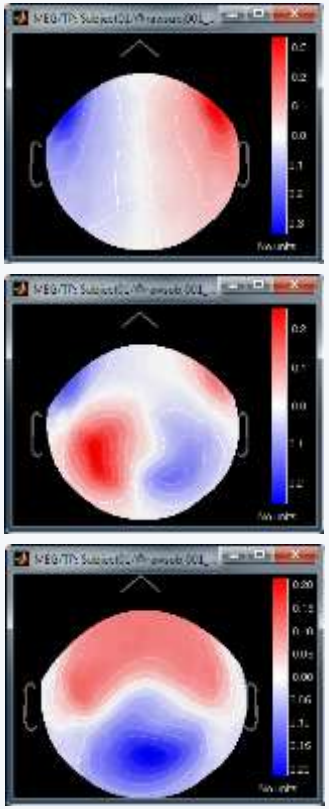
Signal-Space Projection (SSP)

- Detect artifacts
- Concatenate epochs



PCA

Spatial components



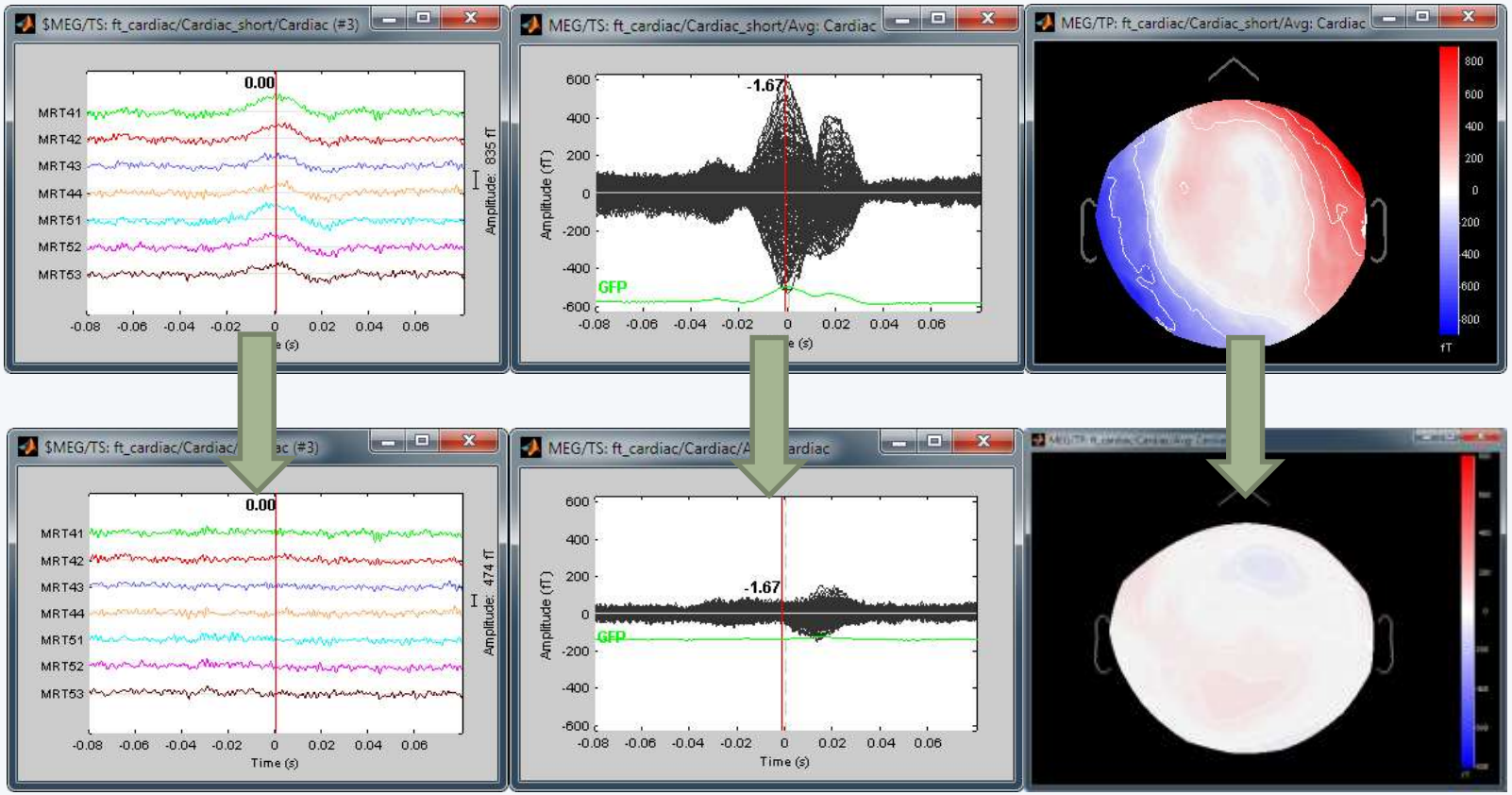
- Select components
- Compute projectors (linear operator)
- Apply to EEG/MEG

Artifact correction

- Example: Cardiac artifact

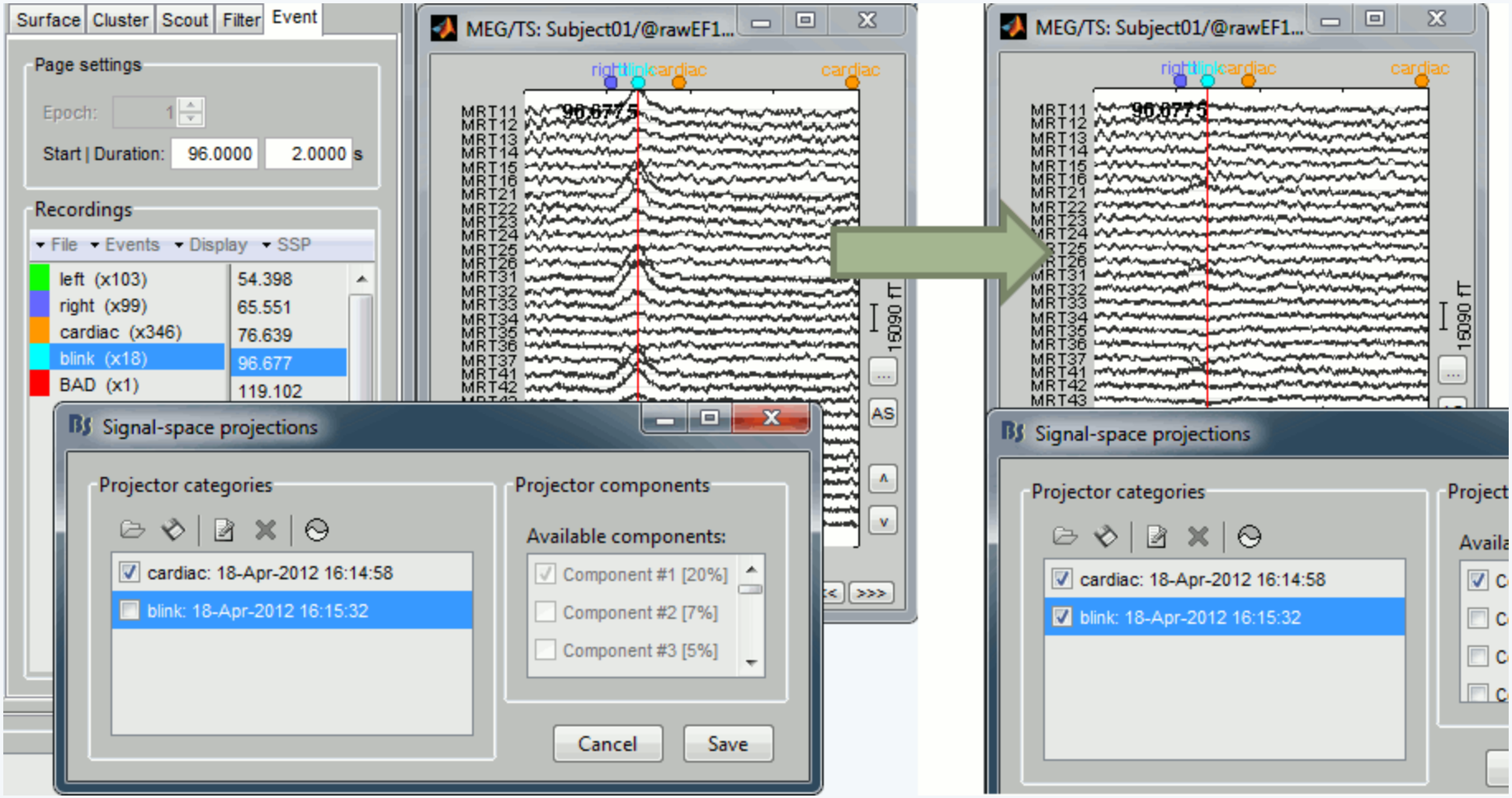
Original

SSP



Brainstorm

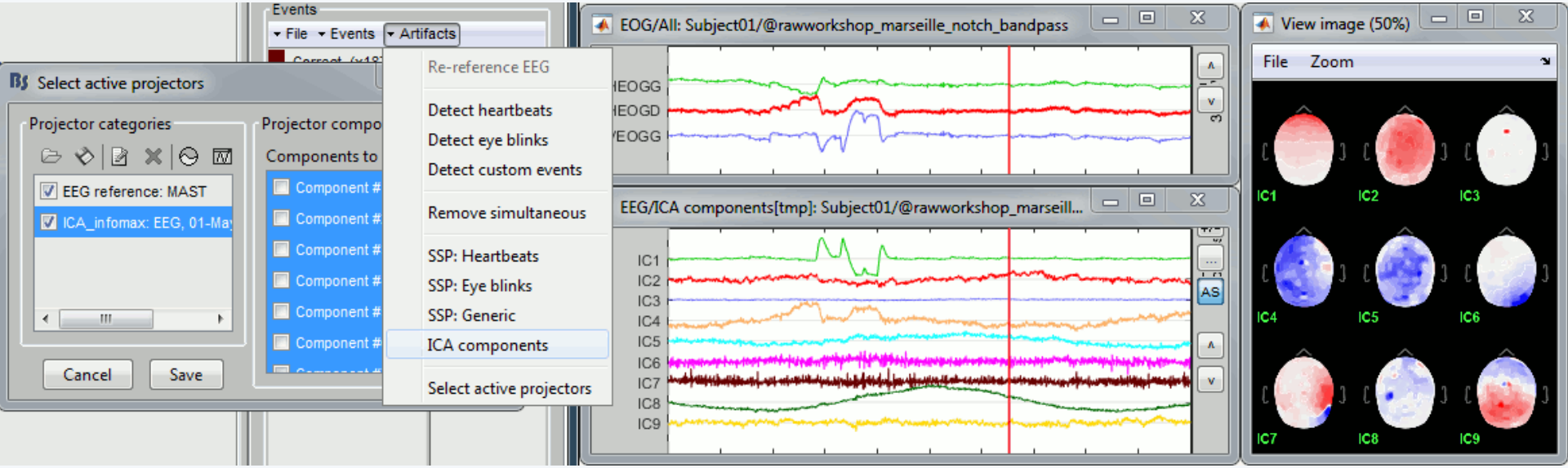
Artifact correction



Brainstorm

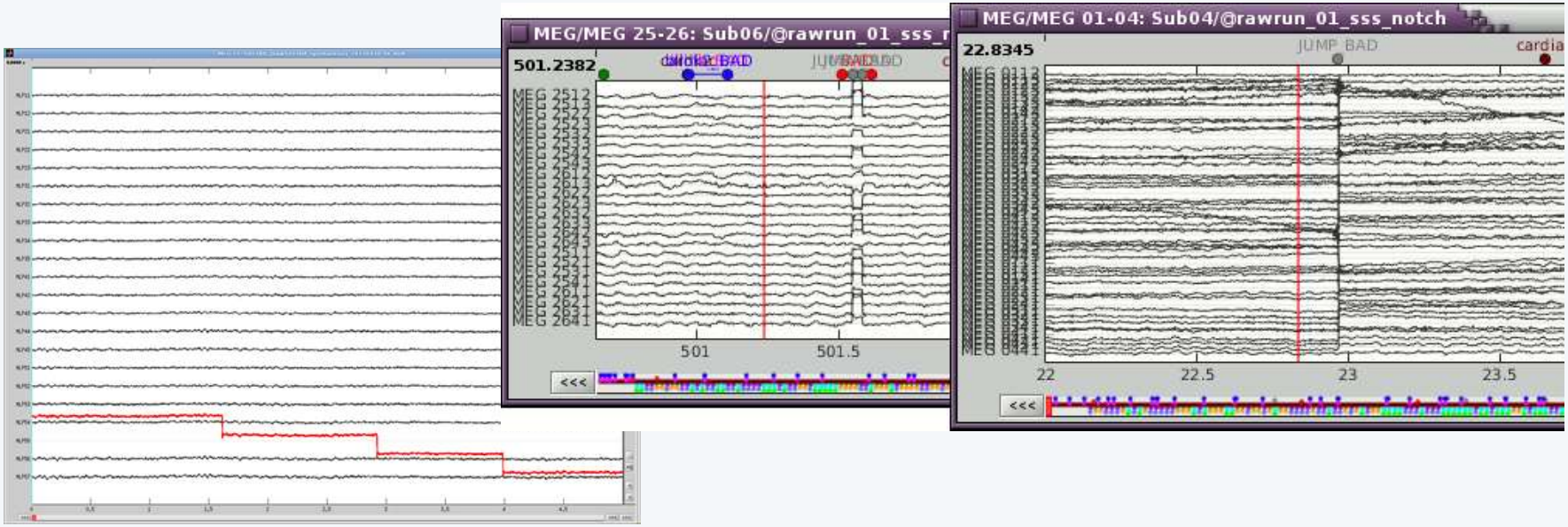
Artifact correction

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



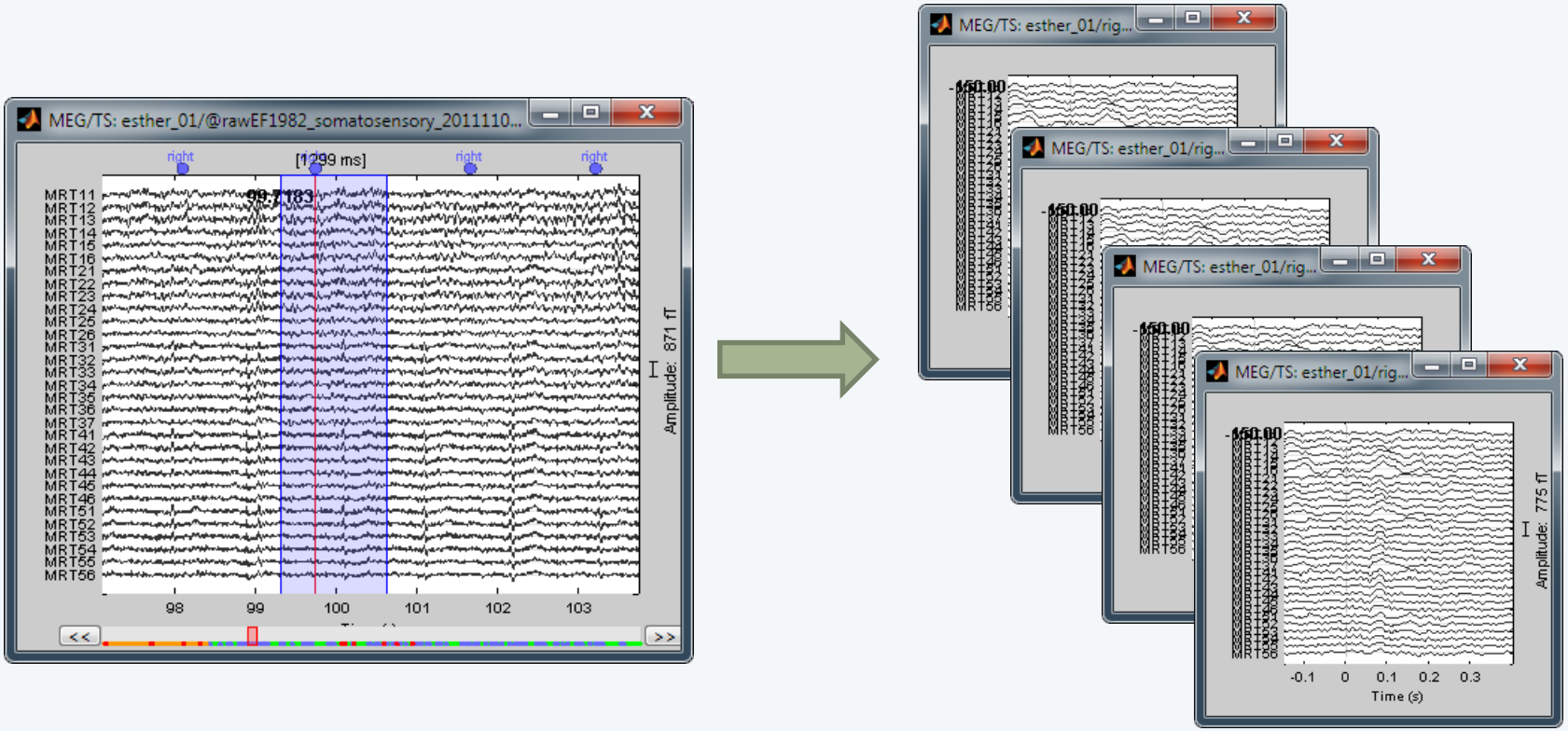
Brainstorm

- 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

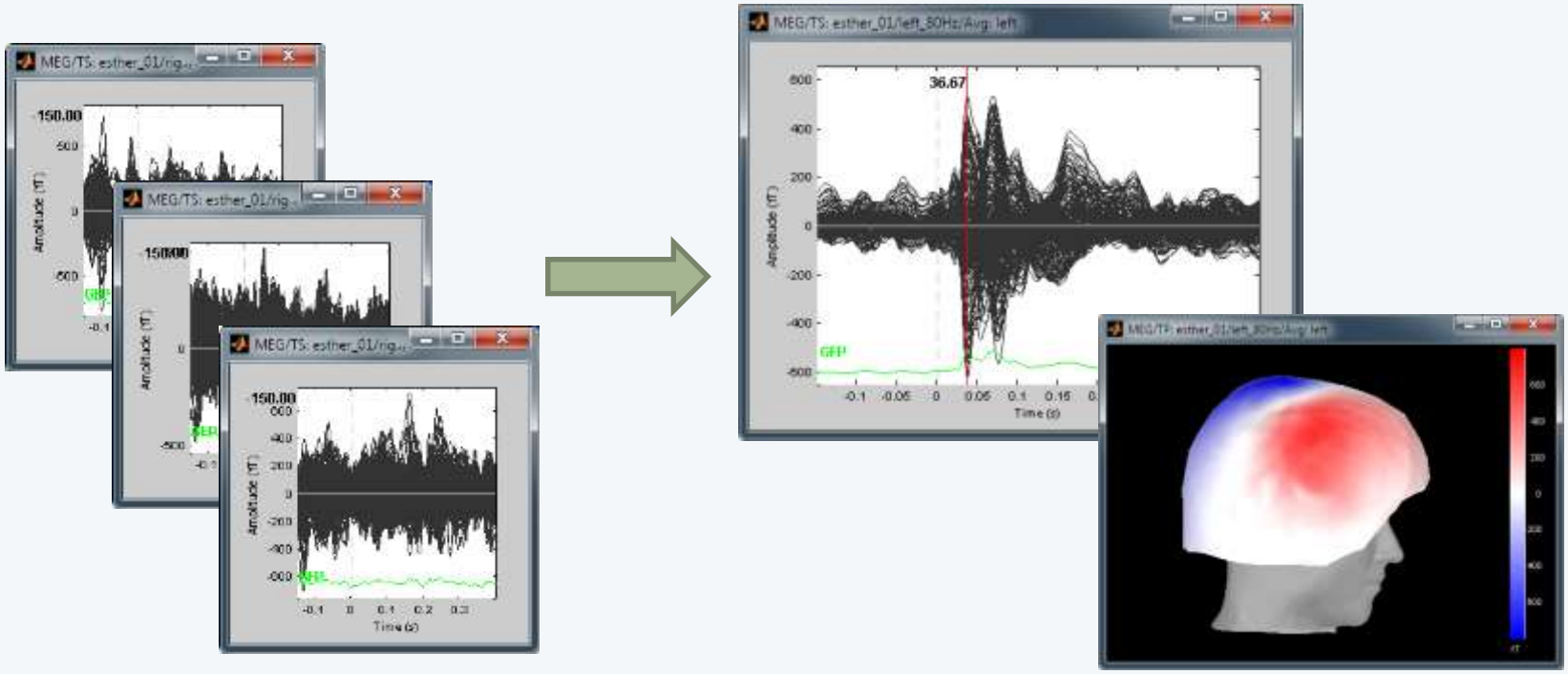
- Epoching: extraction of small blocks of recordings around an event of interest (stimulus, spike…)



Averaging

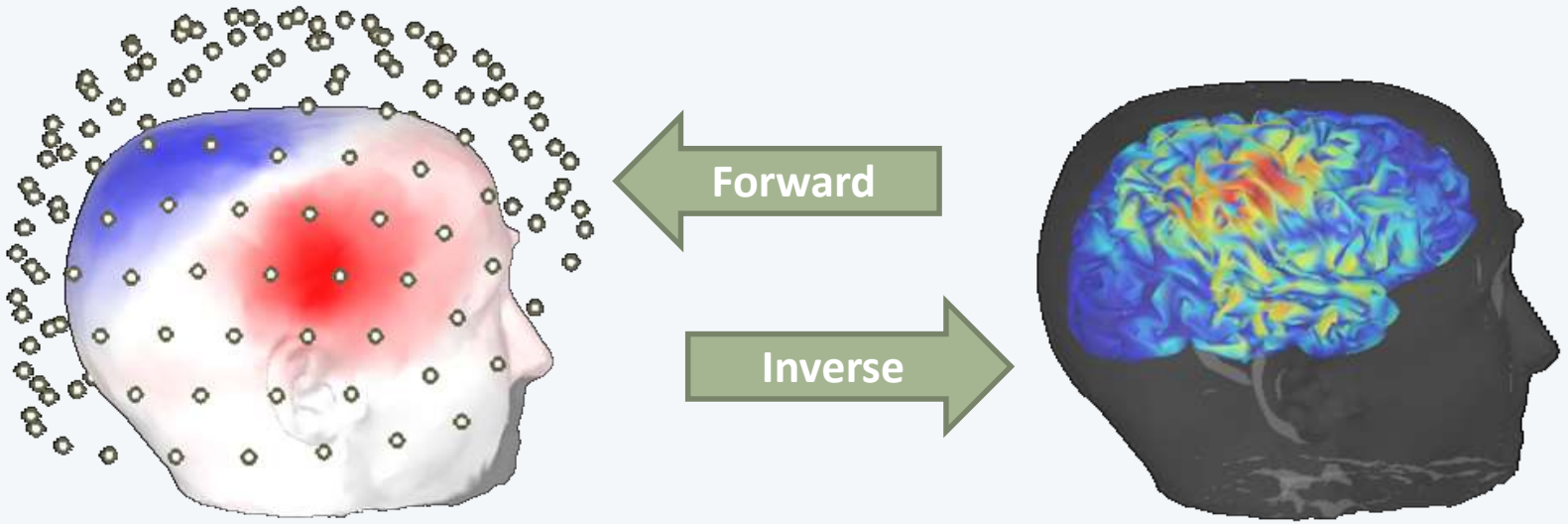
- Averaging all the trials: Reveals the features of the signals that are locked in time to a given event

  => Event-related field (or potential) = Evoked response



Source estimation

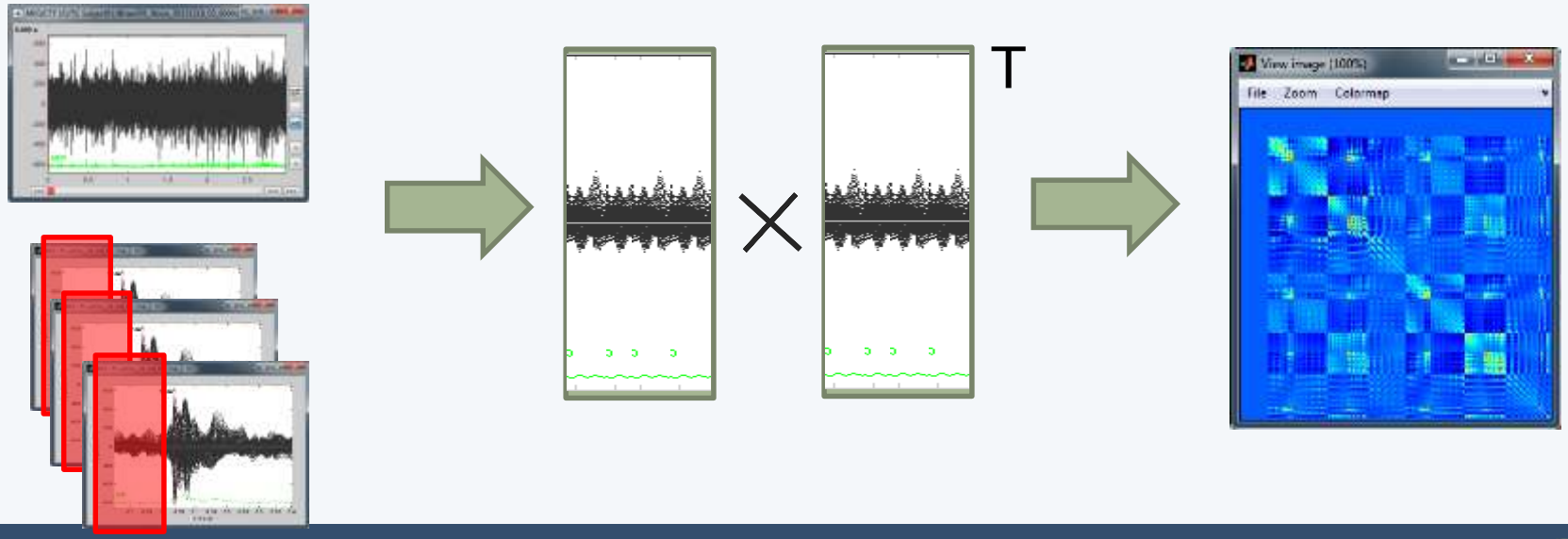
- Source space: Cortex surface or full head volume
- Forward model: Overlapping spheres (MEG)
  OpenMEEG BEM (EEG)
- Inverse model: Minimum norm estimates
  + normalizations (dSPM, sLORETA)



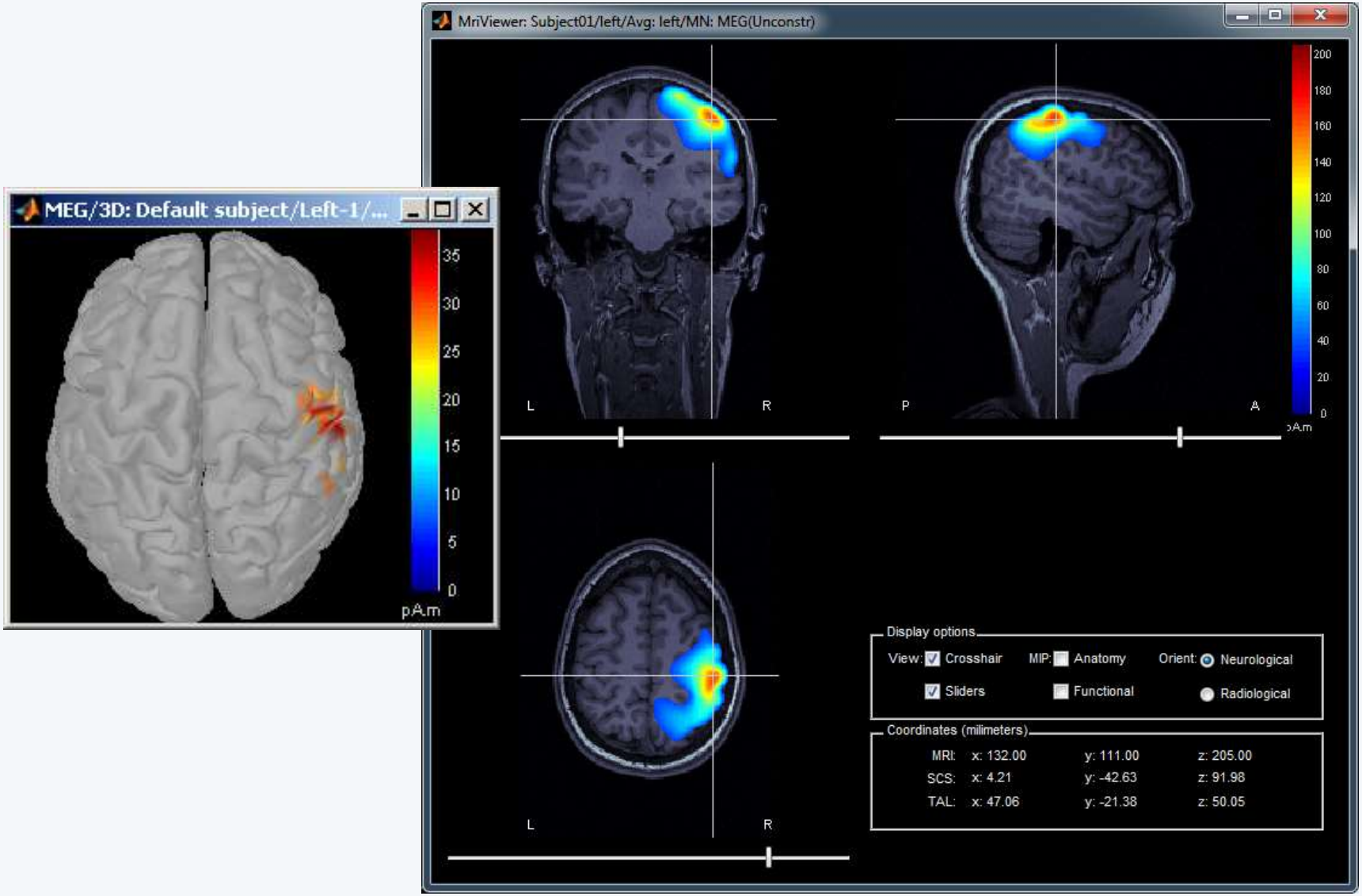
Sensor space *Source space*

Noise covariance matrix

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



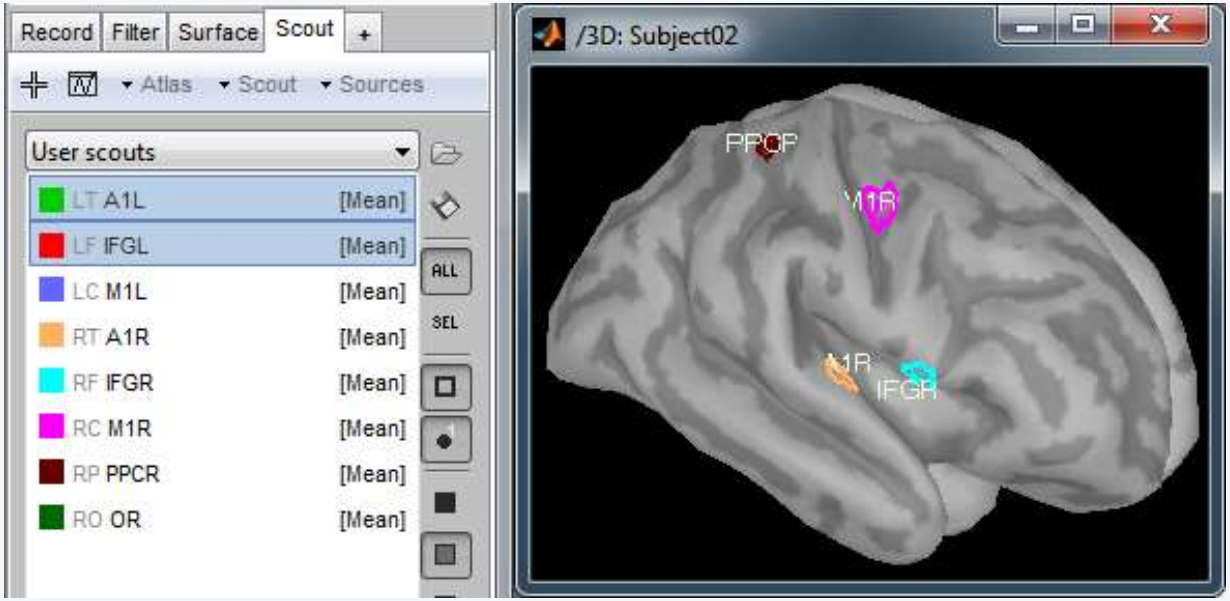
Source activity

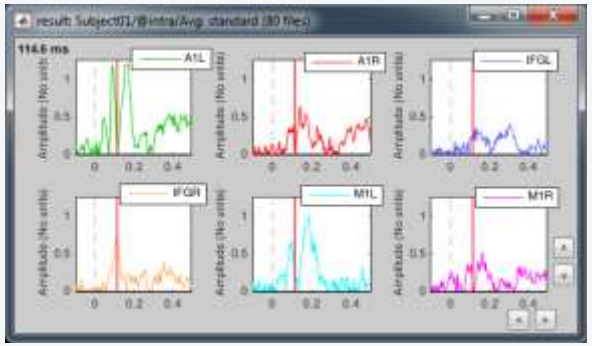


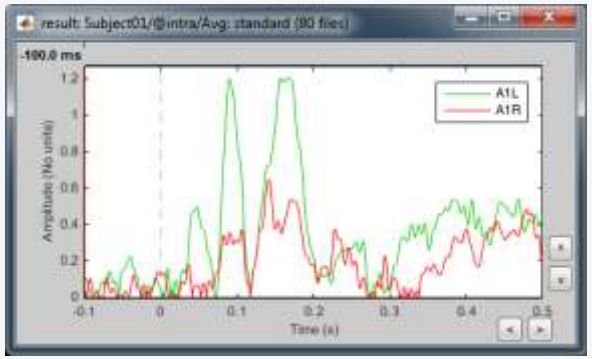
Brainstorm

Regions of interest

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





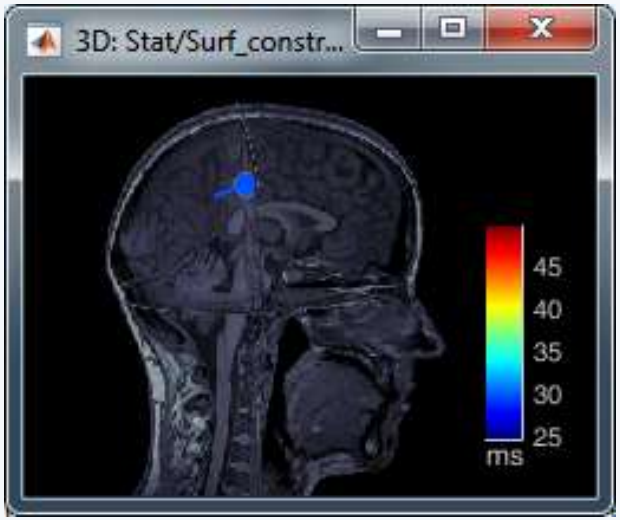


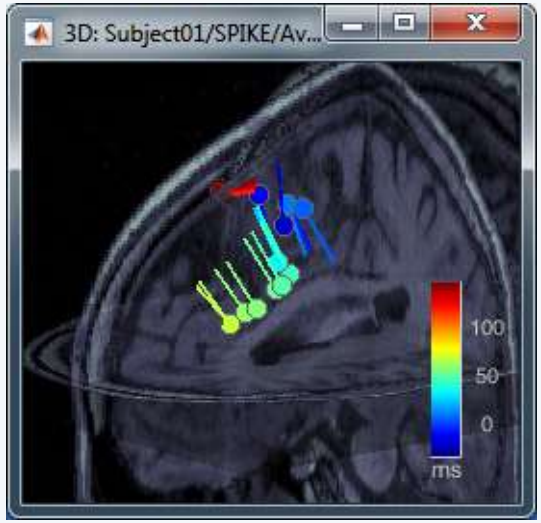
Brainstorm

Single dipoles

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

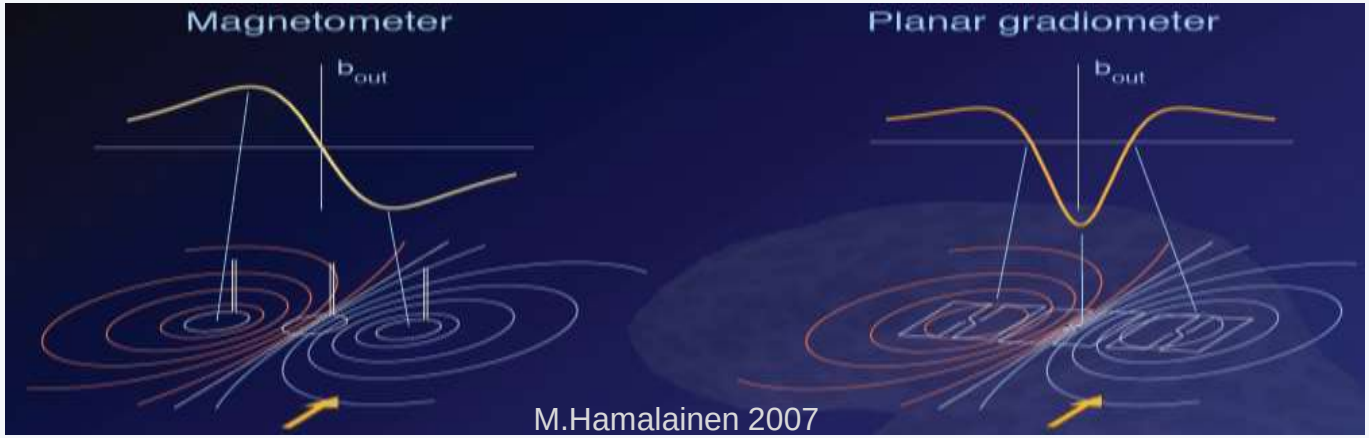
- Dipole fitting (FieldTrip)
  Non-linear search of the dipoles that minimizes the residuals (difference data explained by the dipole - recordings)





Source estimation: MEG

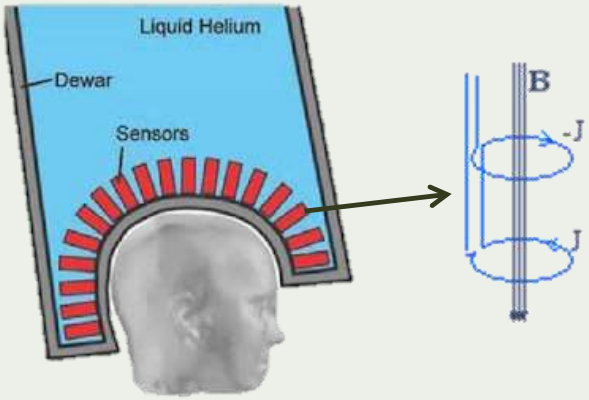
- Recommended in MEG analysis:
  - The subject head can move in the helmet
  - One sensor is not corresponding to one brain region
  - Different types of sensors (magneto / gradiometers)
  - Difficult to read, reproduce or compare
- Converting to source space helps solving those issues



MEG sensors

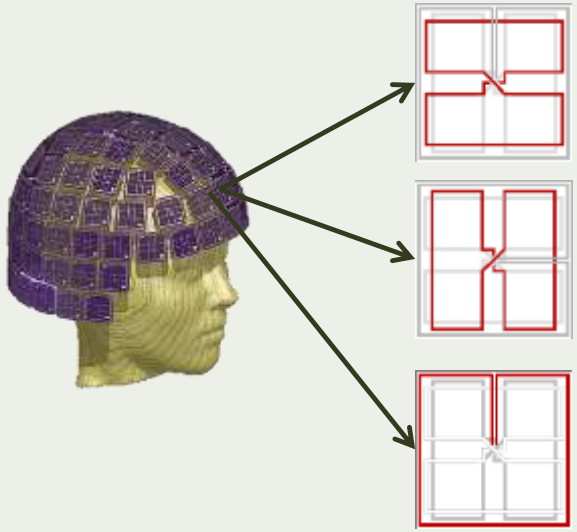
CTF (MNI)

275 axial gradiometers



Elekta (MIT)

204 planar gradiometers
102 magnetometers



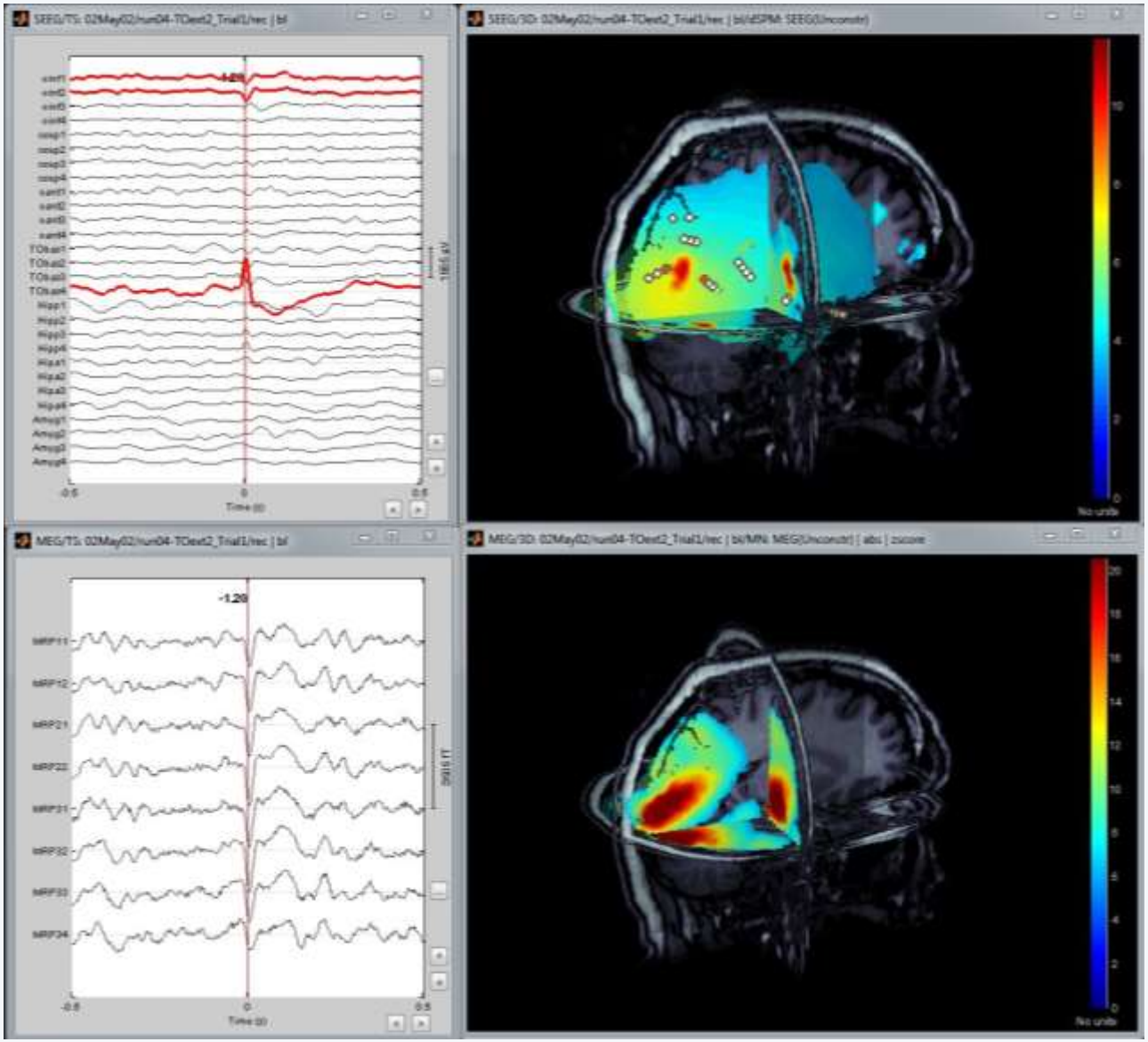
Source estimation: EEG

- In EEG, those problems don't exist:
  - Electrodes positions are fixed and known
  - More reproducible signal shapes and topographies
  - Clinicians are trained to work at the sensor level
- But the source reconstruction is still interesting:
  - Localize the signal generators in the brain (epilepsy and pre-surgical functional mapping)
  - Spatial separation of simultaneous sources

Multi-modal imaging

Easy integration of:

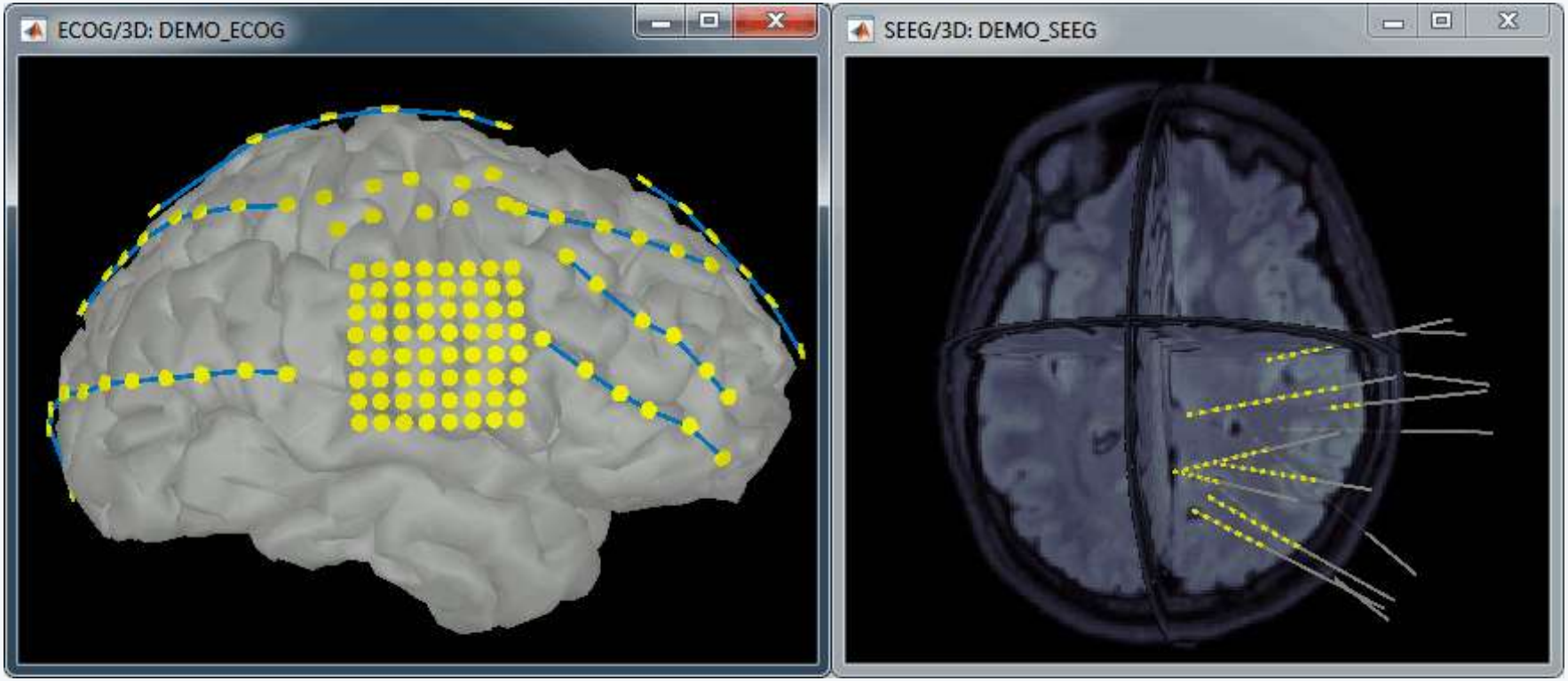
- MEG
- EEG
- ECoG
- SEEG
- NIRS
- Animal LFP
- Eyetracker



Invasive recordings

ECoG

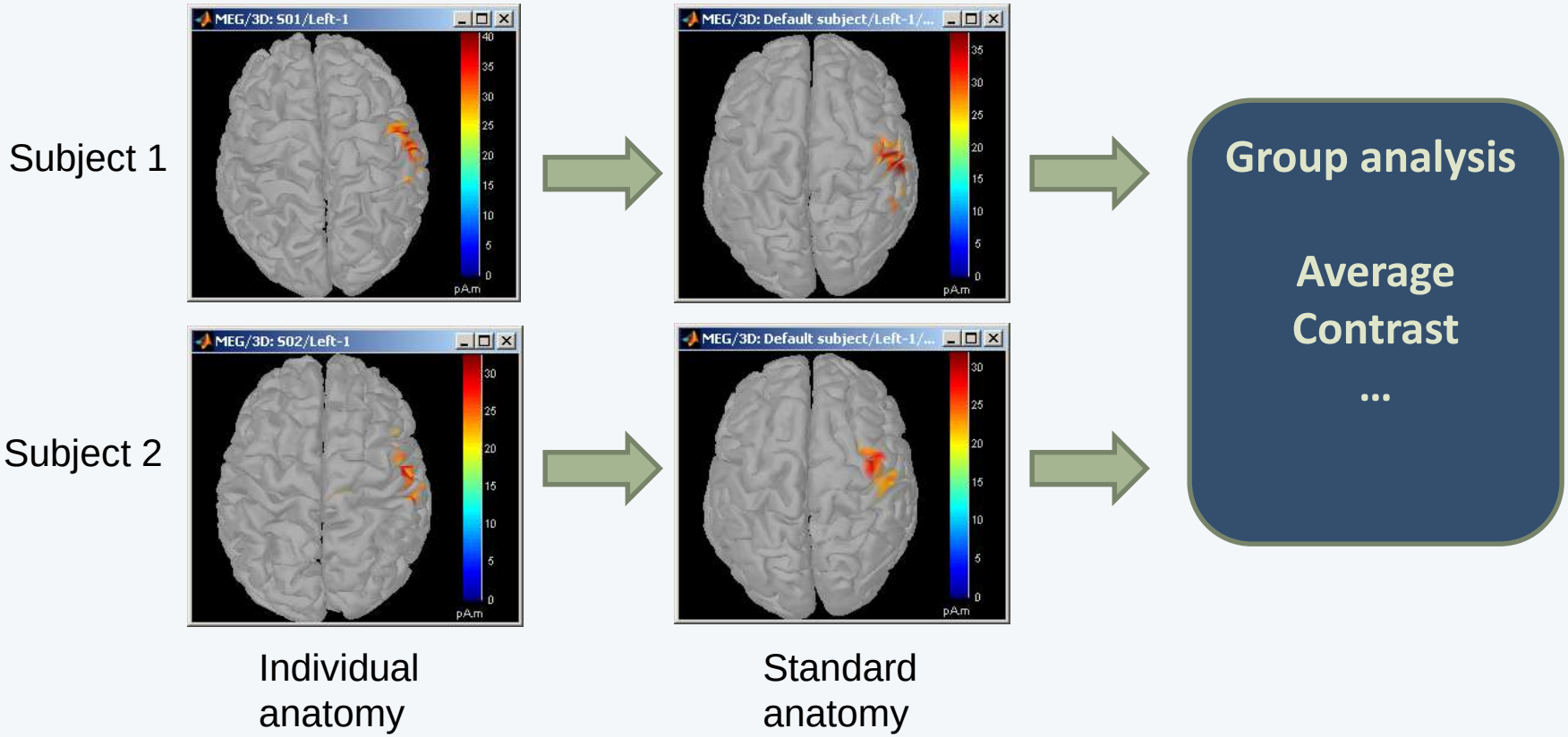
Depth electrodes



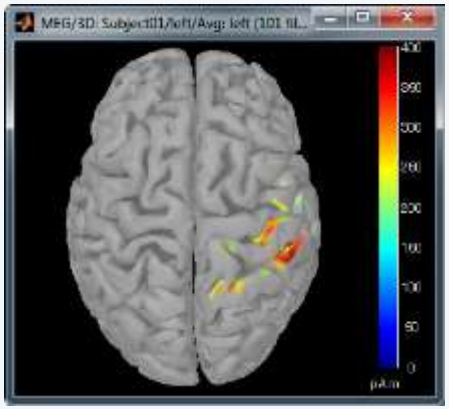
Brainstorm

Group analysis

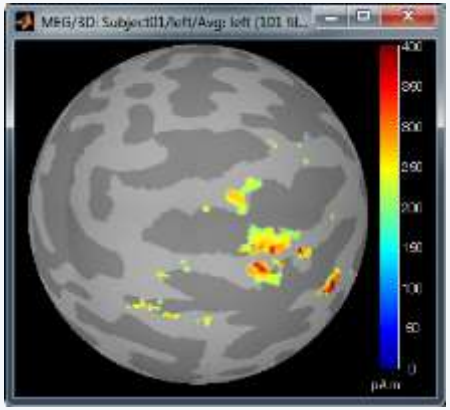
- Registration of individual brains on a template



Subject



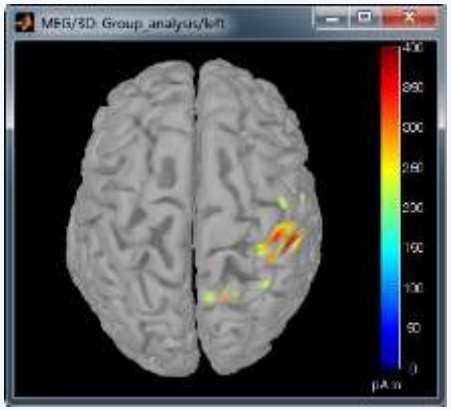
FreeSurfer registration



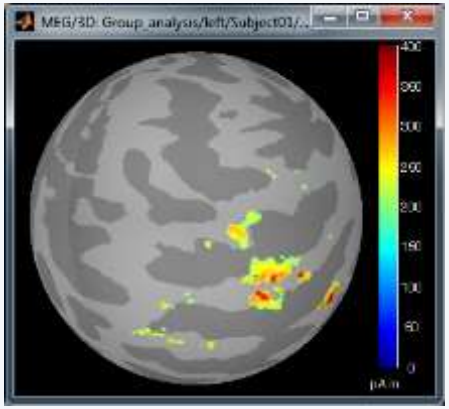
Subject anatomy
Right hemisphere

Shepard interpolation

Default anatomy

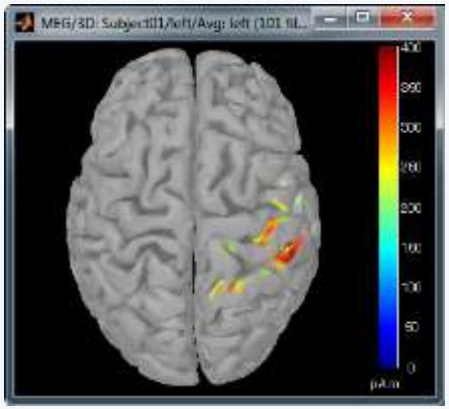


FreeSurfer registration

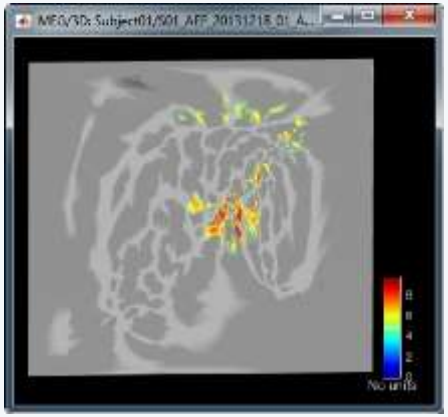


Template
Right hemisphere

Subject



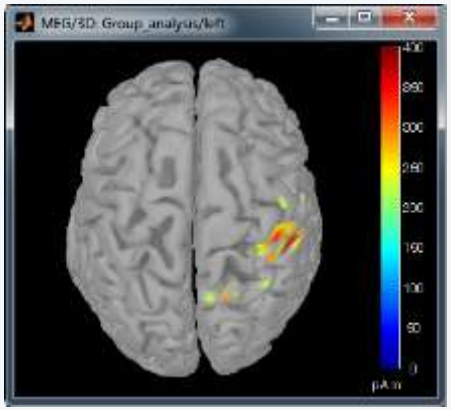
BrainSuite registration



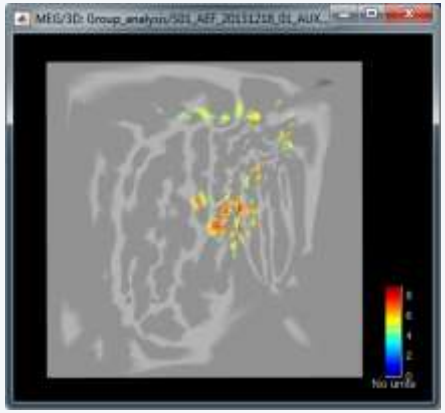
Subject anatomy
Right hemisphere

Shepard interpolation

Default anatomy



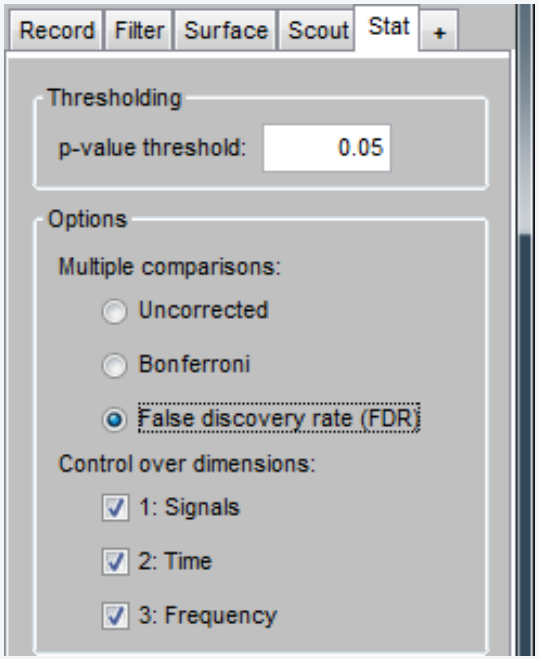
BrainSuite registration

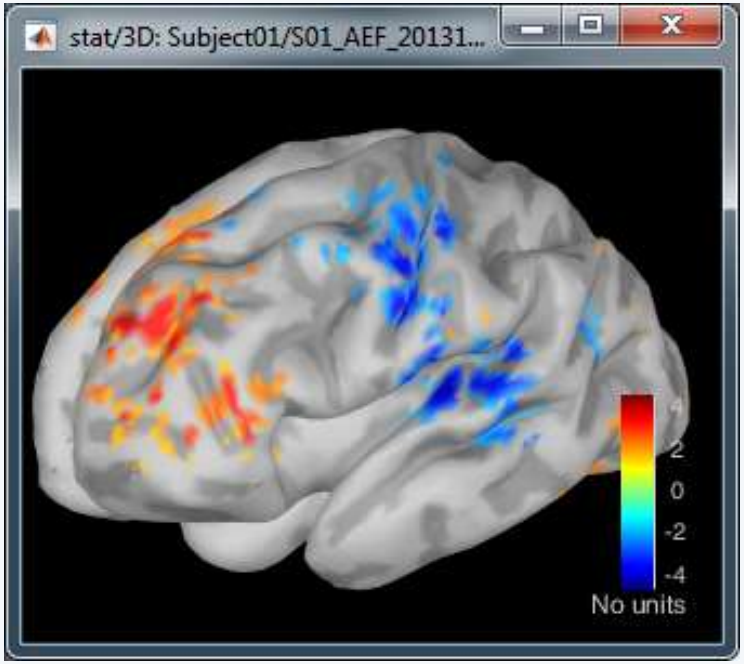


Template
Right hemisphere

Statistics

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

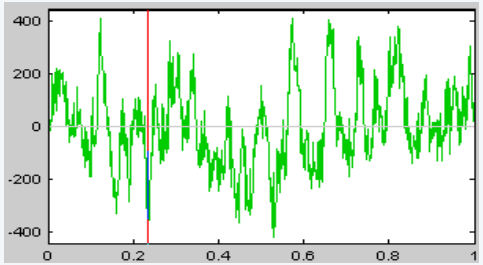


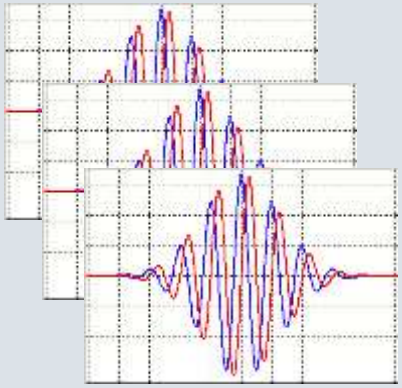


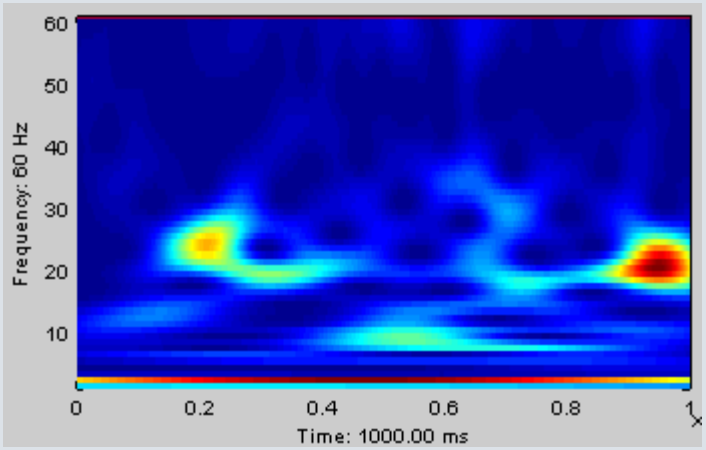
Brainstorm

Time-frequency

Morlet wavelets

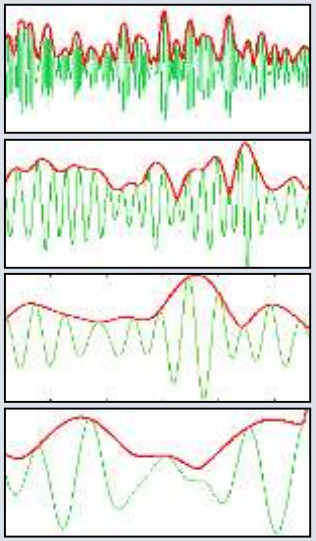


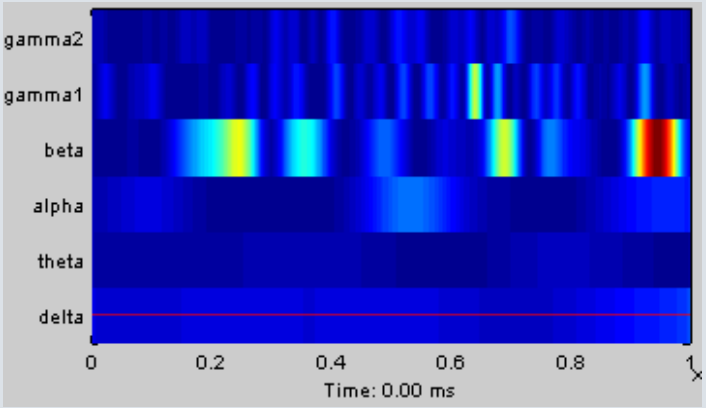




Hilbert transform

+ band-pass filter

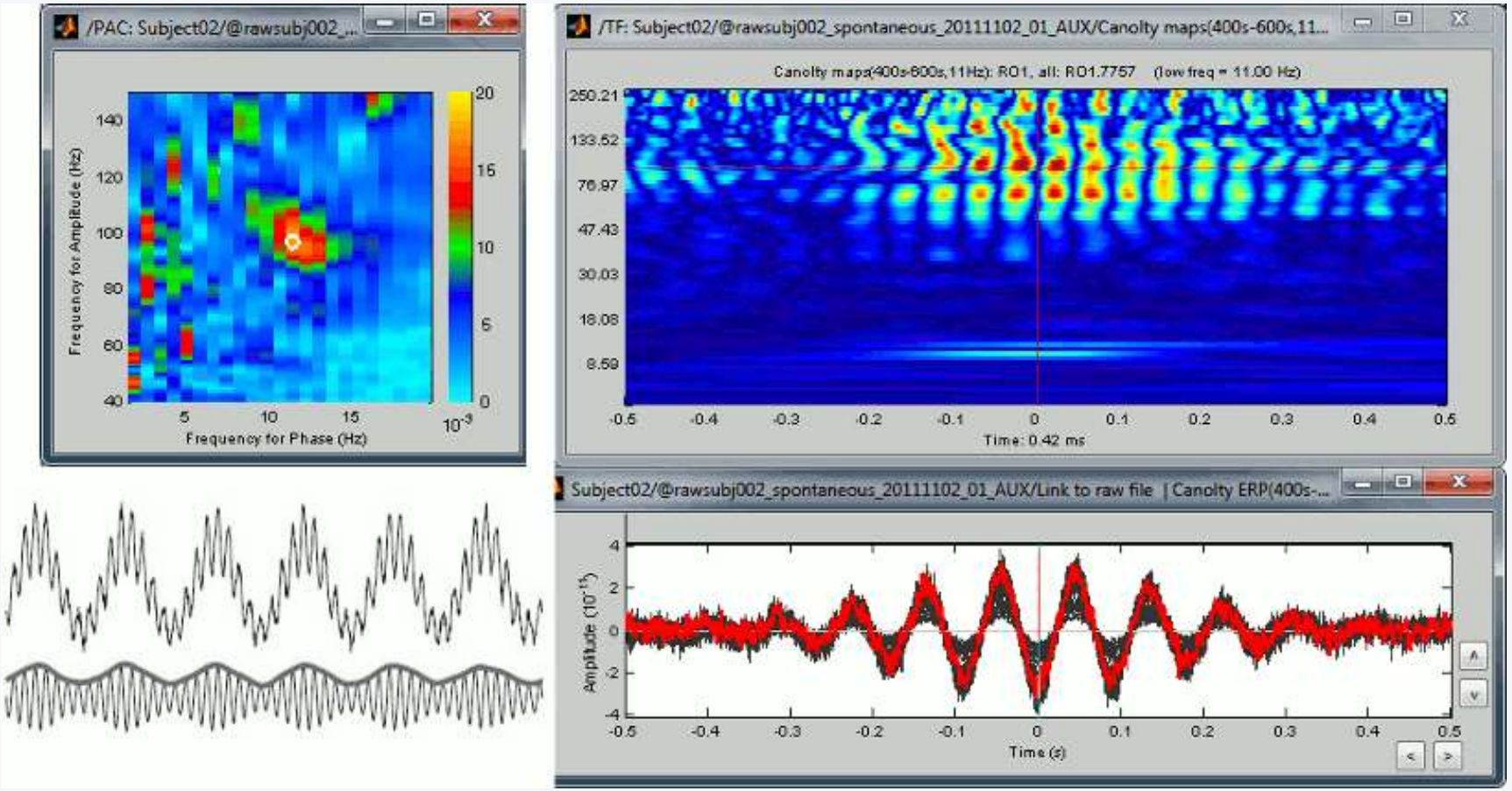




Brainstorm

Cross - frequency coupling

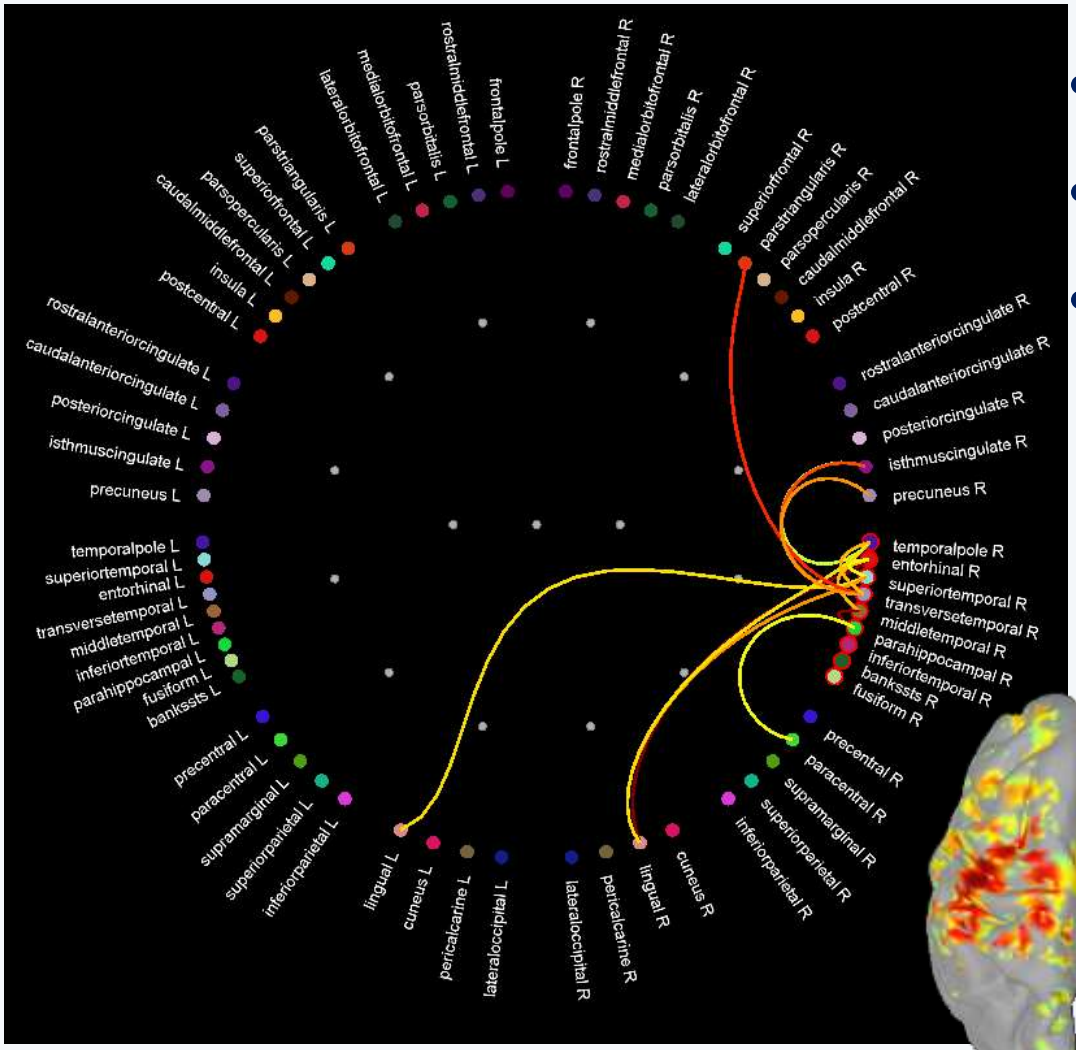
- Phase-amplitude coupling estimation

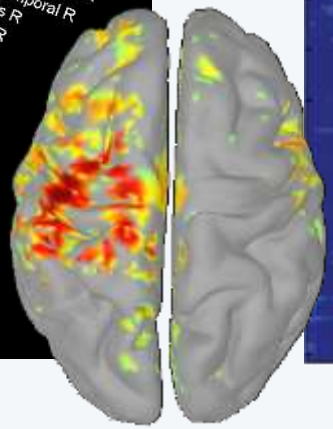


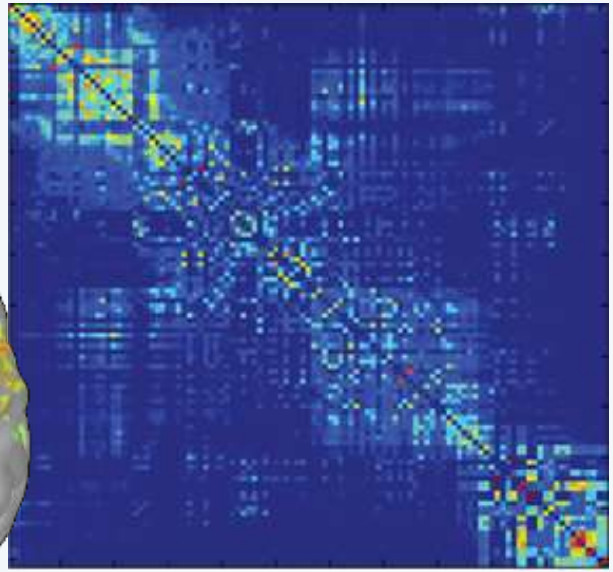
Brainstorm

Connectivity

- Correlation / Coherence
- Phase locking value
- Granger causality
- Sensor or source levels







Brainstorm

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)

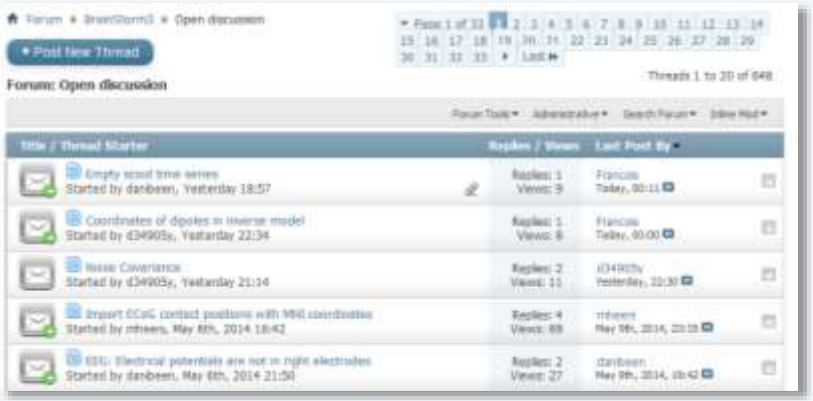
User community

- 12,000 users from 70 countries registered on the website

Brainstorm

User support

- Online tutorials: 30-hour self-teaching program
- Active user forum: 200 posts/month
- Daily updates: 700 downloads/month



- Contact us for specific questions and requests:
  We will help you adding the features you need

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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